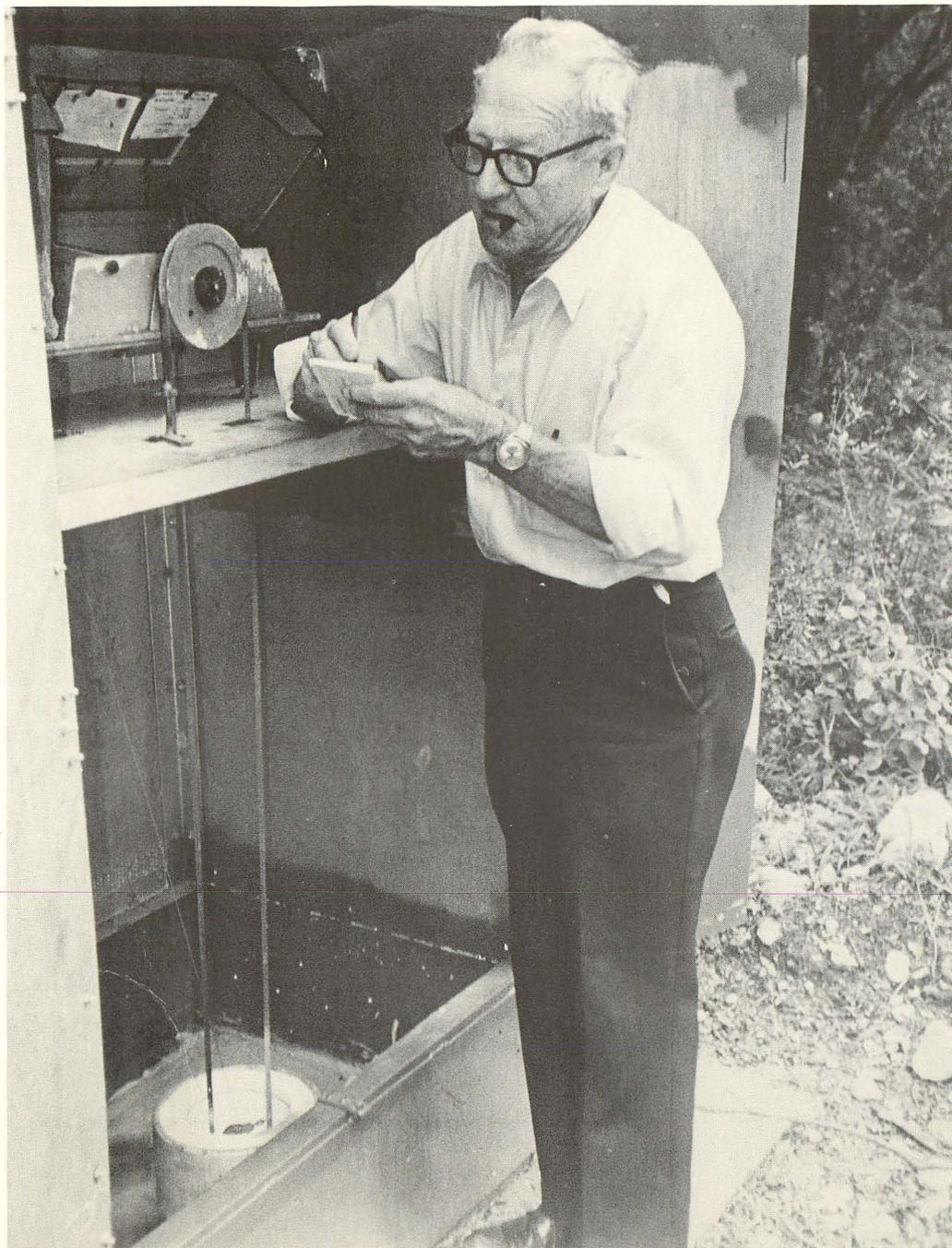


THE
EDWARDS AQUIFER
EXTREMELY PRODUCTIVE, BUT

**A Sole-Source Water Supply for San Antonio and Surrounding
Counties in South-Central Texas**

Prepared by the
U.S. Geological Survey
in cooperation with the
Edwards Underground Water District



Courtesy of the Express-News Corp.

**Dedicated
In Memory of**

OLIVER O. HAAS

**Comal County
Director**

1977 - 1985

**EDWARDS UNDERGROUND
WATER DISTRICT**

THE EDWARDS AQUIFER

EXTREMELY PRODUCTIVE, BUT

**A Sole-Source Water Supply for San Antonio and Surrounding
Counties in South-Central Texas**

**By
Charles R. Burchett, Paul L. Rettman,
and Charles W. Boning**

U.S. Geological Survey

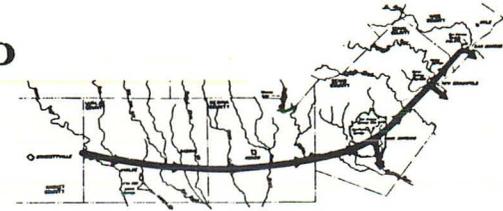
**Prepared by the
U.S. Geological Survey
In cooperation with the
Edwards Underground Water District
1986**

EDWARDS UNDERGROUND WATER DISTRICT BUILDING



EDWARDS UNDERGROUND WATER DISTRICT

1615 North St. Mary's
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(512) 222-2204



Thomas P. Fox
General Manger
Edwards Underground Water District

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JERRI W. MARTIN

Dear Fellow Citizen:

This report, The Edwards Aquifer, Extremely Productive, But. . . is a compilation of technical information presented in a manner to be useful to the lay reader and particularly for the decision-makers of the region. It is intended to bridge the gap between the basic information contained in a textbook, Water, Water Conservation and the Edwards Aquifer and the numerous technical reports of the District and others.

The need for protection of the Edwards Aquifer water quality and the growth of this region with the resultant increasing demand for the water resource, requires a greater understanding of the Edwards Aquifer by all and how it should be protected and managed. The publication of this report will further the general understanding of the Edwards Aquifer and assist everyone in their efforts to reach decisions on the future of our water resource.

Sincerely,

Thomas P. Fox

Thomas P. Fox
General Manager

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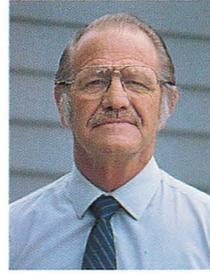
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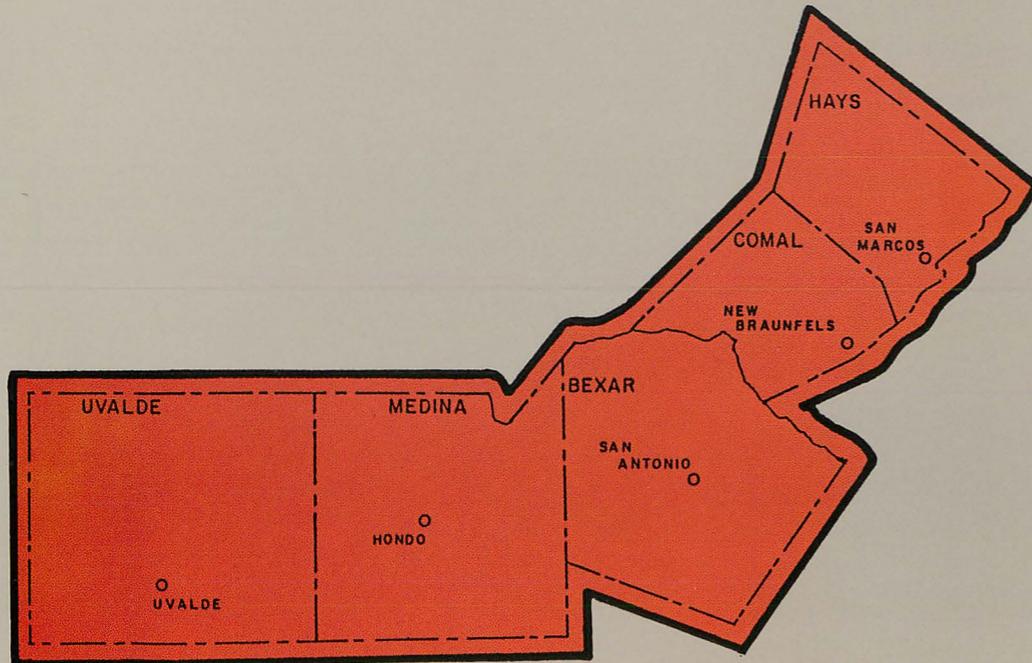
Jerri W. Martin

MESSAGE FROM THE BOARD OF DIRECTORS OF THE EDWARDS UNDERGROUND WATER DISTRICT

The Edwards Underground Water District is a local unit of government created by the Texas Legislature in 1959 for the purpose of conserving, protecting, and recharging the ground water. The District is empowered in various ways to accomplish its purpose. Among these are to cause investigations to be made of the ground water resources; to develop comprehensive plans for the most efficient use and prevention of waste and pollution; to collect, preserve, and publish information and bring it to the attention of the users of the water within the District.

The publication of this report, the **Edwards Aquifer, Extremely Productive, But . . .** represents the accomplishment of many of the objectives of the District. This report summarizes investigations and research concerning the Edwards Aquifer and presents the information in a manner intended to be beneficial to everyone that makes decisions about the use of our most precious natural resource - water.

The Edwards aquifer has, in many respects, shaped this area of south-central Texas. It is an amazing and important work of nature and presently the sole source of water for over a million people. Because of its importance, the Edwards Underground Water District will continue to seek out new information about the Edwards aquifer and make this information available to water users in its mission to conserve, protect, and preserve this water resource.



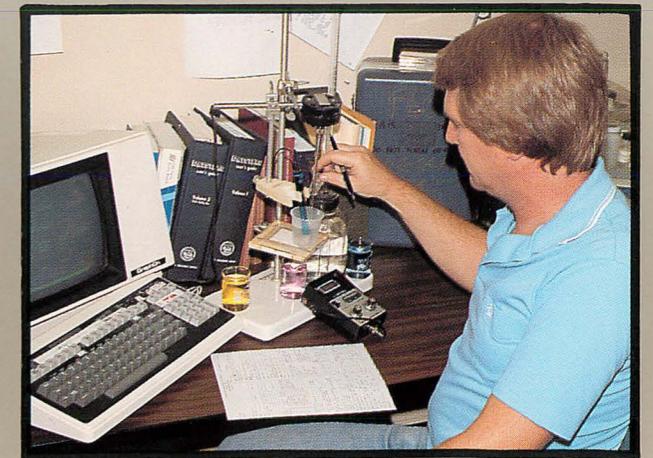
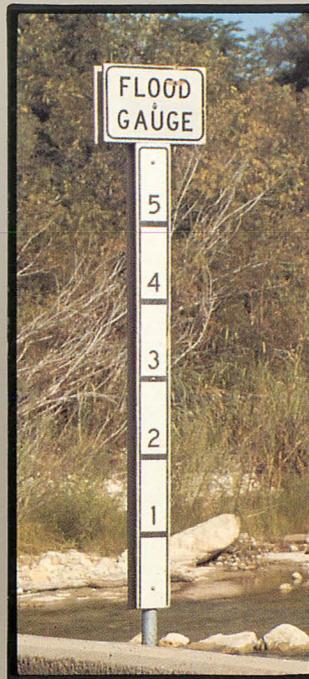
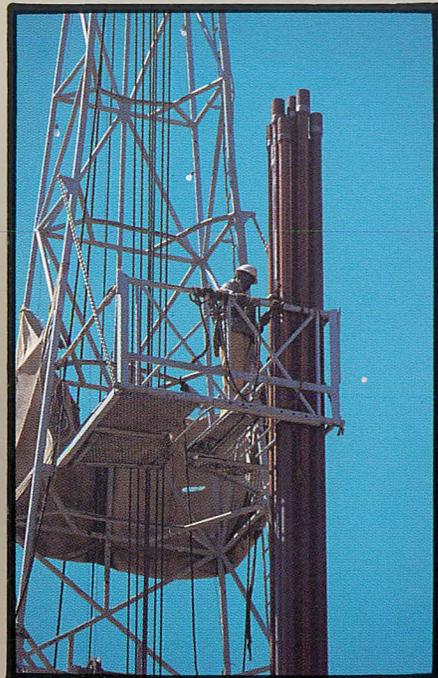
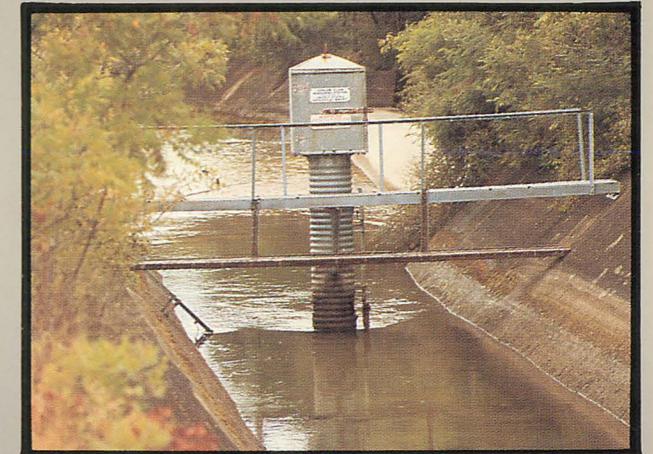
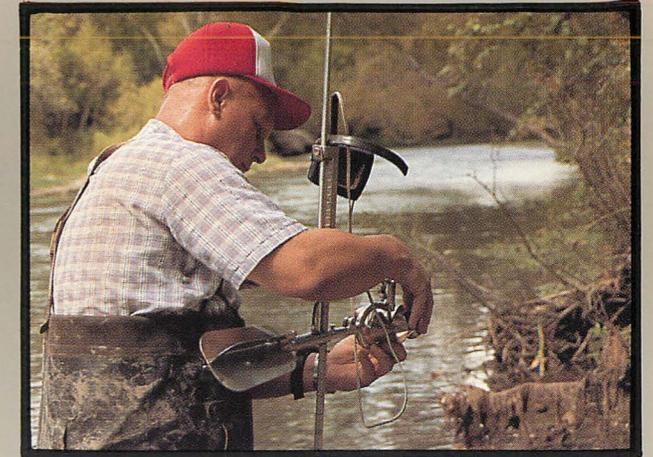
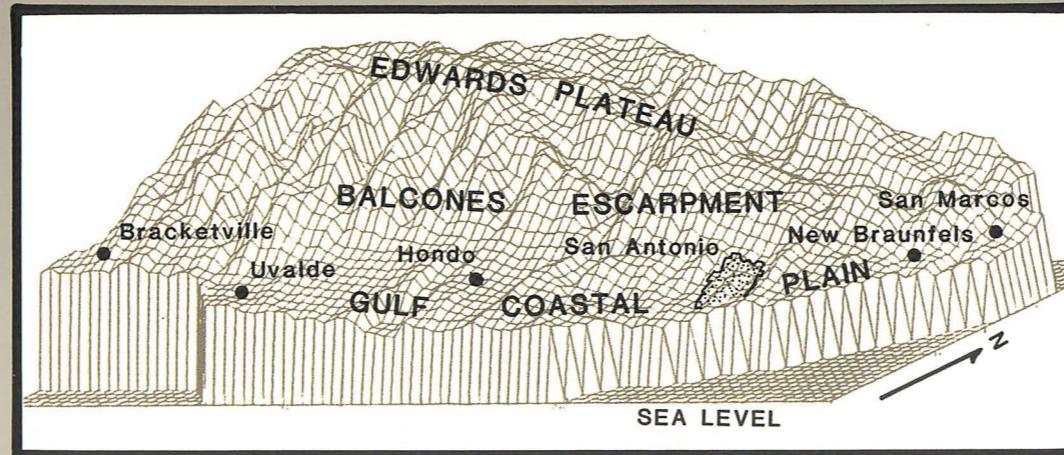
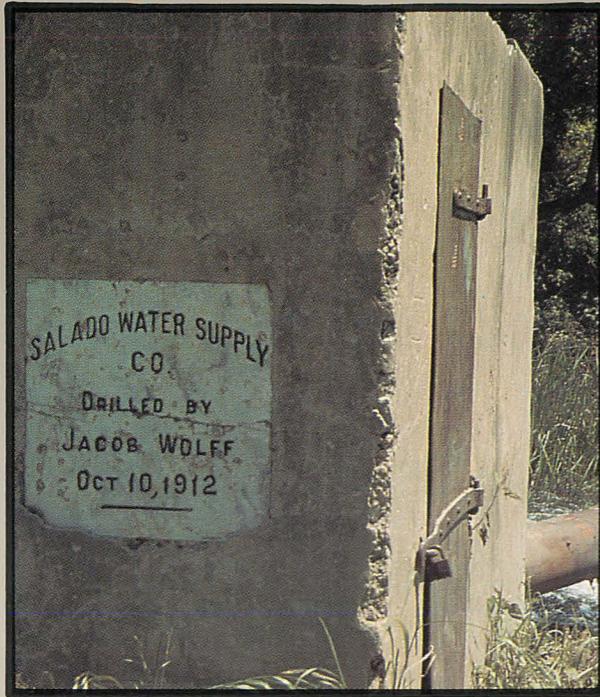
WATER USE FROM THE EDWARDS AQUIFER



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MANAGEMENT DECISIONS DEPEND ON HYDROLOGIC INFORMATION



The Edwards Aquifer Is A Valuable Resource For South-Central Texas

Continued economic development in south-central Texas will depend upon the available water supply. The principal source of water for San Antonio and the surrounding area will continue to be the Edwards aquifer, although supplemental supplies will need to be developed. Intelligent management decisions concerning how, when, and where to develop the additional water supplies can be made only if pertinent data concerning the total water resource are available to the decision makers. Information needed by elected officials and professional water managers include: Rainfall-runoff data on surface streams, maximum potential recharge to the aquifer, storage capacity of the aquifer, movement of water through the aquifer, and safe withdrawal rates.

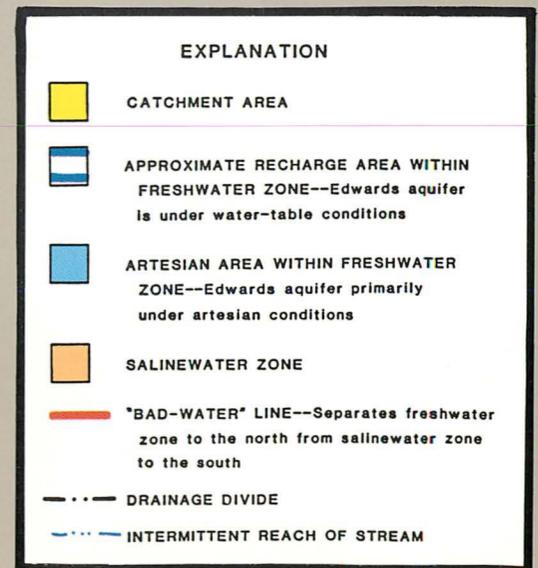
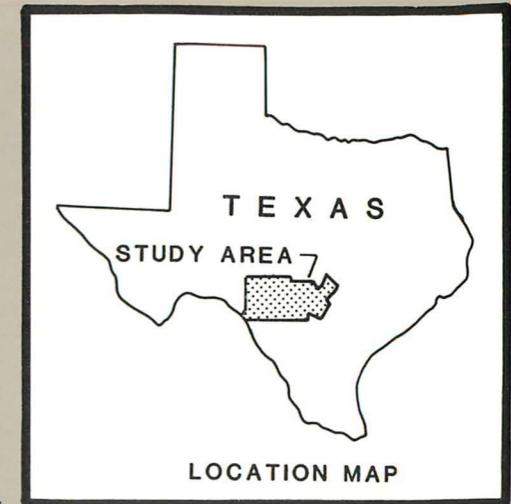
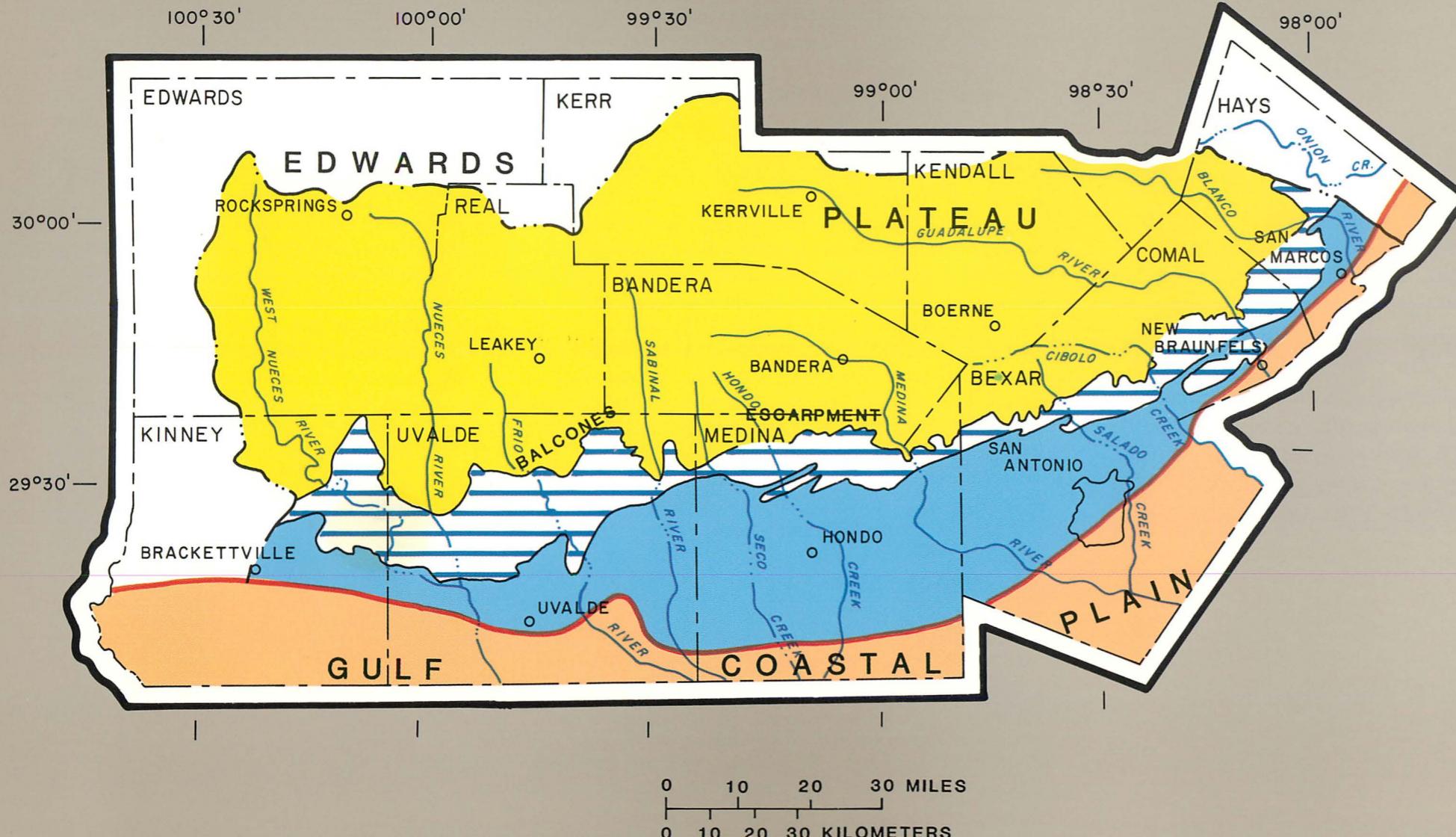
It is readily recognized that the future supply of water provided by the Edwards aquifer will have a significant effect on continued economic development in south-central Texas. Most decision makers agree that alternative water development will be needed to accommodate increased economic development. However, there may be disagreement on the most reliable and cost-effective means of developing alternative water supplies. Supplementing ground-water supplies by constructing surface-water reservoirs and increasing the ground-water supply by enhancing recharge are being considered. Conservation measures have been introduced throughout the area and discussion has begun on considering a water reuse program.

The decision makers--the elected public officials and the professional water managers--need information concerning the hydrology of the Edwards aquifer to select the most suitable plan of water development. The first of many critical decisions is to determine if existing hydrologic information, knowledge, or data are adequate for selection of a proper water-development plan. Subsequent decisions regarding the implementation of plans for supplemental water development also will require detailed information about the aquifer. Information needs include data for determination of the maximum recharge potential and the maximum quantity of water that can be safely withdrawn from the aquifer during periods of various climatic conditions without endangering the quality of the resource and without causing severe hardship for the many various water users. Investigations of the Edwards aquifer are necessary to obtain these data. To make timely and critical decisions, the planners and water managers need to have

knowledge and understanding of many specific and related technical hydrological considerations such as: Quantity of precipitation and its distribution in time and space, an understanding of the recharge mechanism, how water is contained in and moves through the aquifer, the quality of water in the aquifer and the potential for contamination, and the effects of temporary partial depletion of water in storage during droughts.

The report has been prepared to enhance the public's general understanding of the Edwards aquifer, and to aid officials in making decisions about the aquifer. The report also is intended to identify limitations in the understanding and knowledge of the aquifer, thereby facilitating the planning of investigative programs. This report is not intended to provide solutions to currently prevailing unanswered questions.

THE EDWARDS AQUIFER AND CATCHMENT AREA



The Edwards Aquifer And Catchment Area Includes All Or Parts Of 13 Counties

The Edwards aquifer and its catchment area in the San Antonio region is 8,000 square miles and includes all or parts of 13 south-central Texas counties. Most of the region is agricultural or ranch land with some areas of dense population. Populations of communities within the region range from a few hundred residents in D'Hanis to about 1 million people in San Antonio, the tenth most populous city in the United States.

The commonly referred to "Edwards aquifer in the San Antonio area" underlies all or parts of 6 counties, has an area of about 3,600 square miles, and includes the recharge and artesian areas. The catchment area, about 4,400 square miles, contains the drainage basins of streams that recharge the Edwards aquifer.

Natural discharge from the aquifer is through major springs such as San Marcos and Comal Springs. These springs are not only centers of tourism but also contain rare aquatic life.

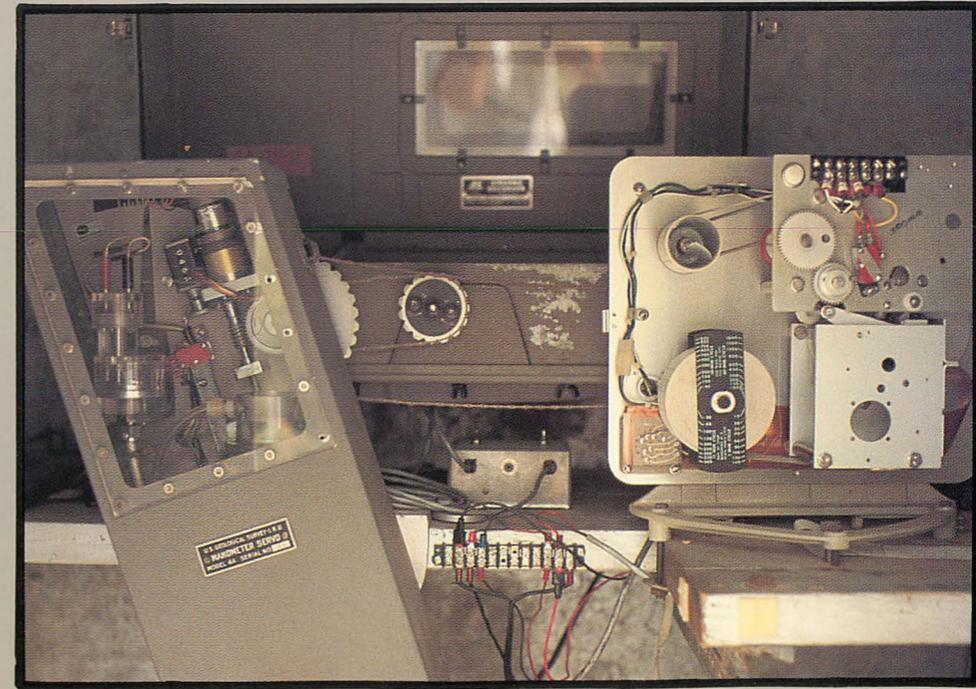
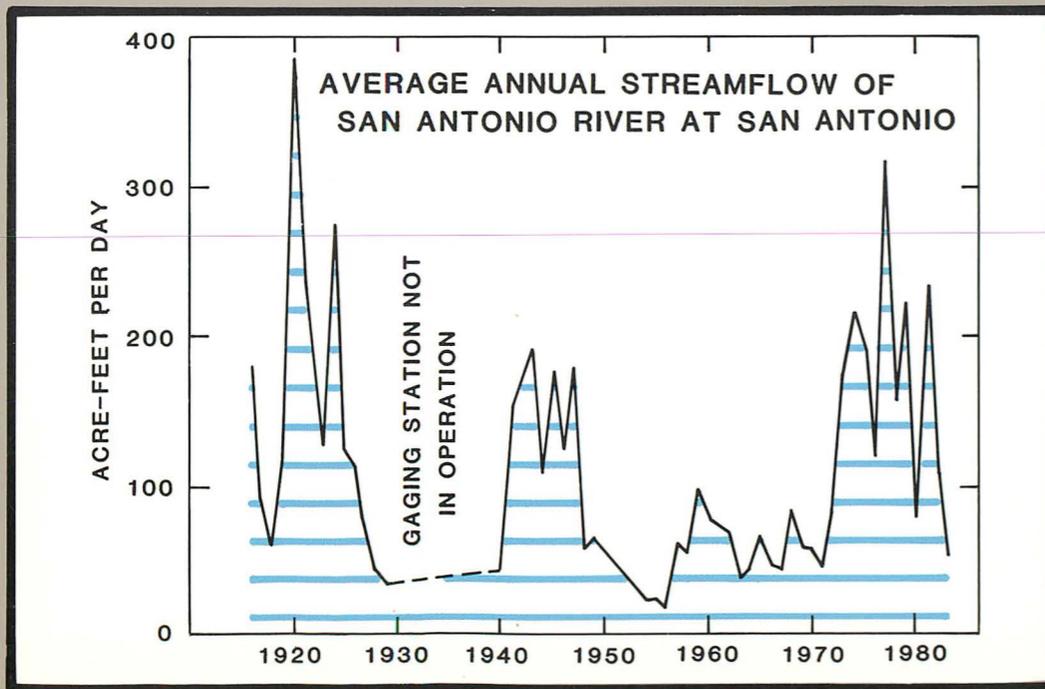
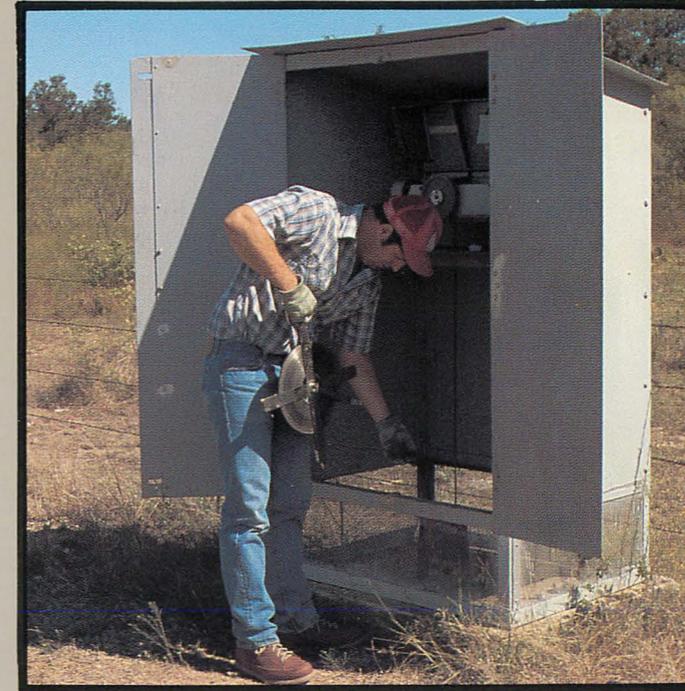
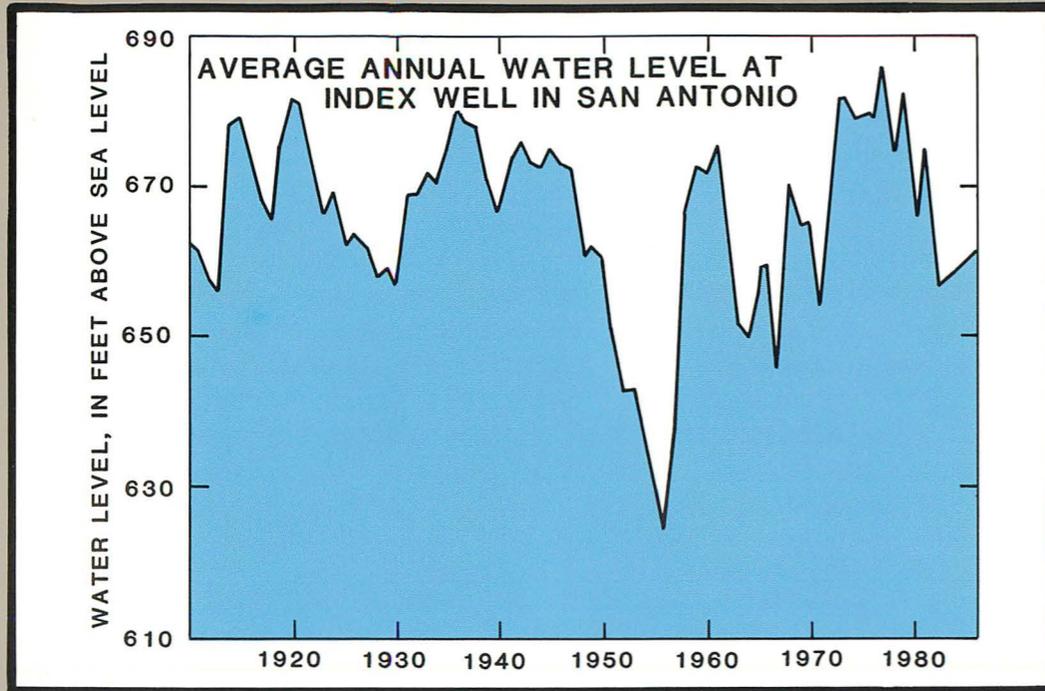
The Edwards aquifer and its catchment area in the San Antonio region is about 8,000 square miles and includes all or parts of 13 counties in south-central Texas. The recharge and artesian areas of the Edwards aquifer underlie the six counties south and east of the Balcones escarpment. The aquifer underlies about 3,600 square miles, is about 180 miles long from west to east, and varies from about 5 to about 30 miles wide. The Edwards aquifer receives most of its water from the drainage basins located on the Edwards Plateau. The catchment area, about 4,400 square miles, contains the drainage basins of streams that recharge the Edwards aquifer.

Much of the area is agricultural or ranch land with some areas of dense population. The Edwards aquifer supplies nearly all the water for the municipal, domestic, and agricultural needs of the area. It has been designated a sole-source aquifer by the U.S. Environmental Protection Agency (EPA). The population of communities in the region during 1980 ranged from a few hundred residents in D'Hanis to about 1,000,000 people in the San Antonio metropolitan area, the tenth most populous city in the United States. Other cities in the area that have populations of more than 1,500 people include Brackettville, Uvalde, Hondo, New Braunfels, and San Marcos.

Recreational establishments depend on water from major springs such as San Marcos Springs and Comal Springs that issue from the aquifer. The springs are tourist attractions where the water is used for water sports; as it moves downstream, the water is used for municipal and agricultural supplies. Rare and unique aquatic life live in the spring water and in the caverns from which the springs flow.

This report is concerned with the freshwater part of the Edwards aquifer in the San Antonio area. This part of the aquifer is defined on the north by the base of the Balcones escarpment, on the west and northeast by ground-water and surface-water divides, and on the south by the downdip limit of freshwater, which is commonly called the "bad-water" line. The "bad-water" line is a local term used to define the location where the mineral content of water in the Edwards aquifer exceeds 1,000 milligrams per liter. The location of the ground-water divides on the west and northeast of the area may shift as a result of changing hydrologic conditions.

AQUIFER INVESTIGATIONS



Data Collection Since 1895 Has Aided In Understanding The Edwards Aquifer

Data collection and studies concerning the Edwards aquifer began in 1895 when the discharge from Comal Springs was first measured by the U.S. Geological Survey. Investigation of the Edwards aquifer has expanded to include studies and collection of data in cooperation with several State and local agencies. These programs include appraisals of the quantity and quality of water within the Edwards aquifer as well as the quantity and quality of surface water both before it recharges the aquifer and after it is discharged from the aquifer through wells and springs.

Studies of the Edwards aquifer began with the measurement of the discharge of Comal Springs in 1895 by the U.S. Geological Survey. When water wells were drilled and put into production, water levels and pumping rates occasionally were measured and recorded. The data-collection program has evolved considerably from this meager beginning. The Edwards Underground Water District, the San Antonio City Water Board, and the Texas Water Commission, the Texas Water Development Board, and their predecessor agencies, have cooperated with the Geological Survey to define the hydrology of the Edwards aquifer. Studies have included the collection, compilation, and analyses of data to determine the storage capacity of the aquifer; the recharge, circulation, and discharge of ground water; and the quality of water in the aquifer.

Geologic mapping of the area was started in 1898 and maps were published by the Geological Survey in 1899. Maps of surface and subsurface geology have been prepared in greater detail since that time. Most of the surface geology has been mapped and published by the Texas Bureau of Economic Geology. Exploration and development by the oil industry has contributed significantly to the knowledge of subsurface geology. A better understanding of the Edwards Limestone was gained from correlations between subsurface exploration of the Edwards Limestone beneath the Coastal Plain and the surface geology of the Edwards Limestone on the Edwards Plateau.

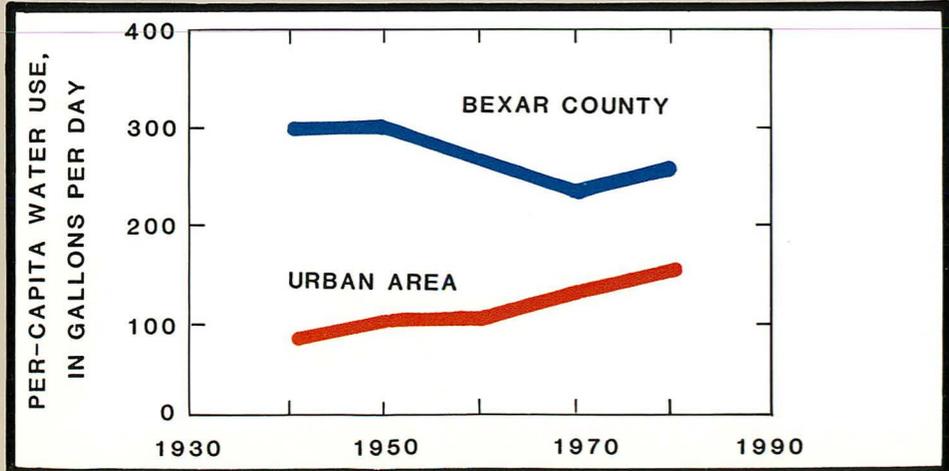
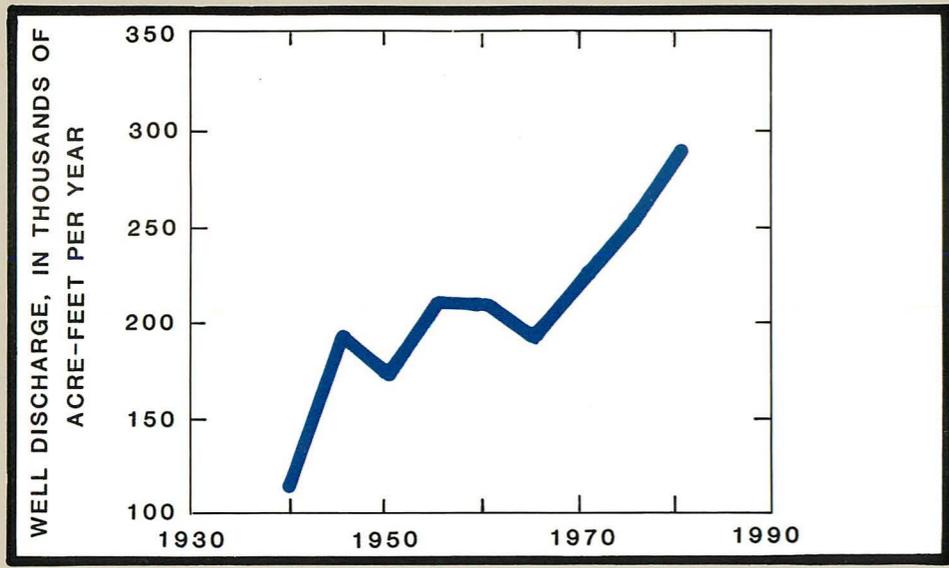
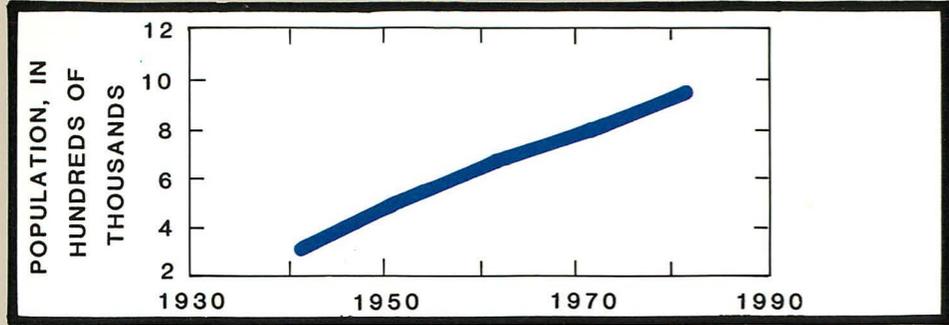
Monitoring of water levels in the Edwards aquifer began in 1910 when a well was measured in San Antonio. Continuous recording of water levels began in 1934. Currently (1986), water levels are monitored in a network of about 150

wells distributed throughout the aquifer area. Included in this network are 19 wells that have continuous water-level recorders.

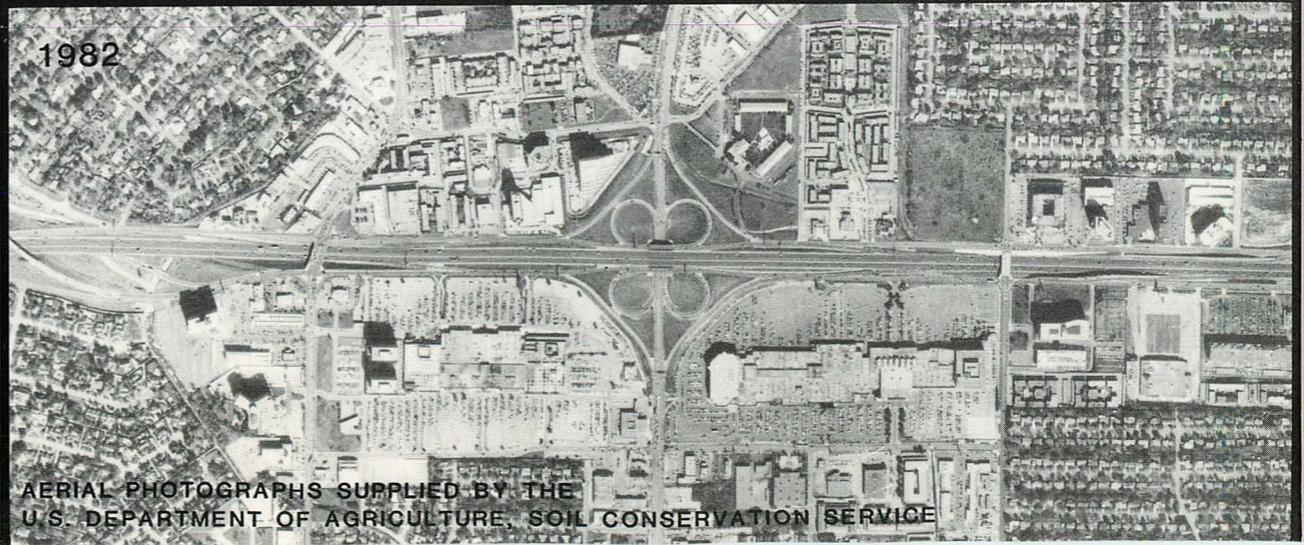
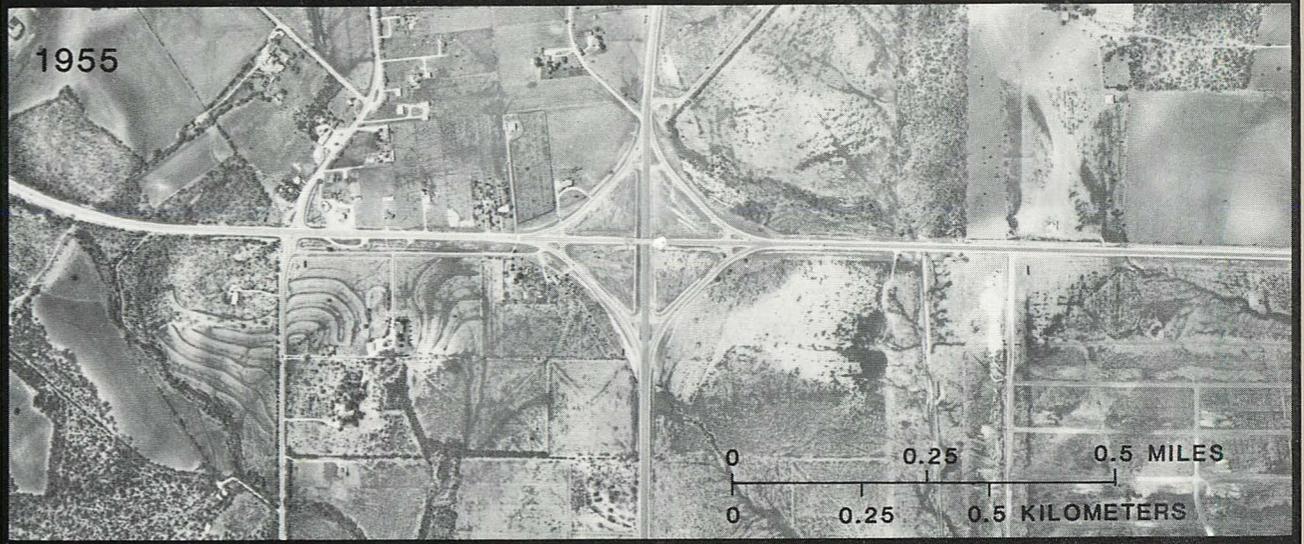
Streamflow-gaging stations have been operated in the area of the Edwards aquifer since 1915. Many gages are located upstream and downstream from the recharge area of the aquifer. The gages are used to determine the quantity of streamflow recharging the Edwards aquifer. Currently (1986), records of 31 streamflow gages are used to calculate recharge.

Water-quality data have been collected from springs and streams, and from wells since 1930. These data are used to determine the quality of recharge water and the quality of water moving through the aquifer. Currently (1986), about 100 wells and 3 springs are included in the water-quality monitoring network. Hydrologic data and interpretive technical reports provide valuable information for water managers and developers in understanding the hydrologic system and in management of the aquifer.

POPULATION AND WATER USE IN BEXAR COUNTY



INTERSTATE HIGHWAY 410 AND SAN PEDRO AVENUE, SAN ANTONIO, TEXAS



AERIAL PHOTOGRAPHS SUPPLIED BY THE U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE

Increased Population Has Caused Changes In Land And Water Use

The first settlements in the area were located near the natural spring outlets. The springs were the major sources of water until wells became common after 1900 when the population of the area increased to 100,000. Demand for water has increased as a result of population increases and industrial expansion. Although urban water consumption has increased over the past several decades, overall per-capita water use has decreased in Bexar County because of reduced irrigation demands.

Since the 1940's, parts of the area served by the Edwards aquifer have changed from predominantly rural to an urban environment. San Antonio, where most of the people in Bexar County live, now contains 5 times the population it had 40 years ago. Large areas of land that had been used for ranching and farming have been developed for greater population density, light industry, and service companies.

Until the first well was dug into the Edwards aquifer in 1865, water from the aquifer was obtained only from springs. In the 18th and 19th centuries, only a small part of the springflow was needed to sustain the area's sparse population. Wells became major suppliers of water after 1900 when the area population reached 100,000. The population has increased at an almost constant rate of about 20,000 per year since 1940. Currently (1986), more than 1 million people live in the area and more than 1.5 million people are projected to live there by 2000.

Bexar County, which contains San Antonio, represents most of the area's population. The standard metropolitan statistical area of San Antonio has increased in population from about 200,000 during 1940 to about 1,000,000 during 1980. Rapid development of light industry and service companies have accompanied the population increases. Between 1940 and 1980, the population of Uvalde increased from 6,679 to 14,178; the population of Hondo increased from about 3,500 to 6,057; and that of San Marcos from about 6,000 to 23,420.

During the past 40 years, many areas within the region have changed from a predominantly rural to a more urban environment. The three aerial photographs, taken in 1938, 1955, and 1982, illustrate some of the changes in land use as a result of increased population. The center of each photograph shows the present intersection of Interstate Highway 410 and San Pedro Avenue in San Antonio. During the 44 years, the area in the photographs changed from rural land to nearly 100 percent developed urban area.

Water withdrawals through wells from the Edwards aquifer have increased, particularly in Bexar County, in response to demands created by the population increases and industrial

expansion. Total annual pumpage in Bexar County increased almost 200 percent, from slightly more than 100,000 acre-feet during 1940 to more than 300,000 acre-feet during 1980. From 1965 to 1980, the water demand increased by 100,000 acre-feet. However, decreased demand from wells was evident during the years of greater-than-normal precipitation after the drought of the 1950's.

Per-capita water consumption in the urban areas of Bexar County has continued to increase through 1980, reflecting the changing lifestyles and industrial expansion during that era. From 1940 to 1980, per-capita demand for water in the urban areas increased more than 50 percent from less than 100 gallons per day to more than 150 gallons per day. Whereas the suburban lifestyle and industrial-commercial expansion typically cause an increase in per-capita water use, such as occurred in San Antonio proper, the recent trends to multifamily dwellings, improvements in agricultural-irrigation efficiency, and industrial water-conservation measures are positive steps toward decreasing water consumption. These factors, and particularly the changing land use from an agricultural setting to an urban environment that greatly decreases the irrigation demand, has resulted in an overall 15-percent decrease in per-capita use in Bexar County from 1950 to 1980.

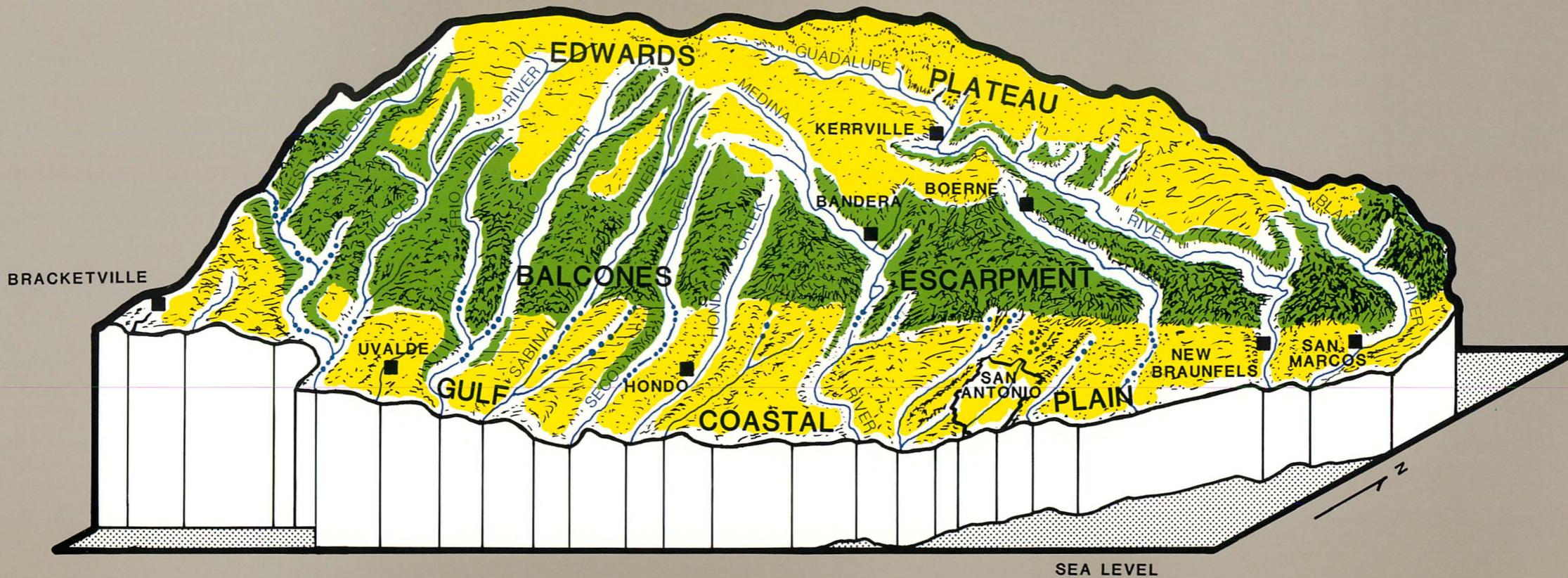
The availability of water from the Edwards aquifer has been sufficient to meet the water demands in the area. Continued urban and industrial development, however, will result in increased demands on the aquifer.

LAND AND VEGETATION

EXPLANATION

VEGETATION TYPES

-  PRIMARILY GRASSES AND BRUSH
-  PRIMARILY WOODS AND BRUSH
-  INTERMITTENT REACH OF STREAM



Topography And Vegetation Are Diverse

Most of the catchment area for the Edwards aquifer is on the Edwards Plateau where the land surface ranges in altitude from 2,300 feet above sea level in the west to about 1,000 feet above sea level in the east. Large areas of woodlands on the plateau have been cleared to provide grassland for grazing livestock. The edge of the plateau, along the Balcones escarpment, has been deeply dissected by surface streams that descend several hundred feet to the Gulf Coastal Plain. The escarpment, which can vary in local relief by 150 feet, is covered by dense growth of native trees and brush. The Gulf Coastal Plain is a gently rolling landscape with local relief of about 50 feet and covered by grass, brush, and trees. Altitude of the plain varies from 1,000 feet above sea level in the western part to about 600 feet above sea level in the eastern part.

The topography of south-central Texas within the Edwards aquifer and its catchment area varies significantly from the Edwards Plateau to the lower and flatter Gulf Coastal Plain that overlies the artesian part of the aquifer. The Edwards Plateau ranges in altitude from about 2,300 feet above sea level in the extreme western part of the area to about 1,000 feet in the extreme eastern part. Local relief on the plateau is as much as 300 feet. Vegetation on the plateau primarily is woodlands comprised of various species of oak, mesquite, and cedar along with grasslands used for grazing cattle, goats, and sheep. Native woodland density and tree size increase from west to east. Large areas of native trees have been cleared to provide increased rangeland throughout the plateau.

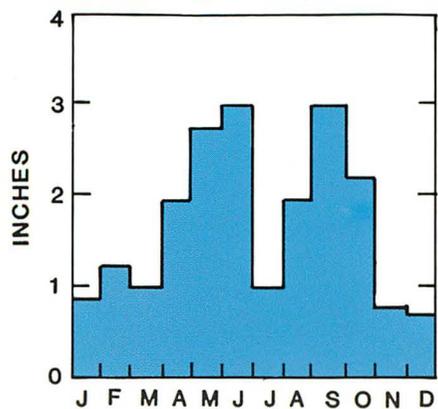
The Balcones escarpment defines the southern and eastern edges of the Edwards Plateau. Here, the land surface is deeply dissected by the streams that flow down the escarpment. Throughout most of the plateau, the streams descend only a few feet per mile, but at the escarpment, stream slopes increase to as much as 15 feet per mile. The streams descend several hundred feet through ravine-like valleys to the Gulf Coastal Plain beyond the mouths of these valleys. The relief may vary as much as 150 feet from the streambed to the ridges above the valleys. Dense vegetation in the valleys of the dissected escarpment consists of brush, cedar, and oak trees. Cypress trees are common along the streams. Vegetation on the ridges is more sparse, with cedar trees being the predominant cover.

Except during floods, the streams flowing from the western part of the plateau lose most of their water through recharge to the Edwards aquifer and generally are dry when they reach the

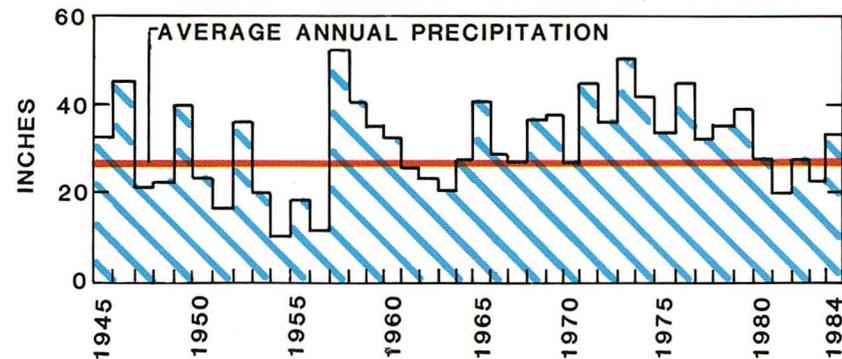
Gulf Coastal Plain. In the eastern part of the area, the major streams continue to flow a larger percentage of time after they have crossed the recharge area. The Gulf Coastal Plain is a gently rolling landscape, with altitudes near the escarpment that vary from about 1,100 feet in the western part of the area to about 600 feet in the eastern part. Local relief is about 50 feet. Vegetation on the plain is mostly grass and brush, with a mixture of mesquite and oak trees.

PRECIPITATION AND TEMPERATURE

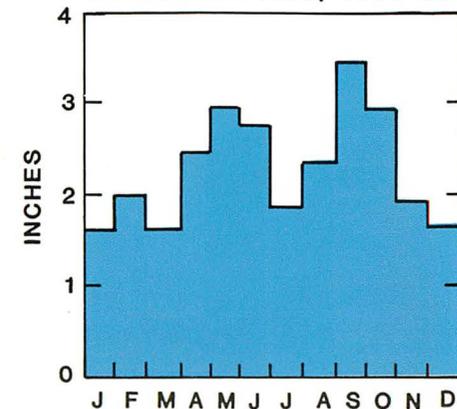
AVERAGE MONTHLY PRECIPITATION
AT BRACKETVILLE, 1951-80



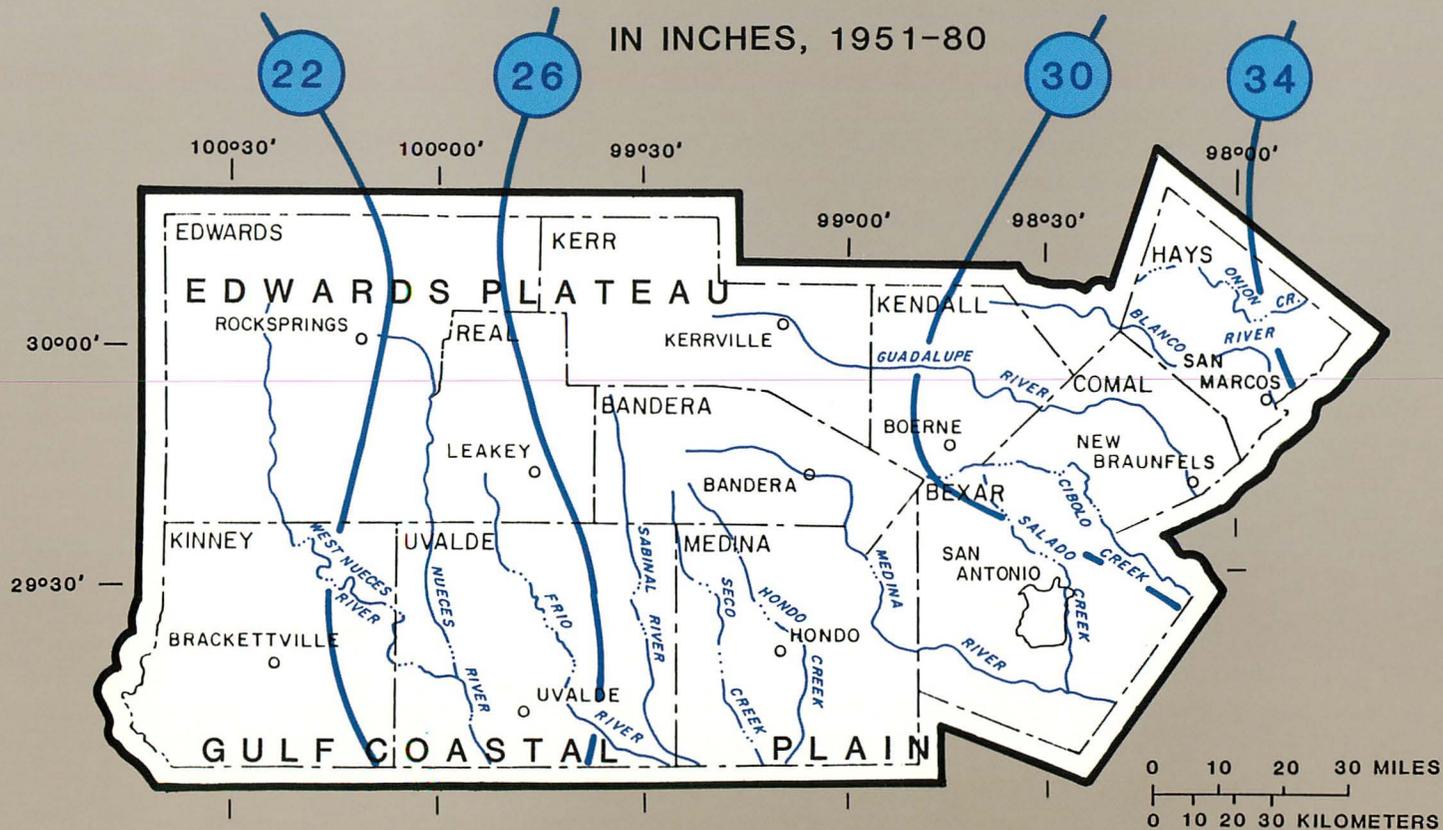
ANNUAL PRECIPITATION AT BOERNE, 1945-84



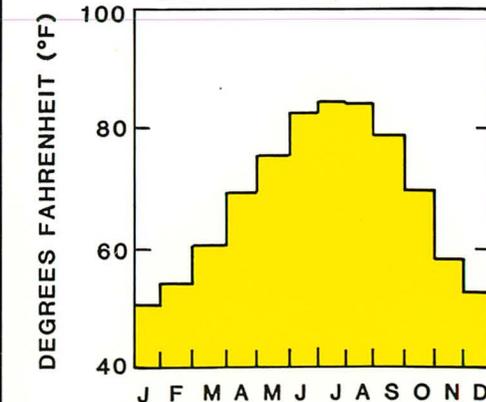
AVERAGE MONTHLY PRECIPITATION
AT SAN ANTONIO, 1951-80



AVERAGE ANNUAL PRECIPITATION,
IN INCHES, 1951-80



AVERAGE MONTHLY TEMPERATURE AT
SAN ANTONIO, 1951-80



Most Precipitation Is Lost To Evapotranspiration

Average annual precipitation across the Edwards aquifer and catchment area varies from about 22 inches in the western part of the area to about 34 inches in the eastern part. Annual precipitation at Brackettville in the western part of the area has ranged between 7.6 and 45.4 inches, and annual precipitation at San Marcos in the eastern part of the area has ranged from 13.4 to 52.2 inches. Average annual precipitation at San Antonio is 27.5 inches and at Boerne it is about 30.4 inches. Average annual temperatures increase southward from 65° Fahrenheit on the Edwards Plateau to 69° Fahrenheit on the Gulf Coastal Plain. These high temperatures contribute to rapid evapotranspiration rates throughout the area.

Records from stream-gaging stations indicate that the average annual runoff resulting from 21 inches of precipitation in the Nueces River basin is only 2.7 inches and 34 inches of precipitation in the Blanco River basin results in only 4.7 inches of runoff per year. About 85 percent of the precipitation that falls on the Edwards aquifer and catchment area is lost back to the atmosphere by evapotranspiration.

Precipitation varies across the region from an average of about 22 inches per year in the western part to about 34 inches per year in the eastern part. Precipitation varies significantly from year to year. At Brackettville, in the western part of the area, the average annual precipitation is 20.7 inches, but for the period of record (1897-1983) precipitation has been as little as 7.6 inches and as much as 45.4 inches. Annual precipitation at San Marcos in the eastern part of the area has ranged from 13.4 inches to 52.2 inches with an average of about 34 inches. Average precipitation at San Antonio is 27.5 inches per year; Boerne has a slightly larger average precipitation of 30.4 inches per year.

Temperature variation is greater from the Edwards Plateau toward the Gulf Coastal Plain than it is from Brackettville to San Marcos. The area within the Edwards Plateau has an average annual temperature of about 65° F (Fahrenheit), whereas the area within the Gulf Coastal Plain has an average annual temperature of about 69° F. These relatively high annual temperatures, that occur throughout the entire region contribute to rapid rates of evapotranspiration.

Recorded runoff from the western part of the Edwards Plateau in the Nueces River Basin averages only 2.7 inches per year, which means that about 18 of the 21 inches of the annual precipitation is lost to the atmosphere through evapotranspiration. Runoff from the Blanco River basin in the eastern part of the Edwards Plateau averages 4.7 inches per year. Evapotranspiration, therefore, in the eastern part of the area is about 28 inches per year. About 85 percent of the precipitation that falls on the region is lost by evapotranspiration. Evapotranspiration, as a percentage of the total

precipitation, is slightly greater in the western part of the area, although total evapotranspiration in the eastern part of the area is significantly greater than in the western part.

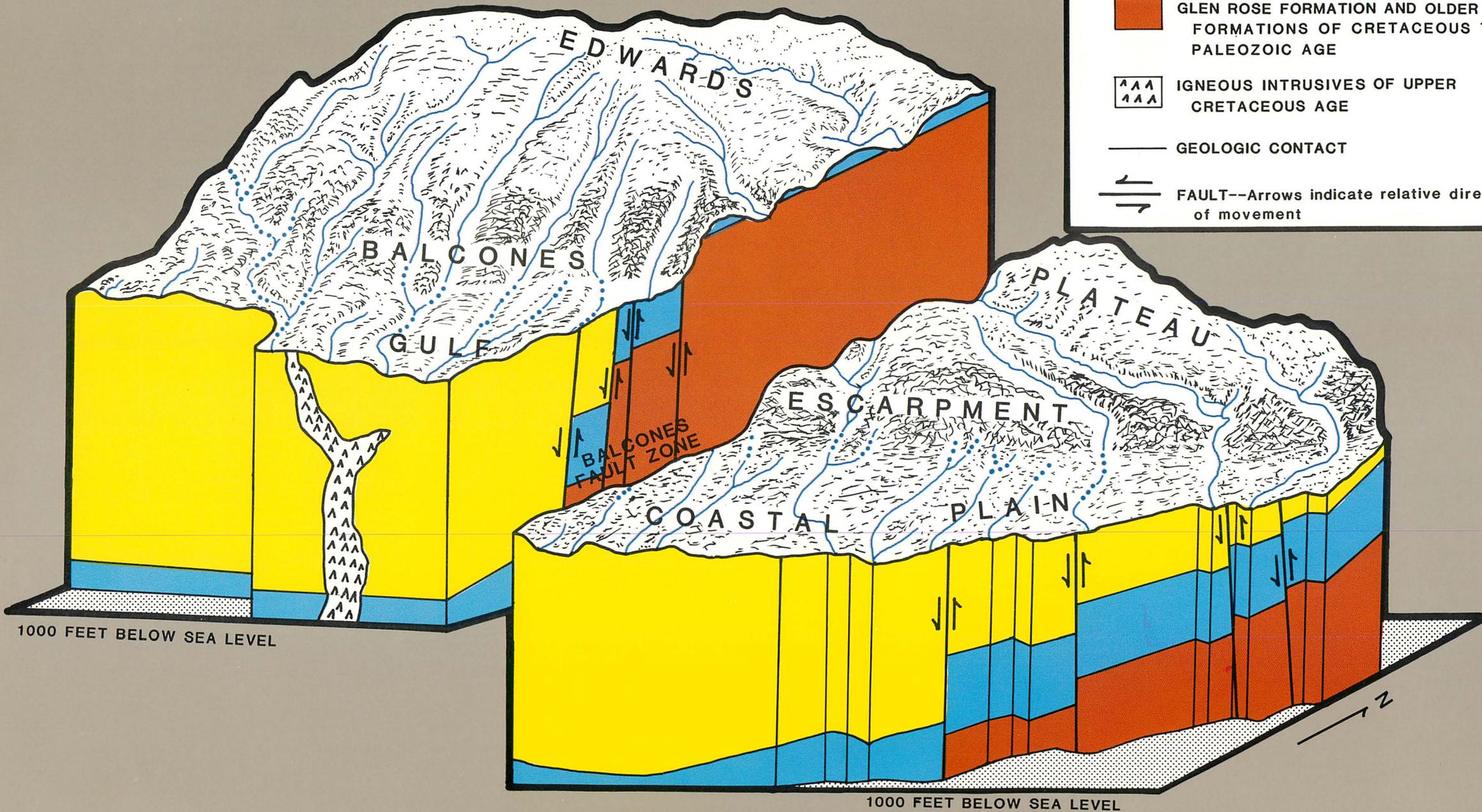
Throughout the Edwards aquifer and catchment area, evapotranspiration and streamflow vary with temperature and precipitation. In years of greater-than-average precipitation and less-than-average temperature, greater percentages of the precipitation in the catchment area will be converted to streamflow. Conversely, in years with less-than-average precipitation and greater temperatures, more of the precipitation that occurs will be lost to evaporation and less water will be available for streamflow to recharge the aquifer.

May, June, and September are the months with the greatest average precipitation. July has one of the smallest monthly averages for precipitation. These months also have high temperatures, averaging about 80° F. Only November, December, January, and February have an average temperature of less than 60° F.

THE EDWARDS LIMESTONE

EXPLANATION

- DEL RIO CLAY AND YOUNGER FORMATIONS OF CRETACEOUS TO QUATERNARY AGE
- EDWARDS LIMESTONE OF CRETACEOUS AGE
- GLEN ROSE FORMATION AND OLDER FORMATIONS OF CRETACEOUS TO PALEOZOIC AGE
- AAA
AAA IGNEOUS INTRUSIVES OF UPPER CRETACEOUS AGE
- GEOLOGIC CONTACT
- FAULT**--Arrows indicate relative direction of movement



Limestone Is The Principal Rock Of The Edwards Aquifer

The Edwards Limestone of Cretaceous age is a layered, carbonate-rock sequence that accumulated in ancient shallow seas. After the seas receded, erosion and dissolution produced solution openings and cavities in the exposed limestone. When the seas moved inland again, younger sediments were deposited on top of the Edwards Limestone.

Uplift of the Edwards Plateau and subsidence of the Gulf of Mexico produced the Balcones escarpment and fault zone. The Edwards Limestone again became exposed due to faulting and erosion, and the Edwards aquifer was formed.

A warm, shallow sea is a prerequisite for the accumulation of carbonate sediments. Marine plants and animals thrive in warm, shallow marine waters. The layered accumulations of their calcium carbonate remains become consolidated to form limestone.

As former warm, shallow seas advanced northward from the Gulf of Mexico, carbonate sediments accumulated. The seas advanced and receded in a cyclic manner from 130 to 100 million years ago. Offshore barrier reefs extended from present-day Mexico across Texas. These reefs would be similar to the present-day Great Barrier Reef off the northeastern coast of Australia. The reefs separated the deep, ancient Gulf of Mexico from the shallow lagoonal seas where carbonate material accumulated and later consolidated into the Edwards Limestone. Uplift of the area above sea level resulted in erosion that removed 100 feet or more of the deposits that were exposed to weathering. The Edwards was later covered by younger sediments as the seas moved inland again. Subsidence of the Gulf of Mexico and uplift of the Edwards Plateau produced the Balcones escarpment and fault zone, and the Edwards Limestone again became exposed to weathering action. The faulting, solution, and erosion caused voids to develop within the limestone and created the Edwards aquifer in its present form.

The Edwards Limestone is present in three general areas in the region. These areas are the Edwards Plateau to the north, the Balcones escarpment and recharge area, and the Gulf Coastal Plain to the south. On the plateau, the Edwards is exposed at land surface and has a maximum thickness of 700 feet but mostly ranges between 350 and 500 feet. Downdip from the escarpment where the Edwards crops out in the

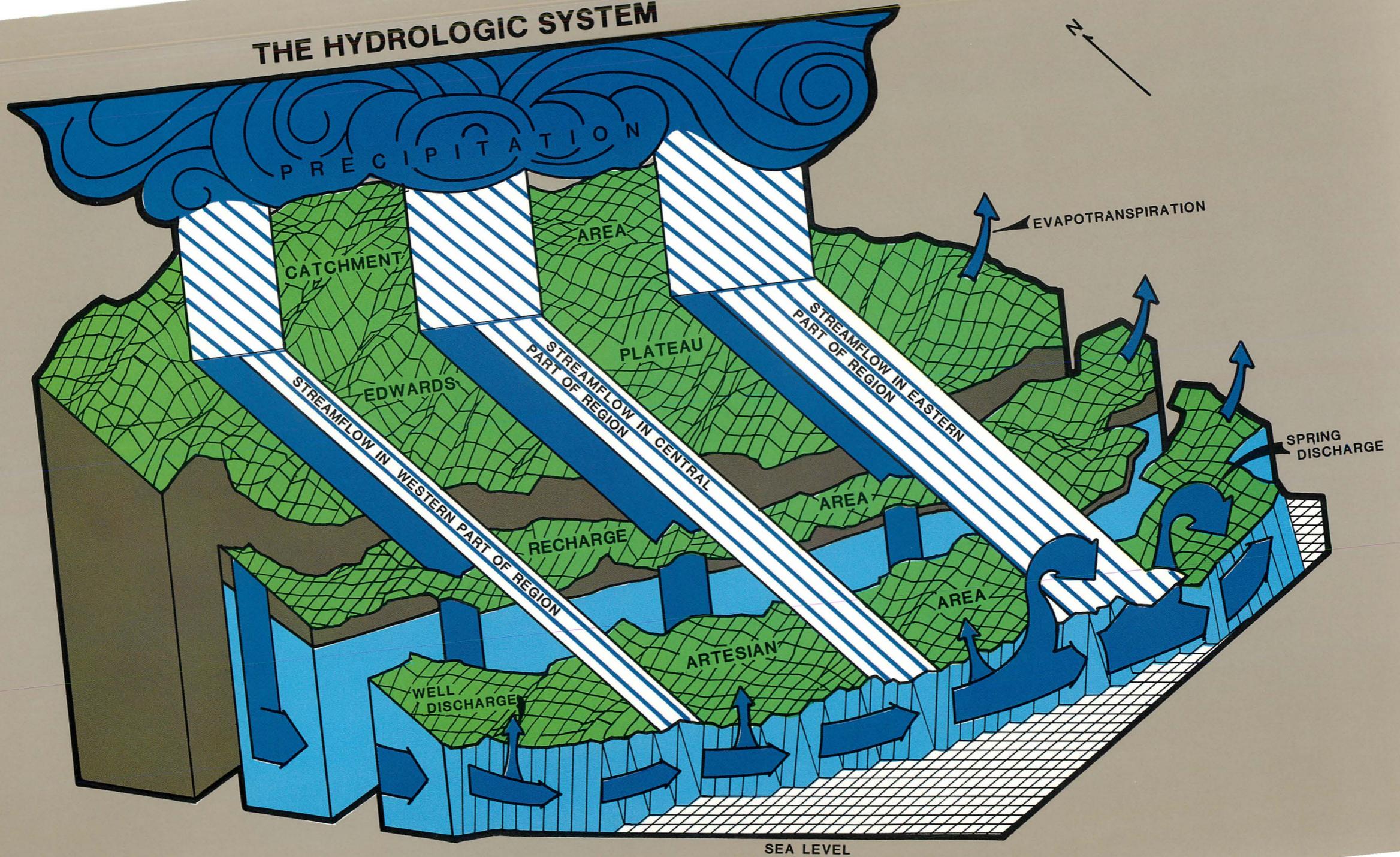
recharge area, its thickness varies from 50 to 500 feet. Beneath the Coastal Plain, the Edwards averages 500 feet thick but is 600 feet thick in some areas.

The Edwards Limestone on the Edwards Plateau is a flat-lying, thick-bedded carbonate sequence that caps most of the higher hills and ridges. Surface streams have eroded through the Edwards Limestone and exposed the underlying medium- to thick-bedded, clayey limestone of the Glen Rose Formation throughout much of the area.

Many closely spaced, steep-angle faults occur along the relatively narrow Balcones fault zone where the Edwards Limestone is exposed at land surface near the base of the Balcones escarpment. The Edwards aquifer, under both water-table and artesian conditions, occur within the Balcones fault zone. The fault zone extends from the Balcones escarpment to approximately 5 to 10 miles downdip of the "bad-water" line. The Edwards Limestone has been offset by as much as 400 feet along faults near the escarpment. As the Edwards Limestone dips steeply to the south and southeast, the horizontal distance between the faults increases.

Igneous intrusions are relatively common in the Edwards Limestone beneath the western part of the Gulf Coastal Plain area. Many of these intrusions are exposed at land surface. The Edwards Limestone, as it dips beneath the Gulf Coastal Plain, is overlain by the Del Rio Clay, which is about 50 feet thick, and by younger formations. Along the southern boundary of the area, the Edwards Limestone is overlain by as much as 2,000 feet of shale, limestone, chalk, dolomite, and unconsolidated sand and clay.

THE HYDROLOGIC SYSTEM



The Hydrologic System Is Complex With Three Major Components

The Edwards aquifer, from a regional perspective, is easily understood. The surface water flowing off the Edwards Plateau enters the aquifer through the recharge area. The water, after it is in the aquifer, moves from west to east and is discharged by springs in the eastern end of the aquifer or is intercepted by wells that penetrate the aquifer. In detail, however, the Edwards aquifer is extremely complicated with the Edwards Limestone having three different and very important roles. The limestone on the plateau stores a part of the available precipitation for later release to the aquifer. The Edwards Limestone, extensively faulted and exposed at land surface at the base of the escarpment, captures as recharge a large part of the streamflow that comes from the catchment area on the plateau. Much of this water is temporarily stored in the recharge area, which is under water-table conditions and is slowly released to move into the artesian aquifer. The limestone, which comprises the artesian part of the aquifer, has the capacity to store and move millions of gallons of water per day for man's use throughout the Edwards aquifer.

From a regional perspective, the flow in the Edwards aquifer appears to be simple. Precipitation on the catchment area is transported by streams to the Balcones fault zone, where it recharges the aquifer. The water then moves through the solution openings in the limestone toward the major springs. Water is withdrawn by wells or is discharged at the springs. From this generalized concept, the aquifer functions in an easily understood manner.

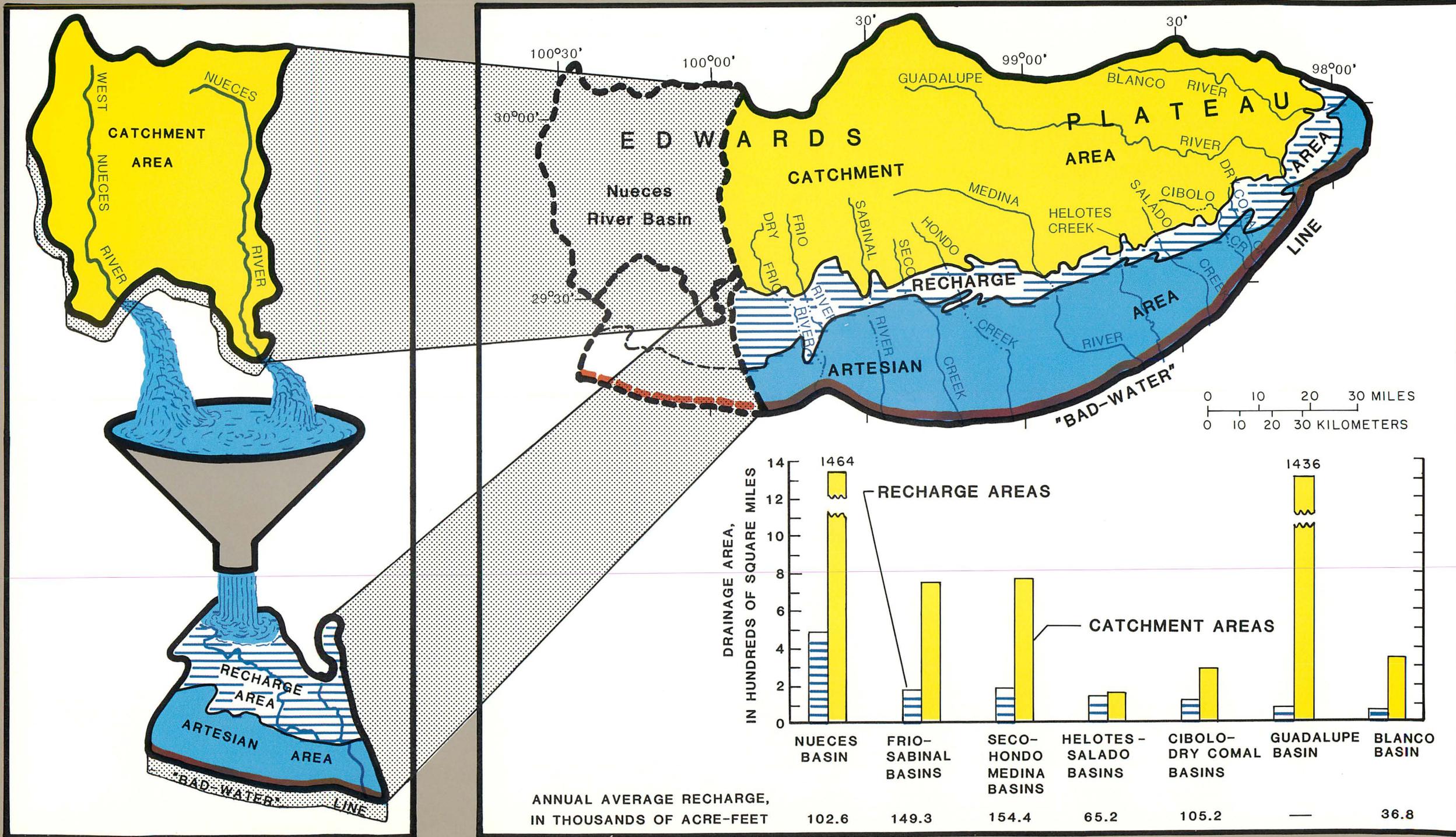
A more detailed examination of the Edwards aquifer, however, indicates that the flow is complicated. The major geologic component of the Edwards aquifer is the Edwards Limestone, which occurs in three major and distinct pieces. The first piece is the Edwards Limestone on the Edwards Plateau. The limestone here is exposed at the land surface and receives recharge directly from the infiltration of precipitation. The limestone is porous and some of the water is stored after precipitation ceases. Some of the water runs off as flood water in streams that flow across the Edwards Plateau. These streams continue to flow for long periods after storms, because the water stored in the porous limestone is slowly released to sustain the base flows of the streams. As the streams flow from the Edwards Plateau, they cross the Balcones escarpment. Many of these streams have completely eroded the Edwards Limestone near the escarpment and have their beds in the Glen Rose Formation.

The second piece of the Edwards Limestone is its exposure below the escarpment along the Balcones fault zone. As the streams cross the fault zone, much of the flow percolates through the streambed to the aquifer. During low-flow periods, virtually all streamflow is recharged to the aquifer. During higher flows, streamflow commonly exceeds the maximum recharge rate,

and much of the water flows across the recharge area to the Coastal Plain.

The final piece of the Edwards Limestone lies beneath the Gulf Coastal Plain. The Del Rio Clay and other overlying confining formations make this part of the Edwards Limestone the artesian area of the Edwards aquifer. The artesian area of the Edwards aquifer, with its many pore spaces and complex network of solution openings, has a great capacity for storing and moving water beneath the Gulf Coastal Plain. The water, after entering the aquifer, moves downdip in a southerly direction toward the coast. Before the water reaches the "bad-water" line or downdip boundary of the fresh-water part of the aquifer, its direction is deflected eastward and then northeastward toward the major springs at New Braunfels and San Marcos. Some water along this general path is pumped from wells or is discharged by flowing wells or from other springs. The direction and rate of movement of water in the aquifer are affected by the extremely complicated physical characteristics of the Edwards Limestone. Solution openings vary in size, and complicated series of steep-angle faults interrupt the movement of water. Igenous intrusions in the limestone also block the flow of water, causing local deviations in the general flow direction.

THE FUNNEL EFFECT OF THE EDWARDS PLATEAU



Drainage Basins Funnel Water To Recharge Area

The drainage basins on the Edwards Plateau funnel runoff from precipitation in the catchment areas to the recharge area of the Edwards aquifer. Without the funnel effect of the catchment area of the aquifer, recharge could be as small as one-fifth the actual recharge. Because streamflow recharges the aquifer and because only a small part of the total precipitation becomes streamflow, the funneling effect is an important facet of the Edwards aquifer.

The size of the catchment areas, the precipitation in the basins, and the characteristics of the recharge areas influence the amount of recharge to the Edwards aquifer. Streamflow from the 1,464 square mile catchment area of the Nueces River basin, the largest in the area, is funneled to a recharge area of 483 square miles. The Nueces River basin, the Frio-Sabinal basin, and the Seco-Hondo-Medina basin supply about 70 percent of the total recharge to the aquifer.

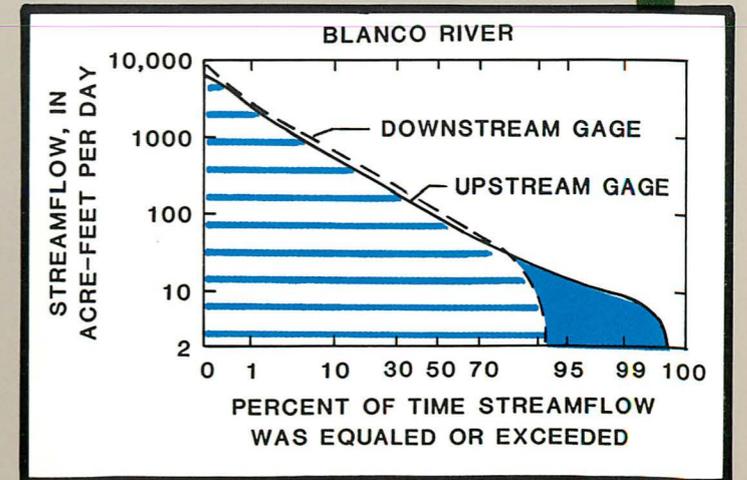
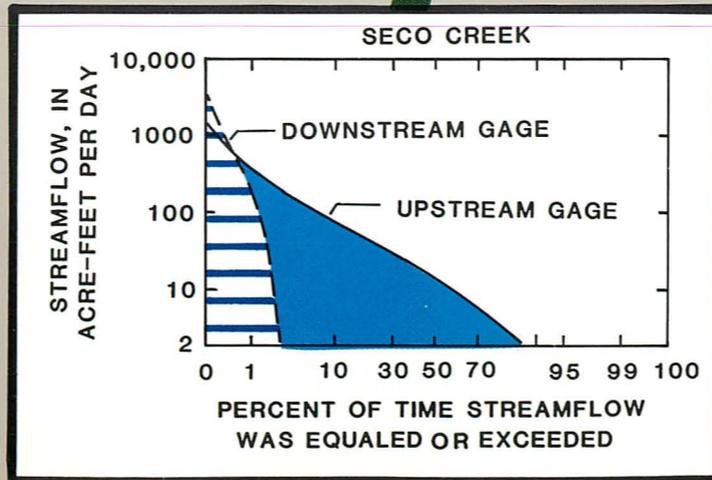
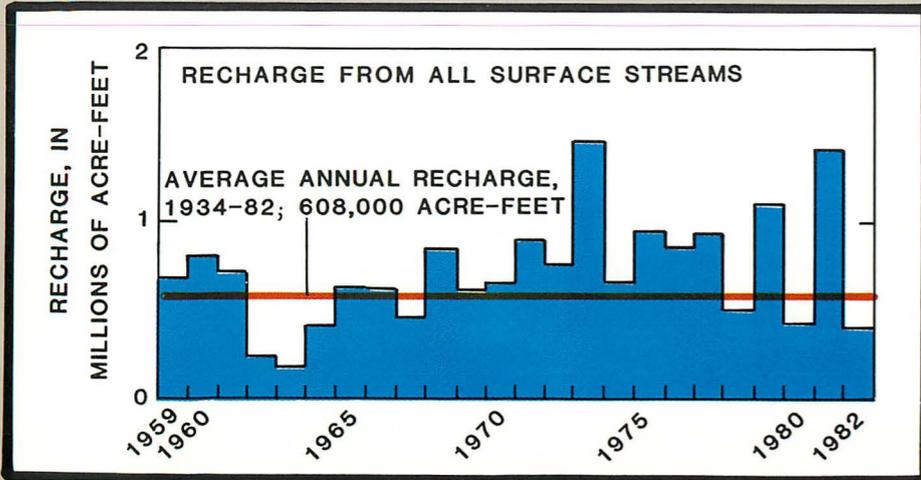
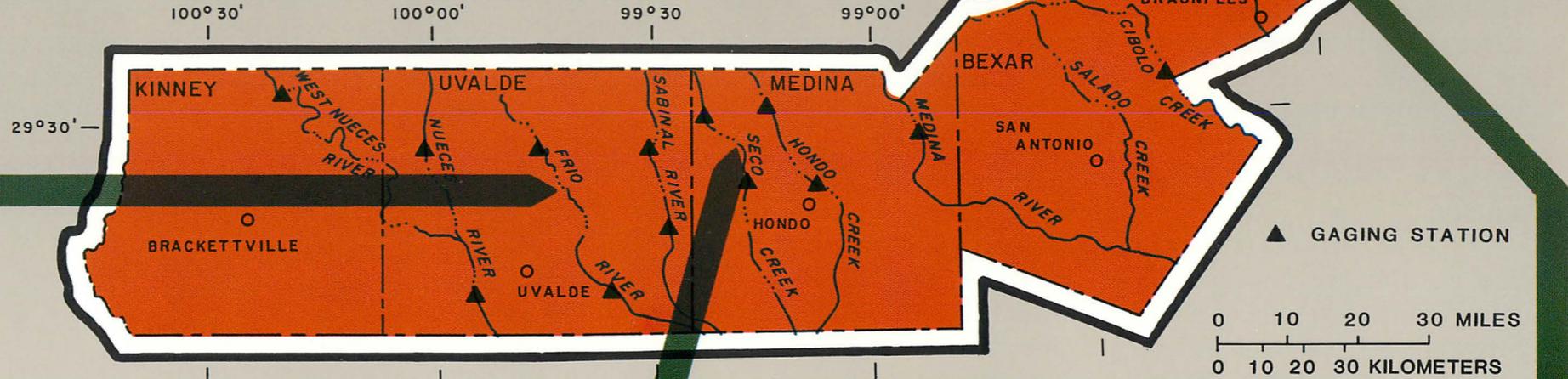
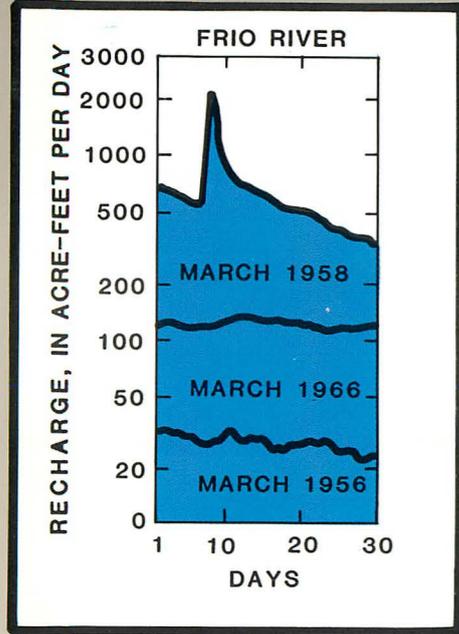
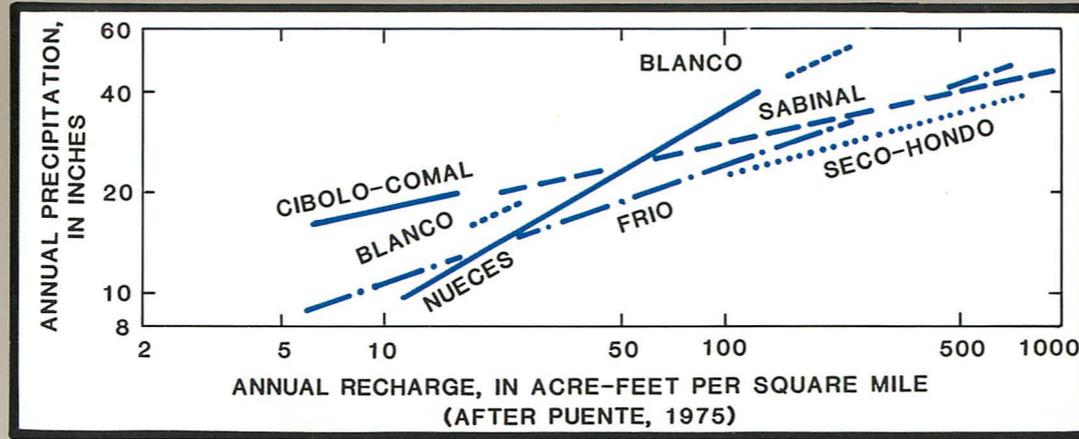
The drainage basins and streams on the Edwards Plateau function as funnels as they collect runoff through the narrow valleys, and recharge the Edwards aquifer through short losing reaches of streambed where the streams cross the recharge area in the Balcones fault zone. This funnel effect significantly increases the area contributing recharge to the aquifer because the catchment area is about four times the size of the recharge area. Eighty-five percent of the precipitation that falls on the catchment area is lost to evapotranspiration. Because the runoff from the Edwards Plateau is such a small part of total precipitation, the funneling effect of the basins and streams to concentrate the runoff in the recharge area is an extremely important facet of the Edwards aquifer.

Rates of recharge vary from stream to stream and probably are affected by various hydrologic and geologic factors, including the runoff characteristics in the part of the drainage basin that is within the recharge area itself.

The catchment areas and recharge areas vary in size for the streams that drain the Edwards Plateau and cross the recharge area of the Edwards aquifer. The size of the catchment area and the average annual precipitation are indicative of the potential availability of water for recharging the aquifer. Although the Guadalupe River has a large drainage basin, there is no evidence that it contributes significant recharge to the aquifer. The characteristics of the recharge area, particularly its size which generally is indicative of the length of the streams over the recharge areas, and the surface geology or the extent to which the Edwards Limestone is exposed in the recharge areas, are very important in governing the actual amount of recharge to the aquifer.

Although precipitation is greater in the eastern basins, the largest contributors of recharge to the Edwards aquifer are the western basins. The western basins also are characterized by larger catchment areas and larger recharge areas than those in the east. The Nueces River basin is the largest in the area with a catchment area of 1,464 square miles and a recharge area of 483 square miles. The average annual recharge from the Nueces River basin is 102,600 acre-feet of water. The Nueces River basin, the Frio-Sabinal basin, and the Seco-Hondo-Medina basin collectively have a catchment area of 2,955 square miles, which is about 60 percent of the total catchment area of the streams from the Edwards Plateau which cross the recharge area of the Edwards aquifer. These three basins supply about 70 percent of the total recharge to the aquifer, which illustrates their importance, and the importance that the recharge areas have, in replenishing the Edwards aquifer.

REPLENISHMENT OF WATER IN THE AQUIFER



Edwards Aquifer Recharged By Losing Streams

Recharge to the aquifer is calculated using records of streamflow-gaging stations located upstream and downstream from the recharge area and estimated precipitation in the recharge area. Minimum recharge to the aquifer occurred during 1956 when precipitation was less than normal. The maximum recharge to the aquifer occurred during 1958 when precipitation was much more than normal. The average annual recharge to the aquifer from 1934 to 1982 has been 608,000 acre-feet. However, recharge has been as little as 43,700 acre-feet and as much as 1,711,000 acre-feet in a given year. During an extended 10-year drought ending in 1956, the recharge averaged 229,000 acre-feet per year. Comparing that period with the wet years of the 1970's when the average recharge was 919,000 acre-feet per year, it can be seen that recharge can vary significantly from decade to decade. The basins in the eastern part of the catchment area of the Edwards Plateau receive more precipitation than the basins in the western part, but they do not necessarily produce more recharge per square mile. Factors such as hydrologic and geologic characteristics of the recharge area plus length of stream reach in the recharge area affect the capacity of the system to accept the water available for recharge. Such information would be valuable if recharge enhancement is to be considered.

Recharge is determined by comparing streamflow records collected at sites upstream and downstream from the recharge area. Recharge calculations are further refined by estimates of precipitation occurring in the recharge area. Relationships between precipitation and recharge have been developed for the major drainage basins that contribute recharge to the Edwards aquifer (Puente, 1975).

The calculated annual recharge to the Edwards aquifer since 1934 has ranged from 43,700 to 1,711,000 acre-feet. The average annual recharge to the aquifer for 1934-82 is 608,000 acre-feet.

Recharge from the Frio River exceeded 2,000 acre-feet on 1 day in March 1958. This volume probably is about the maximum possible 1-day recharge for any of the recharge basins. During March 1956, the recharge rate of the Frio River averaged less than 30 acre-feet per day.

Flow-duration curves for Seco Creek and Blanco River at streamflow stations upstream and downstream from the recharge areas show that the capacity of the aquifer to accept recharge varies areally. The considerable divergence of the curves for Seco Creek indicates that most of the flow is lost in the recharge area of the Edwards aquifer. The negligible divergence of curves for the Blanco River, except during low flow, indicates that a large percentage of water flows across the recharge area for this stream instead of entering the aquifer. Why the Edwards aquifer does not accept a larger volume of the Blanco River flow is not fully understood, but may be attributed to different characteristics of the Edwards Limestone in the recharge area or to relatively high water levels in the Edwards aquifer near the river.

The streamflow data indicate that additional water from streams would be recharged to the aquifer if part of the flow during floods could be temporarily stored upstream from the losing stream reach and released at a later time to flow across the Edwards aquifer recharge area. The average annual recharge from the late 1940's through the drought of the 1950's was 229,000 acre-feet. Comparing this with the average annual recharge of 919,000 acre-feet from 1972 to 1981 indicates that much less than or much more than the long-term average recharge can occur for a number of consecutive years. Recharge less than the long-term average occurred in only 3 of the years from 1970 to 1982, and water from the aquifer was abundant. However, concern exists about the consequences if a drought, similar to that of the 1950's, were to occur with today's (1986) demand for water.

Various stream-channel characteristics, particularly lengths and widths of stream reaches in the recharge area have an effect on recharge capability (Welder and Reeves, 1964), and various features in the drainage basin affect the quantity of water that is available for recharge from each square mile of drainage area. By relating precipitation to recharge volumes per square mile of drainage area, some indication of the efficiency of recharge for each of the streams can be shown. The efficiencies and recharge capacity will be valuable in consideration of recharge enhancement. The Nueces-West Nueces River basin appears to be most efficient during very dry conditions. In years of greater precipitation, the Seco-Hondo-Medina basin has the greatest recharge per square mile of drainage area.

RECHARGE ENHANCEMENT

CATCHMENT AREA

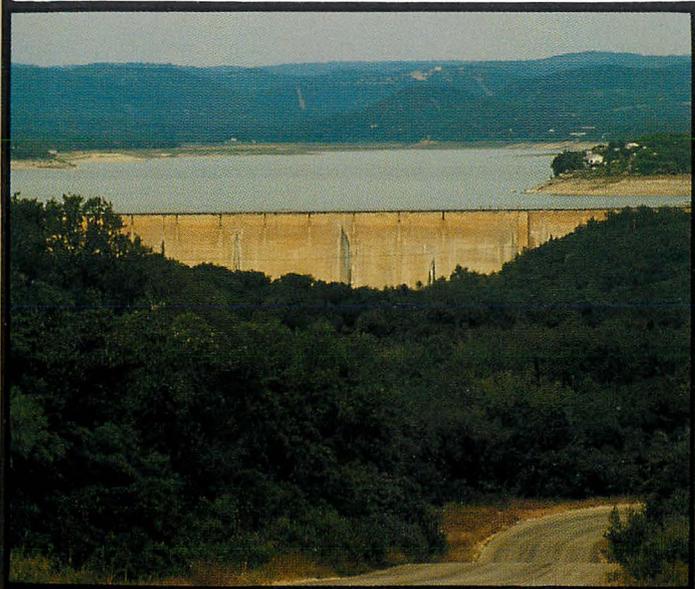
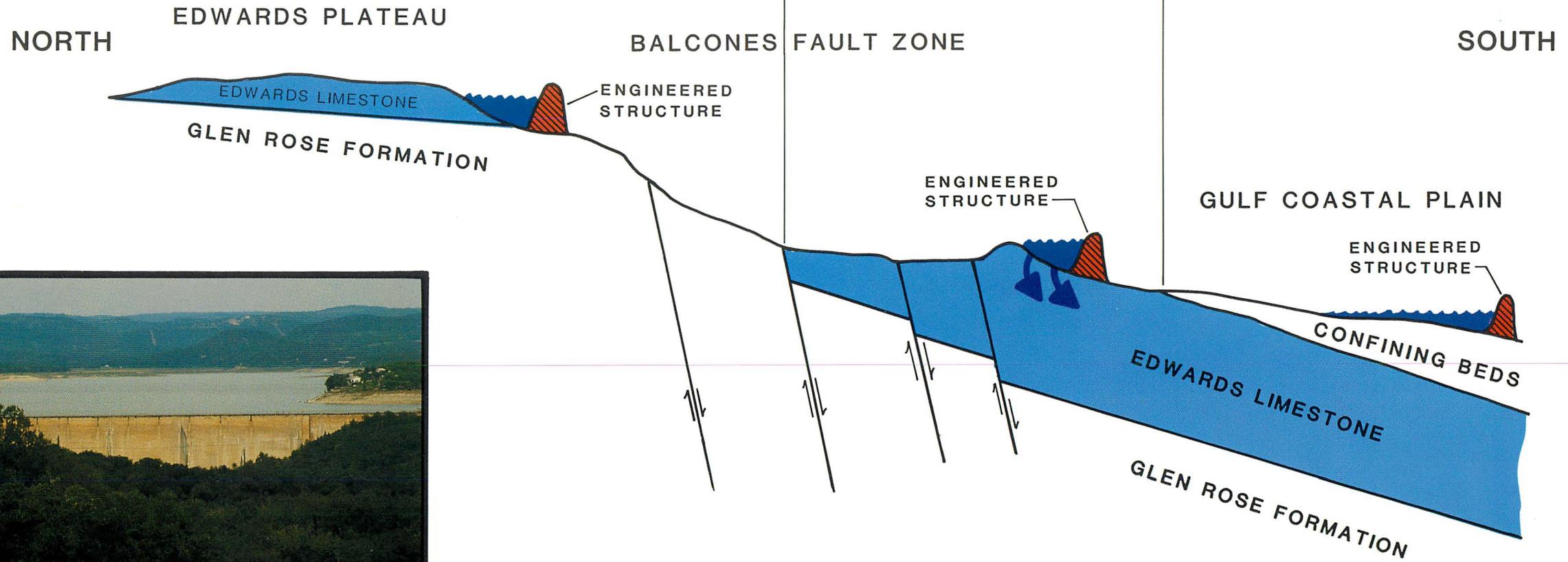
DURING MANY STORMS, RUNOFF FROM THE CATCHMENT AREA IS OF SUCH MAGNITUDE THAT MUCH OF IT FLOWS ACROSS THE RECHARGE AREA WITHOUT PERCOLATING TO THE AQUIFER. ANY TYPE OF ENGINEERED STRUCTURE THAT HOLDS OR RETARDS RUNOFF ON THE PLATEAU SERVES TO PREVENT EXCESSIVE RUNOFF FROM FLOWING BEYOND THE RECHARGE AREA, AND THUS INCREASES RECHARGE TO THE AQUIFER.

RECHARGE AREA

ENGINEERED STRUCTURES THAT HOLD OR RETARD RUNOFF IN THE RECHARGE AREA ARE THE MOST BENEFICIAL FOR RECHARGE ENHANCEMENT.

ARTESIAN AREA

ENGINEERED STRUCTURES BUILT IN THE ARTESIAN AREA DO NOT ENHANCE RECHARGE TO THE EDWARDS AQUIFER. THE SERIES OF ROCKS ABOVE THE EDWARDS LIMESTONE DO NOT READILY TRANSMIT WATER, AND SERVE AS CONFINING BEDS TO THE EDWARDS AQUIFER.



Engineered Structures Can Increase Recharge

Medina Dam and Lake, which were constructed to supply water for irrigation, were inadvertently the first recharge structures built that enhanced recharge to the Edwards aquifer. Smaller dams, which add recharge to the aquifer, have since been constructed across streams by Uvalde County and the Edwards Underground Water District. The U.S. Army Corps of Engineers has prepared engineering surveys for the construction of reservoirs to retain floodwaters upstream from the recharge area, but currently none are under consideration for construction. Drawbacks to the recharge dams include cost, periodic flooding behind the dam, increased potential for contaminated water to enter the aquifer, and decreased streamflow during floods that help fulfill water needs near the Texas coast.

Dams have been constructed on the recharge area of the Edwards aquifer since the early 1900's. For the most part, the dams have been effective in enhancing recharge to the aquifer. Any type of engineered structure on or upstream from the recharge area that retards runoff will increase recharge.

Medina Dam and Lake on the Medina River were constructed as an irrigation project in 1913 with private monies. The dam was constructed down-dip from the Glen Rose Formation-Edwards Limestone contact and was, inadvertently, the first Edwards aquifer recharge structure. The long-term average recharge to the Edwards aquifer from Medina Lake is 59,000 acre-feet per year. The maximum calculated recharge from the lake to the aquifer was 104,000 acre-feet during 1960, and the minimum recharge was 6,300 acre-feet during 1956.

During the 1950's, the residents of Uvalde County funded the construction of small dams on many streams crossing the Edwards aquifer recharge area to increase recharge. These structures still serve the intended purpose. The Edwards Underground Water District also has supported the construction of dams to increase recharge to the Edwards aquifer. Various other reservoir structures, built by individuals or by the U.S. Soil Conservation Service for other purposes, also enhance recharge to the aquifer.

The U.S. Army Corps of Engineers has prepared engineering surveys for the construction of several dams on streams where floodwaters could be retained upstream from the recharge area and released during time of need to sustain the base flow of the river and to recharge the Edwards aquifer (U.S. Army Corps of Engineers and Edwards Underground Water District, 1964). Construction of these dams has not been started. Probably the greatest recharge

from such structures would occur when water levels in the aquifer are very low. Enhancement of recharge would require very large reservoirs on the Edwards Plateau to retain enough flood runoff for recharge to continue long after a drought had commenced.

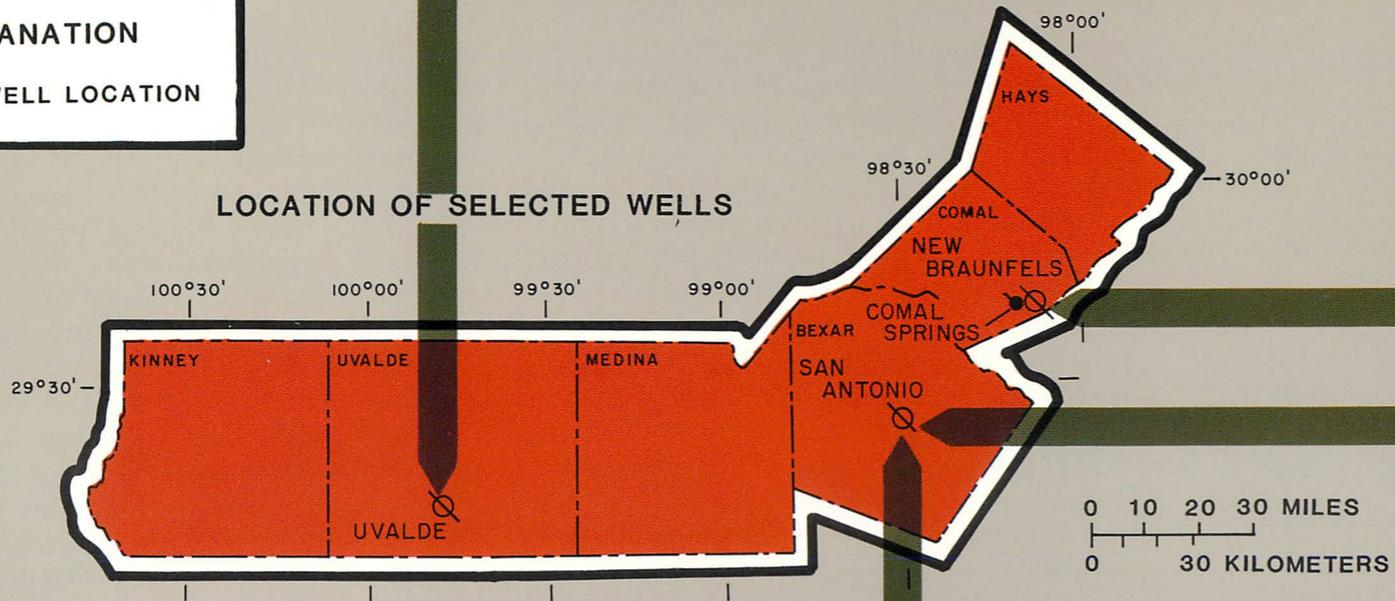
Drawbacks to construction of recharge dams include the cost of construction and land acquisition, periodic flooding behind the dam, increased potential for contamination of recharge water, and decreased streamflow to downstream users during flood runoff. The effectiveness of the recharge structures in increasing recharge also needs to be considered. Flow and pressure transmission within the Edwards aquifer is very rapid. Gains in recharge to the aquifer may be somewhat offset by increases in springflow.

The potential for water-quality degradation associated with impoundments also needs to be considered. Under natural conditions, the quality of water recharging the Edwards aquifer is nearly the same as that contained in the aquifer. Water stored in large reservoirs could change in quality as a result of stratification and be different from the water in the Edwards aquifer. Reservoirs attract recreation and development that increase the potential for contamination of the recharge water.

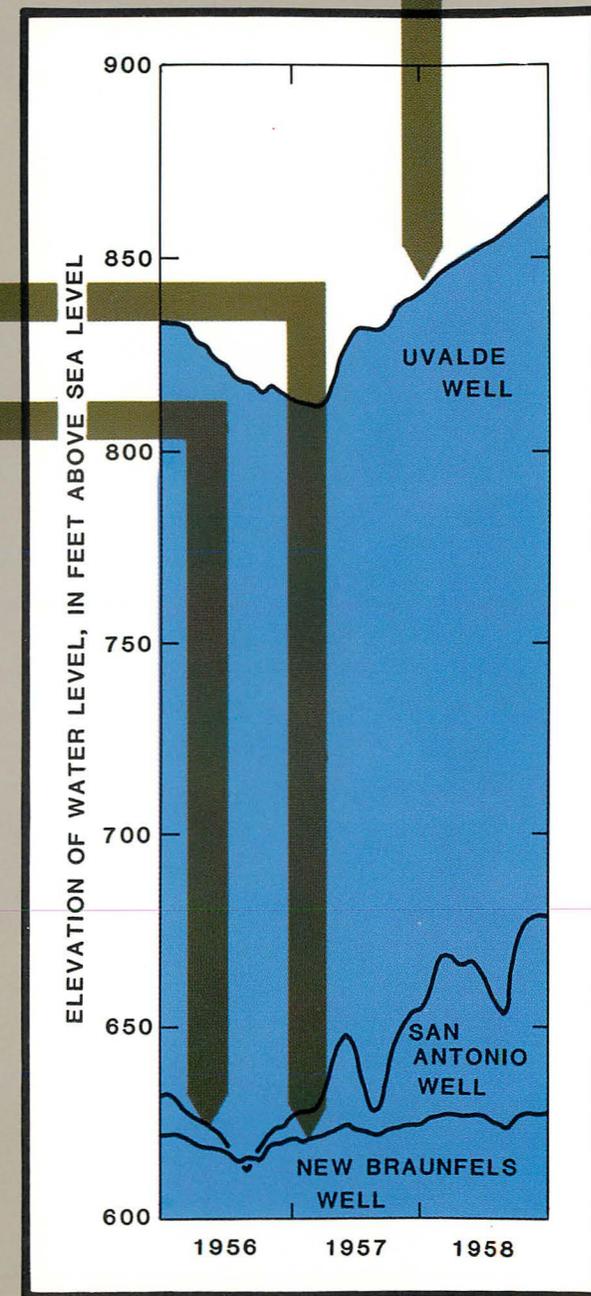
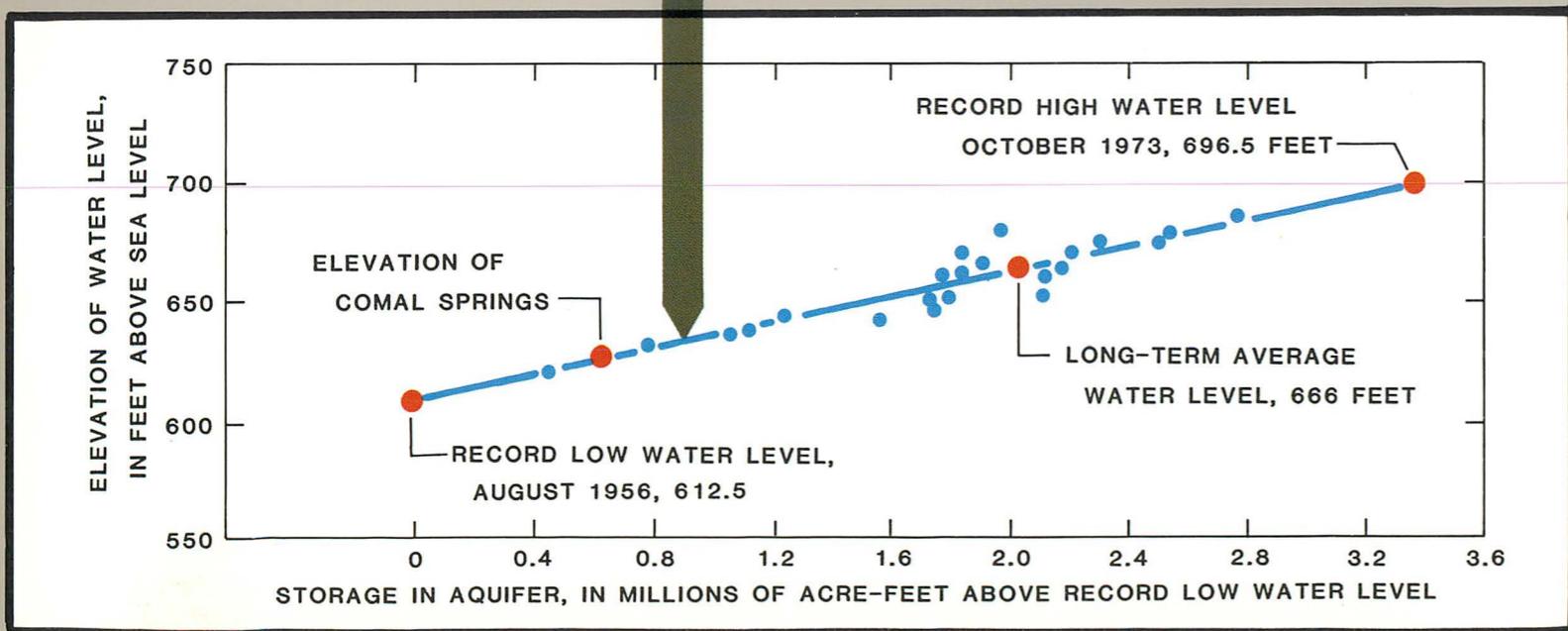
Water users downstream from the area of the Edwards aquifer rely on floodwaters to flush bays and estuaries and to fill reservoirs for municipal, industrial, and agricultural needs. Recharge structures could decrease that supply. Before recharge enhancement is implemented on a large scale, the effect on downstream users needs to be considered and an accord reached in sharing the water resource.

THE AQUIFER STORES WATER

EXPLANATION
 INDEX WELL LOCATION



RELATIONSHIP BETWEEN AQUIFER STORAGE AND WATER LEVELS IN SAN ANTONIO INDEX WELL



WATER LEVELS IN SELECTED INDEX WELLS

Changes In Storage Are Reflected By Fluctuations In Water Level

About 3 million acre-feet of water is stored in the Edwards aquifer between the elevations of the record low and record high water levels in the San Antonio index well. The volume of water in storage below the record low is unknown and cannot be projected with confidence. Water levels throughout the Edwards aquifer have the same general response to climatic extremes and pumping, but the timeliness and rate of response varies. For example, at the end of a 10-year drought in 1956, water levels in the San Antonio area began to rise, whereas water levels in Uvalde declined for an additional 7 months indicating that water was continuing to be released from storage in the west to replenish the water previously removed from storage in the eastern part of the aquifer.

When total discharge from the aquifer exceeds total recharge, water is removed from storage and water levels in the aquifer decline. The extreme case for the Edwards aquifer occurred in 1956, near the end of a 10-year drought, when the water levels in the aquifer reached a stage that Comal Springs ceased to flow for about 5 months.

About 3 million acre-feet of water is stored in the Edwards aquifer between the elevations of the record low and record high water levels in the San Antonio index well. The volume of water stored in the Edwards below the record low water level of 612.5 feet above sea level is unknown and cannot be projected with confidence. If new water-level lows are reached, the storage below 612.5 feet can be calculated and better estimates of total volume in storage can be made.

The water levels in different parts of the area have the same general response to climatic extremes and pumping stresses, but the timeliness and rate of response varies. For example, at the end of a 10-year drought in 1956, the record low water level in the San Antonio and New Braunfels index wells occurred in August 1956. Water levels in the Uvalde index well continued to decline for an additional 7 months until March 1957, when its record low water level was reached. This difference in reaction time resulted from differences in local recharge and discharge and from movement of ground water toward springs and toward localized cones of depression caused by well pumping. Water levels in the San Antonio area began to rise in the fall of 1956 after a small quantity of rainfall, which resulted in a decrease in water use and possibly some recharge. The continued decline of water levels in the Uvalde index well indicates that water continued

to move out of the Uvalde area for 7 months toward the cone of depression east of Uvalde.

Ground Water In Artesian Area Moves Toward The East

Water in the Edwards aquifer moves south from the recharge area into the artesian area and then from west to east and northeast toward the larger springs. In the recharge area and in the artesian part of the aquifer to the west, water does not move as easily through the aquifer as it does in the eastern part of the aquifer. Water moves most freely through the aquifer where the size and number of solution openings are large and restrictions are few. The water-level gradient in the aquifer is the driving force that pushes water through the system. The ability of an aquifer to yield small or large quantities of water to wells is dependent on how freely water can move through the aquifer and on the thickness of the aquifer that is saturated with water. Wells that are completed in the Edwards aquifer vary in yield and some wells in San Antonio were known to flow 18,000 gallons per minute.

Ground water moves by gravity from recharge areas to discharge areas, or from areas where water levels are at higher elevations to areas where water levels are at lower elevations. The water-level surface indicates the general direction of water movement in the Edwards aquifer. In the recharge area, the water-level gradient is steep and ground water generally moves to the south and southeast. In the artesian area, the gradient is relatively flat and ground water moves to the east and northeast. Faults, igneous intrusions, or substantial decreases in void space in the aquifer locally may alter the regional flow directions.

The ability of the Edwards aquifer to accept recharge water and to move that water eastward to the springs is dependent on the regional aquifer characteristics. These aquifer characteristics usually do not change with time, but groundwater levels can vary greatly with time. For example, water levels in the Sabinal index well rose 155 feet between 1955, when the minimum discharge from the aquifer was recorded, and 1977, when the maximum discharge from the aquifer was recorded. During the same time, water levels in the San Antonio index well rose only 38 feet. The rising water levels increase the gradients, thereby creating a driving force to push the water through the aquifer. During 1977, when 960,900 acre-feet of water moved through the aquifer, the gradient was about 2.2 feet per mile. During 1955, when 388,800 acre-feet of water moved through the aquifer, the water-level gradient was only 0.6 foot per mile.

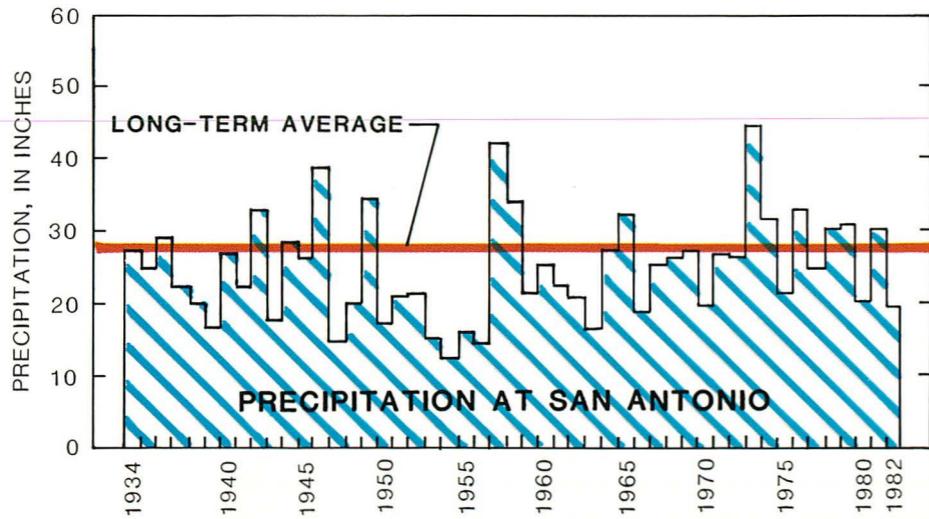
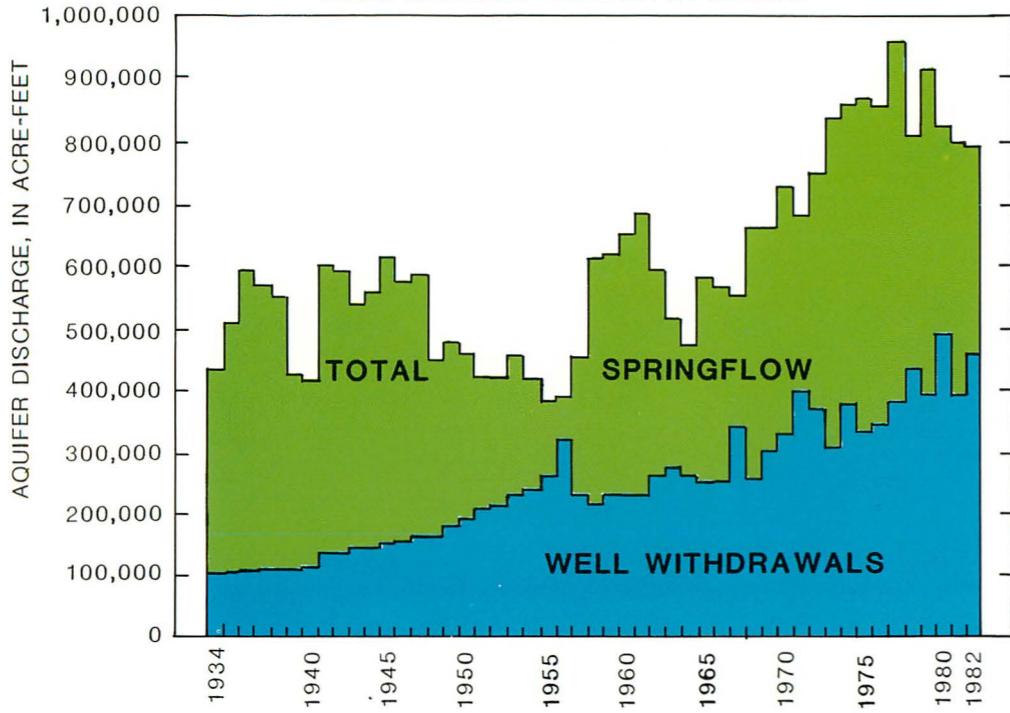
The ability of an aquifer to yield large or small quantities of water to wells is dependent on how freely water can move through the aquifer and on the thickness of the aquifer that is saturated with water. The part of the aquifer with

the greatest pore space and the largest yielding wells is a relatively narrow band from near San Antonio northeastward through the vicinity of the two largest springs. Wells in this band commonly yield water at rates of 6,000 to 7,000 gallons per minute. Wells in the northern and western parts of the aquifer produce much less water, and wells that produce only several gallons per minute are common in northern Bexar County. Also, wells north of the "bad-water" line that pump freshwater usually have significantly greater yield than do wells south of the "bad-water" line that pump salinewater.

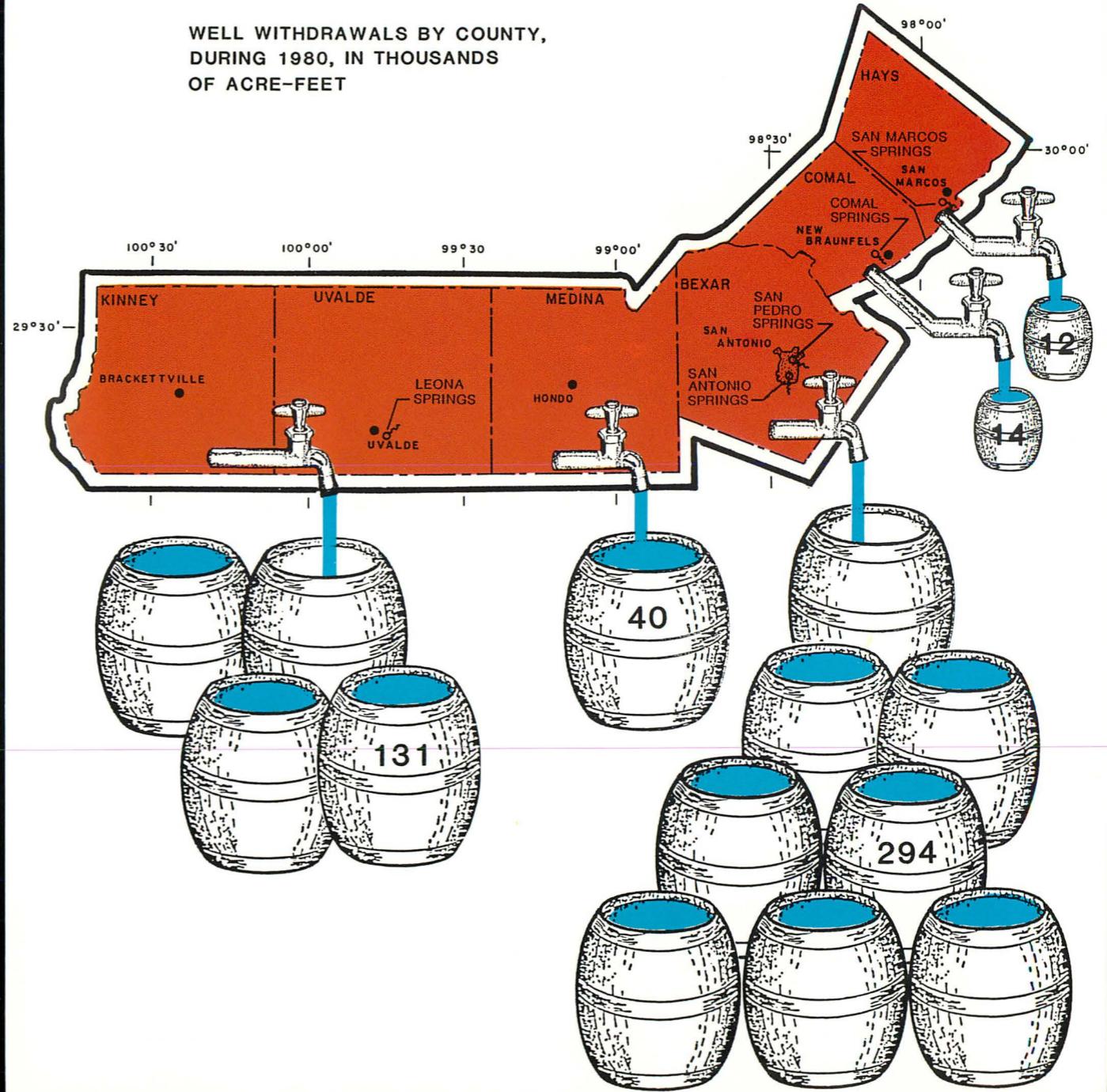
Some wells in the San Antonio area have flowed at rates of as much as 18,000 gallons per minute. Some parts of the artesian area contain wells that flow because the artesian pressure heads are several feet to tens of feet above the land surface. It is possible to fill storage tanks or to irrigate land without lifting the ground water by pumps to the land surface. In this regard, the aquifer truly delivers water to the user.

AQUIFER DISCHARGE

TOTAL SPRINGFLOW AND WELL WITHDRAWALS FROM EDWARDS AQUIFER IN REGION



WELL WITHDRAWALS BY COUNTY, DURING 1980, IN THOUSANDS OF ACRE-FeET



Edwards Aquifer Discharged By Wells And Springs

Water is discharged from the Edwards aquifer almost entirely by pumped and flowing wells and by springs. Well withdrawal has averaged 417,000 acre-feet per year since 1970. Maximum well withdrawal was 491,000 acre-feet during 1980. Well withdrawal is greatest in Bexar County where 294,000 acre-feet were withdrawn during 1980. Total springflow has averaged about 350,000 acre-feet per year since the 1940's, with Comal and San Marcos Springs contributing 95 percent of the flow. Long-term average discharge is 591 acre-feet per day from Comal Springs and 329 acre-feet per day from San Marcos Springs. Both the volume of water withdrawn from wells and by springflow are related to the occurrence of precipitation. During droughts, well withdrawals dominate aquifer discharge; during wet years, springflow generally exceeds well withdrawal. The permeability of the aquifer allows water to flow easily through the aquifer to pumping or flowing wells or to springs. Although this is conducive to the development of productive wells, it also causes relatively rapid depletion of water in storage during years when precipitation is less than average.

Water is discharged from the Edwards aquifer by wells and by springflow. Because the water throughout much of the aquifer is more than 100 feet below land surface, ground-water discharge through evapotranspiration is negligible.

The first well was dug into the Edwards aquifer in 1865; presently the aquifer supplies some of the largest yielding wells in the world. Annual well withdrawals from the aquifer have increased greatly since the introduction of turbine pumps and has averaged about 417,000 acre-feet since 1970. The maximum volume of water withdrawn annually was 491,000 acre-feet during 1980.

Well withdrawals vary significantly from county to county in the area. During 1980, the year of maximum total well withdrawals, about 294,000 acre-feet of water was pumped in Bexar County. In Uvalde County, well withdrawals were about 131,000 acre-feet. The other counties had less pumpage from wells. In addition to well withdrawals, flow from Comal Springs during 1980 was 184,000 acre-feet and flow from San Marcos Springs during 1980 was 86,000 acre-feet. Leona Springs at Uvalde discharged 17,000 acre-feet during 1980.

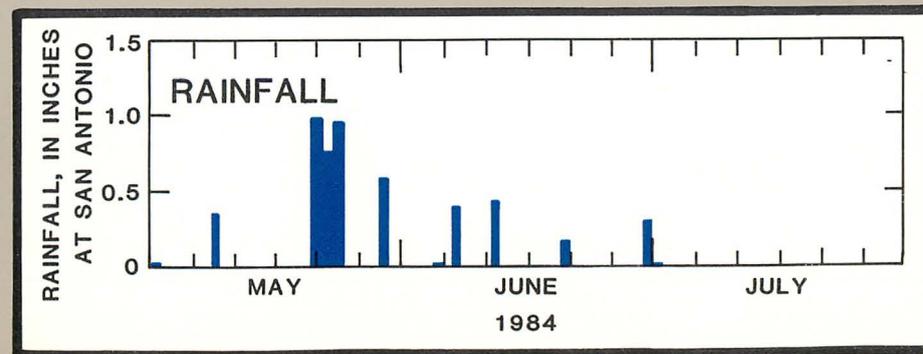
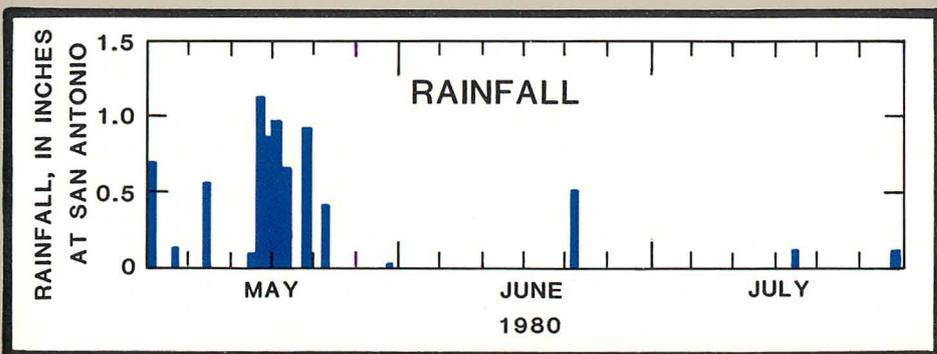
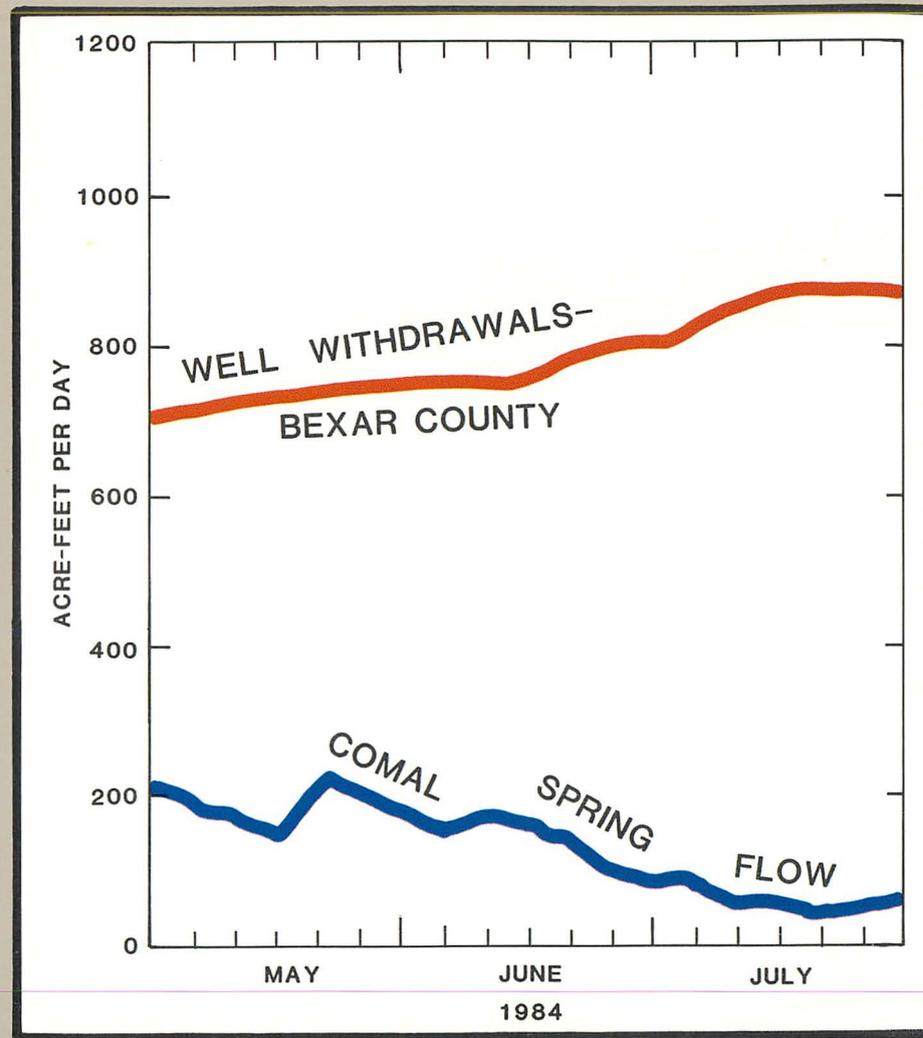
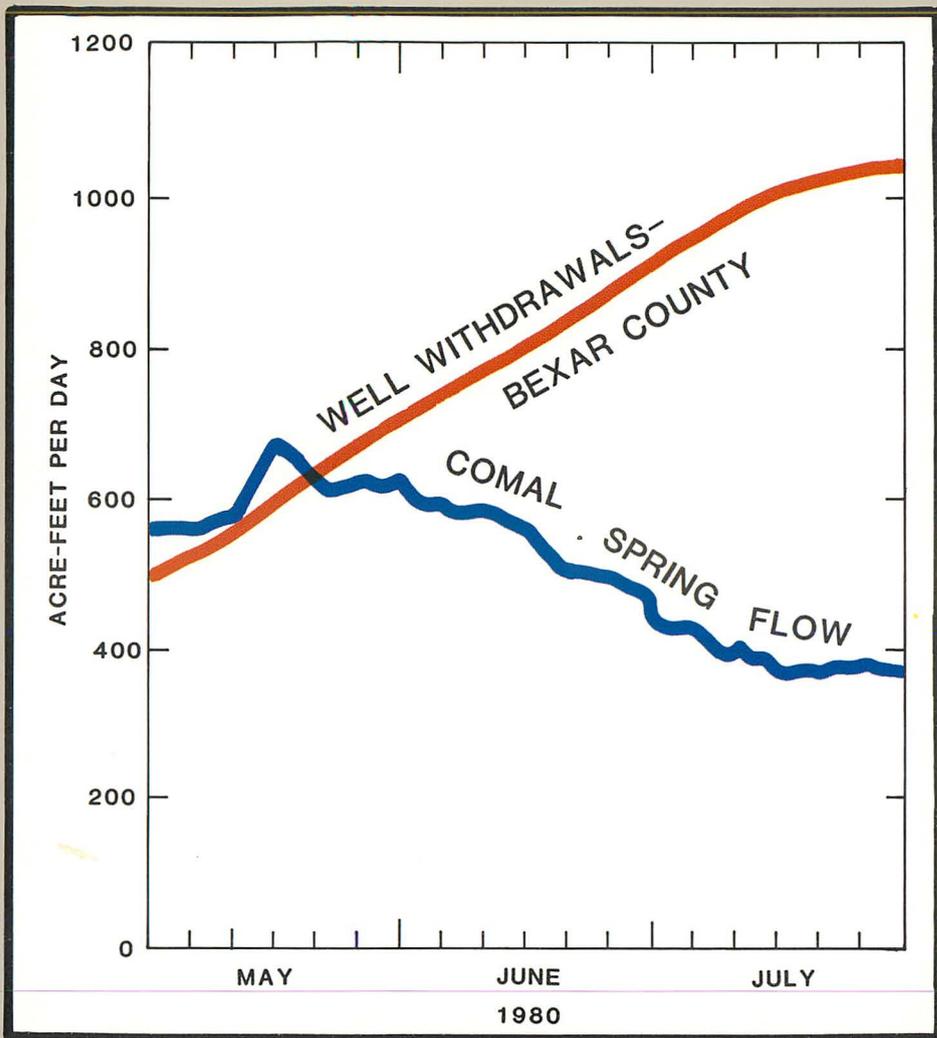
Total springflow from Comal, San Marcos, San Pedro, San Antonio, and Leona Springs averaged about 350,000 acre-feet per year for the past 40 years, with Comal and San Marcos Springs contributing about 95 percent of the flow. Graphs of precipitation and discharge show that the volume of springflow is correlated to precipitation. The large rate of springflow during the 1970's resulted from the greater-than-normal precipitation during the period. The small rate of springflow during the 1950's resulted from drought conditions.

The long-term average discharge is 591 acre-feet per day from Comal Springs and 329 acre-feet per day from San Marcos Springs. These two springs, which are natural outlets in the aquifer, have continued to flow except for a short time during the 1956 drought, when Comal Springs ceased flowing. The flow of San Antonio Springs has been measured intermittently since 1958; the largest measured discharge was 295 acre-feet per day in 1977. The largest measured discharge from San Pedro Springs was 34 acre-feet per day in 1977. During 1983, San Antonio and San Pedro Springs flowed about 25 percent of the time. Leona Springs flows as much as 159 acre-feet per day when water levels are high at Uvalde.

Data collected since the mid-1950's indicate that a correlation exists between precipitation and the volume of water withdrawn from wells. During years of greater-than-average precipitation, well withdrawals tend to decrease, and when annual precipitation is deficient, well withdrawals generally are greater. This indicates that a large part of the well water withdrawn is used for irrigation by the farming population and for lawn watering by home owners.

The permeability of the Edwards aquifer allows the recharge water to move easily through the aquifer to a point where it can be withdrawn through wells or discharged by springs. However, in one sense the aquifer transmits water almost too easily; the water in storage can be depleted very quickly through discharging wells and springs if precipitation is less than normal for a relatively short period.

WELL WITHDRAWALS CAN DEplete SPRINGS



Well Withdrawals Can Deplete Springs

Discharge from Comal and San Marcos Springs is related to water levels within the Edwards aquifer. Water levels in the aquifer are the result of recharge to the aquifer from precipitation and the volume of water being discharged from the aquifer. Major discharge points are Comal Springs, San Marcos Springs and the many wells that have been completed in the Edwards aquifer for municipal, industrial, and irrigation use. In recent years, the well withdrawals in Bexar County were more than 1,000 acre-feet per day during peak demand, and discharge from Comal Springs was decreased to less than 100 acre-feet per day. If well use ceased, part of that 1,000 acre-feet per day would be discharged by the springs.

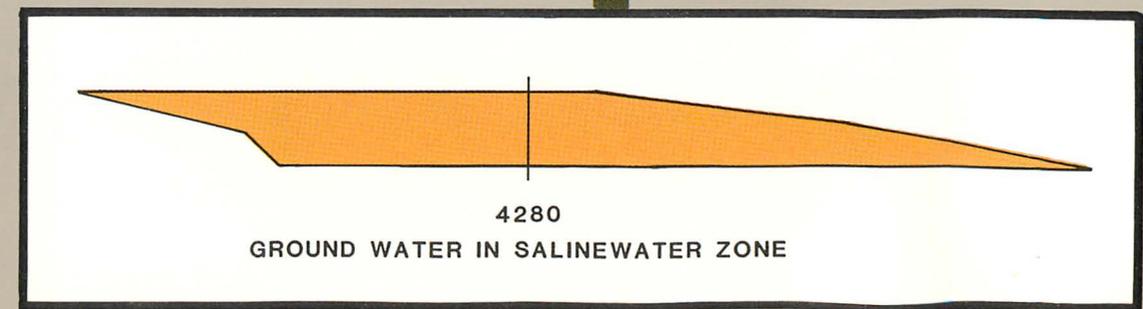
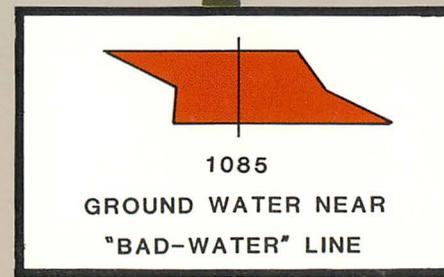
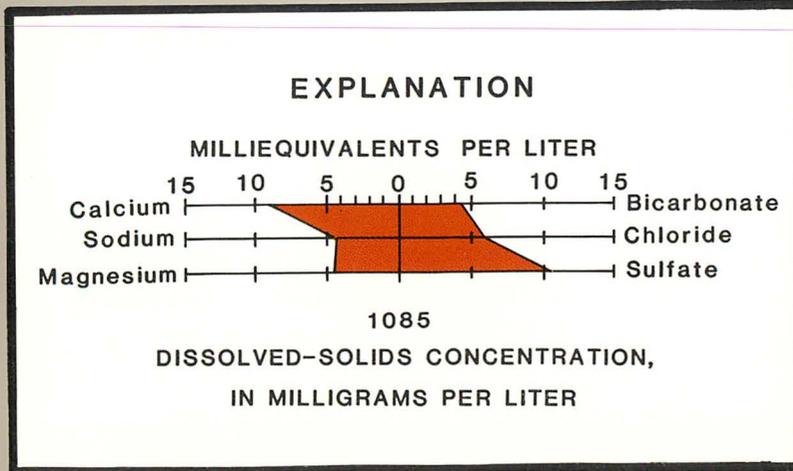
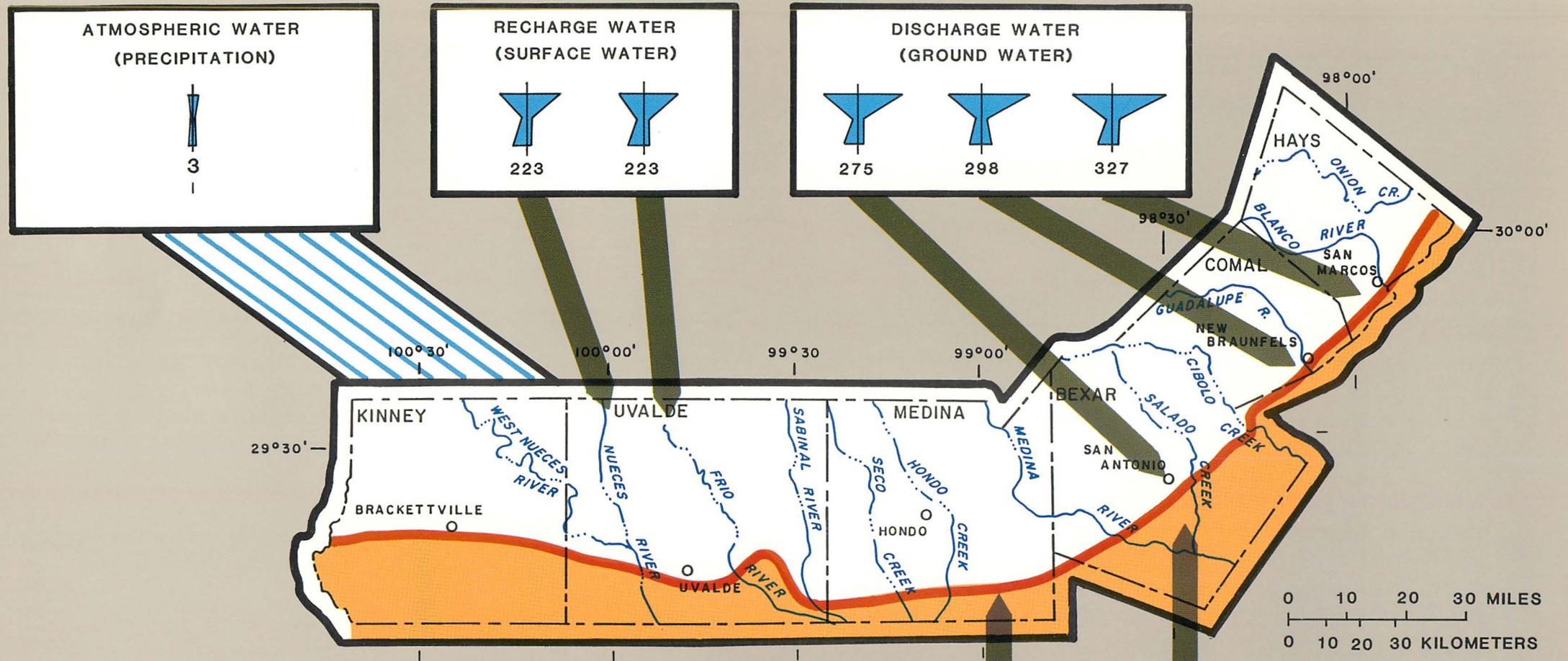
The water obtained from the first well that was completed in the Edwards aquifer started a decrease in springflow from the Edwards aquifer. San Antonio and San Pedro Springs flowed continuously most of the time until about 1945. They stopped flowing for long periods when the artesian head of the aquifer was significantly lowered by increased withdrawal of water by wells. The increase in well withdrawals reflects the rapid increase in population and the increase in demand for water after World War II.

Water-level fluctuations in the aquifer result from differences in recharge and discharge rates of the aquifer. Drought conditions produce noticeable declines in water levels, and the summers of 1980 and 1984 were among the driest in the past decade. At the beginning of May 1980, the water level in the San Antonio index well was about 670 feet above sea level and the flow from Comal Springs was about 600 acre-feet per day. Because of the lack of rainfall in June and July, well withdrawals in Bexar County increased from about 500 acre-feet per day in May to more than 1,000 acre-feet per day in July. The increase in well withdrawals from the aquifer and resulting decline in water levels decreased the flow from Comal Springs to less than 400 acre-feet per day. In May 1984, the water level in the San Antonio index well was about 634 feet above sea level and the flow from Comal Springs was about 200 acre-feet per day. Because of less-than-normal rainfall in June and July, well withdrawals during the summer of 1984 increased from about 700 to 900 acre-feet per day. The summer of 1984 produced the lowest water levels in the Edwards aquifer and the smallest discharge from Comal Springs since the 10-year drought that ended in 1956.

The Edwards Underground Water District and the city of San Antonio initiated an educational and water awareness program in 1984. Summer water demands in Bexar County include considerable water for lawn irrigation. Water conservation by the average citizen can be effective. Should the deficient precipitation and substantial water demands of the summer of 1980 occur simultaneously with a low springflow situation similar to that of the summer of 1984, Comal Springs probably would cease to flow.

The water levels in the San Antonio index well and the discharge from Comal Springs have been correlated to show that a water level of about 645 feet above sea level in San Antonio coincides with a discharge of about 350 acre-feet per day from Comal Springs. A water level of 635 feet at that index well would coincide with a discharge of about 225 acre-feet per day from the springs. In 1956, when the water level in the San Antonio index well reached 623 feet, Comal Springs ceased to flow.

QUALITY OF RECHARGE WATER SIMILAR TO QUALITY OF DISCHARGE WATER



Chemical Quality Of Water Is Suitable For Most Uses

Water chemistry and a characterization of water types and water-quality patterns in the Edwards aquifer can be shown using an illustrative technique developed by Stiff (1951). Precipitation that falls on the catchment area of the Edwards aquifer becomes a calcium bicarbonate water as it moves across and seeps through the Edwards Limestone on the plateau. Therefore, the water that leaves the Edwards Plateau and enters the recharge area of the Edwards aquifer is in equilibrium with the major inorganic ions associated with the Edwards Limestone, and the water quality does not change significantly as the water moves through the aquifer toward the discharge points. Water in the aquifer along the "bad-water" line has greater concentrations of dissolved solids, but it has not affected the quality of water within the freshwater zone of the Edwards aquifer. Minor elements or metals and man-made organic hydrocarbons have been detected in the aquifer but in concentrations less than drinking-water standards established by the U.S. Environmental Protection Agency.

Water in the Edwards aquifer is of excellent quality when compared to drinking-water standards established by the U.S. EPA (1976, 1977), and considerable effort is being expended to insure that this quality will be maintained. The chemical quality of water from the Edwards Limestone has been monitored since the 1920's. Water-quality data are available for several thousand wells. In 1984, more than 200 wells were being sampled on a yearly or bi-yearly basis.

A description of water types and water-quality patterns in the Edwards aquifer can be shown by Stiff diagrams which provide a pictorial presentation of water chemistry. If the shapes and sizes of the diagrams are similar, the chemical character of waters represented by the diagrams are similar. Precipitation has minimal concentrations of dissolved minerals. Precipitation that falls on the catchment area on the Edwards Plateau seeps through the Edwards Limestone toward the surface streams that recharge the Edwards aquifer. Because this water is in contact with limestone, which is composed primarily of calcium carbonate, it becomes a calcium bicarbonate type water before it enters the Edwards aquifer. As can be seen from the Stiff diagrams, there is very little chemical difference in the water entering the Edwards aquifer in the recharge area and the water being discharged from the wells and springs to the east. The recharge water is in chemical equilibrium with respect to calcium, and, therefore, the water dissolves relatively minor quantities of calcium from the limestone in the Edwards aquifer.

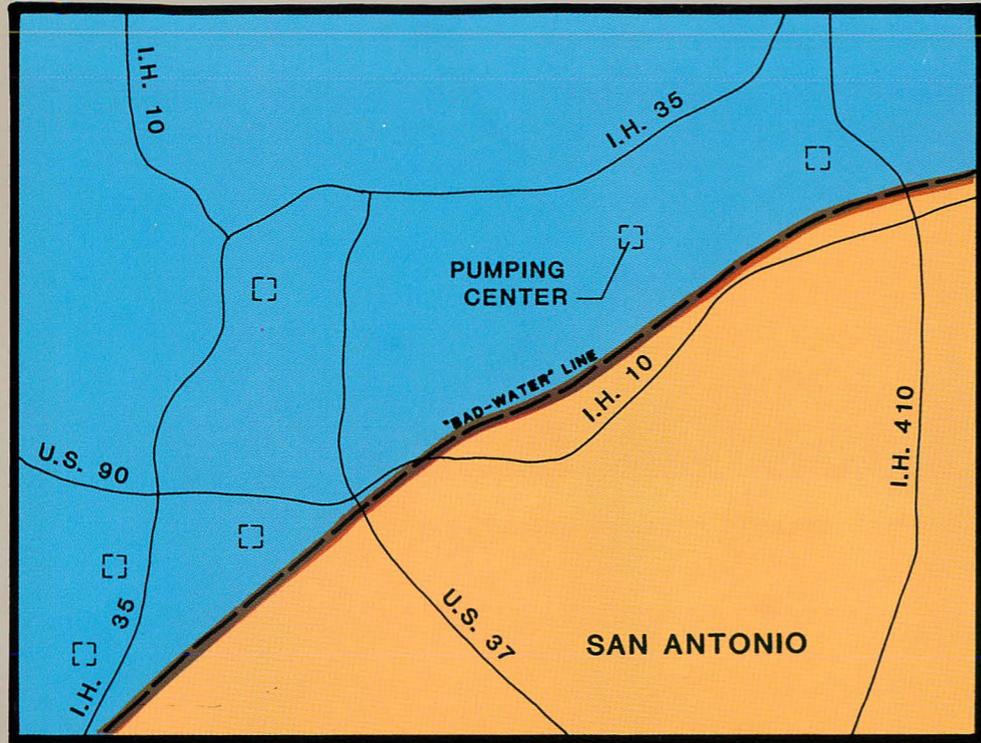
The U.S. EPA has established recommended maximum concentrations of various minor elements in drinking water (1976, 1977). About 600 water samples collected from the Edwards

aquifer have been analyzed for minor elements. In the freshwater part of the aquifer, the concentration of cadmium is about 10 percent of the recommended maximum for that element; iron, lead, manganese, mercury, and zinc range from about 5 percent to less than 1 percent of the recommended limits. Salinewater collected from wells south of the "bad-water" line has greater concentrations of various elements than are recommended by the U.S. EPA.

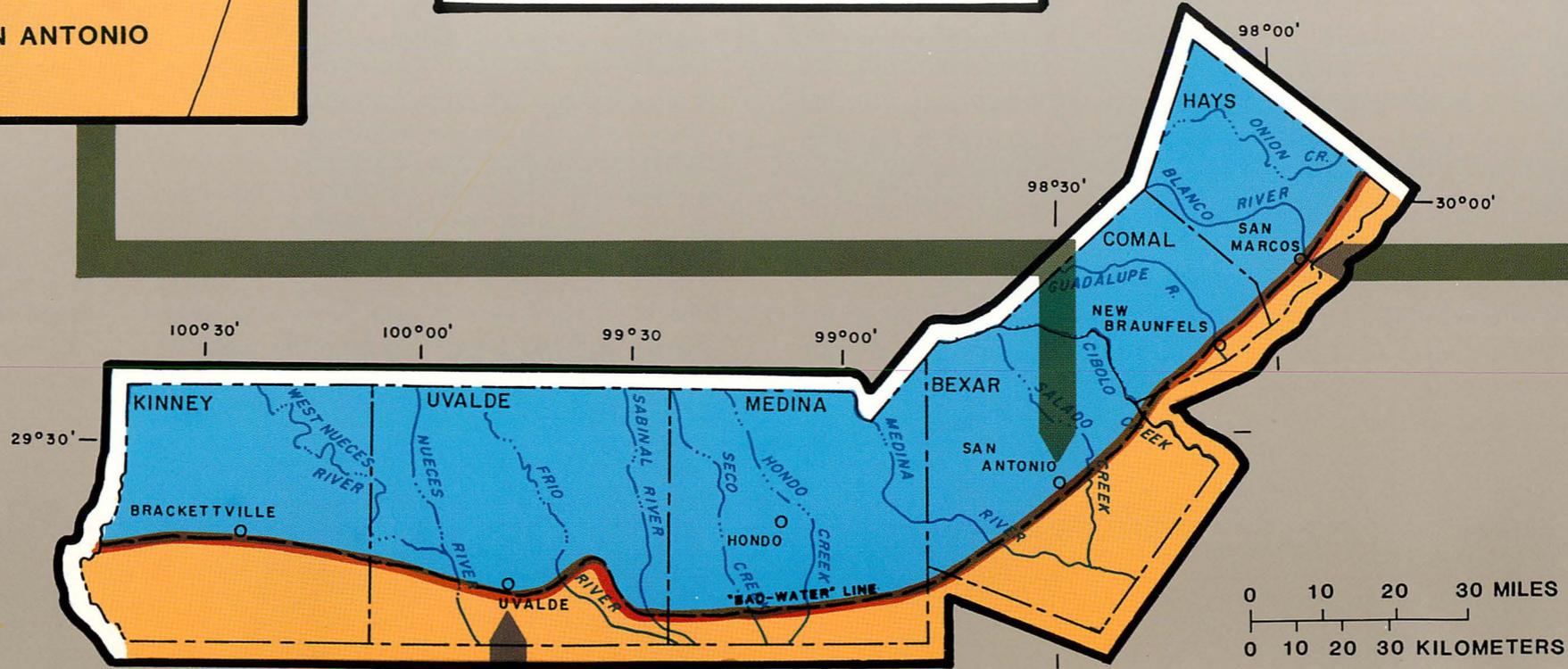
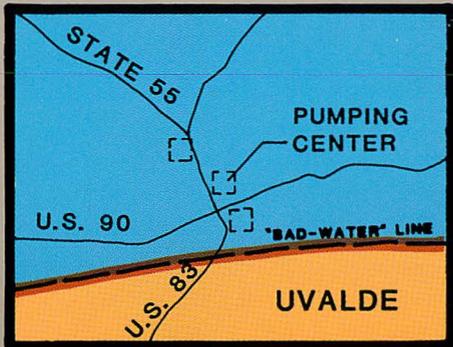
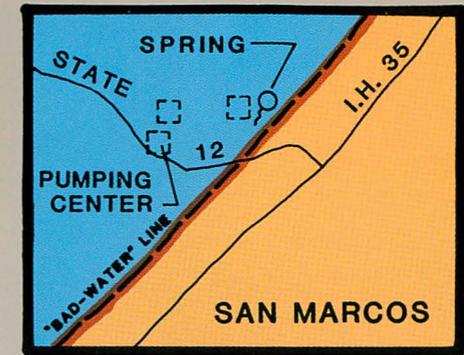
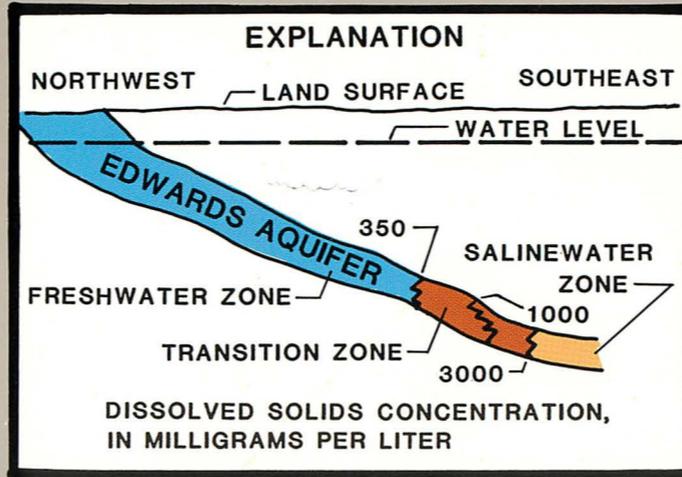
Man-made organic hydrocarbon derivatives such as tetrachloroethylene have been found in ground water sampled from the aquifer. The large volumes of water that move through the Edwards aquifer can quickly spread an organic contaminant throughout the aquifer. This rapid dispersion, however, also dilutes the concentrations of the contaminants. The only wells completed in the Edwards aquifer which persistently yield detectable concentrations of organic compounds are located in two small areas--one in northern San Antonio and the other immediately east of Uvalde. Tetrachloroethylene has been detected in small quantities from several wells in these two areas. The U.S. EPA considers chronic exposure to any detected concentration of tetrachloroethylene in drinking water to be a potential hazard to human health.

Very small concentrations of Freon-11 were detected in a narrow band of the aquifer from northern San Antonio to near San Marcos (Thompson and Hayes, 1979). Although Freon is not a serious contaminant, the detection of this man-made compound was important because it indicated that the rate of movement of water through that part of the Edwards aquifer was more than 1 mile per year.

"BAD-WATER" LINE



0 1 2 MILES
0 1 2 KILOMETERS
SCALE FOR ALL INSET MAPS



Salinewater South Of The “Bad-Water” Line A Cause of Concern

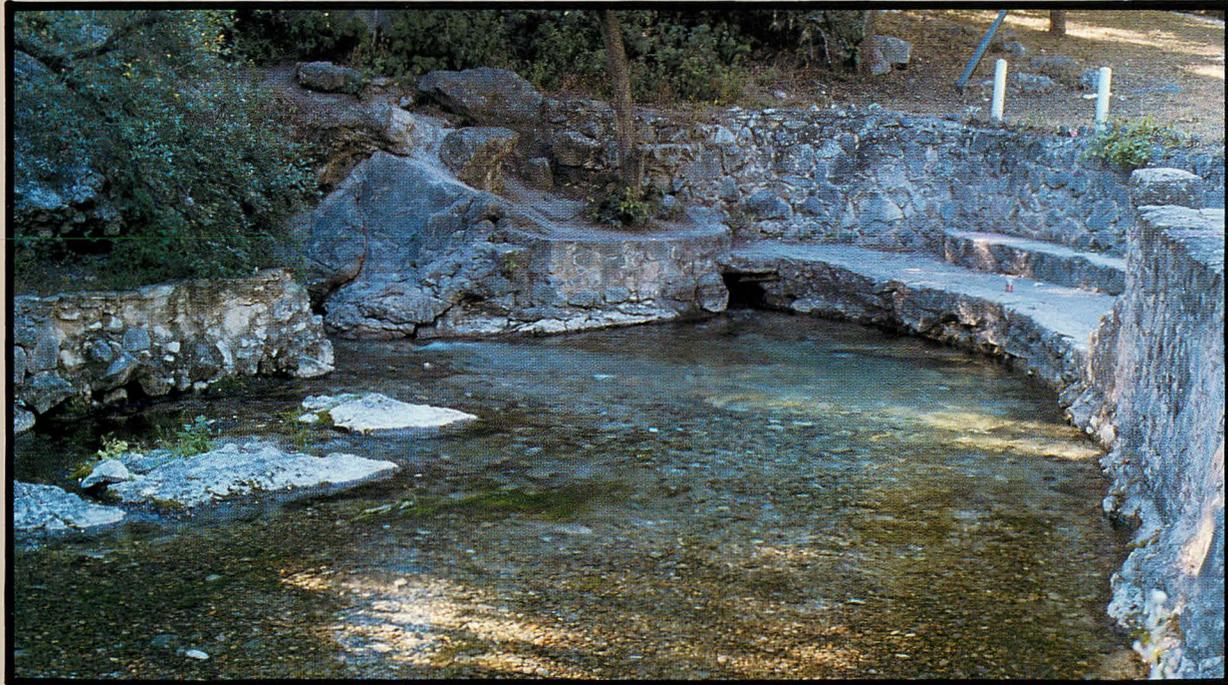
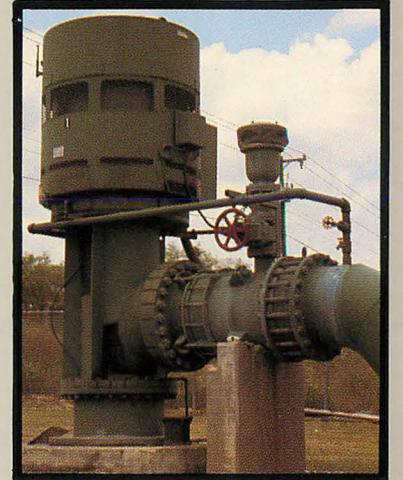
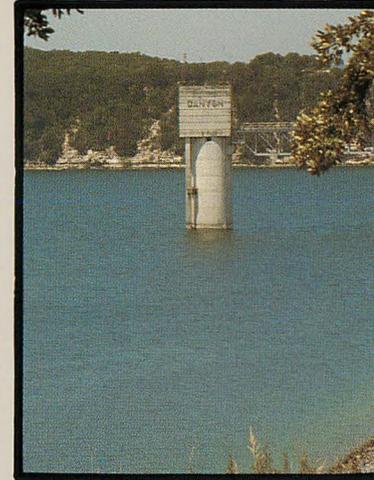
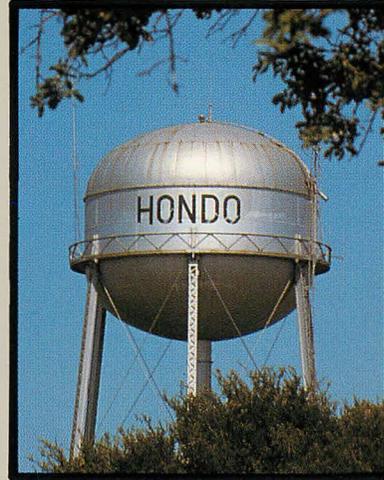
The “bad-water” line is considered the south and southeast boundary of the freshwater zone in the Edwards aquifer. It is located downdip from the freshwater part of the Edwards aquifer and within the transition zone where the dissolved-solids concentration of the water increases from 350 to 3,000 milligrams per liter. The increasing mineral concentration of the water in and farther downdip of the transition zone is the result of negligible circulation and flushing of water of poor quality. Municipal pumping centers are often located close to the “bad-water” line. Although salinewater intrusion has not been apparent, conditions such as a severe drought might cause the “bad-water” or salinewater to move updip into the pumping centers in the freshwater zone of the aquifer.

For the purposes of this report, the southern and southeastern boundary of the freshwater zone of the Edwards aquifer is defined by the locally known “bad-water” line, a line that separates ground water having dissolved-solids concentrations less than 1,000 milligrams per liter (freshwater) from ground water having concentrations of more than 1,000 milligrams per liter (slightly saline water). A transition zone separates freshwater from salinewater, and the dissolved-solid concentration increases from about 350 milligrams per liter on the freshwater side to 3,000 milligrams per liter on the salinewater side. The exact position of this line within the transition zone is unknown at this time (1986). A few miles to the south of the “bad-water” line, the water contains even more dissolved minerals, primarily calcium and sulfate; dissolved-solids concentration is as much as 5,000 milligrams per liter. The combination of faulting and the initial movement of water toward the springs allowed increased development of solution openings in the freshwater part of the aquifer. The water has continued to flow along the path of least resistance, which is toward the springs of the aquifer rather than downdip beyond the “bad-water” line. The large dissolved-solids concentration of the water south of the “bad-water” line is related to the lesser permeability of the Edwards Limestone south of the line. Because water moves so slowly through this part of the limestone, the water has been in contact with the limestone and remaining gypsum for a long time, and the mineral content is, therefore, increased.

Pumping centers commonly are located within about 2 miles of the “bad-water” line. To date (1986), there has been no salinewater produced from these wells. Movement of

salinewater to the production wells in the freshwater zone would require a steep gradient in water levels from the salinewater zone to the freshwater zone. Such conditions might develop during a severe drought. Data are not available, however, to accurately determine the quantity of salinewater that might be drawn into the freshwater zone or to assess the effects on the freshwater zone should this occur.

CAREFUL MANAGEMENT IS ESSENTIAL



Management Decisions Require Additional Answers

Individuals, as well as groups of people, have different needs concerning their water supply. These different needs result in a variety of viewpoints or ideas as to how and where the water is to be made available for use. State and local water managers and decision makers need the best information available to make decisions concerning the water needs of the area and how these needs are to be met. In an expanding economy with increasing population, water use will increase. Water managers and decision makers will need to consider all options of the total water resources in the area to meet the increasing demand in the area underlain by the Edwards aquifer.

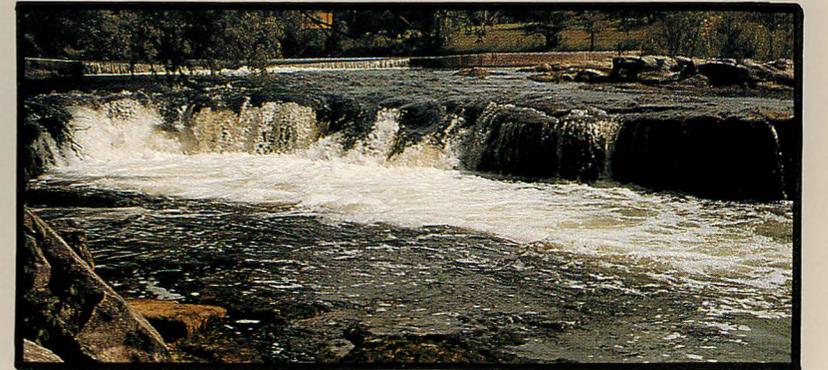
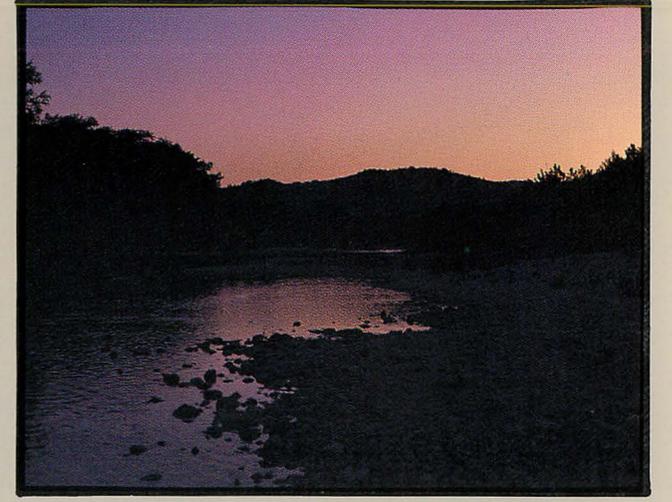
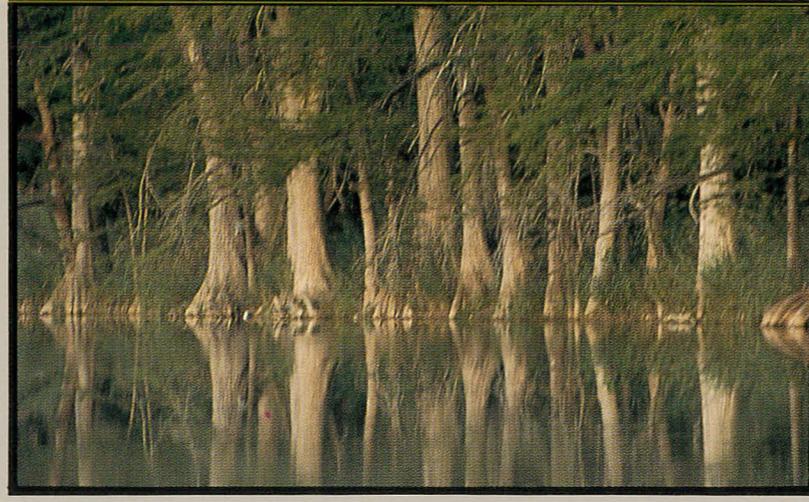
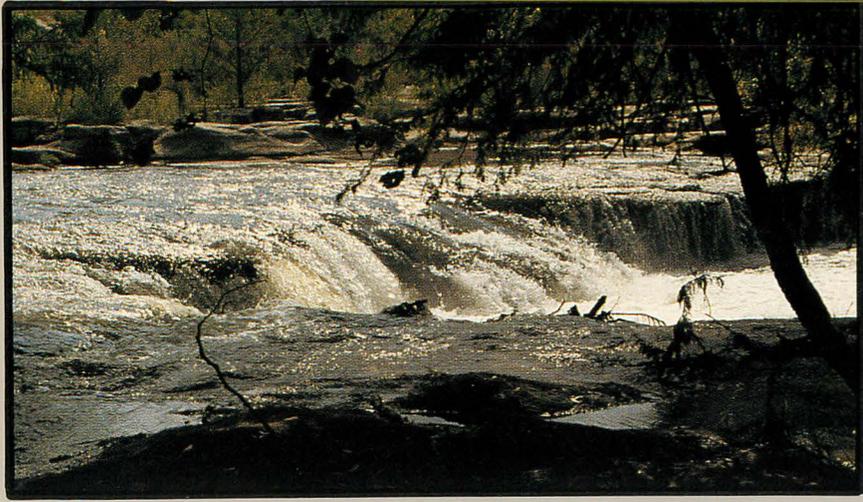
Elected State and local officials, professional water managers, and interested citizens have different but important influences on alternatives for future water management. Each of these groups need to be consulted and their input carefully considered before important decisions related to management of the water resources are finalized. These decisions are difficult to make, even when sufficient hydrologic data are available. As stated more precisely by Alston and Freeman (1975), decision makers have been described “. . . as sociopolitical men who must bargain with diverse clients, knowing that the public good is defined in many conflicting ways by intensely competitive and self-interested groups. Such decision makers know that goals are fluid, multiple, and inconsistent, multidimensional and incommensurable. They also know that no fixed solutions are possible, regardless of their technical or economic elegance.”

Accurate data concerning the total water resources need to be available for efficient management of our water supply. The collection of water information and making of continual decisions are never-ending processes; new information is needed to make new decisions.

Questions concerning specific information needs that would improve confidence in making appropriate and proper planning and management decisions are many and varied. Questions that apply specifically to the recharge area are: What factors control recharge volumes and recharge rates? Where and how do faults and igneous intrusions affect storage and direction of ground-water flow? Can recharge be enhanced at points other than in the streams? What contaminants enter the aquifer in the recharge water? Are contaminants removed from the

water during the recharge process and prevented from entering the aquifer? Are contaminant concentrations decreased in the unsaturated zone above the aquifer? What effect will continued urban development have on contaminant potential? Are ground-water levels affecting recharge rates? Questions concerning the artesian area of the aquifer include: What is the total volume of water in the aquifer? How does this volume vary with changes in water level beyond the range of historical fluctuations? How does storage vary areally throughout the aquifer? How fast does water move through the aquifer? What is the extent of solution cavities and openings throughout the aquifer? What are the local effects of faults and intrusions in changing the local direction of flow? Does water quality vary with depth? What is the likelihood that the “bad-water” line will shift during periods of severe stress? If the “bad-water” line does shift, how extensive will be the effect on water quality? How permanent will be the effect of degraded water quality? How closely related are the various geologic units and the water chemistry? Answers to these questions cannot be derived immediately. Long and continuous study efforts, with well defined objectives and well organized study approaches, are required to supply information vital to optimum water development and management. Refinement of general knowledge concerning the physical characteristics of the Edwards aquifer is needed to determine the effects of stresses, more severe than have ever occurred, that may be placed on the aquifer.

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Glossary

Aquifer--A formation that contains sufficient saturated permeable material to yield water to wells and springs.

Artesian aquifer--Ground water that occurs where an aquifer is overlain by rock or clay to hold water under pressure. An artesian well may or may not flow.

Artificial recharge--Water diverted into an aquifer due to the activities of man.

"Bad-water" line--In the Edwards aquifer, a local term used to define the downdip aquifer boundary, which is a line where the water exceeds a concentration of 1,000 milligrams per liter of total dissolved solids.

Balcones fault zone--A vertical break in the continuity of the Edwards and associated limestones. Includes all of the recharge area and artesian area of the Edwards aquifer.

Coastal Plain--The physiographic province from the Edwards Plateau to the Gulf Coast. The region is mostly sand and clay deposits and local relief is slight.

Contamination--Addition of foreign material causing water to become less useful or desirable for man's use.

Discharge--Water that leaves the zone of saturation of an aquifer by natural or man-made processes.

Edwards Plateau--The high, relatively flat, physiographic province of central Texas underlain by the Edwards Limestone.

Evapotranspiration--Water withdrawn from a land area by evaporation from water surfaces and moist soil, and plant transpiration.

Faults--A fracture resulting in a vertical or horizontal displacement of the earth's structure.

Gaging station--A site on a stream or lake established to measure or observe water level, streamflow, or water quality.

Hydrology--The study of water as it occurs on or beneath the earth's surface.

Permeability--The capacity of a porous medium such as soil, gravel, and rock to transmit a fluid.

Precipitation--All water, liquid or solid, from the atmosphere that falls to the earth's surface. In central Texas, it is mostly in the form of rain.

Recharge--Water that enters the zone of saturation of an aquifer by natural or man-made processes.

Recharge zone--The area where a formation allows available water to enter the aquifer.

Rainfall intensities--The amount of water falling to the earth's surface in a given period of time. The rate is usually expressed in inches per hour.

Runoff--Water from precipitation or ground-water discharge that flows in surface streams.

Solutioning--Dissolving away of rock, notably limestone, by water. The process usually is extremely slow and takes place in the ground-water system.

Springflow--Water that discharges from an aquifer at natural outlets, without man's influence.

Storage values--The volume of water per unit area that can be released from the aquifer through wells or springs.

Voids--A general term for pore space or other openings in rock. The openings can be very small, to cave size, and are filled with water below the water table.

Water-table conditions--That part of the aquifer confined only by atmospheric pressure.

