Chapter 8

An Overview of the Edwards-Trinity Aquifer System, Central–West Texas

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Introduction

Following a statewide drought during 1996, the passage of Senate Bill 1 in 1997 created a renewed public interest in the state's water resources not experienced since the 1950's drought of record. Senate Bill 1 also provided State funding to initiate the development of groundwater availability models for all of the major aquifers of Texas. The development and management of Groundwater Availability Modeling (GAM) has been tasked to the Texas Water Development Board (TWDB) to provide reliable and timely information on the state's groundwater resources. TWDB staff is currently conducting a GAM study for the Edwards-Trinity aquifer system, due for completion in late 2002. For most of West Texas, the 1996 drought has been prolonged and continues to impact West Texans. The purpose of this paper is to provide a brief overview of the Edwards-Trinity aquifer. Most of the information presented here is summarized from U.S. Geological Survey Regional Aquifer-Systems Analysis (RASA) reports.

Geographic Setting

Areal Extent

The Edwards-Trinity aquifer extends over an area of about 35,000 mi^2 and beneath all or parts of 38 counties (Ashworth and Hopkins, 1995) in central-west Texas (fig. 8-1). Most of the counties have relatively sparse populations concentrated in small towns, usually the county seats.

Physiography

The aquifer sediments occupy the southeastern margin of the Great Plains physiographic province within an area known as the Edwards Plateau region and portions of the Trans-Pecos Basin and Range and the Llano Estacado regions. The area of the Edwards

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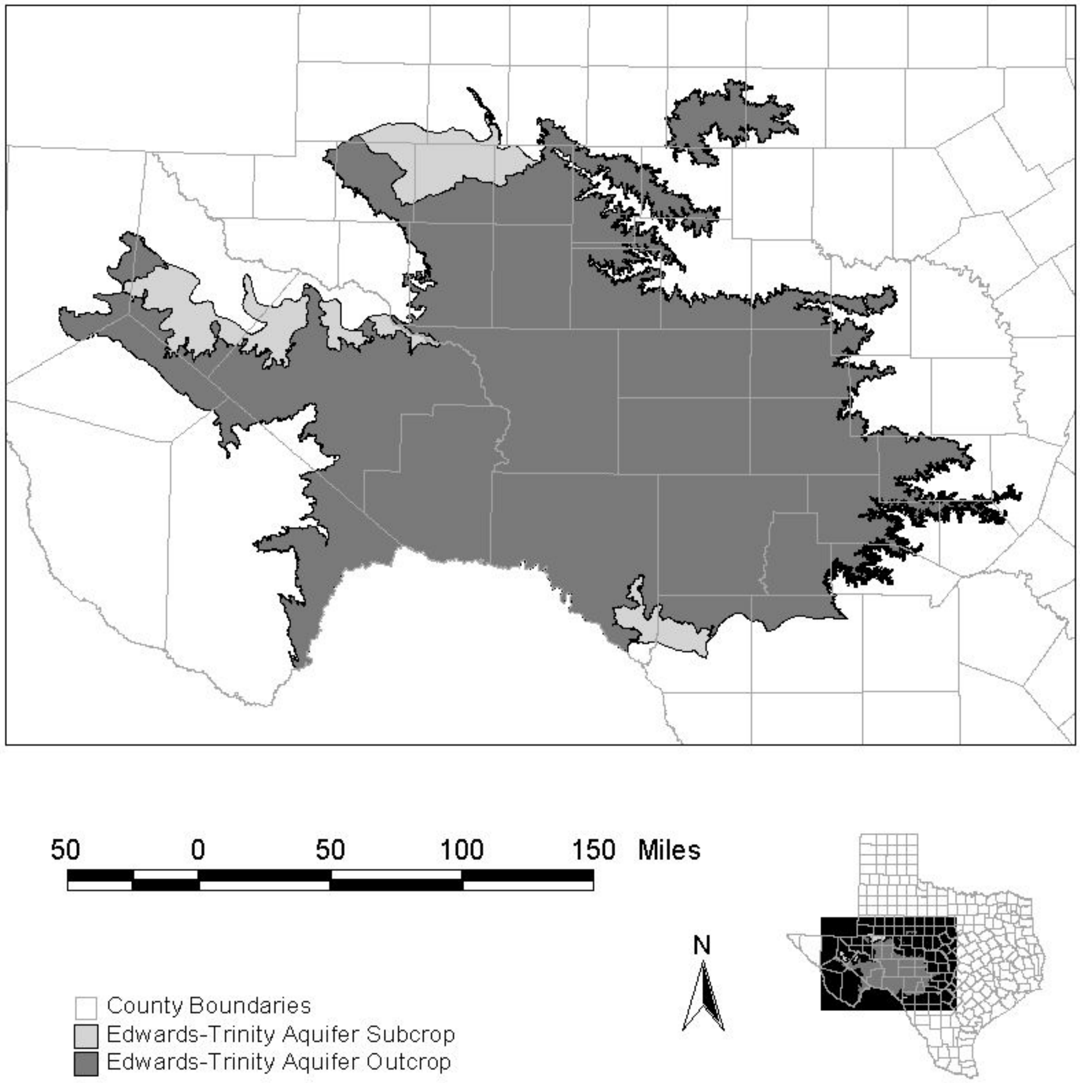


Figure 8-1: Areal extent of the Edwards-Trinity aquifer.

Plateau southwest of the Pecos River is often referred to as the Stockton Plateau. Northwest of the Pecos River, the area is commonly referred to as the Toyah Basin.

Landforms

The headward erosion of streams transecting the Balcones Escarpment form canyon lands traditionally known as the Texas Hill Country that delineate the southern and eastern edge of the Edwards Plateau. The eastern flanks of the Delaware, Apache, Davis, Glass, and Santiago Mountains mark the western edge of the plateau. Playa lakes, characteristic

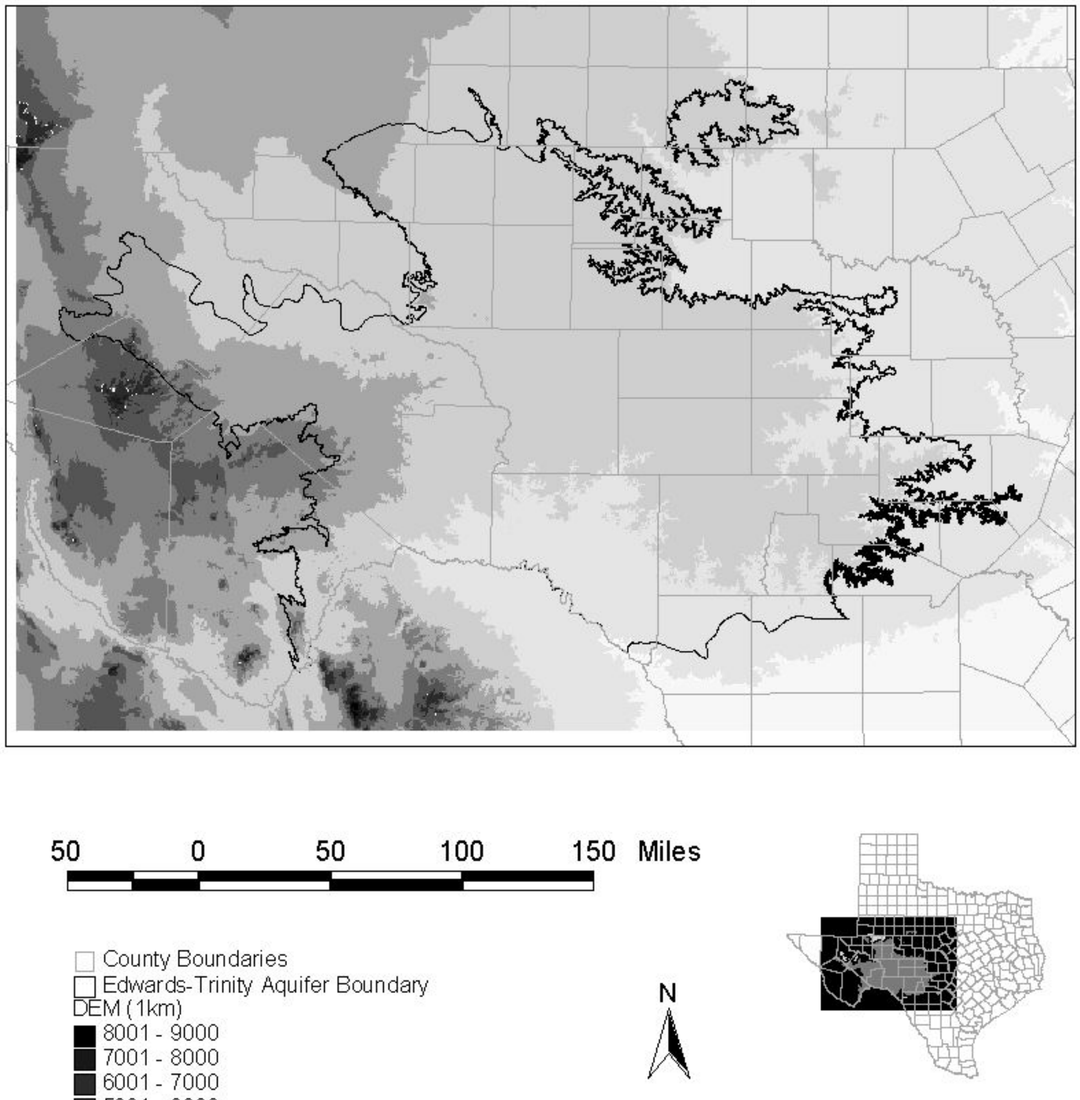


Figure 8-2: Surface topography of the Edwards Plateau.

of the High Plains, extend down into northern portions of the Edwards Plateau. The southwestern edge of the plateau extends into the northeastern margins of the Chihuahua Desert. The northeastern edge of the Edwards Plateau is adjacent to geologically complex Paleozoic and Precambrian landforms of the Central Mineral Region.

Topography

The topography of the Edwards Plateau may be described as a flat tableland with stream-cut canyons in the southern and eastern portions of the plateau. Surface elevations range from about 5,000 ft near the mountains in the west to about 1,100 ft near the Rio Grande in the south (Barker and Ardis, 1996). The greatest surface relief occurs in the southern and western parts of the Edwards Plateau (Walker, 1979). Most of the plateau, however, has a flat surface sloping from the northwest to the southeast between 3,000 and 2,000 ft above sea level (fig. 8-2).

Soils

Soils of the Edwards Plateau generally have thin and stony characteristics except in the northernmost portion of the plateau within the Llano Estacado region, where soils thicken into more sandy, loamy soils.

Surface Drainage

Streams draining the Edwards Plateau have a dendritic or branchlike pattern, with stream density decreasing significantly toward the west (fig. 8-3). Tributary streams of the Colorado River, such as the Concho, San Saba, and Llano Rivers, drain the northeastern portion of the Edwards Plateau. Headwater tributaries of the Guadalupe, San Antonio, and Nueces Rivers drain the southern and southeastern portion of the plateau. The Pecos River and Devils River, major tributaries to the Rio Grande, drain the entire southwestern half of the Edwards Plateau. Although there are several small surface water bodies (<1 mi^2) in the central portion of the plateau, the only significant water bodies within the plateau are Big Lake in Regan County, Orient Reservoir in Pecos County, and Balmorhea Lake in Reeves County. Other much larger water bodies along the edge of the Edwards Plateau include Amistad Reservoir in Val Verde County, Twin Buttes and San Angelo Reservoirs in Tom Green County, and E. V. Spence Reservoir in Coke County.

Climate

The climate ranges from subhumid in the eastern to semiarid in the western plateau (Walker, 1979). The long-term mean annual precipitation (1895–2000) ranges from about 25 inches in the east to about 12 inches in the west (fig. 8-4). Precipitation is greatest during late spring and early fall in the eastern two-thirds of the Edwards Plateau as a consequence of cool northern frontal air masses colliding with warm moist Gulf air masses from the south (fig. 8-5). However, in the western third of the plateau, most of the precipitation occurs during July, August, and September as a result of convectional thunderstorms (fig. 8-5). The variation of total monthly precipitation is greatest for the month of September throughout the plateau. Evaporation rates are high throughout the plateau and range between 43 inches in the east (Walker, 1979) to 80 inches (Rees and Buckner, 1980) in the west. Droughts are common on the Edwards Plateau, with about 10 moderate to severe droughts during the last 100 yr (fig. 8-5). The drought of record

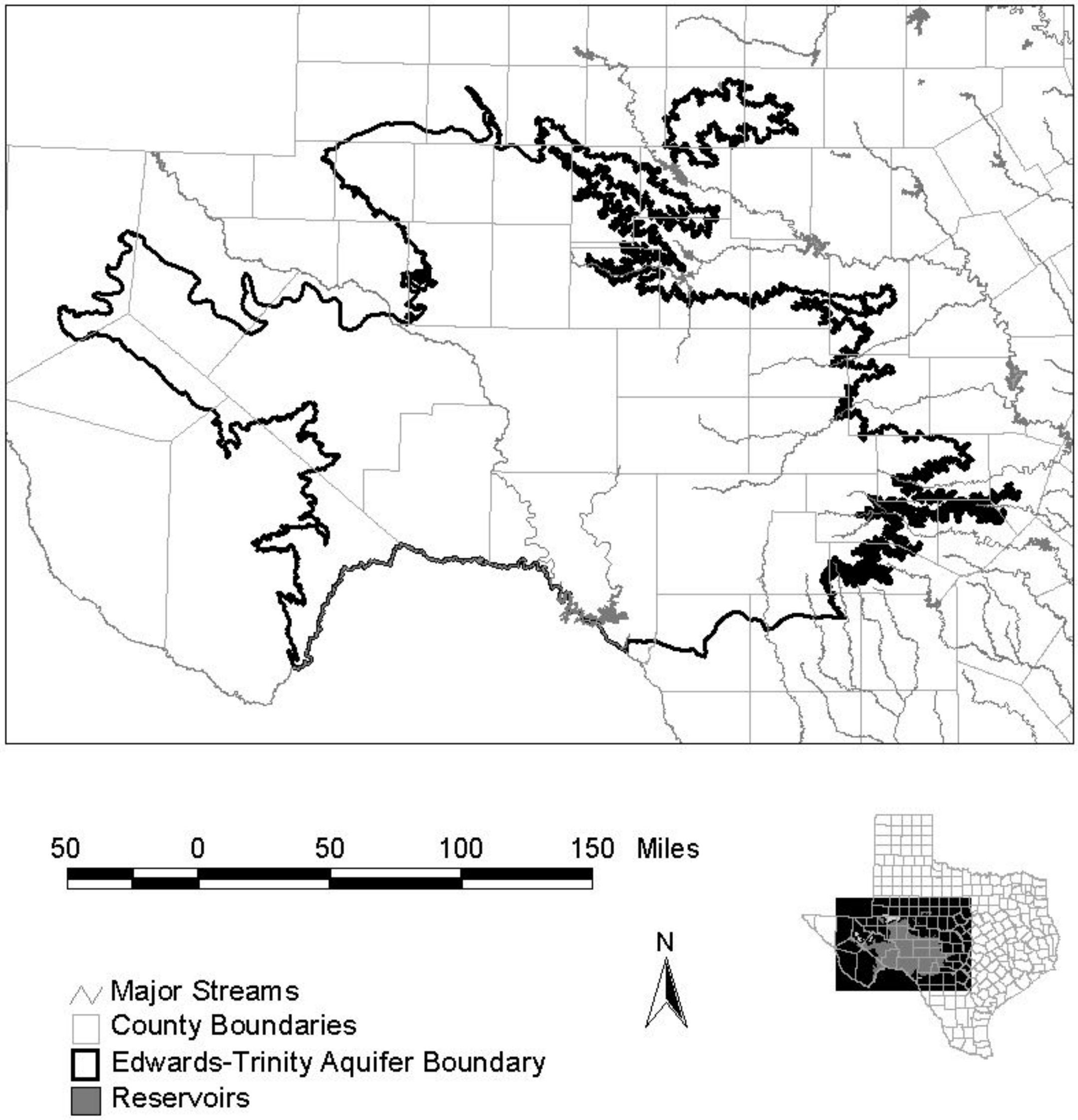
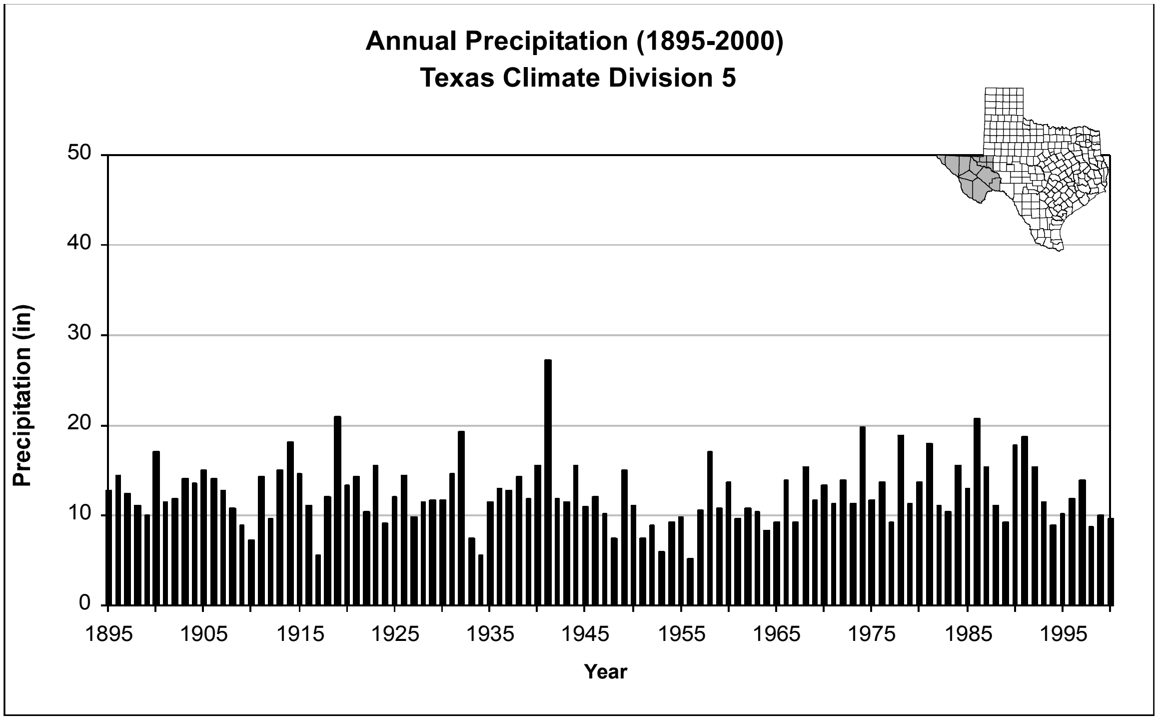


Figure 8-3: Surface-water drainage of the Edwards Plateau.

occurred during the 1950's, consistent with the rest of the state. However, the current drought that began during the mid- to late 1990's may potentially replace the 1950's record.

Land Cover/Land Use

The Edwards Plateau is covered by scrubby savanna of oak-juniper-grass in the north and east and desert shrub and brush in the southwest. Salt cedar and other phreatophytes cover the stream valleys, contributing significant amounts of evapotranspiration. Some



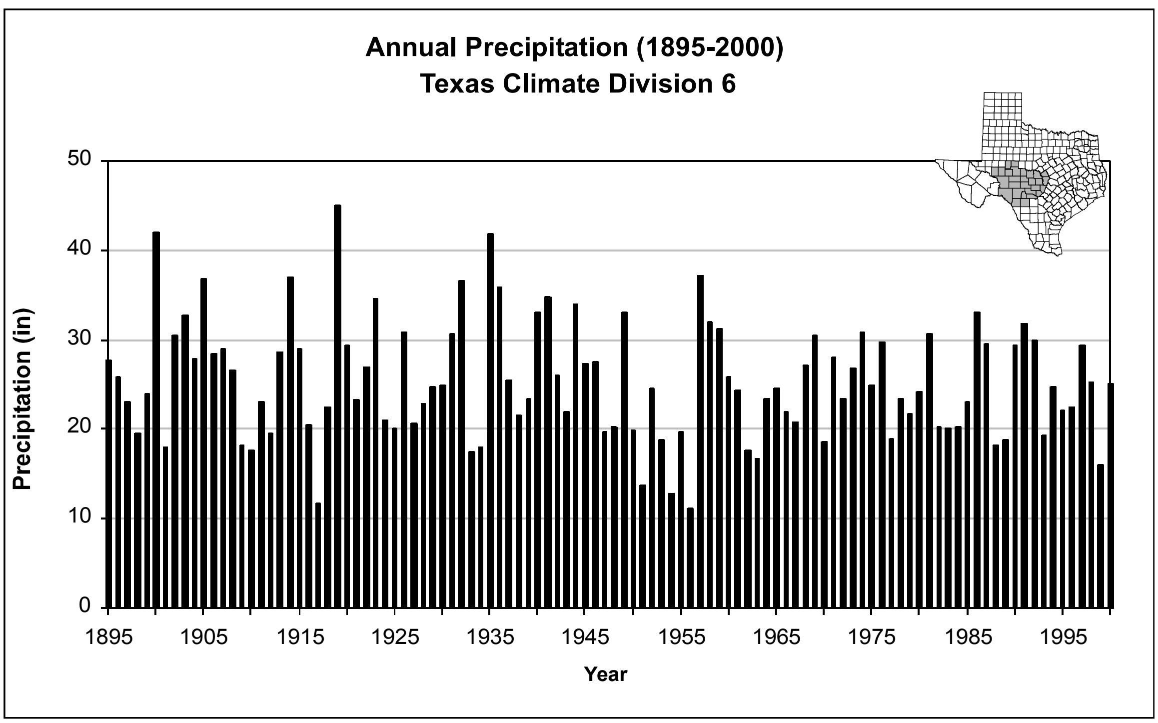
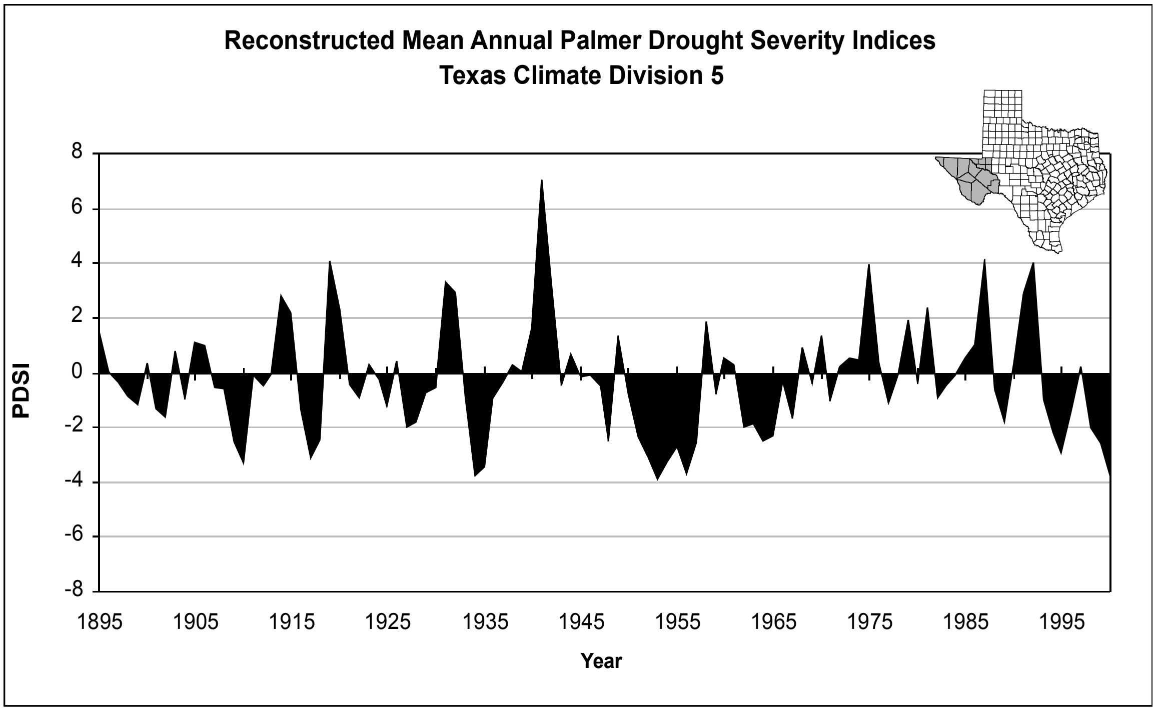


Figure 8-4: Long-term mean annual precipitation.



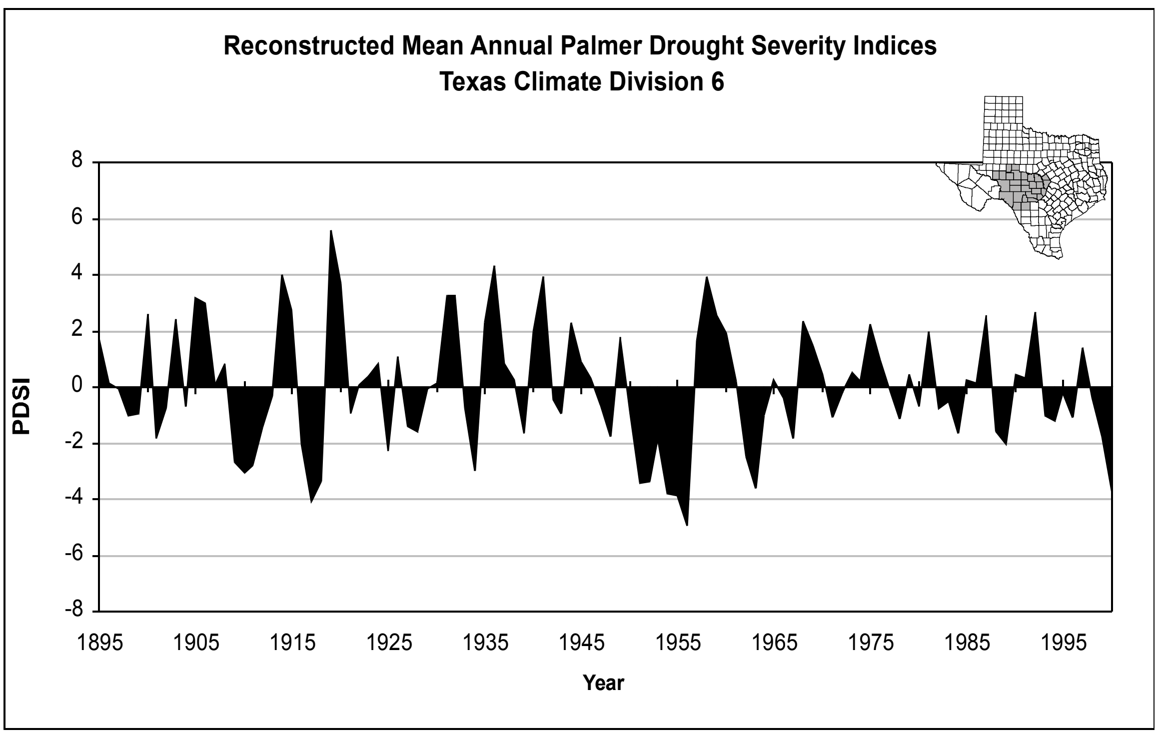


Figure 8-5: Long-term mean annual Palmer Drought Severity Indices.

native land cover has been replaced by cropland in northern portions of the Edwards Plateau. Ranching of cattle, sheep, and goats, along with wild-game-hunting leases are the principle land use, except for the northern portion of the plateau, where irrigated cropland is the dominant land use. Oil and gas production from the Permian Basin is common in the northern and western portions of the plateau.

Groundwater Management Districts

The Edwards-Trinity aquifer falls within four Senate Bill 1 Regional Water Planning Groups (E, F, J, and K), although most of the aquifer falls within regions F and J. There are also about 24 groundwater-management districts with jurisdiction over the aquifer (fig. 8-6).

Geologic History

Paleozoic

The Paleozoic Era ended with a tectonic event known as the Ouachita Orogeny. The orogenic event resulted in the formation of a structural fold belt of sediments deposited during the Ordovician, Silurian, Devonian, and Mississippian Periods. The sediments were uplifted, faulted, and folded into a late Paleozoic mountain range that extended from northern Mexico along the present-day Balcones Escarpment up into the Ouachita Mountains of Oklahoma and Arkansas (Barker and Ardis, 1996). Before a final uplift during the Paleozoic Era, an arid and restricted shallow marine sea deposited Upper Permian sediments and evaporites into the Permian Basin of West Texas.

Triassic

During the Triassic Period, terrigenous clastic red beds were deposited over the Paleozoic rocks as the Dockum Group sediments. The area of the Edwards Plateau was then exposed to erosion during the Jurassic Period to form a rolling peneplain known as the Wichita Paleoplain (Barker and Ardis, 1996). By the end of the Jurassic Period, the Gulf of Mexico had begun to open, and tilting of the peneplain toward the southeast provided a structural base for the deposition of the Cretaceous-age Edwards-Trinity sediments.

Cretaceous

As the Gulf of Mexico continued to open and the Cretaceous seas advanced from the southeast, a broad continental shelf known as the Comanche Shelf began to form. The Llano Uplift, a tectonically active structural feature since the Precambrian, became a prominent structural shelf element for the deposition of the Trinity Group sediments (Barker and Ardis, 1996). The Early Cretaceous seas advanced across the pre-Cretaceous structural base in three cycles of transgressive-regressive stages to deposit the Trinity Group sediments (Barker and others, 1994). The Stuart City Reef trend began to form

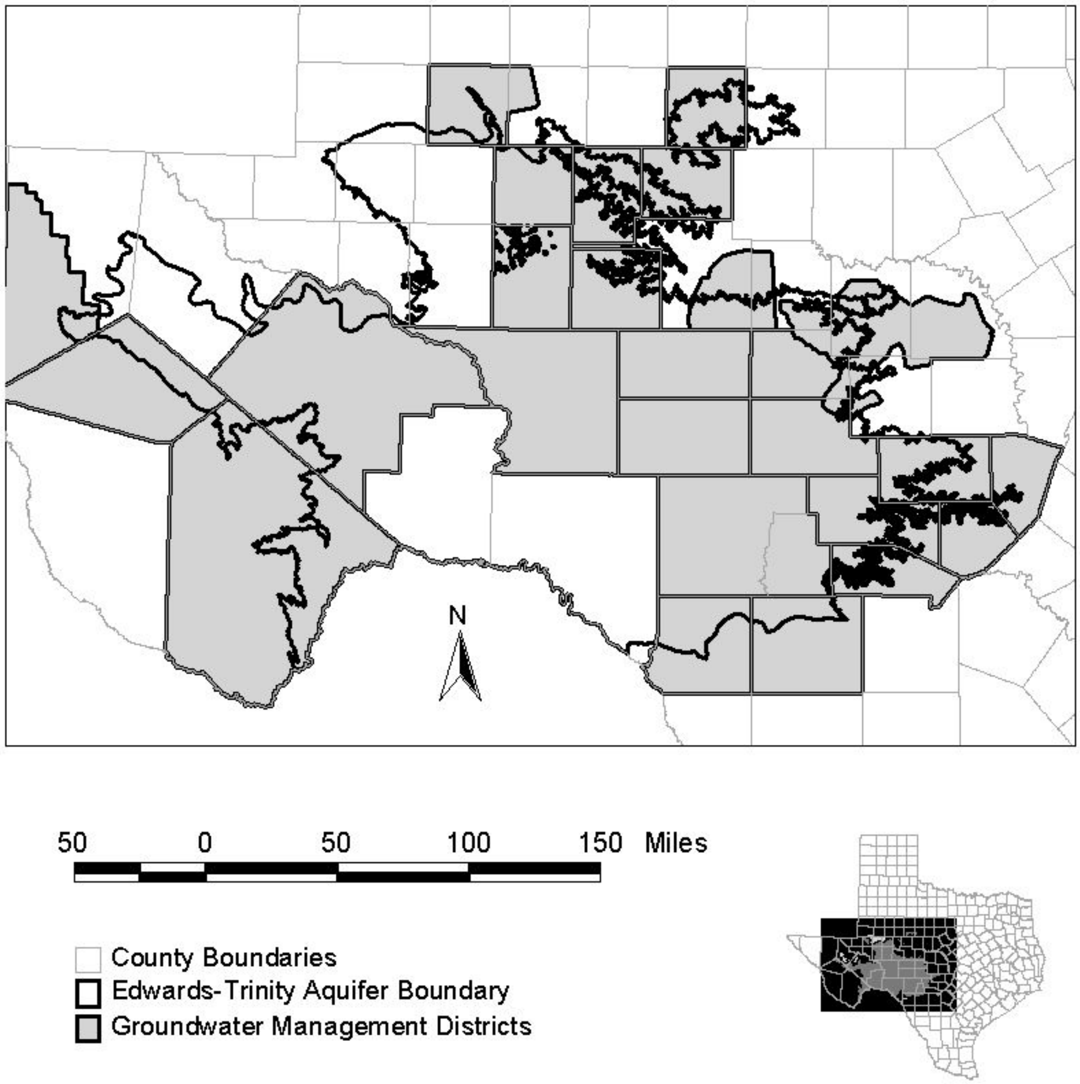


Figure 8-6: Groundwater management districts of the Edwards-Trinity aquifer.

along the present-day Balcones Fault Zone, enabling the carbonate platform deposits of the Edwards Group sediments to accumulate. Other structural shelf elements that formed behind the Stuart City Reef trend and controlled the depositional environments and lithologic characteristics of the Edwards Group formations include the Central Texas Platform, the San Marcos Arch, the Devils River Reef trend, Maverick Basin, and the Fort Stockton Basin. Prior to the deposition of Upper Cretaceous Del Rio, Buda, Boquillas, and Austin Group sediments, much of the Central Texas Platform was subaerially exposed, allowing for an initial karstification of Lower Cretaceous carbonate sediments (Barker and others, 1994).

Cenozoic

Toward the end of the Cretaceous and beginning of the Tertiary Periods, the Laramide orogenic event and the dissolution of Upper Permian sediments resulted in the structural collapse and erosion of overlying Triassic and Cretaceous sediments along the Pecos River valley (Barker and others, 1994). These sediments were then redeposited as the Cenozoic Pecos Alluvium throughout the Tertiary and into the Quaternary Periods. The Ogallala sediments were deposited over a portion of the Edwards-Trinity sediments in the northern region of the plateau during the late Tertiary Period. During the mid-Tertiary Period, regional uplift and continued deposition of sediments into the Gulf of Mexico provided tensional stresses along the ancient Ouachita fold belt. Consequently, the development of the Balcones Fault Zone occurred and displaced Cretaceous and Lower Tertiary sediments by 900 to 1,200 ft (Barker and others, 1994). During the Quaternary, the headward erosion of streams began to reduce the plateau into its current form.

Hydrogeologic Units

The vertical and lateral organization of the various hydrogeologic units of the Edwards-Trinity aquifer system is presented in a stratigraphic chart (fig. 8-7) and the following discussion.

Paleozoic

The Hickory, the Ellenburger-San Saba, and the Marble Falls aquifers are hydraulically connected to the Edwards-Trinity aquifer system along the eastern margin of the plateau surrounding the Llano Uplift. The Permian-age Capitan and Rustler sediments are hydraulically connected to the Edwards-Trinity sediments in the Trans-Pecos portion of the aquifer (Bush and others, 1994). In general, most of the underlying Paleozoic rocks provide a relatively impermeable base for the Edwards-Trinity aquifer sediments (Barker and Ardis, 1992).

Triassic

The Dockum Group consists of Lower (Tecovas Formation), Middle (Santa Rosa Formation), and Upper (Chinle Formation) members (Walker, 1979). Only where the Chinle Formation is missing, allowing for the Basal Cretaceous sands to be in hydraulic communication with the underlying Santa Rosa Formation, is the Santa Rosa Formation considered to be an aquifer (Walker, 1979).

Cretaceous

The Trinity Group sediments are divided into Lower, Middle, and Upper Trinity sediments in the southeastern portion of the plateau (Ashworth, 1983). The Lower Trinity consists of the Hosston and Sligo Formations, the Sycamore Sand, and the Hammett Shale; the Middle Trinity consists of the Cow Creek Limestone, the Hensell Sand, and

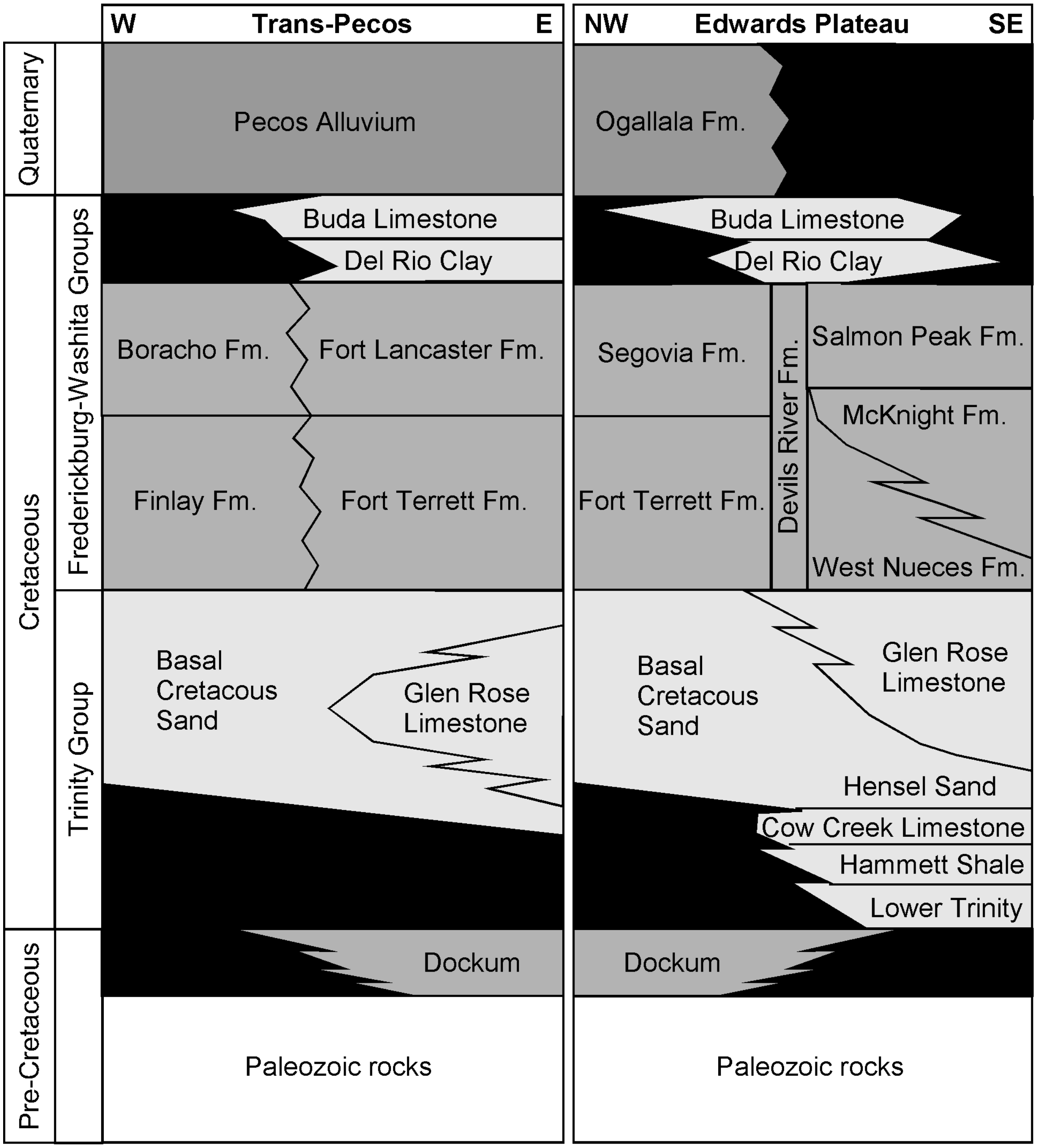


Figure 8-7: Stratigraphic chart for the hydrogeologic units of the Edwards-Trinity aquifer.

the lower member of the Glen Rose Limestone; and the Upper Trinity consists of the upper member of the Glen Rose Limestone (Mace and others, 2000). In the far northwest portion of the plateau, the Trinity Group sediments are divided into the Yearwood Formation and the Cox Sandstone. Elsewhere on the plateau, the Trinity Group sediments are divided into the Basal Cretaceous sand, the Glen Rose Limestone, and the Maxon

Sand. The Basal Cretaceous sand and Maxon Sand are sometimes lumped together and referred to as the Antlers Sand or Trinity Sands where the Glen Rose Limestone is absent.

The Edwards Group and equivalent sediments consist of the Fredericksburg and Washita Group sediments. The Fredericksburg Group is composed of the Finlay Formation within the Fort Stockton Basin, the Fort Terrett Formation within the central Texas platform, the Devils River Formation within the Devils River Reef trend, the West Nueces and McKnight Formations within the Maverick Basin, and the Kainer Formation within the San Marcos Arch. The Washita Group sediments are composed of the Boracho Formation within the Fort Stockton Basin, the Segovia Formation within the Central Texas Platform, the Devils River Formation within the Devils River Reef trend, the McKnight and Salmon Peak Formations within the Maverick Basin, and the Person Formation within the San Marcos Arch.

The Upper Cretaceous sediments include the uppermost section of the Washita Group sediments (the upper confining Del Rio Clay and the Buda Limestone), along with the Eagle Ford Group (Boquillas Formation) and the Austin Group sediments.

Cenozoic

The Cenozoic Pecos Alluvium is hydraulically connected to the Edwards-Trinity aquifer in the northwestern edge of the aquifer. The late Tertiary-age Ogallala sediments are hydraulically connected only in the northernmost portion of the Edwards-Trinity aquifer.

Aquifer Characteristics

Structural Geometry

The initial base depositional surface of the Cretaceous sediments is generally flat and tilted toward the Gulf of Mexico, except for the area surrounding the Llano Uplift in the eastern plateau and areas of the western edge of the plateau along the eastern flanks of the mountains within the Trans-Pecos Basin and Range (fig. 8-8). Consequently, the Edwards-Trinity sediments form a wedge that thickens from the north and northwest toward the south and southeast. The exceptions to this structural trend are in the areas near the Llano Uplift and the mountains of the Trans-Pecos Basin and Range. The wedge of Cretaceous sediments pinches out beneath the Ogallala sediments in the northern portion of the plateau (Barker and Ardis, 1996). The Cretaceous wedge of sediments is terminated along the south and southeast by the Balcones Fault Zone. The entire Edwards Group and equivalent sediments and sections of the Upper Trinity sediments have been removed in the canyon-land areas of the Texas Hill Country. A small portion of the aquifer is confined in Val Verde County, where the Late Cretaceous-age Del Rio Clay overlies the Edwards Group sediments. The semipermeable Upper Cretaceous sediments of the Buda Limestone and Boquillas Formation form a thin cap over the Edwards Group and equivalent sediments in the central and southern portions of the aquifer.

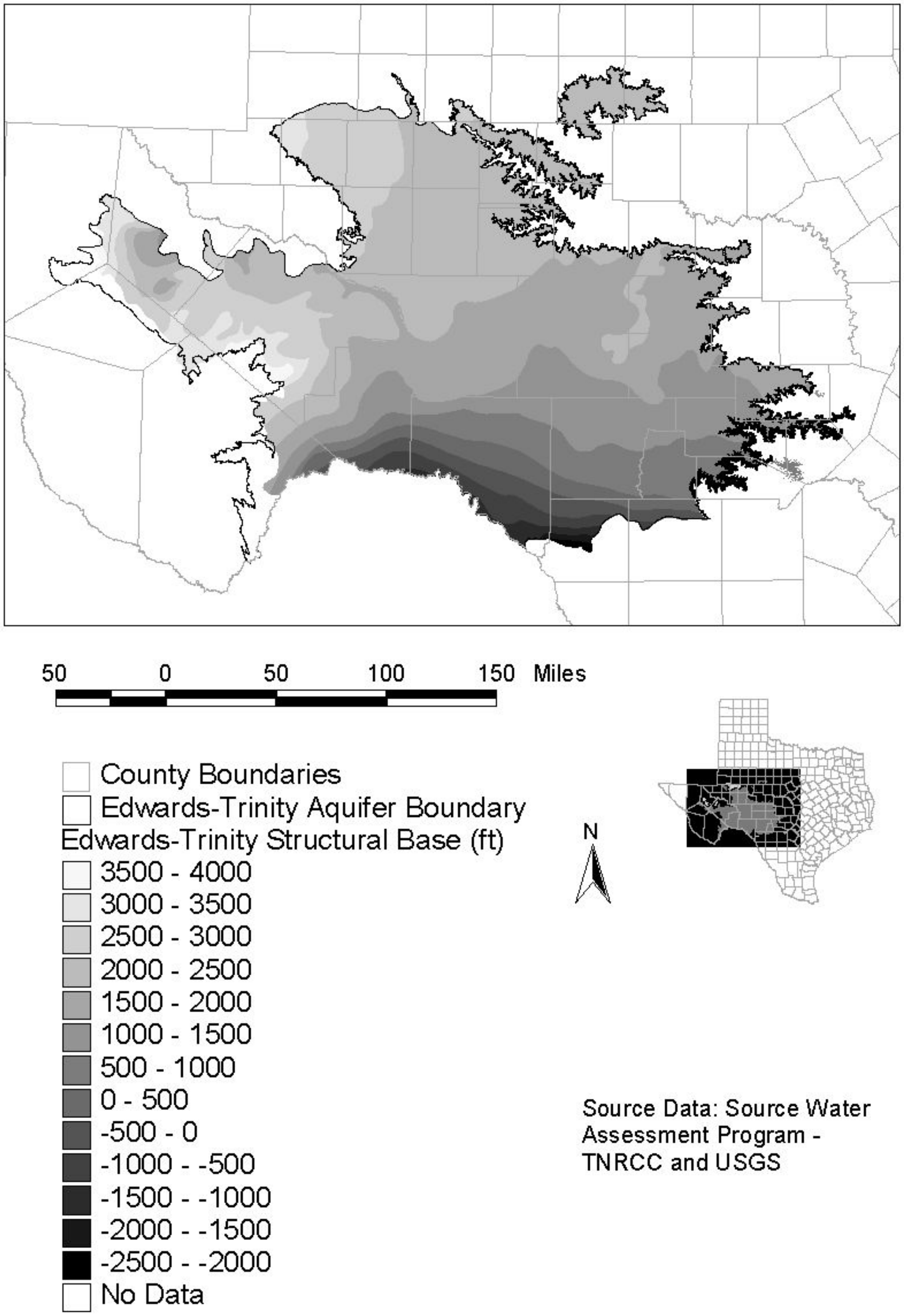


Figure 8-8: Structural base of the Edwards-Trinity aquifer.

Water Levels

Although water levels are influenced by climate, they have remained fairly constant, except in areas of the northern and western plateau where a general trend of declining water levels is a result of increased irrigation pumpage (Ashworth and Hopkins, 1995). Long-term water levels of the Edwards-Trinity indicate the regional-flow groundwater within the aquifer system (fig. 8-9). There is a regional groundwater divide that trends from the northwest in Ector County to the southeast near the common boundary between Real, Kerr, and Edwards Counties that separates flow toward the Colorado River from flow toward the Rio Grande. The Pecos River valley has a significant influence on the groundwater flow in the western half of the plateau.

Hydraulic Properties

The Edwards-Trinity aquifer is hydraulically connected to four major aquifers: (1) the Cenozoic Pecos Alluvium, (2) the Ogallala, (3) the Trinity (Hill Country), and (4) the Edwards (Balcones Fault Zone). The Edwards-Trinity aquifer is also hydraulically connected to several minor aquifers: (1) the Dockum, (2) the Capitan, (3) the Rustler, (4) the Hickory, (5) the Ellenburger-San Saba, (6) the Lipan, and, to a very small degree, (7) the Marble Falls.

The saturated thickness of less than 100 ft to greater than 800 ft for the Edwards-Trinity aquifer system generally increases from north to south and varies the greatest along the western margins of the aquifer (fig. 8-10). Gentle north-south-trending ridges and troughs in the pre-Cretaceous base depositional surface combined with the topographic influence on the water table control the variability in saturated thickness (Barker and Ardis, 1996). The aquifer is mostly under water-table or unconfined conditions, although the Trinity unit of the aquifer may be semiconfined locally where relatively impermeable sediments of the overlying Edwards Group exist (Ashworth and Hopkins, 1995).

Transmissivity is a function of the conductivity of the aquifer sediments and the saturated thickness. The Edwards-Trinity aquifer generally has transmissivity values of less than 5,000 ft^2/d in the north and eastern portions of the aquifer and values between 5,000 and 50,000 ft^2/d in the southern and western portions of the aquifer with an average of less than 10,000 ft^2/d (Barker and Ardis, 1996). Except for areas of significant karst-induced permeability, the average hydraulic conductivity of the Edwards-Trinity sediments is about 10 ft/d, judging from transmissivity and saturated thickness distributions (Barker and Ardis, 1996).

Recharge

Most recharge occurs from the infiltration of precipitation over Edwards-Trinity outcrops and sinkholes and from stream losses of intermittent streams. Rees and Buckner (1980) estimated recharge over the Trans-Pecos region of the plateau to be between about 0.3 and 0.4 inches per year. Kuniansky (1989) estimated recharge over the eastern portion of the plateau to range between 0.12 and 2.24 inches per year. In general, recharge rates

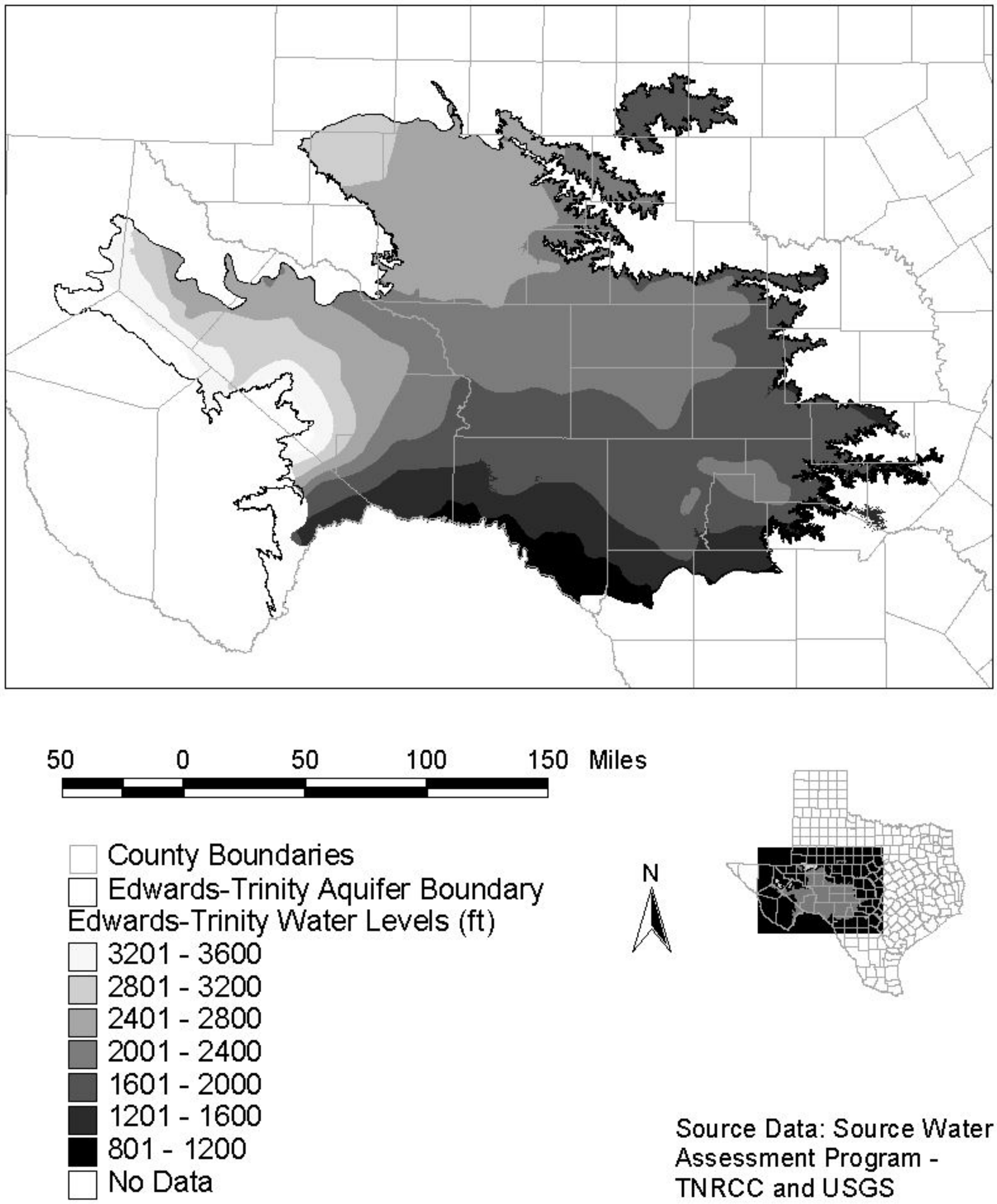


Figure 8-9: Historical water levels of the Edwards-Trinity aquifer.

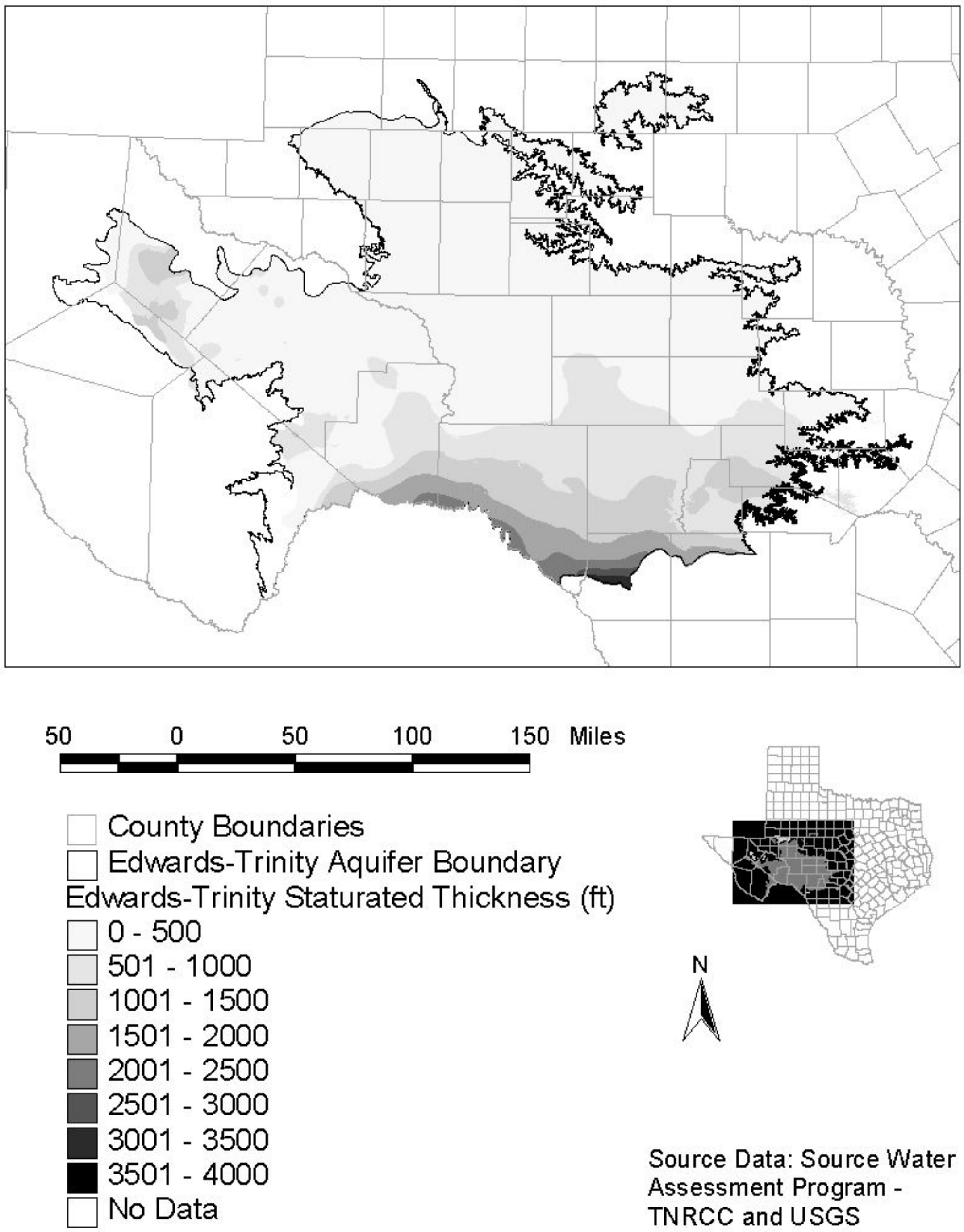


Figure 8-10: Saturated thickness of the Edwards-Trinity aquifer.

vary with climate conditions, surface topography, soils, and land cover/land use. Cross-formational flow from hydraulically contiguous major and minor aquifers also provides recharge to the Edwards-Trinity aquifer system, primarily in the northern and western portions of the aquifer. Induced recharge occurs in Pecos and Reeves Counties as a result of water-level declines due to irrigation pumpage (Barker and Ardis, 1996).

Natural Discharge

Natural discharge from the Edwards-Trinity aquifer occurs mostly from springs where the water table intersects canyons or surface topography to provide base flow to streams. In addition, phreatophytes along major stream valleys discharge the aquifer naturally through evapotranspiration where the water table is shallow enough for the root networks. Cross-formational flow from hydraulically contiguous major and minor aquifers also provides natural discharge from the Edwards-Trinity aquifer system, primarily in the southern and eastern portions of the aquifer. As water levels have declined in the northern and western portions of the aquifer due to increased irrigation pumpage, spring flow within those areas has also declined.

Groundwater Use

The Trinity Group sediments provide much of the water for the northern and western areas of the plateau, while the Fredericksburg Group sediments provide most of the water in the central, southern, and eastern portions of the plateau (Barker and Ardis, 1996). Over three-fourths of the total groundwater pumpage from the Edwards-Trinity is used for irrigation, primarily in the northern and western portions of the aquifer (fig. 8-11). Municipal water suppliers account for the second-most-common groundwater use, followed by minimal industrial, mining, livestock, and rural domestic uses. Climate has a significant effect on the amount of groundwater pumpage from the Edwards-Trinity aquifer because of the high percentage of irrigation use (compare fig. 8-5 with fig. 8-11).

Water Quality

Although water quality is typically hard, it is generally fresh, except for areas in the Trans-Pecos where groundwater from Permian evaporite sediments and/or oil-field brines are able to mix with groundwater from the Edwards-Trinity aquifer (Rees and Buckner, 1980). Water quality is also affected by induced recharge from Pecos River stream losses (Barker and Ardis, 1996). East of the Pecos River, oil-field brines and agricultural runoff have a significant effect on the groundwater quality of the northern portion of the Edwards-Trinity aquifer (Walker, 1979).

Past and Present Studies

Previous studies on the Edwards-Trinity aquifer began with countywide studies by the Texas Board of Water Engineers, Texas Water Commission, Texas Department of Water

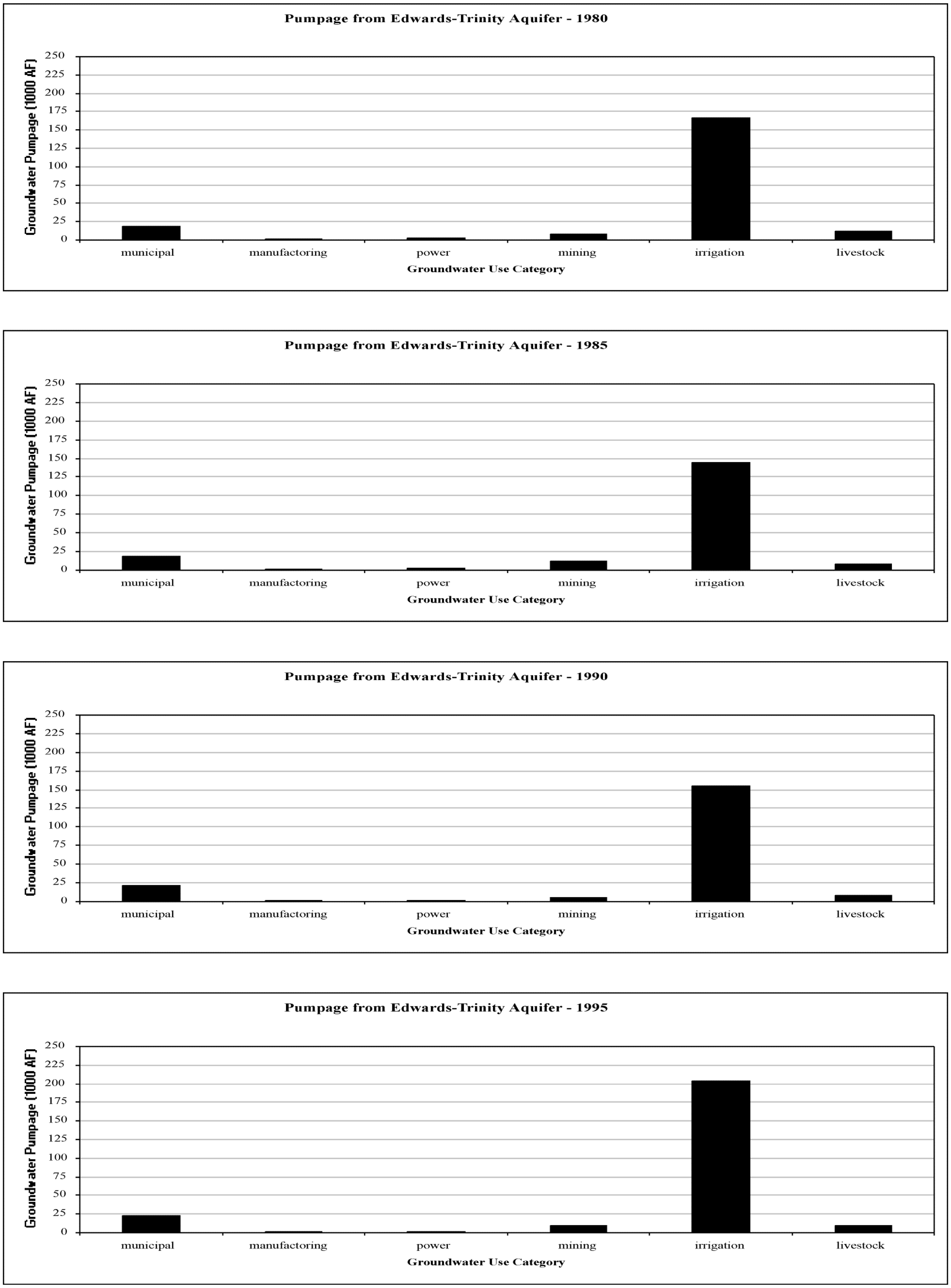


Figure 8-11: Groundwater pumpage from the Edwards-Trinity aquifer.

Resources, Texas Water Development Board, and the U.S. Geological Survey. The Texas Department of Water Resources (Walker, 1979; Rees and Buckner, 1980) was first to publish regional study reports on the Trans-Pecos and Plateau portions of the

Edward-Trinity aquifer. During the 1990's, the U.S. Geological Survey began a Regional Aquifer Systems Analysis (RASA) program for the Edwards-Trinity aquifer system, which resulted in the publication of the most recent and comprehensive reports on the Edwards-Trinity aquifer system, as well as a single-layer, finite-element, steady-state numerical model. Currently the Texas Water Development Board is conducting a comprehensive study to develop a state-of-the-art, multilayer, finite-difference numerical model of the Edwards-Trinity aquifer system, with a final report due for publication in late 2002. Information on this most recent study is updated and maintained at the following Internet Web address: http://www.twdb.state.tx.us/gam/.

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