PLANNING REPORT FOR THE EDWARDS-TRINITY REGIONAL AQUIFER-SYSTEM ANALYSIS IN CENTRAL TEXAS, SOUTHEAST OKLAHOMA, AND SOUTHWEST ARKANSAS

By Peter W. Bush

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CONTENTS

ILLUSTRATIONS

TABLE

METRIC CONVERSIONS

The inch-pound units of measurement used in this report may be converted to metric (International System) units by using the following conversion factors:

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.509	square kilometer (km^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)

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ABSTRACT

The Edwards-Trinity regional aquifer system supplies more than 0.78 million acre-feet per year (700 million gallons per day) of water for central Texas and small adjacent parts of southeast Oklahoma and southwest Arkansas. The system consists of three major aquifers and at least three minor aquifers in predominantly Cretaceous rocks, which together have an areal extent of about 80,000 square miles. The major aquifers are the Edwards-Trinity (Plateau) in west-central Texas, the Edwards (Balcones Fault Zone) in south-central Texas, and the Trinity in north-central Texas, southeast Oklahoma, and southwest Arkansas. Current (1986) and future concerns about the aquifer system involve the ever-increasing demand for water, most of which is associated with rapid population increase. Decreases in or elimination of spring discharges and encroachment of water from downdip salinewater zones into updip freshwater zones are of primary concern in the area underlain by the Edwards (Balcones Fault Zone) aquifer. Water-level declines of several hundred feet in the Trinity aquifer are a serious concern in some metropolitan areas.

The Edwards-Trinity regional aquifer-system analysis project, begun in October 1985 and scheduled to be completed by October 1991, is one of a series of similar projects being conducted nationwide. The project is intended to define the hydrogeologic framework, and to describe the geochemistry and ground-water flow of the aquifer system in order to provide a better understanding of the system's long-term water-yielding potential. A multidisciplinary approach will be used in which computer-based digital simulation of flow in the system will be the principal method of hydrogeologic investigation.

INTRODUCTION

The Edwards-Trinity regional aquifer system is one of 28 regional aquifer systems nationwide that have been identified for study under the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program, begun in 1978. The purpose of the RASA program is to define the regional hydrology and geology, and to establish a framework of background information of geology, hydrology, and geochemistry of the Nation's important aquifer systems (Sun, 1986, p. 1). This report presents the plan of study for the Edwards-Trinity RASA project, begun in October 1985 and scheduled for completion by October 1991.

The Edwards-Trinity RASA project area consists of about 80,000 mi^2 primarily in central Texas, but also includes small adjacent areas in southeast Oklahoma and southwest Arkansas. The northern and western boundaries of the area of interest are defined by the updip limit of hydraulically connected rocks of Cretaceous age. The southern and eastern boundaries of the area are defined by the downdip limit of freshwater (arbitrarily chosen to be where the dissolved-solids concentration is in the range of 7,000-10,000 mg/L), and the Rio Grande where it flows over rocks of Cretaceous age. Rocks of Cretaceous age are of primary interest in the Edwards-Trinity RASA; however, underlying older rocks, where they are hydraulically connected to Cretaceous rocks, may be included in some places.

The major aquifers in the project area, as identified (in Texas) by the Texas Department of Water Resources (TDWR) (1983, plate II-3), are the Edwards-Trinity (Plateau); the Edwards (Balcones Fault Zone); and the Trinity Group (herein referred to as the Trinity) as shown in figure 1. Other aquifers of Cretaceous age, for example the Nacatoch Sand, the Blossom Sand, and the Woodbine Formation, are locally important in parts of northeast Texas, southeast Oklahoma, and southwest Arkansas. However, they are considered minor aquifers by the TDWR because they do not yield large quantities of water in large areas. Accordingly, they will be studied in less detail than the three principal aquifers.

Hydrogeologic Summary

The stratigraphic units[1/] within the Edwards-Trinity RASA project area are shown in table 1. The occurrence and stratigraphy of sedimentary rocks in the project area have been largely controlled by marine deposition, continental erosion, and subsequent continental deposition. Periodic tectonic uplift and subsidence resulted in cycles of marine transgression and regression. At the beginning of Cretaceous time, the seas advanced over Jurassic and Paleozoic rocks from the south and east and deposited marine sediments (the Comanchean Series) throughout the project area. During the Late Cretaceous, a general uplift of the western part of the area caused the Cretaceous seas to move eastward so that deposition of sediments (the Gulfian Series) occurred primarily in the northeastern part of the area. Moderate uplift in the west and continued subsidence near the Gulf Coast during the Tertiary produced one of the major structural features in the project area--an arcuate series of normal, en echelon, faults known as the Balcones fault zone (Klemt and others, 1975, p. 5). The Balcones fault zone is generally coincident with the Edwards (Balcones Fault Zone) aquifer (fig. 1).

The Edwards-Trinity (Plateau) aquifer underlies about 35,000 mi^2 of the Trans-Pecos and Edwards Plateau physiographic regions of Texas (areas I and II, fig. 1 and table 1). The aquifer generally is composed of limestone in its upper part, and sand and sandstone in its lower part. The aquifer dips to the southeast and its thickness varies from a few tens of feet to more than

1/ The stratigraphic nomenclature used in this report was determined from several sources and may not necessarily follow usage of the U.S. Geological Survey.

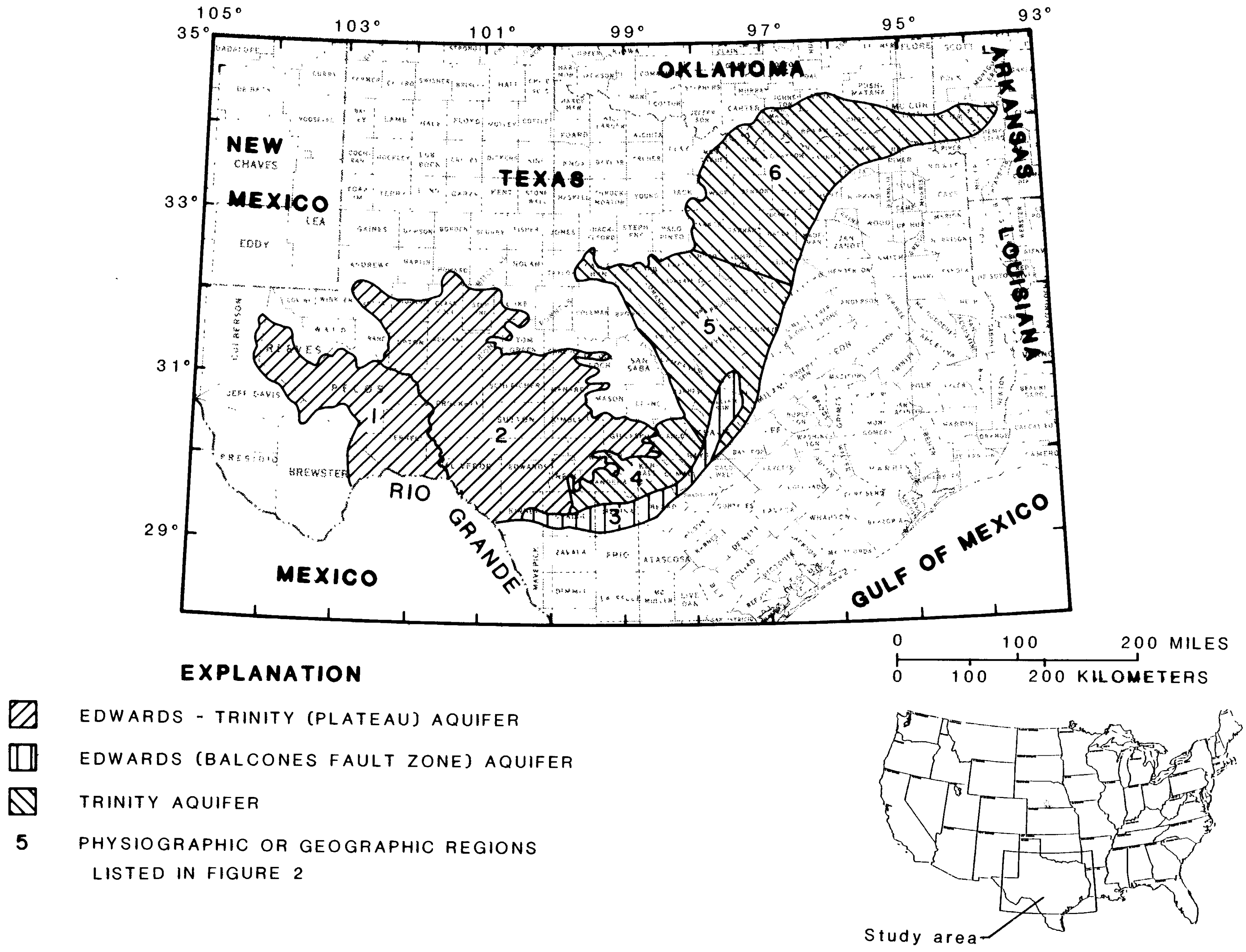


Figure 1.--Major aquifers of the Edwards-Trinity aquifer system.

Table 1.--Stratigraphic units within the project area

System	Provincial series	Group or formation	Trans-Pecos (I) 1/	Edwards Plateau (II) 2/	Balcones fault zone (III) 3/	Hill Country (IV) 4/	East-central Texas (V) 5/	Northeast Texas, southeast Oklahoma, southwest Arkansas (VI) 6/
			Stratigraphic units underlying indicated physiographic or geographic region shown in figure 1					
Quaternary								
Tertiary						Units absent		
Cretaceous	Gulfian	Navarro	Units absent	Units absent				Nacatoch Sand and other units
		Taylor						Numerous formations
		Austin						Blossom Sand and other units
		Eagle Ford	Units absent					Eagle Ford Group
		Woodbine			Units absent		Woodbine Formation	Woodbine Formation
	Comanchean	Washita	Buda Limestone Georgetown Limestone	Buda Limestone Del Rio Clay Georgetown Limestone / Edwards and associated limestones	Buda Limestone Del Rio Clay Salmon Peak Formation / Devils River Limestone / Georgetown Limestone		Buda Limestone Del Rio Clay Georgetown Limestone	Grayson Marl and Mainstreet Limestone Pawpaw Formation Weno Limestone Denton Clay Fort Worth and Duck Creek Limestones
		Fredericksburg	Edwards Limestone	Kiamichi Formation Edwards Limestone Comanche Peak Limestone Walnut Clay	McKnight Formation West Nueces Formation / Devils River Limestone / Edwards Group 7/	Edwards and associated limestones / Edwards Limestone Comanche Peak Limestone Walnut Clay	Kiamichi Formation Edwards Limestone Comanche Peak Limestone Walnut Clay	Kiamichi Formation Edwards Limestone Comanche Peak Limestone / Goodland Limestone Walnut Clay
		Trinity	Trinity Sand (northern part) / Maxon Sandstone Glen Rose Limestone Basal sand	Antlers Formation / Paluxy Sand Glen Rose Limestone Pearsall Formation Hosston and Sligo Formations	Glen Rose Limestone Pearsall Formation Hosston and Sligo Formations	Glen Rose Limestone Travis Peak Formation	Antlers Formation / Paluxy Sand Glen Rose Limestone Travis Peak Formation	Antlers Formation / Paluxy Sand Glen Rose Limestone Twin Mountains Formation
Pre-Cretaceous			Santa Rosa Sandstone (Triassic)	Santa Rosa Sandstone (Triassic)				

1/ Modified from Rees and Buckner (1980, table 1).
2/ Modified from Walker (1979, table 2).
3/ Modified from Maclay and Small (1984, fig. 7); and Rose (1972, fig. 33).
4/ Modified from Ashworth (1983, table 1).
5/ Modified from Klemt and others (1975, table 1).
6/ Modified from Nordstrom (1982, table 1).
7/ Edwards Limestone raised to a stragraphic group by Rose (1972).

1,000 ft. Water in the aquifer exists under both unconfined (water-table) and confined (artesian) conditions. Regional flow generally is to the south and southeast. Numerous springs and seeps discharge from the limestone, particularly along streams in the southeastern part of the aquifer's area of occurrence. Transmissivity values from several aquifer tests in the Plateau region ranged from about 150 to about 1,300 ft^2/d (Walker, 1979, table 4). Well yields may exceed 3,000 gal/min in places where secondary permeability in the limestone is well developed, although yields in most places are much less (Baker and Wall, 1976, p. F6). The dissolved-solids concentration of water in the Edwards-Trinity (Plateau) aquifer typically ranges from 400 to 1,000 mg/L (milligrams per liter) (Baker and Wall, 1976, table 3). However, the water in areas of irrigation in the northwest and west parts of the aquifer generally contains a dissolved-solids concentration of more than 1,000 mg/L.

The Edwards (Balcones Fault Zone) aquifer (area III, fig. 1 and table 1) underlies an area of about 3,500 mi^2 generally coincident with the Balcones fault zone. The aquifer consists of limestone and dolomite ranging in thickness from about 350 to 600 ft. Unconfined conditions occur where the Edwards aquifer is close to the land surface or crops out along its northern and western extent. Confined conditions occur in downdip parts of the aquifer to the south and east of the outcrop. Regional flow is controlled by a complex pattern of barrier faults, which have placed rocks of substantially different permeability adjacent to each other (Maclay and Small, 1984, p. 33). An appreciable part of the regional flow is directed generally northeast, along the strike of the rocks and parallel to the faults, toward three relatively large springs (Comal in Comal County, San Marcos in Hays County, and Barton in Travis County) that together discharge about 500 ft^3/s (320 Mgal/d). The Edwards is by far the most productive aquifer in the project area. Estimated transmissivity values as large as 2 million ft^2/d occur in the San Antonio area (Maclay and Small, 1984, p. 50). Exceptional wells yield more than 16,000 gal/min (Baker and Wall, 1976, p. F7). Water withdrawn from the aquifer usually has a dissolved-solids concentration ranging from 300 to 1,200 mg/L (Baker and Wall, 1976, table 3). Near the downdip limit of freshwater in the San Antonio area, the dissolved-solids concentration increases rapidly from about 1,000 to about 9,000 mg/L (Maclay and others, 1980, p. 13).

The Trinity aquifer underlies about 36,000 mi^2 of central Texas, southeast Oklahoma, and southwest Arkansas (areas IV to VI, fig. 1 and table 1). The aquifer consists of interbedded sand, shale, and limestone, which crop out to the west and north. The aquifer dips and thickens to the east and southeast, and has a maximum thickness of more than 2,000 ft at the downdip limit of freshwater (R. B. Morton, U.S. Geological Survey, written commun., 1986). Water in the aquifer is under unconfined conditions in the outcrop area and under confined conditions downdip. Transmissivity generally is less than 5,000 ft^2/d, although in some places wells yield more than 1,000 gal/min (Baker and Wall, 1976, p. F6). Water pumped from the Trinity aquifer typically has a dissolved-solids concentration ranging from 500 to 1,500 mg/L (Baker and Wall, 1976, table 3).

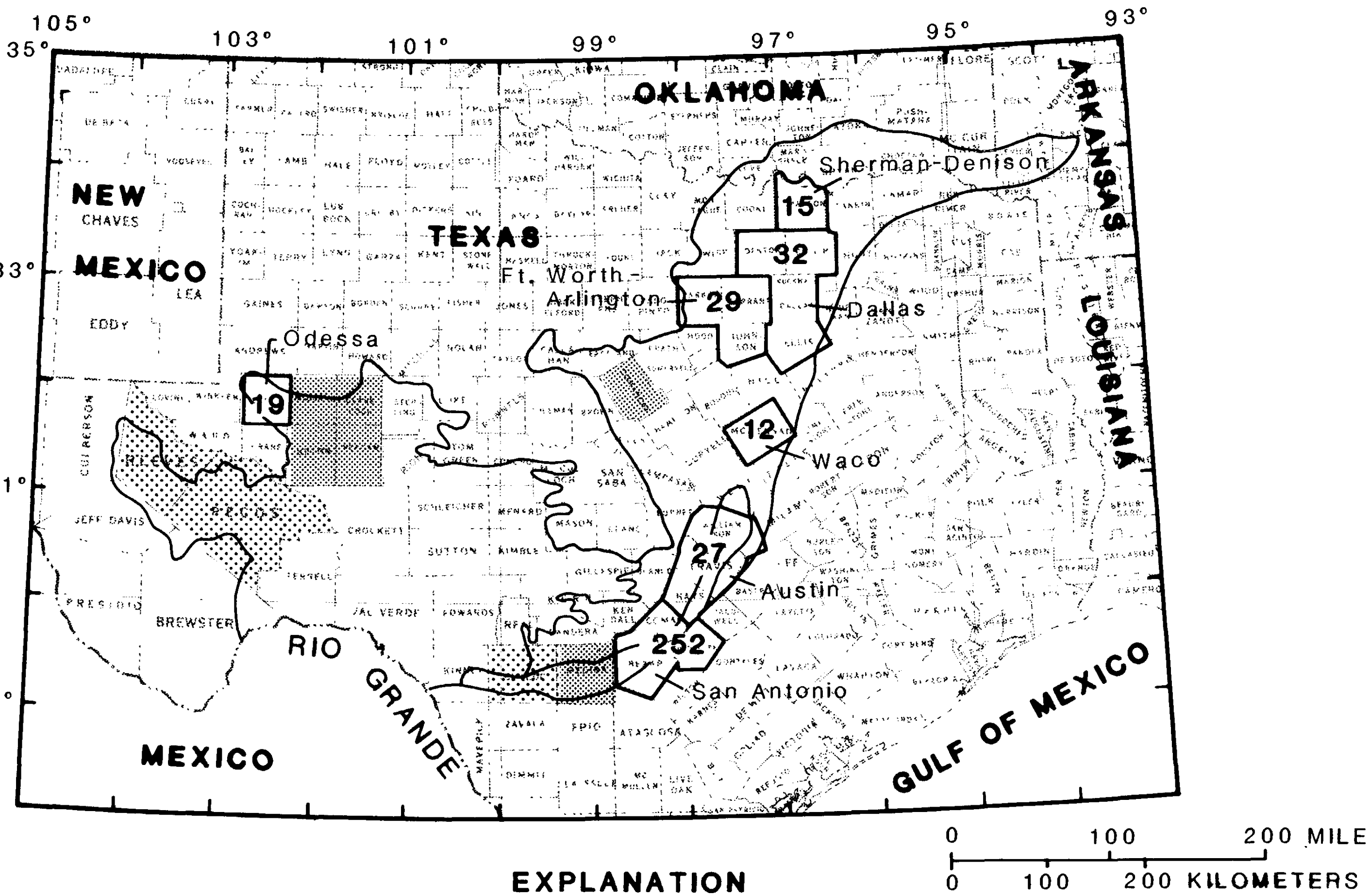
Water Use and Water Issues

During 1980, the Edwards-Trinity regional aquifer system supplied an estimated 780,000 to 840,000 acre-ft (700 to 750 Mgal/d) of water for municipal, industrial, and agricultural use. Areas where most of the withdrawals occurred are shown in figure 2. Municipal and industrial pumpage concentrated in seven areas [designated as Metropolitan Statistical Areas by the TDWR (1985)] accounted for about one-half the pumpage; and irrigation pumpage, the major part of which occurred in the nine counties indicated in figure 2, accounted for most of the other one-half. Pumpage in the San Antonio area is by far the greatest in the project area--at least 30 percent of the total pumpage from the Edwards-Trinity regional aquifer system occurs at San Antonio. The Edwards (Balcones Fault Zone) aquifer is the sole-source water supply for the entire metropolitan area. The Trinity aquifer in the Dallas and Ft. Worth-Arlington areas, although much less productive than the Edwards in the San Antonio area, is extensively developed for muncipal and industrial use. In addition, many smaller cities and towns throughout the project area depend on water from the Edwards (Balcones Fault Zone) or Trinity aquifers for all or part of their water supplies.

The greatest rates of irrigation pumpage in the project area occur in Reeves and Pecos Counties in the western part of the project area, where pumpage is from the Edwards-Trinity (Plateau) aquifer, and in Uvalde and Medina Counties in the southern part where pumpage is from the Edwards (Balcones Fault Zone) aquifer. At least 25 percent of the total pumpage from the regional aquifer system is irrigation pumpage from those four counties.

Current (1986) and future concerns about the regional aquifer system involve the ever-increasing demand for water, most of which is associated with rapid population increase. The combined population of the seven Metropolitan Statistical Areas in figure 2 increased 25 percent between 1970 and 1980, and the TDWR projects future increases of about 20 percent for each of the decades until 2000 (TDWR, 1985). In the San Antonio area, increased withdrawals from the Edwards (Balcones Fault Zone) aquifer have the potential to cause at least two undesirable effects: (1) Decreases in or elimination of some spring discharges, and (2) encroachment of water from downdip salinewater zones of the aquifer into updip freshwater zones. Increased withdrawals have also made the aquifer more sensitive to drought. According to Knowles (1982, p. 43), a given drought occurring in 1982 or later will cause water levels to decline farther and more quickly, and spring flow to decrease faster than in earlier years. Severe drought caused Comal Springs, the largest spring in Texas, to cease flowing from June through November 1956.

In parts of the Dallas and Fort Worth-Arlington areas, pumping has lowered water levels in the Trinity aquifer more than 550 ft. The depth to water is more than 1,000 ft in places, resulting in expensive pumping costs. As water levels have declined, the quality of water in parts of the aquifer has deteriorated (TDWR, 1984, p. 46). Appreciable water-level declines in the Trinity due to pumping also have occurred in the Sherman-Denison area (more than 250 ft) and the Waco area (more than 400 ft). To the west in the Odessa area, pumpage from public-supply wells completed in the Trinity aquifer has caused substantial water-level declines. In each of the Metropolitan Statistical



EXPLANATION

COUNTIES WHERE PUMPAGE FOR IRRIGATION (TEXAS DEPARTMENT OF WATER RESOURCES, 1981) DURING 1979 WAS:

- 10,000 to 50,000 ACRE-FEET
- 50,000 to 100,000 ACRE-FEET

19 METROPOLITAN STATISTICAL AREAS WHERE PUMPAGE FOR MUNICIPAL AND INDUSTRIAL USES (TEXAS DEPARTMENT OF WATER RESOURCES, 1985) WAS GREATER THAN 10,000 ACRE-FEET--Number is pumpage, in thousands of acre-feet

BOUNDARY OF MAJOR AQUIFER--See figure 1 for aquifer names

Figure 2.--Distribution of pumpage from the Edwards-Trinity aquifer system.

Areas in figure 2, current or projected water-level declines have caused planners to recognize a long-term need to develop supplementary surface-water supplies (TDWR, 1985).

General Objectives and Approach

The overall objective of the study is to provide a better understanding of the long-term water-yielding potential of the Edwards-Trinity regional aquifer system. Parts of the system have been and are being studied thoroughly on local or subregional (county or multicounty) scales by several agencies. Much data and interpretive information on the aquifer system exist. This study is intended to combine the data and interpretive information of previous and ongoing studies into a regional description of the hydrogeologic framework, the geochemistry, and the ground-water flow system. To the extent possible, the study will identify the changes that have occurred in the original flow system in response to ground-water development and the changes that might occur as a result of future development.

A multidisciplinary approach will be used in which computer-based digital simulation of flow in the aquifer system will be the principal method of hydrogeologic investigation. Geologists will determine the regional hydrogeologic framework and divide the aquifer system into mappable permeability units. Geochemists will describe the water chemistry and interpret the flow system based on the water chemistry. Ground-water hydrologists experienced in ground-water flow modeling (hydrologist-modelers) will use the hydrogeologic framework and geochemical information to construct digital flow models on regional scales. Different interpretations or hypotheses of the geologic structure of the aquifer system and patterns of flow indicated by geologic, geochemical, and hydrologic studies will be tested with the digital models. The results of the project will be presented in an integrated series of interim and final reports.

Organization and Staffing

The project is headquartered in Austin, Texas. The permanent staff in Austin will consist of the project chief, a full-time geologist and a half-time geologist, a full-time hydrologist-modeler, and a full-time geochemist. The project chief will also serve as a hydrologist-modeler. An additional part-time geochemist may be added to the staff at the project midpoint if the budget allows. Additional professional or technical personnel will be assigned to the project for specific work items. The services of such personnel will be planned for and budgeted annually.

No permanent staff will be assigned in Oklahoma and Arkansas. Funds will be provided to U.S. Geological Survey offices in those States for the purpose of acquisition and compilation of data, and technical consultation. The respective office chiefs will assign personnel from their staffs as appropriate.

PLAN OF STUDY

Geology

The objective of the geologic work is to describe the aquifer system by determining the hydrogeologic framework on a regional scale. The work will include:

1. Identifying and describing the lateral and vertical limits of the system.
2. Identifying and describing the regional aquifers and confining units within the system, and the confining units immediately above and below it. The regional aquifers and associated nomenclature may differ from those of the TDWR used in this report.
3. Mapping the top, bottom, and thickness of regional aquifers within the system.
4. Establishing qualitative or relative areal distributions of permeability of regional aquifers and confining units.
5. Explaining the effects of geology on the flow system; that is, the effects on the flow system of areas of maximum or minimum permeability, areas where faults or solution features exist, areas of rapid or complex facies change, and so forth.

The approach to be used in determining the hydrogeologic framework will involve assembly and analysis of existing borehole geophysical and geologic data from oil, gas, and water test holes or wells. Pertinent data will be synthesized into manual and computer files and compiled on maps and sections for interpretation.

In some parts of the system, particularly the Edwards (Balcones Fault Zone) aquifer in the San Antonio area, much of the hydrogeologic-framework definition has been completed in previous studies. In other parts of the system, less hydrogeologic framework definition has been done and relatively more work will involve identifying geophysical-log patterns representing relative porosity and permeability; and correlating these patterns among wells in order to define aquifers and confining units.

Geochemistry

The objective of the geochemical work is to describe the regional water chemistry, and to use the water chemistry to identify and understand the patterns of regional ground-water flow. The work will include:

1. Mapping the principal dissolved constituents and the hydrochemical facies of the major aquifers.
2. Explaining the effects of geochemistry on the distribution of permeability.
3. Relating aquifer mineralogy, chemical reactions and mixing, isotope data, and hydrochemical facies to the regional ground-water flow patterns.

Computerized data files of dissolved constituents and mineralogy will be created from existing analyses of the U.S. Geological Survey and other agencies.

If important data do not exist and the budget permits, sampling and analyses in selected areas will be conducted.

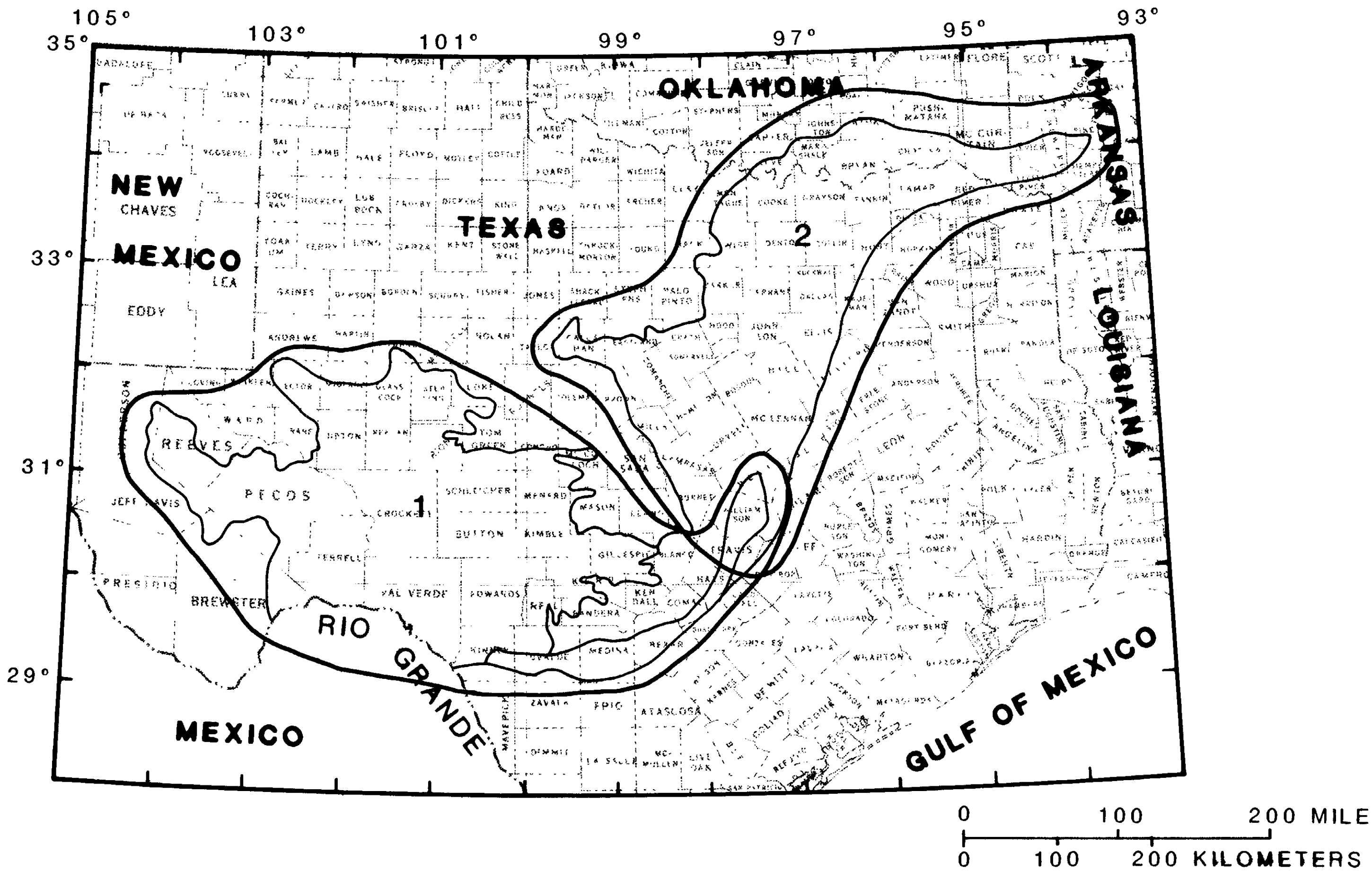
The geochemical work in a particular area will be done in two phases. The first phase will be descriptive; that is, the compilation of maps depicting the principal dissolved constituents and hydrochemical facies of the major aquifers. The second phase will be interpretive. It will involve items 2 and 3 above, and will be done after the descriptive phase is completed. To a certain extent the methods to be applied in the interpretive phase, and the parts of the aquifer system where they are applicable, will be determined from the results of the descriptive work. Some likely methods of investigation include the analysis of carbon isotope data to estimate regional hydraulic conductivity; the analysis of dissolved solids and tritium concentrations to identify recharge areas; the analysis of temperature and chemical data to identify local, intermediate, and regional flow patterns; and the application of mass-balance relations and mass-transfer calculations to derive reactions that simulate the existing water chemistry along flow paths. Ideally, the geochemical studies will provide information on the nature of the flow system that correlates with and confirms the understanding of the flow system obtained from geologic and hydrologic studies.

Digital Modeling of Ground-Water Flow

The objective of the digital modeling of ground-water flow is to describe the regional flow system based on simulation. The work will include:

1. Defining the hydraulic properties of the aquifer system, particularly the transmissivity of regional aquifers, and the leakage coefficient of confining units.
2. Defining the current (mid 1980's) and predevelopment boundary conditions.
3. Mapping the current (mid 1980's) and predevelopment potentiometric surface of each regional aquifer, to the extent possible.
4. Mapping the current (mid 1980's) and predevelopment distributions of recharge to and discharge from the aquifer system.
5. Summarizing ground-water development, and describing the effects of ground-water development on boundary conditions, water levels, recharge, and discharge.
6. Evaluating the effects of future pumpage in selected areas.

At least two regional models are planned to simulate flow in the aquifer system, the general areas of which are shown in figure 3. Area 1 is underlain by the Edwards-Trinity (Plateau) aquifer, the Edwards (Balcones Fault Zone) aquifer, and part of the Trinity aquifer. Area 2 is underlain by the Trinity aquifer and locally important minor aquifers. Where the two model areas are coincident, the Trinity aquifer is beneath the Edwards (Balcones Fault Zone) aquifer and is separated from it by confining units. The models will not be physically linked; however, leakage between the Trinity aquifer and the Edwards (Balcones Fault Zone) aquifer will be consistent in the two models. The modeled areas may extend beyond the boundaries of the aquifers of interest in places where adjacent aquifers are hydraulically connected to the aquifers of interest.



EXPLANATION

[1] AREA OF PROPOSED MODEL, WITH IDENTIFYING NUMBER

—— BOUNDARY OF MAJOR AQUIFER--See figure 1 for aquifer names

Figure 3.--General areas of proposed regional models.

The generic models to be applied in each of the areas have not been selected. However, because extensive faulting greatly influences patterns of flow in the Edwards (Balcones Fault Zone) aquifer, a finite-element model, with its greater latitude in mesh design than that of a finite-difference model, probably will be applied in area 1. Consideration is being given to a multilayer version of MODFE, the U.S. Geological Survey's two-dimensional finite-element model of ground-water flow that is currently (1986) being developed (L. J. Torak, U.S. Geological Survey, written commun., 1986).

Each model will be calibrated to the conditions for which the most complete data are available. In parts of the system where pumpage or seasonal differences in natural stresses have caused appreciable long-term or periodic change in the patterns of ground-water flow, the initial calibrations will be tested or refined or both by attempting to simulate conditions different from the initial calibration conditions.

Currently (1986), there are no plans to simulate variable-density flow in the saline zones of aquifers downdip from the freshwater zones. The saline zones of aquifers will be considered in this study only insofar as their effects, or potential effects, on freshwater zones. The lateral hydraulic gradient between zones of salinewater and zones of freshwater can be defined by freshwater heads (although the vertical hydraulic gradient cannot) (Lusczynski, 1961, p. 4249). Thus, in relatively flat-lying aquifers with little vertical movement of salinewater, the potential for lateral movement of salinewater toward zones of freshwater can be simulated with a single-density flow model.

The emphasis in development of the flow models will be on understanding the patterns of regional flow and controls on regional flow in the major aquifers. This implies gaining an understanding of the effects of boundary conditions and confining units, as well as of the aquifer properties.

Reports

A series of interim and final reports is planned as follows:

Geology--The interim reports will be map reports to define the aquifer system. They will be in one of two forms: (1) Structural maps of the top, bottom, and thickness of the regional aquifers, or (2) atlas maps describing the hydrogeologic setting, which would include aquifer outcrop areas, preliminary sections, correlation charts, and so forth. The final report will be a U.S. Geological Survey Professional Paper that describes the hydrogeologic framework of the entire aquifer system.

Geochemistry--The interim reports will be map reports that show the principal dissolved constituents and hydrochemical facies for the major aquifers. The final report will be a Professional Paper including both descriptive and interpretive geochemistry of the entire aquifer system.

Digital flow modeling--The interim reports, which also may be map reports, will summarize the simulation strategies and preliminary results of the regional modeling. Major topics will be the translation of geologic units into model units, prototype boundary conditions into simulated boundary conditions, and the sensitivity of heads and flows to the controlling properties and boundary conditions. The final report will be a U.S. Geological Survey Professional Paper that describes the hydraulic properties and regional flow system based on simulation of the entire aquifer system.

Summary--A U.S. Geological Survey Professional Paper that briefly summarizes the major features of the flow system, synthesized from the geologic, geochemical, and simulation studies will be prepared. A report to include selected data, or instructions to obtain the data, on which the interpretations of the study are based will be compiled near the end of the project.

Work Schedule

The schedule of major work activities for the duration of the project, fiscal years 1986 through 1991, is shown in figure 4. As the schedule indicates, the aquifer system in area 1 (fig. 3) will be studied during the first one-half of the project; and the system in area 2 will be studied during the second one-half of the project. The staff responsibility for the major work activities is as shown. Final definition of the aquifer system, defining the hydraulic properties, and relating the geology and geochemistry to the regional flow system will be a joint effort among the geologists, geochemists, and hydrologist-modelers.

No specific entry for development of a data-management system appears in the schedule of major activities. It is planned that the P-STAT 1/ system will be used to develop and maintain files of geologic, hydrologic, geochemical, and pumpage data. The design of P-STAT files to manage the project data is included in the "Assemble...data" activities in figure 4.

1/ Use of the trade name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

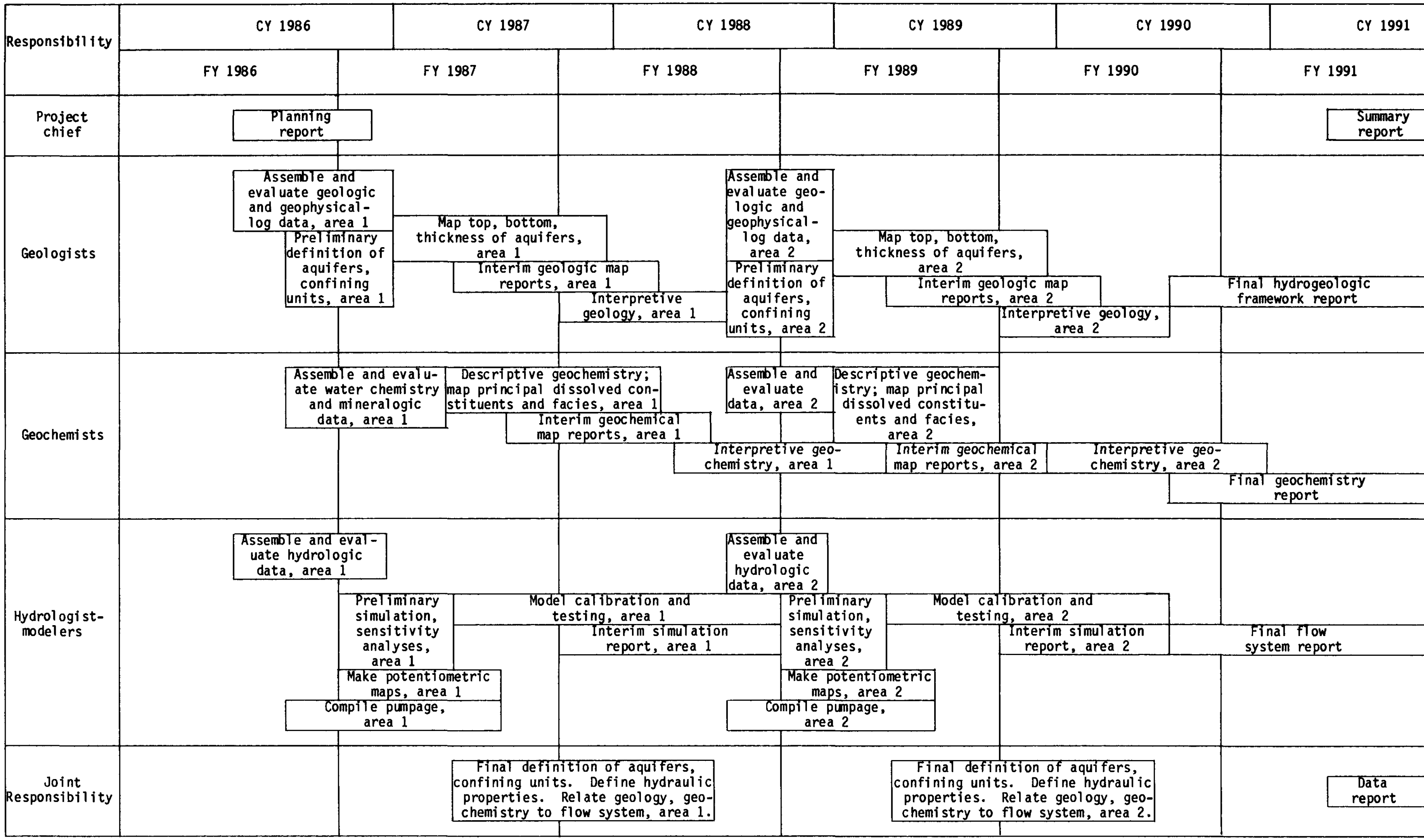


Figure 4.--Schedule of major work activities. (See fig. 3 for location of areas 1 and 2.)

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