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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLANNING REPORT FOR THE SOUTHWEST ALLUVIAL BASINS (EAST) REGIONAL AQUIFER-SYSTEM ANALYSIS, PARTS OF COLORADO, NEW MEXICO, AND TEXAS

By

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In this report figures for measurements, except water temperature, are given in inch-pound units only. The following table contains factors for converting to metric units:

Multiply inch-pound units	By	To obtain metric unit
square mile	2.540	square kilometer
mile	1.609	kilometer
feet	0.3048	meter
gallon per minute	0.06309	liter per second

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ABSTRACT

The study of the Southwest alluvial basins (east) will involve an analysis of the regional aquifer system in parts of Colorado, New Mexico, and Texas. This area has been divided into 22 alluvial basins. The study of the alluvial aquifer-system will be made in the following stages: (1) Project planning, (2) literature searches, (3) compiling existing data, (4) data collection, (5) basin modeling, (6) regional aquifer modeling, and (7) reports.

The regional aquifer study will be accomplished through studying each of the 22 basins. Data compilation and limited data collection will be part of each basin study. Digital-computer models will be made for those basins where data are sufficient. A regional-aquifer model will be developed from the basin models. In addition to this report, there will be basin hydrology reports and the final regional report. Included in the final report will be a description of the regional hydrology and geology.

INTRODUCTION

The history of the southwestern United States emphasizes the relationship between available water resources and the people in the area. The present (1980) occupants of the Southwest are as dependent on water as their predecessors. The increasing use of water and the expanding population coupled with an increasing awareness of our dependency on the total water-resource system have led to studies which are designed to gain a better understanding of the hydrologic system.

The Southwest alluvial basins study is part of a national program to analyze regional aquifer systems. The drought of 1977 emphasized the need for a better understanding of water resources. The alluvial basins in the Southwest are an important source of ground water; information about the quantity and quality of the ground-water resources and their relationship to surface-water supplies must be available if optimum use of the water resources is to be made.

Physiography

The study area, about 70,000 square miles, includes the Rio Grande drainage basin from the San Luis Valley in Colorado south to Presidio, Tex., and the adjoining closed basins in southwestern New Mexico and western Texas (fig. 1).

The study area is located within or adjacent to four separate physiographic provinces (fig. 2). In the northern part of the study area the boundaries of the Southern Rocky Mountains province are formed by the Sangre de Cristo, San Juan, and Jemez Mountains. The San Luis and Espanola Basins, which occur between the mountain ranges, are included in the Southern Rocky Mountains province (fig. 1). For the purpose of this study, the Basin and Range province includes the Rio Grande rift northward to the southern end of the Espanola Basin. The Colorado Plateau province is north of the Basin and Range province and west of the Southern Rocky Mountains province. The Great Plains province is adjacent to the east boundary of the study area.

Bryan (1938) applied the term "Rio Grande depression" to the series of structural basins separated by canyons or restrictions through which the Rio Grande flows. The more recently defined Rio Grande rift includes the San Agustin, Jornada del Muerto, Tularosa, and Mimbres Basins in addition to those of Bryan's Rio Grande depression (Chapin, 1971, p. 193). The basins contain mainly Tertiary and Quaternary rocks and sedimentary deposits; the Santa Fe Group or its equivalent is the principal deposit. The floors of the basins consist of broad plains between mountains; they range from 1 to 35 miles wide and from 29 to 135 miles long. At the margins of the basins, piedmont slopes are formed by alluvial fans or by pediments deposited on crystalline rock or older basin-fill. The basins have a variety of post-Santa Fe geomorphic surfaces that range in age from middle Pleistocene(?) (Hawley, 1965; Ruhe, 1964; Hawley and Kottlowski, 1969) to the present-day flood plain of the Rio Grande. The Rio Grande is generally entrenched about 200 to 500 feet below the older basin surfaces.

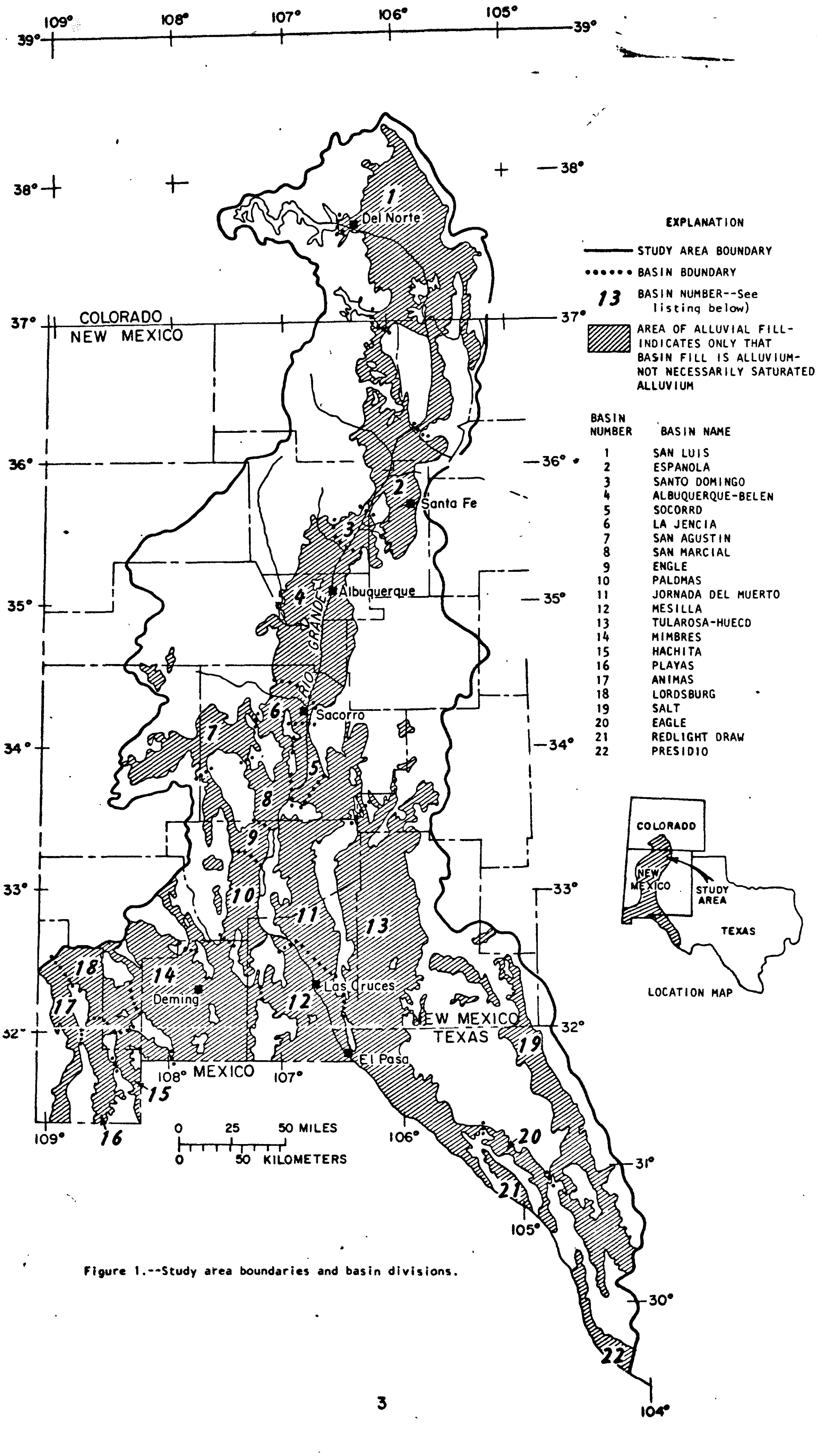


Figure 1.--Study area boundaries and basin divisions.

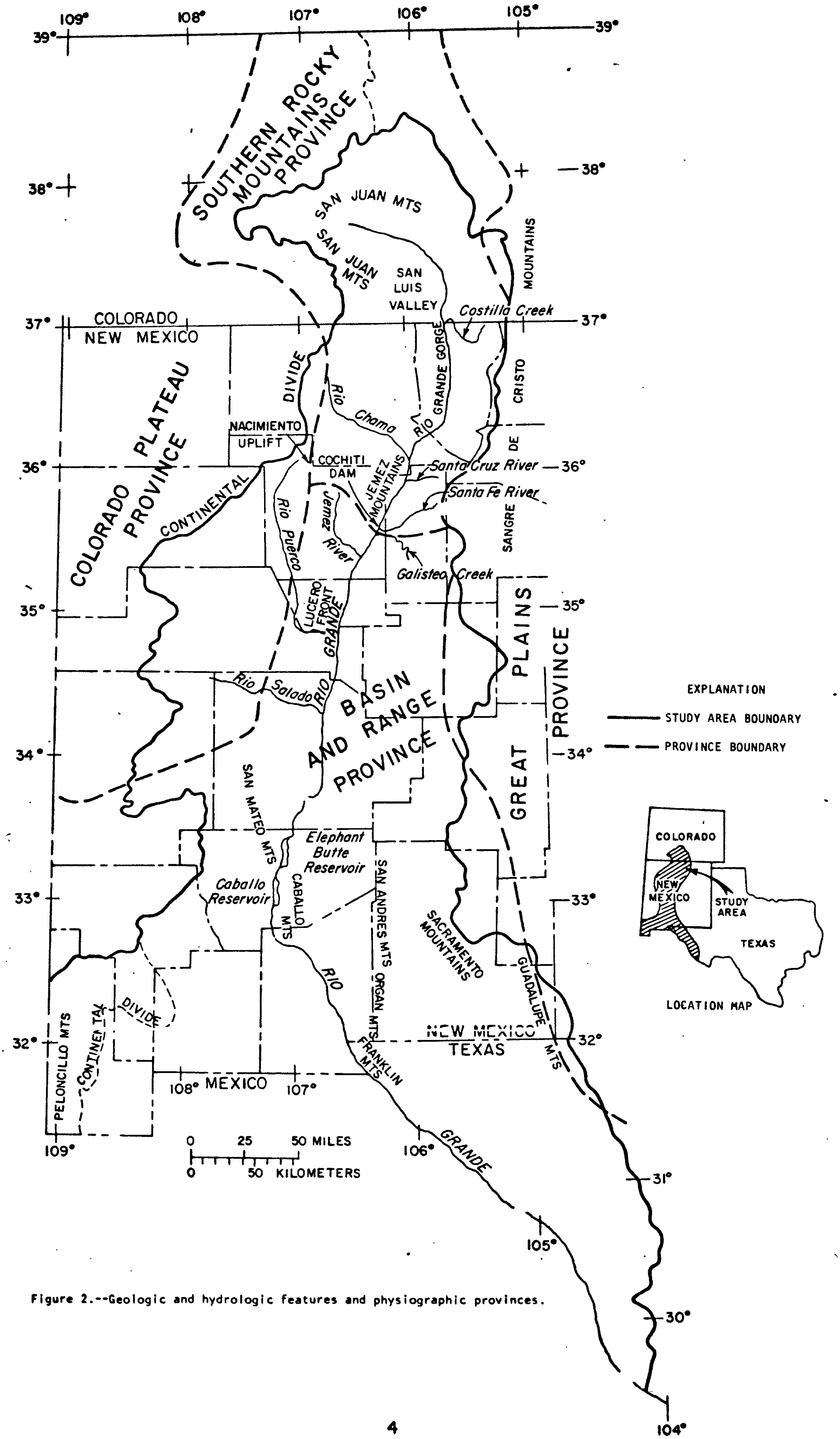


Figure 2.--Geologic and hydrologic features and physiographic provinces.

Geohydrology

More than 50 percent of the study area is within the Rio Grande drainage basin. The part of the study area not within the Rio Grande drainage basin consists of closed basins--basins having no external drainage.

Rio Grande drainage basin--The regional occurrence of ground water is controlled primarily by geologic structure and secondarily by the stratigraphy and lithology of the rock units. West and Broadhurst (1975, p. 11-13) divided the rocks within the study area into the following four basic types: (1) Basin fill--unconsolidated to poorly consolidated sand and gravel interbedded or intermixed with clay and silt; (2) volcanic rocks--primarily basalt, including other volcanic flow rocks, tuff, and small intrusive bodies; (3) consolidated sedimentary rocks--primarily shale and sandstone, including limestone, gypsum, and salt; and (4) crystalline rocks--intrusive igneous rocks and metamorphic rocks. The basin fill is the unit of primary geohydrologic interest to this study. The geology section at the end of this report will discuss the structure and geologic history of the study area.

The basin fill, including the interbedded volcanic rocks, is as much as 9,000 feet thick in New Mexico and is reported to be more than 30,000 feet thick in the north-central part of San Luis Valley, Colo. (West and Broadhurst, 1975, p. 13). These thick deposits of basin fill comprise the principal ground-water reservoir. The principal water-bearing deposits of the basin fill include the recent fan deposits, the inner-valley alluvium, and the Santa Fe Group. These are interconnected hydraulically and collectively make up a single aquifer that is anisotropic and heterogeneous. The ground water in the basin fill generally is unconfined, but locally confined conditions may exist.

Coalescing alluvial fans overlie the Santa Fe Group adjacent to mountains. The fans, which thicken to as much as 200 feet toward the mountains, contain both poorly sorted mudflow materials and well sorted stream gravels. Runoff from the mountains infiltrates into these fan deposits and recharges the underlying ground-water reservoirs. The deposits are generally above the water table and are unsaturated. Along the mountain front they may be saturated, yielding a few tens of gallons per minute of water to wells.

The inner Rio Grande valley alluvium is similar in appearance and composition to sediments of the underlying Santa Fe Group from which the alluvium is largely derived. The contact of the valley alluvium with the Santa Fe Group, generally between 100 and 200 feet below land surface, is probably characterized by a change in lithology and consolidation. Because of the valley alluvial deposits' excellent capacity for recharge, transmission, and storage, they are capable of supplying as much as 3,000 gallons per minute to wells. Most irrigation and domestic wells along the Rio Grande are completed in the valley alluvium.

The Santa Fe Group is the most important and extensive basin fill deposit in the Rio Grande valley. It underlies the surficial-fan and valley alluvial deposits, but crops out in places east and west of the river. The Santa Fe consists of beds of unconsolidated to loosely consolidated sediments and interbedded volcanic rocks. Permeability generally is relatively high except in localized areas of fine-grained sediments or along fault zones where cementation has occured. Wells constructed in the Santa Fe Group can yield from several hundred to several thousand gallons of water per minute. It is the principal source of water for public and industrial use in the study area.

Water in the basin-fill deposits occupies the space between rock particles. The spaces generally are interconnected, allowing water to move through the material due to the force of gravity. The generalized pattern of ground-water movement in the Rio Grande depression is from the bordering highlands into the water-bearing basin fill and downgradient towards the river, where the predominant movement is downstream.

Recharge to the aquifer is from infiltration of water into the basin fill and associated volcanic rocks. Possible sources of recharge include direct infiltration of precipitation; diverted surface water and ground water pumped for irrigation; underflow of ground water from adjacent areas; and seepage from streams, surface reservoirs, and intermittent runoff during intense rainstorms. Because the Rio Grande is the major perennial stream in the rift area, infiltration of surface water from the Rio Grande is probably the greatest single source of recharge to the aquifer.

Discharge from the surface alluvium is by seepage to streams and by pumping from wells. Water also is discharged by evaporation from soil and transpiration by plants in localities where a shallow water table exists, particularly in the inner river valleys. The major discharges from the Santa Fe Group are by wells, springs, and, in places, upward leakage.

The water table fluctuates in response to additions to or withdrawals from the ground-water reservoir. The change in water levels is an index to the change in the amount of water stored in the aquifer. In some areas the quantity of ground water in storage has increased, owing to infiltration of surface water diverted for irrigation; in other areas the quantity in storage has decreased, owing to extensive withdrawal of ground water.

The Rio Grande, one of America's longest rivers, is the major source of surface water in the study area. The total length of the river is about 1,800 miles (West and Broadhurst, 1975, p.2). The river originates in regions of perpetual snow on the eastern crest of the Continental Divide in eastern San Juan County, Colo. Tributaries from the neighboring high mountains join it as it flows eastward to enter the San Luis Valley some 65 miles east of its headwaters.

From the Colorado-New Mexico State line south through the Rio Grande Gorge, the stream has been designated a Wild and Scenic River by Congress. Dams on Costilla Creek, Rio Chama, Santa Cruz River, Galisteo Creek, and Jemez River (fig. 2) control tributary flow from these streams to the Rio Grande (Lansford and others, 1973, p. 30-31). Downstream from Cochiti Dam, most of the water is diverted into the canals of the Middle Rio Grande Conservancy District and the Elephant Butte Irrigation District. Diversion dams, canals, drains, and levees are used to regulate and control the water within the districts. The river forms the boundary between Mexico and Texas for about 1,250 miles from El Paso to its mouth at the Gulf of Mexico.

Geologic and hydrologic investigations have long established that there is direct hydraulic connection between the Rio Grande and the adjacent aquifers. Extensive ground-water withdrawal from this stream-aquifer system results in a reduction in streamflow due to interception of natural ground-water discharge and to induced infiltration from the stream. This, in turn, results in a diminution of the available surface-water supply of the Rio Grande.

Stratigraphy, rock structure, and the time water is in contact with a rock type are the principal factors that determine the chemical character of water derived from wells, springs, and spring-fed streams in the region. The chemical quality of water in the basin-fill aquifers in the region varies widely both laterally and vertically. The water in the shallow alluvial deposits along the river generally is unsuitable for many uses. The unsuitability probably is caused by concentration of dissolved solids from evapotranspiration and by infiltration of return irrigation water that contains dissolved soil salts and fertilizers. The water at a depth of a few thousand feet in the underlying older fill may have concentrations greater than 3,000 mg/L of dissolved solids due to decreasing permeability with depth, which increases the time water is contact with the rock. Water that is suitable for most uses generally occurs at intermediate depths in the Santa Fe Group.

The water of the Rio Grande generally is clear and contains dissolved-solids concentrations less than 500 mg/L as it passes through the San Luis Valley. In New Mexico the sediment load and dissolved-solids concentration generally increase as the river flows downstream. This increase may be due in part to the contributions made by the Jemez River, Rio Puerco, and Rio Salado (fig. 2) and from mineral concentration by evaporation on the irrigated lands (Bryan, 1938, p. 441). Sulfate is the predominant dissolved chemical constituent in surface waters of the Rio Grande basin because it is present in widespread rocks and is readily soluble.

Closed basins - Closed basins in the study area are the northern San Luis Valley, the San Agustin, the Jornada del Muerto, the Tularosa-Hueco, the Mimbres, the Playas, the Animas, and the Salt (fig. 1). All these basins have internal surface drainage, but some water may move underground to adjacent basins or areas.

According to West and Broadhurst (1975), water supplies in the closed basins are derived almost entirely from ground water. The chemical quality of most of the vast quantity of water contained in the aquifers of the closed basins is such that the water is unusable for most purposes. Much water is lost by evaporation in the closed basins; the concentration of salts in the water in and near the central parts of the basins is increased by evaporation, causing a general degradation of the water quality. Hale, Reiland, and Beverage (1965, p. 113-14) reported that water levels in the Mimbres Basin declined as much as 35 to 50 feet from 1940 to 1960. The same magnitude of decline was noted in the Animas Basin during 1948-60. The declines were a result of irrigation development in the basins.

The alluvial deposits of the closed basins are similar in lithology to that described for basins along the Rio Grande, except that they commonly contain extensive beds or lenses of clay and silt. Large water-level declines in areas where clay beds comprise a significant part of the basin may result in subsidence of the land surface. Subsidence results from compaction of the clay as water is removed.

Water use - Water in the study area is supplied from surface sources, underground sources, and combinations of the two. Ground water is used for most municipal, industrial, commercial, mineral production, rural domestic, and stock-watering requirements. According to Lansford and others (1973), surface sources provide the primary supply of water for irrigation. The quantity of water pumped from wells for irrigation varies from year to year and depends in part on the amount of surface water available.

Demographic information

A 1975 estimate of the population of the study area was about 1.2 million (U.S. Bureau of the Census, 1977). Of this number, 34 percent reside in and around Albuquerque, N. Mex., and El Paso, Tex. Approximately 3 percent of the population of the study area is in Colorado, 62 percent in New Mexico, and 35 percent in Texas.

The economy of the area is based mainly on agriculture with the exception of the Albuquerque, Las Cruces, and El Paso areas. In these areas military and related industries, educational institutions, light manufacturing, and transportation add significantly to the economy. Additional industries in the El Paso area include refining of petroleum and smelting and refining of copper and associated metals. El Paso is also one of the largest clothing manufacturing centers in the United States (U.S. Department of the Interior, 1971).

Southwest alluvial basins study

The Southwest alluvial basins (SWAB) study is part of the Regional Aquifer-System Analysis (RASA) program of the U.S. Geological Survey. The SWAB study area includes the southern tip of Nevada; the eastern part of California and western Arizona from Hoover Dam to the Arizona-Mexico border along the Colorado River; closed basins in Arizona, Texas, and New Mexico; and basins adjacent to the Rio Grande in parts of Colorado, New Mexico, and Texas. The western part of the study area, SWAB (west), includes sections of Nevada, California, Arizona, and New Mexico. The study area described in this report, SWAB (east), includes parts of Colorado, New Mexico, and Texas (fig. 1).

Regional Aquifer-System Analysis

The RASA program is a systematic approach to the study of a number of regional ground-water systems in the United States. Congress appropriated $5 million in 1978 to start these studies. Specific objectives vary from one study to the next; however, certain general objectives will be common to all. Among these are the following: (1) To describe, both hydraulically and geochemically, the present ground-water system and the original system as it existed prior to development; (2) to analyze the changes which have led to the present condition of the system; (3) to assemble the results of prior studies dealing with individual segments of the system; and (4) to provide predictive capabilities through which the effects of further ground-water development can be estimated.

Purpose and scope of the Southwest alluvial basins (east) study

The principal objectives of this regional alluvial aquifer study are to develop a computer data base; describe the flow system, the geochemistry, and water use; and develop digital computer models. The geohydrology of basins will be studied within the framework of these principal objectives.

To meet the objectives of this study, many aspects of the hydrologic system will be investigated. Included in the scope of this project will be ground-water quantities, depth to water, and ground-water recharge and discharge areas. Because of the importance of the hydrologic connection between surface and ground water along the Rio Grande and its tributaries, this relationship will be investigated. The rock-water system will be studied in order to develop an understanding of water-quality changes with time and space. The areal and vertical variability in quality of water is an important consideration in water use; therefore, both will be described.

THE STUDY

Approach

The approach to this regional alluvial aquifer study is based on studies of the basins defined in figure 1. The approach to a individual basin study consists of a literature review; compilation and evaluation of available hydrologic data; limited hydrologic-data collection; geophysical, geochemical, recharge, and water use investigations; and development of a model of the basin hydrology.

Regional interpretations will result from geologic and hydrologic information derived from the compiled basin data and from models developed during the basin studies. Basin models will be interfaced with each other for the regional hydrologic model.

Basin studies

The approach of this project is to study individual basins (fig.1). Basins are defined on the basis of hydrology and structural geologic features; however, with continued study and increased knowledge of the area, basin boundaries may be altered.

The basins have been grouped into three priorities for study. The first priority basins are those where population is increasing, agricultural use of water is large, a fairly complete data base exists, or the basin is hydrologically connected to adjacent basins.

Basins in this group are San Luis, Espanola, Albuquerque-Belen, Socorro, Palomas, Mesilla, Tularosa-Hueco, and Mimbres. The second priority basins are those where population is not increasing as in the first group, agricultural use of water is not as great, and the data base is likely to be somewhat incomplete. Basins in the second priority group are Santa Domingo, San Agustin, San Marcial, Engle, Animas, Salt, and Presidio. The third priority basins are those where very little data exists, there is limited agricultural use of water, population is sparce, and an insignificant hydrologic connection to adjacent basins exists. Basins in this category are La Jencia, Jornada del Muerto, Hachita; Playas, Lordsburg, Eagle, and Redlight Draw.

A literature review of appropriate reports about the basin will be made at the beginning of each basin study. The review will result in the accumulation of the reports and a concept of the geohydrologic system. A draft basin report defining the geohydrology of the basin will be completed prior to any data collection or development of an areal model. Review of the literature also will provide guidance in selecting the type and location of geophysical, geochemical, recharge, or water-use studies to be done in a basin.

Existing hydrologic data will be used wherever possible. Well location, construction, and logs; water level; and ground-water quality data from the files of the U.S. Geological Survey and from many State and Federal agencies will be used. These data will be stored in the Geological Survey's WATSTORE national data base. A limited amount of these data will be collected in areas of basins that require better definition. Surface-water discharge and quality data is stored in WATSTORE. There will be no attempt to collect additional surface-water data.

Basin studies will deal with the total water resource. Ground-water data needed for these studies will include saturated thickness of the alluvial aquifer, ground-water inflow and outflow for the basin, aquifer characteristics, location and volume of withdrawal and recharge, chemical quality changes with time and space, and hydraulic connection to a surface-water body. Surface-water data will include stage-discharge relationships, water-quality, and points of diversions and returns. These surface-water data are generally available from Geological Survey and irrigation district records and reports.

Agricultural use of water is generally documented by Federal, State, or local agencies. Water-use data for the San Luis Valley will be compiled by personnel in the Geological Survey's subdistrict office in Pueblo, Colo. Personnel in the Geological Survey's office in El Paso will compute water-use data for the part of the study area in Texas. A contract has been awarded to the New Mexico State Engineer Office to compile water-use data for that part of the study area within New Mexico. This contract calls for both compilation of current water-use data and assistance in determining historical water-use information. Water-use data will include a division between surface and ground-water use.

Recharge for a basin will be estimated using available streamflow information or discharge, drainage area, and infiltration relationships. For those streams that do not intersect the aquifer and have at least two stage-discharge gaging stations within the basin, the loss of streamflow between gages during a period of no inflow between the gages will be used to calculate recharge to the aquifer. The loss per mile between gages will be applied to the entire reach of the stream to estimate the annual recharge to the aquifer by streamflow. For streams with only one streamflow station, a relationship between infiltration and discharge established by Burkham (1970) will be used to estimate recharge. The discharge for each flow is estimated upstream and downstream from the gage, and the infiltration is then estimated using the relationship between infiltration and discharge. A relationship between size of drainage area and discharge has been established from gaged streams in the study area. This relationship will be used to estimate discharge for streams with no stream-gage installations. Infiltration will then be estimated from the infiltration-discharge relationship. Recharge to the aquifer from streams that intersect the aquifer will be calculated using a water budget for the reach of the stream in the basin. The budget will include inflow and outflow at basin boundaries; tributary inflow; sewage returns; estimates of evapotranspiration from crops, phreatophytes, and other non-irrigated acreage within the valley; and estimates of ground-water pumpage based on irrigated acreage and crop type. The residual of the budget will be considered as recharge to or discharge from the aquifer.

Both surface-water and ground-water quality data will be needed for two general aspects of the study. The data will be used to determine the areal and vertical distribution of water quality. Water-quality data will also be used, along with known geology of the area, in defining the geochemistry of the system. The possible reactions that could take place in the water between the recharge and discharge areas during the time the water is in a particular geologic environment will be analyzed. From geochemical studies it may be possible to estimate the volume of a particular water type contributing to a recharge or discharge area. Interpretation of geochemical data may indicate the origin and amount of ground-water inflow to a gaining reach of a stream or of recharge to the ground-water system from a losing reach of a stream.

Geologic studies have been conducted in most basins in the study area. These studies may include lithology, stratigraphy, and structure of the basin fill and surrounding bedrock.

The project will use existing geologic data and interpretations, well-log data, geophysical data, and hydrologic data to investigate the effect of geology on the ground-water flow system and the influence on the geochemistry of the basin. Lithofacies maps, sections, structure maps, water-level maps, and correlation of well log information at different locations are some of the information that will be used in the study of the geohydrology of the basins.

Definition of basin characteristics will be one objective of project geologic studies. Physical characteristics such as areal distributions of permeability, percentage of sand with vertical distance (as shown in drillers' logs), and specific capacity will be computed and plotted on maps. These types of data will be analyzed statistically to determine the correlation of these characteristic with basin surface features.

Surface features of basins where little subsurface geohydrologic data is available will then be used to make assumptions about aquifer properties. These aquifer properties will then be used in developing a model for basins with little available data.

Surface geophysical methods will be used to determine depth to hydrologic basement and basin boundaries. Other results from these studies may be depth to ground water, areal and vertical changes in water quality, lithology of the alluvial aquifers, and structural anomalies within basins.

Two contracts with the University of New Mexico for geophysical studies are in progress. The first contract is to define the areal and vertical extent of the alluvial aquifer in the Albuquerque-Belen Basin using resistivity and gravity data. The second contract is for hydrologic interpretation of existing gravity data in the remaining parts of the study area within New Mexico. The interpretation of these data will produce gravity profiles through the basins, indicating basin boundaries and depth of alluvial fill.

Seismic data collected during the summer and fall of 1979 through a grant to the Colorado School of Mines will be used for basin definition extending from the New Mexico-Colorado State line north into the San Luis Valley. Data about depth of alluvial fill, structural anomalies, and limited aquifer lithology will result from this study.

From the lower Mesilla Valley to Presidio, Tex., Gates and others (1978) made use of electric, seismic-refraction, and aeromagnetic methods to define fresh-saline water interfaces, lithology, and thickness of basin fill.

Hydrologic studies presently being conducted by the U.S. Geological Survey in New Mexico are using earth resistivity studies to determine water-quality changes with horizontal and vertical distance and aquifer lithology. These studies will be used in this project as appropriate. From 4 to 8 weeks of resistivity studies will be done at site-specific locations as part of this project. These locations will be selected after the existing gravity data has been interpreted. The resistivity data collected will be used to define specific water-quality or lithology anomalies and to resolve basin-boundary questions. Commercially collected seismic data will be purchased and interpreted for the southwestern New Mexico part of the study area. These data will provide information on depth to bedrock near the Mexico border and between basins.

Models--A digital computer model of a hydrologic system is a mathematical representation of the interaction of physical forces in that system. The correctness of the mathematical representation depends on knowledge of the hydrologic system, ability to mathematicaly describe the interactions in the physical system, and measurements of these physical interactions. Models are important tools that will be used in the SWAB study. Models of basins within the study area will be developed and calibrated to the extent allowed by available data.

Criteria for the type of model will include the number of dimensions in which a system will be modeled; the ground-water, surface-water, and water-quality components of the water system; and the hydrologic data available. Models of basins will range from uncalibrated models, based on assumptions of aquifer properties resulting from basin characterization studies, to calibrated and verified basin models where geohydrologic data are available. The models used for basin studies will use the finite-difference procedure.

A first model of each basin will be steady state--no change in ground-water storage. When the study-state model is as representative of the physical system as the hydrologic data allow, a transient model will be used to simulate changes in ground-water storage with time if data about historical or current pumpage and water-level change are available. A calibrated transient model can be used to predict the effects on the water-resource system of various water-use plans.

The number of dimensions to be modeled will depend on the geologic and hydrologic complexity of the basin. The first model of some basins will probably be a two-dimensional cross section model. These models will provide experience in modeling and may assist in defining stream-aquifer relationships and the need for additional data. In most basins the boundaries are complex and the aquifer has differing characteristics horizontal and vertical; three-dimensional models will be used in these basins.

The water quality of a basin will be modeled if there is sufficient data. The models used will range from a transport model to one that will give possible chemical reactions that explain water-quality changes from the time and place water is recharged to the aquifer until it is discharged to a downstream basin, to a surface-water body, or pumped from the aquifer. A water-quality model might define circulation patterns in an aquifer or indicate the relative volumes of water entering an aquifer from geologically different recharge areas.

One end product of the basins studies will be some type of model of the hydrologic system. In some basins, a lack of hydrologic data may preclude development of a model. In these basins, the study will result in a compilation of the existing data and documentation of the need for additional data-collection. A uncalibrated model may result for those basins where basin-characterization studies make it possible to assume characteristics of the aquifer. These models will be presented as the best estimate of the physical system. These models can be used to guide additional data-collection and to theorize about the basin hydrologic system. A calibrated, verified model will be the optimum product of the basin studies. This type of model will be attempted in developed basins where sufficient amounts and types of data are available. The models will be available for water-resource planners and managers to use in predicting effects of various water-use plans.

The SWAB aquifer systems are so variable lithologically that it is difficult to associate water-quality changes with mineralogy of the aquifer. To the extent possible, areal water-quality changes will be modeled to determine possible reactions that could cause these changes. Transport models will be used in conjunction with flow models to understand the interaction of the flow system and water-quality changes.

Regional study

The regional study consists of combining interpretations, models, and data from the basin studies. The result of basin studies will be regional surface-water, water-quality, and ground-water data bases, as well as a regional water-resource model.

The regional model will be a coupled-basin model. The degree and type of hydrologic connection between basins will determine the approach that will be taken to develop the regional model. If there is no hydrologic connection between basins or there is no hydrologic effect at the boundaries of a basin from stressing basin models with projected withdrawals, there is no need to link basin models. In this instance, the basin models will be the end product of the modeling effort. From preliminary analysis, the above may be true for the closed basins of southwestern New Mexico and west Texas.

Those basins through which the Rio Grande flows are hydrologically connected. Some type of linkage between basin models will be required for a regional model. The Rio Grande is the most obvious hydrologic connection in these basins. The compacts and treaties that involve Rio Grande waters restrict the depletion of these surface flows. There must always then be flow in the river sufficient to meet a set delivery schedule downstream. The regional model must consider this hydrologic connection as well as any ground-water flow at basin boundaries.

Schedule of work

The schedule of work for the major components of this study is shown in figure 3. The components of the regional study are planning, literature searches, compilation of existing data, data collection, basin studies, regional study, and reports. Because the project is based on basin studies, specific planning, literature search and review, compilation of existing data, data collection, and reporting of results will be done for each basin. Data collection will be completed for the regional study area as the effort to collect a particular type of data is made. Compilation of existing data will start in those basins with the highest priority and progress as rapidly as possible regardless if a basin study has been started.

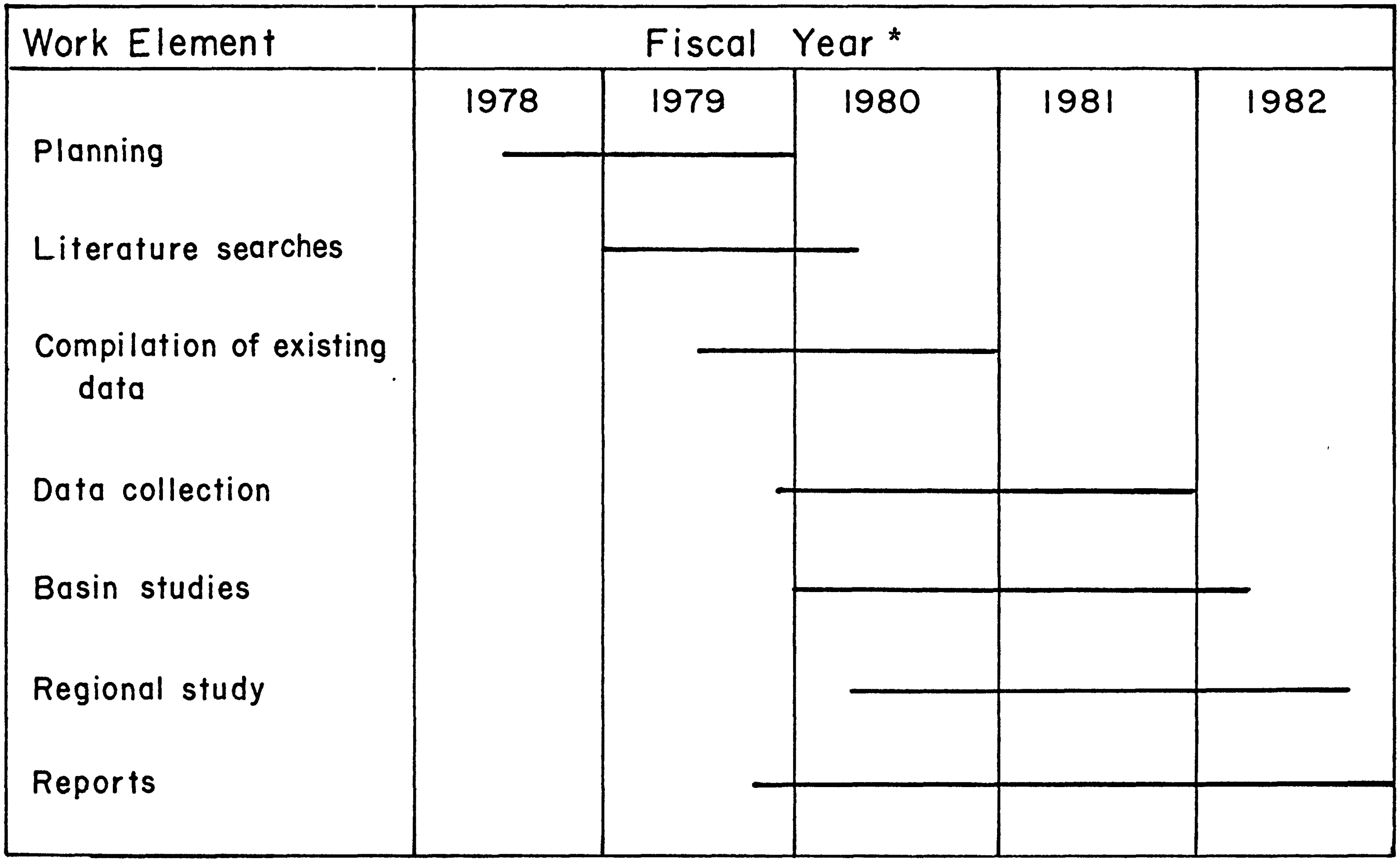
Planning

Planning for this project was divided into two types. The first type of planning involved the evaluation of the regional problem and the approaches to solving that problem. The various approaches and solutions were evaluated; the basin study approach was selected. The selection and overall scheduling of the components shown in figure 3 was completed as was setting priorities for the basin studies

The second type of planning involves planning the basin study. The effort required for literature searches, compilation of existing data, data collection, the model type, and expected reports is estimated. A schedule to complete these tasks is developed and the study is started.

Literature searches

Literature searches were started in early fiscal year 1979 by contract with the New Mexico Bureau of Mines and Mineral Resources for a geology and geophysics literature search. At about the same time a literature search of hydrologic and related data in New Mexico was begun by the U.S. Geological Survey in New Mexico. This second effort will result in four bibliographies for the State of New Mexico.



* Fiscal year begins October 1 and ends September 30

Figure 3.--Schedule of major work elements.

In May of 1979, project personnel began abstracting geohydrologic reports in preparation for beginning basin studies. Included in this effort are study area boundaries, lists of tables, and lists of illustrations included in existing reports. These literature searches will result in a compilation of the existing hydrologic data--tables, maps, and illustrations.

Compilation of existing data

Existing geohydrologic data that will be useful to the project include: geophysical, well location and construction, ground-water level, water quality, surface water, borehole log, and interpretive geological. This data will be used to define the geohydrologic system including direction of ground-water flow; changes in water quality with time in the aquifer distance from a recharge point, and use; changes in depth to water because of pumpage; definition of basin boundaries and characteristics; and the hydrologic relationship between streams and aquifers. A digital model of a basin will be attempted if the data is sufficient to define the geohydrologic system.

Data for the study area is located in many local, State, and Federal agencies. The data will be retrieved using computer magnetic tape, microfilm of paper files, and published and unpublished reports. The data will be evaluated, and selected data coded and entered into the WATSTORE data base.

Compilation of these data began in March of 1979. U.S. Geological Survey ground-water quality data has been coded, corrected, and entered into the WATSTORE data base. Well-site inventory, water-level, and water-quality data from other government agencies will be compiled, coded, and entered into WATSTORE during 1980.

Data collection

In many parts of the study area ground-water level and quality data is either not current or not sufficient to define the system. Data will be collected to update the information for the study area through 1979-80 and to fill in data gaps Geophysical data will be collected at basin boundaries to further define depth of saturated alluvium. Water-use data are needed so an estimate of the ground-water pumpage and diversions from stream-flow can be made. The water-use data will also indicate locations of discharge from aquifers by wells and evapotranspiration. Collection of geophysical and water-use data began during fiscal year 1979 and will continue through fiscal year 1980. Collection of chemical-quality data began during fiscal year 1979 and will continue through fiscal year 1981. Water-level data will be updated in the Texas and Colorado parts of the study area during fiscal years 1979-80 and in the New Mexico part during the winter of 1980-81.

Basin studies and regional modeling

Basin studies will begin during fiscal year 1980 and continue through the early part of fiscal year 1982. The regional modeling effort will begin during fiscal year 1980. With the development of each basin model, a component of the regional model also will be developed. The linkage of the basin models--which will evolve into the regional model--will begin to be researched when models of two adjacent basins are completed.

Products

Products planned from this project include hydrologic data bases, reports, and digital models. The ground-water data base will include well-construction and log information, water levels, and water-quality analyses. A water-use data base will be developed in cooperation with the Office of the New Mexico State Engineer.

This report is the first of a series from the SWAB (east) study. At the completion of each basin study, a report documenting the techniques used and results of the study will be produced. Included in the basin report will be a listing of the hydrologic data and a description of the geology, hydrology, and the models. The description of the model will include assumptions, data used, results, and a sensitivity analysis. The final report of the regional study will describe the regional hydrology including the geology, water-quality, and surface- and ground-water relationships. The regional model also will be described. The assumptions, data used, results, and the sensitivity of the model to variations in the data used will be recorded. As techniques are developed or modified for data analysis or interpretation, these methods will be documented and reported.

Grant and contract work done in conjunction with the project will result in reports. The literature search done by the New Mexico Bureau of Mines and Mineral Resources has resulted in a publication by that agency (Stone and Mizell, 1979). Other reports will include work done by the Office of the New Mexico State Engineer on consumptive use by agriculture, University of New Mexico on geophysics in the New Mexico part of the study area, and the Colorado School of Mines on geophysics in the San Luis Basin.

GENERAL DESCRIPTION OF THE GEOLOGY

The regional geology is important to properly understand and evaluate the purpose and scope of the project. This section of the report was derived from literature reviews during the planning stage of the project and is a compilation of the many geologic studies completed in the SWAB (east) regional aquifer system area. The following material also will serve as regional background for future reports of individual basin studies.

Rock types

The geology of the large region included in the study area is diverse; the description that follows is limited mainly to the Cenozoic (basin-fill) geology due to its hydrologic importance.

The margins of the basins and the highland areas adjacent to the basins are composed of a variety of rock types of Precambrian through early Cenozoic age. The areal distribution of the Precambrian metamorphic and intrusive rocks, Cambrian to early Miocene sedimentary rocks (comprising the largest areas of the upland parts of the study area), and the Eocene to early Miocene (early Tertiary) volcanic rocks is shown in maps by Dane and Bachman (1965) and Hawley (1978, sheets 1 and 2).

Santa Fe Group

The basin fill is composed chiefly of Cenozoic sediments and interbedded igneous rocks. In most instances, the basin fill is Miocene or younger; the basin fill is related to the formation of the Rio Grande rift or to the development of basin-and-range topography. The major part of these rock units belongs to the Santa Fe Group or its equivalents.

The Santa Fe Group, a rock-stratigraphic unit, is classified mainly on the basis of lithology and environment of deposition rather than fossils or time boundaries. The Santa Fe consists of unconsolidated to moderately consolidated sedimentary deposits and some volcanic rocks. Originally, Bryan (1938, p.205) affirmed the name Santa Fe Formation for the basin deposits of presumably Pliocene age along the Rio Grande. Bryan used four general criteria in defining his Santa Fe Formation:

> "(1) All the beds are slightly cemented, and the fine-grained members have concretions of calcium carbonate; (2) all the deposits are deformed, mostly by normal faults, although in the centers of the basins the deformation is so slight as to pass unnoticed except under intensive search;

(3) the beds within any one basin are of diverse lithologic types, ranging from coarse fanglomerate to fine silt and clay, and abrupt changes in the kind and sizes of the contained pebbles are characteristic; and (4) these markedly different materials attributed to one formation conform in their arrangement to a geographic pattern consistent with the laws of deposition in basins."

Since Bryan's time, his Santa Fe Formation has been renamed the Santa Fe Group (Spiegel and Baldwin, 1963). Its subunits have been redefined and been given various names along the Rio Grande depression. In addition, the term "Santa Fe" has been applied by some workers to sediments in intermontane valleys that are adjacent to the Rio Grande depression in the southern one-half of New Mexico.

The correlation chart (fig. 4) illustrates the many formations and subdivisions in the Santa Fe Group and the variation in age range of these units.

The lower limit of the Santa Fe Group is generally placed above the middle Tertiary (Oligocene) volcanic and associated sedimentary rocks. For southern New Mexico, the upper limit is generally placed at the surface of the youngest basin-fill deposits that predate initial entrenchment of the present Rio Grande Valley in middle Pleistocene time (King and others, 1971; Weir, 1965). Most workers in the northern one-half of the study area (Bryan and McCann, 1937; Smith, 1938; Stearns, 1953; Galusha, 1966; Kelley, 1977, fig. 2) have excluded the surface composed of early Pleistocene gravels from the Santa Fe Group.

Basins in the study area are characterized by a variety of alluvial-fan, coalescent-fan, and pediment-cover deposits around the basin margins. These deposits generally grade into, or intertongue with, fine-grained lacustrine or alluvial basin-floor deposits (King and others, 1971). In open systems, medium to coarse fluvial facies, with relatively small amounts of fine-grained sediment, were deposited in the central parts of the basins by axial streams. Volcanism continued during deposition of the Santa Fe Group, but to a lesser extent than during the early Tertiary. Interbedded volcanic rocks, mainly basalts and occasionally andesites, rhyolites, and tuffs, are present in the Santa Fe Group. The interbedded volcanic rocks which generally range from 50 to 200 feet thick, are more prevalent north of Socorro (Bryan, 1938, p. 207).

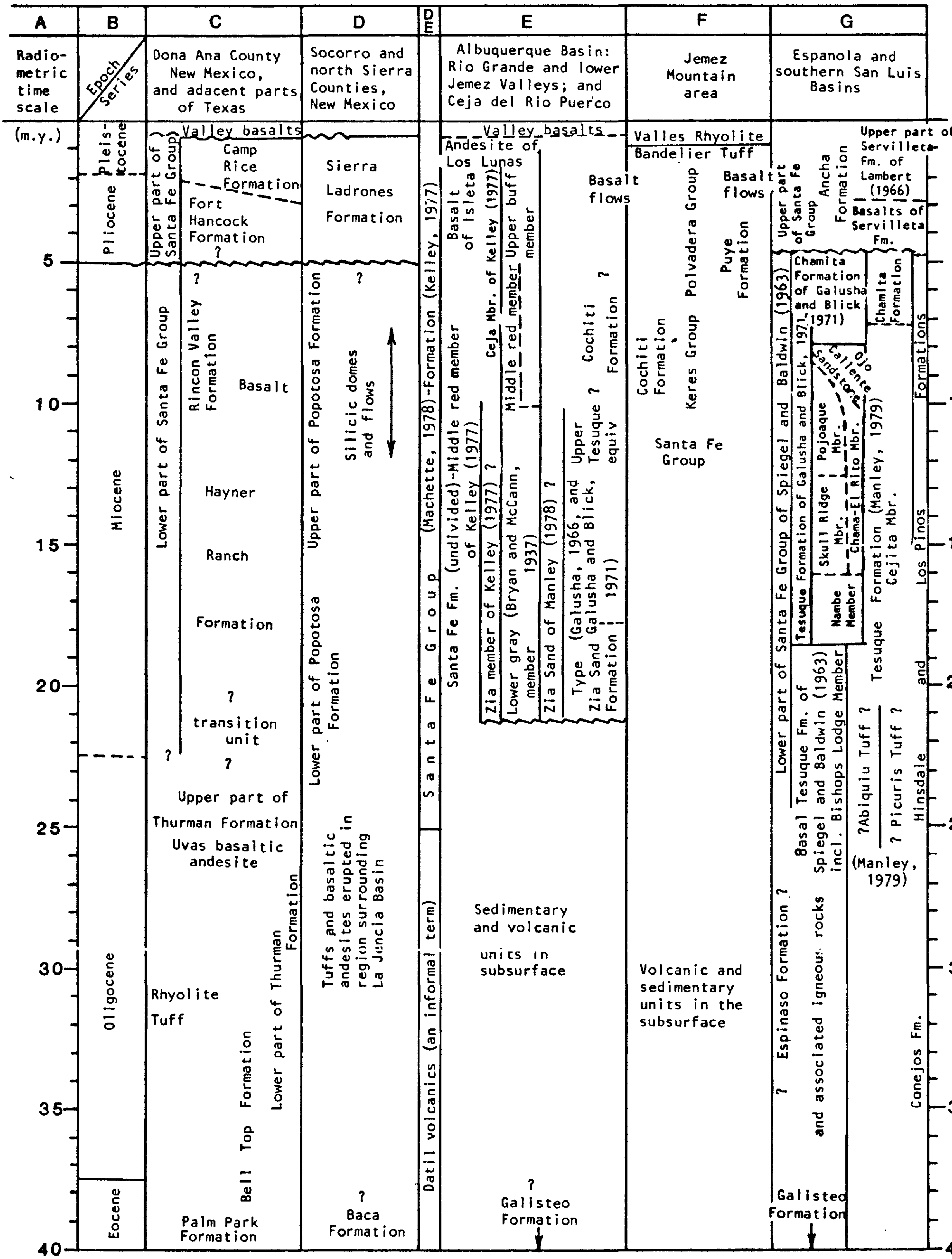


Figure 4.--Santa Fe Group and equivalent units in selected areas of the Rio Grande rift.

<u>References for Figure 4</u>

Modified from J. W. Hawley (1978, p. 239)

Column B: Berggren and Van Couvering (1974), Galusha (1974), Izett (1977)

Column C: Chapin and Seager (1975), Clemons (1976), Hawley (1975), Seager (1973, 1975)

Column D: Bachman and Mehnert (1978), Chapin and Seager (1975), Chapin and others (1978), Machette (1978)

Column E: Bachman and Mehnert (1978), Bryan and McCann (1937), Galusha (1966, Galusha and Blick (1971), Kelley (1977), Kudo and others (1977), Lambert (1968), Manley (1978a)

Column F: Bailey and others (1969), Doell and others (1968), Smith and others (1970)

Column G: Bachman and Mehnert (1978), Galusha (1974), Galusha and Blick (1971), Lambert (1966), Lipman and Mehnert (1975), Lipman and others (1978), Manley (1978b), Manley and Naesser (1977), Ozima and others (1967), Spiegel and Baldwin (1963)

The Santa Fe Group is estimated to have a maximum thickness ranging from 1,200 to 3,000 feet in most of the basins (Weir, 1965, p. 24; King and others, 1971, pp. 17-22; Trauger, 1972, pl. 27; Baltz, 1978, pp. 215-19; Lovejoy and Hawley, 1978, p. 59). Mattick (1967) estimated a thickness of about 9,000 feet in the Tularosa-Hueco Basin near the New Mexico-Texas boundary. Budding (1978, p. 197) estimated a thickness of 6,900 feet in the western part of the Espanola Basin; Kelley (1977, p. 45) estimated more than 9,000 feet of Santa Fe Group in the Albuquerque-Belen Basin.

The equivalent of the Santa Fe Group in the Gila and Mimbres Basins and westward into Arizona is the Gila Conglomerate (or Formation). The boundary between the two sequences has been arbitrarily placed along the eastern drainage divide of the Mimbres Basin (Hawley and others, 1969, p. 55; King and others, 1971, p. 16). The general depositional setting (early basin filling followed at some locations by cyclic partial dissection of the older basin fill due to the development of through drainage) is similar to that of the Santa Fe Group (Trauger, 1972, p.27). In Grant County the lower part of the Gila Conglomerate, which may be greater than 2,000 feet thick, is generally composed of consolidated and deformed fanglomerate, conglomerate, sandstone, silt, and occasional thick deposits of clay. The lower part of the Gila Conglomerate is intertongued and interbedded locally with Tertiary volcanics. The upper part of the Gila Conglomerate, generally less than 1,000 feet thick, contains interbedded basaltic andesite flows and is only slightly deformed (Hawley, 1969, p. 140; Trauger, 1972, p. 27).

Post-Santa Fe deposits

The Quaternary deposits consist primarily of alluvial fans, colluvium, pediment gravels and sands (including dunes), playa muds and sands, river terraces, and inner river-valley flood-plain and channel deposits. A correlation chart of the major Quaternary stratigraphic and geomorphic units is shown in figure 5.

After deposition of the Santa Fe Group, widespread geomorphic surfaces were formed in the Rio Grande depression during middle Pleistocene time prior to deep incision of the present-day Rio Grande Valley. The surfaces were formed by repeated episodes of erosion and deposition over large areas of piedmont slopes. The cover, which is composed of alluvial gravel, silt, and sand, ranges from 0 to more than 500 feet thick (Weir, 1965, p. 25). Deposition has continued along mountain fronts in bolsons that are not yet integrated with the Rio Grande drainage system.

Incision of the Rio Grande Valley was cyclic in nature; there were at least three periods of stabilization, backfilling, and erosion. This process led to the formation of gravel, sand, and silt terraces 30 to 175 feet above the present flood plain. Maximum entrenchment of the Rio Grande during the late Quaternary was between 60 and 130 feet below the present flood plain (Hawley, 1969, p. 140; King and others, 1971, p. 23; Kelley, 1977, p. 33). The flood plain is from 1 to 4 miles wide except in the constrictions between basins. Volcanism took place in the Quaternary both contemporaneously with and after formation of the highest basin surfaces (Bryan, 1938; Dane and Bachman, 1965; Kelley and Kudo, 1978).

Geologic history

During the Paleozoic Era the region was primarily low-lying and partly covered by the sea, except for the southern Colorado area which was uplifted. Low plains were present during the Triassic and Jurassic Periods, and continental sediments, mainly redbeds, were deposited. Triassic and Jurassic rocks were either not deposited in the southern part of the area or were eroded prior to deposition of the Cretaceous rocks. During the Cretaceous and early Tertiary Periods, seas or low-lying plains were the site of deposition of large thicknesses of limestone or clastic sediments. The original thicknesses of Paleozoic and Mesozoic rocks varied according to the topography. Slight uplift and erosion occurred between depositional periods. Strong, broad uplift and compressional deformation took place during Late Cretaceous through Eocene (Laramide) time. During this time the Nacimiento uplift, the Lucero front, and the Franklin Mountains were at least partly formed and numerous faults were active (Bryan, 1938; Kelley, 1977; Lovejoy and Hawley, 1978). The Laramide activity aided erosion of some of the older deposits, resulting in unconformable deposition of early basin deposits on rocks as old as Precambrian. Some volcanic and intrusive activity also took place during this time period and continued through Oligocene time.

Rifting began at least 18 million years ago, in middle Miocene time (Chapin, 1971). Structure models and the observed fault patterns indicate that regional extension caused by differential drift within the continental plate (Chapin, 1971; Kelley, 1977) or broad regional uplift (Baltz, 1978) resulted in down-dropped basins (grabens) and tilted fault blocks which formed the Rio Grande depression. The San Agustin basin, Tularosa Basin, and the Arkansas graben in central Colorado also were formed by this rifting (Burroughs, 1971). Evidence indicates that rifting took place along a general north-south structural grain. The structural grain was established during Laramide (Kelley, 1977) and possibly Precambrian and Pennsylvanian through Tertiary (Miller, Montgomery, and Sutherland, 1963; Kelley and Northrop, 1975; Baltz, 1978; Cordell, 1978) tectonic activity. The basins and bounding uplifts are generally arranged with each basin or uplift offset slightly to the east of the one to its south. This pattern, plus gravity anomaly lineaments, indicates that the crust broke along north-northeast and north-northwest trend oblique to the main north-south structural grain (Ramberg, Cook, and Smithson, 1978). Kelley (1977) postulated that some strike-slip faulting took place during formation of the rift. During this period of rifting, regional extension also began to cause formation of graben-type basins in the remainder of the Basin and Range Province (fig. 1). The Santa Fe Group and its equivalents were deposited in the subsiding basins from Miocene through middle Pleistocene time.

Generalized cross sections of three representative basins are shown in figure 6. The graben structures are complex; many have subsidiary horsts (uplifted blocks) and grabens within the main graben. The basins are often asymmetrical due to a greater total magnitude of fault movement on one side. For the rift in general, structural relief is greater on the east side than on the west (Chapin, 1971).

Late Tertiary uplift of the bordering highlands caused erosion of large thicknesses of Oligocene volcanics across the rift (Chapin 1971). Faulting, warping, and tilting deformed the Santa Fe beds, especially at their margins, prior to deposition of the upper Quaternary sediments. A period of relative tectonic quiescence with possible minor warping, local faulting, and slow uplift of borders (Kelley, 1977, p. 53) took place after deposition of the Santa Fe Group (middle-to-late Pleistocene). The ancestral Rio Grande became a through-flowing river in the basins of the study area beginning in Pliocene time (2.5 to 4.5 million years ago) (Bachman and Mehnert, 1978). The ancestral river formed a base level to which the high basin surfaces were graded.

Following development of the highest basin surfaces, tectonism and localized volcanism occurred. The warping and faulting has caused erosion of large areas of these surfaces (Kelley, 1977; Bachman and Mehnert, 1978). Incision of the Rio Grande was probably affected by integration of the upper Rio Grande system with the lower Rio Grande system and the Gulf of Mexico in the late Pleistocene. Basins outside of the rift area also had cyclic partial dissection of the older basin fill as local through drainage developed.

The present position of the Rio Grande Valley was affected by Pliocene and Pleistocene tectonic events (Hawley, 1969; Baltz, 1978), but the morphology, including the formation of the inset terraces, was probably controlled by climatic fluctuations (King and others, 1971). Maximum entrenchment of the river occurred between 11,000 and 22,000 years ago (King and others, 1971, p. 11).

Fault scarps and minor amounts of displacement in alluvial fans, inner valley fill, and younger (Pleistocene) basin fill indicate that tectonic activity is continuing in the Holocene (Hawley, 1969; Chapin, 1971). Deposition of sediment continues to take place along mountain fronts and in bolsons which do not have through-flowing drainage.

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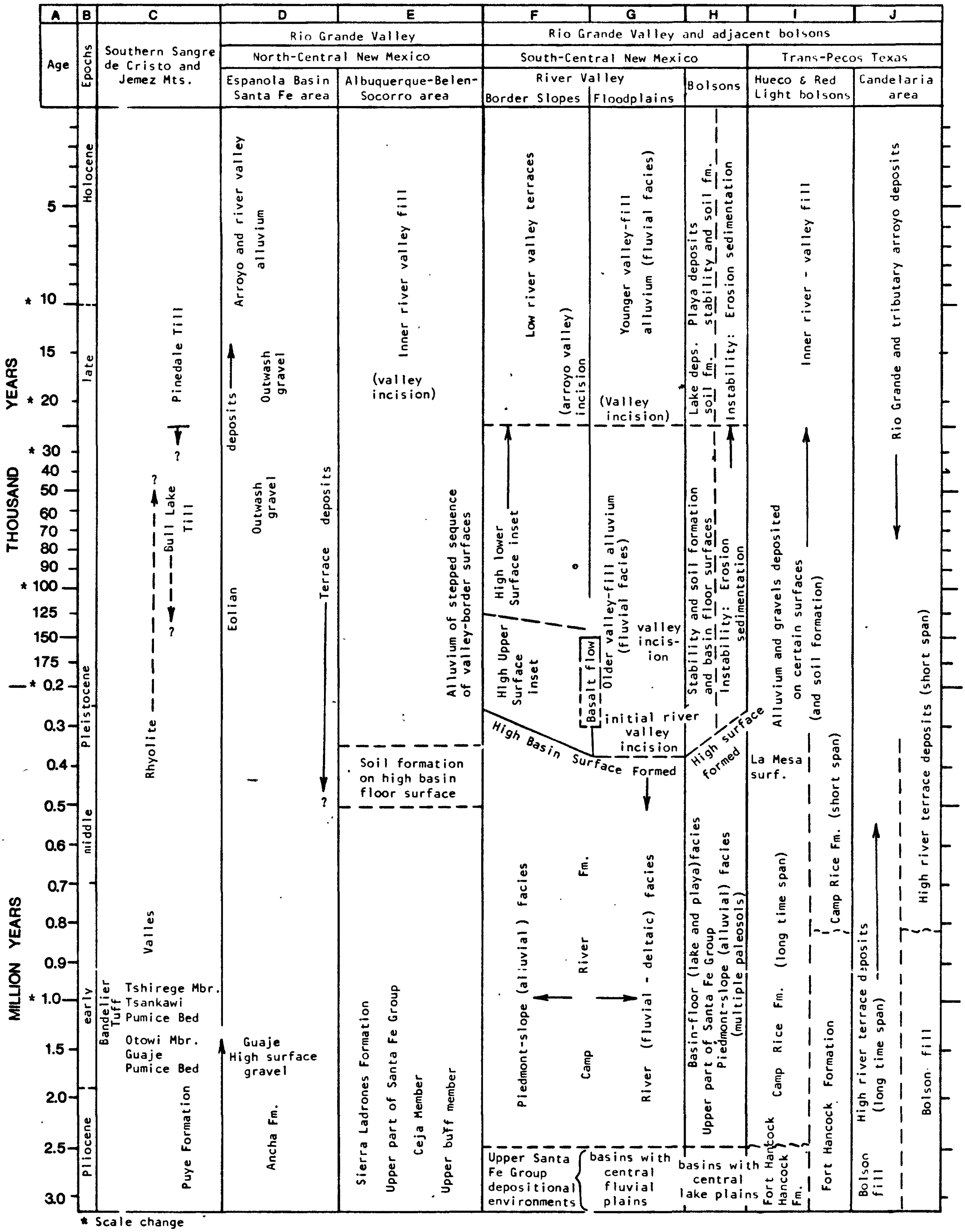


Figure 5.--Major Quaternary stratigraphic and geomorphic units in the Rio Grande rift.

References for Figure 5

Modified from J. W. Hawley (1978, p. 238)

Column C: Bailey and others (1969), Clark and Read (1972), Doell and others (1968), Richmond (1963), Smith and others (1970

Column D: Manley (1976), Manley and Naesser (1977)

Column E: Bachman and Mehnert (1978), Kudo and others (1977), Lambert (1968)

Column F: Hawley (1975), Hawley and others (1976)

Column G: Hawley (1975), Hawley and others (1976)

Column H: Hawley (1975), Hawley and others (1976)

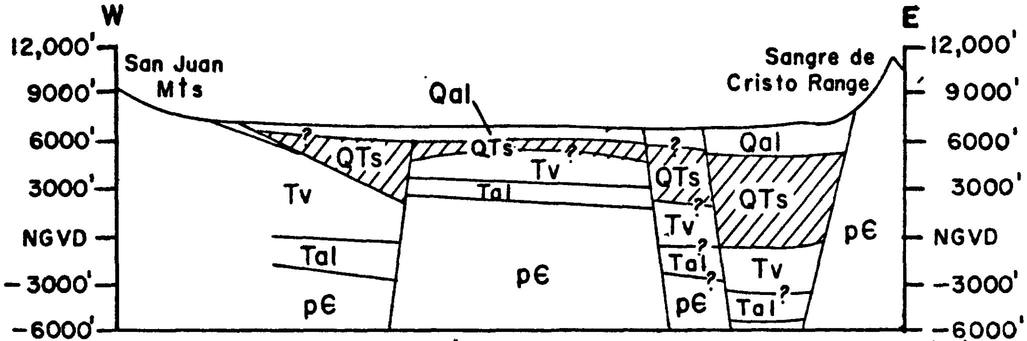
Column I: Albritton and Smith (1965), Hawley (1975), Kottlowski (1958), Strain (1966)

Column J: Groat (1972), Hawley (1975)

EXPLANATION for Figure 6

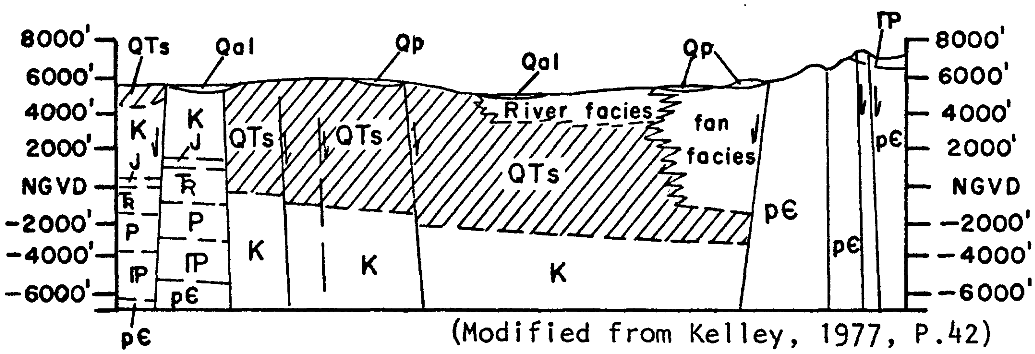
Qal	ALLUVIUM, UNDIVIDED	Also includes Pleistocene-Pliocene Alamosa Formation in Colorado	QUATERNARY	CENOZOIC
Qp	PIEDMONT GRAVEL	Generally a veneer of gravel deposited on surfaces eroded on Quaternary, Tertiary or older formations	QUATERNARY	CENOZOIC
Ql	LAKE DEPOSITS	Pleistocene, in closed basins	QUATERNARY	CENOZOIC
QTs	SANTA FE GROUP	Primarily Pliocene and Miocene age; upper part is early and middle Pleistocene. Sand, silt, clay and gravel. In closed basins includes lacustrine and occasional fluvial or conglomeratric facies. Is equivalent to Gila Conglomerate in south-western New Mexico	TERTIARY	CENOZOIC
Tv	VOLCANICLASTICS AND VOLCANIC ROCKS	Oligocene. Includes localized tuffs.	TERTIARY	CENOZOIC
Tal	ARKOSIC ALLUVIAL SEDIMENTS	Eocene	TERTIARY	CENOZOIC
K	CRETACEOUS SEDIMENTARY ROCKS, UNDIVIDED			MESOZOIC
J	JURASSIC SEDIMENTARY ROCKS, UNDIVIDED			MESOZOIC
TR	TRIASSIC SEDIMENTARY ROCKS, UNDIVIDED			MESOZOIC
P	PERMIAN SEDIMENTARY ROCKS, UNDIVIDED			PALEOZOIC
IP	PENNSYLVANIAN SEDIMENTARY ROCKS, UNDIVIDED			PALEOZOIC
pЄ	PRECAMBRIAN, UNDIVIDED	Metamorphic and granitic plutons		PRECAMBRIAN

– – –	CONTACT	Dashed where approximately located
	FAULT	Arrows indicate relative direction of movement



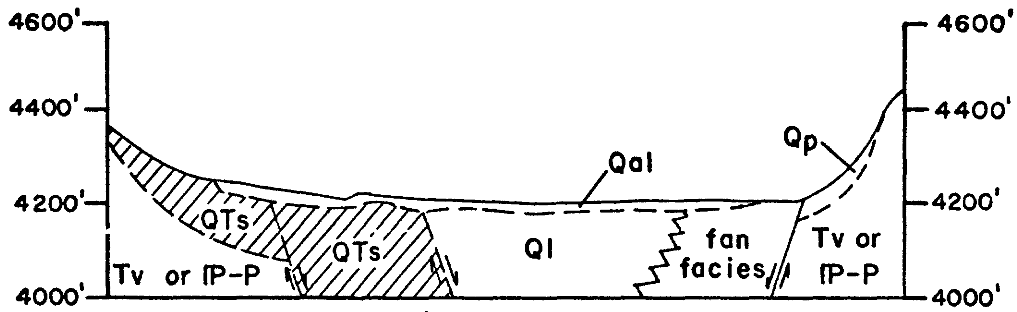
(Modified from Tweto, 1979, p.42)

Typical northern Rio Grande rift area



(Modified from Kelley, 1977, P.42)

Typical middle Rio Grande rift area



(modified from Reeder, 1958, plate 3)

Typical Closed basin

Vertical scale is exaggerated

National Geodetic Vertical Datum of 1929 (NGVD)

Figure 6.--Generalized sections of the Rio Grande rift and of a closed basin.

SUMMARY

RASA studies are designed to develop a regional understanding of the water resources. During the SWAB (east) study, data will be collected and compiled, and the water resources modeled. The study area includes the Rio Grande rift from the San Luis Valley, Colo., to the Presidio Basin near Presidio, Tex. Closed basins from the Peloncillo Mountains in southwestern New Mexico to the Guadalupe Mountains in southern New Mexico and northwestern Texas are included in the study area.

The basin studies will rely on hydrologic data already collected. Some additional data collection will include ground-water quality data relating to the geochemistry of the basin system, water-use data, and an update of water-level data in selected areas. Data will be entered into national or local data bases when the amount and use of the data warrant this approach.

Basin studies, which will include all definable water-resource aspects, will be the basis for developing an understanding of the regional system. Models of selected basins will be developed. Data required for model development may be transferred from modeled basins to basins with similar basin characteristics. An uncalibrated model may be developed for these basins where data suitable for modeling are lacking.

The knowledge gained and data collected during the basin studies will culminate in a regional model of the hydrologic system. The final regional model may be used to predict changes in the regional water-resource system in response to possible future stresses.

The project began during fiscal year 1978 and will end during fiscal year 1982. Overall project planning has been completed; planning for specific basin studies will continue through fiscal year 1981. Compilation of existing data and literature searches will be completed in during fiscal year 1980. Data collection will be completed during fiscal year 1981. Modeling will start during fiscal year 1980 and continue through fiscal year 1982.

Products of the study will include reports and data bases. Reports will include hydrologic data, basin and regional interpretive reports, and reports resulting from grants and contracts. Data bases will be developed or updated as needed.

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