PLAN OF STUDY FOR THE REGIONAL AQUIFER-SYSTEM ANALYSIS OF THE SAN JUAN STRUCTURAL BASIN, NEW MEXICO, COLORADO, ARIZONA, AND UTAH

By G. E. Welder

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CONVERSION FACTORS

In this report measurements are given in inch-pound units only. The following table contains factors for converting these units to metric units.

Multiply inch-pound units	By	To obtain metric units
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
gallon per minute	0.06309	liter per second

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ABSTRACT

The San Juan structural basin is an 18,000-square-mile area that contains several extensive aquifers. The basin includes three surface-drainage basins and parts of New Mexico, Colorado, Arizona, and Utah. Surface water in the area is fully appropriated, and the steadily increasing demand for ground water has resulted in water-supply concerns. Competition is great between mining and electric-power companies, municipalities, and Indian communities for the limited ground-water supplies.

This report outlines a 4-year plan for a study of the regional aquifer system in the San Juan structural basin. The purposes of the study are to define and understand the aquifer system; to assess the effects of ground-water use on the aquifers and streams; and to determine the availability and quality of ground water in the basin.

INTRODUCTION

The San Juan structural basin (fig. 1) is one of several large areas in the country that contain one or more extensive aquifer systems, many of which cross surface-drainage and political boundaries. The demand for ground water in the San Juan basin has increased steadily for many years. Along with the increased demand, water-supply concerns have developed.

To obtain information that may help resolve these concerns and possibly avoid new ones, the U.S. Geological Survey began a 4-year study of the San Juan basin on October 1, 1984. The study is part of the Survey's Regional Aquifer-Systems Analysis (RASA) Program.

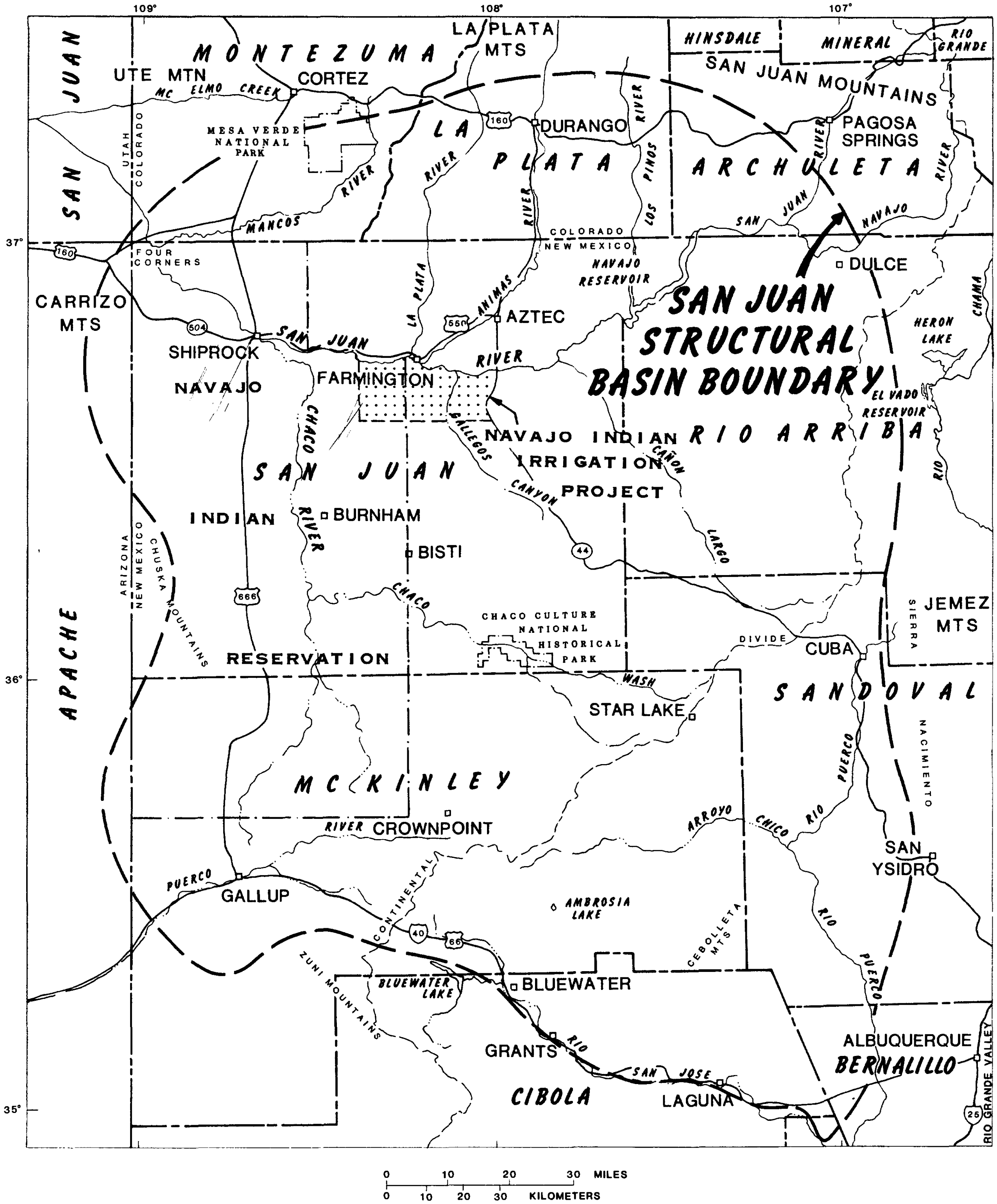


Figure 1.--Location of the San Juan structural basin.

General Geography of San Juan Structural Basin

The San Juan structural basin is located largely in New Mexico (fig. 1). About 15 percent of the basin is in southwestern Colorado and 2 percent is in northeastern Arizona and southeastern Utah. The total area of the basin is about 18,000 square miles. Its dimensions are about 120 miles in the east-west direction and 150 miles in the north-south direction. The annual precipitation in the high mountainous areas that encircle much of the basin ranges from 20 to 30 inches, whereas the central part of the basin receives about 10 inches per year. Farmington, Gallup, and Grants, New Mexico, and Durango, Colorado, are the largest towns in the basin (fig. 1). The 1980 population of the basin was about 190,000. The economy of the basin is supported by exploration and development of petroleum, coal, and uranium; urban enterprise; farming and ranching; tourism; and recreation.

Water Sources, Uses, and Concerns

Ground-water resources are an important source of water in much of the San Juan basin. The main uses of ground water are for municipal, domestic, and stock purposes; however, industrial use has increased considerably during the last decade. Water can be obtained for domestic and stock uses in much of the basin, but well yields generally are less than 50 gallons per minute. Several aquifers such as the Permian Glorieta Sandstone and San Andres Limestone, the Jurassic Morrison Formation, and the Cretaceous Gallup Sandstone locally yield 100 gallons per minute or more to wells. The water quality in these aquifers ranges from potable to nonpotable. Large quantities of water have been pumped to dewater mine areas where uranium ore is excavated from the Morrison Formation, and water levels have declined significantly throughout extensive areas around some of the mines. The towns near the San Juan River and its major tributaries utilize surface water for their supplies. Gallup, Grants, Cuba, and the small communities scattered throughout the basin use ground water.

Competition is great between mining companies, electric-power companies, municipalities, and Indian communities for rights to use the limited ground-water supplies in the basin. Additional ground-water supplies will be needed for mineral and industrial development and associated population increases. The projected amount of ground-water use estimated by the U.S. Bureau of Land Management and cited by Frenzel (1983, p. 53 and 63) indicates that ground-water pumpage could triple from 1980 to 2005. The New Mexico State Engineer Office is in the process of ruling on many requests for permits to use relatively large quantities of ground water for mining of coal and uranium in the basin.

Surface waters of the basin, which primarily are from the Rio San Jose in the south and the San Juan, Animas, and La Plata Rivers in the north, are fully appropriated. Much of the diversion from the San Juan River is for the Navajo Indian Irrigation Project near Farmington (fig. 1).

The quality of surface and ground water has changed in a number of places because of mining, agricultural, and waste-disposal practices. There is great concern about the possible adverse effects of these activities on streams and aquifers, as well as the future availability of potable ground water.

Available Information and Related Hydrologic Investigations

Subsurface information for parts of the stratigraphic section, including geophysical logs, lithologic logs, drill-stem tests, structure-contour maps, and water-level maps, is available in the files of various State and Federal agencies. Numerous reports on various aspects of the geology have been published by the New Mexico Bureau of Mines and Mineral Resources, the U.S. Geological Survey, various universities, and consulting firms. (See Stone and others, 1983, for references.)

Previous studies have described the geohydrology of parts of the system in varying degrees of detail. Shomaker and Stone (1976) provided information on the availability of ground water for coal development. Hejl (1982) described hydrologic investigations in strippable coal areas in the basin. Lyford and others (1980) made preliminary estimates of the effects of uranium-mine dewatering on water levels using a generalized ground-water flow model of the basin. Frenzel and Lyford (1982) estimated vertical hydraulic conductivities and regional flow rates in Jurassic and Cretaceous rocks using a three-dimensional ground-water flow model. Stone and others (1983) described part of the basin's geology and general hydrology. Virtually nothing is known about the geohydrology of the Paleozoic section with the exception of the Glorieta-San Andres aquifer near the south border of the basin. Reports by Irwin (1966), Cooley and others (1969), and Irwin and others (1971) provide hydrologic information for the Arizona and Colorado parts of the San Juan basin.

Hydrologic-data reports containing information on several hundred water wells have been completed by Frenzel and others (1981) for the Crownpoint area, Klausing and Welder (1983) for observation wells in the basin, and Klausing and Welder (1984) for San Juan County. These reports will constitute a significant part of the data base for this study. Historical hydraulic-head data are available for a number of the wells.

The reports by Klausing and Welder (1983, 1984) are part of an ongoing project being done in cooperation with the New Mexico State Engineer Office and the Navajo Tribe to collect ground-water data, such as aquifer characteristics, areal hydraulic-head distribution, and water quality. Project work by the U.S. Geological Survey on a rainfall-runoff model in coal-mining areas, on the effects of coal mining on the San Juan River, and on in situ uranium mining near Crownpoint are nearly complete. At present (1985), three ground-water studies by the U.S. Geological Survey are in progress adjacent to the south and southeast boundaries of the basin. These projects are on the Zuni Indian Reservation, the Acoma and Laguna Indian Pueblos, and in the Jemez Mountains.

The U.S. Geological Survey's Upper Colorado River regional aquifer-system analysis has been in progress since October 1981. The analysis includes all of the Upper Colorado River drainage area (fig. 2) with the exception of the part of the San Juan structural basin that is part of this study. The remainder of the San Juan structural basin is in the Lower Colorado River and Rio Grande drainage areas (fig. 2).

Purpose of This Report

The principal purpose of this report is to present a plan of study for a regional aquifer-system analysis of the San Juan structural basin. The plan outlines the tasks that need to be performed and provides a tentative work schedule for completion of the tasks. The objective of the plan is to provide guidelines that will result in an orderly and efficient execution of project duties and achievement of project goals.

Purpose of San Juan Basin Regional Aquifer-System Analysis

The principal objectives of the San Juan basin RASA study are as follows:

1. To define and understand the aquifer system in the San Juan basin.
2. To assess the effects of past, present, and possible future ground-water use on aquifers and streams.
3. To determine the availability and quality of ground water in the basin.

Descriptions of the principal aquifers and their relation to the main streams will be made. The degree to which the project objectives regarding the stratigraphically and structurally complex and deep aquifers can be achieved will depend upon the types and distribution of geohydrologic data that become available or can be acquired for analysis. The results of the study may serve as guidelines for: (1) various water users to manage their supplies or develop new supplies, (2) potential water users to establish their water rights, (3) the State Engineer Office to administer water rights, and (4) State and Federal agencies to determine and monitor the effects of mineral development on ground- and surface-water resources.

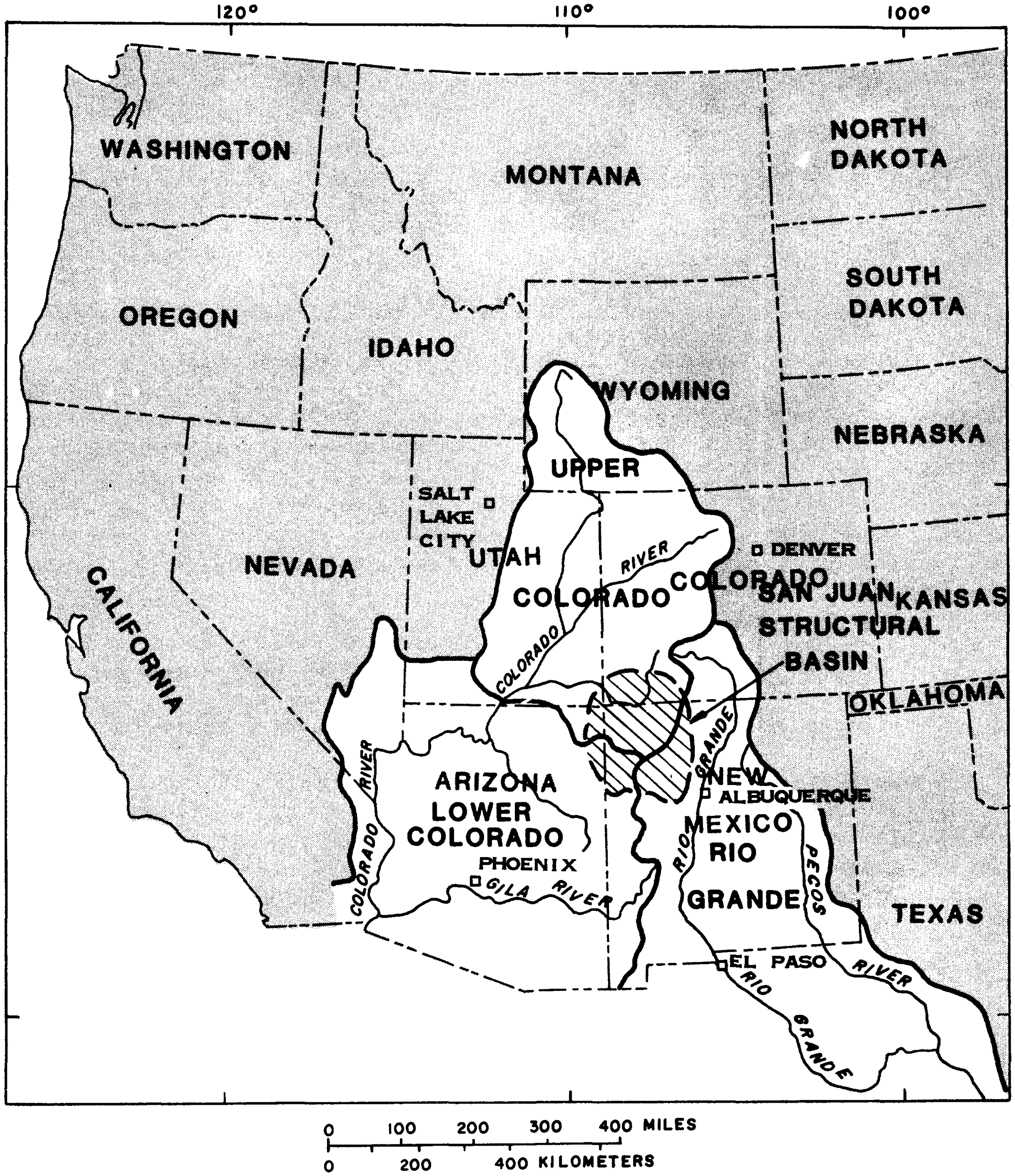


Figure 2.--Location of San Juan structural basin with respect to the Colorado River and Rio Grande basins.

GEOHYDROLOGIC FRAMEWORK

Structure

The San Juan structural basin is a large asymmetrical basin, as illustrated by the contours drawn on the top of the Dakota Sandstone of Cretaceous age in figure 3. Sedimentary rocks dip toward a deep trough in the northeast part of the structure. Older formations that crop out (fig. 4) around the periphery of the basin are overlain by successively younger rocks toward the deep trough. The altitude of the Precambrian basement rock (about 7,500 feet below sea level) in the trough is well below the altitude of the Precambrian basement rock in the geologic structures that surround the basin (fig. 4). Although small folds and faults are present, the major faulting generally is associated with the bordering structures (figs. 4 and 5). Kelley (1957, fig. 3) showed an extensive surface-fracture system throughout most of the basin.

Stratigraphy

The maximum thickness of sedimentary rocks in the San Juan basin probably is about 14,000 feet in the deep northeast trough. The ages of most of the rocks range from Cambrian to Tertiary (fig. 6), but minor thin Pleistocene(?) and Holocene alluvial deposits occur in some stream valleys. The ages and general thicknesses of rocks penetrated by a petroleum test hole in sec. 7, T. 29 N., R. 5 W. (fig. 4) are as follows: Tertiary--2,500 feet; Cretaceous--5,450 feet; Jurassic--1,000 feet; Triassic--250 feet; Permian--2,500 feet; Pennsylvanian--1,900 feet; Mississippian--150(?) feet; Devonian--200(?) feet; and Cambrian--50(?) feet. A very general estimate of the lithologic content of the sedimentary section is 30 percent sandstone, 65 percent siltstone and shale, and 5 percent limestone and evaporite deposits.

The Triassic, Jurassic, and older Upper Cretaceous formations are the most widespread in the basin (fig. 6). Most of the Paleozoic, younger Upper Cretaceous, and Tertiary formations have limited extent. At least 24 geologic units are known to yield water to wells in the basin (fig. 7). The potential of rocks older than the Glorieta Sandstone of Permian age to produce water in the San Juan basin has not been determined.

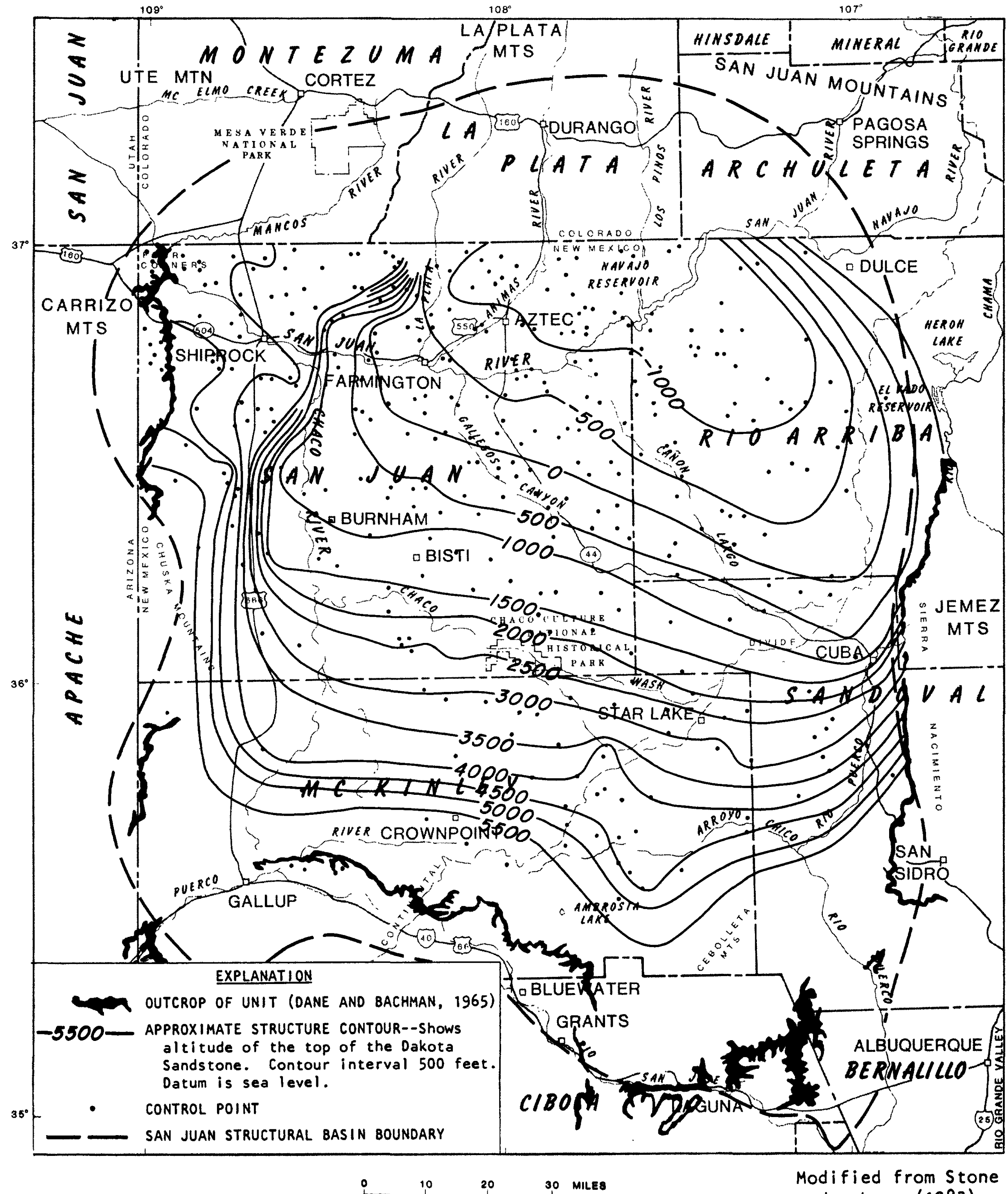
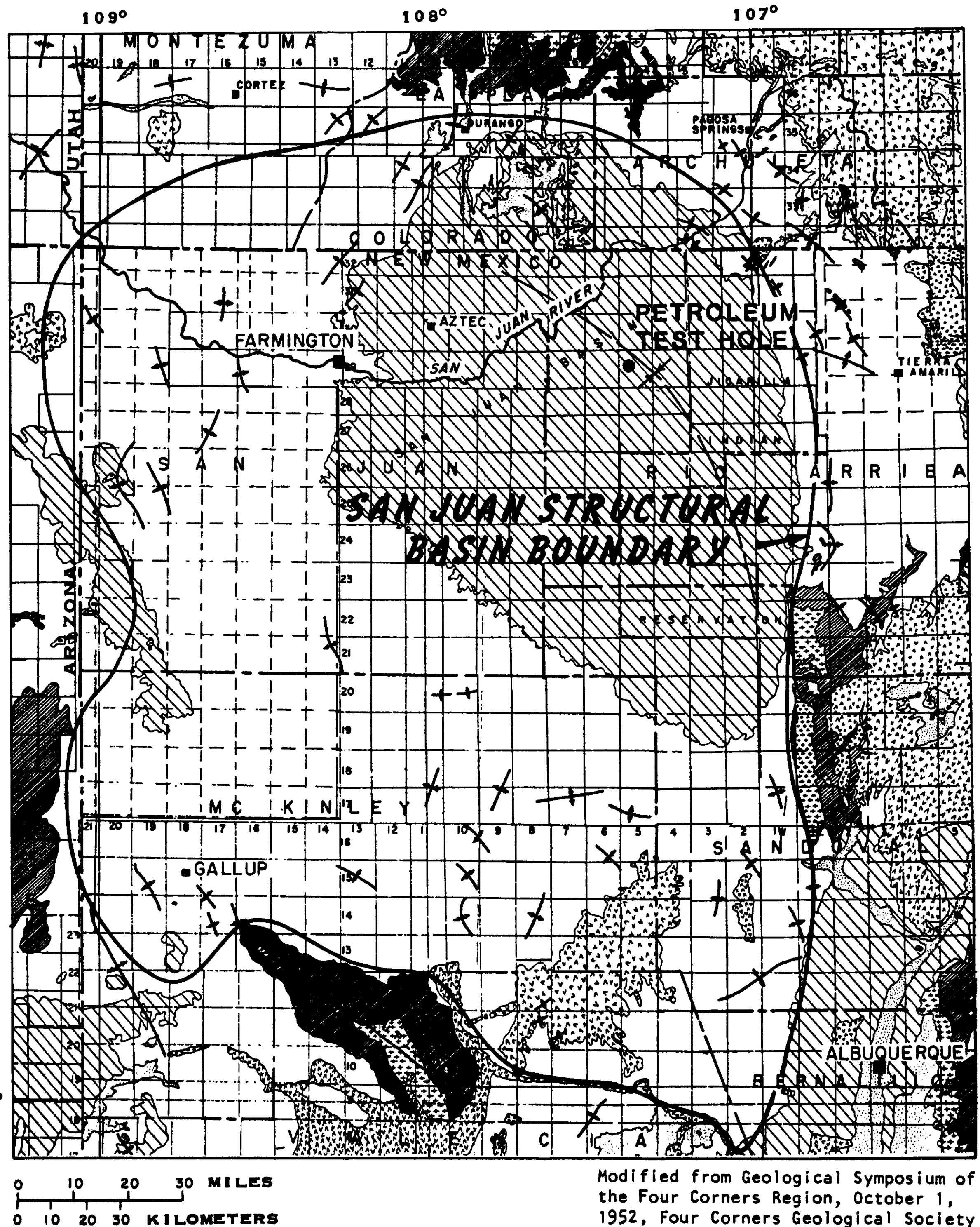


Figure 3.--Structure contours on the top of the Dakota Sandstone in New Mexico.

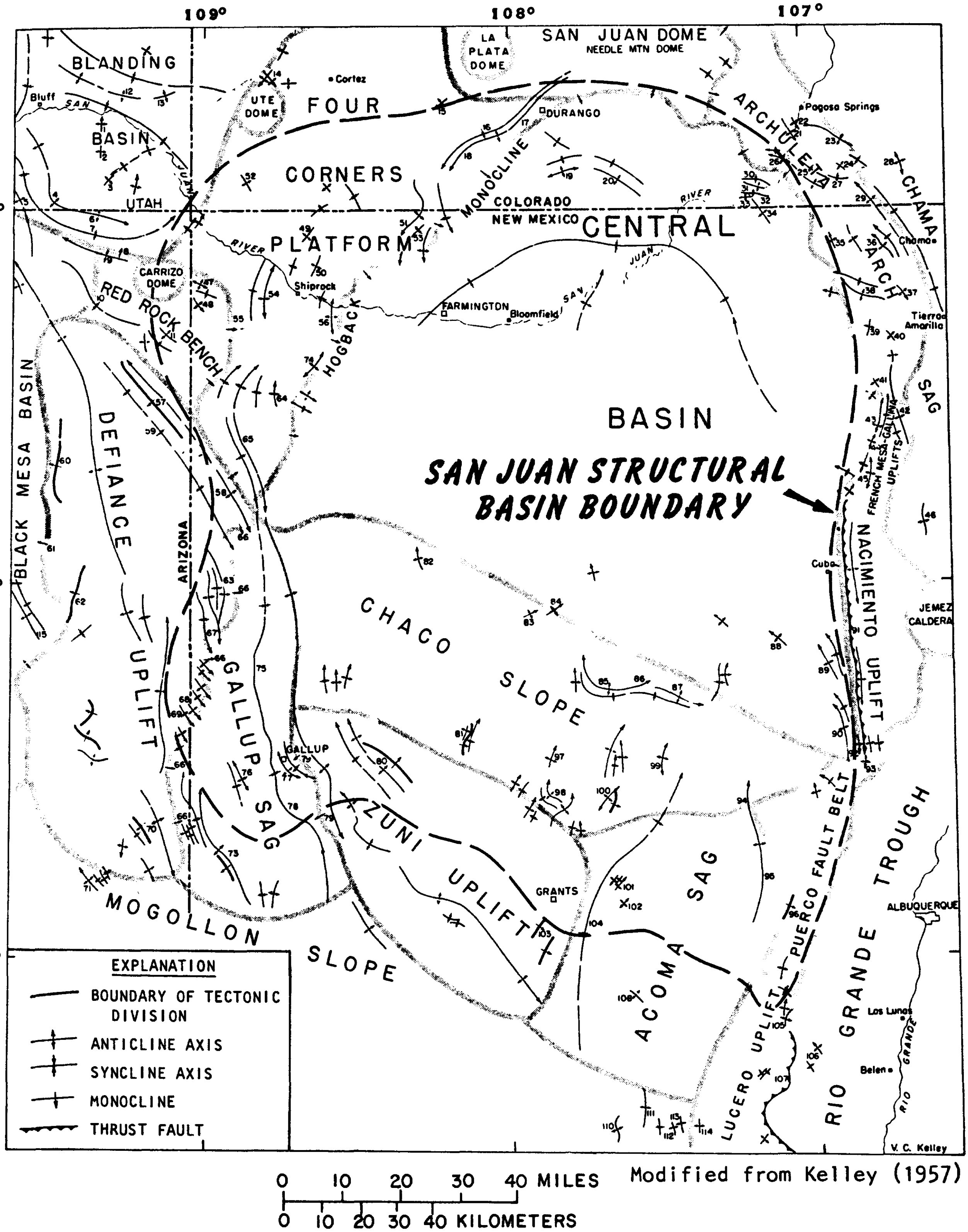


Modified from Geological Symposium of the Four Corners Region, October 1, 1952, Four Corners Geological Society

EXPLANATION

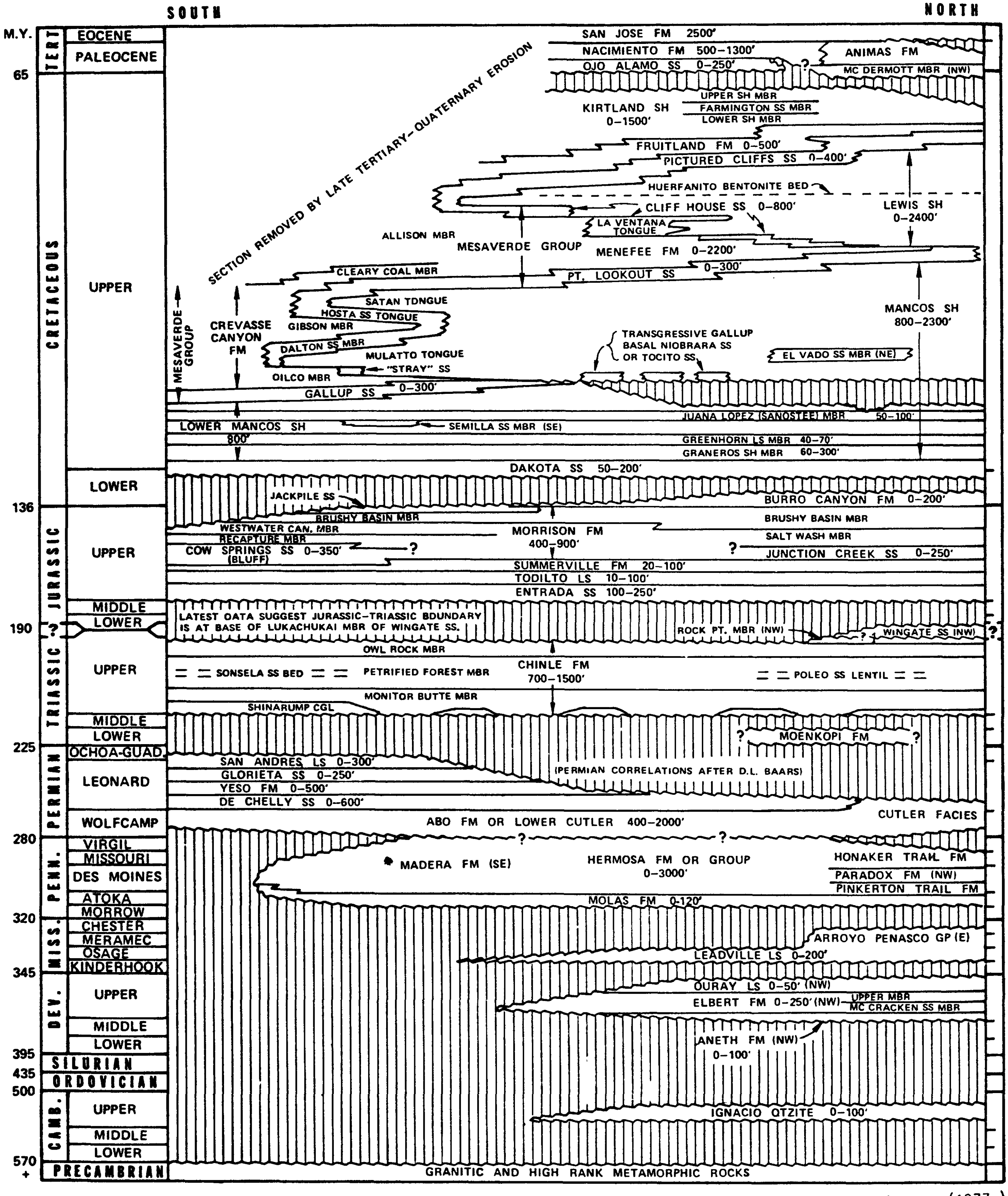
- QUATERNARY DEPOSITS
- TERTIARY SEDIMENTARY ROCKS
- TERTIARY VOLCANIC ROCKS
- MESOZOIC SEDIMENTARY ROCKS
- PALEOZOIC SEDIMENTARY ROCKS
- PRECAMBRIAN ROCKS
- ANTICLINE AXIS
- SYNCLINE AXIS

Figure 4.--Geology of the San Juan structural basin and adjacent areas.



Modified from Kelley (1957)

Figure 5.--Tectonic features of the San Juan structural basin and adjacent areas.



From Molenaar (1977a)

Figure 6.--Time-stratigraphic nomenclature.

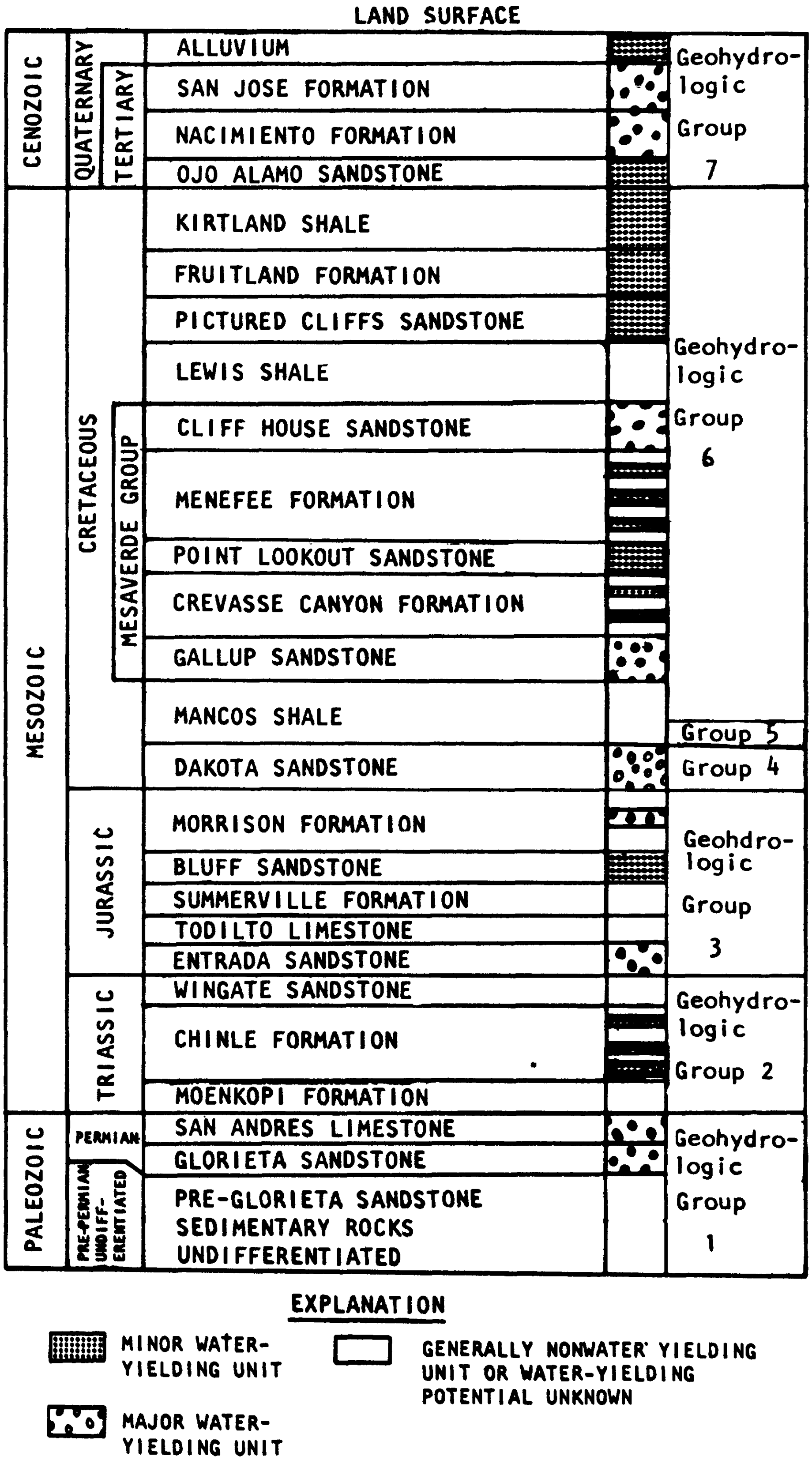


Figure 7.--Generalized stratigraphic column showing the occurrence of ground water.

General Concept of the Aquifer System

The terms "aquifer" and "confining bed," as used in the San Juan structural basin, have been associated with the formal name of a geologic formation, member, or tongue that forms a significant part of the aquifer or confining bed. It is recognized, however, that the aquifers and confining beds are not necessarily restricted to one geologic unit but may include all or parts of several geologic units. The areal extent of an aquifer is controlled by the areal extent of the hydraulic conductivities that are used to define the aquifer. If sufficient hydraulic-head and hydraulic-conductivity measurements were made throughout the San Juan basin, the aquifers and confining beds could be defined without reference to lithology and geologic units. Because this is not feasible, it is necessary to utilize geologic information based on mappable lithologic units that are indicative of hydraulic properties as verified by field measurements of hydraulic head and hydraulic conductivity. Knowledge of the geologic units is the best tool available to use in filling the gaps between site measurements of aquifer properties.

In addition to the 24 geologic units that are known to yield water to wells in the basin (fig. 7), many more water-yielding geologic units probably are present. The way in which these units are grouped into aquifers and intervening confining beds will be an important factor in developing a workable conceptual ground-water flow system.

Ground-water flow is thought to be generally toward the interior of the basin and upward from deeper parts of the aquifer system where artesian conditions exist. Some lateral components of flow are believed to be toward the San Juan River in the north, the Rio Puerco in the southeast, and Puerco River in the southwest. Although the general direction and quantity of flow through part of the aquifer system have been modeled on a gross scale (Frenzel and Lyford, 1982), model refinements are needed to adequately simulate the numerous components of the aquifer system regionally, as well as locally. Runoff from the Chuska Mountains and other highlands around the periphery of the basin and seepage from precipitation on formation outcrop areas provide recharge. Natural recharge to the system, however, is relatively small in most of this arid basin. The principal means of discharge are by mine dewatering, by wells, and through natural flow to the San Juan River.

APPROACH AND PLAN OF STUDY

The aquifers in the San Juan structural basin have natural boundaries (with a few minor exceptions) that do not extend outside of the basin. Several geologic formations, such as the Morrison Formation and the Dakota Sandstone (fig. 7), that are considered to be aquifers, or parts of aquifers, underlie almost the whole basin. Many of the formations that yield usable quantities of water, however, have limited extent. The fine-grained formations that are confining units are similar to the aquifers in that some extend throughout the basin and some do not. Thus, the approach of the study will consist of examination of the mappable rock units and their hydraulic properties and hydrologic interactions, the horizontal and vertical hydraulic-head distribution, the water quality and causes of change in water quality, and the areas of recharge and discharge.

Review of Literature and Data Availability

All pertinent published reports will be reviewed in order to learn what studies have been made and to avoid duplication of work. The quantity, quality, and availability of geohydrologic data that are stored in the files of the U.S. Geological Survey, other government agencies, and private companies will be determined. Mining, petroleum, and electric-power generating companies; the New Mexico State Engineer Office, Bureau of Mines and Mineral Resources, Environmental Improvement Division, and Oil Conservation Division; the Navajo Tribe; and private consultants are known to have files that contain geohydrologic data. Geophysical logs, drill-stem test data, and structure-contour maps available from the Petroleum Information Corp. will be utilized in the analysis.

It will be important to correlate with the Energy Minerals Branch of the Geologic Division of the U.S. Geological Survey on its Evolution of Sedimentary Basins Program. As part of that program, lithologic facies and tectonic maps of the San Juan basin will be prepared. These maps will be very useful in describing aquifers in the basin.

Collection of Additional Data

In addition to using existing data, collection of data in the field will be necessary. The following types of data will be collected at selected wells or test holes: well location and depth; altitude of measuring point; casing type, size, depth, and perforation intervals; aquifer penetration; pump type, installation depth, and discharge capacity; geophysical logs; specific capacity; aquifer transmissivity and storage coefficients; water use; and water quality. Existing wells will be used almost exclusively, but one or more wells may be drilled at key sites for specific purposes.

Additional data will be collected at outcrops of geologic formations, major aquifers, and confining beds. Lithologic characteristics such as mineral content, grain size, sorting, roundness, and cementation; structural features such as bedding dip, fractures, and faults; and formation thicknesses and altitudes will be noted. The information collected will be used as control for structure-contour and facies maps; it will also be used to estimate transmissivities, and to interpret geochemical changes under different hydrologic conditions.

Data Management

Descriptive and geohydrologic data for key wells will be coded on standard Ground-Water Site-Inventory (GWSI) forms and placed in the GWSI data file, which is part of the National Water Data Storage and Retrieval System (WATSTORE) of the U.S. Geological Survey. Chemical-quality data will be stored in the Water-Quality computer file of WATSTORE. The data can then be manipulated with various programs such as Arc Information[1] and the Statistical Analysis System (SAS)[1] through computers. A digitizer and plotter will be used to prepare various types of graphs, maps, and model grids.

Water-Use Inventory

An inventory of water use in the San Juan basin will be made to determine the location of production wells, the aquifers being used, the quantity and quality of water that is pumped, and the purposes for which the water is used. The inventory will include the large springs and surface-water diversions from the San Juan, Animas, and La Plata Rivers, and the Rio San Jose. Past water-use estimates, as well as current and possible future estimates, are needed. The data obtained will be used in the description and appraisal of the basin's aquifer system and for water management.

Partial water-use information for the San Juan basin has been published by the New Mexico State Engineer Office (Dinwiddie and others, 1966, and Sorensen, 1977), by the New Mexico Interstate Stream Commission and State Engineer Office (1974, 1975a, and 1975b), and by the New Mexico Bureau of Mines and Mineral Resources (Stone and others, 1983). Additional data are in the files of the New Mexico State Engineer Office, the Albuquerque office of the U.S. Geological Survey, and the Salt Lake City office of the U.S. Bureau of Reclamation.

[1]The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Recharge-Discharge Estimates

Recharge and discharge estimates for the San Juan basin are needed for model simulations of the hydrologic system. Climatological records of the U.S. Department of Commerce are available at many sites in the basin. These records will be useful in estimating natural recharge and evapotranspiration. Natural recharge is known to be minimal and evapotranspiration is known to be substantial because of the generally arid conditions in the region.

Spring discharge and base-flow gains in the major streams will be measured or calculated from streamflow records collected at gaging stations operated by the U.S. Geological Survey. Ground-water pumpage data will be assembled during the water-use inventory. Areas of recharge and discharge will be inferred from flow directions shown on potentiometric maps of the aquifer systems and analyzed by aquifer simulations.

Preparation of Geologic Maps

Geologic maps and sections are needed to describe the geologic framework and to help define aquifer characteristics and boundaries. Contour maps that show the configuration and structure of many of the rock units, thickness maps, and facies maps that show the distribution of the various rock types will be prepared. Drillers' and geophysical logs, rock-outcrop descriptions, and seismic and gravity surveys will be used to draw the maps. U.S. Geological Survey 7½- and 15-minute quadrangle maps, which are available for the entire basin, will be used for surface location and altitude control for the maps and sections.

Stone and others (1983) prepared generalized geologic maps for the Entrada Sandstone, Morrison Formation, Dakota Sandstone, Gallup Sandstone, Point Lookout Sandstone, Cliff House Sandstone, Pictured Cliffs Sandstone, Ojo Alamo Sandstone, and Nacimiento and Animas Formations (fig. 6). These maps will be revised using additional control in order to depict more detail.

The stratigraphy can be studied best by grouping the rock units according to age and relation to the more widespread units. One approach (fig. 7) is to concentrate studies on each of the following seven geohydrologic groups:

1. Rocks of Paleozoic age
2. Moenkopi and Chinle Formations and Wingate Sandstone of Triassic age
3. Rocks of Jurassic age
4. Dakota Sandstone of Late Cretaceous age
5. Lower part of the Mancos Shale of Late Cretaceous age
6. Upper Cretaceous rocks that are younger than the lower part of the Mancos Shale
7. Rocks of Cenozoic age

Groups 2 and 5, for example, are widespread, very fine grained units that may impede vertical flow of ground water in much of the basin.

Preparation of Hydrologic Maps

Potentiometric-surface, water-level change, top and bottom configuration, and saturated-thickness maps of the aquifers and water-level hydrographs will be compiled and constructed. Hydraulic-head, temperature, and water-density measurements will be used to draw the potentiometric-surface and water-level change maps. Confining-bed thickness maps will be constructed by taking the difference between the surfaces of the top and bottom configuration maps of the adjacent aquifers.

Aquifer-test and drill-stem-test data, potentiometric-surface gradients, geophysical logs, rock lithologies and geochemistry, and water-quality data will be used to make initial assignments of transmissivity and storage coefficients to the mapped aquifer systems and confining beds. The hydrologic maps will be used to designate boundaries and assign simulation values for aquifer-flow models.

Preparation of Water-Quality Maps

The chemical quality of ground water in the San Juan basin varies with depth, distance, mineral content of the water-bearing rock units, temperature, pressure, presence of oxygen, and other conditions. The differences in geochemistry along a ground-water flow path can indicate the rate of water movement, changes in permeability, and the types of rock with which the water may have come into contact. Computer programs, such as WATEQF (Plummer and others, 1976), BALANCE (Parkhurst and others, 1982), and PHREEQE (Parkhurst and others, 1980), will be used to analyze the relation of geochemical processes in the saturated zone to aquifer characteristics.

The relation between saline waters in the deeper parts of the basin and fresher waters in the shallower parts of the basin will be simulated by the flow model. Maps of water-density distribution will be made from chemical analyses and trend projections where data are lacking in the deeply buried rocks.

Maps of specific conductance, which provides an indication of dissolved-solids concentration, and maps of major chemical constituents will be prepared. These maps will be used to interpret the hydrology and to provide information for water-use planning.

Model Design, Simulation, and Adjustment

Several local and areal ground-water flow models of the San Juan basin have been completed by previous investigators. For example, a basinwide area model, which was a seven-layer, steady-state, finite-difference model, was constructed by Frenzel and Lyford (1982). All of the models completed in the basin, however, lacked sufficient control. If feasible, the model by Frenzel and Lyford (1982) will be reactivated and used to assist in the guidance of data-collection activities and preliminary evaluation of boundary conditions and flow-system responses to stress.

After preliminary maps of the aquifer and confining-bed thicknesses and distributions, hydraulic conductivities, and storage coefficients are prepared, they will be reviewed and compared with lithologic-facies, hydraulic-head, and water-quality maps. Cross-sectional models will be constructed to test the impact of variations in density and temperature of water in the aquifer system. Three-dimensional ground-water flow models will be constructed to evaluate the aquifer systems' sensitivity to changes in hydraulic properties and stress. Measured and simulated hydraulic heads and discharge will be compared to calibrate the models. The model will be adjusted until the measured hydraulic heads and discharge are close to the model-simulated ones. After the flow models are calibrated, simulations will be made to evaluate the effects of ground-water pumping on water levels and streamflow.

WORK SCHEDULE

The work schedule for the San Juan basin aquifer-system study is shown in figure 8. The 4-year project is scheduled to be completed in September 1988. Compliance with the work schedule will be dependent upon the availability of funds and staff. The first year of study will be spent in planning, fulfilling staffing requirements, and making reconnaissance studies. The most active time of the project will be the second and third years when field data collections and framework maps are being made. Most model simulations and analyses will be done during the third year and the first part of the fourth year although some preliminary modeling will be done sooner. Various progress reports will be written during the course of the project. The last six months of the project will be devoted almost entirely to writing, reviewing, and processing the final report.

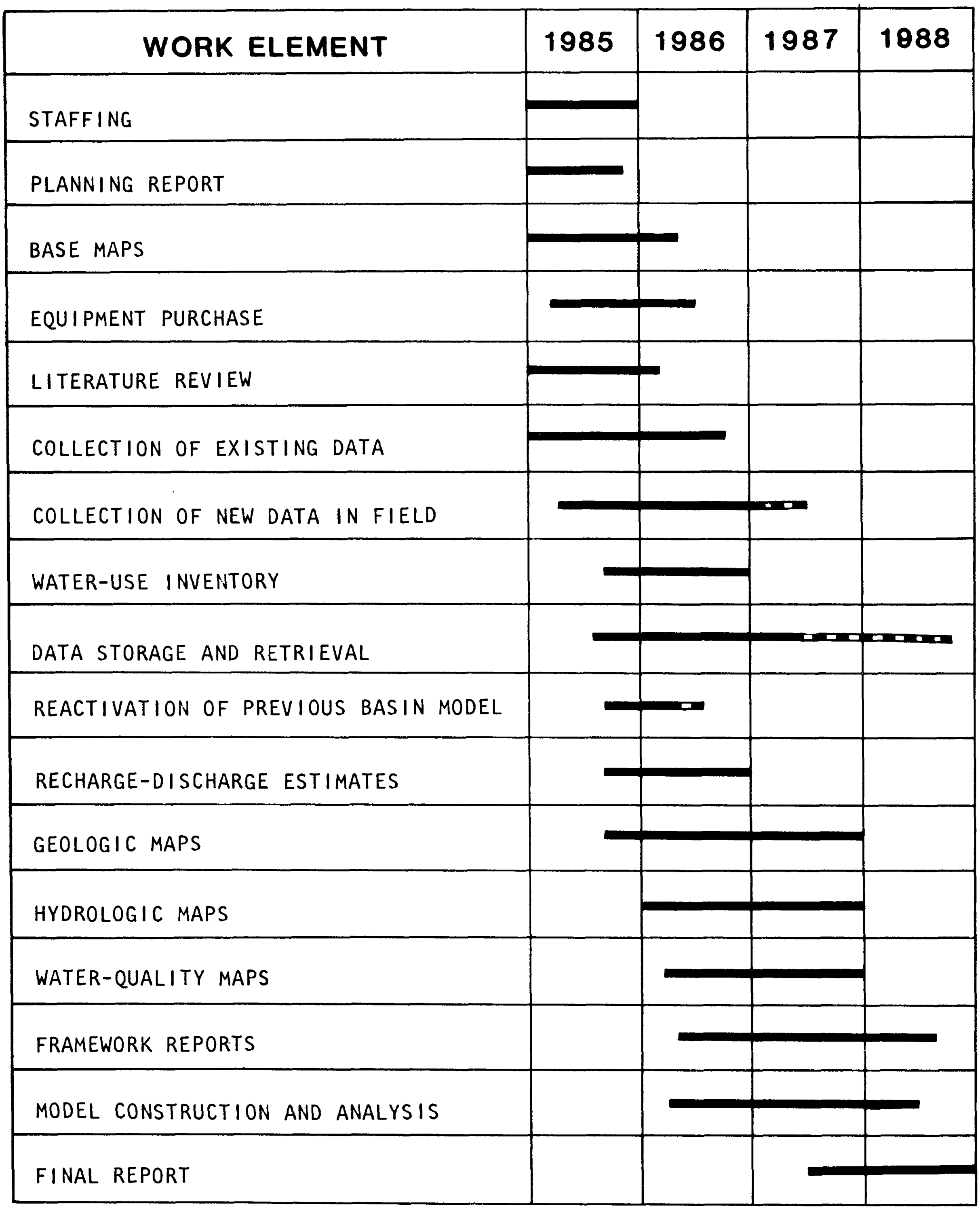


Figure 8.--Tentative work schedule for San Juan basin aquifer system study.

PROJECT STAFF REQUIREMENTS

The staff for the San Juan basin project will consist of four experienced hydrologists and five hydrologic technicians. The project chief needs to be skilled in management and have a good understanding of geology, water chemistry, hydrology, and digital modeling. It is particularly important that the specialist in geology have a strong background in the principles of subsurface stratigraphy, lithology, and mapping because these elements, which are complex in the San Juan basin, will be important indicators of the hydrology. For the same reason, the specialist in geochemistry needs to have a background in geology, as well as in water and rock chemistry. The specialist in hydrology needs to be skilled in ground-water investigations and analytical techniques, with emphasis on ground-water flow modeling. The hydrologists need to be able to direct collection of field data pertaining to their specialties and to assist others with data collection, assemblage, and analyses when their interests are overlapping.

Two hydrologic technicians will assist the three hydrologists in map preparation, model construction, and other specific tasks. The other three technicians will be assigned duties that deal with field work, data management, reports, and miscellaneous office jobs. Consultation with research specialists in the U.S. Geological Survey probably will be needed from time to time as difficult problems arise.

PROJECT REPORTS

A tentative list of reports that will be prepared during the study is as follows:

1. A "Plan of Study" report (this report).

2. Short interim reports on the geohydrologic framework, which may include maps and data on the aquifer thicknesses, water quality, potentiometric surface, water-level changes, and water use. These reports are planned for publication as U.S. Geological Survey Water-Resources Investigations Reports.

3. A detailed project report that includes separate chapters on the geologic, geochemical, and hydrologic framework of the basin in addition to the results of model simulations. It will be published in the U.S. Geological Survey Professional Paper 1420 series.

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