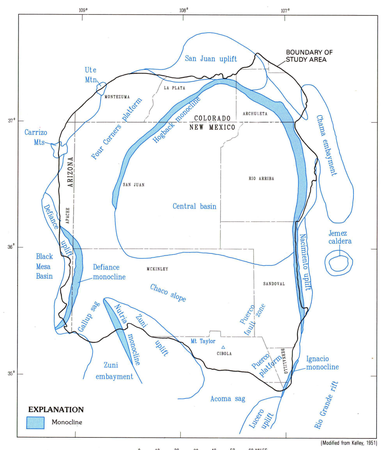
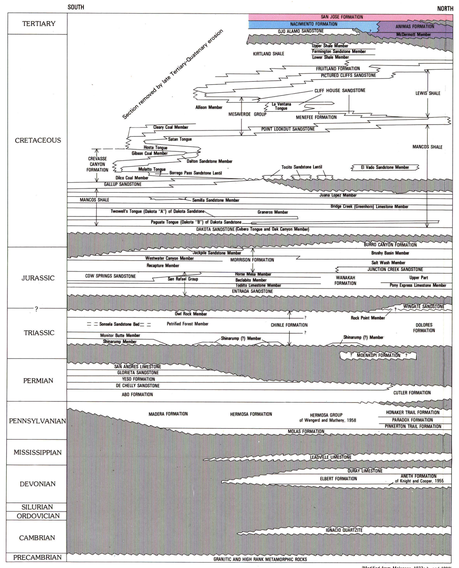
Figure 1. Location of San Juan structural basin, Colorado Plateau, and study area.



(Modified from Kelley, 1951)

Figure 2. Structural elements of the San Juan structural basin and adjacent areas.



(Modified from Molenaar, 1977a,b, and 1988)

Figure 3. Time– and rock–stratigraphic framework and nomenclature.

CONVERSION FACTORS

Multiply inch-pound unit	By	To obtain metric unit
inch	25.4	millimeter
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.09290	meter squared per day
gallon per minute	0.06309	liter per second
gallon per minute per foot	0.2070	liter per second per meter
mile	1.609	kilometer
pound per square inch	6.8948	kilopascal
square mile	2.590	square kilometer

Temperature in degrees Celsius (°C) can be converted to temperature in degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8 \times °C + 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first–order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

INTRODUCTION

This report is one in a series resulting from the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) Study of the San Juan structural basin that began in October 1984. The purposes of the RASA (Welder, 1986) are to: (1) Define and evaluate the aquifer system; (2) assess the effects of past, present, and potential ground-water use on aquifers and streams; and (3) determine the availability and quality of ground water. Previous reports in the series describe the hydrogeology of the Dakota Sandstone (Craigg and others, 1989), Gallup Sandstone (Kernodle and others, 1989), Morrison Formation (Dam and others, 1990a), Point Lookout Sandstone (Craigg and others, 1990), Pictured Cliffs Sandstone (Dam and others, 1990b), Kirtland Shale and Fruitland Formation (Kernodle and others, 1990), Menefee Formation (Levings and others, 1990), Cliff House Sandstone (Thorn and others, 1990a), and Ojo Alamo Sandstone (Thorn and others, 1990b) in the San Juan structural basin.

On a regional scale, the San Jose, Nacimiento, and Animas Formations are hydraulically connected and form one of the primary water-bearing units in the regional aquifer system. This report summarizes information on the geology and the occurrence and quality of water in the San Jose, Nacimiento, and Animas Formations. Data used in this report were collected during the study or were derived from existing records in the U.S. Geological Survey's computerized National Water Information System (NWIS) data base and the Petroleum Information Corporation's data base. Although all data available for the San Jose, Nacimiento, and Animas Formations were considered in formulating the discussions in the text, not all those data could be plotted on the illustrations.

The San Juan structural basin is in New Mexico, Colorado, Arizona, and Utah and has an area of about 21,600 square miles (fig. 1). The structural basin is about 140 miles wide and about 200 miles long. The study area is that part of the structural basin that contains rocks of Triassic or younger age; therefore, the study area is less extensive than the structural basin. Triassic through Tertiary sedimentary rocks are emphasized in the RASA study because the major aquifers in the basin are present in these rocks. The study area is about 140 miles wide (about the same as the structural basin), 180 miles long, and has an area of about 19,400 square miles.

Altitudes in the study area range from about 4,500 feet in southeastern Utah to about 11,000 feet in the southeastern part of the San Juan Mountains in the basin. The area-weighted mean altitude is about 6,700 feet. Annual precipitation in the high mountainous areas along the northern and eastern margins of the basin is as much as 45 inches, whereas annual precipitation in the lower altitude, central part of the basin is 8 or fewer inches. Mean annual precipitation is about 12 inches.

Data obtained from documents published by the U.S. Bureau of the Census (1980 and 1985) were used to calculate the population of the study area. The population in 1970 was calculated to be about 134,000. The population increased to about 194,000 in 1980, 212,000 in 1982, 221,000 in 1984, and then decreased to about 210,000 in 1985. The economy of the basin is supported by exploration for and development of natural gas, petroleum, coal, and uranium resources; urban enterprise; farming and ranching; tourism; and recreation. The rise and fall in population were related to changes in the economic strength of the minerals, oil, and gas industries, and support services. Uranium mining and milling activities underwent rapid growth from the 1950's until the late 1970's when most uranium-mining activity came to an abrupt end. Likewise, the oil and gas industry prospered until about 1983 and then declined rapidly.

REGIONAL GEOLOGIC SETTING

The San Juan structural basin is a northwest-trending asymmetric structural depression formed during the Laramide orogeny (Late Cretaceous–early Tertiary time). Structural boundaries of the basin are well defined in many places; elsewhere, the basin merges gradually into adjacent depressions or uplifts (Kelley, 1951, p. 124). The structural boundaries as defined by Kelley (1951, p. 124–127) principally consist of large, elongate, domal uplifts; low marginal platforms; and abrupt monoclines (fig. 2). Faulting is common, especially in the southeastern part of the basin. Maximum structural relief in the basin is about 10,000 feet (Kelley, 1951, p. 126).

The San Juan structural basin contains a thick sequence of sedimentary rocks ranging in age from Cambrian through Tertiary, but mostly from Pennsylvanian through Tertiary (fig. 3). The maximum thickness of the sequence of rocks is about 14,000 feet (Fassett and Hinds, 1971, p. 4). These sedimentary rocks dip basinward from the basin margins toward the troughlike structural center or deepest part of the basin. Older sedimentary rocks crop out around the basin margins and are successively overlain by younger rocks toward the center of the structural basin. Volcanic rocks of Tertiary age and various deposits of Quaternary age also are present in the basin.

GEOLOGY

Animas Formation

Most of the Animas Formation is of Paleocene age, but the lower part of the formation is of latest Late Cretaceous age (Barnes and others, 1954). It crops out principally inside the northern margin of the central basin (figs. 2 and 4). The Animas is present only in about the northern one-third of the basin, mainly in Colorado; it does not occur south of a line that extends from Dulce, New Mexico, to the La Plata River valley near the New Mexico-Colorado State line. Along this line the Animas Formation grades laterally into the Nacimiento Formation (Fassett and Hinds, 1971, p. 33; Fassett, 1974, p. 229), which occupies the same stratigraphic interval (fig. 3). The Animas conformably overlies the Kirtland Shale of Late Cretaceous age in the north; farther south, near the New Mexico-Colorado State line, the unit may unconformably overlie the Ojo Alamo Sandstone of Tertiary age (Fassett and Hinds, 1971, p. 34).

The Animas Formation consists of two members: the lower McDermott Member of latest Late Cretaceous age, and the unnamed upper member of Paleocene age (Barnes and others, 1954). The upper member disconformably overlies the McDermott Member; this unconformity represents a time gap of about 6 million years (Fassett, 1987). The Animas Formation mainly consists of volcaniclastic deposits; the diagnostic characteristic of the Animas Formation as a whole is the presence of macroscopic volcanic material (Fassett and Hinds, 1971, p. 33). The McDermott Member consists of variicolored (dominantly purple) tuffaceous sandstone and conglomerate with minor variegated shale (Reeside, 1924, p. 25). The unnamed upper member consists of variicolored and interbedded tuffaceous sandstone, conglomerate, and shale (Fassett, 1974, p. 229). Thickness of the Animas Formation ranges from about 230 feet at the type section along the Animas River at Durango (Barnes and others, 1954) to about 2,700 feet near the La Plata–Archuleta County line in Colorado (Fassett and Hinds, 1971, p. 33).

Nacimiento Formation

The Nacimiento Formation is of Paleocene age (Baltz, 1967, p. 35). It crops out in a broad band inside the southern and western margins of the central basin, and in a narrow band along the west face of the Nacimiento uplift (figs. 2 and 4). The Nacimiento is a nonresistant unit and typically erodes to low, rounded hills or forms badlands topography.

The Nacimiento Formation occurs only in approximately the southern two-thirds of the basin where it conformably overlies and intertongues with the Ojo Alamo Sandstone (Baltz, 1967, p. 41; Fassett, 1974, p. 229). Along a line from Dulce, New Mexico, to the La Plata River valley near the New Mexico-Colorado State line, the Nacimiento Formation grades laterally into the main part of the Animas Formation (Fassett and Hinds, 1971, p. 34; Fassett, 1974, p. 229); thus, in this area the two formations occupy the same stratigraphic interval (fig. 3).

Strata of the Nacimiento Formation were mainly deposited in lakebeds in the central basin area with lesser deposition in stream channels (Brimhall, 1973, p. 201; Fassett, 1974, p. 229). In general, the Nacimiento consists of drab, interbedded black and gray shale with discontinuous, white, medium- to very coarse grained arkosic sandstone (Fassett, 1974, p. 229; Stone and others, 1983, p. 30). Anderholm (1979, p. 25) reported local carbonaceous shale and lignite in the unit. Baltz (1967, p. 39) stated that sandstone percentage increases northward. Stone and others (1983, p. 30) indicated that the formation may contain more sandstone than commonly reported because some investigators assume the slope-forming strata in the unit are shales, whereas in many places, the strata actually are poorly consolidated sandstones.

Total thickness of the Nacimiento Formation ranges from about 500 to 1,300 feet (Molenaar, 1977a). The unit generally thickens from the basin margins toward the basin center (Baltz, 1967, p. 38; Steven and others, 1974; Stone and others, 1983). The thicknesses of the sandstone deposits within the Nacimiento Formation are much less than the total thickness of the formation because their environment of deposition was localized stream channels (Brimhall, 1973, p. 201).

San Jose Formation

The San Jose Formation of Eocene age was defined by Simpson (1948a, b). The San Jose Formation occurs in New Mexico and Colorado and its outcrop forms the land surface over much of the central basin area (figs. 2 and 4). It overlies the Nacimiento Formation in the area generally south of the State line, and overlies the Animas Formation in the area generally north of the State line (Fassett, 1974, p. 229). The basal contact of the San Jose varies with location in the basin. This contact is a disconformity along the basin margins, and it is an angular unconformity along the Nacimiento uplift; the contact is conformable in the central basin (Baltz, 1967, p. 54; Fassett, 1974, p. 229).

The San Jose Formation was deposited in various fluvial-type environments (Baltz, 1967, p. 44–55). In general, the unit consists of an interbedded sequence of sandstone, siltstone, and variegated shale. The sandstones are buff to yellow and rusty-colored, crossbedded, very fine to coarse-grained arkose, which are locally conglomeratic and contain abundant silicified wood (Baltz, 1967, p. 46; Fassett, 1974, p. 229; Anderholm, 1979, p. 23).

Baltz (1967, p. 45) recognized four formal members of the San Jose Formation in the east-central part of the basin; he also identified, but did not name, a fifth member in the northeastern part of the basin. The members and their principal lithology in ascending order are Cuba Mesa Member (sandstone), Regina Member (shale), Llaves Member (sandstone), and Tapicitos Member (shale). The stratigraphic relation and subsequent mappability of these members are complicated by extensive intertonguing and pinchouts (Fassett, 1974, p. 229; Anderholm, 1979, p. 23; Stone and others, 1983, p. 25), and whether the members can be identified throughout the basin has been the subject of some discussion.

Thickness of the San Jose Formation generally increases from west to east. Fassett (1974, p. 229) reported a maximum thickness of 2,400 feet in the east-central part of the basin, and Stone and others (1983, p. 25) reported a range of from about 200 feet in the west and south to almost 2,700 feet in the center of the structural basin.

THICKNESS AND CONFIGURATION OF THE BOTTOM OF THE SAN JOSE, NACIMIENTO, AND ANIMAS FORMATIONS

The location of data points used to compute the thickness and altitude of the bottom of the San Jose, Nacimiento, and Animas Formations is shown in figure 4. These data were obtained primarily from oil- or gas-test holes from the Petroleum Information Corporation's data base with supplemental information from water wells from NWIS. Sea level is the datum used in the configuration of the bottom of the Animas and Nacimiento Formations.

The thickness of the San Jose, Nacimiento, and Animas Formations is shown in figure 5. Thickness ranges from zero to more than 3,500 feet in the east-central part of the structural basin.

The altitude and configuration of the bottom of the Nacimiento and Animas Formations are shown on the second structure map (fig. 6). The overall structural configuration of the basin also is shown in figure 6. The bottom of the Nacimiento and Animas Formations decreases from a maximum altitude of more than 8,000 feet above sea level along the northeastern basin rim to less than 4,000 feet above sea level in the east-central part of the basin.

GROUND WATER

The San Jose, Nacimiento, and Animas Formations are a source of water for public-supply, commercial, private domestic, and livestock use in areas where drilling depths and pumping levels are economically feasible and where water quality is suitable. The altitude of the potentiometric surface of ground water in the San Jose, Nacimiento, and Animas Formations at selected water wells and springs is shown in figure 7. The altitude of the potentiometric surface in water wells was determined from measured or reported depths to water or was calculated from pressure-gage readings on flowing wells. Interpretation of completion data for the water wells shown indicates these wells only derive water from the San Jose, Nacimiento, and Animas Formations. The water-well and spring data were collected from 1938 to 1989.

Water in the San Jose, Nacimiento, and Animas Formations occurs under both water-table and artesian conditions. Recharge to the aquifer is from infiltration of precipitation and streamflow on outcrops and from vertical upward leakage of water from underlying units.

Transmissivity data for the San Jose, Nacimiento, and Animas Formations are minimal. Values of 40 and 120 feet squared per day were determined from two aquifer tests (Stone and others, 1983, table 5).

The reported or measured discharge from 79 water wells completed in the San Jose, Nacimiento, and Animas Formations ranges from 1 to 61 gallons per minute and the median is 6 gallons per minute. The specific capacity of 12 of these wells ranges from 0.03 to 2.30 gallons per minute per foot of drawdown and the median is 0.23 gallon per minute per foot of drawdown. The distribution of these data is shown in figure 8.

The location of eight selected wells that derive water only from the San Jose, Nacimiento, and Animas Formations and have five or more water-level measurements is shown in figure 9. Reference numbers on figure 9 correspond to the numbers on the hydrographs. The site identification (SITE ID) used to identify each well in the NWIS data base is posted on the hydrographs. The water-level hydrographs for these wells show both short- and long-term changes in water level. Short-term fluctuations primarily result from periodic changes in discharge from wells and from seasonal changes in recharge. Long-term changes primarily result from prolonged ground-water discharge from wells, from discontinuation of discharge from wells, and from changes in rates of recharge due to climatic variations.

Only one of the eight hydrographs (well 5) shows a long-term change in water level. Water from this well is used in a public water-supply system for a boarding-school dormitory. Continued withdrawal of water for this purpose has caused a steady decline in the water level since the well was completed in 1968.

Hydrographs for the other wells probably show only short-term changes in water level due to seasonal changes in recharge and withdrawals of water. The most recent water-level measurement for most of these wells generally falls within the range of previous measurements. Based on this criterion, the hydrograph for well 8 may indicate a long-term decline; however, this well is only 1,100 feet from well 7, for which the latest water-level measurement is well within the range of previous measurements. These two wells are completed in the San Jose Formation but in different intervals in the aquifer. These and several other wells in the immediate vicinity are used to supply cooling water for a natural-gas transmission station. The differences in the hydrographs are due to differences in withdrawal rates and time intervals for individual wells and to different hydraulic properties of the completion intervals of the wells.

WATER QUALITY

Water-quality data described in this section are from the NWIS data base and were collected during 1938–84. Well records were checked to assure, to the extent possible, that a particular sample represents water only from the San Jose, Nacimiento, and Animas Formations and not a mixture of water from other aquifers. Locally, however, these formations may have substantial differences in the concentration of some water-quality constituents due, in part, to differences in rock characteristics as described in the Geology section. Data presented on the maps do not represent the total quantity of available data for the San Jose, Nacimiento, and Animas Formations. In some instances, the density of data was too great to display for a single well or group of closely spaced wells, in which case the most recent analysis was chosen to be shown on the illustrations. Selected water-quality properties and constituents are presented in table 1; the minimum, maximum, and median were calculated using the most recent analysis from water wells and springs that had multiple analyses.

Temperature data are shown in figure 10 and summarized in table 1. Water from a spring located in the northeastern part of the outcrop area has a temperature similar to surrounding water wells (fig. 10). The two highest reported temperatures (18° C and 23° C) were from wells located in the north-central part of the basin just east of Farmington and in the northwestern section of the outcrop area, just north of the New Mexico-Colorado State line.

Primary (maximum enforced contaminant level) drinking-water standards are shown in table 2. Fluoride concentration in 15 of 199 analyses (8 percent) exceed the primary drinking-water standard shown in table 2. All samples analyzed for nitrate were less than the primary standard. Selenium concentration in 39 of 73 analyses (53 percent) exceeded the standard shown in table 2. Selected secondary (non-enforced contaminant level) drinking-water standards are shown in table 3; these standards were exceeded in some samples for all of the constituents shown by the maximum values listed in table 1. Of 207 analyses for pH, 32 (15 percent) exceed the standard (table 3). Sulfate concentration in 55 of 204 analyses (27 percent) exceeded the standard. Concentrations of chloride, 10 of 209 analyses (5 percent), and fluoride, 43 of 199 analyses (22 percent), exceeded the secondary drinking-water standard. Eighty-two of 151 analyses (54 percent) had concentrations of dissolved solids exceeding the standard shown in table 3.

Concentrations of dissolved solids in water from the San Jose, Nacimiento, and Animas Formations are shown in figure 11. Water samples with the largest concentrations of dissolved solids are in a northwest-trending oval area in the central part of the area of outcrop. The northern extent of this area includes the water well having a dissolved-solids concentration of 6,800 milligrams per liter near the Colorado-New Mexico State line. The southern extent of this area includes the water well having a dissolved-solids concentration of 2,300 milligrams per liter just north of the Rio Arriba-Sandoval County line. In Colorado, the dissolved-solids concentration of all water wells and one spring is less than 1,400 milligrams per liter. In New Mexico, with the exception of the area discussed above, the dissolved-solids concentration of all water wells is less than 1,600 milligrams per liter.

The specific conductance of water can be easily measured with a meter at the sampling site. Because specific conductance correlates with the concentration of dissolved solids (Hem, 1985, p. 67), a measurement of specific conductance can be used to estimate the concentration of dissolved solids by multiplying the specific conductance by 0.62. This number represents the median value of the ratio of the concentration of dissolved solids to specific conductance derived from values for 159 samples.

Concentrations of sulfate from water in the San Jose, Nacimiento, and Animas Formations are shown in figure 12. The concentrations vary greatly and no pattern of occurrence is evident. The largest concentrations of sulfate are in a small area just east of Farmington (fig. 12). The greatest number of wells with the smallest concentrations of sulfate are in the northern part of the area of outcrop in Colorado.

Concentrations of fluoride from water in the San Jose, Nacimiento, and Animas Formations are displayed in figure 13. The concentrations range from 0.1 to 8.8 milligrams per liter with no apparent trend. The largest fluoride concentrations, those greater than the primary drinking-water standard (table 2), are located in La Plata County and southern San Juan and Rio Arriba Counties.

Chemical-constituent diagrams for the San Jose, Nacimiento, and Animas Formations are displayed in figure 14. Alkalinity, shown in figure 14, is the capacity of the solution to neutralize a strong acid (Hem, 1985, p. 106) and consists primarily of bicarbonate ions and small concentrations of carbonate ions. Dominant ions from water in the San Jose, Nacimiento, and Animas Formations are: sulfate, bicarbonate, sodium plus potassium, and calcium. Water with large concentrations of major ions commonly is in the central part of the basin east of Farmington as indicated by the larger diagrams displayed in figure 14. However, water with the greatest concentration of major ions is from a well located in the northwestern part of the outcrop area; the sample is a sodium chloride type water. The smaller concentrations of major ions generally are from wells near the perimeter of the area of outcrop (fig. 14).

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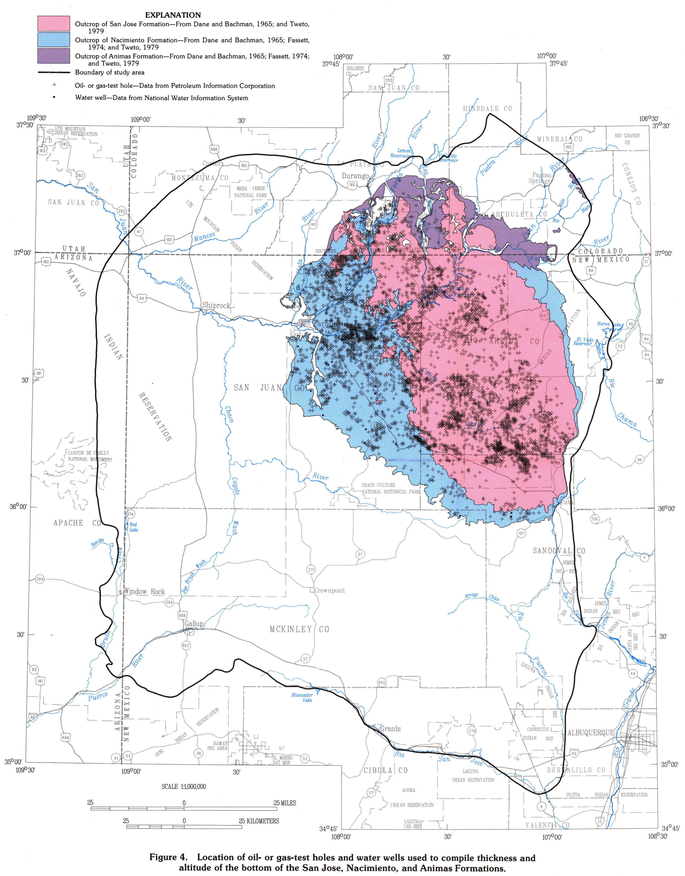

Figure 4. Location of oil- or gas-test holes and water wells used to compile thickness and altitude of the bottom of the San Jose, Nacimiento, and Animas Formations.

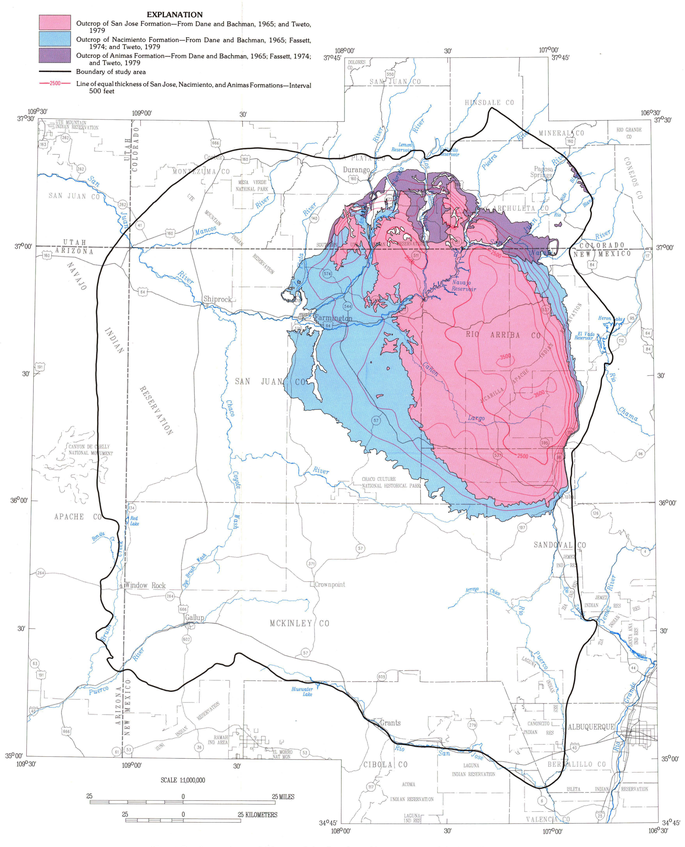

Figure 5. Approximate thickness of the San Jose, Nacimiento, and Animas Formations.

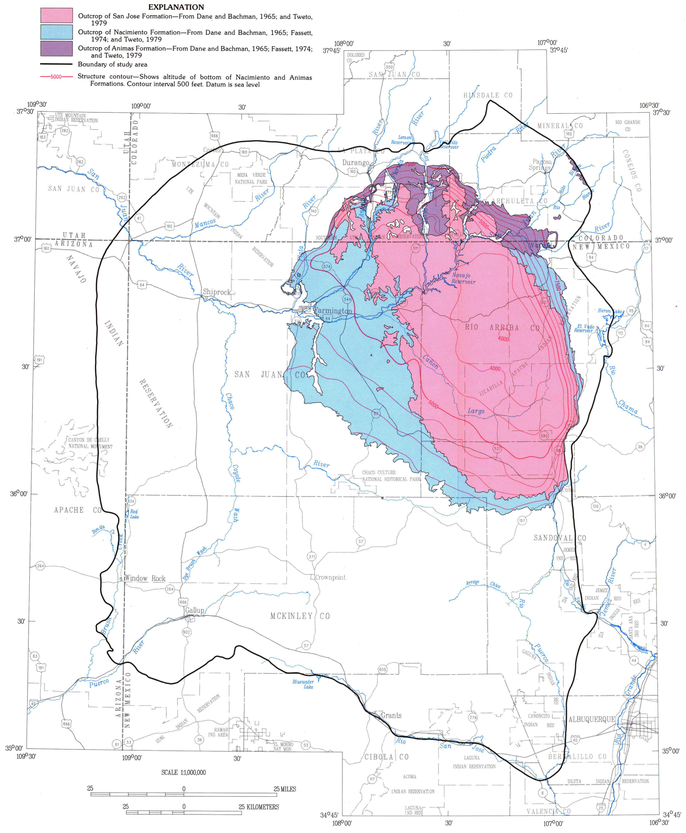

Figure 6. Approximate altitude and configuration of the bottom of the Nacimiento and Animas Formations.

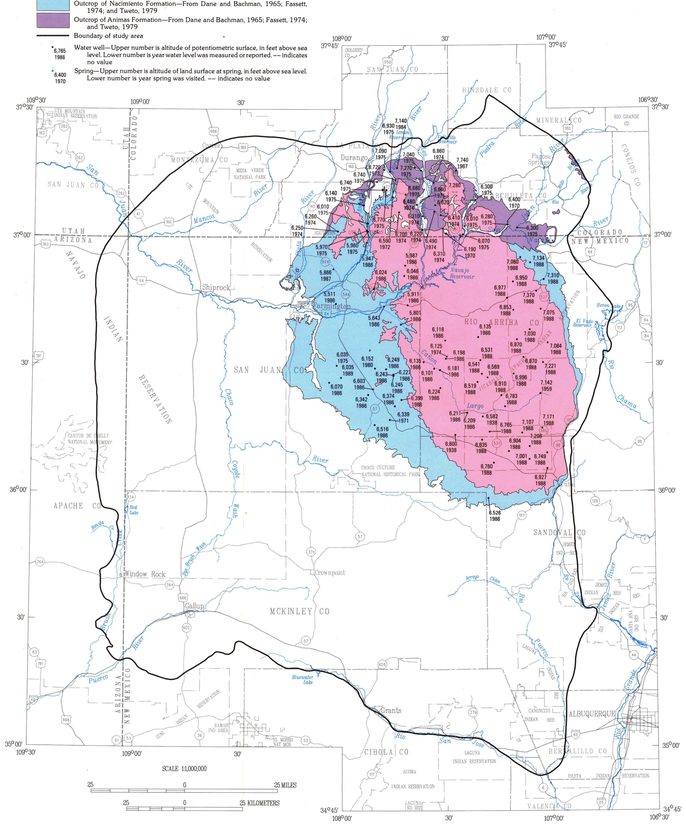

Figure 7. Altitude of potentiometric surface of water in the San Jose, Nacimiento, and Animas Formations at selected water wells and springs.

Base from U.S. Geological Survey, 1:100,000 Digital Data
Universal Transverse Mercator Projection, zone 12

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