EXEMPTION OF THE MENEFEE FORMATION AS AN UNDERGROUND SOURCE OF DRINKING WATER IN THE VICINITY OF THE JOHNSON 7-11 WELL SANDOVAL COUNTY, NEW MEXICO

Submitted To

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EXECUTIVE SUMMARY

Pride Energy Company, as successor in interest to Energy Development Corporation, has filed for an aquifer exemption pursuant to 40 CFR § 144.8. This report demonstrates that there are no aquifers within the zone of endangering influence that are used for a water supply for human consumption and that the quality of the water exceeds either federal or state drinking water standards for some constituents.

The proposed injection zone is within the Menefee Formation which produces hydrocarbons in the area. Oil or gas have also been reported in other production unit wells in the Ojo Alamo, Pictured Cliffs and Cliff House Sandstones as well as the Lewis, Kirtland, Menefee, and Mancos Formations.

The injection zone and other overlying water-bearing units cannot be considered as aquifers under the definition of an aquifer given in 40 CFR § 114.3 because they cannot produce significant quantities of water for any use.

The proposed injection zones and other underground sources of drinking water likely to be affected by the waste water injection are so deep and of such variable water quality as to make them economically and technologically impractical for use as sources of domestic water supply.

Because the cost of water wells capable of exploiting underground sources of drinking water is very high and the yields are expected to be low, the development of domestic ground-water supply is economically impractical

The natural direction of horizontal ground-water flow is to the southwest. There is also ground-water flow vertically upward toward to Cliff House Sandstone. The volumetric rate of movement and the mean approach velocity is very slow.

The proposed injection zone is overlain and underlain by a confining zone that virtually will prevent the migration of injected fluids into any other possible USDW over the period of the project and for at least twice the period of the project after injection terminates.

The zone of endangering influence (ZEI) and the area for which the aquifer exemption is sought lie within a radial distance of six (6) miles from the proposed injection well. There are no water wells within six (6) miles of the project which are deeper than 1,030 feet (ft) and which encounter the proposed injection zone and which could act as short-circuiting conduits to convey injected water into shallower water-bearing units. Oil and gas wells in the area are cased and cemented through the Menefee Formation.

INTRODUCTION

A Disposal Well Application was filed on January 24, 1996 and subsequently went to hearing. The EPA rejected the request of the New Mexico Oil Conservation Divisions for an aquifer exemption on May 30, 1996 because the aerial description of the exemption must encompass the ZEI created by the proposed injection to ensure adequate protection from contamination of the redefined underground source of drinking water (USDW) by upward migration.

Turner Environmental Consultants was retained by Pride Energy Company to assist with the exemption of the Menefee Formation near Cuba, New Mexico as an USDW.

LEGAL FRAMEWORK

Under 40 CFR § 146.4 an aquifer can be exempted under 40 CFR § 144.8 if

(a) it does not currently serve as a source of drinking water; and

(b) It cannot now and will not in the future serve as a source of drinking water because:

(1) It is a mineral, hydrocarbon or geothermal energy producing, or can be demonstrated to contain minerals.

(2) It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical;

(3) It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

(4) It is located over a Class III well mining area subject to subsidence, or

(c) The total dissolved solids content of the ground water is more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system.

Under 40 CFR § 146.5, the area of administrative review is determined based on the determination of the Zone of Endangering Influence (ZEI) for an injection well. The ZEI is defined in 40 CFR § 146.6 and the modified Theis equation for determination of the ZEI is presented. The Theis equation was developed for single phase applications. The calculations given in the report are based on more familiar oilfield mathematical methods and oilfield units.

40 CFR § 146.3 defines an aquifer as a geological formation, group of formations, or part of a formation that is capable of yielding a ***significant*** amount of water to a well or spring.

BACKGROUND INFORMATION

The injection well is the Johnson 7-11 (API No. 30043207290000) which was renamed the San Isidro 7-11 (API No. 30043207290001) located 2,074 ft from the south line and 1,650 ft from the west line of Section 7, Township 20 North, Range 2 East (20.02.07.321 in State Engineer notation) in Sandoval County, New Mexico. The well is situated about 8 miles west-southwest of Cuba.

Depths given in the Disposal Well Application are referenced to the elevation of the Kelly Bushing at 7,030 ft above mean sea level (ft amsl). The ground surface elevation at the well is given the well logs and by Petroleum Information Service (PI) as 7,017 ft amsl.

Depths in this report are given in terms of depth below the Kelly Bushing and depths below ground level (ft bgl). Elevations, where relevant, are given as feet above mean sea level.

Well locations are given according to the notation used by the State Engineer Office.

Permeabilities (hydraulic conductivities) have been obtained from the hydrologic literature where they are given as feet per day (ft/d) which is a field unit rather than an intrinsic permeability which has dimensions of L^2. We have converted the hydrologic units of ft/d to intrinsic permeability in millidarcies (md) using a multiplier of 411 assuming a specific gravity of water of 1 gram per cubic centimeter (gm/cm^3) and a viscosity of 1 centipoise (cp) (Journal of Ground Water, v. 35, n. 1, p. 187).

The Johnson 7-11 well was completed by setting 9-5/8 inch casing to 595 ft and 7-inch casing to 3,366 ft. A 4-1/2 inch liner was set from 3,339 to 4,762 ft when the well was originally drilled. The well was plugged back. The injection zone is 7-inch steel pipe.

This report relies on information provided with the Disposal Well Application. In addition, figures showing the regional geology of the San Juan Basin and the proposed injection well site and maps showing the distribution of transmissivity, hydraulic conductivity, and potentiometric surfaces and gradients from Kernoodle (1996) are in Appendix 1.

GROUND WATER OCCURRENCE

Ground water is found in all Cretaceous and Tertiary sand units throughout the San Juan Basin. The yield of wells varies depending on the transmissivity of the rock units. The usability of the water depends on the chemical quality.

Generally, wells in the Cretaceous rocks are of low yield and produce poor quality water. The yield of wells in Tertiary sand units is much higher and the quality of the water tends to be much better.

GEOLOGICAL SETTING

The Johnson 7-11 well is situated about eight (8) miles southwest of Cuba on the boundary between the Central San Juan Basin and Chaco Slope to the south (Kelley, 1950).

The Central San Juan Basin is defined as that part of the San Juan Basin containing Cenozoic sediment at the surface. The Cenozoic sediment overlies a thick section of Cretaceous sediment. It is the Cretaceous sediment that has been developed for oil and gas.

HYDROSTRATIGRAPHY

The generalized nomenclature of the San Juan Basin stratigraphy is given by Kernoodle (1996, Figure 5) (Appendix 1). The proposed injection zone is within the Menefee Formation. The area of review covered by 40 CFR § 146.6 is concerned with possible contamination of potable water zones above the injection zone. Only the stratigraphy above the Menefee Formation is considered.

SAN JOSE FORMATION

Geometry and Lithology

The San Jose Formation of Eocene age is exposed along the southern part of the Central San Juan Basin where it dips to the north. The formation thickens toward the center of the basin ranging from 200 to 2,700 ft thick (Tansey, 1984, p. 22).

The San Jose Formation overlies the Animas Formation and is comprised of alternating zones of sandstone and shale. The sandstones are fine- to coarse-grained, arkosic, and occasionally conglomeratic. The basal contact of the San Jose Formation with Late Cretaceous rock units is unconformable around the edge of the San Juan Basin. In the Central San Juan Basin, it conformably overlies the Nacimiento Formation (Fassett and Hinds, 1971)

The San Jose Formation has been subdivided into the Cuba Mesa Member, the Regina Member, the Llaves Member and the Tapacitos Member. These units are lithologically sandstone-shale-sandstone-shale respectively. Fassett and Hinds (Fassett, 1974) report tracing the Cuba Mesa Member a few miles west of Cuba where it pinched out. Turner (1972) completed a water well in the Cuba Mesa Member north of Regina, NM at a depth of about 1,500 ft. The shale zones within the San Jose Formation are bentonitic and heaving conditions occur when the formation is drilled.

The San Jose Formation does not occur at the location of the proposed injection well.

The municipal wells serving Cuba are spudded in the San Jose Formation about eight (8) miles to the northeast. It is likely they obtain their water from the Cuba Mesa Member.

ANIMAS FORMATION

Geometry and Lithology

The Animas Formation occurs in the northern part of the San Juan Basin. The Animas grades laterally to the south into the Nacimiento Formation in the vicinity of Dulce, New Mexico, far north of the area of interest.

NACIMIENTO FORMATION

Geometry and Lithology

The Paleocene Nacimiento Formation conformably overlies and intertongues with the Ojo Alamo Sandstone in the Cuba area. The Nacimiento Formation is comprised of black and gray shale with occasional sandstone channel beds. Where it occurs near Bloomfield, it is an unctuous green shale. The sand component of the Nacimiento Formation increases to the north in the San Juan Basin where it grades laterally into the Animas Formation.

The Nacimiento Formation is about 900 ft thick south of the southern tip of Cuba Mesa west of Cuba (Fassett, 1966). At the location of the Cuba municipal wells it is about 1,500 ft thick (Kernoodle, 1996, p. 25). It is very thin at the proposed injection well.

Hydraulic Properties

The primary use of water from the Nacimiento Formation is for livestock and domestic supplies. There are no known aquifer performance test of the Nacimiento Formation. The fine material comprising the Nacimiento Formation, particularly in the Cuba area, will restrict upward and downward movement of water.

Tansey (1984, p. 117) reports the following vertical hydraulic conductivities for the Nacimiento Formation aquitards.

Table 1. Vertical hydraulic conductivity of the Nacimiento Formation

WELL NAME	LOCATION	HYDRAULIC CONDUCTIVITY ($X10^{-9}$m/s)	(md)
Blanco #2	29.09.08	4.8	0.56
Gobernador	27.05.03	5.45	0.63
Jones A #9	28.08.14	68.5	7.94

Tansey (1984, p. 117) gives the geometric mean vertical field hydraulic conductivities of the Nacimiento aquitards as 5.66E-3 ft/d (2E-8 m/s, 2E-6 cm/s, 2.32 md). The Nacimiento Formation is a confining zone.

Engineered earthen liners and/or caps for landfills, tailings pond, and wastewater lagoons must have permeability (hydraulic conductivity) of 1E-06 cm/s. Using this as a criteria for whether or not a rock unit is an aquitard or a confining zone, the Nacimiento Formation may or may not be a confining zone.

OJO ALAMO SANDSTONE

Geometry and Lithology

The Ojo Alamo Sandstone is Paleocene in age. It conformably underlies the Nacimiento Formation. It is the lowermost Tertiary rock unit of the San Juan Basin. It is a sheetlike sandstone unit with some shale zones. It thins northwestward from the Nacimiento Uplift towards Farmington. It is a coarse-grained, arkosic, conglomeratic sandstone.

The Ojo Alamo Sandstone unconformably overlies Late Cretaceous rocks in the Cuba area. As much as 2,100 ft of Kirtland and Fruitland rocks may be missing along the east edge of the basin. Southeast of Cuba, the Ojo Alamo rests directly on the Kirtland Shale-Fruitland Formation.

The Ojo Alamo Sandstone is present in the subsurface at the location of the Cuba municipal wells. At the site of the injection well, it occurs several hundred feet below the surface. In the Johnson 6-16, about one mile northeast of the Johnson 7-11 well, it occurs at 534 ft and is 181 ft thick. In the San Isidro 13-11 about 1.5 miles southwest of the Johnson 7-11 the Ojo Alamo is at 120 ft and is 214 ft thick.

Hydraulic Properties

The median transmissivity of the Ojo Alamo near the outcrop is about 780 gpd/ft (Kernoodle, 1996, p. 28) based on 10 aquifer tests. Anderholm (1979) measured a transmissivity of 91 ft^2/d (682 gpd/ft) near Cuba. Aquifer tests of the Ojo Alamo away from the outcrop yield transmissivity values of 0.37 to 2.9 gpd/ft.

Water Quality

The Ojo Alamo is generally a source of good quality water. Tansey (1984, p. 20) reports 18 analyses. Electrical conductivity ranges from 650 to 1,500 micromhos/cm. In some cases, the sulphate concentration exceeds the 250 mg/l drinking water standard.

Records that are on file with the New Mexico Oil Conservation Division generally indicate the Ojo Alamo contains water without stating its quality. However, a number of records indicate the Ojo Alamo contains gas. This is the case for the San Isidro 5-1, located in 20.02.05 about two miles northeast of the Johnson 7-11, and the San Isidro 11-14, about two miles west of the Johnson 7-11.

KIRTLAND SHALE AND FRUITLAND FORMATION

Geometry and Lithology

The combined Kirtland Shale and Fruitland Formation are Late Cretaceous in age and represents swamp, river, lake, and flood plain continental deposits overlying the Pictured Cliffs Sandstone. The Kirtland Shale overlies the Fruitland Formation. The Kirtland Shale does not contain coal. The Fruitland is comprised of shale, siltstone, coal, carbonaceous shale, and rarely sandstone.

The Kirtland Shale and Fruitland Formation occur within the central part of the San Juan Basin and underlie the Tertiary rocks.

In the vicinity of the proposed injection well, the Kirtland Shale and Fruitland Formation are about 200 ft thick (Kernoodle, 1996, p. 30).

The NTUA wells are likely spudded in or close to the outcrop of the Kirtland Shale and Fruitland Formation.

Kernoodle (1996, p. 32) notes that "recently, there has been extensive exploration for methane gas resources from coal beds in the Fruitland Formation. The gas resources in the coal beds had largely been ignored because initial production from most wells was large quantities of poor-quality water and the gas potential was not recognized." Kernoodle goes on to say "gas and water production is thought to be from both coal in the Fruitland Formation and sandstone in the underlying Pictured Cliffs Sandstone.

Magellan (R) On-Line - Run Current Select
Counts for Historical Well Data -- Rocky Mountains

	Records Found	
Starting number of records	231,160	
Distance from API = "6 miles from API 3004320729"		
		94
Producing Formation Name among:		
NACIMIENTO (651NCMN)	0	
OJO ALAMO (604OJAM)	0	
SAN JOSE (652SNJS)	0	
KIRTLAND (604KRLD)	0	
All of the "FRUITLAND" matches	0	
All of the "PICTURED CLIFFS" matches	0	
LEWIS /SD/ (604LWIS)	0	
CLIFF HOUSE (604CLFH)	0	
MENEFEE (604MENF)	1	
POINT LOOKOUT (604PNLK)	0	
All of the "MANCOS" matches	22	
All of the "GALLUP" matches	32	
All of the "DAKOTA" matches	1	54

Hydraulic Properties

Kernoodle (1996, p. 29) reports that transmissivity determined from five aquifer tests ranges from 4.5 to 972 gpd/ft. The only value of hydraulic conductivity calculated is 0.00001 ft/d. The yield to wells is very low. Tansey (1984) calculated field vertical hydraulic conductivities using thermal methods. His determinations are given in Table 2.

Table 2. Vertical hydraulic conductivity of the Kirtland Formation

WELL NAME	LOCATION	HYDRAULIC CONDUCTIVITY (x 10^{-9} m/s)	md
Angel Peak #3	27.11.20	10.3	1.19
Gasbuggy	29.104.36	0.01	0.0012
Jones A #9	28.08.14	11	1.28
San Juan 72-4	28.04.17	29	3.36

Tansey (1984, p. 117) gives the geometric mean horizontal hydraulic conductivity of the Kirtland-Fruitland aquitard as 1.4E-4 ft/d (5E-10 m/s, 0.058 md)

Kernoodle (1996, Figure 41) (Appendix 1) indicates the combined vertical hydraulic conductivity of the Kirtland Shale-Fruitland Formation is 0.0001 ft/d (3.53E-8 cm/s, 0.041 md).

With a vertical hydraulic conductivity of 3.53E-8 cm/s, the Kirtland Shale-Fruitland Formation is a confining zone. Kernoodle (1996, Figure 36) (Appendix 1) also designates the Kirtland Shale-Fruitland Formation as a confining unit.

Water Quality

There are no chemical analysis of water from the Kirtland Shale-Fruitland Formation. However, the San Isidro 11-14 encountered gas in the Fruitland Formation. All wells encountered coal beds in the Fruitland Formation.

PICTURED CLIFFS SANDSTONE

Geometry and Lithology

The Pictured Cliffs Sandstone is a regressive strandline sandstone deposited during the last retreat of the Late Cretaceous sea from the San Juan Basin. It conformably underlies the Fruitland Formation and conformably overlies the Lewis Shale. In the southern part of the San Juan Basin, the Pictured Cliffs is poorly cemented.

In the injection well, PI indicates the top of the Pictured Cliffs is at 732 ft below the Kelley Bushing and the top of the underlying Lewis Shale is 900 ft. The Pictured Cliffs is 168 ft thick.

Hydraulic Properties

The transmissivity of the Pictured Cliffs from five aquifer tests ranges from 0.0075 to 22 gpd/ft.

Horizontal hydraulic conductivity determined from drill-stem tests in deeper holes averages 0.007 ft/d (2.87 md). In the digital computer model of the San Juan Basin, Kernoodle (1996, Figure 40-D) (Appendix 1) assigned a horizontal hydraulic conductivity of 0.007 ft/d (2.87 md) and vertical hydraulic conductivity of 0.0007 ft/d (2.5E-7 cm/s, 0.287 md).

Under the criteria given above, the Pictured Cliffs Sandstone is a confining bed for vertical flow.

Water Quality

Chemical analyses of water are not available from the Pictured Cliffs Formation. However, the Disposal Well Application reports five unit wells (5-2, 6-16, 11-4, 12-10, 13-11) penetrated the Pictured Cliffs and reported natural gas.

Kernoodle (1996, p. 34) states; "Few water wells are completed in the Pictured Cliffs Sandstone because of the generally poor quality water found in the unit."

LEWIS SHALE

Geometry and Lithology

The Lewis Shale, of Late Cretaceous age, crops out around the margin of the central San Juan Basin. It conformably overlies the Cliff House Sandstone and conformably underlies the Pictured Cliffs Sandstone. It is a gray to dark-gray transgressive marine shale.

The Lewis Shale contains a widespread marker bed known as the Huerfano Bentonite Bed.

PI indicates the top of the Lewis Shale is 900 ft below the Kelly Bushing (6,130 ft amsl) and the top of the Chacra Tongue of the Cliff House Sandstone is 1,160 ft (5,870 ft amsl). The Lewis Shale in the proposed injection well is 260 ft thick.

Hydraulic Properties

Kernoodle (1996, p. 34) states: "The Lewis Shale is not recognized as an aquifer and there are no known tests to determine hydraulic properties of the unit." Furthermore, "The Lewis Shale serves as a confining unit that hydraulically separates the overlying Pictured Cliffs Sandstone and the underlying Cliff House Sandstone aquifers. The low-permeability shale also rejects recharge from precipitation.

For the digital computer model of the San Juan Basin, Kernoodle (1996, Figure 40-E) (Appendix 1) assigned a vertical hydraulic conductivities of 0.00005 ft/d (1.76E-8 cm/s, 0.021 md) and 0.000005 ft/d (1.8E-9 cm/s, 0.002 md).

With a maximum vertical hydraulic conductivity of 1.76E-8 cm/s, the Lewis Shale is a confining zone. Kernoodle (1996, Figure 36) (Appendix 1) also defines the Lewis Shale as a confining bed.

Water Quality

Gas is reported in the San Isidro 5-2 well.

CLIFF HOUSE SANDSTONE

Geometry and Lithology

The Mesaverde Group was subdivided into the Cliff House Sandstone, the Menefee Formation and the Point Lookout Sandstone.

The Cliff House Sandstone represents a transgressive phase of Late Cretaceous sedimentation during which medium- to fine-grained sandstone was deposited. It intertongues upward into the Lewis Shale

The Cliff House consists of two major sandstone tongues - the Chacra Tongue and the La Ventana Tongue. The Chacra Tongue is stratigraphically above and not connected to the La Ventana Tongue.

The Cliff House Sandstone consists of thick- to very thick-bedded sandstone with calcite or silica cement. and a clay matrix. The Cliff House sandstone is moderately well cemented.

PI indicates the top of the Chacra Tongue is 1,160 ft (5,870 ft amsl). It bottoms at about 1,330 ft (5,700 ft amsl). The La Ventana Tongue is not identified in the dual laterolog for the proposed injection well; however, it is likely the lower sand unit identified at 1,632 ft (5,398 ft amsl). The La Ventana Tongue bottoms above the Menefee which PI indicates has its top at 2,312 ft (4,718 ft amsl).

<u>Hydraulic Properties</u>

Transmissivity and hydraulic conductivity data for the Cliff House Sandstone are sparse. A recovery test on a water well in 1961 indicated a transmissivity of 15 gpd/ft (Kernoodle, 1996, p. 38). The median specific capacity for 27 water wells is 0.06 gpm/ft and the estimated transmissivity is 120 gpd/ft (Walton, 1987, p. 19).

Average horizontal hydraulic conductivity from drill stem tests in the deeper part of the San Juan Basin is 0.0015 ft/d (6.16 md).

For the digital computer model of the San Juan Basin, Kernoodle (1996, Figure 40-F) (Appendix 1) assigned a horizontal hydraulic conductivity of 0.1 ft/d (41.1 md) and a vertical hydraulic conductivity of 0.001 ft/d (3.5E-7 cm/s, 0.41 md) to the Cliff House Sandstone.

The Cliff House Sandstone can be considered a confining zone with regard to vertical ground water flow.

<u>Water Quality</u>

Natural gas is reported in the San Isidro 5-2, 11-14, and 13-11 wells. Small amounts of oil and gas are reported in the San Isidro 12-10

MENEFEE FORMATION

<u>Geometry and Lithology</u>

The Menefee Formation is a continental fluvial, interbedded sequence of sandstone, siltstone, shale and coal unit conformably overlying the Point Lookout Sandstone.

PI indicates the top of the Menefee is at 2,312 ft (4,718 ft amsl) and the top of the Point Lookout Sandstone is at 2,940 ft (4,090 ft amsl). The Menefee Formation in the proposed injection well is 628 ft thick.

Hydraulic Properties

Transmissivity of the Menefee Formation depends on the thickness of sandstone lenses penetrated. The median transmissivity from nine aquifer tests is about 75 gpd/ft.

Horizontal hydraulic conductivity calculated from drill-stem tests in oil and gas wells averages 0.017 ft/d (6.98 md). Kernoodle (1996, Figure 40-G) (Appendix 1) assigned a value of 0.05 ft/d (20.5 md) for the horizontal hydraulic conductivity of the Menefee Formation and a vertical hydraulic conductivity of 0.00001 ft/d (3.5E-9 cm/s, 0.0041 md).

With a vertical hydraulic conductivity of 3.5E-9 cm/s, the Menefee Formation is classified as a confining zone. Kernoodle (1996, Figure 36) (Appendix 1) also indicates it is a confining bed.

Water Quality

An analysis of water from the proposed injection well included in the Disposal Well Application reports the total dissolved solids concentration of water in the injection zone is 8,790 mg/l.

An analysis in the records of the U.S. Geological Survey for a well producing from the Allison Member of the Menefee Formation six (6) miles west of the proposed injection well has an electrical conductivity of 28,400 micromhos per centimeter. This is equivalent to a total dissolved solids concentration of about 19,312 mg/l.

Oil and gas is reported in the San Isidro 6-16 and 13-11 wells. Oil alone is reported in the Menefee in San Isidro wells 5-2, 11-14, and 12-10.

SUMMARY OF VERTICAL HYDRAULIC PROPERTIES

The rate of vertical ground-water flow into overlying potential USDWs is determined by the vertical component of hydraulic conductivity. Usually, the vertical component of hydraulic conductivity is very low in shales to classify them as confining zones or confining beds. Therefore, the Kirtland Shale-Fruitland Formation, Lewis Shale, and Menefee Formation are classified as aquitards, confining zones, or confining beds.

Where the vertical component of hydraulic conductivity is very low for sandstones, they too may be considered as aquitards, confining zones, or confining beds. In the San Juan Basin, in the Pictured Cliffs and the Cliff House Sandstones both can be considered as aquitards, confining zones, or confining beds based on the criteria that the vertical component of hydraulic conductivity must be greater than 1E-6 cm/s.

DIRECTION AND SPEED OF GROUND WATER FLOW

HORIZONTAL

The horizontal direction of ground-water flow within the Menefee and Cliff House is to the southwest according to steady state potentiometric contours given by Kernoodle (1996, Figure 48) (Appendix 1).

The horizontal mean approach velocity of flow is calculated from Darcy's Law

$$Q = TIW/A\phi$$

where

Q = Darcian flow rate, L^3/T
T = aquifer transmissivity, L^2/T
I = hydraulic gradient, L/L
W = width of flow section, L
A = unit cross section of aquifer through which flow occurs, L^2
ϕ = effective porosity, percentage

In the present case, the transmissivity of the Cliff House and Menefee are taken as 100 and 75 gpd/ft (13.4 and 10 ft^2/d). The horizontal hydraulic gradients from Kernoodle (1996, Figures 47 and 48 (Appendix 1) for the Cliff House and Menefee are about 5E-3 and 6.3E-3 respectively. If the effective porosity is as high as 20 percent, the mean approach velocity of moving water in the Cliff House and Menefee will be 0.33 and 0.32 ft/d respectively.

VERTICAL

Kernoodle (1996, Figure 48) (Appendix 1) indicates the average potentiometric surface for the Menefee Formation at the location of the injection well is about 7,000 ft amsl. The potentiometric surface for the Cliff House Sandstone is given by Kernoodle (1996, Figure 47 (Appendix 1) as about 6,950 ft amsl. The potentiometric head for the Point Lookout Sandstone, below the Menefee Formation, is given by Kernoodle (1996, Figure 49 (Appendix 1) as about 6,800 ft amsl.

Therefore, the direction of ground-water flow under natural conditions is from the Menefee Formation both upward into the Cliff House Sandstone and downward into the Point Lookout Sandstone.
*

From Darcy's Law, the upward mean approach velocity of ground water is

$$v = K_v I_v/\phi$$

where

Q_v = vertical volumetric flow rate, L^3/T
K_v = vertical hydraulic conductivity, L/T
I_v = vertical hydraulic gradient, L/L
ϕ = porosity, percentage

From Kernoodle (1996, Figures 47 and 48 (Appendix 1) we can calculate the vertical hydraulic gradient as about 1.30 ft H_2O/ft (0.56 psi/ft). If the vertical hydraulic conductivity is 0.00001 ft/d and the effective porosity is 20 percent, the vertical mean approach velocity is about 6.65E-5 ft/d.

HYDRAULIC PROPERTIES FOR COMPUTING THE ZONE OF ENDANGERING INFLUENCE

POROSITY

Exhibit 5 of Case No 11470 gives the porosity of the injection zone within the Menefee Formation as 18.8 percent.

Careful inspection of the compensated density log of the Johnson 7-11 indicates that the perforated interval between 2,438 and 2,624 below the Kelly Bushing ranges from 18 to 26 percent. The average porosity is about 20 percent.

The Archie formula may be used to calculate the porosity also. Archie's Law states:

$$F=\frac{R_o}{R_w}=\frac{1}{\phi^m}$$

where

R_o = resistivity of the saturated formation determined from the deep induction laterolog, ohm-m
R_w = resistivity of the water from the formation, ohm-m
ϕ = porosity, percentage
m = Archie's coefficient

In the present case, analysis of the water from the Menefee injection interval between 2,438 and 2,624 ft gives a total dissolved solids concentration of 8,790 mg/l. This must be converted to electrical conductivity and resistivity (R_w).

The relationship between electrical conductivity expressed as "micromhos/cm" and total dissolved solids expressed as "mg/l" is well known and usually varies between 0.55 and

0.75 (Hem, 1989, p. 66-68). Analysis of the municipal water supply for the Cuba South and West wells (Garcia and Olaechea, 1974) shows that the electrical conductivity can be approximated by dividing the total dissolved solids concentration by 0.68.

For the injection zone, the electrical conductivity will be about 12,926 micromhos/cm or 1.29 mho/m. The resistivity is the reciprocal of the conductivity and the resistivity "R_w" of the formation water in the injection zone will be about 0.77 ohm-m.

The dual induction laterolog shows that the formation conductivity for the injection zones averages about 92 millimhos/m and the average formation resistivity "R_o" is about 11 ohm-m.

The formation resistivity factor then is the quotient of "R_o" and "R_w" or about 14.

If the formation resistivity factor is 14, Archie (1950) indicates that the percent porosity for sandstones falls in the 20 to 30 percent range and varies depending on the cementation of the formation. The hydraulic properties of the Late Cretaceous sandstone described above suggest the sandstone units are moderately well cemented. The Cliff House Sandstone above, the Menefee Formation is a widespread cliff forming unit in the San Juan Basin.

Birdwell (1963, p. F-11) indicates the "m" exponent in the Archie equation for moderately consolidated sandstone is about 1.8. If the formation resistivity factor is 14, the porosity will be 23 percent. This is in excellent agreement with the porosity estimated from the compensated density log.

For further calculations, we will use a conservative porosity value of 20 percent.

WATER SATURATION

Exhibit 5 of Case No. 11470 gives the water saturation as 75 percent.

We can estimate water saturation from

$$S = (FR_w/R_o)^{1/n}$$

where "n" is a cementation factor. Levorsen (1967, p.159) indicates that for moderately cemented sandstone, a cementation factor of about 1.8 is appropriate. If "F" is 14, "R_w" is 0.77 ohm-m and R_o is 11 ohm-m, the water saturation is 99 percent. That is, the rock unit in the injection zone is effectively saturated.

For further calculations, we will consider that the injection zone is completely saturated. The saturation factor is 1.

TOTAL COMPRESSIBILITY

The total compressibility of the saturated rock of the injection zone is equivalent to the volume fraction of water times the compressibility of water plus the compressibility of the rock matrix expressed as psi^{-1}. Water saturation is 100 percent and the volume fraction is "1".

A compressibility of 3E-06 psi^{-1} is usually suitable for water (Mathews and Russell, 1967, p. 21). The effective rock compressibility is dependant on porosity. Mathews and Russell (1967, Figure G.5) indicates an effective rock compressibility of about 3.7E-06 psi^{-1} for sandstone with 20 percent porosity.

The total compressibility for the injection zone is about 6.7E-06 psi^{-1}

RESERVOIR PRESSURE

Exhibit 5 of Case No. 11470 gives the reservoir pressure within the injection zone as 1,000 psia.

The injection zone is between 2,438 and 2,624 ft below the Kelly Bushing. The injection zone is very near the middle of the Menefee Formation.

Kernoodle (1996, Figure 48 (Appendix 1) indicates the average steady state potentiometric surface associated with the Menefee Formation in the vicinity of the proposed injection well is about 7,000 ft amsl. Under slab hydrodynamic theory, the average potentiometric head is attributable to the middle of the slab of rock. Because the injection zone is very near the middle of the Menefee Formation, the average steady state potentiometric head is the head within the injection zone.

The elevation of the base of the injection zone is 2,611 ft bgl or 4,406 ft amsl. The hydrostatic head above the base of the injection zone is about 2,594 ft of water with a specific gravity near one (1). The water within the injection zone is not a brine and the hydrostatic gradient is probably about 0.433 psi/ft. The bottom hole pressure will be about 1,123 psia.

If the average potentiometric surface of the Menefee Formation is 7,000 ft amsl, the depth to water in the injection well with a surface elevation of 7,017 ft amsl is about 17 ft.

For further calculations, we will use an original bottom hole pressure of 1,123 psi.

RESERVOIR TEMPERATURE

Exhibit 5 of Case No. 11470 gives the reservoir temperature of the Menefee injection zone as 105 degrees Fahrenheit (°F). No data was presented to support this estimate.

The dual induction laterolog and the compensated density dog for the Johnson 7-11 well indicate that logging took place on July 19, 1984 to a depth of 3,664 ft and on July 22, 1984 from 3,664 to 4,769 ft. The logs indicate the bottom hole temperature at 3,664 ft was 120°F and at 4,769 it was 145°F.

Reynolds (1956) gives the mean annual surface temperature at Cuba at a station elevation of 6,945 ft amsl as about 46.5°F. Therefore, the increase in temperature from the surface to 3,664 ft is about 74°F and from 3,664 to 4,769 ft it is 25°F. The geothermal gradient from the surface to 3,664 ft is 2.02E-2 degrees Fahrenheit per foot of depth (°F/ft). The geothermal gradient from 3,664 ft to 4,769 ft is 2.26E-2 °F/ft. The lower gradient in the upper part of the hole may be caused by shallow ground-water movement and convective heat transfer. Using the gradient in the upper part of the hole, the temperature at a depth of 2,624 ft (2,611 ft bgl) will be about 99°F.

For further calculations, we will use a bottom-hole temperature of 100°F.

FLUID SPECIFIC GRAVITY

Analysis of fluid produced from several wells that is intended for injection is given in Table 3 below. The specific gravity represents laboratory determination by Petrolite Oilfield Chemicals Group. The specific gravity of the injected fluid at the injection zone must be adjusted for a bottom hole injection pressure. The bottom hole pressure of the injected fluid will increase from 1,123 psi for formation water to 1,146 psi plus the injection pressure ((2,594 ft + 17 ft)*0.439 psi/ft) During an injection test of the well 720 bblpd was injected at a pressure of 700 psi. If the injection pressure is 0.97 psi/bblpd an additional 146 psi must be added for an injection rate of 150 bblpd. The total bottom hole injection zone pressure will be about 1,292 psi.

The specific gravity must be corrected for a pressure of about 1,292 psi and a temperature of 100°F.

Table 3. Specific gravity determination of injection fluid.

WELL NAME	LAB SPECIFIC GRAVITY	GRADIENT (psi/ft)	TEMPERATURE (°F)	INJECTION SPECIFIC GRAVITY*
5-15	1.025	0.444	100	1.014
7-3	1.01	0.437	100	1.004
12-10	1.01	0.437	100	1.004

* Phillips Petroleum Corporation, 1961, Hydrodynamics Manual, Section A-0.

For further calculations, a hydrostatic gradient of 0.439 psi/ft will be used for the injected brine.

VISCOSITY

The viscosity of the fluids on injection have been determined based the percent sodium chloride for fluids at one atmosphere pressure and temperature below 212°F corrected for elevated pressure. The results are given in Table 4 below.

Table 4. Determination of viscosity of injection fluid.

WELL NAME	PERCENT NACL	TEMPERATURE (°F)	INJECTION VISCOSITY (cp)*
5-15	22.9	100	1.17
7-3	0.88	100	0.69
12-10	23.5	100	1.22

* Mathews and Russell, 1967, Figure G.4.

The pressure correction factor is very small at a temperature of 100°F.

For further calculations, we assume that the viscosity of the injected brine is 1.22 cp.

AVERAGE PERMEABILITY (HYDRAULIC CONDUCTIVITY)

The average hydraulic conductivity (permeability) in the injection zone given in Exhibit 5 of Case File No. 11470 is 5 md. Hearing testimony indicated the hydraulic conductivity is in the 5 to 10 md range but no supporting documentation was presented.

Item XII in the Disposal Well Application indicates that an injection test was run on September 28, 1995 and the Menefee tested at a rate of 720 barrels of water per day (bblpd) at a surface injection pressure of 700 psi. This can be considered the mathematical analog of specific capacity in a well which is the production rate of the well divided by the fluid level decline.

In this case, 720 bblpd is 21 gallons per minute (gpm) and the surface pressure of 700 psi is equivalent to a column of fresh water 1,616 ft high. To this must be added the calculated depth to brine in the proposed injection well of 17 ft. The total injection pressure was 1,633 ft of water. The specific capacity is about 0.013 gpm/ft.

Walton (1987, p. 19) indicates that the transmissivity in gallons per day per ft (gpd/ft) of an artesian aquifer can be estimated by multiplying the specific capacity by 2,000. In the present case, the transmissivity of the injection zone will be about 26 gpm/ft.

The transmissivity is the product of the hydraulic conductivity and the injection thickness. The injection interval is 75 ft thick, the hydraulic conductivity will be about 0.046 ft/d or 19 md in oilfield units.

Kernoodle (1996) reported that drill-stem tests of the Menefee indicated a hydraulic conductivity of 0.017 ft/d (6.98 md). He assigned a value of 0.05 ft/d (20.55 md) for the horizontal hydraulic conductivity. This is close to the 0.041 ft/d (16.85 md) estimated from the injection test.

We may say that the horizontal hydraulic conductivity of the injection zone is about 0.05 ft/d or 20 md.

INJECTION ZONE

The injection zone is given as 2,438 to 2,624 ft below the Kelly Bushing.

FORMATION VOLUME FACTOR

Because we are dealing only with water, one stock tank barrel of water is equivalent to one barrel of formation water and the formation volume factor is one (1).

AVERAGE THICKNESS OF INJECTION ZONE

Well logs, presented as Exhibit 6 of Case No. 11470, and Exhibit 5 of Case No 11470 indicate the thickness of the injection zone is 75 ft.

DEPTH TO BASE OF FRESH WATER ZONE

The depth to the base of the nearest fresh water zone having water quality less than a total dissolved solid concentration of 3,000 mg/l can be estimated from the dual induction laterolog of the well.

Using Archie's Law, we can determine the formation resistivity for a formation that is saturated with water of 3,000 mg/l or more. R_w will be about 2.27 ohm-m and R_o will be 31.7 ohm-m.

Based on this criteria, the first sand unit above the injection zone that contains water of 3,000 mg/l occurs at about 1,670 ft below the Kelly Bushing. The total sand thickness is about 30 ft.

Exhibit 6 of Case File No. 11470 indicates that this sand unit is the top of the Cliff House Sandstone or the Chacra Tongue. Chemical analyses of water are not available from the Cliff House Sandstone. However, the Disposal Well Application reports three unit wells (5-2, 11-14, 12-10) encountered natural gas in the Cliff House Sandstone.

It is unlikely that such a thin sand unit will become a USDW not only because of the low yield of wells but because the likely variability of water quality in the Cliff House Sandstone will make it an unreliable and costly aquifer to explore for potable water.

For the purpose of further computations, we assume that the base of the first sand containing less than 3,000 mg/l of total dissolved solids is at 1,670 ft (5,360 ft amsl).

INJECTION RATE

The average injection rate is given in Exhibit 5 of Case File No. 11470 as 150 barrels per day (bblpd).

INJECTION PERIOD

The injection period is given in Exhibit 5 of Case File No. 11470 as 15 years (5,479 days).

TOTAL VOLUME OF WATER INJECTED

The total volume of water to be injected is given in Exhibit 5 of Case File No. 11470 as 821,250 bbl.

RESERVOIR AREA

The surface area overlying the reservoir for brine disposal is given in Exhibit 5 of Case File No. 11470 as 640 acres.

In a letter dated May 30, 1996 from William B. Hathaway, Director of the Water Quality Division of Region 6 of the U.S. Environmental Protection Agency to Mr. William J. LeMay, Director to the New Mexico Oil Conservation Division, it appears that the aquifer exemption covers an area of 720 acres.

WATER IN PLACE

The water presently in place in the injection zone is given in Exhibit 5 of Case File No. 11470 as 52,506 thousand barrels.

If the reservoir area is 640 acres and the thickness of the injection zone is 75 ft with a porosity of 20 percent, the volume of water in place is 9,600 acre ft or about 74,480 barrels.

SUMMARY

For calculational purposes, the relevant information discussed above is given in Table 5.

Table 5. Summary of relevant parameters for calculating the Zone of endangering influence around the injection well.

ITEM	UNITS	VALUE
Specific Gravity	dim	1.014
Hydrostatic Gradient of Injected Fluid	psi/ft	0.439
Injection Rate	B/d	150
Thickness of Injection Zone	ft	75
Compressibility	psi E-1	6.70E-06
Injected Fluid Viscosity	cps	1.22
Injection Period	days	5479
Horizontal Hydraulic Conductivity of Injection Zone	md	20
Vertical Hydraulic Conductivity from TOIC to USDW	ft/d	0.00001
Porosity	%	0.2
Formation Volume Factor	dim	1
Potentiometric Surface of Injection Zone	ft amsl	7000
Base of Injection Zone	ft amsl	4406
Initial Reservoir Pressure	psi	1123
Potentiometric Surface of USDW	ft amsl	6950
Elevation of USDW	ft amsl	5358
USDW Reservoir Pressure	psi	689
Top of Injection Zone	ft bgl	2425
Base of USDW	ft bgl	1657
Distance from TOIZ to Base of USDW	ft	768
Hydrostatic Gradient from TOIZ to Base of USDW	psi/ft	0.56
Hydrostatic Gradient from TOIZ to Base of USDW	ft/ft	1.30

CALCULATION OF THE ZONE OF ENDANGERING INFLUENCE

The zone of endangering influence (ZEI) is calculated from

$$P_r = P_i + 162.6 \frac{Q\mu B}{kh} \log\left[\frac{kt}{70.4\phi\mu c r^2}\right]$$

where "P_r" is the reservoir pressure at distance "r" from the injection well and all other terms are as described in Table 6. The ZEI is normally the distance at which the increase in reservoir pressure is below the base of the USDW. This assumes that the reservoir pressure in the injection zone is always below the potentiometric head in any overlying USDW. This is not always the case. In the present case, there is a very small vertical component of natural ground-water flow. Regardless of the computations of the ZEI, ground-water flow will always be upward from the Menefee Formation into the Cliff House Sandstone.

Table 6 shows the elevation of the potentiometric head in the injection zone above the potentiometric head associated with the Cliff House Sandstone. At a distance of 10,000 ft the potentiometric head in the injection zone is 99 ft above the head in the Cliff House. Though not in Table 6, at a distance of six (6) miles, it is three (3) ft above the head in the Cliff House.

AREA OF AQUIFER EXEMPTION

The radius around the injection well beyond which injection effects will not cause an increase in upward fluid flow in excess of the natural upward ground-water flow at the end of the injection period is about six (6) miles. At a distance of six miles, the increase in reservoir pressure is very near the original reservoir pressure. The area of exemption is 72,382 acres.

EFFECT OF CONFINING BED

The increase in the potentiometric head in the injection zone will create a greater upward hydraulic gradient.

The vertical volumetric flow rate is directly proportional to the vertical hydraulic gradient. We can calculate the maximum percentage increase in vertical flow. The maximum increase in vertical flow will be at the injection well itself where the reservoir pressure during injection will be at a maximum.

Kernoodle (1996) gives the vertical component of the field hydraulic conductivity as 0.00001 ft/d. Under normal conditions, the upward flow rate per square foot of surface area will be 1.30E-5 $ft^3/d\text{-}ft^2$. If the gradient is increased to 0.80 psi/ft, the upward flow rate is increased to 1.85E-5 $ft^3/d\text{-}ft^2$.

The maximum increase in upward vertical volumetric flow is about 42 percent of the original flow.

Before the injected water can enter the Cliff House, however, it must first displace the water within the Menefee Formation and the Cliff House Sandstone below the fresh water zone. The stratigraphic thickness between the top of the injection interval and the base of the good water zone in the Cliff House is about 1,582 ft. If the average total porosity for the shale and cemented sandstone is 20 percent, the total volume of water that must be displaced within one-half mile of the injection well will be 1.23E9 bbls. The total amount of injected fluid is only about 821,813 bbls. Consequently, the injected fluid is of insufficient volume to reach the good water zone at the top of the Chacra Member of the Cliff House Sandstone by displacing the natural formation water.

The upward advance of the injected fluid at any time after injection began can be found from

$$vt = Qt/\phi A$$

where

v = approach velocity, L/T
t = elapsed time since injection began, T
Q = volumetric flow rate, L^3/T
ϕ = porosity, percentage
A = surface area through which flow occurs, L^2

Table 6 shows the upward distance of invasion of injected fluids above the injection zone at the end of the injection period.

Table 6. Reservoir pressures and hydraulic gradients and fluid flow rates.

Radial Distance (ft)	Reservoir Pressure (psi)	Pr Above USDW (ft H2O)	Vertical Gradient (psi/ft)	Vertical Gradient (ft/ft)	Vertical Flow Rate (ft^3/d-ft^2	Mean Pore Velocity (ft/d)	15-Year Fluid Advanc e (ft)
1	1303	465	0.80	1.85	1.85E-05	0.000092	0.51
10	1263	374	0.75	1.73	1.73E-05	0.000086	0.47
100	1224	282	0.70	1.61	1.61E-05	0.00008	0.44
800	1188	199	0.65	1.50	1.50E-05	0.000075	0.41
10000	1144	99	0.59	1.37	1.37E05	0.000068	0.37
INFINITE	1123	50	0.56	1.30	1.30E-05	0.000065	0.36

WATER WELLS

Table 7 lists three wells which were reportedly drilled by the Navaho Tribal Utilities. Recent conversations with Navajo Tribal Utilities Authority personnel indicate they have no knowledge of them. These wells were likely drilled during an exploration program in the 1950's. Their total depths and screened intervals are unknown as are the water quality and the yields of the wells.

Table 7. List of Navajo Tribal Utility Authority wells listed by the State Engineer.

SEO FILE NUMBER	LOCATION*	DEPTH	OWNER
RG-64587	20.03.07.444	Unk	Navajo Tribal Utility (NTUA)
RG-64588	20.03.08.424	Unk	Navajo Tribal Utility (NTUA)
RG-64589	20.03.06.444	Unk	Navajo Tribal Utility (NTUA)

* SEO Locational system.

Table 8 lists other wells and springs found in the files of the U.S. Geological Survey and the New Mexico State Engineer.

Table 8. Wells and springs in the vicinity of the proposed injection well

LOCATION	TYPE	PRODUCING FORMATION	DEPTH	USE	YIELD	SOURCE
20.02.14.3214	Well	Ojo Alamo	65	S	2	USGS
20.02.10.433	Well		150	S		SEO
20.02.16.2144	Well			S	1.3	USGS
20.02.17.1324	Well	Ojo Alamo	240	S		USGS
20.02.19.2131	Well	Ojo Alamo	300	S	20	USGS
20.02.20.11	Well		NWR	S		SEO
20.02.21.220	Spring	Ojo Alamo		S	20	USGS
20.02.23.433	Well		NWR	S		SEO
20.02.31.112	Well		125	S		SEO
20.02.31.2	Well	Ojo Alamo	7	S		USGS
20.02.32.3344	Spring	Ojo Alamo		S	<0.1	USGS
20.02.13.1243	Spring	Ojo Alamo		S	<0.1	USGS
20.02.33.1441	Spring	Ojo Alamo		S	<0.1	USGS
20.03.06	Well		827	S		SEO
20.03.07.44	Well	Allison	794	D?		USGS
20.03.07	Well		758	S		SEO
20.03.08	Well		767	S		SEO
20.03.15.4431	Well	Ojo Alamo	390	S	22	SEO&USGS
20.03.17.223	Well		665	S		SEO
20.03.17.23	Well		1030	O&G		SEO
20.03.17.4444	Well	Alluvium	73	S	75	USGS
20.03.36.411	Well		NWR	S		SEO
21.02.09.124	Well	San Jose		S		USGS
21.02.17.441	Well		600	S		SEO
21.02.17.441	Well		406	S		SEO
21.02.17.444	Well	San Jose	340	S		USGS
21.02.28.142	Well		NWR	C		SEO
21.02.35.	Well		545	S		SEO

S = stock well, O&G = oil and gas drilling water supply, C = construction, D = domestic

The nearest well to the proposed injection well is the well at 20.02.17.1324. The well is reported to be 240 ft deep and producing from the Ojo Alamo Sandstone. The water produced by the well contains 760 mg/l of sulphate. Though it is an aesthetic standard, the sulphate drinking water standard is 250 mg/l. All other water wells are more than two (2) miles from the proposed injection well.

The well at 20.03.07.44 is probably the NTUA well RG-64587. It produces from the Allison Member of the Menefee Formation. The ground water has an electrical conductivity of 28,400 micromhos per centimeter. This is equivalent to a total dissolved solids concentration of about 19,312 mg/l. The well is six (6) miles west of the proposed injection well. It is likely that the NTUA carried out a ground-water exploration program in the 1950's. NTUA officials have no present recollection of wells in this area of the San Juan Basin.

Well 20.02.28.142 was drilled for highway construction purposes. Well 21.02.35 was drilled for water for oil and gas drilling. The remainder of the wells are most likely stock wells.

Most wells are shallow stock wells. The deepest well was drilled to 1,030 ft as a source of water for oil and gas drilling. Well yields are commonly only several gallons per minute. The shallow depths of the wells and their water quality suggest that it is economically impractical to drill deep domestic water supply wells in the area.

The Cuba water supply wells are about eight (8) miles north of the Johnson 7-11. The Cuba water supply wells likely obtain their water from the Cuba Mesa Member of the Nacimiento Formation which is not present at the location of the proposed injection well.

A search was conducted of the U.S. EPA STORET water quality database for a large area around the proposed injection well and no chemical analyses were found for ground water.

OIL AND GAS WELLS

A search of the Petroleum Information System data base was conducted to determine the number of well that have been drilled for oil and gas within six (6) miles of the proposed injection well. The PI search identified 94 oil and gas wells. The results of the search are in Appendix 2.

The search was further refined to determine the main production zones within the wells. The Mancos Shale and Gallup Sandstone are the major producing zones. One well was completed as a Dakota producer and one and a Menefee Producer.

The results of this survey indicate that no wells were completed in any USDW and there is no possibility for inside-the-casing uphole flow into the potential USDWs. If all wells were cemented in place, as is the practice, there should be no behind the pipe flow either.

Of the 94 wells identified, 40 have been abandoned.

WELL CONSTRUCTION COSTS

The depth to the Cliff House is about 1,657 ft bgl. Drilling equipment capable of drilling a water well to the Cliff House will require a 12-inch borehole. Experience in the area and elsewhere in New Mexico suggests that the well will be cased with 8-inch steel casing. The author has recently drilled a 1,000 foot well near Taos for a cost of about $35,000 or $35/ft. The larger equipment necessary to drill a deeper hole should boost drilling costs.

We obtained drilling costs including mobilization and demobilization costs for wells ranging in depth from 1,670 ft to 2,624 ft from Stewart Brothers Drilling Company in Grants, New Mexico. Stewart Brothers has extensive experience in drilling in this area. Their estimated drilling cost for these wells is about $92/ft. Therefore, a well to 1,670 feet will cost about $162,000 including tax. A well constructed to 2,624 ft will cost about $255,000 including tax. Pumping and surface equipment including power lines is not included.

If the well is intended as a municipal supply well, to the cost of the well should be added the cost of any pipeline to move the water to Cuba, the nearest community. Six-inch buried PVC water line will cost about $10/ft to install. Cuba is about 10 miles to the northeast and water line costs will be about $528,000.

We regard the construction of a well for a domestic supply as economically impractical. We regard the expenditure of at least $150,000 for a well in this area as speculative because of low and unknown well yield and unknown water quality.

Poor quality water would require treatment and we regard this as technologically difficult and economically impractical for the small community of Cuba.

DISCUSSION

There is very slow natural ground-water flow from the Menefee upward toward the Cliff House Sandstone. The injection well will increase pressure and the rate of ground-water flow vertically upward. Because the vertical hydraulic conductivity of the shale and sandstone above the injection zone is extremely low, the rate of upward migration of injected fluids will be very low. The zone of invasion above the injected zone will be very small.

The volume of fluid invasion into the rock units overlying the injection zone is small compared to the amount of fluid that must be displaced before injected fluids could reach the overlying zone of better quality water. Cessation of injection in 15 years will reduce the vertical hydraulic gradient. Dissipation of pressure in the injection zone will return hydraulic gradients to normal in about 30 years.

The low vertical hydraulic conductivity and computations carried out in this report make the Menefee shale an effective confining bed as defined in 40 CFR § 146.3.

CONCLUSIONS

In conclusion, we may say that

1. The Menefee Formation contains producible oil and gas and is an exempt aquifer pursuant to 40 CFR § 146.4(b)(1)(a).

2. The Menefee Formation and the Cliff House Sandstone are not aquifers pursuant to 40 CFR § 146.3 because they can not produce ***significant*** quantities of water.

3. The first sand above the Menefee Formation containing water of 3,000 mg/l and the Menefee Formation are not now sources of drinking water in the area and are unlikely to become drinking water sources because the depth of the water zones and the variable quality of the water make it economically and technologically impractical to obtain water from these zones.

4. All Late Cretaceous rock stratigraphic units within six (6) miles of the proposed injection well may be considered as confining zones with vertical components of hydraulic conductivity less than 1E-06 cm/s.

5. The location of the proposed injection well is distant from Cuba making it unlikely that it will ever be used as a drinking water source.

6. Though the total dissolved solids concentration of water in the Menefee Formation is less than 10,000 mg/l, the water exceeds federal and state drinking water standards for chloride and barium. It is economically and technologically impractical to treat this water for human consumption.

7. The shale of the Menefee Formation is an effective confining zone as defined in 40 CFR § 146.3 that is capable of limiting fluid movement above the injection zone.

8. Water wells within six (6) miles of the proposed injection well do not penetrate any USDW that may be affected by disposal operations.

9. Oil and gas wells within six (6) miles of the proposed injection well are cemented across all USDWs.

RECOMMENDATIONS

Based on our exhaustive technical analysis we conclude that there is no danger to underground sources of drinking water and that the Menefee Formation should be classified as an exempt aquifer pursuant to 40 CFR § 144.8.

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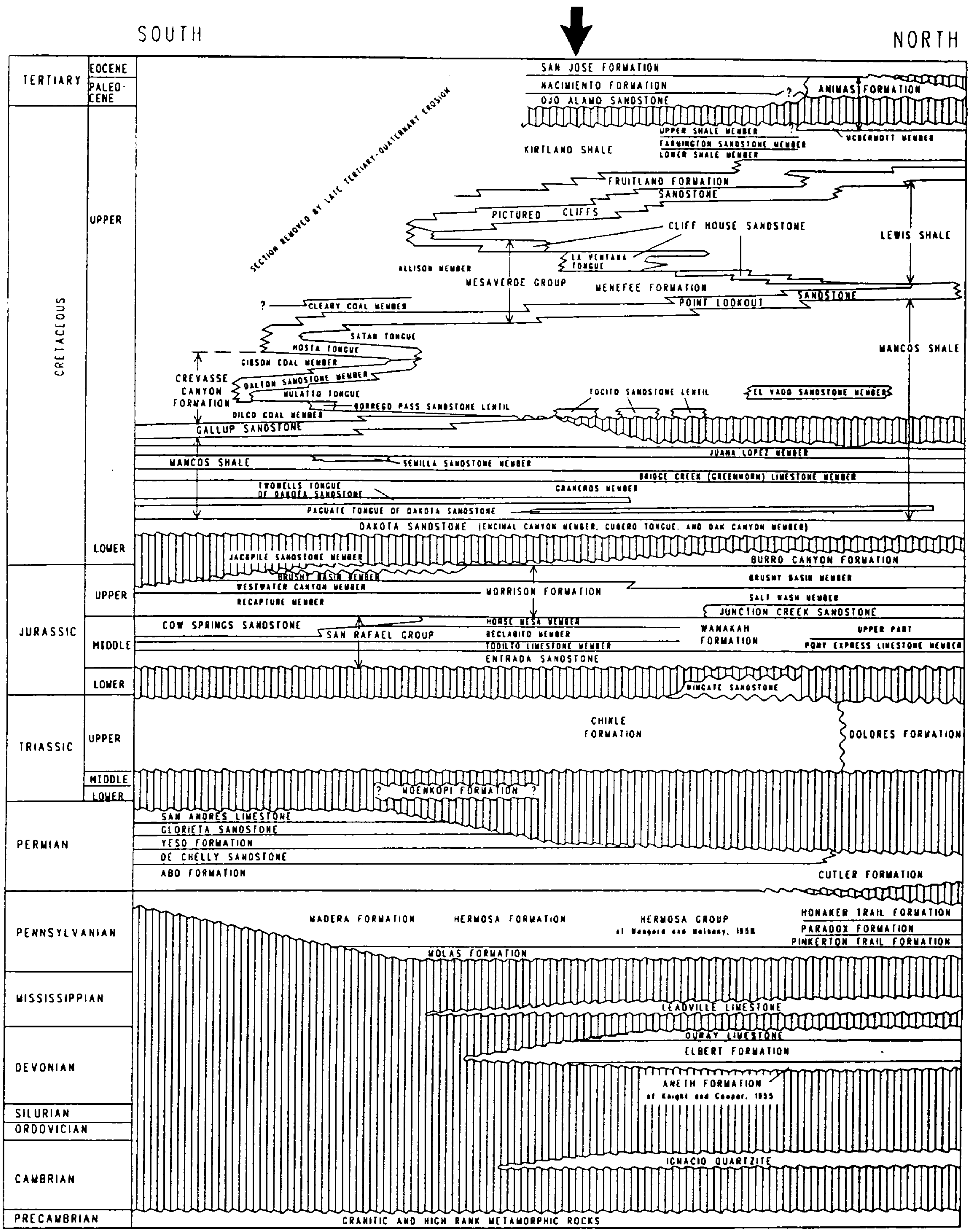
APPENDIX 1

FIGURES



(Modified from Molenaar, 1977a,b, and 1989)

Figure 5.--Time- and rock-stratigraphic framework and nomenclature.

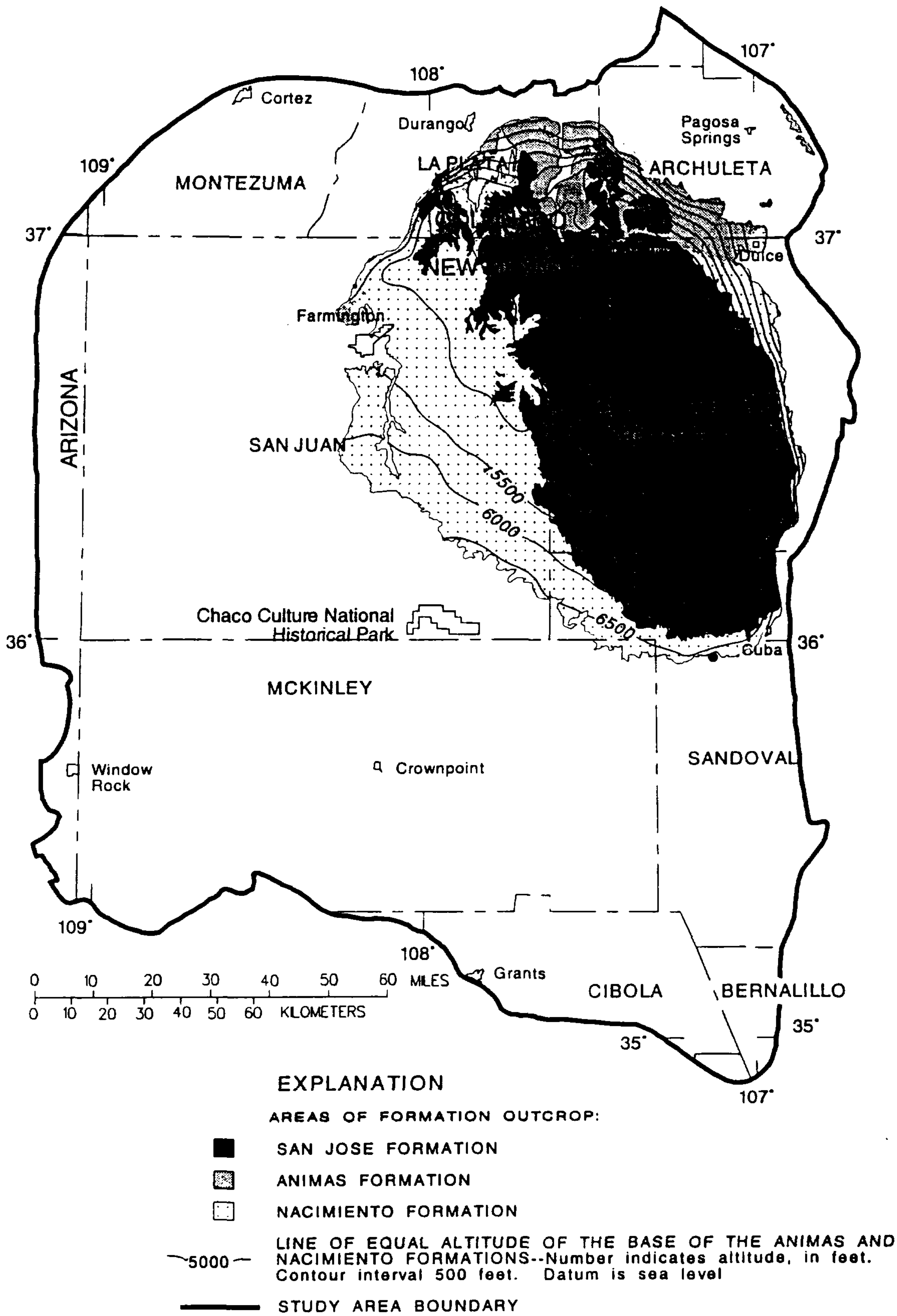
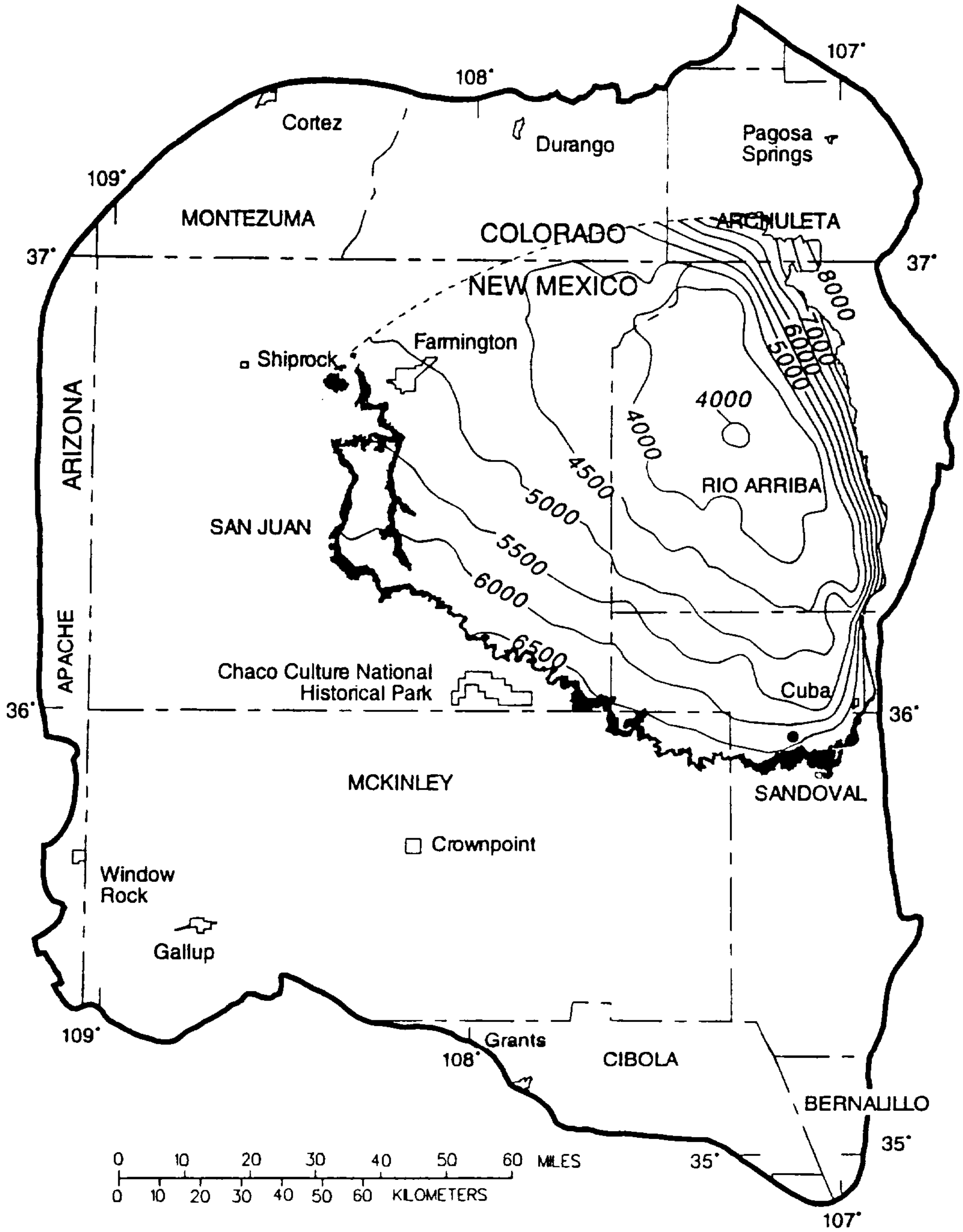


Figure 13.--Approximate altitude and configuration of the base of the Animas and Nacimiento Formations.



EXPLANATION

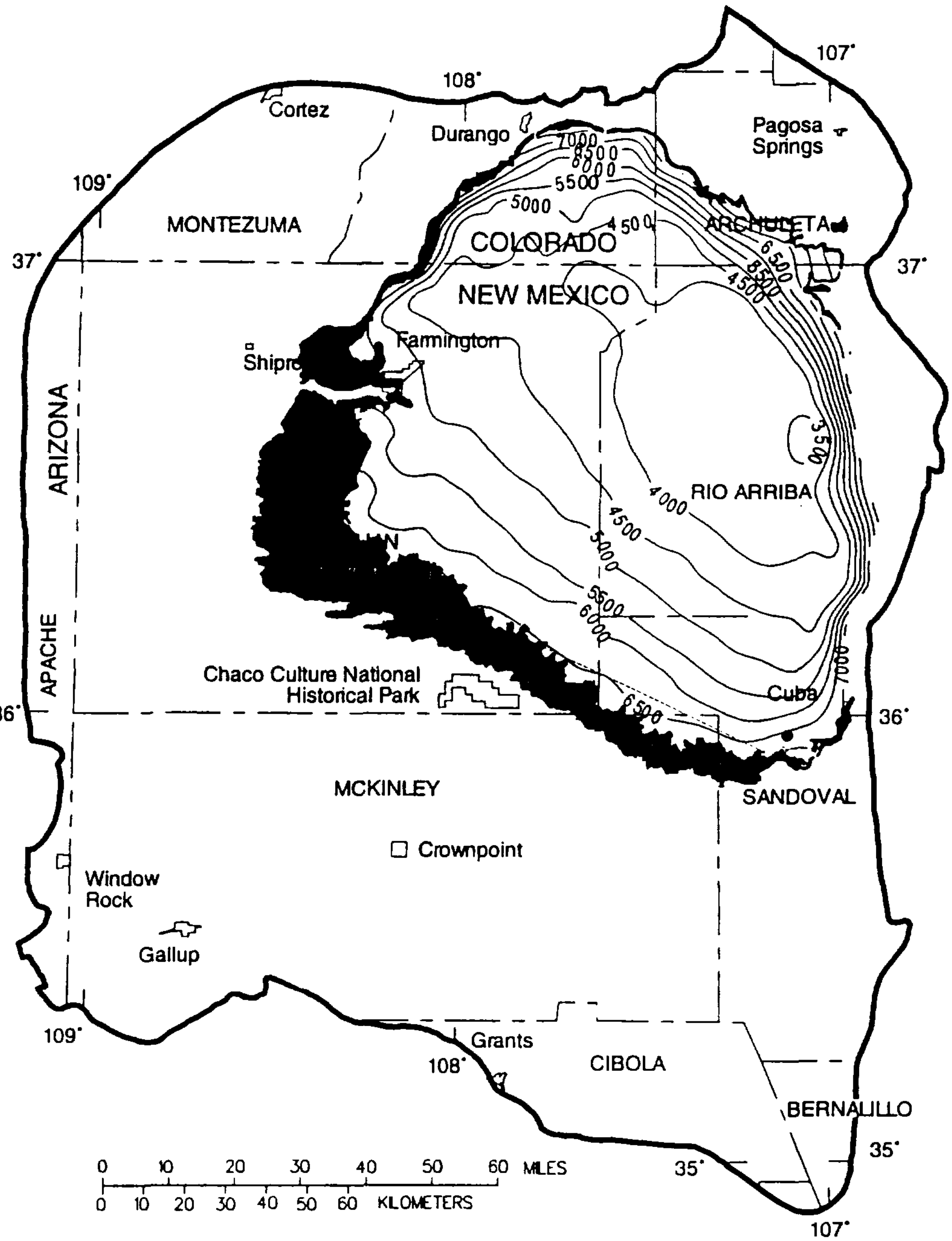
OUTCROP OF OJO ALAMO SANDSTONE

APPROXIMATE NORTHERN SUBSURFACE EXTENT OF THE OJO ALAMO SANDSTONE

6500 — LINE OF EQUAL ALTITUDE OF THE TOP OF THE OJO ALAMO SANDSTONE--Number indicates altitude, in feet. Contour interval 500 feet. Datum is sea level

STUDY AREA BOUNDARY

Figure 15.--Approximate altitude and configuration of the top of the Ojo Alamo Sandstone.



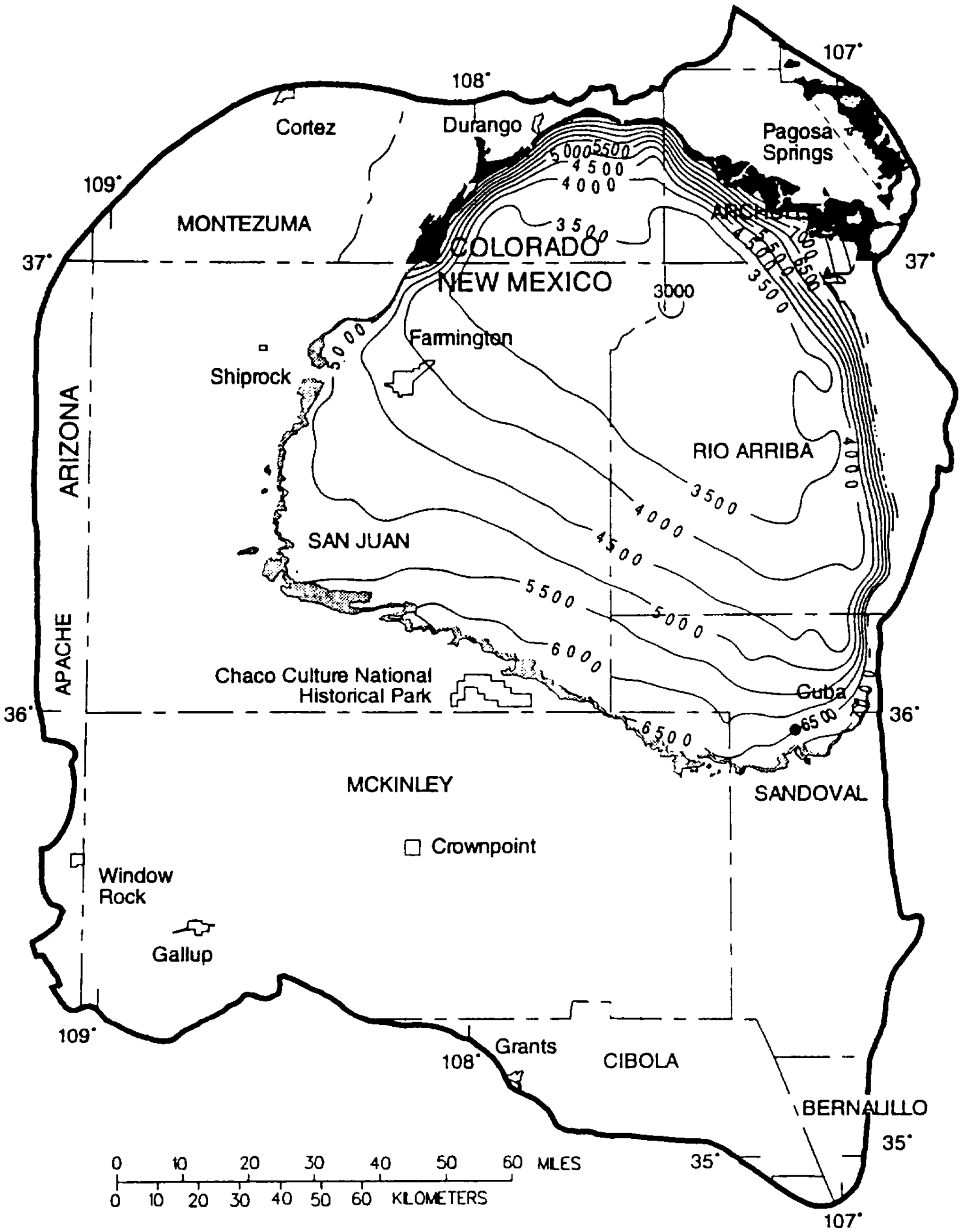
EXPLANATION

OUTCROP OF KIRTLAND SHALE AND FRUITLAND FORMATION

4000 — LINE OF EQUAL ALTITUDE OF THE TOP OF THE KIRTLAND SHALE--Number indicates altitude, in feet. Contour interval 500 feet. Datum is sea level

STUDY AREA BOUNDARY

Figure 17.--Approximate altitude and configuration of the top of the Kirtland Shale.



EXPLANATION

AREAS OF FORMATION OUTCROP:

PICTURED CLIFFS SANDSTONE

PICTURED CLIFFS SANDSTONE AND LEWIS SHALE, UNDIVIDED

—6500— LINE OF EQUAL ALTITUDE OF THE TOP OF THE PICTURED CLIFFS SANDSTONE--Number indicates altitude, in feet. Contour interval 500 feet. Datum is sea level

STUDY AREA BOUNDARY

Figure 18.--Approximate altitude and configuration of the top of the Pictured Cliffs Sandstone.

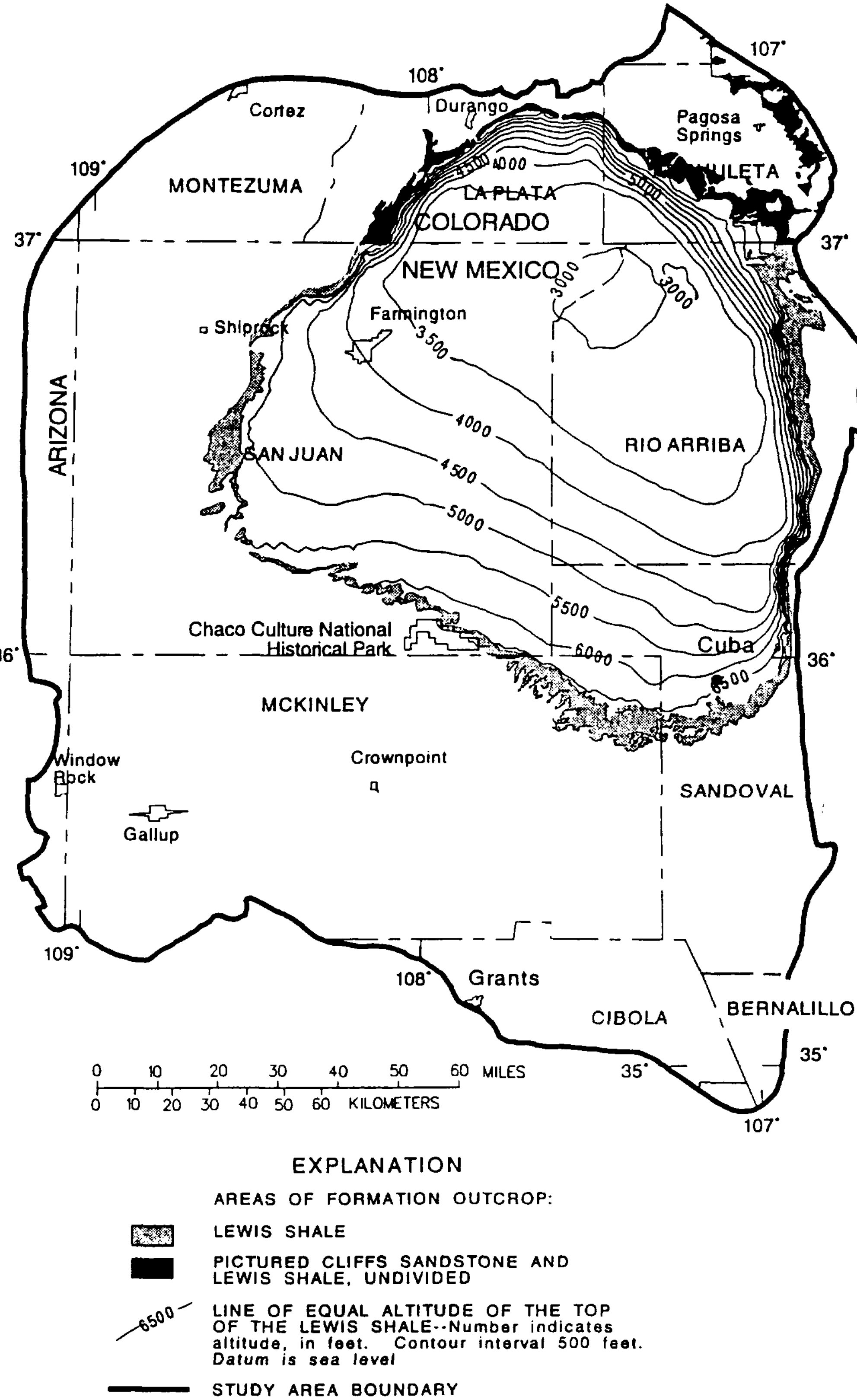
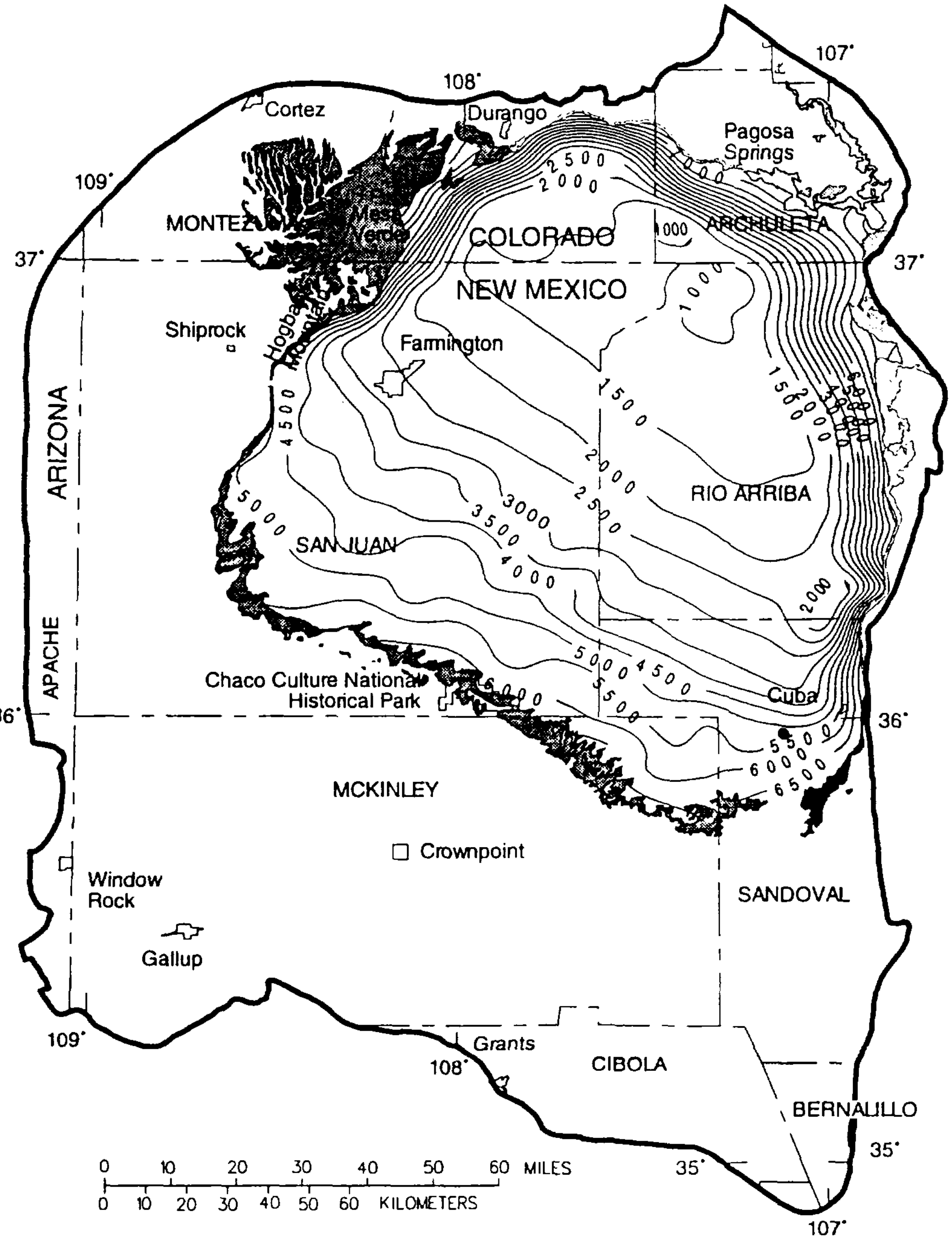


Figure 19.--Approximate altitude and configuration of the top of the Lewis Shale.



EXPLANATION

AREAS OF FORMATION OUTCROP:

CLIFF HOUSE SANDSTONE

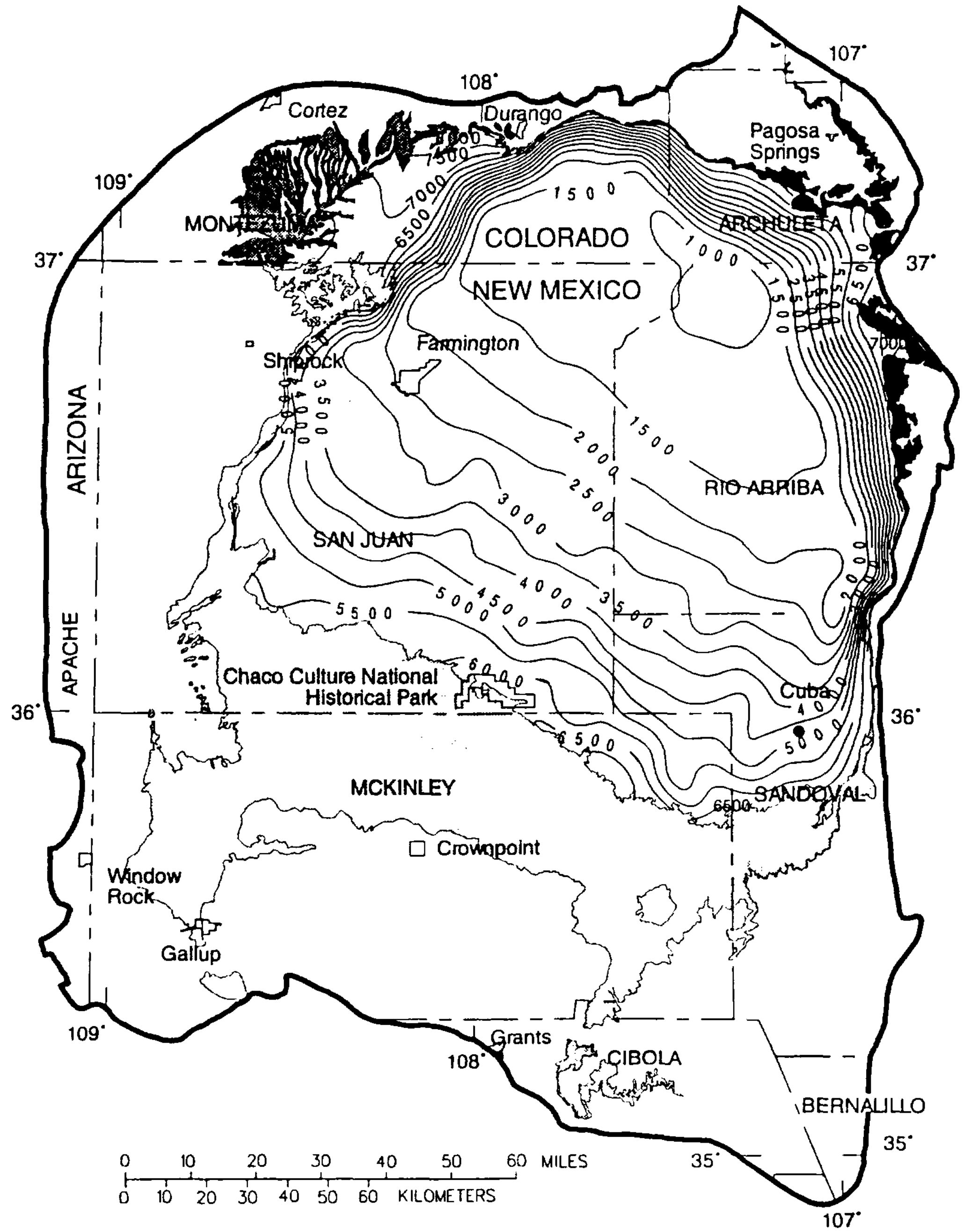
LA VENTANA TONGUE OF CLIFF HOUSE SANDSTONE

MESAVERDE GROUP, UNDIVIDED--Includes Cliff House Sandstone

6500 — LINE OF EQUAL ALTITUDE OF THE TOP OF THE CLIFF HOUSE SANDSTONE, LA VENTANA TONGUE, AND MESAVERDE GROUP--Number indicates altitude, in feet. Contour interval 500 feet. Datum is sea level

STUDY AREA BOUNDARY

Figure 20.--Approximate altitude and configuration of the top of the Cliff House Sandstone.



EXPLANATION

AREAS OF FORMATION OUTCROP:

MENEFEE FORMATION

MENEFEE FORMATION AND POINT LOOKOUT SANDSTONE

MESAVERDE GROUP, UNDIVIDED--Includes Menefee Formation

6500 LINE OF EQUAL ALTITUDE OF THE TOP OF THE MENEFEE FORMATION, POINT LOOKOUT SANDSTONE, AND MESAVERDE GROUP--*Number indicates altitude, in feet. Contour interval 500 feet. Datum is sea level*

STUDY AREA BOUNDARY

Figure 21.--Approximate altitude and configuration of the top of the Menefee Formation.

EXPLANATION

AQUIFER

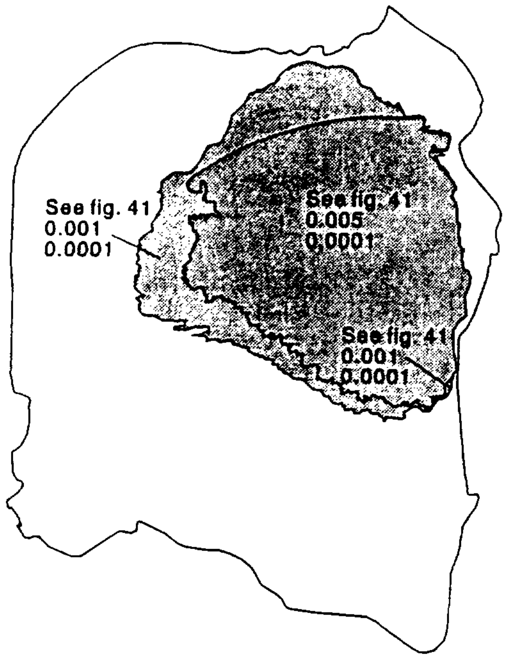
CONFINING UNIT

NOT SIMULATED

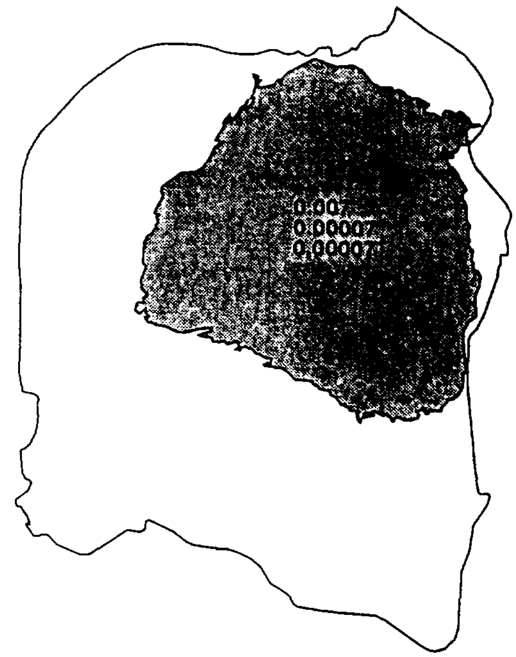
VK-Implicitly simulated using a computed vertical harmonic leakance

HYDROSTRATIGRAPHIC UNIT	LAYER
San Jose Formation	1
Animas and Nacimiento Formations	2
Ojo Alamo Sandstone	3
Kirtland Shale	3
Fruitland Formation	3
Pictured Cliffs Sandstone	4
Lewis Shale	5
Cliff House Sandstone and La Ventana Tongue	6
Menefee Formation	7
Point Lookout Sandstone	8
Hosta Tongue	VK
Crevasse Canyon Formation	VK
Upper Mancos Shale	VK
Gallup Sandstone / **Mancos Shale**	9
Lower Mancos Shale	VK
Dakota Sandstone	10
Morrison Formation	11
Wanakah Formation	VK
Entrada Sandstone	12
Chinle Formation	

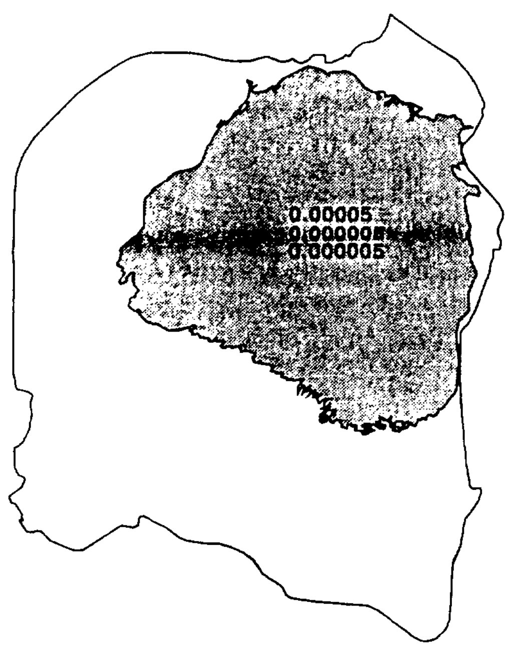
Figure 36.--Correlation of geologic units and model layers.



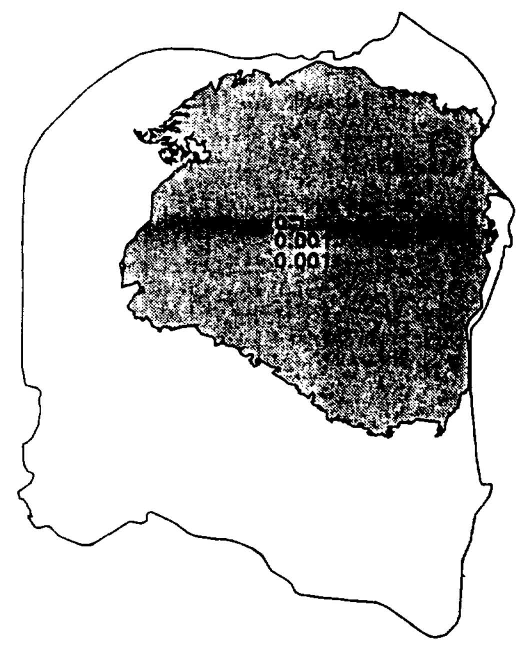
C. Simulated vertical hydraulic conductivities for the *combined Ojo Alamo Sandstone*, Kirtland Shale, and Fruitland Formation.



D. Simulated horizontal and vertical hydraulic conductivities for the Pictured Cliffs Sandstone.

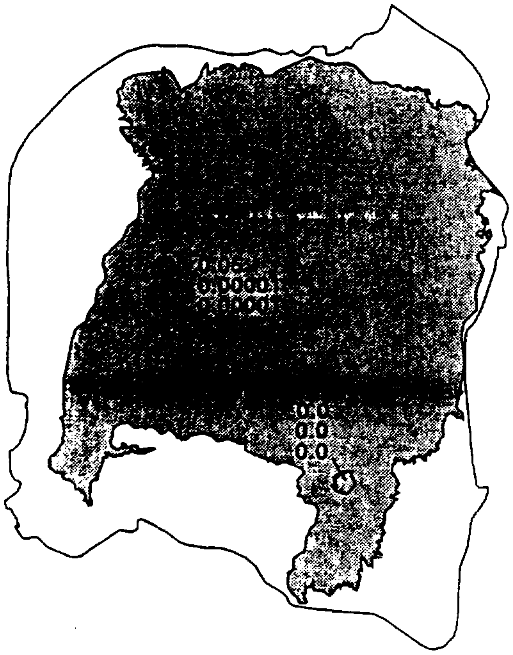


E. Simulated horizontal and vertical hydraulic conductivities for the Lewis Shale.

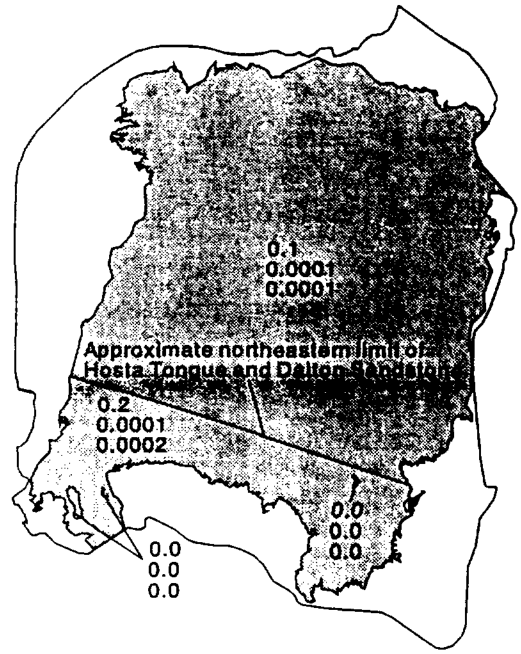


F. Simulated horizontal and vertical hydraulic conductivities for the Cliff House Sandstone.

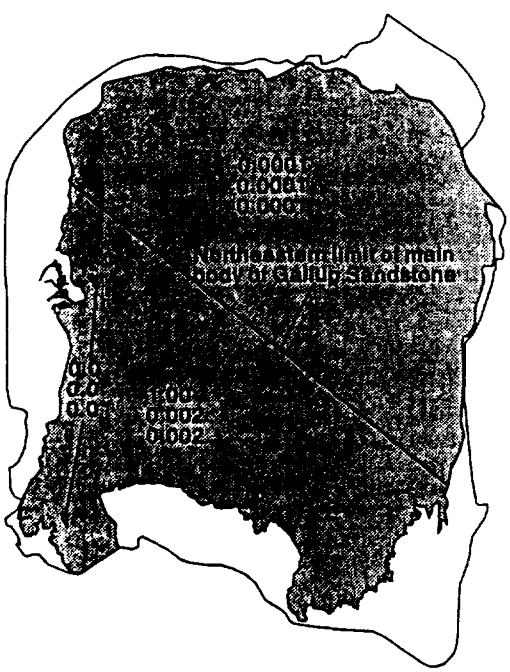
Figure 40.--Simulated horizontal and vertical hydraulic conductivities--Continued.



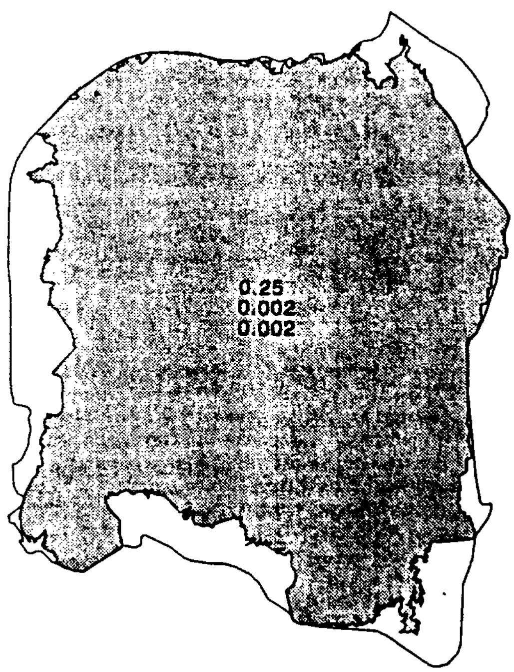
G. Simulated horizontal and vertical hydraulic conductivities for the Menefee Shale.



H. Simulated horizontal and vertical hydraulic conductivities for the Point Lookout Sandstone.

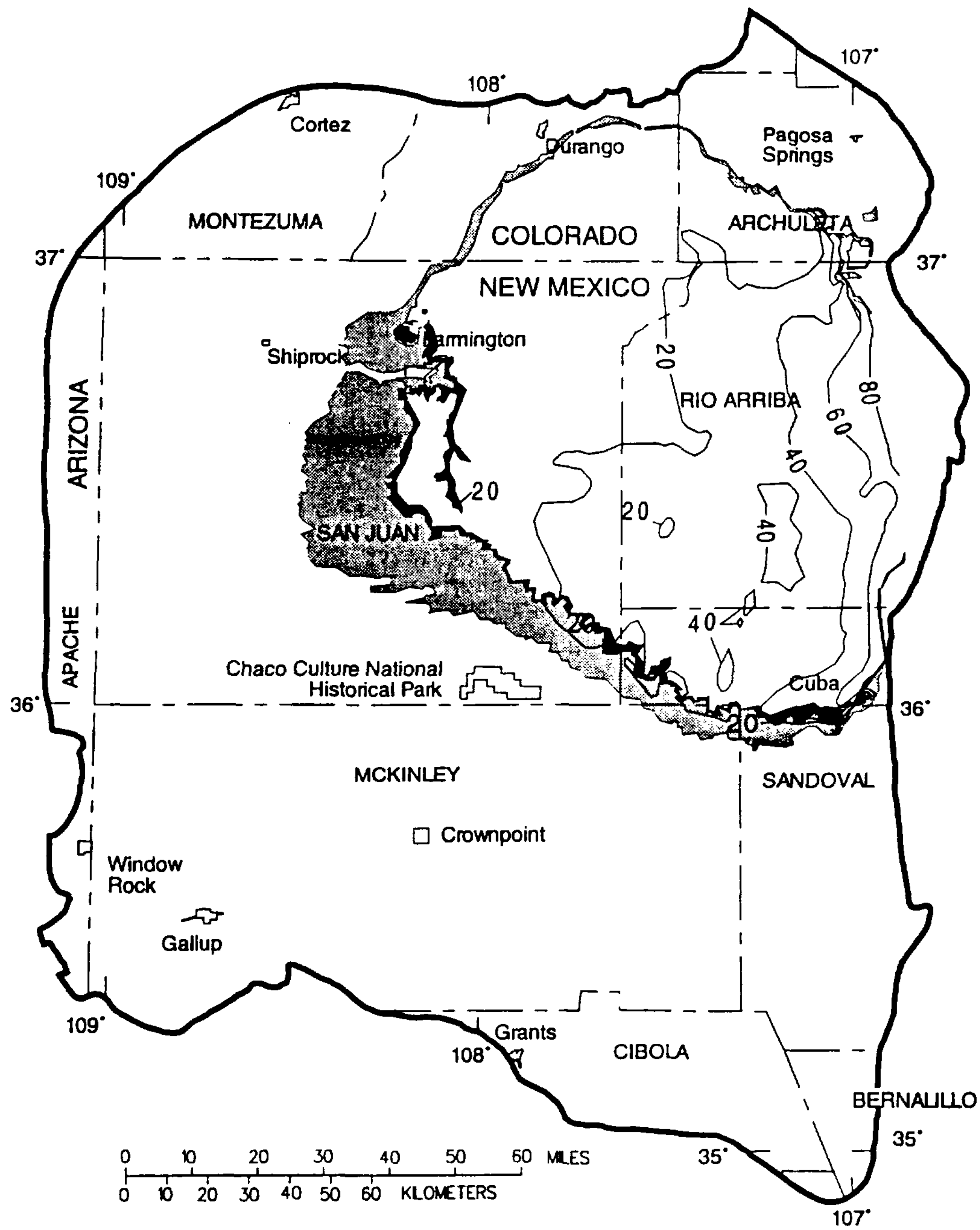


I. Simulated horizontal and vertical hydraulic conductivities for the Gallup Sandstone and Mancos Shale.



J. Simulated horizontal and vertical hydraulic conductivities for the Dakota Sandstone.

Figure 40.--Simulated horizontal and vertical hydraulic conductivities--Continued.



EXPLANATION

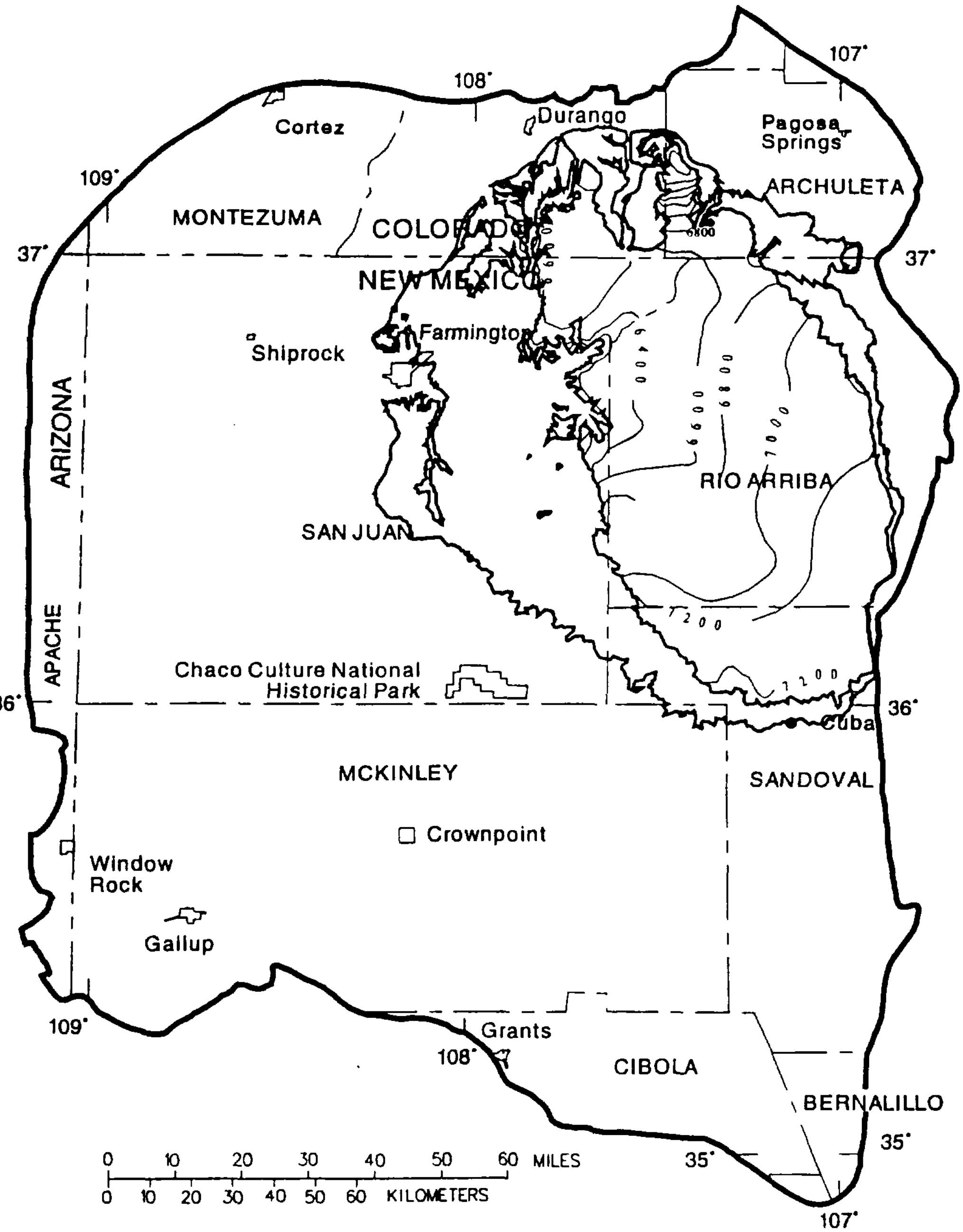
OUTCROP OF THE OJO ALAMO SANDSTONE

OUTCROP OF THE COMBINED KIRTLAND SHALE AND FRUITLAND FORMATION

40 LINE OF EQUAL HYDRAULIC CONDUCTIVITY--Number indicates hydraulic conductivity, in feet per day times 10^2

STUDY AREA BOUNDARY

Figure 41.--Simulated horizontal hydraulic conductivity for the combined Ojo Alamo Sandstone, Kirtland Shale, and Fruitland Formation.



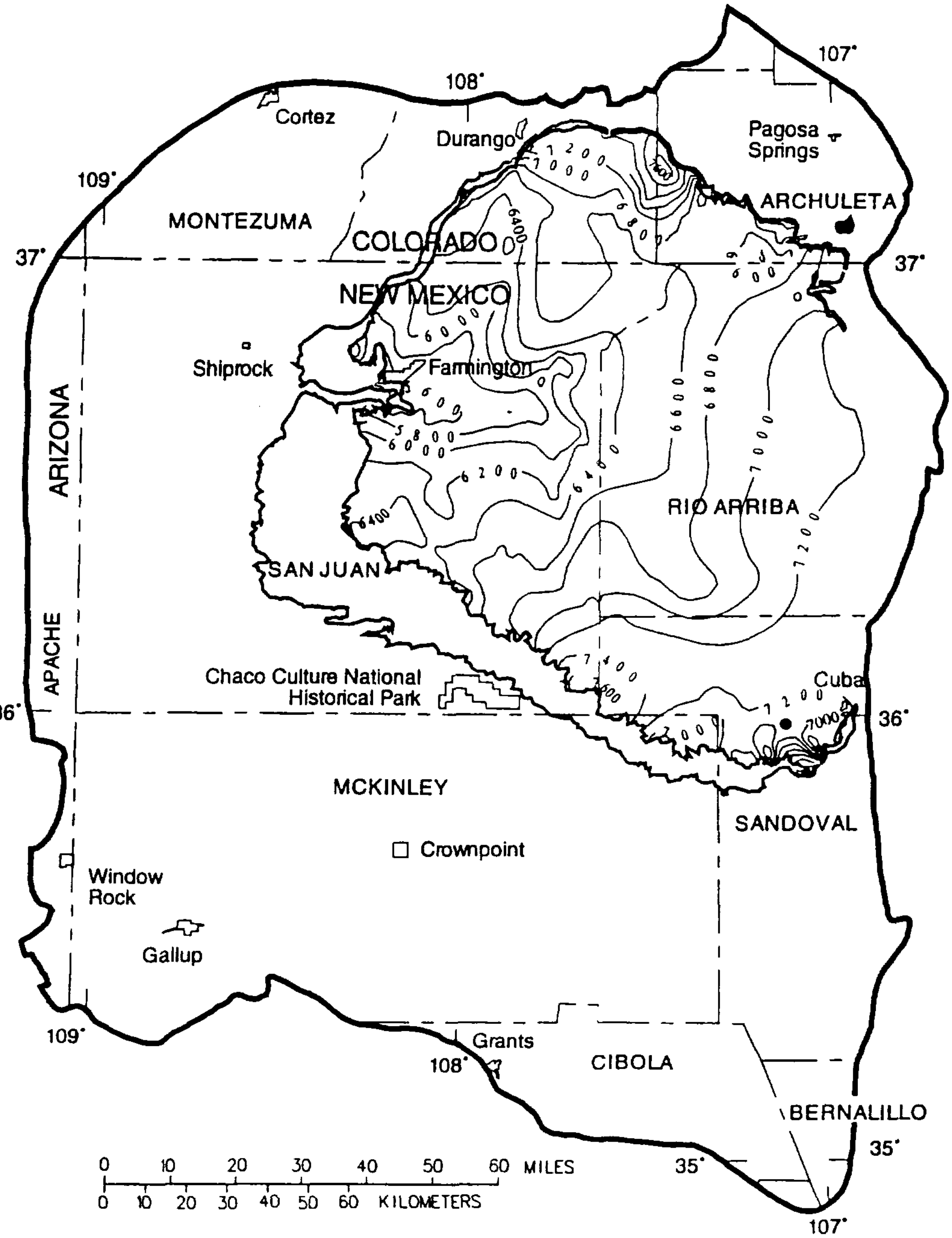
EXPLANATION

EXTENT OF THE ANIMAS AND NACIMIENTO FORMATIONS

7200 — LINE OF EQUAL COMPUTED STEADY-STATE HEAD--Number indicates altitude of head, in feet above sea level. Contour interval 200 feet

STUDY AREA BOUNDARY

Figure 44.--Computed steady-state head in the Animas and Nacimiento Formations.



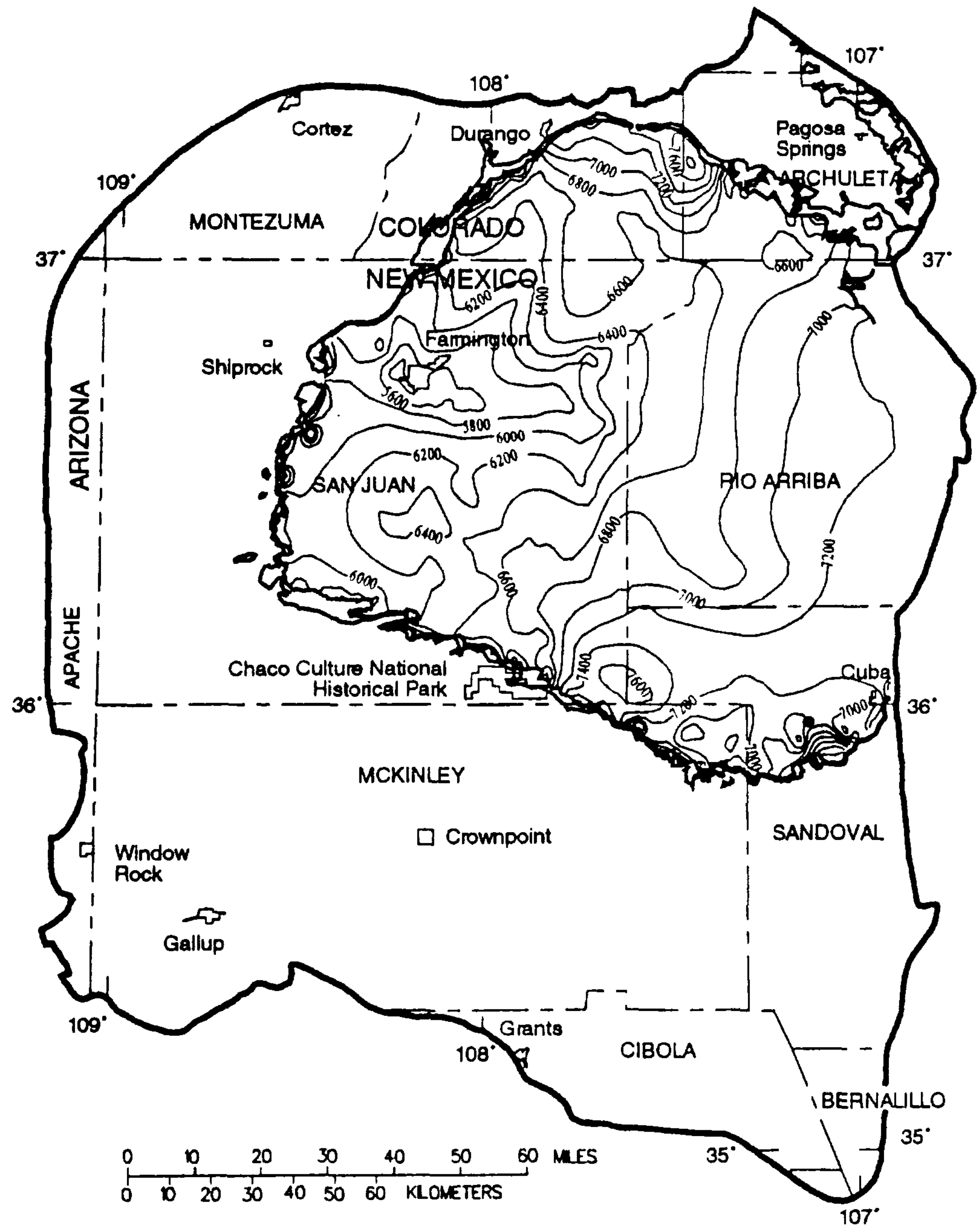
EXPLANATION

EXTENT OF THE COMBINED OJO ALAMO SANDSTONE, KIRTLAND SHALE, AND FRUITLAND FORMATION

7000 LINE OF EQUAL COMPUTED STEADY-STATE HEAD--Number indicates altitude of head, in feet above sea level. Contour interval 200 feet

STUDY AREA BOUNDARY

Figure 45.--Computed steady-state head in the combined Ojo Alamo Sandstone, Kirtland Shale, and Fruitland Formation.



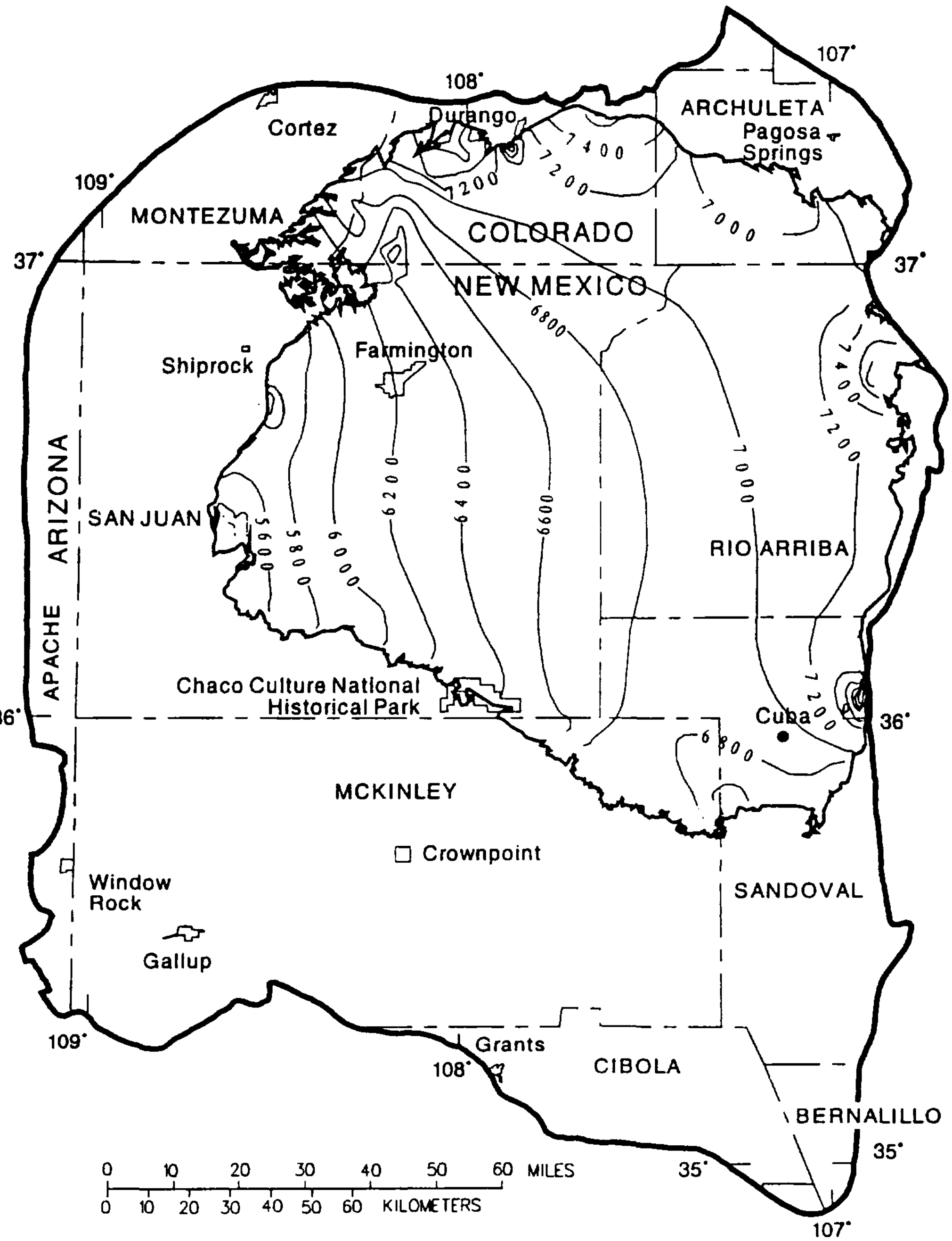
EXPLANATION

EXTENT OF THE PICTURED CLIFFS SANDSTONE

7000 LINE OF EQUAL COMPUTED STEADY-STATE HEAD--Number indicates altitude of head, in feet above sea level. Contour interval 200 feet

STUDY AREA BOUNDARY

Figure 46.--Computed steady-state head in the Pictured Cliffs Sandstone.



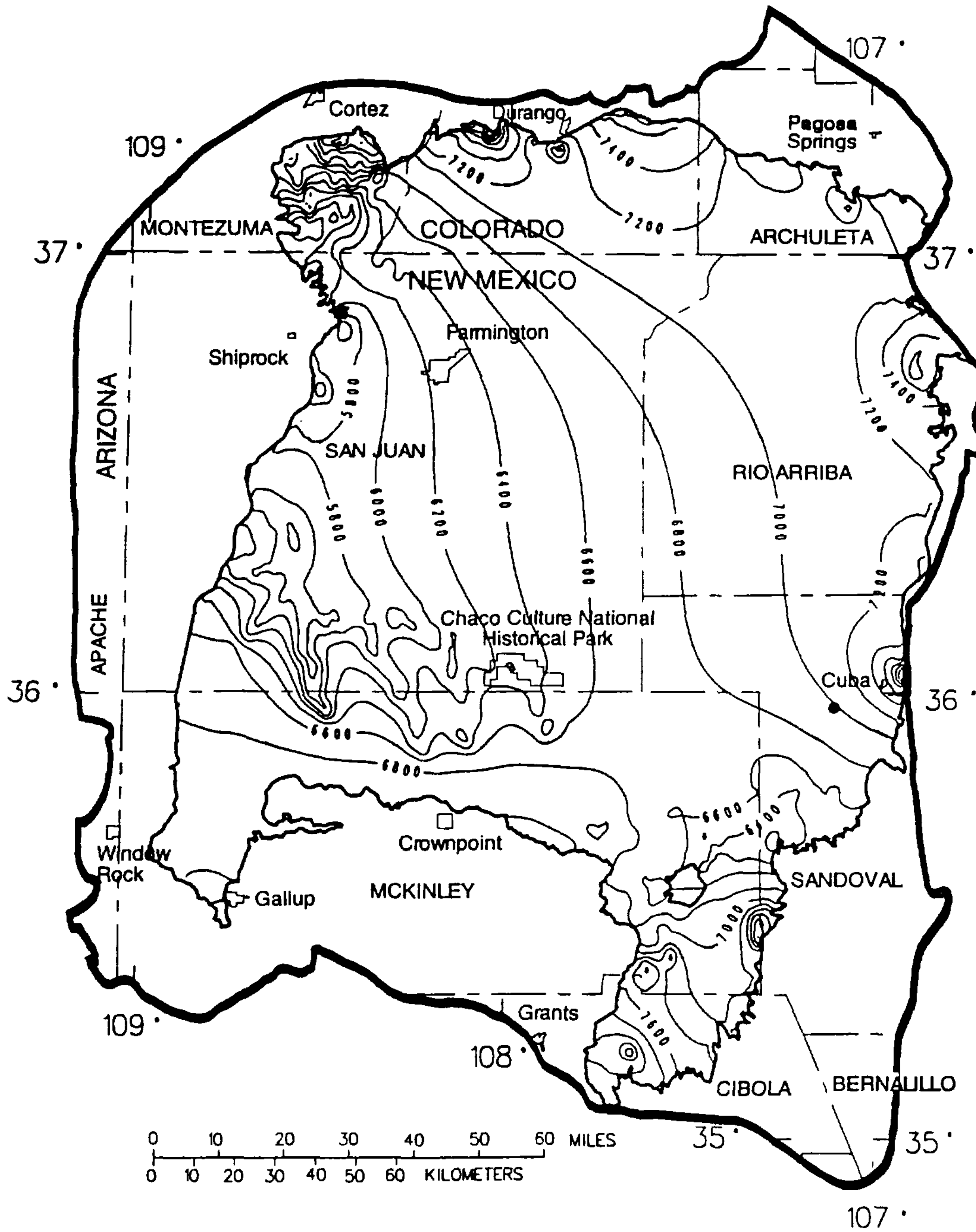
EXPLANATION

EXTENT OF THE CLIFF HOUSE SANDSTONE

6800 LINE OF EQUAL COMPUTED STEADY-STATE HEAD--Number indicates altitude of head, in feet above sea level. Contour interval 200 feet

STUDY AREA BOUNDARY

Figure 47.--Computed steady-state head in the Cliff House Sandstone.



EXPLANATION

EXTENT OF THE MENEFEE FORMATION

7600 LINE OF EQUAL COMPUTED STEADY-STATE HEAD--Number indicates altitude of head, in feet above sea level. Contour interval 200 feet

STUDY AREA BOUNDARY

Figure 48.--Computed steady-state head in the Menefee Formation.

APPENDIX 2

RESULTS OF PETROLEUM INFORMFORMATION SERVICES SEARCH