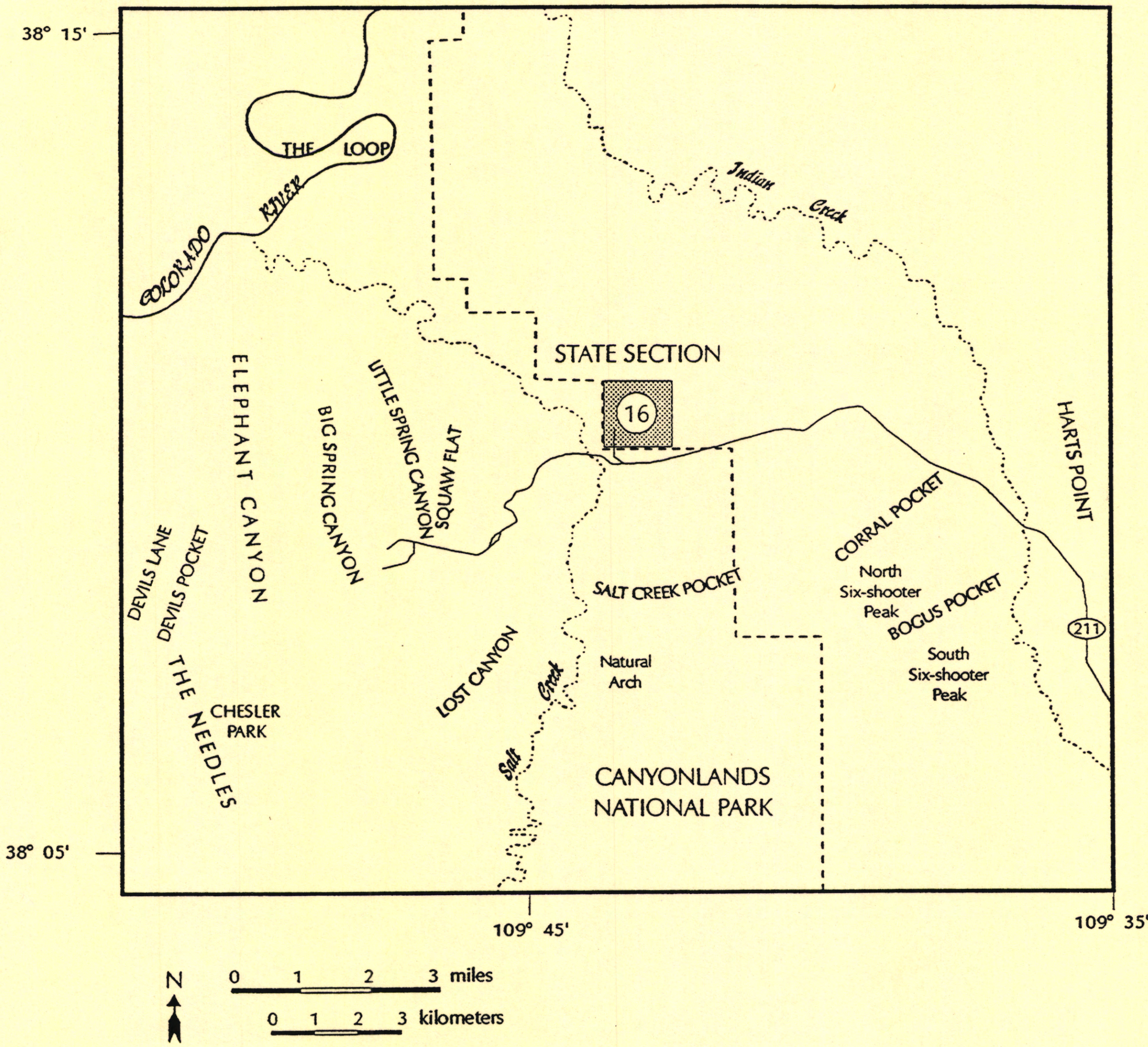
POTENTIAL FOR POTABLE GROUND WATER ON STATE LAND NEAR CANYONLANDS NATIONAL PARK, UTAH SECTION 16, T. 30 S., R. 20 E.

by
Charles E. Bishop
Utah Geological Survey



Report of Investigation 230 May 1996
UTAH GEOLOGICAL SURVEY
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ABSTRACT

This study evaluates the potential of finding potable ground water in a section of state land near Canyonlands National Park, Utah. Pennsylvanian and Permian sedimentary rocks with variable hydraulic properties are possible aquifers in the area. These rocks dip gently toward the east-northeast, but are folded and faulted due to salt flowage and dissolution. The Permian Cedar Mesa Sandstone of the Cutler Group is the major water-bearing rock in the Canyonlands area. The potential for developing ground water in other rocks is low; water is present but quality varies widely and deteriorates with depth.

This investigation indicates that the Cedar Mesa Sandstone is the most likely aquifer in the state section, but the potential for finding a significant supply of high-quality ground water is low. Recharge to this aquifer is principally from local precipitation and possibly from Indian and Salt Creeks. Well yields from shallow aquifers in the Cedar Mesa Sandstone would probably be low, and the quality of water is likely poor. The risk of failure in drilling a water well anywhere in section 16 is high.

INTRODUCTION

Purpose and scope

In response to a request from Kevin S. Carter, Deputy Director, Utah School and Institutional Trust Lands Administration (Trust Lands), I conducted this study of a section of state land (section 16, T. 30 S., R. 20 E., Salt Lake Baseline and Meridian) in San Juan County, Utah (figure 1). Trust Lands presently leases land on section 16 to the Needles Outpost (a small retail outlet), and wishes to develop the leases to their highest potential. A potable water supply would allow additional development on the leases. Previous attempts to find water in section 16 have failed; water is purchased from the National Park Service at the Canyonlands visitor center and hauled to the Needles Outpost. Trust Lands needs a potable ground-water supply to increase the value of its leases on section 16. This investigation evaluates ground-water conditions and assesses the potential for obtaining a high-quality supply of ground water from section 16. The scope of this investigation consisted of a literature review, and field reconnaissance on February 20-21, 1996. Because of the lack of data specific to section 16, I used regional data to prepare this report and present no detailed hydrogeologic maps. Without additional new data, conclusions in this report should be considered preliminary.

Setting

Section 16 is along Utah Highway 211, about 1 mile (1.6 km) east of the Squaw Flat visitor center in Canyonlands National Park. The area is in the Inner Canyonlands section of the Colorado Plateau physiographic province (Stokes, 1977). Elevations in the region range from less than 4,000 feet (1,219 m) in the Colorado River canyon to over 6,000 feet (1,829 m) at Harts

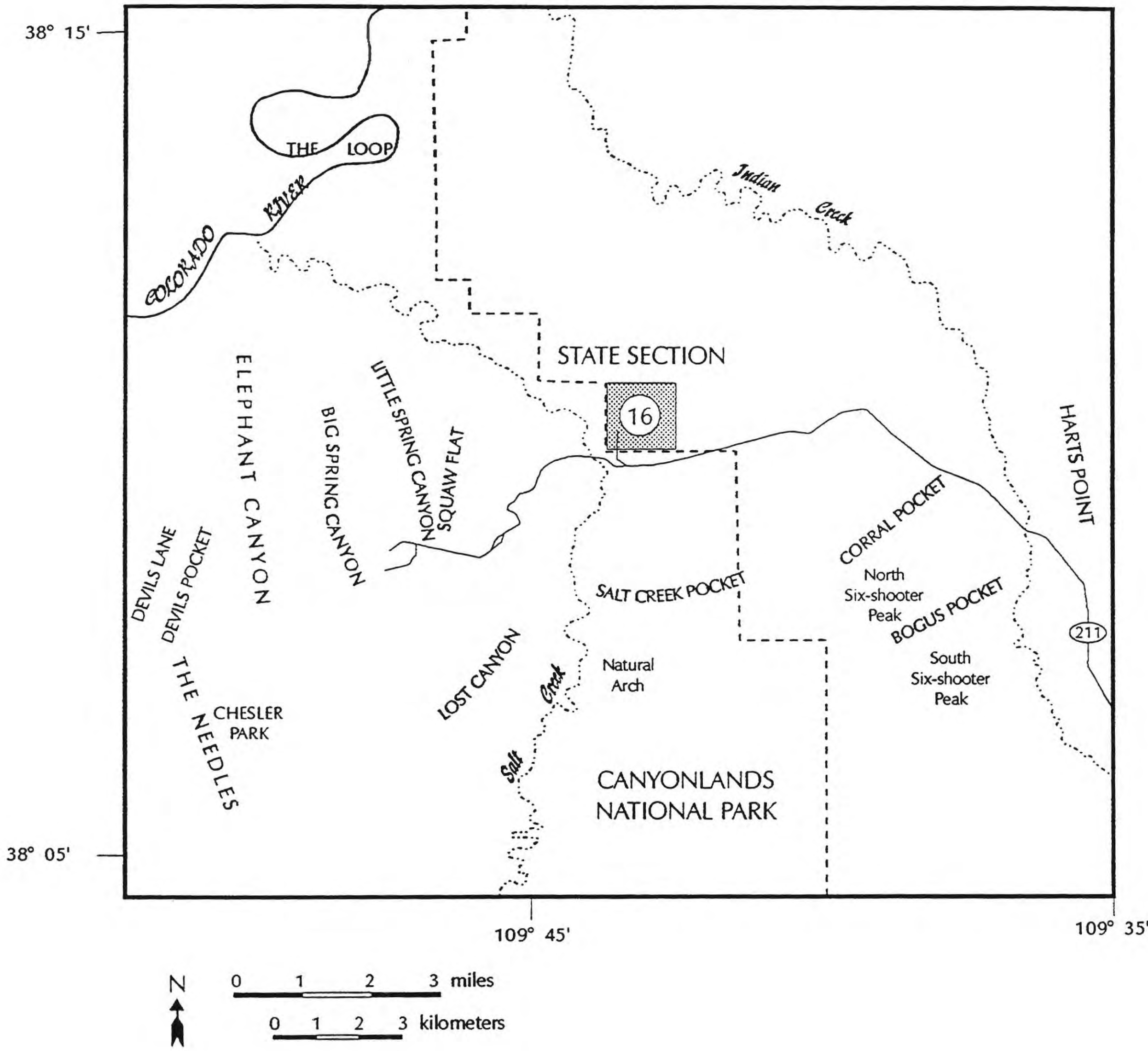


Figure 1. Study area showing locations of features discussed in text.

Point (figure 1). The Canyonlands region consists of high mesas with vertical cliff faces, steep talus slopes, flat benches, and deep canyons with entrenched meanders. Warm summers, cold winters, and low year-round precipitation characterize the climate. The amount of precipitation is lowest in the fall and highest in winter and spring. Figure 2 shows the average annual precipitation for parts of southeastern Utah (Woodward-Clyde Consultants, 1982a). Elevations within section 16 are between 4,900 and 5,150 feet (1,494-1,570 m), and the average annual precipitation is approximately 8 inches (20 cm).

The Colorado River, the major drainage of the Colorado Plateau, flows in a deep, incised canyon west of section 16. The Colorado River and its larger tributaries are perennial, but smaller tributaries are intermittent. Indian Creek, a perennial tributary to the Colorado River, drains most of the eastern and northern parts of the region and the nearby Abajo Mountains. Salt Creek, which drains section 16 and areas to the south and west, is also a tributary of the Colorado River. The upper reaches of Salt Creek are perennial, but it is intermittent near section 16 and rarely contains water.

GENERAL GEOLOGY

The rock unit exposed in the area is the Permian Cutler Group. Pennsylvanian Hermosa Group underlies the Cutler Group, and locally thin, unconsolidated Quaternary surficial deposits overlie it. Figure 3 shows the stratigraphic column of this region's dominantly carbonate and clastic rocks. Because Quaternary deposits are discontinuous and thin, they are not shown in figure 3. Pre-Hermosa Group rocks underlie the area but are not considered in this study because of their great depth. Salt flowage and associated dissolution and collapse have

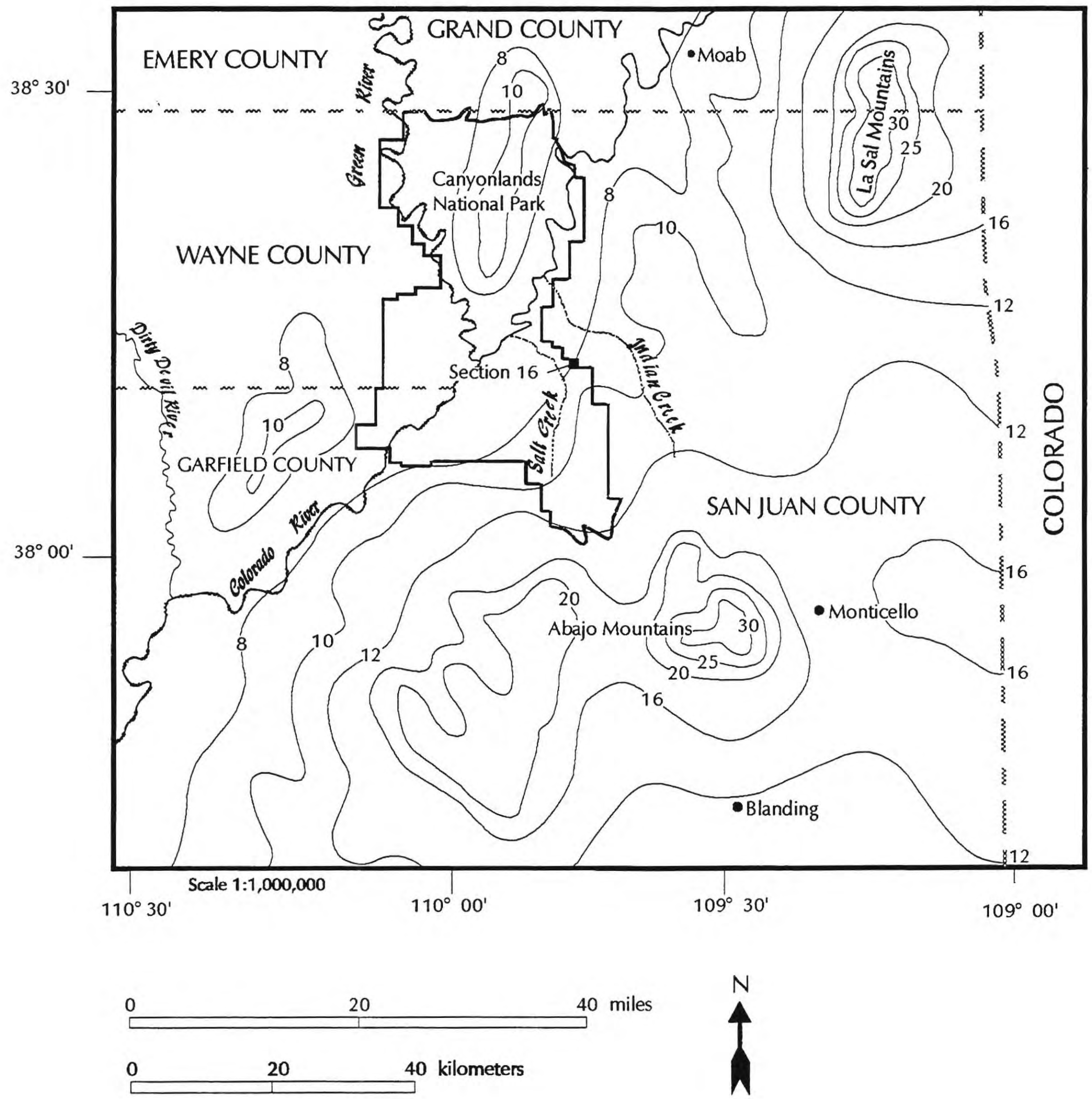


Figure 2. Isolines of average annual precipitation for parts of southeastern Utah (modified from Woodward-Clyde Consultants, 1982a).

Age	Stratigraphic Unit		Thickness (Feet)	Lithology	
PERMIAN	Cutler Group	Organ Rock Shale	0-300		
		Cedar Mesa Sandstone	300-1,000		Outcrops in The Needles area; interfingers eastward with arkosic rock within Canyonlands National Park
		Elephant Canyon Formation	500-900		Thickens and becomes less limy toward Uncompahgre Uplift to the east
					Unconformity
PENNSYLVANIAN	Hermosa Group	Honaker Trail Formation	1,000-1,500		Oldest rocks exposed in area, at Colorado River level.
		Paradox Formation	1,300-2,400		Salt and potash interbedded with black shale and anhydrite

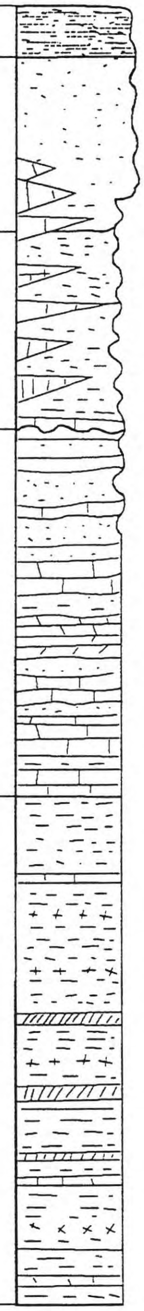


Figure 3. Generalized stratigraphic section in the vicinity of the state land section (modified from Hintze, 1988).

caused local folding and faulting, but the regional structure is a broad homocline, in which rocks dip toward the northeast.

The Pennsylvanian Hermosa Group includes the Paradox and Honaker Trail Formations. The Paradox Formation does not crop out in the area, but underlies it and is a hydrologically significant unit. It consists of interbedded evaporites, dolomite, limestone, siltstone, and shale. The evaporites, notably salt, have readily deformed over the past 300 million years and have locally influenced geologic structure in the area. This Paradox salt facies is as thick as 5,000 feet (1,524 m) in the Canyonlands region (Huntoon, 1988). Upper rocks of the Paradox Formation are a dark gray, calcareous siltstone, and the lower salt beds are white or shades of gray to red (Huntoon, 1988). The top of the Paradox Formation includes a distinct siltstone and shale unit that grades into the basal Honaker Trail Formation. The thickness of the Paradox Formation in the area ranges from 1,300 to 2,400 feet (396-732 m).

The oldest formation exposed in the region is the Honaker Trail Formation. Its upper beds crop out in the Colorado River canyon west of section 16 (figure 1) and in some large tributaries of the Colorado River. The Honaker Trail Formation consists of cherty limestone with minor sandstone and sandy siltstone, and varies from light to dark gray (Ritzma and Doelling, 1969). The thickness of the Honaker Trail Formation in the area ranges from 1,000 to 1,500 feet (305-457 m).

The Permian Cutler Group consists of the undivided Cutler Group and divided Elephant Canyon Formation, Cedar Mesa Sandstone, and Organ Rock Shale (figure 3). The Cutler Group is undivided east of section 16. The Cedar Mesa Sandstone crops out over a large portion of the region east of the Colorado River, including section 16. Outcrops of the Elephant Canyon

Formation and Organ Rock Shale are much more restricted in the region.

Ritzma and Doelling (1969), describe the Elephant Canyon Formation (formerly the Rico Formation) as consisting of limestone and calcareous siltstone, sandstone, silty sandstone, and silty claystone. It is dominantly limestone interbedded with fine-grained clastics and shale, and near its top is a resistant limestone. The formation is commonly thin bedded, but some cross-bedded sandstone beds are thick. Limestones are gray and grayish green, thin to thick bedded, and cherty. Sandstones are fine to coarse grained and reddish brown to greenish gray. Shale and siltstone units are feldspathic, thin bedded, and red to purple (Ritzma and Doelling, 1969). The thickness of the Elephant Canyon Formation in the area ranges from 500 to 900 feet (152-274 m).

Ritzma and Doelling (1969), describe the Cedar Mesa Sandstone as a massive white, light-gray, tan, or pale-red quartz sandstone that contains thin interbeds of reddish-brown siltstone. The quartz sand is medium to fine grained, subrounded, well sorted, and usually well cemented with carbonates. The Cedar Mesa Sandstone is generally cross-bedded between parallel bedding planes. The eroded top of the Cedar Mesa Sandstone forms the wide Cedar Mesa topographic bench east of the Colorado River (Ritzma and Doelling, 1969). The thickness of the Cedar Mesa Sandstone in the area ranges from 300 to 1,000 feet (91-305 m).

The Organ Rock Shale overlies the Cedar Mesa Sandstone. The rocks are reddish-brown sandy siltstone to mudstone with subordinate fine-grained sandstone (Ritzma and Doelling, 1969). It is exposed in the basal portion of cliffs east of the area and at the tops of a few isolated peaks. The thickness of the Organ Rock Shale in the area ranges from 0 to 300 feet (0-91m).

Scattered deposits of Quaternary eolian sand and silt are found throughout the area.

Floodplain, channel, valley-fill, and terrace deposits are mainly along perennial streams. Talus deposits consisting of rock-fall blocks and smaller angular fragments accumulate below the bedrock cliffs in some areas (Woodward-Clyde Consultants, 1982b). Quaternary deposits in section 16 are mostly eolian sand; alluvial processes have reworked some deposits.

Geologic structures in the area are mostly due to the Paradox salts undergoing flowage and dissolution periodically in the region since their deposition. For the past 50 million years the region has been undergoing uplifting, which has resulted in destabilization of the salt and overlying rocks. Salt-related structural features have influenced deposition of the various rock units (Huntoon, 1988). Rocks in the area dip gently toward the east-northeast, but a series of salt-related, broad, northwest-plunging anticlines and synclines, and a major zone of faulting has deformed them. Figure 4 is a northwest-southeast cross section showing the regional stratigraphic relationships and structure. This profile, south of section 16, illustrates the relative simplicity of stratigraphic relationships in the area. To the southwest is the structurally complex, solution-collapsed area of The Needles; to the northeast are the gentle structural folds of Gibson Dome. Except for The Needles (an area of Quaternary faults related to salt dissolution and flowage), faults in the area are few and probably do not significantly affect the ground-water system (Detterman, 1955; Joesting and others, 1966; Huntoon and others, 1982). Joints are the dominant type of fracture and are particularly well developed in some areas in the Cedar Mesa Sandstone (Richter, 1980). Rocks within the state land section are relatively flat lying with dips less than 5 degrees.

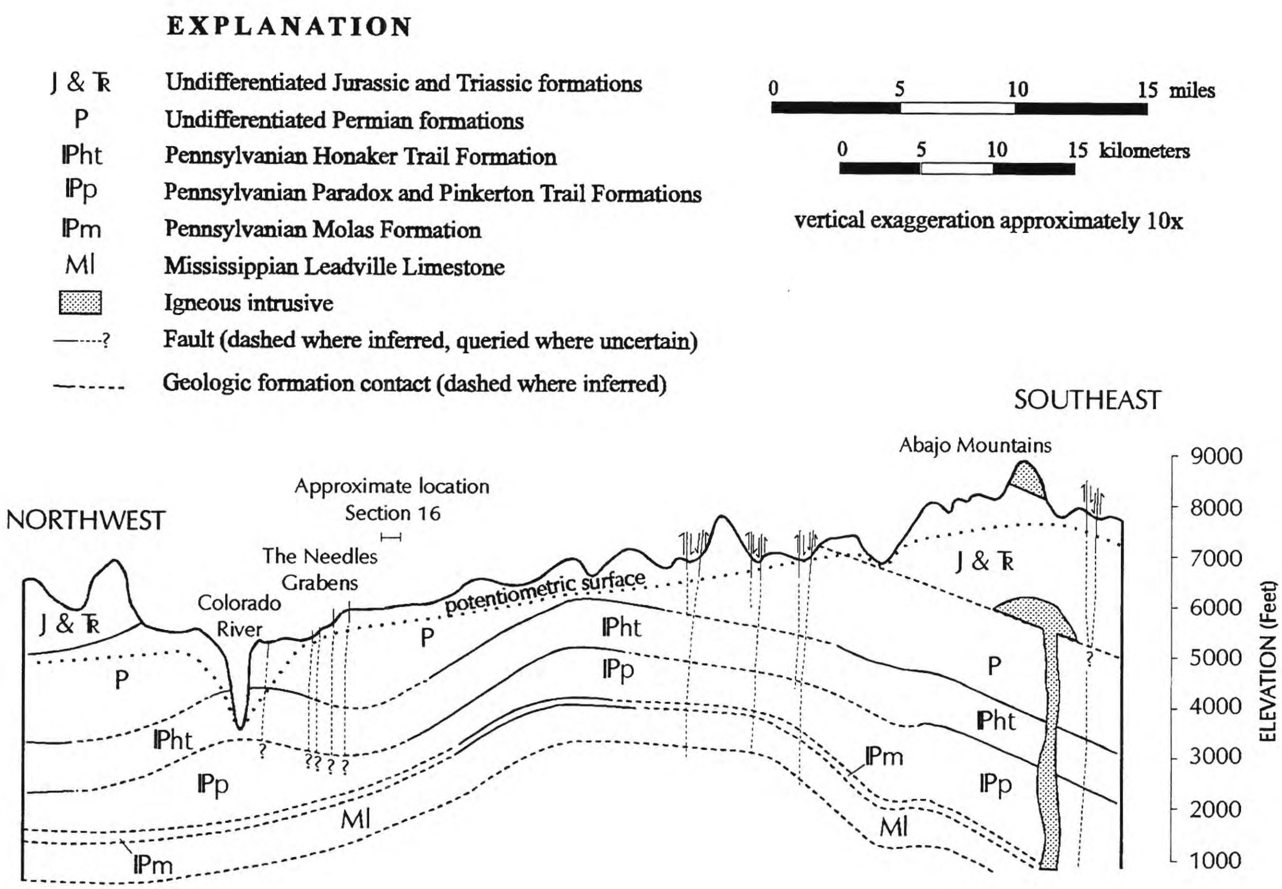


Figure 4. Generalized regional stratigraphic cross section showing potentiometric surface (modified from Woodward-Clyde Consultants, 1982b).

REGIONAL GROUND-WATER CONDITIONS

Aquifer Characteristics

Hydrogeologic characteristics significant to siting a well include flow rate and direction, recharge and discharge, and water quality. Sandstones and other rocks in the area are probably partially saturated in many isolated areas above the regional water table and are saturated in all intergranular openings and open fractures below the regional and perched (local) water tables. Rocks in the area comprise a sequence of potential water-bearing zones of variable permeability and have poorly defined hydrologic boundaries. The primary permeability of rocks in the area can be low, and fractures and partings along bedding planes provide most of the overall permeability of the rocks. Fractures transmit water much more readily than the intergranular pore spaces within the rocks. This secondary fracture permeability provides lateral and vertical interconnection of water-bearing zones (Richter, 1980). Fracture density increases toward the folds and fault zones in the area. Additionally, ground-water recharge from infiltration of precipitation is greater in areas having a higher density of fractures, usually near folded and faulted rocks.

Regional ground-water levels indicate that greater precipitation in the highland areas (figure 2), and incised drainages strongly control the regional ground-water flow. The regional potentiometric-surface map (figure 5) is based on deep wells in the region and show a general pattern of recharge in the Abajo Mountains, and north and northwest ground-water flow, toward the Colorado River. However, local perched water tables create local uncertainty in the potentiometric surface map (Thackston and others, 1981; Paiz and Thackston, 1987).

Permeabilities in the Paradox and Honaker Trail Formations range from low to high. The

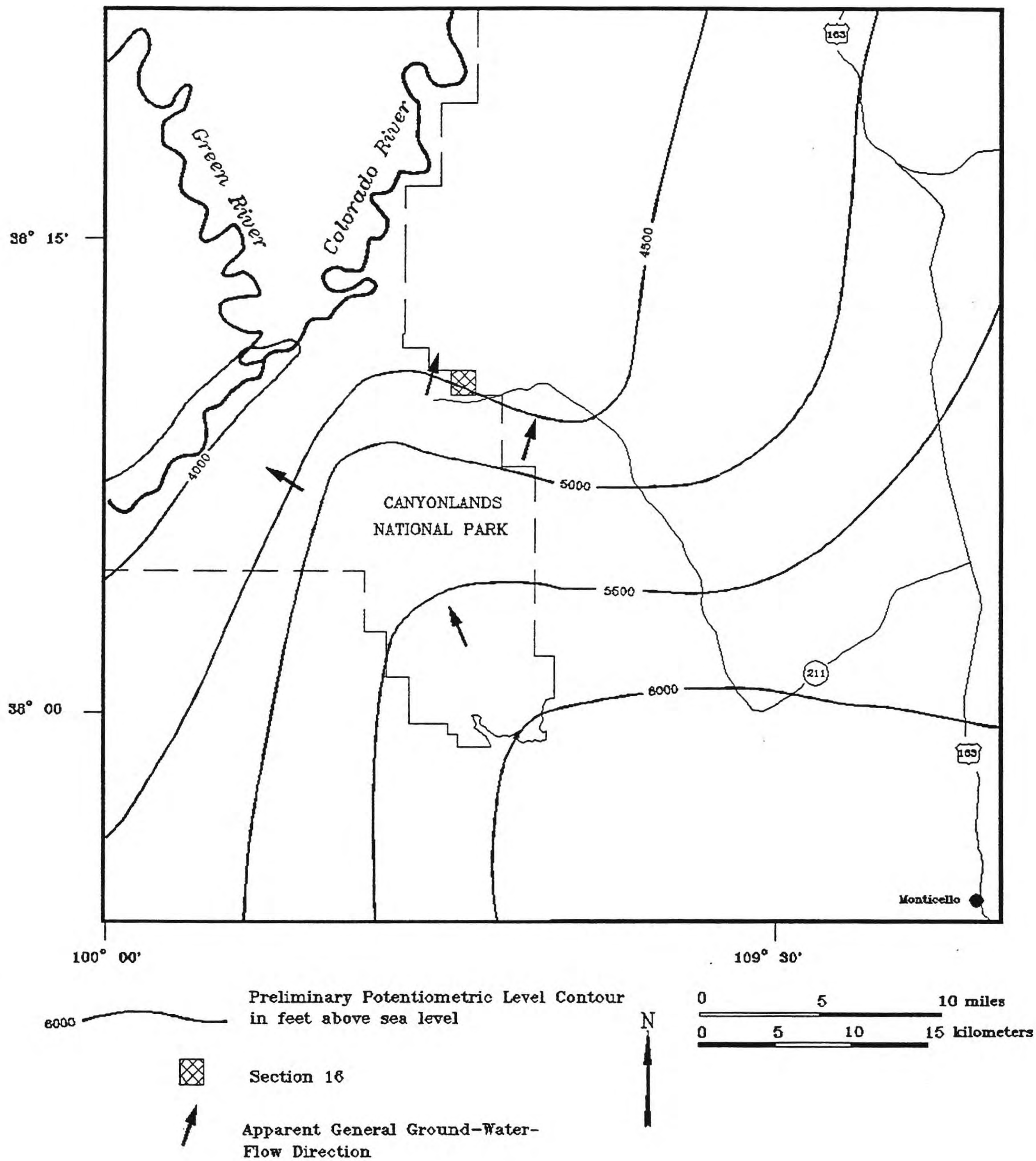


Figure 5. Preliminary regional potentiometric-surface map

(modified from Woodward-Clyde Consultants, 1982b; Paiz and Thackston, 1987).

Paradox Formation contains some of the least permeable rocks in the area. Evaporites and shales in this formation generally are barriers to ground-water movement. The salt of the Paradox Formation is considered isolated from the ground-water-flow system in the overlying rocks. Overall, the flow system within the Paradox Formation is stagnant and lacks well-defined flow paths (Paiz and Thackston, 1987). However, fractured rocks could allow some local mixing of Paradox Formation water with water from above. The upper part of the Hermosa Group, the Honaker Trail Formation, contains brines and has both permeable intervals and intervals that act as barriers to ground-water movement. Oil-well tests conducted throughout the region have shown confined ground-water conditions in the Honaker Trail aquifer (Richter, 1980). A Hermosa Group (probably Honaker Trail Formation) spring in T. 33 S., R. 16 E., approximately 25 miles (40 km) southwest of section 16, had a reported flow of 450 gallons per minute (gpm) (2.83×10^{-2} m/sec) (Feltis, 1966).

Permeabilities in the Elephant Canyon Formation are highly variable. Well records indicate definite permeable zones, but their distribution is unknown (Paiz and Thackston, 1987). Springs that discharge from the Elephant Canyon Formation are generally above shale beds. Water in the formation circulates through fractures or partings along the bedding planes. Springs from limestones in the Elephant Canyon Formation are either from water perched above the limestone or from fractures within the limestone (Huntoon, 1979). Oil-well tests in the Elephant Canyon Formation have encountered confined ground water at several locations. An oil and gas well north of section 16 encountered sufficient water in the Elephant Canyon Formation to produce a flow of 100 gpm (6.3×10^{-3} m/sec) (Huntoon, 1979). The upper 50 feet (15 m) of the Elephant Canyon Formation are considered a productive ground-water zone (Richter, 1980).

The Cedar Mesa Sandstone is a major water-yielding formation in San Juan County and springs and seeps characterize it throughout the area, particularly along the Colorado River and associated drainages. Direct infiltration from precipitation and streams recharge the Cedar Mesa Sandstone where it crops out. Indian Creek and Salt Creek could be possible sources of recharge (Thackston and others, 1986). Semi-confined or confined ground-water conditions exist in the Cedar Mesa Sandstone aquifer. Siltstone and fine-grained sandstone make up the confining and semi-confining layers, whereas permeable zones are coarse-grained sandstone (Richter, 1980). Regional permeability generally increases from east to west, from less than 20 to more than 148 millidarcies, as does hydraulic conductivity, which increases from 0.035 to 0.05 feet per day (1.06×10^{-2}-1.5×10^{-2} m/d) (Jobin, 1962). The specific capacities of wells completed in the Cedar Mesa Sandstone in T. 30 S., R. 20 E. ranged from 0.2 and 0.7 gallons per minute per foot (1.3×10^{-2}-4.4×10^{-3} liter per second per foot) (Avery, 1986). The most productive ground-water zone in the Cedar Mesa Sandstone aquifer includes the basal 150 feet (46 m) (Richter, 1980).

Permeabilities within the Organ Rock Shale are very low. These rocks are not known to produce water anywhere in the area. The hydrologic settings of springs in the undivided Cutler Group are similar to those in the Cedar Mesa Sandstone in which water moves along fractures and partings along bedding planes. Springs discharging from the undivided Cutler Group have small flow rates (Huntoon, 1979).

The unconsolidated deposits in the area can be water bearing and in some places yield small quantities of water to wells, but they are of small areal extent and generally thin. Unconsolidated alluvium along Indian and Salt Creeks may provide small amounts of water.

Quality

Chemical analyses of water from springs and water, oil, and gas wells indicate that water quality in the Hermosa and Cutler Groups is extremely variable, ranging from fresh to briny. Generally, water quality deteriorates with depth and distance from recharge areas (Avery, 1986; Gloyn and others, 1995). Poor-quality water results from long residence times and long flow paths, or leakage of poor-quality water from adjacent rocks. Recharge from local precipitation on nearby outcrops most likely supplies the good-quality water in the area. Most wells in rock units below the Elephant Canyon Formation have poor-quality water (Huntoon, 1979). Water in springs from the Hermosa Group, even near recharge areas, is usually moderately saline to briny, and classified as a calcium-bicarbonate type. Water from wells in the Hermosa Group at depth is generally briny of a sodium-chloride type (Howells, 1990). Water-quality analyses from the Hermosa Group range from 5,342 to 397,061 parts per million (ppm) total dissolved solids (TDS), but the large spring in the Hermosa Group mentioned earlier (T. 33 S., R. 16 E.) contained only 414 ppm TDS (Feltis, 1966).

The Cedar Mesa Sandstone has highly variable water quality that depends on the type of flow system yielding the water. Some water in the Cedar Mesa Sandstone is probably of suitable quality. Wells in section 12 and 20, T. 30 S., R. 20 E. have TDS concentrations of less than 1,000 milligrams per liter (Avery, 1986). The water is a calcium-bicarbonate or a calcium-magnesium-bicarbonate-sulfate type. In section 16, two wells in the Cedar Mesa Sandstone at depths of 74 feet (23 m) and 163 feet (50 m) reportedly yield salty water. Eastward, where the Cedar Mesa Sandstone is more than 5,000 feet (1,524 m) below ground level, analyses indicate moderately to very saline water of a calcium or magnesium-sodium-sulfate type (Avery, 1986).

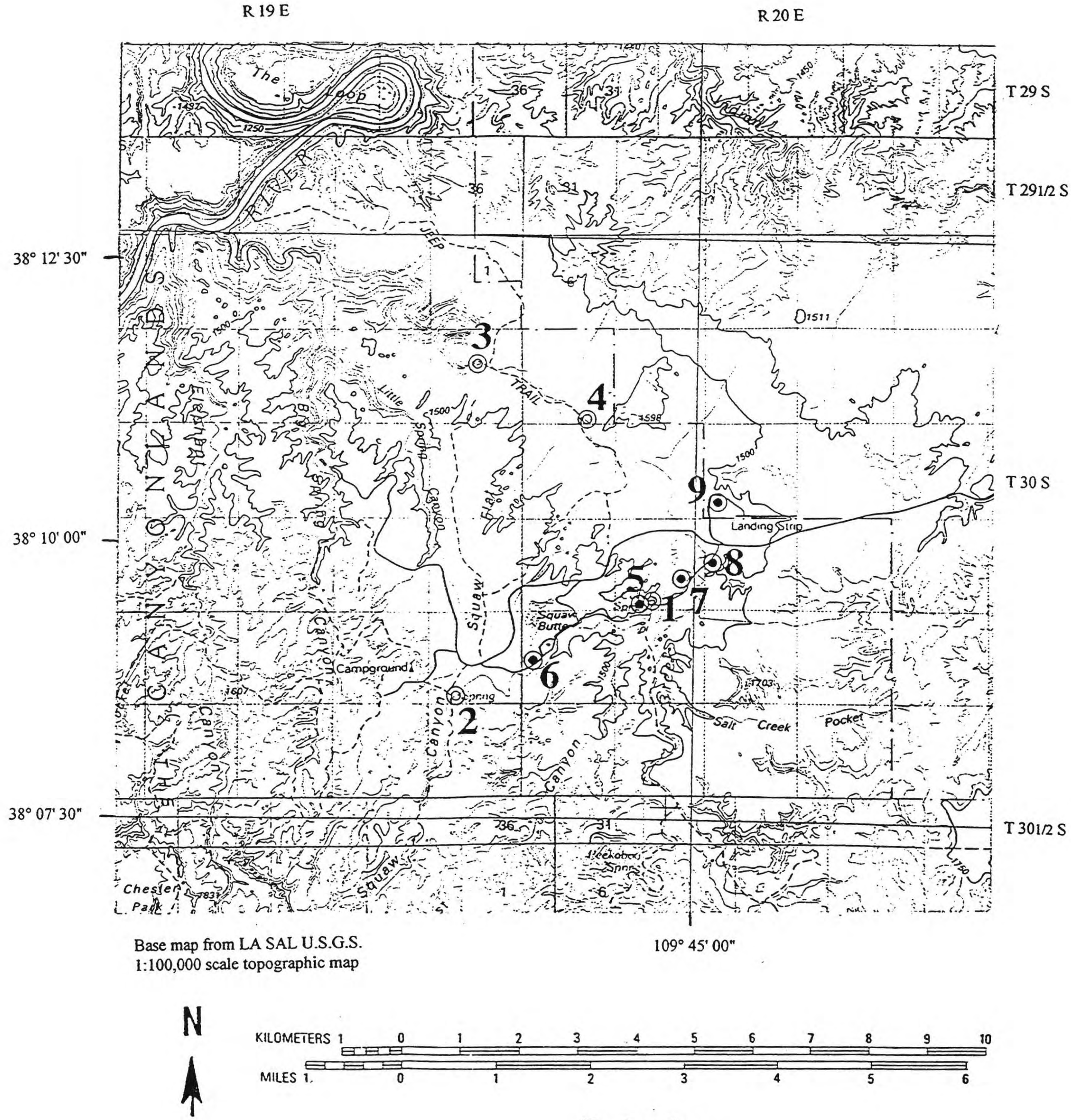
Contamination of fresh water in the Cedar Mesa Sandstone may occur due to upward leakage from the Hermosa Group. Shallow ground water in the Cedar Mesa Sandstone can have low TDS concentrations and is a calcium-bicarbonate type.

LOCAL GROUND-WATER CONDITIONS

Only the Cedar Mesa Sandstone crops out in section 16. It extends to possible depths of several hundred feet. Cliff exposures around a rock ridge in the center of section 16 show complexly intertongued and gradational relationships in these rocks. Although mapped as Cedar Mesa Sandstone, they are transitional between the Cutler undivided, containing predominately fine-grained red-bed sandstones, and more typical Cedar Mesa Sandstone, with light-colored medium- to coarse-grained sandstones. A traverse through the area showed that fine-grained red, purple, and maroon arkosic sandstones predominate in the lower part of the stratigraphic section. If these fine-grained rocks persist at depth, wells drilled in section 16 below the rock ridge are unlikely to encounter rocks with significant primary permeability. Fracturing of the rocks in section 16 was not significant, indicating a lack of secondary permeability as well.

Figure 4 indicates a regional ground-water level more than 400 feet (122 m) below the ground surface near section 16. However, water wells throughout the area (figure 6, appendix) encountered water at shallower depths in aquifers perched on less permeable zones. Too few wells are present in the area to construct meaningful local potentiometric-surface maps for these aquifers. My interpretation of the sparse water-level data, from shallow wells and springs in the Cedar Mesa Formation in the area, indicates ground-water flow toward the north and northwest.

Individual wells and springs in the area differ in the amount of water they yield and the



Explanation

9 ◉ Water wells, number corresponds to well number in table 2.

1 ◎ Springs, number corresponds to well in table 1.

Figure 6. Location and number of wells and springs used in this report.

depth from which they obtain water. Discontinuous ground-water systems like those found in this area commonly supply water to springs and seeps along or at the base of cliffs. I examined section 16 for springs and seeps, but found no springs and only one small seep within the section. Four springs and five wells are in the area surrounding and including section 16 (tables 1 and 2, figure 6, appendix). Two of the springs and three of the wells were observed in the field to determine the stratigraphic position, structural controls, and elevation of the well head or spring at each location. The remaining springs and wells were either inaccessible or not located.

Table 1. Inventory of selected springs in the area.

No. Name	Formation	Elevation (Feet)	Geologic Control
1 Cave Spring	Cedar Mesa Sandstone	5,020	Bedding, fractures
2 Squaw Spring	Cedar Mesa Sandstone	5,100	Bedding, fractures
3 Lower Jump Spring	Elephant Canyon	4,720	Fractures, bedding
4 Salt Creek Spring	Cedar Mesa Sandstone	4,800	Unknown

Number refers to figure 6.

Table 2. Inventory of selected wells in the area.

No. Name	Formation	Elevation (Feet)	Depth (ft)
5 Cave Spring Well	Cedar Mesa Sandstone	4,940	72
6 Squaw Campground Well	Cedar Mesa Sandstone	5,020	50
7 Salt Creek Well	Cedar Mesa Sandstone	4,940	65
8 Section 21 Well	Cedar Mesa Sandstone	5,000	253
9 No 1 Well	Cedar Mesa Sandstone		75
9 No 2 Well	Cedar Mesa Sandstone		163

Number refers to figure 6.

Cave Spring issues intermittently from the Cedar Mesa Sandstone in section 20, T. 30 S., R. 20 W., (figure 6, table 1) with a reported flow from 0 to 0.2 gpm (0-1.3 x 10^{-5} m^3/sec) (Richter, 1980). Squaw Spring issues year round from the Cedar Mesa Sandstone in section 25, T. 30 S., R. 19 W. and discharges 10.5 gpm (6.6 x 10^{-4} m^3/sec) (Richter, 1980). Salt Creek Spring, section 12, T. 30 S., R. 19 W. (figure 6, table 1), issues from the Cedar Mesa Sandstone, but no information is available. Bedding and/or fractures appear to control all springs in the area. Analysis of the water from Cedar Mesa Sandstone springs in the area shows they are a calcium-magnesium-bicarbonate type with low TDS concentrations (Richter, 1980). Lower Jump Spring, (figure 6, table 1) issues from the Elephant Canyon Formation in section 12, T. 30 S., R. 19 W., and is estimated to discharge 13 gpm (8.2 x 10^{-4} m^3/sec) year round. Analysis of water from springs of the Elephant Canyon Formation indicates it is a calcium-sodium-potassium-bicarbonate type (Richter, 1980).

Wells provide most of the water for domestic use in the area. Logs of wells are in the appendix. Three wells produce potable water and three encountered saline, non-potable water. The three potable wells produce from the Cedar Mesa Sandstone west of Salt Creek and from a depth of less than 75 feet (23 m). The water-bearing zones in each well appear to depend on permeability characteristics. The well at the Squaw Campground (figure 6, table 2) produces from unconsolidated material and the sandstone bedrock. This well originally yielded 4 gpm (2.5 x 10^{-4} m^3/sec) with a drawdown of 20 feet (6 m) in 1965 and the water had a TDS concentration of 867 milligrams per liter (mg/L) (Richter, 1980). The Cave Spring wells produce from unconsolidated materials and sandstone bedrock. One of these wells yielded 33 gpm (2.1 x 10^{-3} m^3/sec) with a drawdown of 10 feet (3 m). Water from these shallow wells has a TDS concentration of 305 mg/L (Richter, 1980).

Two wells in section 16 are listed at the same location but at different depths. The No. 1 ends in limestone at a depth of 75 feet (23 m). The No. 2 well ends in sandstone at a depth of 163 feet (50 m). Salt water is indicated on driller's logs for both wells; no other information is available. A well south of section 16, in section 21, T. 30 S., R. 20 E., was drilled to a depth of 253 feet (77 m). The driller's log indicates salt water in this well also.

Recharge to these aquifers probably occurs from local precipitation on outcrops along the flanks of the Abajo Mountains and on wide flat-lying surfaces, and from stream flow, including Indian Creek. I examined Salt Creek to determined whether it recharged local shallow aquifers or discharged from them. I found no evidence of ground-water seepage into the creek, and believe that near section 16, Salt Creek is most likely a losing stream that recharges local aquifers, when it flows.

POTENTIAL FOR POTABLE GROUND WATER

Little development of ground-water resources has occurred in the region to date. Local precipitation is low and thus the volume of recharge to, and water stored in, shallow perched aquifers is small. The regional water table is deep and the quality of water in these aquifers is generally poor. Despite these negative aspects, some potable ground water is available for uses.

In section 16, I recommend that development of ground water from rocks below the Honaker Trail Formation not be considered. Obtaining water from such great depths usually requires costly drilling, and these rocks generally have poor water quality. In the overlying Cedar Mesa Sandstone, Elephant Canyon, and Honaker Trail Formations, the locations of water-bearing-sandstones are not well understood and are difficult to predict. Potable water can be expected in some parts of the Cedar Mesa Sandstone, but in rocks below the Cedar Mesa Sandstone water quality is more uncertain, but likely saline.

The probability of finding a significant source of high-quality ground water in section 16 is low. Although existing wells in the southeastern corner of the section encountered ground water, yields were low and water was saline. Wells in a similar geologic setting in the northeastern corner of the section may also yield water from alluvium and underlying bedrock, but because no wells are in this area, neither the yield nor the quality of the water can be predicted. However, a successful well is unlikely because the site would be in fine-grained arkose, which would produce low yields. Also, poor-quality water was found in a similar setting in the southeastern corner of section 16 and a spring north of the section.

Another possible source of water might be a site in the center and east side of section 16 on the upper bedrock bench. However, wells at these sites would be in fine-grained arkosic sandstones and there is no evidence in cliff faces surrounding the bench of any ground water in the area. The recharge area is also small. No wells have been drilled here, so neither the yield nor the quality is known.

The presence and quality of water in rocks cannot be accurately determined without drilling. Therefore, the possibility exists that potable ground water may be found in section 16. However, I believe the risk of failure associated with drilling a water well anywhere in section 16, based on the above analysis, is high.

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APPENDIX
Logs of Water Wells

Section 16, T. 30 S., R. 20 E.

No. 35979, no. 1

depth (ft)	material
0-30	sand
30-70	sandstone
70-75	limestone, with salt water

No. 35979, no. 2

depth (ft)	material
0-14	sand and silt
14-160	sandstone
160-163	sandstone, salt water

Section 20, T. 30 S., R. 20 E.
No. 36771

depth (ft)	material
0-5	sand
5-15	silt and sand
15-30	sand
30-32	clay and sand with water
32-50	sand with water
50-55	sand and gravel with water
55-65	sandstone with water

No. 36771

depth (ft)	material
1-14	sand
14-28	sand and gavel
28-31	clay and sand
31-38	sand and gravel
38-51	sand, gravel, and cobbles with water
51-68	sandstone with water
68-72	sandstone

Section 21, T. 30 S., R. 20 E.

No. 36771

depth (ft.)	material
0-16	clay and sand
16-190	sandstone
190-200	sandstone and claystone
200-220	limestone
220-240	limestone and claystone
240-253	sandstone with salt water