CONCEPTUAL HYDROGEOLOGIC MODEL OF THE NATIONS DRAW AREA, CATRON AND CIBOLA COUNTIES, NEW MEXICO

Report to

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ABSTRACT

The Nations Draw area is located just north of the town of Quemado in a sparsely populated portion of west-central New Mexico approximately twenty miles east of the Arizona border. Comprising part of the headwaters of the Little Colorado river system, Nations Draw is an ephemeral stream with a drainage area of nearly 230 mi^2 which flows westerly across the center of the study area. Much of this region is part of the Salt Lake coal field, which is located within a southern extension of the Zuni Basin. Substantial measured and inferred coal resources exist within the Moreno Hill Formation (Cretaceous) in this as yet unmined field. Mining is currently planned by the Salt River Project for a lease area within the Nations Draw basin. No comprehensive conceptual hydrogeologic model has been formulated to assist mine planners and regulatory personnel in decision making. The purpose of this report is to compile, analyze, and interpret existing data and develop such a model for the Nations Draw area in general and for the Salt River Project's Fence Lake Leasehold in particular.

Because of the semiarid climate, ground water is the major source of water. Principal near-surface aquifers consist of Quaternary alluvium and fluvial sandstones within the Baca Formation (Eocene) and the Moreno Hill Formation. Most water wells in the area have been completed in these units and yield variable amounts of water. Deeper, more extensive Cretaceous sandstone aquifers include the Atarque Sandstone and three tongues of the Dakota Sandstone (Twowells, Paguate, and Main Body) interbedded with three tongues of the Mancos

Shale.

The occurrence of significant ground water within these deposits is controlled by the location and geometry of the relatively permeable alluvium and sandstone bodies. In the case of the alluvium, these factors are in turn controlled by the Quaternary geologic history of the area. Sandstone location and geometry are influenced by depositional environment and postdepositional history. Lenticular Moreno Hill sandstone channels within the leasehold vicinity yield relatively large amounts of ground water where extensively fractured. Recharge occurs mainly as transmission loss from ephemeral streamflows. The regional pattern of horizontal and vertical ground-water flow is controlled primarily by topography. Flow is roughly east to west in correspondence with the surface system. Geologic structure and the geometry and distribution of high hydraulic conductivity zones exert an influence both regionally and locally on vertical flow patterns. Ground-water discharge does not generally occur at the surface in this area except from perched zones of limited extent. The major controls on ground-water quality are residence time and order of encounter with sedimentary minerals. Dissolved ion concentrations are dominated by sodium and bicarbonate and have specific conductances of less than 2000 micromhos/cm, indicating relatively young ground water flowing through abundant shale. Further hydrologic monitoring within the lease area should concentrate on quantifying the effects of channel sandstone aquifers on vertical gradients and on the possibility of vertical flow within the alluvial aquifer.

INTRODUCTION

Location and purpose of study.

The Nations Draw area is located in west-central New Mexico along the border of Catron and Cibola counties. Located within the Little Colorado river drainage basin and covering eight 7.5 minute topographic quadrangles, it includes the entire course of Nations Draw and part of the course of Largo Creek. Quemado is situated 3 mi to the south and Fence Lake is just 2 mi to the north. Zuni Salt Lake is located just beyond the western boundary of the area along New Mexico state highway 32 (Figure 1). Much of the area is within the Salt Lake coal field, which is located within a southern extension of the Zuni Basin.

A cooperative surface mapping and subsurface exploration project covering 8 quadrangles was conducted in the coal field by the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) and the U. S. Geological Survey (USGS) from 1979 to 1982 to describe the Cretaceous stratigraphy and coal resources of the area. Much of this work, which encompasses roughly the northern half of the field, has been summarized by Campbell and Roybal (1984). Their report, plus those by Campbell (1981) and Roybal (1982), indicate significant coal-resource potential in the eastern part of the field. Concurrent exploration programs by several coal lease holders, including the Salt River Project (SRP), have further delineated potential surface coal mining areas.

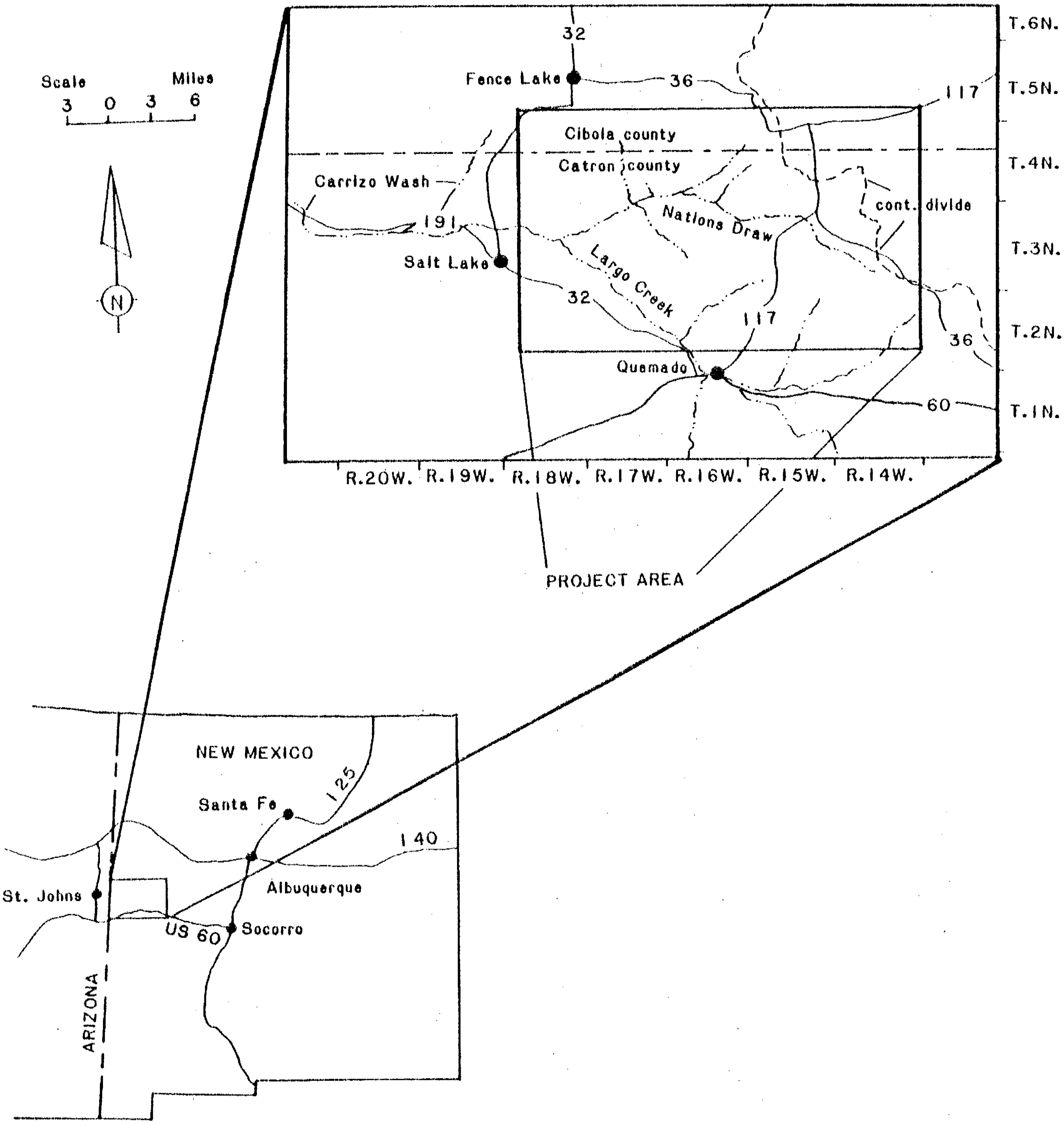

Figure 1. Location map

Although a substantial amount of baseline geologic and hydrologic data has been collected in this region, little hydrologic information has been published. No comprehensive conceptual hydrogeologic model has been formulated to assist mine planners and regulatory personnel in decision making. The purpose of this report is to compile, analyze, and interpret existing data and develop such a model for the Nations Draw area in general and for the Salt River Project's Fence Lake leasehold in particular.

Sources of data.

The data base can be divided into two groups. The largest portion consists of coal exploration and groundwater monitoring data gathered by SRP on the Fence Lake leasehold. The second group is generally derived from sources other than SRP. This is composed of surface geologic data, drill logs, and water well information collected throughout the project area.

Locations have been referred to in this study according to the Public Land Survey System (township, range, and section) as used by the New Mexico State Engineer (Figure 2). Due to the abundance of data points located within the same section, each drillhole, water well, spring, and monitoring well used has been assigned a unique accession number. Numbering begins with the lowest township and range present within the area and ends with the highest. The only exceptions to this procedure are data

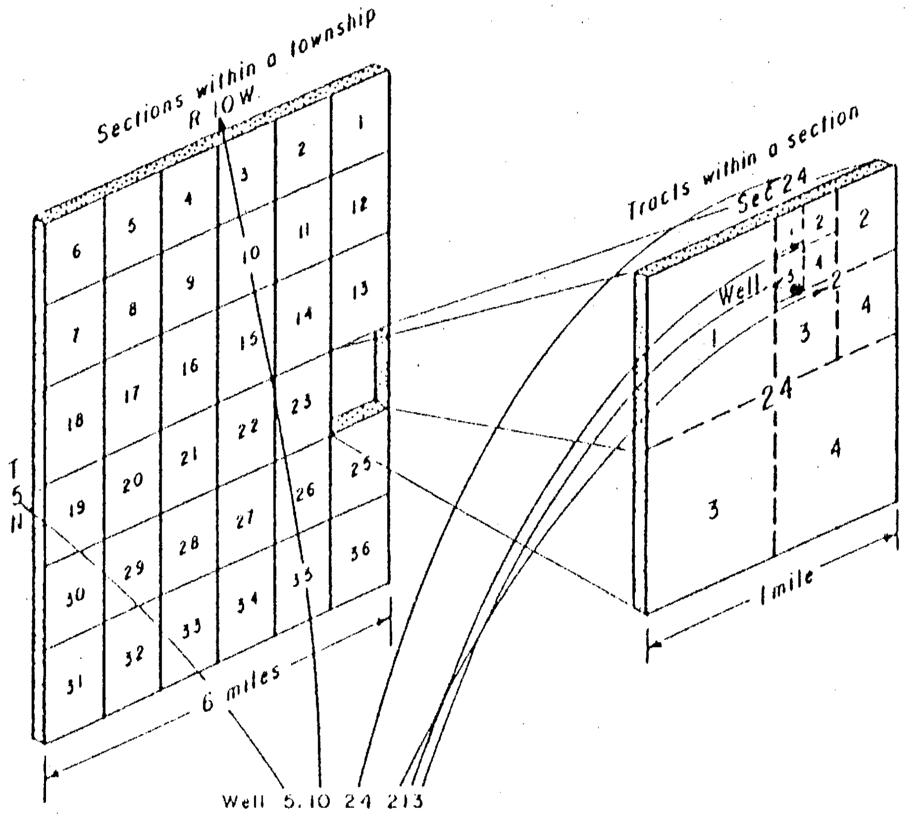

Figure 2. New Mexico well numbering system; well indicated by dot would be numbered 5.10.24.213.

points 279, 280, and 281, which were obtained late in the study. Plate 1 displays data point locations along with corresponding numbers. Accession numbers missing from Plate 1 are associated with confidential drill holes which were used but not plotted. Note that existing or abandoned water wells or springs which were not inventoried are shown without an accession number.

The Salt River Project's exploration and monitoring well data specific to the Fence Lake leasehold include:

-drilling records, lithologic logs, and geophysical logs from 79 coal exploration holes

-construction details, water levels, water quality analyses, and results of pumping and slug tests from 23 groundwater monitoring stations. Thirteen of these consist of multiple monitoring or observation wells while the rest consist of a single monitoring well. Station names have been referred to in the same manner as that used by Seifert and Greenberg (1985) and SRP (1986), followed by accession number and location in parentheses. Monitoring and observation wells were differentiated by using M and OB as suffixes, respectively. Stations with multiple wells were assigned a single accession number due to the close spacing (usually less than 50 ft) of wells. The only exceptions are water supply well FL-30 (196, 4.16.30.421) and observation wells FL30-OB1 (197, 4.16.30.421) and FL30-OB2 (198, 4.16.30.422). These were each assigned separate numbers because the two observation wells are located

237 ft and 603 ft from FL-30, respectively. Analyses of samples from some of these wells, in addition to construction and development methods, were published by Seifert and Greenberg (1985).

-drilling details, construction methods, water quality analyses, and aquifer-test results from two water production wells. This information was discussed in detail by Salt River Project (1983).

Other data sources are listed below.

-Geologic maps of the following USGS 7.5' topographic quadrangles: Fence Lake SW (Landis et al., 1985), Cerro Prieto (Campbell, 1981), Techado and Veteado Mountain (Arkell, 1984a and 1984b), Lake Armijo (eastern half, Roybal, in preparation), Tejana Mesa (Roybal, 1982), parts of Techado, Tejana Mesa, and Mariano Springs (Guilinger, 1982), Mariano Springs and Adams Diggings (Willard, 1957). These maps have been combined and presented on a single sheet as Plate 2.

-Lithologic and geophysical logs of 56 holes drilled by the NMBMMR and several private companies other than the Salt River Project. Five of these are petroleum exploration holes. Eighteen other holes were confidential and are not identified in appendices or on plates.

-Water well inventories conducted by the USGS, the U. S. Department of Energy (DOE), the U. S. Bureau of Land Management (BLM), and the NMBMMR.

The USGS inventory is part of an on-going evaluation of water resources in Catron and Cibola counties. Two separate DOE surveys (Maasen, et al., 1980, and Morgan, et al., 1980) were conducted in the area as part of the National Uranium Resource Evaluation (NURE). Field analyses of well waters throughout the area were obtained from Maasen et al., while more complete chemical analyses were made in the latter study. Analyses of samples from data points 86 (3.17.08.141), 140 (3.18.22.232), and 265 (418.28.211) were published by Levitte and Gambill (1980). The BLM data, which consist of well construction and water level information as well as several drill logs, resulted from a compilation of records made by the Soil Conservation Service and from field work by BLM personnel. Water well records, driller's logs, and analyses of water samples collected by the Salt River Project (SRP, 1982, and SRP, 1983) were also used.

Water well records and spring information, along with the corresponding data sources for each, are listed in Appendix 1. Lists of exploration drillholes, monitoring well construction and water level data, and laboratory and field water quality analyses are presented in Appendices 2 through 6. Lab analyses with less than or equal to 5 percent error in their cation-anion balances were plotted on trilinear diagrams. Those water well drill logs which were not listed in Appendix B of SRP (1982) are included in Appendices 7 and 8 for inventoried and non-inventoried wells, respectively.

Geophysical log interpretation techniques used were those described by Pirson (1977), Selley (1978), and Schlumberger (1972). Most of the logs interpreted are of the type commonly used in coal exploration. These are natural gamma, apparent density, caliper, and single point resistance or resistivity logs. Self-potential (SP) and neutron logs had also been run for a few test holes. Electric logs from the petroleum test wells consist of a combination of either SP and resistivity (short and long normal plus 18', 8" lateral), or dual induction (laterolog resistivity plus induction). Foster (1964) provided interpretations of two of these logs (28, 2.16.11.222; and 69, 3.16.06.231). Parts of several logs were compared with descriptions of available cored intervals from the NMBMMR studies. In addition, Campbell and Roybal (1984) described characteristic log signatures of Cretaceous strata within the area.

REGIONAL SETTING

Physiography and climate.

The Nations Draw area straddles the border of two physiographic divisions (Hawley, 1982). Most of the region is within the Zuni-Acoma section of the Colorado Plateau Province. The southeast third is within the Datil-Mogollon Section, which is a transition zone between the Colorado Plateau and the Basin and Range Province. The Navajo section of the Colorado Plateau, which is typified in this region by Mesozoic outcrops without late Cenozoic volcanic influence (John Hawley, personal communication, 1986), is represented only along the west-central border of the area.

Topography ranges from broad, flat alluvial valleys through rugged uplands to gently sloping mesa tops. The slopes of Santa Rita Mesa and Flattop Mesa in the northwest, Cerro Blanco in the north, and Tejana Mesa and Mariano Mesa in the south form steep escarpments of up to 400 ft in height. Generally, however, the land surface rises gradually in an easterly direction. The lowest elevation is at the western edge of the area, along Largo Creek near Zuni Salt Lake, at approximately 6,340 ft. The continental divide passes through the eastern third of the study area at elevations ranging from 7,500 to 8,270 ft, forming the topographic divide between the west-flowing Largo and Nations drainages and the broad, gently sloping North Plains region. The highest point in the area (8,525 ft) is located just northwest of the divide at the peak of Veteado Mountain, a volcanic neck situated in the northeast. Four other volcanic necks (Cerro Prieto, Techado Mountain, El Portocito, and Eagle Peak) are within the Largo/Nations drainages.

Roughly 80 percent of the land surface is drained by Largo Creek and two of its tributaries. Nations Draw (termed Hubbell Draw in its upper reaches) is the largest tributary. It has a drainage area of approximately 227 mi^2, almost all of which is within the project area. Rito Creek, which joins Largo Creek at Quemado, drains approximately 52 mi^2 in the southeast.

The climate is arid to semiarid with annual precipitation at Quemado and Fence Lake usually varying between 9 and 15 inches (Johnson, 1985; Morris and Haggard, 1985). Half of the yearly total is associated with thunderstorms during the summer months. Annual precipitation generally increases approximately 4 inches for every 1000 ft increase in elevation. Potential evaporation is roughly 3 times the rainfall rate at 31.04 inches (Gabin and Lesperance, 1977).

Five of the nine general soil map units described by Johnson (1985) occur in the Catron County portion of the study area. These are the Catman-Manzano-Hickman, Cabezon-Datil-Hubbell, Celacy-Datil-Typic Ustorthents, Penistaja-Veteado, and Tolman-Smilo-Pleioville soils. The last two are very minor in extent, having been mapped only in the northeast near Veteado

Mountain.

Geology

The contact between Upper Cretaceous and Tertiary rocks passes through the area trending roughly southwest-northeast (Plate 2). Fluvial and volcaniclastic rocks of Eocene and younger age overlie the Cretaceous deposits south and east of this boundary. Volcanic and hypabyssal rocks have been extruded onto and emplaced within these rocks since the Oligocene period (Guilinger, 1982).

The deep petroleum wells located in the area have penetrated Tertiary, Cretaceous, Triassic, and Permian sedimentary rock, reaching the Precambrian at depths ranging from 4008 ft in drillhole 223 (4.17.08.242) to 5930 ft in hole 2 (2N.14W.02.114). General relationships between these units are portrayed on Plate 3 as hydrogeologic cross section A-A'. This section was drawn roughly parallel to the gentle southeastward regional dip.

Outcropping Upper Cretaceous strata were first described in this region by Herrick (1900), who noted the presence of coal seams throughout the Zuni Basin area. Shaler (1907) noted coal outcrops in the Cerro Prieto area and assigned the section to the "Upper Mancos Shale". More recently, Roybal and Campbell (1981), McClellan et al. (1983), and Campbell (1984) have discussed the nomenclature, stratigraphy, and depositional environments of these rocks. In ascending order, they include the Twowells Tongue of the Dakota Sandstone, a marine shoal deposit; the Rio Salado Tongue of the Mancos Shale, an offshore marine deposit; the Atarque Sandstone, a regressive beach deposit; and the nonmarine Moreno Hill Formation, consisting of low gradient, meandering fluvial sequences of sandstone, mudstone, carbonaceous shale, and coal. Hook et al. (1983) described the lateral relationships between these units and others of similiar age to the north and east. The Atarque and Moreno Hill section is stratigraphically equivalent to the Tres Hermanos Formation, Gallup Sandstone, and Crevasse Canyon Formation. A nomenclature change occurs at the landward pinchout of the Pescado/D-Cross tongue of the Mancos Shale, which separates the Tres Hermanos from the Gallup. It is believed that this change should occur in the southeastern portion of the study area. The distinctive signatures of a regressive beach sand (Gallup) overlying a thin marine shale (D-Cross) are apparent on the geophysical log of drillhole 2 (2.14.02.114). No other subsurface data are available in this area, however, so a precise location of where the nomenclature change should be applied is not possible.

These strata were uplifted slightly and eroded during the Laramide orogeny. A wet climate weathering profile (pedalfer) subsequently developed on the exposed beds. This paleosol, or 'oxidation zone' is found in a 25 to 150 ft thick interval immediately beneath the erosional contact with the Baca Formation of Eocene age (Chamberlain, 1981; Guilinger, 1982). The Baca contains sequences of interbedded claystone, siltstone, sandstone, and conglomerate of braided alluvial and lacustrine origin deposited in a structural basin that developed during late Laramide time (Cather and Johnson, 1984).

Volcaniclastic sediments of the Spears Formation (early Oligocene) were deposited conformably on the Baca. During the late Oligocene a series of northwest trending basaltic dikes were intruded along a regional fault system (Arkell, 1984b). Some of these dikes are present en echelon in the northeastern portion of the project area, extending from near Adams Diggings to the northeastern corner of the Cerro Prieto quadrangle (Plate 2). Subsequent to the dike emplacement the Spears and older formations were tilted slightly to the southeast and eroded by northwest flowing streams which deposited the Fence Lake Formation (Miocene). The Fence Lake is a fluvial sequence of sandstones and conglomerates derived from the Spears and from basalt flows associated with the dike system (McClellan et al., 1982; Guilinger, 1982).

The gentle (less than 5°) south and southeastward regional dip is interrupted in places by folds and flexures associated with Cenozoic volcanism. This is evident in the area around Cerro Prieto where several folds of less than 10° dip were recognized by Campbell (1981) and Roybal (1982).

A northeast trending zone of high-angle normal faults and volcanic structures is present in the south-central portion of the Nations Draw area. Guilinger (1982) named this the Tejana Mesa Fault Zone and recognized three Pliocene volcanic episodes associated with it. The major fault, which Guilinger mapped and projected from Tejana Mesa northeast across Hubbell Draw to section 28, T4N, R15W, is reported to have 250 ft of stratigraphic throw. He noted that this fault zone, as well as the alignment of a large number of volcanic necks and vents in the region, is parallel to the Jemez lineament described by Laughlin et al. (1978). There may be other southwest-northeast trending fault or fracture zones of a regional nature in the area. In fact the Nations Draw valley itself has this trend from its junction with Largo Creek to Cerro Prieto.

Hydrology

This area is part of the Carrizo Wash watershed which meets the Little Colorado River north of St. Johns, Arizona. Largo Creek and Nations Draw flow through the region in roughly northwestward and westward directions, respectively. Largo Creek is intermittent approximately 6 mi south of Quemado as it flows north from the Gallo and Mangas Mountains. It is ephemeral by the time it reaches the town, however, as are all other streams within the project area. El Portocito nearly bisects the alluvial valley of Largo Creek approximately 4.5 mi downstream from Quemado. Small surface flows of less than 1 gpm have been noted within the meandering alluvial channel just upstream of the volcanic-rock outcrop. This area appears limited to within approximately 0.25 mi of El Portocito and is the only known intermittent stream segment in the project area. Surface flow is predominately due to runoff from thunderstorms and snowmelt. Ranchers have dammed up portions of many of the arroyos to reduce erosion and form temporary stock-watering ponds.

Groundwater is the most abundant source of domestic and stock water. Perched aquifers within the hills and larger mesas provide a limited supply via springs and wells. Depth to the regional water table ranges from less than 20 ft in the western valleys of the major draws to more than 900 ft at the highest points on Mariano and Tejana mesas.

Two contour maps of the regional water table were constructed using the available drillhole, static water level and well construction data. Plate 4 is an approximate map of the regional water table in the Nations Draw area. Plate 5 is a more detailed map of the regional water table in the vicinity of the Fence Lake leasehold. Five assumptions were made in constructing these maps:

(1) The regional water table is a smooth, continuous surface that exists everywhere below the ground-surface elevation.

(2) Static water levels in Salt River Project monitoring wells which are within the screened interval represent the water-table elevation.

(3) Unless it is constructed solely within a perched aquifer, the elevation of the bottom of a well is less than the water-table elevation.

(4) Water-invasion depths noted on water well and coal exploration drill logs are below the water-table elevation, unless perched.

(5) The water-table gradient is always equal to or less than the topographic gradient.

From these maps it can be readily seen that shallow groundwater flow patterns generally mimic the topography. Groundwater divides roughly coincide with the surface drainage divides and flow is toward the major draws. Recharge areas occur in the uplands near divides as well as along slopes and in the upper reaches of dry arroyos. Discharge areas are limited to downstream portions of the major draws and localized areas where flow conditions near the water table are influenced by subsurface permeability variations. The water-table contours suggest that the Nations Draw and Largo Creek valleys are, at least near the surface, separate groundwater basins. The Fence Lake lease area straddles the center of the Nations Draw basin. The southern portion, in T3N, is located in an area where groundwater flow is mainly to the northwest. The northern group of leased sections, in T4N, are situated where ground-water flow from the southeast, east, and north converges on the Nations Draw valley.

With the exception of aquifer testing of the Cretaceous strata and alluvium in the lease area, hydrologic properties have not been measured in this region. Values from similar formations in other areas are given where available from the literature. Due to the abundance of fine-grained materials in these units, hydraulic conductivity is usually low. Higher values would be expected in sandstones and unconsolidated alluvium.

HYDROGEOLOGIC CHARACTERISTICS OF STRATIGRAPHIC UNITS

This chapter summarizes the geologic and hydrologic characteristics of each of the units that crop out in the Nations Draw area (Plate 2). Outcrop pattern, lithologic makeup, and total thickness are described for each. If applicable, saturated thickness and aquifer characteristics are also discussed. Facies relationships are reviewed for important water-bearing units. The number of wells and/or springs known to be completed or issuing from each unit is given as well as water chemistry information. Completion data on domestic and stock wells are mostly lacking. Only wells with known depths have been associated with particular aquifers. Units are discussed in descending order, as they would be encountered during drilling.

Basalt and Colluvium (Quaternary)

The southernmost portion of a large Quaternary basalt flow is present along the northern border of the Veteado Mountain quadrangle and also as a small outlier on Santa Rita Mesa. Arkell (1984b) described it as highly vesicular with a grayish-black color and an aphanitic texture. The average thickness in this area is not known, however, Campbell (1981) reported an average thickness of 60 to 70 ft on The Dyke quadrangle. Colluvium of unknown thickness is shown on Plate 2 overlying the Moreno Hill Formation on the slopes of Cerro Prieto and the Baca Formation on the flanks of Techado Mountain. These deposits, as well as the basalt flow, are well above the regional water table and not associated locally with any wells or springs.

Alluvium (Quaternary)

Unconsolidated alluvium occurs within and adjacent to ephemeral stream channels. These deposits consist mainly of fine-grained sand, silt, and clay with lesser amounts of coarse sand and gravel. Alluvium is thickest within the major valleys. The maximum known thickness is 190 ft near the confluence of Frenches and Nations Draws. Observation well 198 (4.16.30.422) is located in the center of the Nations Draw buried valley and is 200 ft deep. However, no log is available for this well and it is not clear whether it was completed solely in alluvium or partially in bedrock. In any case, it is reasonable to assume that alluvial fill downstream in the Nations and Largo Creek valleys reaches at least this and possibly a greater thickness. Plates 6, 7, and 8 are maps of alluvium thickness, buried bedrock elevation, and saturated alluvium thickness in the Fence Lake leasehold area. These maps show buried valleys located near the centers of the alluvium outcrop areas.

Drilling near Nations and Tejana draws indicated a similar stratigraphy for the unconsolidated sediments of these valleys (SRP, 1983). An upper layer of light brown sand and sandy clay ranges from near 0 to more than 130 ft thick. This zone often includes gray, sticky clay at its base. Beneath this is a layer of coarse sand and gravel. The gravel is composed of volcanic cinders near the top and large, angular rock fragments near the bottom. Maximum observed thickness of this coarse layer is approximately 79 ft at hole 169 (4.16.20.432). A relatively thin interval of very fine grained alluvium or weathered rock often separates the gravel from consolidated bedrock. Plates 9 and 10 depict the elevation of the top and thickness of the sand and gravel layer. These maps contour the coarse basal layer logged in drillholes located in both deep (buried valleys) and shallow (outside buried valleys) alluvium. The basal layer is not necessarily continuous between these areas but it is assumed to be continuous within the buried valleys.

Saturated alluvium probably lies in the centers of Nations Draw and Largo Creek valleys throughout this region. Depth to the regional water table ranges from less than 20 ft in the downstream valleys to approximately 80 ft in the upland parts of Frenches and Nations Draws. Saturated thickness isopachs of the sand and gravel layer in the leasehold area are shown on Plate 11. Appreciable thicknesses occur mainly within and on the flanks of the buried valleys.

The Salt River Project has completed one production well (196, 4.16.30.421) and seven observation and monitoring wells in the sand and gravel within the Fence Lake leasehold (Appendix 3). A 15-day yield of 200 gpm has been reported for the production well. Specific capacity is 5.7 gpm/ft (based on a pumping rate of 350 gpm for 1 hour). Transmissivity and storativity estimates using the Cooper et al. (1967) slug test method and the pump test methods of Theis, Jacob's time-drawdown, and recovery analysis (described by Lohman, 1972) were provided by SRP with the unpublished monitoring well data. Aquifer parameters determined for well 196 using distance-drawdown procedures were also presented by SRP (1983).

When measurements are made only at the pumping well, the recovery test method is considered superior to the Theis and Jacob time-drawdown techniques. Because of the well-loss effects on drawdown measurements in pumping wells, it is very difficult to recognize behavior due to partial penetration, leakage, boundary effects, and gravity drainage in unconfined situations. Thus, only results of recovery analyses have been included in this report for single-well pumping tests.

Appendix 9 lists results of aquifer tests for monitoring wells screened in alluvium. Horizontal hydraulic conductivity (Kxy) estimates were made by dividing each transmissivity value by the aquifer thickness or the thickness of the gravel pack if the well is partially penetrating. Slug-test data from monitoring well 416-29-4M1 (192, 4.16.29.441) were analyzed directly for horizontal hydraulic conductivity (Kxy) using the technique described by Bouwer and Rice (1976). A transmissivity value for this well was then calculated by simply multiplying the

Kxy by the stratum's thickness. Values obtained by this and the Cooper et al. method were quite similar (columns 8 and 9 of Appendix 9). Conductivities and transmissivities from well 196 differ between analysis methods by a factor of about two. Values calculated using drawdown and recovery data from the observation wells near FL30 (197, 4.16.30.421; and 198, 4.16.30.422) are not as disparate, however, and lie between the endpoints derived from the production well.

Hydraulic conductivity of the sandy clay is a little more than an order of magnitude lower than that of the sand and gravel (Table 1). Transmissivity and conductivity estimates from 417-36-124M1 (255, 4.17.36.124) are intermediate between those from the other sites. It is not clear from the construction schematic whether this well was completed in fine or coarse alluvium or both.

The average storativity estimate at the FL30 wells is 0.000337, indicating that the sand and gravel is confined or semi-confined where overlain by a significant thickness of saturated sandy clay.

Wells obtaining water from the alluvium are mostly limited to the Largo Creek valley. Here, four wells with reported depths of less than 100 ft are located near the middle of the alluvium outcrop. Yields of these wells are not known. Only one stock well in the Nations Draw drainage is known to be completed in the alluvium. This is the L. S. Brown windmill (203, 4.16.31.111),

Table 1. Average values of transmissivity (T) and horizontal hydraulic conductivity (Kxy) in alluvium

Accession Number	Monitoring Well Site	Lithology	Avg. T (ft^2/day)*	Avg. Kxy (ft/day)*
101	317-11-14	sand & gravel	263.5	7.53
192	416-29-4M1	sandy clay	6.8	0.34
196 197 198	416-30-42	sand & gravel	909.2	14.66
255	417-36-124	sand?	41.2	2.06

* arithmetic average of values computed using different analysis methods (see Appendix 9)

which pumps sand and is probably screened in fine sand and sandy clay. Well 203 is the only stock well known to be completed in the alluvium for which a complete chemical analysis is available. This analysis plots in the sodium-bicarbonate field (Figure 3). Water quality analyses are also available for FL-30 and three of the monitoring wells screened in the basal sand and gravel (101, 3.17.11.142; 197, and 251, 4.17.34.433). Conductivity values from these wells range from 685 to 850 micromhos/cm. Their analyses also plot in the sodium-bicarbonate field (Figure 4).

Samples from four other stock wells believed to be completed in the alluvium (30, 2.16.19.342; 40, 2.17.11.333; 137, 3.17.29.111; and 141, 3.18.25.243) were collected as part of the Morgan et al. (1980) study. Tests for sulfate and chloride were not conducted, therefore, only cation chemistry can be displayed on a trilinear diagram (Figure 5). These samples have specific conductivities ranging from 372 to 942 micromhos/cm. Three other wells (31, 2.16.20.324; 36, 2.17.5.233; and 142, 3.18.26.211) are located near the edge of the alluvium outcrop and may be completed in both the alluvium and the underlying Moreno Hill Formation. Analyses from all seven wells plot in the sodium-potassium field (Figure 5). Their conductivities vary between 211 and 1,093 micromhos/cm.

Alluvium unconformably overlies the Spears and Baca Formations, as well as all of the Upper Cretaceous units, in valleys and draws throughout the region.

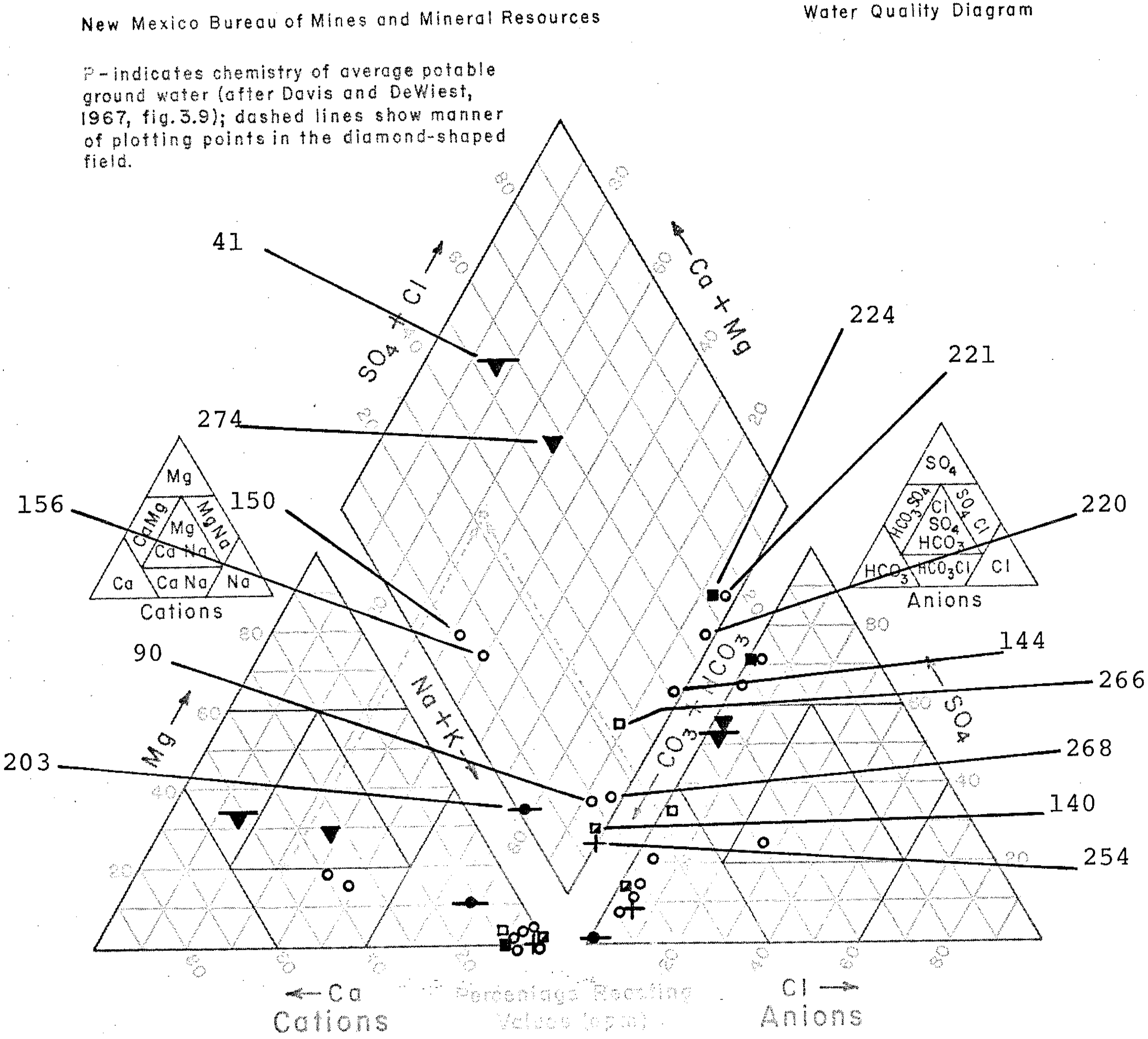

Figure 3. Trilinear plot of water chemistry, wells in Quaternary alluvium, Tertiary rocks, Cretaceous rocks other than Moreno Hill Formation, and wells of unknown depth.

-●- Quaternary alluvium
-▼- Tertiary volcanics
▼ Fence Lake Formation
○ depth unknown
\+ Main Body, Dakota Sandstone

□ Atarque Sandstone
■ Twowells Tongue, Dakota Sandstone
◩ Twowells Tongue and Paguate Tongue, Dakota Sandstone

(Points are identified by accession number; see Plates 1 and 27, Appendices 5 and 6.)

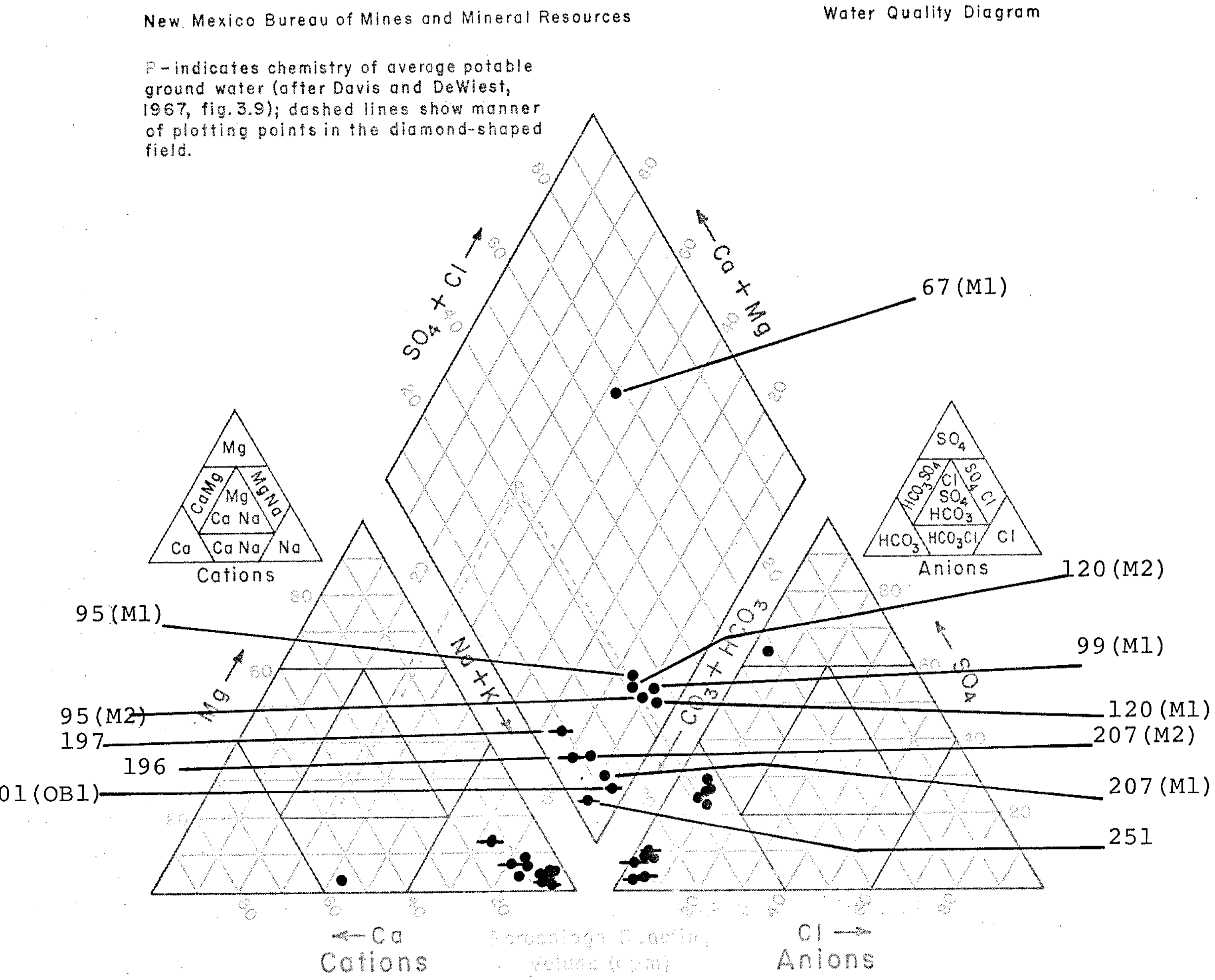

Figure 4. Trilinear plot of water chemistry, Salt River Project monitoring wells; points are identified by accession number and monitoring well number in parentheses (see Plates 1 and 27, Appendices 3 and 4).

Key:
- ◆ Quaternary alluvium
- ● Moreno Hill Formation

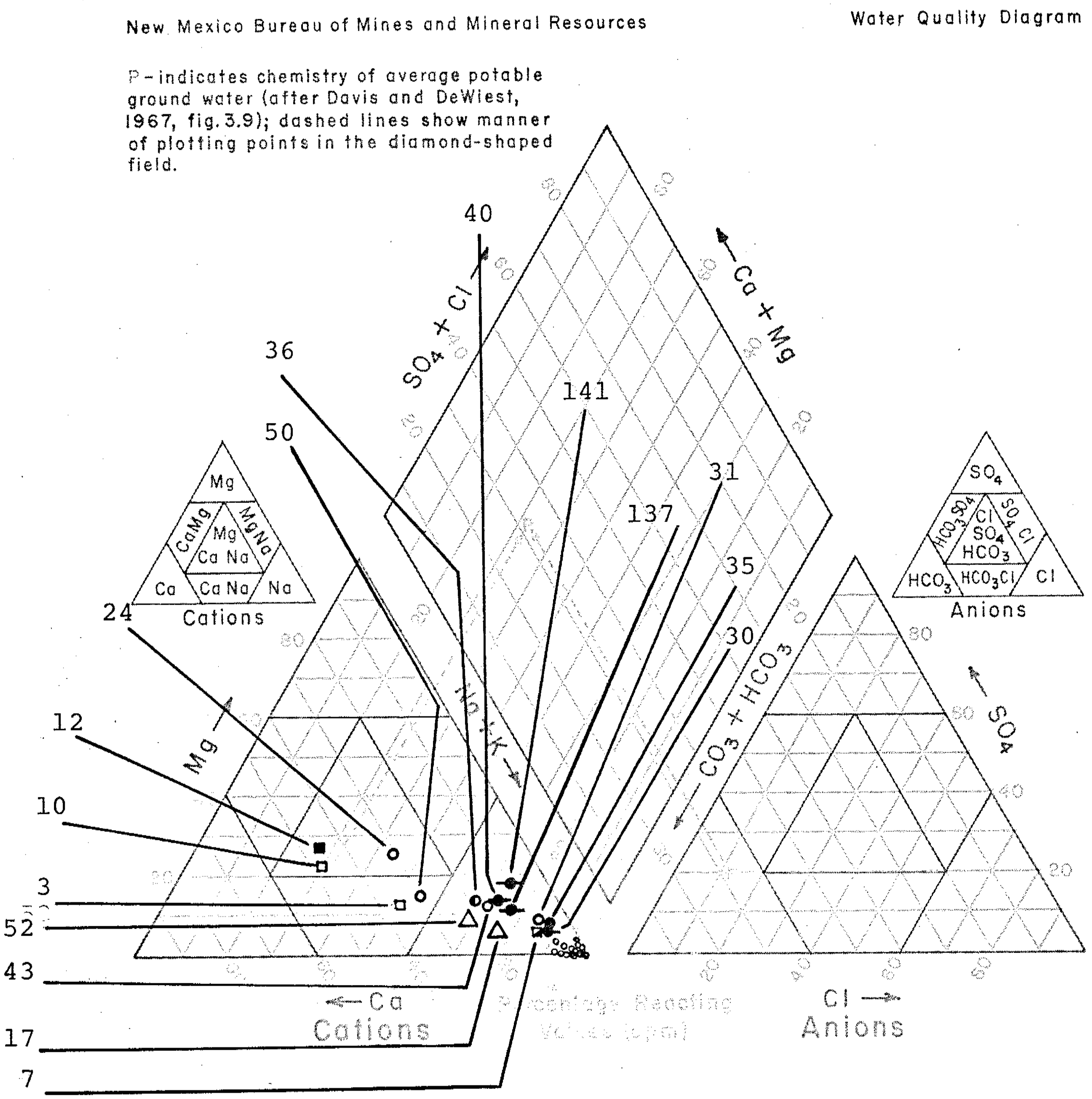

Figure 5. Trilinear plot of cation chemistry, National Uranium Resource Evaluation (NURE) data (sulfate and chloride concentrations are unavailable); points with less than 90 percent epm Na + K are identified by accession number (see Plates 1 and 27, Appendices 5 and 6).

- ◆ Quaternary alluvium
- ■ Spears Fm.
- △ Baca Fm.
- ● Moreno Hill Fm.
- ◉ Quaternary Alluvium and Moreno Hill Fm.
- ◘ Spears Fm. and Baca Fm.
- □ undifferentiated Tertiary deposits
- ○ depth unknown
- ∘ greater than 90 percent epm Na + K

Fence Lake Formation (Miocene)

The Fence Lake Formation consists of lenses of calcareous sandstone and conglomerate and caps the higher mesas and ridges. Grain size ranges from fine sand to boulders greater than 3 ft in diameter; boulders are basaltic (McClellan et al., 1982). Thickness ranges from 0 to more than 350 ft in the northern part of the Techado quadrangle (Arkell,1984a).

The Fence Lake is above the regional water table. A perched zone of saturation occurs in at least one area, however. A small spring located 0.9 mi southeast of Cerro Blanco (274, 5.16.36.431) emerges from the base of the Fence Lake where it overlies the Moreno Hill Formation. An analysis of this spring plots near the center of the cation triangle and in the bicarbonate-sulfate field of the anion triangle (Figure 3). It has a conductivity value of 1,550 micromhos/cm. Noninventoried springs to the south on Mariano Mesa such as Pine Canyon Spring (3.15.36.432) and Balm Tank (3.15.35.434) may indicate perched flow within the Fence Lake.

The Fence Lake Formation unconformably overlies the Spears, Baca, and Moreno Hill Formations in several areas throughout the Nations Draw region.

Volcanic Rocks (Oligocene - Pliocene)

Volcanic flows and shallow intrusives such as vents, necks, and dikes occur in small areas throughout the region. Although the areal extent of these hypabyssal rocks is localized, they extend vertically to great depths. An exception to this may be the stock mapped by Arkell (1984b) in the southeast quarter of the Veteado Mountain quadrangle. This may be a sill which was injected horizontally between planes of weakness in the host rock (Richard Chamberlain, 1986, personal communication). The cores of Techado Mountain and the stock consist of diabase and diorite, respectively (Arkell, 1984b). All of the other volcanic rocks, including Cerro Prieto, have an olivine basaltic composition with a porphyritic or microcrystalline texture.

The only extensive Tertiary flow is the one capping Tejana Mesa. This flow averages roughly 40 ft in thickness and lies 500 to 900 ft above the regional water table. However, one undeveloped spring (41, 2.17.13.242) with a flow of less than 1 gpm was sampled from near the vent area in the southern part of this mesa (Appendices 1 and 5). This indicates that there is some perched groundwater within the basaltic flow. Specific conductivity of a sample from this spring is 490 micromhos/cm and its analysis is high in calcium and magnesium, with bicarbonate and sulfate as dominant anions. No wells are known to be associated with volcanic rocks in the area.

Tertiary flows overlie the Fence Lake Formation, the Spears Formation, the Baca Formation, and undifferentiated Tertiary deposits in various areas throughout the region.

Spears Formation (Oligocene)

The Spears Formation crops out mainly in the Mariano Springs and Adams Diggings quadrangles, forming prominent escarpments of light gray and pink rock on the northern flanks of Mariano Mesa. It has also been mapped on the sides of Veteado Mountain by Arkell (1984b). Guilinger (1982) described the Spears as interbedded, laterally continuous volcaniclastic fine-grained sandstones, mudstones, and claystones containing abundant granule to cobble size clasts.

The maximum thickness reported by Guilinger is 520 ft at the north end of Mariano Mesa. Cuttings from the wildcat well drilled at data point 2 (2.14.2.113) indicate that the contact between the Spears and the underlying Baca Formation is at a depth of 250 ft. Plates 12 and 13 depict the approximate thickness and saturated thickness of the Tertiary deposits. The lack of detailed information prohibits accurate estimates of the total and saturated Spears thickness in this area.

Several wells in this vicinity are either fully or partially completed in the Spears or in undifferentiated Tertiary deposits (Plate 2 and Appendix 1). Yields from these wells are unknown. However, Trauger (1972) reported that similar water laid volcaniclastic rocks in Grant county are locally water-bearing with average yields of 0.5 to 10 gpm. According to Trauger, much higher yields are possible where wells are completed in coarse grained lenses.

Aquifer characteristics such as porosity, hydraulic conductivity, and storage coefficient vary greatly with lithology. Because of abundant clay matrix and the poorly sorted nature of the sandstones, hydraulic conductivity is probably not high.

Only three chemical analyses are available from wells thought to tap the Spears Formation (Appendix 5). These are also from the NURE study of Morgan et al. (1980). In two of these analyses (7, 2.14.10.144; and 16, 2.15.12.221) sodium is by far the dominant cation while the third (12, 2.14.20.344) plots in the center of the cation diagram (Figure 5). Specific conductances from wells 7, 12, and 16 range from 464 to 700 micromhos/cm.

The Spears conformably overlies the Baca Formation.

Baca Formation (Eocene)

The Baca Formation crops out in or underlies roughly the southeastern third of the project area. The Baca is a sequence of red and brown fluvial claystone, mudstone, sandstone, and conglomerate. According to Cather and Johnson (1984), the Baca in this area comprises either the distal fan facies of a large east-flowing braided alluvial plain system, or more rarely, small-scale lacustrine fan-deltas situated on the fluvial system floodplain. They described both facies as dominated by very coarse to fine sandstone with subordinate conglomerate, mudstone, and claystone. Sandstone beds commonly occur as either sheetlike, horizontally laminated bodies or as lenticular channels up to 50 ft thick and as much as 165 ft wide. Conglomerates occur as very thin channel and sheetlike deposits with a mud or sand matrix. Mudstone and claystone occur as thin, laterally continuous beds in the alluvial facies, but are thicker and more abundant in the fan-delta facies. The carbonate content of mudstones in the latter facies was noted to range between 10 and 15 percent by weight (Cather and Johnson, (1984). Clay minerals are predominantly smectites (Guilinger, 1982). The Baca is often conglomeratic at its erosional base, containing gray sandstone and shale clasts from the Moreno Hill Formation (Arkell, 1984a; Arkell, 1984b; Guilinger, 1982; Roybal, 1982).

The Baca pinches out on the flanks of Tejana Mesa and the escarpment in the northeastern part of the Techado quadrangle (Arkell, 1984a). The maximum observed thickness in outcrop is approximately 450 ft on the flanks of Veteado Mountain. Its thickness increases in a southeasterly direction to 720 ft in the subsurface at hole 2 (2.14.02.113). Saturated thickness also increases to the south and east. The entire Baca interval probably lies below the regional water table in the southern half of the Adams Diggings quadrangle (Plate 13).

The hydrologic characteristics of the Baca strata are unknown. Like the Spears, porosity and hydraulic conductivity are likely to vary widely over short distances, due to the interbedded and laterally heterogeneous nature of the deposits. Unlike the Spears, however, the more abundant coarse sandstones and conglomerates can act as localized aquifers. For example, well 19 (2.15.18.420) has a reported yield of 20 gpm while wells 17 and 18, (both 2.15.18.242) which are located less than 0.5 mi to the north, yield less than 1 gpm.

Twenty-five wells in the area are known to wholly or partially penetrate the Baca. Two springs that emerge from perched zones on the western flank of Mariano Mesa were inventoried. These are Mariano Springs (13, 2.15.5.213) and Cottonwood Spring (59, 3.15.22.112). Specific conductivity values of samples from these springs are 290 and 591 micromhos/cm.

Eleven of the wells were sampled as part of the NURE project. All of these plot in the sodium-potassium field (Figure 5). Conductivity values from Baca well samples range from 260 to 600 micromhos/cm.

The Baca unconformably overlies the Moreno Hill Formation.

Moreno Hill Formation (Upper Cretaceous)

The Moreno Hill Formation crops out over most of the western half of the Nations Draw area. It is unconformably overlain by either Quaternary basalt, the Fence Lake Formation, or the Baca Formation. It is composed of continentally-derived sequences of sandstone, mudstone, claystone, and coal. These deposits have been interpreted by various workers as meandering alluvial channel fills, crevasse splays, overbank muds, and lower delta-plain deposits.

Plates 14, 15, and 16 display the structure, thickness, and saturated thickness of the Moreno Hill. On Santa Rita Mesa the Moreno Hill/Fence Lake erosional surface slopes northward. This is evidence of the erosional thinning of the Cretaceous rocks by the northwest flowing streams that deposited the Fence Lake gravel. The generally southward and southeastward dip direction elsewhere reflects tilting of the Cretaceous, Eocene, and Oligocene beds, probably by extension and sagging of the Colorado Plateau margin (Guilinger, 1982). Total thickness (Plate 15) on Santa Rita Mesa (275, 5.17.31.211) is 696 ft. This increases to 1,120 ft at hole 28 (2.16.11.222). To the east total thickness is generally between 1,000 and 1,200 ft. The saturated thickness of the Moreno Hill Formation varies from 0 in the northwest to 1,200 ft where the unit is entirely saturated.

In the western one-third of the Nations Draw area the Moreno Hill is divisible into three members based on the presence of a middle sandstone unit. Plates 17 to 21 are thickness and structure maps of these members. The upper member is present only on Santa Rita Mesa and Tejana Mesa and as scattered erosional remnants on the Cerro Prieto and Lake Armijo quadrangles. Its lithological makeup is dominated by yellow and green, easily eroded siltstones and claystones with minor amounts of carbonaceous shale, coal, and ledge-forming sandstones (Campbell, 1984). These deposits were laid down in a low-energy, meandering alluvial channel environment. In the north, its thickness decreases from more than 300 ft on Flattop Mesa and Hawkins Peak to less than 50 on Santa Rita Mesa. It reaches its greatest thickness on Tejana Mesa, however, where it is approximately 600 ft thick.

The middle member is a pinkish-yellow, medium to coarse grained sandstone with little or no silt or clay matrix. It is composed of trough and planar cross-bedded channel sands that form a sheetlike braided stream deposit (Campbell and Roybal, 1984). The areal extent of the middle member is similar to that of the upper member, but in outcrop its resistant sandstone beds often form prominent cliffs on the sides of the mesas and smaller hills. Thickness ranges from 0 to approximately 80 ft. This member apparently pinches out in the subsurface along a northeast-southwest trending line as shown on Plates 17 to 21. Subsurface data southeast of this line show no evidence of a thick, braided stream channel deposit. Thus, division of the Moreno Hill into three members has not been continued beyond it.

The lower member has a much more extensive outcrop than the other two, lying at the surface over much of the Cerro Prieto, Fence Lake SW, and Lake Armijo quadrangles. Lithology is similar to the upper member except that sandstone, carbonaceous shale, and coal are more abundant. It was described by Campbell (1984), Campbell and Roybal (1984), and Landis et al., (1985) as a relatively thick sequence of laterally discontinuous sandstone channel fills, crevasse splays, and floodplain deposits laid down in a similar, but more humid, environment than the upper member. Thickness ranges from 0 to approximately 600 ft. Thinner values are associated with places where the overlying middle member has been eroded away and western areas where the entire Moreno Hill interval is thinner. A representative complete thickness of the lower member is indicated in hole 275 (5.17.31.211) where 505 ft are penetrated.

The middle and upper members are above the regional water table throughout their extent. Thus the saturated Moreno Hill thickness north and west of the middle sand pinchout is equivalent to that of the lower member.

Mineable coal seams are found in two zones within the lower member. The Rabbit zone is located approximately 60 ft below the base of the middle sandstone member. The Cerro Prieto zone lies roughly 150 to 200 ft below the Rabbit interval. Coals within this lower zone have been the primary exploration targets within the Fence Lake leasehold area (Greenberg et al., 1984). Salt River Project drill logs have designated separate coal beds in the Cerro Prieto zone as the A, BC, and Tejana seams in descending order. The A and BC beds join to form a single thick seam in the northeast portion of the lease area. Extraction of the Tejana seam at the Fence Lake No. 1 mine is not planned (SRP, 1986).

A contour map of the base of this coal zone was constructed from the available data (Plate 22). This map was drawn by contouring the base of the BC seam in the Tejana Draw area and the base of the lowest coal logged elsewhere in the lease area. Although not a true structure contour map, it nevertheless displays the minor flexures discussed by Roybal (1982), Campbell (1984), and SRP (1986) in this area. A sharp drop in elevation of the base of the coal zone along the southeastern border of the leasehold is readily apparent. The dip of this surface is greater than the surface dips in this area (Plate 2), suggesting a normal fault with 100 ft of downdrop to the southeast. The approximate location of the middle sand member pinchout lines up well with the steeply dipping contours, suggesting a different explanation for its apparent disappearance. The sandstone body may be thinning in this direction (Plate 19), and consequently was not recognized on the available subsurface logs.

Using Plates 5 and 22, a contour map was drawn of the saturated thickness of overburden above the base of the Cerro Prieto coal zone (Plate 23). The thickest cover in the lease area occurs southeast of the apparent fault zone in sections 28 and 32 of T4N and the southeast half of section 13, T3N. In these areas the saturated bedrock cover exceeds 100 ft. By overlaying Plate 8 over Plate 23, the saturated thickness of alluvial overburden can be estimated. Extensive areas with saturated alluvium overlying the coal are in sections 20, 28, 29 of T4N, R16W. In Tejana Draw, areas with significant saturated bedrock and alluvium are limited to relatively smaller parts of the buried valley in the south-central and eastern portions of section 11.

The base of the coal zone is above the regional water table over much of the central and western portions of the lease area (and thus the saturated overburden thickness is zero). However, portions of sections 25 and 26 in T4N, R17W have up to approximately 70 ft of saturated overburden.

Exploration drilling has indicated that sandstone is often found within and immediately beneath the Cerro Prieto coal zone. Saturated sandstone thicknesses in the 50-ft intervals above and below the datum contoured on Plate 23 are shown on Plates 24 and 25. Only sandstone beds having a thickness of 5 ft or more were considered. Plate 25 includes only that area where the base of the coal zone is saturated. In other words, saturated sandstones underlying areas where the coal is unsaturated were not mapped. Of the 46 drill logs examined in preparing Plate 25, 39 contained a single sandstone bed varying from 10 to 36 ft thick in the 50-ft interval below the coal. The interval between this bed and the coal zone ranged from 0 to 40 ft. However, in most of the drill holes it is less than 20 ft. In many of the holes in sections 20, 28, 29, and 32, T4N, R16W, sandstone lies immediately beneath the base of the coal. It is not clear whether or not the same continuous sandstone channel system extends throughout the lease area beneath the coal. Unless the major paleodrainage trend was northerly or northeasterly across the lease area, it is unlikely that this sandstone is physically connected to that underlying the Tejana seam at the Fence Lake No. 1 mine. Estimates of sandstone porosity are available from drillholes for which density, neutron, and caliper logs were run. Porosity ranges from about 10 to 20 percent and is sometimes higher near the base of channel sands.

Hydraulic properties of the the coal, bedrock overburden, and sandstones underlying coal and alluvium have been estimated from slug and pumping tests at several of the monitoring points. These, along with information concerning the aquifer tests, are listed in Appendices 10 and 11. As with the alluvium, only recovery analyses of single-well pumping tests have been listed. Multi-well tests were conducted at 317-13-1 (124) in sandstone both above and below the coal zone. Data are also available for a total of 13 slug tests and five single well pumping tests in the Moreno Hill Formation. Five of the slug tests were at wells screened in coal, seven were in sandstone below the coal zone, and one tested shale above the coal. Three of the single-well pumping tests were conducted in the basal sandstone, one was in sandstone overburden, and another was in the bedrock beneath the Tejana Draw alluvial channel. Hydraulic conductivities were calculated in the same manner as those from tests in alluvium. Application of the graphical procedure described by Schwartz (1975) to the slug test data from 317-12-14M2 (122, 3.17.12.142) provided estimates of percent fracture porosity and both matrix and fracture conductivity of the coal seam it is screened in.

Transmissivity and horizontal hydraulic conductivity estimates from the different slug-test analyses are fairly close. Values are within an order of magnitude at all but two monitoring points. At 417-36-41 (258, 4.17.36.411) the screen apparently fully penetrates a sandstone bed from a depth of 117 to 127 ft. However, there is no bentonite seal above this interval and the resulting connection with an overlying sandstone may have affected the results. Results from the Cooper et al. (1967) and Bouwer and Rice (1976) techniques are also quite different at 317-12-42M2. However, at this well the use of the Schwartz method illustrates the importance of fracture flow in the coal seam. Although fracture porosity is only 3 percent of total porosity, fracture conductivity is more than 20 times greater than matrix conductivity. The predominance of fracture conductivity in coal has been well demonstrated (Stone and

Snoeberger, 1977, Rehm et al., 1980). Curiously, this was the only slug test in which fracture flow was indicated by this procedure.

Note that the upper sandstone pumped at 317-13-1M2 (124) has been listed in Appendix 10 as unconfined. The mean static water level in this well (Appendix 6) is approximately 96 ft below ground surface, which is 1 ft below the top of the sandstone. The storativity values listed for 317-13-10B1 must then represent the elastic storage coefficient in response to a release of pressure in the aquifer (Neuman, 1972). A longer pumping time would be needed to estimate the actual specific yield (Neuman, 1974). The Hantush (1964) r/B solution was applied to drawdown data from 317-13-10B2, which is screened in confined sandstone (Appendix 11). This type-curve method affords an estimate of vertical hydraulic conductivity when a flattening out of the time-drawdown curve suggests the possibility of vertical leakage. The vertical conductivity was estimated at 0.1 ft/day.

Mean values of transmissivity and horizontal hydraulic conductivity were computed from the results of different analysis methods for each aquifer test (Tables 2 and 3). Hydraulic conductivities in coal range from 0.2 to 4.36 ft/day with a mean value of 1.59 ft/day. Those for sandstone below coal range between 0.12 and 13.42 ft/day and have a mean of 3.55 ft/day.

Table 2. Average values of transmissivity (T) and horizontal hydraulic conductivity (Kxy) in coal and bedrock overburden, Moreno Hill Formation

Accession Number	Monitoring Well Site	Lithology	Avg. T (ft^2/day)[1]	Avg. Kxy (ft/day)[1]
67	316-06-13M2	coal	27.0	2.25
95	317-10-42M1	coal	2.4	0.48
120	317-11-34M2	coal	7.9	0.66
122	317-12-14M2	coal	39.2[2]	4.36[2]
207	416-32-311M2	coal	2.0	0.20
124	317-13-1M2&OB1	sandstone	458.7	10.20
238	417-26-22M1	shale	3.6	0.14

[1] arithmetic average of values computed using different analysis methods (see Appendix 10)

[2] determined by summing matrix and fracture estimates from Schwartz (1975) method and averaging with results of Cooper et al., (1967) method; results of Bouwer and Rice (1976) method not included for this well (see Appendix 10)

Although leakage undoubtedly occurs when the confined sandstones are pumped, fractures probably have a greater effect on drawdown behavior (and thus transmissivity estimates) at those wells on Tables 2 and 3 with very large T values. The flattening of drawdown curves with time from the pump tests at 317-11-34M1 (120) and both monitoring wells at 317-13-1 (124) provide evidence of this. At well 120M1, a widening of the caliper log trace at 120 ft further supports this interpretation. In addition, the driller's log at 417-35-34 (252, 4.17.35.342) reports a partial loss of air return at the depth of the sandstone tested.

Forty four of the inventoried stock and domestic wells are completed in the Moreno Hill Formation. Known yields range from less than 1 gpm to 20 gpm. Two wells (261, 4.18.5.144A; 262, 4.18.5.144B) are apparently completed in the middle sandstone member. These wells, one of which has a reported yield of 4 gpm, are located less than 1 mi from Moreno Spring. This non-inventoried spring is located at the middle member outcrop on the southern escarpment of Santa Rita Mesa (section 8, T4N, R18W). Water levels in these wells are roughly equal to the surface elevation of the spring. This suggests that perched groundwater exists within the middle member in this area. No wells or springs derive water from the upper member in the Nations Draw area.

Specific conductance of water samples from monitoring points and wells in the Moreno Hill ranges from 211 to 1,250 micromhos per cm. Figure 6 is a trilinear plot for 12 well and spring samples from the Moreno Hill Formation. Six fall within the sodium-bicarbonate field. An analysis from well 263 plots in the calcium-bicarbonate field. All others have subequal amounts of calcium, sodium, bicarbonate, and sulfate ions.

Atarque Sandstone (Upper Cretaceous)

The name Atarque Sandstone was proposed by McClellan et al. (1983) for a sequence of very fine grained to fine grained shallow marine sandstone and siltstone beds which crop out along the southern side of Santa Rita Mesa and along Largo Creek. They, as well as Landis et al. (1985) and Campbell and Roybal (1984) described the Atarque as a regressive coastal barrier deposit. This sandstone is readily identifiable in geophysical logs due to a sharp upper contact, fining downward log signature, and a thick underlying sequence of marine shale (Rio Salado Tongue of Manco Shale).

Although subsurface data are limited to the east, the Atarque is assumed to be present in the subsurface throughout the Nations Draw area, mainly because of its beach-barrier depositional environment. Plate 26 is a structure map drawn on

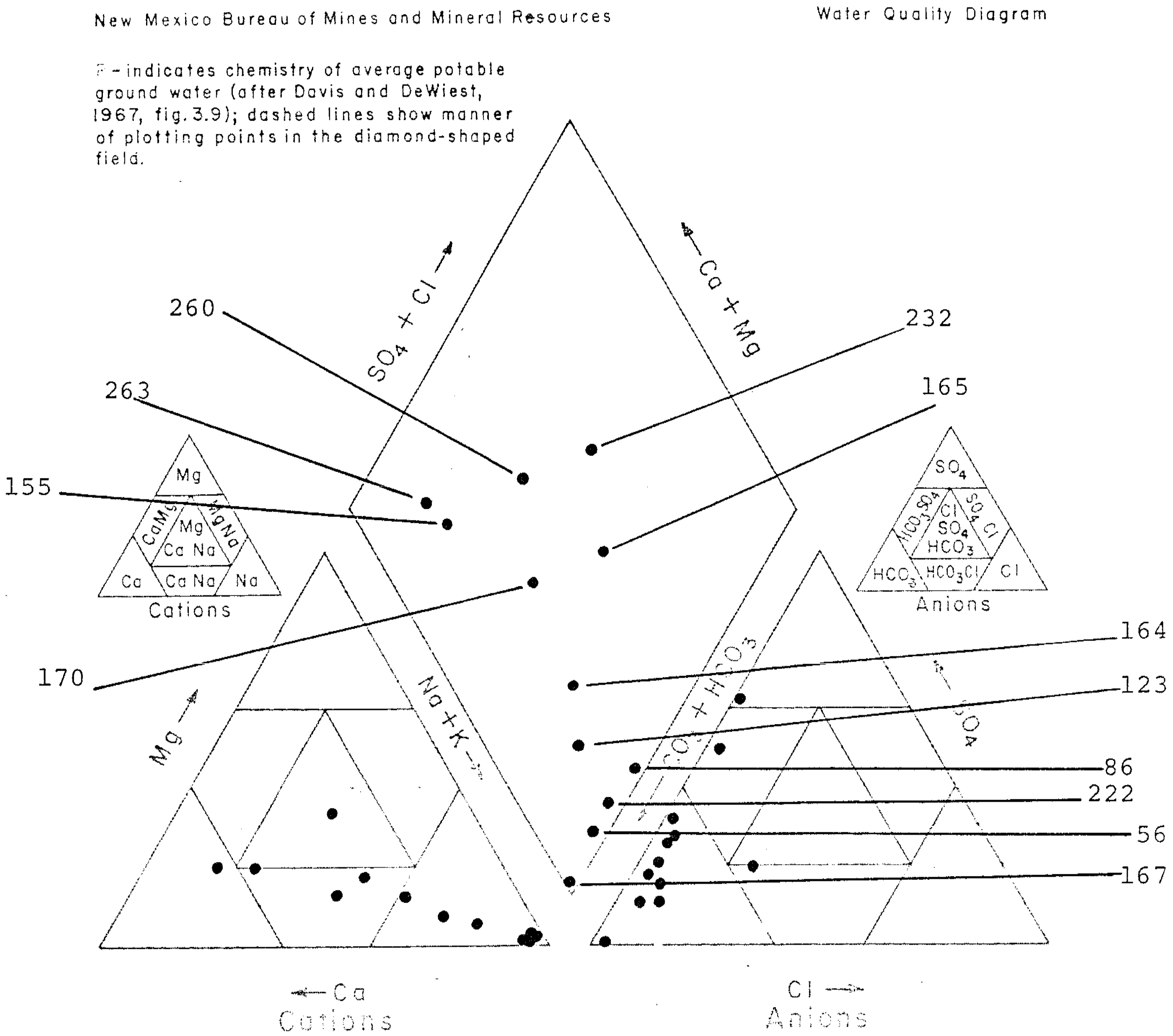

Figure 6. Trilinear plot of water chemistry, stock and domestic wells in Moreno Hill Formation; points are identified by accession number (see Plates 1 and 27, Appendices 5 and 6).

the top of the Atarque. With the exception of a northwest-southeast trending synclinal feature in T4N, R17 and R18W, this unit generally dips gently southeastward. As inferred on Plate 26, the regional dip direction may swing to the south in the eastern part of the project area. Note that the Tejana Mesa fault zone appears to have no influence on the Atarque structure. Although this may well be a reflection of the scarcity of data, a difference in elevation of 250 ft across the major fault does not seem apparent between the two data points oriented perpendicular to the zone.

Thickness of the Atarque in the subsurface ranges from 35 to 90 ft. Landis et al. (1985) reported that the thickness in outcrop varies from 20 to 100 ft. It is above the regional water table in the southern half of the Fence Lake SW quadrangle and northern half of the Lake Armijo quadrangle, partially saturated in the extreme northern part of the Cerro Prieto quadrangle, but completely saturated throughout the rest of the region.

Little is known about the hydrologic properties of the Atarque. Estimates from geophysical logs indicate a porosity of slightly more than 20 percent for the massive, crossbedded beach sandstone that forms the upper portion of the unit. Stone et al. (1983) reported transmissivity values from marine sandstones in the San Juan Basin (Pictured Cliffs, Point Lookout, and Gallup) ranging from 0.001 to 350 ft^2/day. The Atarque could be considered an aquifer, however its great depth over much of the area precludes its use for domestic or stock water supply.

Only two inventoried wells are known to be perforated in the Atarque. One is a monitoring well (39, 2.17.9.343) owned by the Salt River Project. The static water level in this well lies approximately 150 ft below land surface at an elevation of 6,550 ft. Although screened in the Atarque, the hole is open at the bottom to approximately 380 ft of Mancos Shale. Yield or water quality data are not available from either well 39 or the other well (273, 5.16.31.441). A developed spring issues from the Atarque outcrop south of Santa Rita Mesa (266, 4.18.28.211). A sample from this spring has a conductance of 865 micromhos/cm and its analysis plots in the sodium-bicarbonate field (Figure 3).

The Atarque conformably overlies the Rio Salado Tongue of the Mancos Shale.

Rio Salado Tongue of the Mancos Shale (Upper Cretaceous)

The Rio Salado Tongue of the Mancos Shale crops out in the west-central portion of the Nations Draw area on either side of the Largo Creek valley. This unit is composed mainly of gray to yellow-brown marine shale with thin siltstone interbeds. Thin beds of glauconitic calcarenite and fossiliferous limestone concretions also occur (Campbell and Roybal, 1984). The average total drilled thickness is slightly more than 230 ft in this area. Like the Atarque Sandstone, it is fully saturated over most of the region.

Although there are no local estimates, hydraulic conductivity in the Rio Salado is probably very low. Frenzel and Lyford (1982) estimated vertical hydraulic conductivities of major confining bed sequences in the San Juan Basin, including the lower Mancos Shale, at 10^{-4} to 10^{-5} ft/day.

No wells in the area are known to obtain water solely from the Rio Salado, although well 39, as mentioned above, is open to it. Another well (142, 3.18.26.211) which is reportedly 60 ft deep, is located near the edge of the Largo Creek valley fill and may be open to both alluvium and the Rio Salado.

Twowells Tongue of the Dakota Sandstone (Upper Cretaceous)

The Twowells Tongue of the Dakota Sandstone is a very fine to medium grained sandstone, lying between the Rio Salado and Whitewater Arroyo Tongues of the Mancos Shale. It is the oldest unit that crops out within the Nations Draw area and it has been mapped on the surface only in a very small area in section 32, T4N, R18W on the western border of the Fence Lake SW quadrangle. Deep exploration wells show that its thickness averages 30 ft in the subsurface. The Twowells is probably fully saturated everywhere in the Nations Draw region but the lower reaches of the Largo Creek valley.

Beneath the Whitewater Arroyo Tongue, whose thickness ranges from 65 to 105 ft, lies another relatively thin tongue of the Dakota: the Paguate. The aquifer potential of these two sandstone bodies is not known in this area. Porosity estimates of the Twowells Tongue range from less than 5 percent to 20 percent. Brod and Stone (1981) reported that sandstones in the Lower Mancos Shale interval near San Mateo in McKinley County yielded large amounts of water to underground mines in the underlying Morrison Formation (Jurassic). Aquifer testing at FL-36 (254, 4.17.36.122) in the Main Body of the Dakota Sandstone yielded a transmissivity of 709 ft^2/day and a 1-hour specific capacity of 0.86 gpm/ft (SRP, 1983). If this value is divided by an average regional thickness of 103 ft, the resulting horizontal hydraulic conductivity is 6.9 ft/day. If one assumes an identical hydraulic conductivity for both the Twowells and Paguate Tongues, the approximate transmissivity of these 2 units would be 380 ft^2/day for the Paguate and 207 ft^2/day for the Twowells. These are based on mean regional thicknesses of 55 ft and 30 ft, respectively. These conductivity estimates are probably high, however. The drill log of well 254 reports that most of the water flowing into the uncased hole after drilling was from the Main Body of the Dakota Sandstone (SRP, 1983).

Like the Atarque, the depth of these units precludes their use for domestic and stock water supply over most of the region. However, four wells in the western part of the area apparently tap these sandstones. The log from one (267, 418.35.331) indicates that it is completed in one or both units (Appendix B of SRP, 1982). No yield or water quality data are available for this well. Another windmill, the Lucero (224, 4.17.10.211), has a reported depth of 425 ft and is located roughly 200 to 250 ft above the Atarque Sandstone (see Plates 21 and 26), indicating that it is probably open to the Twowells. An analysis from this well plots in the sodium-sulfate field (Figure 3). Depending on local structure in the northern half of the Lake Armijo quadrangle, two other wells are probably perforated in the Twowells and possibly in the Paguate. These are the Carter well (139, 3.18.9.223), and the Jerry windmill (140, 3.18.22.232). It is possible that the Jerry well is also completed in the main body of the Dakota Sandstone. Reported yield of these wells are 30 gpm (Carter) and 20 gpm (Jerry). Specific conductance values are 900 micromhos/cm from the Carter well, and 844 and 860 micromhos/cm from the Jerry well. Major ion chemistry of the latter plots in the sodium-bicarbonate field (Figure 3), which is the same field that contains analyses of well 254 (SRP, 1986).

GEOLOGIC CONTROLS OF GROUNDWATER OCCURRENCE

Location and geometry of permeable deposits.

In the saturated zone, groundwater exists as a continuum within interstitial pore spaces and fractures. Significant amounts of water will flow into a well or excavation only from materials with relatively high hydraulic conductivity. In most of the Nations Draw area, the more permeable deposits include unconsolidated alluvium, sandstone and conglomerate.

The occurrence of significant amounts of groundwater in the saturated part of the alluvium is controlled by its geometry and 'stratigraphy', or, the location and areal distribution of the coarser grained sand and gravel. These are, in turn, controlled by the Quaternary geologic history of the setting.

Saturated alluvium is restricted to the valleys of the larger draws of the Fence Lake leasehold. In Nations Draw, saturated sand and gravel deposits are mainly limited to the deeper buried valley, and usually make up less than 50 percent of the total saturated thickness. In Tejana Draw the percent of saturated alluvium composed of coarser material varies from 0 to 100 percent and is not confined to the center of the buried valley. For example, all of the saturated alluvium at drill hole 110 (119, 3.17.11.342) is coarse grained sand or gravel.

The occurrence of significant groundwater in sandstones and conglomerates is primarily controlled by their geometry, porosity, and hydraulic conductivity. These factors are in part controlled by the depositional environment of the deposits.

The Baca Formation in the Nations Draw area was deposited in a fairly dry, savannah-like alluvial plain environment with isolated lacustrine sediments (Cather and Johnson, 1984). Baca sandstone and conglomerate geometries include sheetlike or broad, shallow, channel-shaped bodies in the distal alluvial fan facies and either similarly shaped channels or, more rarely, large distributary channels with low width-to-depth ratios in the lacustrine fan-delta facies. These coarse grained bodies are interbedded with very fine-grained mudstones. Too few subsurface data exist within the Baca to make a further observation of vertical stratification.

The Moreno Hill Formation was laid down in a humid, low energy, meander belt and/or lower delta-plain environment. The meander belt system commonly produces conglomeratic channel-lag and sandy, cross-bedded point-bar deposits with a 'shoestring' geometry and, in general, an upward decrease in grain size. Deltaic distributary channels have a similar shape, but sometimes display an upward increase in grain size. Such discontinuous, lenticular sandstones are abundant within the Moreno Hill. Where the Moreno Hill is divided into 3 members, channel sandstones are more abundant in the lower member than in the upper one

(Campbell, 1984; Roybal, 1982). In drill holes penetrating 200 ft or more of the Moreno Hill, an average of 22 percent of the total thickness consists of sandstone beds greater than 5 ft thick (excluding the middle sand where present). In general, as Plates 24 and 25 suggest, the areal distribution of subsurface channel sandstone bodies is difficult to predict accurately without closely spaced drilling.

Sandstones deposited in a nearshore environment have a sheetlike form that are much more areally extensive than fluvial sands. Reworking of sand grains during deposition winnows out finer grained particles, producing a higher primary porosity and more uniform hydraulic characteristics than most alluvial plain sediments. Thus, this type of sandstone deposit also has a greater potential for yielding water than fluvial sandstones.

Postdepositional history.

An additional control of groundwater occurrence is provided by the postdepositional history of the water-bearing units. Consolidation and compaction of fine-grained, unconsolidated alluvium further reduces its hydraulic conductivity. Cementation of lithified sediments by both carbonate and clay minerals reduces primary porosity and thus hydraulic conductivity. Fracturing causes secondary porosity, thus increasing hydraulic conductivity in coal, shale, and sandstone. Depending on their thickness, coals can act as aquifers by transmitting water through their fractures.

In a few cases, sandstones within the Moreno Hill Formation in the lease area are fractured. Gibbons et al. (1981) discussed three types of fracture patterns in Mesaverde rocks of the Colorado Plateau in northwestern New Mexico. These are: (1) local fracture patterns associated with specific local tectonic structures, (2) regional fracture patterns resulting from widespread tectonic events, and (3) regional orthogonal fracture patterns of a diagenetic origin which cannot be related to basement-rooted strain fractures. They developed a modeling strategy to predict the distribution of the third type and conclude that fracture spacing can be related to bed thickness where lithology is consistent. This type of fracture pattern may be present and mappable within the lower Moreno Hill sandstones of the lease area. Fracture zones of the first and possibly the second type may be present near Cerro Prieto.

GEOLOGIC CONTROLS OF GROUNDWATER MOVEMENT

Recharge

Differences in potential energy provide the driving force for groundwater movement. Groundwater flows from areas of higher potential energy to those of lower potential energy. Recharge occurs where there is a downward flux of moisture within the vadose zone which adds water to the groundwater flow system. More specifically, Freeze (1969) defines recharge as the "... entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone". A recharge area is characterized by groundwater flow away from the water table. The magnitude and direction of the flux below the water table are controlled by the dimensions of the groundwater basin, the water-table configuration, and the permeability distribution resulting from the subsurface stratigraphy. In an actual groundwater basin, a state of dynamic equilibrium usually exists in which water-table fluctuations are kept within relatively narrow bounds and the rate of recharge is relatively constant at a given location but varies areally throughout the basin (Freeze, 1969). In the same paper, Freeze listed several general factors which control the addition of water to the saturated zone. These are: (1) the relationships between soil/rock type, pressure head, hydraulic conductivity, specific moisture capacity, and moisture content; (2) the rate and duration of rainfall and evaporation; (3) recharge/discharge rates (flux below the water table); (4) antecedent soil moisture conditions; and (5) depth to water table.

In the Nations Draw area, recharge to the groundwater system is achieved by areal infiltration and percolation from the land surface and as transmission loss from ephemeral streamflow. Due to the fine-grained nature of the majority of the deposits, short duration of rainfall events, and high evaporation rates, the rate of areal recharge is very low. Stone (1984) estimated recharge rates at several sites in the vicinity of the Fence Lake leasehold based on a chloride mass-balance approach. Rates in alluvial settings are approximately 0.08 inches/yr whereas those in bedrock settings are approximately 0.05 inches/yr. These rates may be higher where very fractured bedrock occurs at the surface. Evidence for this mechanism may be the springs near volcanic rocks in sections 9 and 10, T3N, R14W. These springs discharge well above the regional water table at contacts with less permeable bedrock. Greater rates of recharge may occur in natural or man-made depressions, where temporary ponds develop during storms, or as transmission loss from ephemeral streamflow. An additional control on this type of recharge is the sediment load. A high amount of suspended clay may clog pond or channel bottoms. The velocity and channel geometry may also be important. High velocity flow can erode fine-grained material deposited earlier, exposing coarser sediments. The quantity of water recharged in this manner may be greatest in the valleys of the major arroyos where the water table is closest to the surface. This would include the Nations Draw channel in the western portion of the lease area.

Where vertical fractures are not present to enhance water movement beyond the root zone, areal recharge may take a very long period of time. Age estimates for soil water at the base of the unsaturated zone in the lease area are on the order of thousands of years (Stone, 1984). In upland areas where the depth to the regional water table is very great, recharge water probably passes through one or more perched zones of saturation before reaching the regional flow system. Some of this is discharged via springs (266, 418.28.211) or even wells (262, 418.05.144A).

Flow

The difference in hydraulic head (and thus potential energy) at two points defines the hydraulic gradient between them. Considered in three dimensions, points of equal hydraulic head define an equipotential surface. Groundwater flows from surfaces of higher potential energy to those with lower potential energy. There are three major factors affecting the pattern of flow between equipotential surfaces in a groundwater basin (Freeze and Witherspoon, 1967). These are: (1) water-table configuration;

(2) the stratigraphy and resulting subsurface variations in hydraulic conductivity; and (3) the depth/lateral extent ratio of the basin. Topography controls the elevation and shape of the water table surface, and thus controls the location of recharge and discharge areas and the general direction of groundwater flow. The topography of an area is shaped by structural and geomorphic processes acting over time on the local stratigraphic sequence (Stone et al., 1983). The stratigraphy, or more specifically, the three-dimensional hydraulic conductivity distribution, can have both regional and local effects on groundwater flow patterns. The depth-lateral extent ratio refers to the relationship between the depth of significant groundwater flow and the horizontal distance from groundwater divide to major discharge area. This ratio affects the depth to which near-surface, localized flow systems become separated from regional flow systems. Both of the latter two factors are ultimately controlled by the depositional and structural history of the region.

In the Nations Draw area, topography determines the general pattern of groundwater flow. This area is part of a larger, westward flowing system which coincides with the Carrizo Wash surface drainage. The continental divide roughly coincides with the eastern boundary of this system, which includes all of the drainage areas of Largo Creek and Nations Draw. The boundaries of these two drainage systems enclose local groundwater flow systems (Plate 4). A ground-water divide separating the Nations

Draw basin from the Largo Creek basin extends westward from just southwest of Adams Diggings to the Mesa Tinaja-Tejana Mesa area. The higher elevations along this boundary are recharge areas, with downward flow directions on either side of the groundwater divide. The water-table surface is smooth, without minor variations due to topographic changes. Such variations in, for example, the Nations Draw basin, would suggest the existence of small-scale flow regimes enclosed within it. Flow is probably upward (indicating discharge areas) in the lower reaches of the Nation Draw and Largo Creek valleys. Hydrogeologic cross-sections A-A' and B-B' (Plate 3) depict approximate flow patterns in two dimensions within the Nations Draw system. Section A-A' was drawn across the valley and parallel to the regional structural dip direction, but perpendicular to the major direction of regional groundwater flow. Thus, A-A' illustrates flow in the Nations Draw ground-water basin only, showing a central discharge area with recharge areas on either side. In order to portray ground-water flow within the regional (Carrizo Wash) system, a much larger section oriented roughly west to east would be needed. Much of section B-B' is oriented nearly parallel to a water table contour, and thus the water table depression across Nations Draw is not apparent on this section. Equipotential contours were omitted from B-B' because of the lack of detailed subsurface data for the lower part of the Moreno Hill Formation.

As discussed earlier, a great deal of heterogeneity in hydraulic conductivity exists within the suite of sedimentary layers underlying this region. Freeze and Witherspoon (1967) demonstrated that layers of high conductivity extending throughout a groundwater basin have a pronounced effect on flow patterns. The Cretaceous marine sandstone aquifers have much higher hydraulic conductivities than the Mancos Shale and the Moreno Hill Formation shales and siltstones. Groundwater flow directions have been drawn on Plate 3 to reflect this difference. Flow is generally vertical in the Mancos Shale. In the sandstone aquifers it is parallel to dip but still toward the center of the basin, in response to the influence of the water-table configuration. The flow direction arrows are not meant to imply any significant hydraulic connection between groundwater in the tongues of the Mancos Shale and near-surface groundwater. Due to its very low hydraulic conductivity, specific discharges through marine shale should be so low that travel times for water to pass vertically upward through, for example, the Rio Salado Tongue, would be measured on the geologic time scale rather than an historical one.

The depth of the Carrizo Wash regional flow system may extend beneath the permeable San Andres Limestone and Glorieta Sandstone. The western equivalents to these units, the Kaibab Formation and Coconino Sandstone, underlie and supply water to the Coronado Generating Station at St. Johns (SRP, 1983). ¶ The effective depth of the Nations Draw sub-basin is hard to discern from the available data. As Freeze and Witherspoon (1967) explain, a thick layer of very low permeability beneath a regional aquifer will have a negligible affect on flow patterns within a basin. Flow directions in such a layer will be horizontal and parallel to those in the aquifer. In the Nations Draw area, the low permeability layer could be the Rio Salado Tongue of the Mancos Shale and the Atarque Sandstone could be the overlying regional aquifer. However, three other aquifers of regional extent lay beneath the Rio Salado Tongue. If the Dakota Sandstone aquifers (particularly the Main Body) affect flow above, the basal low permeability layer would then be the Chinle Formation. In any case, due to the extremely low hydraulic conductivities expected in the marine shales, upward flow volumes to the Nations Draw valley would not be significant.

The actual pattern of flow directions is more complex than illustrated due to the heterogeneity of the Moreno Hill Formation. This is because the geometry and areal distribution of less extensive, highly conductive zones also controls the direction of groundwater flow in localized areas. Freeze and Witherspoon (1967), as well as more recent site-specific studies by Fogg (1986), and Krabbenhoft and Anderson (1986), have shown that lenses of higher hydraulic conductivity than the surrounding rocks cause localized vertical gradients. The local gradient will be downward above the upgradient end of the lens and upward above the downgradient end (Figure 7). The alluvial sand and gravel layer as well as sandstones within the Moreno Hill and

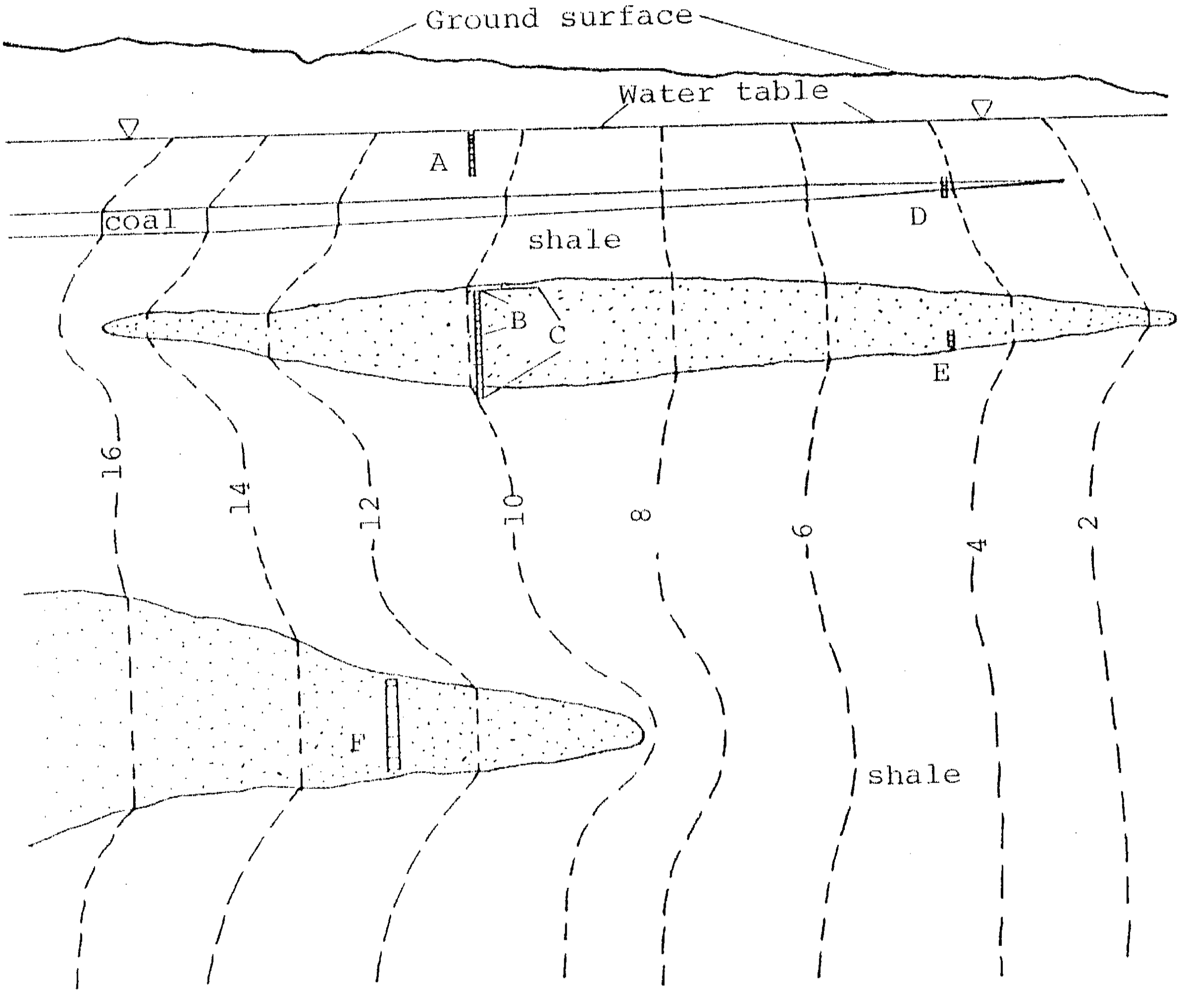

Figure 7. Schematic diagram showing effect of high conductivity lenses on a local ground-water flow system (not to scale), A - E are examples of screened intervals in this study, F is a hypothetical screened interval for a stock well

— — 10— — potentiometric contour (units arbitrary)

▨ sandstone

Baca could cause this flow behavior.

Differences in hydraulic head between observation wells at multiple-well monitoring sites provide evidence ~~of vertical~~ ~~gradients in~~ the vicinity of the lease area. Downward gradients are indicated at four sites, upward gradients at four others, and gradients in both directions are indicated at three points ~~where~~ ~~head measurements~~ have been made at three elevations (Table 4). Screened intervals A, B, and C on Figure 7 ~~could be~~ represent~~ative of~~ flow conditions at monitoring point 317-13-1 (124, 3.17.13.114) and intervals D and E ~~could~~ represent conditions at 317-11-34 (120, 3.17.11.344).

The effect of faulting and fracturing on groundwater flow depends on the type of rock, whether the fractures are open or closed, and depth. Faulting often acts as a barrier to lateral flow by offsetting permeable beds or by the formation of a zone of low permeability gouge along the fault planes. Thus, vertical gradients can be formed by structural truncation of aquifers as well as by depositional pinchouts. Alternatively, zones of open fractures along faults or folds can provide fracture permeability. In a study of hydraulic conductivity in Cretaceous marine shales above the Dakota aquifer in South Dakota, Neuzil et al. (1984) compared numerically-determined regional values to local values obtained by aquifer and core testing. They attributed the higher regional values to vertical fracture zones within the shale. Fracture aperture, and thus hydraulic

Table 4. Vertical hydraulic gradients at multiple-well monitoring sites

Accession Number	Monitoring Well Site	Lithology[1]	Midpoint of Screen[2]	Mean SWE[3]	Vertical Gradient[4]
67	316-06-13M1	sandstone	155	6618.23	-0.366
67	316-06-13M2	coal	198	6602.50	
95	317-10-42M2	coal	65.5	6574.29	-0.116
95	317-10-42M1	sandstone (bc)	88.5	6571.62	
101	317-11-14OB1	sand & gravel	95	6577.62	-0.308
101	317-11-14M1	sand & gravel	110	6573.00	+0.076
101	317-11-14OB2	sandstone (ba)	190	6579.07	
120	317-11-34M2	coal	72	6585.00	+0.079
120	317-11-34M1	sandstone (bc)	123	6589.03	
122	317-12-14M2	coal	119	6600.76	-0.055
122	317-12-14M1	sandstone (bc)	165	6598.23	
124	317-13-1M2	sandstone (ac)	115	6601.42	-0.034
124	317-13-1OB2	sandstone (bc)	206	6598.28	+0.187
124	317-13-1M3	sandstone (bc)	215	6599.96	
175	416-20-4M1	sand & gravel	115	6624.80	+0.019
175	416-20-4M2	sandstone (bc)	157.5	6625.63	
192	416-29-4M1	silty alluvium	83	6630.97	+0.014
192	416-29-4M2	sandstone (bc)	164	6632.08	
196	416-30-42M1	sand & gravel	157	6620.01	+0.028
198	416-30-42OB2	bedrock?	180	6620.66	
207	416-32-311M2	coal	130	6618.26	-0.194
207	416-32-311M1	sandstone (bc)	165	6611.47	
239	417-26-22M1	shale (ac)	62.5	6602.14	-0.185
239	417-26-22M2	sandstone, shale	105	6594.28	+0.062
239	417-26-22M3	coal, shale	140	6596.44	

1 (ac) = above coal; (bc) = below coal; (ba) = below alluvium
2 feet below land surface
3 mean static water elevation from Appendix 3
4 Vertical Gradient (I); + = upward; - = downward

Example: I = [mean SWE(M1) - mean SWE(M2)] / (m2 - m1)
= [(6602.00-6600.00) / (130-100)] = -0.067

where m1 = midpoint of screen in well M1 = 100 ft
m2 = midpoint of screen in well M2 = 130 ft

conductivity, is reduced in these shales with depth due to increasing compressive stress. Marine shales beneath the lease area may be buried too deeply for fracture flow to be significant, but it is possible that shales within the Moreno Hill Formation transmit water in this fashion.

A fault or fracture zone extending for many miles could affect flow patterns indirectly by influencing the geometry and distribution of high conductivity layers. For instance, the formation of a valley along a fracture-controlled lineament can result in the deposition of unconsolidated sand and gravel within it. The linear trend of Nations Draw from the center of the lease area southwest to T3N, R18W may be an example. More obvious alterations in flow patterns which could be attributed to large-scale faulting or fracturing are not evident on the water-table maps (Plates 4 and 5).

The presence of dense, crystalline, igneous rocks can influence groundwater flow in localized areas also. Unless very fractured, these rocks should act as barriers to flow. This is apparently the case at El Portocito, where the alluvial aquifer has been constricted by a volcanic neck. This neck, which may be attached to related dikes in the subsurface, forms enough of a barrier to force the water table to the surface just upstream. Where extensively fractured igneous rocks occur within less fractured fine-grained sedimentary rock, however, they could affect gradients in much the same way as the sandstone lenses described above. Volcanic necks and vents can act as conduits by enhancing vertical flow. Bradbury (1966) described Zuni Salt Lake as fed by springs originating in this manner. The northwest trending, vertically oriented dike system is located near the regional groundwater divide in an area of essentially downward flow. Thus, it may have little or no effect on flow patterns except at great depth where flow paths become horizontal. Flow alterations by the several necks and vents may be too local to show up on Plates 4 and 5. In the lease area, any flow alterations caused by Cerro Prieto are not apparent.

Discharge

The regional water table does not, with the sole exception of El Portocito, intersect the land surface in this semi-arid region. However, discharge at the water table beneath the land surface probably does occur via evapotranspiration. Discharge areas are defined by Freeze and Witherspoon (1967) as those areas where the groundwater flow direction is upward and toward the water table. Their existence and/or distribution are closely related to and ultimately controlled by the same three major factors that influence groundwater flow. These factors affect the percentage of flow in a basin that discharges into its major valley. The valley of a relatively homogeneous basin with a smoothly sloping water table surface may receive concentrated discharge. A stratified system, like the Carrizo Wash regional flow system, is more likely to have smaller sub-basins with discharge locations governed by both the regional and local stratigraphy. Freeze and Witherspoon (1967) described three cases in which discharge can result from geologic control: (1) below the outcrop of a downstream sloping aquifer; (2) at the outcrop of an upstream sloping aquifer; and (3) above the pinchout of a buried high permeability aquifer. They noted that, in the third case, the extent of the discharge area and the intensity of the discharge depend on both the position of the high permeability lens within the flow system and the hydraulic conductivity contrast between it and the surrounding rock.

Localized discharge areas due to case 1 may occur in the northern part of the Nations Draw area below where south and southeastward dipping sandstones intersect the water table. Discharge areas could result from case 2 where the Atarque and Dakota sandstone aquifers intersect the water table in the Fence Lake SW and Lake Armijo quadrangles. They may also occur locally where southeastward dipping Moreno Hill and Baca sandstones intercept a northward or northwestward sloping water table. The gentle structural dip of these units makes discharge due to these mechanisms problematical, however. Localized discharge areas due to the third case seem more likely in this region.

In order to examine the possibility of discharge areas within the lease area, three graphs of well depth versus depth to static water level have been made from monitoring and stock well data (Figures 8, 9, and 10). This type of plot can serve as a rough indicator of whether a well is in a recharge or a discharge area. Its disadvantage is that a constant depth to the water table is required, which is a difficult condition to meet in this vicinity. Some information can still be obtained from them, however. In general, monitoring sites with downward gradients on Table 4 plot in the recharge fields of these figures. Several sites with upward gradients plot in the transition zone between recharge and discharge areas.

Several wells plot in the discharge fields. Although the depth to the water table at monitoring point 317-11-34 (120) is probably a little less than the average computed for wells in the Tejana Draw valley (Figure 8), the upward gradient at this site may justify its location on the graph. Other wells which fall in this field are stock wells 123 (3.17.12.314) and 135 (3.17.24.232) on Figure 8, and monitoring points 251 (4.17.34.433) and 255 (4.17.36.124) on Figure 9. Except for well 135, their positions may also be functions of the differences in depth to the water table. At 135, however, the water table is greater than 60 ft below the land surface. Flow patterns at this well could be caused by a situation similar to the deeper sandstone pinchout shown on Figure 7. A well perforated along interval F would have a static water level above the water table elevation. Well 135 would then be in a recharge area, as shown by the downward gradients at the water table above F.

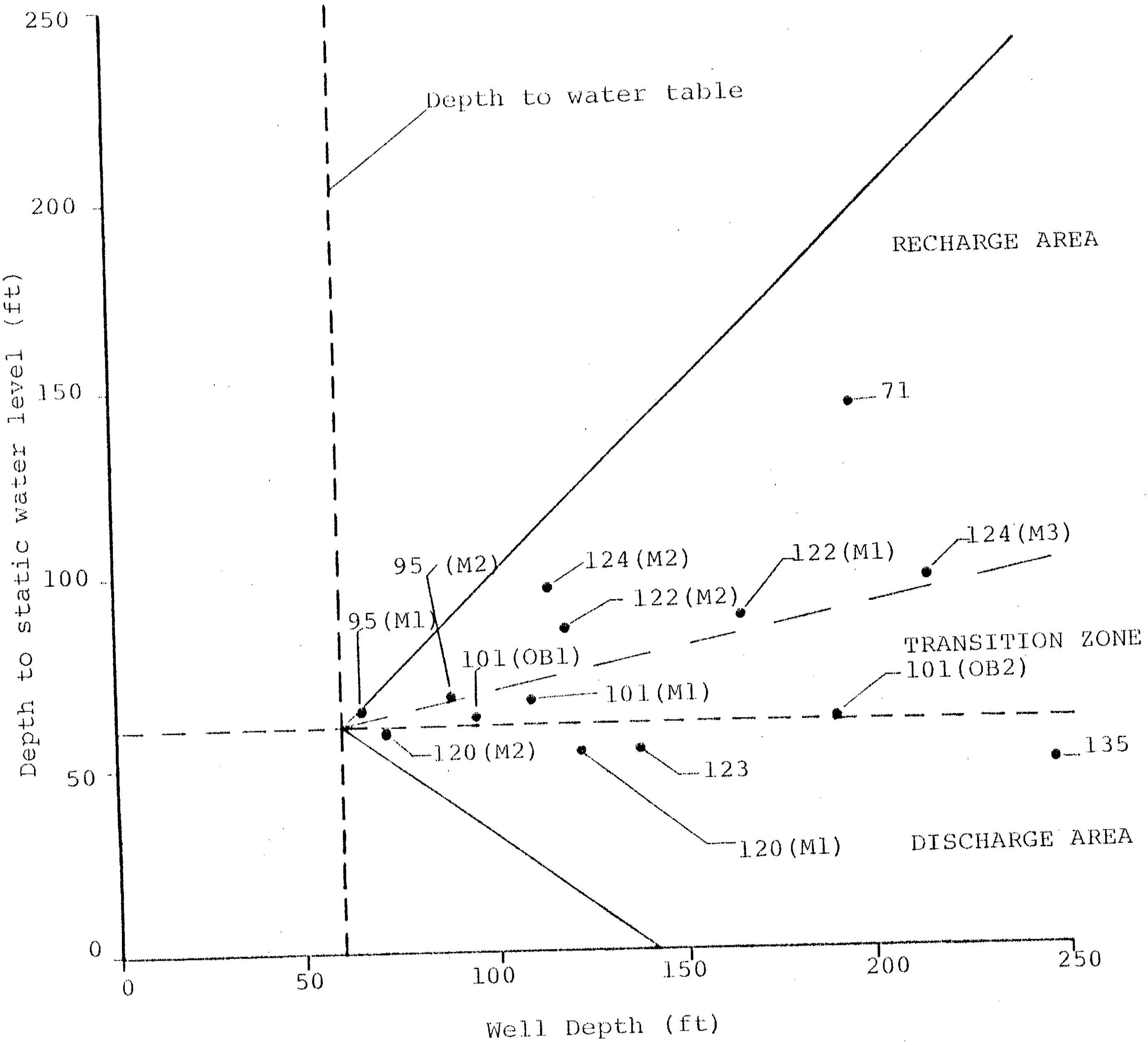

Figure 8. Well depth vs depth to static water level, Tejana Draw valley, wells and monitoring points less than 50 ft above valley floor; wells are identified by accession number and monitoring well number in parentheses (see Plate 1 for location).

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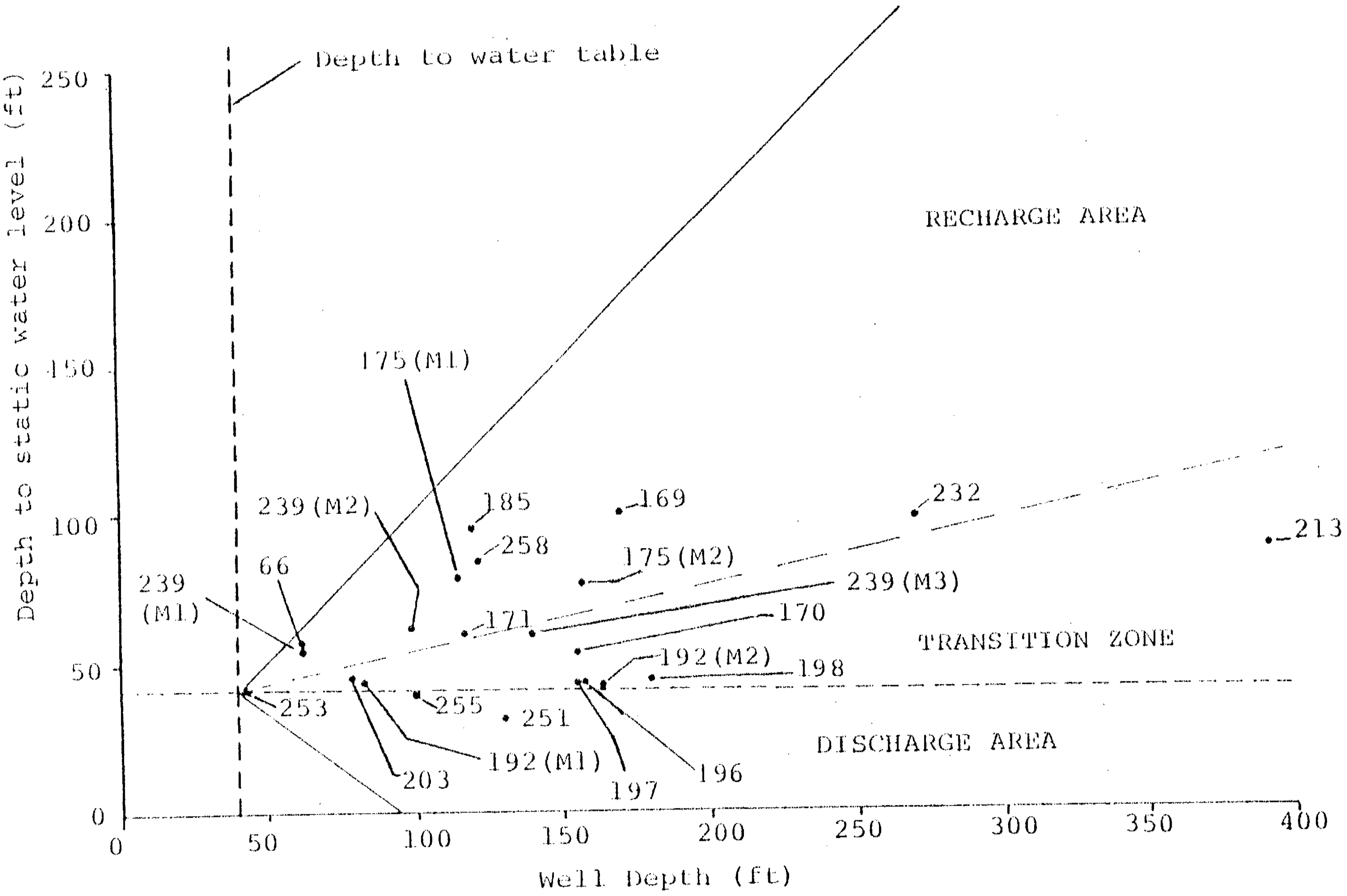

Figure 9. Well depth vs depth to static water level, Nations Draw valley, wells and monitoring points less than 50 ft above valley floor; wells are identified by accession number and monitoring well number in parentheses (see Plate 1 for location).

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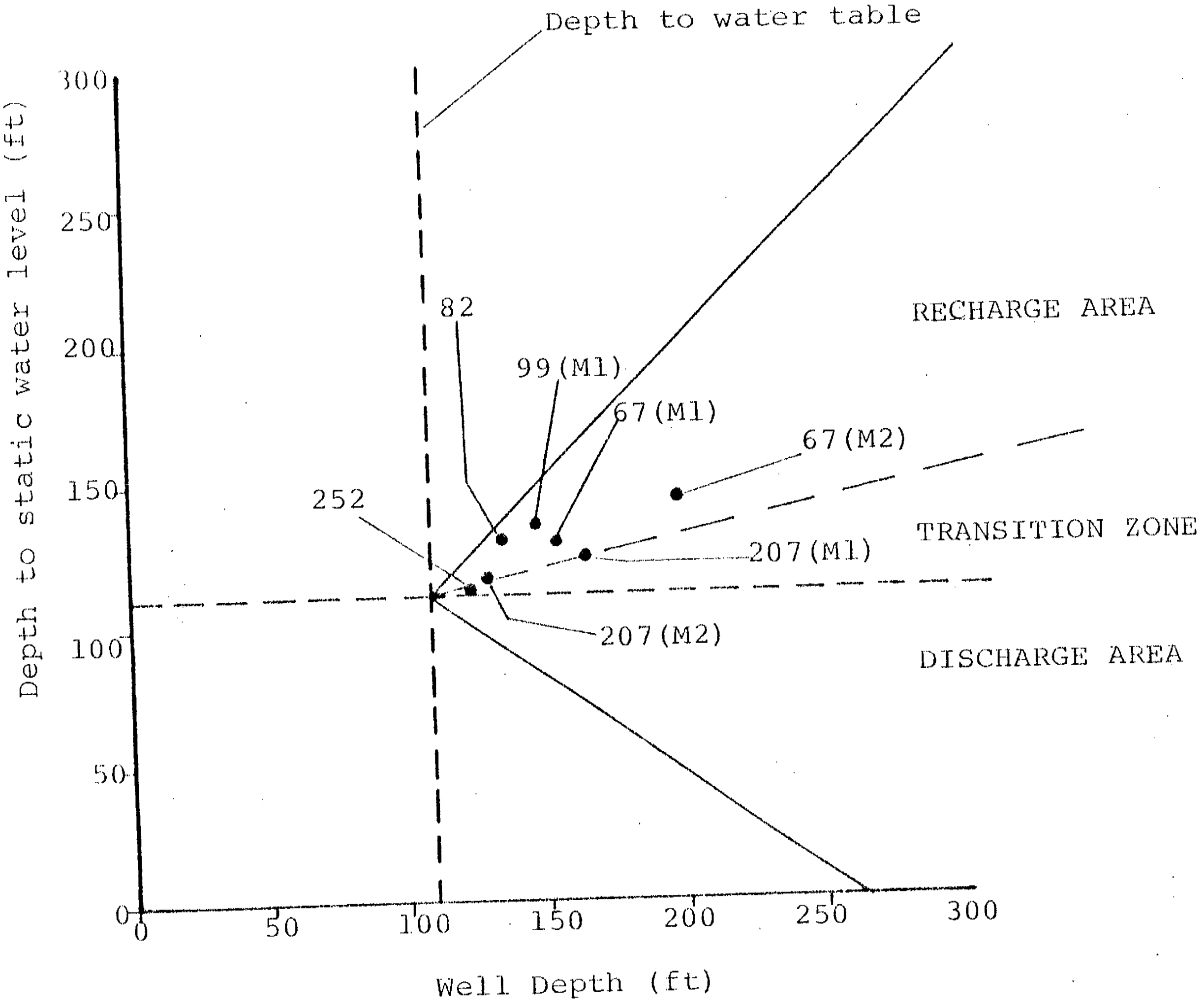

Figure 10. Well depth vs depth to static water level, upland areas in vicinity of Fence Lake leasehold, monitoring points greater than 50 ft above valley bottoms; wells are identified by accession number and monitoring well number in parentheses (see Plate 1 for location).

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Tejana Draw is located on the southeast slope of the water table surface rather than in a major depression (Plate 5). Thus, the apparent discharge areas located there might be best explained as examples of geologic control 3 of Freeze and Witherspoon. As suggested by the downward gradients in bedrock and alluvium at other sites in Tejana Draw and in Taylor Draw (Table 4), these valleys and the uplands surrounding them are probably, on the whole, recharge areas with localized sites of discharge caused by high conductivity lenses near the water table. These lenses may consist of sand and gravel, fractured sandstone, or, where thick enough, coal seams.

The Nations Draw valley lies parallel to the axial depression of the water table surface and acts as the discharge area for the Nations Draw ground-water basin. In the lease area, possible discharge areas due to topographic control include sections 20, 29, and 30 in T4N, R16W, as well as the center of the valley downstream. Discharge is influenced by geologic factors here as well. Upward gradients from bedrock into sand and gravel indicate upward flow into the alluvial aquifer. Because of the low permeability of much of the bedrock, discharge would be greatest where more permeable sandstones subcrop beneath the alluvium. However, where the saturated sand and gravel is thick, flow is mainly horizontal and southwestward along the slope of the buried paleochannel. The contrast in hydraulic conductivity between bedrock and coarse alluvium may be great enough that the upward flow from the bedrock basin is not transmitted to the water table surface. In this case, discharge areas along the valley would be restricted to those areas not overlain by the sand and gravel aquifer. At monitoring point 416-29-4 (192, 4.16.29.441) a slightly upward gradient into fine-grained alluvium is indicated. South of this site, but still within the valley, saturated alluvium becomes thin or nonexistent. It is here that the sandstone underlying the Cerro Prieto coal zone could cause localized discharge zones. Other places within the valley where sandstone appears to underly a potential mining area not far below the water table are section 19 and the northern half of section 30 in T4N, R16W.

GEOLOGIC CONTROLS OF GROUNDWATER QUALITY

The chemical quality of groundwater is ultimately controlled by the geologic framework of the flow system. In a complexly layered sedimentary basin this control is manifested in two interrelated ways. These are the order of encounter of groundwater with soluble minerals and its residence time in the system. Residence time means simply the length of time between recharge and discharge. It depends on the length of the flow path as well as the hydraulic conductivity of the rocks through which the water flows. In general, the concentrations of dissolved constituents increase with length of flow path and decreasing hydraulic conductivity. Specific conductance generally is higher in discharge areas than in recharge areas. Order of encounter refers to the order in which various types of minerals are encountered by the water as it moves through the flow system (Freeze and Cherry, 1979). Different materials in a layered sequence contain different soluble minerals. While flowing through these rocks, groundwater will react with and dissolve different mineral species. The sequence of sedimentary layers, and some of the sedimentary minerals they contain, is controlled by fluctuations in the depositional settings of the units.

According to Groenewald et al. (1981), geochemical processes in the unsaturated zone within recharge areas are important to groundwater chemistry in coal-bearing strata. Depending on the depositional setting, processes such as calcite and gypsum dissolution and concomittant bicarbonate production, pyrite oxidation, and cation exchange occur in the zone of percolating water. Commonly, the only important saturated-zone geochemical processes are cation exchange and sulfate reduction. Calcium ions replace sodium ions on clay-mineral lattices and anaerobic bacteria reduce sulfate in order to metabolize organic carbon. In the process, hydrosulfide ion is produced which, if reactive iron compounds are present, form solid iron sulfides (Drever, 1982). In clayey, sodium-rich rocks, these reactions account for the predominance of sodium-bicarbonate waters.

The abundance of sodium-montmorillonitic materials in the Nations Draw area has a profound effect on water chemistries. Of the 59 points plotted on Figures 3 through 6, 54 (91 percent) contain sodium as the dominant cation. In fact, only two analyses on all four of these figures have less than 20 percent epm sodium. These two (spring 41, 2.17.13.242; and well 262, 418.05.144A) are from perched water in volcanic rocks on Tejana Mesa and the Middle Sand Member of the Moreno Hill Formation, respectively.

Twenty-eight of the 38 analyses on Figures 3, 4, and 6 plot within the sodium-bicarbonate field and five of the remaining ten are within either the calcium, sodium-bicarbonate or sodium-bicarbonate/sulfate fields. Thus, it appears that cation exchange and sulfate reduction may be the dominant processes in both the Nations Draw and Largo Creek flow systems. Water sampled from discontinuous sandstones or from alluvium has probably spent much of its travel time in clay rich shale, siltstone, or sandy-clay alluvium.

Higher proportions of either calcium or sulfate in some samples can be explained in two ways. First, analyses from monitoring point 67 (3.16.06.133) may represent 'new' groundwater in a recharge zone in which both calcium and sulfate from carbonate and gypsum dissolution are still relatively abundant. Second, water from the Lucero windmill (224, 4.17.10.211) is of a sodium-sulfate type. This well is believed to be completed in the Twowells Tongue of the Dakota Sandstone. The relatively high hydraulic conductivity and extensive nature of this sand makes it a preferred pathway for groundwater. Although cation exchange has proceeded to where sodium is the dominant cation, there may be insufficient organic carbon for sulfate reduction.

Lab and field values for specific conductance throughout the Nations Draw area (Appendices 5 and 6) are shown on Plate 27. One generalization that can be made concerning this map is that lower values are found at higher elevations while higher ones occur at wells completed in bedrock within the major valleys. There are obvious exceptions to this, for example, well 40 (2.17.11.333) and the Martinez windmill (220, 4.17.03.324B). It is interesting that all five of the analyses containing sulfate as the dominant anion are among those with the highest conductances. These may represent waters from the intermediate zone of the Chebotarev (1955) sequence, in which ground-waters pass from bicarbonate dominated to sulfate dominated, with an increase in total dissolved solids (Domenico, 1972). The average conductance at FL-36 (254, 4.17.36.122) is 638 micromhos/cm. This well is completed in the highly transmissive Main Body of the Dakota Sandstone which acts as a conduit for groundwater flow, providing a quicker flow path than the interbedded sandstones and mudstones of the overlying strata. All conductance values are less than 2,000 micromhos/cm, providing evidence that the shallower continental deposits comprise a sub-basin of a larger regional system that discharges to the west. Higher conductances would be expected if water following the deeper flow paths of the regional system discharged in this area.

SUMMARY AND CONCLUSIONS

Geologic and hydrologic data from eight quadrangles representing the Nations Draw area have been compiled, mapped, and analyzed. Sedimentary rocks of Permian to Miocene age underlie or crop out within the region. Those younger than Eocene lie above the regional water table in the Nations Draw basin. Ground water is the major source of domestic and stock water supplies. Important shallow water-yielding units include Quaternary alluvium, the Baca Formation (Eocene), and the Moreno Hill Formation (Upper Cretaceous). Buried valleys, commonly containing more than 100 ft of Quaternary alluvial fill, exist within the larger draws. Coarse sand and gravel deposits with relatively high hydraulic conductivity lie within the buried valleys. Sheetlike or lenticular channel sandstone bodies form localized aquifers within the Baca and Moreno Hill Formations. The Moreno Hill overlies a sequence of four extensive, relatively permeable Upper Cretaceous marine sandstone units separated by three tongues of the relatively impermeable Mancos Shale. Thick Triassic and Permian sedimentary sequences of variable lithology underlie the region.

The occurrence of significant amounts of ground water is controlled by the location and geometry of the sand and gravel and sandstone units. These factors are, in turn, determined by depositional environment and postdepositional history. Ground water flows generally south and west in response to topographically controlled changes in the regional water-table configuration. Major recharge areas probably occur within the alluvial valleys and at higher elevations in the north and east while topographically-controlled discharge may occur in major valleys where flow from bedrock is not diverted laterally by high-conductivity alluvium. Subsurface permeability variations also exert regional and local influences on ground-water flow patterns. Localized zones of recharge and discharge occur where sand and gravel or channel sandstones pinch out just below the water table. Flow at depth is influenced by both continental and marine sandstones. The continental sandstones are local but the marine sandstones are more extensive. Slow movement in contact with abundant montmorillonitic clay results in a predominately sodium-bicarbonate ground-water chemistry.

The Fence Lake leasehold lies within the Nations Draw ground-water basin, which is part of a larger, regional system corresponding with the Carrizo Wash watershed. Leased sections with substantial saturated overburden include section 13, T3N, R17W, and sections 19, 20, 28, 29, 30, and 32 in T4N, R16W. Those in T4N, R16W are situated astride the Nations Draw buried valley. Thus, substantial thicknesses of saturated sand and gravel may lie adjacent to, or even above, potential mining areas. The existence of channel sandstones above and immediately below the targeted coal zone in this valley suggests that areas with upward gradients may be widespread.

Geologic units may be grouped or subdivided into hydrogeologic units, based on their relative water-yielding characteristics. The manner in which this is done depends upon the scale at which the system is viewed. Figures 11 and 12 display the relations between geologic units or lithologies and hydrogeologic units at two scales appropriate for the Nations Draw ground-water basin.

Figure 11 depicts a scheme that might be used for the entire basin. It contains major water-yoelding hydrogeologic units 3, 5, 7, 9, and 11, which correspond to the Cretaceous marine sandstones and the San Andres Limestone/Glorieta Sandstone interval (Permian). Although quite different lithologically, the latter two formations were combined because the San Andres has been described as locally permeable in this region (Foster, 1964; Maxwell and Nonini, 1977) and because the two units are believed to interfinger in this area (Foster, 1964). Due to its limited areal extent, unit 1 (alluvium) is considered a localized aquifer. Hydrogeologic units 2, 10, and 12 represent extensive but very heterogeneous intervals containing relatively discontinuous high conductivity zones. Units 4, 6, and 8 are aquitards corresponding to tongues of the Mancos Shale.

Figure 12 shows the hydrogeologic units that might be recognized at the scale of the Fence Lake leasehold. Major water-yielding units include sand and gravel (2), sandstone (4 and 9), and thick coal with underlying sandstone (6). Shale units 5 and 7 are aquitards. Unit 1 (sandy clay) acts as an aquitard relative to the more conductive unit 2, and as an aquifer relative to the less conductive thin interbeds of sandstone, siltstone, and shale in unit 3. Where unit 2 is present, ground water flows toward it from units 1 and 3. Where it is not present, ground water flows from unit 3 to unit 1.

In contrast to the hydrogeologic units in Figure 11, those in Figure 12 are hypothetical in relative thickness, but represent what might be a typical lithologic sequence in the northeast portion of the lease area. These units change in thickness, pinch out, and interfinger in a complex fashion over relatively short distances. With adequate subsurface data, their extent and geometry can be predicted, using fluvial-deltaic depositional models commonly developed for coal-bearing strata.

RECOMMENDATIONS FOR FURTHER WORK

A conceptual model of groundwater flow throughout the area in general and in the Fence Lake lease area in particular has been described. The impetus for this work lies in the need to prepare a groundwater-control plan for those areas of the Fence Lake leasehold where mining would be below the water table. Additional subsurface geologic data exist which were not available for inclusion in this report. Many of these were collected in the northeastern portion of the leasehold where saturated overburden is extensive. These data need to be incorporated into those maps dealing specifically with the lease area. In particular, Plates 6 through 11 and 22 through 25 could serve as starting points for more detailed maps as mine planning proceeds.

Collection of additional data would obviously improve the conceptual model presented here and provide more of a data base for groundwater control planning. Examples of additional work in this regard may be:

(1) Fracture-trace mapping to indicate areas where greater than expected mine inflows could occur due to extensive fractures.

(2) Identification of places where vertically upward gradients exist.

(3) Determination of aquifer characteristics in unconfined portions of the alluvium.

(4) Quantitative modeling as an attempt to predict both dewatering needs and the effect of a large mine in the northeast portion of the leasehold on groundwater flow patterns.

The first of these may already be in progress or completed. The second and third should be incorporated into mine planning for the northeastern sections of the lease area where the quantity of groundwater encountered will be greatest. High pit floor uplift pressures may occur in areas where upward vertical gradients exist. The mining area overlain by unconfined sandy clay overburden is potentially very extensive. Laboratory permeameter testing of representative samples from the alluvium could provide adequate point estimates of porosity and specific yield. If conducted, additional pumping tests should run long enough so that specific yield and vertical-hydraulic-conductivity estimates can be obtained from the drawdown data.

Determination of the depth of the ground-water flow system discharging to Nations Draw in the lease area should be considered if quantitative flow modeling is attempted. Wilson and Hamilton (1978) used a numerical model based on that of Freeze and Witherspoon (1967) to show that the effect of a mine on an homogeneous and isotropic flow field of regional extent could extend far beyond the 'cone of depression' at the water-table surface. The effect would depend on the depth and areal extent of the mine in relation to the depth of the flow system in which it is located. The Nations Draw basin is definitely not homogeneous and isotropic. Nevertheless, a single mined area extending throughout sections 20, 29, 30, and 32 in T4N, R16W to an average depth of 75 ft below the water table may constitute, and possibly impact, a significant portion of the basin if the effective base is at the Rio Salado Tongue of the Mancos Shale.

According to Johnson (1983), the decision as to how involved quantitative evaluation methods should be depends on two factors. The first is the amount of accuracy needed. A large mine may require a complex water handling and treatment system which must be matched to estimated discharges. An intensive study utilizing both analytical and numerical modeling would then be warranted. For smaller mines, factor number two, the hydrogeologic system, is more important. Relatively simple hydrogeology around the mine area would allow more confidence in application of the limiting assumptions of analytical models. The complexity of groundwater flow patterns in the leasehold vicinity indicates that care should be taken in designing a groundwater control plan, especially if a single large mine is to be developed in the northern half of the leasehold.

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Appendix 1 - Records of wells and springs excluding Salt River Project monitoring and observation wells; see explanation at end.

No.	Location	Quad	Well Name	Cdate	Type	W Dep	GSE	WL Dep	WL Date	WL E	Aquifer	Yield	ML	PS	Use	
1	C2.14.01.122	ADAM	Taylor Well		Drld	R 285	7464				TB			W	S	NM
3	C2.14.03.113	ADAM	Preacher		Drld	R 80	7412				TU			W	S	NM
4	2.14.05.421	ADAM			Drld	R 190	7395				TU			W	S	NM
5	C2.14.06.211	ADAM			Drld	R 400	7500				TB		C	E	D	NM
6	2.14.08.441	ADAM	Myrtle Cox	1967	Drld	R 221	7380				TS/TB		N	N	N	BI
7	C2.14.10.144	ADAM			Drld	R 300	7420				TS/TB			W	S	NM
8	2.14.12.112	ADAM	Nelson Well		Drld		7439							W	S	NM
9	C2.14.17.334	ADAM			Drld		7420							W	S	NM
279	2.14.18.412	ADAM			Drld		7550	R 340		7210					S	US
10	C2.14.18.424	ADAM			Drld	R 520	7485	R 96	06-14-79	7389	TU			W	S	NM
11	C2.14.20.344	ADAM	Moore Well		Drld	R 830	7341				TB			W	S	NM
12	C2.14.20.344	ADAM	Lower Well		Drld	R 100	7296	R 47	06-14-79	7249	TS			W	S	NM
13	2.15.05.213	MARS	Mariano Spr			0	7193	0	01-17-86	7193	TB	<1			S	NM
14	C2.15.06.121	MARS	M. Maisel		Drld	R 200	7090	>52	12-06-85	<7038	TB	5P	P	W	S	NM
15	2.15.09.233	MARS	J. Carroll	A1964	Drld	R 450	7520		05-28-86	>7095	TB	R10	C	E	S,D	NM
16	C2.15.12.221	ADAM	Jenson Well		Drld	R 480	7628				TS/TB			W	S	NM
17	C2.15.18.242	MARS	V. Swears		Drld	R 380	7325				TB	<1	N	N	D*	NU
18	L2.15.18.242	MARS	V. Swears	1986	Drld	500	7325	*R 233	01-21-86	7092	TB	R1	P	G	D	NM
19	2.15.18.420	MARS	J. Marron	A1983	Drld	R 575	7380				TB	R20	E	E		NM
20	2.15.23.132	MARS	E. Ball	B1940	Drld	R 178	7328				TU		P	W	S	BI
21	2.15.24.441	ADAM	E. Ball		Drld	R 230	7320				TU		C	E	D	NU
23	C2.16.03.421	MARS	M. Maisel		Drld	R 200	6960				KHM		C	E	D	NU
24	C2.16.05.244	TEJM	F. Hubbell		Drld		7097					A5	P	W	S	NU
25	2.16.08.223	TEJM	Gillentine	1985	Drld	300	6980	*56	11-29-85	6924	TB,KHM	R3	N	N	D*	NM
26	L2.16.09.312	TEJM	O. Maisel	1979	Drld	172	6940	70	12-06-85	6870	KMH		N	N	N	NM
27	2.16.10.133	TEJM	O. Maisel		Drld	104	6925	68	05-14-85	6857	KMH		P	W	S	US
290	2.16.12.110	MARS	M. Maisel	1982	Drld		7150	R 225	05-14-85	6925			C		S	US
29	2.16.13.213	MARS	J. Armstrong		Drld	R 250	7459				TU			W	S	NU
30	C2.16.19.342	TEJM			Drld	51	6779	27	05-14-85	6752	QAL		P	W	S	US
31	C2.16.20.324	TEJM			Drld		6780						P	G	S	NU
32	2.16.21.434	TEJM			Drld	74	6885	32	12-06-85	6852	OAL		N	N	S*	NM
33	2.16.22.122	TEJM	McKinley	1967	Drld	R 247	6967				KMH	A1	P	W	S	US
34	2.16.24.424	MARS	Padilla		Drld	R 380	7218				TB		P	E	S	NU
35	C2.17.04.443	TEJM	Chavez		Drld	R 90	6585				KMH			W	D	NU
36	C2.17.05.233	LARM	Little Wells		Drld	R 64	6555	30	05-14-85	6525	QAL/KMH		C	E	S	US
39	L2.17.09.343	LARM	SRP	1983	Drld	1001	6700	148	07-10-84	6552	KAR/KMR		N	N	I	NM
								162	01-17-86	6538						NM
40	C2.17.11.333	TEJM	New Well	A1960	Drld	87	6670	72	05-23-85	6598	QAL		P	W	S	US
41	C2.17.13.242	TEJM	Spring			0	7050	0	03-12-81	7050	TV					BI
43	C2.17.18.343	LARM	Finch Well		Drld		6780							W	S	NU
44	C2.17.23.121	TEJM	Mesa Ranch		Drld	R 250	6770				KMH		C	E	D	NU
45	2.17.24.423	TEJM	Brierley	1966	Drld	R 160	6840	R 60	01-22-86	>6760	KMH		C	E	D	NM
47	C3.14.07.314	ADAM			Drld	R 170	7250				TB		C	E	D	NU
48	3.14.09.212	VETM			Drld		7535							W	S	NU
49	C3.14.13.141	ADAM	Hayes Well		Drld	R 400	7298				KMH			W	S	NU
50	C3.14.16.133	ADAM			Drld		7270							W	S	NU
51	C3.14.21.443	ADAM			Drld	R 235	7380	R 215	06-06-79	7165	TB		C	E	D	NU
52	C3.14.24.311	ADAM	"Wm"		Drld	R 200	7416				TB			W	S	NU
53	3.14.28.212	ADAM			Drld	R 200	7362				TB			W	S	NU
54	C3.14.29.344	ADAM	Toms Rock		Drld		7397							W	S	NU
55	3.14.30.222	ADAM	Lee Wright		Drld		7356							W	S	NU
56	*3.15.05.413	TECH	F. A. Hubbell	1961	Drld	150	6935	72	05-21-85	6863	KMH	2	P	W	S	US
57	3.15.10.421	MARS			Drld	127	7103	113	01-17-86	6990	KMH		P	W	S*	NM
58	3.15.20.323	MARS	Webb Well		Drld	104	7111	P 87	05-21-85	7024	TB		C	E	S	US
59	C3.15.22.112	MARS	Cottonwood Spring			0	7300	0	03-24-81	7300	TB					SR
60	3.15.27.312	MARS	Crossman	A1946	Drld	R 240	7355	R 200	10-20-75	7155	TB	R10	P	W	S	SR
61	C3.15.28.121	MARS	Barton	A1944	Drld	R 240	7210	R 200	10-20-75	7010	TB	R10	C	E	D,S	SR
62	3.15.31.424	MARS	Maisel Ranch		Drld	180	7174	143	05-14-85	7031	TB		P	W	S	US
63	3.15.33.434	MARS	Jones Well		Drld	R 100	7345				TB		C	E	D	NM
64	L3.16.02.323	TECH	F. Hubbell	1961	Drld	270	6790	74	10-04-85	6716	KMH		N	N	S*	NM
66	L3.16.06.123	CPTO	Strang Cabin		Drld	62	6660	57	12-27-85	6603	KMHL		N	N	S*	NM
73	3.16.22.331	TEJM	M. M. Ranch		Drld	116	6990	88	05-21-85	6902	TB		C	E	D	US
74	3.16.24.142	MARS	M. M. Ranch		Drld	111	7012	90	05-21-85	6922	KMH		P	W	S	US
75	C3.16.26.443	MARS	Maisel		Drld	R 200	7115				KMH			W	S	NU
85	3.17.08.123	FLSW	F. Hubbell		Drld	40	6510	30	05-14-85	6480	KMHL		P	W	S	US
86	C3.17.08.141	FLSW	Garcia Spr.			0	6520	0	01-22-86	6520	KMHL	<1		S		NM
90	C3.17.10.223	CPTO	Tejana Windmill		Drld		6620						P	W	S	SR
123	*3.17.12.314	TEJM	W. Strang		Drld	138	6657	P 53	05-21-85	6604	KMHL		P	W	S	SR
132	3.17.14.442	TEJM	Old Tej Well		Drld		6708	120	10-05-85	6588			N	N	S*	NM
135	3.17.24.232	TEJM	SRP		Drld	248	6755	49	05-21-85	6706	KMH		P	W	S	US
137	C3.17.29.111	LARM	Jeremillas		Drld	63	6480	36	05-23-85	6444	QAL		P	W	S	US
139	3.18.09.223	FLSW	Carter Well	1978	Drld	R 186	6390	R 90	01-20-79	6300	KDT,KDP	R30	P	G	S	SR
140	C3.18.22.232	LARM	Jerry Well	1949	Drld	R 400	6394	R 120	01-20-79	6274	KDT,KDP	R20	P	W	S	SR
141	C3.18.25.243	LARM	Tapia Well		Drld	R 90	6440				QAL	5	P	W	S	NU
142	C3.18.26.211	LARM	Whitley		Drld	R 60	6415				QAL/KMR?	4	P	W	S	NU
144	C3.18.33.233	LARM	New Well		Drld		6465						P	W	S	BL
148	L4.14.14.133	VETM	D. K. Fischer	1978	Drld	R 308	7370	*R 200	04-10-78	7170	KMH	8			S	BL
281	4.14.19.211	VETM		1982	Drld		7580	R 260		7320					S	US
149	L4.14.30.140	VETM	Fred Black		Drld	265	7400				KMH	5				BL
150	C4.15.04.423	TECH	C. Cox		Drld		7630					12	C	E		US
151	L4.15.18.134	TECH	H. Moore		Drld	R 176	6990				KMH	<1	P	W	S	BL
152	4.15.22.222	TECH	F. Hubbell	B1940	Drld	R 345	7440				KMH		P	G	S	BL
153	L4.15.31.231A	TECH	South Well		Drld	191	6973	95	05-21-85	6878	KMH		P	W	SI	US

Appendix 1 (cont'd)

Acc	Location	Quad	Well Name	Cdate	Type	W Dep	GSE	WL Dep	WL Date	WLE	Aquifer	Yield	ML	PS	Use	S
154	4.15.31.213B	TECH			Drld	142	6973	125	05-21-85	6847	KMH				N	US
155	C4.15.33.114	TECH	F. Hubbell		Drld	175	7100	118	05-28.86	6982	KMH	3	P	W	S	NM
156	C4.15.34.324	TECH	F. Hubbell		Drld		7092					1	P	W	S	NM
158	4.15.04.241	CPTO	J. C. Brown		Drld		6970	279	12-18-80	6691			P	W	S	US
159	4.16.07.212	CPTO	Montano	1971	Drld	R 230	6870	185	02-11-81	6685	KMHL		P	W	S	US
161	4.16.07.432	CPTO	Montano	1980	Drld	R 120	6840	83	02-11-81	6757	KMHL	<1	P	W	S	US
								86	08-20-83	6754						SR
164	C4.16.10.331A	CPTO	T. Williamson		Drld	280	6860	141	12-17-80	6719	KMH	1	P	E	D,S	US
165	C4.16.10.331B	CPTO	T. Williamson		Drld	230	6840				KMH	1	P	E	S	US
166	4.16.11.332	TECH	T. Williamson		Drld		6894	153	12-17-80	6741			P		S	US
167	C4.16.12.221	TECH			Drld	215	7040	107	05-28-86	6932	KMH	2	P	W	S	NM
170	C4.16.19.241	CPTO	Crro Prto Wm		Drld	R 155	6700	53	02-11-81	6647	KMHL			W	S	US
								53	08-20-83	6647						SR
179	I4.16.24.400	TECH	Davis, North		Drld	212	6900	128	05-28-86	6772	KMH		N	N	S*	NM
180	4.16.26.141	TECH	Single Mill		Drld	130	6795	108	05-14-85	6686	KMH		P	W	S*	US
181	4.16.26.314	TECH	F. Hubbell		Drld	285	6780	50	10-04-85	6730	KMH		N	N	S*	NM
196	*4.16.30.421	CPTO	FL30	1983	Drld	177	6666	*46	09-07-83	6620	QAL	200			I	SR
203	C4.16.31.111	CPTO	L. S. Brown		Drld	79	6643	P 45	09-28-83	6596	QAL		P	W	S	SR
								P 11	05-14-85	6632						US
206	I4.16.32.210	CPTO	F. A. Hubbell	1961	Drld	410	6675				KMH		N	N	N	BL
213	4.16.33.341	CPTO	Apodaca Wm.		Drld	R 390	6718	88	09-27-83	6630	KMH		P	W	S	SR
219	4.17.03.324A	CPTO	Green Well		Drld		6820	100	10-13-80	6720					S	US
220	C4.17.03.324B	CPTO	Martinez Wm.	1980	Drld		6820	117	10-13-80	6703		2	P	W	S	US
221	C4.17.04.233	CPTO	M. Bell		Drld		6808					1	P	W	S	US
222	*4.17.08.121	FLSW	Medanoso Wm.		Drld	252	6846	189	10-14-80	6656	KMHL	2	P	W	S	US
224	C4.17.10.211	CPTO	Lucero Wm.		Drld	R 435	6797				KDT		P	W	S	US
232	C4.17.23.212	CPTO	Taylor Wm.		Drld	270	6745	97	08-20-83	6648	KMHL	2	P	W	S	US
								97	01-06-81	6648						SR
								100	01-22-86	6645						NM
247	I4.17.28.113	FLSW	B. Cox	1951	Drld	150	6640				KMHL	16	C	G	S	BL
253	4.17.36.111	CPTO	Dipping Vat		Drld	41	6610	40	09-28-83	6570	KMHL		P	W	S	SR
254	*4.17.36.121	CPTO	FL36	1983	Drld	1080	6624	*+191	09-26-83	6815	KDM	162	C	E	I	SR
260	*4.18.03.442	FLSW	Meyers	1951	Drld	480	7300	337	10-31-80	6963	KMHL	R50	P	G	S	US
261	I4.18.03.444	FLSW	B. Cox		Drld	450	7303				KMHL	R40	P	W	S	BL
262	4.18.05.144A	FLSW	Semi-Lonesome		Drld	R 320	7339	192	10-31-80	7147	KMHM		P	W	S	US
263	C4.18.05.144B	FLSW	Cox		Drld	R 320	7339	164	10-31-80	7175	KMHM	4	P	G	S	US
264	4.18.05.212	FLSW	Dodson		Drld		7315	133	10-08-80	7181			P	W		US
266	C4.18.28.211	FLSW	New Sr Spr.			0	6630	0	11-20-80	6630	KAR				S	US
267	I4.18.35.331	FLSW	R. L. Cox	1944	Drld	300	6513				KDT,KDP					BL
268	C4.18.36.312	FLSW	Escojeda Wm.		Drld		6566	120	11-20-80	6446		4	P	W	S	US
269	5.15.28.431	CHIM	C. Cox		Drld	R 500	7490	R 261	12-16-80	7229	KMH	4	P	G	S	US
270	5.15.31.222A	TECH	H. Towner		Drld	710	7425	R 320	12-04-80	7105	KMH	20	C	E	D	US
271	5.15.31.222B	TECH	H. Towner		Drld		7422	406	12-04-80	7015			N	N	N	US
273	5.16.31.441	CPTO	Montano		Drld	R 300	6980	57	02-11-81	6923	KAR		P	W	S	US
274	C5.16.36.431	TECH	Spring			0	7200	0	12-17-80	7200	TFL				S	US
276	5.17.31.211	FLSW	B. Cox		Drld	425	6968				KMHL	3	P	G	S	US

APPENDIX 1, EXPLANATION

Acc (accession number): unique number, assigned this study (see (Plate 1)

Location: State Engineer's well location number; C before the location number = chemical analysis available (Appendix 5), L = log available, * = both chemical analysis and log available

Quad (quadrangle): USGS 7.5 minute topographic map on which well is located; key to abbreviations given below

Well Name: based on owner, tenant, or name on USGS 7.5 minute topographic map

Cdate (construction date): year constructed; A before the year = approximate, B before the year = well constructed generally before that year

Type (type of well): Drld = drilled and other types of wells; blank = spring

W Dep (well depth): depth in feet below land surface; R before depth = reported value, value of 0 = spring

GSE (ground-surface elevation): elevation in feet of land surface at well or spring

WL Dep (water-level depth): depth to water in ft below land surface; P before depth = pumping well; > = minimum depth; R before depth = reported value; D = dry well; blank space = depth not known; * before last entry = perforation data available in source; + = height above ground for flowing wells; value of 0 = spring

WL Date (water-level date): date value measured or reported

WL E (water-level elevation): elevation of water level in ft; < = dry well and thus maximum elevation; > = minimum elevation (number given = reported pump setting elevation), if same as GSE = spring

Aquifer: / between names = composite aquifer; comma between names = multiple aquifer; key to abbreviations given below

Yield: maximum production rate (gpm); R = reported value

ML (method of lift): C = centrifugal pump, N = none, P = plunger or cylinder pump

PS (power source): E = electric motor, G = gasoline engine, W = windmill

APPENDIX 1 (cont'd)

Use (use of water): D = domestic, I = industrial, S = stock, N = not used; * after use = purpose for which well intended if not in use

Srce (data source): BLM = US Bureau of Land Management, NMBMMR = New Mexico Bureau of Mines and Mineral Resources, NURE = National Uranium Resource Evaluation (conducted by US Department of Energy), SRP = Salt River Project, USGS = US Geological Survey

Aquifer Abbreviations

Quaternary

QAL = alluvium

Tertiary

TFL = Fence Lake Formation
TV = Tertiary volcanic rocks
TS = Spears Formation
TB = Baca Formation
TU = undifferentiated Tertiary rocks

Cretaceous

KMHM = Middle Member of Moreno Hill Formation
KMHL = Lower Member of Moreno Hill Formation
KMH = Moreno Hill Formation, undivided
KAR = Atarque Sandstone
KMR = Rio Salado Tongue of Mancos Shale
KDT = Twowells Tongue of Dakota Sandstone
KDP = Paguate Tongue of Dakota Sandstone
KDM = Main Body of Dakota Sandstone

Quadrangle Abbreviations

ADAM = Adams Diggings
CPTO = Cerro Prieto
FLSW = Fence Lake SW
LARM = Lake Armijo
MARS = Mariano Springs
TECH = Techado
TEJM = Tejana Mesa
VETM = Veteado Mountain
CHIM = Chimney Hill

Appendix 2. Source of nonconfidential subsurface stratigraphic data; see explanation at end.

Acc[1]	Location	Surface elevation (ft)	Depth (ft)	Data source	Type of Log[2]
2	2.14.02.110	7511	6030	Transocean Oil	G, C
22	2.16.03.114	7030	265	NMBMMR	C
26	2.16.09.312	6940	175	NMBMMR	C
28	2.16.11.222	7100	4596	Transocean	G
39	2.17.09.343	6700	1001	SRP	G
46	2.18.15.223	6740	427	NMBMMR	G
56	3.15.05.413	6935	150	BLM, water well	DL
64	3.16.02.323	6790	270	BLM, water well	DL
66	3.16.06.123	6670	62	NMBMMR	G
67	3.16.06.133	6747	240	SRP, monitoring pt.	S, PA
68	3.16.06.212	6670	59	NMBMMR	R
69	3.16.06.231	6690	2602	Cleary Petroleum	G
70	3.16.07.443	6780	480	SRP, monitoring pt.	C, PA
77	3.17.02.141	6704	200	SRP (317-2-13)	G
78	3.17.02.211	6676	200	SRP (317-2-21)	G
79	3.17.02.232	6846	300	SRP (317-2-2)	G
80	3.17.02.311	6704	180	SRP (317-2-31)	G
81	3.17.02.332	6700	180	SRP (317-2-3)	G
82	3.16.02.422	6713	150	SRP, monitoring pt.	C, PA
83	3.17.02.432	6665	160	SRP (317-2-4)	G
84	3.17.02.434	6637	120	SRP (317-2-SC1)	G
88	3.17.09.214	6680	197	Santa Fe Minerals	G
89	3.17.09.323	6757	277	Santa Fe Minerals	G
91	3.17.10.214	6614	157	Santa Fe Minerals	G
92	3.17.10.323	6625	157	Santa Fe Minerals	G
93	3.17.10.421	6625	120	SRP (124)	PA
94	3.17.10.424	6624	140	SRP (105)	G
95	3.17.10.424	6640	120	SRP, monitoring pt.	G, PA
96	3.17.10.424	6627	80	SRP (117)	PA
97	3.17.10.444	6671	100	SRP (118)	PA
98	3.17.10.444	6684	180	SRP (104)	G
99	3.17.10.444	6707	180	SRP, monitoring pt.	G, PA
100	3.17.11.113	6639	210	SRP (317-11-113)	G
101	3.17.11.142	6640	220	SRP, monitoring pt.	S, PA
102	3.17.11.143	6639	200	SRP (317-11-SC4)	G
103	3.17.11.211	6635	145	SRP (317-11-SC1)	G
104	3.17.11.212	6658	109	SRP (317-11-21)	G
105	3.17.11.222	6685	120	SRP (126)	G
106	3.17.11.313	6635	140	SRP (108)	G
107	3.17.11.321	6639	200	SRP (317-11-SC3)	G
108	3.17.11.323	6640	200	SRP (317-11-SC2)	G
109	3.17.11.323	6637	410	SRP (317-11-3, 122)	G
110	3.17.11.331	6661	160	SRP (317-11-33)	G
111	3.17.11.331	6646	140	SRP (114)	G
112	3.17.11.331	6645	140	SRP (107)	G
113	3.17.11.332	6641	80	SRP (121)	PA

Appendix 2 (cont'd)

Acc[1]	Location	Surface elevation (ft)	Depth (ft)	Data source	Type of Log[2]
114	3.17.11.332	6666	160	SRP (115)	G
115	3.17.11.333	6657	160	SRP (106)	G
116	3.17.11.334	6644	180	SRP (113)	G
117	3.17.11.334	6650	180	SRP (109)	G
118	3.17.11.342	6648	190	SRP (111)	G
119	3.17.11.342	6642	180	SRP (110)	G
120	3.17.11.344	6643	180	SRP, monitoring pt.	G
121	3.17.11.400	6659	200	SRP (317-11-4)	G
122	3.17.12.143	6686	200	SRP, monitoring pt.	C, PA
123	3.17.12.314	6680	101	NMBMMR	G
124	3.17.13.114	6698	210	SRP, monitoring pt.	G, PA
125	3.17.13.133	6705	220	SRP (317-13-13)	G
126	3.17.13.214	6730	260	SRP (317-13-2)	G
127	3.17 13.222	6763	280	SRP (317-13-22)	G
128	3.17.13.222	6763	380	SRP (317-13.22X)	G
129	3.17.13.341	6714	400	SRP (317-13-3)	G
130	3.17.13.423	6732	303	SRP (317-13-4)	G
133	3.17.16.214	6795	277	Santa Fe Minerals	G
134	3.17.16.323	6720	257	Santa Fe Minerals	G
147	4.14.05.114	7325	400	NMBMMR	G
148	4.14.14.133	7370	305	BLM, water well	DL
149	4.14.30.140	A7420	265	BLM, water well	DL
151	4.15.18.134	6997	176	BLM, water well	DL
153	4.15.31.213	6973	211	BLM, water well	DL
157	4.16.03.321	6980	260	NMBMMR	G, C
160	4.16.07.223	6850	77	NMBMMR	G
162	4.16.07.434	6845	211	NMBMMR	G
163	4.16.10.131	6920	272	NMBMMR	G
168	4.16.18.421	6790	116	NMBMMR	G
169	4.16.18.421	6779	190	SRP, monitoring pt.	S
171	4.16.19.423	6690	132	SRP, monitoring pt.	G
172	4.16.20.132	6711	157	Santa Fe Minerals	G
173	4.16.20.232	6722	197	Santa Fe Minerals	G
174	4.16.20.323	6700	237	Santa Fe Minerals	G
175	4.16.20.432	6703	180	SRP, monitoring pt.	G, C
176	4.16.40.432	6704	180	Santa Fe Minerals	G
178	4.16.22.121	6810	280	NMBMMR	G
179	4.16.24.400	6900	212	SRP (1982), water well	DL
182	4.16.27.122	6810	250	NMBMMR	G
183	4.16.28.123	6695	178	Santa Fe Minerals	G
184	4.16.28.214	6730	317	Santa Fe Minerals	G
185	4.16.28.214	6736	260	SRP, monitoring pt.	G
186	4.16.28.341	6680	258	Santa Fe Minerals	G
187	4.16.29.123	6680	237	Santa Fe Minerals	G
188	4.16.29.211	6691	67	NMBMMR	R
189	4.16.29.214	6682	143	Santa Fe Minerals	G
190	4.16.29.323	6664	258	Santa Fe Minerals	G

Appendix 2 (cont'd)

Acc[1]	Location	Surface elevation (ft)	Depth (ft)	Data source	Type of Log[2]
191	4.16.29.423	6674	177	Santa Fe Minerals	G
192	4.16.29.441	6674	159	SRP, monitoring pt.	S
193	4.16.30.223	6668	200	SRP (416-30-2)	G
194	4.16.30.243	6668	200	SRP (416-30-SC1)	G
195	4.16.30.323	6648	200	SRP (416-30-3)	G
196	4.16.30.421	6666	239	SRP (FL30)	G
199	4.16.30.424	6660	49	NMBMMR	R
200	4.16.30.432	6659	120	SRP (416-30-SC3)	G
201	4.16.30.443	6659	100	SRP (416-30-SC4)	G
202	4.16.30.444	6655	200	SRP (416-30-44)	G
204	4.16.31.233	6690	258	NMBMMR	G
205	4.16.32.132	6716	235	SRP (416-32-1)	G
206	4.16.32.210	6670	410	SRP (1982), water well	DL
207	4.16.32.311	6734	170	SRP, monitoring pt.	CO
208	4.16.32.323	6721	220	SRP (416-32-323)	G
209	4.16.32.324	6727	340	SRP (416-32-324)	G
210	4.16.32.331	6752	360	SRP (416-32-33)	G
211	4.16.32.413	6747	200	SRP, monitoring pt.	S
212	4.16.32.442	6755	300	SRP (416-32-44)	G
214	4.16.35.333	6754	620	Northwestern Resources	G
215	4.17.01.444	6940	276	NMBMMR	G
216	4.17.02.214	6900	237	NMBMMR	G
217	4.17.02.314	6875	237	NMBMMR	G
218	4.17.03.312	6870	233	NMBMMR	G
222	4.17.08.121	6846	225	SRP (1982), water well	DL
223	4.17.08.242	6781	4493	Tiger Oil	G
225	4.17.12.314	6985	257	NMBMMR	G
226	4.17.13.213	6870	247	NMBMMR	G
227	4.17.13.342	6790	257	Santa Fe Minerals	G
228	4.17.14.143	6810	248	NMBMMR	G
231	4.17.23.113	6740	229	NMBMMR	G
233	4.17.25.143	6671	310	SRP (417-25-14)	G
234	4.17.25.222	6712	240	SRP (417-25-22)	G
235	4.17.26.131	6807	280	SRP (417-26-1)	G
236	4.17.26.211	6676	140	SRP (417-26-21)	G
237	4.17.26.212	6676	200	SRP (417-26-SC1)	G
238	4.17.26.223	6664	200	SRP (417-26-SC2)	G
239	4.17.26.223	6656	150	SRP, monitoring pt.	C
240	4.17.26.322	6659	55	SRP (417-26-32)	C
241	4.17.26.344	6669	200	SRP (417-26-34)	G
242	4.17.27.141	6848	357	SRP (417-27-1)	G
243	4.17.27.232	6840	270	SRP (417-27-2)	G
244	4.17.27.324	6836	275	SRP, monitoring pt.	CO
245	4.17.27.424	6669	200	SRP (417-27-42)	G
246	4.17.27.434	6740	200	SRP (417-27-43)	G
247	4.17.28.113	6650	150	SRP (1982), water well	DL
249	4.17.34.122	6672	160	SRP (417-34-12)	G

Appendix 2 (cont'd)

Acc[1]	Location	Surface elevation (ft)	Depth (ft)	Data source	Type of Log[2]
250	4.17.34.144	6714	260	SRP (417-34-14)	G
251	4.17.34.433	6573	175	SRP, monitoring pt.	S
252	4.17.35.342	6680	180	SRP, monitoring pt.	C
254	4.17.36.122	6624	1080	SRP (FL36)	G
256	4.17.36.244	6629	44	NMBMMR	R
257	4.17.36.343	6775	198	SRP (417-36-34)	G
258	4.17.36.411	6669	130	SRP, monitoring pt.	S
259	4.17.36.444	6670	160	SRP (417-36-44)	G
260	4.18.03.442	7302	480	SRP (1982), water well	DL
261	4.17.03.444	7303	450	SRP (1982), water well	DL
265	4.18.11.211	7330	438	NMBMMR	G
267	4.18.35.331	6513	300	SRP (1982), water well	DL
272	5.16.31.413	7020	263	NMBMMR	G
275	5.17.31.211	7145	1060	NMBMMR	G
277	5.17.34.143	6910	277	NMBMMR	G
278	5.18.33.143	7290	395	NMBMMR	G

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[1] Accession number, see Plate 1

[2] G = geophysical logs
C = cuttings
CO = core
DL = driller's log
R = NMBMMR recharge study (Stone, 1984)
PA = Fence Lake No. 1 Mine permit application (SRP, 1986)
S = monitoring well construction schematic

Appendix 3 - Construction details for monitoring and observation wells (from Seifert and Greenberg, 1985; SRP, 1986; SRP, unpublished files); see explanation at end.

Accession number	Well name	Depth (ft)	Depth of casing (ft)	Sealed interval (ft)	Gravel pack (ft)	Screened interval (ft)	Borehole diameter (in)	Casing I.D. (in)	Lithology
67	316-06-13M1	172	170	NONE	138-172	145.0-165.0	7-7/8	4	ss(ac)
67	316-06-13M2	210	208	183-188	188-210	193.0-203.0	7-7/8	4	coal
70	316-07-44M1	227	225	190-195	195-227	200.0-220.0	7-7/8	4	ss(ac)
82	317-02-42M1	150	150	118-123	123-150	125.0-145.0	7-7/8	4	ss(bc)
82	317-02-42OB1	150	150	116-121	121-150	125.0-145.0	6-1/4	2	ss(bc)
95	317-10-42M1	110	103	70- 75	75-110	78.5- 98.5	7-7/8	4	ss(bc)
95	317-10-42M2	78	68	40- 45	45- 78	63.0- 68.0	7-7/8	4	coal
95	317-10-42OB1	100	99	65- 75	75-100	79.0- 99.0	5	2	ss(bc)
99	317-10-44M1	167	155	120-125	125-167	135.0-150.0	7-7/8	4	ss(bc)
99	317-10-44M2	108	105	NONE	97-108	99.0-104.0	5	2	coal
101	317-11-14M1	155	150	NONE	NONE	85.0-135.0	13.0	10	al(s & g)
101	317-11-14OB1	120	110	NONE	75-110	85.0-105.0	7-7/8	4	al(s & g)
101	317-11-14OB2	205	205	170-175	175-205	180.0-200.0	7-7/8	4	ss(ba)
120	317-11-34M1	137	133	108-113	113-133	118.0-128.0	7-7/8	4	ss(bc)
120	317-11-34M2	87	82	45- 55	55- 87	67.0- 77.0	7-7/8	4	coal
120	317-11-34OB1	87	82	52- 57	57- 87	67.0- 77.0	5	2	coal
122	317-12-14M1	177	175	145-150	150-177	160.0-170.0	7-7/8	4	ss(bc)
122	317-12-14M2	131	129	104-109	109-131	114.0-124.0	7-7/8	4	coal
124	317-13-1M1	100	100	51- 56	56-100	60.0- 90.0	7-7/8	4	al(s & g)
124	317-13-1M2	135	135	85- 90	90-135	100.0-130.0	7-7/8	4	ss(ac)
124	317-13-1OB1	124	124	84- 94	94-124	99.0-119.0	6-1/4	2	ss(ac)
124	317-13-1M3	240	240	187-192	192-240	195.0-235.0	7-7/8	4	ss(bc)
124	317-13-1OB2	223	221	NONE	BRIDGED	196.0-216.0	5	2	ss(bc)
169	416-18-42M1	190	188	NONE	145-190	155.0-185.0	7-7/8	4	ss(bc)
171	416-19-4M1	132	132	97-102	102-132	107.0-127.0	7-7/8	4	ss(bc)
175	416-20-4M1	158	130	85- 90	90-158	105.0-125.0	7-7/8	4	al(s & g)
175	416-20-4M2	180	170	NONE	143-180	150.0-165.0	5	2	ss(bc)
185	416-28-2M1	260	145	47- 52	52?-260	100.0-140.0	7-7/8	4	ss,sh(ac)
192	416-29-4M1	98	98	?	?	73.0- 93.0	7-7/8	4	al(silt)
192	416-29-4M2	179	179	145-150	150-179	154.0-174.0	7-7/8	4	ss(bc)
196	416-30-42M1	184	177	NONE	NONE	137.0-177.0	13	10	al(s & g)
197	416-30-42OB1	186	186	NONE	NONE	136.0-176.0	6-1/4	4	al(s & g)
198	416-30-42OB2	205	205	NONE	NONE	160.0-200.0	6-1/4	4	al & bedrock?
207	416-32-311M1	190	190	135-140	140-190	145.0-185.0	7-7/8	4	ss(bc)
207	416-32-31OB1	190	190	125-135	135-190	145.0-185.0	6-1/4	2	ss(bc)
207	416-32-311M2	140	140	115-120	120-140	125.0-135.0	7-7/8	4	coal
207	416-32-31OB2	140	140	110-120	120-140	125.0-135.0	6-1/4	2	coal
211	416-32-41M1	195	195	132-142	142-195	145.0-160.0 180.0-190.0	7-7/8	4	ss,sh(ac)
239	417-26-22M1	75	75	48- 53	53- 75	55.0- 70.0	7-7/8	4	sh(ac)
239	417-26-22OB1	75	75	?	?	55.0- 70.0	6-1/4	2	sh(ac)
239	417-26-22M2	125	125	83- 88	88-125	90.0-120.0	7-7/8	4	ss,sh(ac)
239	417-26-22M3	150	150	129-134	134-150	135.0-145.0	7-7/8	4	coal, sh
244	417-27-32M1	275	275	240-245	245-275	250.0-270.0	7-7/8	4	ss(bc)
251	417-34-43M1	180	150	?	?	120.0-140.0	7-7/8	4	al(s & g)
252	417-35-34M1	140	139	105-110	110-140	114.0-134.0	7-7/8	4	ss,sh(bc)
255	417-36-124M1	130	120	47- 52	52?-130	90.0-110.0	?	4	al(s & g?)
258	417-36-41M1	130	130	NONE	37?-130 BRIDGED	117.0-127.0	7-7/8	4	ss(bc)

Key to Lithologies:
al = alluvium
s & g = sand and gravel
ss = sandstone
sh = shale

(ac) = above coal
(bc) = below coal
(ba) = beneath alluvium

(coal, sandstone, and shale are all within the Moreno Hill Formation)

Appendix 4 - Records of Salt River Project monitoring and observation wells. See Appendix 3 for key to lithology; SWE = static water elevation. Water quality data available in Salt River Project (1985, 1986) or Seifert and Greenberg (1984).

Accession number	Well name	Ground surface elevation (ft)	Screened interval (ft)	Lithology	Date measured	Depth to water (ft)	SWE	Mean SWE
67	316-6-13M1	6746.76	145-165	ss(ac)	9-14-84	128.5	6618.26	6618.23
					7-24-86	128.56	6618.20	
67	316-6-13M2	6746.76	193-203	coal	9-16-84	144.3	6602.46	
					1- -85	144.2	6602.56	6602.50
					4- -85	144.22	6602.54	
					7-24-86	144.31	6602.45	
70	316-7-44M1	6780.53	200-220	ss(ac)	9-14-84	122.25	6658.28	6658.50
					7-23-86	121.80	6658.73	
82	317-2-42M1	6713.38	125-145	ss(bc)	9-17-84	129.60	6583.80	
					1- -85	129.50	6583.90	6583.83
					4- -85	129.70	6583.70	
					4-16-86	129.48	6583.92	
95	317-10-42M1	6640.10	78.5-98.5	ss(bc)	9-16-84	68.21	6571.89	6572.33
					7-24-86	67.33	6572.77	
95	317-10-42M2	6640.10	63- 68	coal	9-16-84	64.94	6575.16	6574.29
					7-24-86	66.68	6573.42	
95	317-10-42OB1	6640.10	79- 99	ss(bc)	9-16-84	68.48	6571.62	6571.62
99	317-10-44M1	6707.20	135-150	ss(bc)	9-16-84	135.16	6572.04	
					1- -85	134.94	6572.26	6572.20
					4- -85	135.23	6571.97	
					7-24-86	134.67	6572.53	
99	317-10-44M2	6707.20	99-104	coal	9-16-84	DRY	<6603.2	
					1- -85	DRY	<6603.2	<6603.20
					4- -85	DRY	<6603.2	
					7-24-86	DRY	<6603.2	
101	317-11-14M1	6639.86	85-135	al(s & g)	9-20-84	67.20	6572.69	
					1- -85	66.95	6572.95	6573.00
					7-24-86	66.50	6573.36	
101	317-11-14OB1	6639.86	85-105	al(s & g)	9-20-84	62.70	6577.10	
					1- -85	62.71	6577.09	6577.22
					4- -85	62.63	6577.17	
					7-24-86	62.28	6577.52	
101	317-11-14OB2	6639.86	180-200	ss(bal)	9-17-84	60.76	6579.04	
					1- -85	60.65	6579.15	6579.07
					4- -85	60.67	6579.13	
					7-24-86	60.83	6578.97	
120	317-11-34M1	6642.70	118-128	ss(bc)	9-07-84	53.80	6589.00	
					1- -85	53.70	6589.00	6589.03
					4- -85	53.69	6589.01	
					7-24-86	53.59	6589.11	
120	317-11-34M2	6642.70	67- 77	coal	9-16-84	57.90	6584.80	
					1- -85	57.89	6584.81	6585.00
					4- -85	57.30	6585.40	
					7-24-86	57.76	6584.94	
122	317-12-14M1	6686.5	160-170	ss(bc)	9-14-84	87.70	6598.80	
					1- -85	88.30	6598.20	6598.23
					4- -85	88.54	6597.96	
					7-23-86	88.52	6597.98	
122	317-12-14M2	6686.5	114-124	coal	9-15-84	85.60	6600.90	
					1- -85	85.58	6600.92	6600.76
					4- -85	85.94	6600.56	
					7-23-86	85.85	6600.65	
124	317-13-1M1	6697.60	60- 90	al(s & g)	9-15-84	DRY	<6607.60	
					1- -85	DRY	<6607.60	<6607.60
					4- -85	DRY	<6607.60	
					7-23-86	DRY	<6607.60	
124	317-13-1M2	6697.60	100-130	ss(ac)	9-15-84	96.15	6601.45	
					1- -85	96.01	6601.59	6601.42
					4- -85	96.14	6601.46	
					7-23-86	96.42	6601.18	
124	317-13-1OB1	6697.60	99-119	ss(ac)	9-15-84	96.55	6601.05	6601.05
124	317-13-1M3	6697.90	195-235	ss(bc)	9-15-84	97.75	6600.15	
					1- -85	97.78	6600.12	6599.96
					4- -85	97.90	6600.00	
					7-23-86	98.04	6599.56	
124	317-13-1OB2	6697.60	196-216	ss(bc)	9-15-84	99.32	6598.28	6598.28
169	416-18-42M1	6779.38	155-185	ss(bc)	7-19-85	100.06	6679.32	6679.32
171	416-19-4M1	6689.70	107-127	ss(bc)	9-19-84	59.98	6629.72	6629.68
					7-23-86	60.06	6629.64	
175	416-20-4M1	6703.00	105-125	al(s & g)	9-12-84	78.23	6624.77	6624.80
					7-23-86	78.17	6624.83	
175	416-20-4M2	6703.00	150-165	ss(bc)	9-12-84	77.32	6625.83	6625.63
					7-23-86	77.42	6625.58	
185	416-28-2M1	6735.90	100-140	ss,sh(ac)	9-11-84	96.70	6639.20	6640.87
					7-23-86	93.36	6642.54	

Appendix 4 (cont'd)

Accession number	Well name	Ground surface elevation (ft)	Screened interval (ft)	Lithology	Date measured	Depth to water (ft)	SWE	Mean SWE
192	416-29-4M1	6674.13	73- 93	al(silt)	9-18-84	43.33	6630.80	6630.97
					7-23-86	42.99	6631.14	
192	416-29-4M2	6674.13	154-174	ss(bc)	9-18-84	42.81	6631.32	6632.08
					7-23-86	41.29	6632.84	
196	416-30-42M1	6665.99	137-177	al(s & g)	8-29-83	46.72	6619.27	
					9-07-83	45.40	6620.59	6620.01
					10-06-83	45.83	6620.16	
197	416-30-42OB1	6665.14	136-176	al(s & g)	8-29-83	46.23	6618.91	
					9-27-83	45.57	6619.57	6619.37
					7-24-86	45.51	6619.63	
198	416-30-42OB2	6664.47	160-200	al,bedrock?	8-26-83	43.94	6620.53	
					9-27-83	43.55	6620.92	6620.66
					7-24-86	43.95	6620.52	
207	416-32-311M1	6734.13	145-185	ss(bc)	9-16-84	122.47	6611.66	6611.47
					7-24-86	122.84	6611.29	
207	416-32-311M2	6734.13	125-135	coal	9-12-84	115.76	6618.37	6618.26
					7-24-86	115.97	6618.16	
211	416-32-41M1	6747.05	145-160 180-190	ss,sh(ac)	7-23-86	119.20	6627.85	6627.85
239	417-26-22M1	6656.27	55- 70	sh(ac)	9-17-84	54.54	6601.73	6602.14
					7-23-86	53.71	6602.56	
239	417-26-22M2	6656.27	90-120	ss,sh(ac)	9-18-84	61.99	6594.28	6594.28
					7-23-86	61.99	6594.28	
239	417-26-22M3	6656.30	135-145	coal,sh	9-18-84	57.64	6598.63	6596.44
					7-23-86	62.02	6594.25	
244	417-27-32M1	6835.92	250-270	ss,sh(bc)	?	DRY	<6560.92	6561.65
					4-14-86	274.27	6561.65	
251	471-34-43M1	A6753	120-140	al(s & g)	9-29-83	A32	A6541	A6541.50
					7-23-86	A31	A6542	
252	417-35-34M1	6680.01	114-134	ss,sh(bc)	9-19-84	111.32	6568.69	6568.97
					4-16-86	110.75	6569.26	
255	417-36-124M1	6623.71	90-110	al(s & g?)	9-19-84	39.00	6584.71	6584.71
					4-16-86	38.99	6584.72	
258	417-36-41M1	6668.94	117-127	ss(bc)	9-12-84	83.92	6585.02	6585.01
					4-16-86	83.93	6585.01	

Appendix 5 - Water quality data excluding Salt River Project monitoring and observation wells; see Appendix 1 for source of data; see explanation at end.

Acc	Location	Date	Aquifer	Ca	Mg	Na + K	HCO_3	CO_3	SO_4	Cl	F	NO_3	H	Tmp	TDS	Sc	pH	O
1	2.14.01.122	06-07-79	TB	3	0	139	165	24			N		N	15.5		436	8.9	Y
3	2.14.03.113	06-07-79	TU	51	11	89	215	0			N		N	14.0		512	7.9	Y
5	2.14.06.241	06-15-79	TB	1	0	176	56	84			N		N	15.9		550	9.2	Y
7	2.14.10.144	06-07-79	TS/TB?	13	4	134	123	56			N		N	15.5		507	8.5	Y
9	2.14.17.334	06-08-79	TU	6	0	76	54	20			N		N	14.5		295	8.9	Y
10	2.14.18.424	06-14-79	TU	64	18	46	185	0			N		N	13.7		452	8.1	Y
11	2.14.19.322	06-14-79	TB	4	0	85	15	60			N		N	16.0		295	9.2	Y
12	2.14.20.344	06-14-79	TS	92	32	62	345	0			N		N	13.1		582	7.7	Y
14	2.15.06.121	06-14-79	TB	7	0	168	230	0			N		N	16.9		539	7.8	Y
16	2.15.12.221	06-15-79	TS/TB?	1	0	142	98	90			N		N	16.1		464	9.5	Y
17	2.15.18.242A	06-06-79	TB	16	3	77	140	10			N		N	15.5		260	8.7	Y
23	2.16.03.421	06-14-79	KMH	1	0	211	170	60			N		N	15.1		621	9.0	Y
24	2.16.05.244	06-14-79		24	12	41	140	0			N		N	16.6		283	8.1	Y
30	2.16.19.342	06-13-79	QAL	47	14	631	790	0			N		N	14.7		695	7.6	Y
31	2.16.20.324	06-13-79		28	11	319	555	0			N		N	16.2		1093	7.8	Y
35	2.17.04.443	06-20-79	KMH	24	16	381	285	0			N		N	15.1		312	7.7	Y
36	2.17.05.233	06-20-79	QAL/KMH	68	23	275	183	0			N		N	14.5		211	7.1	Y
40	2.17.11.333	06-20-79	QAL	40	20	237	313	0			N		N	14.3		942	7.1	Y
41	S2.17.13.242	03-12-81	TV	55	21	19	256	0	23	12.0	0.4	1.7	220	7.0		490	7.7	Y
43	2.17.18.343	06-20-79		104	31	462	223	0			N		N	15.5		633	7.0	Y
44	2.17.23.121	06-22-79	KMH	1	0	142	145	50			N		N	17.7		508	8.5	Y
47	3.14.07.314	06-15-79	TB	4	1	106	160	50			N		N	17.5		363	8.7	Y
49	3.14.13.141	06-07-79	KMH	95	28	205	196	0			N		N	17.0		1115	7.8	Y
50	3.15.16.133	06-15-79		5	1	269	366	44			N		N	14.3		864	8.5	Y
51	3.14.21.443	06-06-79	TB	4	0	175	185	2			N		N	17.8		578	8.2	Y
52	3.14.24.311	06-07-79	TB	37	9	136	255	0			N		N	15.5		560	7.9	Y
54	3.14.29.344	06-27-79		2	0	263	232	38			N		N	16.9		791	8.0	Y
56	3.15.05.413	05-28-86	KMH	6	1	174	413	0	40	14.0	0.5	0.8	21	16.0	445	650	8.1	Y
59	S3.15.22.112	03-24-81	TB		18	28.0			19	14.0	N	0.1	N			591	8.0	N
61	3.15.28.121	06-12-79	TB	7	0	147	168	0			N		N	16.1		505	8.1	Y
75	3.16.26.443	06-14-79	KMH	2	0	136	171	34			N		N	15.0		415	8.7	Y
86	S3.17.08.141	07-00-79	KMHL	12	2	241	536		180	19.0	1.0		N				7.5	Y
		01-22-86		2	3	256	485	0	158	13.6	N		19		677	930	6.7	N
90	3.17.10.223	11-04-83		8	2	171	410	1	58	9.2	2.3	0.1	28	16.0		767	8.4	Y
		08-29-83		9	0	184	366	18	61	11.0	3.2	0.0	N		467	770	8.8	Y
123	3.17.12.314	05-22-84	KMHL	24	4	160	366	0	73	9.6	1.5	0.0	80	14.0	462	730		Y
137	3.17.29.111	06-19-79	QAL	56	31	401	450	0			N		N	13.8		372	7.1	Y
140	3.18.22.232	07-00-79	KDT,KDP	1	0	241	536		180	19.0	1.6		N	24.0			8.5	Y
		02-11-83		1	0	210	452	6	45	13.0	1.5	0.1	4	21.5		844	8.8	Y
		09-27-83		2	0	198	366	30	47	14.0	1.5	0.6	N	21.1	474	860	9.1	Y
141	3.18.25.243	06-19-79	QAL	56	56	476	457	0			N		N	15.7		608	7.2	Y
142	3.18.26.211	06-19-79	QAL/KMR	16	6	306	291	0			N		N	15.6		1027	6.9	Y
144	3.18.33.233	08-19-80		5	1	271	365	1	150	120.0	2.4	0.0	17	17.0		1291	8.2	Y

Acc	Location	Date	Aquifer	Ca	Mg	Na + K	HCO_3	CO_3	SO_4	Cl	F	NO_3	H	Tmp	TDS	Sc	pH	O
150	4.15.04.423	12-16-80		33	8	41	219	0	16	7.0	0.3	0	120	15.5		420	8.0	Y
155	4.15.34.324	05-28-86	KMH	87	18	44	360	0	58	12.0	0.2	.8	291	16.0	391	580	7.1	Y
156	4.15.34.324	06-28-86		40	10	65	285	0	28	11.0	0.3	1.6	141	17.0	299	475	7.6	Y
164	4.16.10.331A	12-17-80	KMH	22	5	90	231	0	68	5.7	0.7	0.0	76			533	8.0	Y
165	4.16.10.331B	12-17-80	KMH	43	11	122	243	1	200	9.5	0.6	0	150	11.0		846	7.7	Y
167	4.16.12.221	05-28-86	KMH	3	0	134	339	0	0	7.4	5.8	0.0	11	17.5	321	500	8.2	Y
170	4.16.19.241	05-29-86	KMHL	57	17	100	353	0	125	8.0	0.6	.3	212	16.0	484	950	7.1	Y
196	4.16.30.421	08-26-83	QAL	17	7	151	394	18	26	7.8	1.1	1.2	N		422	695	9.0	Y
		10-08-83		24	6	150	433	0	25	11.0	1.1	0.0	N	56.0	430	685	8.5	Y
		10-08-83		23	6	139	433	0	30	7.1	1.1	0.0	N	56.0	422	685	8.2	Y
203	4.16.31.11	08-29-83	QAL	17	14	175	514	20	5	7.1	1.7	3.7	N		497	820	9.0	Y
		05-14-85		28	13	152	563	1	2	6.3	1.4	.9	120	13.0		802	8.1	Y
220	4.17.03.324B	10-13-80		6	0	382	328	1	520	8.9	1.4	0.2	20	13.5		1782	8.3	Y
221	4.17.04.233	10-13-80		7	0	331	231	1	530	14.0	0.4	0.0	23	14.0		1550	8.3	Y
222	4.17.08.121	10-14-80	KMHL	5	0	121	280	1	44	10.0	0.6	0.0	17	15.0		530	8.4	Y
		01-12-81		6	0	117.0	269	0	38	14.0	N	0.0	N			540	8.3	N
224	4.17.10.211	01-12-81	KDT	24	0	387.0	224	30	624	14.0	N	0.0	N			1800	8.3	N
232	4.17.23.212	01-06-81	KMHL	140	27	184	393	1	500	6.4	0.2	.1	460	16.0		1480	8.1	Y
		01-06-82		17	4	178.0	269	0	244	10.0	N	0.0	N			1000	8.1	N
		01-22-86		143	24	181	353	0	501	7.4	N		456		1034	1270	6.8	N
254	4.17.36.121	08-22-83	KDM	1	0	162	314	30	35	11.0	0.8	0.0	N	23.3	395	665	9.4	Y
		09-01-83		0	0	163	311	30	31	11.0	0.8	0.0	N		389	640	9.5	Y
		10-05-83		1	0	156	221	42	28	11.0	0.6	0.0	N	23.3	348	610	9.3	Y
260	4.18.03.442	10-31-80	KMHL	50	32	65	247	0	66	63.0	0.6	66	260	13.0		795	8.0	Y
263	4.18.05.144B	10-31-80	KMHM	47	8	14	195	0	21	15.0	0.7	1.8	150	14.0		418	7.7	Y
266	S4.18.28.211	08-00-79	KAR	14	3	153	374		118	10.4	0.5		N	16.4			6.0	Y
		10-30-80		16	3	201	378	1	150	8.6	0.5	0.0	54	13.0		865	8.2	Y
268	4.18.36.312	11-20-80		1	0	170	341	13	100	7.9	1.0	0.2	7	14.0		723	9.0	Y
		01-12-81		8	0	173.0	288	37	78	11.0	N	0.0	N			740	8.6	N
274	S5.16.36.431	12-17-80	TFL	110	57	142	451	0	430	14.0	0.4	.4	510	11.0		1550	7.7	Y

Explanation

Acc (Accession number): unique number, assigned this study (see Plate 1)

Location: State Engineer's well location number; S before the location number = spring; see Appendix 1 for topographic quadrangle.

Date: date sample collected

Aquifer: / between names = composite aquifer; comma between names = multiple aquifers; key to abbreviations given below

Ca = Calcium (mg/L)
Mg = Magnesium (mg/L)
Na = Sodium (mg/L)
Na + K = Sodium plus potassium (mg/L)
K = Potassium (mg/L)
HCO_3 = Bicarbonate (mg/L)
CO_3 = Carbonate (mg/L)
SO_4 = Sulfate (mg/L)
Cl = Chloride (mg/L)
F = Fluoride; N = not available
NO_3 = Nitrate (mg/L)
HD = Hardness based on carbonate (mg/L); N = not available
TMP = Temperature (degrees C)
TDS = Total dissolved solids (mg/L)
SC = Specific conductance (micromhos/cm)
pH = Hydrogen ion activity of the water
O = other constituents given in source? Y = yes, N = no

Aquifer abbreviations

Quaternary
QAL = alluvium

Tertiary
TFL = Fence Lake Formation
TS = Spears Formation
TB = Baca Formation
TU = undifferentiated Tertiary deposits
TV = Tertiary volcanic rocks

Upper Cretaceous
KMHU = Upper member, Moreno Hill Formation
KMHM = Middle member, Moreno Hill Formation
KMHL = Lower member, Moreno Hill Formation
KMH = Moreno Hill Formation, undivided
KAR = Atarque Sandstone
KMR = Rio Salado Tongue, Mancos Shale
KDT = Twowells Tongue, Dakota Sandstone
KDP = Paguate Tongue, Dakota Sandstone
KDM = Main body of Dakota Sandstone

Appendix 6. Water quality data, field observations.

Acc[1]	Location	Date sampled	Temp. (C°)	pH	SC[2]	Unit	Data source[3]
1	2.14.01.122	6/18/76	18.0	8.8	478	Tb	NURE*
3	2.14.03.113	6/18/76	17.0	8.2	550	Tu	NURE*
7	2.14.10.144	6/18/76	17.0	8.1	600	Ts/Tb	NURE*
8	2.14.12.112	6/18/76	17.0	8.3	750	---	NURE
10	2.14.18.424	6/18/76	16.5	8.6	479	Tu	NURE*
11	2.14.19.322	6/18/76	17.5	8.9	348	Tb	NURE*
12	2.14.20.344	6/18/76	16.5	7.8	700	Ts	NURE*
13	2.15.05.213	1/17/86	5.8	---	290	TBl	NMBM
16	2.15.12.221	6/18/76	18.0	9.4	510	Ts/Tb	NURE*
20	2.15.23.132	5/15/85	14.0	---	430	Tu	USGS
30	2.16.19.342	7/04/76	18.5	7.9	2500	Qal	NURE*
33	2.16.22.122	5/23/85	17.0	---	520	Kmh	USGS
40	2.17.11.333	5/23/85	16.0	---	1000	Qal	USGS*
49	3.14.13.141	6/18/76	16.5	8.0	1050	Kmh	NURE*
50	3.14.16.133	6/18/76	16.5	9.0	680	---	NURE*
51	3.14.21.443	6/18/76	17.0	8.6	590	Tb	NURE*
55	3.14.30.222	6/18/76	16.5	8.6	990	---	NURE
56	3.15.05.413	5/21/85	18.5	---	790	Kmh	USGS
		5/28/86	16.0	---	530	Kmh	NMBM*
58	3.15.20.323	6/17/76	17.5	8.7	580	Tb	NURE
60	3.15.27.312	6/17/76	---	8.9	460	Tb	NURE
123	3.17.12.314	5/21/85	15.0	---	670	Kmbl	USGS*
139	3.18.09.223	7/08/76	16.0	8.8	900	Kdt,Kdp	NURE
150	4.15.04.423	12/16/80	15.5	8.3	350	---	USGS*
151	4.15.18.134	6/09/76	16.5	8.4	600	Kmh	NURE
155	4.15.33.114	5/28/86	16.0	---	405	Kmh	NMBM*
156	4.15.34.324	5/28/86	17.0	---	350	---	NMBM*
159	4.16.07.212	7/11/76	14.5	8.5	1250	Kmhl	NURE
164	4.16.10.331A	12/17/80	---	8.1	460	Kmh	USGS*
165	4.16.10.331B	12/17/80	11.0	7.7	700	Kmh	USGS*
167	4.16.12.221	5/28/86	17.5	---	370	---	NMBM*
170	4.16.19.241	7/11/76	14.3	7.4	925	Kmhl	NURE
		5/29/86	16.0	---	680	Kmhl	NMBM*
203	4.16.31.111	7/12/76	13.5	7.9	800	Qal	NURE
		5/14/85	14.5	---	750	Qal	USGS*
213	4.16.33.341	7/12/76	15.5	7.1	610	Kmh	NURE
220	4.17.03.324B	10/14/80	13.5	8.2	---	---	USGS*
221	4.17.04.233	7/12/76	17.0	8.5	1500	---	NURE
		10/13/80	14.0	8.3	1550	---	USGS*
222	4.17.08.121	7/08/76	16.5	8.4	500	Kmhl	NURE
		10/14/80	15.0	8.1	600	Kmhl	USGS*
247	4.17.28.113	7/08/76	14.0	8.7	700	Kmhl	NURE
263	4.18.05.144B	10/31/80	13.9	7.6	350	Kmhm	USGS*
264	4.18.05.212	10/08/80	14.5	---	520	---	USGS
269	5.15.28.431	12/16/80	13.0	9.4	500	Kmh	USGS
270	5.15.31.222A	12/04/80	15.0	8.9	340	Kmh	USGS
276	5.17.31.211	10/20/80	12.5	7.4	450	Kmhl	USGS

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[1] accession number, refer to Plate 1 for location

[2] specific conductance, micromhos/cm

[3] * indicates laboratory analysis available, see Appendix 5; NURE data are from Maasen et al., 1980

Appendix 7. Logs from inventoried stock and domestic water wells, excluding those published by SRP (1982); logged interval is depth in ft below surface.

Accession number	Location Owner Construction Date	Logged interval (ft)	Lithology	Comments
18	2.15.18.242 V. Swears 1/86	0 - 50	sand	
		50 - 250	packsand	(has clay)
		250 - 300	sand	water, <1 gpm
		300 - 380	packsand and shale streaks	(reddish color throughout)
56	3.15.05.413 SRP 9/61	0 - 20	topsoil	
		20 - 110	shale	
		110 - 140	sandstone	water
		140 - 150	shale	
			(completed with 150 feet of 7 inch casing)	
66	3.15.05.413 Strang Cabin Well	0 - 21	interbedded siltstone, shale, and sandstone	
		21 - 53	sandstone	
		53 - 62	shale	
			(from log by NMBM 9/80)	
123	3.17.12.314 Strang windmill	0 - 27	alluvium	
		27 - 67	interbedded siltstone and shale	
		67 - 76	sandstone	
		76 - 85	shale/siltstone	
		85 - 92	sandstone	
			(from log by NMBM 9/80)	
148	4.14.14.133 D. K. Fischer 3/78	0 - 11	dirt	
		11 - 25	blue sandrock	
		25 - 40	yellow shale	
		40 - 95	blue shale	
		95 - 145	blue sandrock	
		145 - 232	blue shale	
		232 - 265	sandrock	water, 8 gpm at 250 feet
		265 - 280	blue shale	
		280 - 297	sandrock	
		297 - 308	blue shale	
			(310 feet of 6 & 5/8 inch welded casing; perforations: 250-265)	
149	4.14.30.140 F. Black 8/68	0 - 10	brown topsoil	
		10 - 100	white sandrock	
		100 - 200	red clay	
		200 - 240	red sandrock	
		240 - 250	brown sandrock	water, approx. 5 gpm
		250 - 265	yellow clay	
			(265 feet of 6 7 5/8 inch casing)	
151	4.15.18.134 H. Moore	0 - 90	blue and yellow clay	
		90 - 117	blue shale	seep @ 90'
		117 - 176	sandstone	
153	4.15.31.213A South well J. D. Davis	0 - 60	fill	
		60 - 175	blue shale	
		175 - 210	sandstone	water @ 204'
		210 - 211	blue shale	

Appendix 8. Logs from non-inventoried water wells, excluding those published by SRP (1982); logged interval is depth in ft below surface.

Location Owner	Logged interval (ft)	Lithology	Comments
2.16.05	0 - 4	mantle	
(south 1/2)	4 - 20	soft sandstone	
H. Phillips	20 - 60	sandy shale	
(Mangum)	60 - 82	sticky shale	
	82 - 90	sandy shale	water, 1 gpm
	90 - 235	blue shale	very dry
2.16.24	0 - 17	fill	
?	17 - 225	brown sandstone	
	225 - 245	gray sand & boulders	
3.14.13.110	0 - 140	malpais boulders, conglomerate, etc.	
	140 - 160	coal and blue shale	
	160 - 164	white sandstone	
	164 - 200	unknown	
3.14.19.100	0 - 120	red sandy shale	
Hubbell Ranch	120 - 212	gray shale	
	212 - 213	red clay	
	213 - 215	sandstone	water, 2.5 gpm
	215 - 242	gray shale	
3.14.24.100	0 - 120	red sandstone	water at 120 ft
?	120 - 212	gray shale	
	212 - 213	red shale	
	213 - 215	sandstone	water
	215 - 242	gray shale	
5.17.31.430	0 - 75	pack sand	
Tom Bell	75 - 125	hard gray sandstone	
	125 - 172	?	
	172 - 175	shale	
	175 - 195	gravel	water, 12 gpm
	195 - 225	blue shale and sand	6 inch casing

Appendix 9 - Aquifer test results, alluvium; explanation at bottom also applies to Appendices 10 and 11.

Accession number	Well name	Lithology	Thickness (ft)	Screened interval (ft)	Gravel interval (ft)	Method	T (ft/dy)	Kxy (ft/dy)	S	SC	Pumping time (min)	Meas. point	Aquifer type
101	317-11-14OB1	Sand and * Gravel	50	85.0-105.0	75-110	R R	225.0 302.0	6.43 8.63		1.70	249	P	C
101	317-11-14M1	Sand and * Gravel	50	85.0-135.0	NONE	R	333.0	6.66		2.50	721	P	C
192	416-29-4M1	Sandy * clay	A20	73.0- 93.0	UNKNOWN	C BR	7.3 6.4	0.365 0.32+					U
196	416-30-42M1	Sand and Gravel	62	137.0-177.0	NONE	R DD	612.0+ 1206.0	9.37 19.45	 0.00021	5.70	1451	P P,O (237,603)	C
197	416-30-42OB1	Sand and ** Gravel	A62	136.0-176.0	NONE	T R	924.0+ 704.0+	14.90 11.35	0.00045	5.70	1451	O(237) O	C
198	416-30-42OB2	Sand and ** Gravel	A62	160.0-200.0	NONE	T R	1031.0+ 978.0+	16.63 15.77	0.00035	5.70	1451	O(603) O	C
255	417-36-124M1	Sand? *	20?	90.0-110.0	52-130	R	41.2	2.06		0.20	263	P	C

Lithology (of unit tested): * = poor lithologic log
** = no lithologic log
= no lithologic log for entire screened interval
? = estimated from unpublished SRP files

Thickness (of unit tested): A = approximate, ? = estimated from unpublished SRP files

Method:
C = slug-test method of Cooper et al. (1967)
BR = slug-test method of Bouwer & Rice (1976)
S = slug-test method of Schwartz (1975)
DD = distance-drawdown method (Lohman, 1972)
R = Jacob's straight-line recovery method (Lohman, 1972)
T = Theis time-drawdown method (Lohman, 1972)
H = Hantush r/B solution (Hantush, 1964)
J = Jacob's straight-line drawdown method (Lohman, 1972)

T (transmissivity): + = calculated from SRP drawdown or slug-test data

Kxy (horizontal hydraulic conductivity): + = calculated from SRP drawdown or slug-test data;
(a) and (b) in Appendix 10 refer to matrix and fracture conductivity, respectively (from Schwartz method)

S (storativity): dimensionless

SC (specific capacity): in gpm/ft of drawdown after 1 hour of pumping

Meas point (measuring point): P = pumping well; O = observation well (number in parentheses is distance in ft from pumping well)

Aquifer type: U = unconfined (static water level below top of unit tested),
C = confined (static water level above top of unit tested)

Appendix 10- Aquifer test results, coal and bedrock overburden, Moreno Hill Formation (refer to Appendix 9 for explanation).

Accession number	Well name	Lithology	Thickness (ft)	Screened interval (ft)	Gravel interval (ft)	Method	T (ft^2/dy)	Kxy (ft/dy)	S	SC	Pumping time (min)	Meas. point	Aquifer type
67	316-6-13M2	coal	12	193.0-203-0	188-218	C	36.0	3.0					C
						BR	18.0	1.50+					
95	317-10-42M1	coal	5	63.0- 68.0	45- 78	C	4.1	0.82					U
						BR	0.7	0.14+					
120	317-11-34M2	coal	12	67.0- 77.0	55- 87	C	10.4	0.87					C
						BR	5.4	0.45+					
122	317-12-14M2	coal	9	114.0-124.0	109-131	C	43.8	4.87					C
						BR	1.9	0.21+					
						S	1.4	0.16+(a)					
						S	33.3	3.70+(b)					
124	317-13-1M2	sandstone	45	100.0-130.0	90-135	R	244.0	5.42		1.30	240	P	U
124	317-13-10B1	sandstone	45	99.0-119.0	94-124	T	439.0	9.76	0.0000014		240	O	U
						J	498.0	11.07	0.00008		240	(50)	
						R	439.0	9.76	0.00058		240		
206	416-32-3111M2	coal	10	125.0-135.0	120-140	C	2.6	0.26					C
						BR	1.5	0.15+					
238	417-26-22M1	shale*	A25	55.0- 70.0	53- 75	C	4.5	0.18					U
						BR	2.7	0.11+					

Appendix 11 - Aquifer test results, sandstone beneath coal and alluvium, Moreno Hill Formation (refer to Appendix 9 for explanation).

Accession number	Well name	Lithology	Thickness (ft)	Screened interval (ft)	Gravel pack interval (ft)	Method	T (ft^2/dy)	Kxy (ft/dy)	S	SC	Pumping time (min)	Meas. point	Aquifer type
82	317-2-42M1	Sandstone	A25	125.0-145.0	123-150	C	42.1	1.68					U
		* ##				BR	27.5	1.10+					
95	317-10-42M1	Sandstone	17	78.5- 98.5	75-110	C	9.2	0.54					C
						BR	10.2	0.60+					
99	317-10-44M1	Sandstone	13	135.0-150.0	125-167	C	72.7	5.59					U
						BR	31.2	2.40+					
101	317-11-14OB2	Sandstone, Shale? *	A30	180.0-200.0	175-205	R	63.0	2.10		0.5	47	P	C
120	317-11-34M1	Sandstone	12	118.0-128.0	118-137	R	161.0	13.42		0.6	244	P	C
122	317-12-14M1	Sandstone*	A10	160.0-170.0	150-177	R	9.3	0.83		0.14	201	P	C
124	317-13-1M3	Sandstone##	A45	195.0-235.0	192-240	R	897.7	22.44		0.57	180	P	C
124	317-13-1OB2	Sandstone##	A45	196.0-216.0	Unknown	T	286.2	7.16	0.000024		180	O	C
						J	446.5	11.16	0.0016		180	(50)	C
						R	409.9	10.25	0.00052		180		C
						H	247.0+	6.17	0.0022		180		C
171	416-19-4M1	Sandstone##	A25	107.0-127.0	102-132	C	5.0	0.20					C
						BR	6.5	0.26+					
296	416-32-311M1	Sandstone##	A50	145.0-185.0	140-190	C	6.3	0.13					C
						BR	7.5	0.15+					
252	417-35-34	Sandstone, Shale	25	114.0-134.0	110-139	C	66.0	2.64					U
						BR	97.5	3.90+					
258	417-36-124	Sandstone*	A10	117.0-127.0	Unknown	C	0.2	0.02					C
						BR	2.3	0.23					