Information Series 37

Water Resources Beneath State Lands in Part of T. 16 S., R. 63 W., Black Squirrel Creek Basin, El Paso County, Colorado

By Robert M. Kirkham, Susan H. Cannon, William P. Rogers,
Bruce K. Stover, and Randy Streufert

Prepared for the Colorado State Board of Land Commissioners

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DOI: https://doi.org/10.58783/cgs.is37.wcan5649

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ACKNOWLEDGEMENTS

Several individuals contributed data, references, personal knowledge, advice, and/or editorial comments to us on the project. They include Ted Schubert, Purushottam Dass, Don Fawcett, John Romero, George Moravec, David Nettles, Bob Ermel, Ken Watts, Wilbur Davis, and Shorty Hammacher. The cooperation of Wilbur Davis, manager for T Cross Ranch which leases the State property, increased efficiency of our field work and drilling program. We thank everyone for their assistance.

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EXECUTIVE SUMMARY

The Colorado Geological Survey entered into an agreement with the Colorado State Board of Land Commissioners to conduct a ground water investigation of about 8,160 contiguous acres of land in T. 16 S. R. 63 W. in El Paso County. Eight thousand acres of the property is administered by the State Board of Land Commissioners, while the remaining 160 acres is a private in-holding surrounded by the State lands. The project area is adjacent to the southern boundary of the existing Upper Black Squirrel Creek designated ground-water basin. This report contains the data collected during this investigation and conclusions based on the available data. The report is believed to contain sufficient information to allow the Land Board to approach the Colorado Ground Water Commission, if so desired, for the purpose of proposing that this area become a designated ground-water basin, or be added to an existing one.

All of sections 1 to 4 and 9 to 16, and the W½ and W½ E½ of section 21, T. 16 S., R. 63 W. are included in the project area. The modern channel of Black Squirrel Creek flows across the northeast corner of the project area, but the remaining part of the project area is blanketed by a veneer of wind-blown sand that forms prominent sand dunes separated by interdune areas from which there is no external drainage. The area is presently used for livestock grazing.

This investigation focuses upon the unconfined alluvial aquifer which is the primary aquifier beneath the property. Other potential aquifers, such as the Dakota Sandstone and Pierre Shale, exist beneath the area, but none are capable of economically producing large amounts of water at high production rates. The alluvial aquifer consists of gravelly coarse sand with lesser amounts of very fine to medium sand, silty sand, gravel, and clay that fill ancient stream channels buried beneath the wind-blown eolian deposits which mantle the surface. Deposits within the buried channel are herein called older alluvium to distinguish it from alluvium in the modern channel of Black Squirrel Creek.

Most of the saturated alluvial aquifer is within a main buried channel, but a smaller, secondary buried channel in the southwest corner of the property also contains saturated sand and gravel. Bedrock highs or ridges consisting of Pierre Shale form the margins of the buried channels within the project area and effectively prevent lateral of ground water out of the buried channels. The modern channel of Black Squirrel Creek, which lies one to two miles east of the main buried channel, is separated from it by one of the bedrock ridges in the project area.

Saturated thickness of the alluvial aquifer ranges up to about 80 feet in the project area. Total saturated volume is estimated at 400 million cubic yards (248,000 acre-ft), and the total amount of water stored in the alluvial aquifer beneath the project area is around 74,400 acre-ft, assuming a porosity of 30 percent. Based on a specific yield of 25 percent, 62,000 acre-ft of the stored water is drainable by gravity.

The main buried channel enters the project area along its northern boundary and exits along the southeast boundary. It flows generally southward till nearing the El Paso—Pueblo County line. At that point the channel floor widens and the channel walls flatten. We estimate that nearly one-half of the ground water flowing through the buried channel discharges over the western channel margin in an area herein called the "spill over" area. The shallow ground water, springs, and seeps in the spill over area create a 2,200 acre wetland along the northeast side of Chico Creek above its confluence with Black Squirrel Creek. Much of the ground water remaining in the buried channel flows into a second discharge area associated with a wetland of about 2,500 acres along the modern channel of Black Squirrel Creek above its confluence with Chico Creek. A small amount of ground water from the buried channel may move southeastward into a third wetland discharge area along Haynes Creek that contains about 300 acres of wetland vegetation. About 13,000 acre-ft of ground water from the buried channel is annually lost to transpiration in the three wetlands, and more is evaporated from standing bodies of water present in these areas.

The first recorded water well was constructed in the project area during 1913. A total of nine water wells exist on the property, seven of which were active in March and April, 1988. Four of the wells are used exclusively for livestock, and the remaining five are permitted for domestic, irrigation, and/or livestock and mechanical uses.

Appendix C lists the eight water wells constructed in the project area over fifteen years ago. Also contained in this appendix are the owner, location, permit number, initial year of use, annual amount withdrawn, and current status. Two of the eight wells are presently inactive. The six active wells currently withdraw water for livestock purposes and are estimated to annually withdraw a total of 6.6 acre-ft of water. Five of the wells at least 15 years old are permitted for combined uses, and each claimed 182 to 183 acre-ft annually on their permits. Over 900 acre-ft of ground water may have been withdrawn annually from these wells in past years, if they were ever fully utilized.

Since stream flow is not significantly involved in the recharge or discharge of the alluvial aquifer, and current well withdrawals are negligible, the water budget for the project area involves only a few elements. Recharge results from ground water underflow in both buried channels and deep percolation of precipitation. An estimated 7,200 acre-ft of ground water flows into the project area through the alluvial aquifer in the buried channels each year. Deep percolation of precipitation contributes an additional 560 acre-ft each year, resulting in a total annual recharge of 7,760 acre-ft. Discharge occurs as underflow through both buried channels and amounts to approximately 7,760 acre-ft annually. Volume differences between underflow out of the project area and evapotranspiration in the wetlands are thought to largely result from additional recharge to the aquifer due to precipitation infiltration and underflow in tributary buried channels between the project area and the wetlands. Variations in the assumed values for vegetation transpiration in the wetlands and in hydraulic conductivity and hydraulic gradient of the alluvial aquifer may also contribute to the difference.

Black Squirrel Creek flows only during short duration flood events that commonly are separated by several years of dry conditions. Prior to extensive ground water development upstream, the creek sustained somewhat more frequent flows in this area than today, but even then it would have been classified as an intermittent stream. Most of the project area consists of sand dunes and interdune areas that form a network of closed depressions from which there is no external drainage. All precipitation that falls in this region either evaporates, transpires by vegetation, or infiltrates to the underlying aquifer.

"Designated ground water" is defined in CRS 37-109-103(6) as *1)* "ground water which in its natural course would not be available to and required for the fulfillment of decreed surface rights," or *2)* "ground water in areas not adjacent to a continuously flowing natural stream wherein ground water withdrawals have constituted the principal water usage for at least fifteen years preceding the date of the first hearing on the proposed designation of the basin".

The project area is not adjacent to a continuously flowing stream, and the only known water usage over the past 15 years has been ground water. The project area certainly satisfies the second criteria listed in CRS 37-109-103(6), and therefore should be eligible for designation.

Ground water within the alluvial aquifer can confidently be traced to two wetlands and perhaps to a third. About 13,000 acre-ft of ground water is annually lost to transpiration in the three wetlands. Significant additional amounts of water evaporate from these 5,000 acres of wetlands. Very little, and perhaps none of the water in the alluvial aquifer beneath the project area is available to and required for fulfillment of decreed surface water rights along the Arkansas River. This factor was a key element in the successful creation of the upper Black Squirrel Creek designated ground water basin.

Eleven decreed surface water rights exist in the northwest corner of the spill over wetland and five are located in the Haynes wetland. Adjudicated amounts in both areas total 88.8 acre-ft and 6.6 CFS.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

On January 20, 1988 the Colorado Geological Survey (CGS) and Colorado State Board of Land Commissioners (SBLC) signed a Memorandum of Understanding which authorized the CGS to conduct a ground water investigation on approximately 8,000 acres of State land and a 160 acre private parcel enclosed within the State lands in T. 16 S. R. 63 W. in El Paso County. Of primary interest is the character and extent of a buried channel consisting of water-saturated coarse sand and gravel that had been identified during a prior study. Our investigation involved *1)* drilling nearly 1,300 ft of test holes on the property and casing of five test holes for use as observation wells, *2)* surveying the location of each CGS test hole, the three previously drilled test holes, and pertinent water wells on the property, and *3)* preparation of a report that contained the findings of the study, including a series of cross sections and plan maps that depict the hydrogeologic conditions of the site in sufficient detail to satisfy the requirements of CRS 37-90-106 and 37-109-103(6) (determination of designated ground water basins).

The investigation involved several phases of work, many of which overlapped chronologically. Initially, a bibliographic search for available published and unpublished reports and maps was conducted. A complete listing of these references is at the end of this report. Subsurface information from test holes, water wells, oil and gas exploration holes, and mineral exploration holes was evaluated to obtain relevant hydrogeologic information. Aerial photography and satellite imagery at a variety of scales were examined to assist the hydrogeologic interpretation. A number of individuals familiar with the geology, hydrology, and/or well development of the area were interviewed.

Field work encompassed a number of tasks that were conducted not only in the project area, but also in surrounding areas. All registered water wells within the project area were visited to ascertain their current status. Many of the registered water wells within one mile of the project area were also field inspected. Wherever possible, water levels were measured in all visited wells. Unfortunately, many of the windmills in and adjacent to the project area are completed in such a way or are in such a deteriorated condition that it was not possible to measure them. During April, 1988 eleven test holes ranging from 58 to 187 in depth were drilled on the property. Total footage was 1,283 ft and five of the test holes were cased as observation or monitor wells. Hydrogeologic evaluation of the area was based on test hole data, field mapping, water well data, water-level measurements, aerial photography, and satellite imagery. All data collected during the investigatory phases of this study were incorporated into our interpretation of the ground water resources of the project area.

In order for the Colorado Ground Water Commission to create a new designated ground water basin or revise the boundaries or description of an existing basin, it is necessary for them to make the following findings:

a) The name of the aquifer within the proposed designated basin;
b) The boundaries of each aquifer being considered;
c) The estimated quantity of water stored in each aquifer;
d) The estimated annual rate of recharge;
e) The estimated use of the ground water in the area; and
f) If the source is an area of use exceeding fifteen years as defined in CRS 37-90-103 (6), the commission shall list those userswho have been withdrawing water during the fifteen year period, the use made of the water, the average annual quantity of water withdrawn, and the year in which the user began to withdraw water.

Information on all of the above described items for the project area is contained in this report.

LOCATION OF THE PROJECT AREA

The project area includes all of sections 1 to 4 and 9 to 16, and the W and W½ of the E½ of section 21, T. 16 S., R. 63 W. in El Paso County, Colorado (Figure 1). It lies about 13 mi east of Fountain, is bordered by Squirrel Creek road on the north and the Peyton highway on the west, and is adjacent to the southern boundary of the existing Upper Black Squirrel Creek designated ground water basin.

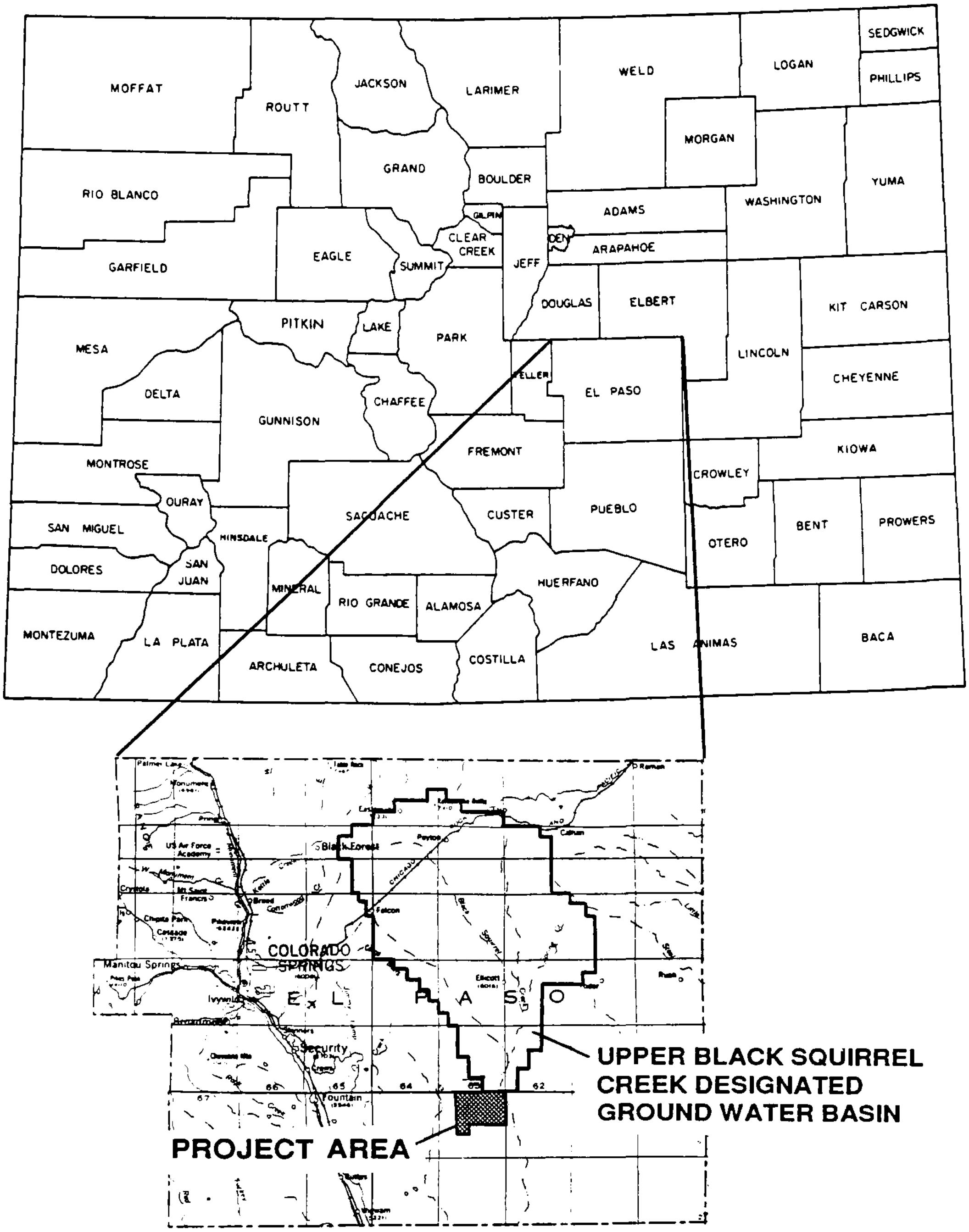

Figure 1. Location map of the project area and its spatial relationship with the existing Upper Black Squirrel Creek Designated Ground Water Basin.

DESCRIPTION OF THE PROJECT AREA

TOPOGRAPHIC SETTING

Figure 2 shows the topography and stream drainage system of the project area. The area is characterized by two type of topographic landforms: sand dunes and floodplains. Approximately 96 percent of the project area is underlain by wind-blown (eolian) fine sand and silt that has been deposited in a series of northwest to southeast-trending dunes and interdune basins or depressions. The remaining four percent of the project area lies on the gently southeasterly sloping floodplain of Black Squirrel Creek. The modern channel of Black Squirrel Creek cuts across the northeast corner of the project area through section 1. Black Squirrel Creek is an intermittent stream (some people suggest it no longer is even intermittent!) that only rarely flows in this reach. It trends generally south for about 20 mi to where it joins Chico Creek, which in turn merges with the Arkansas River about 13 mi below its confluence with Black Squirrel Creek.

Much of the area underlain by the wind-blown dune material consists of hummocky terrain with no external or through-going stream drainage. Precipitation that falls in this area with no external drainage does not run off from the project area; it either evaporates, transpires, or infiltrates into the unconfined aquifer.

Elevations in the project area range from a high of nearly 5,680 ft in the northwest corner to 5,449 ft in the southwest corner. A prominent sand dune extends across the area, beginning in the northwest corner of section 4 and running southeastward to the southeast corner of section 15. Local relief from the base to the top of this dune is as much as 140 ft.

The northern and central parts of the area are underlain by soil material that generally is capable of supporting vehicular traffic. The southern part of the area, especially parts of sections 13 and 14 are underlain by loose, fine grained sand. Vehicular traffic in this area is limited to four-wheel drive or track vehicles. Most of the project area is at least sparsely vegetated, but a few blowouts are present in the southern part of the area where loose sand and silt is exposed with no vegetative cover.

CLIMATE

Climate of the project area is typical of the semi-arid plains environment. Precipitation is generally available in sufficient quantities to support short grasses and various types of brush, but irrigation would be necessary to consistently produce most crops. Irrigation through use of ground water does occur in close proximity to the project area, but there is no evidence of major irrigation having been conducted on the property in the recent past.

The nearest climatic station to the project area was located at Big Springs Ranch about 12 mi north-northeast of the project area. Unfortunately, data is available only for the time periods January to June 1948, August 1948 to October 1950, and January 1951 to September 1951. Other nearby climatic stations are found at Colorado Springs and at Fountain. The Colorado Springs station has not only the longest record, but it is the only station also to record temperatures. Figure 3 graphically illustrates the average monthly precipitation and temperature at Colorado Springs, and Figure 4 shows the annual precipitation since 1914.

Only one complete year of record (1949) is available for the Big Springs Ranch station. The reported precipitation was 12.83 in. for this year. To determine whether this might represent an average figure for the Big Springs Ranch area, records were compared for 1949 to both the Colorado Springs and Fountain stations. Precipitation at the Colorado Springs station in 1949 was 2.5 in. less than the long-term average. The precipitation record at the Fountain station is incomplete for 1949, but monthly comparisons suggest that precipitation was running about three inches lower than normal.

Assuming the precipitation at Big Springs Ranch was lower than normal by a similar amount, the average annual precipitation might be as much as 15.33 in. (12.83 in. + 2.5 in.). This amount is slightly higher than the long-term averages from both the Colorado Springs station (15.14 in.) and Fountain station (14.76 in.), which, in view of the types of native vegetation present in these areas, seems somewhat suspect.

Another source of precipitation data is the Colorado Climate Center at Colorado State University. Their mapping suggests the average annual precipitation in the project area was 13 to 14 in. for the period 1951 to 1980.

Based on the above information we conclude that the average annual precipitation in the project area is around 13.75 in., which is less than the long-term averages at the Colorado Springs and Fountain stations, but very similar to the 14 in. average used by Erker and Romero (1967) in their study of upper Black Squirrel Creek basin.

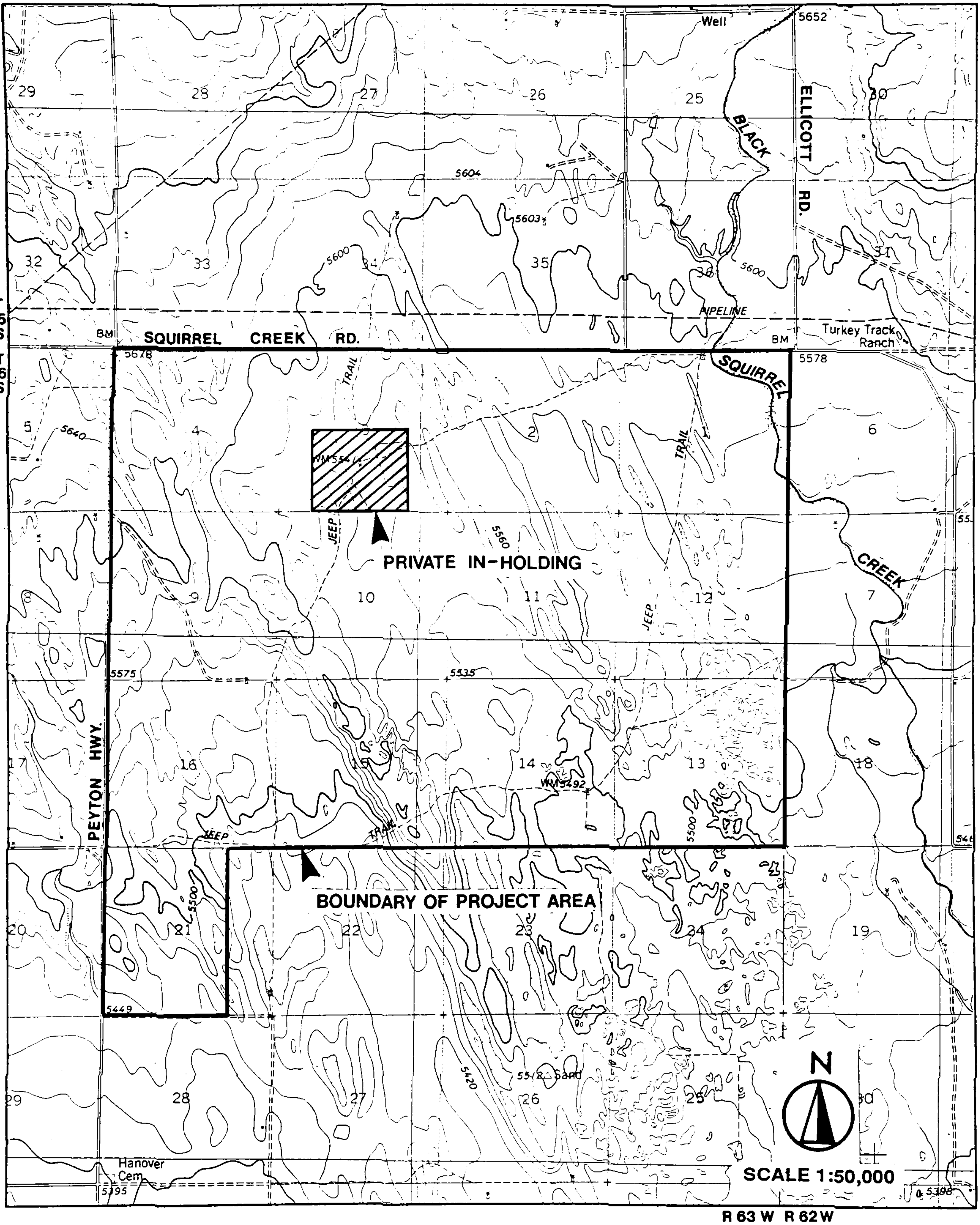

Figure 2. Topographic map of project area. Boundary of project area is outlined by the heavy line. Location of private in-holding within the State lands is indicated by the cross hachuring.

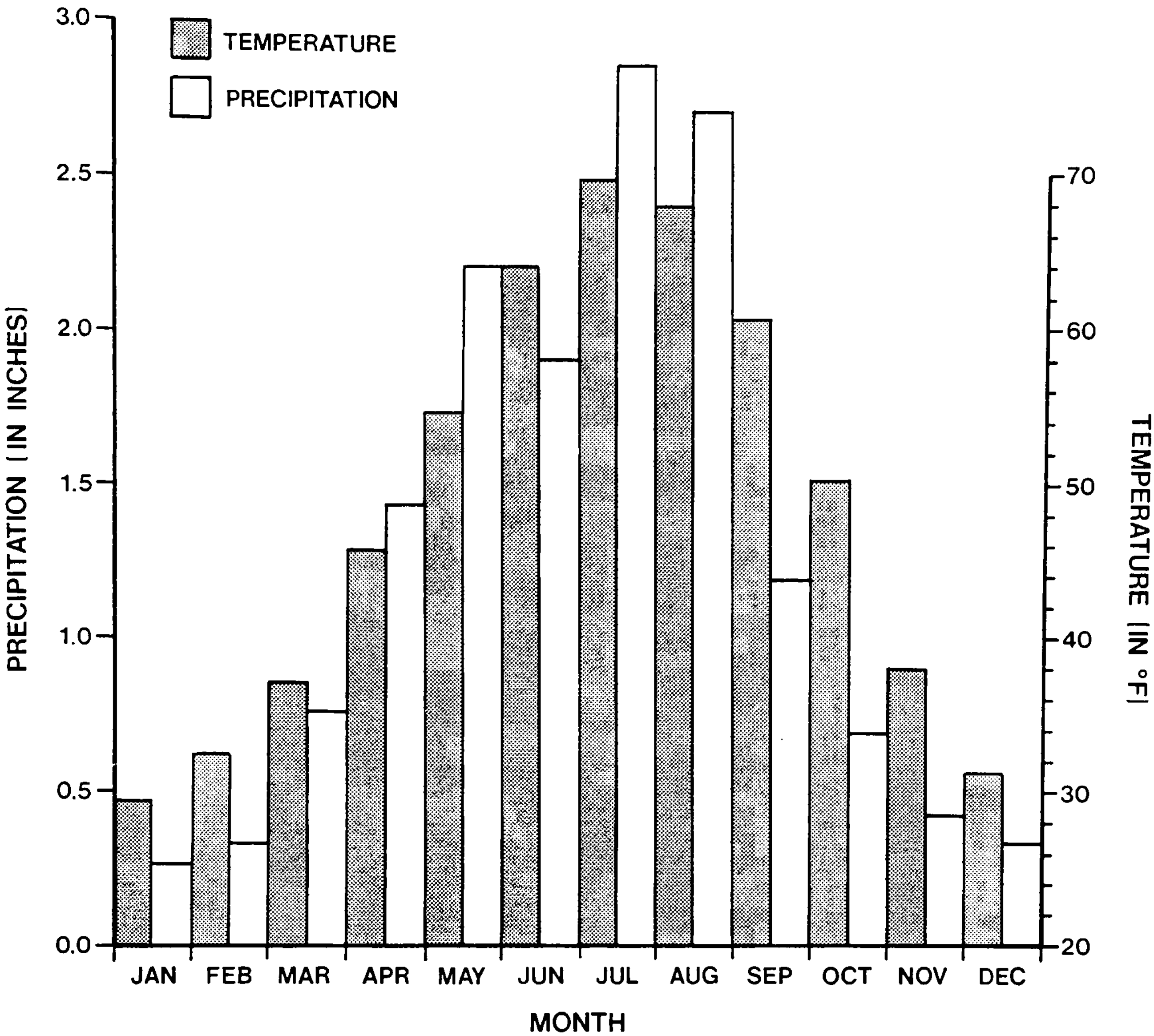

Figure 3. Average monthly precipitation and temperature at Colorado Springs. (from NOAA, 1914–1986)

Land Use, Population, and Ownership

The entire project area is currently used only for grazing purposes, and there are no domiciles on the property.

Approximately 8,160 acres are included within the project area, of which 8,000 acres are State of Colorado lands administered by the SBLC. The remaining 160 acres lie within section 3, are privately owned by the T Cross Ranch, and are entirely surrounded by the State of Colorado lands (see Figure 2).

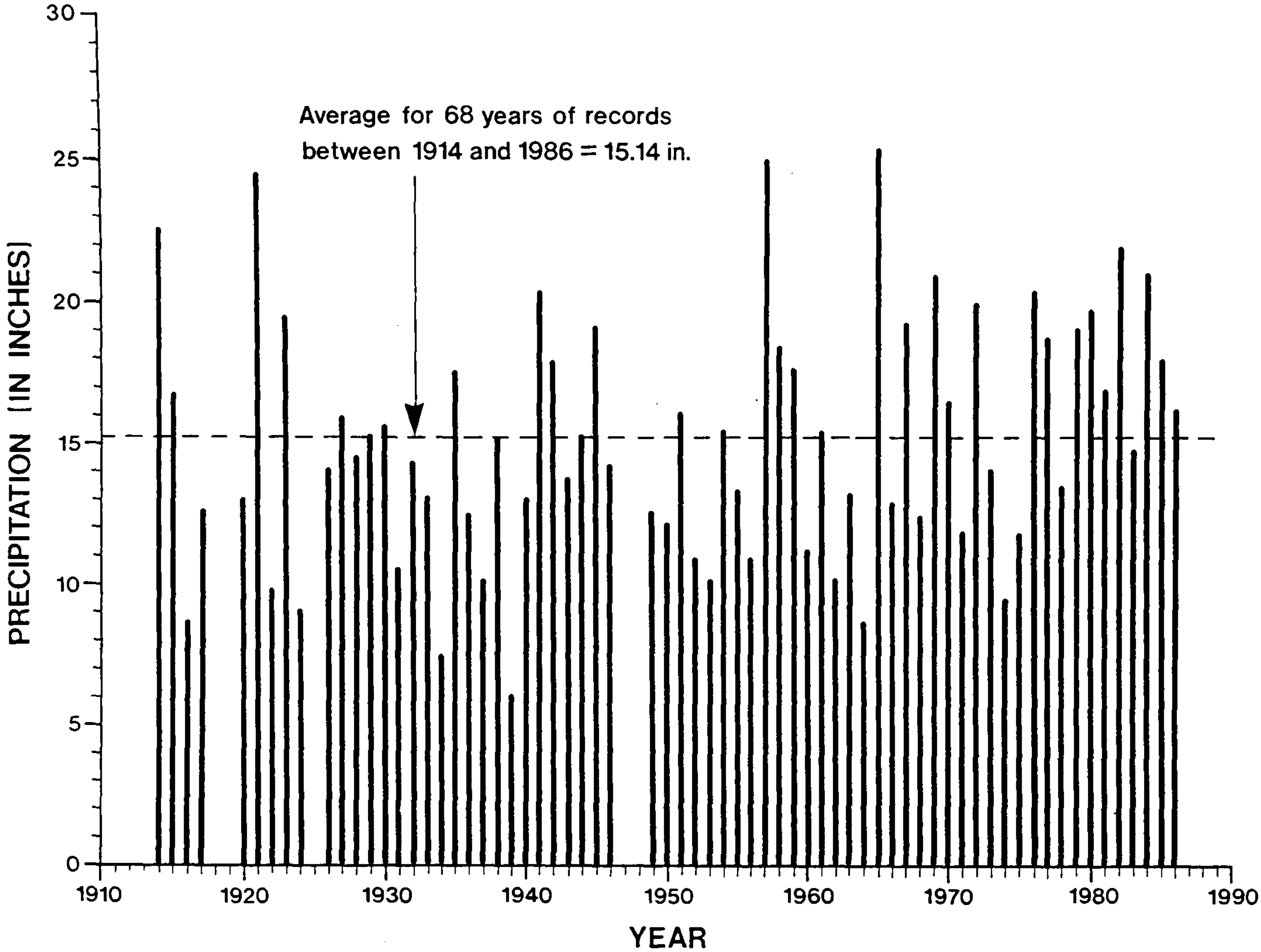

Figure 4. Annual precipitation at Colorado Springs between 1914 and 1986. (From NOAA, 1914–1986)

Drilling and Surveying Program

The initial phase of the drilling and surveying program involved evaluation of existing information, selection and staking of ten proposed test hole locations, and surveying of a traverse loop through the property to provide horizontal and vertical control for the ten proposed test holes and for the three previously drilled KKBNA test holes. The initial survey traverse also provided accurate ground control which allowed field personnel to better locate relevant cultural and topographic features on utilized topographic maps, a task made difficult by the hummocky, irregular dune topography and the absence of prominent landmarks in the area. A request to drill the test holes was filed with the State Engineer's Office prior to initiation of the drilling program. This resulted in successful permitting of the test holes.

A drilling contract based on an hourly rate was procured through the Colorado Division of Purchasing and awarded to Can-American Drilling from Simla, Colorado. Drilling commenced on April 13, 1988 and was completed on April 15. As the drilling project proceeded and data on the buried channel configuration was collected and evaluated, it was necessary to revise the locations of certain drill holes to maximize information obtained from the drilling program. Test holes 1, 2, 4, 6, and 7 were drilled in their original staked locations. Locations 3, 5, and 8 were slightly changed, with the new locations being designated 3a, 5a, and 8a to indicate they were drilled in alternative locations. Test holes 9 and 10 were not drilled because they were situated beyond the apparent boundary of the buried channel. Three additional test holes, numbers 11, 12, and 13, were drilled to better define the character and extent of the buried channel.

Thus, eleven test holes, numbers 1, 2, 3a, 4, 5a, 6, 7, 8a, 11, 12, and 13 were drilled during this project, involving a total footage of 1,283 ft of drilled hole. Five of the test holes, 1, 4, 5a, 8a, and 12, were cased with four inch diameter schedule 40 pvc casing to serve as monitor or observation wells. Each annulus of the five cased holes was gravel packed from the bottom of each hole to within 10 ft of the surface, while the upper 10 ft was cement grouted. Each of the five cased test holes has been converted to a permitted monitoring well. The six uncased holes were plugged and abandoned in accordance with State regulations. Sand and gravel cuttings were used to backfill the uncased test holes from the bottom to within 10 ft of the surface and a cement grout was utilized to plug the upper 10 ft. A well abandonment affidavit has been submitted to the State Engineer's office for each uncased test hole.

Upon completion of drilling, the survey team returned to the area to accurately locate the new test holes. Figure 5 illustrates the surveyed locations of each test hole and traverse point. A compilation of all survey traverse data is included in Appendix A.

Generalized graphic logs for each test hole are shown in Figure 6. Copies of the detailed logs have been submitted to Mr. Killip, and additional copies will provided upon request. Grab samples were collected and bagged at five foot intervals from each test hole. These samples will be retained by us for at least six months, in case additional analysis is necessary. The samples can be delivered to the SBLC, if requested.

Cased holes were drilled using a seven inch diameter wing bit, while uncased holes were drilled using a 4 3/4 in. bit. The static water levels for the uncased test holes were measured just prior to plugging and abandonment. Each uncased test hole was bailed to lower its water level below the static water level. The water level was then periodically measured until it stabilized. Static water levels reported for the cased test holes were measured five to seven days after completion. This value often differed from the level measured immediately following completion which was reported on the original detailed log, because cased holes were not always bailed after completion.

The following paragraphs summarize the pertinent characteristics of each test hole. Note that all test holes are within T. 16 S., R. 63 W. Static water levels in the following listing are reported as depths below ground level.

Test Hole 1
Permit TH-12834
Monitoring Well Permit 033767-M
Location: SE1/4 NW1/4 sec. 1
Elevation: 5574.16 ft
Depth: 75 ft
Casing: 55 ft solid wall, 20 ft perf.
Date Drilled: 4/13/88
Static Water Level: 59.2 ft
Formations Encountered: 0 to 12 ft—eolian deposits; 12 to 63 ft—older alluvium; 63 to 67 ft—weathered Pierre Shale; 67 to 75 ft —Pierre Shale

Test Hole 2:
Permit TH-12836
Location: SE1/4 NW1/4 sec. 3
Elevation: 5560.54 ft

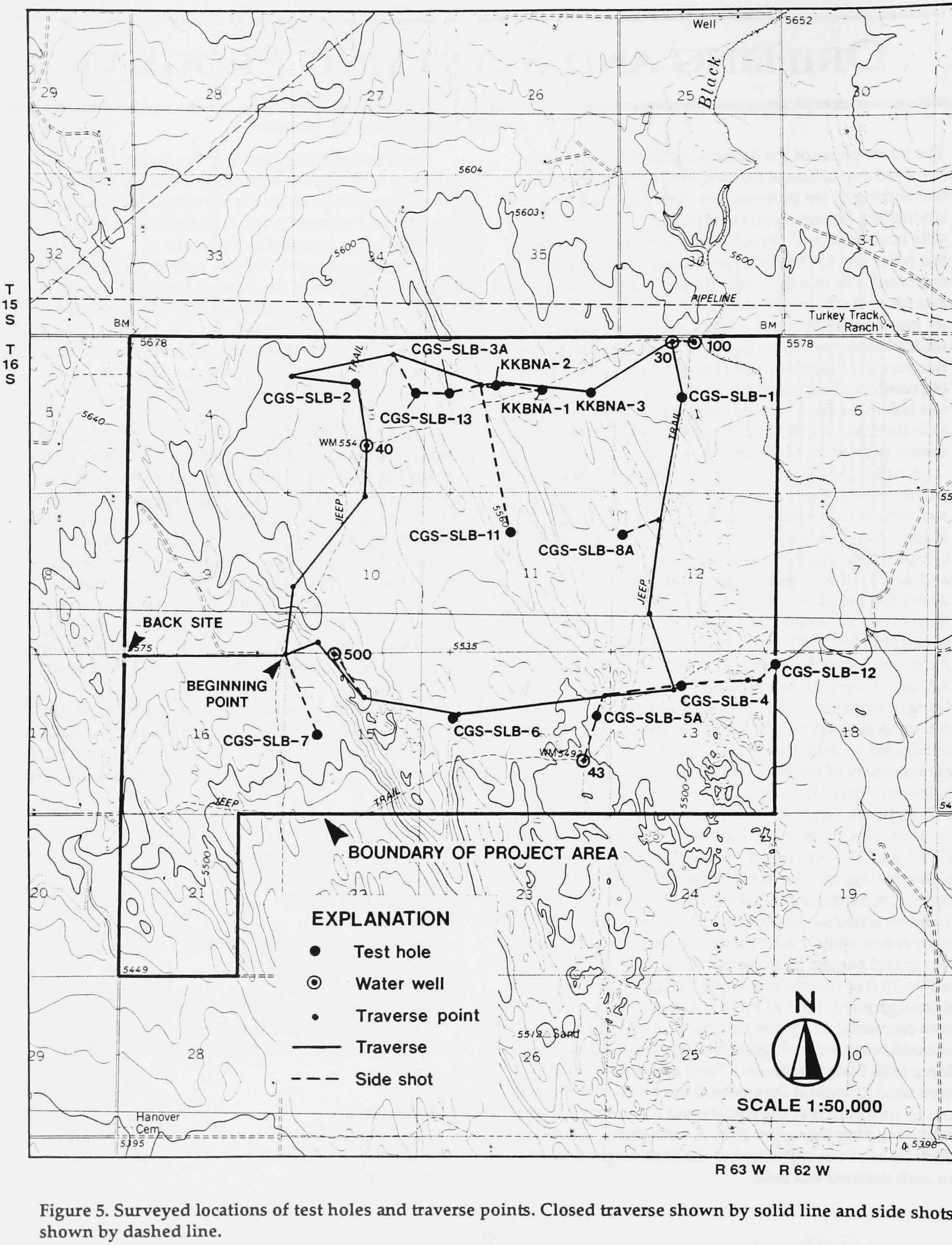

Figure 5. Surveyed locations of test holes and traverse points. Closed traverse shown by solid line and side shots shown by dashed line.

Depth: 58 ft
Casing: none
Date Drilled: 4/15/88
Static Water Level: dry hole
Formations Encountered: 0 to 9 ft—eolian deposits; 9 to 18 ft—older alluvium; 18 to 43 ft—weathered Pierre Shale; 43 to 58 ft—Pierre Shale (note: it was originally thought that material at 18 to 43 ft might be Piney Creek alluvium or Peoria loess with older alluvium below; we continued to drill until definite Pierre Shale cuttings were recovered)

Test Hole 3a:
Permit TH-12844
Location: SE1/4 NE1/4 sec.3
Elevation: 5561.99 ft
Depth: 120 ft
Casing: none
Date Drilled: 4/15/88
Static Water Level: 50.75 ft
Formations Encountered: 0 to 19 ft—eolian deposits; 19 to 102 ft—older alluvium; 102 to 110 ft—weathered Pierre Shale; 110 to 120 ft—Pierre Shale

Test Hole 4:
Permit TH-12843
Monitoring Well Permit 033768-M
Location: NE1/4 NW1/4 sec. 13
Elevation: 5529.31 ft
Depth: 187 ft
Casing: 145 ft solid wall; 40 ft perf.
Date Drilled: 4/13/88
Static Water Level: 99.43 ft
Formations Encountered: 0 to 32 ft—eolian deposits; 32 to 167 ft—older alluvium; 167 to 181 ft—weathered Pierre Shale; 181 to 187 ft—Pierre Shale

Test Hole 5a:
Permit TH-12842
Monitoring Well Permit 033769-M
Location: SE1/4 NE1/4 sec. 14
Elevation: 5509.63 ft
Depth: 140 ft
Casing: 115 ft solid wall; 20 ft perf.
Date Drilled: 4/13/88
Static Water Level: 73.60 ft
Formations Encountered: 0 to 7 ft—eolian deposits; 7 to 135 ft—older alluvium; 135 to 140 ft—Pierre Shale (no obvious weathered shale cuttings or second drilling break noted)

Test Hole 6:
Permit 12841
Location: SW1/4NW1/4 sec. 14
Elevation: 5540.72 ft
Depth: 135 ft
Casing: none
Date Drilled: 4/14/88
Static Water Level: 91.95 ft
Formations Encountered: 0 to 59 ft—eolian deposits; 59 to 128 ft—older alluvium; 128 to 131 ft—weathered Pierre Shale; 131 to 135 ft—Pierre Shale

Test Hole 7:
Permit TH-12840
Location: SW1/4 NW1/4 sec. 15
Elevation: 5507.36 ft
Depth: 78 ft
Casing: none
Date Drilled: 4/15/88
Static Water Level: 61.00 ft
Formations Encountered: 0 to 47 ft—eolian deposits; 47 to 56 ft—older alluvium; 56 to 76 ft—weathered Pierre Shale; 76 to 78 ft —Pierre Shale

Test Hole 8a:
Permit TH-12839
Monitoring Well Permit 033770-M
Location: SW1/4 NW1/4 sec. 12
Elevation: 5548.11 ft
Depth: 120 ft
Casing: 80 ft solid wall; 40 ft perf.
Date Drilled: 4/14/88
Static Water Level: 71.02 ft
Formations Encountered: 0 to 13 ft—eolian deposits; 13 to 115 ft—older alluvium; 115 to 117 ft—weathered Pierre Shale; 117 to 120 ft—Pierre Shale

Test Hole 11:
Permit TH-12837
Location: NE1/4 NW1/4 sec. 11
Elevation: 5538.53 ft
Depth: 140 ft
Casing: none
Date Drilled: 4/14/88
Static Water Level: 56.46 ft
Formations Encountered: 0 to 12 ft—eolian deposits; 12 to 137 ft—older alluvium; 137 to 140 ft—Pierre Shale (note: small amount of weathered shale in cuttings, but a second drilling break was not observed)

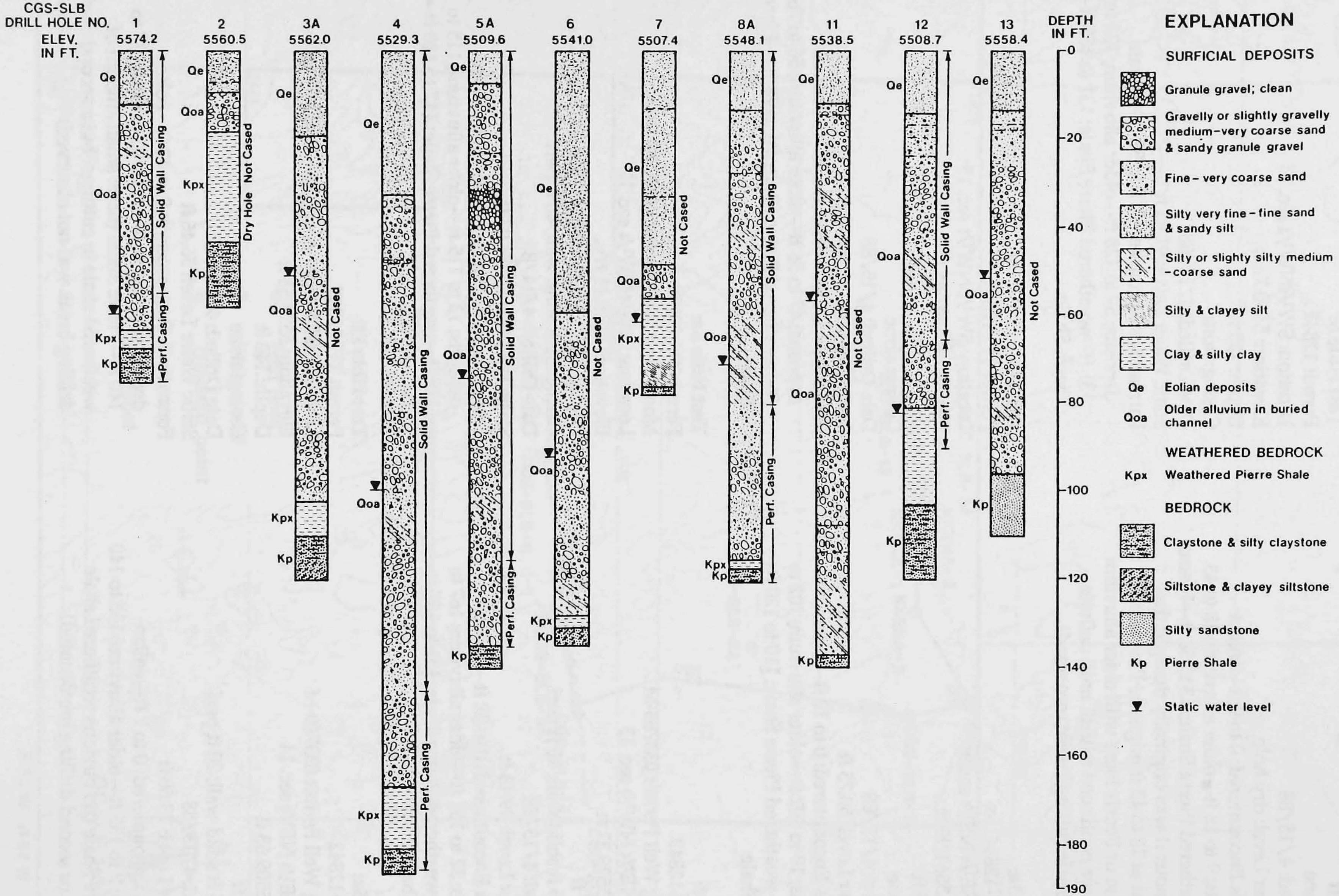

Figure 6. Generalized lithologic logs for the eleven test holes.

Test Hole 12:
Permit TH-12838
Monitoring Well Permit 033771-M
Location: NE1/4 NE1/4 sec. 13
Elevation: 5508.74 ft
Depth: 120 ft
Casing: 65 ft solid wall; 25 ft perf.
Date Drilled: 4/14/88
Static Water Level: 82.34 ft
Formations Encountered: 0 to 14 ft—eolian deposits; 14 to 81 ft—older alluvium; 81 to 103 ft—weathered Pierre Shale; 103 to 120 ft—Pierre Shale

Test Hole 13:
No Permit Assigned
Location: SE1/4 NE1/4 sec. 3
Elevation: 5558.43 ft
Depth: 110 ft
Casing: none
Date Drilled: 4/15/88
Static Water Level: 51.76 ft
Formations Encountered: 0 to 13 ft—eolian deposits; 13 to 96 ft—older alluvium; 96 to 110 ft—Pierre Shale (note: a small amount of weathered shale was observed in cuttings, but a second drilling break was not detected)

The three test holes previously drilled by KKBNA in section 2 were surveyed to provide horizontal and vertical locations. The test holes are located as follows:

KKBNA 1—3,000 ft from the west line and 1,700 ft from the north line; elevation is 5566.86 ft.
KKBNA 2—1,450 ft from the west line and 1,500 ft from the north line; elevation is 5571.42 ft.
KKBNA 3—750 ft from the east line and 1,750 ft the north line; elevation is 5581.08 ft.

Geologic Setting

Stratigraphy of the surficial units and bedrock formations, along with aquifer nomenclature are described in Table 1. Figure 7 is a geologic map that depicts both surficial and bedrock formations in the project area and the locations of cross sections through the area. Figures 8 and 9 are east-west cross sections (A—A' and B—B') and Figure 10 is a north-south cross section (C—C') that illustrate the shallow subsurface conditions in the project area. The cross sections extend through the test holes to utilize the factual data available at those locations.

Table 1. Surficial and bedrock stratigraphy and primary aquifer nomenclature.

Age	Unit	Primary Aquifer Name
Holocene	Modern Stream Alluvium	
	Eolian Deposits	
Pleistocene	Older Alluvium	Alluvial Aquifer
Cretaceous	Fox Hill Sandstone	
	Pierre Shale	
	undifferentiated Cretaceous rocks	
	Dakota Group	
Mesozoic, Paleozoic and Precambrian	undifferentiated Mesozoic, Paleozoic, and Precambrian	

Structural Setting

The project area lies on the southern flank of a large structural basin known as the Denver-Cheyenne basin, also sometimes called the D-J or Denver-Julesburg basin. Relationship between the project area and the structural Denver-Cheyenne basin is illustrated in Figure 11. The project area coincides with the synclinal axis of the basin. In the eastern part of the project area the bedrock dips about 0.5 to the north, while in the western part it dips about 1.5 to the northeast (Scott and others, 1978).

Another frequently discussed basin in eastern Colorado is the hydrogeologically defined Denver basin. The boundaries of this basin are delimited by the extent of the Fox Hills Sandstone, the lowermost of the well known "Denver Basin aquifers". As shown in Figure 12, the project area lies

generally south of the outcrop or subcrop of the generally northward dipping Fox Hills Sandstone, and is therefore south of the hydrogeologic Denver basin. Crows Roost, a local landmark about two mi north-northeast of the project area in section 19, T. 1 5 S., R. 62 W., is formed by a northward dipping outcrop of massive sandstone in the upper part of the Fox Hills Sandstone. Visual extension of this outcrop into the project area suggests that the thick, massive sandstones within the upper part of the Fox Hills Sandstone have been eroded from the project area. Subsequent to erosion of the Fox Hills Sandstone, older stream alluvium was deposited over the eroded surface, effectively concealing bedrock beneath the project area.

Mapping by Soister (1968) suggests a thin sliver of the lower part of the Fox Hills Sandstone may encroach onto a small, approximately 10 acre part of the project area in section 4 (see Figure 7 for location). No test holes were drilled in this area, so the presence of this formation in this area was not verified. Our northwestern-most test holes, particularly no.13, encountered coarser grained material typical of the transition zone of the Pierre Shale, indicating that the Fox Hills Sandstone probably occurs nearby and that Soister (1968) mapped the bedrock fairly accurately at this location.

Minor structural folds, faults, and joints likely exist in bedrock beneath the project area. Their occurrence was not documented during this investigation due to the absence of bedrock outcrops on the property and to the limited amount of bedrock structure data obtained from the rotary drilled holes that intentionally extended only a short distance into bedrock.

Surficial Deposits

Three distinct surficial deposits are recognized within the project area: *1)* modern stream alluvium (Qal) in the present channel of Black Squirrel Creek, *2)* wind-blown eolian deposits (Qe) that blanket nearly the entire project area, and *3)* older alluvial deposits (Qoa) found in a buried channel that is hidden beneath the eolian

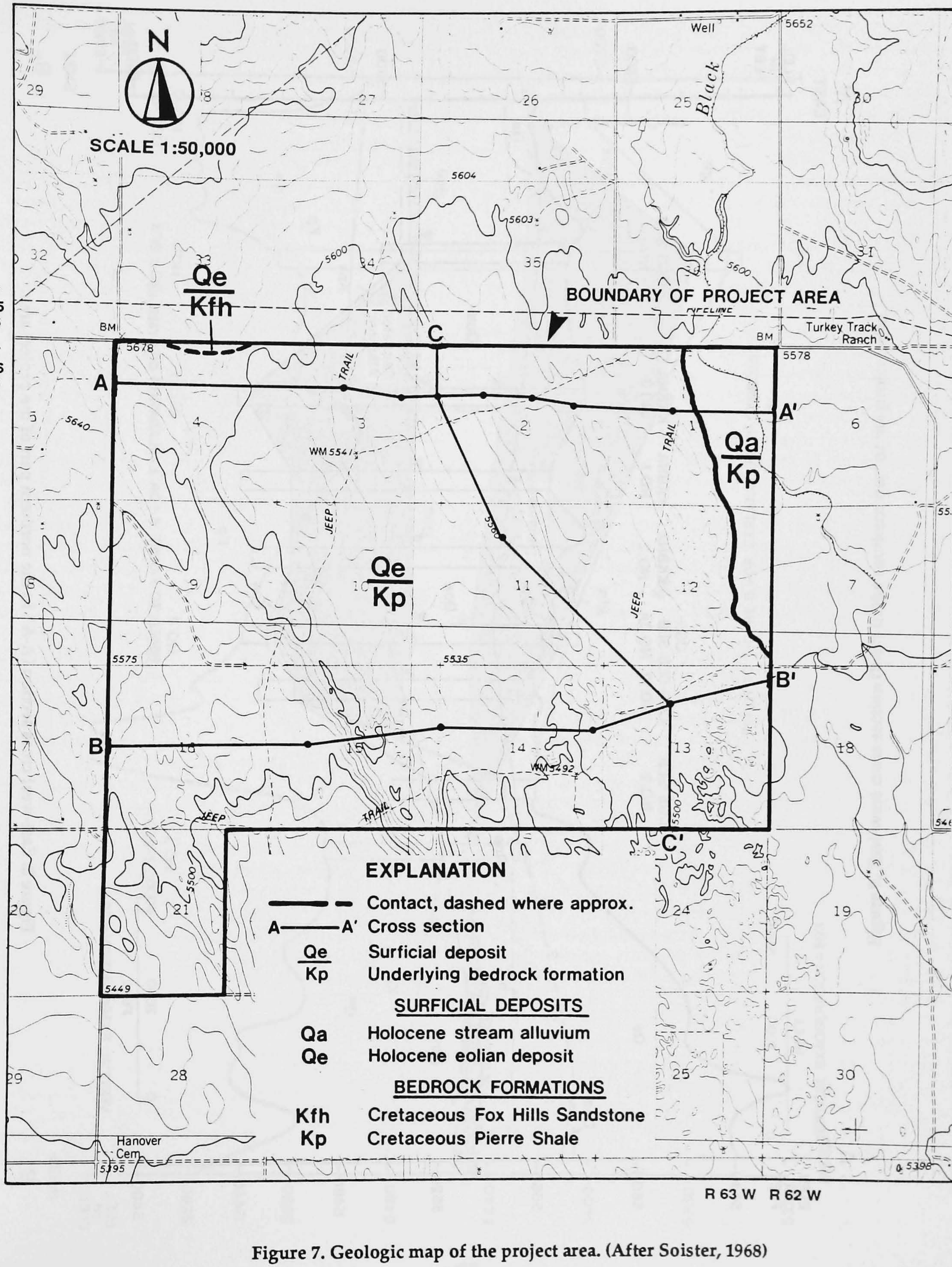

Figure 7. Geologic map of the project area. (After Soister, 1968)

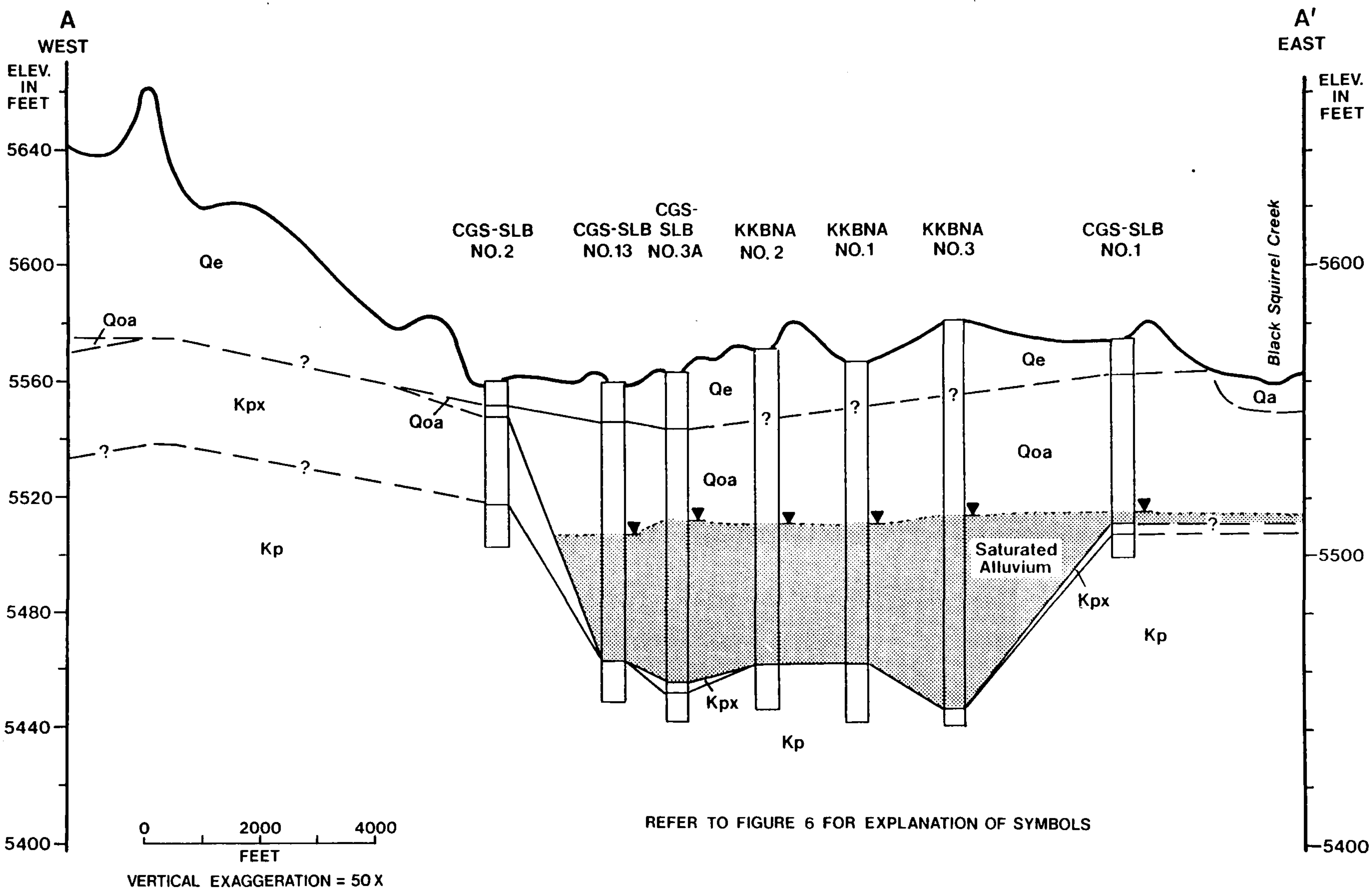

Figure 8. East-west cross section (A-A') in the northern part of the project area.

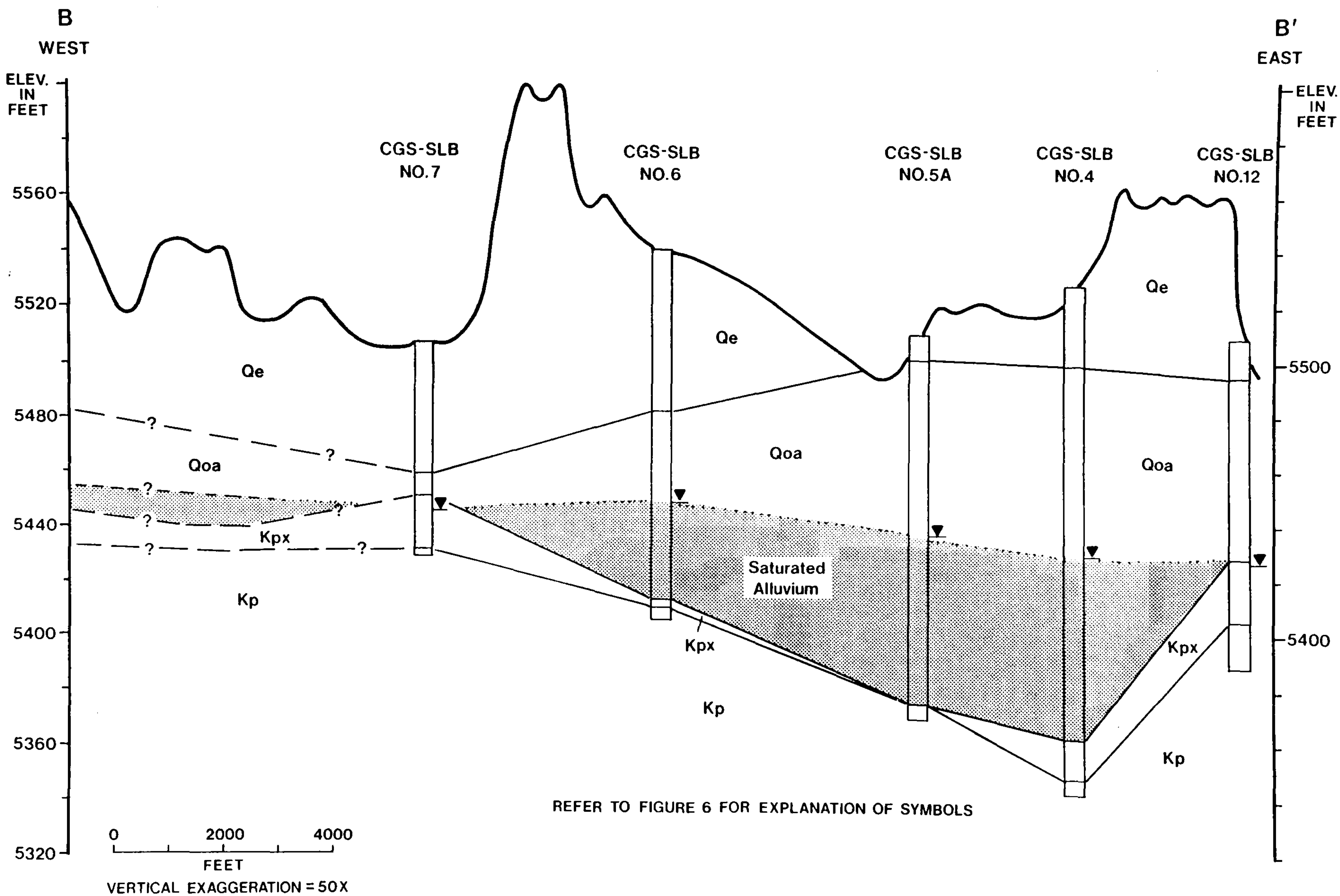

Figure 9. East-west cross section (B-B') in the southern part of the project area.

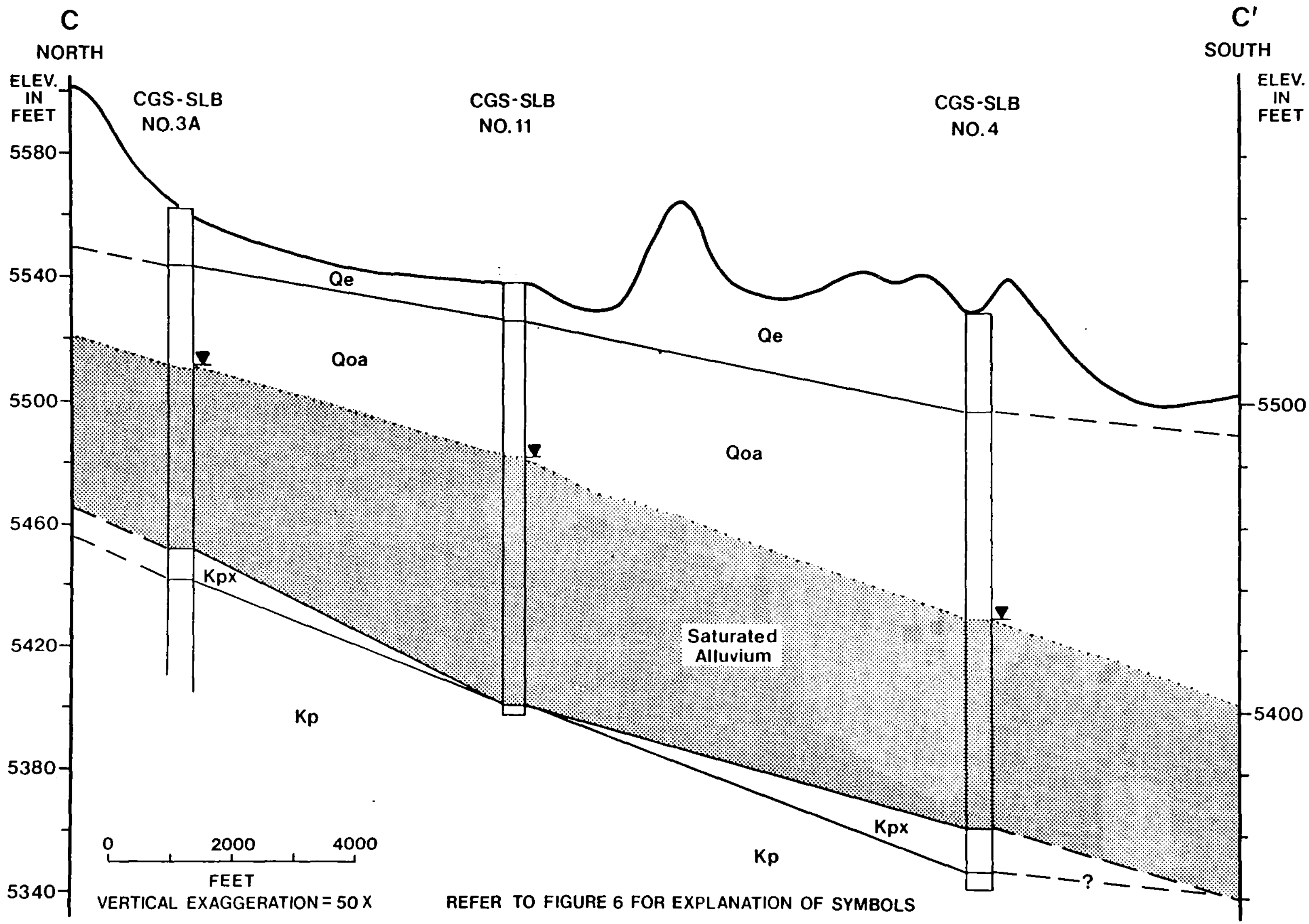

Figure 10. North-south cross section (C-C') along the center of the buried channel.

deposits. The older alluvial deposits contain virtually all of the shallow ground water beneath the property, and are therefore of primary interest to this investigation.

Soister (1968) mapped the surficial deposits of the Hanover NW quadrangle, in which the project area is situated, in a somewhat detailed style. In addition to the above three surficial deposits, he recognized a fourth unit which was mapped as Piney Creek Alluvium, a "mostly clayey, sandy silt and silty sand deposited in alluvial and pond or bog environments" over the eolian unit. Because this unit is well above the water table, is mapped over only a limited part of the project area, is reportedly only 5 to 15 ft thick, and was not recognized in any of our test holes, it is not differentiated as a separate unit in this investigation. Another variation between our mapping and that of Soister (1968) relates to his mapping of the older alluvial deposits at the surface in several topographically low areas within the property. Several of our test holes were located in areas where he mapped the older alluvial deposits as being at the surface. In all of these locations our test holes encountered from 9 to 13 ft of wind-blown eolian deposits over the older alluvial deposits. Because of this, we elect to map eolian deposits across all but the northeast corner of the property. The only possible area where 1older alluvium may occur directly beneath or at the surface is in the small topographic depression in the SW1/4 NE1/4 of section 14, west of test hole 5A (see Figure 9).

Holocene age or modern stream alluvium is found only within or adjacent to the present channel of Black Squirrel Creek in the northeastern corner of the project area in section 1. It may locally include deposits of Piney Creek alluvium as mapped by Soister (1968). None of our test holes encountered any modern stream alluvium, therefore the descriptions of this unit are based on surface exposures and on the work of Soister (1968). The unit consists of sand, gravel, and silt that is generally less than 15 ft thick. Modern stream deposits are very similar texturally and lithologically to the older alluvium.

The blanket of wind-blown eolian sand that covers all but the northeast corner of the project area consists of very fine to medium sand, silt, and silty sand. Thin layers of coarse grained sand, gravelly sand, and silty clay are sometimes present. Thickness of the eolian deposits range up to about 20 ft thick in interdune areas, but are probably 140 ft thick or more in section 15 where the tallest sand dune on the property occurs. The greatest thickness of eolian deposits penetrated by our test holes was 59 ft in test hole 6. Most sand grains are quartz or feldspar, but other lithologies are sometimes present. Individual sand grains are generally frosted. Soister (1968) suggests the eolian material is derived from Pleistocene age older alluvium in and northwest of the project area.

The buried stream channel initially recognized by Soister (1968) and confirmed by KKBNA (1986) has been further characterized by our test holes (see Figures 8, 9, 10, 13, and 14). Stream alluvium within the buried channel is herein called "older alluvium" or "older alluvial deposits" to differentiate it from the modern stream alluvium associated with the modern channel of Black Squirrel Creek. Older alluvium within the buried channel was detected in all test holes, but it was not saturated in all areas.

Thickness of the older alluvium within the project area is depicted in Figure 13. Only test hole data and reliable driller's logs were used to prepare this map. The buried channel is readily identified on Figure 13. Note the smaller, secondary buried channel in the southwest corner of the project area. On the western margin of the main buried channel the test holes encountered about nine feet of older alluvium (which was unsaturated), while up to 135 ft was observed in the central part of the buried channel in section 13 (test hole 4). The older alluvium may be thicker within other parts of the channel, and it may be thinner or even completely absent in other channel margin areas.

As shown in Figures 8, 13, and 14, the modern channel of Black Squirrel Creek is generally parallel to, but lies one to two miles east of the buried channel in the project vicinity. The modern channel alignment does not reflect the configuration of the underlying bedrock surface.

The secondary buried channel that extends through the western margin of the project area in the W1/2 of section 9, section 16, and the E1/2 of section 21 is also apparent on Figure 14. It contains far less water than the main buried channel, but it may deserve further evaluation. Records in the State Engineer's office indicate that a water well in the southeast corner of section 21, which is probably within this smaller buried channel, penetrated about 40 ft of saturated sand and gravel.

Sediments within the buried channel are dominantly slightly gravelly to gravelly medium to very coarse sand, but textures range from silty very fine to fine sand to sandy granule gravel. A few thin beds of granule gravel and clay were also noted in the cuttings. Textures of the older alluvium, where saturated, are classified by percent of total saturated footage as follows: 64.3 percent slightly gravelly or gravelly medium to very coarse sand, 9.7 percent slightly silty or silty very fine to medium sand, 9.2 percent very fine to medium sand, 8.7 percent sandy granule gravel, 6.5 percent medium to very coarse sand, 0.8 percent granule gravel, and 0.8 percent clay. Much of the sand, gravelly sand, and gravel are clean and free of fines. The gravel fraction is primarily granule sized, but may range up to small to medium pebble sizes.

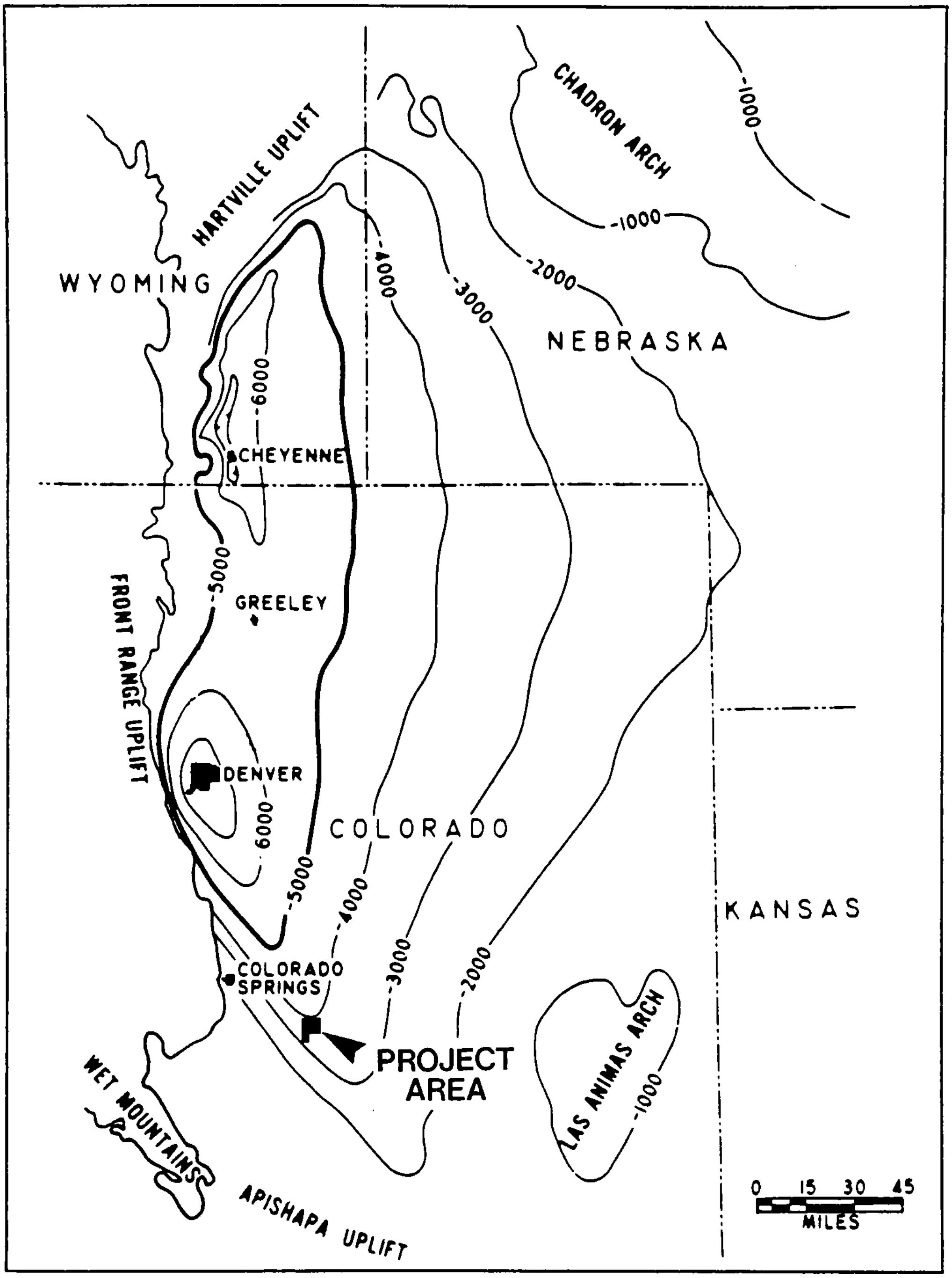

Figure 11. Structure contour map on the top of the Precambrian surface in Denver-Cheyenne Basin. (After Matuszczak, 1973)

Arkosic lithologies predominate in the sediments within the buried channel. The gravel fraction typically consists of 50 to 60 percent quartz, 20 to 30 percent feldspar, 10 to 15 percent granitic rock fragments, and a few percent sedimentary rock fragments, including both ironstone and petrified wood. Provenance area for the older alluvial deposits is thought to primarily be the Dawson Arkose, with minor contributions from underlying formations.

Bedrock Formations

The Pierre Shale underlies surficial deposits beneath nearly all of the property except for a small area in section 4

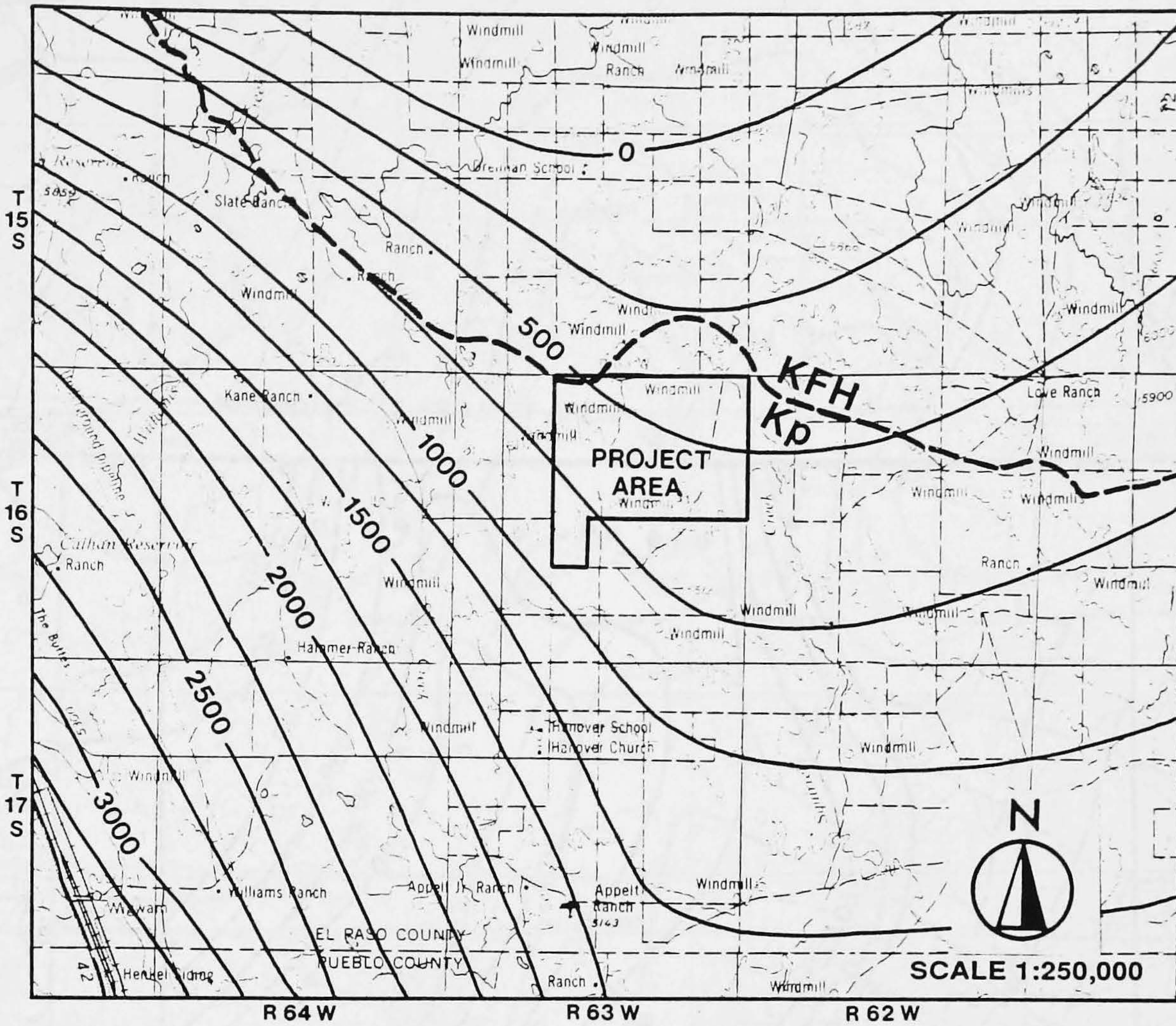

Figure 12. Relationship between the project area and the southern end of of the hydrogeologic Denver Basin, as defined by the extent of the base of the Laramie-Fox Hills aquifer. Structure contours (in feet above sea level) on the top of the Dakota Sandstone illustrate the structural configuration of bedrock beneath the project area. (After Scott and others, 1978)

where the lowermost part of the Fox Hills Sandstone may be present (Figure 7). The lower part of the Fox Hills Sandstone typically consists of interbedded claystone, shale, siltstone, sandstone, and limestone. North of the project area, the Fox Hills Sandstone, particularly the massive sandstones in the upper part of the formation, is considered an important aquifer. Hydrogeologists often include the Fox Hills Sandstone and lower part of the Laramie Formation in a single hydrogeologic unit called the Laramie-Fox Hills aquifer. Since the Fox Hills Sandstone occurs beneath only about 0.1 percent of the project area (10 acres out of 8,000 total acres) and only the lowermost part of the formation is present, it is not of great importance as an aquifer within the project area.

The Pierre Shale consists of approximately 4,500 ft of medium to dark gray marine claystone, shale, siltstone, limestone, and sandstone that was deposited in regressing Cretaceous seaway. Several geologic and engineering analyses have focused on the Pierre Shale in the past few years, a result of proposed major engineering projects involving hazardous waste disposal and potential siting of the Department of Energy's Super Collider within this formation. These studies have greatly expanded knowledge of the Pierre Shale. In some areas certain intervals within the Pierre Shale are capable of producing significant amounts of ground water, but this possibility was not investigated on this property, since it focused upon the buried channel filled with older alluvium.

Only the uppermost part of the Pierre Shale underlies the project area at shallow depths. Immediately below the Fox Hills Sandstone and at the very top of the Pierre Shale is a 125-to 175-ft-thick layer of interbedded claystone, siltstone, sandstone, and limestone commonly referred to as the Fox Hills-Pierre transition zone. It was deposited near the margin or coastal areas of the Cretaceous seaway in fairly shallow water. Although our test

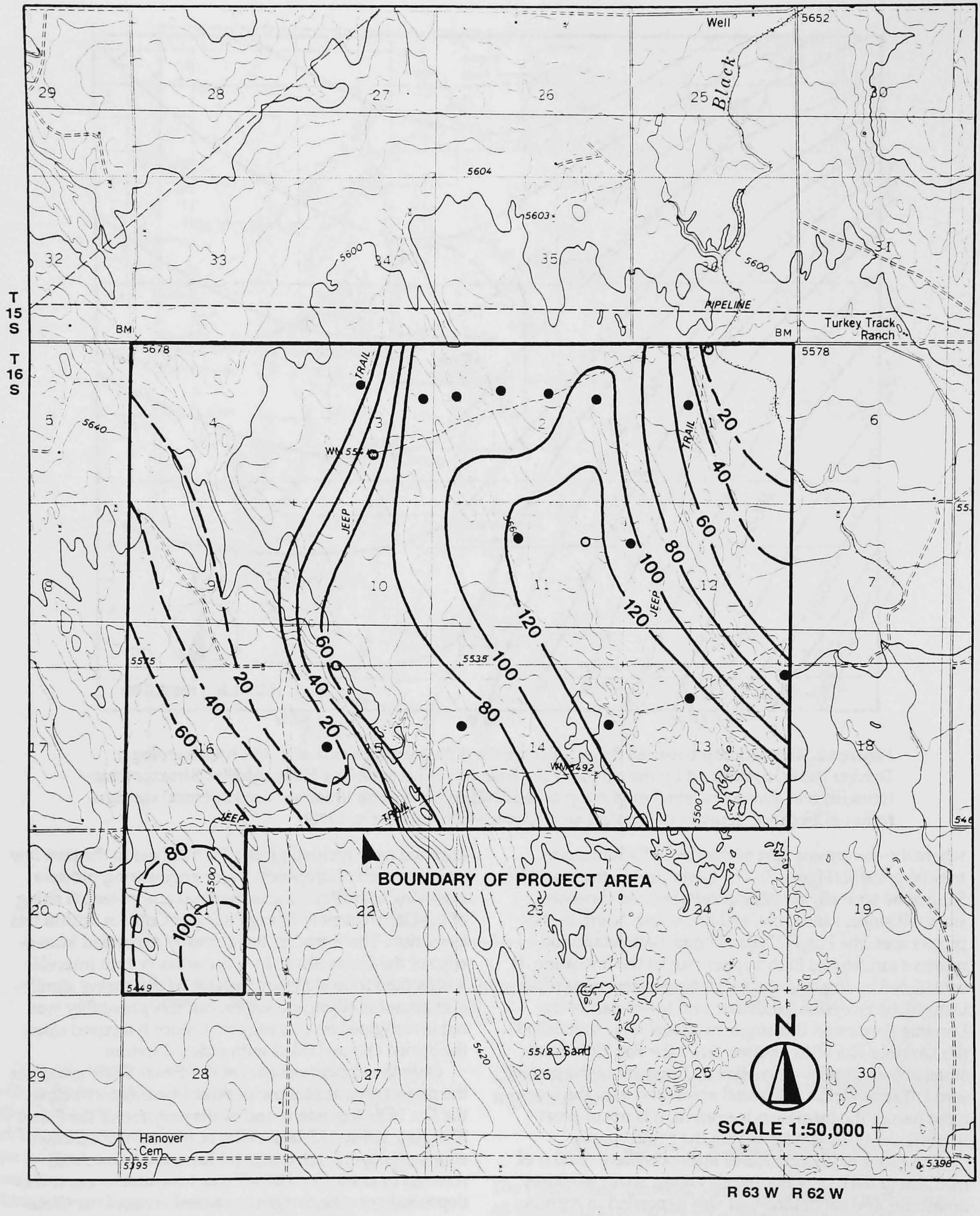

Figure 13. Isopach map of the older alluvium within the buried channel in the project area. Solid circles are test holes and open circles are water wells.

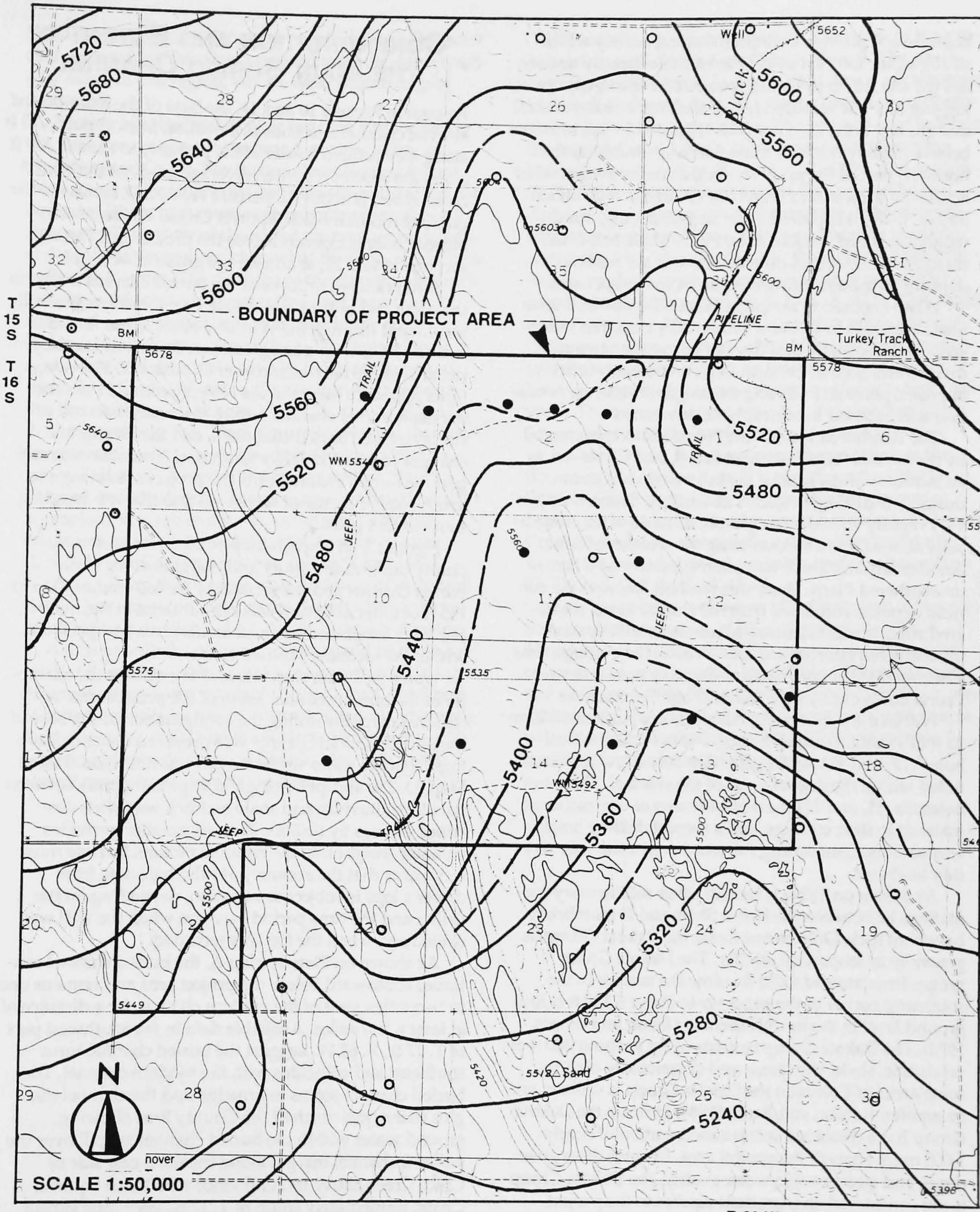

Figure 14. Map showing elevation of the base of the buried channel in and adjacent to the project area. Contour interval is 40 feet, with supplemental contours at 20-feet intervals. Extent of older alluvium is shown by the heavy dark line. Solid circles are test holes and open circles are water wells with utilized data.

holes do not provide definitive data on exactly which stratigraphic interval of the Pierre Shale directly underlies the site (to do so would require coring or geophysical logging of a few hundred feet of the Pierre Shale) and oil and gas test holes are very widely spaced in this area, we believe it likely that this transition zone underlies the northern part of the property. In that the structural relief across the project area is around 200 to 350 ft (Scott and others, 1978), it is possible that an underlying, dominantly claystone section of the Pierre Shale below the transition zone occurs directly beneath the surficial deposits in the southernmost part of the project area.

When exposed to atmospheric conditions, the Pierre Shale weathers to a yellow brown silty clay. The weathered zone is usually best developed on interstream divides and thinner beneath thick sections of surficial deposits, perhaps reflecting the length of time the formation was exposed to atmospheric conditions.

The weathered zone of the Pierre Shale, represented by the symbol "Kpx" on Figures 8, 9, and 10, served as an indicator of the base of the buried alluvial channel during our drilling project. The surficial deposits drilled very rapidly with the winged bit, but drill rates immediately slowed upon encountering the weathered zone. Another drilling break was often experienced when unweathered Pierre Shale was reached. Because the surficial deposits contained material similar to the weathered zone, it was necessary to continue drilling until unweathered bedrock was observed in the cuttings, thus assuring that the encountered silty clay beds were not Peoria Loess overlying additional aquifer material.

Within the project area, the test holes penetrated 20 to 25 ft of weathered shale on the channel margins (test holes 2, 7, and 12), while generally only a few feet was noted within the deeper parts of the channel. Three test holes (5a, 11, and 13) showed only a trace of weathered material in their cuttings, and a second drilling break was not noted, indicating the weathered zone was very thin or absent.

As shown on Table 1, several other sedimentary formations lie between the Pierre Shale and Precambrian basement rock. Only one of these, the Dakota Group, is generally an important aquifer. The Dakota Group ranges from around 4,600 ft below the surface in the southwest corner of the property to about 5,300 ft below ground level in the northeast corner (Scott and others, 1978). The Dakota Group consists of up to about 200 ft of sandstone, shale, claystone, and occasionally coal. In some areas of Colorado the Dakota Group is utilized as an aquifer. Robson and Banta (1984) indicate the Dakota Group has a dissolved solids concentration of nearly 1,000 mg/l beneath the project area. Because of its great depth and questionable water quality, the Dakota Group is not considered an important aquifer in the project area.

Configuration and Extent of the Main Buried Channel

As seen in Figures 10 and 14, the base of the main buried alluvial channel descends in elevation from about 5,470 ft along the northern border of the property to about 5,330 ft along the southern border. Average grade of the buried channel bed is about 0.8 percent (42 ft/mi), similar to the grade of modern Black Squirrel Creek. The secondary buried channel extends across the project area through sections 16 and 21, at an average grade of 44 ft/mi.

Two branches or forks of the buried channel merge in the north end of the project area. One fork runs generally southward through the W1/2 of section 2, and the other extends southwest through section 36 and enters the project area at the northeast corner of section 2. The two forks appear to merge in the N1/2 of section 11 to form the main buried channel (which is usually referred to simply as the "buried channel"), and then it slightly changes course and flows southeast. Available data suggest the buried channel exits the project area along the south quarter corner of section 13 and that it is trending south at that point.

Figure 13, an isopach map of the older alluvium, clearly outlines the center and margins of the main buried channel and the secondary buried channel. Up to 135 ft of older alluvium was encountered in the main buried channel, and as much as 100 ft may be presently within the secondary buried channel.

Water-well data were utilized to evaluate the character of the buried channel south of the project area. A regional map illustrating the configuration of the base of the buried alluvial channel was prepared using driller's logs from the water wells and our test hole data (Plate 1, Map A). The abrupt lithologic change that occurs between the older alluvium and shale bedrock was often described on logs by drillers. This information provides valuable insight into the regional picture, but one must remember that the accuracy of lithologic data from driller's logs is subject to variation, depending on the driller and the time period between when the well was drilled and when the log was recorded.

As shown on Plate 1, Map A, the buried channel continues southward below the project area and remains one to two miles west of the modern channel for a distance of at least a few miles. Available data in the southwest part of T. 17 S., R. 62 W. suggest the buried channel turns southeast and coincides with the modern channel. The buried channel seems to broaden and the channel margins flatten just north of the County line, allowing ground water within the buried channel to spill over the western channel margin along the northeast side of Chico Creek above its confluence with Black Squirrel Creek. Immediately south of T. 17 S., very little subsurface data is available. The absence of sufficient data preclude development of definitive conclusions on the exact channel location. Privately acquired test hole data reportedly exists in this region, but we were unable to gain access to it.

Areas where bedrock is at or near the surface define the flanks or margins of the broad, ancient valley of Black Squirrel Creek. The buried channel must follow this ancient valley to the mainstream alluvium along the Arkansas River, or it must surface somewhere above the Arkansas. The center of theburied channel seems to generally follow the modern channel of Black Squirrel Creek in Pueblo County. The gradient of the alluvium-bedrock contact in this reach is apparently lower than that observed in the project area, resulting in the shale bedrock lying closer to the surface. The channel may again flare or flatten just above its theorized junction with Chico Creek. Water within the buried channel in this area surfaces in sections 19, 20, 29, and 30 in T. 17 S., R. 62 W., creating the "Black Squirrel" wetland that contains several springs and abundant shallow ground water. Extent of all wetlands are depicted on Figure 1. They are readily detectable and mappable based on their anomalous vegetative growth, prominent infra-red responses on satellite imagery, and distinctive soils (U.S.D.A. Soil Conservation Service, 1979 and 1981).

Plate 1, Map B illustrates total thickness of unconsolidated Quaternary deposits in the project vicinity based on all types of available data. A regional map showing thickness of only the older alluvium would be more useful, but it is not feasible to make the necessary lithologic differentiations using available driller's logs. Thickness of eolian deposits increases dramatically only where tall sand dunes are visible on the surface. This effect can be subtracted from contours on Plate 1, Map B to reveal overall trends of the buried channel.

The southerly channel trend in and north of the project area is well defined on Plate 1, Map A. The southeasterly channel trend in the southeast part of the project area is also present, as is the change back to a southerly course below the project area. The isopach map indicates the buried channel has a south-southeast orientation between about section 35, T. 16 S., R. 63 W. and section 29, T. 17 S., R. 62 W. Thickness of the unconsolidated deposits decreases in the spill over area, reflecting the broadening channel floor, flattening channel margins, and shallowing shale bedrock in this area. Insufficient data is available to us to conclude exactly where the buried channel runs through T. 18 S., R. 62 W. Two water wells in sections 28 and 29 indicate that up to 146 ft of Quaternary deposits, most of it older alluvium, are present at this location. Other water wells further south, however, reportedly encountered significantly less alluvium. The buried channel may *1)* follow modern Black Squirrel Creek to the confluence with Chico Creek, where most water is lost to evapotranspiration in the Black Squirrel wetland, or *2)* it may lie east of Black Squirrel Creek and extend into the Pueblo Ordnance Depot, perhaps following the modern channel of Haynes Creek. If the latter case proves valid, water remaining within the buried channel probably surfaces in sections 22, 23, and 26, T. 19 S., R. 62 W.

Reconnaissance evaluation of driller's logs in the area between the confluence of Black Squirrel and Chico Creeks and the Arkansas River suggest another buried channel may exist beneath the Pueblo Ordnance Depot east of Chico Creek. The relationship between this buried channel and the buried channel beneath the project area will not be clarified until additional subsurface data is available for the intervening area.

WATER RESOURCES

This section on water resources is divided into subsections on ground water and surface water. Within the ground water subsection the alluvial aquifer is described, along with ground water recharge, discharge, underflow, and movement. Water level fluctuations and amounts of water in storage in the alluvial aquifer are also discussed, as are adjudicated water rights and suitability of the alluvial aquifer for designation. Included in the subsection on surface water are descriptions of the historic surface water flow based on discussions with local residents, the Water Commissioner, and published stream flow data. Information on water use in the project area is describedin the next chapter (see page 33).

GROUND WATER

Ground water beneath the project area was encountered in our test holes within the unconfined alluvial aquifer, the weathered zone of the Pierre Shale, and the Pierre Shale. Other bedrock formations deeper beneath the project area may also contain ground water, but only the alluvial aquifer is capable of economically producing large amounts of ground water at high production rates.

ALLUVIAL AQUIFER

Within the project area the alluvial aquifer consists of water-saturated sand, gravel, silt, and clay that occurs within the older alluvium in the buried channel. Figure 15 illustrates the elevation of the water table in the alluvial aquifer between late March and mid-April 1988, while extent and saturated thickness are shown in Figure 16. Elevation of the water table is also depicted of the cross sections (Figures 8, 9, and 10) and on the summary lithology logs (Figure 6).

Information contained in all figures is based upon water level measurements recorded in late March to mid-April 1988. All water wells within the project area and most within one mile of the property boundary were visited during our field investigation, and water levels were measured whenever possible. Unfortunately, many of the windmills are completed in such a way or are in such a deteriorated condition that it was not possible to safely enter them for measurement purposes. We did not attempt to measure water levels in any wells with submersible pumps, due to potential complications arising from probe entanglements with pump wiring.

Accurate water level information was obtained from all cased test holes, from all but one uncased test hole, and from a few existing water wells. Water levels in all cased test holes were measured immediately following completion and again five to seven days later, to assure that static equilibrium had been attained. The KKBNA test holes were re-measured during this study to provide water level data for the same time interval. Uncased test holes were measured periodically for one-half to thirty-one hours after drilling until the water level stabilized. Measurements for all uncased test holes except no.7 are believed to be accurate. Water in test hole no.7 occurred in the weathered zone of the Pierre Shale. Transmissivities in this aquifer are so low that it would take many days for the water level to fully stabilize, but the magnitude of any change should be low, perhaps rising no more than a foot or two.

Many of the measured windmills were pumping small amounts of water when visited. The mills were turned off prior to measurement, but they were measured shortly thereafter. For wells completed in a reasonably thick section of sandy alluvial aquifer, this would not significantly lower the water table. Wells completed in tighter deposits might show noticeable drawdowns when measured immediately after turning off the mill.

Most of the irrigation wells near the project area were producing large amounts of water during our field investigation. Because of significant water level drawdowns and interference with irrigation schedules, these wells were not measured.

Regional water table elevation and saturated thickness maps were prepared for the region surrounding the project area using data from the State Engineer's office to provide a generalized overview of the parameters. Since water levels contained in these records were measured over a very large time period, they may not portray modern conditions. The regional data assisted extrapolations between the recently measured wells and the property boundary. These maps are not included within this report, but are preserved in the CGS project file.

The unconfined water table occurs within the alluvial aquifer across most of the project area, but in places it is within the weathered zone or possibly even in unweathered Pierre Shale. Across most of the buried channel within the project area the water table contours slightly "V" or are flexed upstream, indicating that infiltrating precipitation recharges the alluvial aquifer. "V" shaped

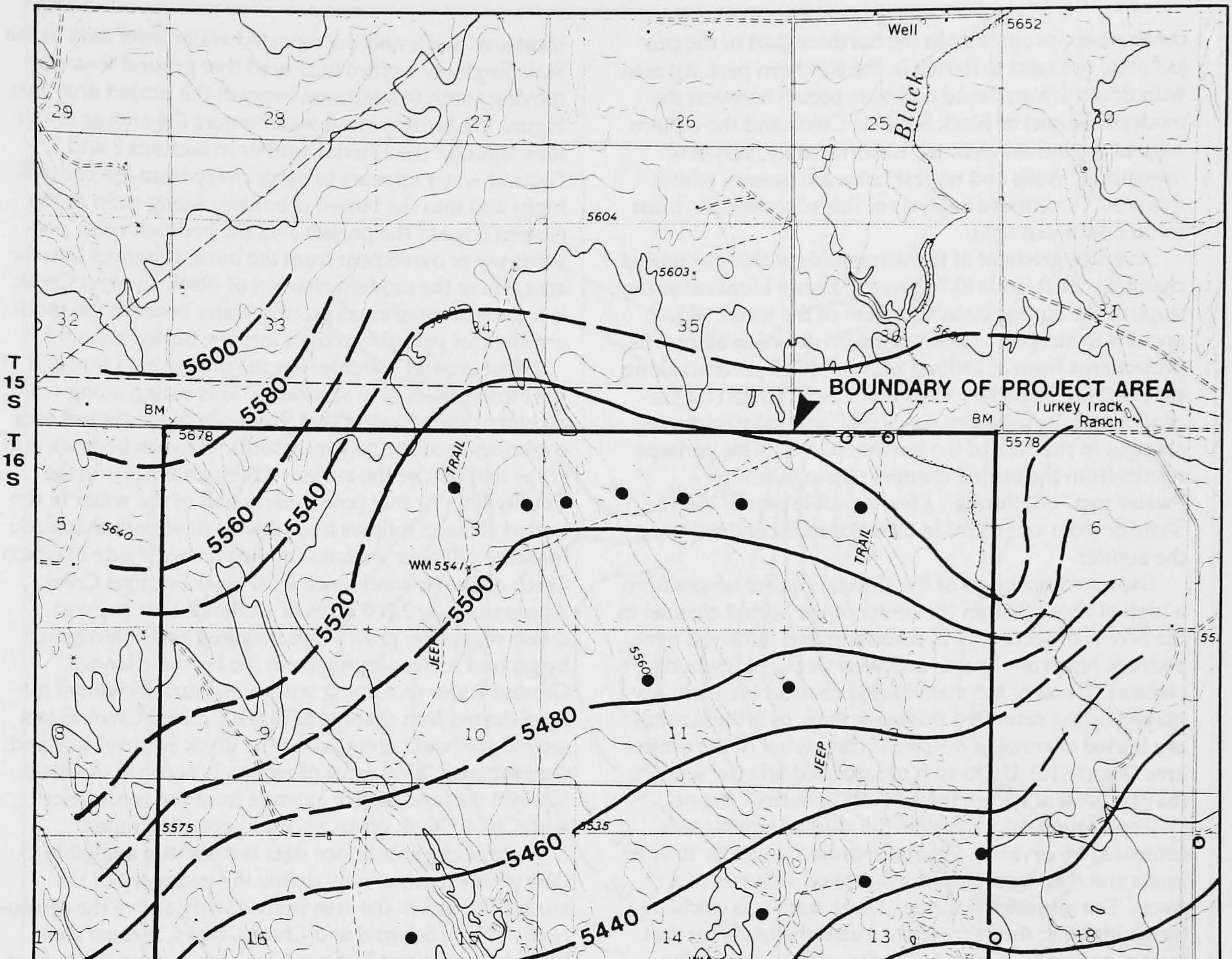

Figure 15. Elevation of the water table in feet above sea level in and adjacent to the project area during March and April, 1988. Solid circles are test holes, and open circles are measured water wells.

contours are prominent in the northern part of the project area, but tend to flatten in the southern part. An area with downstream flexed contours occurs between the modern channel of Black Squirrel Creek and the eastern edge of the buried channel. Unfortunately, very few measurable wells and no test holes are present within this area. Conclusive analysis of this phenomenon must await additional data.

Average gradient of the water table within the buried channel is 37 ft/mile (0.7 percent), nearly identical to the slope of the aquifer base. Gradient of the water table appears to steepen in a downstream direction across the project area from as little as 24 ft/mi (0.45 percent) along the northern boundary to as much as 61 ft/mi (1.2 percent) along the southern boundary, generally mirroring changes in the base of the buried channel. This perhaps results from the buried channel passing through a "water gap" cut through a less erodible part of Pierre Shale or from variations in the hydraulic conductivity of the aquifer.

Saturated thickness of the alluvial aquifer ranges from a high of about 80 ft in the center of the buried channel in the NW1/4 of section 11 to zero saturated thickness over bedrock highs on the east and west flanks of the buried channel. Trend of the main buried channel is clearly displayed by the saturated thickness map, as is the secondary buried channel in the southwest corner of the project area (Figure 16). Up to 40 ft of saturated alluvial aquifer may be present within the secondary buried channel.

Total saturated volume of the alluvial aquifer was estimated by dividing the entire project area into 10 acre tracts and then summing the saturated volumes of all tracts. The saturated volume of each tract was calculated by multiplying the average saturated thickness for that tract as shown in Figure 16, by the surface area of the tract. Approximately 400,000,000 cubic yards (248,000 acre-ft) of saturated alluvial aquifer is present within the project area, based on this calculation method.

Several water wells are completed within the alluvial aquifer in the project area, all of which are used principally for livestock and their pumps are wind powered. These wells reportedly yield up to 112 gal/min, but are not truly representative of what a properly constructed well with an adequate pump might produce. Irrigation wells completed in the alluvial aquifer outside the project area reportedly produce up to 2,500 gal/min, which is probably an optimistic sustained yield.

Ground Water Movement, Recharge, and Discharge

Movement

Figure 17 illustrates the general flow paths of ground water in the alluvial aquifer. Water levels in the nineteen measured wells and the reported water level data in the State Engineer's office indicated that ground water is moving south to southeast beneath the project area (see Figure 15). Most ground water enters the area as underflow through the alluvial aquifer in sections 2 and 3. Ground water appears to move away from the bedrock highs and into the buried channels. Along most of the eastern edge of the project area the bedrock ridge prevents water movement from the buried channel into the area where the modern channel of Black Squirrel Creek is found. In some areas ground water beneath the modern channel probably moves into the buried channel.

Most ground water leaves the project area through the buried channel in section 13. This water, along with all other ground water that flows out of the project area continues to move generally south between bedrock outcrops that border the ancient valley until nearing the County line. At that point nearly half of the water in the buried channel follows a southwest flow path that leads into the spill over wetland on the northeast side of Chico Creek above its confluence with Black Squirrel Creek. Approximately 2,200 acres of wetlands that support dense vegetative growth are irrigated and subirrigated by ground water seeping from the buried channel. Ground water remaining within the buried channel follows the modern channel of Black Squirrel Creek into a second wetland herein called the Black Squirrel wetland. An estimated 2,500 acres of wetlands occur in the Black Squirrel wetland, which extends from the confluence with Chico Creek upstream for almost five miles.

Insufficient subsurface data is presently available to the authors to accurately define the geometry of the buried channel in the area immediately above the confluence of Black Squirrel and Chico Creeks. A third wetlands located along Haynes Creek in sections 22, 23, and 26, T. 19 S., R. 62 W. suggests that some ground water within the buried channel may flow southeast into the 300 acre "Haynes" wetland.

Amounts of ground water from the buried channel lost to transpiration can be estimated based on the acreage of the wetlands and the type of vegetation (willows, cottonwood trees, grama grass, galleta grass, saltbush, greasewood, cactus, etc.). Vegetation present within these wetlands include dense, medium, and light types as classified by Blaney and Criddle (1949). An estimated average of 32 in. of water is transpired from these types of vegetation, resulting in approximately 13,000 acre-ft of ground water being consumed annually by the vegetation in the 5,000 acres of wetlands. Evaporation from the numerous bodies of standing water account for additional water losses. Significantly more ground water is lost in the wetlands than what flows out of the project area. Most, if not all ground water beneath the project area apparently is lost to evapotranspiration prior to reaching the Arkansas River.

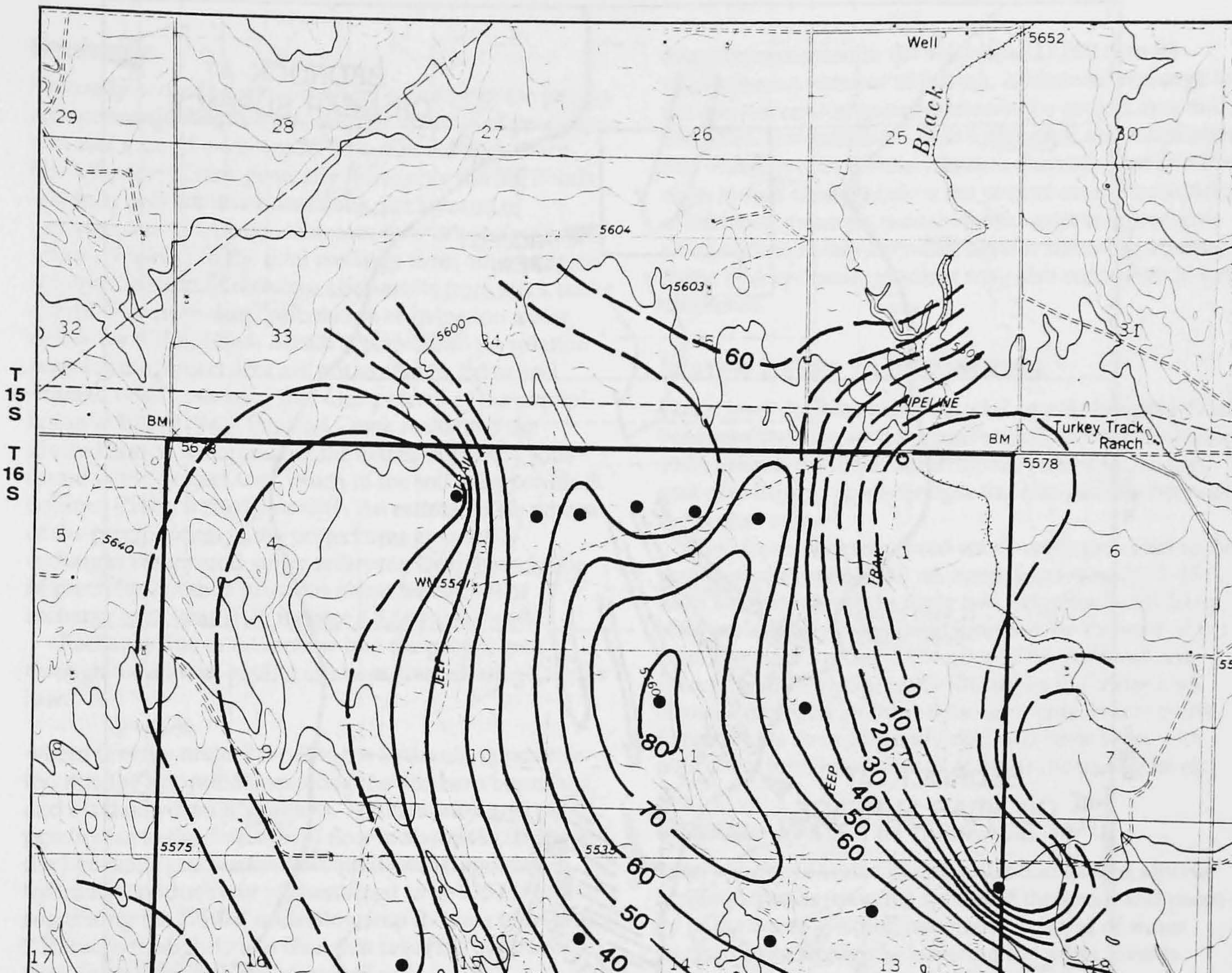

Figure 16. Extent and saturated thickness in feet of the alluvial aquifer as measured during March to April, 1988. Solid circles are test holes, and open circles are measured water wells.

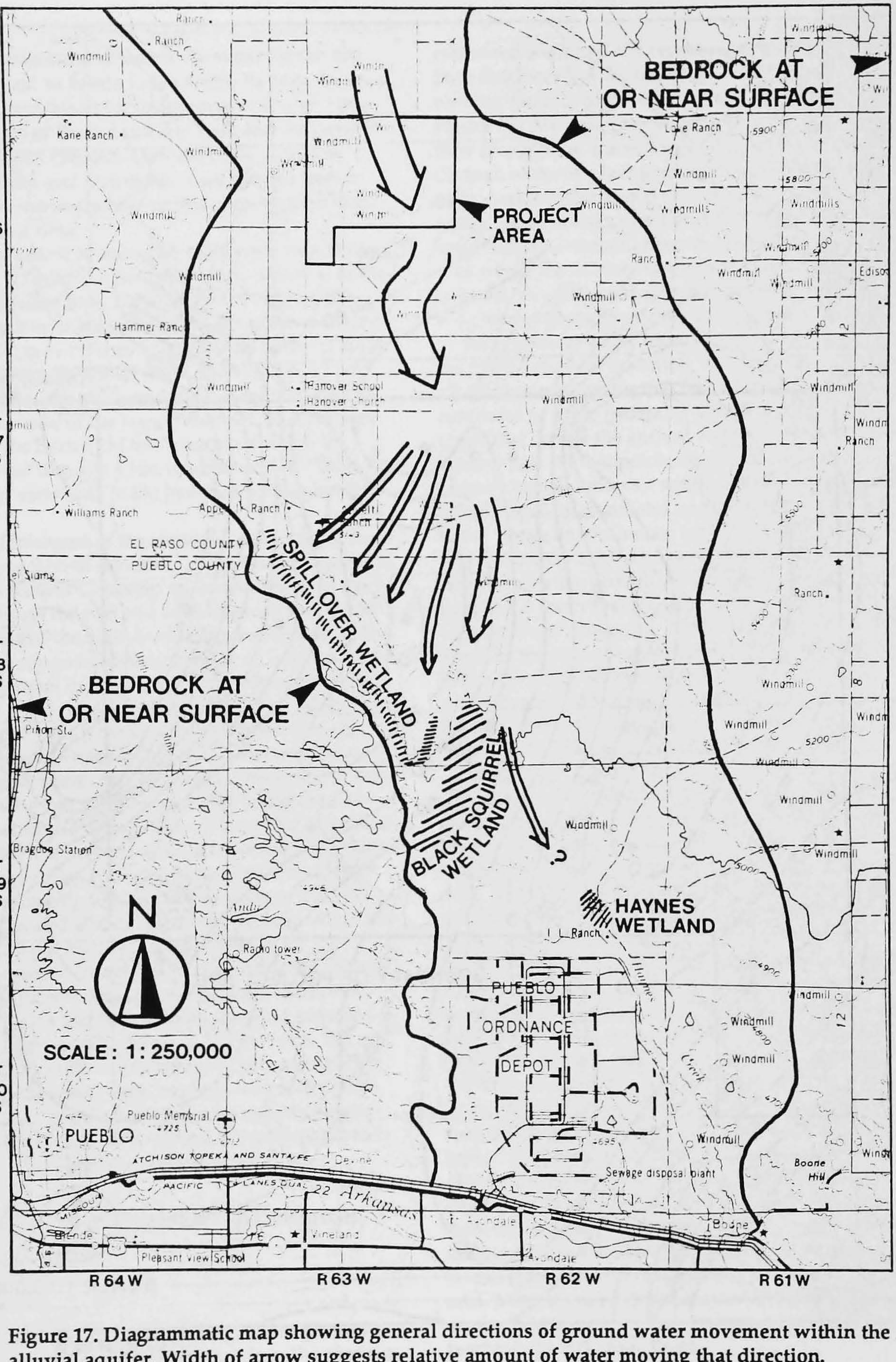

Figure 17. Diagrammatic map showing general directions of ground water movement within the alluvial aquifer. Width of arrow suggests relative amount of water moving that direction. Hachures indicate locations of wetlands.

Recharge

Naturally occurring ground-water recharge in the project area primarily results from deep percolation of precipitation and ground water underflow into the area. Since Black Squirrel Creek generally flows only during floods and then only for short durations, the amount of recharge due to seepage of stream flow is not significant when compared to the total recharge from other sources. A minor amount of recharge also results from stock tank overflow or from deep percolation of irrigation water, whenever it is applied. Actual precipitation percolation rates for the project area are not available. Erker and Romero (1967) assumed that four percent of the precipitation in upper Black Squirrel Creek recharged the ground water. In contrast to the extremely sandy soils found in the project area, much of the soil in upper Black Squirrel Creek is clayey or silty. An estimated six percent of the precipitation in the project area eventually recharges the ground water reservoir. Deep percolation of precipitation thus provides about 560 acre-ft of recharge each year (1.15 ft/year × 8,160 acres × 6%).

Recharge due to underflow into the project area through the alluvial aquifer can be estimated using Darcy's law:

$$Q = KAi$$

where Q is the underflow, K is the hydraulic conductivity, A is the saturated area along the northern boundary, and i is the hydraulic gradient. The saturated area perpendicular to the direction of flow is about 489,000 sq ft, the hydraulic gradient is 34 ft/mi (0.0064), and the hydraulic conductivity was assumed to be 275 ft/day, suggesting the annual underflow into the area is around 7,200 acre-ft, slightly less than that reported by Erker and Romero (1967) north of the project area.

Total recharge to the alluvial aquifer from underflow and precipitation infiltration is estimated at 7,760 acre-ft/year.

Discharge

Underflow and well pumping account for virtually all ground water discharge in the project area. Because the water table is relatively far below the ground surface, little ground water is discharged by evapotranspiration. Underflow out of the area was calculated based on a hydraulic gradient of 47 ft/mile (0.0089), a saturated area of 378,000, and hydraulic conductivity of 275 ft/day, resulting in 7,760 acre-ft of underflow each year. Well pumping amounts to only 7.7 acre-ft per year, assuming the wells permitted for combined uses produce only for livestock purposes, as they are today. If well use increases to permitted amounts, well pumping could withdraw as much as 900 acre-ft of ground water annually (see page 33).

Differences between the underflow (7,760 acre-ft) from the project area and the amount of water lost to evapotranspiration in the wetlands (13,000 acre-ft) results from a number of factors. Additional recharge to the alluvial aquifer occurs between the project area and wetlands. It results from both infiltration of precipitation and underflow in tributary buried channels that join the main buried channel below the project area. Inaccuracies of assumed parameters such as the water requirements of vegetation in the wetlands, aquifer hydraulic conductivity, and hydraulic gradient may also contribute to the difference.

Water Level Fluctuations

Water level declines in the alluvial aquifer in upper Black Squirrel Creek are well documented (Erker and Romero, 1967; Bingham and Klein, 1973), but prior studies suggest very little or no declines in the area directly north of the project area.

Two frequently measured water wells proximal to the project area are about 2.5 mi. north in section 24, T. 15 S., R. 63 W. Water levels in these two irrigation wells have been periodically measured since 1966 by the staff of the State Engineer's office (D. Nettles, 1988, personal commun.). Figure 18 graphically illustrates the water level changes recorded by these measurements. Water levels in both wells have gradually declined since 1966, with only a few brief interludes of static or increasing levels.

Ground Water in Storage

Total volume of water stored in the unconfined alluvial aquifer depends upon the saturated thickness and porosity of the water-yielding materials. Amount of water released from storage by lowering the water level is expressed as a percentage of the total formation volume and is called specific yield. Specific retention refers to the amount of water that will not drain by gravity and remains in the formation. The amount of water in storage can be calculated by multiplying the total saturated volume, determined from the saturated thickness map as 400,000,000 cu yds (248,000 acre-ft), by the porosity of the alluvial aquifer, which is estimated at 30 percent, based on Johnson (1967):

water in storage = saturated volume
(248,000 acre-ft) × porosity (30%)
= 74,400 acre-ft

The amount of ground water drainable by gravity is calculated as follows:

gravity drainable water = saturated
volume (248,000 acre-ft) × specific
yield (25%) = 62,000 acre-ft

A specific yield of 25 percent is the average value for gravelly sand based on 15 determinations reported by Johnson (1967) which ranged from 20 to 35 percent. Erker and Romero (1967) used a specific yield of 20 per-

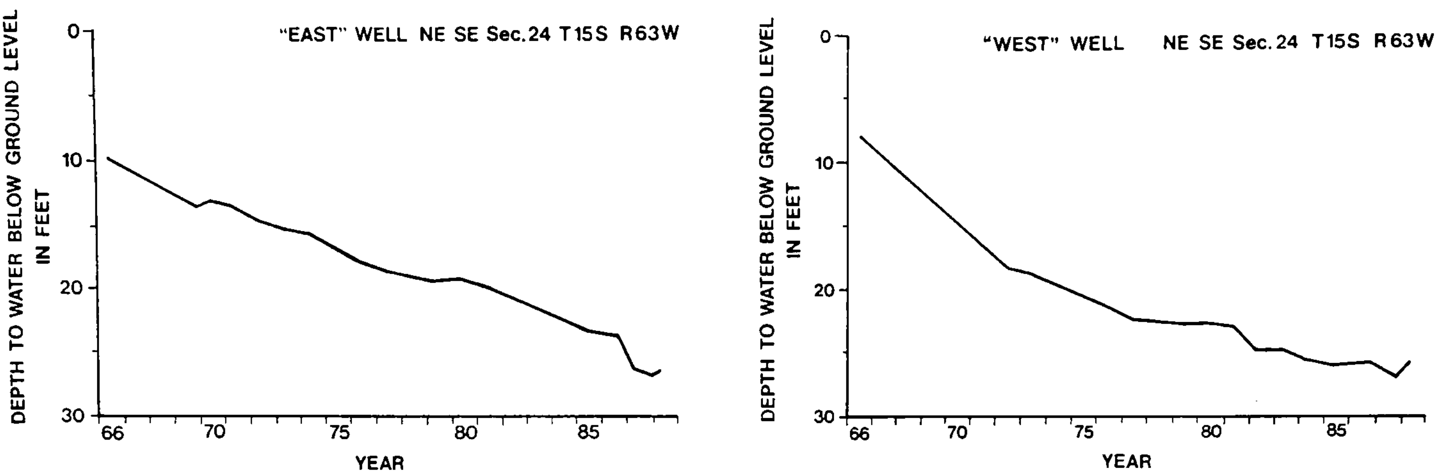

Figure 18. Hydrographs of two irrigation wells located about 2.5 miles north of the project area. Data furnished by State Engineer's Office.

cent in upper Black Squirrel Creek, but the alluvial aquifer in the project area appears to be better sorted with less fines.

Economically recoverable water is less than the amount drainable by gravity. Water remains in the aquifer between the cones of depression of adjacent wells after the water level in the well approaches the base of the aquifer. If well spacing is optimal for maximum water recovery, and pumps are set below the base of the aquifer, perhaps as much as 90 percent of the recoverable water or 55,800 acre-ft can be economically withdrawn.

Surface Water

Black Squirrel Creek extends across the northeast corner of the project area through section 1. It is the only significant stream within or adjacent to the property and is an intermittent creek in which surface flows are rare in this reach. It is generally dry in the vicinity of the project area except during and following very large flood-generating rainstorms. No gages are known to have ever operated on Black Squirrel Creek, hence very little quantitative data on historic flows are available.

Snipes and others (1974) describe the only known flow data for Black Squirrel Creek. It was obtained during the June, 1965 flood and involves peak flow estimations at two locations upstream of the project area. One location was about 25 mi north near Peyton. The drainage basin above this point is only 16.3 sq mi, but the peak flow was around 10,400 CFS, based on contracted-opening measurement. A second measured location was directly north of the property in section 36, T. 16 S., R. 63 W. The drainage basin is about 353 sq mi at this location, and the peak flow during the June 17, 1965 flood was 141,000 CFS, as determined by the slope-area measurement method. Obviously, Black Squirrel Creek is capable of tremendous discharge when flooding.

Based on discussions with several knowledgeable individuals, Black Squirrel Creek sustained more surface flow prior to construction of and appropriations from large production irrigation and municipal wells located north of the project area. Surface flows in Black Squirrel Creek will probably continue to occur only sporadically unless significant reductions in ground water withdrawals are implemented upstream.

During our field investigations in March and April, 1988 the creek was dry and looked as if no surface water had been present for a considerable length of time. Flotsam and flood debris were observed on bridge supports about 2 ft above the channel bed, suggesting moderate flows in the not too distant past.

Water Budget

The volume of water recharging an area must equal the discharge from it. The balance of recharge and discharge is the water budget. In an area such as the SBLC property in T. 16 S., R. 63 W., with little or no surface streams or well withdrawals, only a few elements enter into the water budget. Both recharge and discharge volumes are estimated values based on available hydrologic data and may be subject to revision as new data is acquired. Please refer to sections 6.1.2 and 7.0 for discussions of the procedures used to calculate water use, recharge, and discharge.

Since Black Squirrel Creek rarely flows in this reach, and then only for very short durations, nearly all stream flow entering the area is discharged from it. Only two factors, underflow into the area and deep percolation of precipitation contribute significantly to annual recharge in the project area. The only discharge of any consequence results from underflow out of the area through the alluvial aquifer. Discharge to surface water, consumptive use from well pumping, and evapotranspiration are negligible. The water budget for the project area is summarized in Table 2.

Table 2. Estimated annual water budget for the alluvial aquifer.

Recharge	
Underflow	= 7,200 acre-ft
Deep percolation of precipitation	= 560 acre-ft
Stream flow infiltration	= negligible
TOTAL	= 7,760 acre-ft
Discharge	
Underflow	= 7,760 acre-ft
Seepage of ground water into Black Squirrel Creek	= negligible
Consumptive use from well pumping	= negligible
Evapotranspiration	= negligible
TOTAL	= 7,760 acre-ft

Adjudicated Water Rights

According to the State Engineer's records, no adjudicated water rights exist within the project area. Five of the wells within the property are fee wells, but they apparently have never been adjudicated. The SBLC filed an application for underground water rights on this property on December 23, 1986 with the District Court in Pueblo. Action on this application is pending.

Adjudicated water rights exist on nearby private lands. All nearby decreed water rights are for wells that withdraw underground water. The closest adjudicated water well is located in NW1/4 NW1/4 section 6, T. 16 S., R. 62 W., immediately adjacent to the northeast corner of the project area (permit 57661; civil action 2266). This well was not observed during our field investigation, suggesting the possibility that the wrong location has been recorded for this well, or it has been abandoned.

The nearest downstream adjudicated water wells are found in sections 19 and 30, T. 16 S., R. 62 W. (permits 19000-F and 19099-F; civil action 3951) and in section 26, T. 16 S., R. 63 W. (permit 29181; civil action 4892). Several other adjudicated water rights occur further downstream.

No decreed surface water rights exist along the modern channel of Black Squirrel Creek below the project area. Sixteen decreed surface water rights are present in the northwest corner of the spill over wetland and in the Haynes wetland. Those in the spill over wetland are about 11 mi below the project area, while surface water rights in the Haynes wetland are about 19 mi below the project area. Total amounts appropriated under all adjudications in these areas are 88.8 acre-ft and 6.6 CFS. Table 3 lists pertinent data for the surface water rights in the wetlands.

Suitability for Designation

"Designated ground water" is defined in CRS 37-109-103(6) as *1)* "ground water which in its natural course would not be available to and required for the fulfillment of decreed surface rights," or *2)* "ground water in areas not adjacent to a continuously flowing natural stream wherein ground water withdrawals have constituted the principal water usage for at least fifteen years preceding the date of the first hearing on the proposed designation of the basin".

The project area is not adjacent to a continuously flowing stream, and the only known water usage over the past 15 years has been ground water. Thus, the project area qualifies for designation based on the second criteria in CRS 37-109-103(6).

As described in Section 6.1.2, water within the alluvial aquifer moves generally south below the project area to near the county line. At that point nearly half of the ground water moves into the spill over area along the northeast side of Chico Creek above its confluence with Black Squirrel Creek and is lost to evapotranspiration in about 2,200 acres of wetlands. Much of the water remaining in the buried channel moves into a second wetlands that covers about 2,500 acres along Black Squirrel Creek above its confluence with Chico Creek where it evaporates and transpires. Any ground water remaining within the buried channel may move southeast into a third 300 acre wetland along Haynes Creek where it also is lost to evaporation and transpiration. An estimated 13,000 acre-ft of ground water is consumptively used by the vegetation in the three wetlands and a significant additional amount evaporates. All or nearly all of the water in the buried channel never reaches the Arkansas River to become available for decreed water rights.

Sixteen decreed surface water rights exist within the northwest corner of the spill over wetland and in the Haynes wetland, but these water rights appropriate only part of the water available in the wetlands. Using estimated values for porosity and hydraulic conductivity that are within a reasonable range for this type of aquifer material and the character of the buried channel, one can conclude that ground water exiting the project area will not reach the adjudicated surface rights within 100 years.

Table 3. Adjudicated surface water rights in the wetland below the project area. (from data on the master list for District 14 in the State Engineer's office)

Name	Location	Type	Amount	Year Adj.	Year Appr.	Priority No.
		Northwest corner of spill over wetland				
HOP 1	Sec. 28/T17S/R63W	R	0.6 AF	1914	1880	1403
HOP 2	Sec. 28/T17S/R63W	R	0.6 AF	1914	1888	1406
HOP 3	Sec. 28/T17S/R63W	R	0.6 AF	1914	1882	1405
HOP 1	Sec. 29/T17S/R63W	D	2.0 CFS	1914	1881	1404
HOP 2	Sec. 29/T17S/R63W	D	2.0 CFS	1914	1875	1402
HOP	Sec. 32/T17S/R63W	R	68 AF	1914	1902	1598
Curiton	Sec. 32/T17S/R63W	R	6.8 AF	1914	1903	1612
Smith 1	Sec. 5/T18S/R63W	D	1.0 CFS	1914	1895	1407
Smith 1	Sec. 5/T18S/R63W	R	6.1 AF	1914	1902	1584
Smith 2	Sec. 5/T18S/R63W	D	1.0 CFS	1914	1902	1586
Smith 2	Sec. 5/T18S/R63W	R	3.1 AF	1914	1903	1611
		Haynes wetland				
Springs 1,2, 3, 4	Sec. 22/T19S/R62W	SP	0.033 CFS	1971	1910	5280
Springs 1,2, 3, 4	Sec. 22/T18S/R62W	SP	0.157 CFS	1971	1910	5280
Reservoir 1	Sec. 22/T18S/R62W	R	0.334 CFS	1971	1915	5282
Reservoir 2	Sec. 26/T18S/R62W	R	0.0334 CFS	1971	1915	5282
Reservoir 3	Sec. 26/T18S/R62W	R	3.0 AF	1971	1915	5282

WATER USE

GROUND WATER USE

Ground water in the alluvial aquifer beneath the project area has been withdrawn from wells for at least 75 years and is permitted for livestock, irrigation, domestic, and mechanical uses. Appendix B lists the eight registered water wells and one unregistered water well existing on the property. The owner, permit number, completion date, location, depth, water level, and yield are described for each well. None of the wells are adjudicated, but five are fee wells. Locations of the nine wells are shown on Figure 19.

HISTORICAL USE

The earliest recorded water well in the project area was constructed in 1913. Hand dug wells along the modern channel of Black Squirrel Creek may have been constructed earlier, but we are not aware of any documentation to support their existence. Other old wells were drilled in 1920 and 1935, followed by newer wells in 1950, 1970, 1971, and 1982. These wells primarily have been used for livestock watering, but five wells are permitted for combined domestic, irrigation, and/or livestock and mechanical usage.

Appendix C lists all water wells that have been in existence for the past fifteen years (since June, 1973). To satisfy CRS 37-90-106 (1f), the list includes the registered owner, use, initial year of use, and average annual quantity of water withdrawn. The current status of these wells is also indicated. Eight of the nine wells within the project area have been in use since June, 1973, but only six of these older wells were active during March and April 1988.

PRESENT USE

Of the nine water wells in the project area seven were in use during March and April 1988. The pumps were removed from wells 22992-F in section 9 and 22993-F in section 12. Both wells remain open and were sounded using the water-level indicator, but water was not detected in either well to the depth the sounder could attain. The seven active wells are pumped by windmills, with the water flowing into large stock tanks. Overflow from the stock tanks irrigates small areas below most stock tanks, but evidence of domestic, mechanical, or other irrigation uses was not observed.

Amounts of water annually withdrawn by each well are estimated based on the current status of each well. All seven active wells apparently are presently used only for livestock watering. Assuming each well provides 10 gallons of water per day per cow 365 days a year, and that 100 cows are watered by each well, the average annual amount withdrawn from each well is 1.1 acre-ft, of which all is consumptively used.

The seven wells would annually withdraw about 7.7 acre-ft. The average annual quantity of water withdrawn by these eight wells in use before 1973, based on their current status, is 6.6 acre-ft (two are currently inactive).

The five older wells permitted for combined uses each claimed 182 to 183 acre-ft of water per year on their permits, so annual withdrawals could have been over 900 acre-ft in past years, significantly greater than the amount reported above. If any of the five wells permitted for combined uses were to pump the 182 to 183 acre-ft claimed on their permits, future withdrawals could increase dramatically.

SURFACE WATER USE

There are no adjudicated surface water rights on Black Squirrel Creek within the project area, and we are not aware of any surface water use. Many decades ago, prior to extensive ground water development upstream, Black Squirrel flowed more frequently and perhaps some use may have been made of the surface water at that time.

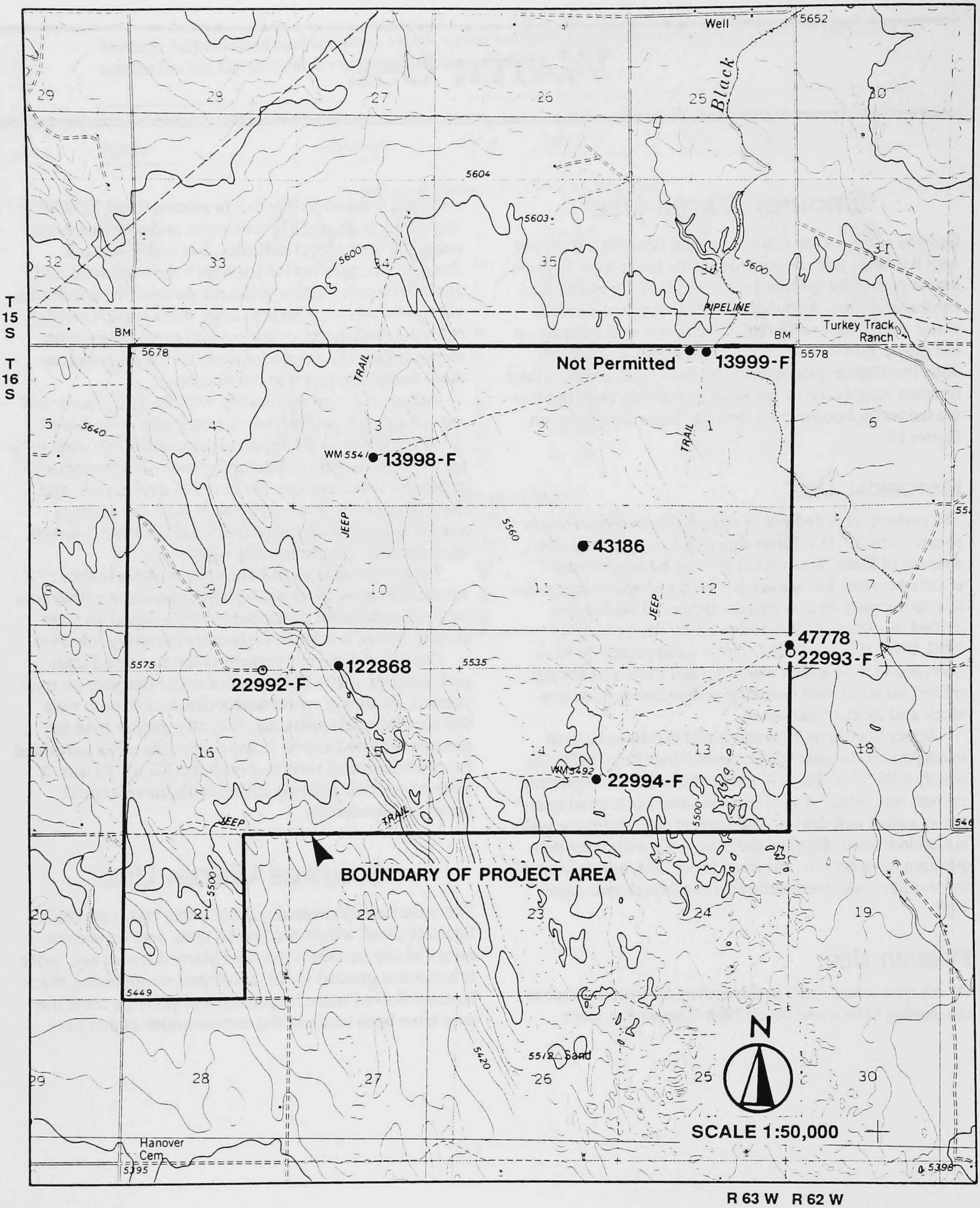

Figure 19. Locations of water wells in the project area. Solid circles are currently active wells, while open circles are inactive. Permit numbers are shown next to each well.

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APPENDIX A
Survey Traverse Data

X-Coor	Y-Coor	Elevation	ID #	Description
5000.00	5000.00	0.00	1	Back Site
10300.00	5000.00	5525.00	2	Point of Beginning
10533.59	7270.91	5640.69	3	TRAV-1
12846.50	10244.64	5563.09	5	TRAV-2
12883.18	11914.18	5538.86	6	WELL 40
12566.02	13964.78	5560.54	7	CGS-SLB-2
10523.62	14182.28	5593.29	8	TRAV-3
13753.99	14904.73	5575.40	10	TRAV-4
16608.90	13872.24	5585.14	11	TRAV-5
17142.36	13862.68	5571.42	12	KKBNA-2
17369.15	13924.26	5583.63	13	TRAV-6
18655.57	13721.10	5566.86	14	KKBNA-1
20263.33	13602.56	5581.08	15	KKBNA-3
22867.52	15269.80	5591.88	16	WELL 30
23622.49	15216.14	5581.05	17	WELL 100
23211.03	13427.41	5574.16	18	CGS-SLB-1
22457.74	9448.64	5577.96	19	TRAV-7
22952.60	3893.64	5530.13	21	TRAV-8
23156.47	4007.40	5529.31	22	CGS-SLB-4
20676.73	3675.06	5551.47	23	TRAV-9
20007.02	1512.57	5492.56	25	WELL 43
15901.76	3079.29	5548.91	26	TRAV-10
15733.64	2936.63	5541.04	27	CGS-SLB-6
12789.75	3606.00	5608.34	28	TRAV-11
11855.09	5024.83	5598.80	29	WELL 450
11310.16	5430.06	5588.77	30	TRAV-12
10300.00	5000.00	5525.00	31	CLOSE
15544.96	13638.02	5561.99	33	CGS-SLB-3A
14490.07	13619.99	5558.43	34	CGS-SLB-13
17603.05	9075.82	5538.53	35	CGS-SLB-11
21272.44	8963.56	5548.11	36	CGS-SLB-8A
20419.04	3038.91	5509.63	37	CGS-SLB-5A
25319.38	4216.94	5581.33	38	TRAV-8A
25712.21	4202.37	5577.70	39	TRAV-8B
26208.55	4684.51	5508.74	40	CGS-SLB-12
11391.56	2388.52	5507.36	41	CGS-SLB-7

APPENDIX B
Water wells located within the project area

All wells are in T. 16 .S, R. 63 W. Data based on State Engineer's records and field investigations.

Owner	Permit No.	Location	Well Depth (Ft)	Date Completed	Use*	Depth to Water (Ft)	Yield (GPM)
			Registered Wells				
SBLC**	13999-F	NE1/4NW1/4 sec. 1	61	Jan 1935	C	44.51	112
J.B. Ackerman	13998-F	NE1/4SW1/4 sec. 3	75	Jan 1913	C	38.00	112
SBLC	22992-F	SE1/4SE1/4 sec. 9	NA	1950	C	NA	112
SBLC	122868	SE1/4SW1/4 sec. 10	194	Jul 1982	2	131.00	10
SBLC	43186	NE1/4NE1/4 sec. 11	136	Sep 1970	2	58.00	20
SBLC	22993-F	SE1/4SE1/4 sec. 12	NA	Jan 1950	C	NA	112
SBLC	47778	SE1/4SE1/4 sec. 12	150	Jul 1971	2	68.00	15
SBLC	22994-F	NE1/4SE1/4 sec. 14	NA	Jan 1920	C	64.19	112
			Unregistered Well				
SBLC	—	NE1/4NW1/4 sec. 1	NA	pre-1973?	2	58.16	NA

* C—combined domestic, irrigation, and/or livestock and mechanical
2—livestock

** State Board of Land Commissioners

APPENDIX C

Water wells in use for the past fifteen years in the project area.

Owner	Permit No.	Location	Use*	Initial Year of Use	Annual Amount Pumped acre-ft	Current Status
		Registered Wells				
SBLC**	13999-F	NE1/4NW1/4 sec. 1	C	1935	1.1	active
J.B. Ackerman	13998-F	NE1/4SW1/4 sec. 3	C	1913	1.1	active
SBLC	22992-F	SE1/4SE1/4 sec. 9	C	1950	—	inactive
SBLC	43186	NE1/4NE1/4 sec. 11	2	1970	1.1	active
SBLC	22993-F	SE1/4SE1/4 sec. 12	C	1950	—	inactive
SBLC	47778	SE1/4SE1/4 sec. 12	2	1971	1.1	active
SBLC	22994-F	NE1/4SE1/4 sec. 14	C	1920	1.1	active
		Unregistered Well				
SBLC	—	NE1/4NW1/4 sec. 1	2	pre-1973?	1.1	active

* C—combined domestic, irrigation, and/or livestock and mechanical
2—livestock

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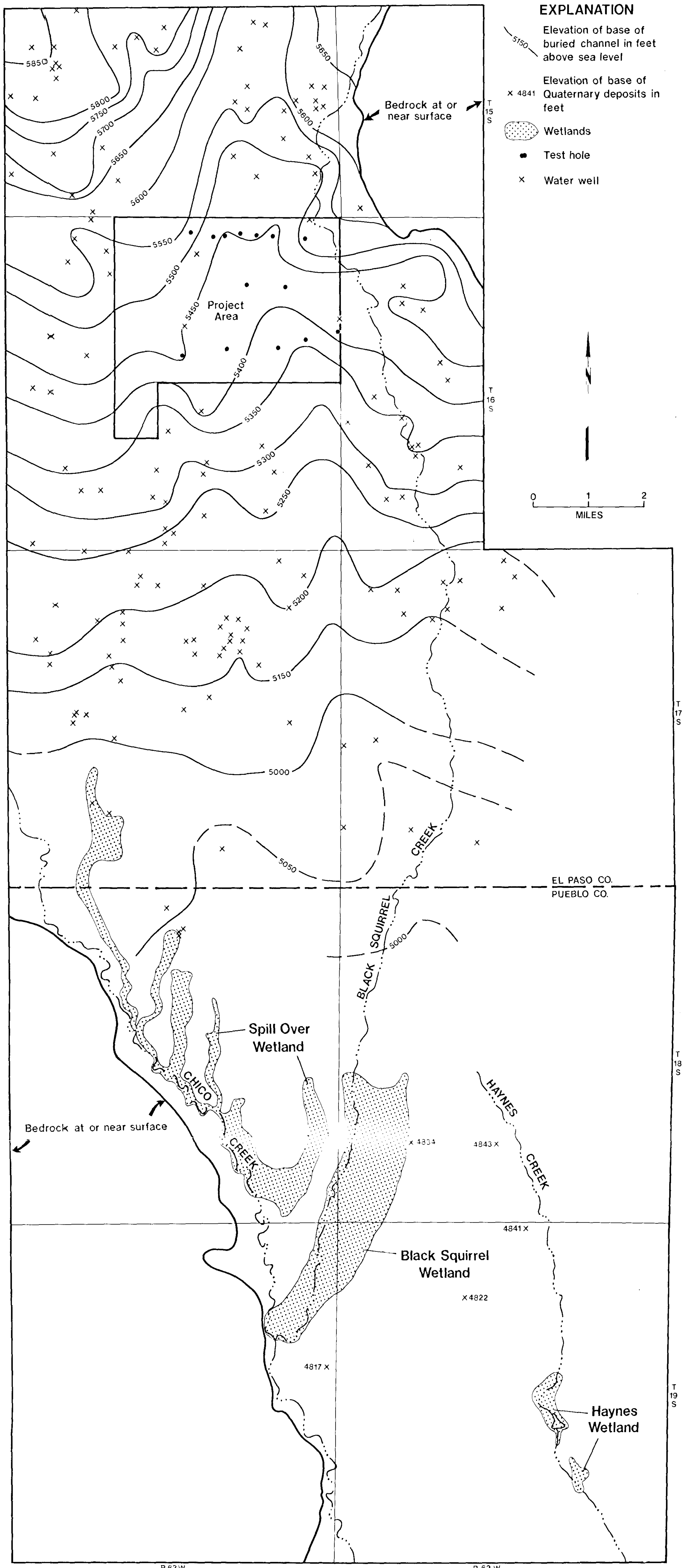
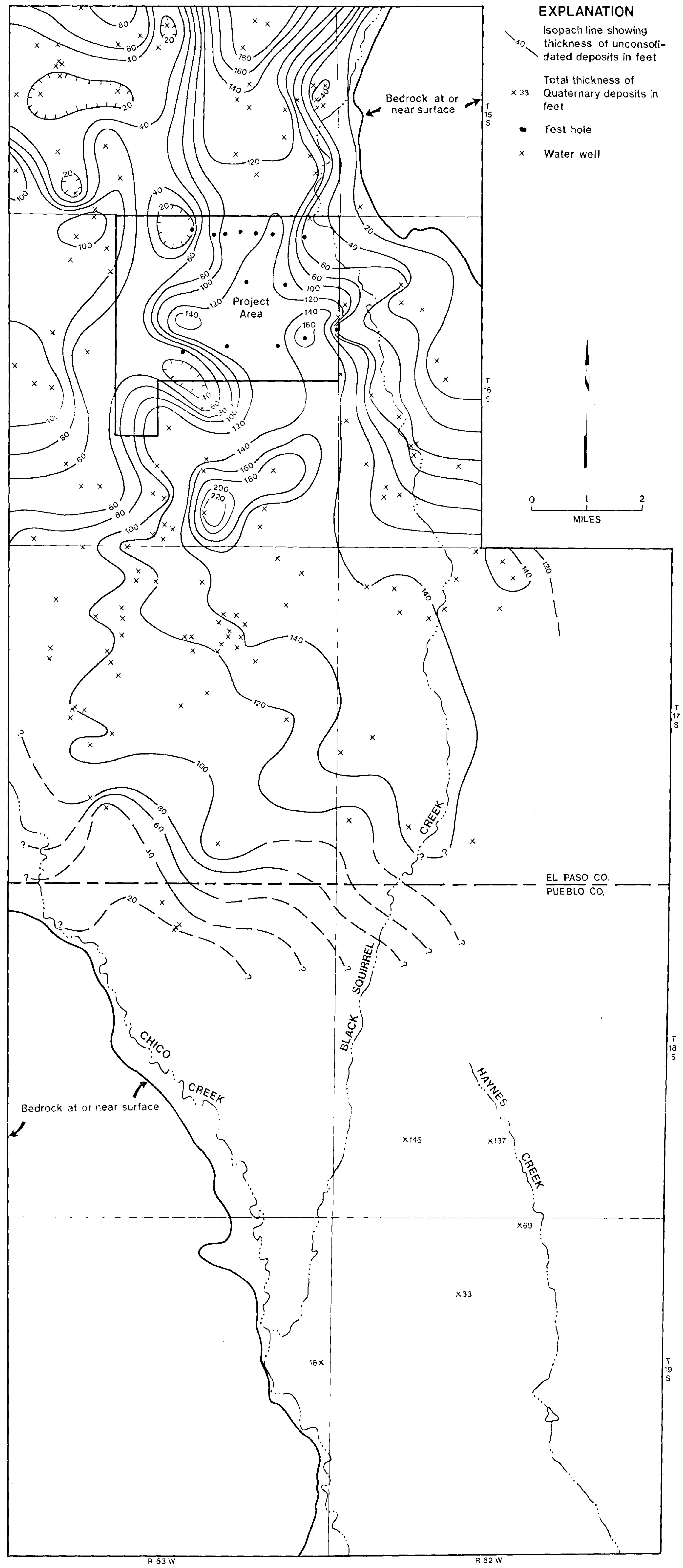


Map A. Regional Map Showing Elevation of the Base of the Buried Channel in the Project Vicinity



Map B. Regional Isopach Map Showing Thickness of Unconsolidated Quaternary Deposits in the Project Vicinity

By Robert M. Kirkham