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WATER RESOURCES OF UPPER CROW CREEK, COLORADO

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1.0 EXECUTIVE SUMMARY

At the request of the Colorado state legistature the Colorado Geological Survey has investigated the water resources of Upper Crow Creek and prepared this report containing the results of the study. It is intended for use by the Colorado Ground Water Commission in their deliberations concerning the possible creation of a designated ground-water basin along Upper Crow Creek in the north-central part of Weld County.

1.1 BOUNDARY OF STUDY AREA

Upper Crow Creek is defined as the mainstem of Crow Creek from its confluence with Little Crow Creek in section 34, T9N, R62W to its headwaters in the Laramie Range above Cheyenne, Wyoming. The study area includes that part of the Upper Crow Creek drainage basin within Colorado, and parts of townships T11N, R60W and R61W, and T12N, R60W, R61W, and R62W between the drainage basin boundary and the outcrop of the Ogallala Formation. Rationale for including this northeastern part in the study area is primarily based on: 1) the fact that about 30% of the total irrigation wells in this part of the state lie just outside of the Upper Crow Creek drainage basin and are within this added area, and 2) this added area is hydrogeologically connected with the Crow Creek drainage basin.

The boundary of the study area is depicted on Plates 1 through 3 and on many of the figures. It coincides with the drainage divide of Upper Crow Creek on its western, southern, and southeastern sides, while the outcrop of the Ogallala Formation forms its northeastern boundary, and the Colorado-Wyoming line serves as the northern border. A legal description of the study area is contained in Appendix A.

1.2 AQUIFER CHARACTERISTICS AND WATER IN STORAGE

Five main aquifers occur in the study area: 1) Alluvial Aquifer, 2) Fan Aquifer, 3) White River Aquifer, 4) Upper Laramie Aquifer, and 5) Laramie-Fox Hills Aquifer. The Alluvial, Fan, and White River Aquifers are unconfined and act as a single aquifer system which has provided all the water withdrawn from irrigation wells in the study area. The Upper Laramie and Laramie-Fox Hills Aquifers are confined or semi-confined and have supplied water for limited municipal and industrial needs. All five aquifers have been utilized for domestic and livestock purposes during the past fifteen years.

The Alluvial Aquifer is relatively narrow, but covers 42.3 square miles in the study area. It occurs in the valley floor of Upper Crow Creek and its tributaries, entering the study area northwest of Hereford and exiting at the confluence of Little and Upper Crow Creeks. The Fan Aquifer is saturated under about 25 square miles in the northern part of the study area.

Extent and saturated thickness of the Alluvial and Fan Aquifers, and the elevation of the bedrock surface beneath them are shown on Plates 1 and 2. Both aquifers consist of unconsolidated sand, gravel, silt, and clay and are Quaternary in age. An estimated 53,000 acre-feet of water are stored in the Alluvial Aquifer downstream of section 1, T11N, R62W, while water stored in the Fan Aquifer and in the Alluvial Aquifer in and upstream of section 1, T11N, R62W amounts to approximately 150,000 acre-feet.

All but the southern tip of the study area is underlain by the White River Aquifer. It consists of massive siltstone beds that have very low primary permeability and local channel deposits of sandstone and conglomerate. Water is sometimes produced from the sandstone and conglomerate beds, but most water occurs in pipes, tubes, and caverns that appear to be hydraulically connected to saturated unconsolidated deposits. Approximately 400,000 acre-feet of water are stored in the White River Aquifer, based on estimates of the aquifer's secondary permeability characteristics and its saturated thickness.

The Upper Laramie and Laramie-Fox Hills Aquifers underlie the entire study area. Both aquifers consist of interbedded sandstone, siltstone, claystone, and shale. Thin beds of lignite up to about 5 feet thick also occur within the Upper Laramie Aquifer. Net thickness of saturated sandstone in the Upper Laramie varies from less than 25 feet to over 190 feet in the study area, while the Laramie-Fox Hills has from 100 to 225 feet of saturated sandstone within it. An estimated 2,500,000 acre-feet of water are stored in the Upper Laramie Aquifer and approximately 3,800,000 acre-feet are stored in the Laramie-Fox Hills Aquifer.

1.3 GROUND-WATER USE

The first recorded irrigation well was constructed in the study area in 1909, but until about 1940 only a limited number of wells are known to have existed. Ground-water development underwent major growth during the 1950's and remained prominent until 1978. Permits for new non-exempt wells (irrigation, municipal, and industrial wells) have not been issued in the study area since 1978.

A total of 209 registered and adjudicated water wells were present within the study area as of August 7, 1984. Of this amount 169 are registered, and 40 are adjudicated but not registered. There are 79 irrigation wells, 74 stock wells, 22 domestic wells, 27 combined domestic and stock wells, three municipal wells, three industrial wells, and one unclassified well known to exist within the study area. Of the 79 irrigation wells 28 withdraw water from the Alluvial Aquifer, 28 utilize the Fan Aquifer, 11 tap the White River Aquifer, and 10 are completed in two of the unconfined aquifers.

The total average annual amount of ground water withdrawn from all wells in the study area is estimated at 14,000 acre-feet. Approximately 11,500 acre-feet of ground water are consumptively used each year. The remaining 2,500 acre-feet are returned to the aquifers through deep percolation.

Appendix E lists all wells that have been in use for the past 15 years (since 1/1/71). Also contained in this appendix are the location, permit number, owner, use, and initial year of use for each well. A total of 145 wells have been in use during the past 15 years, including 58 irrigation wells, 51 livestock wells, 15 domestic wells, 15 combined domestic and livestock wells, three municipal wells, two industrial wells, and one unclassified well. An average of 9,100 acre-feet of water has been withdrawn annually by these wells during the past 15 years.

1.4 WATER BUDGET AND WATER MOVEMENT

The volume of water recharging an area must equal the volume of water being discharged from it. This balance is commonly referred to as the water budget. In areas where ground water is withdrawn from wells, water levels may lower, reflecting reductions in stored water, unless natural recharge and/or discharge rates vary to accommodate the pumping.

Unconfined aquifers within the study area are recharged by infiltration of precipitation, seepage of surface water in Upper Crow Creek, underflow from Wyoming, and reduction in the amount of ground water in storage. Total average annual recharge to the unconfined aquifers is estimated at 19,000 acre-feet. Precipitation accounts for 5,700 acre-feet, seepage from Upper Crow Creek for an estimated 500 to 1,000 acre-feet, and underflow from Wyoming for 11,300 acre-feet. An estimated 1,300 acre-feet is also removed from storage each year. Confined aquifers are recharged by underflow from outside of the study area, and vertical water movement between the confined and unconfined aquifers probably also occurs, but there are insufficient data available to determine their recharge.

Unconfined ground water flows into the study area from Wyoming through the Alluvial, Fan, and White River Aquifers and moves generally southeastward. A ground-water divide near Hereford causes part of this water to return to Wyoming along the northeast boundary of the study area. Bedrock hills within the alluvial valley west of Grover, along with thinning of the Alluvial Aquifer, create another ground-water divide and cause much of the unconfined water to move to the southeast towards Grover and the head of Jackson Draw. Water moves generally southward from the head of Jackson Draw until reaching the White River paleovalley, where it then turns to the southeast and apparently follows the paleovalley. Another ground-water divide occurs in the region of the Big Bend, with part of the remaining unconfined water flowing westward within the Alluvial Aquifer and part moving southeastward, probably along the abandoned paleovalley of Wildcat Creek.

An estimated 19,000 acre-feet of ground water is discharged from the study area each year through withdrawals from wells, underflow out of the area, and evapotranspiration. Approximately 3,000 acre-feet are discharged along the northeast boundary as underflow into Wyoming, while an estimated 500 acre-feet are discharged along the southeast boundary through the White River paleovalley and perhaps through the paleochannel of Wildcat Creek. Most of the underflow along the southeast boundary is believed to be lost to evapotranspiration prior to reaching downstream adjudicated water rights. Less than 50 acre-feet of ground water flows westward from the Big Bend through the Alluvial Aquifer and is discharged from the study area each year as underflow at the confluence of Little and Upper Crow Creeks. Evaporation and transpiration occurring in areas where the water table is shallow within the study area may account for losses of 4,000 acre-feet of water annually.

About 11,500 acre-feet of water are lost each year as a result of consumptively used water withdrawn from wells.

Recent well pumping has affected the water budget of the study area. Much of the water consumed by well pumping apparently has been compensated for by a reduction in evapotranspiration and underflow losses resultant from lowering the water table. However, an estimated 1,300 acre-feet is currently removed from storage in the unconfined aquifers each year.

1.5 WATER-LEVEL FLUCTUATIONS

Water levels within the study area fluctuate seasonally and show long-term changes resultant from the reduction of stored water. Three continuously recorded observation wells just north of the study area display seasonal water-level declines as great as 26 feet during the irrigation season. Water levels in twelve irrigation wells within or adjacent to the study area have been periodically measured since 1962. All measured wells that withdraw water from the Fan Aquifer have experienced generally declining water levels since 1962. Declines of up to 17 feet have occurred along the Colorado-Wyoming border northeast of Hereford. Two measured Alluvial Aquifer wells near Hereford have experienced water-level declines of 5.9 and 2.5 feet since 1962. Measured wells west of Grover indicate that water-levels in the Alluvial Aquifer in this area have been fairly stable during the period of record, with two wells actually showing rising water levels. Recharge efforts made during the 1983 flood are probably at least partially responsible for the rising water levels in the area west of Grover.

1.6 SURFACE WATER FLOW, ADJUDICATED RIGHTS, AND USE

Upper Crow Creek is an intermittent stream within the study area. It heads in the Laramie Range above Cheyenne, Wyoming and flows generally eastward into the Carpenter area. Near Carpenter the stream turns to the southeast and crosses into Colorado. Just below Hereford, the creek changes course and flows generally southward, past Grover and into the area known as the Big Bend. At this point the creek makes an abrupt, nearly right-angle change in flow direction and turns westward. Little Crow Creek and Upper Crow Creek merge at their confluence and the resulting stream, known as Crow Creek, extends to the South Platte River. Surface flow in Upper Crow Creek relies mainly upon precipitation. Snow melt in its headwaters provide most surface flow, and summer thunderstorm activity contributes additional water. The city of Cheyenne returns water to the creek by discharging treated sewage effluent into the creek.

Historically, Upper Crow Creek reportedly flowed into Colorado with a sustained base flow up until the 1950's. At that time numerous dams were constructed on Upper Crow Creek in Wyoming for municipal and irrigation purposes, and extensive ground-water development in the Carpenter area began. Surface flows in Upper Crow Creek in Colorado were apparently affected by this upstream activity. Since the 1950's surface flow in Upper Crow Creek within the study area normally occurs only during spring runoff. During other seasons in normal years there often is no surface flow in Upper Crow Creek in Colorado. Testimony and depositions from Water Court cases, along with personal observations of the Division 1 Water Commissioners, indicate that surface flow in years of normal precipitation now rarely passes beyond Grover even during spring runoff. Precipitation and corresponding surface flows have been unusually high for the past two or three years. Flows in excess of 300 cfs occurred during the 1983 flood in the study area, and the creek flowed continuously even west of Grover up until August of 1984.

There are ten adjudicated surface water diversion ditches and eleven adjudicated storage reservoirs within the study area. Because of the reduced stream flow since the 1950's, many of these adjudicated structures have been abandoned and in some cases replaced by irrigation wells. The five Larson ditches now use a single diversion called the Consolidated Larson. During the past fifteen years only two ditches (Consolidated Larson and Benton) and one reservoir (Larson #2) have been active on Upper Crow Creek. The Pierce reservoirs are recently adjudicated and still active structures that collect precipitation runoff in an unnamed tributary to Upper Crow Creek.

Diversion records provided by the appropriators for the past fifteen years indicate about 650 acre-feet of surface water is diverted from Upper Crow Creek within the study area during normal runoff years. If the 1983 flood year is included, the annual amount of diverted surface water averages about 1,100 acre-feet.

2.0 INTRODUCTION

2.1 PURPOSE AND SCOPE OF INVESTIGATION

This investigation was undertaken by the Colorado Geological Survey (CGS) at the request of the state legislature. CGS was charged with the responsibility of developing a report on the water resources of Upper Crow Creek in northeastern Colorado that would assist the Colorado Ground Water Commission in their deliberations concerning the creation of a "designated ground water basin", as defined in Colorado Revised Statute 37-90-103(6) and amended by 1985 House Bill No. 1173.

The primary goal of this investigation was the collection of sufficient information on the water resources of the Upper Crow Creek region to enable the Ground Water Commission to decide whether to designate a ground-water basin in the area. This report provides information on the following aspects, all of which are elements required by the Colorado Revised Statute 37-90-106:

1) the names of the water-bearing formations or aquifers,
2) the boundaries of each aquifer being considered,
3) the estimated quantity of water stored in each aquifer,
4) the estimated annual rate of recharge,
5) the estimated use of ground water in the area,
6) a list of ground-water users during the past 15 years, along with the use of the water, the year in which the user began to withdraw water, and the average annual quantity of water withdrawn.

Additional information provided in this report include a list of decreed surface water rights and their current status, a map illustrating the location of surface water diversions and reservoirs, the historic use of surface water, a list of all registered water wells, a list of adjudicated wells that are not registered, climatic data, information on ground-water quality, data on water-level fluctuations, and maps depicting the elevation of or depth to the various aquifers, elevation of the bedrock surface, saturated thickness of the unconfined aquifers, net sandstone thickness within the Upper Laramie and Laramie-Fox Hills Aquifers, and locations of registered and adjudicated water wells.

In order to fully understand the water resources of the Upper Crow Creek area, it was necessary to study not only the drainage basin, but also surrounding areas, including parts of Wyoming and Nebraska. As a result, data was collected and mapping was conducted over an area of approximately 812 square miles. The location of the mapped area is shown on Figure 1. All or parts of the following townships are within the mapped area: T7N to T13N, R59W to R63W.

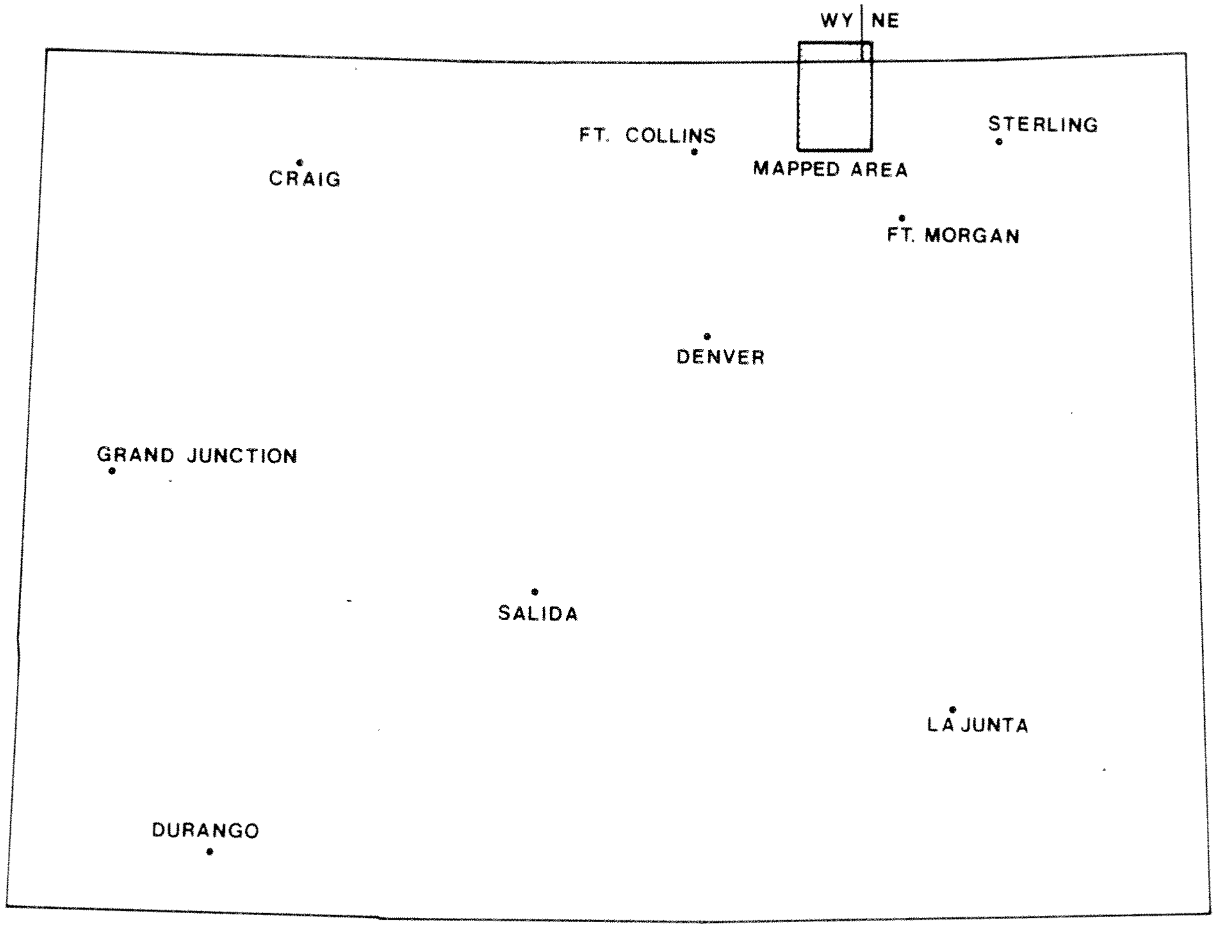


Figure 1. Location map for the mapped area.

2.2 PREVIOUS INVESTIGATIONS

The geology and hydrology of Upper Crow Creek has been studied during several previous investigations. Only part of these investigations are described in this section. Please refer to the bibliography in Section 7.0 for a complete listing of the references utilized in the preparation of this report.

Darton (1905) was one of the original scientists to study the geology and ground-water resources of the central Great Plains, including the Upper Crow Creek area. The Wyoming part of the mapped area was included in a ground-water investigation by Rapp and others (1953). This report was soon followed by the investigation of Babcock and Bjorklund (1956), which evaluated the ground-water geology of most of the Crow Creek drainage basin. In the following year Bjorklund (1957) described the ground-water resources of parts of Weld, Logan, and Morgan Counties.

Weist (1964) provided data on water wells and chemical analyses of ground water. In the following year he published an evaluation of the ground-water resources of an area that included Upper Crow Creek (Weist, 1965). The hydrologic characteristics of the White River Group were described in a brief paper by Lowry (1966). Lowry and Crist (1967) coordinated to produce a comprehensive study of the geology and ground water of Laramie County, Wyoming. An enlightening evaluation of the White River, Fan, and Alluvial Aquifers in the Carpenter, Wyoming area was conducted by Crist and Borchert (1972).

Brookman (1973) reported on water levels in twelve wells in or adjacent to the study area. Water-level monitoring was continued by Major and Vaught (1977). The geology of the Greeley 1° X 2° quadrangle was mapped by Braddock and Cole (1978), while Scott (1978) mapped the adjoining Sterling 1° X 2° quadrangle. Ethridge and others (1979) reported on the structure and depositional environment of the Laramie and Fox Hills Formations in the Cheyenne Basin.

Wacinski (1979) described the hydrogeology of Crow Creek drainage basin in Weld County. The stratigraphy and hydrogeology of the Cheyenne Basin, as related to uranium mining, was evaluated by Kirkham and others (1980). Chemical analyses on 104 water wells in the Hereford-Keota area were included in that report. The effects of pumping on ground-water levels in the Carpenter-Hereford area were modeled by Crist (1980).

A generalized fence diagram showing the stratigraphy and potentiometric surface of the Tertiary formations in southeast Wyoming and the Hereford area was prepared by Cooley and Crist (1981). The Dakota Aquifer was studied by Robson and Banta (1984) as part of their deep aquifer investigation in eastern Colorado. Water-level records for the Carpenter area, including some continously recorded data, were published by Ragsdale and Oberender (1985).

2.3 ACKNOWLEDGMENTS

This investigation benefited from the assistance, advice, and cooperation of many individuals. Marvin Crist, U.S. Geological Survey, provided reports and unpublished data on the White River, Fan, and Alluvial Aquifers, and shared his many years of experience working in the area. S.G. Robson, U.S. Geological Survey, assisted our interpretations of the Dakota Aquifer by providing a preliminary copy of Robson and Banta (1984). The U.S. Geological Survey also contributed unpublished data on stream gaging stations and water levels in wells.

Several employees of the Colorado Division of Water Resources, including Robert Longenbaugh, Keith Kepler, Andrew Wacinski, George Moravec, John Romero, and Bob Hamburg, provided valuable data and advice. Robert Samples, Division 1 Water Commissioner, supplied information on surface water usage, and unpublished water-level records for two wells. The manuscript benefited from review by several staff members of the State Engineer's office.

Special thanks goes to Clarence Tietmeyer, president of the Upper Crow Creek Irrigators Association, for his assistance and coordinating efforts with area well owners, saving the authors considerable field time. The hospitality shown by Mr. and Mrs. Tietmeyer is greatly appreciated. This investigation would not have been possible without the cooperation of numerous well owners in the study area who provided data and gave permission to measure water levels in their wells. Willard Owens loaned copies of previous reports on proposed designated basins.

Typing, drafting, and editorial services were provided by CGS staff members Cheryl Brchan, Peggy Kelley, Chris Avila, Betty Jones, and Brenda Richardson. Lois Kirkham assisted with editing and drafting.

3.0 DESCRIPTION OF THE STUDY AREA

3.1 GEOGRAPHIC EXTENT

The Upper Crow Creek study area lies within the Great Plains east of the Rocky Mountains. Figure 2 illustrates the location of the Upper Crow Creek drainage divide and the boundaries of the study area. Its boundaries and topography are also shown on Plates 1, 2, and 3. In the north-central part of the mapped area, the drainage divide on the east side of Upper Crow Creek swings abruptly northwestward. Near Hereford the east and west drainage divides are only about three miles apart. An area underlain by the White River and Fan Aquifers, in which about 30% of all irrigation wells in this region of Colorado are found, extends <u>outside</u> of the actual limits of the Upper Crow Creek drainage basin. Although this area drains into Spring Creek in Wyoming, it is an integral part of the hydrogeologic system of Upper Crow Creek. The outcrop of the Ogallala Formation serves as a convenient topographic and hydrologic boundary in this northeast corner. Thus, the study area boundary coincides with the drainage divide of Upper Crow Creek on its western, southern, and southeastern sides, while the outcrop of the Ogallala Formation serves as the boundary on the northeastern side and the Colorado-Wyoming line forms the northern boundary. Approximately 264 square miles are included within the study area.

Appendix A contains a legal description of the study area boundary. Note that the state line does not always coincide with a section line. Only that part of these sections which is within Colorado is included in the study area. Please refer to the U.S.G.S. 7 1/2 minute quadrangle maps which depict this relationship.

3.2 TOPOGRAPHY AND DRAINAGES

The entire study area, with the exception of its northeast corner, lies within the drainage basin of Upper Crow Creek, a tributary to the South Platte River. The northeast corner of the study area drains into Wyoming along Spring Creek, a tributary to Muddy Creek. Muddy Creek flows into Lodgepole Creek near Pine Bluffs, Wyoming.

With the exception of the northeast corner of the study area, the area generally slopes southward, towards the South Platte River. Surface

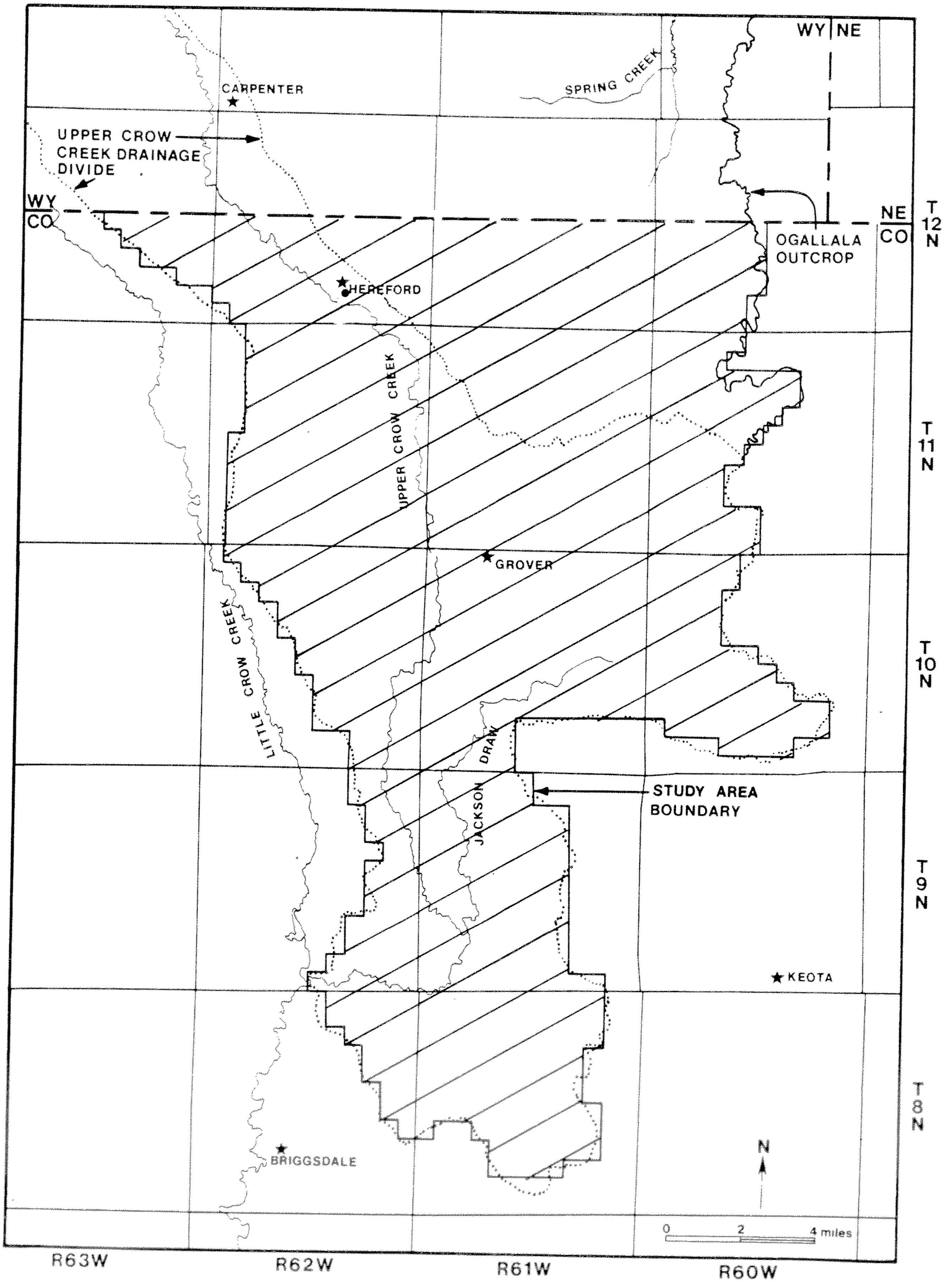


Figure 2. Location map showing boundaries of the study area and the Upper Crow Creek drainage divide.

elevations in the study area range from about 5,500 feet in the northwest corner along the Colorado-Wyoming line and along Chalk Bluffs on the east side, to about 4,875 feet at the confluence of Upper Crow Creek and Little Crow Creek. Much of the land surface in the study area consists of gently rolling country created primarily by stream erosion and eolian processes. Areas underlain by fan deposits in the north end have gently sloping, nearly planar land surfaces.

Numerous closed depressions, many of which contain intermittent ponds, occur throughout the study area, but are especially prevalent in its southern half. The closed depressions are generally found in areas covered by a thin blanket of wind-blown sand and silt, and most are believed to be eolian features that may have been later modified by animal use.

The northeast side of the study area is formed by the prominent Chalk Bluffs, an escarpment composed of the White River Group and capped by the erosion resistant Ogallala Formation. Local relief along Chalk Bluffs averages about 200 feet. Other sides of the study area are less prominent topographically.

Several interesting geomorphic features occur along Upper Crow Creek (Figure 3). The creek trends southeasterly as it enters Colorado and maintains this orientation while underlain by or adjacent to the fan deposits. In this area the creek has established its course along the contact between the older and younger fan deposits, and it has a grade of about 23 feet per mile. Gradient of the present-day creek is greater than the gradient of the fan surfaces, and the modern valley floor cuts progressively deeper into the fan deposits.

After exiting the fan deposits Upper Crow Creek tends to flow nearly due south. The creek maintains this southerly course for about 16 miles, until it reaches the area known as the Big Bend. At this point the creek makes a nearly right-angle bend and flows west to its confluence with Little Crow Creek, herein called the Confluence. During the 16 mile southerly course, the creek has an average gradient of only about 12 feet per mile, nearly half that present in the Hereford area. Throughout this reach the White River Group is the underlying bedrock formation. Between the Big Bend and the Confluence the stream valley rests on the Laramie Formation and has an average gradient of only about 10 feet per mile.

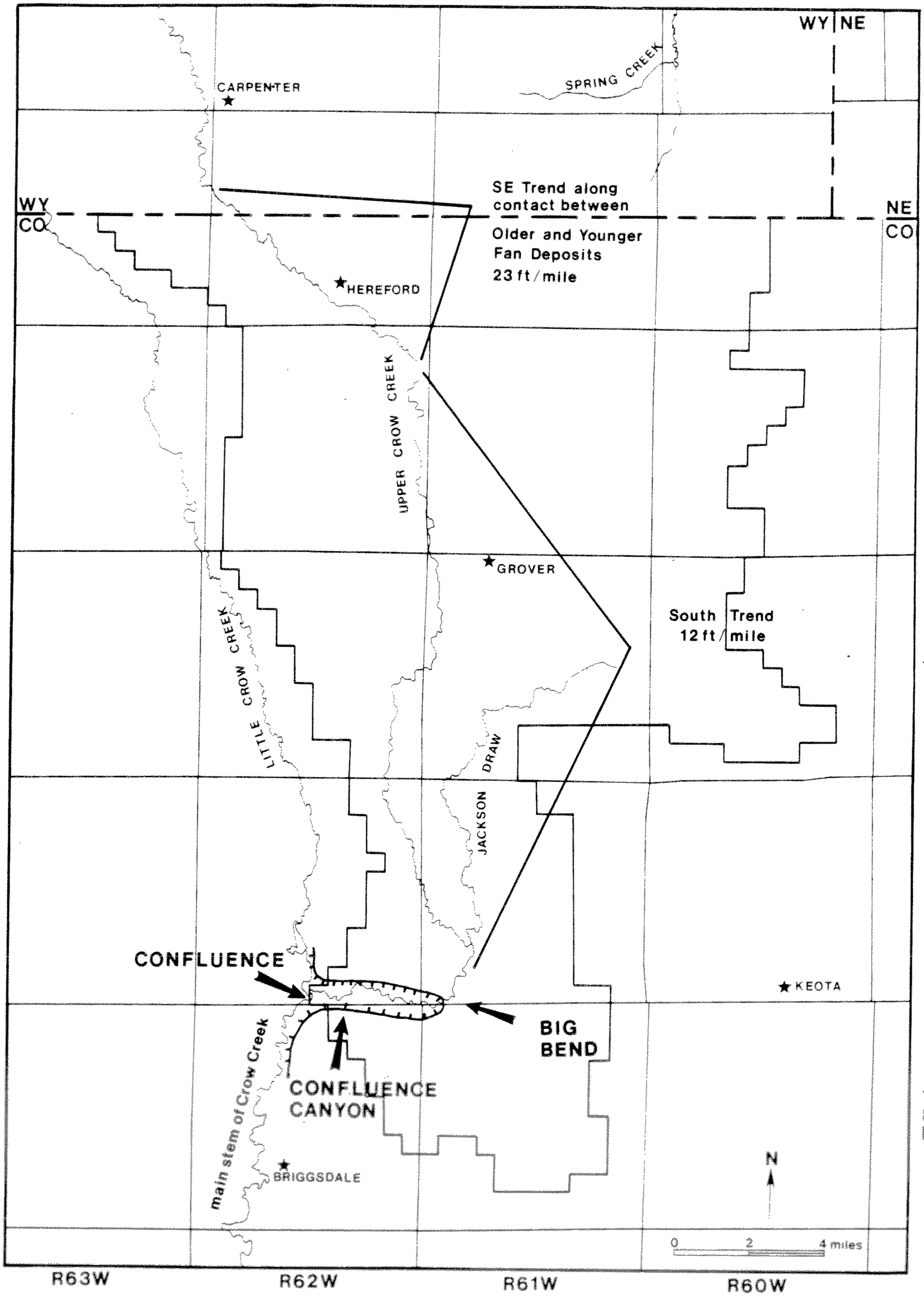


Figure 3. Geomorphic features of Upper Crow Creek.

Above the Big Bend the valley walls of Upper Crow Creek have low relief and are gently sloped.. Starting at the Big Bend and extending just below the Confluence the valley walls are steeper sloped and have local relief up to 100 feet. This area where the valley walls are steeper and higher is referred to as Confluence Canyon in this report.

The Big Bend of Upper Crow Creek is an intriguing geomorphic feature that has been the subject of considerable study. Petroleum explorationists suspected the bend reflected an underlying structural feature that might possibly have yielded oil or gas. Seismic reflection studies failed to detect any geologic structures that might have been responsible for creating the Big Bend.

Our preferred explanation of the Big Bend involves stream piracy. We believe Upper Crow Creek once flowed along a valley that extended southeastward from the Big Bend and connected with the head of Wildcat Creek. Headward erosion by a tributary of Crow Creek may have enabled stream prir acy to occur and created the modern drainage system. A topographic low, now partially filled with wind-blown materials, extends from the Big Bend southeastward to the headwaters of Wildcat Creek and is probably the abandoned paleochannel. Based on available data, the point of piracy appears to have been in section 31 or 32, T9N, R61W. The paleochannel extends generally southeastward, crosses Colorado Highway 14 between sections 24 and 25 of T8N, R61W and joins Wildcat Creek in the NW/4 of section 31, T7N, R59W. The limited amount of available drill hole data documents the presence of a topographic low now filled with sand and silt. Infrared aerial photography and satellite imagery suggest the presence of at least a small amount of shallow ground water along the trend of the paleovalley, but additional test holes are needed to confirm the existence of a buried alluvial channel that may be water saturated.

This now abandoned paleochannel appears to have followed the outcrop of the easily eroded White River Group in this segment. Seven Cross Hill, which is composed of the slightly more erosion-resistant Laramie Formation, prevented the southwestward connection and forced the creek to flow to the southeast.

Figure 4 illustrates the probable stream pattern that existed prior to stream piracy in the Big Bend area. At that time Upper Crow Creek was

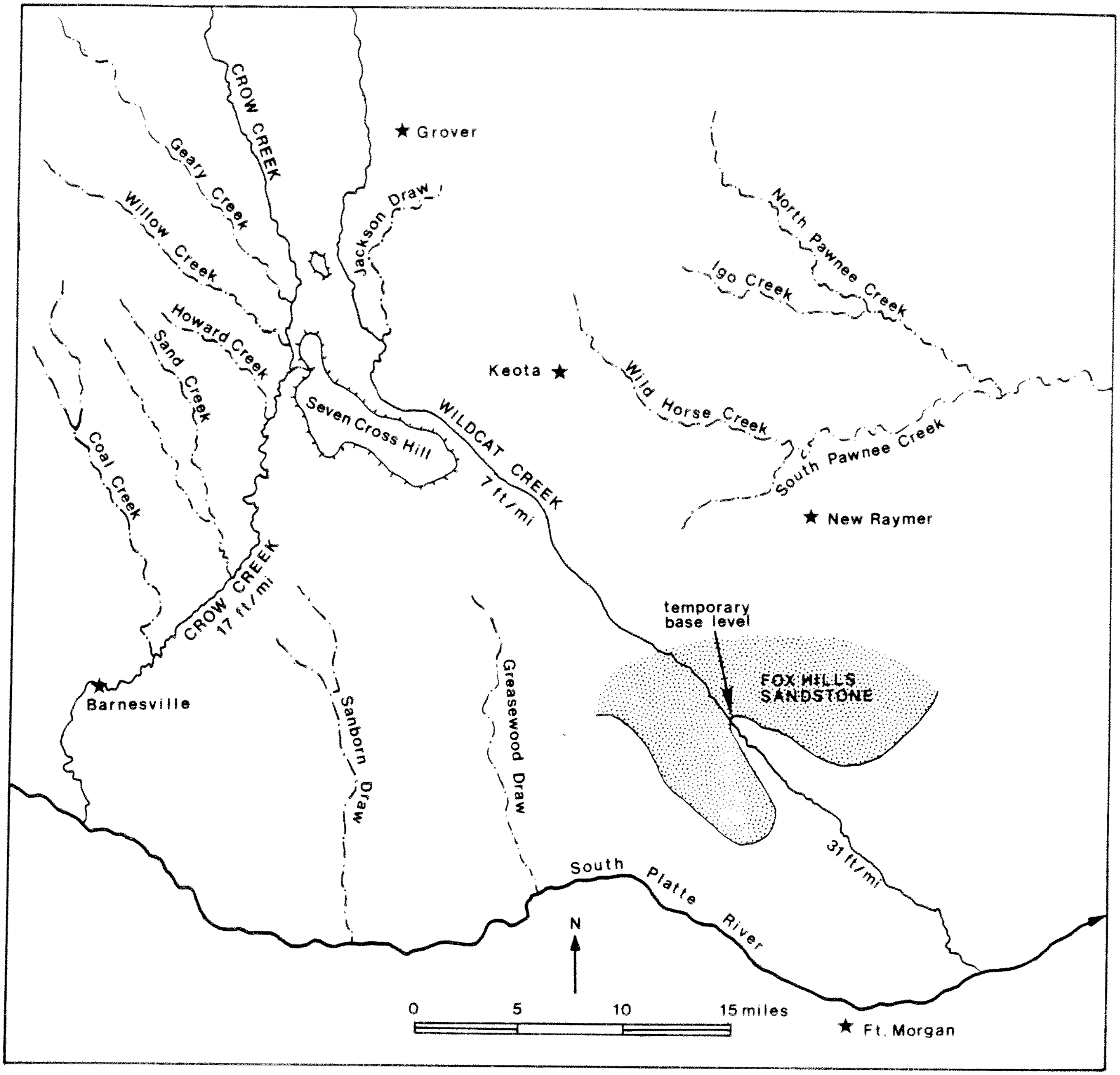


Figure 4. Hypothesized drainage patterns of Crow Creek and Wildcat Creek prior to stream piracy in the Big Bend area. Crow Creek and Wildcat Creek are intermittent streams, but are shown as solid lines on this map for emphasis.

actually part of Wildcat Creek, forming a continuous drainage that extended from Wyoming, flowed past the northeast side of Seven Cross Hill, and joined the South Platte near Fort Morgan. The creek flowed across an outcrop of erosion-resistant Fox Hills Sandstone between Seven Cross Hill and the South

Platte which created a temporary base level at the point where the creek crossed the sandstone outcrop. Above this temporary base level the stream gradient and erosion rates were quite low, while below it they were much higher. During this time, the deep valley of Wildcat Creek upstream from the South Platte River, herein called Wildcat Canyon, was carved into the easily eroded Pierre Shale by stream erosion and accompanying mass wasting.

In the meantime stream erosion was actively downcutting the valley of Crow Creek, because base level for Crow Creek was at the South Platte, which is considerably lower in elevation than the sandstone outcrop along Wildcat Creek. A tributary to Crow Creek on the northwest end of Seven Cross Hill carved its way eastward by headward erosion, until capturing the upper reach of Wildcat Creek and diverting its flow into the tributary of Crow Creek. Thus, the present-day drainage of Upper Crow Creek was established (Figure 5). After abandonment of the paleochannel, wind-blown sand and silt accumulated in the paleochannel and raised surface elevations 10 to 40 feet. Confluence Canyon was deepened and enlarged as a result of increased stream flow and accompanying erosion.

This theory of stream piracy explains some of the geomorphic features of the region. Above the Big Bend the valley of Upper Crow Creek has low relief and gently sloping valley walls, while the valley walls of Confluence Canyon are relatively high and steep-sided. The theory also helps to explain the relatively deep Wildcat Canyon. These topographic relationships are readily apparent in the field and on U.S.G.S. 7 1/2 minute topographic maps, and are easily accounted for by stream piracy.

3.3 CLIMATE

The Upper Crow Creek area is typical of the semi-arid plains environment. Precipitation is generally adequate to support natural grasses and some short grains. Dry-land crop production is dependent on seasonal variation of precipitation. Irrigation was employed to stabilize yields and allow the growth of crops such as corn, alfalfa, and sugar beets.

Limited precipitation and temperature data are available for Grover and Briggsdale during certain years, but the nearest comprehensive climatic data come from Greeley, Colorado or Carpenter, Wyoming. Figure 6 illustrates the average mean monthly temperature and precipitation for Greeley. Average monthly precipitation in Greeley ranges from 0.28 inches in February to 2.50

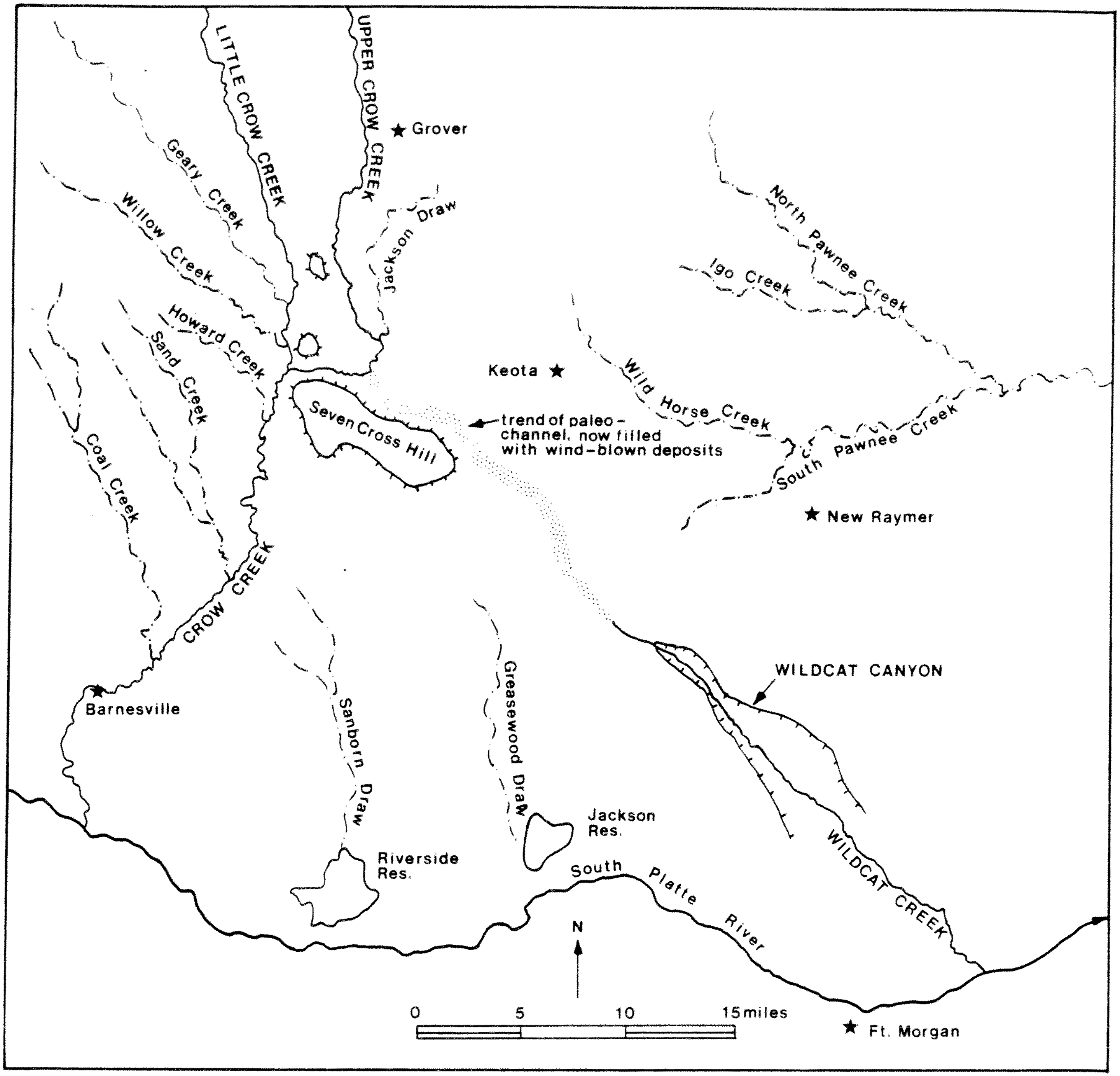


Figure 5. Present-day drainage system of Crow Creek and Wildcat Creek. Upper and Little Crow Creeks and Wildcat Creek are intermittent streams, but are shown as solid lines on this map for emphasis.

inches in May, while the average annual precipitation is 12.68 inches. Normal mean monthly temperature ranges from 25.0°F in January to 73.6°F in July, and the normal mean annual temperature is 49.0°F.

Climatological data for Carpenter, Wyoming are similar (Figure 7). In Carpenter the average monthly precipitation ranges from 0.21 inches in

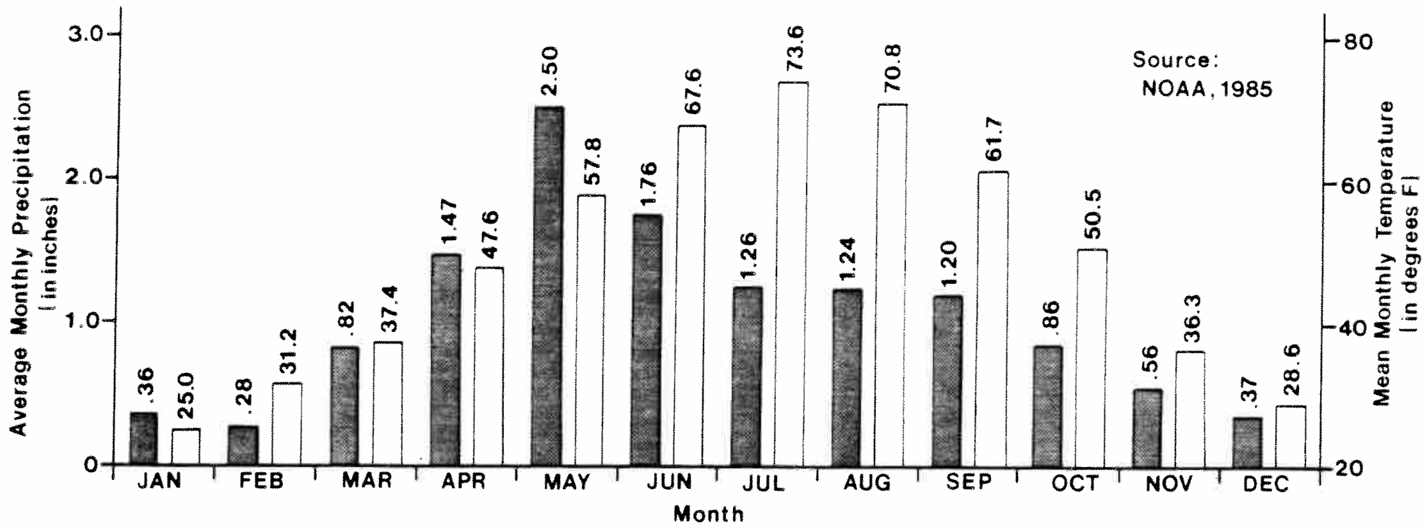


Figure 6. Average monthly precipitation and mean monthly temperature, Greeley, Colorado. Stipple pattern indicates precipitation.

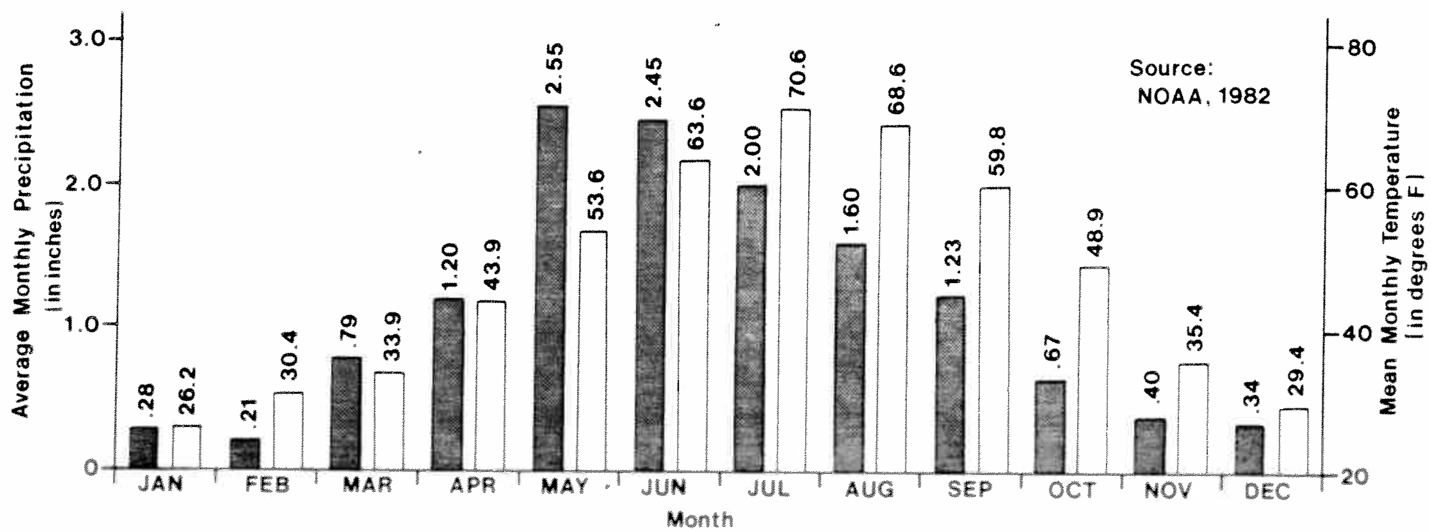


Figure 7. Average monthly precipitation and mean monthly temperature, Carpenter, Wyoming. Stipple pattern indicates precipitation.

February to 2.55 inches in May, with an average annual precipitation of 13.72. The normal mean monthly temperature varies from 26.2°F in January to 70.6°F in July with a normal mean annual temperature of 47.0.

An interesting climatological aspect of the study area is that precipitation reaches its peak in May and then gradually declines over the growing season, whereas temperatures reach their peak during July, and generally remain fairly high throughout the growing season.

3.4 POPULATION

Just under 300 people live within the study area according to 1980 census figures provided by the Colorado Division of Local Affairs. The only incorporated town within the study area is Grover, which had a population of 158 in 1980. The remaining population live in unincorporated Hereford or reside in rural areas.

3.5 LAND USE AND OWNERSHIP

Most land within the study area is used for agricultural purposes. Irrigated and dry-land farming is common, with approximately 6,820 acres being flood or sprinkler irrigated. Ranching is also a primary land use in the area, with considerable pasture land used for livestock grazing. Small parcels of land are utilized for oil and gas development, and during the 1970's an in-situ uranium solution mine operated on a pilot scale just outside of Grover. Several missile silos are also present in the study area.

Most of the area is rural, with only the two small towns of Grover and Hereford being within the study area. Approximately 2.1 square miles are Federal lands under the control of the Pawnee National Grasslands and about 9.5 square miles are state of Colorado lands. Remaining lands are privately owned.

4.0 GEOLOGIC SETTING

Geologic aspects of the Upper Crow Creek study area are described in this section. A geologic map of the area is shown on Plate 1, while Plates 4, 5, 6, and 7 and Figure 14 are geologic cross sections. Figure 8 depicts the locations of the cross sections.

4.1 STRUCTURAL SETTING

Upper Crow Creek is situated on the eastern side of a structural depression called the Cheyenne Basin. The Cheyenne Basin and its neighboring basin to the south, the Denver Basin, are within a large structural basin that covers northeastern Colorado, southeastern Wyoming, and western Nebraska, and is known to the petroleum industry as the D-J, Denver-Julesburg, or Denver-Cheyenne Basin. The latter name is used in this study for the large basin.

Figure 9 illustrates the regional setting of the larger Denver-Cheyenne Basin. The structural contours are drawn on top of the Precambrian surface. Figure 10 shows the outline of the Cheyenne Basin within Colorado, as delineated by the top of the Fox Hills Sandstone. Location of the mapped area is indicated on both figures. Within the study area, bedrock formations generally dip gently to the northwest. Minor structural folds are imposed upon the regional trend.

No faulting is known to exist within the study area, but it is likely that at least a few minor faults are present. Due to the lack of good exposures in the area, the orientation and spacing of joints are poorly understood. The White River Group is often extensively fractured in outcrops, but the fractures appear to be randomly oriented. The regional trend of fractures in the White River Group is believed to be dominantly N50° to 60°W and N20° to 30°E, as suggested by M.E. Cooley in Crist (1980). Orientation and spacing of joints in other bedrock formations is unknown.

4.2 QUATERNARY DEPOSITS

Quaternary and bedrock stratigraphy and aquifer nomenclature are depicted in Table 1. Geologic data was obtained from previously published

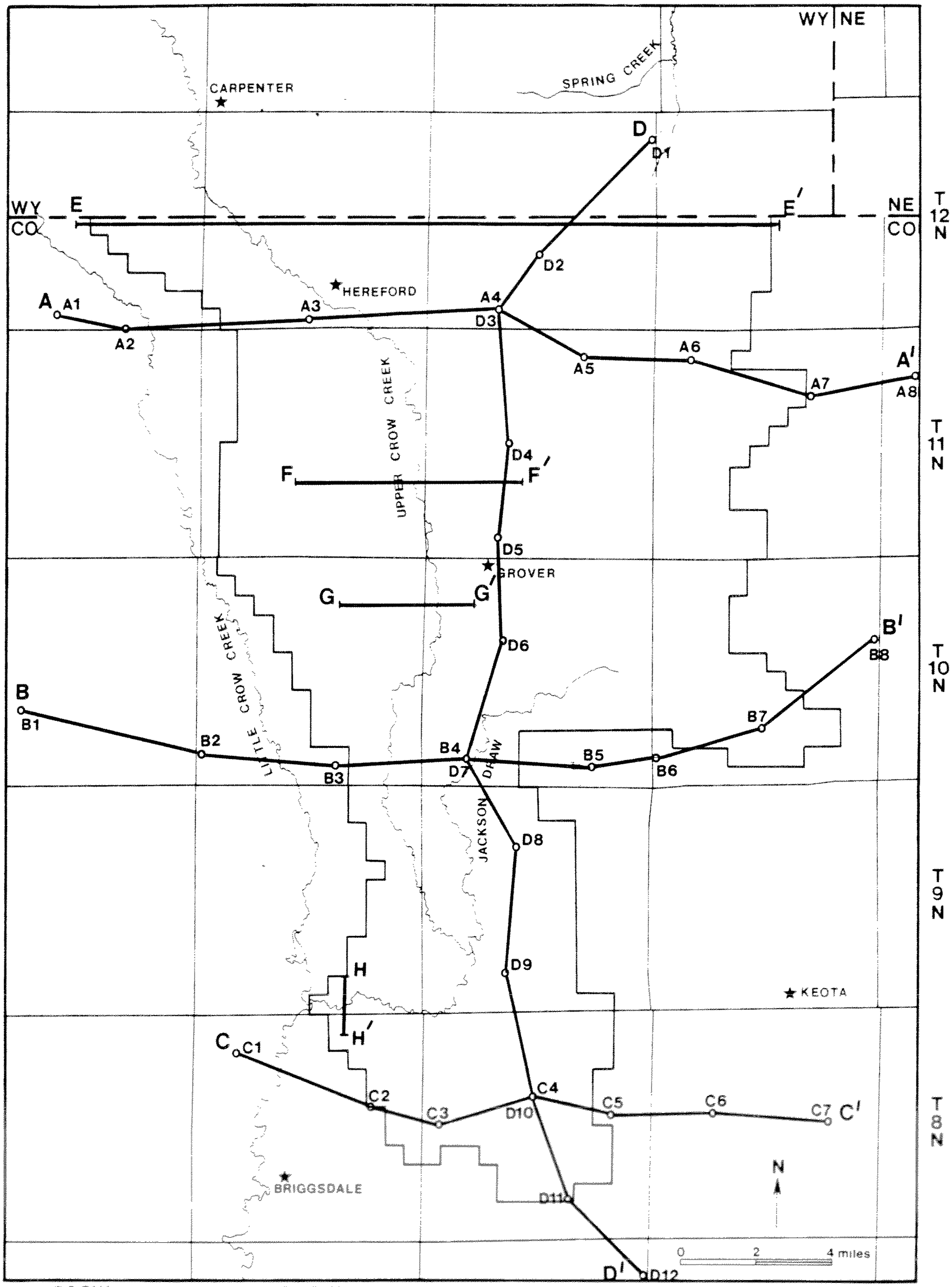


Figure 8. Cross-section location map. Open circles indicate locations of geophysical logs used to construct the cross sections, each of which is numbered for identification purposes.

sources, interpretation of aerial photographs, drill hole logs, and field inspection.

Table 1. Quaternary and bedrock stratigraphy and aquifer nomenclature.

AGE	FORMATION OR UNIT	AQUIFER
Quaternary	Wind-blown Deposits	
	Stream Alluvium	Alluvial Aquifer
	Fan Deposits	Fan Aquifer
Miocene	Ogallala Formation	
Oligocene	White River Group	White River Aquifer
Cretaceous	Laramie Formation	Upper Laramie Aquifer
	Fox Hills Sandstone	Laramie-Fox Hills Aquifer
	Pierre Shale	Upper Pierre Aquifer
	undifferentiated Cretaceous Rocks	
	Dakota Group	Dakota Aquifer
Mesozoic, Paleozoic and Precambrian	undifferentiated Mesozoic, Paleozoic, and Precambrian Rocks	

Three general types of unconsolidated Quaternary deposits exist in the study area: stream alluvium, fan deposits, and wind-blown deposits. Stream alluvium, also referred to as alluvial deposits in this report, consists of interbedded and interfingered sand, gravel, silt, and clay deposited primarily by streams. The stream alluvium is generally coarser in the northern part of the area and the percentage of gravel and sand within the deposit decreases downstream. Near the Confluence the stream alluvium is described as fine to

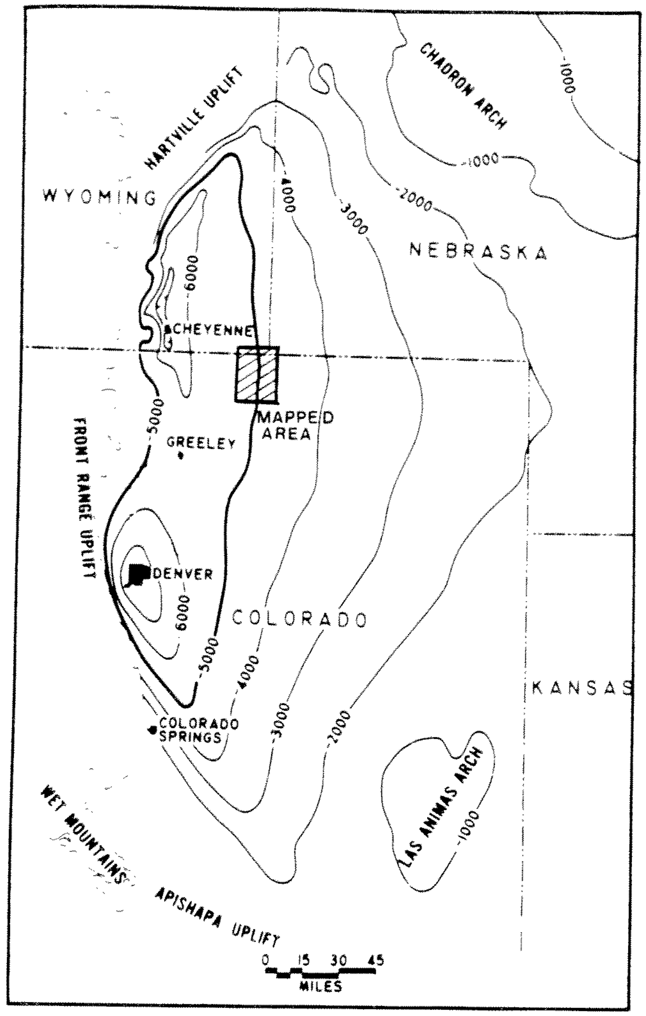
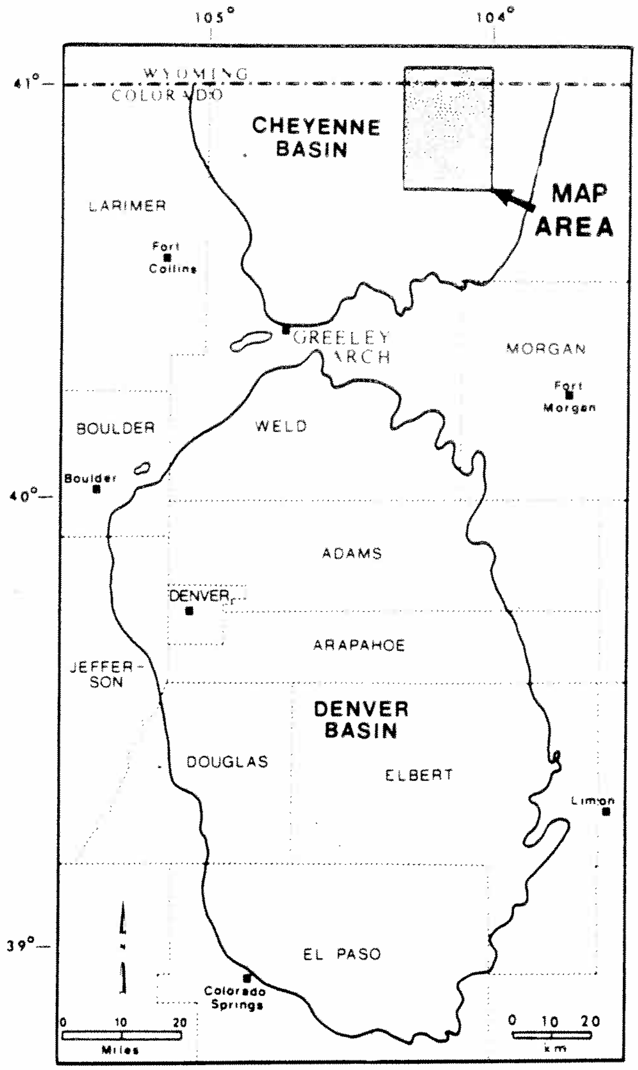


Figure 9. Structure contour map (in feet below sea level) on the top of the Precambrian surface in the Denver-Cheyenne Basin. (after Matuszczak, 1973)

coarse sand with minor gravel, silty or clayey sand, and sandy silt or clay. Small areas of slopewash and colluvium are locally included with the mapped alluvial deposits in the Upper Crow Creek area. Maximum known thickness of stream alluvium is about 60 feet in the Hereford area, and thickness generally decreases in a downstream direction. Just above the Confluence, drill hole data reveal a maximum thickness of only about 20 feet. Elevation of the bedrock surface beneath the alluvial deposits is shown on Plate 1.

As shown on Plate 1, stream-laid alluvial deposits are mapped in Upper Crow Creek, Little Crow Creek, Crow Creek, Jackson Draw, and Willow Creek. Other small tributaries in the mapped area contain thin alluvial deposits that are not of great hydrologic significance, and for that reason are not shown on



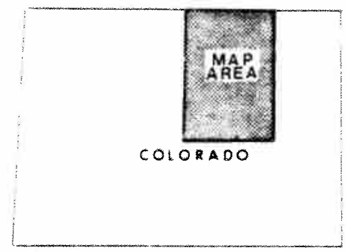


Figure 10. Location of the mapped area within the Cheyenne Basin. Outline of the Cheyenne and Denver Basins is delineated by the top of the Fox Hills Sandstone. Only that part of the Cheyenne Basin within Colorado is shown.

the geologic map. An interesting characteristic of the alluvial deposits along Upper Crow Creek is the variation in width of the alluvial valley and its associated alluvial deposits. In the Hereford area valley width averages around 3,000 to 4,000 feet. As the creek departs the area underlain by fan deposits, the mainstream alluvium merges with alluvium in tributaries to the west. In this area the alluvial deposits range up to 5.3 miles wide. Just above the Confluence, the alluvial valley and associated alluvial deposits are as narrow as 500 feet. This prominent narrowing, along with the decreasing thickness and textural fining described above, have important hydrologic influence that is described in Section 5.1.1.

Fan deposits are found in the northern part of the study area and are subdivided into older and younger fan deposits on Plate 1. Previous investigators have described these units as terrace deposits, but closer study indicates they more likely are fan deposits. Stream terraces generally have low width to length ratios, while alluvial and debris fans have much higher width to length ratios and often are "cone-shaped". As shown on Figure 11, the younger fan deposit occurs over a nearly equidimensional area and displays the characteristic cone shape. Note that only a small part of the younger fan lies within Colorado. Unfortunately, much of the older fan has been removed

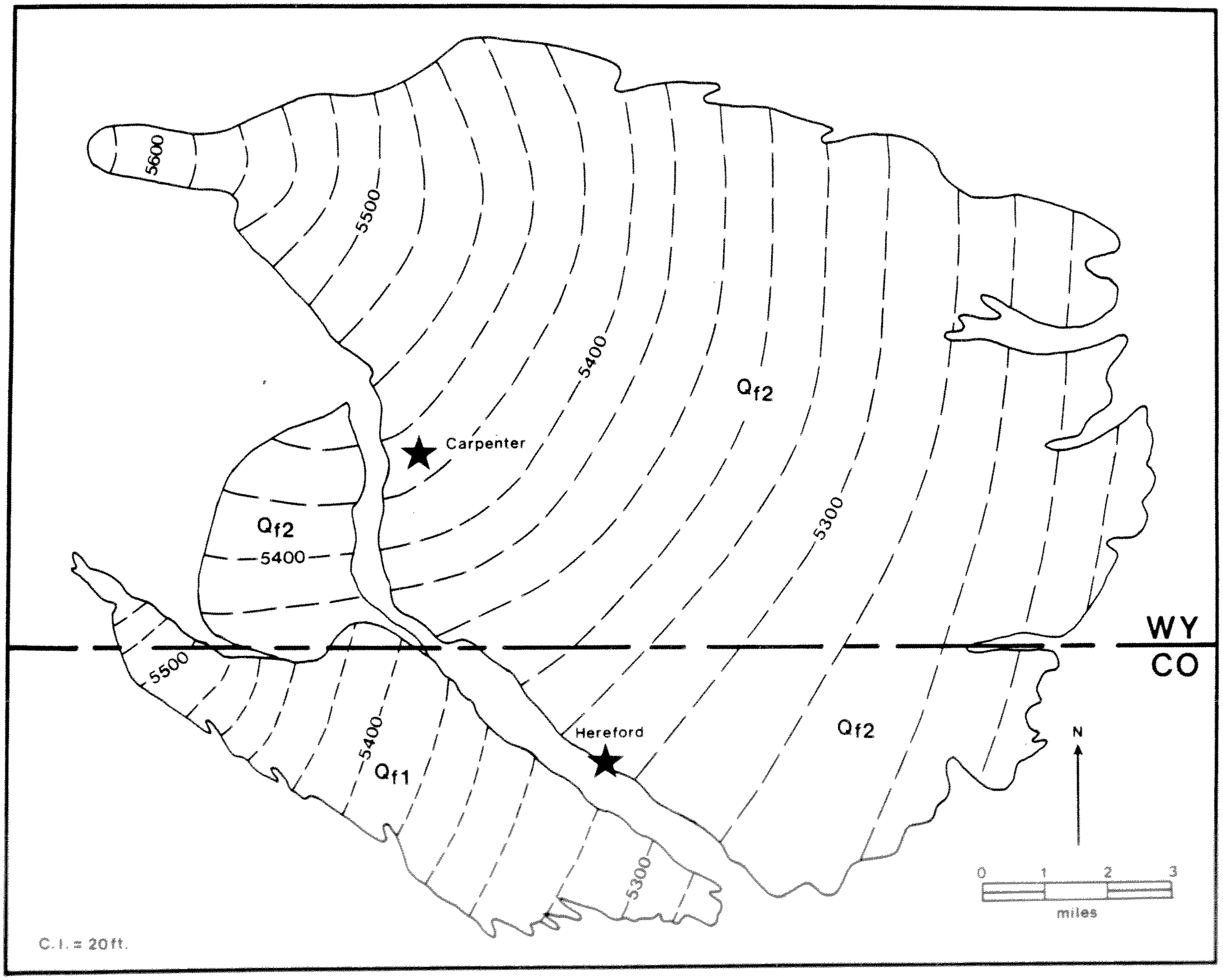


Figure 11. Map showing present-day extent of the fan deposits and topographic contour lines drawn on their estimated original surface along Upper Crow Creek in Colorado and Wyoming.

by erosion and it is not valid to use its eroded dimensions in a comparative analysis of this type. The original dimensions of the older fan are also believed to have been nearly equidimensional, and it likely was cone-shaped. A terrace deposit usually occurs at a fairly constant elevation above the stream bed. The deposits along Upper Crow Creek are only about 10 feet above the stream in the north, whereas they are 60 feet higher south of Hereford.

Another common characteristic of fan deposits is the configuration of topographic contour lines drawn on the original fan surface. Contour lines on an original fan surface are generally convex in the downslope direction and become closer spaced near the head of the fan. Contour lines drawn on the restored original surface of the younger fan deposit are clearly convex in a downstream direction and are closer spaced near the head or apex of the fan (Figure 11). Topographic contours on the remnant of the original older fan surface do not clearly define any pattern, but they are suggestive of a convex pattern. The contour lines are also closer spaced on the upper part of the old fan surface.

There are also textural differences between fan and terrace deposits. Fan deposits tend to be more poorly sorted than the usually well-sorted terrace deposits. Based on limited outcrop and drill hole data, the deposits along Upper Crow Creek appear to have textures characteristic of fan deposits. Thus, it is fairly clear that the younger materials were indeed deposited in a fan environment, whereas the origin of the older fan is somewhat less certain.

The surfaces of the older and younger fan deposits lie at disparate elevations. Along the Colorado-Wyoming border northwest of Hereford the surface of the older fan is 60 to 80 feet higher than the surface of the younger fan. The fan surfaces tend to merge in a downstream direction, and their differences in elevation diminish accordingly. South of Hereford the older surface is only 10 to 20 feet higher than the younger surface.

Numerous driller's logs are available for wells drilled into the younger fan deposit, but we have no stratigraphic information for wells drilled into the older fan. Local landowners have drilled several test holes into the older fan in efforts aimed at locating sufficient water to support irrigation. Our current information on the older fan deposit is based on discussions with these landowners and on limited outcrop data.

The younger fan deposit is composed of interbedded sandy gravel, gravelly sand, fine to coarse sand, and sandy silt or clay. Most gravel is granule to pebble-sized, but occasionally cobble or larger sizes are present. Most clasts are composed of granitic material derived from the Laramie Range. Textural and lithologic characteristics of the older fan deposit are generally similar to that of the younger fan deposit.

Elevation of the bedrock surface beneath the fan deposits is shown on Plate 1. Thickness of the fan deposits at a particular location can be determined by subtracting the bedrock elevation from the surface elevation at that location. Maximum thickness of the younger fan deposit is about 150 feet and occurs in an area along the Colorado-Wyoming border about three miles northeast of Hereford. Maximum thickness of the older fan deposit is thought to be around 50 feet.

A thin veneer of wind-blown sand and silt blankets much of the study area, particularly its southern part. Many of the closed depressions present within the study area and in surrounding areas are the result of eolian processes. Average thickness of the wind-blown deposits is 5 to 20 feet, but locally the wind-blown sand and silt is as much as 30 to 50 feet thick. Orientation of eolian features suggests a dominant wind direction blowing from northwest to southeast during deposition.

4.3 BEDROCK FORMATIONS

Numerous bedrock formations underlie the study area, but only those with hydrologic significance are described in this report. Bedrock stratigraphy is listed in Table 1. As shown on Plate 1, only three formations, the Ogallala, White River, and Laramie, crop out within the study area. Plates 4, 5, 6, and 7 are cross sections that illustrate the characteristics of bedrock in the study area.

The Miocene Ogallala Formation caps the High Plains to the east of the study area. Well cemented to nearly unconsolidated sand, silt, and gravel, along with local freshwater limestone and volcanic ash, comprise the Ogallala Formation.

All but the southern tip of the study area is underlain by the Oligocene White River Group. Two formations, the Brule and underlying Chadron

Formations, are included within the White River Group. The Brule is dominantly a light-colored, blocky, ashy siltstone that locally contains channel deposits of arkosic conglomerate and sandstone. The relatively homogeneous siltstone of the Brule is readily identifiable on geophysical logs by its characteristic response, as demonstrated on the cross sections. In well A6 on Plate 4, the typical log response of the Brule is present from the log top to 355 feet. The very low resistivity recordings from 355 to 387 feet typify the Chadron Formation in the study area. The Chadron consists of varicolored claystone beds that may represent a paleosol developed on the unconformity at the top of the Laramie Formation prior to deposition of the Brule (described by Cooley in Crist, 1980).

Sandstone and conglomerate channel deposits occur randomly throughout the Brule within the study area, as is demonstrated in well A8 at a depth of 350 feet. They also commonly occur in paleovalleys cut into the Laramie Formation. This phenomenon is illustrated by well A7 on Plate 4. Brule channel deposits are usually more resistant to erosion than the ashy siltstone beds, and when present near modern-day ground level form prominent topographic ridges. The ridge about one and one-half miles north of Grover near the Home of Peace Cemetary is capped by a Brule channel deposit. Brule channels generally trend east or southeast, but occasionally a channel trends northeast.

Figure 12 shows the elevation of the base of the White River Group. The contour lines depicted on Figure 12 represent the topographic configuration of the eroded land surface or unconformity prior to deposition of the White River Group. Part of the general eastward slope of this surface is the result of regional tilting, but the local relief so apparent on this map reflects the topographic conditions existing prior to deposition of the White River Group.

Two prominent paleotopographic features dominate the mapped area. A southeast-trending paleovalley cut into the Laramie Formation extends from T10N, R62W to T8N, R60W. Local relief of the valley walls is up to 180 feet. A bedrock high lies on the northeast side of the paleovalley and runs parallel to it in the mapped area. Another paleovalley, this one having a northeast orientation, is present in the northeast corner of the mapped area.

Maximum known thickness of the White River Group is around 600 feet in the northeast part of the study area. The formation generally becomes thinner

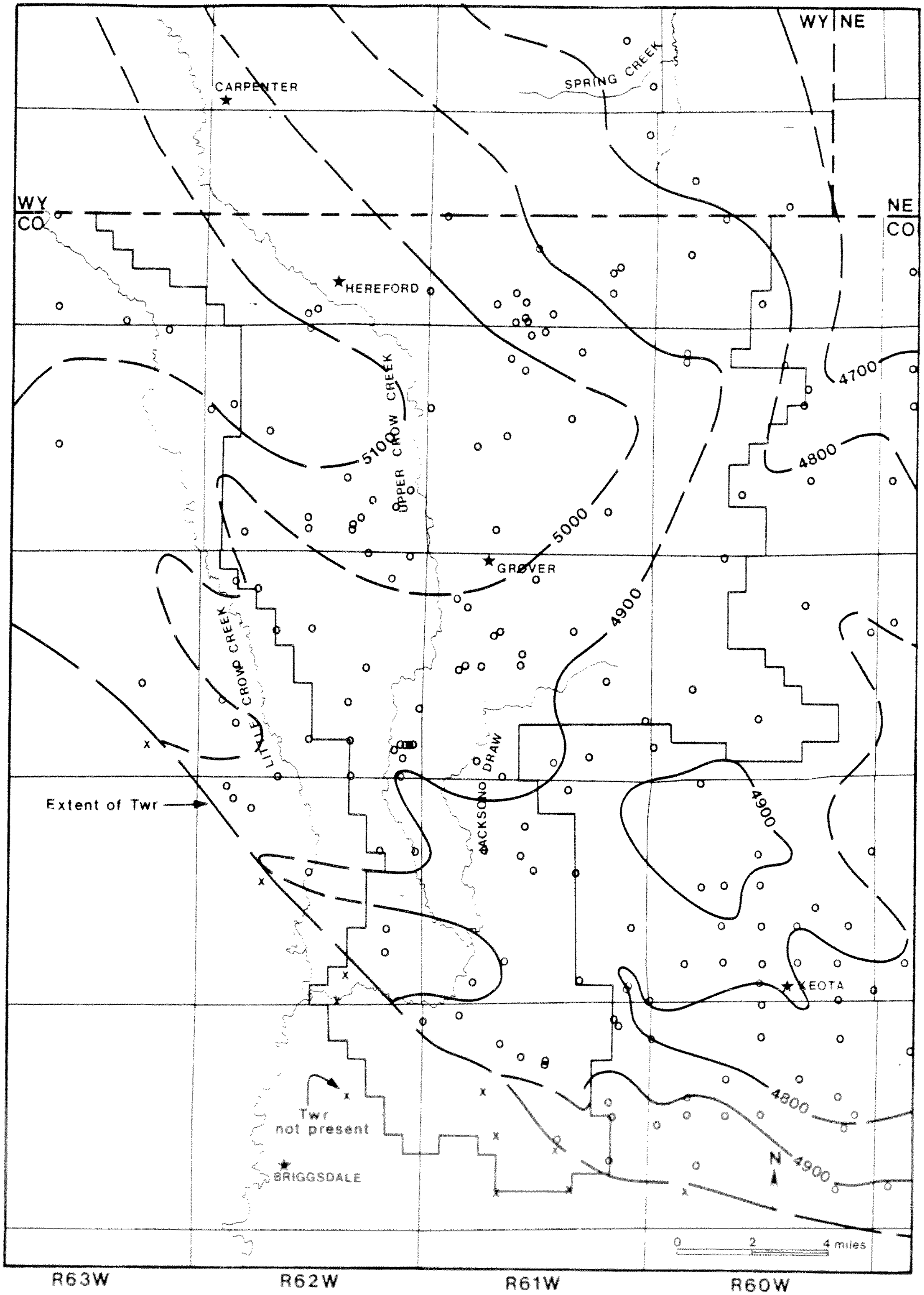


Figure 12. Map showing elevation of the base of the White River Group. Contour interval is 100 feet. Note prominent paleovalley that extends from T10N,R62W to T8N,R60W and is eroded into the Laramie Formation. A topographic high running from T12N,R63W to T9N,R60W underlies much of the proposed basin and served as a drainage divide prior to deposition of the White River Group.

southwestward and has been entirely removed by erosion southwest of the outcrop line on Plate 1. The mapped extent of the White River Group, as depicted on Plate 1 and Figure 12, varies from previous mapping by Weist (1965), Braddock and Cole (1978), and Wacinski (1979). Our mapped contact is based on drill hole data not available to previous authors, and is in our view more accurately located.

The Upper Cretaceous Laramie Formation occurs throughout the study area and underlies the White River Group. It consists of light to dark gray carbonaceous shale and claystone, sandstone, siltstone, and lignite. Kirkham and others (1980) describe the characteristics of the Laramie Formation in the Cheyenne Basin. The formation is up to 1,800 feet thick in the deepest part of the basin and includes numerous sandstone beds that range up to 125 feet thick. Kirkham and others (1980) suggest that the Laramie Formation in the Cheyenne Basin is perhaps more similar to the Lance Formation in Wyoming than to the Laramie Formation in the Denver Basin. We utilize the currently accepted nomenclature for this investigation, but recognize that what herein is termed Laramie Formation may actually be more suitably called Lance Formation.

Thickness of the Laramie Formation is primarily controlled by structural dip and the erosional angular unconformity at the top of the formation. The formation generally dips northwestward, thus the base of the formation becomes shallower to the southeast. Topographic relief of the angular unconformity is illustrated in Figure 12 and on Plates 4 through 7. The unconformity generally decreases in elevation southeastward. In areas where the Laramie Formation is overlain by the White River Group the top of the Laramie is at the same elevation as the base of the White River. Outside the area underlain by the White River Group, the preserved top of the Laramie Formation coincides with the ground surface, or it lies directly beneath any surficial Quaternary deposits. Within the study area, thickness of the Laramie Formation ranges from about 50 feet in the southeast corner to almost 800 feet in the northwest corner. The Laramie Formation has been removed by erosion in at least two areas along the eastern border of the mapped area, as is demonstrated by drill hole data in section 7, T10N, R59W and section 11, T11N, R60W (see Figure 13).

Of primary interest to this study are the water-bearing sandstones present within the Laramie. The most prominent sandstone bed within the

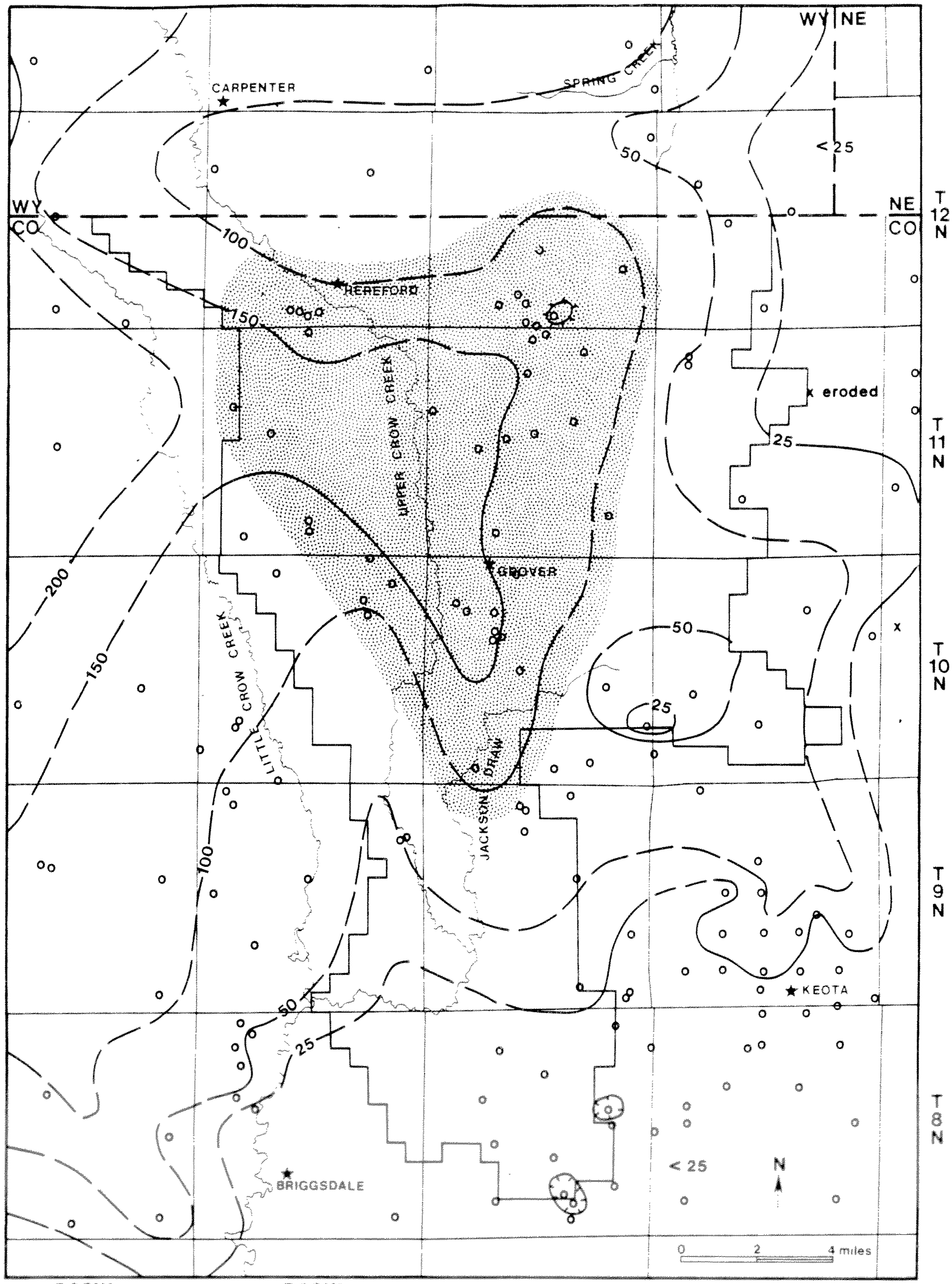


Figure 13. Sandstone isolith map (in feet) for the Upper Laramie Aquifer. Contour interval is 50 feet. Open circles indicate data points. "X" marks locations where Upper Laramie Aquifer has been removed by erosion prior to deposition of the White River Aquifer. Stipple pattern marks area where the Grover sandstone member is generally well developed.

Laramie Formation in the study area is called the Grover sandstone member. Areas where the Grover sand is especially thick are depicted in Figure 13. Other previously recognized sandstone members in the Laramie include the Porter Creek and Sand Creek members, but these are not particularly well developed or may not be present within the study area.

Beneath the Laramie Formation lies the Upper Cretaceous Fox Hills Sandstone. Within the Cheyenne Basin the Fox Hills Sandstone consists of three to seven generally upward-coarsening sandstone beds that are overlain by as many as five massive sandstone beds (Kirkham and others, 1980; Ethridge and others, 1979). Interbeds of shale, claystone, and siltstone separate the sandstones of the Fox Hills.

The contact between the Fox Hills and Laramie is sometimes difficult to identify. The upper massive sandstone members of the Fox Hills often split into two or more thinner beds that are often mapped with the Laramie. Because of this, many researchers include the lower Laramie sandstones with the Fox Hills and call the combined unit the Laramie-Fox Hills Aquifer, an approach utilized in this investigation.

The basal members of the Fox Hills are similarly transitional to the underlying Pierre Shale. Some researchers recognize a separate unit called the Fox Hills-Pierre transition zone, but for hydrologic studies the lower transitional sandstones of the Fox Hills should be included with the upper massive sandstones in a single aquifer. Please refer to Section 5.1.2 and Plates 4, 5, 6, and 7 for additional information on this stratigraphic issue.

The Upper Cretaceous Pierre Shale underlies the Fox Hills and is composed primarily of shale and claystone, but it also contains several zones of siltstone, sandy siltstone, and sandstone. Thickness of the Pierre Shale in the study area averages about 5,600 feet.

Kitely (1978) described useful nomenclature for dividing the Pierre Shale into several members. A sequence of sandstones and siltstones in the upper part of the Pierre are termed the C, D, and unnamed sandstone members, and are separated from the Fox Hills by about 180 to 300 feet of shale. Kirkham and others (1980) recognized the aquifer potential of these sandy members within the upper Pierre and included them in what they called the Upper Pierre Aquifer. This terminology is adopted for the Upper Crow Creek area. Regional studies by Rogers and others (1985) indicate the Upper Pierre Aquifer has higher resistivity on geophysical logs north of the South Platte River. Thus, the Upper Pierre Aquifer may be more productive in the study area than in areas south of the South Platte River.

The Dakota Group is the lowermost formation of hydrologic importance in the study area. It is separated from the base of the Pierre Shale by 800 to 900 feet of limy shale, carbonaceous shale, limestone, siltstone, and bentonite contained in the Niobrara Formation, Carlile Shale, Greenhorn Limestone, and Graneros Shale. Stratigraphic and age relationships between the various members of the Dakota Group are an issue of debate among researchers. Because this investigation is concerned only with hydrologic aspects, we include the "D" and "J" sandstones and Dakota Sandstone all within the Dakota Group. Aggregate sandstone thickness for the Dakota Group ranges from 150 to 250 feet (Robson and Banta, 1984). Depth to the top of the Dakota Group varies from about 7,100 feet in the southeast part of the study area to almost 8,400 in the northwest corner.

5.0 WATER RESOURCES

This section on water resources is subdivided into subsections on ground water and surface water. Within the ground-water subsection each bedrock and unconsolidated Quaternary aquifer is described, along with ground-water recharge, discharge, underflow, and movement. Water-level fluctuations and amounts of water in storage for each aquifer are also described. Included in the subsection on surface water are descriptions of the historic surface water flow based on testimony and depositions by local residents and the experience of Division 1 Water Commissioners, and analyses of available stream flow measurements. Please refer to Section 6.0 for information on water use.

5.1 GROUND WATER

Ground water occurs in confined and unconfined aquifers within the study area. The two unconsolidated Quaternary aquifers and the White River Aquifer are unconfined and act as a single aquifer system. The Upper Laramie and Laramie-Fox Hills Aquifers are the primary confined or semi-confined aquifers in the study area.

5.1.1 UNCONSOLIDATED AQUIFERS OF QUATERNARY AGE

Two unconsolidated aquifers of Quaternary age are present within the study area, the Alluvial Aquifer and Fan Aquifer. These two aquifers, along with the White River Aquifer provide water for all irrigation wells in the proposed basin. The Alluvial Aquifer corresponds to the unit mapped on Plate 1 and described in Section 4.2 as stream alluvium. The Fan Aquifer encompasses both older and younger fan deposits. In the northern part of the study area the Fan and Alluvial Aquifers are in direct physical contact. Water is readily transmitted from one aquifer to the other in this region, and hydrologically both aquifers act as a single aquifer in this northern region. Water within the Alluvial Aquifer downstream of section 1, T11N, R62W does not freely commingle with water in the Fan Aquifer. Both aquifers are unconfined throughout the study area.

Extent of the unconsolidated aquifers and the elevation of the bedrock surface beneath them are shown on Plate 1. The Alluvial Aquifer covers approximately 42.3 square miles and the Fan Aquifer, where saturated, about 25 square miles within the study area. The bedrock elevation map was prepared by subtracting the thickness of the Quaternary deposits from the surface elevation, and then contouring the data. In the lower reaches of Upper Crow Creek drill hole data is sparce, and the bedrock elevation map is based on limited control in that area. Bedrock elevations shown in Wyoming are taken from Crist and Borchert (1972) with slight modification based on drill hole data available to the authors.

Figure 14 contains a series of cross sections that depict the Alluvial and Fan Aquifers and the potentiometric surface of the unconfined aquifers. Note the change in both the horizontal and vertical scales between E-E' and the other three cross sections. The cross sections are sequenced in a downstream order. Please refer to Figure 8 for the location of each cross section.

The most dramatic feature of these cross sections is the decrease in width and thickness of the unconsolidated aquifers in a downstream direction. At the state line the combined width of both unconsolidated aquifers is over 13 miles, and the maximum thickness of the Fan Aquifer is about 150 feet. Along section F-F' the width of the Alluvial Aquifer is just over five miles and the aquifer is a maximum of about 50 feet thick. Cross section G-G' illustrates the bedrock hill that splits the Alluvial Aquifer into an eastern and western channel whose combined widths total about 1 mile. Maximum thickness in this area is 35 to 40 feet. The bedrock hill and abrupt thinning of the aquifer appear to cause the development of a ground-water divide that is discussed in Section 5.3. Just above the Confluence along cross section H-H' the Alluvial Aquifer is only 500 feet wide and around 20 feet thick.

Saturated thickness of the Alluvial and Fan Aquifers is shown in Plate 2 and on the cross sections in Figure 14. In the southern half of the study area the saturated thickness of the Alluvial Aquifer is always less than 20 feet. At section H-H' only about 10 feet of the aquifer is saturated. Northwest of Grover the saturated thickness ranges up to about 30 or 35 feet. The Fan Aquifer attains its maximum saturated thickness of just over 100 feet along the Colorado-Wyoming border between Range 61 and 62 West.

Reported yields from irrigation wells in the Alluvial Aquifer range from 180 gpm to 1,500 gpm and average 300 to 500 gpm. Well yields for the Fan Aquifer, as reported by drillers, range from 170 to 1,200 gpm and average

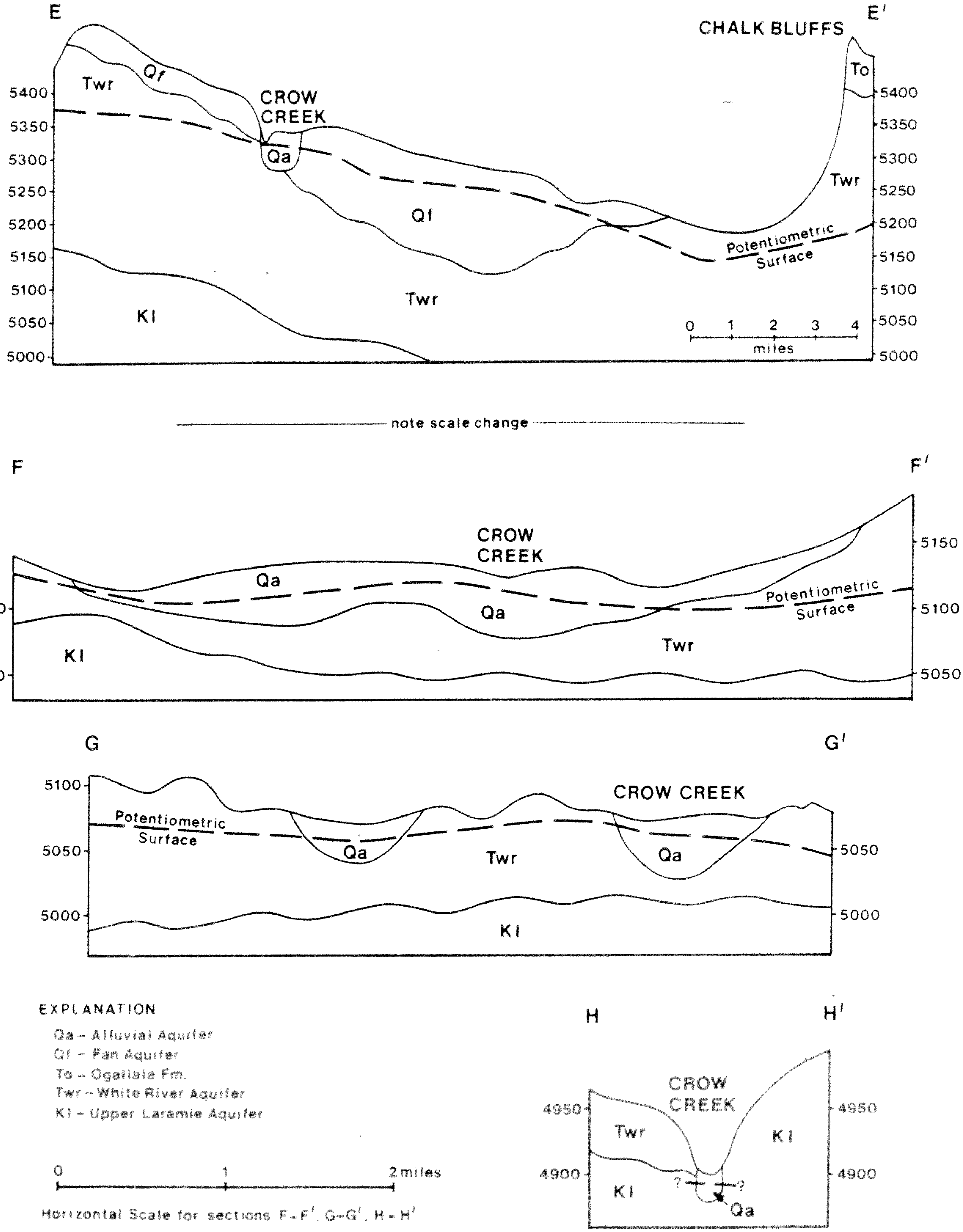


Figure 14. Cross sections E-E', F-F', G-G', and H-H', which illustrate the characteristics of the Quaternary aquifers. Note that the section E-E' is drawn at a different scale than sections F-F', G-G', and H-H'. All geologic contacts are approximately located.

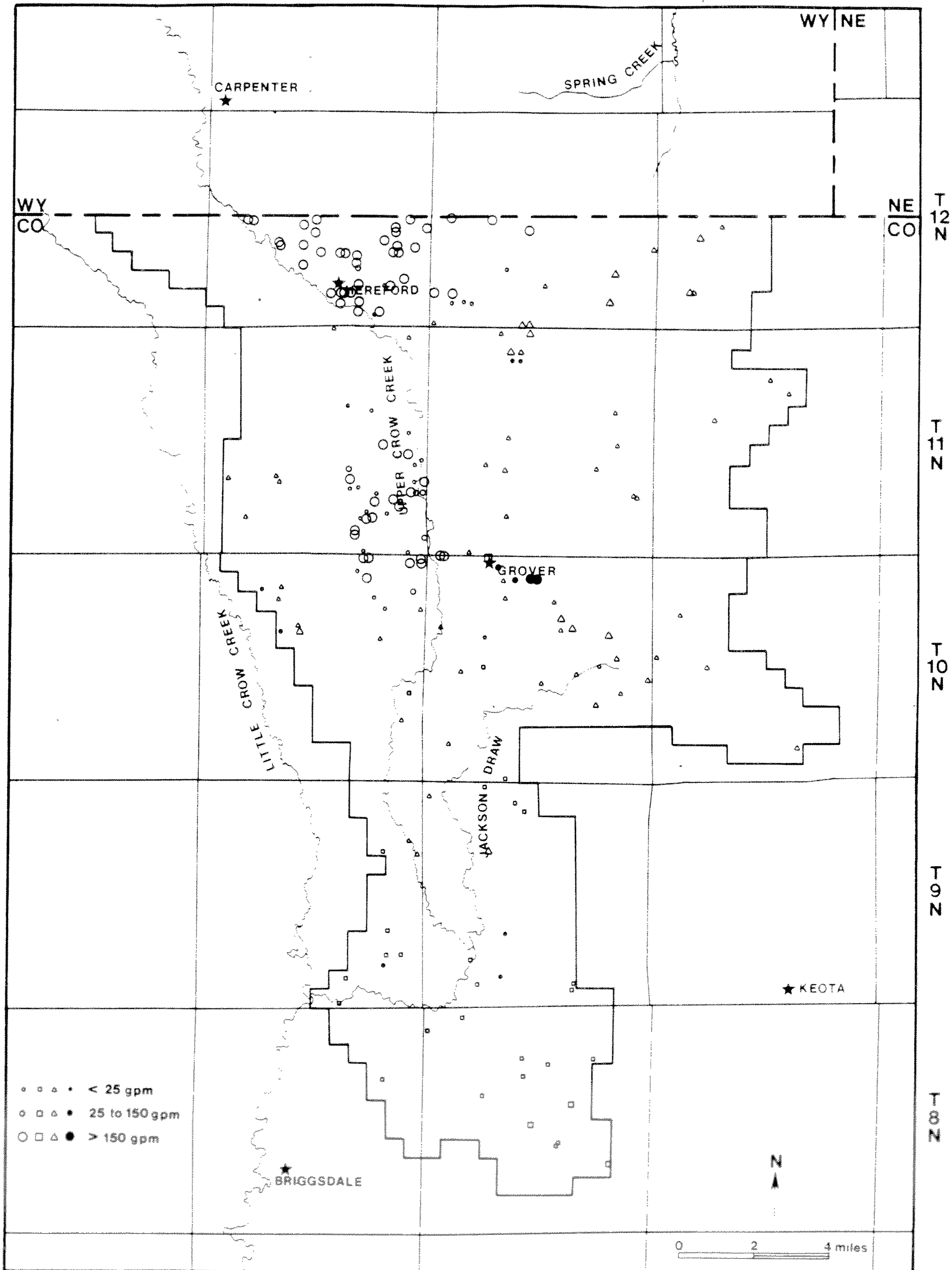


Figure 15. Map showing reported yields or adjudicated production of water wells. Open circles represent wells completed in the Alluvial and Fan Aquifers, triangles represent wells completed in the White River Aquifer, squares indicate Upper Laramie or Laramie-Fox Hills wells, and solid circles indicate wells completed in two aquifers or in an unknown aquifer. (data from State Engineer's records)

about 600 to 800 gpm. As would be anticipated, highest yields are reported from areas with the greatest saturated thickness. Reported yields from domestic and stock wells completed in the Alluvial and Fan Aquifers are often substantially lower.

No pump test data are available for either unconsolidated aquifer within the study area. Lowry and Crist (1967) reported pump test data for wells just north of the study area near Carpenter that are completed in the Fan Aquifer. They describe transmissivities of 6,003 and 19,560 square feet per day, storage coefficients of 4.65×10^{-3} and 5.43×10^{-2}, and specific capacities ranging from 13.9 to 58.0 gpm per foot of drawdown. Babcock and Bjorklund (1956) state that wells completed in the Fan Aquifer have specific capacities varying from 19 to 72 gpm per foot and averaging 33 gpm per foot. Wilson (1965) reported on two pump tests conducted in alluvium along Crow Creek far below the Confluence. Transmissivities for these tests were 8,040 and 14,070 square feet per day, while specific capacities were respectively 25 and 17 gpm per foot. Specific capacities reported by Babcock and Bjorklund (1956) range from 6 to 60 and average about 31 gpm per foot of drawdown for the Alluvial Aquifer in the Carpenter-Hereford-Grover area.

Ground water within the Alluvial and Fan Aquifers is generally of suitable quality for irrigation and most other uses. Please refer to Kirkham and others (1980) for specific analyses.

5.1.2 BEDROCK AQUIFERS

Three major bedrock aquifers, the White River, Upper Laramie, and Laramie-Fox Hills Aquifers, are present in the study area and have been utilized during the past fifteen years. Two less usable aquifers, the Upper Pierre and Dakota Aquifers, occur at greater depths and are of questionable quality. Neither of these two aquifers is currently utilized in the study area.

All bedrock aquifers extend beyond the limits of the study area, and all except the White River Aquifer are confined or semi-confined. The White River Aquifer is the only bedrock aquifer currently proven capable of producing sufficient water for irrigation and other high production needs, and this occurs only in certain areas. The Upper Laramie and Laramie-Fox Hills Aquifers typically yield only moderate amounts of water suitable for domestic, stock, municipal and industrial uses. The Upper Pierre Aquifer produces only minor amounts of water that is often of poor quality, while the Dakota Aquifer is present at too great a depth to be economically useful. Ground water within the Dakota Aquifer is also of poor quality in the study area. Additional deeper aquifers underlie the study area, but because of their great depth and probable poor quality are not considered important to this investigation.

WHITE RIVER AQUIFER

The White River Aquifer includes the entire White River Group. It consists of relatively impermeable siltstone beds with few, but sometimes thick channel deposits of sandstone and conglomerate. Part of the water produced from the White River Aquifer is from the channel deposits, but by far the greatest permeability within the aquifer results from secondary piping or solution features. Originally, water within the White River Aquifer was thought to occur in fractures or in a pebble zone of the base of the aquifer (Rapp and others, 1953; Babcock and Bjorklund, 1956). Later studies by Lowry (1966) and Crist and Borchert (1972) have demonstated that the large yields from the White River Aquifer are being produced from various sized open tubes or caverns that have developed in the siltstone as a result of piping or solution. Moderate amounts of water could probably be produced from the conglomerate and sandstone channel deposits, but they are difficult to locate in the absence of concentrated test hole data. The saturated thickness of the White River Aquifer is generally less than 200 feet across most of the study area, but ranges up to about 500 feet in the northeast corner (Figure 16).

Occurrence of ground water in quantities sufficient for irrigation is highly sporadic in the White River Aquifer (Figure 15). Only in two main areas of the study area are there irrigation wells completed in this aquifer. One area lies east of the Fan Aquifer in the northeast corner of the study area and the second area is southeast of Grover in the broad basin of Jackson Draw. A single White River irrigation well exists in section 16, T10N, R62W, and has a reported production of 300 gpm. Another White River irrigation well was drilled in section 8, T9N, R61W, but this well never produced a great amount of water (reported yield was 180 gpm) and has now been abandoned.

In both of the main areas described above, saturated unconsolidated aquifers are nearby and probably serve as the source of the water being pumped

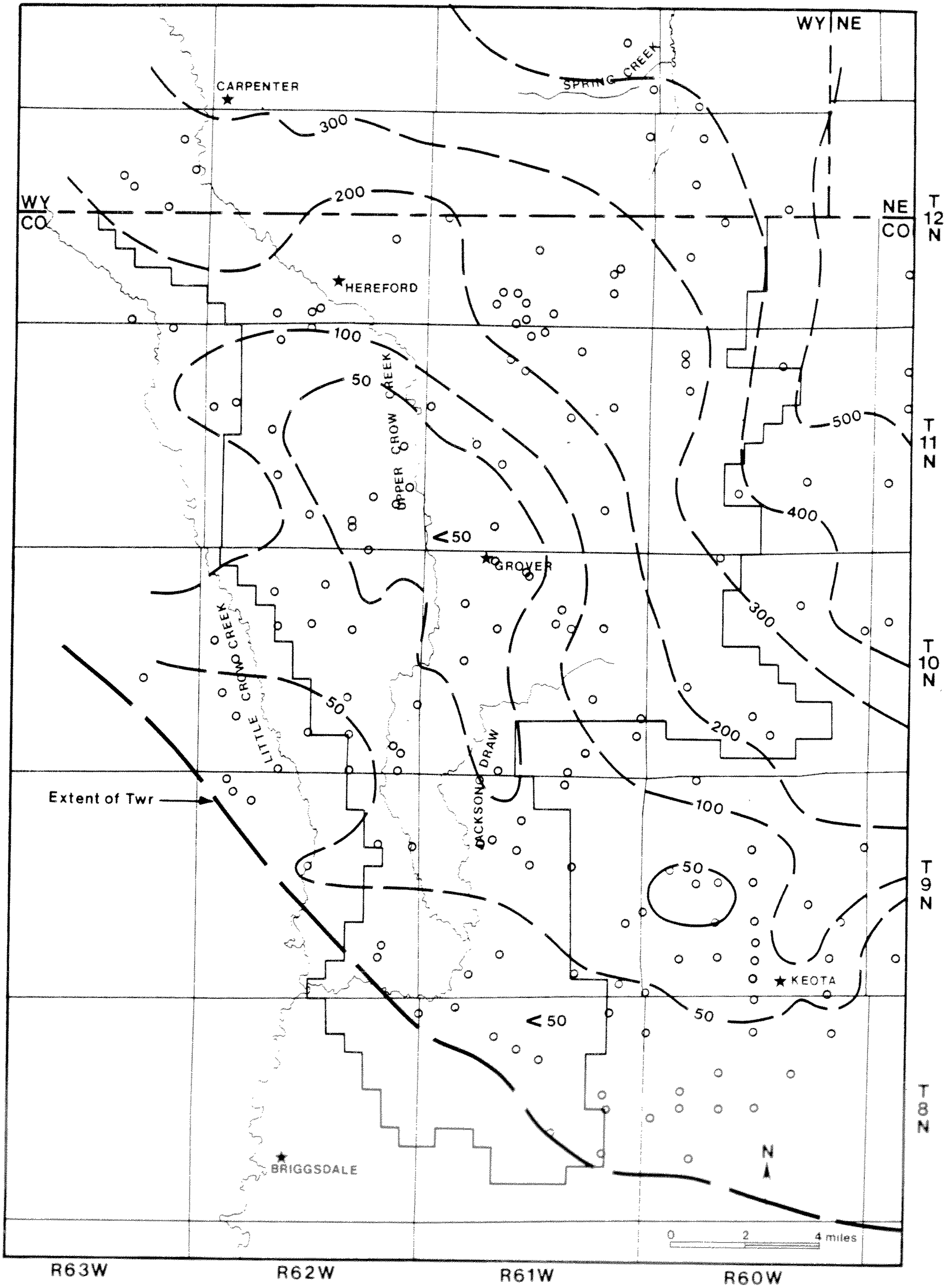


Figure 16. Map showing estimated saturated thickness of the White River Aquifer. Contour interval is 100 feet, with a supplemental contour at 50 feet.

from the pipes and caverns in the White River Aquifer. The well in T10N, R62W also lies near a saturated unconsolidated aquifer. In other areas well yields from the White River Aquifer generally are low. Even in the two main areas where White River irrigation wells exist, it is possible to drill a well with insufficient production for irrigation purposes.

Test holes are commonly drilled when prospecting for the larger production needed for irrigation. An interesting drilling technique has been devised for wells into the White River Aquifer. After drilling the initial borehole, a devise not unlike a chainsaw is lowered down the hole in a vertical manner. The saw is operated hydraulically and brought into a horizontal position, thus cutting slots several feet deep into the formation in hopes of intersecting a highly permeable tube or cavern. Several slots may be cut for each well.

The White River Aquifer supplies water for irrigation, municipal, domestic, and stock purposes. Drillers report yields from irrigation wells completed in the White River Aquifer that range from 81 to 1,100 gpm and average 550 gpm. The lower yields are reported from wells along the ground-water divide in the northern part of T11N, R61W while highest reported yields are in the Jackson Draw area southeast of Grover. Reported yields from stock and domestic wells completed in the White River Aquifer are considerably lower.

Siltstone samples from the White River Aquifer in Wyoming have been laboratory tested to determine their coefficient of permeability (Lowry and Crist, 1967). Results ranged from "too small to be measured accurately" to 0.027 feet per day, supporting the conclusion that ground water in this aquifer mainly occurs in secondary permeability features.

Data from a single pump test within the study area are available for the White River Aquifer. This test was run on a well in section 4, T11N, R61W. The well was perforated from 162 to 415 feet, testing about 40 feet of the White River Aquifer and 213 feet of the Upper Laramie Aquifer. Since these test results probably are more representative of the Upper Laramie Aquifer, they are discussed in that section.

Rapp and others (1953) measured specific capacities of White River wells in the Egbert-Pine Bluffs-Carpenter area varying from 14 to 257 gpm per foot. Three pump tests were performed on White River wells by Crist and Borchert (1970). Two of the tests could not be interpreted because of the aquifer's inhomogeneity at those locations, indicating the importance of the secondary permeability features. The third test yielded transmissivities ranging from 12,800 to 32,600 square feet per day and storage coefficients of 1.57×10^{-3} to 3.18×10^{-3}.

Ground water within the White River Aquifer is generally suitable in quality for irrigation and most other uses, although Kirkham and others (1980) point out that the water in some White River wells contains rather high vanadium and uranium concentrations.

UPPER LARAMIE AQUIFER

The Upper Laramie Aquifer includes all of the Laramie Formation except for any basal sandstone beds that may be present. Basal Laramie sandstone beds are included within the Laramie-Fox Hills Aquifer. Where the Upper Laramie Aquifer is overlain by the White River Aquifer, its top coincides with the base of the White River Aquifer (Figure 12). In other areas, the land surface or the bedrock surface beneath the Quaternary deposits constitutes the top of the Upper Laramie Aquifer. The base of the Upper Laramie Aquifer is the same as the top of the Laramie-Fox Hills Aquifer. The elevation of this stratigraphic horizon is shown on Figure 17, and the depth to it is illustrated on Plate 3. Total thickness of the Upper Laramie Aquifer reaches 1,500 feet in the center of the Cheyenne Basin. Within the study area total thickness varies from less than 50 feet in the southeast to 750 feet in the northwest.

The principal water-bearing bed within the Upper Laramie Aquifer in the study area is the Grover sandstone member. Other less prominent sandstone beds are present within the Upper Laramie Aquifer and yield lesser amounts of water. Figure 13 depicts the total thickness of all sandstone beds within the Upper Laramie Aquifer. The distinctive isolith high in the center of the mapped area is due to the presence of the Grover sandstone member. The light stippled pattern in Figure 13 marks the area where the Grover sandstone member is particularly well developed.

Net sandstone thickness in the Upper Laramie Aquifer ranges from less than 25 feet in the south end to over 190 feet where the Grover sandstone

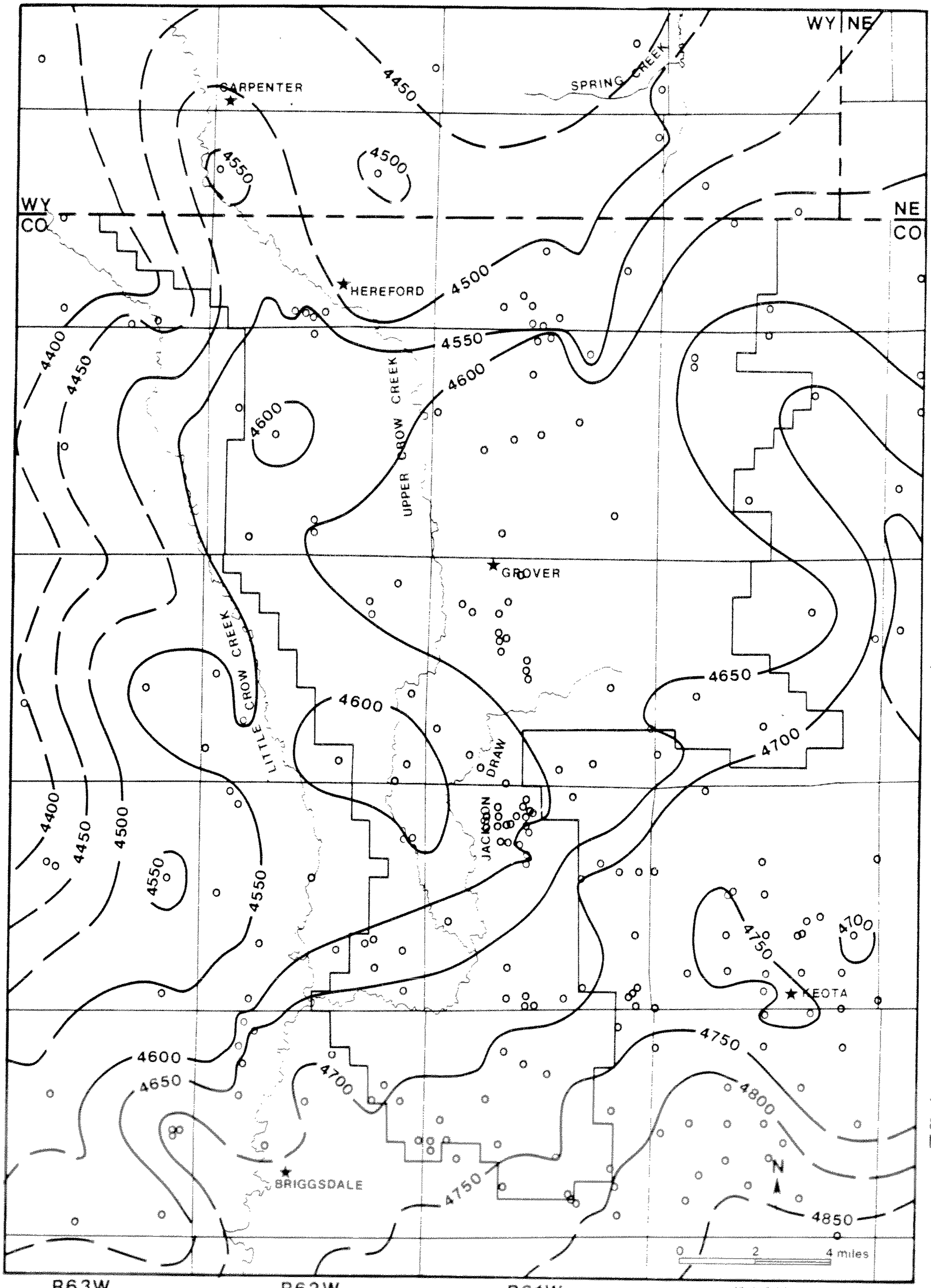


Figure 17. Map showing elevation (in feet) of the top of the Laramie-Fox Hills Aquifer. Contour interval is 50 feet. Open circles indicate data points.

member occurs. The amount of sandstone present within the aquifer reflects in part the proximity to the outcrop of the Upper Laramie Aquifer and the aquifer thickness. The aquifer has been entirely removed by erosion in at least two areas on the east side of the mapped area (designated by the symbol "X" on Figure 13). Thickness of the aquifer generally increases westwardly, and as the thickness of the entire aquifer increases, so does the amount of sandstone within the aquifer. On the western edge of the mapped area slightly over 200 feet of sandstone has been identified. Ethridge and others (1979) report as much as 400 to 500 feet of sandstone in the Upper Laramie Aquifer in the deeper parts of the Cheyenne Basin.

Eighteen domestic and stock wells are completed in the Upper Laramie Aquifer (Appendix C), but no irrigation wells are known to tap this aquifer. Reported yields for Upper Laramie domestic and stock wells range from 4 to 25 gpm and average about 16 gpm.

An industrial well at the Keota oil field also utilizes the Upper Laramie Aquifer and reportedly yields 23 gpm. One of the Grover municipal wells also apparently pumps Upper Laramie water. This well reportedly yields 220 gpm, considerably more water than other Upper Laramie wells in the study area. This may relate to the greater saturated thickness of the aquifer at this location or it may be an incorrect yield.

Analyses of four core samples from an Upper Laramie well in section 24, T10N, R62W are described by Wacinski (1979). Porosity ranged 29.2 to 35.2%, horizontal permeability varied from 3.3 to 3.5 feet per day, and vertical permeability ranged from 0.67 to 3.2 feet per day.

Weist (1965) reported on two aquifer tests run on wells that tap the Upper Laramie Aquifer. One test was on a well in the SE SW of Section 4, T11N, R61W. The perforated interval in this well included about 40 feet of basal White River Aquifer and about 213 feet of the Upper Laramie Aquifer. The results are probably more characteristic of the Upper Laramie than the White River. This test indicated a specific capacity of 0.35 gpm per foot of drawdown, transmissivity of 46.9 square feet per day, hydraulic conductivity of 0.54 feet per day, and a storage coefficient of 0.0002. An Upper Laramie well outside of the proposed basin in section 36, T10N, R66W indicated a specific capacity of 0.42 gpm per foot of drawdown, transmissivity of 67.0

square feet per day, and hydraulic conductivity of 0.402 feet per day when tested (Weist, 1965).

The quality of water from the Upper Laramie Aquifer varies considerably (Kirkham and others, 1980). Most quality problems seem to occur near known uranium deposits, where uranium, manganese, iron, selenium, and molybdenum may be present in undesirable quantities.

LARAMIE-FOX HILLS AQUIFER

The Laramie-Fox Hills Aquifer includes the entire Fox Hills Sandstone and any sandstone beds that may be present in the basal Laramie Formation. In some places within the study area the basal Laramie does not contain any sandstone beds; only the Fox Hills Sandstone constitutes the Laramie-Fox Hills Aquifer in those areas. Figure 17 illustrates the elevation of the top of the Laramie-Fox Hills Aquifer, while the elevation of the base of the aquifer is shown in Figure 18. The depth to the top of the Laramie-Fox Hills Aquifer is depicted on Plate 3.

The top of the Laramie-Fox Hills Aquifer lies at an elevation of about 4,800 feet above sea level in the southeast corner of the study area. It generally dips northwestward, and in the northwest corner of the study area it is at an elevation of just under 4,400 feet. A broad structural bench is present in the Grover area and the top of the aquifer dips an average of 5 to 10 feet per mile at this location. Since the elevation of the top of this aquifer decreases to the northwest and elevation of the land surface increases to the north, the depth to the top of the aquifer also increases to the northwest and north. In the southeast corner of the study area the aquifer top is only 200 feet deep, while in the northwest corner it is almost 1,100 feet deep.

The base of the Laramie-Fox Hills Aquifer also generally dips to the northwest. It occurs at an elevation of about 4,350 feet in the southeast corner of the study area, while in the northwest corner it lies at about 3,970 feet.

Total aquifer thickness averages about 550 feet in the study area. Figure 19 illustrates the net thickness of all saturated sandstone beds within the aquifer, which ranges from a little over 100 feet along the east side of

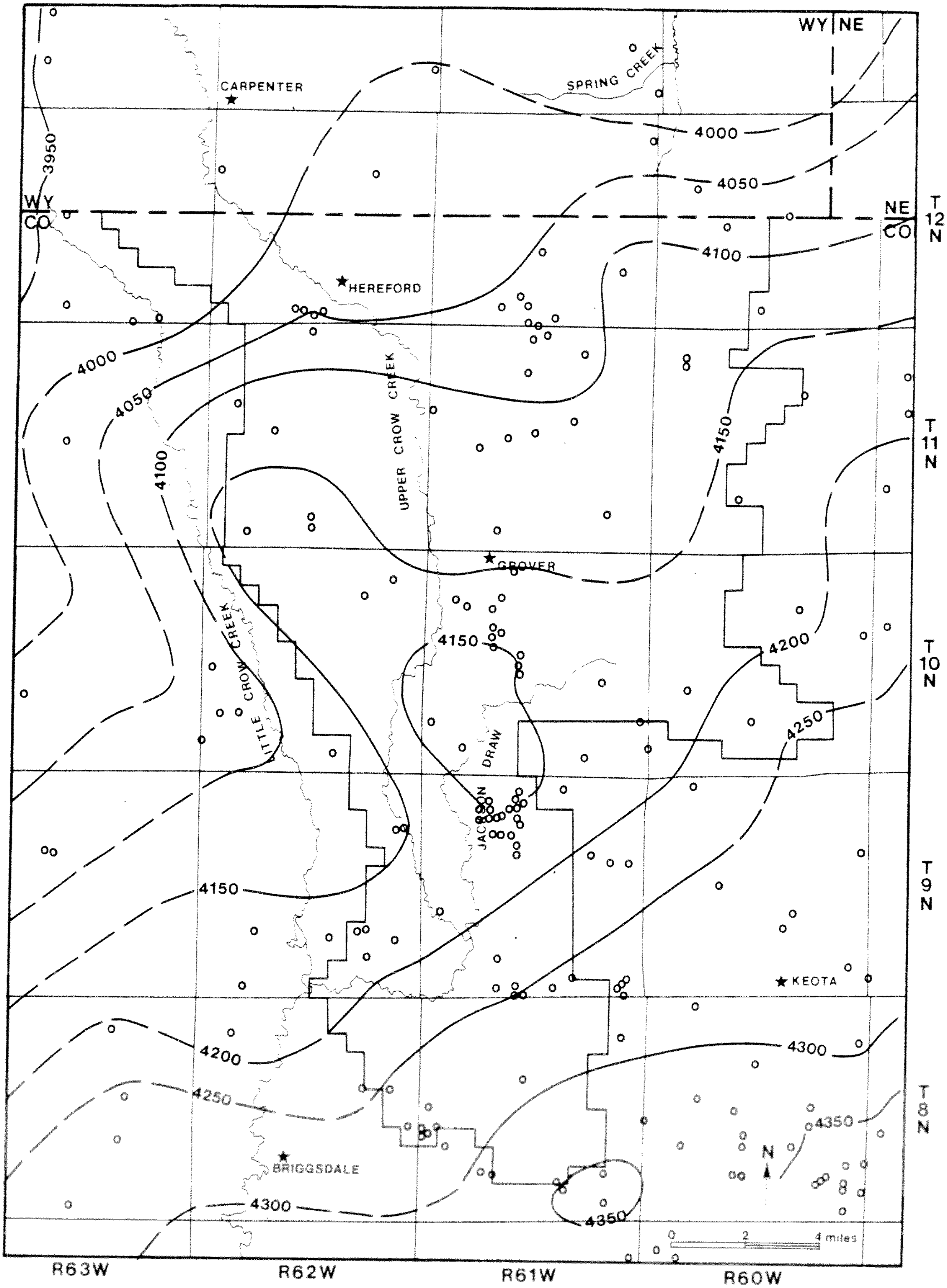


Figure 18. Map showing elevation (in feet) of the base of the Laramie-Fox Hills Aquifer. Contour interval is 50 feet. Open circles indicate data points.

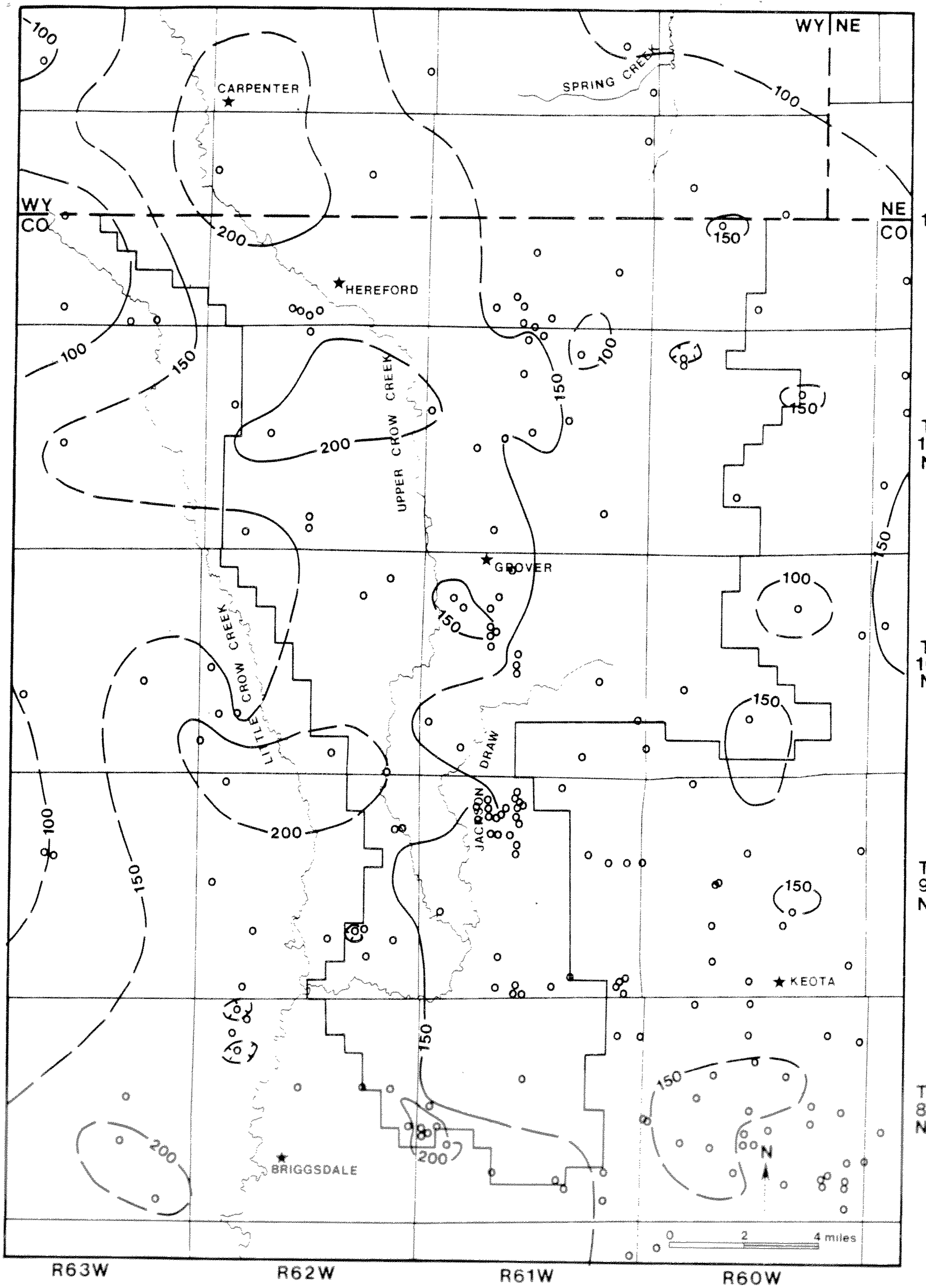


Figure 19. Sandstone isolith map (in feet) for the Laramie-Fox Hills Aquifer. Contour interval is 50 feet. Open circles indicate data points.

the area to 225 feet along the west side. A north-trending isolith high parallels the west side of the area, and sandstone thickness exceeds 150 feet throughout this region.

No water wells tap the Laramie-Fox Hills Aquifer in the northern part of the study area, but in the southern part at least nine domestic and stock wells are completed within this aquifer (Appendix C). In some areas the Laramie-Fox Hills Aquifer is the primary source of ground water because other aquifers are absent, dry, or too deep for utilization. Reported yields from domestic and stock wells in the Laramie-Fox Hills Aquifer range from 7 to 30 gpm and average about 17 gpm. An industrial well at the Keota oil field is also completed in the Laramie-Fox Hills Aquifer and has a reported yield of 23 gpm. No irrigation wells utilize this aquifer at this time.

Analyses of core data for the Laramie-Fox Hills Aquifer by Wyoming Mineral Corporation (1978) just outside the mapped area near Keota indicate porosities of 35.6 and 39.5% for the main sandstone beds within the aquifer at that location. Pump tests run on the Laramie-Fox Hills Aquifer by Wyoming Mineral Corporation near Keota resulted in the following values: transmissivity - 30.8 to 45.0 square feet per day, hydraulic conductivity - 1.0 to 1.5 feet per day, and storage coefficient - 9.37×10^{-6} to 1.2×10^{-4}.

Weist (1965) reported on a pump test for a well that he indicated was completed in the Laramie Formation. Based on the location and depth of the tested interval and recently acquired drill hole data available to the authors, it is likely that this test was actually run on the Laramie-Fox Hills Aquifer just southwest of the study area. Test results are as follows: transmissivity - 134 square feet per day, hydraulic conductivity - 0.8 feet per day, and storage coefficient - 2.0×10^{-4}

Quality of water from the Laramie-Fox Hills Aquifer varies appreciably (Kirkham and others, 1980). Major problems seem to involve the naturally poor quality water often associated with uranium deposits. Undesirable amounts of uranium, vanadium, molybdenum, iron, manganese, and selenium may be present in ground water within the Laramie-Fox Hills Aquifer.

UPPER PIERRE AQUIFER

Although the Pierre Shale is composed primarily of shale and claystone, several horizons within this formation are sandy and yield water to wells. The main zone of interest to this investigation occurs approximately 180 to 300 feet below the base of the Laramie-Fox Hills Aquifer (Plates 4 to 7). Kirkham and others (1980) called this zone the Upper Pierre Aquifer, and Rogers and others (1985) suggested that the most favorable hydrologic conditions for this aquifer exist north of the South Platte River.

Figure 20 illustrates the elevation of the top of the Upper Pierre Aquifer. Within the study area the top ranges from about 4,050 feet above sea level in the southeast to 3,640 feet in the northwest. Total thickness of the aquifer varies from about 500 to 850 feet.

No water wells are known to be completed in the Upper Pierre Aquifer within the study area. Upper Pierre wells are present southeast and south of the study area beyond the outcrop of the Laramie-Fox Hills Aquifer. Well yields are generally fairly low, but are acceptable for domestic and stock uses. It is unlikely that the Upper Pierre Aquifer could produce sufficient water for irrigation, municipal, or industrial purposes. Water quality is often poor, commonly being excessively high in sulfates. Because of the availability of other more productive aquifers, its relative great depth (900 to 1,900 feet), and its poor quality, the Upper Pierre Aquifer will probably never experience significant utilization in the study area.

DAKOTA AQUIFER

The Dakota Aquifer consists of the Dakota Sandstone and overlying "D" and "J" sandstone members. A structure contour map on the top of the "J" sand is shown in Figure 21. It was prepared using only part of the available drill hole data. This aquifer is found at 2,150 to 2,800 feet below sea level in the study area and at depths of 7,000 to 8,200 feet below ground level.

The members of the Dakota Aquifer are better known for their oil and gas potential, but the aquifer also produces significant quantities of water. Robson and Banta (1984) evaluated the hydrology of the Dakota Aquifer throughout eastern Colorado. The aquifer contains around 200 feet of sandstone in the vicinity of the study area, had a pre-development

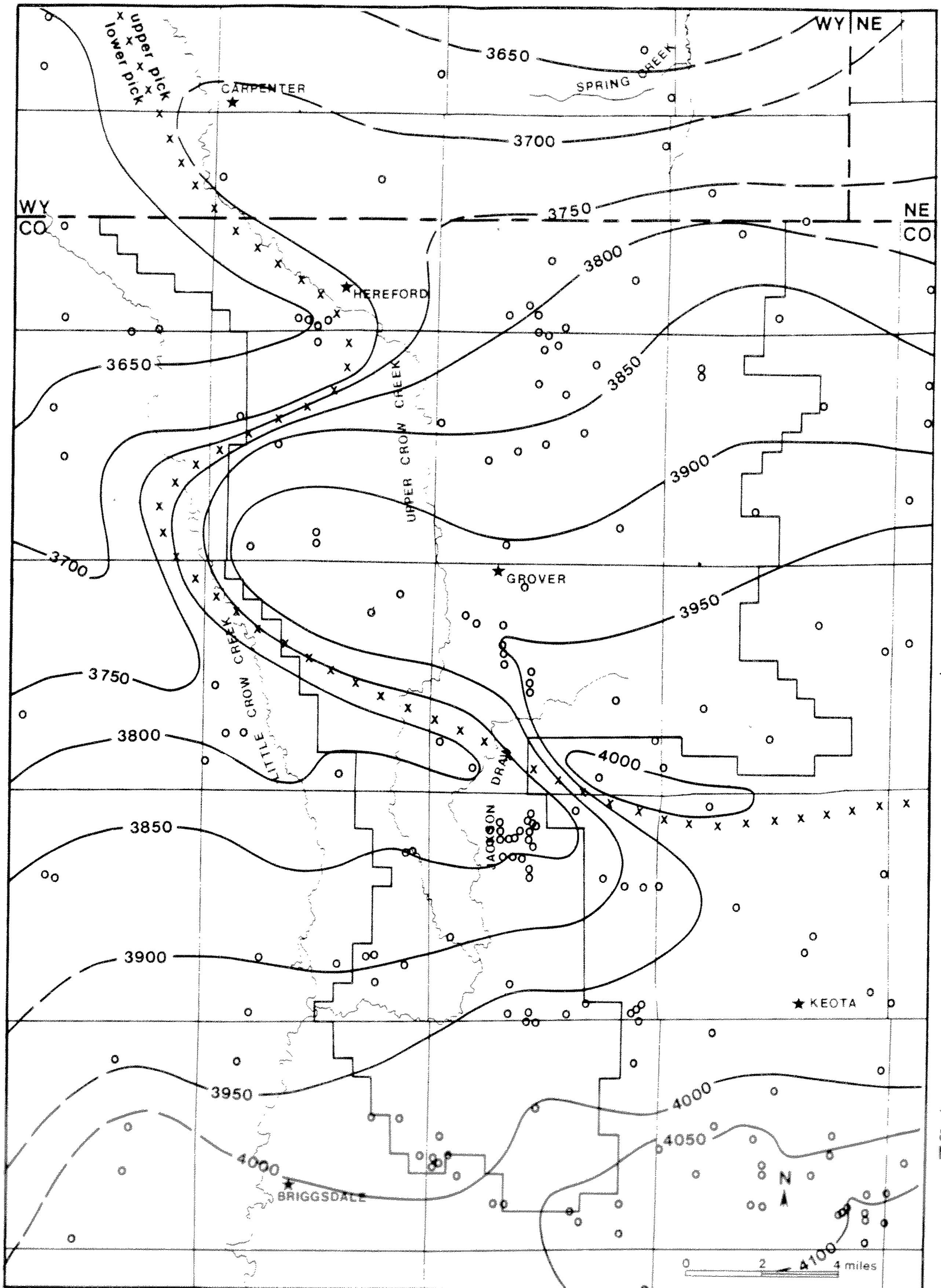


Figure 20. Map showing elevation (in feet) of the top of the Upper Pierre Aquifer. Line of X's indicates boundary between areas where different stratigraphic picks are utilized to define the top of the aquifer. Contour interval is 50 feet. Open circles mark locations of data points.

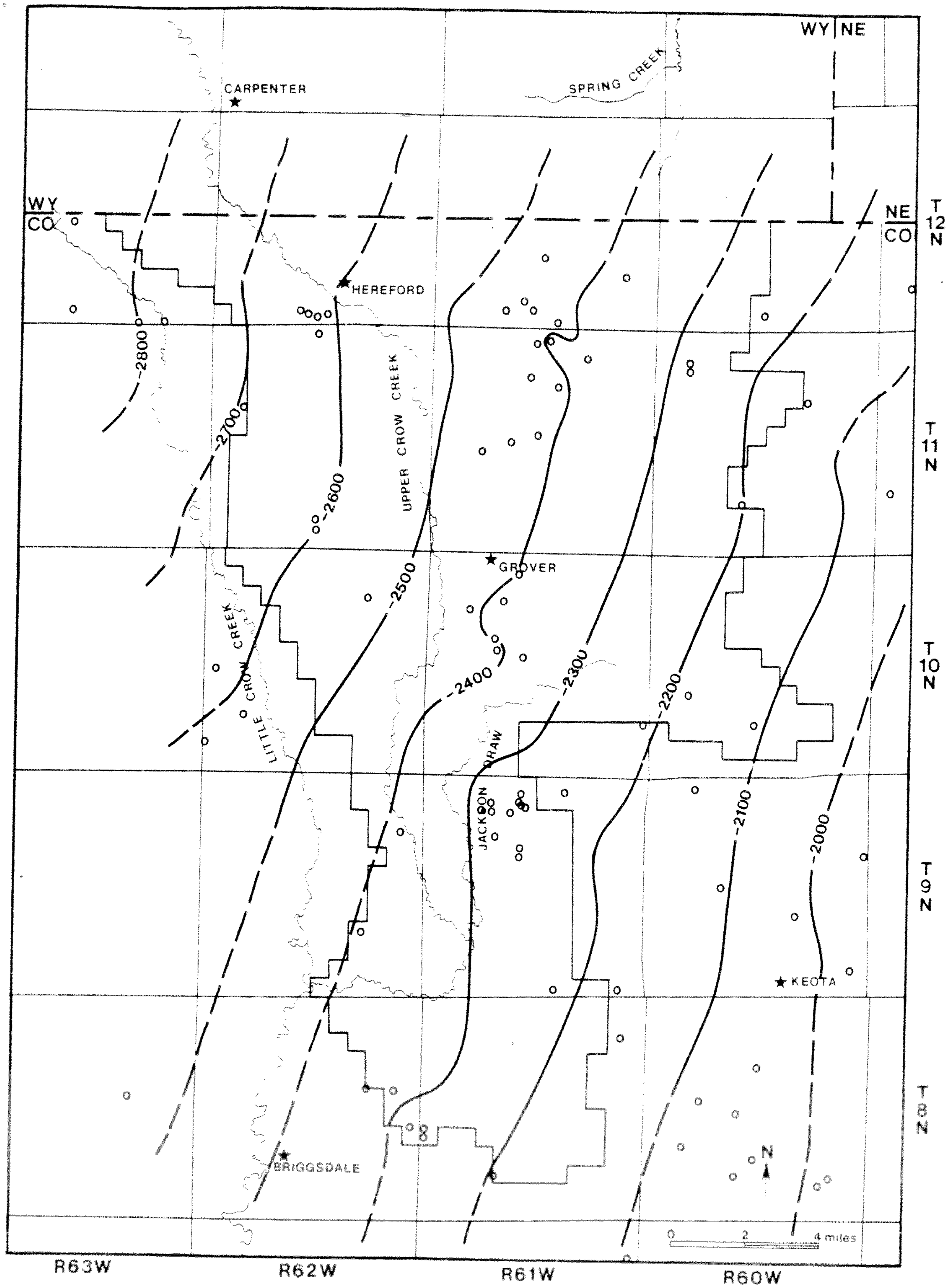


Figure 21. Generalized structure contour map on the top of the "J" sandstone member of the Dakota Aquifer. Contour interval is 100 feet. Contour lines illustrate the elevation below mean sea level. Open circles indicate location of data points.

potentiometric surface at an elevation around 2,500 feet, porosity of 8 to 12%, average hydraulic conductivity of 0.03 to 0.2 feet per day, and dissolved solids in excess of 2,000 milligrams per liter. The great depth of this aquifer and its questionable quality restrict its potential use.

5.1.3 GROUND-WATER MOVEMENT, RECHARGE, AND DISCHARGE

MOVEMENT

Water levels in 80 wells were measured during January of 1986 at a time when water levels are fairly stable and not subject to the sudden changes that occur during the irrigation season. These measurements were used to construct the potentiometric surface of the unconfined aquifers, which is shown on Plate 2. Direction of ground-water movement at a particular location is generally perpendicular to the potentiometric contours. The flow direction of unconfined water within the study area is shown in Figure 22.

Ground-water enters the northwest side of the study area from Wyoming and flows southeastwardly through the unconfined aquifers. A ground-water divide near Hereford causes part of the water to return to Wyoming along the northeast boundary of the study area through the White River Aquifer. This divide was first recognized by Crist and Borchert (1972) and its presence is confirmed by our measurements.

Part of the ground water continues moving to the southeast and south, parallel to Upper Crow Creek. Bedrock hills present within the alluvial valley west of Grover combine with the thinning of the Alluvial Aquifer to act as a ground-water divide, causing much of the ground water to move towards Grover and the head of Jackson Draw. The White River Aquifer is believed to have relatively high secondary permeability in the Grover-Jackson Draw area, and this probably influences ground-water movement. Part of the ground water continues to flow down Upper Crow Creek but most flows into the head of Jackson Draw where it then turns to the south and southeast, and flows through the White River Aquifer. Closely spaced potentiometric contours on the east side of the mapped area suggest low permeabilities in the White River Aquifer in this eastern region. It is unlikely that any significant amount of ground water moves eastward out of the study area through the White River Aquifer. Most water appears to move into the White River paleovalley, follows the

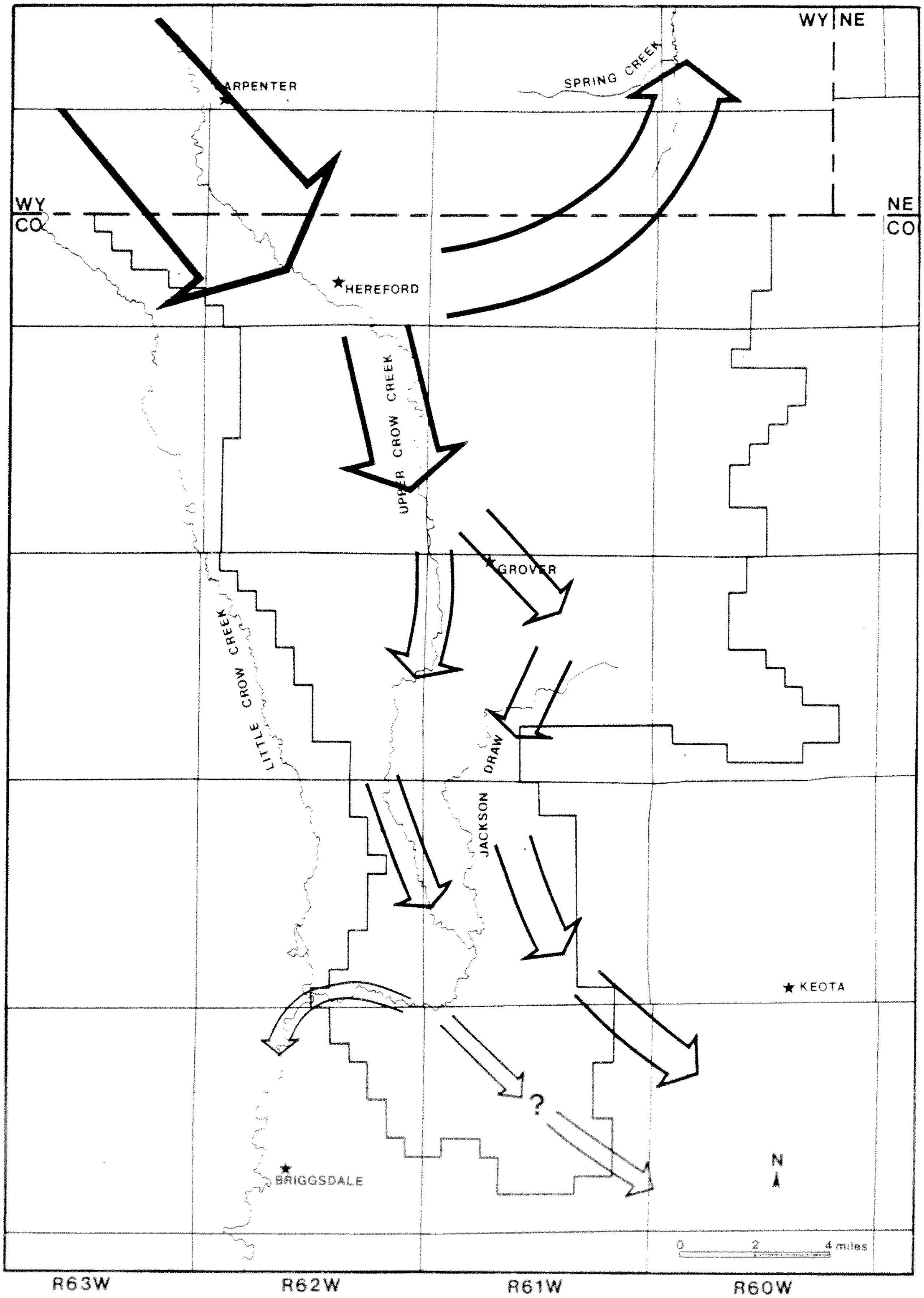


Figure 22. Map showing direction of ground-water movement within the unconfined aquifer.

paleovalley southeastward, and is discharged along the southeast side of the study area.

The tendency for water to flow southeastward along the paleovalley within the White River Aquifer relates to a number of geologic factors. Fractures within the aquifer generally have a southeast trend in this region and are believed to influence ground-water movement. Channel sandstones and conglomerates are generally more common in the paleovalley and also often trend southeastward. Another factor affecting water movement in the White River is the configuration of the base of the aquifer. Within this area the underlying Laramie Formation is relatively impermeable when compared to the secondary permeability features of the White River Aquifer and serves as an aquitard, forcing most ground water to remain within the paleovalley cut into the Laramie Formation.

Ground water that remains in the alluvium of Upper Crow Creek west of Grover flows generally to the south, following the creek valley. At the Big Bend additional ground water in the Alluvial Aquifer probably moves into the abandoned paleochannel of Wildcat Creek and part stays in the modern channel and heads towards the Confluence where it is discharged from the study area.

Specific information on ground-water movement within the confined Upper Laramie and Laramie-Fox Hills Aquifers is not available in the study area. The general characteristics of water table maps shown by Wacinski (1979) and Kirkham and others (1980) suggest water in the confined aquifers moves southeast. Wyoming Mineral Corporation (1978) reported that ground water within the Buckingham sand member of the Laramie- Fox Hills Aquifer was flowing S55°E at 1.2 feet/day near Keota.

RECHARGE

Naturally occurring ground-water recharge within the study area results from deep percolation of precipitation, seepage of surface water in Upper Crow Creek, and ground-water underflow into the study area. An estimated 3% of all precipitation within the proposed basin infiltrates through surficial deposits and recharges the ground-water system. The following equation was used to calculate recharge due to precipitation:

recharge from precipitation = average annual precipitation (1.125 feet) times area of study area (264 square miles X 640 acres/mile) times 3% =5,700 acre-feet per year.

Recharge from seepage of creek water is highly variable and dependent on the volume of water within the creek, the volume of water diverted for irrigation purposes, and the type of surficial material underlying the creek. In some years there is no surface flow in Upper Crow Creek in Colorado, and during such years there is no recharge by surface water seepage. In years of high stream flow when water in excess of irrigation needs is present, a considerable amount of recharge may occur. During the unusually high stream flows of 1983 approximately 6,000 acre-feet was diverted from the creek to aid recharge of the Alluvial Aquifer. Based on water-level records in wells and reports of basements flooding in Grover, this effort was successful. Assuming 30% of the water diverted in 1983 eventually recharged the aquifer, at least 1,800 acre-feet of stored water was added by this artificial recharge effort.

The Wyoming State Engineer's Office has reported that Crow Creek can lose as much as 13 cfs (25.8 acre-feet per day) to seepage near Carpenter (Crist, 1980). This occurs in an area where surface flows are greater than in the study area and the geologic setting is favorable for high seepage rates. A somewhat lower, but still respectable seepage rate may develop in the northern part of the study area during years of high stream flow.

Quantifying recharge due to seepage from variable surface flows in the absence of any gaging stations is highly speculative. We estimate that an average of 500 to 1,000 acre-feet of water recharges the unconfined aquifers within the study area annually, but recognize that this is only a rough approximation of a highly variable quantity.

The volume of water recharging the unconfined aquifers due to underflow into the study area was estimated using a modified form of Darcy's law:

$$Q = KAi \times \text{cosine of } 70^\circ$$

where Q is the volume of water entering the study area as underflow, K is the hydraulic conductivity, A is the saturated area, and i is the hydraulic gradient. The cosine of 70° is used to account for the fact that the potentiometric contours are at an average angle of 70° to the state line. The hydraulic gradient in this area is approximately 21 feet/mile or 0.00398, based on the potentiometric map. The saturated area of the Alluvial and Fan Aquifers was calculated to be 3,750,000 square feet while the saturated area of the White River Aquifer was 15,900,000 square feet. The hydraulic conductivity of the Alluvial and Fan Aquifers was assumed to be 225 feet per day based on hydraulic properties of the aquifers, while the White River Aquifer was assumed to have a hydraulic conductivity of 10 feet per day. There is a high degree of uncertainty in the value used for the White River Aquifer, but the authors believe it to be a valid approximation.

The following equation illustrates how the amount of recharge due to underflow through the unconfined aquifers was calculated using the above assumptions:

$$Q = [(225 \text{ ft/day} \times 3.75 \times 10^{6} \text{ ft}^{2}) + (10 \text{ ft/day} \times 1.59 \times 10^{7} \text{ ft}^{2})] \times 0.00398 \times \text{cosine } 70° \times 2.30 \times 10^{-5} \text{ acre/ft}^{2} \times 365 \text{ days/year}$$

$$= 11{,}300 \text{ acre-feet/year}$$

DISCHARGE

Ground water is discharged from the study area by well pumping, underflow, and evapotranspiration. Consumptive water use from pumping of wells amounts to 11,500 acre-feet each year (see Section 6.1.2). Underflow out of the study area occurs in the unconfined aquifer at the Confluence, along the southeast boundary through the White River paleovalley and the Wildcat Creek paleochannel, and along the northeast boundary where it returns to Wyoming.

Based on data presented in Water Court cases and on data collected during this investigation the saturated area of the Alluvial Aquifer near the Confluence is 7,200 square feet, the hydraulic gradient is 16 feet per mile, and the hydraulic conductivity is between 100 to 250 feet per day. Using Darcy's law, the underflow out of the study area through the Alluvial Aquifer at the Confluence is estimated to range from only 18 to 45 acre-feet each year.

The underflow discharged through either the White River paleovalley and/or Wildcat Creek paleochannel along the southeast boundary of the study area accounts for an estimated 500 acre-feet per year, while the amount returned to Wyoming along the northeast boundary is estimated at 3,000 acre-feet each year. Most of the discharge along the southeast boundary is believed to be lost to evapotranspiration prior to reaching downstream adjudicated water rights.

Discharge due to evaporation and transpiration within the study area may be as high as 4,000 acre-feet per year, assuming an average of 24 inches of water is lost annually over 2,000 acres of closed depressions, areas with dense stands of cottonwoods, and other areas where the water table is shallow.

Confined ground water is also discharged from the study area as underflow, but because of the lack of information on the hydraulic gradient of the confined aquifers, it is not feasible to determine the amount.

5.1.4 WATER-LEVEL FLUCTUATIONS

Knowledge of water-level fluctuations in the study area rely upon water-level data from 12 irrigation wells that have been periodically measured since 1962, three U.S.G.S. observation wells located just north of the study area that have been equipped with digital water-level recorders since 1976, and two water wells measured periodically by Division 1 Water Commissioners. Locations of wells for which hydrographs are available are shown in Figure 23. Each well is numbered and this is used to identify their corresponding hydrograph shown in Figures 24 through 30.

Hydrographs 1, 2, and 3 are from the U.S.G.S. observation wells located just north of the study area. Effects of ground-water withdrawals during the irrigation season are clearly expressed by these hydrographs. Sharp water-level declines generally occur during May, June, and July, the primary irrigation months. Water levels rapidly recover during September, October, and November. The rate of recovery usually slows down beginning in November, but it may start as early as October. Water levels continue to recover at a slow rate until pumping is initiated for the following irrigation season. According to these hydrographs, water levels may decline from 6 to 26 feet during the irrigation season.

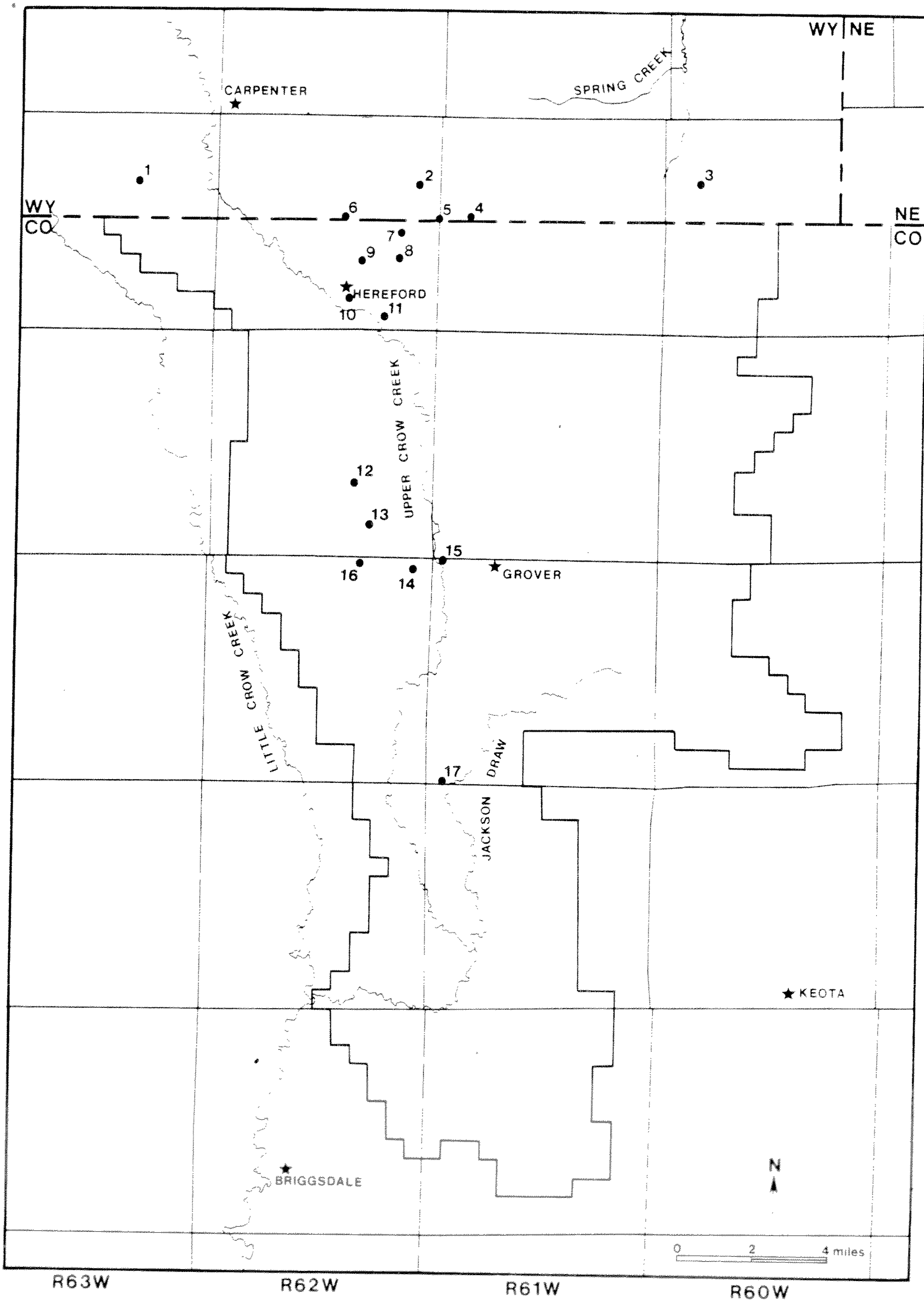
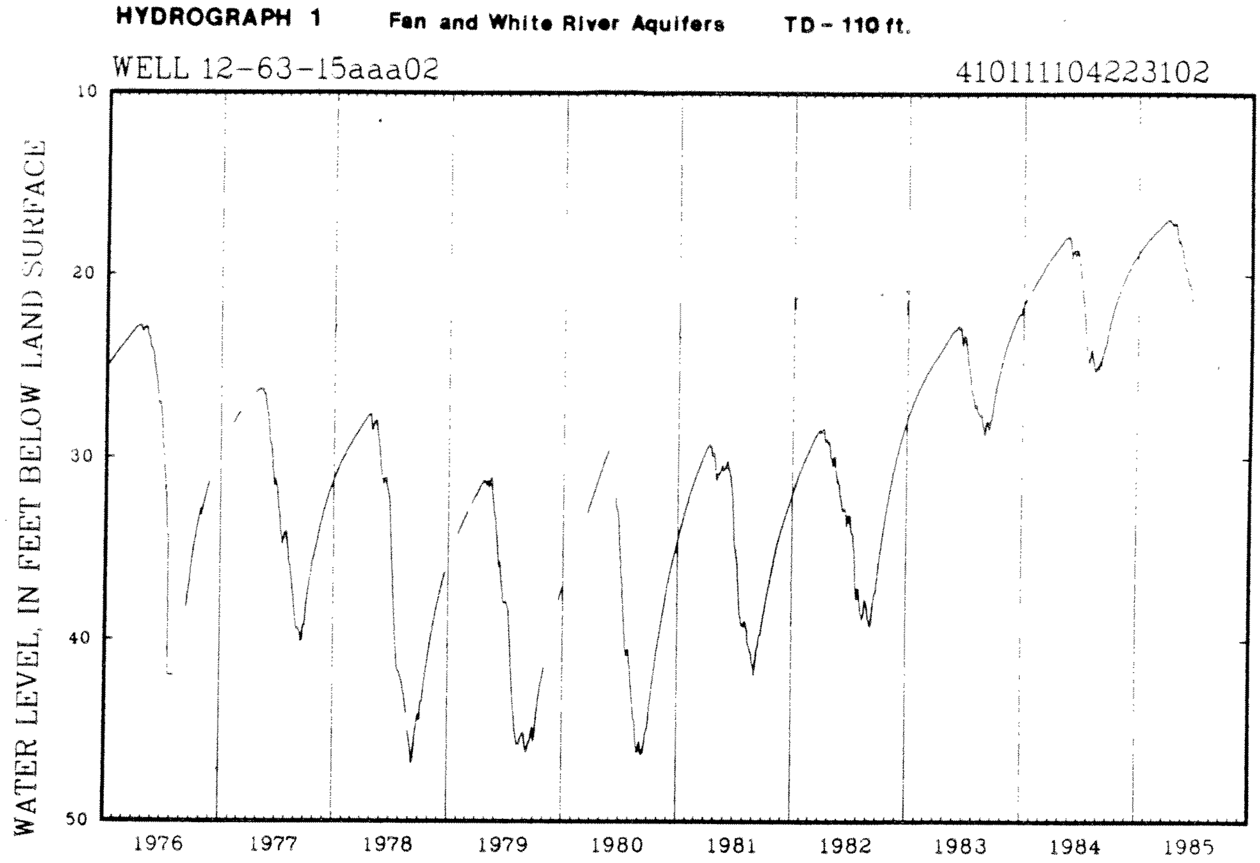


Figure 23. Map showing location of wells for which hydrographs are available. Numbers are keyed to each hydrograph and are utilized to describe them in the text.



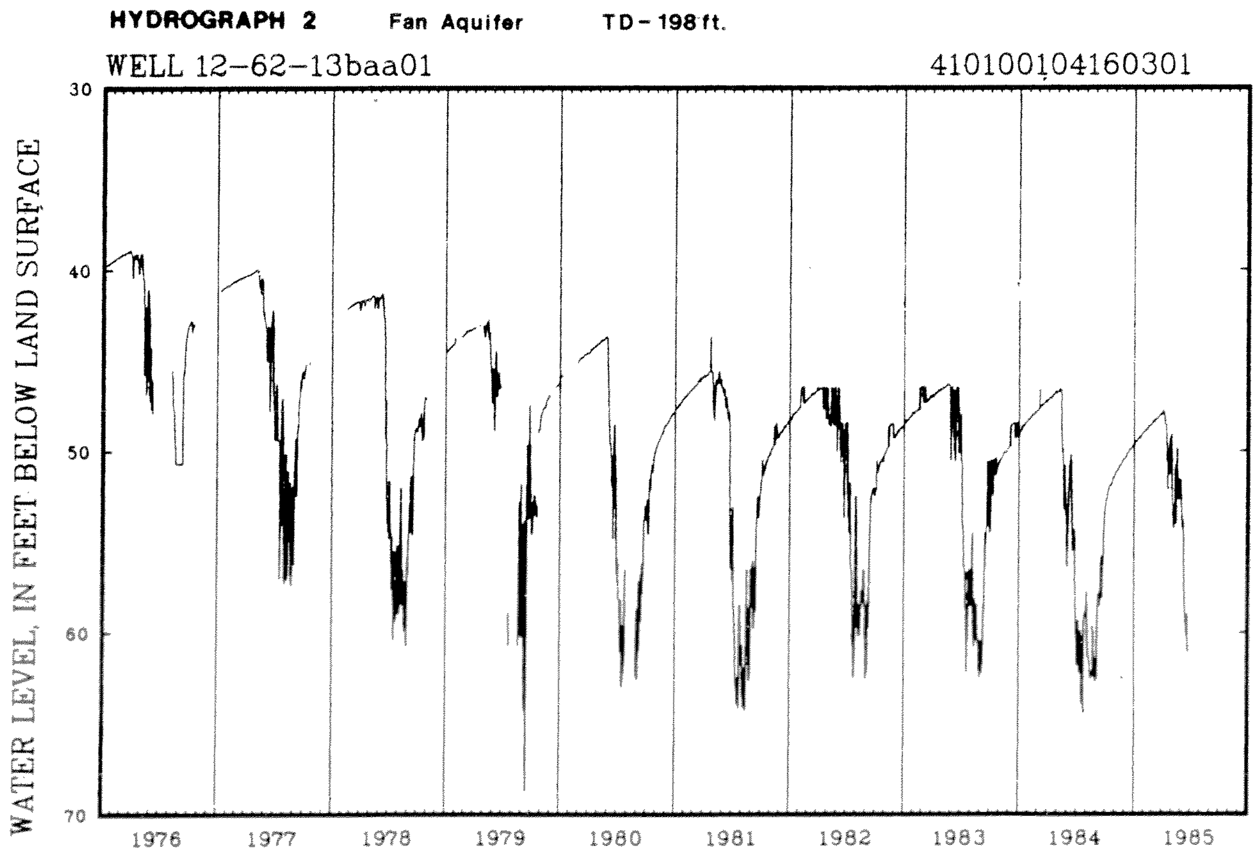


Figure 24. Hydrographs 1 and 2 of U.S.G.S. observation wells in the NE NE NE Sec. 15, T12N, R63W and NE NE NW Sec. 13, T12N, R62W. (modified from Ragsdale and Oberender, 1985; data for 1984 and 1985 based on unpublished U.S.G.S. measurements)

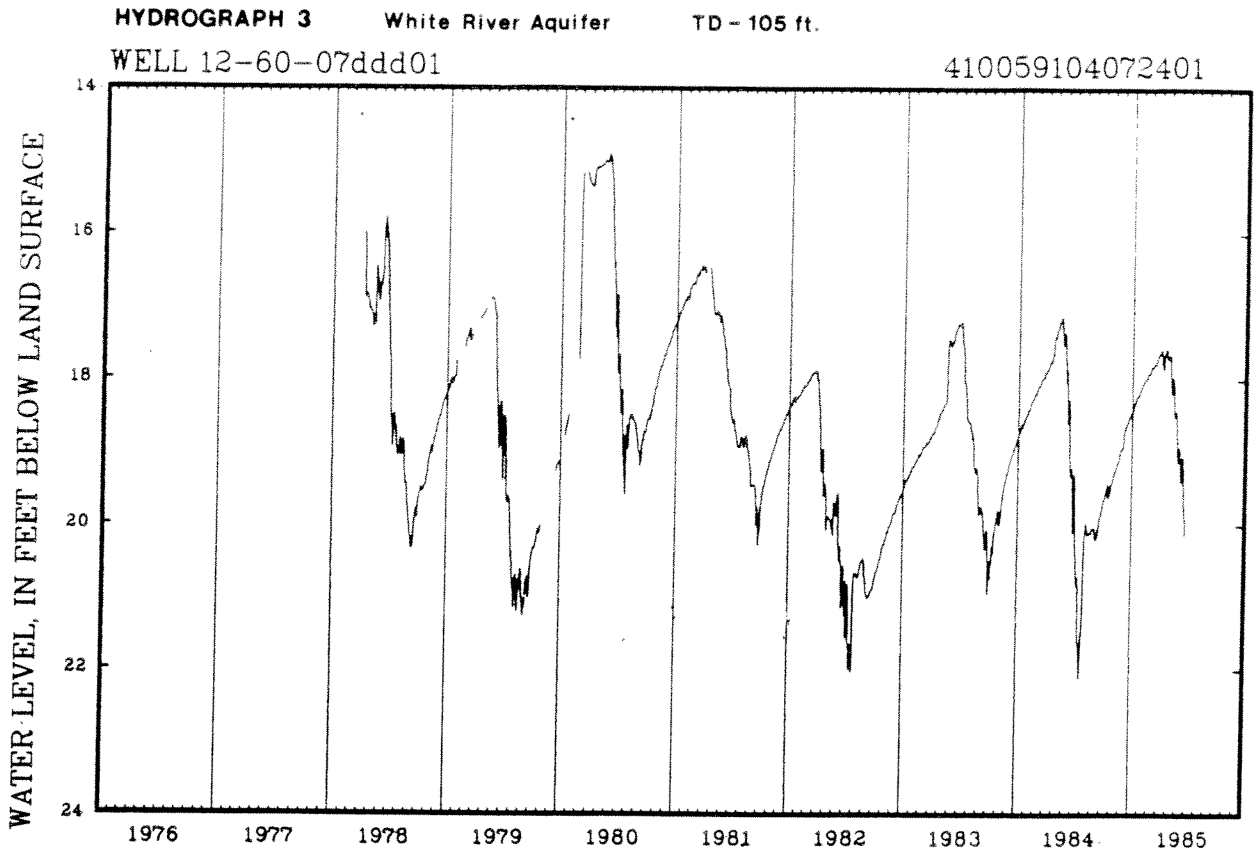
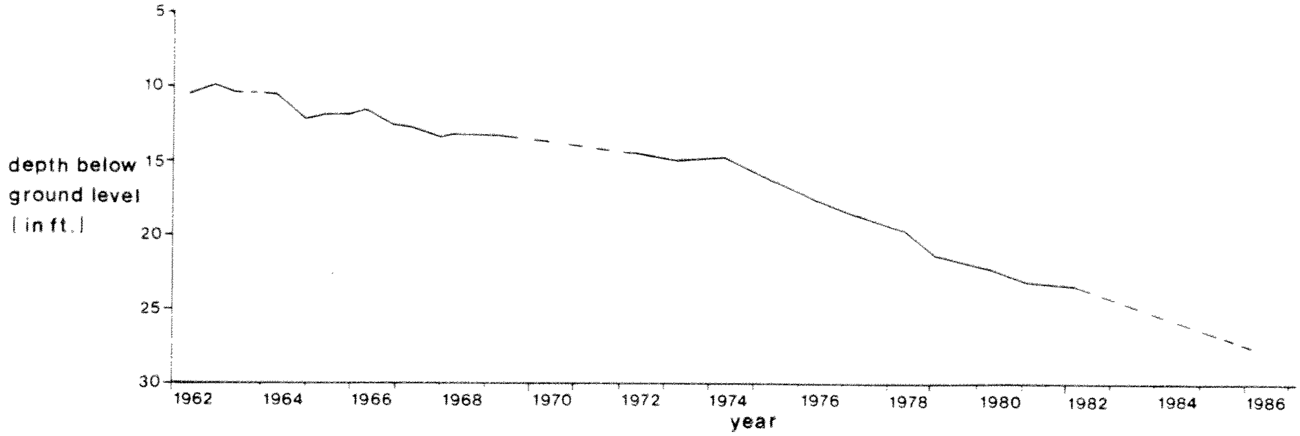


Figure 25. Hydrograph 3 of U.S.G.S. observation well in the SE SE SE Sec. 7, T12N, R60W. (modified from Ragsdale and Oberender, 1985; data for 1984 and 1985 based on unpublished U.S.G.S. measurements)

The overall water-level trends during the period of record can be determined by comparing the highest annual levels for each well. Hydrograph 2 illustrates a nearly continuous gradual decline in water level that amounts to a total decline of about 9 feet from 1976 to 1985. This well is located in the area of greatest saturated thickness and near the center of the heavily irrigated region. It is probably near the area where water-level declines have been greatest during the period of record. Hydrograph 3 indicates that water levels in this eastern area are variable. There appears to be a general declining trend, but in some years (1980 and 1983) the water levels returned to a higher level than during the previous year, suggesting recharge was greater than discharge. Between 1978 and 1985 the water level has declined about 2 feet in the well monitored by hydrograph 3. Hydrograph 1 shows a general decline in the water level in this western region from 1976 to 1979, a period of fairly stable water levels from 1979 to 1982, and a prominent rise in the water level from 1982 to 1985. The recent water level rise probably

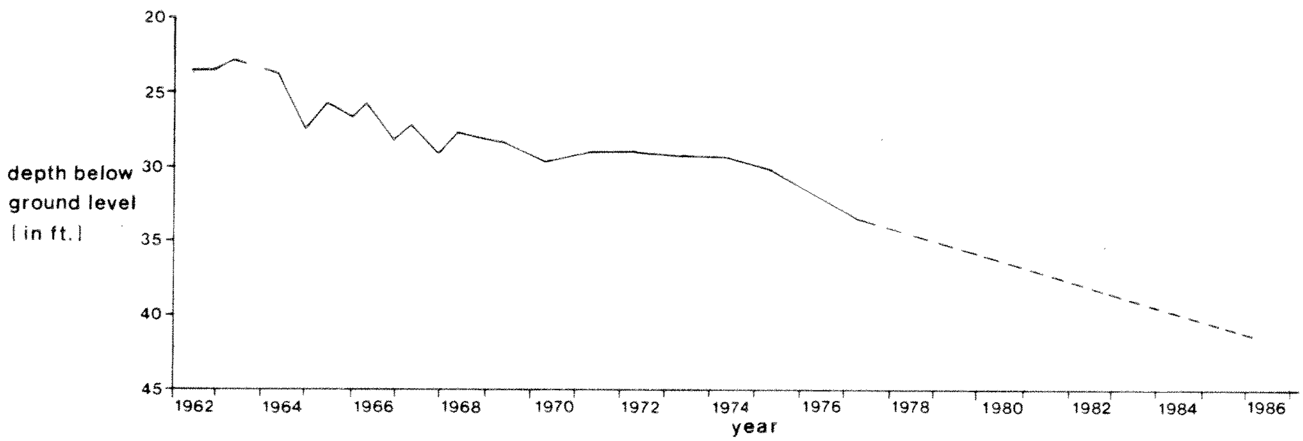
Hydrograph 4

NW NE NE 19-12N-61W
fan aquifer



Hydrograph 5

NW NW NW 19-12N-61W
fan aquifer



Hydrograph 6

NW NW NE 22-12N-62W
fan aquifer
TD - 124 ft.

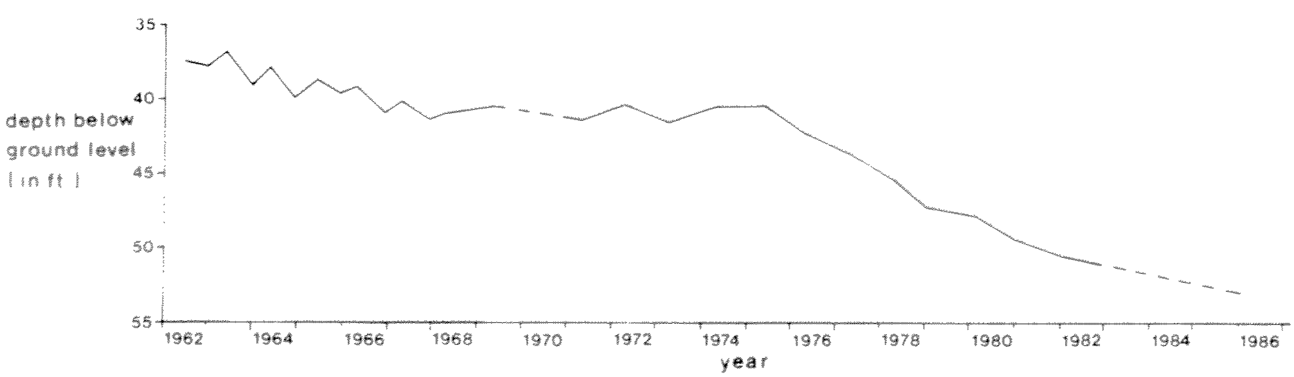
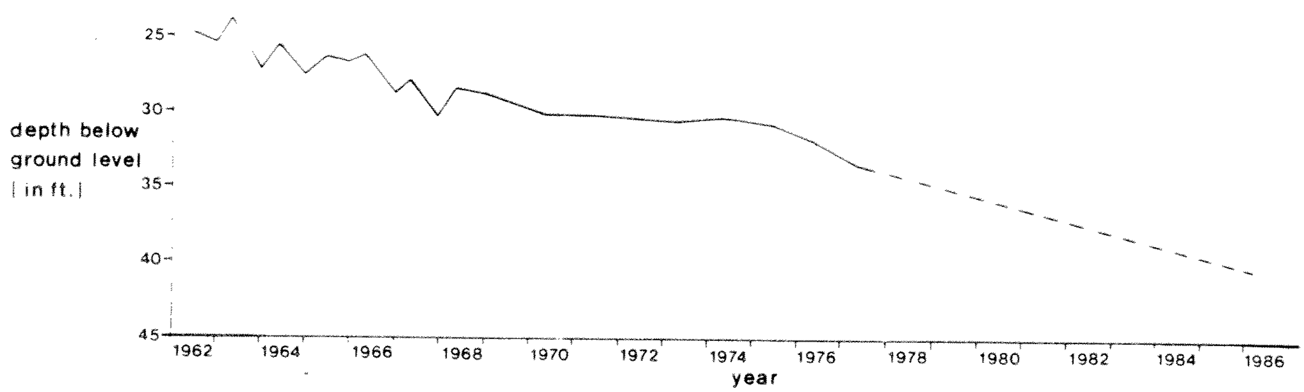


Figure 26. Hydrographs 4, 5, and 6 of irrigation wells completed in the Fan Aquifer. Dashed lines indicate periods where measurements were not taken. (data from Brookman, 1973 and 1985 - pers. comm.; Major and Vaught, 1977; U.S.G.S. computer printout of water-level records, 1982; and measurements taken during this study)

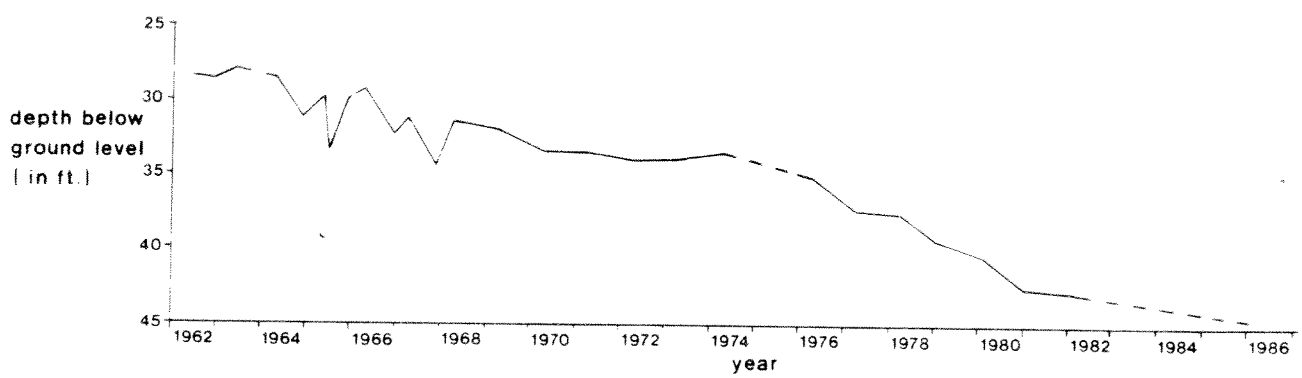
Hydrograph 7

SW SW NW 24-12N-62W
fan aquifer
TD- 153 ft.



Hydrograph 8

NW NW NW 25-12N-62W
fan aquifer
TD- 136 ft.



Hydrograph 9

NW SW NW 26-12N-62W
fan aquifer
TD-120 ft.

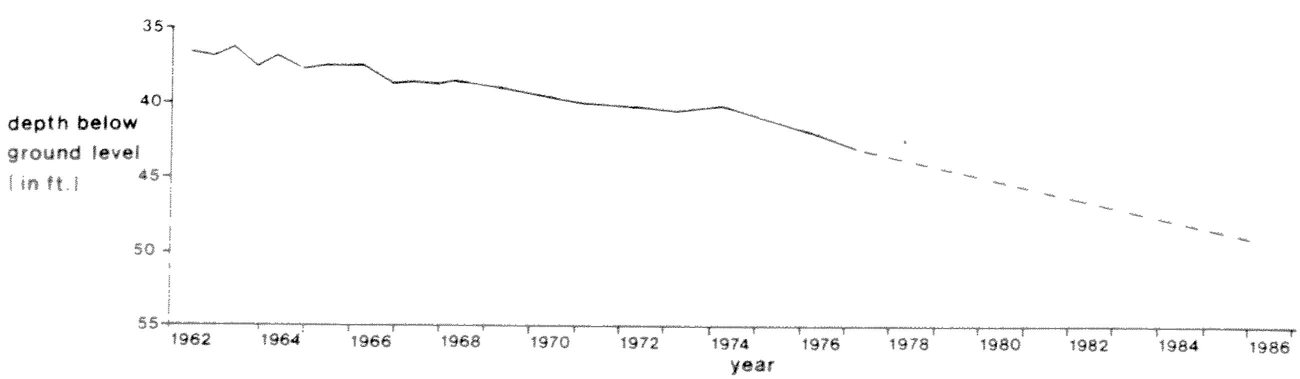


Figure 27. Hydrographs 7, 8, and 9 of irrigation wells completed in the Fan Aquifer. Dashed lines indicate periods where measurements were not taken. (data from Brookman, 1973 and 1985-pers. comm.; Major and Vaught, 1977; U.S.G.S. computer printout of water-level records, 1982; and measurements taken during this study)

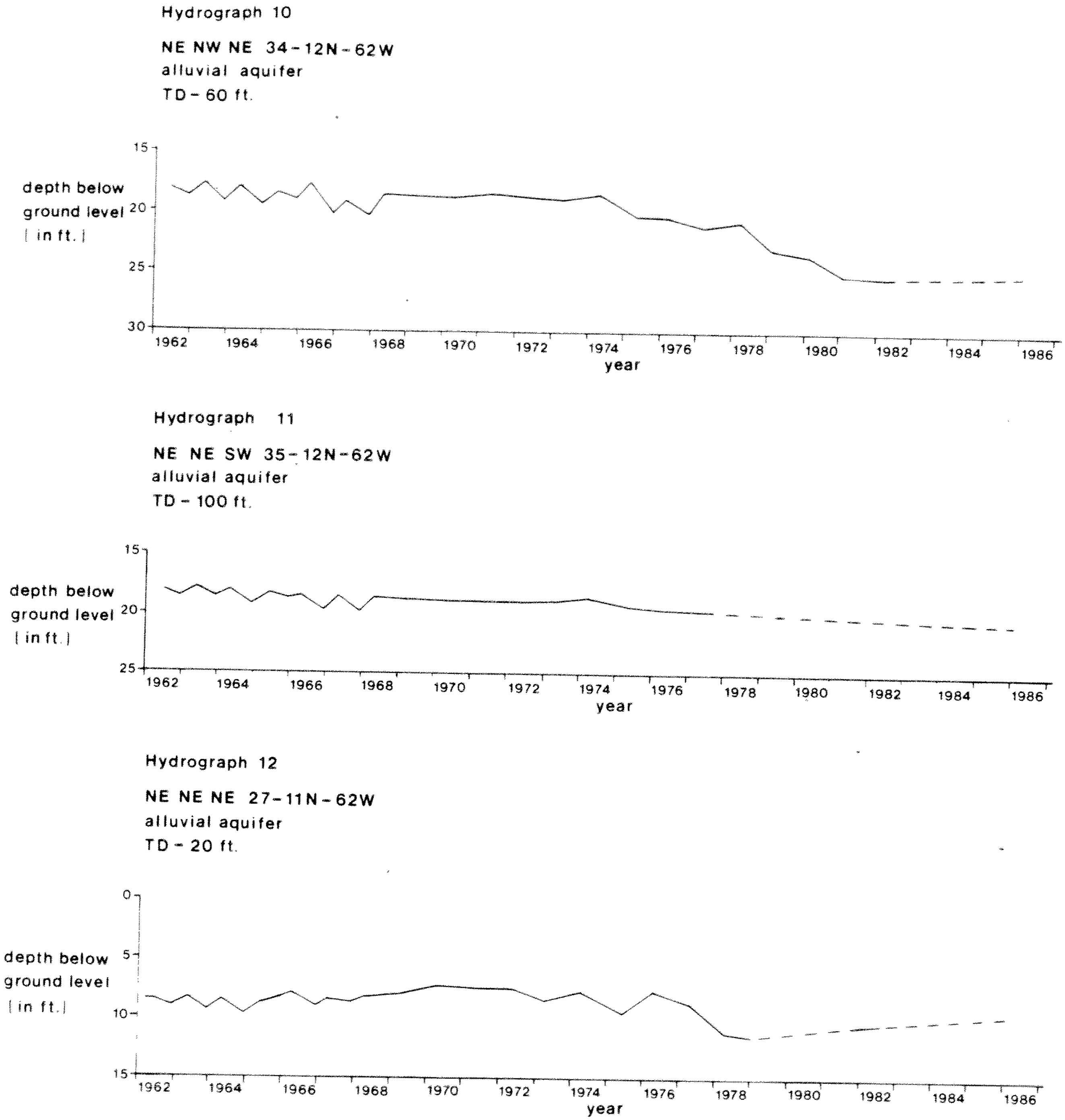


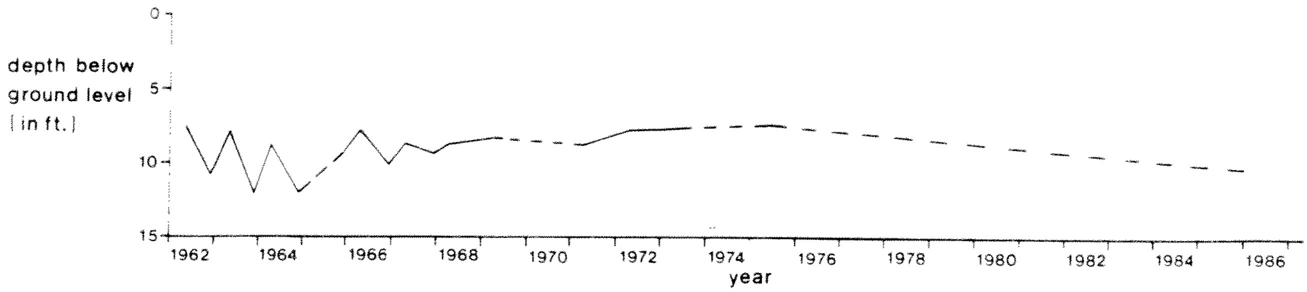
Figure 28. Hydrographs 10, 11, and 12 of irrigation wells completed in the Alluvial Aquifer. Dashed lines indicate periods where measurements were not taken. (data from Brookman, 1973 and 1985-pers. comm.; Major and Vaught, 1977; U.S.G.S. computer printout of water-level records, 1982; and measurements taken during this investigation)

relates to the unusually high precipitation and stream flows during this period, and it may indicate that the Carpenter area experiences increased recharge before other areas underlain by the Fan Aquifer.

Hydrographs 4 through 15 illustrate water-level fluctuations in irrigation wells within or immediately adjacent to the study area (wells 4, 5,

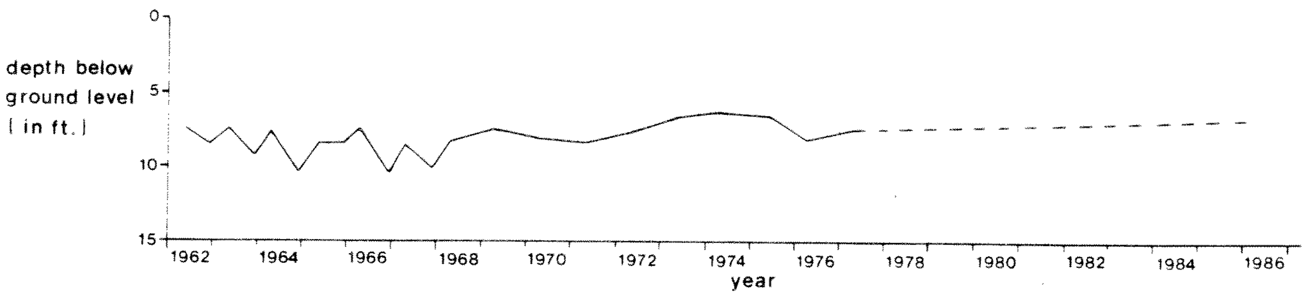
Hydrograph 13

SW NE NW 35-11N-62W
alluvial aquifer
TD- 59 ft.



Hydrograph 14

SW NW NE 1-10N-62W
alluvial aquifer
TD- 36 ft.



Hydrograph 15

NW NE NW 6-10N-61W
alluvial aquifer
TD- 48 ft.

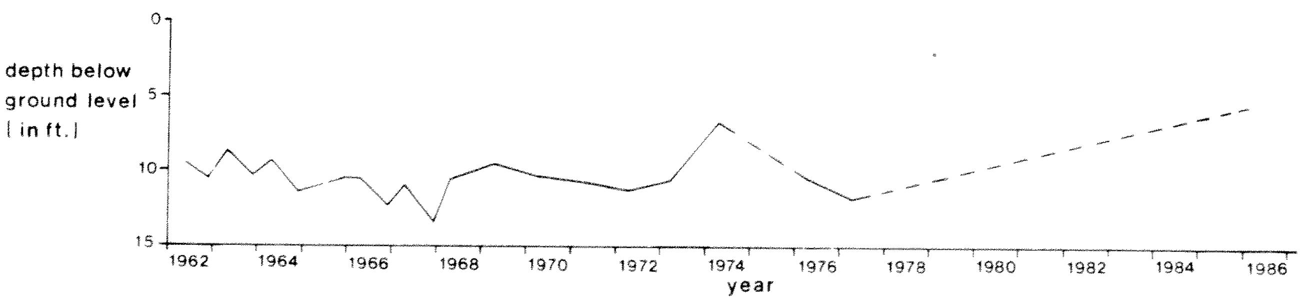
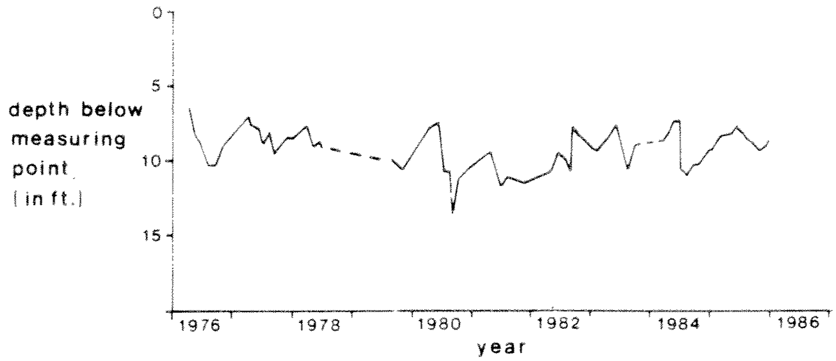


Figure 29. Hydrographs 13, 14, and 15 of irrigation wells completed in the Alluvial Aquifer. Dashed lines indicate periods where measurements were not taken. (data from Brookman, 1973 and 1985-pers. comm.; Major and Vaught, 1977; and measurements taken during this study)

and 6 are only 100 to 250 feet north of the state line). These wells were originally measured by researchers from Colorado State University in November and March, and the effects of seasonal irrigation withdrawals on water levels are apparent on their hydrographs for the period from 1962 to 1968. The U.S.G.S. assumed responsibilities for making the measurements during the

Hydrograph 16

NW NW 2-10N-62W
alluvial aquifer



Hydrograph 17

SE SW 31-10N-61W
alluvial aquifer in Jackson Draw
TD - 14.45 ft.

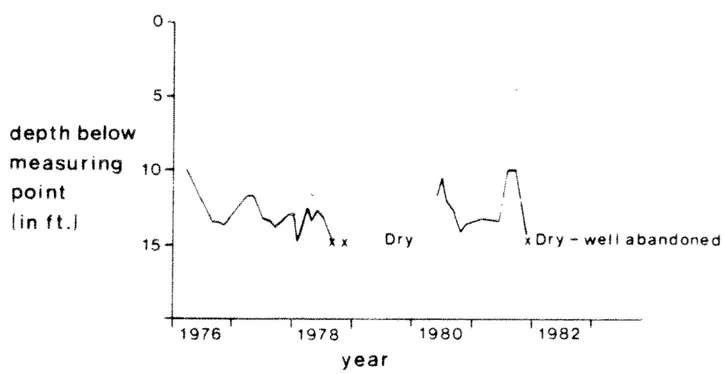


Figure 30. Hydrographs 16 and 17 of an irrigation and stock well completed in the Alluvial Aquifer. Dashed lines indicate periods where measurements were not taken. (data provided by Division 1 Water Commissioners)

1970's, but no measurements had been taken for the past several years until January of 1986 when each of the wells were measured as part of this study. The hydrographs record water levels in the Fan and Alluvial Aquifers, and they are grouped by aquifer in the figures.

Figure 31 depicts the water-level changes that occurred in these 12 wells between 1962 and 1986. All wells completed in the Fan Aquifer have experienced gradually declining water levels during the period of record, except for a short period of stable or slightly increased levels during 1974. Maximum recorded declines of up to 17 feet over the past 24 years occurred along the state line northeast of Hereford in the area of greatest saturated thickness and near the center of the concentrated irrigation activity.

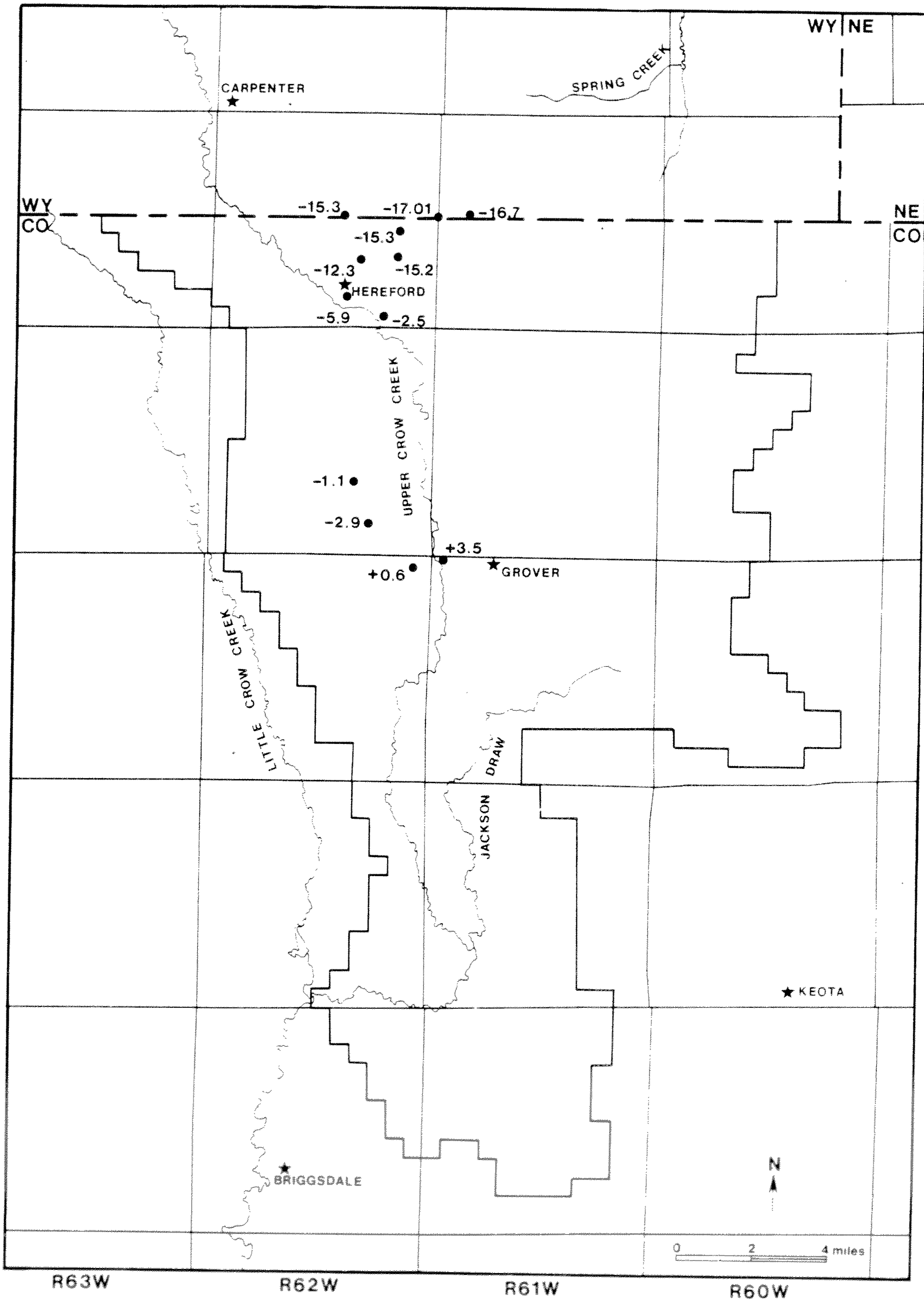


Figure 31. Map showing changes in water levels in wells from 1962 to 1986. A positive number indicates a rise in the water level and a negative number reflects a decline.

The two Alluvial Aquifer wells near Hereford have also experienced gradually declining water levels over the past 24 years, with the exception of the stable period during 1974. Water-level declines in these two wells were 5.9 and 2.5 feet, with the greater decline occurring in the well closer to the Fan Aquifer. Water levels in measured wells west of Grover have been fairly stable over the past 24 years. Water levels in two of these wells have actually increased during the last few years, perhaps a result of the recharge effort during the 1983 flood.

Hydrographs 16 and 17 were prepared from data provided by the Division 1 Water Commissioners. Although these records extend only to 1976, they are valuable as the only wells within the study area that were measured fairly frequently. Hydrograph 16 indicates that except for seasonal declines due to irrigation, the water level has been relatively stable during the past 10 years. A similar relationship is noted on Hydrograph 17, but this well has now caved-in and, unfortunately, had to be abandoned.

The effect of irrigation pumpage on water levels in Laramie County, Wyoming and the northern part of the proposed basin were modeled by Crist (1980). His model was first developed to simulate the hydrologic conditions present within the area, and then applied to a hypothetical case where increased pumpage and irrigation at unspecified area in Wyoming was allowed. The initial application indicated a decline in water levels in the area northeast of Hereford as great as 20 to 30 feet between 1920 and 1987.

5.1.5 GROUND WATER IN STORAGE

The amount of water stored in an unconfined aquifer depends upon the thickness and porosity of the water-yielding materials. The volume of water released from storage in a porous rock by lowering the water table may be expressed as a percentage of the total rock volume. This percentage is called the specific yield of the aquifer. The volume of water that will not drain by gravity from a porous rock also may be stated as a percentage of the total rock volume and is called specific retention. Specific yield plus specific retention equals the porosity of a fully saturated rock. For this study the amount of water stored in each unconfined aquifer was calculated by multiplying the total saturated volume by the specific yield:

Water in storage = total saturated volume X specific yield

There are two factors that relate to the amount of water stored in confined aquifers: 1) water available from the confining pressures and 2) water available from gravity drainage. The first factor depends on the confining or artesian pressure and the confined storage coefficient. The amount of water available because of the confining pressure can be calculated by multiplying the area of the aquifer by the pressure head of the aquifer by the confined storage coefficient. After confining pressures are released from an aquifer, it acts as an unconfined aquifer and the water remaining in storage can be determined by applying the previous equation using saturated volume and specific yield. Since the storage coefficient is a very small number compared to the specific yield, the amount of water available from confined pressures is much less than the amount available from gravity drainage.

Robson (1984) states that the volume of water stored in aquifers under confined conditions in the Denver Basin constitutes less than 0.1 percent of the total volume of ground water in storage. A similar relationship probably exists in the study area. Thus, the amount of water available for withdrawal under water table conditions nearly equals the total amount of water stored in a confined aquifer. Available data used to calculate the amount of water in storage in this study have error factors larger than 0.1 percent. Because of this, the amount of water drainable by gravity is assumed to be representative of the total amount contained in a confined aquifer.

Specific yields used to calculate the amounts of stored water in each aquifer were estimated based on available hydrologic data in the study area, and previously published and unpublished values contained in numerous other designated basin reports. Woodward-Clyde-Sherard and Associates (1966) employed a specific yield of 20% for the combined alluvial and Ogallala aquifers in eastern Colorado. Duke and Longenbaugh (1966) reported specific yields of 20% for their alluvial aquifer and 1% for the Fox Hills in the Kiowa-Bijou Creek area. A specific yield of 20% was also used for the alluvial aquifer in Black Squirrel Creek by Erker and Romero (1967). Hamilton and Owens (1971) utilized specific yields of 20% for their alluvial aquifer and 15% for the Laramie-Fox Hills in the Big Sandy Creek area.

Romero (1976) reported specific yields of 15% for the Laramie-Fox Hills and 10% for the Laramie in the Denver Basin, while Robson (1984) indicated an average specific yield of 20% for the Laramie-Fox Hills. An average specific yield of 29.6% was reported by Wenzel and others (1946) for the White River in Wyoming, and Crist and Borchert (1972) determined the storage coefficient for White River in Wyoming to range from 1.57 X 10^{-3} to 3.18 X 10^{-3}.

Specific yields used in this investigation are as follows: Alluvial and Fan Aquifers - 20%, White River Aquifer - 2%, Upper Laramie Aquifer-17%, and Laramie-Fox Hills Aquifer - 15%. The specific yield of the White River Aquifer is the least accurately known value because the water within this aquifer is mainly stored in secondary permeability features whose hydraulic properties are poorly understood. Previously published values by Crist and Borchert (1972) and Wenzel and others (1946) of specific yield and storage coefficient for the White River Aquifer in other areas range from 0.1 to 33.1%. Based on the hydrologic characteristics of the aquifer within the study area, we believe a value of 2% should be used to determine the amount of stored water.

Table 2 lists the estimated amounts of water in storage for each designated aquifer within the study area. Note that all ground water within the Alluvial Aquifer in and north of Section 1, T11N, R62W is included with the Fan Aquifer. These estimates represent the amount of stored water recoverable by gravity in each aquifer.

The vast majority of ground water within the study area is contained in the confined bedrock aquifers. Most of this water will not be available for withdrawal until the water level is lowered to the point where water-table conditions develop for each formerly confined aquifer.

The amount of economically recoverable ground water in the aquifers is less than the amount drainable by gravity. A considerable amount of water will remain in each aquifer between the cones of depression of wells after the water level in the pumped wells approaches the base of the aquifer. Unless existing and new wells are drilled completely through the entire aquifer it will not be possible to set their pumps deep enough to lower the water level to the aquifer base even directly at the well. Only an estimated 80% of the water drainable by gravity (approximately 5,500,000 acre-feet) is economically recoverable within the proposed basin.

Table 2. Amount of water stored in aquifers within the study area that is drainable by gravity. Amounts of water stored under confined conditions are not included, because these volumes are insignificant compared to the total volumes.

AQUIFER	SPECIFIC YIELD	SATURATED VOLUME (acre-feet)	STORED WATER (acre-feet)
Alluvial Aquifer (S. of 1-11N-62W)	20%	264,000	53,000
Fan and Alluvial Aquifers (N. of 1-11N-61W)	20%	746,000	149,000
White River Aquifer	2%	20,100,000	402,000
Upper Laramie Aquifer	17%	14,900,000	2,500,000
Laramie-Fox Hills Aquifer	15%	25,600,000	3,800,000
Total			6,904,000

5.2 SURFACE WATER

Upper Crow Creek is the only drainage within the study area in which surface water flows at times other than in direct response to local precipitation. No stream gages have ever recorded flows on Upper Crow Creek within the proposed basin. The USGS has operated stream gages on Crow Creek near Barnesville approximately 18 miles downstream from the Confluence and near Cheyenne about 27 miles upstream from the proposed basin, but these were active only for a short period of time.

The gage near Barnesville operated from July 25, 1951 to September 30, 1957, but no surface flow was recorded during this period. The Cheyenne gage station functioned from October 1, 1922 to October 31, 1924 and from July 1, 1951 to September 30, 1957. Surface flows recorded near Cheyenne are listed in Table 3. The average mean flow for the eight years of record was 12.0 cfs. Surface flows during the 1920's were greater than flows during the 1950's.

Table 3. Recorded surface flow in Crow Creek near Cheyenne, Wyoming. (data provided by USGS)

Water Year	Mean cfs	Maximum cfs	Minimum cfs	Total Acre-feet
1923	12.9	210	2.0	9,370
1924	24.4	150	3.8	17,720
1952	10.4	29	5.3	7,590
1953	9.6	78	4.9	6,960
1954	7.9	17	4.3	5,690
1955	10.2	140	4.1	7,400
1956	8.5	43	3.7	6,200
1957	12.0	68	4.4	8,710

Because stream flow within the study area has never been accurately gaged for any length of time, there are no precise records of the volume or timing of surface flows entering or leaving the study area. The testimony and affidavits from Water Court cases, along with personal observations by Division 1 Water Commissioners, provide descriptive information on the surface flows in Upper Crow Creek.

Prior to the 1950's, Upper Crow Creek reportedly flowed into Colorado with a sustained base flow. Surface flow generally existed from the State line into the area west of Grover. During periods of high runoff, surface flow continued downstream from Grover and reached the Confluence. Such flow apparently only rarely lasted longer than several weeks in the spring. During the 1950's, several dams were constructed across Crow Creek in Wyoming for municipal and irrigation purposes. Extensive irrigation well development initiated in the Carpenter, Wyoming area at this time, and continued into the 1970's. From the 1950's up until 1983, surface flows into Colorado were reduced considerably. Many surface water diversions were abandoned and irrigators drilled wells to supply water for their crops. Limited surface flows entered Colorado during spring runoff and continued as far downstream as west of Grover during this time, but surface flow below Grover occurred only for short periods following unusually large floods.

During 1983, melt waters from the heavy snow pack in the Laramie Range created flood conditions on Upper Crow Creek, and flows in excess of 300 cfs were reported in the study area. On May 27, a flow of approximately 340 cfs was reaching the South Platte River from Crow Creek. Surface flow was continous on Upper Crow Creek as far downstream as Grover up until August of 1984.

About six inches of precipitation fell in two hours in Cheyenne on August 1, 1985, creating flood conditions in which eleven lives were lost. Continuous surface flow on Crow Creek resulted from this storm, taking about one week to reach the South Platte River and having a flow of approximately 50 cfs entering the river.

While on field assignment in the study area during January of 1986, the authors observed surface flow in Upper Crow Creek. A flow of an estimated five cfs was noted at the state line and three cfs was occurring west of Hereford. No flow was observed west of Grover or at any other downstream location along Upper Crow Creek.

Thus, it appears that during years of normal precipitation since the 1950's surface water flows in Upper Crow Creek as far downstream as Grover during spring runoff, but does not generally flow below Grover. During much of the irrigation season there is no surface flow west or downstream of Grover, unless the precipitation in the drainage basin is well above normal.

5.3 WATER BUDGET

The volume of water recharging an area must equal the volume of water discharged from it. The balance of recharge and discharge is referred to as the water budget. Types and amounts of recharge and discharge to the unconfined aquifers in the Upper Crow Creek study area are discussed in Section 5.1.3, and Table 4 lists the elements of the water budget during a normal year. All volumes are estimated values based on available hydrologic data and may be subject to revision as new data are acquired.

Recharge in the study area results from infiltration of surface water in Upper Crow Creek, infiltration of precipitation, underflow from Wyoming, and reduction in stored water in the unconfined aquifers. Infiltration of surface water is estimated at 500 to 1,000 acre-feet per year, with an average of 700 acre-feet used to calculate the water budget. Approximately 5,700 acre-feet of recharge results from infiltration of precipitation across the entire study area. Underflow from Wyoming through the unconfined aquifers accounts for about 11,300 acre-feet each year. Declining water levels in the Hereford area indicate a reduction in stored ground water in the unconfined aquifers. An estimated 1,300 acre-feet is removed annually from storage, based on the recorded water level declines over the past 24 years and the area over which the decline has occurred.

Discharge in the study area results from consumptive water use incurred by well pumping, naturally occurring evapotranspiration, and underflow out of the study area. No surface water flows out of the study area during normal years. Consumptive use by well pumping represents the volume of water consumed for irrigation, domestic, stock, industrial and municipal uses, and amounts to 11,500 acre-feet annually (see Section 6.1). Naturally occurring evapotranspiration discharges about 4,000 acre-feet each year. Underflow into Wyoming through the White River Aquifer along the northeast boundary is estimated at 3,000 acre-feet, while underflow through the Alluvial Aquifer at the confluence is less than 50 acre-feet. Underflow through the White River paleovalley and Wildcat Creek paleochannel is estimated at around 500 acre-feet.

Table 4. Estimated Annual Water Budget for the Unconfined Aquifers

RECHARGE

Surface Water (infiltrates into the aquifer)	=	700 acre-feet
Precipitation infiltration	=	5,700 acre-feet
Underflow from Wyoming	=	11,300 acre-feet
Reduction in storage	=	1,300 acre-feet
Total		19,000 acre-feet

DISCHARGE

Surface Water	=	0 acre-feet
Consumptive use from well pumping	=	11,500 acre-feet
Evapotranspiration	=	4,000 acre-feet
Underflow into Wyoming	=	3,000 acre-feet
Underflow at Confluence	=	< 50 acre-feet
Underflow out southeast boundary	=	500 acre-feet
Total		19,000 acre-feet

6.0 WATER USE

6.1 GROUND WATER

6.1.1 HISTORICAL USE

Ground water within the study area has been withdrawn from wells in the past and utilized for irrigation, municipal, industrial, domestic, and livestock purposes. Appendix C lists all water wells registered with the State Engineer. The permit number and date, location, owner, depth, water level, yield, and aquifer for each well is described in Appendix C. Wells that are adjudicated, but not registered are listed in Appendix D.

Initial use of ground water within the area probably began shortly after the first settlers arrived in the area. Unfortunately, no complete records of early use exist today. Records held by the State Engineer were examined to allow preparation of Figure 32, a graph that shows both the cumulative total number of registered and adjudicated water wells in the study area and the cumulative number of irrigation, municipal, and industrial wells. The first irrigation well was reportedly constructed in 1909, but until about 1940 only a limited number of wells are known to have existed within the study area. Most of the early wells were used for livestock purposes. A few additional wells were completed during the 1940's, but it was not until the 1950's that significant ground-water development occurred. The maximum completion rate for irrigation wells was attained during the early 1950's, and a nearly steady increase in the number of irrigation, municipal, and industrial wells occurred from the 1950's to 1978. No new wells with these uses have been registered since 1978. A dramatic increase in the number of domestic and stock wells since 1960 is also apparent on Figure 32.

Certain limitations apply to the available historical data on ground-water wells in the study area. Wells that were drilled prior to enactment of registration requirements and also many of those drilled during the initial years of registration were often never permitted or adjudicated. For example, Babcock and Bjorklund (1956) reported that 65 irrigation wells existed in the vicinity of the study area in 1952. According to registration and adjudication records, only 22 wells date back to 1952. Some of the 65 wells may have been registered later, but many were probably abandoned, leaving no record of their existence. Another problem involves the stock wells. Comparison of registered stock wells with windmills shown on U.S.G.S. topographic maps and observed in the field reveals that perhaps 100 stock wells exist in the study area, but only 74 of these are registered or adjudicated. We do not know of any currently active irrigation, municipal, or industrial wells that are not either registered or adjudicated.

As is apparent from Figure 32, many of the wells have been in use for the past fifteen years (since 1/1/71). A list of registered and/or adjudicated wells that have been in use during the past fifteen years is contained in Appendix E. Included in this list are the location, permit number, well owner, use, and initial year of use. A total of 145 wells have been in use for at least fifteen years, of which 63 were irrigation, municipal, or industrial wells and 82 were domestic and/or stock wells. The average annual quantity of water withdrawn by these 145 wells is approximately 9,100 acre-feet.

6.1.2 PRESENT USE

A total of 209 registered or adjudicated wells were present within the study area as of August 7, 1984, the date when the currently available master list was prepared. Of this amount, 169 were registered and 40 were adjudicated, but not registered. There were 79 irrigation wells, 74 stock wells, 22 domestic wells, 27 combined domestic and stock wells, three municipal wells, three industrial wells, and one unclassified well known to exist within the study area. Figure 33 shows the locations of these wells.

The following list describes the total number of registered or adjudicated wells completed in each aquifer and the number of wells completed in each aquifer by the type of use. The "commingled or unknown" category indicates the number of wells that withdraw water from more than one aquifer or from an unknown aquifer. Wells for which the depth and completion record are unavailable are classified as having an unknown aquifer, if it is not obvious which aquifer the well taps.

All wells (209):

Alluvial Aquifer - 49 wells; Fan Aquifer - 38 wells; White River Aquifer - 69 wells; Upper Laramie Aquifer - 20 wells; Laramie-Fox Hills Aquifer - 9 wells; commingled or unknown aquifers - 24 wells

Irrigation Wells (79):

Alluvial Aquifer - 29 wells; Fan Aquifer - 29 wells; White River Aquifer - 11 wells; commingled aquifers - 10 wells

Municipal Wells (3):

Upper Laramie Aquifer - 1 well; commingled aquifers - 2 wells

Industrial Wells (3):

Upper Laramie Aquifer - 2 wells; Laramie-Fox Hills Aquifer - 1 well

Domestic Wells (22):

Alluvial Aquifer - 3 wells; Fan Aquifer - 4 wells; White River Aquifer - 9 wells; Upper Laramie Aquifer - 2 wells; Laramie-Fox Hills Aquifer - 1 well; commingled aquifers - 3 wells

Stock Wells (74):

Alluvial Aquifer - 14 wells; Fan Aquifer - 3 wells; White River Aquifer - 32 wells; Upper Laramie Aquifer - 16 wells; Laramie-Fox Hills Aquifer - 4 wells; commingled or unknown aquifers - 5 wells

Combined Domestic and Stock Wells (27):

Alluvial Aquifer - 5 wells; Fan Aquifer - 2 wells; White River Aquifer - 15 wells; Laramie-Fox-Hills Aquifer - 3 wells; commingled aquifers - 2 wells

Unclassified Wells (1):

commingled aquifers - 1 well

All irrigation wells are completed in unconfined aquifers. Ten irrigation wells commingle water from the Alluvial, Fan, and/or White River Aquifers. Most domestic and stock wells utilize the White River, alluvial, or Upper Laramie Aquifers. Only nine wells within the study area are known to withdraw water from the Laramie-Fox Hills Aquifer.

Ground-water withdrawals within the study area were calculated using the available well data. Domestic wells were assumed to pump an average of 2.5 acre-feet per year and to consumptively use 2 acre-feet. Each stock well was assumed to pump an average of 10 gallons per day per steer, 365 days a year

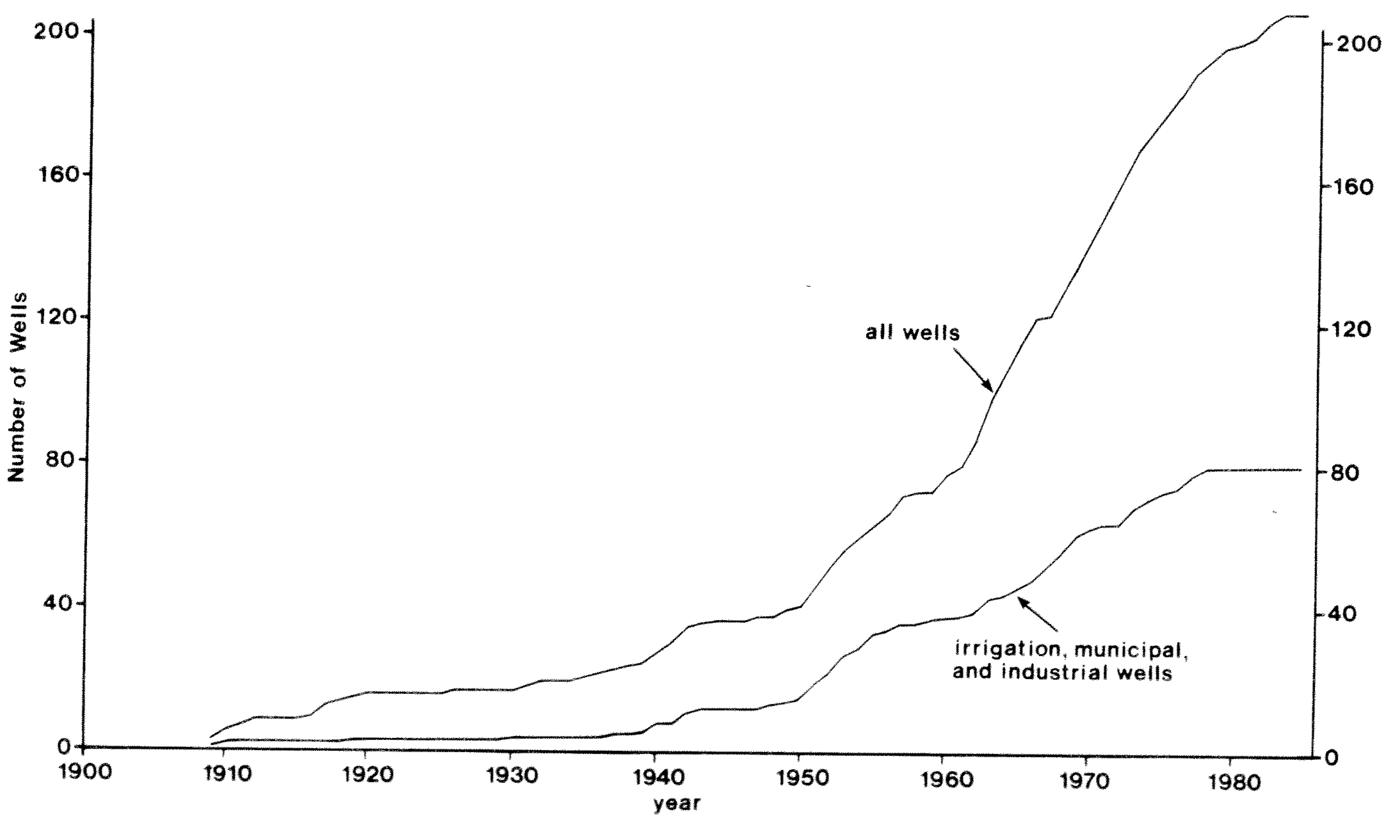


Figure 32. Graph showing cumulative number of registered and adjudicated water wells versus the year of completion. Lower curve indicates cumulative number of irrigation, municipal, and industrial wells, while upper curve shows cumulative total of all wells. (data from State Engineer's records)

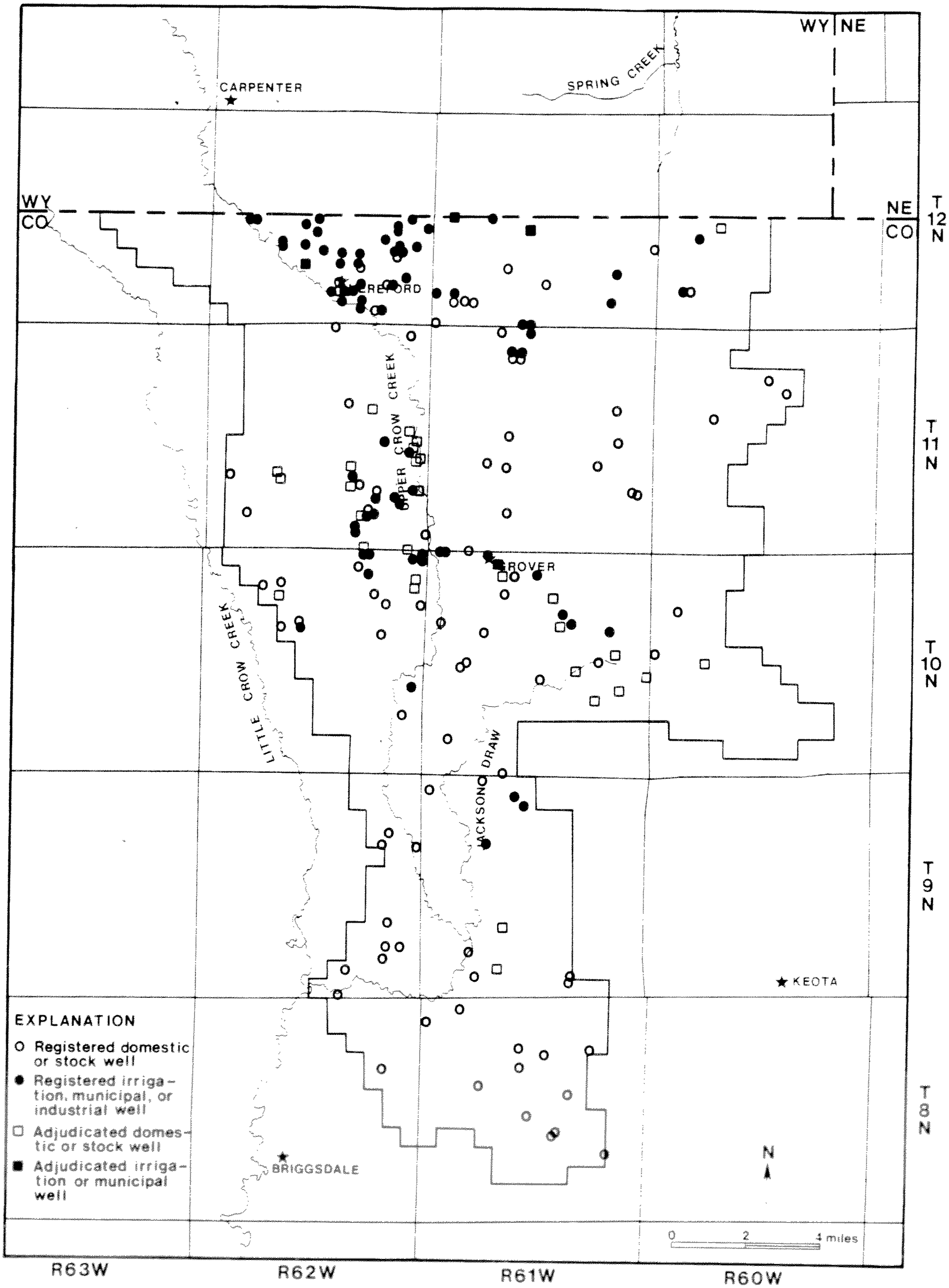


Figure 33. Map showing location of registered water wells and wells that are adjudicated but not registered in the study area. (data from State Engineer's records, Division 1 Water Commissioner, and field inspection)

for 40 head of steers. Thus, each stock well pumps an estimated 0.4 acre-feet of water each year, none of which is returned directly to the aquifer. A well used for domestic and stock purposes was assumed to pump 2.9 acre-feet and consumptively use 2.4 acre-feet annually. The unclassified well was assumed to be a domestic well.

All three municipal wells serve the town of Grover, which had a population of 158 people in 1980. Assuming each household contains 3 people, there are approximately 53 households in Grover. This closely agrees with the number of houses shown in Grover on the U.S.G.S. topographic map. If each household uses 0.3 acre-feet per year, the municipal wells would need to pump about 16 acre-feet of water per year. We estimate that about 80% of withdrawn water (12.8 acre-feet) is consumptively used.

Limited data are available for the three industrial wells. One was associated with the pilot uranium solution mine near Grover and the other two serve facilities at the Keota oil field. We estimate that all three wells pump approximately 5 acre-feet of water each year.

The vast majority of ground water withdrawn in the study area is used for irrigation. When actual pumping records are not available, several methods may be employed to estimate the volume of water pumped for irrigation purposes. The primary methods involve interpretation of electricity consumption or application of crop-irrigation requirements. Because a high percentage of the irrigation wells in the study area are powered by combustion engines, it was not practical to use electrical power consumption records. Thus, the quantity of water pumped for irrigation was estimated by determining the number of irrigated acres, type of irrigation system (flood or sprinkler), type of crop, and water requirements of the crops.

An estimated 6,820 acres of irrigated farm land are present within the study area. The number of irrigated acres was approximated using a combination of approaches that included field inspection, interpretation of aerial photography, data supplied by the irrigators, the number of irrigated acres claimed in the "Statement of Beneficial Use" or decree, and records held by Weld County. Approximately 80% is irrigated by sprinkler and 20% by flood irrigation. A 70% efficiency was assumed for sprinkler irrigation, with 15% of the pumped water being lost to evaporation and 15% returning to the aquifer by deep percolation. A 55% efficiency was assumed for flood irrigation, with

30% returned by deep percolation and 15% lost to evaporation and non-beneficial plant growth.

The average consumptive water requirement for corn silage, corn grain, pasture grass, alfalfa, and spring grain for the period 1963 to 1983 were determined by Bob Hamburg, CDWR, using the Blaney-Criddle method of computation. Climatic data employed in this calculation were taken from the Briggsdale climatic station when available. Data from the Greeley station was substituted for any missing Briggsdale data. Between 1963 and 1983 the average annual net irrigation requirements were as follows: corn silage - 1.24 feet, corn grain - 1.34 feet, pasture grass - 1.52 feet, alfalfa - 1.88 feet, and spring grain - 0.76 feet.

During the past 15 years an estimated 50% of all irrigated acres were used for corn silage, 10% for corn grain, 15% for pasture grass, 15% for alfalfa, and 10% for spring grain, based on discussions with irrigators and government employees. Other types of crops were also raised in the study area during the past 15 years, but the above acreages are believed to be sufficiently representative to enable estimations of required irrigation water to be made.

The volume of water required for each crop was calculated by multiplying the number of acres of that crop times the consumptive crop requirement. The total volume of water required for irrigation equals the sum of the volumes needed for each crop. The total amount of water pumped for irrigation was determined by dividing the volume required by the efficiency of the irrigation method. The net amount of ground water consumptively used in the study area equals the amount pumped minus the amount returned to the aquifers by deep percolation. Application of the above described criteria to the study area resulted in the determinations shown in Table 4.

Approximately 14,000 acre-feet of ground water is presently being withdrawn each year from wells within the study area, of which about 11,500 acre-feet is consumptively used. Water wells that have been registered or permitted for at least 15 years pump an average of 9,100 acre-feet each year.

Table 5. Average annual amount of ground-water pumped and consumptively used according to the type of use.

USE	WATER PUMPED (acre-feet)	NET WATER CONSUMED (acre-feet)
Irrigation	13,800	11,300
Municipal	16.0	12.8
Industrial	5.0	5.0
Domestic	55.0	44.0
Livestock	40.0*	40.0*
Domestic and Livestock	78.3	64.8
Other	2.5	2.0
TOTAL	13,997	11,464

* Assumes 100 registered and unregistered livestock wells are active in the study area.

6.2 SURFACE WATER

6.2.1 HISTORIC AND PRESENT USE

Appendix B lists the adjudicated surface water rights in Colorado on Upper Crow Creek above its confluence with Little Crow Creek. According to the records held in the office of the State Engineer there are ten decreed diversion ditches and eleven decreed storage reservoirs in the drainage basin of Upper Crow Creek. The appropriation dates for the ditches range from 1885 to 1910, while the reservoirs were appropriated from 1907 to 1969. Locations of both the ditches and reservoirs are shown on Figure 34. All diversions and reservoirs are either directly on or adjacent to Upper Crow Creek with the exception of the Grover ditch, Grover reservoir, and Pierce reservoirs. These are in valleys tributary to Upper Crow Creek west of Grover.

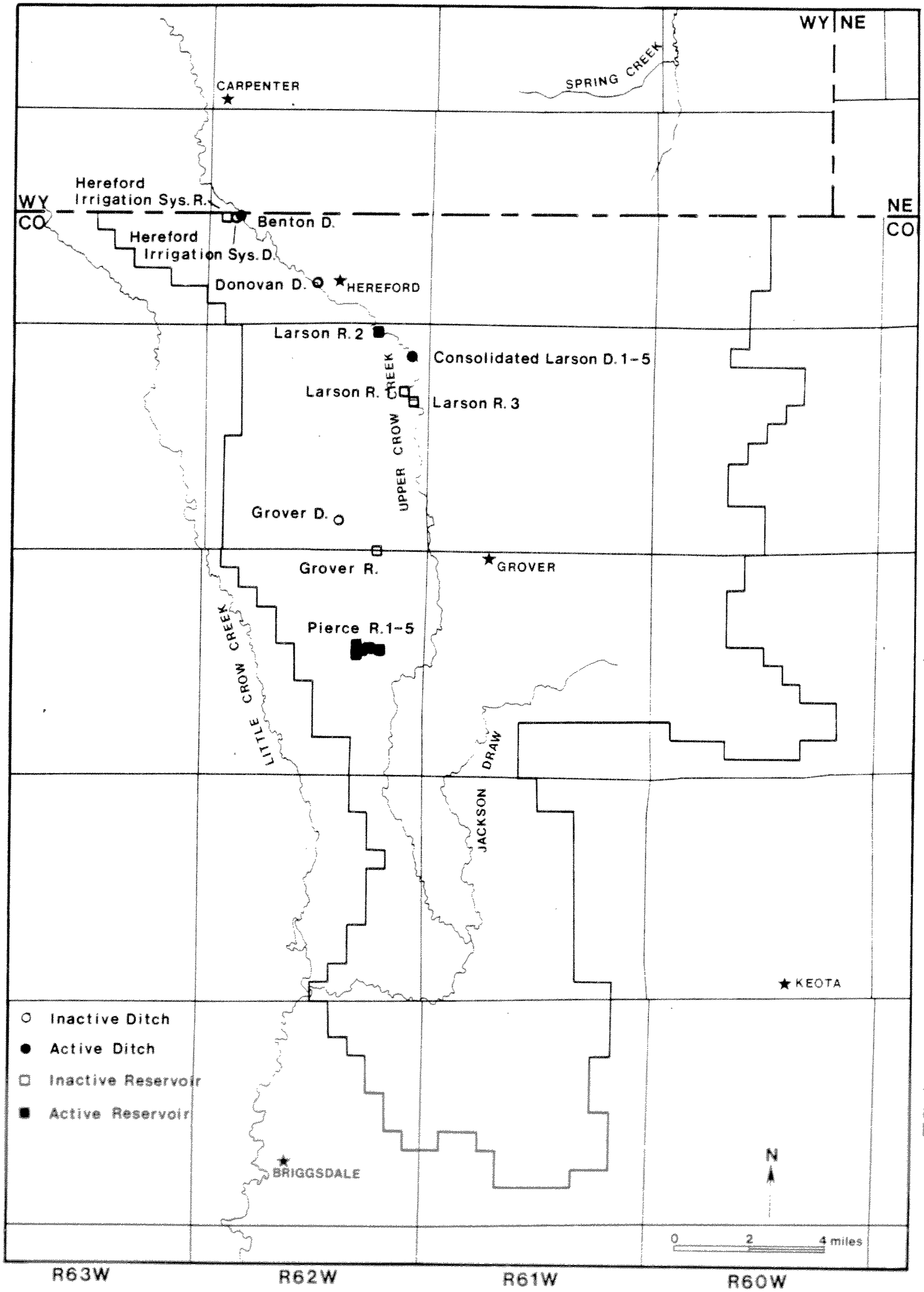


Figure 34. Map showing location of decreed surface water rights within the study area. (data from records held by the State Engineer and Division 1 Water Commissioner)

Information on historic flows in Crow Creek and historic surface water use on Upper Crow Creek was obtained from testimony and depositions from Water Court cases and from interviews with Robert Samples, Division 1 Water Commissioner. Historically, Crow Creek reportedly flowed relatively consistently with a sustained base flow into Colorado from Wyoming up until the early 1950's. At that time dams were built on Crow Creek to provide storage for Cheyenne's water supply system and for irrigation use. Utilization of these reservoirs may have diminished flow in Crow Creek to some extent, but irrigation well development near Carpenter, Wyoming in the late 1950's appears to have had a major effect on surface flows in Crow Creek. Many of the adjudicated surface water diversions near Hereford and Grover were no longer able to provide the volume of water needed for irrigation, and irrigators were forced to drill wells to supplement or replace their decreed surface water rights.

According to the records of the State Engineer and Division 1 Water Commissioner, there has been only limited use of surface water during the past 15 years on Upper Crow Creek. During this period only two ditches have diverted water from Upper Crow Creek (Consolidated Larson and Benton ditches) and only one decreed reservoir (Larson Reservoir #2) has been functional on Upper Crow Creek during the past 15 years. The Pierce reservoirs are also active, but they only collect precipitation runoff along a tributary to Upper Crow Creek. The five Larson ditches shown in Appendix B are now consolidated into a single ditch. Table 5 presents the best available diversion figures for the active structures. The data were supplied to the state annually by the water appropriators.

In 1983, a year of unusually high stream flow due to the heavy snow pack, about 6,000 acre-feet was diverted by the Consolidated Larson ditch. This water was spread out over a large area and utilized for both irrigation and recharge of the Alluvial Aquifer. The success of the recharge effort was demonstrated by the rise in the water table, particularly in the Grover area where residents complained of flooded basements.

Although these records are not sufficiently detailed to precisely define historic water usage, they are adequate to provide a general estimate of the volume of appropriated surface water on Upper Crow Creek. Average annual appropriations of each ditch or reservoir were calculated by summing the

Table 6. Surface Water Usage in Upper Crow Creek drainage, 1970 to 1985. (prepared from records held by the State Engineer and Division 1 Water Commissioner)

	STRUCTURE		
YEAR	Consolidated Larson Ditch	Benton Ditch	Pierce Reservoirs 1-5
1985	120 acre-feet	washed out	35.61 acre-feet
1984	300 acre-feet	washed out	36.71 acre-feet
1983	6,000 acre-feet	washed out	35.61 acre-feet
1982	80 acre-feet	10 acre-feet	36.71 acre-feet
1981	84 acre-feet	no info. available	36.71 acre-feet
1980	390 acre-feet	102 acre-feet	36.71 acre-feet
1979	450 acre-feet	95 acre-feet	36.71 acre-feet
1978	no info. available	105 acre-feet	36.71 acre-feet
1977	612 acre-feet	105 acre-feet	36.71 acre-feet
1976	612 acre-feet	no info. available	-
1975	616 acre-feet	water used; amount not known	-
1974	no info. available	no info. available	-
1973	1,500 acre-feet	105 acre-feet	-
1972	water used; amount not known	water not available	-
1971	water used; amount not known	400 acre-feet	-
1970	water used; amount not known	448 acre-feet	-

reported yearly usage and dividing this by the number of years in which usage data was provided. Excluding 1983, the Consolidated Larson ditch has used an average about 476 acre-feet per year. If the 6,000 acre-feet diverted in the 1983 flood is included, the annual usage averages 979 acre-feet. Benton ditch, which was washed out during the 1983 flood and as of January, 1986 had not been replaced, diverted an average of 160 acre-feet per year. Note that in at least one year (1972) water was not available for diversion by the Benton ditch. The Pierce reservoirs, which catch and retain precipitation runoff and do not actually take water from Crow Creek, report an average annual usage of 36.4 acre-feet.

Thus, the average annual amount of surface water diverted from Upper Crow Creek in Colorado for irrigation and stock purposes during normal years is estimated at 672 acre-feet. If the 1983 flood year is included, the average is 1,175 acre-feet per year.

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APPENDIX A. Legal Description of the Study Area

T8N R61W:	Sec. 2-10; NE/4, NW/4 & SW/4 of Sec. 11; W/2 of Sec. 14; Sec. 15-18; NE/4, NW/4 & SW/4 of Sec. 19; NE/4, NW/4 & SE/4 of Sec. 20; Sec. 21-23; N/2 of Sec. 26; Sec. 27-28
T8N R62W:	Sec. 1-2; E/2 of Sec. 3; NE/4, NW/4 & SE/4 of Sec. 11; Sec. 12-13; NE/4 of Sec. 14; NE/4, NW/4 & SE/4 of Sec. 24
T9N R61W:	Sec. 4-10; Sec. 15-22; Sec. 27-34; S/2 of Sec. 35
T9N R62W:	Sec. 1-2; E/2 of Sec. 11; Sec. 12-13; SE/4 of Sec. 14; E/2 of Sec. 23; Sec. 24-26; NE/4, SW/4 & SE/4 of Sec. 34, Sec. 35-36
T10N R60W:	W/2 of Sec. 4; Sec. 5-8; S/2 of Sec. 16; Sec. 17-21; NW/4, SW/4 & SE/4 of Sec. 22; Sec. 26-29; NE/4, NW/4 & SE/4 of Sec. 30; N/2 of Sec. 33; N/2 of Sec. 34
T10N R61W:	Sec. 1-24; N/2 of Sec. 25; N/2 of Sec. 26; N/2 of Sec. 27; NE/4, NW/4 & SW/4 of Sec. 28; Sec. 29-32; W/2 of Sec. 33
T10N R62W:	Sec. 1-5; NE/4 of Sec. 6; NE/4 of Sec. 8; Sec. 9-15; NE/4, NW/4 & SE/4 of Sec. 16; NE/4 of Sec. 21; Sec. 22-27; Sec. 35-36.
T11N R60W:	NW/4 of Sec. 4; Sec. 5-10; NW/4 of Sec. 15; Sec. 16-20; NW/4 of Sec. 21; S/2 of S/2 of Sec. 28; Sec. 29-33
T11N R61W:	ALL SECTIONS
T11N R62W:	Sec. 1-5; Sec. 8-17; E/2 of Sec. 19; Sec. 20-29; E/2 of Sec. 30; E/2 of Sec. 31; Sec. 32-36
T12N R60W:*	Sec. 19-21; Sec. 28-32; W/2 of Sec. 33
T12N R61W:*	ALL SECTIONS IN COLORADO
T12N R62W:*	Sec. 19-30; NE/4, NW/4 & SE/4 of Sec. 31; Sec. 32-36
T12N R63W:*	NE/4, NW/4 & SE/4 of Sec. 22; Sec. 23-25; N/2 of Sec. 26

* only those parts of the sections in these townships that are within Colorado are included in the study area

Appendix B.

Decreed Surface Water Rights on Upper Crow Creek
(from records held by the State Engineer and Division 1 Water Commissioner)

NAME OF STRUCTURE	LOCATION SEC.	TWN.	RNG.	DECREE AMOUNT	TYPE[1] ADJ.	ADJ. DATE	PREV. ADJ. DATE	APPROP. DATE	USE[2]	BASIN[3] RANK	STATUS
RESERVOIRS				acre-feet							
LARSON RES #1	11 & 14	12N	62W	59.5	S	01/15/1914	11/21/1895	03/23/1907	I	1852	inactive
LARSON RES #2	NE 02	11N	62W	17.5	S,C	01/15/1914	11/21/1895	05/21/1907	I	1861	active
LARSON RES #3	NW NE 13	11N	63W	251.5	S,C,	01/15/1914	11/21/1895	10/15/1908	I	1935	inactive
GROVER RES	NE 02	11N	62W	2506.0	S,C,	01/15/1914	11/21/1895	11/26/1908	I	1939	inactive
HEREFORD IRR SYS RES	NW 19	12N	62W	2525.0	S	01/15/1914	11/21/1895	05/10/1910	I	2017	inactive
HEREFORD IRR SYS RES	NW 19	12N	62W	4627.0	S,C	01/15/1914	11/21/1895	07/20/1910	I	2033	inactive
PIERCE RES #1	NE NW SW 14	10N	62W	2.27	S	12/31/1976	12/31/1975	05/15/1908	I,S	10,202	active
PIERCE RES #2	SE NE SW 14	10N	62W	2.94	S	12/31/1976	12/31/1975	05/15/1908	I,S	10,202	active
PIERCE RES #3	SE NW NW 14	10N	62W	30.40	S	12/31/1976	12/31/1975	05/15/1908	I,S	10,202	active
PIERCE RES #4	SW NE SE 14	10N	62W	0.53	S	12/31/1976	12/31/1975	10/09/1969	S	10,311	active
PIERCE RES #5	SW NE SW 14	10N	62W	0.57	S	12/31/1976	12/31/1975	10/09/1969	S	10,311	active
DITCHES				cfs							
CONSOLIDATED LARSON D	NE NW NE 12	11N	62W	3.0	S	01/15/1914	11/21/1895	12/28/1885	I	1319	active *
CONSOLIDATED LARSON D	NE NW NE 12	11N	62W	3.0	S	01/15/1914	11/21/1895	03/15/1886	I	1320	active *
BENTON DITCH	NW NE 19	12N	62W	9.57	S	01/15/1914	11/21/1895	07/01/1888	I	1325	active
DONOVAN DITCH	SW 27	12N	62W	4.0	S	01/15/1914	11/21/1895	01/09/1894	I	1338	inactive
CONSOLIDATED LARSON D	NE NW NE 12	11N	62W	2.0	S	01/15/1914	11/21/1895	03/05/1895	I	1341	active *
CONSOLIDATED LARSON D	NE NW NE 12	11N	62W	5.0	S	01/15/1914	11/21/1895	02/08/1900	I	1435	active *
CONSOLIDATED LARSON D	NE NW NE 12	11N	62W	400.00	S	01/15/1914	11/21/1895	05/15/1903	I	1540	active *
GROVER DITCH	SW NW NE 34	11N	62W	380.0	S	01/15/1914	11/21/1895	11/26/1908	I	1939	inactive
HEREFORD IRR SYS D1	NE 19	12N	62W	42.0	S,C	01/15/1914	11/21/1895	05/20/1910	I	2019	inactive
HEREFORD IRR SYS D2	NE 19	12N	62W	52.0	S,C	01/15/1914	11/21/1895	07/20/1910	I	2033	inactive

1. S = SUPPLEMENTAL; C = CONDITIONAL; O = ORIGINAL; CA = CONDITIONAL TO ABSOLUTE; AB = ABANDONMENT
2. I = IRRIGATION; S = STOCK
3. RELATIVE STANDING WITH RESPECT TO ALL OTHER ACTIONS IN THE SAME BASIN

* ALL CONSOLIDATED LARSON DITCHES NOW USE A SINGLE DIVERSION STRUCTURE

APPENDIX C.
Registered Water Wells in the Study Area
(from State Engineer's Records; data occasionally modified based on field investigation or Water Court decree)

LOCATION	PERMIT NO.	OWNER	COMPLETION DATE	WELL DEPTH (ft)	DEPTH TO WATER (ft)	YIELD (gpm)	USE[1]	AQUIFER[2]
T8N R61W S.05 NW NW	8243	GRAEFE & GRAEFE INC.	05/02/61	160	35	24	2	Kul
T8N R61W S.06 NW SW	8242	GRAEFE & GRAEFE INC.	04/28/61	177	50	8	2	Kul
T8N R61W S.09 SW SE	40746	W. SCHAWO	04/11/70	131	30	10	2	Twr?, Kul
T8N R61W S.09 SW NE	78261	W. SCHAWO	03/19/75	300	160	15	3	Klf
T8N R61W S.10 NE SW	19333	K. PIERCE	04/30/64	288	202	7	2	Kul
T8N R61W S.11 SW NE	23209	L. JESSOŃ	04/20/65	195	85	12	2	Kul
T8N R61W S.15 NE SE	23214	BRIGGSDALE GRAZING ASSOC.	04/22/65	315	84	25	2	Klf
T8N R61W S.17 SW NE	20732	W. SIEVERS	05/14/64	288	252	7	2	Klf
T8N R61W S.21 NE NE	23212	BRIGGSDALE GRAZING ASSOC.	04/21/65	315	77	25	2	Klf
T8N R61W S.22 NW SE	13963	K. WASHBURN	01/09/63	86	50	3	1	Twr
T8N R61W S.22 NW SE	126281	K. WASHBURN	05/11/82	308	172	15	1	Kul
T8N R61W S.26 NE NE	12377	O. HILL	04/11/80	530	265	30	3	Klf
T8N R62W S.11 SE SE	36955	P. FREEMAN	01/16/69	435	195	10	1	Klf
T9N R61W S.04 NE SW	4668F	PEPPER TANK CO.	09/28/63	701	70	23	5	Klf
T9N R61W S.04 SW SE	4734F	PEPPER TANK CO.	10/04/63	220	50	23	5	Kul
T9N R61W S.05 NW NE	58738	BASHOR & SONS INC.	07/30/72	150	45	6	2	Kul
T9N R61W S.06 SW NW	5603	W. JOHNSON	05/20/60	45	7	6	1	Twr
T9N R61W S.08 SW SE	12861R	E. DUNBAR	00/00/39	154	21	180	6	Twr
T9N R61W S.29 SW SW	61296	R. COCHRAN	05/00/72	62	8	20	2	Kul
T9N R61W S.32 SE NW	29506	R. COCHRAN	12/05/66	60	12	15	2	Kul
T9N R61W S.34 NE SE	453	D. KENNISON	08/28/57	215	179	5	2	Twr?, Kul
T9N R61W S.34 NE SE	620	D. KENNISON	08/28/57	215	90	5	2	Twr?, Kul
T9N R62W S.11 SE SE	75593	H. GRACIK	07/30/74	185	87	4	2	Kul
T9N R62W S.12 NW SE	118053	C. BASHOR	02/28/81	59	15	5	2	Twr
T9N R62W S.12 SE SE	125432	K. JOHNSTON	06/19/82	58	14.9	15	3	Twr
T9N R62W S.24 SW SW	110326	GRAEFE & GRAEFE INC.	09/15/79	260	95	15	2	Kul
T9N R62W S.25 NW SW	12014	GRAEFE & GRAEFE INC.	06/00/62	175	70	12	2	Kul
T9N R62W S.25 NE SW	46812	GRAEFE & GRAEFE INC.	06/24/71	195	110	15	2	Kul
T9N R62W S.26 SE SE	51079	GRAEFE & GRAEFE INC.	02/08/72	155	72.1	15	2	Twr, Kul
T9N R62W S.34 SE SE	56039	N. MAGNUSON	04/19/72	165	30	4	2	Kul
T9N R62W S.34 NE NE	81854	N. MAGNUSON	01/07/76	485	193.5	10	3	Klf
T10N R60W S.07 NE SE	50791	US FOREST SERVICE	00/00/11	85	60	2	2	Twr
T10N R60W S.18 NW SW	91966	W. SCHEUB	10/27/77	70	57	4	2	Twr
T10N R60W S.34 NE NE	20154	J. HOFFMAN	08/02/64	315	140	7	3	Twr
T10N R61W S.04 NE SE	17454F	D. BRUNNER	06/28/74	165	26.7	278	6	Qa, Twr

1) USE: 1=domestic, 2=livestock, 3=combined domestic and livestock, 4=commercial, 5=industrial, 6=irrigation, 8=municipal, 9=other

2) AQUIFER: Qa=Alluvial Aquifer, Qf=Fan Aquifer, Twr=White River Aquifer, Kul=Upper Laramie Aquifer, Klf=Laramie-Fox Hills Aquifer

LOCATION	PERMIT NO.	OWNER	COMPLETION DATE	WELL DEPTH (ft)	DEPTH TO WATER (ft)	YIELD (gpm)	USE	AQUIFER
T10N R61W S.04 SE SE	17455F	D. BRUNNER	00/00/00	?	26.0	?	6	Qa, Twr?
T10N R61W S.04 NE SW	43496	C. BARR	10/20/70	180	22	25	1	Twr, Kul
T10N R61W S.05 NW NE	11174F	TOWN OF GROVER	12/12/66	230	32	100	8	Twr?, Kul
T10N R61W S.06 NE NW	6406R	MARICK	04/27/55	48	6.1	710	6	Qa
T10N R61W S.06 NE NW	6407R	MARICK	05/11/53	33	5	500	6	Qa
T10N R61W S.07 SE SW	12352	W. BASHOR	07/15/63	122	28.2	10	2	Twr
T10N R61W S.09 NW NW	16093	C. RAWLEY	07/02/63	55	20	8	2	Twr
T10N R61W S.10 NW SE	12873F	W. EVERITT	04/22/68	150	16.3	600	6	Qa?, Twr
T10N R61W S.10 SE SE	13379F	W. EVERITT	02/04/69	150	17.2	1100	6	Qa?, Twr
T10N R61W S.14 NE NE	11484R	STONE	04/01/49	54	30.9	1000	6	Qa?, Twr
T10N R61W S.14 SW SE	13859	C. RAWLEY	12/22/62	20	10	8	2	Qa, Twr?
T10N R61W S.17 SW SE	12351	W. BASHOR	07/10/62	192	35	10	2	Kul
T10N R61W S.17 NW NE	75952	BASHOR & SONS INC.	08/17/74	210	120	5	3	Twr, Kul
T10N R61W S.19 NE NE	32124	D. BASHOR	11/20/67	110	63	3	1	Twr
T10N R61W S.22 SW NW	75950	BASHOR & SONS INC.	10/10/74	110	40	15	3	Twr
T10N R61W S.30 SW SE	132931	A. SIERMAN	09/15/83	100	?	15	3	Twr
T10N R61W S.33 SW SW	6396	W. BASHOR	07/12/60	554	?	10	2	Klf
T10N R62W S.01 NW NE	8276R	T-R INC.	06/00/52	36	9.4	400	6	Qa
T10N R62W S.01 NW NE	8277R	T-R INC.	07/00/09	31	7	350	6	Qa
T10N R62W S.01 NW NE	8278R	T-R INC.	05/00/53	42	7	200	6	Qa
T10N R62W S.02 NE NW	4516R	J. & H. GRACIK	10/00/52	?	9.4	800	6	Qa
T10N R62W S.02 NE NW	4517R	H. & J. GRACIK	10/00/52	23	4	500	6	Qa
T10N R62W S.02 NE SW	8740R	H. GRACIK	05/00/55	27	5	800	6	Qa
T10N R62W S.02 SW NW	49356	H. GRACIK	10/18/71	32	4	15	2	Qa
T10N R62W S.04 SW SW	85675	J. KONIG	08/16/76	115	50	5	1	Twr
T10N R62W S.05 SW SE	78327	J. BURNETT	08/21/75	158	43	12	2	Twr, Kul
T10N R62W S.09 SW SE	90293	F. LAWRENCE	06/01/77	45	7	20	2	Twr
T10N R62W S.11 NW NE	49357	H. GRACIK	10/18/71	29	7	15	2	Qa
T10N R62W S.11 SE NE	49358	H. GRACIK	10/20/71	38	16	15	2	Qa
T10N R62W S.12 SE NE	123769	D. BASHOR	02/06/82	154	40	15	2	Twr
T10N R62W S.14 NW NE	28606	H. GRACIK	08/28/66	108	20	20	2	Twr
T10N R62W S.16 NW NE	2038F	G. KONIG	05/01/59	100	3	300	6	Twr
T10N R62W S.16 NW NW	13276	A. WERNER	10/00/62	190	24	10	3	Twr, Kul
T10N R62W S.24 NW SE	22499F	WY. MINERAL CORP.	06/21/78	120	?	7	5	Kul
T10N R62W S.25 SE NW	68198	BASHOR & SONS INC.	03/29/73	125	53	5	2	Twr
T11N R60W S.10 NW SW	29357	R. STEINER	11/28/66	207	162	5	2	Twr
T11N R60W S.10 SE SE	42518	R. STEINER	08/03/70	255	100	3	2	Twr
T11N R60W S.17 SW NE	20734	M. FOSTER	07/15/64	335	80	3	2	Twr
T11N R61W S.04 NE SW	17914F	S. TIMM	11/29/75	130	33	81	6	Twr
T11N R61W S.04 NW SW	22089F	LOYD FARMS	08/27/77	165	31	185	6	Twr
T11N R61W S.04 NW NE	22090F	LOYD FARMS	10/27/77	180	31.4	415	6	Twr
T11N R61W S.04 SW SW	82527	C. & L. ZIPPERER	09/01/60	561	?	15	9	Twr, Kul
T11N R61W S.04 SE SW	106982	C. & L. ZIPPERER	09/01/60	560	?	15	1	Twr, Kul
T11N R61W S.05 NE NE	116725	I. TIMM	08/20/81	150	25	15	3	Twr
T11N R61W S.14 NE NE	94826	D. MEYER	06/06/79	98	56.2	15	3	Twr

LOCATION	PERMIT NO.	OWNER	COMPLETION DATE	WELL DEPTH (ft)	DEPTH TO WATER (ft)	YIELD (gpm)	USE	AQUIFER
T11N R61W S.16 SW SW	66795	CO. STATE LAND BD. COMM	04/18/73	421	180	15	1	Twr
T11N R61W S.20 NW SE	93418	BAUMAN RANCH INC.	04/10/79	122	33	10	2	Twr
T11N R61W S.21 NW SW	108033	BAUMAN RANCH INC.	06/00/49	100	69.9	30	2	Twr
T11N R61W S.23 NW SE	20733	B. WILSON	05/24/64	178	60	5	2	Twr
T11N R61W S.24 NW NW	80770	B. WILSON	08/18/75	210	98	10	2	Twr
T11N R61W S.25 SE NW	16432	C. SMOCK	07/29/63	110	?	?	2	Twr
T11N R61W S.25 SE NW	16837	C. SMOCK	08/16/63	87	?	7	2	Twr
T11N R61W S.28 SW SW	132932	B. WILSON	10/01/83	255	89	15	3	Twr
T11N R61W S.32 SW SW	12498	R. ARDOUREL	07/31/62	158	20	10	2	Twr
T11N R62W S.01 SW NE	45197	V. HNIZDIL	04/06/71	154	25	15	1	Twr
T11N R62W S.03 NE NW	84241	R. BURBACH	06/13/76	105	57	12	1	Twr
T11N R62W S.15 NE NE	13277	G. KONIG	10/00/62	84	60	12	1	Qa, Twr
T11N R62W S.23 NE NE	19519F	E. ANDERSON	09/12/10	?	?	415	6	Qa?
T11N R62W S.24 SE NW	7050R	T-R INC.	06/00/55	50	20	500	6	Qa
T11N R62W S.25 C SW	12729F	T-R INC.	02/28/68	43	15	550	6	Qa
T11N R62W S.25 C SW	13043F	T-R INC.	00/00/68	43	?	200	6	Qa
T11N R62W S.25 SW NE	13041F	T-R INC.	06/00/68	38	16	200	6	Qa
T11N R62W S.25 NE NE	13188F	T-R INC.	?	?	?	?	6	Qa?
T11N R62W S.25 NW SW	13042F	T-R INC.	06/00/68	43	14	200	6	Qa
T11N R62W S.26 NW SE	12734F	O. DOUGLAS	03/01/69	79	20	680	6	Qa
T11N R62W S.26 SW NE	39815	C. KONIG	11/05/69	39	19	10	2	Qa
T11N R62W S.26 SE SW	119589	O. DOUGLAS	00/00/34	?	?	5	1	Qa?
T11N R62W S.26 SW NW	129084	C. NUSSBAUM	03/01/83	45	11	15	2	Qa
T11N R62W S.27 NE NE	7366R	C. NUSSBAUM	06/18/78	42	11.4	340	6	Qa
T11N R62W S.30 NW NE	24654	B. REICHLEY	07/16/65	133	29	18	3	Twr
T11N R62W S.32 NW NW	28461	J. BURNETT	08/20/66	118	28	15	3	Twr
T11N R62W S.35 NE NW	5303F	T-R INC.	04/21/64	56	12	450	6	Qa
T11N R62W S.35 SW NW	8279R	T-R INC.	05/00/53	60	12.2	850	6	Qa
T11N R62W S.35 NE NW	8280R	T-R INC.	05/00/54	59	9	1500	6	Qa
T11N R62W S.35 SW NW	13198F	T-R INC.	03/20/65	58	15	1000	6	Qa
T11N R62W S.36 NE SE	64658	T-R INC.	09/27/72	62	15	25	2	Twr
T12N R60W S.20 NW SW	15086F	L. JESSEN	03/27/70	150	?	800	6	Twr
T12N R60W S.31 NE NE	10460F	C. TIETMEYER	01/11/66	350	68.0	650	6	Twr
T12N R60W S.31 NE NE	25784	C. TIETMEYER	11/20/65	195	48	40	3	Twr
T12N R61W S.20 NW NE	15359F	BAUMAN RANCH INC.	01/21/71	100	13	1000	6	Qf
T12N R61W S.24 SE SE	23210	BRIGGSDALE GRAZING ASSOC.	04/15/65	75	30	25	2	Twr
T12N R61W S.26 NE SE	22806F	V. ZITEK	08/10/74	190	28	750	6	Twr
T12N R61W S.27 SW SW	25658	S. CLAYPOOL	11/13/65	175	31	18	3	Twr
T12N R61W S.28 SW NW	80002	E. GORDON	07/22/75	45	7	15	3	Qf
T12N R61W S.31 SE NE	14198	W. PETERS	03/07/63	60	32	4	2	Qf
T12N R61W S.31 NW NW	16344F	J. LOYD	04/01/73	120	36	170	6	Qf
T12N R61W S.31 NW NE	16345F	J. LOYD	10/17/77	116	43	250	6	Qf
T12N R61W S.31 SW SW	82326	LOYD FARMS	03/25/76	120	44	15	1	Qf?, Twr
T12N R61W S.31 SW NE	97430	J. LOYD	04/18/78	120	45.1	15	2	Qf
T12N R61W S.32 SW NW	43057	J. LOYD	09/03/70	93	36	20	1	Qf

LOCATION	PERMIT NO.	OWNER	COMPLETION DATE	WELL DEPTH (ft)	DEPTH TO WATER (ft)	YIELD (gpm)	USE	AQUIFER
T12N R61W S.33 SE SW	20522F	J. LOYD	04/01/73	73	25	625	6	Twr
T12N R61W S.33 SW SE	21497F	J. LOYD	07/20/77	102	33	700	6	Twr
T12N R61W S.35 C NE	20524F	L. JESSEN	10/10/76	180	36	150	6	Twr
T12N R62W S.20 NW NW	251R	A. & C. JOHNSON	05/00/48	70	17	180	6	Qa, Qf
T12N R62W S.20 NW NW	252R	A. & C. JOHNSON	06/00/57	85	17	550	6	Qa, Qf
T12N R62W S.20 SE SE	253R	A. & C. JOHNSON	05/00/51	110	23	540	6	Qa, Qf
T12N R62W S.20 SE SE	254R	A. & C. JOHNSON	05/00/57	100	6.0	500	6	Qa, Qf
T12N R62W S.21 SW NE	13896F	J. LOYD	10/08/69	125	50	564	6	Qf
T12N R62W S.21 SW SE	13897F	J. LOYD	08/30/69	110	47	800	6	Qf
T12N R62W S.21 NE SE	14645F	J. LOYD	05/07/70	131	42	900	6	Qf
T12N R62W S.21 NE NE	16334F	J. LOYD	04/01/75	145	35	400	6	Qf
T12N R62W S.23 NW SE	4920F	T-R INC.	12/10/63	122	32	1000	6	Qf
T12N R62W S.24 SW SW	2677F	E. LESH	07/00/60	148	29	1100	6	Qf
T12N R62W S.24 SW NW	2699F	E. LESH	00/00/00	?	?	?	6	Qf
T12N R62W S.24 NE NW	9188F	E. LESH	11/07/73	159	34	700	6	Qf
T12N R62W S.24 SW SE	9189F	LOYD FARMS	05/15/73	?	?	750	6	Qf
T12N R62W S.24 SW NW	10991R	E. LESH	00/00/42	153	34	1000	6	Qf
T12N R62W S.24 SW NW	10922R	E. LESH	04/00/55	101	39	600	6	Qf
T12N R62W S.24 SE NE	16875F	D. FOGG	09/03/73	137	32	700	6	Qf
T12N R62W S.25 NW NW	4886F	E. LOYD	12/02/63	136	31	1200	6	Qf
T12N R62W S.25 NE SW	13183F	C. TIETMEYER	09/25/68	130	44.4	900	6	Qf
T12N R62W S.25 NW NW	16236R	E. & J. LOYD	00/00/54	135	44.2	1200	6	Qf
T12N R62W S.25 NW NW	66706	T-R INC.	12/06/72	75	35	12	2	Qf
T12N R62W S.26 NW NW	12102R	E. LOYD	00/00/30	150	80	800	6	Qf
T12N R62W S.26 SW NW	12103R	J. LOYD	09/27/51	150	49.0	950	6	Qf
T12N R62W S.26 SE SE	13184F	C. TIETMEYER	10/31/68	135	45.0	1200	6	Qf
T12N R62W S.26 SW SW	13185F	C. TIETMEYER	10/27/69	140	37	459	6	Qf
T12N R62W S.26 SW NW	22374	M. HOKE	12/00/64	120	40	30	1	Qf
T12N R62W S.26 SE SE	43594	C. TIETMEYER	10/18/70	120	56	20	1	Qf
T12N R62W S.27 SW NW	2161F	J. LOYD	06/01/62	110	63	800	6	Qf
T12N R62W S.27 NE NW	6900F	J. LOYD	00/00/42	125	?	1200	6	Qf
T12N R62W S.27 NE NW	6901F	J. LOYD	11/00/51	128	37	1100	6	Qf
T12N R62W S.27 SE SW	13957	F. MASON	02/27/63	100	35	10	1	Qa, Qf
T12N R62W S.28 SW NE	24136R	JOHNSON	?	?	?	?	6	Qa?
T12N R62W S.34 SW NE	6758F	T-R INC.	05/00/65	45	5	700	6	Qa
T12N R62W S.34 NE NW	6941R	T-R INC.	00/00/53	60	22	700	6	Qa
T12N R62W S.34 NW NE	6942R	T-R INC.	00/00/42	60	24.5	600	6	Qa
T12N R62W S.34 NE NE	6943R	T-R INC.	00/00/40	100	36	450	6	Qf
T12N R62W S.34 NW NE	6946R	F. MASON	10/00/53	42	18	350	6	Qa
T12N R62W S.34 NE NW	47855	R. BREAZEALE	08/03/71	83	15	15	1	Twr
T12N R62W S.35 NW SW	6944R	T-R INC.	00/00/00	52	9	500	6	Qf
T12N R62W S.35 NW SE	6940R	T-R INC.	06/00/40	80	22.5	800	6	Qa
T12N R62W S.35 SW NW	6945R	T-R INC.	00/00/43	100	35	1000	6	Qa, Qf
T12N R62W S.35 NW SE	105040	T-R INC.	04/01/79	80	?	15	3	Qa?, Twr

APPENDIX D
Water Wells that are Adjudicated, but not Registered
(data from State Engineer's records)

LOCATION			NAME	APPROPRIATION DATE	ADJUDICATED AMOUNT(CFS)	USE[1]	AQUIFER[2]
T9N	R61W	S.28 NW NW	COCHRAN WELL 4	12/31/31	0.0266	2	?
T9N	R61W	S.29 SW SW	COCHRAN WELL 3	12/31/17	0.033	2	?
T9N	R61W	S.33 NW NW	COCHRAN WELL 1	12/31/17	0.0264	2	?
T10N	R60W	S.17 SE SW	SCHUEB WELL 5	05/31/16	0.011	2	Twr
T10N	R60W	S.04 NW SW	EVERITT WELL 10	09/20/31	0.013	2	Qa?; Twr
T10N	R61W	S.05 SE NE	GROVER WELL 1	12/31/19	0.124	8	Twr; Kul?
T10N	R61W	S.05 SE NE	GROVER WELL 2	12/31/56	0.133	8	Twr; Kul?
T10N	R61W	S.10 SW SE	EVERITT WELL 6	09/20/25	0.033	2	Qa?; Twr
T10N	R61W	S.10 SW SE	EVERITT WELL 7	09/20/41	0.033	2	Qa?; Twr
T10N	R61W	S.10 NE NW	EVERITT WELL 8	09/20/57	0.033	2	Qa?; Twr
T10N	R61W	S.13 NW SW	SCHEUB WELL 1	05/31/09	0.223	2	Twr
T10N	R61W	S.23 SW SE	SCHEUB WELL 4	09/30/56	0.167	2	Twr
T10N	R61W	S.23 NW NW	EVERITT WELL 9	12/15/62	0.044	2	Twr
T10N	R61W	S.24 NW SW	SCHEUB WELL 2	09/30/56	0.011	2	Twr
T10N	R61W	S.24 SE NE	SCHEUB WELL 3	05/31/42	0.167	2	Twr
T10N	R62W	S.01 SW SE	T-R INC. WELL 22	06/20/15	0.0288	2	Qa
T10N	R62W	S.01 SW SE	T-R INC. WELL 18	06/20/51	0.12	1	Qa
T10N	R62W	S.09 NW NW	McDOWALL WELL 1	06/28/52	0.018	3	Twr
T11N	R62W	S.13 SE SW	T-R INC. WELL 28	06/20/36	0.0266	2	Qa
T11N	R62W	S.14 NW NE	T-R INC. WELL 29	06/20/71	0.0333	2	Qa
T11N	R62W	S.20 SE SE	REICHLEY WELL 1	03/15/10	0.016	3	Twr
T11N	R62W	S.22 NE SE	KONIG WELL 2	09/01/09	0.111	3	Qa
T11N	R62W	S.24 NW SE	T-R INC. WELL 20	06/20/34	0.05	3	Qa
T11N	R62W	S.24 NE SE	T-R INC. WELL 21	06/20/40	0.022	1	Qa
T11N	R62W	S.25 SW NE	T-R INC. WELL 19	06/20/35	0.17	3	Qa
T11N	R62W	S.25 NW NE	T-R INC. WELL 27	06/20/66	0.0444	2	Qa
T11N	R62W	S.25 SE NE	T-R INC. WELL 17	06/20/72	0.44	6	Qa
T11N	R62W	S.26 SE SE	KONIG WELL 3	06/15/41	0.022	3	Qa
T11N	R62W	S.27 NE NE	GRACIK WELL 5	12/31/52	0.021	2	Qa
T11N	R62W	S.28 NW NW	KONIG WELL 1	04/10/10	0.0089	3	Twr
T11N	R62W	S.35 SE SW	T-R INC. WELL 24	06/20/15	0.02	2	Qa
T11N	R62W	S.35 NE NW	T-R INC. WELL 25	06/20/52	0.0355	2	Qa
T11N	R62W	S.35 NW NE	DOUGLAS WELL 2	10/15/54	0.84	3	Qa
T11N	R62W	S.36 SE SW	T-R INC. WELL 23	06/20/17	0.0244	2	Qa
T12N	R60W	S.20 SW NE	BAUGH WELL 1	10/15/41	0.01	2	Twr
T12N	R61W	S.19 NW NE	LAMMEY WELL 1	12/19/50	2.44	6	Qf
T12N	R61W	S.22 SW NE	McCURRY WELL 1	07/10/37	0.78	6	Qf
T12N	R62W	S.24 SW NW	LESH WELL 4	12/31/46	0.051	1	Qf
T12N	R62W	S.26 SW NW	HOKE WELL 3	09/01/18	0.033	3	Qf
T12N	R62W	S.28 SW NE	BLAKE WELL 1	06/20/51	0.78	6	Qa

1) USE: 1=domestic, 2=livestock, 3=combined domestic and livestock, 4=commercial, 5=industrial, 6=irrigation, 8=municipal, 9=other

2) AQUIFER: Qa=Alluvial Aquifer, Qf=Fan Aquifer, Twr=White River Aquifer, Kul=Upper Laramie Aquifer, Klf=Laramie-Fox Hills Aquifer

APPENDIX E
Registered and Adjudicated Wells that have been in Use for the Past Fifteen Years (since 1/1/71).
(data from State Engineer's records)

LOCATION	PERMIT #	OWNER	USE[1]	FIRST YEAR OF USE
T8N R61W S.05 NW NW	8243	GRAEFE & GRAEFE INC.	2	1961
T8N R61W S.06 NW SW	8242	GRAEFE & GRAEFE INC.	2	1961
T8N R61W S.09 SW SE	40746	W. SCHAWO	2	1970
T8N R61W S.10 NW SW	19333	K. PIERCE	2	1964
T8N R61W S.11 SW NE	23209	L. JESSON	2	1965
T8N R61W S.15 NE SE	23214	BRIGGSDALE GRAZING ASSOC.	2	1965
T8N R61W S.17 SW NE	20732	W. SIEVERS	2	1964
T8N R61W S.21 NE NE	23212	BRIGGSDALE GRAZING ASSOC.	2	1965
T8N R61W S.22 NW SE	13963	K. WASHBURN	1	1963
T8N R61W S.11 SE SE	36955	P. FREEMAN	1	1969
T9N R61W S.04 NE SW	4688F	PEPPER TANK CO.	5	1963
T9N R61W S.04 SW SE	4734F	PEPPER TANK CO.	5	1963
T9N R61W S.06 SW NW	5603	W. JOHNSON	1	1960
T9N R61W S.05 NW NE	12861R	E. DUNBAR	6	1939
T9N R61W S.28 NW NW	-	COCHRAN	2	1931
T9N R61W S.29 SW SW	-	COCHRAN	2	1917
T9N R61W S.32 SE NW	29506	R. COCHRAN	2	1966
T9N R61W S.33 NW NW	-	COCHRAN	2	1917
T9N R61W S.34 NE SE	453	D.KENNISON	2	1957
T9N R61W S.34 NE SE	620	D. KENNISON	2	1957
T9N R62W S.25 NW SW	12014	GRAEFE & GRAEFE INC.	2	1962
T10N R60W S.07 NE SE	50791	U.S. FOREST SERVICE	2	1911
T10N R60W S.17 SE SW	-	SCHUEB	2	1916
T10N R60W S.34 NE NE	20154	J. HOFFMAN	2	1964
T10N R61W S.04 NE SW	43496	C. BARR	1	1970
T10N R61W S.04 NW SW	-	EVERITT	2	1931
T10N R61W S.05 NW NE	11174F	TOWN OF GROVER	8	1966
T10N R61W S.05 SE NE	-	TOWN OF GROVER	8	1919
T10N R61W S.05 SE NE	-	TOWN OF GROVER	8	1956
T10N R61W S.06 NE NW	6406R	MARICK	6	1955
T10N R61W S.06 NE NW	6407R	MARICK	6	1953
T10N R61W S.07 SE SW	12352	W. BASHOR	2	1963
T10N R61W S.09 NW NW	16093	C. ROWLEY	2	1963
T10N R61W S.10 SW SE	-	EVERITT	2	1925
T10N R61W S.10 SW SE	-	EVERITT	2	1941
T10N R61W S.10 NE NW	-	EVERITT	2	1957
T10N R61W S.10 NW SE	12873F	W. EVERITT	6	1968
T10N R61W S.10 SE SE	13379F	W. EVERITT	6	1969
T10N R61W S.13 NW SW	-	SCHUEB	2	1909
T10N R61W S.14 NE NE	14484R	STONE	6	1949

LOCATION	PERMIT #	OWNER	USE[1]	FIRST YEAR OF USE
T10N R61W S.14 SW SE	13859	C. RAWLEY	2	1962
T10N R61W S.17 SW SE	12351	W. BASHOR	2	1962
T10N R61W S.19 NE NE	32124	D. BASHOR	1	1967
T10N R61W S.23 SW SE	-	SCHUEB	2	1956
T10N R61W S.23 NW NW	-	EVERITT	2	1962
T10N R61W S.24 NW SW	-	SCHUEB	2	1956
T10N R61W S.24 SE NE	-	SCHUEB	2	1942
T10N R61W S.33 SW SW	6396	W.BASHOR	2	1960
T10N R62W S.01 NW NE	8276R	T-R INC.	6	1952
T10N R62W S.01 NW NE	8277R	T-R INC.	6	1909
T10N R62W S.01 NW NE	8278R	T-R INC.	6	1953
T10N R62W S.01 SW SE	-	T-R INC.	2	1915
T10N R62W S.01 SW SE	-	T-R INC.	1	1951
T10N R62W S.02 NE NW	4516R	J. & H. GRACIK	6	1952
T10N R62W S.02 NE NW	4517R	J. & H. GRACIK	6	1952
T10N R62W S.02 NE SW	8704R	J. & H. GRACIK	6	1955
T10N R62W S.09 NW NW	-	McDOWALL	3	1952
T10N R62W S.14 NW NE	28606	H. GRACIK	2	1966
T10N R62W S.16 NW NE	2038F	G. KONIG	6	1959
T10N R62W S.16 NW NW	13276	A. WERNER	3	1962
T11N R60W S.10 NW SW	29357	R. STEINER	2	1966
T11N R60W S.10 SE SE	42518	R. STEINER	2	1970
T11N R60W S.17 SW NE	20734	M. FOSTER	2	1964
T11N R61W S.04 SW SW	82527	C. & L. ZIPPERER	9	1960
T11N R61W S.04 SE SW	106982	C. & L. ZIPPERER	1	1960
T11N R61W S.21 NW SW	108033	BAUMAN RANCH INC.	2	1949
T11N R61W S.23 NW SE	20733	B. WILSON	2	1964
T11N R61W S.25 SE NW	16432	C. SMOCK	2	1963
T11N R61W S.25 SE NW	16837	C. SMOCK	2	1963
T11N R61W S.32 SW SW	12498	R. ARDOUREL	2	1962
T11N R62W S.13 SE SW	-	T-R INC.	2	1936
T11N R62W S.15 NE NE	13277	G. KONIG	1	1962
T11N R62W S.20 SE SE	-	REICHELY	3	1910
T11N R62W S.22 NE SE	-	KONIG	3	1909
T11N R62W S.23 NE NE	19519F	E. ANDERSON	6	1910
T11N R62W S.24 NW SE	-	T-R INC.	3	1934
T11N R62W S.24 NE SE	-	T-R INC.	1	1940
T11N R62W S.24 SE NW	7050R	T-R INC.	6	1955
T11N R62W S.25 C SW	12729F	T-R INC.	6	1968
T11N R62W S.25 C SW	13043F	T-R INC.	6	1968

LOCATION	PERMIT #	OWNER	USE[1]	FIRST YEAR OF USE
T11N R62W S.25 SW NE	13041F	T-R INC.	6	1968
T11N R62W S.25 NE NE	13188F	T-R INC.	6	1968
T11N R62W S.25 NW SW	13042F	T-R INC.	6	1968
T11N R62W S.25 SW NE	-	T-R INC.	3	1935
T11N R62W S.25 NW NE	-	T-R INC.	2	1966
T11N R62W S.26 SE SE	-	KONIG	3	1941
T11N R62W S.26 NW SE	1273F	O.DOUGLAS	6	1969
T11N R62W S.26 SW NE	39815	G. KONIG	2	1969
T11N R62W S.26 SE SW	119589	O.DOUGLAS	1	1934
T11N R62W S.27 NE NE	-	GRACIK	2	1952
T11N R62W S.28 NW NW	-	KONIG	3	1941
T11N R62W S.30 NW NE	24654	B. REICHLEY	3	1965
T11N R62W S.32 NW NW	28461	J. BURNETT	3	1966
T11N R62W S.35 NE NW	5303F	T-R INC.	6	1964
T11N R62W S.35 NE NW	8280R	T-R INC.	6	1954
T11N R62W S.35 SW NW	13198F	T-R INC.	6	1965
T11N R62W S.35 SE SW	-	T-R INC.	2	1915
T11N R62W S.35 NE NW	-	T-R INC.	2	1952
T11N R62W S.35 NW NE	-	DOUGLAS	3	1954
T11N R62W S.36 SE SW	-	T-R INC.	2	1917
T12N R60W S.20 SW NE	-	BAUGH	2	1941
T12N R60W S.20 NW SW	15086F	L. JESSEN	6	1970
T12N R60W S.31 NE NE	10460F	C. TIETMEYER	6	1966
T12N R60W S.31 NE NE	25784	C. TIETMEYER	3	1965
T12N R61W S.19 NW NE	-	LAMMEY	6	1950
T12N R61W S.22 SW NE	-	McCURRY	6	1937
T12N R61W S.24 SE SE	23210	BRIGGSDALE GRAZING ASSOC.	2	1965
T12N R61W S.27 SW SW	25658	S. CLAYPOOL	3	1965
T12N R61W S.31 SE NE	14198	W. PETERS	2	1963
T12N R61W S.32 SW NW	43057	J. LOYD	1	1970
T12N R62W S.20 NW NW	251R	JOHNSON	6	1948
T12N R62W S.20 NW NW	252R	JOHNSON	6	1957
T12N R62W S.20 SE SE	253R	JOHNSON	6	1951
T12N R62W S.21 SW NE	13896F	J. LOYD	6	1969
T12N R62W S.21 SW SE	13897F	J. LOYD	6	1969
T12N R62W S.21 NE SE	14645F	J. LOYD	6	1970
T12N R62W S.23 NW SE	4920F	T-R INC.	6	1963
T12N R62W S.24 SW NW	-	LESH	1	1946
T12N R62W S.24 SW SW	2677F	E. LESH	6	1960
T12N R62W S.24 SW NW	2699F	E. LESH	6	prior to 1971

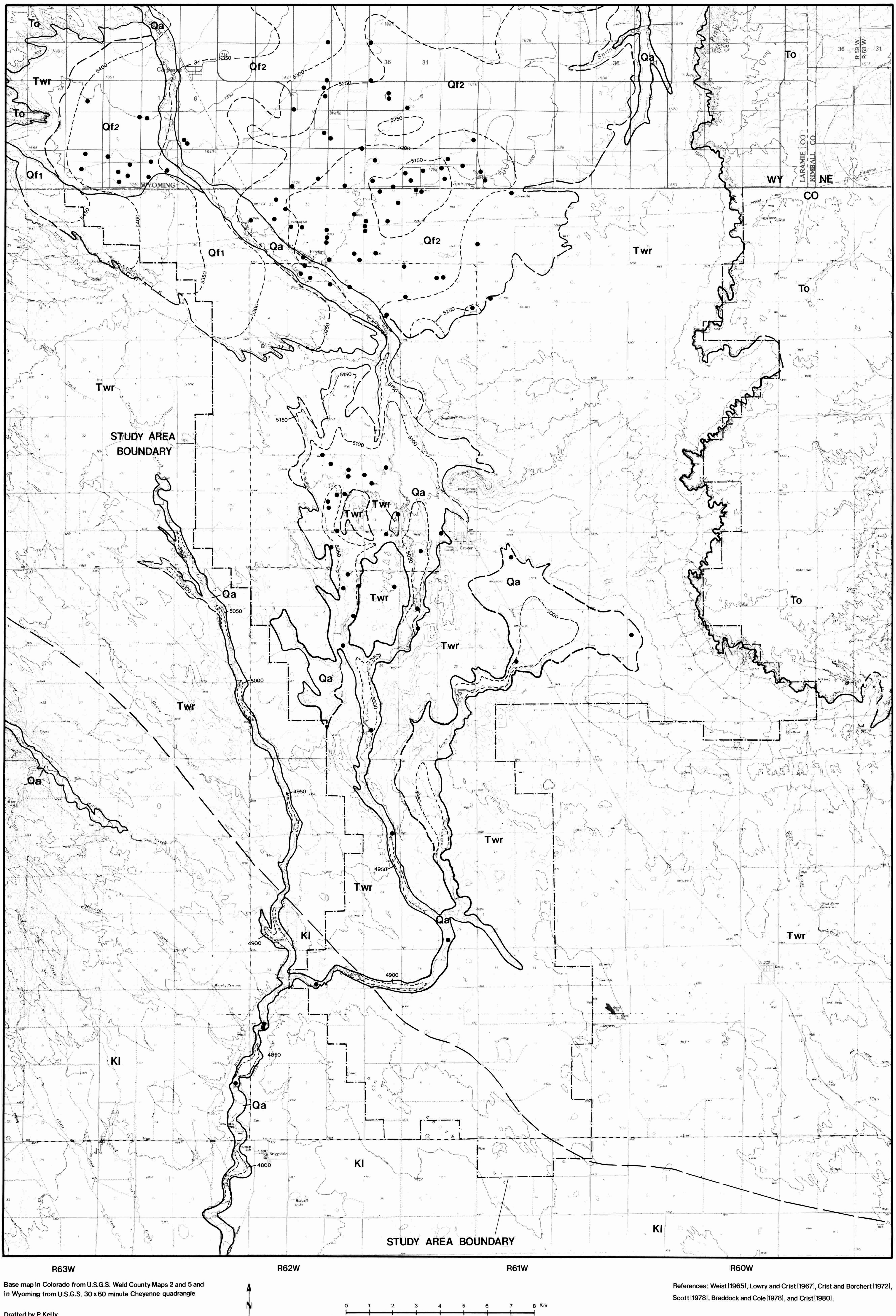
LOCATION	PERMIT #	OWNER	USE[1]	FIRST YEAR OF USE
T12N R62W S.24 SW NW	10991R	E. LESH	6	1942
T12N R62W S.24 SW NW	10992R	E. LESH	6	1955
T12N R62W S.25 NW NW	4886F	E. LOYD	6	1963
T12N R62W S.25 NW NW	16236F	E. & J. LOYD	6	1954
T12N R62W S.25 NW SW	13183F	C. TIETMEYER	6	1968
T12N R62W S.26 SW SW	13185F	C. TIETMEYER	6	1969
T12N R62W S.26 SW NW	-	HOKE	3	1918
T12N R62W S.26 NW NW	12102R	LOYD FARMS	6	1930
T12N R62W S.26 SW NW	12103R	J. LOYD	6	1951
T12N R62W S.26 SE SE	13184F	C. TIETMEYER	6	1968
T12N R62W S.26 SW NW	22374	M. HOKE	1	1964
T12N R62W S.26 SE SE	43594	C. TIETMEYER	1	1970
T12N R62W S.27 SW NW	2161F	J. LOYD	6	1962
T12N R62W S.27 NE NW	6900F	J. LOYD	6	1942
T12N R62W S.27 NE NW	6901F	J. LOYD	6	1951
T12N R62W S.27 SE SW	13957	F. MASON	1	1963
T12N R62W S.28 SW NE	-	JOHNSON	6	1951
T12N R62W S.34 SW NE	6758F	T-R INC.	6	1965
T12N R62W S.34 NE NW	6941R	T-R INC.	6	1953
T12N R62W S.34 NW NE	6942R	T-R INC.	6	1942
T12N R62W S.34 NE NE	6934R	T-R INC.	6	1940
T12N R62W S.34 NW NE	6946R	T-R INC.	6	1953
T12N R62W S.34 NE NE	6944R	T-R INC.	6	1942
T12N R62W S.35 NW SE	6940R	T-R INC.	6	1940
T12N R62W S.35 SW NW	6945R	T-R INC.	6	1943

1)SEE APPENDIX C

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
JOHN W. ROLD, DIRECTOR

Geologic Map and Elevation of the Bedrock Surface Beneath the Alluvial and Fan Deposits, Upper Crow Creek Area, Colorado

by Robert M. Kirkham



Base map in Colorado from U.S.G.S. Weld County Maps 2 and 5 and in Wyoming from U.S.G.S. 30 x 60 minute Cheyenne quadrangle

Drafted by P. Kelly

References: Weist (1965), Lowry and Crist (1967), Crist and Borchert (1972), Scott (1978), Braddock and Cole (1978), and Crist (1980).

Explanation

Qa Quaternary Stream Alluvium – Composed of interbedded sand, gravel, silt, and clay up to 60 feet thick. Generally becomes finer grained southward. Locally includes adjacent low-lying terrace deposits.

Qf1
Qf2 Quaternary Fan Deposits – Consists of interbedded sand, gravel, silt, and clay up to 150 feet thick. Number indicates relative age. Qf1 is older and topographically higher than Qf2.

To Miocene Ogallala Formation – Consists of unconsolidated to well-cemented sand, silt, and gravel. Locally includes freshwater limestone and volcanic ash.

Twr Oligocene White River Group – Includes the Brule Formation and underlying Chadron Formation. Dominantly blocky, ashy, mica-bearing siltstone. Typically light gray to light brown, but occasionally is variegated, particularly in lower part. Includes local channel deposits of arkosic conglomerate and sandstone.

Kl Cretaceous Laramie Formation – Consists of carbonaceous claystone, siltstone, sandstone, and lignite.

Note: Much of the mapped area is blanketed by a thin veneer of wind-blown sand and silt. Topographic features typical of eolian processes are common in these areas. The Fox Hills Sandstone and other deeper formations underlie the study area, but do not crop out in it.

Geologic Contact – dashed where approximately located.

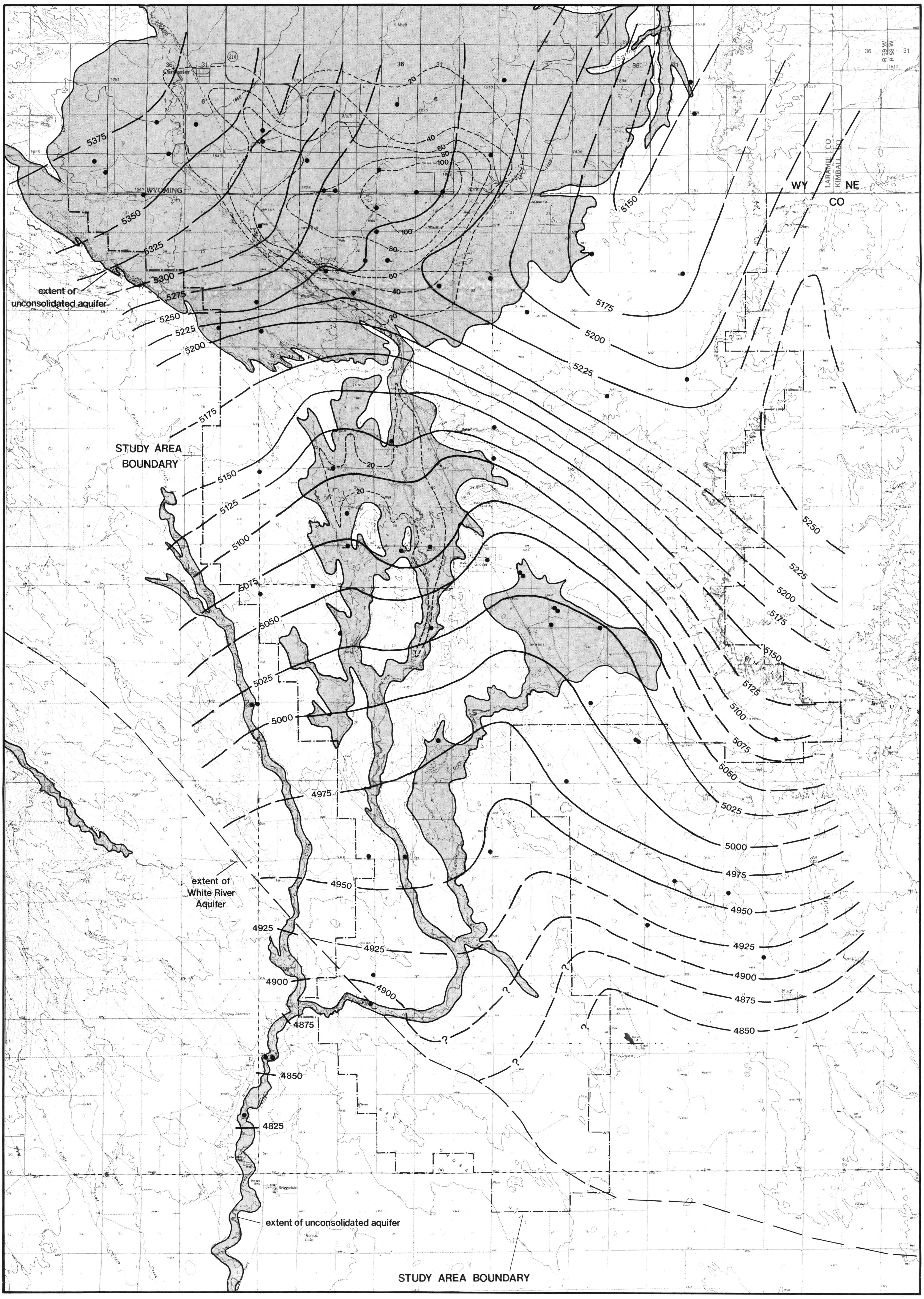
Elevation of Bedrock Surface beneath Quaternary Deposits – Contours marked in feet above sea level and are approximately located.

Bedrock elevation control point.

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
JOHN W. ROLD, DIRECTOR

Map Showing Saturated Thickness of the Alluvial and Fan Aquifers and the Potentiometric Surface of the Unconfined Aquifers During January, 1986, Upper Crow Creek Area, Colorado

by Robert M. Kirkham



R63W R62W R61W R60W

Base map in Colorado from U.S.G.S. Weld County Maps 2 and 5 and in Wyoming from U.S.G.S. 30 x 60 minute Cheyenne quadrangle

Drafted by P. Kelly

References: Crist and Borchert (1972), Crist (1980), Kirkham and others (1980).

0 1 2 3 4 5 6 7 8 Km
0 1 2 3 4 5 6 Mi

Explanation

—5000— Potentiometric Contour – shows altitude in feet above mean sea level at which the water level would have stood in tightly cased wells during January, 1986; dashed where approximately located. Contour interval is 25 feet.

• Water-level Control Point.

– – 20 – – Saturated thickness of Quaternary age Alluvial and Fan Aquifers in feet. Contour interval is 20 feet.

[shaded box] Area underlain by the Alluvial or Fan Aquifers

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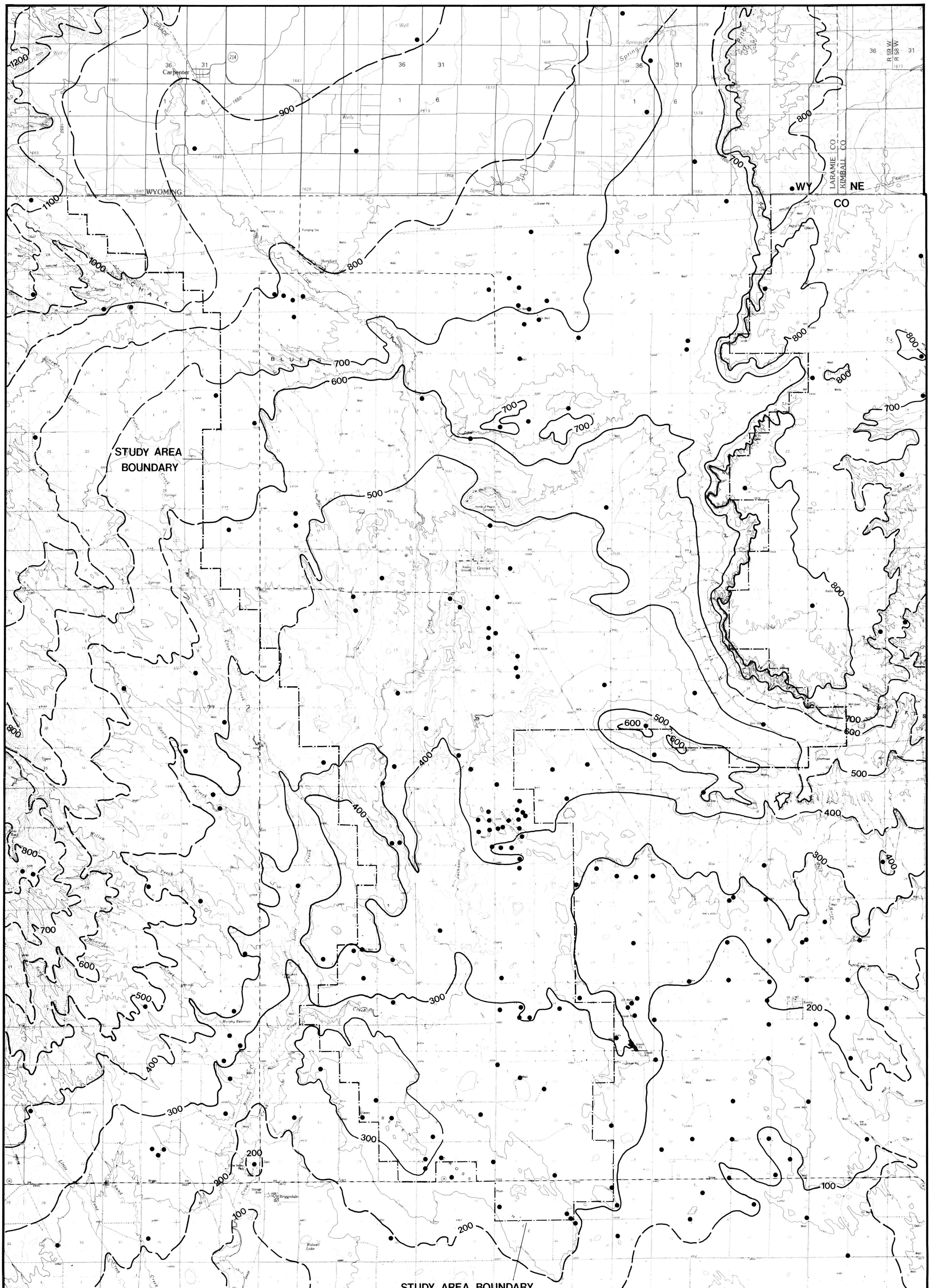
Map Showing Depth to the Top of the Laramie-Fox Hills Aquifer, Upper Crow Creek Area, Colorado

by Robert M. Kirkham



Base map in Colorado from U.S.G.S. Weld County Maps 2 and 5 and in Wyoming from U.S.G.S. 30 x 60 minute Cheyenne quadrangle

Drafted by P. Kelly

Explanation

Contour line showing depth in feet to the top of the Laramie-Fox Hills Aquifer; dashed where approximately located.

Depth control point.

COLORADO GEOLOGICAL SURVEY
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Cross-section A-A′

by Robert M. Kirkham

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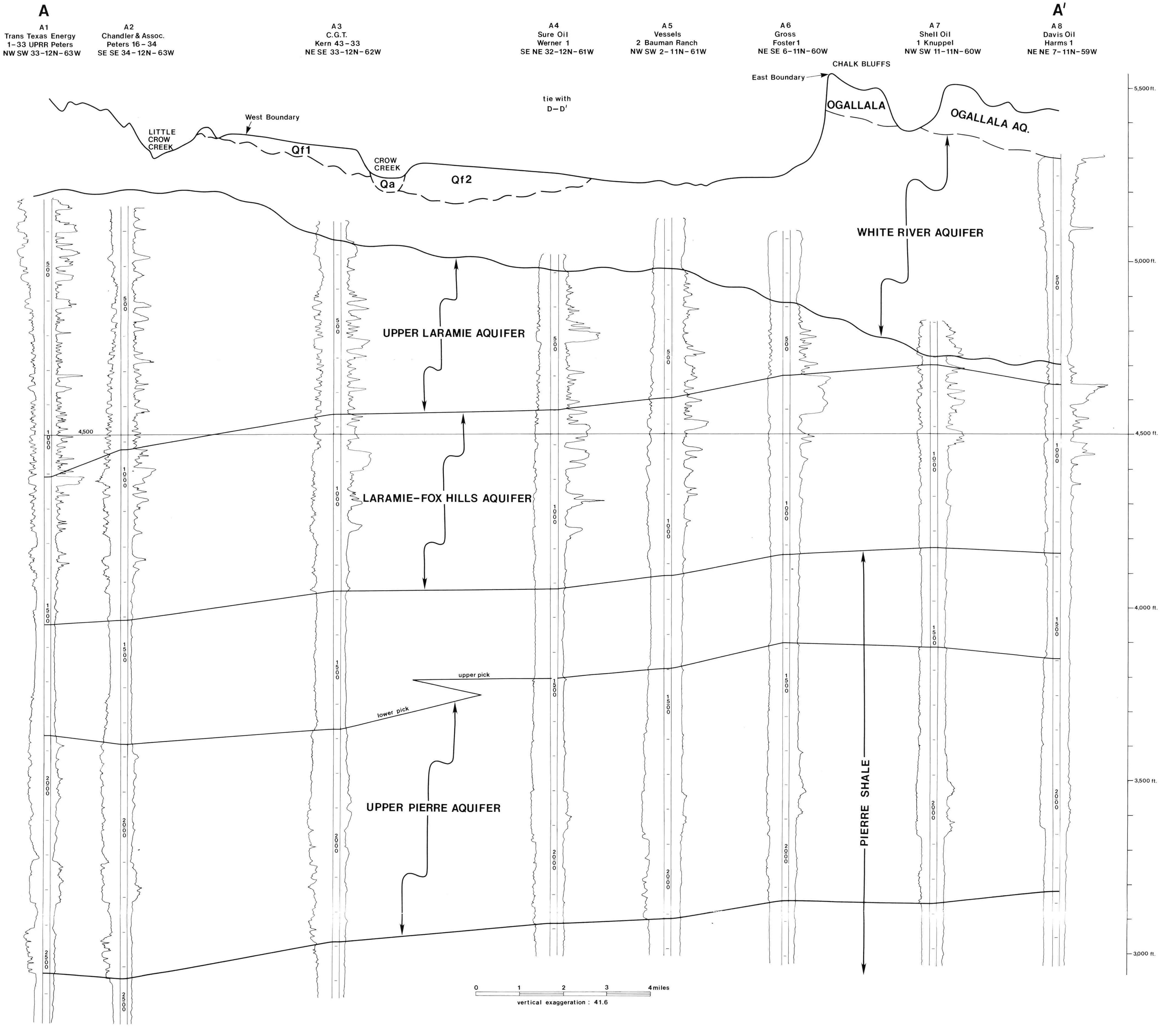

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Cross-section B – B′

by Robert M. Kirkham

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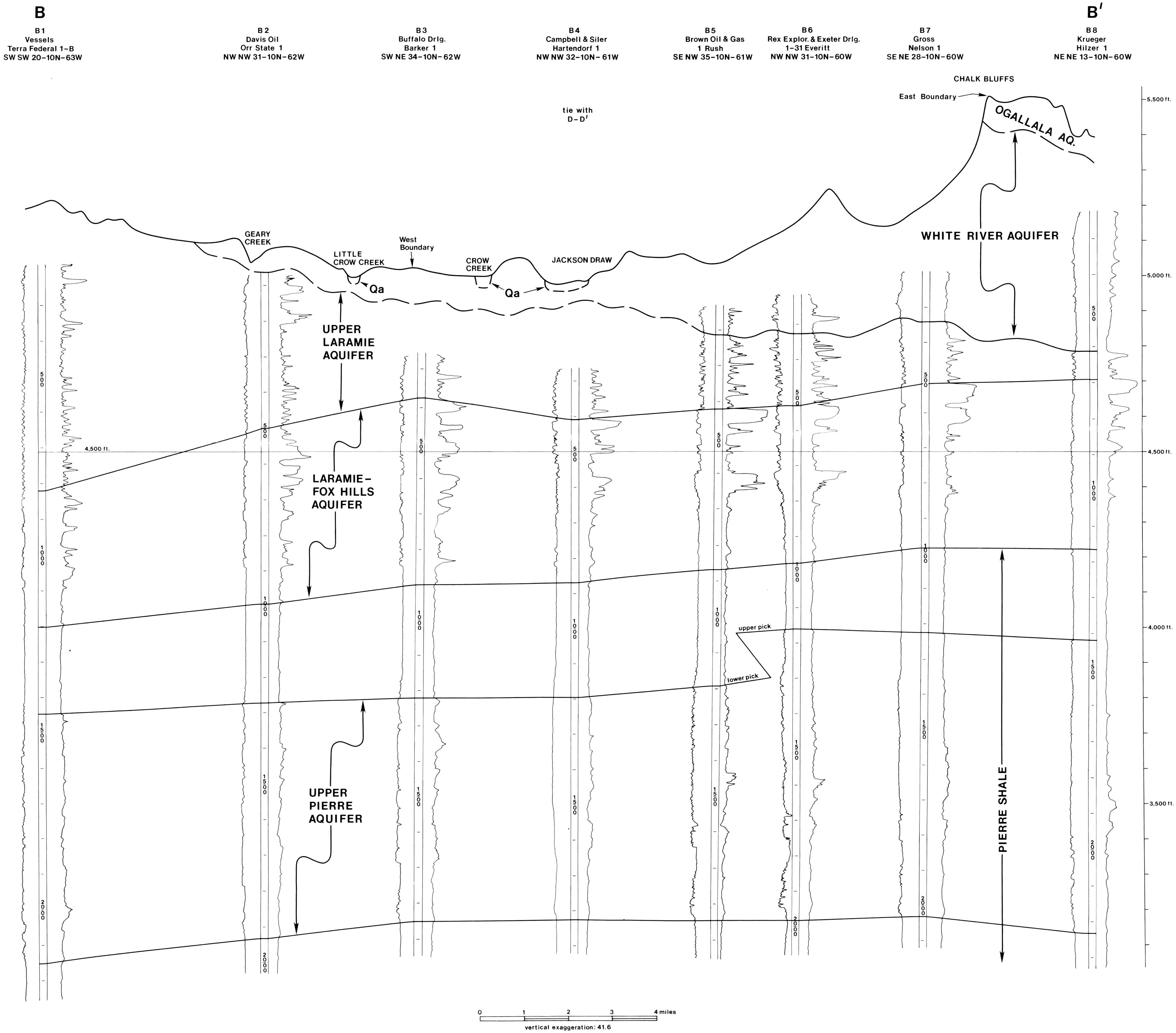

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Cross-section C-C′

by Robert M. Kirkham

SPECIAL PUBLICATION 29
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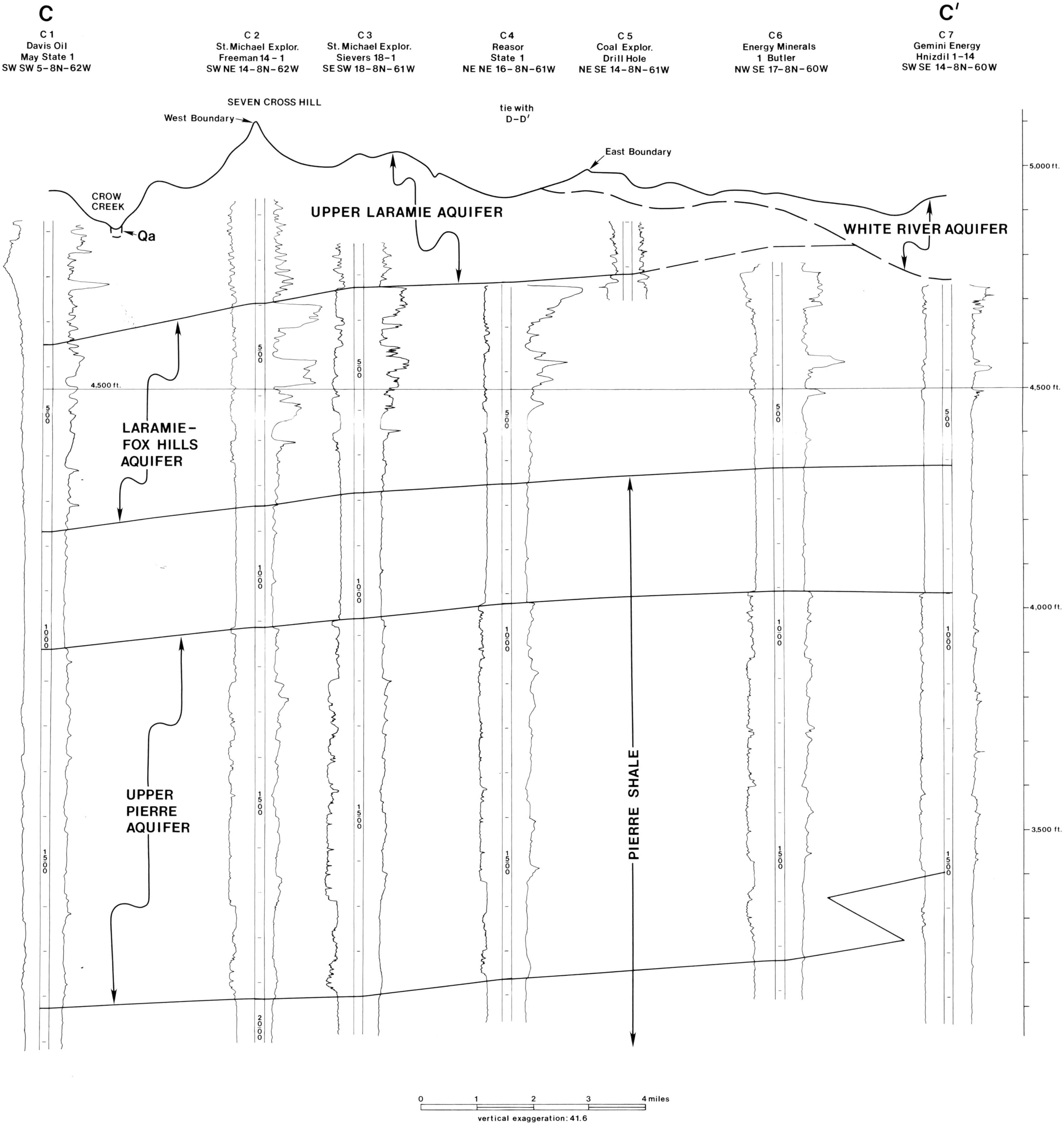

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Cross-section D-D′

by Robert M. Kirkham

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