WATER RESOURCES OF THE RATTLESNAKE BUTTE AREA, A SITE OF POTENTIAL LIGNITE MINING IN WEST-CENTRAL NORTH DAKOTA

by W. F. Horak

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SELECTED FACTORS FOR CONVERTING INCH-POUND UNITS TO THE INTERNATIONAL SYSTEM OF UNITS (SI)

For those readers who may prefer to use the International System of units (SI) rather than inch-pound units, the conversion factors for the terms used in this report are given below.

Multiply inch-pound unit	By	To obtain SI unit
Acre	0.4047	hectare
Cubic foot per second (ft^3/s)	0.02832	cubic meter per second
Foot	0.3048	meter
Foot per foot (ft/ft)	1	meter per meter
Foot per day (ft/d)	0.3048	meter per day
Foot per mile (ft/mi)	0.1894	meter per kilometer
Foot squared per day (ft^2/d)	0.0929	meter squared per day
Gallon	0.003785	cubic meter
	3.785	liter
Gallon per minute (gal/min)	0.00006309	cubic meter per second
Gallon per minute per foot [(gal/min)/ft]	0.000207	cubic meter per second per meter
Inch	25.40	millimeter
Micromho per centimeter (μmho/cm) (at 25°C)	1	microSiemen
Mile	1.609	kilometer
Square mile (mi^2)	2.590	square kilometer

To convert degrees Fahrenheit (°F) to degrees Celsius (°C) use the following formula °C = (°F-32)x5/9.

Milligrams per liter (mg/L) is a unit expressing the concentration of a chemical constituent in a solution as weight (milligrams) of solute per unit volume (liter) of water; 1 mg/L equals 1,000 micrograms per liter (μg/L).

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

WATER RESOURCES OF THE RATTLESNAKE BUTTE AREA, A SITE OF POTENTIAL LIGNITE MINING IN WEST-CENTRAL NORTH DAKOTA

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ABSTRACT

In much of western North Dakota, minable lignite beds and associated sand beds are valuable local aquifers. Strip mining disrupts the aquifers and could significantly impact the local hydrology, imposing hardships on local residents. This comprehensive water-resources study of a 147-square-mile coal area in west-central North Dakota was done to facilitate sound management decisions regarding the suitability of the site for mining.

Two strippable lignite beds, identified as the D and E beds, in the lower 250 to 300 feet of the Sentinel Butte Member of the Fort Union Formation underlie much of two small stream basins. The lignites and two closely associated sand deposits are the only consistently occurring aquifers within several hundred feet of the land surface.

The D lignite bed underlies nearly the entire study area, but is not water bearing where it is structurally uplifted beneath upland areas. It is, for the most part, marginally confined. The E lignite bed overlies the D bed and is extensively eroded along North Creek in the southern part of the study area. The E bed is either unsaturated or unconfined in most of its area of occurrence. Direction of ground-water flow in both lignite aquifers is largely controlled by topography.

Interconnected sand beds deposited as channel fill in braided streams form aquifers between the E and D beds (E-D aquifer) and below the D bed (D-HT aquifer). Both aquifers underlie the central part of the study area and each consists of as much as 100 feet of predominantly fine to medium silty unconsolidated sand. Maximum depth to the top of the aquifers was 200 feet for the E-D aquifer and 320 feet for the D-HT aquifer. The E-D aquifer, where near land surface, is unconfined, whereas the D-HT aquifer is entirely confined. Direction of ground-water flow in the D-HT aquifer is not influenced by the local topography as in the three overlying aquifers.

Aquifers also occur at much greater depth beneath the study area in strata of Late Cretaceous and early Tertiary age. The Fox Hills and Tongue River aquifers are most commonly utilized and lie at depths of about 1,700 and 750 feet, respectively.

Water in all aquifers beneath the study area is a sodium bicarbonate or sodium sulfate type. Mean dissolved solids in the four aquifers in the Sentinel Butte Member ranged from 1,290 to 1,970 milligrams per liter. Most of the samples were soft water, had low dissolved iron concentration, and were slightly to moderately colored (tan to brown) by dissolved organics.

Several samples from the four aquifers had a perceptible hydrogen sulfide odor.

North Creek and an unnamed tributary of the Green River drain most of the study area. North Creek flows intermittently during most years, while the Green River tributary flows perennially and has base flow of about 0.2 cubic foot per second. North Creek has predominately a sodium sulfate type water and the Green River tributary has a sodium bicarbonate-sulfate type water. At high flows, the dissolved solids generally are less than 1,000 milligrams per liter, and the water contains greater percentages of calcium and magnesium than at low flow.

The impacts of strip mining on the shallow ground-water flow system would be very localized due to the already low water levels and the segmented nature of the flow system. Similarly, water-quality impacts on the ground-water system would be localized. Natural geochemical processes are effective in limiting the severity and lateral spread of chemically enriched waters.

Streamflow magnitudes should not be significantly affected by mining activities. Stream quality impacts should be readily manageable by ordinary routing, impoundment, and treatment techniques.

INTRODUCTION

The U.S. Department of the Interior, in 1974, invited the mining industry to nominate specific tracts of federally owned coal-mineral land for consideration in future mineral leases. Based in part on the input from the solicitation, the Department delineated several blocks of land or "coal tracts" in western North Dakota for systematic evaluation of the environmental impacts of the anticipated coal development. A large area underlain by minable lignite, popularly known as the Dickinson deposit, was included in one of the tracts. The U.S. Bureau of Land Management then delineated a 65-mi^2 area, identifying it as the Rattlesnake Butte Environmental Mining Rehabilitation Inventory and Analysis (EMRIA) study site, in the central part of the Dickinson deposit for intensive hydrologic study. The area was selected for study because much of the coal is federally owned and because it is located within the drainage basin of the Heart River, the major source of water for the city of Dickinson.

Two lignite beds in the middle to lower Sentinel Butte Member of the Fort Union Formation constitute the strippable coal deposit in the Rattlesnake Butte study area. In many areas of western North Dakota, minable lignites and depositionally associated sand beds are valuable local aquifers. The destruction of these aquifers at mining sites and the resulting decline of water levels in wells in adjacent areas can impose hardships on local residents, especially if alternate sources of water are not available, or lie at great depth. The U.S. Bureau of Land Management requested this study to provide the hydrologic information essential to evaluating impacts of coal development on the water resources of the area.

Objectives and Scope

The objectives of the study were to: (1) Determine the geographic extent of the minable lignite beds and identify aquifers down to a depth of about 400 feet beneath the lower minable lignite; (2) assess the ground-water flow regime in all aquifers found; (3) evaluate the flow characteristics of the two streams draining the study area; (4) evaluate the water quality of the aquifers and streams in the study area; and (5) qualitatively assess the impacts mining might have on the hydrologic system.

The 65-mi^2 study area designated by the Bureau of Land Management was enlarged by the U.S. Geological Survey to include all of the basin of an unnamed tributary to the Green River and all but the lowermost two-thirds of a mile of North Creek. The resultant "Rattlesnake Butte study area" (fig. 1) represents 147 mi^2.

The geologic interpretations in this report are based on data from 68 lithologic and geophysical borehole logs. Forty-two observation wells were constructed to provide data on the ground-water flow system and 33 of the wells were sampled for chemical analysis.

Acknowledgments

The cooperation of landowners in allowing well-siting easements and trespass privileges to project personnel for data collection is gratefully acknowledged. Kelvin Boespflug, U.S. Geological Survey hydrologic technician, performed most of the data-collection activities for the project.

Previous Investigations

One of the earliest published accounts that describes the Dickinson lignite deposit was the statewide lignite survey of Leonard, Babcock, and Dove (1925). Brant (1953) later described and renamed the same Dickinson lignite-area beds. Northern Pacific Railway Company's coal resource evaluation program provided reliable subsurface data from which the deposit was first mapped and reserve tonnages computed (Northern Pacific Railway Company, 1963). Pollard, Smith, and Knox (1972) utilized these data in their review of North Dakota strippable lignite deposits. Kirschbaum and Schneider (1981) presented, by township and section, the estimated lignite tonnages in each of three beds underlying the Rattlesnake Butte EMRIA study site.

The only prior water-resources studies in the Rattlesnake Butte study area were the cooperative (U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and county water-management boards) county ground-water studies in Stark and Hettinger Counties (Trapp and Croft, 1975), Dunn County (Klausing, 1979), and Billings, Golden Valley, and Slope Counties (Anna, 1981).

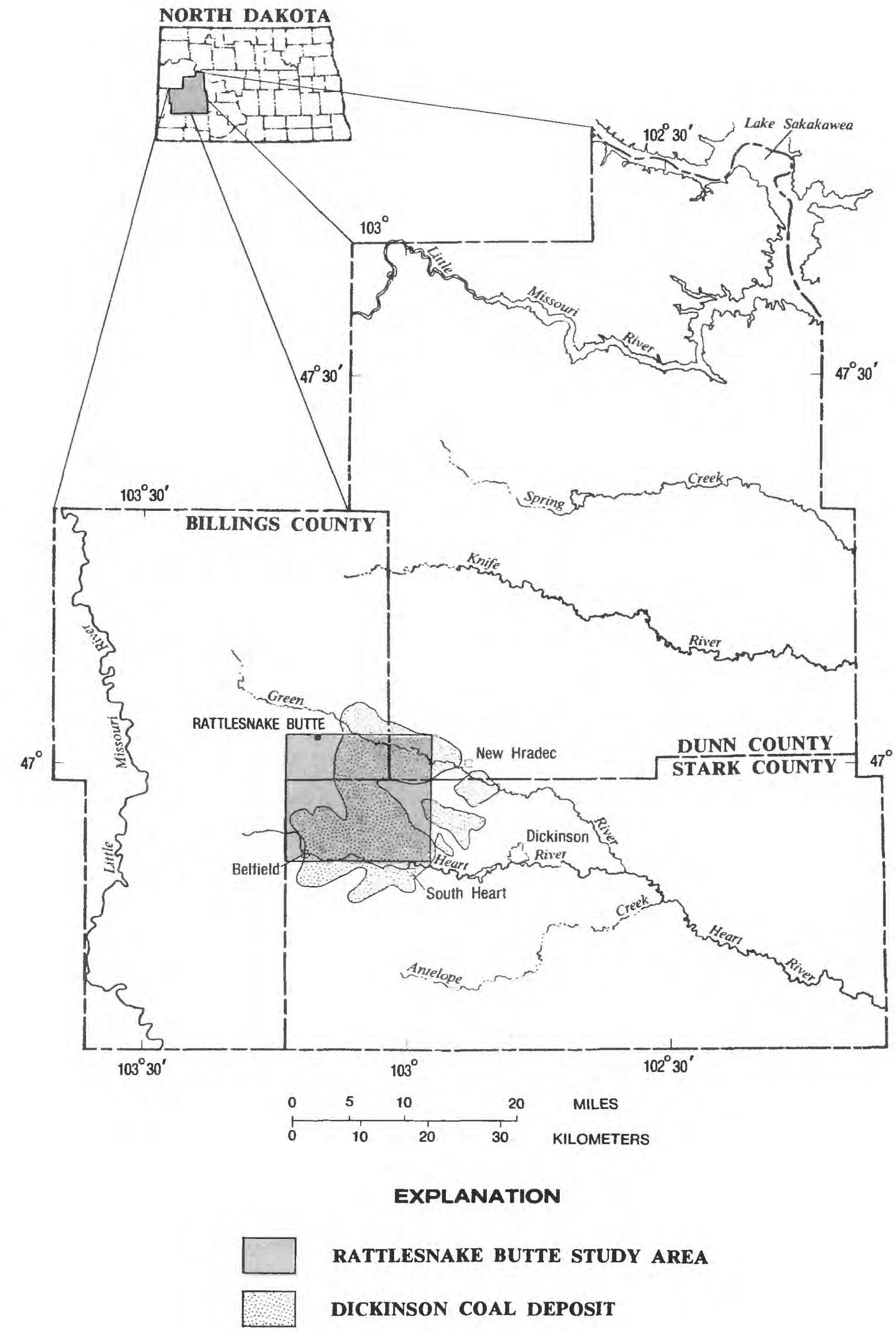


Figure 1. Location of study area.

Location-Numbering System

The wells and test holes referred to in this report are numbered according to a system of land survey modified from one in use by the U.S. Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral denotes the section in which the well is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). For example, well 140-098-15ADC would be in the SW1/4SE1/4NE1/4 sec. 15, T. 140 N., R. 98 W. Consecutive terminal numerals are added if more than one well or test hole is recorded within a 10-acre tract.

The surface-water stations have been assigned a station number in downstream order. A station on a tributary that enters between two main-stream stations is listed between them. Gaps are left in the series of numbers to allow for new stations that may be established. The complete eight-digit number for each station, such as 06342970, includes the two-digit part number "06", which identifies the major drainage, plus the six-digit downstream order number "342970."

Sources of Subsurface Data

Locations of test holes and observation wells which provided information for the subsurface data base for the geologic and hydrologic interpretations in this report are shown in figure 3. The Northern Pacific Railway Company drilled 13 test holes in the study area in 1961 and 1962 for the purpose of determining the extent of coal reserves within their mineral holdings. The U.S. Geological Survey, Water Resources Division, constructed seven observation wells in the study area in 1976 as part of a coal hydrology reconnaissance project. The U.S. Geological Survey, Conservation Division, drilled six test holes in 1977 and 1979 as part of a program to evaluate the coal resources within the Federal mineral reserve. The U.S. Bureau of Reclamation cored 15 test holes in 1978 and 1979 to recover lignite for fuels analysis and to evaluate the physical and chemical properties of overburden materials for reclamation potential. The U.S. Geological Survey, Water Resources Division, drilled 42 test holes and constructed 35 observation wells during the summers of 1979 and 1980 as part of this study. Depths of the 42 test holes ranged from 40 to 762 feet, and averaged 308 feet.

GEOGRAPHY

Topography and Drainage

The study area lies within the unglaciated Missouri Plateau section of the Great Plains physiographic province (Fenneman, 1946). Low, rounded hills and deeply incised stream valleys accent the otherwise rolling landscape. Land surface altitudes in the study area range from over 2,800 feet atop a few isolated buttes in the northwestern part to about 2,460 feet along North Creek in the southeast corner.

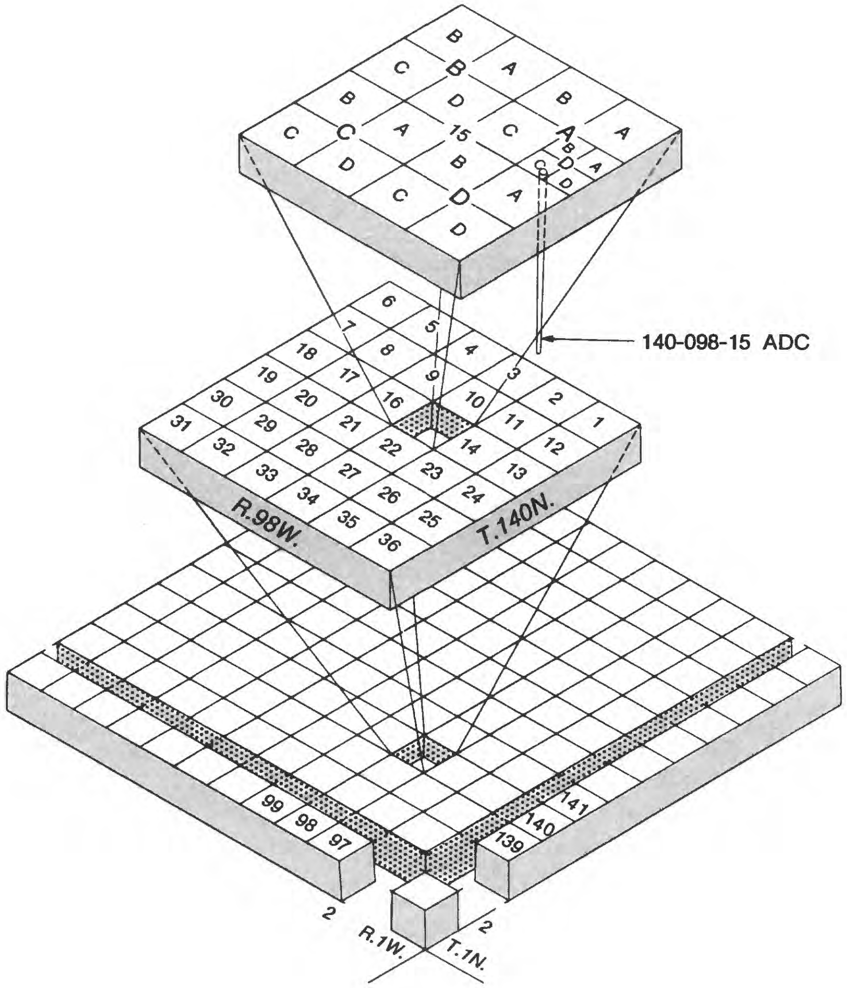
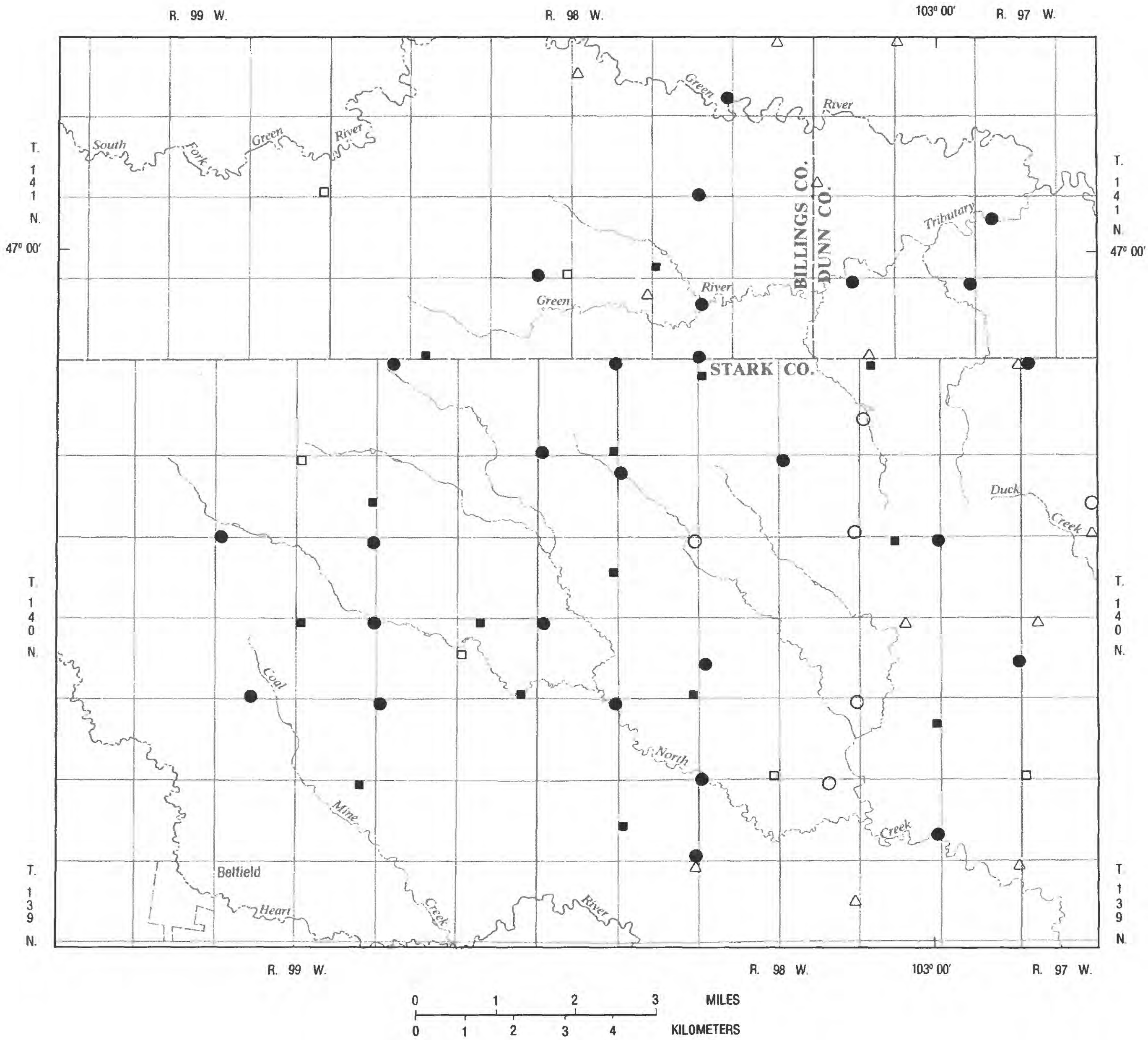


Figure 2. Location-numbering system.



EXPLANATION

○ U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION TEST HOLE, 1976

● U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION TEST HOLE, 1979 and 1980

□ U.S. GEOLOGICAL SURVEY, CONSERVATION DIVISION TEST HOLE, 1977 and 1979

■ U.S. BUREAU OF RECLAMATION TEST HOLE, 1978 and 1979

△ NORTHERN PACIFIC RAILWAY COMPANY TEST HOLE, 1961 and 1962

Figure 3. Locations of test holes.

Major streams in the study area are the Heart River, a tributary of the Missouri River, and the Green River, a tributary of the Heart River (fig. 4). North Creek, also a tributary of the Heart River, flows southeasterly and drains an area of 46 mi^2 in the central part of the area. An unnamed tributary of the Green River drains an area of 23 mi^2 in the northeastern part of the study area.

Climate

The semiarid climate of the study area is characterized by long, cold winters and short, hot summers. The mean annual temperature at Dickinson Experiment Station is 40.5°F (U.S. Environmental Data Service, 1973). The daily high temperature is greater than or equal to 90°F on an average of 22 days per year. The daily low temperature is less than or equal to 0°F on an average of 45 days per year. About 80 percent of the mean annual precipitation of 16.56 inches occurs during the months of April through September. The mean pan evaporation is about 50 inches per year (U.S. Environmental Data Service, 1968).

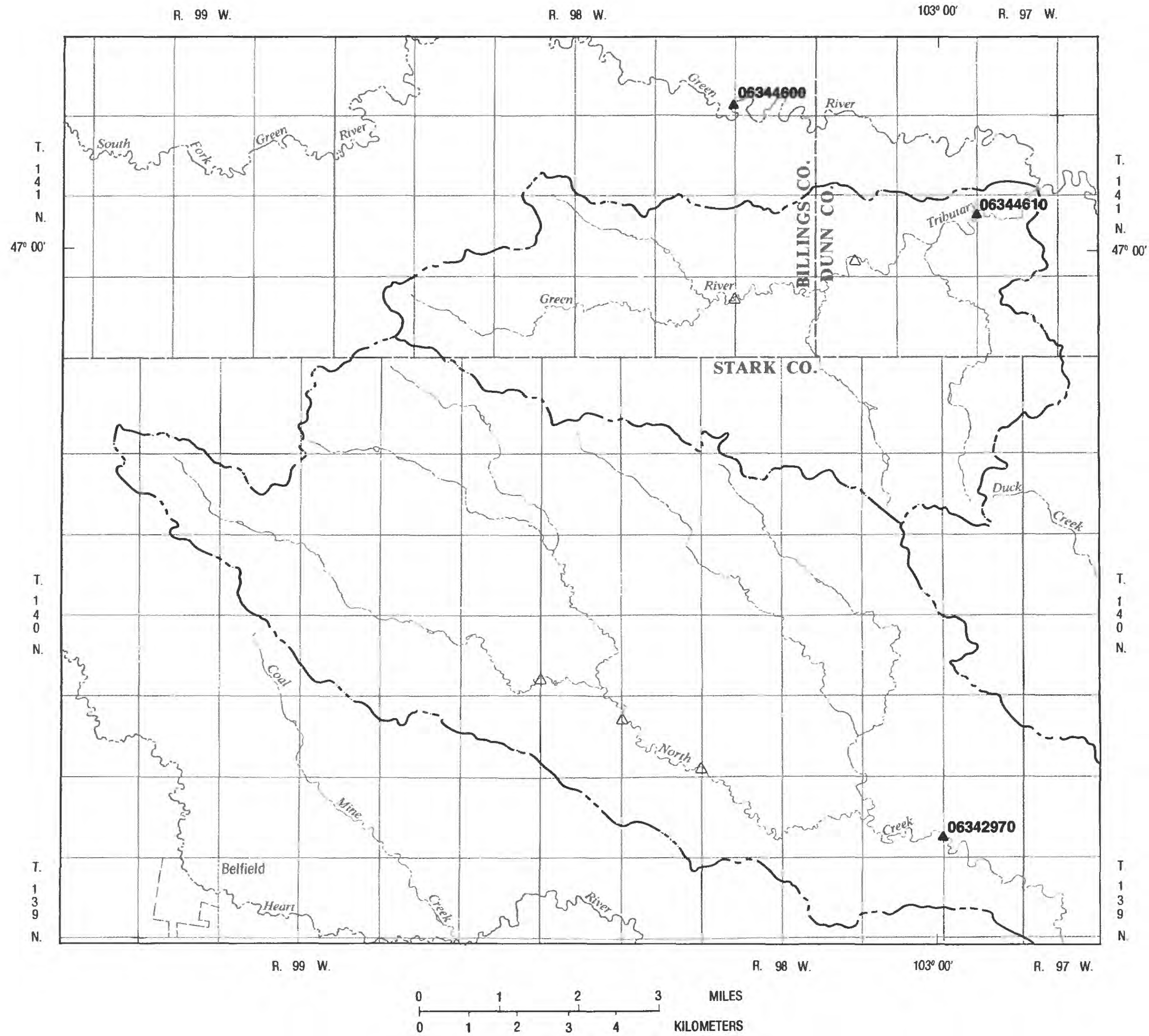
The length of the growing season, defined as the number of days between the average date of the last spring frost and the first fall frost, is about 120 days and extends from May 20 to September 16 (U.S. Environmental Data Service, 1968).

GEOLOGY

The Rattlesnake Butte study area is on the southern flank of the Williston structural basin and is underlain by some 14,000 feet of sedimentary rocks. From the basin center (near Williston, N. Dak.) all beds, representing every system from the Precambrian to the Tertiary, ascend in altitude and thin toward the basin fringes, where each feathers to nonexistence due either to erosion or nondeposition.

A generalized stratigraphic column of the study area, ascending from the base of the Upper Cretaceous section, is shown in table 1. In western North Dakota the Upper Cretaceous Fox Hills Sandstone generally is recognized as the stratigraphically lowest of the economically important water-bearing formations. The deposits below the Fox Hills consist of beds of shale, limestone, dolomite, sandstone, and evaporites. As much as 12,000 feet of these deposits overlie the Precambrian crystalline rocks beneath the study area. With a few possible exceptions, the deposits underlying the Fox Hills Sandstone contain brackish water. The Upper Cretaceous Pierre Shale underlies the Fox Hills Sandstone and consists of 2,000 to 3,000 feet of dark-gray marine shale. Its top is considered the base of the fresh-water reservoir. Klausing (1976, p. 121) picked the top of the Pierre at a depth of 1,948 feet (altitude 535 feet) from the log of a test hole 4 miles east of the study area.

The study area is about 30 miles southwest of the furthest advance of Pleistocene glaciation. The only Quaternary deposits present in the study area consist of undetermined thicknesses of alluvial material beneath and immediately adjacent to the major streams.



EXPLANATION

DRAINAGE BASIN BOUNDARY

06342970 CONTINUOUS-RECORD GAGING STATION AND NUMBER

MISCELLANEOUS STREAMFLOW SITE

Figure 4. Drainage basin boundaries and locations of stream-monitoring sites.

TABLE 1.--Generalized Tertiary-Upper Cretaceous section for the Rattlesnake Butte study area

Erathem	System	Series	Formation or member		Lithologic characteristics
Cenozoic	Quaternary				Alluvium: Silt, sand, and gravel.
	Tertiary	Eocene	Golden Valley Formation		Gray to purplish clay or claystone, silt, tan sand or sandstone, and lignite.
		Paleocene	Fort Union Formation	Sentinel Butte Member	Interbedded sand, silt, clay, and lignite.
				Tongue River Member	Interbedded greenish-gray to grayish-brown clay, silt, sand or sandstone, and lignite.
				Cannonball Member / Ludlow Member	Cannonball Member: Greenish-gray marine silt and clay; minor sand. Ludlow Member: Gray clay, silt, sand, and lignite.
Mesozoic	Cretaceous	Upper Cretaceous	Hell Creek Formation		Interbedded claystone, siltstone, and gray sandstone.
			Fox Hills Sandstone		Grayish-white sandstone and interbedded gray siltstone and shale.
			Pierre Shale		Dark-gray fissile marine shale with thin limestone concretions.
			Niobrara Formation		Interbedded gray calcareous shale and marl.
			Carlile Shale		Interbedded gray marl, shale, and siltstone.
			Greenhorn Formation		Gray calcareous shale and marl.
			Belle Fourche Shale		Gray shale with scattered limestone concretions.

Upper Cretaceous Rocks

Fox Hills Sandstone

The Fox Hills Sandstone is a marine deposit consisting of interbedded sandstone, siltstone, and shale. The sandstone generally is semiconsolidated but in places is well cemented. Lignitic shale laminae are present in the upper part of the formation.

The Fox Hills Sandstone underlies not only the study area, but the western two-thirds of North Dakota and a large part of eastern Montana. Depth to the top of the Fox Hills in a test hole at New Hradec, N. Dak., (141-096-29CCC, 4 miles east of the study area) is 1,652 feet (altitude 831 feet). Structure-contour maps by Klausing (1979) and Anna (1981) indicate that the top of the Fox Hills is at an altitude of about 900 feet in the center of the study area.

In western North Dakota the Fox Hills ranges in thickness from about 60 feet (Hares, 1928) to nearly 400 feet (Cvancara, 1976). Klausing (1976) reported a thickness of 296 feet for the Fox Hills in the test hole at New Hradec.

Hell Creek Formation

The Hell Creek Formation is a subaerial, deltaic sequence representing the eastward progradation of detrital sediments behind the retreating Fox Hills sea. The Hell Creek consists primarily of bentonitic claystone, siltstone, and sandstone. Concretions and siderite nodules are common, as are localized, thin lignite beds.

The Hell Creek Formation underlies the western half of North Dakota, including all of the study area. Depth to the top of the Hell Creek in test hole 141-096-29CCC at New Hradec was 1,250 feet (altitude 1,233 feet; Klausing, 1976). Full thickness of the Hell Creek Formation ranges from about 200 feet to 400 feet (Carlson, 1979; R. D. Butler, written commun., 1980).

Tertiary Rocks

Fort Union Formation

Ludlow and Cannonball Members

Erosion of the highlands that were created to the west of the Williston basin during the Late Cretaceous Laramide Orogeny continued to supply detrital materials to the slowly subsiding basin uninterruptedly into the Cenozoic Era. In North Dakota, Tertiary deposition began with the fluvial sedimentation of the Ludlow Member of the Fort Union Formation (Paleocene). Contemporaneously a final westward transgression of the waning inland sea into western North Dakota resulted in the deposition of the marine and marginal marine Cannonball Member of the Fort Union Formation. The two members are lateral equivalents and may be loosely described as opposite-facing, intertonguing, clastic wedges.

The Ludlow Member is composed of alternating beds of gray clay, silt, sand, and sandstone. The clays and silts generally are unconsolidated, but in places the sand is moderately cemented. Thin lignite beds are common throughout the member. Hares (1928) described a lignite bed of commercial thickness near Rhame, N. Dak., some 60 miles southwest of the study area. The Cannonball Member consists of greenish-gray silt and clay and has minor occurrences of silty sand. All lithologies are poorly consolidated.

Ludlow and Cannonball strata underlie the entire study area. In general, across western North Dakota, the Ludlow Member constitutes an eastward thinning clastic wedge, while the Cannonball wedge thins toward the west and pinches to virtual extinction near the Montana border. Difficulties in differentiating between the units in the subsurface have caused many investigators to treat the two members as one undifferentiated unit.

Anna (1980) picked the top of the Ludlow at a depth of 818 feet (altitude 1,742 feet) in test hole 141-098-15AAA, but only the upper 142 feet of the unit was penetrated. At a site 5 miles northwest of the study area (142-100-25DDA) Anna (1980) picked the top of the Ludlow at a depth of 812 feet (altitude 1,838 feet) and recognized a combined total of 573 feet of Ludlow and Cannonball strata. Klausing (1976), in the test hole at New Hradec, identified 320 feet of undifferentiated Ludlow-Cannonball material, the top of which is at a depth of 930 feet (altitude 1,553 feet).

Tongue River Member

The Tongue River Member, an upper deltaic sequence, consists of clay, silt, fine- to (rarely) medium-grained sand, sandstone, lignite, and thin limestone lenses. All clastic deposits are shades of gray and green or, if abundant organic material is included, grayish brown to nearly black. Except for occasional sandstone "ledges" that generally are only inches thick, all clastic deposits are poorly consolidated. Only the sand and lignite beds attain thicknesses of more than a few inches to a few feet. Although not observed in the study area, relatively uniform sand beds nearly 100 feet thick and lignites as much as 34 feet thick occur in the Tongue River in western North Dakota. The thickest sand and lignite beds generally occur in the lower part of the member.

The Tongue River Member underlies the entire study area. Depth to the top of the member generally is between 200 and 400 feet. Although none of the test holes of this project were drilled to the base of the Tongue River Member, test hole 140-098-28CCC was bottomed in a fine- to medium-grained sand after penetrating 555 feet of Tongue River material. Anna (1980, p. 181-182) reported a full thickness of Tongue River material of 626 feet in test hole 141-098-15AAA. The HT Butte lignite bed generally is recognized as the upper contact of the Tongue River Member.

Sentinel Butte Member

The Sentinel Butte Member constitutes the land surface throughout the study area, except atop Rattlesnake Butte (N1/2 sec. 13, T. 141 N., R. 99 W.)

where the Golden Valley Formation forms the caprock. The Sentinel Butte was deposited higher on the eastward-sloping alluvial plain complex than was the Tongue River, but the lithologic composition is virtually undistinguishable between the two. Lignite and sand beds occur throughout the Sentinel Butte Member, but the thickest and most persistent sands generally occur near the base.

The thickest section of Sentinel Butte material found in the study area was 415 feet in test hole 140-099-10BBB. Test drilling indicated that typical thicknesses of Sentinel Butte material in the study area generally range from 200 to 400 feet.

Golden Valley Formation

The Golden Valley Formation occurs in the study area only atop Rattlesnake Butte. Its thickness there is unknown, but the formation is reported to be about 200 feet thick on several buttes northeast of Dickinson (Trapp and Croft, 1975, p. 20). The Golden Valley consists of gray to purplish clay or claystone, silt, tan sand or sandstone, and lignite. The Golden Valley Formation is not an aquifer in the study area.

Major Lignite Beds

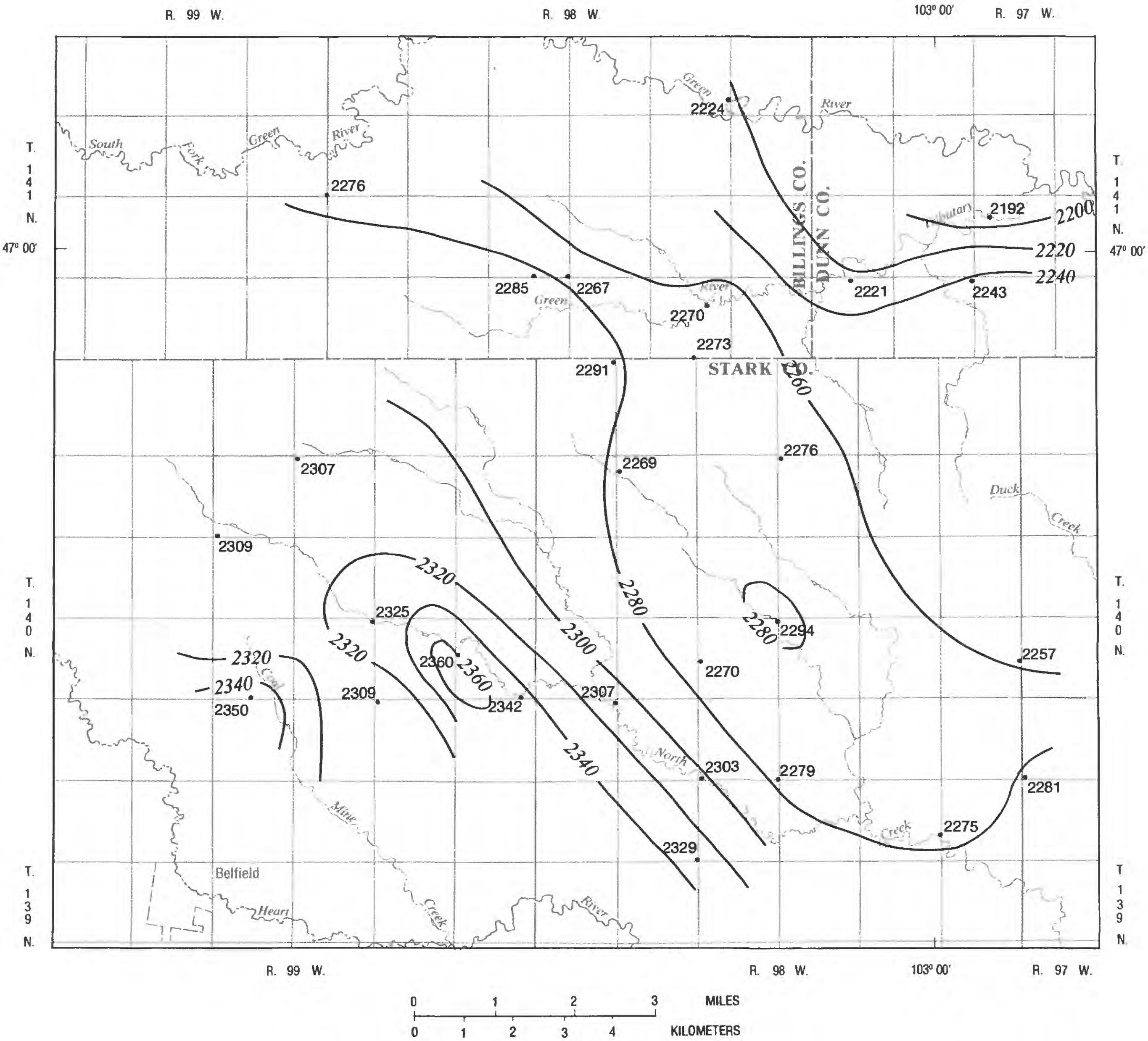
Two lignite beds of economic importance occur in the lower 250 to 300 feet of the Sentinel Butte Member in the Rattlesnake Butte study area. Leonard and others (1925, p. 140) designated the lower bed as the Fryburg bed and the upper as the Heart River bed. A later report by the Northern Pacific Railway Company (1963) referred to the Fryburg bed as the D bed and the Heart River bed as the E bed. The D bed and E bed designations are used in this report. The HT Butte lignite bed, the uppermost unit in the Tongue River Member, is not recoverable by present strip-mining methods. The three lignite beds will be discussed in ascending order.

The HT Butte bed was penetrated by 28 test holes scattered throughout the study area. Structure contours of the top of the HT Butte reflect a northeasterly dip (fig. 5). The bed is continuous in the southernmost part of the area, but separates into two (pl. 1, in pocket) or three progressively diverging splits toward the north. Therefore, because thickness determinations involved a subjective process of identifying these thin beds presumed to be HT Butte splits, no thickness map was prepared. The greatest uninterrupted thickness observed for the HT Butte was 11 feet.

The interval between the HT and the D lignite beds, in 27 test holes, ranged from 124 to 224 feet and averaged about 170 feet.

The D bed underlies all of the study area except where removed by penecontemporaneous fluvial erosion in the northeast part of T. 140 N, R. 99 W. A structure-contour map of the top of the D bed (fig. 6) indicates a generalized northeasterly dip.

The thickness of the D bed ranged from 3 to 17 feet and averaged about 8 feet in 55 test holes. The bed generally is less than 6 feet thick in the

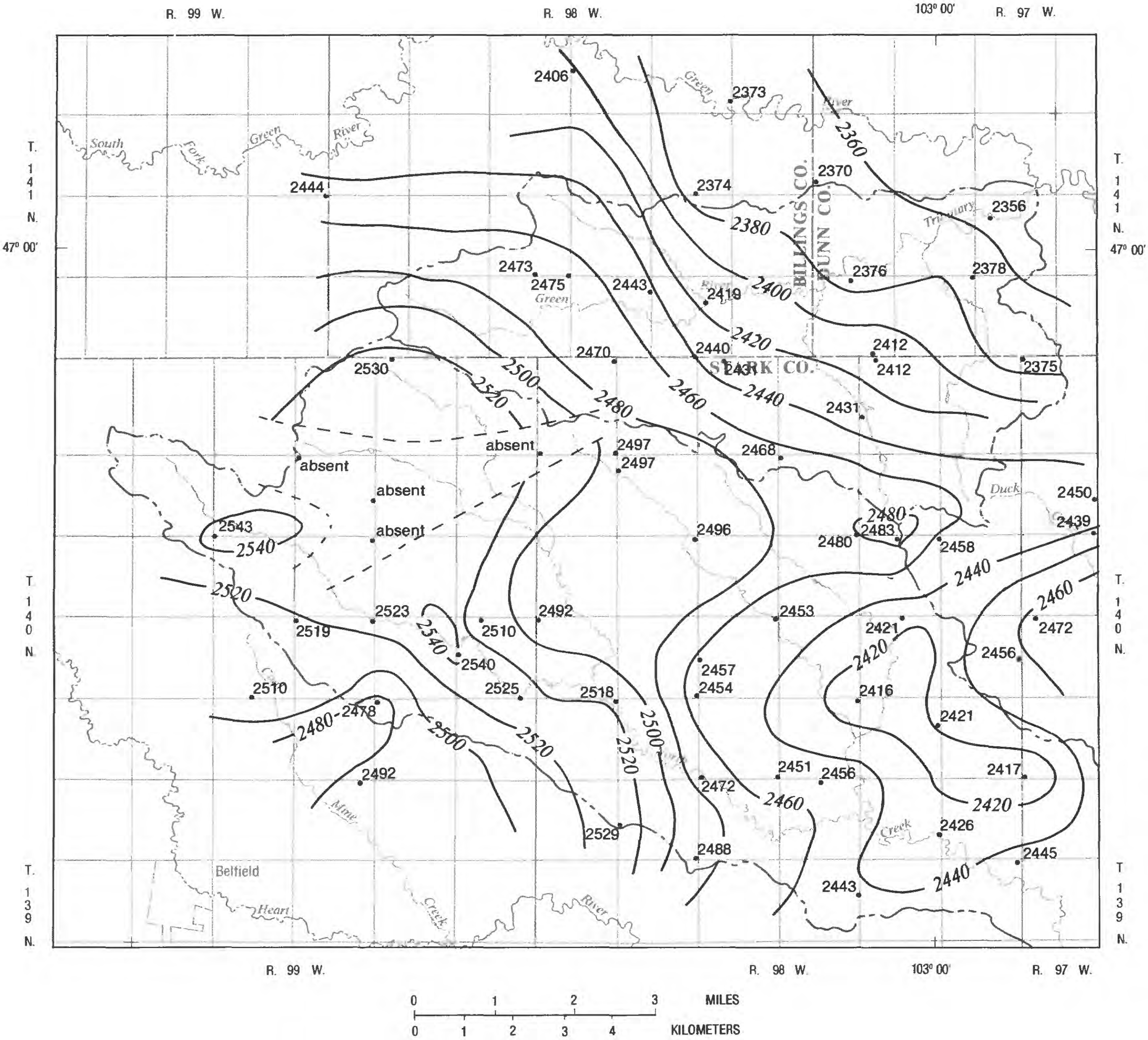


EXPLANATION

— 2300 — **STRUCTURE CONTOUR** Shows altitude of top of HT Butte lignite bed. Contour interval 20 feet. National Geodetic Vertical Datum of 1929

•2350 **TEST HOLE** Number is altitude of top of HT Butte lignite bed, in feet above National Geodetic Vertical Datum of 1929

Figure 5. Structure of the top of the HT Butte lignite bed.



EXPLANATION

—2500—	**STRUCTURE CONTOUR** Shows altitude of top of D lignite bed. Contour interval 20 feet. National Geodetic Vertical Datum of 1929
– – – –	**D BED ABSENT** May indicate presence of channel sand.
——·——	**DRAINAGE BASIN BOUNDARY**
.2540	**TEST HOLE** Number is altitude of top of D lignite bed, in feet above National Geodetic Vertical Datum of 1929

Figure 6. Structure of the top of the D lignite bed.

central and west-central parts of the study area (fig. 7), and may thin to extinction in the area west of the limit of available data. Sparse data indicate that the D bed may be 15 to 20 feet thick in parts of T. 139 N., R. 98 W., to the south of the study area.

The interval between the E and D beds, as determined from logs of 42 test holes, ranged from 38 to 137 feet and averaged about 80 feet.

The E bed underlies the northern half of the study area, but has been removed by erosion throughout most of North Creek basin and along the Heart River (fig. 8). The E bed also is absent along a presumed erosional valley in the southwest corner of T. 141 N., R. 97 W. and the southeast corner of T. 141 N., R. 98 W.

Although the structure of the E bed is quite erratic, the generalized dip is toward the northeast (fig. 8).

Thickness of the E bed, as determined from logs of 52 test holes, ranged from 5 to 20 feet and averaged about 9.5 feet (fig. 9). The thickest section of E bed occurs north of the Green River. The E bed is within 100 feet of the land surface in most of the study area.

GROUND-WATER RESOURCES

Geohydrology

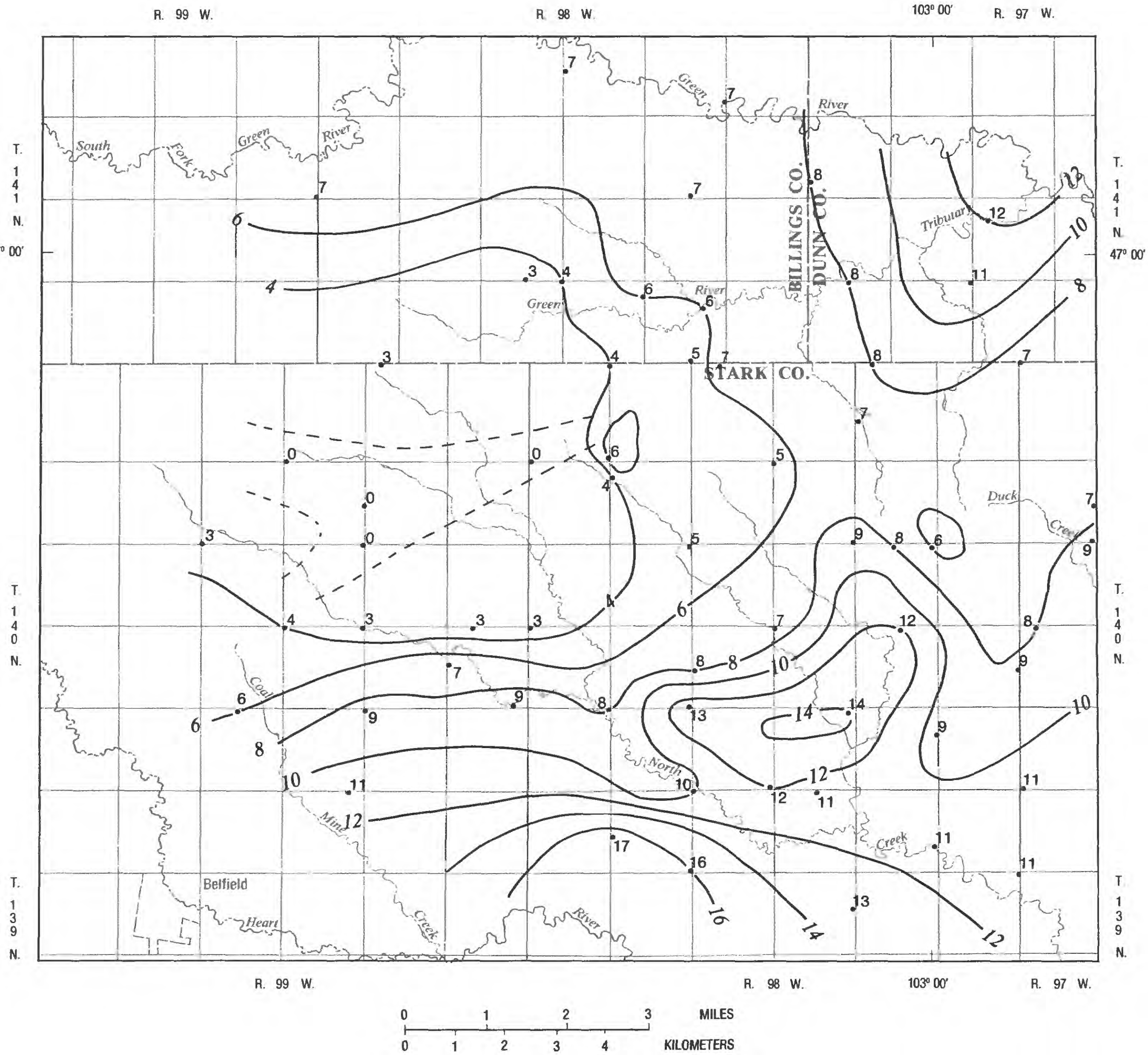
The shallow aquifers associated with the minable lignite beds are the major focus of this study. Aquifers in the Fox Hills Sandstone, Hell Creek Formation, and the Ludlow and Cannonball and Tongue River Members of the Fort Union Formation probably would not be disrupted by surface mining. However, they are discussed in this section because they could serve as a source of water to replace supplies lost due to destruction of the shallow aquifers.

Well-construction and water-level data pertaining to observation wells used in this study are listed in Attachment A.

Aquifers in the Fox Hills Sandstone

Extensive sandstone beds in the upper part of the Fox Hills constitute an important aquifer throughout western North Dakota. In some areas, such as the southwestern part of the State, the sandstone beds in the Fox Hills have an apparent hydraulic connection with those in the lower part of the Hell Creek, thereby forming an aquifer "system" that bridges formational boundaries (Croft, 1978; Anna, 1981).

In test hole 141-096-29CCC at New Hradec (4 miles east of the study area), the sandstone in the upper part of the Fox Hills is 145 feet thick (exculusive of an 18-foot shale parting) and another sandstone section in the lower part of the formation is 66 feet thick. The top of the upper sandstone is 1,652 feet below the surface (altitude 831 feet). In test hole 139-099-05AC at Belfield, 45 feet of sandstone was penetrated in the upper



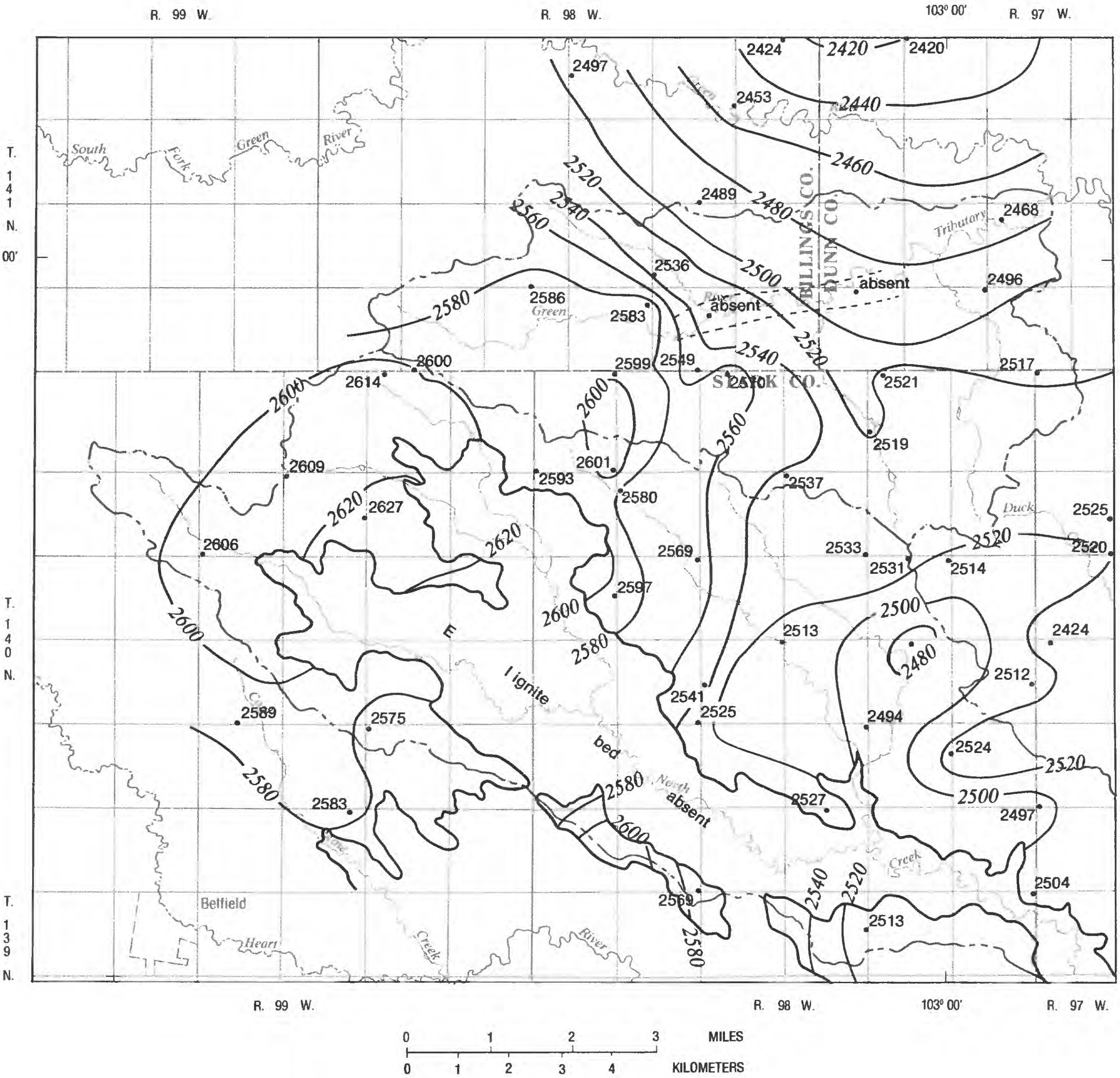
EXPLANATION

—8— **LINE OF EQUAL THICKNESS OF THE D LIGNITE BED** Interval 2 feet.

— — — — **D BED ABSENT** May indicate presence of channel sand.

•12 **TEST HOLE** Number is thickness of D lignite bed, in feet.

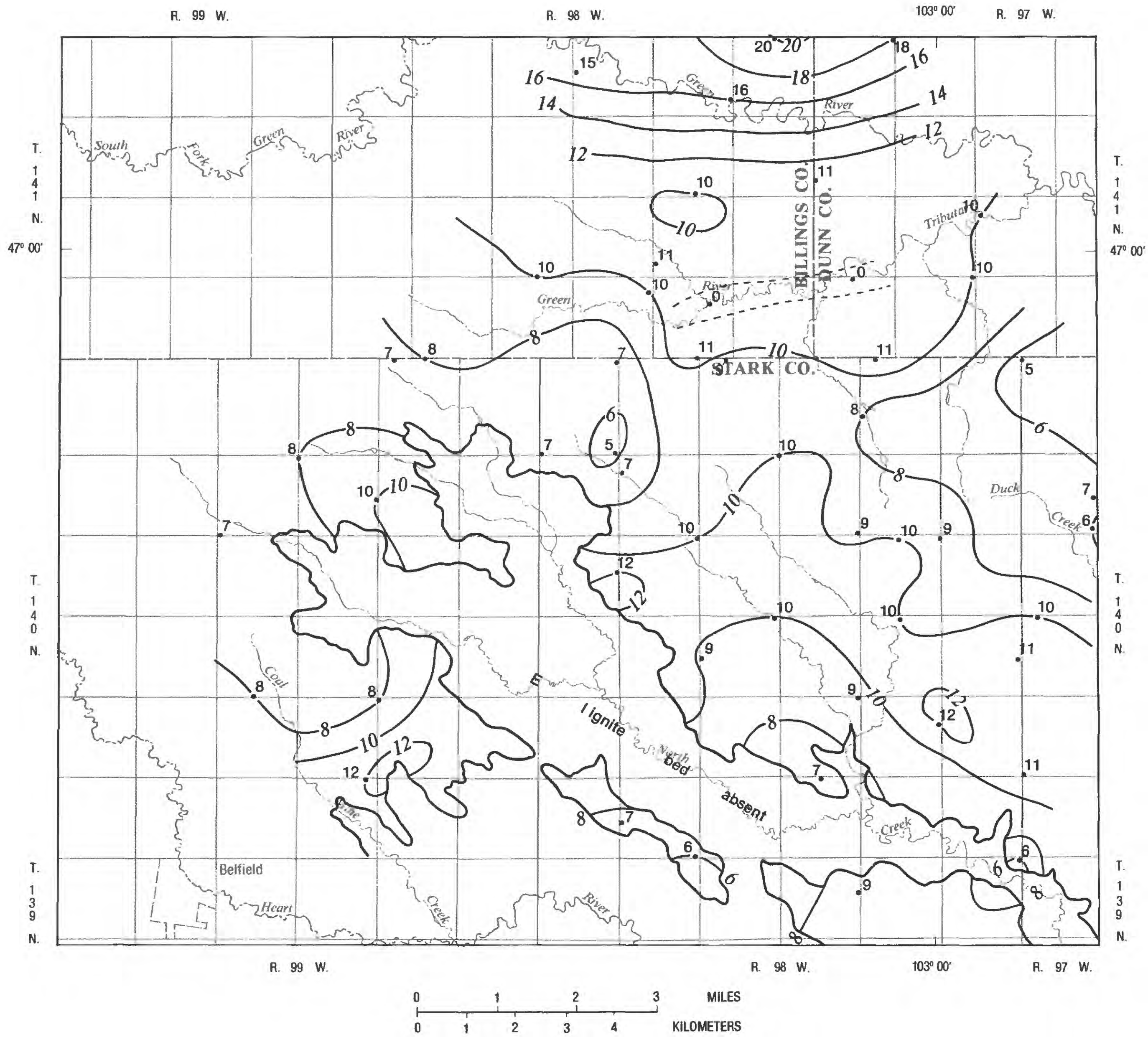
Figure 7. Thickness of D lignite bed.



EXPLANATION

—2500—	**STRUCTURE CONTOUR** Shows altitude of top of E lignite bed. Contour interval 20 feet. National Geodetic Vertical Datum of 1929
———	**OUTCROP OF E LIGNITE BED**
- - - - -	**E BED ABSENT** May indicate presence of channel sand.
—··—	**DRAINAGE BASIN BOUNDARY**
.2600	**TEST HOLE** Number is altitude of top of E lignite bed, in feet above National Geodetic Vertical Datum of 1929

Figure 8. Structure of the top of the E lignite bed.



EXPLANATION

—6— LINE OF EQUAL THICKNESS OF THE E LIGNITE BED—Interval 2 feet.

—— OUTCROP OF E LIGNITE BED

- - - - E BED ABSENT May indicate presence of channel sand.

.10 TEST HOLE Number is thickness of E lignite bed, in feet.

Figure 9. Thickness of the E lignite bed.

part of the Fox Hills. The top of the sandstone is at a depth of 1,705 feet (altitude 865 feet).

Transmissivities and specific capacities reported for the Fox Hills-Hell Creek aquifer system vary widely. Klausing (1979, p. 13) reported transmissivities of as much as 1,200 ft^2/d and specific capacities of as much as 6.6 (gal/min)/ft for the Fox Hills aquifer in Dunn County. Potential yields from the aquifer or aquifer system may be as much as 300 gal/min (Anna, 1981, p. 17), but more generally are about 25 to 75 gal/min (Trapp and Croft, 1975, p. 29). Flow gradients range from 6 to 20 ft/mi. The water level in the observation well at New Hradec was about 230 feet below land surface in 1973.

Many cities in southwestern North Dakota, including Belfield, Bowman, and Dickinson, obtain part or all of their municipal water supplies from the Fox Hills aquifer or Fox Hills-Hell Creek aquifer system.

Aquifers in the Hell Creek Formation

Sandstone beds at various depths within the Hell Creek Formation constitute aquifers, but because most are quite localized, no consistent sequence of sandstone beds has been recognized throughout the region. In some areas, basal and upper sandstone beds of the Hell Creek are assumed to form a hydraulic continuum with sandstone beds of the upper Fox Hills Sandstone and lower Ludlow Member (Fort Union Formation), and are described as aquifer systems (Croft, 1973; Croft, 1978; Anna, 1981). In another area, three aquifer zones were recognized in the Hell Creek (Randich, 1979). In still other areas, aquifers were indicated as randomly occurring in the Hell Creek section with little or no hydraulic interconnection (Klausing, 1979; Ackerman, 1980). Klausing (1976) reported a total aggregate sandstone thickness of 181 feet in the Hell Creek at the New Hradec site. The top of the uppermost sandstone was penetrated at a depth of 1,250 feet (altitude 1,233 feet) and the thickest of any of the four beds was 78 feet. The base of the lowest sandstone bed was recorded at a depth of 1,632 feet.

Hydraulic conductivities reported for aquifers in the Hell Creek Formation range from 0.6 to 19 ft/d and specific capacities range from 0.2 to 1.0 (gal/min)/ft. Potential yields may be as much as 150 gal/min, but generally are much less. Hydraulic flow gradients range from about 5 to 20 ft/mi. Water-level data are not available for aquifers in the Hell Creek Formation for the study area.

The Hell Creek aquifers commonly are used for water supplies along the fringes of the Williston basin where the formation lies at shallow depth. Elsewhere, including the study area, wells usually are drilled through the Hell Creek to the Fox Hills aquifer.

Aquifers in the Ludlow and Cannonball Members, Fort Union Formation

Previous reports of ground-water studies in western North Dakota have either (1) described individual sand beds within the undifferentiated Ludlow-Cannonball interval as discrete aquifers or (2) discriminated the respective intertongues of Ludlow and Cannonball strata and identified each as either an aquifer, part of an aquifer system, or a confining bed. In Dunn County, at test hole 141-096-29CCC, Klausing (1976, p. 119) identified an aggregate thickness of 154 feet of silty sand in the undifferentiated Ludlow-Cannonball unit and Anna (1980), in Billings County (at 142-100-25DDA), reported 61 feet of sand in an upper Ludlow tongue and 33 feet of sand in a lower Ludlow tongue--separated by 167 feet of Cannonball material that acts as a confining bed. The uppermost Ludlow-Cannonball sand occurred at a depth of 962 feet (altitude 1,521) in the Dunn County test hole and 900 feet (altitude 1,750 feet) in the Billings County test hole.

In west-central North Dakota, near Beach (about 35 miles west of the study area), detailed test drilling indicated about an 80 percent probability of finding a sand bed at least 15 feet thick in the upper 200 feet of the Ludlow Member at any given location. Individual bed thicknesses near Beach were as much as 84 feet (Horak, 1983). Data are not available to assess the persistence of the Ludlow-Cannonball sands beneath the Rattlesnake Butte study area. The aquifer, if present, would lie at depths of 800 feet or more.

Hydraulic conductivities reported for the Ludlow-Cannonball aquifers range from about 0.02 to 0.45 ft/day (Klausing, 1979, p. 18). Specific capacities probably do not exceed 1 (gal/min)/ft. Estimated potential yields to wells range from 1 to 50 gal/min. Aquifers in the Ludlow and Cannonball Members generally are not utilized in the study area due to the relatively great depth and generally low yield.

Aquifers in the Tongue River Member, Fort Union Formation

Channel sand deposits and lignite beds constitute aquifers in the Tongue River Member. Although sand beds tens of feet thick and lignite beds several feet thick occur sporadically throughout the Tongue River section in the Williston basin, the thickest and most consistently occurring sands and lignites lie in the lower part of the member. Ground-water studies in several western North Dakota counties have noted this sand distribution pattern biased toward the lower part of the member, and some studies have defined a basal sand as the only aquifer of more than localized importance (Croft, 1973; Randich, 1979; Anna, 1981).

Of the test holes drilled in the study area, 12 penetrated the upper 100 feet of the Tongue River, and 9 of these 12 penetrated the upper 200 feet. The sand generally was very silty and occurred mostly in beds 20 to 40 feet thick. However, sand beds greater than 60 feet thick were penetrated at three sites. The maximum observed thickness was 79 feet. The average aggregate thickness of sand was about 60 feet in test holes penetrating at least 200 feet of Tongue River material. Depth to the uppermost of the Tongue River sand beds ranged from about 300 feet in the south-central part of the study area to over 400 feet in the northeast. The sand bed penetrated at 750 feet in test hole 140-098-28CCC is part of what generally is considered the lower or basal Tongue River aquifer. Sufficient data are not available for the study area and vicinity to determine if the lower Tongue River aquifer occurs consistently.

Nearly all Tongue River lignite beds in the study area, except the HT Butte bed, were less than 4 feet thick. Only one observation well was completed in a Tongue River lignite, and that was in the HT Butte bed. Due to generally low transmissivities, it is unlikely that yields from domestic wells completed in the thin, deeply buried lignites would be satisfactory.

Hydraulic conductivity values for Tongue River sands in the Beach area ranged from 0.6 to 19 ft/d (Horak, 1983). Klausing (1979) reported specific capacities ranging from 0.15 to 2.3 (gal/min)/ft in Dunn County. Yields of 10 gal/min generally should be available from wells fully screened through sand beds at least 20 feet thick.

Two observation wells were completed in the Tongue River Member. The water level in observation well 140-098-28CCC1, completed in a lower Tongue River sand bed at a depth of 762 feet, is 187 feet. The water level in observation well 140-98-32DDD1, completed in the HT Butte lignite at a depth of 272 feet, is 110 feet.

Aquifers in Tongue River sand beds are utilized extensively by local residents for water supplies because commonly, either shallower aquifers do not exist or the shallower aquifers yield an unsatisfactory quality of water.

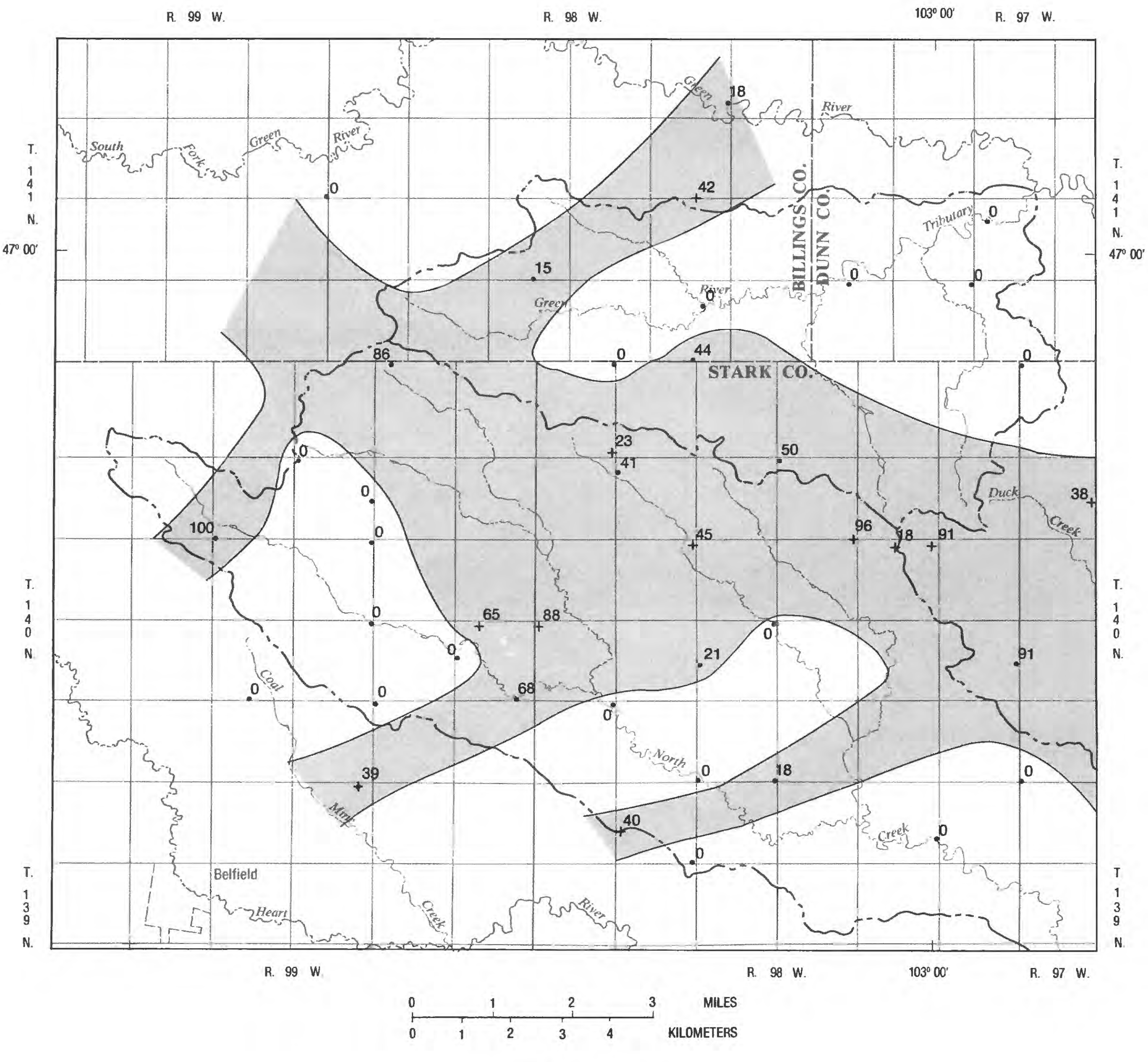
Aquifers in the Sentinel Butte Member, Fort Union Formation

Four aquifers, including the E and D lignite beds, have been identified within the Sentinel Butte Member in the study area. Because the E and D beds are readily traceable throughout the study area, they serve as a convenient means of stratigraphic zonation for identification of two other aquifers. All sand beds encountered between the E and D lignite beds are ascribed to the E-D aquifer, and all sand beds between the D and HT Butte lignite beds are ascribed to the D-HT aquifer. Plate 1 shows the stratigraphic relationships among the various aquifers and confining beds.

Monthly water-level measurements were obtained from seven observation wells from July 1976 to May 1977 and from March 1979 to April 1982. Monthly measurements also were obtained through April 1982 for the 35 observation wells constructed during 1979 and 1980. These measurements, along with the stratigraphic information gathered from the drilling programs previously detailed, are the basis for the following interpretations. The aquifers will be discussed in ascending order.

D-HT aquifer

The D-HT aquifer consists of interconnected sand beds that probably were deposited as channel fill in braided streams. The aquifer occurs only in the central part of the study area. A possible geometric configuration of stream channels during deposition of the sand is shown as the shaded area in figure 10. Although a number of similar geometries could be interpreted from the data, it is apparent that the streams flowed in a generally eastward direction.



EXPLANATION

AREA OF SAND OCCURRENCE Indicates possible configuration of stream channels during deposition of sand.

DRAINAGE BASIN BOUNDARY

.86 **TEST HOLE** Number indicates aggregate thickness of sand in D-HT aquifer.

• **Fully penetrated Sentinel Butte Member**

\+ **Did not fully penetrate Sentinel Butte Member**

Figure 10. Aggregate thickness of sand in the D-HT aquifer.

The D-HT aquifer generally contains considerable interstitial silt and clay, although well-sorted sections were observed in places. The sand grain size is predominantly fine, but inclusions of medium-sized material are common and, less frequently, beddings of well-sorted medium-grained sand occur.

The aggregate thickness of sand is shown in figure 10. Most of the thicknesses represent a single bed. Where present, sand thicknesses ranged from 15 to 100 feet and the median was about 45 feet. Several of the test holes penetrated less than the entire D-HT interval.

Depth to the top of the D-HT aquifer ranged from 60 to 320 feet, but is about 100 to 250 feet below land surface in most of the area of occurrence.

The D-HT aquifer is confined throughout the study area. The potentiometric-surface map (fig. 11) shows that ground water in the D-HT aquifer flows from west to east. The flow, unlike that of the three shallower aquifers, is largely independent of the localized flow regime. The gradient in the central part of the aquifer is about 5 ft/mi. Thinning of the aquifer in the vicinity of 141-098-28DCC may be responsible for the steep gradient in the northern tributary arm of the aquifer (fig. 11).

The D-HT aquifer is recharged by leakage from overlying beds. Discharge occurs as leakage to underlying confining beds and as outflow across the eastern boundary of the study area.

The hydraulic properties of both the D-HT and the E-D aquifers probably are similar to those of the Tongue River sand aquifers. However, because the Sentinel Butte sands tend to be slightly coarser than the Tongue River sands, the hydraulic conductivities and specific capacities may be somewhat higher.

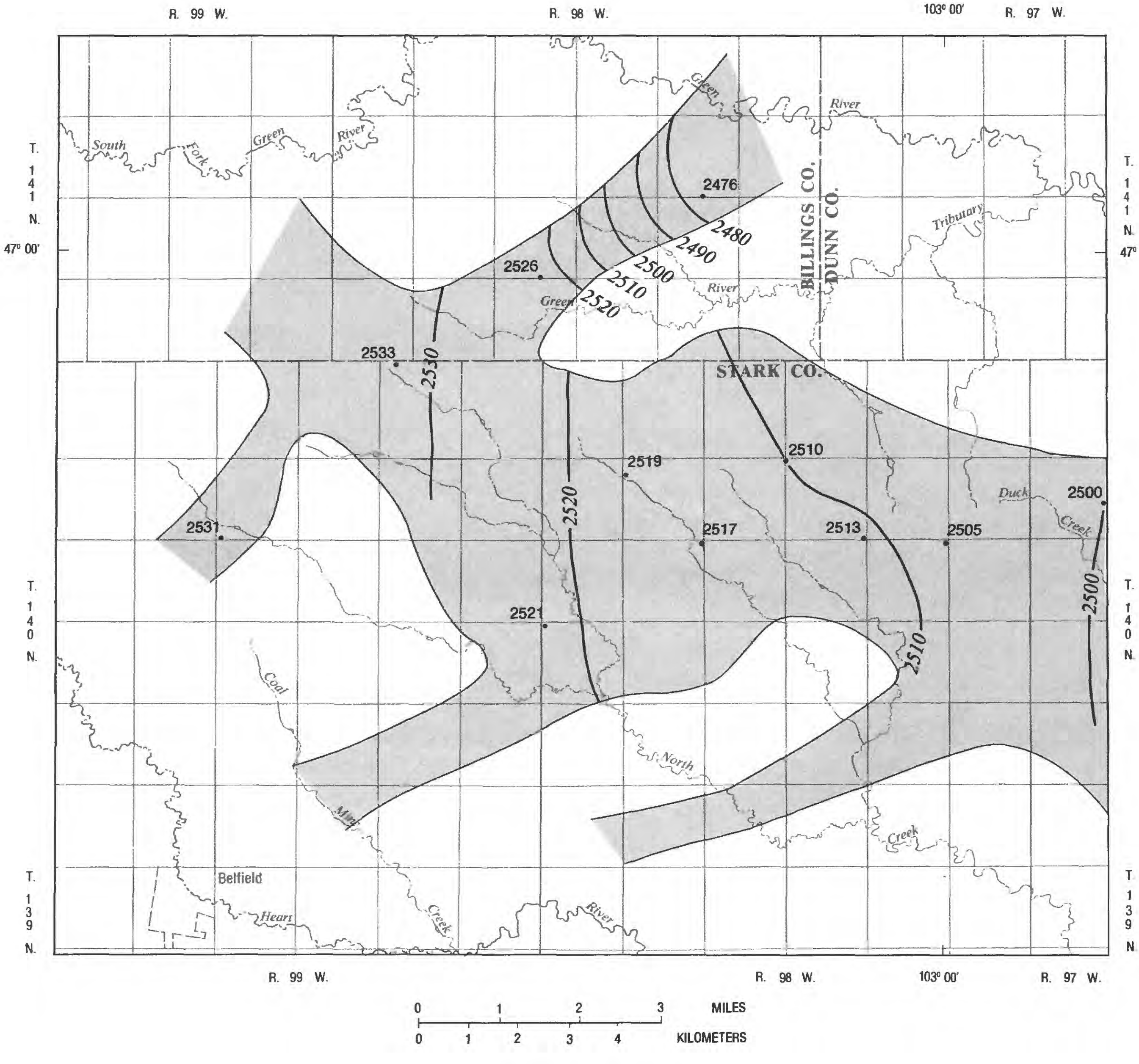
Wells completed in the D-HT aquifer over most of its area of occurrence should yield water supplies adequate for domestic use. Potential yields from properly constructed wells may be several tens of gallons per minute in areas where the aquifer thickness approaches 100 feet.

Water levels in the D-HT aquifer generally have been rising very gradually during the period from mid-1979 through 1981. Net water-level changes in most wells during this period were less than 1 foot. Water levels in wells 140-099-02BBA1 and 141-098-28DCC, however, rose about 2 feet in response to recharge from the melting of a very heavy snowpack in the spring of 1982.

D lignite aquifer

The D lignite underlies nearly the entire study area and generally dips toward the northeast (fig. 6). The thickness of confining materials (silt and clay) between the D-HT aquifer and the D bed ranged from virtually zero to more than 100 feet and averaged about 30 feet.

Thickness of the D bed in 55 test holes averaged about 8 feet (fig. 7). Depth to the top of the D bed ranged from 22 to 256 feet, but over much of the study area the D bed is between 100 and 200 feet deep.



EXPLANATION

AREA OF SAND OCCURRENCE

—*2520*— **POTENTIOMETRIC CONTOUR** Shows altitude at which water level would have stood in tightly cased wells. Contour interval 10 feet. National Geodetic Vertical Datum of 1929

•2519 **OBSERVATION WELL** Number is altitude of water level, in feet above National Geodetic Vertical Datum of 1929

Figure 11. Potentiometric surface of the D-HT aquifer, November 1981.

Water levels in observation wells completed in the D lignite aquifer are shown in figure 12. Data are not available for the northwestern part of the study area where the lignite is either less than 5 feet thick or totally absent due to erosion. Observation wells were not constructed in that area because of the minimal lignite thickness. Also, the D bed lies near the land surface in some of the area and probably is under minimally confined conditions, if saturated. Therefore, the D lignite probably is not a productive aquifer beneath much of the study area unrepresented by data in figure 12.

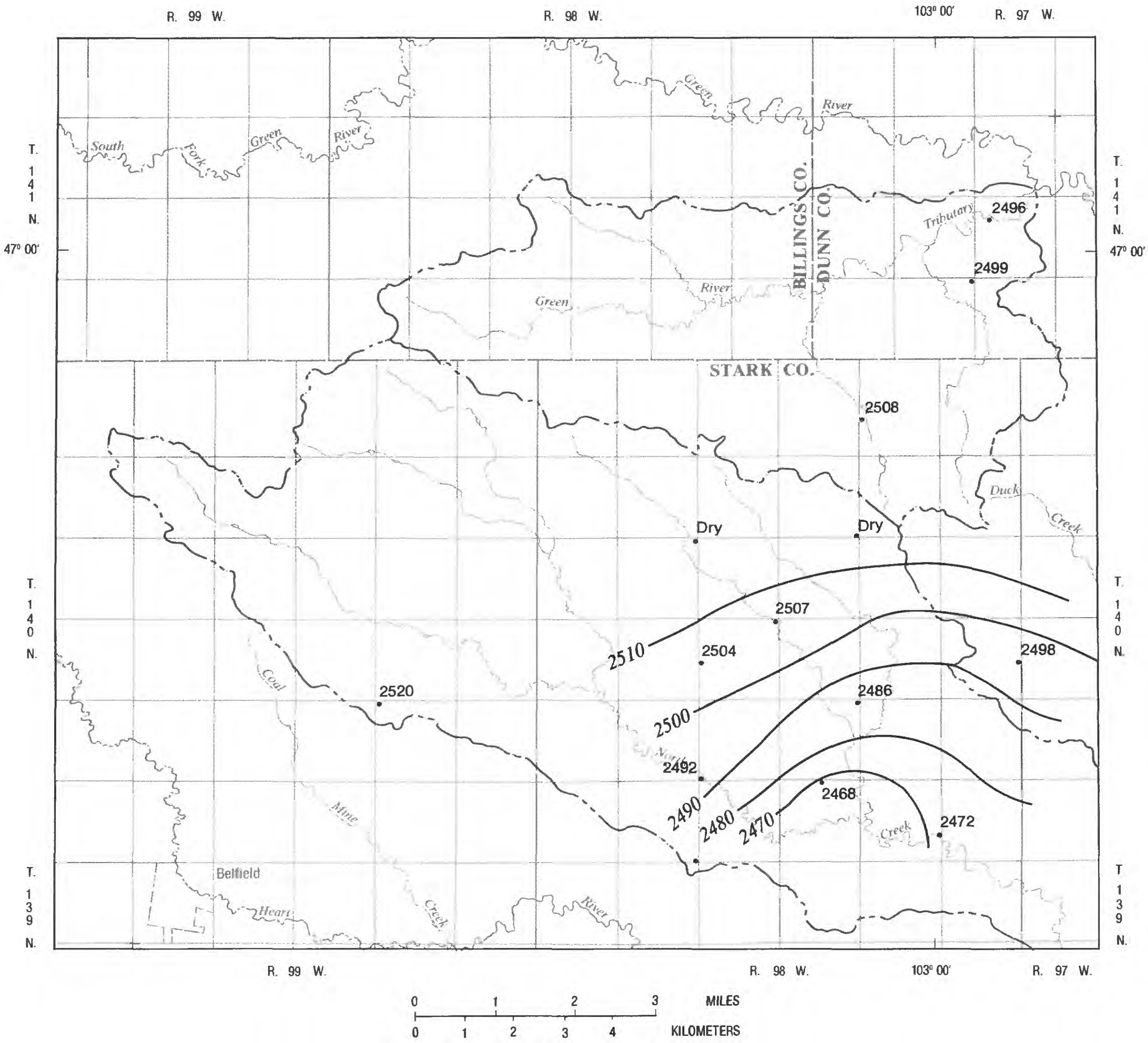
The potentiometric surface in the D lignite is influenced by the lignite structure and the land-surface topography. An anticlinal feature in the east-central part of the study area that roughly coincides with the topographic divide between North Creek and Green River tributary is evident in figure 6. Water-level data and potentiometric contours shown in figure 12 (and the dry condition of the D bed at 140-098-10DDD and 140-098-17AAA) indicate that this area is also a divide relative to ground-water flow in the D lignite aquifer. Ground water flows from the upland divide area toward the structurally and topographically low areas near the mouths of North Creek and Green River tributary.

The D lignite was dry in test holes 140-098-10DDD and 140-098-17AAA--a probable indication that the lignite is unsaturated all along the structural ridge. The dry condition encountered at 140-098-32DDD suggests that the D bed also may be unsaturated in the structurally high area south of North Creek, in the south-central part of the study area. The aquifer was confined at all other well locations shown in figure 12.

The D lignite aquifer is recharged by downward leakage in areas where it is overlain by other aquifers and by infiltration and subsequent percolation of precipitation in areas where it lies near the land surface. The aquifer, because it does not outcrop within the study area, discharges mainly by downward leakage. Beneath the valleys of the Green River and Green River tributary near the northeast corner of the study area, however, vertical components of gradient are upward, thereby inducing minor leakage upward. Some water probably discharges to areas south and east of the study area, particularly at the D bed outcrop along the Heart River near the town of South Heart (139-097-6).

Determinations of hydraulic conductivity were not made for the lignite aquifers in the study area. However, many slug tests performed on a Tongue River lignite in the Beach area indicated that its hydraulic conductivity generally ranged from 0.1 to 10 ft/d (Horak, 1983). This range is assumed to be representative of the D and E lignites.

Water levels declined in observation wells completed in the D lignite aquifer between the fall of 1979 and spring of 1982. Most water levels declined from 1 to 3 feet during the period, except at well 140-098-28CCC (a few feet from North Creek) where the water level declined 10 feet. The declining water-level trend, reflecting a decrease in aquifer storage, was in response to below normal precipitation. Slight to quite dramatic water-level recoveries were measuerd in the spring of 1982, following the melting of a very heavy snowpack.



EXPLANATION

2480 **POTENTIOMETRIC CONTOUR** Shows altitude at which water level would have stood in tightly cased wells. Contour interval 10 feet. National Geodetic Vertical Datum of 1929

DRAINAGE BASIN BOUNDARY

2492 **OBSERVATION WELL OR TEST HOLE** Number is altitude of water level, in feet above National Geodetic Vertical Datum of 1929. 'Dry' indicates that D lignite is unsaturated, based on the condition of cuttings during test drilling.

Figure 12. Potentiometric surface of the D lignite aquifer, November 1981.

E-D aquifer

The sand beds comprising the E-D aquifer represent a depositional phase analogous to that which gave rise to the D-HT aquifer. The E-D aquifer occurs consistently in the central part of the study area (fig. 13) over a similar, although somewhat greater area than the D-HT aquifer.

The E-D aquifer overlies and commonly is in direct contact with the D lignite bed. The thickness of the confining materials (silt and clay) between the D lignite bed and the E-D aquifer ranged from zero to 50 feet and averaged 16 feet in 22 test holes.

The lithologic composition of the E-D aquifer is not perceptively different from that of the D-HT aquifer. Where present, thickness of the E-D aquifer ranged from 10 to 100 feet (fig. 13) and averaged about 50 feet. In most places the aquifer consists of a single sand bed. Depth to the top of the aquifer ranged from zero in parts of the stream valleys to about 200 feet in the extreme northern part of the study area. However, in most of the study area the aquifer lies at depths between 50 and 150 feet.

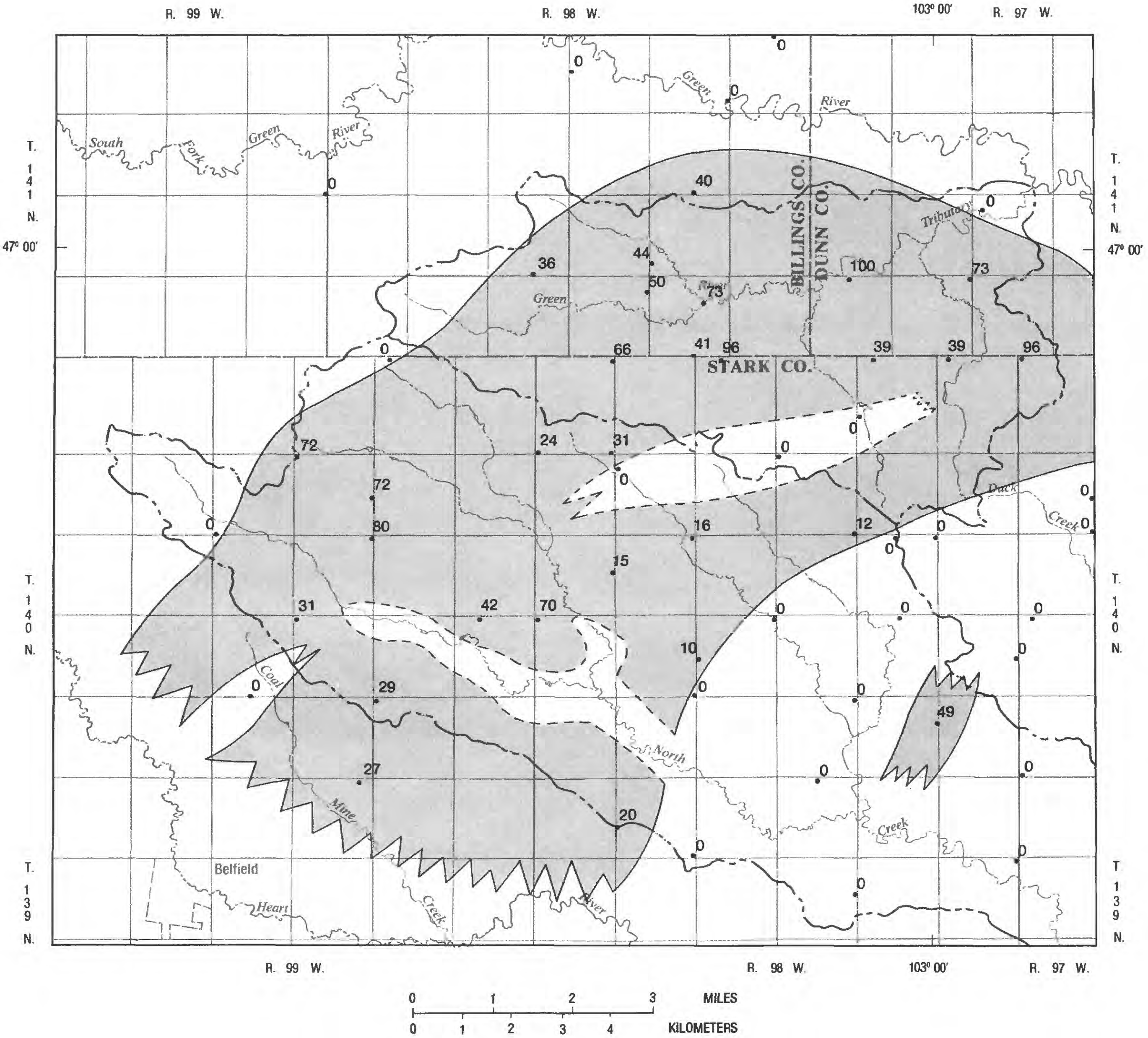
The E-D aquifer exists under both unconfined and confined conditions. Although the aquifer was found to be unconfined at only one observation-well site (140-098-6AAA), it is assumed to be unconfined in most areas where it lies within several tens of feet of the land surface.

Water-level data (fig. 14) from the seven observation wells completed in the E-D aquifer indicate that the flow primarily is in response to local topography. North of the topographic divide between North Creek and Green River tributary, ground water flows toward the northeast, roughly parallel to the stream. Data for the two observation wells in the North Creek basin indicate a gradient toward the southwest.

The E-D aquifer is recharged over most of its area of occurrence by leakage through overlying materials. Where it lies within several feet of the land surface, the aquifer is recharged directly by percolation of precipitation.

Discharge from the E-D aquifer occurs mainly as downward leakage. Also, some of the base flow of 0.15 to 0.25 ft^3/s measured at the gaging station on Green River tributary (fig. 4) may be discharge from th E-D aquifer. Logs of test holes 141-097-31BAA and 141-098-35ACA indicate that the aquifer may outcrop along the stream in the vicinity of the Billings-Dunn county line.

Water-level fluctuations in the E-D aquifer generally were less than 1 foot from the fall of 1979 until the spring of 1982. The 1982 snowmelt and subsequent ground-water recharge, however, induced water-level rises ranging from 1.2 to 3.3 feet in the three observation wells nearest the presumed surface exposures of the aquifer.



EXPLANATION

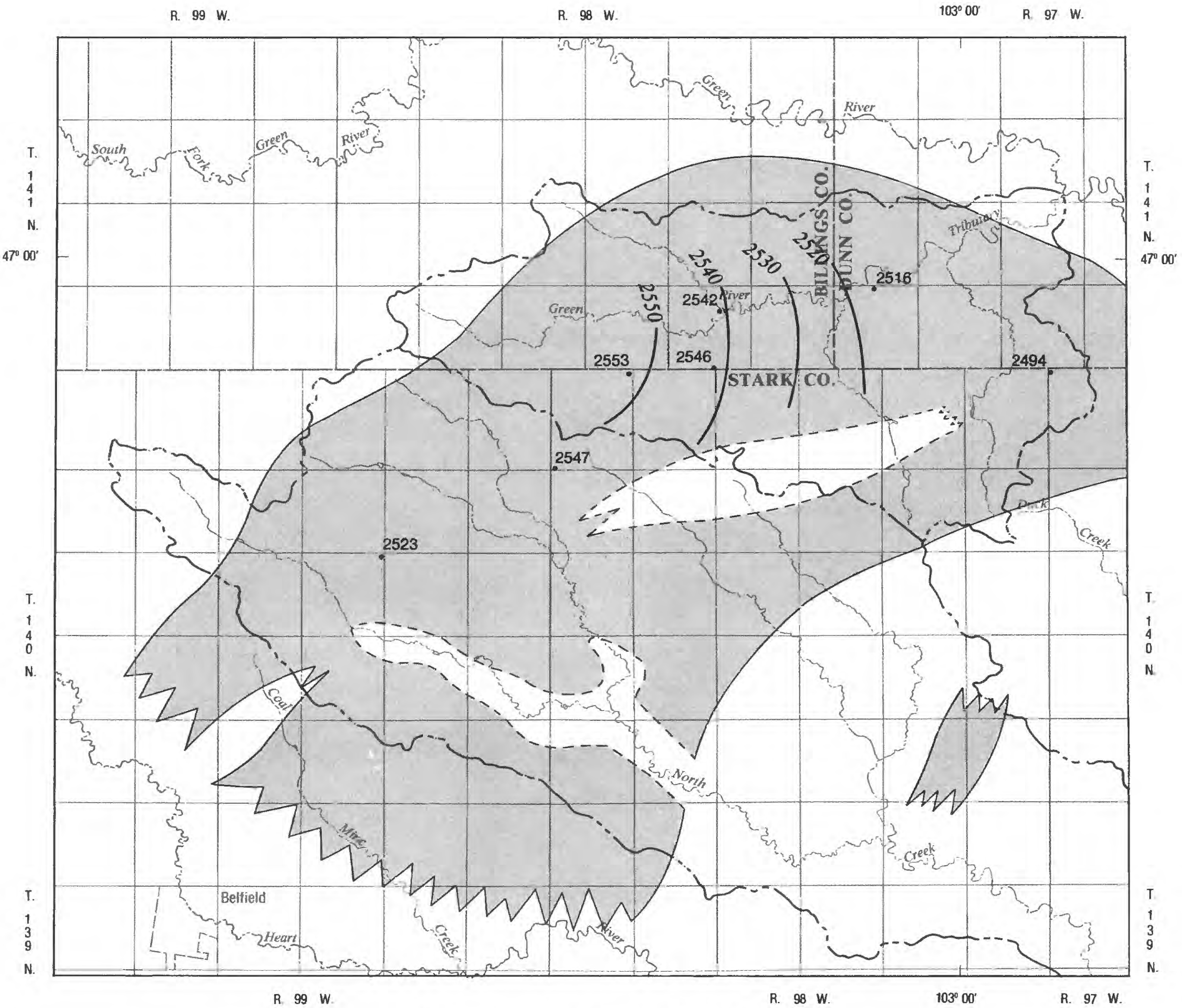
AREA OF SAND OCCURRENCE

OUTCROP Sand partly or totally removed by post-depositional erosion. Position of terrace inferred.

DRAINAGE BASIN BOUNDARY

.27 TEST HOLE Number indicates aggregate thickness of sand, in feet.

Figure 13. Aggregate sand thickness in the E-D aquifer.



0 1 2 3 MILES

0 1 2 3 4 KILOMETERS

EXPLANATION

AREA OF SAND OCCURRENCE

—*2540*— **POTENTIOMETRIC CONTOUR** Shows altitude at which water level would have stood in tightly cased wells. Contour interval 10 feet. National Geodetic Vertical Datum of 1929

- - - - - - **OUTCROP** Sand partly or totally removed by post-depositional erosion. Position of terrace inferred.

—·—·— **DRAINAGE BASIN BOUNDARY**

.2523 **OBSERVATION WELL** Number is altitude of water level, in feet above National Geodetic Vertical Datum of 1929

Figure 14. Potentiometric surface of the E-D aquifer, November 1981.

E lignite aquifer

The E lignite bed has been eroded from much of the North Creek basin and along the Heart River (fig. 8). It underlies the rest of the study area at depths ranging from zero to 150 feet in the vicinity of the Green River. The top of the bed is within 100 feet of the land surface in most of the study area. Thickness of the silty and clayey material between the E-D aquifer and the E bed ranged from 3 to 69 feet and averaged slightly over 40 feet. Thickness of the E bed ranged from 5 to 20 feet and averaged about 9.5 feet.

The E lignite is unsaturated in a major part of its area of occurrence. Those sites where it was proven dry by the condition of test-hole cuttings are indicated as "dry" on the water-level map (fig. 15). The lignite aquifer is unconfined or minimally confined in the remaining part of the study area except along the Green River and the lower reaches of Green River tributary where water levels are more than 20 feet above the top of the aquifer.

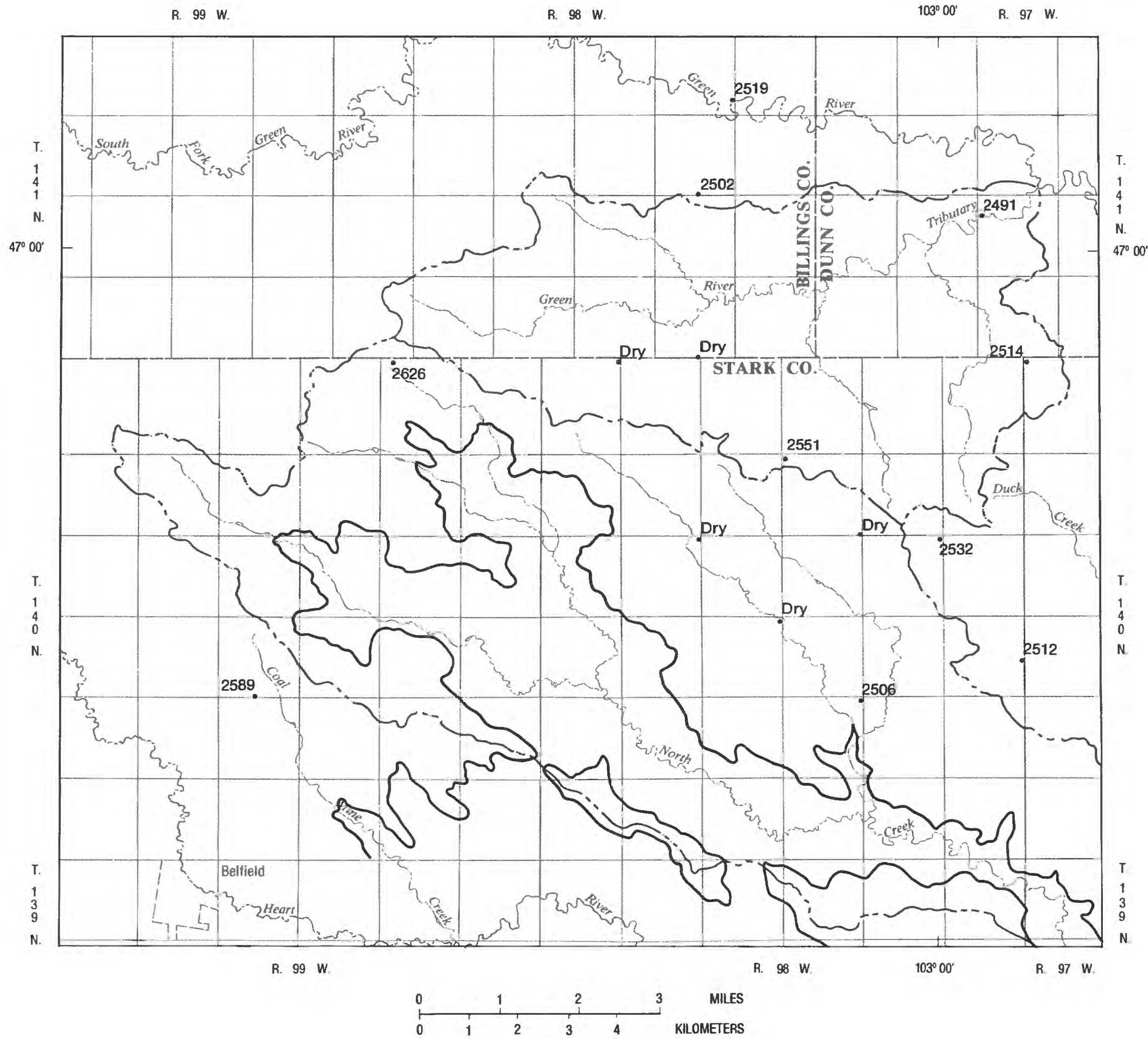
The highest water levels in the E lignite aquifer occur in the far western area and coincide with the highest structural area, while the lowest levels occur along the stream valleys (fig. 15). Therefore, ground water moves from the upland areas toward the stream valleys. Superimposed on the generalized flow regime are areas where the aquifer is unsaturated. The E bed at four of the five "dry" sites shown in figure 15 lies within 36 feet or less of the land surface. Thus, the E bed generally is not water bearing where it lies within about 50 feet of the surface in the upland areas. However, saturation is maintained to depths of less than 50 feet beneath the stream valleys.

The E lignite aquifer is recharged by percolating precipitation in the upland areas. Discharge occurs mainly as downward leakage. Also, part of the base flow measured at the gaging station on Green River tributary may originate as discharge from the E lignite. The unsaturated conditions prevailing in the North Creek basin probably account for the absence of measurable base flow at the North Creek gaging station.

Water levels in most of the wells in the E lignite aquifer reflected only minor seasonal fluctuations, indicating a fairly balanced water budget. Water levels in seven of the nine observation wells monitored through the spring of 1982 rose from 0.5 to 2.5 feet following the 1982 snowmelt period.

Water-level Relationships Among the Sentinel Butte Aquifers

Multiple well completions at several sites provided water-level data for evaluation of the ground-water-flow system in the vertical dimension. The vertical hydraulic gradient between any two of the four Sentinel Butte aquifers is downward in the upland areas and ranges from 0.14 to 0.55 ft/ft. The vertical gradient, however, between the E and D lignite aquifers along the Green River and Green River tributary in the northeastern part of the study area is upward.



EXPLANATION

OUTCROP OF E LIGNITE BED

DRAINAGE BASIN BOUNDARY

.2502 **OBSERVATION WELL OR TEST HOLE** Number is altitude of water level, in feet above National Geodetic Vertical Datum of 1929. 'Dry' indicates that E lignite is unsaturated, based on the condition of cuttings during test drilling.

Figure 15. Water levels in the E lignite aquifer, November 1981.

Water Quality

The quality of water in aquifers below those investigated in this study, i.e., aquifers in the Fox Hills Sandstone, Hell Creek Formation, and the Ludlow and Tongue River Members of the Fort Union Formation, is documented in reports on the ground-water resources of various counties in western North Dakota (Trapp and Croft, 1975; Croft, 1978; Klausing, 1979; Anna, 1981). The following section will only synopsize those interpretations. For more detailed information the reader may refer to reports in the County Ground-Water Studies series available through the North Dakota State Water Commission.

The quality of water in the four shallowest aquifers underlying the study area has been documented by the sampling program of this project and is described herein.

Aquifers in the Fox Hills Sandstone, Hell Creek Formation, and Ludlow Member, Fort Union Formation

All aquifers in the three stratigraphic units yield a sodium bicarbonate type water. Reported dissolved-solids concentrations range from about 900 to 2,500 mg/L and average between 1,160 to 1,860 mg/L. In general, the dissolved-solids concentration decreased from the shallower to the deeper aquifers. Sodium constituted over 90 percent of the cations and bicarbonate over 60 percent of the anions. The water usually is soft and often contains detectable levels of hydrogen sulfide, which imparts a "rotten egg" odor to water from the aquifers in parts of southwestern North Dakota.

Aquifers in the Tongue River Member, Fort Union Formation

Two observation wells were completed in Tongue River aquifers--one in the lower Tongue River aquifer at 140-098-28CCC1 and one in the HT Butte lignite bed at the top of the Tongue River Member at 140-098-32DDD1. Analyses of water samples from these wells show that both aquifers contain a sodium bicarbonate type water with sodium representing over 99 percent of the cations and bicarbonate over 70 percent of the anions. The dissolved-solids concentration was 956 mg/L in the lower Tongue River aquifer and 1,470 mg/L in the HT Butte lignite. Both waters were soft and contained 0.11 mg/L or less dissolved iron.

Chemical data representing samples from 10 wells completed in Tongue River aquifers in Billings, Golden Valley, and Slope Counties (Anna, 1981) and from 20 wells in Tongue River aquifers in Dunn County (Klausing, 1979) also were indicative of predominantly soft, sodium bicarbonate type water with all but one of the dissolved-solids concentrations in the range from 900 to 2,610 mg/L.

Aquifers in the Sentinel Butte Member, Fort Union Formation

Water samples were collected from 29 observation wells developed in the D-HT, D lignite, E-D, or E lignite aquifer. Repetitive sampling of selected wells indicated that no appreciable change in water quality occurred during the 5-year sampling period. All the analyses are shown on Attachment B. Table 2 is a statistical summary of chemical data for the four principal aquifers. Where more than one analysis was available for a given well, an average analysis was calculated for the well and used in the compilation of table 2 and in the trilinear diagrams. The analysis for one well was omitted from the E-D aquifer summary because it was an obvious outlier (validity unknown) and would have imposed an unrepresentative bias on the summary. Trilinear diagrams are used to illustrate the relative ionic composition of the various water samples from each of the four aquifers.

D-HT aquifer

Sodium constituted 96 percent or more of the cations in samples collected from 10 wells completed in the D-HT aquifer (fig. 16). The mean sodium concentration was 710 mg/L (table 2). The anionic composition varied from a sample with 10 percent sulfate and 87 percent bicarbonate to one with 67 percent sulfate and 32 percent bicarbonate (fig. 16). Chloride constituted no more than 3 percent of the anions in any sample. The standard deviations shown in table 2 indicate that the concentrations of most constituents varied widely among the 10 analyses.

Dissolved-solids concentrations in samples from the D-HT aquifer ranged from 1,100 to 4,230 mg/L and the mean was 1,970 mg/L. The water generally was soft and contained only minor concentrations of dissolved iron. Some tan or brown coloration caused by dissolved organic complexes was observed in most samples. A slight hydrogen sulfide odor was evident in one sample.

D lignite aquifer

As in the D-HT aquifer, the cationic makeup of water in the D lignite aquifer is almost exclusively sodium (fig. 17). Water samples from 8 of the 10 wells contained 95 percent or more sodium, while the other 2 had 88 and 92 percent sodium. The mean sodium concentration was 610 mg/L (table 2), or about 14 percent less than in the D-HT aquifer. Bicarbonate constituted 50 percent or more of the anions in 8 of the 10 samples. The two samples with greater than 50 percent sulfate were taken from wells less than 100 feet deep. Chloride represented no more than 5 percent of the anions in any of the samples.

Dissolved-solids concentrations ranged from 1,140 to 2,640 mg/L and had a mean of 1,700 mg/L. The water predominantly was soft. One-half of the samples contained iron greatly in excess of the recommended limit of 0.3 mg/L. Most of the samples had a brown coloration, some very intense. Hydrogen sulfide odor was detectable in 5 of the 10 samples.

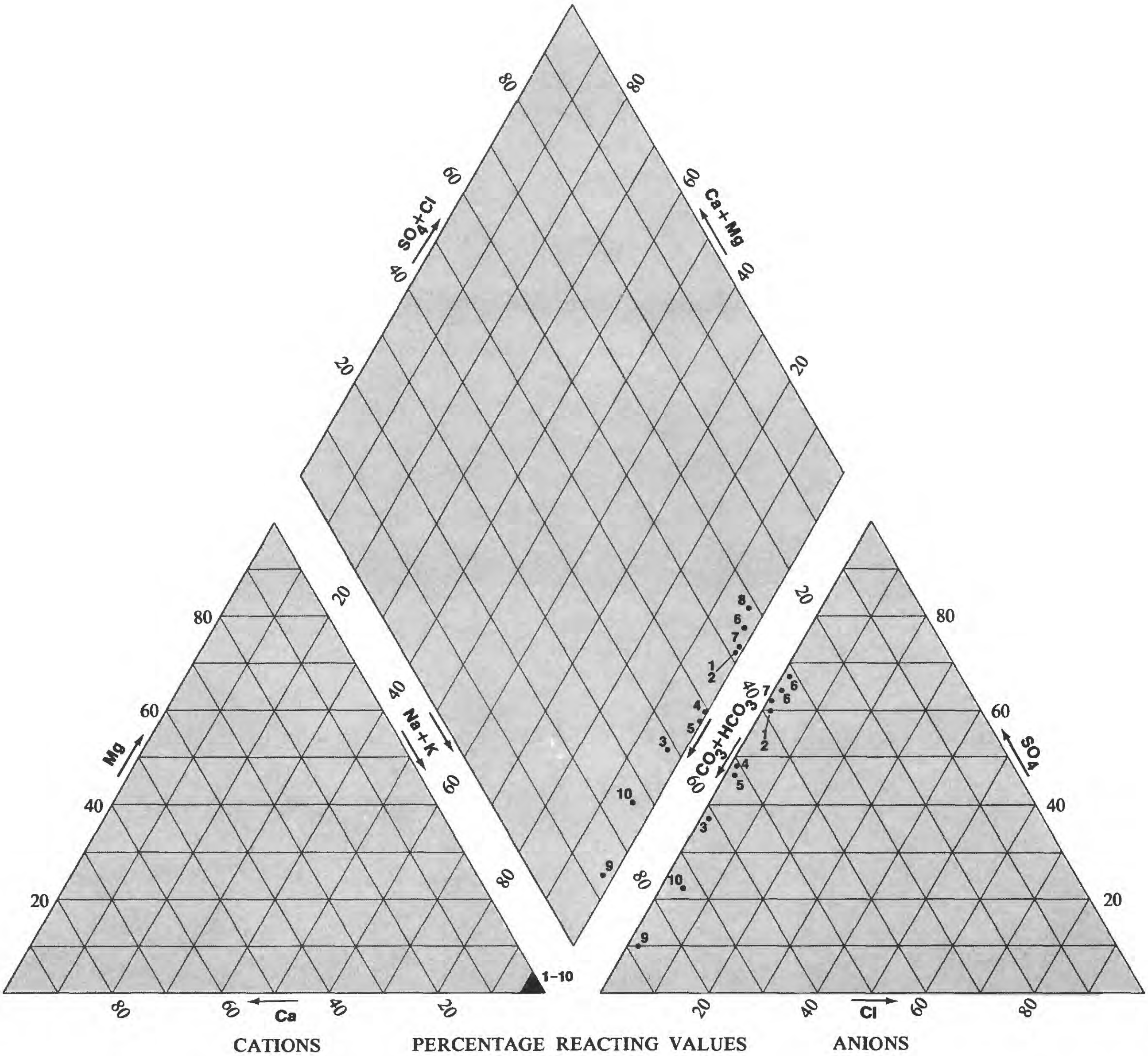
E-D aquifer

The diversity of water quality in the E-D aquifer was much more pronounced than in the other three aquifers. Although sodium constituted 98 percent or more of the cations in three samples, it was 80 percent or less in the other four (fig. 18). Sulfate was the predominant anion in three samples and bicarbonate was predominant in the other four. The standard

TABLE 2.--Means and standard deviations of selected chemical parameters in water samples from aquifers in the Rattlesnake Butte study area

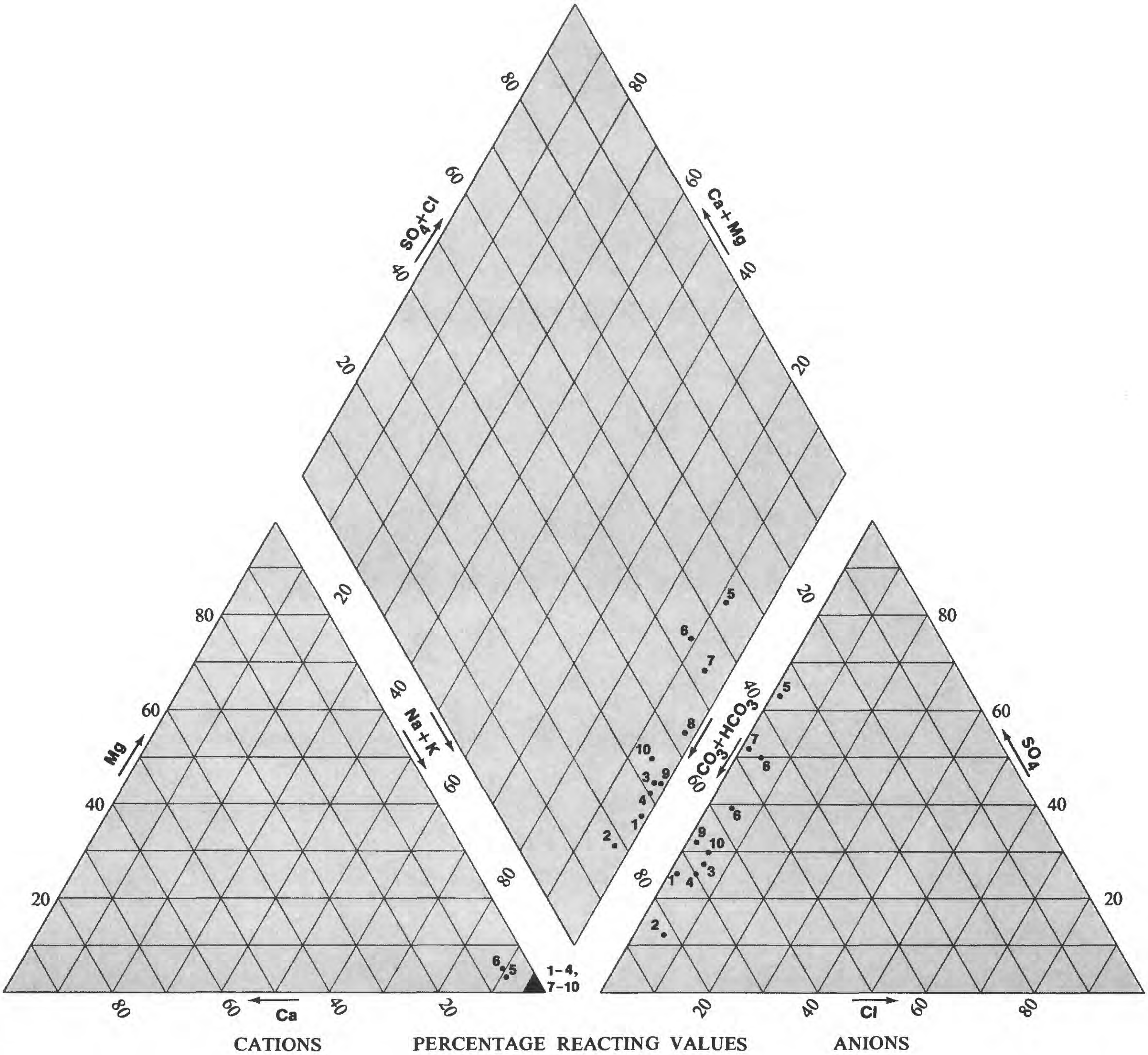
[Concentrations are in milligrams per liter (mg/L) unless otherwise indicated]

	E lignite aquifer		E-D aquifer		D lignite aquifer		D-HT aquifer	
Number of samples	3		6		10		10	
Parameter	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Sodium (Na)	490	140	520	420	610	140	710	320
Potassium (K)	3.2	1.5	4.1	1.8	5.7	3.8	3.6	2.0
Calcium (Ca)	2.5	1.6	29	26	14	13	5.7	4.2
Magnesium (Mg)	1.7	1.6	13	12	6.9	5.6	2.9	2.7
Alkalinity ($CaCO_3$)	660	150	640	240	960	290	740	230
Sulfate (SO_4)	380	200	580	540	520	220	790	580
Chloride (Cl)	7.0	4.6	6.6	7.1	34	23	8.9	7.0
Fluoride (F)	1.4	.7	1.1	1.6	2.3	1.7	2.1	1.2
pH (units)	8.2	.4	--	--	8.1	.6	8.6	.8
Dissolved solids	1,290	410	1,550	1,060	1,700	400	1,970	950
Specific conductance (micromhos per centimeter at 25°C)	2,150	640	2,170	1,330	2,600	670	2,830	1,040
Sodium-adsorption ratio	63	8	39	39	43	20	71	26
Percent sodium	99	.6	80	25	96	3.3	98	1.0
Hardness ($CaCO_3$)	13	11	130	110	65	53	32	18
Iron (Fe) (micrograms per liter)	180	150	270	200	1,510	2,040	200	230



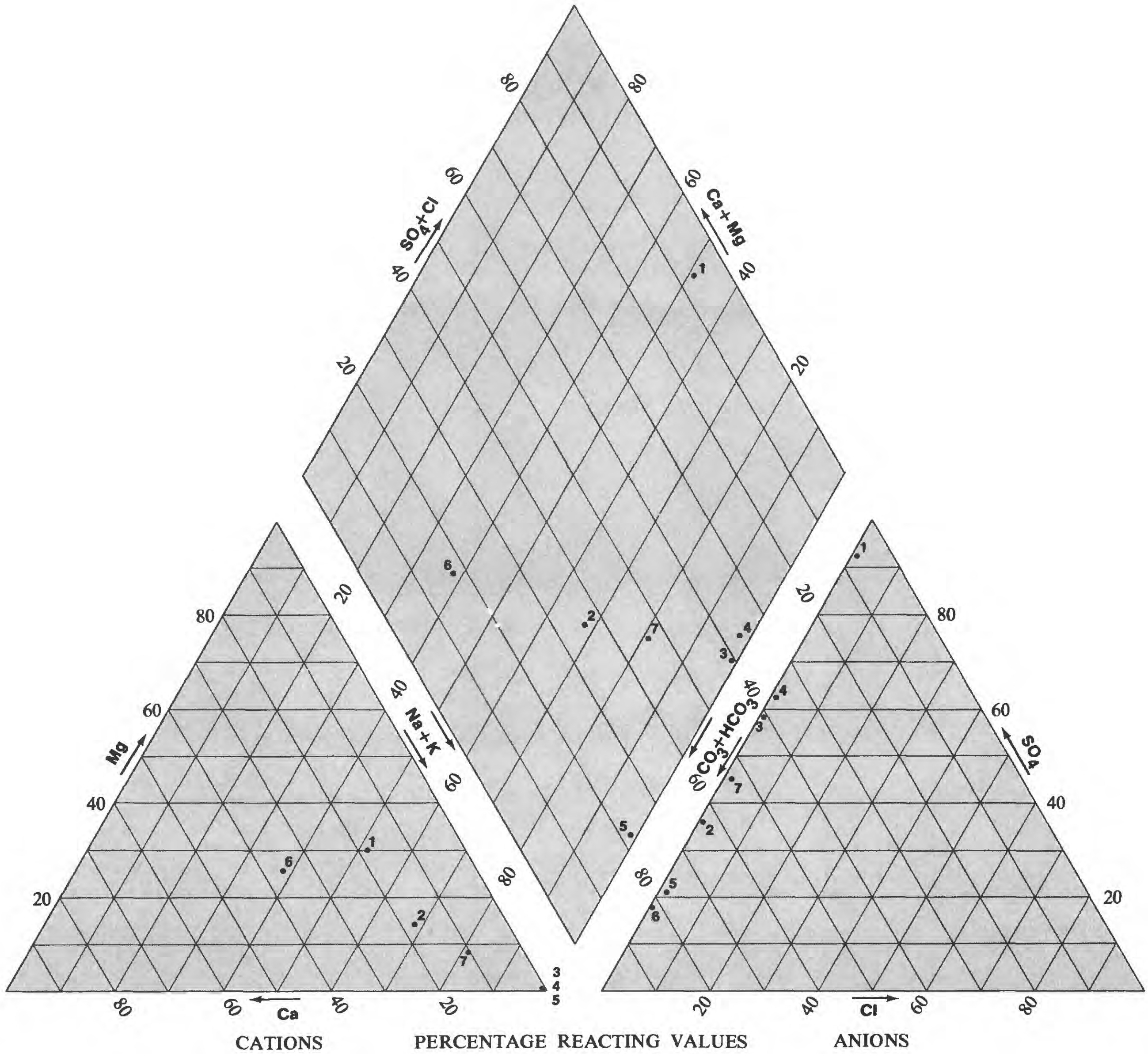
Well	Index number	Well depth, in feet	Dissolved-solids concentration, in milligrams per liter
140-098-08BBC1	1	190	2,000
140-098-10BBB1	2	294	1,940
140-098-10DDD	3	192	1,100
140-098-14AAA1	4	240	1,550
140-098-17AAA	5	140	1,180
140-098-19BBB	6	160	4,230
140-099-02BBA1	7	250	2,170
140-099-09CCC	8	252	2,800
141-098-23DCC1	9	344	1,460
141-098-28DCC	10	180	1,310

Figure 16. Relative concentrations of common ions in water samples from the D-HT aquifer.



Well	Index number	Well depth, in feet	Dissolved-solids concentration, in milligrams per liter
140-098-02CBB	1	151	1,140
140-098-21AAA	2	90	1,580
140-098-24DDA1	3	140	1,220
140-098-27AAA1	4	147	1,730
140-098-28CCC2	5	48	1,360
140-098-34ABB	6	95	2,130
140-098-35DAD	7	76	1,940
140-099-26BBB	8	136	2,410
141-097-28BBD1	9	150	1,860
141-097-32AAA	10	178	2,640

Figure 17. Relative concentrations of common ions in water samples from the D lignite aquifer.



Well	Index number	Well depth, in feet	Dissolved-solids concentration, in milligrams per liter
140-097-06BBB1	1	180	9,560
140-098-06AAA	2	106	972
140-098-06CCC	3	140	3,260
140-099-15AAA	4	170	2,380
141-097-31BAA	5	162	1,100
141-098-35ACA	6	80	427
141-098-35DCC1	7	100	1,150

Figure 18. Relative concentrations of common ions in water samples from the E-D aquifer.

deviations of constituent concentrations shown in table 2 attest to the variable water chemistry in the E-D aquifer.

Dissolved-solids concentrations ranged from 427 to 3,260 mg/L--or to 9,560 mg/L if an extreme outlier is included (140-097-06BBB1). The mean value (omitting the outlier) was 1,550 mg/L (table 2). The water ranged from soft to very hard and dissolved iron concentrations ranged from 0.05 to 36 mg/L. Brown coloration and hydrogen sulfide odor were observed in two samples.

E lignite aquifer

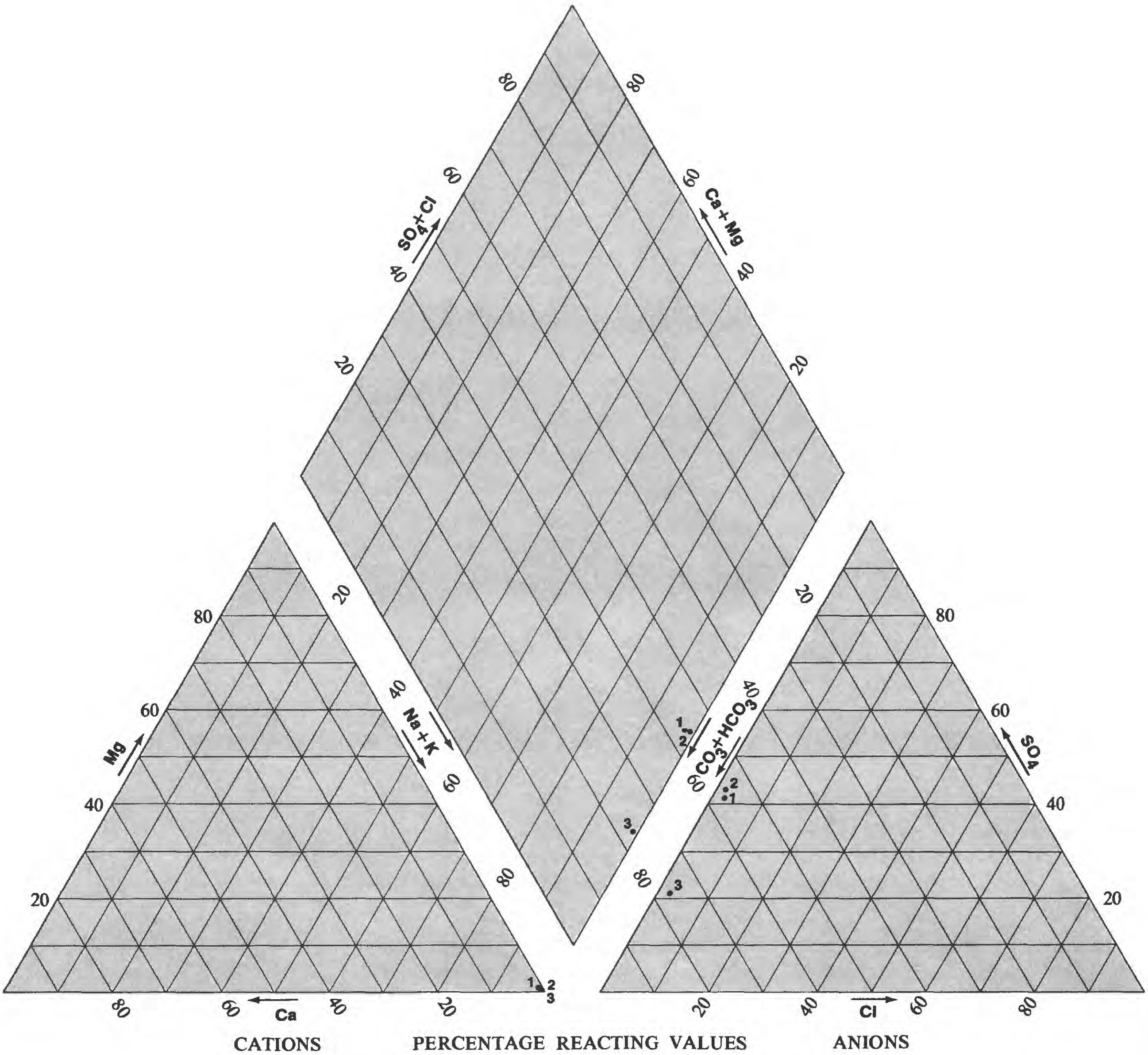
Only three water samples were obtained from the E lignite aquifer because the water levels in most of the wells were so low that development was not possible. The three samples were a sodium (98 or 99 percent) bicarbonate type water (fig. 19). Dissolved-solids concentrations were 942, 1,190, and 1,740 mg/L. All three water samples were soft. Dissolved-iron concentrations were 0.08, 0.12, and 0.35 mg/L. Two of the three samples were slightly colored and one had a slight hydrogen sulfide odor.

It is very probable that the E lignite aquifer contains water in parts of its saturated areas that is quite unlike the water represented by the three analyses. This may be inferred because the three sampled wells are somewhat removed from the principal recharge areas where the lignite lies at shallow depth (although the well at 141-097-28BBD2 is only 40 feet deep, the E bed discharges upward at this site). Other studies (R. L. Houghton, written commun., 1982; Horak, 1983) have demonstrated that chemically enriched ground waters commonly exist where lignite aquifers lie at shallow depth and receive oxygenated recharge water. Hydrolysis and oxidation-reduction reactions involving readily available minerals in the shallow lignite and overburden sediments may generate waters with pH in the 6.0 to 6.2 range, very high calcium, magnesium, sulfate, and iron concentrations, and dissolved-solids concentrations of several thousand milligrams per liter. It should be noted, therefore, that much poorer quality water probably could be found in the E lignite aquifer, given a broader sampling coverage.

SURFACE-WATER RESOURCES

Hydrology

Streams that drain parts of the study area include the Green and Heart Rivers, Coal Mine, Duck, and North Creeks, and an unnamed tributary of the Green River. Most of the minable area is drained by North Creek and Green River tributary. The basin boundaries of the two streams and the stream-monitoring sites used for data collection are shown in figure 4. Also, a continuous-recording gage (06344600) has been maintained on the Green River (fig. 4) since 1964. The streamflow gages on North Creek and Green River tributary were established in October 1978. The discharge data and station descriptions for each of the continuous-recording gages are published in the annual U.S. Geological Survey report "Water Resources Data for North Dakota." The miscellaneous sites on North Creek and Green River tributary were used for seepage runs made between November 1978 and the end of 1981.



Well	Index number	Well depth, in feet	Dissolved-solids concentration, in milligrams per liter
141-097-28BBD2	1	40	1,740
141-098-14DDA3	2	86	1,190
141-098-23DCC2	3	152	942

Figure 19. Relative concentrations of common ions in water samples from the E lignite aquifer.

Monthly and annual mean flows and instantaneous maximum and minimum flows for North Creek and Green River tributary are summarized in table 3.

North Creek

North Creek has a deeply incised channel through most of its course. The stream flows during the spring snowmelt period and after summer rainstorms, but generally ceases to flow by mid to late summer (plate 2, in pocket). Following the killing frosts of fall and the cessation of consumptive water use by riparian vegetation, the stream generally flows at a few hundredths of a cubic foot per second. Flow again ceases with the extreme winter cold when all water is stored in the channel as ice.

Flow was not detected during any of the fall seepage measurements at any of the upper three monitoring sites on North Creek (fig. 4). The intermittent base flow observed at the gaging station generally ranges between 0.01 and 0.05 ft^3/s and probably is derived from saturated beds adjacent to the stream.

Green River Tributary

Green River tributary flows perennially within a deeply incised channel. Discharge magnitudes exceed 1 ft^3/s only during the few weeks following the start of spring snowmelt and for several hours following heavy rain storms. Base flow generally ranges from 0.10 to 0.25 ft^3/s. November seepage runs indicated that base flow begins between the upper and middle monitoring sites (fig. 4) and increases between the middle site and the downstream station. Ground-water discharge from the E lignite aquifer or the E-D aquifer, or both, is the presumed source of the base flow.

Water Quality

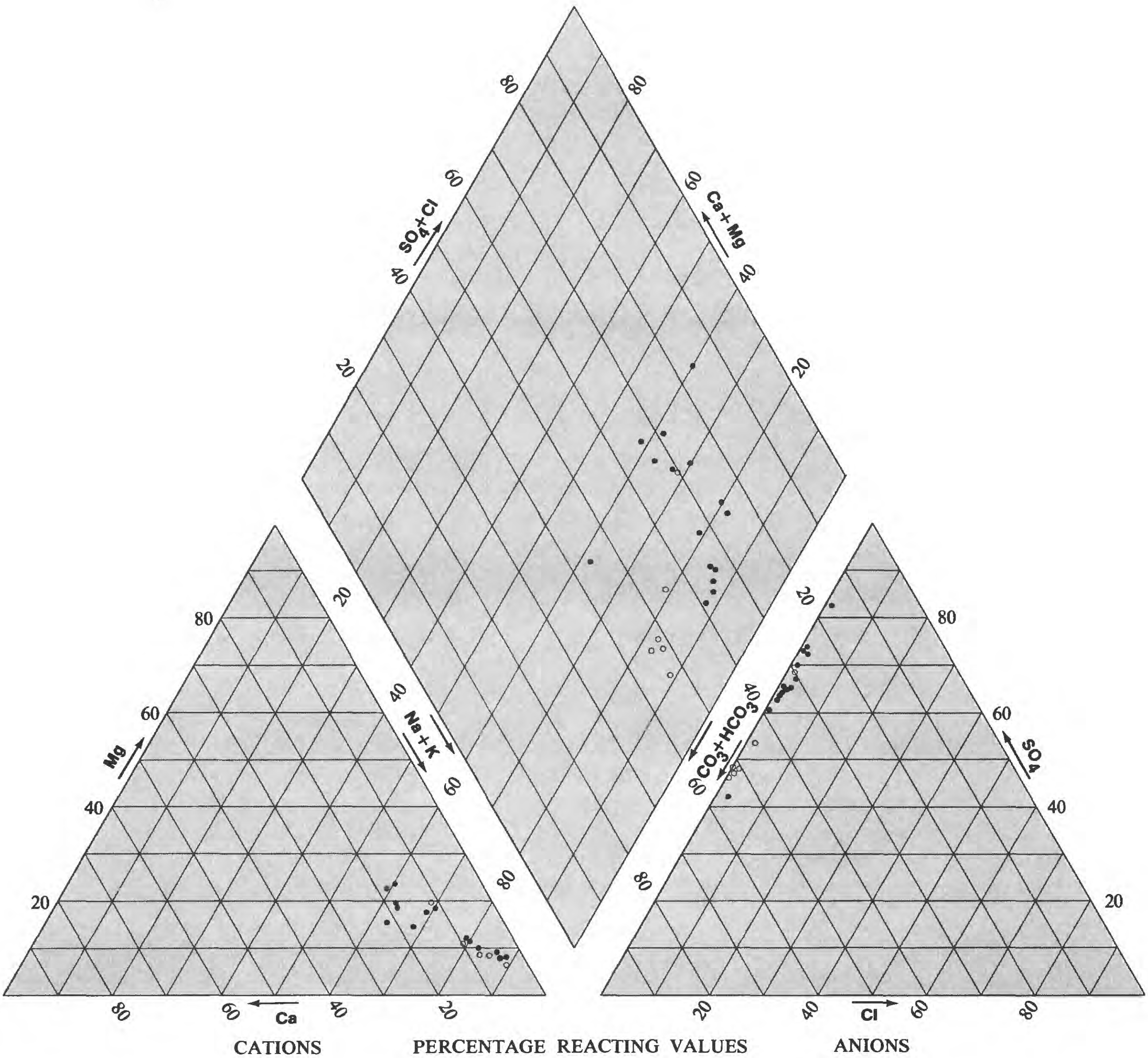
North Creek

Water samples were collected from North Creek for analysis of common ions on a monthly schedule during periods of flow. The results of these analyses are published in the annual U.S. Geological Survey reports "Water Resources Data for North Dakota" and are not repeated in this report.

The water flowing in North Creek is a sodium sulfate type (fig. 20). During periods of relatively high flow (greater than 0.50 ft^3/s), the sodium generally constitutes 60 to 70 percent of the cations. During low flow or base-flow periods, sodium generally constitutes 80 and 90 percent of the cations--similar to the cationic composition of the shallow ground water. Sulfate accounted for greater than 50 percent of the anions in all but one of the samples; the average was about 65 percent. Dissolved-solids concentrations varied inversely with the discharge, but the relationship is not well defined. The dissolved-solids concentrations ranged from 209 mg/L at a discharge of 74 ft^3/s to 3,460 mg/L at a discharge of 0.02 ft^3/s.

TABLE 3.--Streamflow statistics for North Creek and Green River tributary

Drainage area (square miles)	Period of record	Instantaneous extremes for period of record (cubic feet per second)		Year	Monthly mean flows (cubic feet per second)												Annual mean discharge (cubic feet per second) (water years)
		Maximum	Minimum		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
North Creek (06342970)																	
40.8	October 1978	260	0.0	1978	--	--	--	--	--	--	--	--	--	0.053	0.040	0.019	
	through			1979	0.000	0.000	18.6	47.9	0.48	0.026	2.01	0.005	0.19	.014	.046	.007	5.76
	September			1980	.000	.000	.55	.18	.017	2.54	.000	.000	.000	.58	.035	.000	.28
	1981			1981	.000	.098	.12	.021	.001	1.91	.006	4.20	.000	--	---	---	
Green River tributary (06344610)																	
22.4	October 1978	3,100	0.0	1978	--	--	--	--	--	--	--	--	--	.23	.21	.16	
	through			1979	.14	.09	53.9	29.5	.45	.39	.61	.27	.17	.18	.22	.22	7.23
	September			1980	.17	.18	.60	.31	.16	1.44	.11	.13	.15	.27	.19	.15	.32
	1981			1981	.17	1.46	.33	.28	.21	3.93	.21	25.2	.18	--	--	--	2.74



EXPLANATION

• NORTH CREEK

○ GREEN RIVER TRIBUTARY

Figure 20. Relative concentrations of common ions in water samples from North Creek and Green River tributary.

Green River Tributary

Green River tributary was sampled for chemical analysis during November of each of the years 1978 through 1981 and twice during June of 1980. All except one of the June samples represents low-flow conditions.

Green River tributary has a sodium bicarbonate-sulfate type water. In each of the samples collected at low flow, sodium constituted from 79 to 90 percent of the cations (fig. 20). Sodium represented 69 percent of the cations in the sample taken at a discharge of 3.9 ft^3/s. Bicarbonate and sulfate each represented between 45 and 55 percent of the anions in each of the low-flow samples. Sulfate represented 68 percent of the anions in the sample taken at the higher discharge.

The dissolved-solids concentrations for the five samples taken at low flow ranged from 1,460 to 1,710 mg/L, whereas the one sample taken at higher flow was 688 mg/L. Specific conductance was measured each time a discharge measurement was made. A plot of discharge versus specific conductance (fig. 21) indicates the variation of dissolved solids with flow magnitude.

PROBABLE HYDROLOGIC EFFECTS OF STRIP MINING

The E and D lignite beds are aquifers, but both have substantial areas that are not saturated. The E bed, where saturated, is mostly under unconfined conditions. The potentiometric surface in the saturated parts of the D bed is only slightly above the top of the aquifer. Thus, if the aquifers were severed at a mine pit and allowed to drain, the hydraulic head available for drawdown at the mine face would not be more than several feet. Drawdowns in the aquifer at a distance of a mile or more will be very minor. This would be particularly true in areas where the aquifer is unconfined.

The thickness of overburden per foot of minable lignite is least in the lowland areas near North Creek and Green River tributary. The E bed is minable in most of its area of occurrence except in the uplands near the divide between the two streams. The D bed is economically recoverable probably only near the valley of North Creek and in the area near the confluence of the Green River and Green River tributary. Both beds are relatively thick and lie at shallow depth near North Creek in the southern part of T. 140 N., R. 98 W. This is the most likely part of the study area for the development of a strip mine.

Water-level data for the two lignite aquifers indicate that ground water moves toward the North Creek valley (whether or not it discharges there) from the upland area to the north. Thus, a mine cut opened near the valley of North Creek would intercept ground water that moved toward the stream valley under premining conditions and would only increase that movement for some moderate distance away from the mine. Again, water-level changes in areas more than a mile from the mine probably would be minor.

No appreciable impact on the D-HT aquifer is expected unless the D bed is mined in an area where the confining bed separating the two aquifers is very thin. Aquifers in the Tongue River Member and lower units would be

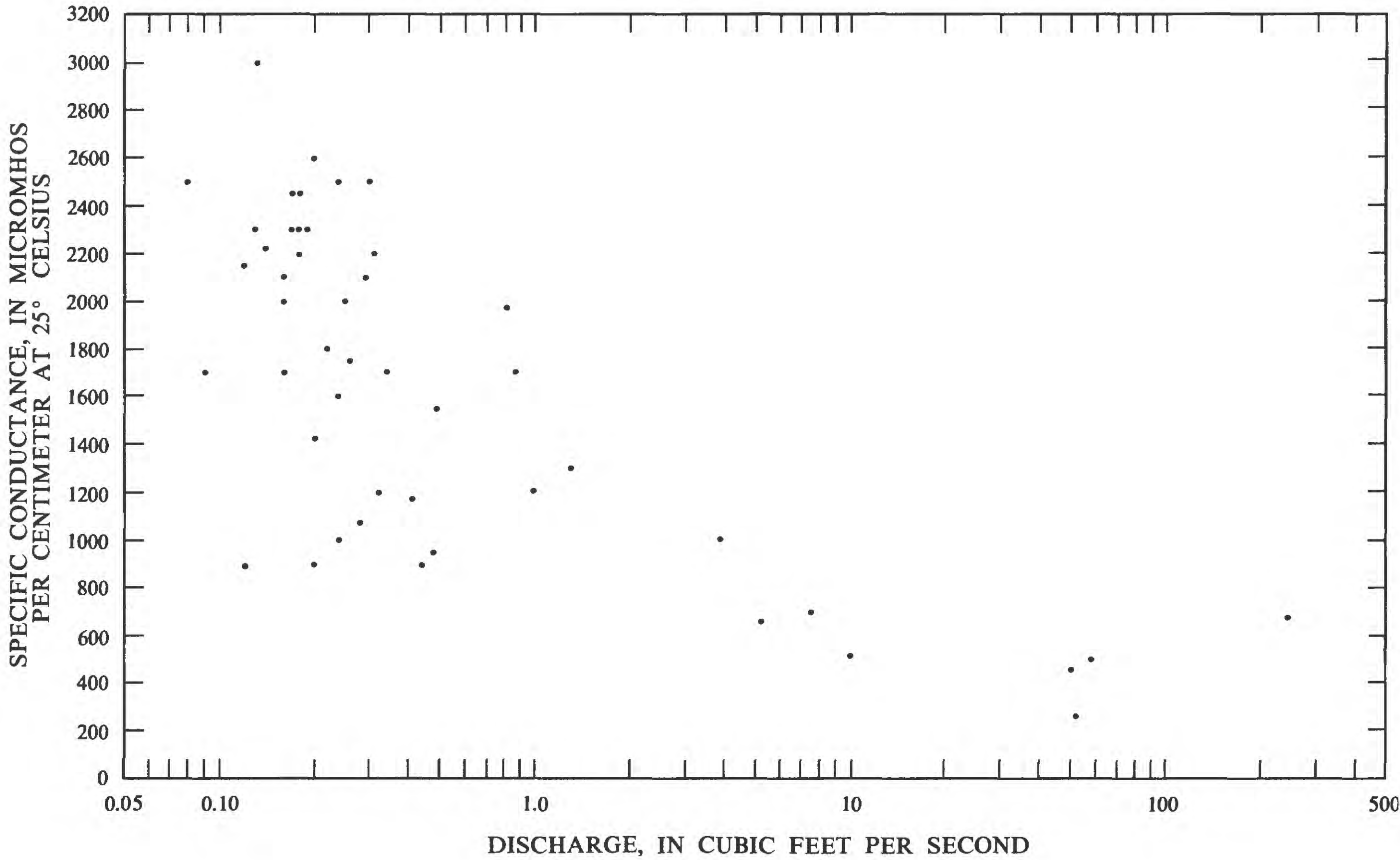


Figure 21. Relationship between discharge and specific conductance for Green River tributary, October 1978 to November 1981.

unaffected by mining and could serve as alternative sources of water to replace supplies lost due to destruction of the E lignite, D lignite, or E-D aquifers.

The suite of chemical reactions and mineral diagenesis typically associated with the strip-mining process are well documented in the literature and will not be repeated here. The deleterious hydrochemical impacts observed or projected for some mine sites in the United States would, by comparison, be less severe in the Rattlesnake Butte study area. Much of the shallow ground water currently available in the study area is colored, has a hydrogen sulfide odor, and contains relatively large concentrations of dissolved solids. Therefore, any subtle changes in ground-water quality that might result from the mining process probably would go unnoticed. Other studies involving Fort Union stratigraphy have shown that oxidation-reduction reactions and the processes of cation exchange, adsorption, and carbonate buffering effectively limit the areal and depth dispersion of "plumes" of objectionable concentrations of chemical species. Thus, it is probable that any severe water-quality impacts would be confined to the immediate mine area and would soon, with distance from the mine, dissipate to obscurity within the prevailing background hydrochemical environment.

Impacts of mining on the surface-water resources in the study area would be minor. The watershed area subject to active mining at any one time is too small to significantly alter the flow magnitudes, except possibly during periods when there is only base flow. Major mining activity of the E bed along the downstream reaches of Green River tributary could, for example, divert some of the ground-water discharge that normally accounts for the 0.10 to 0.25 ft^3/s of streamflow at the gaging station. Water-quality impacts on the surface waters should be readily manageable by routing techniques, construction of impoundments, and by chemical treatment, if necessary.

SUMMARY

Two lignites, the D (lower) and E (upper) beds, in the lower 250 to 300 feet of the Sentinel Butte Member of the Fort Union Formation constitute a strippable deposit that underlies much of the basins of North Creek, a tributary of the Heart River, and an unnamed tributary of the Green River.

Aquifers occur intermittently throughout a sequence of some 2,000 feet of Upper Cretaceous and Tertiary sedimentary deposits beneath the study area. Sandstone beds in the Fox Hills Sandstone constitute a major regional aquifer and occur in the study area at depths of about 1,650 to 1,700 feet. Well yields of 25 to 75 gal/min should be available from the aquifer in most areas. The depth to water in wells in the Fox Hills aquifer probably exceeds 200 feet in much of the study area.

Sandstone beds as much as 78 feet thick and formational (member) aggregate sandstone thicknesses of as much as 181 feet were reported at depths ranging from 900 to 1,632 feet in the Hell Creek Formation and Ludlow and Cannonball Members of the Fort Union Formation in test holes near the study area. Estimates of maximum potential yields were 150 gal/min, but average

yields would be much less. Well yields adequate for domestic use should be available from these aquifers.

Sand beds in the lower part of the Tongue River Member constitute an important aquifer in western North Dakota. The aquifer was penetrated at only one location in the study area and was at a depth of 750 feet. Silty, generally thin sand beds were penetrated at various horizons in the middle and upper parts of the Tongue River at depths as shallow as 300 feet, but well yields from these beds, as well as from numerous thin lignite beds, generally would not be adequate for domestic needs.

The D-HT, D lignite, E-D, and E lignite aquifers, in ascending order, occur in the Sentinel Butte Member in the study area. The D-HT aquifer occurs in the central part of the study area and consists of interconnected sand beds (from 15 to 100 feet thick) between the HT Butte and the D lignite beds. Depth to the top of this confined aquifer ranged from 60 to 320 feet. Ground-water movement in the aquifer is toward the east and is largely independent of the local flow system.

The D lignite aquifer is separated from the underlying D-HT aquifer by an average of 30 feet of interbedded silt and clay. The D bed averages about 8 feet in thickness and lies from 22 to 256 feet below the land surface. In the northwestern part of the study area the D lignite bed has limited potential as an aquifer. It is unsaturated along the divide between North Creek and Green River tributary and in the structurally high area south of North Creek, but is under confined conditions at other well locations. The upland area between North Creek and Green River tributary is a ground-water divide relative to flow in the D lignite aquifer.

The E-D aquifer is separated from the underlying D lignite aquifer by an average of 16 feet of silt and clay. The E-D aquifer consists of interconnected sand beds and, like the D-HT aquifer, occurs in the central part of the study area. Where present the aquifer is from 10 to 100 feet thick and averages about 50 feet. It generally lies at depths between 50 and 150 feet below the surface and is under both confined and unconfined conditions. Ground-water flow is primarily in response to local topography. The aquifer may discharge some water to Green River tributary.

The E lignite aquifer has been eroded from much of the North Creek basin and along the Heart River. Where present, it overlies and is separated from the E-D aquifer by an average of 40 feet of confining materials. The aquifer averages 9.5 feet in thickness and generally lies within 100 feet of the land surface. The E lignite aquifer is unsaturated in a major part of the area. Ground-water flow is in response to local topography. Some of the base flow in Green River tributary may be discharge from the E lignite aquifer.

Aquifers in the Fox Hills Sandstone, Hell Creek Formation, and Ludlow and Tongue River Members of the Fort Union Formation yield a soft, sodium bicarbonate type water which has a mean dissolved-solids concentration ranging from 1,160 to 1,860 mg/L.

Water in the four Sentinel Butte aquifers also is a sodium bicarbonate type. Sulfate, however, was the predominant anion in some of the samples. The mean dissolved-solids concentrations for the aquifers ranged from 1,290 to 1,970 mg/L. Either brown coloration from dissolved organics or a "rotten egg" odor characteristic of hydrogen sulfide, or both, were observed in many samples representing all of the aquifers.

The study area is drained by the Heart and Green Rivers and their tributaries. North Creek, tributary to the Heart River, has a basin area of about 46 mi^2 and drains a large part of the study area. Most flow in North Creek is from snowmelt and summer rainstorms. The stream either ceases to flow or flows less than 0.05 ft^3/s during base-flow periods.

Green River tributary drains an area of 23 mi^2 in the northeast part of the study area. Flow rarely exceeds 1 ft^3/s, but the stream is perennial with base flow generally ranging from 0.10 to 0.25 ft^3/s. The base flow probably originates from either the E-D or the E lignite aquifer, or both.

Chemical analysis of water samples from North Creek indicate that the water is a sodium sulfate type and from Green River tributary is a sodium bicarbonate-sulfate type. Dissolved-solids concentrations, which vary inversely with discharge, ranged from 209 to 3,460 mg/L in North Creek and from 688 to 1,710 mg/L in Green River tributary.

Potential hydrologic impacts from lignite mining probably would be minor and localized. The very low water levels in the D and E lignite aquifers would preclude the spread of severe water-level declines in adjacent areas. Water-level declines in areas that are more than 1 mile from a mine generally would be minor and not of economic significance. The D-HT or lower aquifers should undergo no appreciable hydrologic change unless mining occurs in an area where the confining bed beneath the D bed is very thin or absent.

Because much of the shallow ground water in the study area already is highly colored, contains noticeable hydrogen sulfide gas, and is moderately mineralized, mining-induced impacts on the quality of the water probably would be noticeable only in the immediate mine area. Natural geochemical processes are very effective in drastically abating or even neutralizing the sometimes severe chemical ramifications of strip mining (in Fort Union sediments) within a short distance from a mine.

Streamflow magnitudes would not be significantly affected by mining except possibly during periods when there is only base flow. Water quality impacts on the surface waters should be readily manageable by routing techniques, construction of impoundments, and by chemical treatment, if necessary.

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ATTACHMENT A.--Drilling, well-completion, and water-level data for test holes and observation wells.

EXPLANATION

Aquifer

125 - Paleocene

SBLG - Sentinel Butte lignite
SNLB - Sentinel Butte sand
SBTR - Sentinel Butte-Tongue River
TGRVL - Lower Tongue River

Water level (feet)

F - flowing well

Types of logs available

D - Drillers
E - Electric
G - Geologists
J - Natural gamma
N - Neutron
U - Gamma-gamma density

LOCAL NUMBER	ALTITUDE OF LAND SURFACE (FEET)	DATE COMPLETED	DEPTH DRILLED (FEET)	DEPTH TO FIRST OPENING (FEET)	CASING DIAMETER (INCHES)	DEPTH TO AQUIFER (FEET)	PRINCIPAL AQUIFER	LITHOLOGY OF PRINCIPAL AQUIFER	WATER LEVEL (FEET)	DATE WATER LEVEL MEASURED	TYPES OF LOGS AVAILABLE
140-097-06BBB1	2595	08/11/1980	340	160	2	124	125SNLB	SAND, E-D INTERVAL	101.08	11/13/1981	D,G,J,U
140-097-06BBB2	2595	08/12/1980	85	75	2	78	125SBLG	LIGNITE, E BED	80.70	11/13/1981	D,G,J,U
140-097-07DAA	2615	05/20/1976	220	212	2	182	125SNLB	SAND, D-HT INTERVAL	114.76	05/18/1977	E,G
140-098-02CBB	2575	06/30/1976	220	145	2	144	125SBLG	LIGNITE, D BED	67.25	11/13/1981	J,N
140-098-06AAA	2610	08/07/1980	360	96	2	44	125SNLB	SAND, E-D INTERVAL	56.85	11/13/1981	D,G,J,U
140-098-06CCC	2650	06/21/1979	262	130	2	116	125SNLB	SAND, E-D INTERVAL	102.50	11/13/1981	D,G,H,J
140-098-08BBC1	2610	06/21/1979	702	180	2	165	125SNLB	SAND, D-HT INTERVAL	90.52	11/13/1981	D,E,G,J,U
140-098-08BBC2	2610	06/21/1979	40	--	--	--	--	--	--	--	--
140-098-10BBB1	2660	08/06/1980	397	284	2	245	125SNLB	SAND, D-HT INTERVAL	150.35	11/13/1981	D,G,J,U
140-098-10BBB2	2660	08/06/1980	134	124	2	123	125SBLG	LIGNITE, E BED	109.34	11/13/1981	D,G
140-098-10DDD	2605	05/21/1976	240	186	2	146	125SNLB	SAND, D-HT INTERVAL	91.64	11/13/1981	E,G
140-098-14AAA1	2635	06/30/1979	342	220	2	185	125SNLB	SAND, D-HT INTERVAL	129.94	11/13/1981	D,E,G,J
140-098-14AAA2	2635	06/30/1979	130	120	2	121	125SBLG	LIGNITE, E BED	103.35	11/13/1981	D,E,G,J
140-098-17AAA	2580	06/30/1976	140	128	2	95	125SNLB	SAND, D-HT INTERVAL	63.38	11/13/1981	J,N
140-098-19BBB	2580	06/26/1979	220	150	2	104	125SNLB	SAND, D-HT INTERVAL	59.21	11/13/1981	D,E,G,J,U
140-098-21AAA	2535	08/05/1980	300	80	2	82	125SBLG	LIGNITE, D BED	27.94	11/13/1981	D,G,J,U
140-098-21CBB	2565	06/28/1979	342	108	2	108	125SBLG	LIGNITE, D BED	61.42	11/13/1981	D,G,J,U
140-098-24DAA1	2585	08/12/1980	400	130	2	129	125SBLG	LIGNITE, D BED	87.22	11/13/1981	D,G,J,U
140-098-24DAA2	2585	08/12/1980	85	75	2	73	125SBLG	LIGNITE, E BED	73.28	11/13/1981	D,G,J,U
140-098-27AAA1	2550	07/01/1976	152	135	2	134	125SBLG	LIGNITE, D BED	64.15	11/13/1981	J,N
140-098-27AAA2	2550	07/02/1976	67	58	2	56	125SBLG	LIGNITE, E BED	43.66	11/13/1981	--
140-098-28CCC1	2510	06/26/1979	762	749	2	750	125TGRVL	SAND	186.66	11/13/1981	D,E,G,J,U
140-098-28CCC2	2510	06/27/1979	50	38	2	38	125SBLG	LIGNITE, D BED	17.65	11/13/1981	D,E,G,J,U
140-098-30AAA	2540	08/05/1980	300	--	--	--	--	--	--	--	D,G,J,U
140-098-32DDD1	2590	06/27/1979	402	262	2	261	125SBTR	LIGNITE, HT BUTTE BED	109.51	11/13/1981	D,G,J,U
140-098-32DDD2	2590	06/27/1979	125	--	--	--	--	--	--	--	--
140-098-34ABB	2540	07/06/1976	120	89	2	84	125SBLG	LIGNITE, D BED	72.11	11/13/1981	J,N
140-098-35DAD	2490	08/12/1980	340	66	2	64	125SBLG	LIGNITE, D BED	17.79	11/13/1981	D,G,J,U
140-099-02BBA1	2690	06/22/1979	400	240	2	172	125SNLB	SAND, D-HT INTERVAL	157.21	11/13/1981	D,G,J,U
140-099-02BBA2	2690	06/22/1979	90	72	2	76	125SBLG	LIGNITE, E BED	63.83	11/13/1981	D,G,J,U
140-099-09CCC	2640	06/25/1979	400	240	2	180	125SNLB	SAND, D-HT INTERVAL	109.32	11/13/1981	D,G,J,U
140-099-15AAA	2630	06/22/1979	300	160	2	110	125SNLB	SAND, E-D INTERVAL	107.05	11/13/1981	D,E,G,J,U
140-099-21CDD1	2665	08/13/1980	600	--	--	--	--	--	--	--	D,E,G,J,U
140-099-21CDD2	2665	08/13/1980	88	78	2	76	125SBLG	LIGNITE, E BED	76.33	11/13/1981	D,E,G,J,U
140-099-22AAA	2575	06/25/1979	400	--	--	--	--	--	--	--	D,G,J,U
140-099-26BBB	2605	06/25/1979	300	126	2	127	125SBLG	LIGNITE, D BED	84.71	11/13/1981	D,G,J,U
141-097-28BBD1	2495	08/11/1980	380	140	2	139	125SBLG	LIGNITE, D BED	F	--	D,G,J,U
141-097-28BBD2	2495	08/11/1980	40	30	2	27	125SBLG	LIGNITE, E BED	4.11	09/04/1981	D,G,J,U
141-097-31BAA	2540	06/30/1979	342	152	2	130	125SNLB	SAND, E-D INTERVAL	23.75	08/16/1980	D,G,J,U
141-097-32AAA	2545	06/30/1979	762	168	2	167	125SBLG	LIGNITE, D BED	46.31	11/13/1981	D,E,G,J,U
141-098-14DDA1	2520	08/07/1980	700	--	--	--	--	--	--	--	D,E,G,J,U
141-098-14DDA2	2520	08/08/1980	123	113	2	115	125SBLG	LIGNITE, E-D INTERVAL	F	--	D,E,G,J,U
141-098-14DDA3	2520	08/08/1980	86	66	2	67	125SBLG	LIGNITE, E BED	1.29	11/13/1981	D,E,G,J,U
141-098-23DCC1	2630	06/29/1979	402	334	2	320	125SNLB	SAND, D-HT INTERVAL	153.99	11/13/1981	D,G,J,U
141-098-23DCC2	2630	06/29/1979	152	142	2	141	125SBLG	LIGNITE, E BED	127.52	11/13/1981	D,G,J,U
141-098-28DCC	2615	06/28/1979	402	170	2	170	125SNLB	SAND, D-HT INTERVAL	88.76	11/13/1981	D,G,J,U
141-098-35ACA	2550	06/29/1979	402	50	2	15	125SNLB	SAND, E-D INTERVAL	8.49	11/13/1981	D,G,J,U
141-098-35DCC1	2585	06/28/1979	402	90	2	62	125SNLB	SAND, E-INTERVAL	39.40	11/13/1981	D,G,J,U
141-098-35DCC2	2585	06/28/1979	47	--	--	--	--	--	--	--	--

ATTACHMENT B.--Water-quality data for sampled observation wells.

[MG/L = milligrams per liter; UMHOS = micromhos per centimeter at 25° Celsius; DEG C = degrees Celsius; E = estimated; UG/L = micrograms per liter; < = less than]

EXPLANATION

Aquifer

125 - Paleocene
SBLG - Sentinel Butte lignite
SNLB - Sentinel Butte sand
SBTR - Sentinel Butte-Tongue River
TGRVL - Lower Tongue River

LOCAL IDENT-I-FIER	PRINCIPAL AQUIFER	DEPTH OF WELL, TOTAL (FEET)	DATE OF SAMPLE	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	ALKA-LINITY FIELD (MG/L AS CACO3)	SULFATE DIS-SOLVED (MG/L AS SO4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	PH (UNITS)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	SODIUM AD-SORP-TION RATIO	PERCENT SODIUM	TEMPER-ATURE (DEG C)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	HARD-NESS (MG/L AS CACO3)	BORON, DIS-SOLVED (UG/L AS B)	IRON, DIS-SOLVED (UG/L AS FE)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)	MOLYB-DENUM, DIS-SOLVED (UG/L AS MO)	NITRO-GEN, AM-MONIA + ORGANIC DIS. (MG/L AS N)	SILICA, DIS-SOLVED (MG/L AS SIO2)	STRON-TIUM, DIS-SOLVED (UG/L AS SR)
140-097-06BBB1	125SNLB	180	80-09-30	1600	23	530	500	500	6500	46	.3	6.6	9560	8000	12	51	19.0	2900	3400	2600	36000	990	9	6.3	15	9000
140-098-02CBB	125SBLG	151	79-09-12	420	1.6	.2	.7	750	200	--	.9	8.8	1080	1500	49	99	9.0	0	4	1700	160	20	1	1.7	1.9	100
	125SBLG	151	79-09-12	420	1.7	.7	.3	750	200	--	.9	8.9	1060	1550	106	99	9.0	0	5	1700	150	--	--	1.5	2.1	--
	125SBLG	151	80-07-16	410	1.5	2.0	.5	710	340	14	15	7.6	1270	1800	67	99	11.5	0	7	1300	320	20	5	1.0	57	--
	125SBLG	151	80-12-11	420	5.4	1.5	.7	690	130	190	3.7	6.7	1180	1825	71	99	7.0	0	7	1200	200	10	3	1.4	8.0	130
	125SBLG	151	81-06-30	420	1.0	1.5	.8	710	210	15	4.0	8.9	1110	1730	69	99	11.0	--	7	21000	150	0	4	1.0	8.0	100
	125SBLG	151	81-06-30	430	.9	2.8	.8	710	230	10	3.8	8.9	1130	1730	58	99	13.0	--	10	21000	210	10	4	.95	8.0	100
140-098-06AAA	125SNLB	106	80-09-29	250	5.3	59	27	540	290	2.1	.2	7.7	972	1525	6.8	67	10.5	0	260	460	80	160	<10	.44	12	710
140-098-06CCC	125SNLB	140	80-06-20	1200	3.9	6.0	2.8	1020	1400	20	1.5	9.5	3260	4100	101	99	22.0	0	27	930	50	20	5	2.2	9.7	250
140-098-08BBC1	125SNLB	720	80-06-18	690	2.4	2.9	1.3	590	830	28	2.8	8.4	1920	2700	85	99	20.0	0	13	480	270	20	5	2.1	11	130
	125SNLB	720	81-06-30	670	1.9	3.0	1.2	662	960	11	2.7	8.8	2060	2900	83	99	8.6	0	13	5200	170	10	2	--	11	80
	125SNLB	720	81-06-30	480	6.5	3.2	.4	705	540	30	2.9	9.2	1500	2900	67	98	8.6	0	10	5400	80	0	16	--	9.9	50
	125SNLB	720	81-06-30	720	1.9	3.1	1.2	602	940	11	2.7	8.8	2060	2940	88	99	8.6	0	13	3200	190	10	3	--	11	90
	125SNLB	720	81-06-30	630	2.0	3.9	1.2	603	980	11	2.8	8.9	2010	2900	72	99	8.6	0	15	3200	160	20	2	--	11	80
	125SNLB	720	81-07-23	710	3.5	2.1	2.4	603	910	9.6	2.7	8.9	2020	2900	79	99	16.7	0	15	690	130	10	--	--	11	--
	125SNLB	720	81-07-23	710	3.5	2.2	2.8	601	910	10	2.5	8.9	2020	2800	75	99	16.7	0	17	850	160	20	--	--	11	--
	125SNLB	720	81-07-23	710	2.7	2.3	2.3	603	910	9.3	2.5	8.8	2010	2800	79	94	16.7	0	15	1100	170	10	--	--	11	--
	125SNLB	720	81-07-23	700	2.8	3.0	2.1	600	890	10	2.7	8.8	1990	2900	76	99	16.7	0	16	1100	190	10	--	--	12	--
140-098-10BBB1	125SNLB	294	80-09-30	690	2.9	3.1	1.5	590	860	8.5	2.9	8.5	1940	3300	81	99	18.0	0	14	2800	120	10	4	4.8	10	160
140-098-10DDD	125SNLB	192	76-07-13	430	1.8	1.4	.7	593	340	3.8	1.6	9.2	1150	1850	74	99	11.0	0	6	1400	280	20	8	.23	9.4	60
	125SNLB	192	79-08-16	370	12	7.1	3.6	570	340	3.9	1.1	8.9	1090	1540	28	96	9.0	0	33	900	110	30	9	.89	6.2	100
	125SNLB	192	79-08-16	370	11	6.9	3.4	570	340	3.2	1.1	9.3	1090	1600	29	96	13.0	0	31	920	140	20	9	.84	6.3	100
	125SNLB	192	80-07-16	370	12	6.0	3.9	570	340	3.5	.6	8.0	1090	1750	27	94	11.0	0	56	920	210	10	9	.87	.5	200
	125SNLB	192	81-07-01	410	2.8	7.3	1.5	560	300	21	1.4	9.3	1090	1750	36	97	9.5	--	25	2900	80	20	9	5.9	7.7	90
140-098-14AAA1	125SNLB	240	80-07-01	570	2.4	1.0	.5	650	580	2.5	1.9	9.4	1550	2390	116	99	30.0	0	5	2000	100	10	11	.77	.7	150
140-098-17AAA	125SNLB	140	76-07-14	420	1.7	2.1	.5	531	420	2.8	.6	9.2	1180	1850	68	99	12.0	0	7	810	60	<10	<1	.52	10	50
	125SNLB	140	79-09-12	400	1.5	.9	<.0	530	460	2.0	.6	9.1	1190	1680	116	100	9.0	0	2	830	20	6	<10	.64	9.7	20
	125SNLB	140	79-09-12	400	1.2	.9	.3	530	460	1.8	.6	9.2	1190	1680	93	100	10.5	0	4	830	30	6	<10	.73	10	20
	125SNLB	140	80-07-16	420	1.3	1.1	.2	510	380	1.6	.6	8.2	1120	1880	97	99	12.0	0	4	870	30	6	<10	.37	10	20
	125SNLB	140	81-07-01	410	.8	91	.1	520	440	1.9	.5	9.3	1270	1800	12	80	10.0	--	230	790	20	8	<10	.98	11	20
	125SNLB	140	81-07-01	420	.8	1.1	.3	510	400	1.8	.5	9.3	1140	1800	92	99	11.0	--	4	800	30	8	<10	1.1	11	20
140-098-19BBB	125SNLB	160	79-12-21	1500	5.9	11	8.5	1140	2000	12	.8	8.9	4230	5000	83	98	9.0	0	63	1200	10	0	2	.97	8.1	320
140-098-21AAA	125SBLG	90	80-09-25	590	4.0	9.1	4.2	1220	170	52	3.7	8.7	1580	2390	41	97	11.0	0	40	7200	1300	50	0	8.5	.9	350
140-098-24DDA1	125SBLG	140	80-11-28	580	5.4	7.2	3.1	1130	430	51	4.4	7.4	1220	2300	46	97	7.5	0	31	7000	3600	80	2	10	--	200

LOCAL IDENT-I-FIER	PRINCIPAL AQUIFER	DEPTH OF WELL, TOTAL (FEET)	DATE OF SAMPLE	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	ALKA-LINITY FIELD (MG/L AS CACO3)	SULFATE DIS-SOLVED (MG/L AS SO4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	PH (UNITS)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	SODIUM AD-SORP-TION RATIO	PERCENT SODIUM	TEMPER-ATURE (DEG C)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	HARD-NESS (MG/L AS CACO3)	BORON, DIS-SOLVED (UG/L AS B)	IRON, DIS-SOLVED (UG/L AS FE)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)	MOLYB-DENUM, DIS-SOLVED (UG/L AS MO)	NITRO-GEN,AM-MONIA + ORGANIC DIS. (MG/L AS N)	SILICA, DIS-SOLVED (MG/L AS SIO2)	STRON-TIUM, DIS-SOLVED (UG/L AS SR)
140-098-27AAA1	125SBLG	147	76-07-14	560	3.7	13	5.8	1250	180	31	4.4	8.5	1570	2200	32	95	12.0	0	56	5000	1500	50	1	6.5	8.7	520
	125SBLG	147	79-08-16	530	3.0	10	4.9	1150	39	53	<.1	8.4	1340	2000	34	96	9.5	0	46	2900	1600	20	<1	5.8	<.1	420
	125SBLG	147	79-08-16	500	2.8	10	4.7	1140	47	58	<.1	8.1	1310	2000	33	97	13.5	0	45	3300	1100	20	<1	2.0	.1	460
	125SBLG	147	80-07-16	540	3.0	10	4.5	1200	950	56	29	E8.2	2580	2200	36	96	12.0	0	44	1300	1900	40	0	3.0	260	--
	125SBLG	147	80-12-16	580	3.1	11	5.0	1150	150	170	1.2	8.0	1620	2100	36	96	8.0	0	44	580	1600	30	0	--	6.0	380
	125SBLG	147	81-07-01	560	2.1	12	5.3	1120	500	70	2.8	8.6	1860	2000	34	96	13.0	--	52	21000	1200	30	350	8.8	13	460
	125SBLG	147	81-07-01	570	2.1	14	5.4	1100	500	75	2.7	8.3	1860	1750	33	95	13.0	--	56	21000	1200	30	0	9.2	11	460
140-098-28CCC1	125TGRVL	762	81-01-08	360	1.8	3.0	.5	590	220	7.9	3.1	6.9	956	1500	51	99	4.5	0	10	770	90	9	13	1.2	3.9	60
140-098-28CCC2	125SBLG	48	79-12-21	410	4.1	28	14	390	650	5.7	.3	6.8	1360	1850	16	92	8.0	0	130	850	140	90	0	.57	13	470
140-098-32DDD1	125SBTR	272	80-07-01	640	3.9	3.0	2.1	1120	140	6.9	4.0	8.7	1470	2200	69	99	27.0	0	16	0	110	10	0	1.4	.6	210
140-098-34ABB	125SBLG	95	80-07-16	650	14	43	18	780	800	130	.2	E8.0	2130	3250	21	88	11.0	0	180	820	6400	150	0	6.3	.1	--
140-098-35DAD	125SBLG	76	80-09-25	670	5.8	12	11	740	780	3.5	.6	8.3	1940	3200	34	95	10.5	0	76	800	60	20	0	.88	11	540
140-099-02BBA1	125SNLB	250	80-06-20	770	2.7	3.9	1.9	630	990	3.2	2.7	6.8	2170	3250	80	99	18.0	0	18	990	110	20	6	1.1	11	160
140-099-09CCC	125SNLB	252	80-06-19	940	4.2	13	6.7	700	1400	4.7	1.2	4.9	2800	3800	53	97	12.0	0	60	1200	70	50	3	1.5	8.0	310
140-099-15AAA	125SNLB	170	80-06-19	830	4.1	9.0	4.0	680	1100	8.3	.5	6.9	2340	3500	58	98	19.0	0	39	1300	310	40	5	1.6	11	200
140-099-26BBB	125SBLG	136	79-12-21	900	11	11	4.5	1100	710	100	2.5	7.9	2410	3600	58	98	9.0	0	47	890	270	20	5	1.5	8.5	670
141-097-28BBD1	125SBLG	150	80-09-24	710	4.1	3.0	2.7	1050	480	9.5	4.8	E6.3	1860	3200	72	98	11.5	0	19	3500	100	20	0	1.9	7.5	200
141-097-28BBD2	125SBLG	40	80-09-25	640	4.8	4.4	3.6	820	570	12	1.9	5.7	1740	2450	55	98	9.0	0	26	1600	350	50	0	2.2	10	260
141-097-31BAA	125SNLB	162	79-12-19	420	1.2	1.7	1.6	750	190	4.4	4.2	5.5	1100	1590	56	99	4.5	0	11	940	170	10	4	1.1	20	110
141-097-32AAA	125SBLG	178	80-08-16	580	4.0	16	6.2	1280	1100	110	11	5.4	2740	2400	31	95	13.0	0	66	8000	1200	110	2	15	130	670
	125SBLG	178	80-12-16	670	4.1	18	5.8	1310	280	750	1.3	8.9	2530	2500	35	95	8.0	0	64	890	1900	90	0	--	14	520
141-098-14DDA2	125SBLG	123	80-09-24	570	2.8	3.5	1.7	930	320	23	5.0	E6.3	1490	2350	63	98	9.0	0	16	3000	240	30	0	2.8	.9	180
141-098-14DDA3	125SBLG	86	80-09-24	450	2.8	1.9	1.1	530	390	3.1	.6	E7.9	1190	2000	64	99	9.0	0	9	2800	120	10	0	1.7	14	90
141-098-23DCC1	125SNLB	344	80-07-02	600	3.0	5.0	1.8	1130	130	22	12	E8.6	1460	2300	59	98	22.0	0	20	1500	430	20	4	2.8	.1	200
141-098-23DCC2	125SBLG	152	80-07-15	370	1.9	1.3	.5	640	170	5.8	1.7	8.1	942	1600	70	99	10.5	0	5	720	80	9	<10	1.1	5.0	30
141-098-28DCC	125SNLB	180	79-12-20	510	3.0	9.6	3.6	840	240	18	4.5	7.9	1310	1925	36	98	9.0	0	39	1500	760	40	8	2.9	9.1	120
141-098-35ACA	125SNLB	80	79-12-20	67	3.5	57	24	320	66	.9	.1	8.0	427	660	1.9	37	8.0	0	240	240	520	130	<10	.36	14	940
141-098-35DCC1	125SNLB	100	79-12-20	330	6.6	40	18	530	420	3.6	.1	5.4	1150	1620	11	80	8.0	0	170	1000	470	80	10	.95	11	620