EVALUATION OF THE HYDROLOGIC SYSTEM AND POTENTIAL EFFECTS OF MINING IN THE DICKINSON LIGNITE AREA, EASTERN SLOPE AND WESTERN STARK AND HETTINGER COUNTIES, NORTH DAKOTA

By C. A. Armstrong

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4194

Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

Bismarck, North Dakota

April 1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief, WRD
U.S. Geological Survey
821 East Interstate Avenue
Bismarck, ND 58501

Copies of this report can
be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225
(Telephone: (303) 776-7476)

CONTENTS

ILLUSTRATIONS

TABLES

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

For those readers who may prefer to use the International System (SI) of units 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)	28.32	liter per second
Foot (ft)	0.3048	meter
Foot per day (ft/d)	0.304	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 (gal)	3.785	liter
Gallon per minute (gal/min)	0.06309	liter per second
Gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter
Inch (in.)	25.40	millimeter
Mile (mi)	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.

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

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 (ug/L).

EVALUATION OF THE HYDROLOGIC SYSTEM AND POTENTIAL EFFECTS OF MINING IN THE DICKINSON LIGNITE AREA, EASTERN SLOPE AND WESTERN STARK AND HETTINGER COUNTIES, NORTH DAKOTA

By C. A. Armstrong

ABSTRACT

The investigation of the water resources of the Dickinson lignite area, an area of about 500 square miles, was undertaken to define the hydrologic system of the area and to project probable effects of coal mining on the system.

Aquifers occur in sandstone beds in: the Fox Hills Sandstone and the lower Hell Creek Formation of Cretaceous age, the upper Hell Creek Formation of Cretaceous age and the lower Ludlow Member of the Fort Union Formation of Tertiary age, and the upper Ludlow and lower Tongue River Members of the Fort Union Formation of Tertiary age. Aquifers also occur in the sandstone and lignite lenses in the upper Tongue River Member and the Sentinel Butte Member of the Fort Union Formation.

Depths to the Fox Hills-lower Hell Creek aquifer system range from about 1,300 to 1,710 feet. Well yields range from 18 to 100 gallons per minute. The water is soft and is a sodium bicarbonate type. Dissolved-solids concentrations in samples collected from the aquifer system ranged from 1,230 to 1,690 milligrams per liter.

Depths to the upper Hell Creek-lower Ludlow aquifer system range from about 720 to 1,040 feet. Well yields generally are less than 30 gallons per minute but may be as much as 150 gallons per minute. The water is soft and a sodium bicarbonate type. Dissolved-solids concentrations in samples collected from the aquifer system ranged from 1,010 to 1,450 milligrams per liter.

Depths to the upper Ludlow-lower Tongue River aquifer system range from about 440 to 713 feet. Well yields may range from about 1 to 100 gallons per minute. The water generally is soft and a sodium bicarbonate type but may be moderately hard and a sulfate type in the southwestern part of the area. Dissolved-solids concentrations in samples collected from the aquifer system ranged from 995 to 1,990 milligrams per liter.

Depths to the upper Tongue River-Sentinel Butte aquifer system range from near land surface to about 530 feet below land surface. Well yields generally range from about 1 to 185 gallons per minute. Yields from the lignite parts of the system range from about 2 to 60 gallons per minute. The water generally is a sodium bicarbonate type, but locally sulfate is the dominant anion. Dissolved-solids concentrations in samples collected from the aquifer system generally ranged from 574 to 2,720 milligrams per liter.

Lignite beds contribute little water to the Cannonball or Heart Rivers. Mining of lignite will have negligible effect on the flow in tributaries of either the Cannonball or Heart Rivers.

Mining of the lignite beds in the Dickinson lignite area will destroy all aquifers in and above the mined lignite. Mining will expose sulfide minerals to oxidation and may result in a minimal increase in concentrations of sulfate and other dissolved solids in water in the upper Tongue River-Sentinel Butte aquifer system.

INTRODUCTION

The investigation of the hydrologic system of the Dickinson lignite area was made in cooperation with the U.S. Bureau of Land Management. The purpose of the investigation was to describe the hydrologic system which will assist the Bureau in its evaluation of the probable impacts of potential coal development in the area.

The Dickinson lignite area occupies an area of about 500 mi^2 in northeastern Slope, southwestern Stark, and northwestern Hettinger Counties (fig. 1). The area is bounded on the north by Interstate Highway 94, on the west by the divide between the Little Missouri River drainage and the Heart River and Cannonball River drainages, and on the south by the southern divide of the Cannonball River drainage. The eastern side of the area approximates North Dakota Highway 22 but excludes the city of Dickinson. The area of the study includes all of the area within the U.S. Bureau of Land Management planning boundary as well as the area outside of the planning boundary but within the upper reaches of the drainage area of the two rivers.

Objectives and Scope

The primary objective of the investigation in the Dickinson lignite area was to define the hydrologic system consistent with the time and funding available. The objective included assessment of the ground-water flow system and chemical characteristics of ground water, and determination of surface-water flow magnitudes, surface-water chemistry, and sediment concentration.

The second objective was to make a reasonable projection of the hydrologic effects resulting from surface mining. Management agencies, including the U.S. Bureau of Land Management, will use these projections to assist their decision-making processes on mining. There currently (1984) are no mining activities in the study area. Therefore, mining impacts were not observable directly during the study. As a result, all hydrologic data are of premining or natural conditions, and effects related to coal development are projections based on these data.

This project consisted of collecting, organizing, and evaluating all available data. In addition, low-flow measurements were made to determine flow characteristics of the tributary streams in the area. Water samples were collected and analyzed for chemical characteristics, and sediment

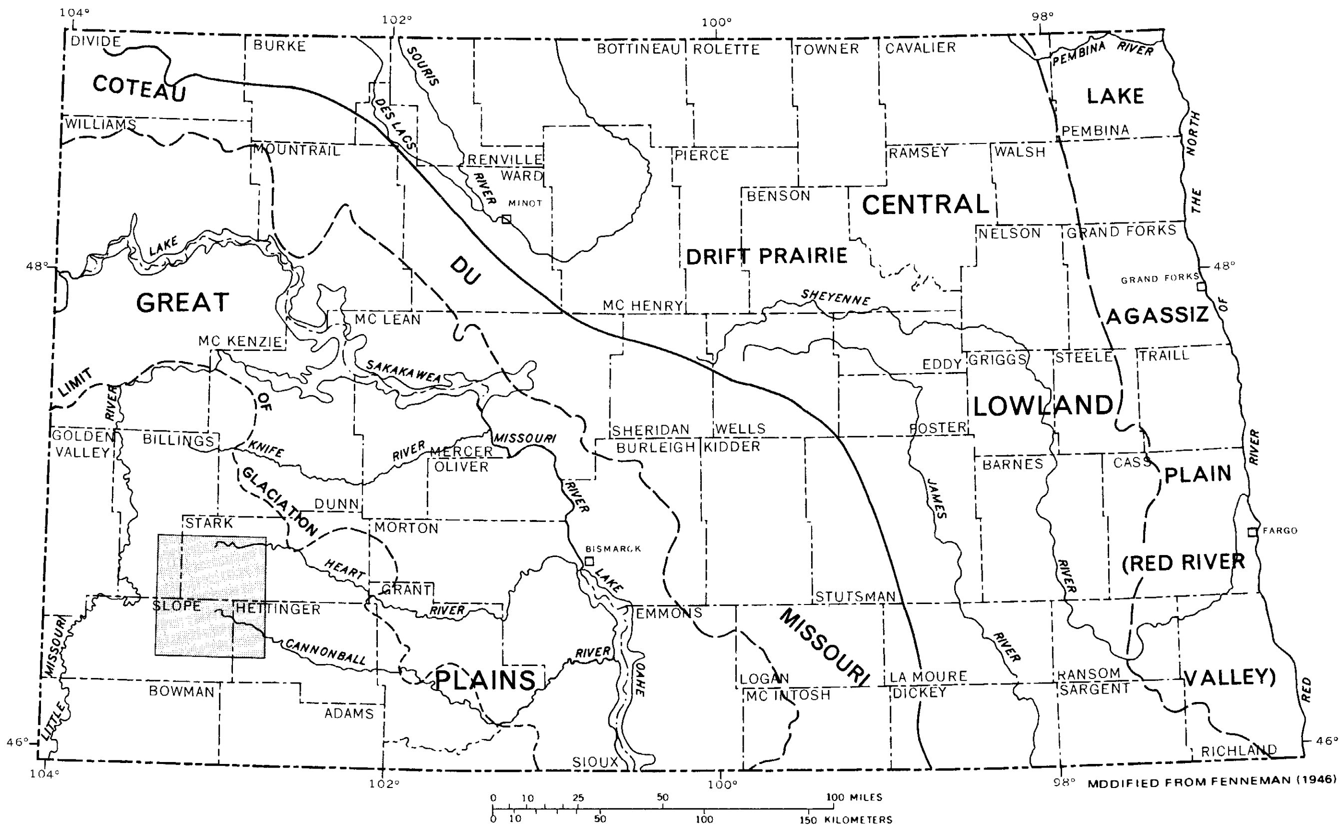


Figure 1.—Physiographic divisions in North Dakota and location of study area.

concentrations were determined. The interpretation of all the data collected was then used to project probable effects on the future water resources in the area.

Location-Numbering System

The location-numbering system used in this report (fig. 2) is based on the Federal system of rectangular surveys of the public lands. The first numeral denotes the township, the second denotes the range, and the third denotes the section in which the well, spring, stream site, or test hole 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). Thus, well 136-099-15ADC would be located in the SW1/4SE1/4NE1/4 sec. 15, T. 136 N., R. 99 W. Consecutive final numbers are added if more than one well or test hole is recorded within a 10-acre tract. This numbering system also is used in this report for the location of small areas.

Previous Investigations

One of the earliest published accounts that dealt in part with the Dickinson lignite deposit was the statewide lignite survey of Leonard, Babcock, and Dove (1925). Brant (1953) later described the same Dickinson area beds and renamed them. Northern Pacific Railway Company's evaluation program provided reliable subsurface data which was used to map the Dickinson lignite deposit and calculate reserve tonnages of lignite (Northern Pacific Railway Company, written commun., 1963). Pollard, Smith, and Knox (1972) used the railway company data in their summary of North Dakota strippable lignite locations and tonnages. Lewis (1979) described the geology of the lignite beds in the Bowman-Gascoyne area, Adams, Billings, Bowman, Golden Valley, and Slope Counties. His description included some of the southern part of the Dickinson lignite area. Owens (1979) described the lignite beds in the New England area, which includes much of the upper Cannonball River drainage basin.

Several earlier investigators described the problem of inadequate production of water from the Dickinson well field[1/] and investigated the

---

1/ Before the Heart River was dammed for a municipal water supply, Dickinson's water was provided by several shallow wells just west of the city.

---

immediate area for additional sources of shallow ground water (McLaughlin and Greenlee, 1946; Tychsen, 1950; Schmid, 1963; Lindvig, 1964). Trapp (1971) inventoried the available ground-water data for Hettinger and Stark Counties, and Trapp and Croft (1975) reported on the geology and ground-water resources of Hettinger and Stark Counties. Anna (1980) inventoried the available ground-water data and reported on the ground-water resources of Billings, Golden Valley, and Slope Counties. Wald and Norbeck (1983) inventoried wells and published logs of test holes

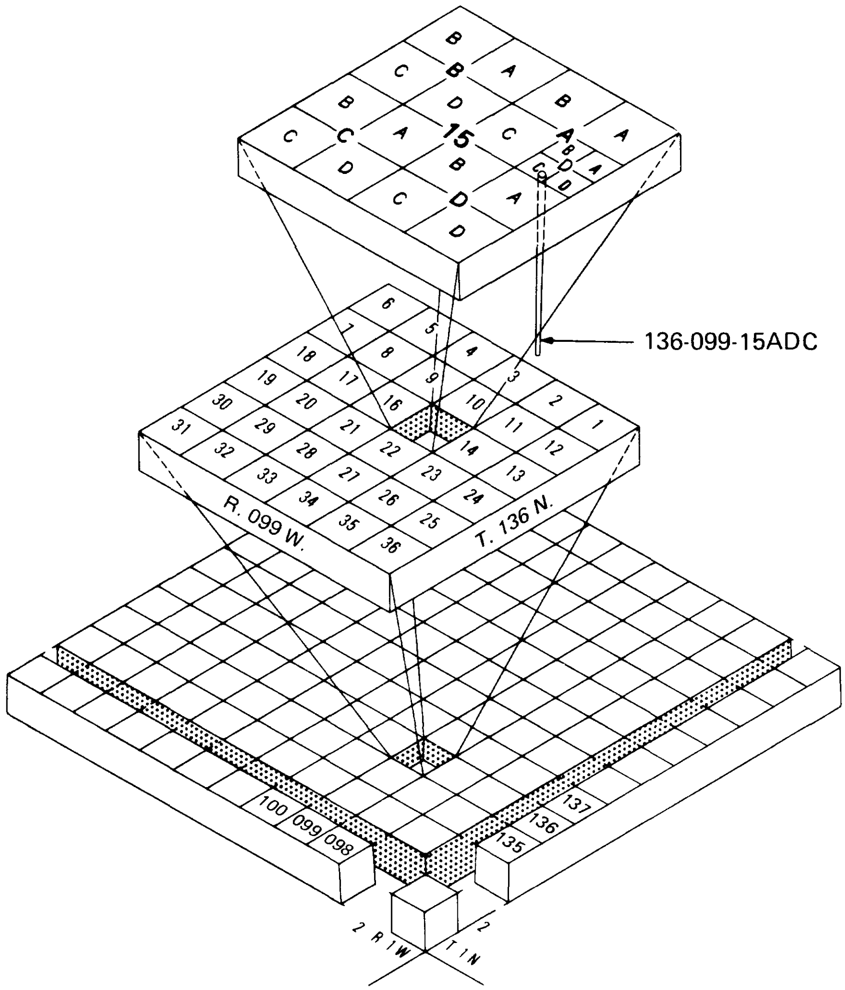


Figure 2.—Location-numbering system.

and wells as a preliminary part of this study. The data in their report are used freely in this report without further reference.

Topography

The study area lies within the unglaciated part of the Great Plains physiographic province (Fenneman, 1946) of North Dakota (fig. 1). The Dickinson lignite area is one of rolling prairie and is moderately dissected by shallow stream valleys, and a few hills and buttes rise above the surface. Local relief is subdued, rarely exceeding 150 ft. However, the few buttes that rise above the landscape may have a relief in excess of 400 ft. Altitudes range from about 2,416 ft at the edge of Patterson Lake in the northeastern part of the area to 3,340 ft on West Rainy Butte at 135-098-18CAD in the southern part of the study area.

The integrated drainage system has little natural surface storage. The Cannonball River and its tributaries drain the southern part of the area (fig. 3). The Heart River and its intermittent tributaries form the drainage system in the northern part of the area.

Climate

The climate is semiarid, and mean annual precipitation is about 16.35 in. at Dickinson and 16.75 in. at New England (U.S. Environmental Data and Information Service, 1982). About 75 percent of the precipitation falls during the April through September growing season. The mean annual temperature is 40.7°F at Dickinson and 42.0°F at New England.

WATER USE AND SUPPLY

The principal uses of water in the Dickinson lignite area are for domestic, livestock, and public supplies. Most of the water used is from ground-water sources. However, surface water, where available, is used for stock watering.

The cities of New England and Belfield are the only water users that keep records of water use. During 1982, New England obtained about 60 million gallons of water from the Sentinel Butte aquifer. Belfield obtained about 27 million gallons of water from the Tongue River aquifer and about 25 million gallons from the Fox Hills-lower Hell Creek aquifer system.

EFFECTS OF MINING ON AREA HYDROLOGY

Strip mining of lignite in the Dickinson lignite area will have some effect on the hydrology of the area. Mining will destroy all water-bearing zones in and above the lignite that is to be mined as well as the wells tapping these beds. The small springs and seeps that are scattered along the southern edge of the lignite field also will be destroyed.

After the area is reclaimed, wells will have to be drilled to the upper Tongue River-Sentinel Butte aquifer system or the upper Ludlow-lower Tongue

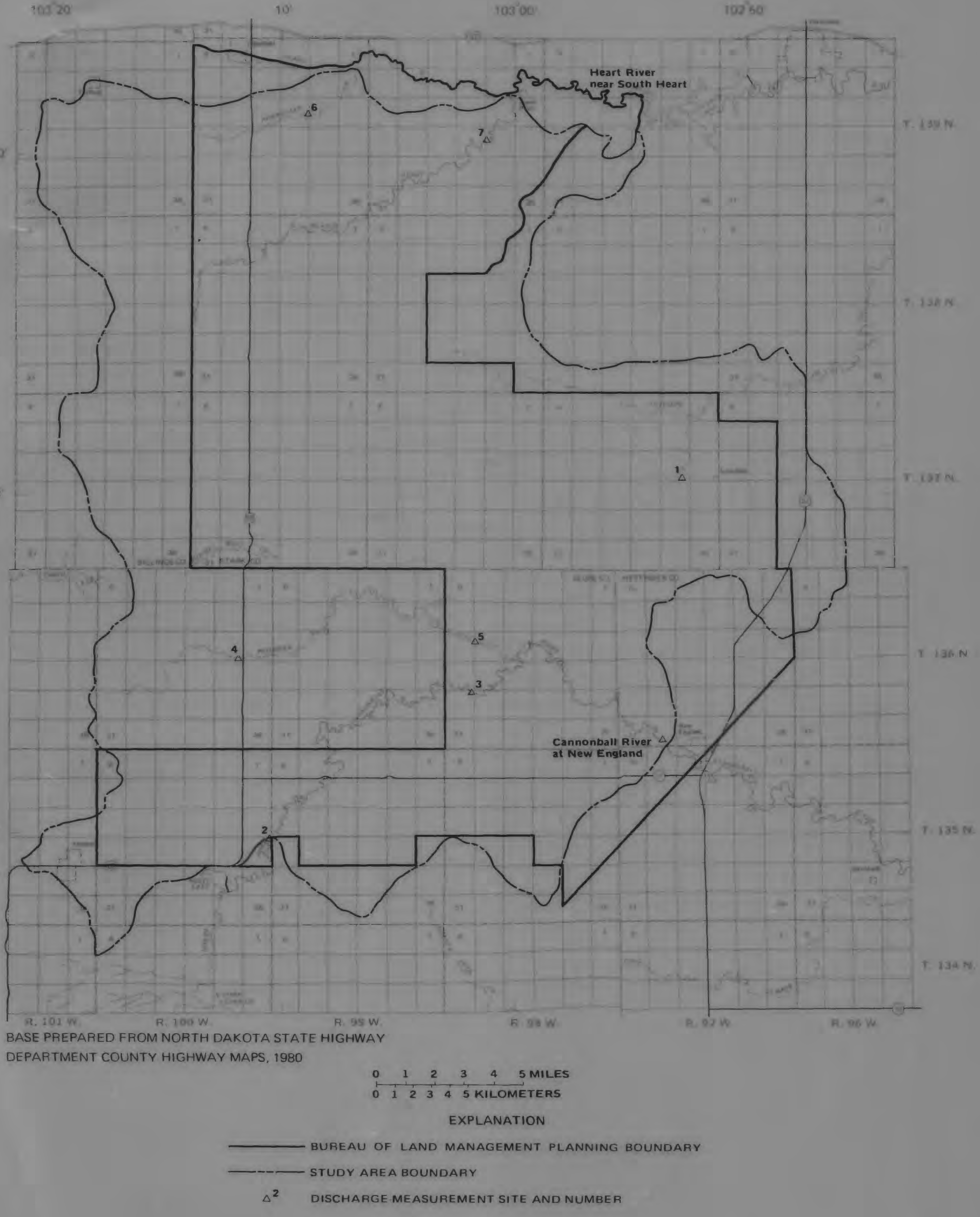


Figure 3.—Location of discharge-measurement sites.

River aquifer system. If for any reason these aquifers cannot be used, water will have to be obtained from the deeper upper Hell Creek-lower Ludlow aquifer system or the Fox Hills-lower Hell Creek aquifer system.

As mining proceeds below the water table, a cone of depression will form, and water levels in wells finished in the lignite or immediately above the lignite will decline. However, this effect will be minimal because the beds generally have small hydraulic conductivity values, and, except near the mines, the change in the hydraulic gradient will be small. Mining probably will have little or no effect on water levels more than a mile from the area being mined; however, some of the wells near the mine and finished in or above the lignite to be mined may become unusable while mining is at some distance from the wells.

Operational water needs during mining and the early stages of reclamation probably can be obtained from the mine pits. The latter stage of reclamation, however, is the planting of small grains or forage crops. There is not an adequate supply of chemically suitable ground or surface water in the area available for irrigation, so crops will have to depend on precipitation.

During mining, the bed of lignite will be removed, and the overburden below the soil zone will be turned over and mixed. Exposure of the overburden will allow natural oxidation of minerals to accelerate. Recharge through the exposed overburden will cause leaching of oxidized minerals and may result in an increase in the concentration of sulfate and other dissolved solids in the underlying aquifers. However, because of the reducing properties of lignitic material, lower lignite beds may tend to reverse the chemical processes and minimize any changes below the uppermost unmined lignite beds.

Generally, beds beneath lignite in the area have low permeability, so recharge to lower aquifer systems will be slow, probably so slow that dilution of contaminants with water already in the aquifer system will cause any increases in sulfate and dissolved-solids concentrations to be small. No recognizable effects likely will occur in aquifer systems below the uppermost unmined lignite bed in the Cannonball drainage area or the basal part of the upper Tongue River-Sentinel Butte aquifer system in the Heart River drainage because of the low permeability of the clayey beds in the upper part of the Tongue River Member of the Fort Union Formation and the reducing potential of the unmined lignite beds. Locally, in the Heart River drainage, there are sandstone beds in the basal part of the Sentinel Butte Member that underlie minable lignite. There may be some deterioration of water quality in these sandstone beds when they are below the spoil piles, but, because of the reducing properties of lignitic materials, the deterioration probably will be small below the uppermost unmined lignite.

GEOLOGY

The Dickinson lignite area is located 50 to 70 mi south of the center (northwestern McKenzie County) of the Williston sedimentary basin (fig. 1).

The study area is underlain by about 13,000 ft of sedimentary rocks. Several thousand feet of predominantly shale, carbonates, evaporites, and sandstone comprise the Paleozoic and Mesozoic rock section between the Precambrian crystalline rocks and the top of the Upper Cretaceous Pierre Shale. The top of the Pierre Shale generally is considered the base of the freshwater-bearing units in western North Dakota. In this report, the top of the Pierre is considered the practical limit of test drilling and for aquifer evaluation.

Rocks Overlying the Pierre Shale

Conformably overlying the Pierre Shale (table 1), the Fox Hills Sandstone is the lowermost unit in a sequence of about 1,800 ft of rock strata. The Fox Hills Sandstone, which generally is about 300 ft thick but may be as much as 390 ft thick, is of marine origin and consists largely of silty sandstone with silty claystone and siltstone. Sandstone beds in the upper part of the Fox Hills Sandstone and lower Hell Creek Formation form an aquifer that is as much as 25 ft thick in Slope and Stark Counties.

The Hell Creek Formation, deposited in a continental environment during latest Cretaceous time, overlies the Fox Hills. The Hell Creek generally is composed of about 440 ft of interbedded very fine sandstone, claystone, and siltstone with thin interbedded lignite and carbonaceous claystone beds. Locally, however, the beds contain fine- to medium-grained poorly consolidated sandstone.

The Tertiary System is represented in this area in ascending order by the Fort Union (Paleocene) Formation, the Golden Valley (Eocene), the White River (Oligocene), and the Arikaree (Miocene). Strata of Tertiary age are as much as 1,110 ft thick in the study area. Four members recognized in the Fort Union are, in ascending order, Ludlow, Cannonball, Tongue River, and Sentinel Butte. Facies of the Ludlow and Cannonball Members intertongue in the Dickinson lignite area and generally are not differentiated in this report (see table 1).

The Ludlow Member consists of alternating claystone, siltstone, sandstone, and thin lignite beds. The Cannonball Member is composed of poorly consolidated claystone and silty sandstone. In contrast to the other Fort Union members, the Cannonball Member is marine and does not contain lignite beds. The combined thickness of the two members is reported to be as much as 387 ft (Trapp, 1971, p. 336-337).

The Tongue River and Sentinel Butte Members were deposited in a fluvial system that originated in Wyoming and Montana along the eastern side of the Rocky Mountains. The alternating beds of claystone, siltstone, sandstone, and lignite represent flood-plain, levee, river channel, and swamp deposits. The various lithologic units are lenticular and discontinuous. Some lignite beds, however, extend for many miles.

The Tongue River Member consists of interbedded claystone and siltstone (both commonly carbonaceous), sandstone, lignite, and locally a "ledge" of indurated sandstone. Depth to the Tongue River Member ranges from about 50

Table 1.--Generalized stratigraphic column in the Dickinson lignite area

System	Series	Formation	Member	Maximum thickness (feet)	Lithologic description
Tertiary	Miocene	Arikaree		8	Tuffaceous sandstone.
	Oligocene	White River		250?	Conglomerate, arkose, sandstone, siltstone, and lignite.
	Eocene	Golden Valley		200	Shale, sandy claystone, and sandstone.
	Paleocene	Fort Union Formation	Sentinel Butte	369	Claystone, bentonitic or carbonaceous; siltstone; silty very fine to medium sandstone; and lignite.
			Tongue River	530	Claystone, bentonitic, carbonaceous; siltstone; silty very fine to medium sandstone; and lignite
			Ludlow / Cannonball / Ludlow	387	Ludlow--claystone, siltstone, sandstone, and lignite. Cannonball--marine claystone, siltstone, and silty sandstone.
Cretaceous	Upper Cretaceous	Hell Creek Formation		440	Sandstone, claystone, siltstone, thin-bedded lignite, and carbonaceous claystone.
		Fox Hills Sandstone		390	Sandstone, silty, brown to gray; silty claystone; and siltstone.
		Pierre Shale		1,100±	Shale, dark-gray, marine.

to 450 ft. The member ranges from 256 to 530 ft in thickness (Trapp, 1971, p. 364). According to lithologic logs, sandstone beds are scattered throughout the Tongue River Member, but the beds are most abundant in the basal part.

The Sentinel Butte Member of the Fort Union Formation overlies the Tongue River and constitutes the land surface throughout much of the study area (fig. 4). Where the top of the member has not been eroded, its total thickness is about 370 ft (Trapp, 1971). Sentinel Butte lithology is similar to that of the Tongue River. Beds of very fine to medium-grained gray sandstone are scattered throughout the member but generally are more common in the basal part of the Sentinel Butte Member.

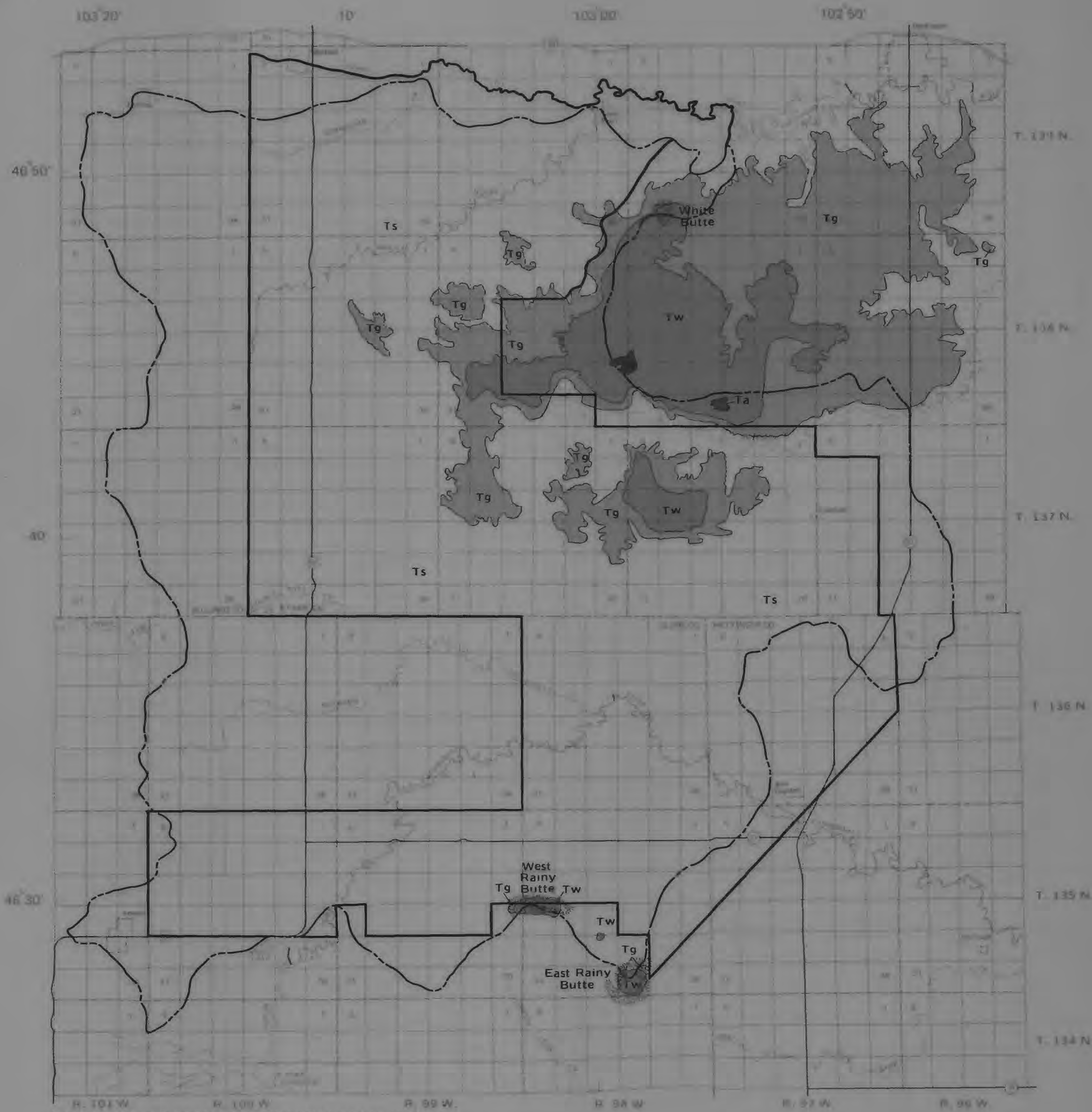
The sandstone lenses were deposited in long, narrow Paleocene stream channels that meandered in an easterly direction across a lower lying plain, which was subsequently buried. It is nearly impossible to correlate sandstone lenses from one test hole to another. The lignite beds, however, were deposited in widespread swampy areas, and some beds can be correlated for several square miles.

Thin lignite beds are numerous in the Sentinel Butte Member, but only two beds are consistently thick and continuous throughout the deposit area. Generally, claystone or siltstone lenses directly overlie the lignite beds, but locally the lignite is overlain by sandstone. Lithologic logs from the area of minable lignite indicate that the thicker lignite generally is underlain by at least 10 ft of claystone or siltstone (pl. 1). A few logs, however, show that some of the lignite is underlain by sandstone.

The Tongue River and Sentinel Butte Members contain most of the commercial lignite beds in North Dakota. The lignite beds in these two members generally are aquifers in the study area and locally may be the only source of ground water above the basal part of the Tongue River Member.

The Golden Valley Formation of Eocene age crops out extensively in western Stark County and in northwestern Hettinger County (fig. 4) and reaches a thickness of about 200 ft on some buttes southwest of Dickinson. Benson (1952, p. 70-72) described two informal members of the Golden Valley Formation. The lower member typically has a basal bed of light-purplish-gray shale, a middle bed of tough white sandy claystone that in the upper part is stained yellow or orange, and an upper bed of light-gray to purplish shale. Where exposed, the lower member is conspicuous, and Benson referred to it as a "marker bed." Benson's upper member of the Golden Valley Formation predominantly is a tan micaceous crossbedded sandstone with olive-drab claystone and siltstone and a few thin lignite beds.

The White River Formation of Oligocene age underlies about 38 mi^2 of southwestern Stark County and about 3 mi^2 of south-central Stark and north-central Hettinger Counties (fig. 4). The formation forms part of the rimrock of the higher buttes. A small outlier of White River also occurs in eastern Stark County. Its maximum thickness, in southwestern Stark County, is 200 to 250 ft.



BASE PREPARED FROM NORTH DAKOTA STATE HIGHWAY DEPARTMENT COUNTY HIGHWAY MAPS, 1980

0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

EXPLANATION

Ta	ARIKAREE FORMATION	MIOCENE	TERTIARY
Tw	WHITE RIVER FORMATION	OLIGOCENE	
Tg	GOLDEN VALLEY FORMATION	EOCENE	
Ts	SENTINEL BUTTE MEMBER of the Fort Union Formation	PALEOCENE	

BUREAU OF LAND MANAGEMENT PLANNING BOUNDARY

STUDY AREA BOUNDARY

CONTACT

Figure 4.–Generalized surficial geology. [From Clayton and others, 1980.]

The lower part of the White River Formation, which lies unconformably on the Golden Valley Formation, consists of conglomerate, arkose, tuffaceous sandstone, siltstone, and freshwater limestone. The upper part of the White River in southwestern Stark County consists of pinkish-gray nodular claystone with thin interbeds of fluvial sandstone and conglomerate.

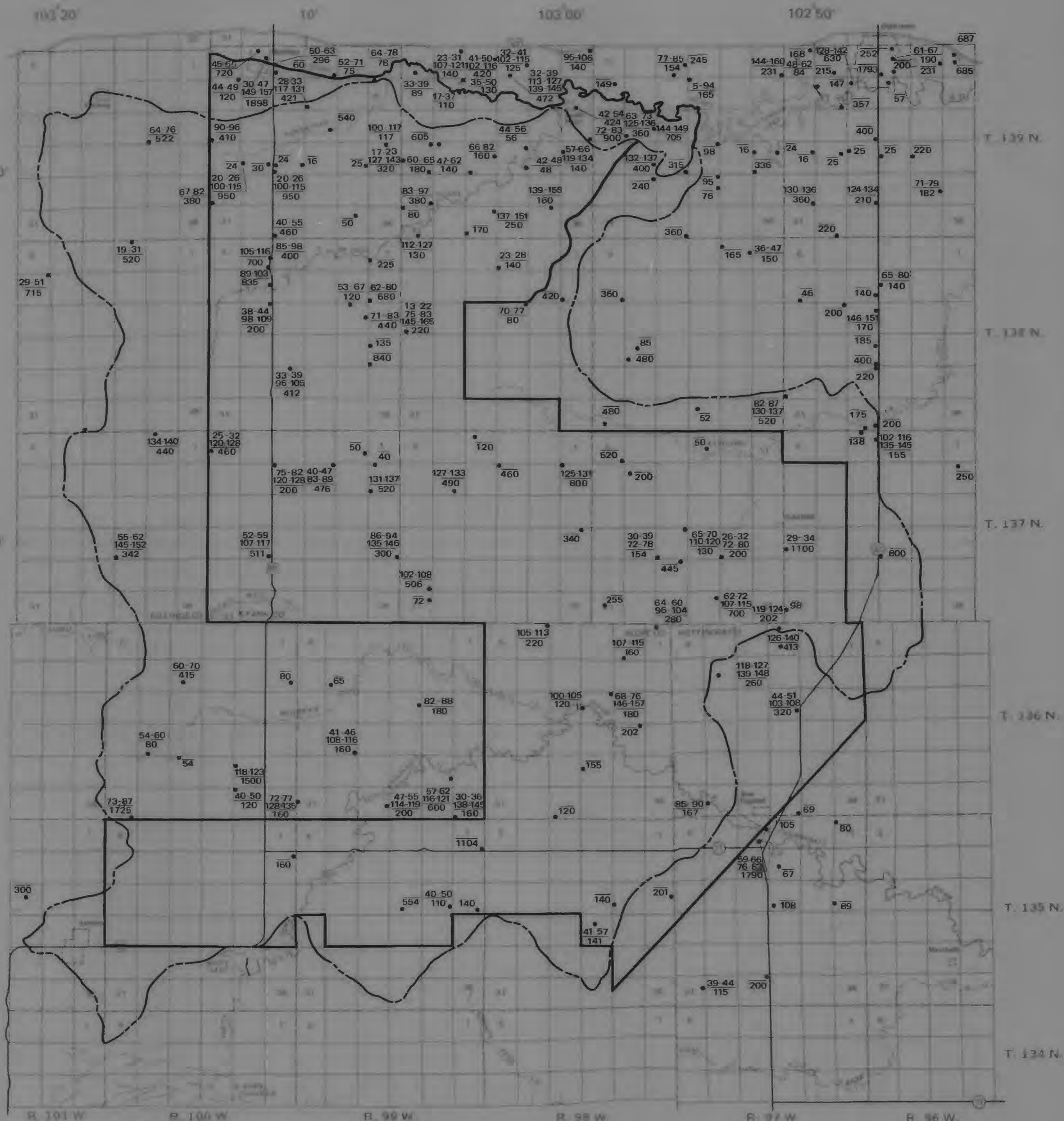
The Arikaree Formation of Miocene age is the youngest Tertiary formation in the Dickinson lignite area. It caps a few high buttes in southwestern Stark County and in north-central Hettinger County (fig. 4). The Arikaree consists of about 8 ft of tuffaceous sandstone (Denson and Gill, 1965, pl. 3).

Lignite

Most test holes or wells that have been drilled to a depth of more than 150 ft in the Dickinson lignite area have penetrated at least one lignite bed and most have penetrated more--as many as 14. Most lignite beds are only 1 to 4 ft thick but may be as much as 20 ft thick (figs. 5 and 6). Correlation of the various lignite beds is tenuous; however, there are only three lignite beds sufficiently extensive and thick enough to be considered minable based on the economical factor of 1 ft of lignite for each 10 ft of overburden. The three beds, in ascending order, are the HT Butte bed, the Fryburg (or D) bed, and the Heart River (or E) bed.

Owens (1979) described six lignite beds that occur consistently in the Tongue River Member in the New England area. Lewis (1979) also described the six lignite beds in the Gascoyne area. These six lignite beds probably are present under the northern part of the Dickinson lignite area, but no attempt was made to correlate the beds below the HT Butte beds for this study. In ascending order, beginning with the bed that generally lies within 50 to 100 ft of the base of the Tongue River Member, the bed names are: Hansen, Harmon, Nomad, Garner Creek, Coal Bank Creek, and HT Butte. Locally, many of the lignite beds split into more than one seam separated by a few inches to a few feet of silty clay or sand. The top of the HT Butte bed is widely recognized as the contact between the Tongue River and Sentinel Butte Members. The lignite beds in the Sentinel Butte Member are, in ascending order: Fryburg, Heart River, and Lehigh (Owens, 1979). In addition, there are several other thin lignite beds in the Sentinel Butte Member that have not been correlated or named.

The HT Butte bed is the lowest commercially recoverable lignite bed in the study area. It also is the most persistent within the area. The bed apparently is more persistent in an east-west direction (pl. 1, secs. A-A' through D-D') than in a north-south direction (pl. 1, sec. E-E'). The thickness of the bed, where present, ranges from about 2 to 14 ft and averages about 8 ft. The structure and continuity of the HT Butte bed is illustrated on the five sections shown on plate 1. Although none of the sections parallel the regional dip, they indicate an approximate regional dip of 20 to 35 ft/mi to the northeast. The HT Butte bed lies at less than 100 ft in depth only in the drainage basin of the Cannonball River and its tributaries.



BASE PREPARED FROM NORTH DAKOTA STATE HIGHWAY
DEPARTMENT COUNTY HIGHWAY MAPS, 1980

0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

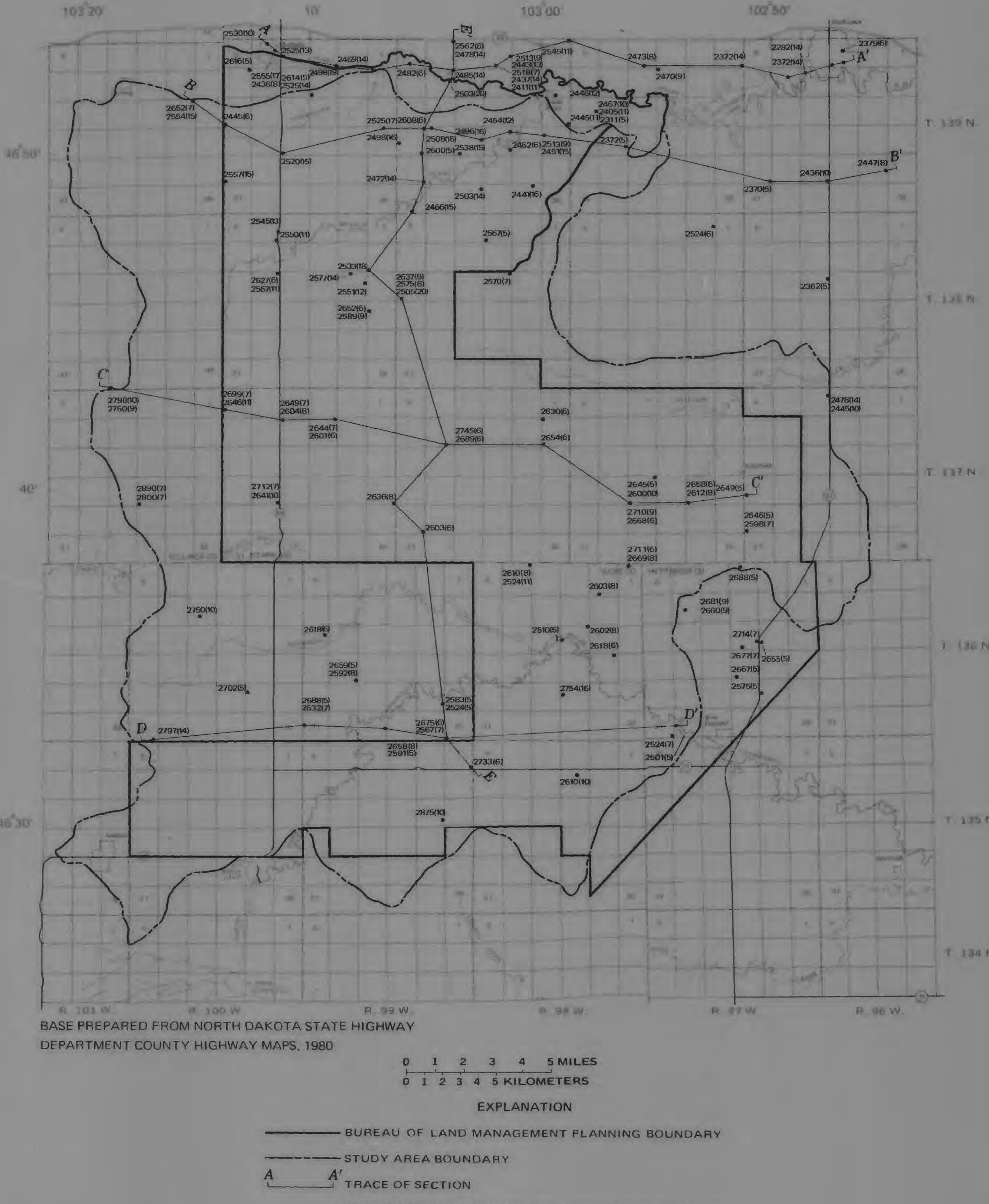
EXPLANATION

BUREAU OF LAND MANAGEMENT PLANNING BOUNDARY

STUDY AREA BOUNDARY

$\frac{39\text{-}44}{115}$ WELL OR TEST HOLE—Upper numbers are top and bottom of lignite beds, in feet below land surface. Number below line is depth of well or test hole

Figure 5.—Location of wells and test holes and depth of lignite beds.



BASE PREPARED FROM NORTH DAKOTA STATE HIGHWAY DEPARTMENT COUNTY HIGHWAY MAPS, 1980

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

EXPLANATION

BUREAU OF LAND MANAGEMENT PLANNING BOUNDARY

STUDY AREA BOUNDARY

A A' TRACE OF SECTION

2610(10) WELL OR TEST HOLE WITH LOG—Number is altitude of top of lignite bed, in feet above National Geodetic Vertical Datum of 1929. Number in parentheses is thickness of lignite bed, in feet. Beds less than 5 feet thick are not shown

Figure 6.—Altitude and thickness of selected lignite beds.

The Fryburg bed overlies the HT Butte bed and is separated from it by 70 to 150 ft of claystone, siltstone, and locally, sandstone. The separating material averages about 100 ft thick. The Fryburg bed may be present beneath some of the topographically higher areas along the flanks of the Cannonball drainage basin, but it is not present in the low areas. Owens (1979) reported that the average thickness of the Fryburg bed, where present in the New England area, is about 7 ft.

The lignite beds of economic importance in the Heart River drainage are the Fryburg, the Heart River, and remnants of what may be the Lehigh bed. Stratigraphically, they lie near the middle of the Sentinel Butte section. Leonard, Babcock, and Dove (1925, p. 140) assigned the name Fryburg to the lower bed and Heart River to the middle bed. A later report by Northern Pacific Railway Company (written commun., 1963) designated the two beds D and E, respectively (pl. 1). Some of the higher beds may be the erosional remnants of the Lehigh bed (pl. 1, secs. B-B', C-C', and E-E').

Lithologic logs show the lower, or Fryburg, bed is as much as 20 ft thick and averages about 15 ft in thickness in the northwestern part of the study area. The bed apparently thins to the east and south.

The structure of the Fryburg bed is discernible from secs. A-A' through E-E' (pl. 1), which show that the bed dips to the east and north at about the same rate as the HT Butte bed. Secs. A-A' through C-C' also indicate a north-south trending anticlinal structure in Tps. 137, 138, and 139 N., R. 98 W. Sec. C-C' shows that the anticlinal structure continues in the deeper coal beds.

The upper, or Heart River, bed generally lies from about 35 to 85 ft above the Fryburg bed (pl. 1, secs. A-A'-C-C') but has been eroded from the Heart River and the lower reaches of its tributaries. Where present, the bed generally ranges in thickness from about 4 to 14 ft and averages about 9 ft in the minable areas. The bed nearly parallels the Fryburg bed and also has a regional dip of about 20 to 35 ft/mi to the northeast. The anticlinal structure that is present in the Fryburg bed also appears to be present in the Heart River bed.

Erosional remnants of the Lehigh bed are as much as 7 ft thick in the higher parts of the Heart River drainage. These remnants are not extensive enough to determine regional structure of the bed, but there are sufficient remnants to indicate a similar regional dip of about 20 to 35 ft/mi.

AQUIFERS IN THE DICKINSON LIGNITE AREA

Fox Hills-Lower Hell Creek Aquifer System

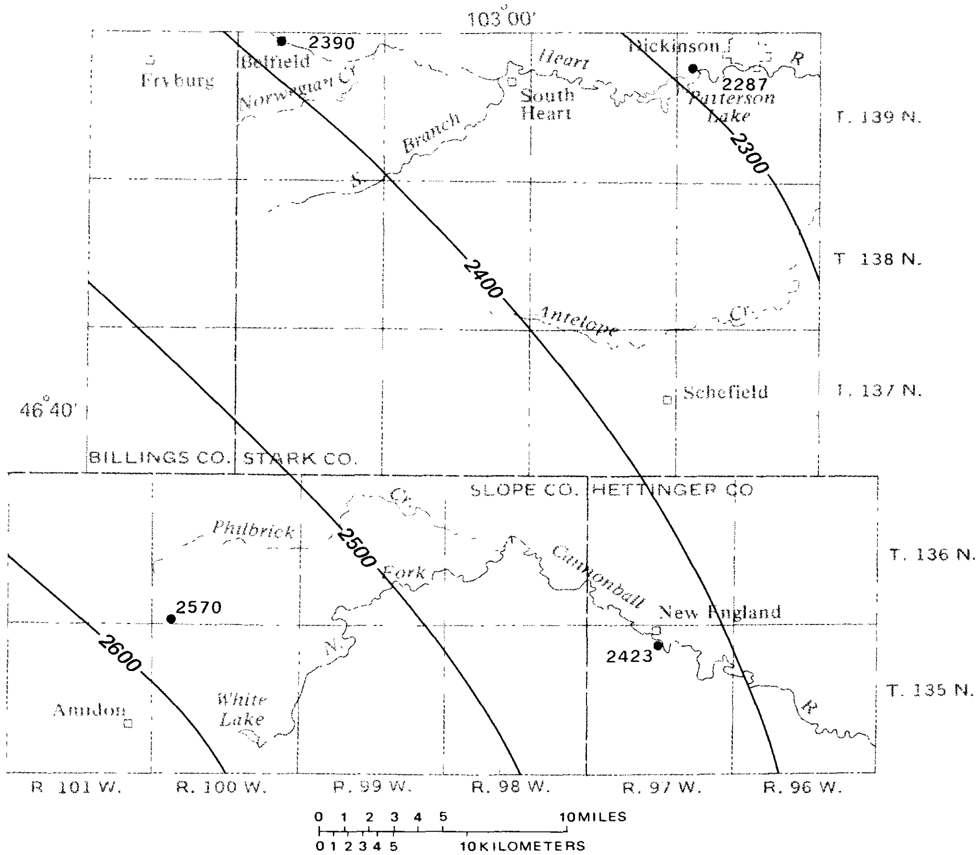
The Fox Hills Sandstone and the lower part of the Hell Creek Formation form a confined aquifer system that underlies all of the study area and extends into adjoining areas. The aquifer system includes all of the Fox Hills Sandstone except shale beds and generally includes sandstone beds in the lower part of the Hell Creek Formation. The aquifer system consists of fine- to medium-grained sandstone interbedded with siltstone and claystone.

The top of the aquifer system is about 1,300 ft deep (altitude about 1,124 ft) in test well 135-097-04DCA, about 1,550 ft deep (altitude about 1,220 ft) in well 139-099-05ABD at Belfield, and about 1,710 ft deep (altitude about 720 ft) in well 139-096-07ADA about a mile west of Dickinson. Based on these three wells, the top of the Fox Hills-lower Hell Creek aquifer system dips N.63°E at a rate of about 34 ft/mi. Trapp and Croft (1975, p. 23) stated that the aquifer ranged in thickness from 410 to 530 ft along the lines of two of their sections. Aggregate sandstone thickness, however, ranged from 88 to 192 ft. Trapp and Croft (1975, pl. 2) showed an overlying impermeable bed about 50 to 60 ft thick in this study area that separates the Fox Hills-lower Hell Creek aquifer system from the overlying aquifers.

A map of the potentiometric surface of the Fox Hills-lower Hell Creek aquifer system (fig. 7) shows that ground water generally moves to the northeast in response to a gradient of about 9 ft/mi. The hydraulic gradient of the potentiometric surface probably varies to some extent but averages about 9 ft/mi to the northeast. The water levels used to construct figure 7 were measured at different times over a 10-year period; therefore, there may be distortions in the constructed potentiometric surface. However, the errors, if they exist, probably are small because the measurements were made in nonpumping test wells and in newly constructed stock or public-supply wells. A comparison of figures 7 and 8 indicates that the hydraulic head in the Fox Hills-lower Hell Creek aquifer system is lower than the hydraulic head in the overlying aquifer.

The transmissivity of the Fox Hills-lower Hell Creek aquifer system varies considerably from place to place because of the different aggregate sandstone thicknesses as well as differences in grain size of the sandstone beds, both of which affect the transmissivity. Trapp and Croft (1975, p. 23) ran a 4-hour specific-capacity test on well 135-097-04DCA. They calculated a specific capacity of about 1 (gal/min)/ft of drawdown. They also published a map that illustrates some of the transmissivity variations. R. W. Schmid (oral commun., 1983) conducted a 50-hour aquifer test using well 139-096-07ADA. The well was pumped at 218 gal/min, and the final drawdown was 222 ft, for a specific capacity of 0.98 (gal/min)/ft of drawdown. The calculated transmissivity of the aquifer was 130 ft^2/d. L. W. Veigel and Company (oral commun., 1983) reported that the Belfield well, 139-099-05ABD, was pumped for several hours at a rate of 90 gal/min. The drawdown was 510 ft, for a specific capacity of 0.18 (gal/min)/ft of drawdown. No storage values have been reported, but the aquifer system is artesian so the storage coefficient should be about 0.0001.

Yields from the aquifer system depend primarily on well construction, well development, and transmissivity at the well site. Specific capacities of wells range from about 0.18 to 1 (gal/min)/ft of drawdown, and everywhere in the study area water levels are such that several hundred feet of drawdown are available. The yield at 24 hours of a fully penetrating well can be determined by multiplying specific capacity by the drawdown. For example, the well at 139-096-07ADA would yield about 98 gal/min with 100 ft of drawdown. The well at 139-099-05ABD would yield only 18 gal/min with 100 ft of drawdown.

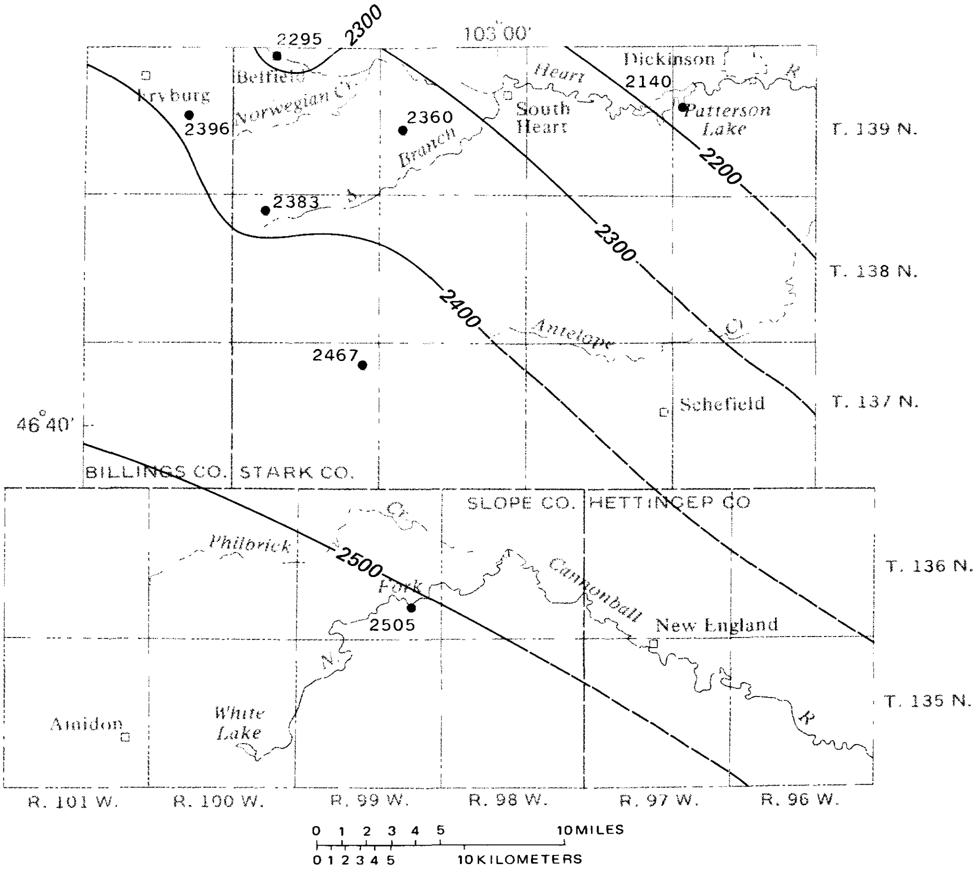


EXPLANATION

—— *2400* —— POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells. Contour interval 100 feet. Datum is National Geodetic Vertical Datum of 1929

•2570 WELL—Number indicates altitude of water level

Figure 7.—Potentiometric surface of the Fox Hills-lower Hell Creek aquifer system.



EXPLANATION

—2500— POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 100 feet. Datum is National Geodetic Vertical Datum of 1929

•2467 WELL—Number indicates altitude of water level

Figure 8.—Potentiometric surface of the upper Ludlow-lower Tongue River aquifer system.

The potentiometric surface shown in figure 7 indicates that the principal source of recharge to the study area is lateral flow from the southwestern part of the aquifer. Some recharge also may be from vertical leakage through the overlying beds. Discharge from the aquifer system in the study area primarily is by flow to the northeast. Discharge by pumping, however, is becoming more significant in Belfield and near Dickinson.

Water from the Fox Hills-lower Hell Creek aquifer system in the Dickinson lignite area is soft, less than 20 mg/L hardness, and is a sodium bicarbonate type. Dissolved-solids concentrations in the water ranged from 1,230 mg/L at well 136-100-31DDC1 to 1,690 mg/L at well 139-099-05ABD. Sodium concentrations ranged from 470 to 606 mg/L and constituted at least 98 percent of the cations in the water. Chloride concentration apparently increases in an easterly direction from 57 mg/L at well 136-100-31DDC1 to as much as 190 mg/L at well 135-097-04DCA. Fluoride concentration ranges from 2.3 to 4.7 and exceeds the optimum concentrations generally recommended for drinking-water supplies. Water from the aquifer is not suitable for prolonged irrigation because of large sodium-adsorption ratios.

The city of Belfield obtains part of its water supply from a well in the Fox Hills-lower Hell Creek aquifer system and was in the process of installing a second well in the aquifer system during the summer of 1983. The total quantity of water pumped from the Fox Hills-lower Hell Creek aquifer system by the city during 1982 was about 24.5 million gallons.

Upper Hell Creek-Lower Ludlow Aquifer System

The upper part of the Hell Creek Formation and the lower part of the Ludlow Member of the Fort Union Formation form a regional confined aquifer system that underlies all of the study and adjacent areas. Locally, the overlying Cannonball Member of the Fort Union Formation contains sand lenses that yield water. The Cannonball Member, where present, is considered part of the underlying upper Hell Creek-lower Ludlow aquifer system in this report. The depth to the top of the aquifer system is about 720 ft near Amidon, 730 ft near New England, and as much as 1,040 ft near Dickinson. The aquifer system is composed of very fine to medium-grained sandstone lenses that generally contain some silt and clay, as much as 30 percent. Individual sandstone lenses range from 2 to 74 ft with an aggregate sandstone thickness of as much as 324 ft. Trapp and Croft (1975, pl. 2) showed that the aquifer system is separated from the overlying aquifer by a confining bed that ranges in thickness from about 40 to 150 ft.

Anna (1981, p. 23) reported that the hydraulic conductivities of two sidewall cores taken from the aquifer system were 0.6 and 0.8 ft/d and that the low values were caused by poor sorting and a large percentage of silt. He also reported that transmissivities determined from recovery tests on flowing wells (probably from wells in the Little Missouri River valley which is west of the study area) ranged from 1 to 160 ft^2/d and had a mean of 77 ft^2/d. Even though these values were obtained from wells outside of the study area, they should be representative of the aquifer system in the study area. Trapp and Croft (1975) reported that the specific capacities of two wells in the upper Hell Creek-lower Ludlow aquifer system were 0.2 and 0.33 (gal/min)/ft of drawdown. Transmissivities calculated from these specific capacities are about 53 ft^2/d and 88 ft^2/d,which are within the limits determined by Anna. Yields of as much as 150 gal/min might be obtainable (Anna, 1981), but yields greater than about 30 gal/min with 100 ft of drawdown would be unusual. Trapp (1971, table 1) reported the yield from six wells in the report area; three yielded 12 gal/min, two yielded 8 gal/min, and one yielded 2 gal/min.

Data are not sufficient to construct a potentiometric surface map of the upper Hell Creek-lower Ludlow aquifer system, but the available data indicate that the surface slopes to the northeast. The slope of the potentiometric surface indicates that the recharge area is to the southwest. However, some leakage from shallower aquifers does occur. Natural discharge from the area is to the northeast, but some small but undetermined quantity is discharged through wells.

Water in samples from four wells in the upper Hell Creek-lower Ludlow aquifer system is soft and a sodium bicarbonate type. Sodium concentrations ranged from 412 to 640 mg/L and constituted either 98 or 99 percent of the cations present. Bicarbonate plus carbonate ion concentrations ranged from 93 to 98 percent of the anions in the samples. Sulfate concentrations ranged from 0.8 to 37 mg/L, chloride concentrations ranged from 5.3 to 14 mg/L, and fluoride concentrations ranged from 1.5 to 5.6 mg/L. Dissolved-solids concentrations ranged from 1,010 to 1,450 mg/L, and sodium-adsorption ratios ranged from 50 to 74.

Upper Ludlow-Lower Tongue River Aquifer System

The upper Ludlow-lower Tongue River aquifer system includes thin sandstone lenses in the upper part of the Ludlow Member and thick beds of sandstone in the lower part of the Tongue River Member of the Fort Union Formation. The aquifer system is confined and underlies all of the Dickinson lignite area at depths that generally range from about 440 to 713 ft below land surface but may be deeper beneath some of the buttes in the area. The thickness of the aquifer ranges from 36 to 161 ft and in nine wells averages about 94 ft. The thickness at any location includes any siltstone or claystone lenses that may be present in generally sandy zones within the aquifer system. Trapp and Croft (1975, pl. 2) showed that the aquifer is separated from the overlying aquifer by an impermeable member that ranges from about 110 to nearly 300 ft thick in the report area. However, their section did not underlie the Cannonball River valley where the confining bed may be only a few tens of feet thick.

The aquifer system generally is composed of very fine to medium-grained semiconsolidated sandstone lenses that contain varying quantities of interstitial silt and clay. The aquifer system also commonly contains siltstone, claystone, or shale lenses that may be as much as 64 ft thick. Aggregate thicknesses of siltstone, claystone, or shale may be as much as 140 ft. Trapp and Croft (1975, p. 14) drew a transmissivity map of the aquifer system. The map shows that well yields should range from about 1 to 100 gal/min with 50 ft of drawdown, with the greatest yield being in the Belfield area. Yields as large as 250 gal/min (North Dakota State Water Commission, written commun., 1982) have been reported at Belfield, but the drawdown was not measured.

A generalized potentiometric-surface map of the upper Ludlow-lower Tongue River aquifer system is shown in figure 8. The contours indicate that subsurface flow generally is toward the northeast. The contours, however, show an irregularity in the Belfield area that indicates a large cone of depression has formed due to pumping at Belfield. However, some of the irregularity of the contour lines may be due to head differences that are influenced by structural control.

Analyses of water in samples collected from four wells in the aquifer indicate the water generally is soft (less than 20 mg/L hardness), but the water from the sample from well 136-100-31DDC2 in the southwestern part of the area was moderately hard (78 mg/L hardness). The water generally is a sodium bicarbonate type, but in the southwestern part of the area it may be a sodium sulfate type. Dissolved-solids concentrations in the water ranged from 995 to 1,990; however, only the water from well 136-100-31DDC2, in the southwestern part of the area, contained dissolved-solids concentrations that exceeded 1,080 mg/L. Sodium concentrations ranged from 390 to 670 mg/L, and sulfate concentrations ranged from 33 to 1,000 mg/L. The concentration of sulfate ions decreases from the southwest to the northeast in a downdip direction. Fluoride concentrations ranged from 1.4 to 5.9 mg/L. The sodium-adsorption ratio ranged from 33 to 73 and generally indicates that the water is not suitable for irrigation.

The city of Belfield has three wells completed in the upper Ludlow-lower Tongue River aquifer system. The total quantity of water pumped from these wells during 1982 was about 26.5 million gallons.

Upper Tongue River-Sentinel Butte Aquifer System

The upper Tongue River-Sentinel Butte aquifer system is composed of discontinuous sandstone lenses and relatively extensive lignite beds in the upper part of the Tongue River Member and lower part of the overlying Sentinel Butte Member. Lithologic logs show that the aquifer system ranges from near land surface to about 530 ft in depth. However, some of the deeper lenses may or may not be hydraulically connected to the shallower part of the aquifer system. The deeper parts of the aquifer system generally are confined, but some of the shallower parts are unconfined and water-table conditions exist.

Generally, the sandstone lenses are less than 30 ft thick, but they may be as much as 147 ft thick. The sandstone generally is very fine to medium grained, contains varying quantities of silt or clay, and commonly is semiconsolidated. Therefore, the hydraulic conductivity of the beds is small. However, some of the sand in the lenses is reported to be well sorted and coarse grained, and the hydraulic conductivity of these coarse beds is large.

Lignite beds range from less than 1 to about 19 ft in thickness in well 139-099-03DDD. The lignite generally contains fractures, which are the source of most of the permeability within the lignite. The size of the fractures varies considerably from place to place and within short distances, so the hydraulic conductivity of the lignite beds also varies.

Yields to wells completed in the sandstone lenses in the upper Tongue River-Sentinel Butte aquifer system generally range from 1 to 130 gal/min and average about 27 gal/min, based on reported yields from 111 wells (Trapp, 1971) in the Dickinson lignite area. Yields from the lignite beds range from about 2 to about 60 gal/min. The mean yield from 23 wells completed in lignite beds in the area is about 16 gal/min.

Water levels (fig. 9) in closely spaced wells completed in the upper Tongue River-Sentinel Butte aquifer system indicate that water leaks downward from one sand lens to another. The water moves laterally downgradient within a sand lens toward the Cannonball River in the southern part of the area and toward the Heart River in the northern part. Because of the difficulty of correlating individual sand lenses and the corresponding water levels, the water-level gradients have not been determined.

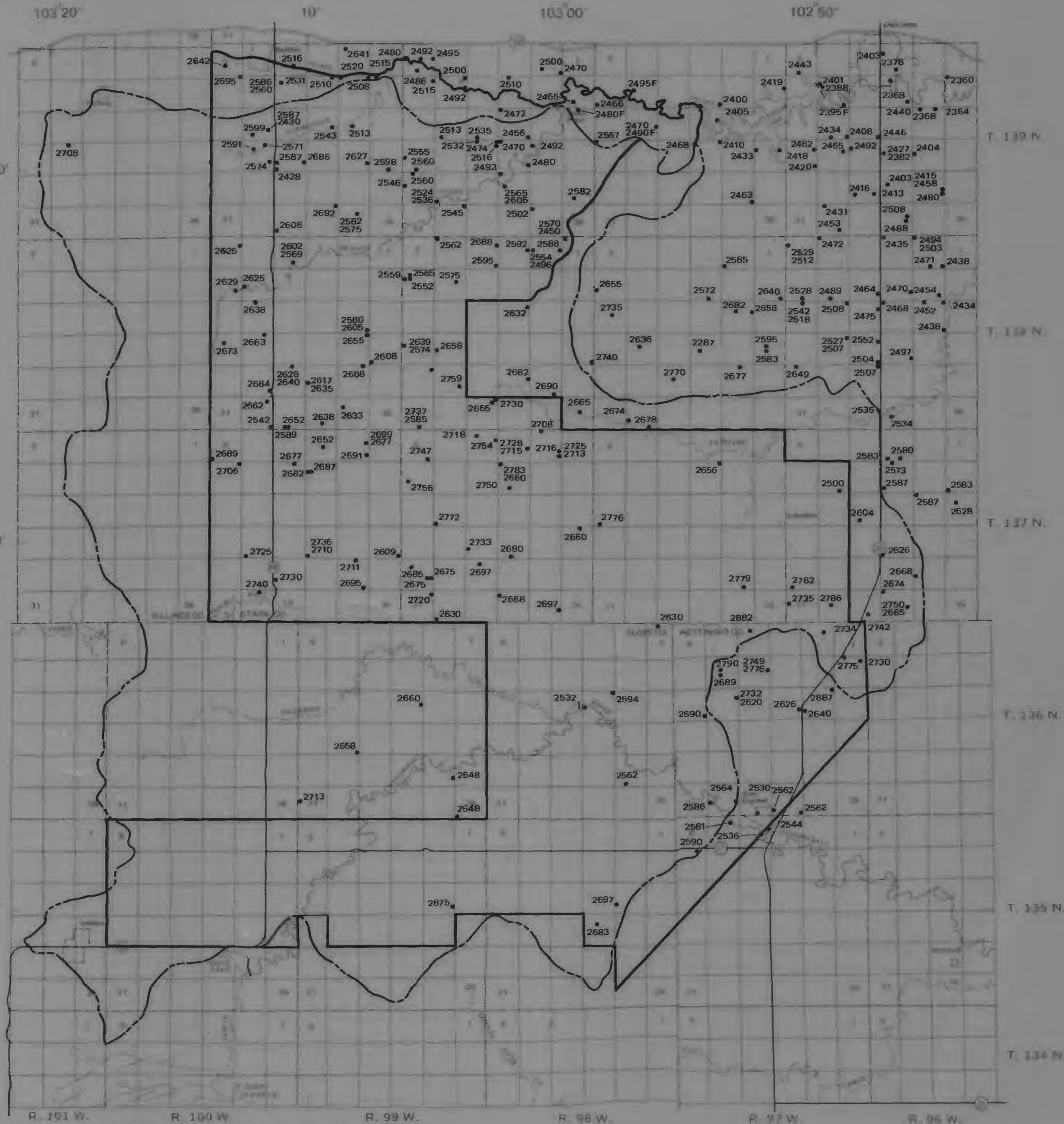
Analyses of water in samples collected from 36 wells in the upper Tongue River-Sentinel Butte aquifer system show that the hardness of the water ranged from 10 to 1,280 mg/L and had a mean of 215 mg/L. Fifteen of the samples contained concentrations of hardness greater than 180 mg/L, which is considered very hard water. Generally, the water is a sodium bicarbonate type. Twenty-two of 26 samples that were analyzed for sodium contained more than 50 percent sodium, and bicarbonate concentrations exceeded sulfate concentrations in 26 of the 36 samples. Dissolved-solids concentrations in samples from 35 wells ranged from 574 to 2,720 mg/L and had a mean of 1,174 mg/L. Sulfate concentrations ranged from 12 to 1,660 mg/L and had a mean of 426 mg/L. Sulfate concentrations exceeded the North Dakota Public Health Service recommended limit of 250 mg/L in 21 of the 36 samples. Sodium-adsorption ratios ranged from 2.5 to 68. Generally, the water is not suitable for irrigation.

The city of New England obtains its water supply from the upper Tongue River-Sentinel Butte aquifer system. They reportedly pumped 58 million gallons of water from four wells during 1982.

A few shallow wells have been completed in the Golden Valley and White River Formations. The wells yield only small quantities of water that is used for livestock supplies. Trapp (1971, p. 418-419) showed partial analyses of samples from three wells. Dissolved-solids concentrations in the wells were 400, 600, and 824 mg/L. Calcium concentration exceeded sodium in one of the two samples that were analyzed for both ions. Bicarbonate ion concentrations exceed that of the sulfide in the only sample analyzed for those ions.

SURFACE WATER IN THE DICKINSON LIGNITE AREA

Streams in the Dickinson lignite area are intermittent except for the



BASE PREPARED FROM NORTH DAKOTA STATE HIGHWAY
DEPARTMENT COUNTY HIGHWAY MAPS, 1980

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

EXPLANATION

——— BUREAU OF LAND MANAGEMENT PLANNING BOUNDARY

– – – STUDY AREA BOUNDARY

• 2875 WELL—Number is altitude of the water level, in feet above National Geodetic Vertical Datum of 1929. Two numbers indicate two wells in same 10 acre location. F indicates well flows.

Figure 9.—Water levels in wells in the upper Tongue River-Sentinel Butte aquifer system.

Cannonball River at New England and the Heart River near South Heart (fig. 3). The mean daily discharge of both rivers at the above stations from October 1980 through September 1981, the 1981 water year, are shown in table 2 (U.S. Geological Survey, 1982). The extreme flows for the period of record also are shown in the table. The records for both streams show that there are small discharges, generally base flow, through the winter followed by an increase during March and early April that includes base flow and runoff from snowmelt. This flow pattern is typical. However, the winter of 1980-81 was drier than normal, and the snow cover was thin in both drainage basins. Consequently, flows following the snowmelt were comparatively small. The March and April flows following winters with deep snow cover are much greater than those shown in table 2. Base flow in both rivers during the 1979 water year (a wet year), shown in table 3 (U.S. Geological Survey, 1980), were about two to five times greater than the base flow during the 1981 water year. The large flows during the summer and fall months of 1979 primarily are caused by runoff from thunderstorms. In the Dickinson lignite area, the base flow in the Cannonball River generally is less than 0.2 ft^3/s, and the base flow in the Heart River generally is less than 1 ft^3/s. Base flow is derived from ground-water seepage from sandstone or lignite beds or underflow from the stream sediments. However, data are insufficient to make estimates of the quantity or proportion of water from each source.

When strip mining begins in the area, there may be a slight decrease in base flows in either the Cannonball or Heart Rivers because of the quantity of ground water that is intercepted at the mine. Since the base flow generally is small, any impact that mining might have on the base flow also will be small. However, pumping of water from mine pits to the streams temporarily would increase the flow of water downstream from the mines.

Results of the chemical analyses of water from both the Cannonball and Heart Rivers during the 1981 water year are shown in table 4. These data are representative of the premining chemistry of streamflow from the study area. The concentrations of the various chemical constituents at base flow generally indicate the quality of ground water near the rivers. The reduced concentrations at large flows, such as occurred August 18, are caused by the diluting effect of the large flows on small quantities of dissolved solids. At flows only slightly greater than base flow, the quality of water is variable. The increased concentrations may be because of redissolved salts that accumulate in the soils near the streams as flow decreases. Apparently, early runoff contains enough contaminants to be significant at small flows but would not be apparent at large flows.

Streamflow records were collected at two sites (6 and 7, fig. 3) for the period October 1978 to September 1981. The sites were established as part of a U.S. Geological Survey program to monitor the effects of energy development in the United States. The period of record is not long enough to develop reliable statistics but can be used as an indicator of some characteristics (table 5). Flow at both sites generally is the result of direct runoff from snowmelt or precipitation. There are long periods of no flow each year.

Table 2.--Flow of the Cannonball River at New England and the Heart River near South Heart, October 1980 to September 1981

[Extremes for period of record, Cannonball River at New England.--Maximum discharge, 1,450 ft^3/s, April 10, 1979; no flow for parts of several days in October 1980 when water was being pumped from gage pool. Data from U.S. Geological Survey, 1982, p. 337.]

	Mean values of discharge, in ft^3/s, water year October 1980 to September 1981											
Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
	Cannonball River at New England											
1	0.02	0.02	0.01	0.06	0.03	0.09	0.64	0.03	0.05	0.22	0.05	0.60
2	.02	.03	.01	.05	.03	.09	.36	.03	.07	48	.05	.49
3	.02	.03	.01	.05	.03	.12	.28	.04	.07	35	45	.37
4	.02	.03	.01	.05	.03	.11	.24	.05	.09	12	114	.30
5	.03	.02	.01	.06	.05	.10	.31	.05	.06	5.2	372	.27
6	.03	.02	.01	.05	.05	.11	.29	.05	.05	2.6	280	.62
7	.03	.02	.01	.05	.02	.27	.30	.05	.05	1.9	175	8.3
8	.03	.03	.01	.05	.02	.81	.19	.05	.09	1.0	73	2.4
9	.03	.03	.01	.05	.01	1.0	.18	.05	.07	.60	40	1.1
10	.02	.02	.01	.06	.01	.98	.15	.06	.05	.30	27	.54
11	.02	.02	.04	.09	.01	1.0	.15	.06	.05	.60	19	.37
12	.02	.02	.05	.07	.02	.98	.15	.07	.05	13	14	.30
13	.02	.02	.05	.06	.04	.95	.12	.07	.22	2.0	8.9	.25
14	.02	.02	.04	.04	.08	.95	.11	.07	.13	47	5.2	.20
15	.02	.03	.11	.04	.11	.86	.09	.07	2.6	13	49	.19
16	.05	.03	.12	.06	.14	.95	.08	.07	15	4.1	556	.19
17	.06	.03	.11	.09	.19	.79	.04	.07	11	2.0	276	.19
18	.03	.03	.06	.10	.11	.41	.05	.06	7.4	.72	161	.19
19	.02	.03	.03	.10	.10	.22	.04	.07	6.2	.22	82	.19
20	.02	.03	.04	.10	.10	.22	.03	.06	5.7	.14	41	.19
21	.02	.02	.05	.09	.09	.20	.03	.05	4.9	.13	25	.19
22	.02	.02	.05	.10	.08	.27	.03	.06	3.0	.11	18	.19
23	.05	.01	.03	.11	.08	.33	.03	.09	1.9	.10	13	.19
24	.02	.01	.01	.10	.08	.37	.03	.05	.79	.10	8.9	.19
25	.02	.02	.02	.09	.07	.37	.03	.05	.50	.09	5.5	81
26	.02	.02	.03	.09	.09	.31	.03	.06	.25	.07	2.8	8.5
27	.02	.02	.05	.07	.12	.34	.07	.07	.25	.06	2.0	.41
28	.02	.02	.08	.05	.11	.37	.07	.10	.22	.06	1.5	.27
29	.02	.02	.08	.04	--	.33	.05	.07	.19	.07	1.0	.25
30	.02	.02	.09	.05	--	.33	.04	.04	.18	.06	.79	.20
31	.02	--	.09	.04	--	.57	--	.04	--	.05	.72	--
Total	.78	.69	1.33	2.11	1.9	14.8	4.21	1.81	61.18	190.5	2,417.41	108.64
Mean	.025	.023	.043	.068	.068	.48	.14	.058	2.04	6.15	78	3.62
Maximum	.06	.03	.12	.11	.19	1.0	.64	.10	15	48	556	81
Minimum	.02	.01	.01	.04	.01	.09	.03	.03	.05	.05	.05	.19
Acre-feet	1.5	1.4	2.6	4.2	3.8	29	8.4	3.6	121	378	4,790	.19

[Extremes for period of record, Heart River near South Heart.--Maximum discharge, 8,080 ft^3/s, May 9, 1970; no flow at times in some years. Data from U.S. Geological Survey, 1982, p. 299.]

Mean values of discharge, in ft^3/s, water year October 1980 to September 1981

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
						Heart River near South Heart						
1	0.16	0.70	0.94	0.60	0.88	1.2	0.68	0.88	0.38	2.3	0.16	0.70
2	.16	.70	.76	.60	.88	1.1	.76	.76	.53	2.5	.10	.49
3	.16	.70	.68	.60	.88	1.1	.82	.76	3.5	2.6	.10	.30
4	.16	.76	.76	.60	.76	1.1	.82	.82	3.3	2.3	16	.23
5	.16	.82	.82	.56	.70	1.1	.82	.82	3.0	2.0	63	.16
6	.16	.76	.70	.53	.70	1.1	.82	.88	3.8	1.4	179	23
7	.16	.76	.68	.60	.70	1.1	.88	.93	2.2	.85	191	57
8	.16	.88	.63	.63	.68	1.1	.88	.82	1.5	.42	54	25
9	.16	.94	.65	.65	.65	1.1	1.3	.75	2.0	.38	26	16
10	.16	1.0	.60	.65	.65	1.0	.70	.65	3.8	.30	15	11
11	.16	1.1	.60	.65	.60	1.0	.65	.63	1.7	.23	9.8	8.0
12	.16	1.1	.63	.65	.60	1.0	.63	.65	1.0	.23	6.1	5.4
13	.23	1.2	.65	.63	.65	1.0	.63	.60	68	.23	4.3	3.8
14	.16	1.5	.60	.65	.70	1.0	.56	.60	112	.16	3.8	3.1
15	.23	1.3	.60	.64	.94	.94	.56	.49	26	.05	4.3	2.2
16	.82	1.2	.65	.65	1.2	.99	.53	.49	13	.00	293	1.6
17	6.6	1.1	.72	.70	1.9	1.6	.49	.56	8.3	.00	892	1.1
18	4.4	1.1	.76	.68	2.7	.82	.49	.49	5.1	.00	641	1.0
19	2.5	1.0	.60	.68	3.2	.82	.49	.49	3.5	.00	130	.94
20	1.6	1.1	.49	.76	3.7	.82	.49	.44	3.3	.00	52	.90
21	1.1	1.1	.49	.76	2.4	.80	.44	.23	3.8	.19	30	.85
22	.76	1.1	.53	.76	2.3	.76	.38	.49	22	.23	19	.80
23	1.1	1.0	.60	.82	2.1	.68	.46	.60	9.6	.16	12	.74
24	3.0	.97	.63	.94	1.7	.60	.53	.49	4.5	.16	78	.70
25	2.5	.93	.63	1.0	1.5	.60	.65	.38	2.6	.10	6.0	.66
26	1.5	.90	.63	1.1	1.6	.71	.76	.38	1.7	.10	4.2	.62
27	1.1	.91	.65	1.1	1.5	.53	.94	.53	2.0	.10	2.7	.58
28	.94	.95	.70	1.0	1.3	.60	1.1	.56	1.9	.10	1.6	.56
29	.88	1.1	.68	1.0	--	.63	1.1	.56	2.3	.16	1.2	.54
30	.82	1.0	.68	.94	--	.65	.94	.53	2.6	.48	.88	.52
31	.70	--	.65	.88	--	.65	--	.38	--	.45	.70	--
Total	32.86	29.68	20.39	23.01	38.07	28.20	21.30	18.64	318.91	18.18	2,736.94	168.49
Mean	1.06	.99	.66	.74	1.36	.91	.71	.60	10.6	.59	88.3	5.62
Maximum	6.6	1.5	.94	1.1	3.7	1.6	1.3	.93	112	2.6	892	57
Minimum	.16	.70	.49	.53	.60	.53	.38	.23	.38	.00	.10	.16
Acre-feet	65	59	40	46	76	56	42	37	633	36	5,430	334

Table 3.--Flow of the Cannonball River at New England and the Heart River near South Heart, October 1978 to September 1979

[Data from U.S. Geological Survey, 1980, p. 599.]

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
	Mean values of discharge, in ft3/s, water year October 1980 to September 1981											
	Cannonball River at New England											
1	0.11	0.17	0.60	0.60	0.50	0.70	280	19	2.9	0.39	0.54	0.06
2	.11	.20	.60	.60	.50	.80	240	18	2.7	.39	.22	.06
3	.11	.20	.60	.60	.50	1.1	210	17	2.5	.22	.17	.06
4	.11	.23	.60	.60	.50	1.4	140	15	2.2	.17	.17	.06
5	.11	.25	.60	.60	.50	1.9	90	14	2.0	.17	.11	.06
6	.11	.25	.60	.60	.60	1.8	75	15	1.9	.14	.11	.06
7	.10	.28	.60	.60	.50	1.6	105	15	1.6	.14	.11	.06
8	.10	.28	.60	.60	.50	1.5	295	15	1.6	.17	.11	.06
9	.09	.39	.60	.60	.47	1.4	795	14	2.7	.22	.11	.06
10	.09	.44	.80	.60	.44	1.6	1,250	15	2.5	.28	.14	.06
11	.08	.49	1.4	.60	.44	2.0	1,300	15	1.9	.39	.14	.06
12	.08	.51	1.8	.60	.44	3.3	584	14	1.6	.45	.14	.06
13	.08	.51	1.2	.50	.49	5.6	246	13	1.4	.80	.17	.06
14	.07	.51	1.4	.50	.60	3.8	128	12	1.1	.65	.17	.06
15	.07	.51	1.6	.50	.50	4.4	156	11	.69	1.2	.17	.06
16	.06	.51	1.5	.60	.50	6.7	462	11	.54	.17	.17	.06
17	.06	.51	1.4	.60	.50	14	617	9.9	.32	.11	.14	.06
18	.05	.54	1.2	.70	.50	69	447	8.4	.32	.14	.11	.06
19	.05	.54	1.0	.70	.60	38	279	8.1	4.2	.14	.09	.06
20	.06	.54	.90	.80	.65	35	158	7.6	10	.11	.11	.06
21	.03	.54	.80	.80	.60	40	95	7.3	8.7	.14	.11	.06
22	.03	.54	.70	.90	.60	62	63	7.0	6.4	.14	.11	.06
23	.06	.54	.60	.80	.60	100	47	6.4	4.0	.11	.09	.06
24	.09	.60	.60	.80	.60	135	38	6.1	2.7	.11	.06	.06
25	.11	.60	.60	.70	.70	213	32	5.6	2.0	.11	.06	.06
26	.17	.60	.60	.70	.75	110	27	5.1	1.9	.14	.06	.06
27	.17	.60	.60	.70	.70	75	26	4.3	1.4	.11	.06	.06
28	.17	.60	.60	.70	.70	65	23	3.8	1.1	.14	.06	.06
29	.17	.60	.60	.60	--	90	22	2.9	.80	.11	.06	.06
30	.17	.60	.60	.60	--	75	20	3.1	.54	.17	.06	.06
31	.17	--	.60	.60	--	165	--	3.1	--	.65	.06	--
Total	3.04	13.66	26.50	20.00	15.48	1,326.10	8,250	321.7	74.21	8.38	3.99	1.8
Mean	.098	.46	.85	.65	.55	42.8	275	10.4	2.47	.27	.13	.06
Maximum	.17	.60	1.8	.90	.75	213	1,300	19	10	1.2	.54	.06
Minimum	.03	.17	.60	.50	.44	.70	20	2.9	.32	.11	.06	.06
Acre-feet	6.0	27	53	40	31	2,630	16,360	638	147	17	7.9	3.6

[Data from U.S. Geological Survey, 1980, p. 545.]

Day	Mean values of discharge, in ft³/s, water year October 1978 to September 1979											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
	Heart River near South Heart											
1	0.88	0.70	0.76	0.65	0.82	0.94	320	16	2.4	0.88	2.5	0.87
2	.30	.69	.73	.68	.82	.94	330	15	2.1	.88	1.5	.82
3	.38	.68	.70	.68	.82	.94	200	13	2.1	1.0	1.0	1.3
4	.49	.65	.71	.68	.82	.95	150	12	1.9	.88	.76	1.7
5	.44	.63	.76	.68	.82	1.0	130	11	1.8	.68	.68	1.1
6	.49	.66	.73	.68	.68	1.0	130	11	1.8	.70	.44	.86
7	.56	.69	.70	.65	.88	1.0	170	16	1.9	.63	.38	.69
8	.53	.69	.70	.63	.94	1.2	300	12	1.8	.63	.30	.64
9	.49	1.0	.70	.63	.94	1.2	650	11	1.7	.63	.30	.59
10	.53	.90	.70	.63	.94	1.1	900	9.9	1.6	.76	.30	.72
11	.60	.70	.71	.63	.94	1.1	750	9.1	1.7	.88	.16	17
12	.56	.65	.80	.63	.93	1.4	300	8.8	1.6	.88	.16	12
13	.56	.70	.82	.63	.93	1.7	140	8.3	1.4	.88	.30	2.6
14	.60	.70	.82	.60	.95	1.6	110	7.3	1.2	1.3	.23	1.7
15	.56	.70	.82	.63	.99	1.8	140	6.6	1.2	1.3	.23	1.2
16	.60	.70	.82	.63	1.0	3.0	507	6.2	1.1	1.1	.23	.75
17	.60	.70	.81	.63	1.0	20	841	5.6	1.0	.88	.23	.65
18	.63	.76	.82	.63	1.0	100	694	5.1	1.0	.76	.16	.57
19	.63	.73	.80	.65	.95	120	365	4.9	1.3	.68	.23	.44
20	.63	.70	.74	.68	.94	90	206	4.7	3.3	.65	.23	.38
21	.65	.70	.72	.68	.94	100	112	4.9	2.5	.60	.56	.38
22	.65	.70	.74	.68	.96	160	71	4.5	1.8	.56	36	.38
23	.68	.70	.76	.70	1.0	300	48	4.5	1.4	.49	9.7	.33
24	.68	.70	.77	.70	1.0	500	39	4.5	1.1	.53	5.4	.40
25	.65	.70	.76	.70	.94	700	34	4.2	.88	29	2.9	.44
26	.68	.74	.76	.70	.94	550	29	3.9	.88	18	2.2	.43
27	.65	.82	.76	.76	.94	450	25	3.6	.88	6.8	1.8	.33
28	.65	.82	.76	.76	.94	350	24	3.2	.88	7.7	2.0	.30
29	.68	.87	.76	.76	--	250	22	3.1	.82	5.4	3.6	.30
30	.68	.79	.68	.76	--	190	18	2.8	.76	3.3	2.1	.30
31	.70	--	.63	.82	--	240	--	2.6	--	7.6	1.1	--
Total	18.41	21.87	23.23	20.95	25.97	4,140.87	7,755	235.3	45.80	96.96	77.68	50.17
Mean	.59	.73	.75	.68	.93	134	259	7.59	1.53	3.13	2.51	1.67
Maximum	.88	1.0	.82	.82	1.0	700	900	16	3.3	29	36	17
Minimum	.30	.63	.63	.60	.82	.94	18	2.6	.76	.49	.16	.30
Acre-feet	37	43	46	42	52	8,210	15,380	467	91	192	154	100

Table 4.--Water quality of the Cannonball River at New England and the Heart River near South Heart, October 1980 to September 1981

[Data for Cannonball River at New England from U.S. Geological Survey, 1982, p. 338; data for Heart River near South Heart from U.S. Geological Survey, 1982, p. 300: ft^3/s, cubic foot per second; umho, micromhos per centimeter at 25° Celsius; deg. C, degrees Celsius; mg/L, milligrams per liter; FET-fld, fixed-end point (pH = 4.5) electrometric titration, field; acre-ft, acre-feet.]

Date	Stream-flow, instan-taneous (ft^3/s)	Spe-cific con-duct-ance (umho)	pH (units)	Temper-ature, air (deg. C)	Temper-ature (deg. C)	Oxygen, dis-solved (mg/L)	Oxygen, dis-solved (per-cent satur-ation)	Hard-ness, (mg/L as $CaCO_3$)	Hard-ness, noncar-bonate (mg/L $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Percent sodium	Sodium ad-sorp-tion ratio	Potas-sium, dis-solved (mg/L as K)	Alka-linity, carbon-ate FET-fld (mg/L $CaCO_3$)	Sulfate, dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)	Fluo-ride, dis-solved (mg/L as F)	Solids, residue at 180 deg. C, dis-solved (mg/L)	Solids, sum of consti-tuents, dis-solved (mg/L)	Solids, dis-solved (tons per acre-ft)	Sedi-ment, sus-pended (mg/L)
										Cannonball River at New England													
Oct. 8	0.03	1,880	8.2	16.5	10.0	12.2	118	300	220	59	37	340	70	8.5	8.5	475	560	5.3	0.4	1,290	1,310	1.7	51
Nov. 26	.02	1,825	7.9	2.5	2.0	10.8	82	340	0	58	47	330	67	7.8	10	450	570	7.4	.4	1,290	--	1.7	54
Dec. 10	.01	2,170	7.9	-14.5	1.0	8.4	65	440	0	81	57	370	64	7.7	12	540	680	6.2	.4	1,470	1,540	2.0	48
Jan. 28	.05	2,050	7.3	-6.0	1.0	6.4	51	480	0	93	60	360	62	7.2	7.6	550	640	6.5	.3	1,520	1,510	2.0	58
Feb. 25	.07	1,770	7.9	-3.0	.0	9.5	74	400	0	79	48	290	61	6.4	6.7	490	530	5.0	.2	1,230	1,260	1.6	26
Mar. 13	.95	2,700	8.0	8.5	5.0	12.5	105	580	220	94	83	490	65	8.9	8.3	360	1,200	15	.4	2,010	2,110	2.7	52
25	.41	2,580	8.1	10.5	9.5	11.1	108	--	--	--	--	--	--	--	--	358	--	--	--	--	--	--	67
Apr. 7	.35	2,730	8.3	6.5	7.0	10.3	94	590	190	95	86	480	63	8.6	9.1	400	1,200	21	.4	2,110	--	2.8	68
21	.03	2,700	8.3	16.5	13.0	9.6	102	--	--	--	--	--	--	--	--	444	--	--	--	--	--	--	74
May 12	.07	2,800	8.2	--	10.5	--	--	590	--	100	83	490	64	8.8	9.4	--	1,200	18	.4	2,160	--	2.9	83
June 3	.09	2,780	8.4	23.5	21.0	10.5	128	--	--	--	--	--	--	--	--	449	--	--	--	--	--	--	133
25	.53	4,080	8.5	13.5	17.5	6.8	76	810	330	110	130	720	66	11	12	480	1,900	20	.4	3,170	3,180	4.3	199
July 29	.08	1,300	8.3	31.0	29.0	9.6	133	280	0	55	34	190	60	5.5	.5	320	370	3.9	.3	893	858	1.2	63
Aug. 18	191	432	8.1	12.5	20.0	--	--	110	--	23	12	45	45	2.1	10	--	130	42	.1	296	--	.40	1,560
Sept. 2	.46	1,240	8.3	27.0	18.0	9.6	110	260	0	53	31	180	59	5.4	8.7	290	370	4.4	.2	844	833	1.1	80
										Heart River near South Heart													
Oct. 10	.18	2,250	8.5	10.5	7.5	10.5	94	95	0	18	12	490	91	22	6.9	617	530	19	1.0	1,520	1,460	2.0	175
Nov. 13	1.4	2,680	8.8	-.5	2.5	12.6	98	190	0	37	24	570	86	18	7.0	554	860	27	.8	1,870	1,870	2.5	104
Dec. 17	.72	3,730	8.2	1.0	2.0	11.0	86	290	--	54	38	870	86	22	10	--	930	62	2.6	2,770	--	3.7	182
Jan. 15	.64	3,800	8.0	-6.0	.5	10.3	77	310	0	59	40	620	81	15	11	910	820	8.8	.7	2,710	2,120	3.6	158
Feb. 18	3.1	3,100	8.4	11.0	.5	13.3	102	280	0	52	37	690	84	13	7.0	710	1,100	36	.9	2,300	2,360	3.1	130
24	1.8	2,000	8.0	4.5	.0	9.2	69	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Mar. 17	.87	1,920	8.3	1.0	2.5	12.6	100	120	0	23	16	390	87	15	3.7	440	510	19	.7	1,270	1,230	1.7	94
26	.52	1,950	8.5	3.0	4.5	10.6	88	--	--	--	--	--	--	--	--	476	--	--	--	--	--	--	--
Apr. 9	.93	2,140	8.7	12.0	6.5	10.3	90	--	--	--	--	--	--	--	--	518	--	--	--	--	--	--	63
22	.37	2,320	8.3	15.0	13.5	9.6	100	160	0	31	19	490	87	17	5.0	580	670	23	.9	1,600	1,600	2.1	91
May 12	.61	3,420	8.7	10.0	9.0	10.2	96	330	0	59	44	740	83	13	6.8	740	1,200	49	1.0	2,570	2,550	3.5	155
June 4	3.5	3,290	8.6	11.5	20.5	7.1	85	--	--	--	--	--	--	--	--	772	--	--	--	--	--	--	153
24	3.8	3,130	8.4	24.0	22.0	8.2	100	340	0	56	49	630	79	15	12	430	1,300	20	.4	2,390	2,340	3.2	144
July 29	.04	2,980	8.6	30.0	25.0	8.3	108	210	0	41	26	660	87	20	7.2	630	980	20	.7	2,100	2,120	2.8	137
Aug. 18	808	450	7.7	24.0	20.0	4.7	55	85	0	21	8.0	63	59	3.2	8.3	92	130	8.5	.2	300	303	.41	916
Sept. 1	.76	1,340	8.4	27.0	16.5	8.0	89	170	0	38	18	240	74	8.8	9.0	290	350	11	.4	918	852	1.2	85

Table 5.--Streamflow characteristics at selected sites

Site number	Drainage area (square miles)	Average discharge (cubic feet per second)	Instantaneous maximum (cubic feet feet per second)	7-day 10-year high flow (cubic feet feet per second)
6	39.8	2.28	644	124
7	132	16.1	1,310	628

Table 6 lists the results of miscellaneous discharge measurements and field measured specific conductances at sites 1-5 (fig. 3). These data were collected to get an idea of the magnitude and variability occurring naturally in the streams.

Table 6.--Miscellaneous measurements of stream discharge and specific conductance in the study area

Site number	Location	Date	Discharge (cubic feet per second)	Specific conductance (micromhos per centimeter at 25°C)
1	Antelope Creek tributary at 137-097-14DCD	3-17-73	0.01	1,900
		4-20-75	21	300
		10-29-75	.02	4,300
2	North Fork Cannonball River at 135-100-24AAA	3-17-75	.02	5,500
		4-19-75	80	1,100
		10-30-75	.13	2,880
3	North Fork Cannonball River at 136-098-30AAA	3-17-75	2.8	1/9,000
		4-20-75	265	900
		10-29-75	.12	6,000
4	Philbrick Creek at 136-100-14DDD	3-17-75	.65	2,000
		4-20-74	30	300
		10-30-75	.11	2,350
5	Philbrick Creek at 136-098-18ADA	3-17-75	.0	--
		4-20-75	242	260
		10-29-75	.0	--

1/Estimated; exceeded scale of instrument.

Mining operations near the streams may have a short-term minor impact on the chemical quality. Water in the streams at base flow and the water in the mines generally is derived from ground water; therefore, the quality may be very similar. The chemical variability from site to site and with time and discharge is so great that minor changes due to the mining will be difficult to detect. Data are insufficient to determine the long-term effects that mining and subsequent leaching of reclaimed spoils might have on the flow and quality of water in the streams.

SUMMARY

Ground water in the Dickinson lignite area, an area of about 500 mi^2, is available from sandstone beds in the Fox Hills-lower Hell Creek aquifer system, upper Hell Creek-lower Ludlow aquifer system, and upper Ludlow-lower Tongue River aquifer system. Water also is available from the lignite beds, which are in the upper Tongue River-Sentinel Butte aquifer system.

The Fox Hills-lower Hell Creek aquifer system is at depths ranging from about 1,300 to 1,710 ft and sandstone thickness ranges from 88 to 192 ft in the study area. Potential well yields may range from about 18 to 100 gal/min. Water in the aquifer system is soft and is a sodium bicarbonate type. Dissolved-solids concentrations ranged from 1,230 to 1,690 mg/L, sodium concentration ranged from 470 to 606 mg/L, chloride concentration ranged from 57 to 190 mg/L and increased from west to east, and fluoride concentration ranged from 2.3 to 4.7 mg/L.

The upper Hell Creek-lower Ludlow aquifer system is at depths ranging from 720 to more than 1,040 ft. The aquifer is composed of sandstone beds that range in thickness from 2 to 74 ft, with an aggregate thickness of as much as 324 ft. Potential well yields might be as much as 150 gal/min, but yields greater than 30 gal/min are not unusual. Water in the system is soft and is a sodium bicarbonate type. Concentrations of dissolved solids ranged from 1,010 to 1,450 mg/L, sodium concentration ranged from 412 to 640 mg/L, sulfate concentration ranged from 0.8 to 37 mg/L, chloride concentration ranged from 5.3 to 14 mg/L, and fluoride concentration ranged from 1.5 to 5.6 mg/L.

The upper Ludlow-lower Tongue River aquifer system consists mostly of the basal Tongue River sandstone. The system generally is at depths that range from about 440 ft to 713 ft. The thickness of the aquifer ranges from about 36 to 161 ft; mean thickness is about 94 ft. Potential well yields may range from about 1 to 100 gal/min with 50 ft of drawdown. Analyses show that water in the aquifer generally is soft but may be moderately hard in the southwestern part of the area. The water generally is a sodium bicarbonate type. Locally, in the southwestern part of the area, sulfate exceeds the bicarbonate. Concentrations of dissolved solids ranged from 995 to 1,990 mg/L, sodium concentration ranged from 390 to 670 mg/L, sulfate concentration ranged from 33 to 1,000 mg/L, and fluoride concentration ranged from 1.4 to 5.9 mg/L.

The upper Tongue River-Sentinel Butte aquifer system is composed of discontinuous sandstone lenses and relatively extensive lignite beds. Lithologic logs show that the aquifer system ranges from near land surface to about 530 ft below land surface. The sandstone beds generally are less than 30 ft thick but may be as much as 147 ft thick. The lignite beds range in thickness from less than 1 ft to about 19 ft. Well yields from the aquifer system in the area range from about 1 to 185 gal/min and average about 28 gal/min. Yields from lignite beds range from 2 to 60 gal/min and average about 16 gal/min.

Analyses of water from the 36 wells completed in the aquifer system show that the water generally is a sodium bicarbonate type with bicarbonate concentrations exceeding sulfate concentrations in 26 of 36 samples. Dissolved-solids concentrations ranged from 574 to 2,720 mg/L, sulfate concentrations ranged from 12 to 1,660 mg/L, and sodium-adsorption ratios ranged from 2.5 to 6.8.

Measurements of flow in the Cannonball River show that the base flow in the river generally is less than 0.2 ft^3/s. Base flow in the Heart River generally is less than 1 ft^3/s. The effects of mining on streamflow probably will be small.

The mining of lignite will destroy all wells and aquifers that are in or above the mined lignite, but aquifers below the lignite will not be disturbed so new wells can be completed in lower aquifers. The mining also will expose sulfide and other minerals in the overburden and allow oxidation to accelerate. Water that may become recharge will cause leaching, and an increase in sulfate and other dissolved-solids concentrations in the underlying aquifers may result. Because of the generally low permeability of the beds beneath the lignite and the dilution effect in the underlying aquifer, increases in sulfate and dissolved-solids concentrations are expected to be small.

SELECTED REFERENCES

Anna, L. O., 1980, Ground-water data for Billings, Golden Valley, and Slope Counties, North Dakota: North Dakota State Water Commission County Ground-Water Studies 29, Part II, and North Dakota Geological Survey Bulletin 76, Part II, 241 p.

____1981, Ground-water resources of Billings, Golden Valley, and Slope Counties, North Dakota: North Dakota State Water Commission County Ground-Water Studies 29, Part III, and North Dakota Geological Survey Bulletin 76, Part III, 56 p.

Benson, W. E., 1952, Geology of the Knife River area: U.S. Geological Survey open-file report, 323 p.

Brant, R. A., 1953, Lignite resources of North Dakota: U.S. Geological Survey Circular 226, 78 p.

Clayton, Lee, Moran, S. R., Bluemle, J. P., and Carlson, C. G., 1980, North Dakota geologic map: U.S. Geological Survey map, 1:500,000.

Denson, N. M., and Gill, J. R., 1965, Uranium-bearing lignite and carbonaceous shale in the western part of the Williston basin--A regional study: U.S. Geological Survey Professional Paper 463, 75 p.

Fenneman, N. M., 1938, Physiography of eastern United States: New York, McGraw-Hill Book Company, 559 p.

____1946, Physical divisions of the United States: U.S. Geological Survey map.

Leonard, A. G., Babcock, E. J., and Dove, L. P., 1925, The lignite deposits of North Dakota: North Dakota Geological Survey Bulletin No. 4, 240 p.

Lewis, R. C., 1979, Coal geology of the Bowman-Gascoyne area, Adams, Billings, Golden Valley, and Slope Counties, North Dakota: U.S. Geological Survey Open-File Report 79-1698, 35 p.

Lindvig, M. O., 1964, City of Dickinson aquifer test; Supplement to North Dakota Ground-Water Studies No. 51: North Dakota State Water Commission open-file report, 9 p.

McLaughlin, T. G., and Greenlee, A. L., 1946, Ground water at Dickinson, North Dakota: North Dakota State Water Commission Ground-Water Studies No. 3, 31 p.

Owens, Hal, 1979, Coal geology of the New England-Mott area, Billings, Stark, Slope, Hettinger, and Adams Counties, North Dakota: U.S. Geological Survey Open-File Report 79-564, 77 p.

Pollard, B. C., Smith, J. B., and Knox, C. C., 1972, Strippable lignite reserves of North Dakota: U.S. Bureau of Mines Circular 8537, 37 p.

Schmid, R. W., 1963, Ground water in the vicinity of Dickinson, Stark County, North Dakota: North Dakota State Water Commission, Ground-Water Studies No. 51, 34 p.

Trapp, Henry, Jr., 1971, Ground-water basic data, Hettinger and Stark Counties, North Dakota: North Dakota State Water Commission County Ground-Water Studies 15, Part II, 455 p.

Trapp, Henry, Jr., and Croft, M. G., 1975, Geology and ground-water resources of Hettinger and Stark Counties, North Dakota: North Dakota State Water Commission County Ground-Water Studies 15, Part I, 51 p.

Tychsen, P. C., 1950, Geology and ground-water hydrology of the Heart River irrigation project and the Dickinson area, North Dakota, with a section on Mineral quality of water of the Heart River project by H. A. Swenson: U.S. Geological Survey Circular 34, 59 p.

U.S. Environmental Data and Information Service, 1982, Monthly normals of temperature, precipitation, and heating and cooling degree days 1951-80: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Climatography of the United States, no. 81 (by State).

U.S. Geological Survey, 1980, Water resources data for North Dakota, water year 1979: U.S. Geological Survey Water Data Report ND-79-1, 784 p.

____1982, Water resources data, North Dakota; water year 1981, volume 2, Missouri River basin: U.S. Geological Survey Water-Data Report ND-82-2, 492 p.

Wald, J. D., and Norbeck, S. W., 1983, Ground water for selected coal areas in western North Dakota: U.S. Geological Survey Open-File Report 83-219, 229 p.