UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EVALUATION OF THE HYDROLOGIC SYSTEM IN THE NEW LEIPZIG COAL AREA, GRANT AND HETTINGER COUNTIES, NORTH DAKOTA

by C. A. Armstrong

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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	0.3048	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	3.785	liter
Gallon per minute (gal/min)	0.06309	liter per second
Inch	25.40	millimeter
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.

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."

Micrograms per liter (µg/L) is a unit expressing the concentration of a chemical constituent in solution as weight (micrograms) of solute per unit volume (liter) of water.

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

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ABSTRACT

The investigation of the water resources of the New Leipzig coal area 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 the Hell Creek Formation of Cretaceous age, and in the Cannonball, Ludlow, and basal Tongue River Members of the Fort Union Formation of Tertiary age. Aquifers also occur in sandstone and lignite lenses in the upper part of the Tongue River Member and the Sentinel Butte Member of the Fort Union Formation.

Depths to the Fox Hills aquifer range from about 890 to 1,500 feet. Well yields should range from about 5 to 100 gallons per minute. The water is soft and is a sodium bicarbonate type. Dissolved-solids concentration was 1,280 milligrams per liter.

Depths to the Hell Creek aquifer range from about 550 to 1,100 feet. Well yields should range from about 1 to 60 gallons per minute. The water is soft and a sodium bicarbonate type. Dissolved-solids concentrations ranged from 1,220 to 1,370 milligrams per liter.

Depths to the Cannonball and Ludlow aquifer system range from about 228 to 785 feet. Well yields may be as much as 40 gallons per minute. The water is soft and is a sodium bicarbonate type. Dissolved-solids concentrations ranged from 1,150 to 1,770 milligrams per liter.

Depths to the basal Tongue River aquifer range from about 90 to 437 feet. Well yields should range from about 5 to 100 gallons per minute. The water may be either soft or very hard and generally is a sodium bicarbonate type. Dissolved-solids concentrations ranged from 292 to 2,642 milligrams per liter.

Depths to the upper Tongue River and Sentinel Butte aquifer system range from near land surface to 320 feet below land surface. Well yields generally range from about 1 to 36 gallons per minute. The water generally is very hard and is either a calcium

bicarbonate or sodium bicarbonate type, but locally sulfate is the dominant anion. Dissolved-solids concentrations generally ranged from 269 to 1,470 milligrams per liter, but were as much as 3,553 milligrams per liter beneath areas where the Harmon lignite bed of the Tongue River Member has been oxidized.

In the area of mineable coal, the Harmon lignite bed contributes little or no water to Thirty Mile Creek or the Cannonball River. Mining of lignite will have negligible effect on the flow in Antelope Creek.

Mining of the Harmon lignite bed in the New Leipzig area will destroy all aquifers in and above the mined lignite; however, the lower aquifers will not be disturbed. Also, mining will expose sulfide minerals to oxidation, and result in an increase in dissolved solids and sulfate in water in the basal Tongue River aquifer, although the increase will be minimal.

INTRODUCTION

The investigation of the hydrologic system of the New Leipzig coal area was made in cooperation with the U.S. Bureau of Land Management. The purpose of the investigation is to assist the Bureau in its evaluation of probable hydrologic impacts of potential coal development in the area.

The New Leipzig coal area occupies about 170 mi^2 in western Grant County and eastern Hettinger County, North Dakota (fig. 1). The area is bounded on the south by the Cannonball River, and includes parts of T. 133 N., Rs. 89 through 92 W., and all of Tps. 134 and 135 N., Rs. 89 through 92 W.

Objectives and Scope

The primary objective of the investigation in the New Leipzig coal area was to define the hydrologic system in the greatest possible detail consistent with the time and funding available. This included assessment of the ground-water flow system and chemical characteristics, and determination of surface-water flow magnitudes, water chemistry, and sediment concentration. By defining the hydrologic system of the study area, a second objective was attained--the establishment of a historical data base with which to monitor changes in the system as mining proceeds.

The third objective was to make reasonably accurate projections of the hydrologic effects resulting from surface mining. Management agencies including the U.S. Bureau of Land Management would then be able to use these projections to augment their decision-making processes. However, there currently (1981) is only one small coal mine active in the study area. Therefore,

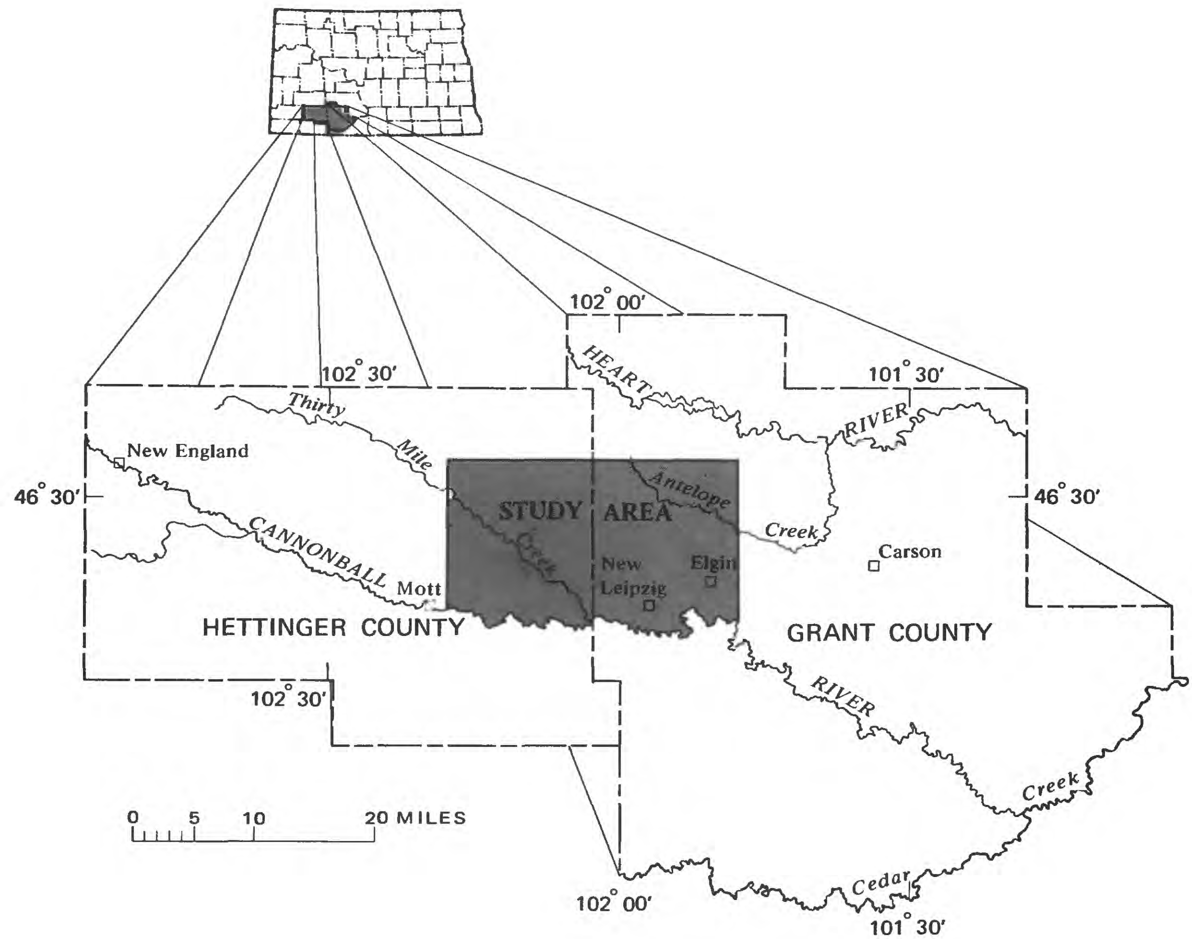


FIGURE 1.—Location of New Leipzig coal area in North Dakota.

mining impacts were not observable directly during the study. As a result, all hydrologic data are of premining or natural conditions, and projections of effects related to coal development are 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 obtained and analyzed for chemical characteristics and sediment concentrations were determined.

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, 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 134-090-15DAD would be located in the SE1/4NE1/4SE1/4 sec. 15, T. 134 N., R. 90 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 and Current Investigations

Leonard (1904) investigated lignite along the Cannonball River from its junction with Cedar Creek to 10 miles northwest of New England. Lloyd (1914) examined the Cannonball River lignite field to classify the land as coal or noncoal land. Leonard and others (1925) described the lignite deposits and locations of mines in parts of the study area. Trapp (1971) and Trapp and Croft (1975) published lithologic descriptions for water wells and described the geology and hydrology in Hettinger County and Randich (1975 and 1979) published similar data for Grant County. Hal Owens (U.S. Geological Survey, written commun., 1980) described the geology of nine lignite beds in the New Leipzig-Elgin areas.

The Knife River Coal Company has released to the U.S. Geological Survey logs of 358 test holes and water-level data from 31 observation wells in Hettinger and Grant Counties, which contributed much to the understanding of the geohydrology of the area. The North Dakota Geological Survey in conjunction with the U.S. Geological Survey has drilled several test holes in and near the New Leipzig coal area. Logs of these holes contributed much data for this study. The logs of a typical test hole are shown in figure 3.

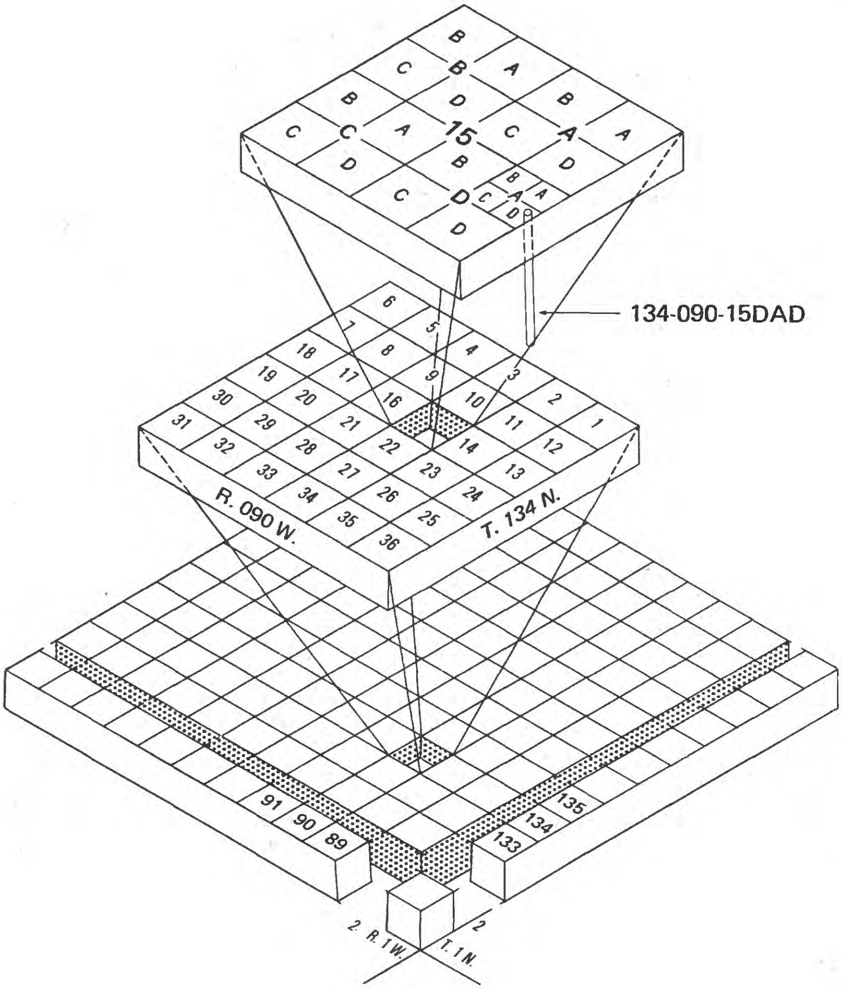
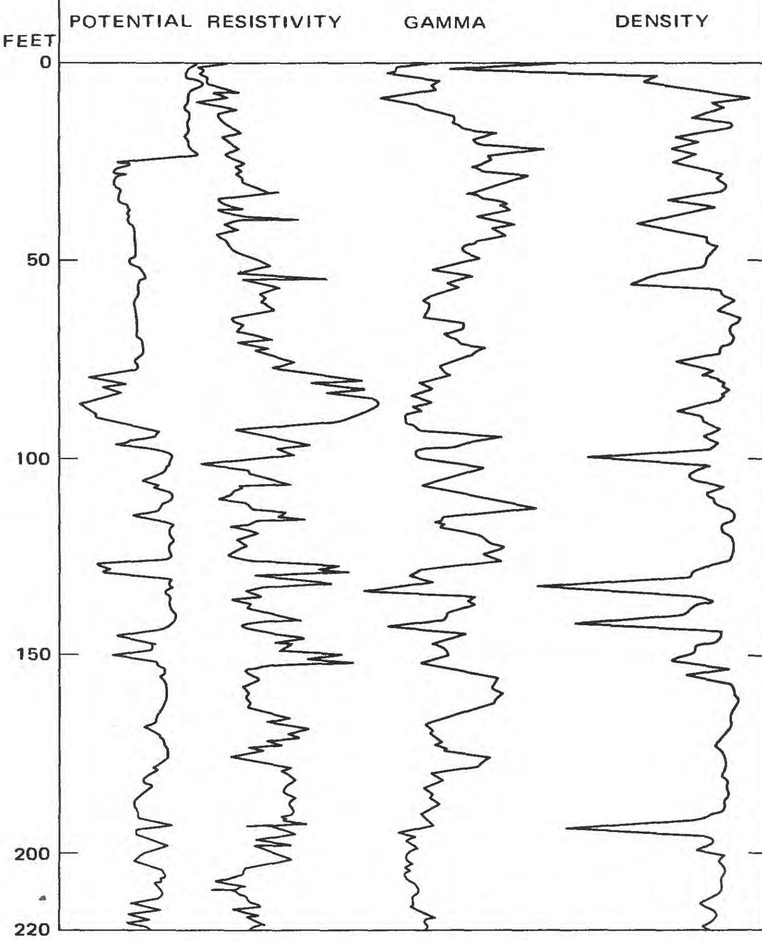


FIGURE 2.—Location-numbering system.

LOCATION: 134-090-32CCC DATE DRILLED: October 12, 1977

ALTITUDE: 2355 feet DEPTH: 220 feet



DEPTH (feet)	LITHOLOGY
0-2	Claystone, yellowish-brown.
2-3	Lignite, brown.
3-5	Claystone, yellowish-gray.
5-20	Claystone, brownish-gray.
20-21	Lignite, black.
21-32	Claystone, bluish-green.
32-34	Lignite, black.
34-39	Claystone, dark-brown, carbonaceous.
39-40	Lignite, black.
40-50	Claystone, greenish-gray.
50-55	Claystone, dark-brown, carbonaceous.
55-57	Lignite, black.
57-74	Claystone, medium-gray, silty.
74-87	Siltstone, light- to medium-gray.
87-90	Siltstone, medium-gray, clayey.
90-94	Claystone, medium-gray.
94-95	Lignite, black.
95-106	Claystone, medium-grayish-green, silty.
106-108	Claystone, dark-brown, carbonaceous.
108-129	Siltstone, light-gray, clayey.
129-133	Lignite, black.
133-140	Claystone, grayish-green.
140-141	Lignite, black.
141-150	Claystone, medium-gray.
150-165	Claystone, brownish-gray, silty.
165-173	Sandstone, brownish-gray, fine-grained.
173-175	Claystone, medium-gray.
175-188	Sandstone, light-greenish-gray, fine-grained.
188-190	Lignite, black.
190-220	Sandstone, medium-gray.

FIGURE 3.—Lithologic and geophysical logs of a typical test hole in the New Leipzig coal area.

Topography

The study area lies within the unglaciated part of North Dakota. It is an area of rolling prairie modified by small stream valleys (fig. 4A) and a few hills and buttes (fig. 4B). Relief is subdued, rarely exceeding 150 ft/mi. However, a few buttes rise above the landscape and relief may exceed 350 ft/mi. Altitudes range from about 2,240 feet at the edge of the Cannonball River in the southeast part of the area to 2,820 feet on North Star Butte at 135-091-28A (fig. 4B) in the northwest part of the study area. The regional slope of the land is eastward, but it is modified by gentle northward slopes toward Antelope Creek and steeper southward slopes to the Cannonball River.

The area is dissected by an integrated drainage system with very little natural surface storage. Thirty Mile Creek, a perennial tributary of the Cannonball River, is the principal stream in the southwestern part of the area (fig. 1). Other unnamed intermittent tributaries to the Cannonball River also exist in the southern part of the area. Antelope Creek, an intermittent tributary of the Heart River, is the principal stream in the northeastern part of the area.

Climate

The climate is semiarid with a mean annual precipitation of about 16 inches (17.31 inches at Carson and 15.39 inches at Mott; U. S. Environmental Data Service, 1980a-81a). About 75 percent of the precipitation falls during the April through September growing season. The mean annual temperature is 41.4°F at Carson and 41.9°F at Mott.

During October 1980 through April 1981, 4.68 inches of precipitation fell at Carson and 4.51 inches at Mott (U.S. Environmental Data Service, 1980b-81b), which is near normal. However, about one-half of this precipitation fell October 15 through October 17, resulting in less than normal precipitation for the remainder of the period.

WATER USE AND SUPPLY

The principal uses of water in the New Leipzig coal area are for domestic, livestock, and public supplies. Most of the water used is from ground-water sources. However, some surface water is used for stock watering.

The city of New Leipzig is the only water user that keeps records of water use. During 1981, it used about 6 million gallons of water from the Cannonball and Ludlow aquifer system and about 4 million gallons from the Hell Creek aquifer system.

A–ROLLING PRAIRIE AND STREAM VALLEY AT 134-091-25A

B–ROLLING PRAIRIE AND NORTH STAR BUTTE AT 135-091-28A

FIGURE 4.–Rolling prairie and buttes typical of the study area.

The city of Elgin does not keep records, but it uses water from the Hell Creek aquifer system, the Cannonball and Ludlow aquifer system, and the basal Tongue River aquifer.

Every farmstead in the area has at least one well to supply the needed water, and some, especially those that have wells finished in or above the lignite, may have more than one well. Many of the farms also have one or more stock wells. These domestic and stock wells generally are capable of yielding from about 1 to 30 gal/min, but generally are not pumped for more than a few hours per day. Estimates of total water usage have not been made.

About 20 wells will be destroyed during mining operations. After reclamation, about 10 of these wells can be replaced by wells drilled to the same horizon as the present wells. The other 10 are shallow wells in aquifers that will be destroyed. These wells can be replaced by wells drilled to deeper aquifers.

EFFECTS OF MINING ON AREA HYDROLOGY

Strip mining of lignite in the New Leipzig coal area will have an effect on the hydrology of the area. Mining will destroy all water-bearing zones in and above the lignite that will be mined, and all present wells tapping the lignite or overlying beds will be destroyed. 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 can be drilled to the basal Tongue River aquifer or Cannonball and Ludlow aquifer system. If for any reason these aquifers can not be used, water can be obtained from the still deeper Hell Creek aquifer system or Fox Hills aquifer.

As mining proceeds, a cone of depression will form and water levels in wells finished in the lignite or immediately above the lignite will decline. Some of the wells may become unusable while mining is at some distance from the wells. However, the shape of the present potentiometric surface near subcrops of the lignite indicates that mining probably will have little or no effect on water levels more than a mile from the area being mined.

Operational water needs during mining and the early stages of reclamation probably can be supplied from the mine drainage. The final stage of reclamation, however, is the planting of small grains or forage crops. Water for these crops will be dependent on precipitation as an adequate supply of chemically suitable ground or surface water is not available for irrigation.

During mining, the thick 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 the oxidized minerals and will result in an increase in the concentration of dissolved solids and sulfate in the underlying aquifers.

The beds beneath the lignite generally have very low permeability so recharge to the basal Tongue River aquifer will be slow; probably so slow that dilution with water already in the basal Tongue River aquifer will cause any increase in dissolved-solids and sulfate concentrations to be minimal. There probably will be no recognizable effects in aquifers below the basal Tongue River aquifer because of the very low permeability of the clayey beds separating each of the lower aquifers and because most of the flow of water in the basal Tongue River aquifer is toward the Cannonball River and Thirty Mile Creek.

GEOLOGY

The New Leipzig coal area is located on the south flank of the Williston basin, about 90 miles from the basin's center. Depth to the Precambrian surface near New Leipzig is about 9,500 to 10,500 feet. Several thousand feet of predominantly marine sedimentary rocks consisting of sandstone, shale, carbonate and evaporite rocks comprise the stratigraphic section between the Precambrian and the top of the Upper Cretaceous Pierre Shale. The top of the Pierre Shale generally is considered the base of fresh-water-bearing units in western North Dakota; therefore, the Pierre Shale is considered the practical limit of test drilling 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 1,650 feet of rock strata. The Fox Hills Sandstone, which generally is about 300 feet 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 form an aquifer that ranges from 39 to 170 feet in thickness in Grant County (Randich, 1979, p. 12).

The continental Hell Creek Formation of latest Cretaceous age overlies the Fox Hills. The Hell Creek is composed of about 290 feet of interbedded fine sandstone, claystone, and siltstone with thin interbedded lignite or carbonaceous claystone beds. Randich (1979, p. 17) divided the Hell Creek into three aquifers in Grant County; the lower aquifer generally ranges from 10 to 55 feet in thickness and the middle aquifer generally ranges from 6 to 60 feet in thickness. Both aquifers are discontinuous. The upper aquifer, which is continuous, ranges from 15 to 159 feet in thickness and has a mean thickness of about 70 feet.

TABLE 1.--Generalized stratigraphic column in the New Leipzig coal area

System	Series	Formation	Member	Maximum thickness (feet)	Lithologic description
Tertiary	Paleocene	Fort Union Formation	Sentinel Butte Member	300±	Claystone, bentonitic or carbonaceous; siltstone, silty very fine to medium sandstone, and lignite.
			Tongue River Member	360	Claystone, bentonitic or carbonaceous; siltstone, silty very fine to medium sandstone, and lignite.
			Ludlow and Cannonball Members	465±	Ludlow--claystone, siltstone, sandstone, and lignite. Cannonball--marine claystone, siltstone, and silty sandstone.
Cretaceous	Upper Cretaceous	Hell Creek Formation		290±	Sandstone, claystone, siltstone, thin bedded lignite, and carbonaceous claystone.
		Fox Hills Sandstone		300±	Sandstone, silty brown to gray, silty claystone, and siltstone.
		Pierre Shale		1,100±	Shale, dark-gray, marine.

Strata of Tertiary age are as much as 1,120 feet thick in the study area. These rocks are represented by the Fort Union Formation, which consists of the Ludlow and its lateral equivalent the Cannonball, the Tongue River, and Sentinel Butte Members.

The Ludlow Member consists of alternating claystone, siltstone, sandstone, and thin lignite beds. The Cannonball Member, which is of marine origin, is composed of poorly consolidated claystone and silty sandstone. In contrast to the other Fort Union members, the Cannonball does not contain lignite beds. Facies of these two members intertongue and are not differentiated in this report. The combined thickness of the two members is reported to be as much as 465 feet (Randich, 1979, p. 8). A few wells in the area are finished in the sandy sections of the Ludlow and Cannonball Members.

The Tongue River and Sentinel Butte Members were deposited near the terminus of a fluvial system that originated in Wyoming and Montana along the eastern side of the Rocky Mountains. The alternating claystone, siltstone, sandstone, and lignite lithologies (fig. 5) represent the vertical succession of flood-plain, levee, channel, and back-swamp facies. The various lithologic units are lenticular and discontinuous. Some lignite beds, however, extend for many miles.

The Tongue River Member crops out in much of the study area. It consists of interbedded claystone and siltstone (both commonly carbonaceous), sandstone, lignite, and occasionally a "ledge" of poorly consolidated sandstone. This member is as much as 360 feet thick, but generally is thinner. In places it may be as little as 150 feet thick due to erosion. According to lithologic logs, sandstone beds are scattered throughout the member, but they are most abundant in the basal part. Many farm wells in the study area obtain their water supply from the uppermost sandstone or lignite bed that will yield a sufficient quantity of water. Commonly this is in the basal Tongue River Member.

The Sentinel Butte Member underlies much of the study area where altitudes are about 2,425 feet or higher. The lithology of the Sentinel Butte Member is very similar to that of the Tongue River and, except for color variations in surface exposures, the members cannot be differentiated with certainty. The two members have not been differentiated in this report. Lenticular beds of fine- to medium-grained gray sandstone are found most commonly in the basal part of the Sentinel Butte Member, but are not plentiful anywhere in the study area. This member may be as much as 300 feet thick beneath some of the buttes in the area but generally is much thinner. Some rural domestic and stock wells in the higher parts of the study area obtain their water supplies from shallow wells finished in sandstone beds in the Sentinel Butte.

FIGURE 5.—Lignite bed overlain by claystone and thin interbedded siltstone and sandstone lenses.

Lignite

Most test holes or wells that have been drilled to a depth of more than 100 feet in the New Leipzig area have penetrated at least one lignite bed and most have penetrated more--as many as nine. Generally, the lignite beds are only 1 to 4 feet thick, but they may be as much as 15 feet thick. Correlation of the various lignite beds is tenuous; however, the thick lignite bed northwest of New Leipzig tentatively has been correlated with the Harmon (Haynes) lignite bed of the Tongue River Member of the Fort Union Formation.

The Harmon bed is the only lignite in the study area that is known to be economically extracted using present large-scale strip-mining methods. The top of the bed lies at an altitude of 2,330 to 2,380 feet (fig. 6). Stratigraphically it lies about 150 to 225 feet above the base of the Tongue River Member. The bed ranges in thickness from 5 to 15 feet and has a mean thickness somewhat greater than 10 feet under an area of about 12 mi^2. Outside of the 12 mi^2 area the bed generally is less than 5 feet thick or cannot be identified in some of the test holes. Based on thickness and depth of burial considerations of 1 foot of lignite to 10 feet of overburden, the optimal stripping area would be limited to about 10 mi^2 on the north slope of the Cannonball River valley and the northeast slope of Thirty Mile Creek valley about 2 to 9 miles northeast of the mouth of the creek.

Apparently the Harmon bed was not deposited in much of the area to the north and northwest of the minable lignite area (fig. 6). The bed extends a considerable distance to the east and locally to the west, but in these areas it is too thin for large-scale mining operations. The bed probably extended to the south, but erosion and oxidation have removed most of the lignite. The bed was present in the hill at 134-090-34 about 1.5 miles west-northwest of New Leipzig, but the lignite was strip mined before 1969 and the mine abandoned (fig. 7).

AQUIFERS IN THE NEW LEIPZIG COAL AREA

Fox Hills Aquifer

The Fox Hills aquifer underlies the study area at depths ranging from about 890 feet in the low lying areas near the Cannonball River to about 1,500 feet beneath the higher parts of the area in eastern Hettinger County. Two test holes (Randich, 1975) penetrated the Fox Hills aquifer in the study area. Test hole 133-089-04DAD, in the southeast part of the study area, penetrated 95 feet of aquifer, and test hole 135-090-23BBB1, in the north-central part, penetrated 71 feet of aquifer.

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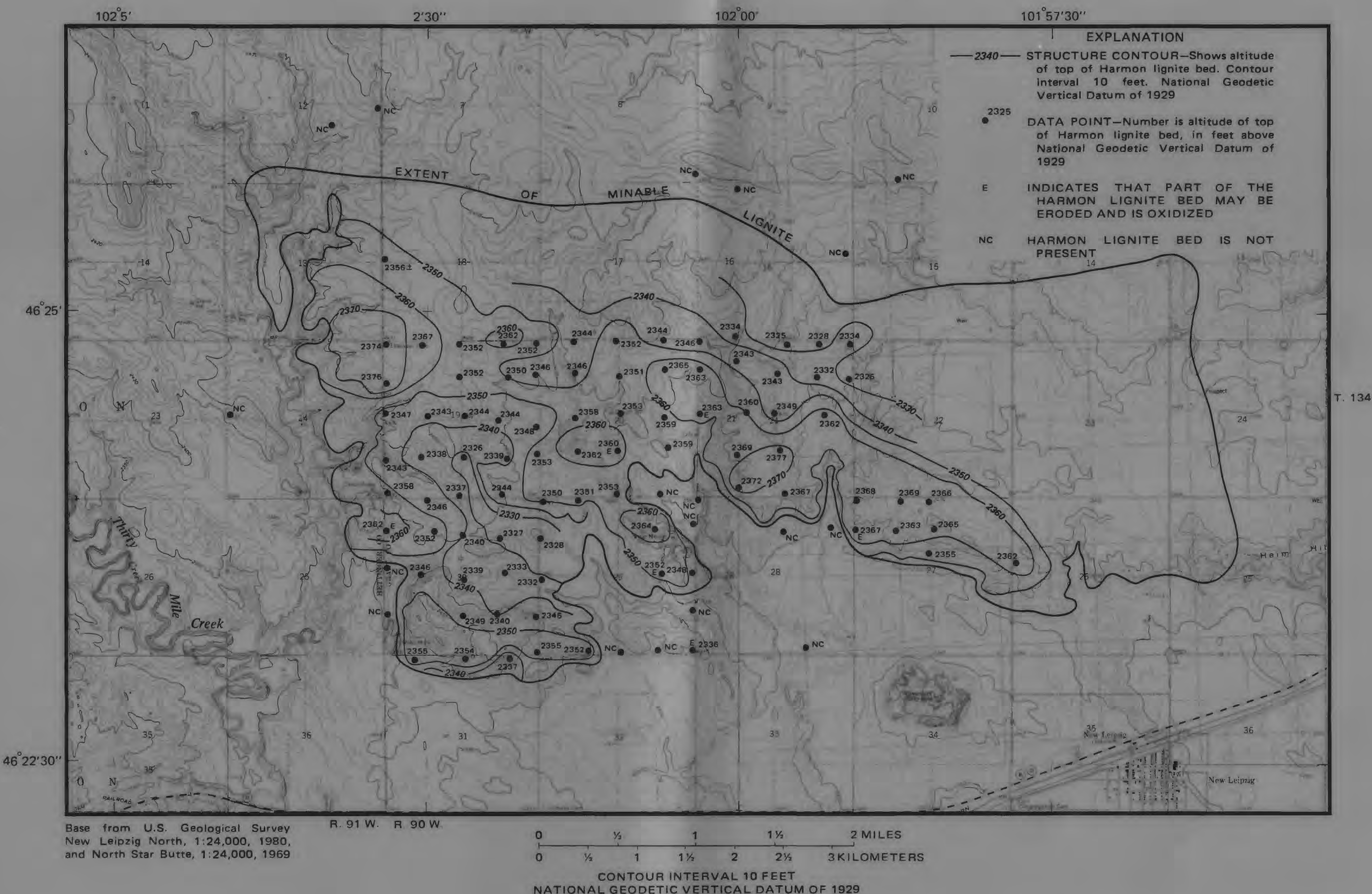

FIGURE 6.—Altitude and configuration of the top of the Harmon lignite bed of the Tongue River Member of the Fort Union Formation and the extent of the minable lignite.

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FIGURE 7.—Abandoned strip mine located at 134-090-34.

The aquifer generally is composed of very fine to medium-grained sandstone in the upper part of the Fox Hills Sandstone. The sandstone contains from 5 to 30 percent silt and 5 to 14 percent clay (Randich, 1979, p. 12). Randich also reported that the transmissivity of the aquifer ranged from 18 to 135 ft^2/d and potential yields from wells ranged from 5 to 100 gal/min. Although much of Randich's data were collected outside of the New Leipzig area, they probably are representative of the aquifer within the study area as well.

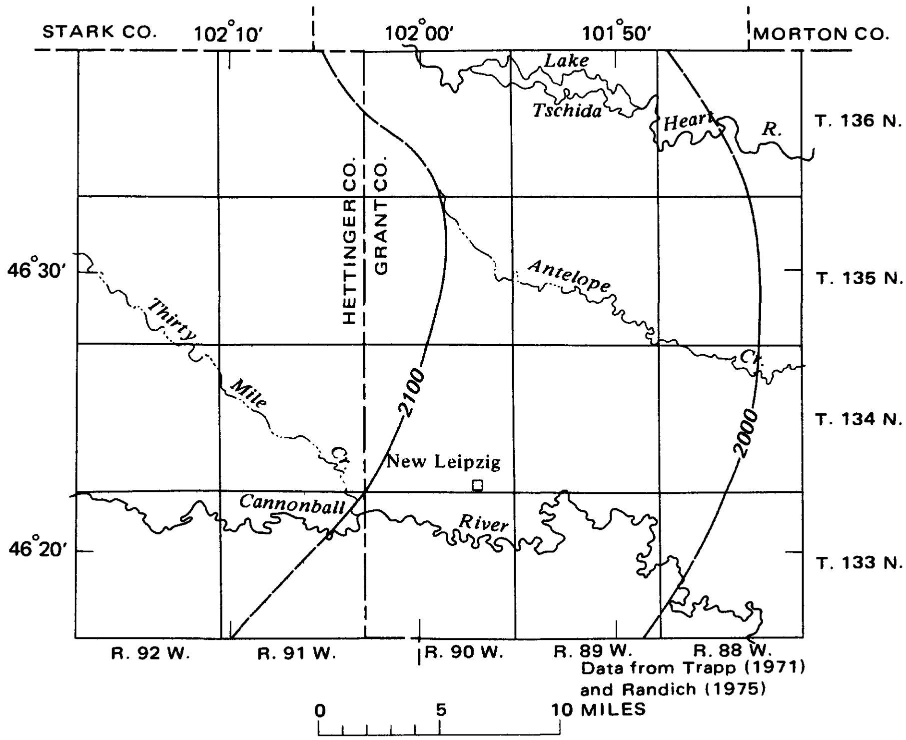
The generalized potentiometric surface of the Fox Hills aquifer is shown in figure 8. Ground water generally moves from west to east under a hydraulic gradient of about 8 to 10 ft/mi. Although data are few, it appears that the potentiometric surface of the Fox Hills aquifer is about 30 to 70 feet lower than that of the overlying Hell Creek aquifer. Therefore, some leakage from the Hell Creek aquifer recharges the Fox Hills aquifer.

An analysis of water collected from well 134-090-23BBB1 (Randich, 1975) finished in the Fox Hills aquifer shows that the water is soft (hardness is less than 20 mg/L) and is a sodium bicarbonate type. Dissolved-solids concentration was 1,280 mg/L. Sodium concentration was 570 mg/L, bicarbonate was 1,080 mg/L, sulfate was 20 mg/L, chloride was 170 mg/L, and fluoride was 4.6 mg/L. The SAR (sodium-adsorption ratio) was 71. Analyses of water from other wells in the Fox Hills aquifer within 10 to 15 miles of the New Leipzig area show that the quality of water throughout is similar even though small differences in each constituent do occur.

At the present time (1981) no known wells finished in the Fox Hills Sandstone are being pumped in the New Leipzig study area. One well in the city of New Leipzig is reported to be finished in the Fox Hills aquifer, but the depth of the well indicates that it is finished in the Hell Creek aquifer.

Hell Creek Aquifer System

The Hell Creek aquifer system underlies Grant and Hettinger Counties at depths of about 550 feet in the low-lying areas to more than 1,100 feet beneath the topographic highs in the northwest part of the area. Randich (1979, p. 17) stated "Beds of sandstone form aquifers in the upper, middle, and in some places, the lower part of the formation." The upper aquifer, which ranges from 27 to 115 feet in thickness, and the middle aquifer, which ranges from 18 to 82 feet in thickness, are present throughout the New Leipzig area. Locally, 7 to 24 feet of sandstone that may be equivalent to the lower aquifer is present. A cross section (Randich, 1979, pl. 4) shows that there is 19 to 190 feet of materials having low hydraulic conductivity separating the Hell Creek aquifer system and Fox Hills aquifer in the study area.



EXPLANATION

2000 —— POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells, 1970-73. Dashed where approximately located. Contour interval 100 feet. National Geodetic Vertical Datum of 1929

FIGURE 8.—Generalized potentiometric surface of the Fox Hills aquifer.

Randich (1979, p. 17) reported that the sediments in the aquifers generally are fine-grained sandstone, but include from 9 to 43 percent silt and 5 to 23 percent clay. He also reported that the transmissivities calculated from slug tests ranged from 15 to 79 ft^2/d. Potential yields to wells penetrating the aquifer range from 1 to 5 gal/min for each 10 feet of aquifer thickness. Thus, yields from wells finished in only one aquifer should range from about 1 to 60 gal/min in the study area.

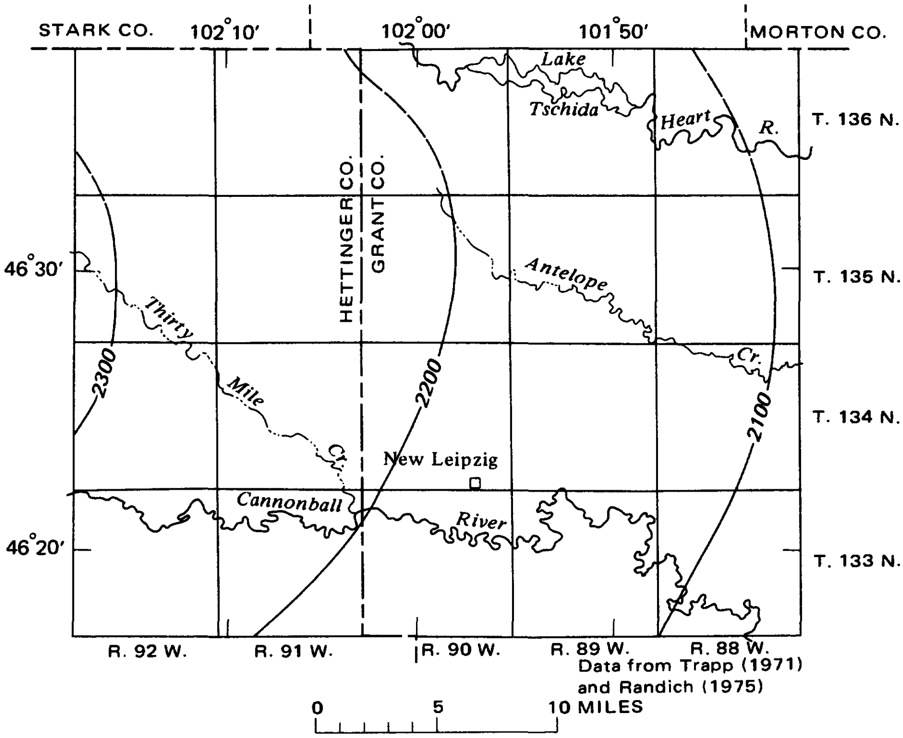
Hydraulic heads decrease from the upper to the lower aquifers within the Hell Creek aquifer system. The generalized potentiometric surface in the Hell Creek aquifer system is shown in figure 9. Ground water generally moves from west to east, except in the southern part of the area where movement is toward the northeast. The gradient ranges from about 7 to 11 ft/mi. The potentiometric surface of the Hell Creek generally ranges from 100 to 200 feet below the potentiometric surface in the overlying Cannonball and Ludlow aquifer system and indicates that there is some leakage from the overlying system to the Hell Creek.

Analyses of four water samples (Randich, 1975) collected in or near the study area from wells finished in the Hell Creek aquifer system show that the water is soft and is a sodium bicarbonate type. Dissolved-solids concentrations ranged from 1,220 to 1,370 mg/L, sodium ranged from 480 to 540 mg/L, bicarbonate ranged from 1,070 to 1,260 mg/l, sulfate ranged from 2.5 to 12 mg/L, chloride ranged from 92 to 110 mg/L, and fluoride ranged from 0.9 to 7.8 mg/L.

The cities of Elgin and New Leipzig each have a well finished in the Hell Creek aquifer system. The quantity of water pumped from these wells was not determined. However, the city of New Leipzig reportedly pumped about 4 million gallons of water from its well during both 1980 and 1981.

Cannonball and Ludlow Aquifer System

The Cannonball and Ludlow aquifer system underlies the New Leipzig area at a depth of 228 feet near the Cannonball River in the southeast part of the area. Trapp (1971, p. 203) showed that 1 mile west of the study area the top of the highest sandstone bed that could be considered a usable aquifer was at a depth of 785 feet. Aquifers probably exist at similar depths in the higher northwest part of the study area. Test-hole logs published by Trapp (1971) and Randich (1975) indicate that the aquifer system ranges from 24 to 105 feet in thickness. Individual aquifers in the system are lenticular and discontinuous and range from 7 to 57 feet in thickness; mean thickness is about 20 feet. A cross section (Randich, 1979, pl. 4) shows that there is at least 65 feet of materials having low hydraulic conductivity separating the Hell Creek and the Cannonball and Ludlow aquifer systems.



EXPLANATION

——*2200*—— POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells, 1970-73. Dashed where approximately located. Contour interval 100 feet. National Geodetic Vertical Datum of 1929

FIGURE 9.—Generalized potentiometric surface of the Hell Creek aquifer system.

Randich (1979, p. 19) described the aquifer materials as consisting of fine-grained sandstone that includes 7 to 26 percent silt and 1 to 30 percent clay. Assuming similar hydraulic conductivities in the New Leipzig area, the average transmissivity of a 20-foot thick sandstone lens should be about 65 ft^2/d. Thus, an 80 percent efficient well should yield about 10 gal/min with 50 feet of drawdown. Maximum potential well yields should be about 40 gal/min. Yields at any particular site may vary considerably because of variation in silt and clay content in the aquifers.

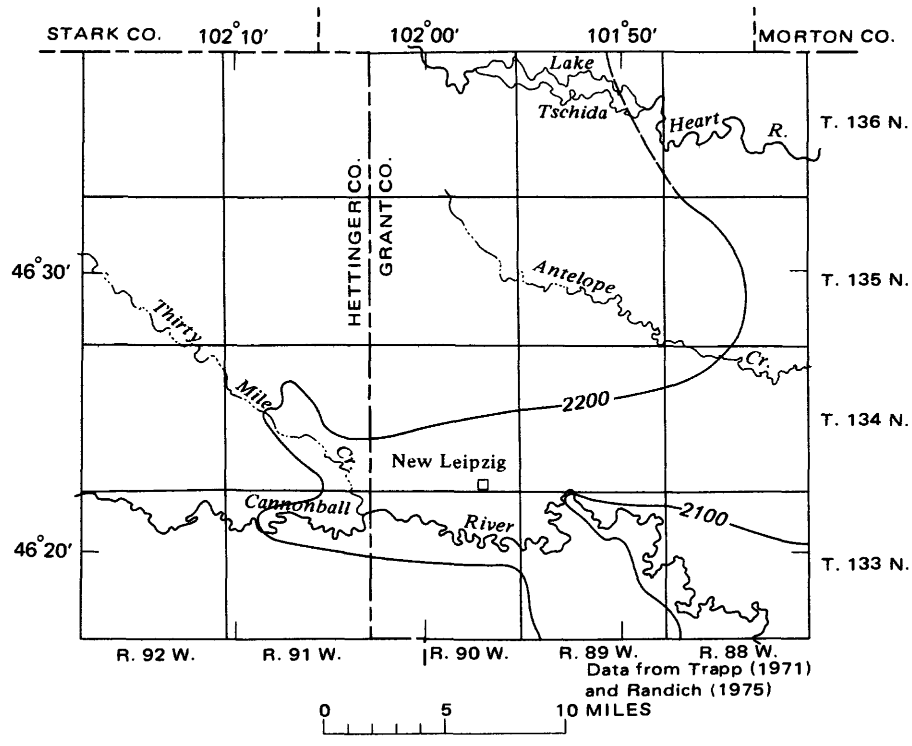
A generalized potentiometric surface map of the Cannonball and Ludlow aquifer system is shown in figure 10. The contours imply that some water is being discharged into the Cannonball River. However, hydraulic heads in the Cannonball and Ludlow aquifer system are lower than the water levels in the river, except where the aquifer system crops out in T. 133 N., R. 88 W. Therefore, discharge cannot occur except in the outcrop area. The phenomenon of lower hydraulic heads under the valley apparently is a reflection of hydraulic-head distribution in the overlying basal Tongue River aquifer. The contours indicate an apparent eastward to northeastward gradient that ranges from about 2 to 8 ft/mi. However, data are few and water levels may have been measured in wells finished in discontinuous sandstone lenses that occur at different stratigraphic horizons within the members, so figure 10 may not accurately show horizontal movement. Generally there is a downward vertical gradient within the aquifer system, that is, the deeper the aquifer the lower the water level. This vertical gradient indicates that there is some recharge from above and discharge to beds below.

Analyses of water collected from four wells (Randich, 1975) within 8 miles of the New Leipzig area finished in the Cannonball and Ludlow aquifer system show that the water is soft and is a sodium bicarbonate type. Dissolved-solids concentrations ranged from 1,150 to 1,770 mg/L, sodium ranged from 470 to 760 mg/L, bicarbonate ranged from 1,020 to 1,880 mg/L, sulfate ranged from 7.4 to 130 mg/L, chloride ranged from 52 to 100 mg/L and fluoride ranged from 1.5 to 4.0 mg/L.

The city of New Leipzig has three wells reportedly finished in the Cannonball aquifer. There also are a few domestic and stock wells scattered throughout the area. The city of New Leipzig reports that about 6 million gallons of water was pumped from the aquifer during both 1980 and 1981.

Basal Tongue River Aquifer

The basal Tongue River aquifer underlies all of the New Leipzig area at depths that generally range from about 90 to 437 feet below land surface. However, it crops out in the southeast



EXPLANATION

——2200—— POTENTIOMETRIC CONTOUR— Shows altitude at which water level would have stood in tightly cased wells, 1970-73. Dashed where approximately located. Contour interval 100 feet. National Geodetic Vertical Datum of 1929

FIGURE 10.—Generalized potentiometric surface of the Cannonball and Ludlow aquifer system.

part of the area and probably is at a depth of as much as 600 feet beneath some of the higher topography in the northwest part of the area.

Thicknesses of the basal Tongue River aquifer, as determined from lithologic logs (Trapp, 1971, and Randich, 1975), range from 23 to 150 feet and have a mean of about 64 feet. A cross section (Randich, 1979, pl. 4) shows that there is at least 30 feet of materials having low conductivity separating the basal Tongue River aquifer and Cannonball and Ludlow aquifer system.

The aquifer generally is composed of very fine to medium-grained semiconsolidated sandstone that contains varying quantities of silt and clay. Drillers have reported some coarse sand in a few holes and considerable very fine or fine silty or clayey sand in most holes. Randich (1979, p. 23) reported that three core samples from the aquifer were predominantly fine-grained sandstone that contained from 7 to 18 percent silt and 8 to 15 percent clay. He also estimated that potential well yields should range from about 5 to 100 gal/min.

A generalized potentiometric-surface map of the basal Tongue River aquifer is shown in figure 11. The contours indicate that flow roughly parallels the land surface in a subdued manner and flow is toward the major stream valleys.

Water levels plotted in figure 12 apparently reflect seasonal variations of water in storage in the basal Tongue River aquifer. Generally water levels are lowest during the summer when evapotranspiration dissipates nearly all of the precipitation before it can become recharge to the aquifer. However, water-level variations are so small that air pressures due to weather changes could account for the water-level fluctuations.

Analyses of water in samples collected from seven wells (Trapp, 1971; Randich, 1975) in the basal Tongue River aquifer in the New Leipzig area show that the water can be either soft or very hard (hardness is more than 180 mg/L), although generally the water in the deeper parts of the aquifer is soft. Generally the water is a sodium bicarbonate type, although locally calcium exceeds the sodium concentration and sulfate exceeds the bicarbonate concentration. Dissolved-solids concentration ranged from 292 to 1,470 mg/L, sodium ranged from 83 to 609 mg/L, bicarbonate ranged from 294 to 1,470 mg/L, sulfate ranged from 13 to 400 mg/L, chloride ranged from 1.1 to 43 mg/L, and fluoride ranged from 0.4 to 4.2 mg/L. The SAR ranged from 20 to 62.

An eighth well, 134-090-29DDA, is finished in the basal Tongue River aquifer in an area where the higher lignite bed or beds have been oxidized and in part eroded. Water from this well was analyzed by the Minnesota Valley Testing Laboratories, Inc.

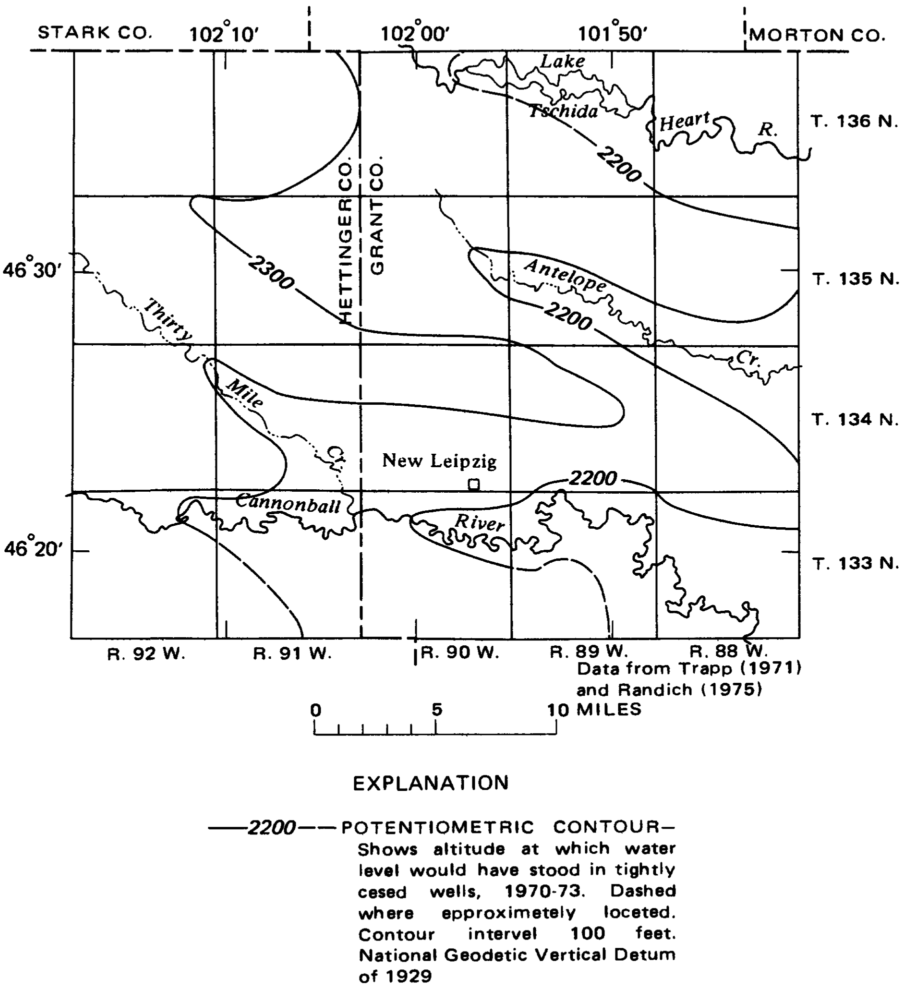


FIGURE 11.—Generalized potentiometric surface of the Tongue River aquifer.

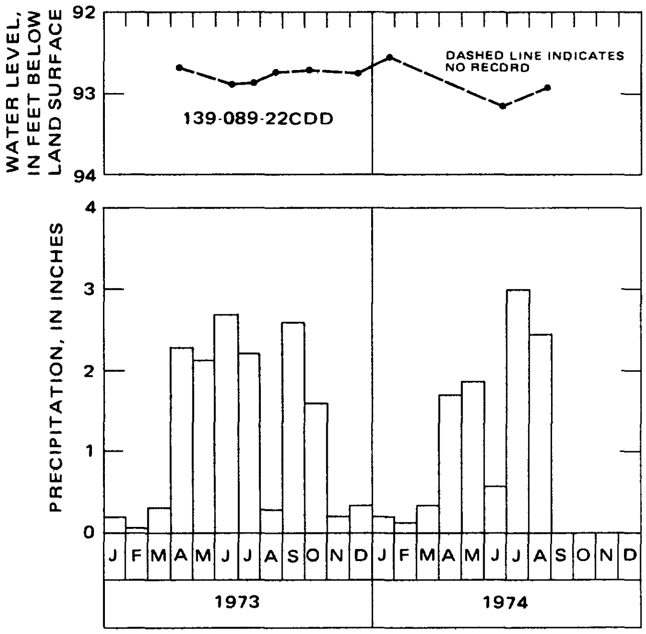


FIGURE 12.—Water-level fluctutations in the basal Tongue River aquifer and precipitation at Mott.

It contained 2,642 mg/L dissolved solids, 250 mg/L calcium, 620 mg/L sodium, 484 mg/L bicarbonate, 1,110 mg/L sulfate, and 43.3 mg/L chloride. The large concentrations of dissolved solids and sulfate apparently were caused by recharge dissolving some of the oxidized sulfide minerals from the lignite bed as the water infiltrated downward to recharge the aquifer.

Many of the domestic and stock wells in the area are finished in the basal Tongue River aquifer. However, estimates of water use have not been made.

Upper Tongue River and Sentinel Butte Aquifer System

The upper Tongue River and Sentinel Butte aquifer system is composed of discontinuous sandstone lenses and lignite beds that range in depth from near land surface to as much as 320 feet below land surface. Generally the sandstone lenses are less than 15 feet thick, but they may be as much as 79 feet thick. Most of the thicker lenses near land surface contain some undifferentiated alluvium or colluvium and generally are dry. Lignite beds range from less than 1 to 15 feet thick.

The sandstone lenses were deposited in long, narrow Paleocene stream channels that meandered across a lower lying plain, which has since been 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.

The sandstone generally is very fine to fine-grained, contains varying quantities of silt or clay, and commonly is semiconsolidated. However, some of the sand in the lenses is reported to be well sorted and as coarse as medium grain size. Grain-size analyses of 1,471 samples from 105 test holes drilled by the Knife River Coal Mining Company and analyzed by Minnesota Laboratories, Inc., indicate a wide range of grain sizes. Sand ranged from 0 to 88.8 percent, silt ranged from 5 to 70 percent, and clay ranged from 1.2 to 85 percent. Only 36 samples contained less than 20 percent silt and clay, and most of these were from the upper 25 feet of the test holes. 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 feet of claystone. A few logs, however, show that some of the lignite is underlain by siltstone. The lignite generally contains fractures, which are the source of most of the permeability within the lignite.

Yields to wells finished in the sandstone lenses in the upper Tongue River and Sentinel Butte aquifer system generally range from less than 1 to 36 gal/min and average about 8 gal/min (based on reported yields from 33 wells (Trapp, 1971) in the New Leipzig area). Yields from the Harmon lignite bed range from less than 1 to about 5 gal/min. Three 4-inch wells were drilled as part of an aquifer test (R. W. Schmid, Water Supply, Inc., written commun., 1978). The first two would not yield enough water to collect samples, the third was pumped at 3.68 gal/min.

Water seeps from the Harmon lignite bed into the Sprecher Coal Mine at 134-090-29A. The water runs into a ditch along the base of the south side of the mine and empties into a pit (fig. 13). The water from the pit is pumped over the south hill at a reported rate that varies between 200 and 250 gal/min for 4 hours per week (D. J. Davison, Knife River Coal Mining Co., oral commun., August 1981). Thus, the average seepage rate is about 5 gal/min. During some summers when the mine is not operating, the water rises to the top of the lignite bed. If a larger area of lignite is exposed, the rate of seepage also would increase. However, because the hydraulic conductivity of the lignite is small, there probably will not be any serious drainage problem.

Water levels in the area, except those in the Harmon lignite bed and a few sandstone lenses that directly overlie the lignite, indicate that most of the water movement in the upper Tongue River and Sentinel Butte aquifer system is vertical. Gradients generally range from about 1 foot of hydraulic-head change for 10 feet of depth, to 1 foot of hydraulic-head change for every 1 foot of depth. The differences in gradients are caused primarily by the different materials that water moves through. Randich (1979, p. 25) stated that laboratory tests of vertical hydraulic conductivities of cores range from 0.000023 to 0.19 ft/d. Locally clay beds with small hydraulic conductivities underlie sandstone beds and cause perched water. Where perched water exists, there are apparent vertical gradients of as much as 2.5 feet of hydraulic-head loss for every 1 foot of depth. Water levels in wells finished in the Harmon lignite bed away from the outcrop area rise as much as 17 feet above the lignite (R. W. Schmid, written commun., 1978).

R. W. Schmid (written commun., 1978) conducted an aquifer test on the Harmon lignite bed in the northwest quarter of sec. 21, T. 134 N., R. 90 W. He reported that the production well was pumped at a rate of 3.68 gal/min. The transmissivity of the lignite at the test site ranged from 800 to 1,600 ft^2/d. The hydraulic conductivity of the lignite would, therefore, range from about 65 to 120 ft/d. However, two wells that were constructed for the test could not be pumped at a rate fast enough to collect sufficient water for chemical samples. This indicates that, at least locally, the transmissivity of the lignite bed is much less than that calculated from the aquifer test.

FIGURE 13.—Sprecher coal mine located at 134-090-29A.

Water levels in the Harmon lignite (fig. 14) bed indicate a hydraulic gradient of about 20 ft/mi to the south in areas where the lignite is deeply buried. The gradient becomes quite steep in areas where the lignite either crops out or is very near the land surface.

Analyses of water in samples collected from 13 wells and a mine pit (134-090-29ADB) in the upper Tongue River part of the aquifer system in the New Leipzig area are shown in table 2. The analyses show that the water generally is very hard. Generally the water is either a calcium or a sodium bicarbonate type. However, in areas where lignite is near land surface and has been oxidized and leached (well 134-090-29DAD), sulfate is the dominant anion. Dissolved-solids concentrations in samples from 12 wells ranged from 269 to 1,470 mg/L. Sodium ranged from 24 to 580 mg/L, bicarbonate ranged from 296 to 1,040 mg/L, sulfate ranged from 27 to 580 mg/L, chloride ranged from 0.0 to 22 mg/L, and fluoride ranged from 0.2 to 4.0 mg/L.

A sample of water taken from a shallow well finished in the upper Tongue River aquifer at 134-090-29DAD, which underlies an area near where the Harmon lignite has been oxidized and leached, had a dissolved-solids concentration of 3,553 and a sulfate concentration of 1,625 mg/L. The pH of the water was 6.9. The pH and the sulfate concentration in water in the mine pit together with the sulfate concentration in water from well 134-090-29DAD indicate that during the oxidation of the lignite, sulfide minerals also were oxidized and sulfate was made available for solution.

A sample of water collected from the mine pit at 134-090-29ADB was analyzed for three additional trace elements; lithium, 100 μg/L; molybdenum, 0 μg/L; and strontium 7,700 μg/L. Concentrations of all trace elements were within a normal range except manganese and strontium. The manganese concentration of 280 μg/L is more than five times the U.S. Environmental Protection Agency's (1976) 50-μg/L recommended limit for drinking water. The strontium concentration of 7,700 μg/L is about 2 to 7 times the concentration of strontium generally found in water from carbonaceous or lignite beds within the Tongue River and Sentinel Butte aquifer system elsewhere in southwestern North Dakota.

Analysis of one sample from the Sentinel Butte part of the aquifer system shows that the water is very hard and a calcium bicarbonate type. The dissolved-solids concentration in the sample was 522 mg/L, sodium was 11 mg/L, bicarbonate was 427 mg/L, sulfate was 107 mg/L, chloride was 4.2 mg/L, and fluoride was 0.2 mg/L.

Lithologic samples from 105 test holes were made available by the Knife River Coal Company. The samples, which numbered 1,471,

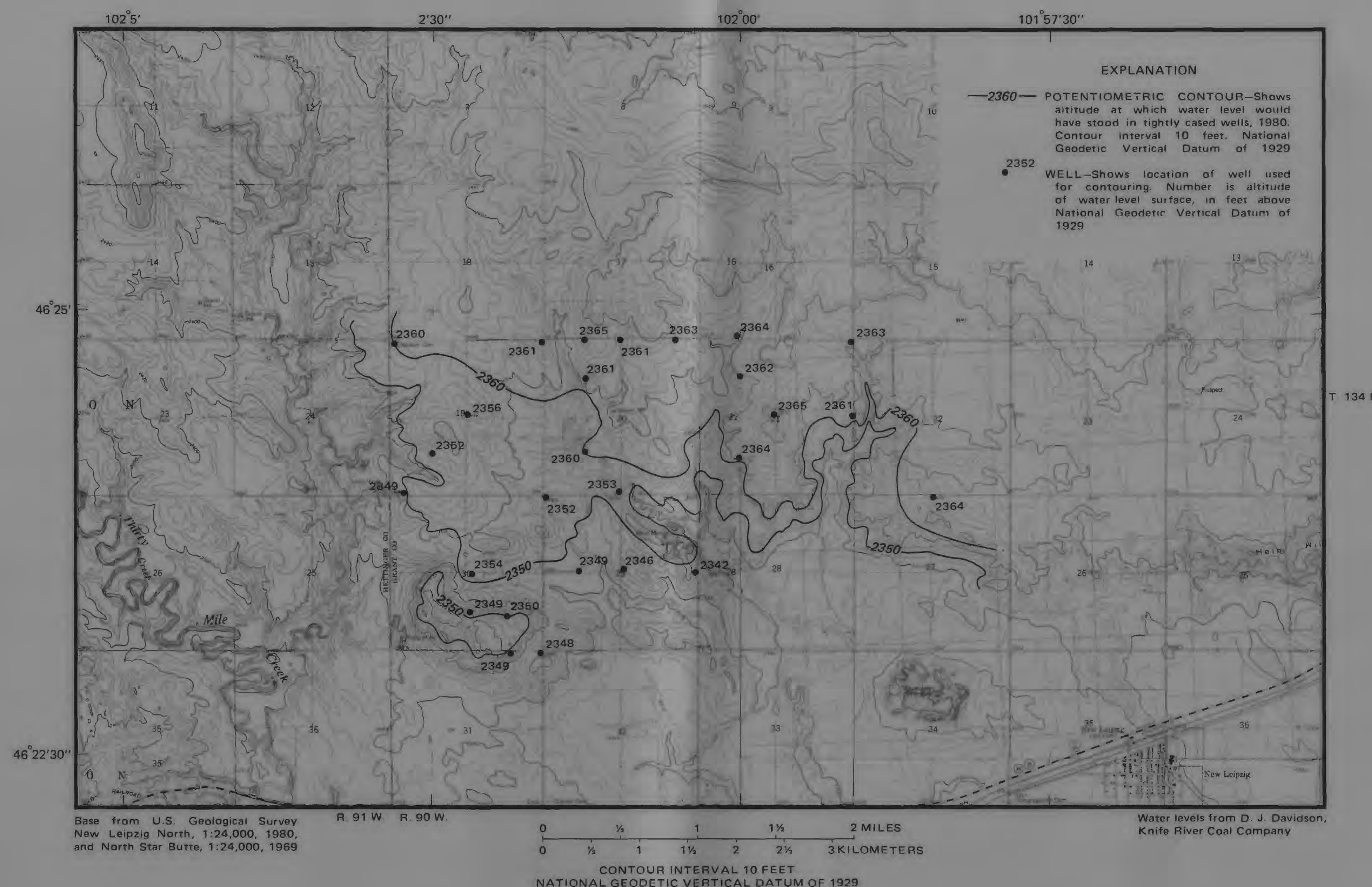


FIGURE 14.—Potentiometric surface of the Harmon lignite bed of the Tongue River Member of the Fort Union Formation, November 20, 1980.

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TABLE 2.--Chemical analyses of water from the upper Tongue River and Sentinel Butte aquifer system

[125 = Paleocene; SNLB = Sentinel Butte Member, TGRV = Tongue River Member, Fort Union Formation; deg. C = degrees Celsius; mg/L = milligrams per liter; micromhos = micromhos per centimeter at 25°C; ug/L = micrograms per liter]

Local identifier	Depth of well total (feet)	Geologic unit	Date of sample	Specific conductance (micromhos)	pH (units)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/l as Mg)	Sodium, dissolved (mg/L Na)	Sodium percent	Sodium-adsorption ratio
134-089-22DBB3	68	125TGRV	72-09-25	1,100	7.6	580	220	140	55	45	14	0.8
134-089-27ABC1	69	125TGRV	72-09-25	1,610	7.8	860	490	200	88	45	10	.7
134-090-20DAD	--	125TGRV	79-05-21	2,100	8.2	37	0	9.2	3.5	480	--	34
134-090-21BAC1	--	125TGRV	78-07-19	590	8.3	250	--	51	29	65	--	1.8
	--	125TGRV	78-08-29	670	7.5	280	0	72	25	59	--	1.5
134-090-21BAC2	--	125TGRV	78-07-19	600	8.1	250	0	51	30	53	--	1.5
134-090-21BAC3	--	125TGRV	78-07-19	610	8.1	240	0	51	28	70	--	2.0
134-090-21BAC4	--	125TGRV	78-07-20	730	7.4	260	0	57	30	60	32	1.6
134-090-21BBD2	--	125TGRV	78-07-19	590	8.2	250	0	53	28	59	--	1.6
134-090-29ADB1/	--	125TGRV	81-05-12	2,400	8.1	1,500	--	330	160	88	11	1.0
134-090-29DAD2/	--	125TGRV	79-05-21	--	6.9	2,200	--	520	216	250	--	2.3
134-091-34DDD	112	125TGRV	69-05-09	572	7.8	138	0	3.3	13	82	--	3.0
134-092-2CCC2	131	125TGRV	69-06-02	1,950	7.8	25	0	6.7	2.1	457	--	40
135-091-12CAB2	144	125TGRV	69-06-03	505	7.7	216	0	54	20	24	--	.7
135-091-28CCB3	120	125TGRV	69-06-03	2,330	8.2	41	0	9.8	4.0	580	--	39
135-092-03CCD	80	125SNLB	67-07-25	790	8.1	447	97	108	43	11	--	.2

Local identifier	Potassium, dissolved (mg/L as K)	Bicarbonate, (mg/L as HCO_3)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica dissolved (mg/L as SiO_2)	Solids, at 180 deg. C dissolved (mg/L)	Nitrite dissolved (mg/L as NO_3)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Manganese dissolved (µg/L as Mn)
134-089-22DBB3	5.3	440	300	12	0.2	15	834	1.0	300	1,800	300
134-089-27ABC1	4.7	450	580	22	.2	13	1,250	2.0	170	1,900	440
134-090-20DAD	--	296	462	11	--	--	1,453	<1.0	--	1	--
134-090-21BAC1	--	--	34	11	--	--	430	<1.0	--	0	--
	--	387	42	5.0	--	--	476	<1.0	--	0	--
134-090-21BAC2	--	322	53	8.5	--	--	426	<1.0	--	<0	--
134-090-21BAC3	--	360	39	8.5	--	--	448	<1.0	--	<0	--
134-090-21BAC4	11	405	66	2.5	--	--	426	8.9	--	0	0
134-090-21BBD2	--	346	27	11	--	--	424	<1.0	--	<0	--
134-090-29ADB1/	11	--	1,300	33	.1	11	--	--	1,400	50	280
134-090-29DAD2/	--	--	1,625	44	--	--	3,553	2.2	--	1	--
134-091-34DDD	4.0	332	42	.0	.3	9.7	362	3.0	0	2,000	--
134-092-2CCC2	2.7	696	457	3.6	4.0	7.0	1,260	1.0	890	400	--
135-091-12CAB2	4.3	296	28	1.0	.7	15	269	1.0	70	660	--
135-091-28CCB3	4.3	1,040	437	1.0	2.0	7.5	1,470	1.0	740	0	--
135-092-03CCD	2.5	427	107	4.2	.2	11	522	.50	30	460	--

1/ Sample from mine pit.

2/ Sample from area where lignite has been oxidized and leached.

generally represent 5-foot intervals above depths of 100 feet and 10-foot intervals, or more, below depths of 100 feet. Most of the samples were analyzed for grain size. A leachate of each sample was made, using distilled water. Generally, the analyses of the leachates show that calcium and magnesium concentrations exceed the sodium concentration. The SAR is less than 10 in the upper 25 to 50 feet of each test hole. There are, however, more than a few exceptions. The pH of the leachates ranged from 3.2 to 8.9, but most samples ranged from about 7.8 to 8.7. Samples with pH values less than 7.8 generally were described as brown, carbonaceous, lignitic, or as lignite. The pH of a particular 5-foot sample depended both on the proportion of carbonaceous material in the sample and the original position of the sample in relation to the zone of oxidation, which generally is 20 to 30 feet below land surface. Carbonaceous samples from below the zone of oxidation generally had pH values ranging from 7.0 to 7.5, but some had a pH value as low as 6.2. Samples from within the zone of oxidation had pH values ranging from 3.2 to about 4.5. Samples that contained less carbonaceous material had pH values that ranged from about 4.5 to 7.5. Even though sulfate concentrations were not included in the analyses, the acidic pH values together with large sulfate concentrations in the water near the outcrops of the lignite bed, where the lignite has been oxidized, indicate that oxidized sulfide minerals are the cause of many of the acidic pH values.

The upper Tongue River and Sentinel Butte aquifer system supplies water for domestic and stock purposes as well as part of the supply for the city of Elgin. No records of water use are available.

SURFACE WATER IN THE NEW LEIPZIG COAL AREA

Streams in the New Leipzig coal area are intermittent except for the Cannonball River on the south edge of the study area and its tributary Thirty Mile Creek. Miscellaneous flow measurements have been made at at four sites, 135-092-21CCC, 134-091-07BBB, 134-091-36CCC, and 133-091-01DCD, on Thirty Mile Creek (fig. 15 and table 3). The flow measured at site 133-091-01DCD, which is about 200 feet upstream from the confluence of Thirty Mile Creek and the Cannonball River, was approximately 25 percent of the flow (9.0 ft^3/s) in the Cannonball River, measured about 0.25 mile downstream from the confluence with Thirty Mile Creek, on November 25, 1980, and about 27 percent of the Cannonball flow (8.7 ft^3/s) on April 23, 1981 (U.S. Geological Survey files). The flow relationship probably has changed little if any since the 1953 to 1956 measurements were made at site 134-091-36CCC (table 3), so the flows should be fairly representative of present-day (1981) base-flow conditions. The relationship would be different and variable for other than base-flow conditions.

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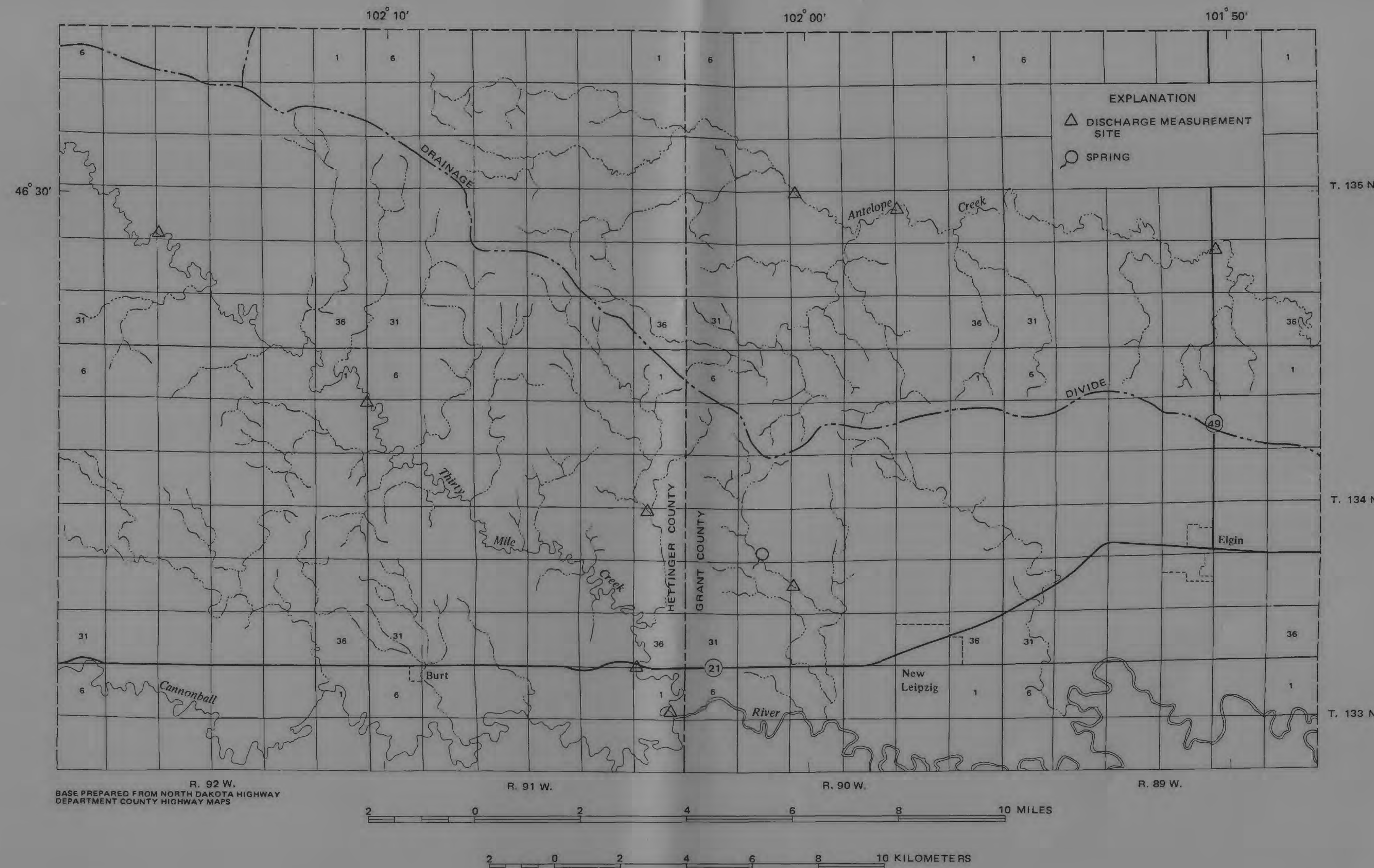

FIGURE 15.—Location of discharge measurement sites.

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TABLE 3.--Flow measurments and sediment concentrations on Thirty Mile Creek

(Flow in cubic feet per second; mg/L = milligrams per liter)

Date		Flow	Date		Flow	Date		Flow	Date		Flow
Site 134-091-36CCC[1]											
1953			1954			1955			1956		
July	22	1.88	Apr.	27	6.21	May	12	1.27	Apr.	24	2.55
Aug.	25	.42	June	15	3.80	June	6	3.16	May	23	2.10
Sept.	23	1.21	July	15	.22	July	15	5.57	June	25	.29
Oct.	22	2.20	Aug.	13	.89	Aug.	30	.18	July	23	2.28
			Sept.	10	1.78	Sept.	21	3.14	Aug.	21	1.70
						Oct.	21	.45	Sept.	20	1.09

Date		Flow	Date		Flow	Date		Mean sediment concentration (mg/L)
Site 135-092-21CCC								
1980			1981			1981		
Nov.	25	0.89	Apr.	22	0.92	Apr.	22	73
Site 134-091-07BBB								
1980			1981			1981		
Oct.	7	0.04[2]	Apr.	22	0.72	Apr.	22	77
Nov.	25	0.96						
Site 133-091-01DCD								
1980			1981			1981		
Nov.	25	2.27	Apr.	23	2.13	Apr.	22	14

[1] Data from U.S. Geological Survey, 1955-58.
[2] Estimated flow.

The 1980 and 1981 measurements made at three sites on Thirty Mile Creek (fig. 15 and table 3) show only small differences in flow between sites 135-092-21CCC and 134-091-07BBB. The increase in flow rates between sites 134-091-07BBB and 133-091-01DCD is believed to be caused by seepage from thin sandstone lenses and lignite beds where the stream crosses the contact between the Tongue River and Sentinel Butte Members.

The sediment concentration in Thirty Mile Creek is small during base-flow conditions. The sediment concentrations listed in table 3 may have been affected by strong winds that were present while the samples from sites 135-092-21CCC and 134-091-7BBB were being collected. Winds were calm while the sample from site 133-091-01DCD was being collected. Some of the decrease of sediment concentration in the downstream reach may be caused by sediment settling behind beaver dams, such as the one shown in figure 16A. No sediment concentrations are available for other than base flow.

There was no flow in the tributaries at sites 134-091-24BAB or 134-090-28BCB when they were visited October 7, 1980, November 25, 1980, and April 22, 1980; however, there were ponds in depressions in the channels (fig. 16B). It is not known whether the ponds are the result of underflow coming to the surface in the channels or of runoff that accumulated in the depressions that did not evaporate or infiltrate through the bottom. The ponds become fewer in number in a downstream direction from the observation sites, indicating that any underflow that may occur in the upstream reaches probably is lost by leakage through the channel bottom or by evapotranspiration. Thus, there is little or no water from aquifers in the minable coal area that reaches the mouth of Thirty Mile Creek or the Cannonball River during dry years such as 1980 and 1981.

All of the small stream valleys that cross the near surface subcrop of the minable coal contain small springs at the horizon of the coal. The flow from springs emerges in the form of small seeps that form bogs in an area of several hundred square feet. The accumulated water either evaporates or percolates into the stream bed. Generally the water disappears within a few hundred yards of the springs. However, residents of the area report that there generally is some streamflow during the early part of wet years, so there may be some surface discharge from the minable coal area during the wetter periods.

Three sites on Antelope Creek, 135-090-21BBB, 135-90-23BCC, and 135-089-26BBB, were included in the flow inventory (fig. 15). There was no flow at any of the three sites on October 7, 1980. At site 135-089-26BBB there was a flow of 0.24 ft^3/s on November 25, 1980, and a flow of 0.40 ft^3/s on April 22, 1981, but there was no flow at the other two sites on either date. A sample

A–BEAVER DAM ON THIRTY MILE CREEK AT 134-091-07BB

B–PONDED WATER IN TRIBUTARY TO THIRTY MILE CREEK AT 134-091-24BAB

FIGURE 16.–Instream storage in Thirty Mile Creek drainage basin.

obtained at site 135-089-26BBB contained 64 mg/L of sediment, which is too small to be significant--a strong gust of wind in the channel could more than double the quantity of sediment present.

There were scattered ponds of water along the creek channel between sites 135-090-23BCC and 135-089-26BBB. The ponds became more abundant in the downstream direction. The volume of water present, although not measured, was considerable and indicates there probably is some underflow between ponds as well as some recharge from precipitation that infiltrates through the banks near the creek. There also may have been some residual from runoff that had not evaporated or infiltrated through the stream bottom.

The physical properties and concentrations of significant chemical constituents in samples collected at three sites on Thirty Mile Creek and at one site on Antelope Creek are shown in table 4. Specific conductance and pH values were determined at the sites. The relatively large strontium concentrations in the streamflow at sites 135-092-21CCC and 134-091-7BBB on Thirty Mile Creek indicate that some of the ground water that reaches the stream has filtered through carbonaceous material, possibly lignite beds. The smaller concentration in the downstream reach indicates that much of the ground water that reaches the stream is derived primarily from leakage from near-surface sand beds.

SUMMARY

Ground water in the New Leipzig area can be obtained from sandstone beds in the Fox Hills aquifer, the Hell Creek aquifer system, Cannonball and Ludlow aquifer system, basal Tongue River aquifer, and upper Tongue River and Sentinel Butte aquifer system. Ground water also can be obtained from the Harmon lignite bed, which is part of the upper Tongue River and Sentinel Butte aquifer system.

The Fox Hills aquifer is at depths ranging from about 890 to 1,500 feet and is 71 and 95 feet thick in two test holes in the study area. Potential well yields should range from about 5 to 100 gal/min. Water in the aquifer is soft and is a sodium bicarbonate type. Dissolved-solids concentration in a sample was 1,280 mg/L, sodium was 570 mg/L, bicarbonate was 1,080 mg/L, sulfate was 20 mg/L, chloride was 170 mg/L, and fluoride was 4.6 mg/L.

The Hell Creek aquifer system is at depths ranging from 550 to more than 1,100 feet. The aquifer is composed of two and locally three separate sandstone units that range in thickness from 7 to 115 feet. Potential well yields should range from about 1 to 60 gal/min. Water in the system is soft and is a

TABLE 4.--Chemical analyses of water from Thirty Mile and Antelope Creeks

(mg/L = milligrams per liter; micromhos = micromhos per centimeter at 25°C; NTU = nephelometric turbidity units; µg/L = micrograms per liter)

	Thirty Mile Creek at			Antelope Creek at
	135-092-21CCC	134-091-07BBB	133-091-01DCD	135-089-26BBB
Date of sample	81-04-22	81-04-22	81-04-23	81-04-22
Time (hours)	1327	1519	0852	1051
Streamflow, (cubic feet per second)	0.92	0.72	2.13	0.40
Turbidity (NTU)	34	24	3.3	11
Specific conductance (micromhos)	1,800	1,775	1,325	1,400
pH, (units)	8.4	8.4	8.5	8.5
Hardness (mg/L as $CaCO_3$)	490	500	430	350
Harness, noncarbonate (mg/L as $CaCO_3$)	210	190	120	0
Calcium, dissolved (mg/L as Ca)	92	98	86	62
Magnesium, dissolved (mg/L as Mg)	62	62	53	46
Sodium, dissolved (mg/L as Na)	250	240	160	210
Sodium, percent	52	51	44	56
Sodium-adsorption ratio	4.9	4.7	3.3	4.9
Potassium, dissolved (mg/L as K)	10	9.2	7.1	8.0
Alkalinity (mg/L as $CaCO_3$)	280	310	310	400
Sulfate, dissolved (mg/L as SO_4)	720	690	430	390
Chloride, dissolved (mg/L as Cl)	37	17	77	42
Fluoride, dissolved (mg/L as F)	0.4	0.4	0.3	0.4
Silica, dissolved (mg/L as SiO_2)	1.9	2.0	4.6	0.7
Boron, dissolved (µg/L as B)	250	270	210	410
Iron, dissolved (µg/L as Fe)	20	10	30	20
Lithium, dissolved (µg/L as Li)	70	60	50	50
Manganese, dissolved (µg/L as Mn)	120	140	30	10
Molybdenum, dissolved (µg/L as Mo)	<10	<10	<10	<10
Strontium, dissolved (µg/L as Sr)	1,700	1,600	1,200	980

sodium bicarbonate type. Concentrations of dissolved solids ranged from 1,220 to 1,370 mg/L, sodium ranged from 480 to 540 mg/L, bicarbonate ranged from 1,070 to 1,260 mg/L, sulfate ranged from 2.5 to 12 mg/L, chloride ranged from 92 to 110 mg/L, and fluoride ranged from 0.9 to 7.8 mg/L.

The Cannonball and Ludlow aquifer system is at depths that range from about 228 to 785 feet. The aquifer system ranges from 24 to 105 feet in thickness. Individual aquifers in the system are lenticular and discontinuous, and range in thickness from 7 to 67 feet; mean thickness is about 20 feet. Potential well yields may be as much as 40 gal/min, but probably would average about 10 gal/min. Water in the system is soft and is a sodium bicarbonate type. Concentrations of dissolved solids ranged from 1,150 to 1,770 mg/L, sodium ranged from 470 to 760 mg/L, bicarbonate ranged from 1,020 to 1,880 mg/L, sulfate ranged from 7.4 to 130 mg/L, chloride ranged from 52 to 100 mg/L, and fluoride ranged from 1.5 to 4.0 mg/L.

The basal Tongue River aquifer is at depths that range from about 90 feet to 437 feet and may be at depths of as much as 600 feet. The thickness of the aquifer ranges from about 23 to 150 feet; mean thickness is about 64 feet. Potential well yields should range from about 5 to 100 gal/min. Analyses show that water in the aquifer can be either soft or very hard and generally is a sodium bicarbonate type. Locally calcium exceeds the sodium and sulfate exceeds the bicarbonate. Concentrations of dissolved solids ranged from 292 to 2,642 mg/L, sodium ranged from 83 to 620 mg/L, bicarbonate ranged from 294 to 1,470 mg/L, sulfate ranged from 13 to 1,110 mg/L, chloride ranged from 1.1 to 43 mg/L, and fluoride ranged from 0.4 to 4.2 mg/L.

The upper Tongue River and Sentinel Butte aquifer system ranges in depth from near land surface to 320 feet. The aquifer system is composed of discontinuous sandstone lenses and lignite beds that generally are less than 15 feet thick, but the sandstone lenses may be as much as 79 feet thick. Most of the water movement in the system is in a vertical direction, but the water-level gradient in the Harmon lignite bed averages about 20 ft/mi to the south. Well yields from the aquifer system range from less than 1 to about 5 gal/min. Analyses of water from the aquifer system show that the water generally is very hard and is either a sodium or calcium bicarbonate type. Locally sulfate is the dominant ion. Concentrations of dissolved solids generally ranged from 269 to 1,470 mg/L, but were as much as 3,553 mg/L beneath areas where the Harmon lignite has been oxidized. Sodium concentrations ranged from 11 to 580 mg/L, bicarbonate ranged from 296 to 1,040, sulfate ranged from 27 to 1,625 mg/L, chloride ranged from 0.0 to 44 mg/L, and fluoride ranged from 0.2 to 4.0 mg/L. The larger dissolved-solids and sulfate concentrations were from areas near where lignite has been oxidized and leached.

Measurements of base flow in Thirty Mile and Antelope Creek together with observed lack of flow in other tributaries to the Cannonball River indicate that there is little or no contribution of water from the Harmon lignite bed in the area of minable coal that reaches either Thirty Mile Creek or the Cannonball River during dry years, such as 1980 and 1981. During large-scale mining (if it occurs), some water that will be pumped from the mine pits may reach either Thirty Mile Creek or the Cannonball River, and may add to the flow in the streams. There also may be a slight increase in dissolved-solids concentration in the flow. Mining of lignite will have negligible effect on the flow in Antelope Creek.

The mining of lignite will destroy all aquifers that are in or above the mined lignite, but aquifers below the lignite will not be disturbed. All wells in the mined area will be destroyed, but new wells can be finished in the lower aquifers. The mining also will expose sulfide minerals in the overburden and allow oxidation to accelerate. Recharge will cause leaching and an increase in dissolved-solids and sulfate concentrations in the underlying basal Tongue River aquifer will result. Because of the low permeability of the beds beneath the lignite and the dilution effect in the aquifer, increases in dissolved-solids and sulfate concentrations are expected to be small.

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