# THE GEOHYDROLOGIC SYSTEM AND PROBABLE EFFECTS OF MINING IN THE SAND CREEK-HANKS LIGNITE AREA, WESTERN WILLIAMS COUNTY, NORTH DAKOTA

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

| Multiply inch-pound unit | By | To obtain SI unit |
|---|---|---|
| Acre | 0.4047 | hectare |
| Cubic foot per second ($ft^3/s$) | 28.32 | liter per second |
| Foot (ft) | 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 ($ft^2/d$) | 0.09290 | meter squared per day |
| Gallon per day per foot [(gal/d)/ft)] | 12.42 | liter per day per meter |
| Gallon per minute (gal/min) | 0.06309 | liter per second |
| Gallon per minute per foot [(gal/min)/ft] | 0.2070 | liter per second per meter |
| Inch (in.) | 25.40 | millimeter |
| Mile (mi) | 1.609 | kilometer |
| Square mile ($mi^2$) | 2.590 | square kilometer |

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

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.

# THE GEOHYDROLOGIC SYSTEM AND PROBABLE EFFECTS OF MINING IN THE SAND CREEK-HANKS LIGNITE AREA, WESTERN WILLIAMS COUNTY, NORTH DAKOTA

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## ABSTRACT

*The investigation was undertaken to define the geohydrology of the Sand Creek-Hanks area and to project probable hydrologic effects of lignite mining on the area.*

*Aquifers occur in sandstone beds in the Fox Hills Sandstone and the Hell Creek Formation of Cretaceous age and in sandstone lenses and lignite beds in the Tongue River and Sentinel Butte Members of the Fort Union Formation of Tertiary age.*

*The top of the Fox Hills aquifer ranges from about 1,200 to 2,000 feet below land surface. Yields of wells completed in the aquifer could be as much as 60 gallons per minute. Water in the Fox Hills aquifer is a sodium bicarbonate type and generally contains between 1,300 and 2,100 milligrams per liter dissolved solids.*

*Depths to the top of the Hell Creek aquifer range from about 900 to 1,600 feet. Well yields range from less than 10 to 40 gallons per minute. Water in the aquifer is a sodium bicarbonate type and generally contains between 1,000 and 2,200 milligrams per liter dissolved solids.*

*Depths to aquifers in the Tongue River and Sentinel Butte Members of Fort Union Formation range from near land surface to about 1,000 feet below land surface. Wells completed in the aquifers may yield as much as 40 gallons per minute of sodium bicarbonate or a sodium sulfate type water that contains about 800 to 4,100 milligrams per liter dissolved solids.*

*Glacial drift covers most of the study area. The drift thickness ranges from a veneer to about 380 feet. Well yields range from a few gallons per minute to 900 gallons per minute. Dissolved-solids concentrations in water from the glacial drift generally range from 477 to 2,050 milligrams per liter.*

*Mining of lignite will destroy all aquifers in and above the mined lignite and will expose overburden to oxidation. Leaching will cause an increase in dissolved solids in ground water immediately beneath the mines and possibly will cause some increase in the dissolved solids in low flows in area streams.*

# INTRODUCTION

The study area (fig. 1) consists of about 700 $mi^2$ in western Williams County. Two areas of greatest potential for lignite mining were outlined by the U.S. Bureau of Land Management. These areas consist of about 175 $mi^2$ each in the southern and northern parts of the study area (fig. 2). The southern area is referred to as the Sand Creek area. It is comprised of two major drainage basins, Painted Woods Creek and Sand Creek, both tributary to the Missouri River, and two small intermediate basins, Chinaman Coulee and Camp Creek, both tributary to the Little Muddy River. The northern area, referred to as the Hanks area, is drained by Scorio Creek, Pats Coulee, Heidemann Coulee, and Blacktail Creek on the east and Cottonwood and Willow Creeks on the west.

Williston (population 13,336; U.S. Bureau of the Census, 1981) is at the southeastern end of the Sand Creek basin. U.S. Highway 2 borders the southern part of the study area and U.S. Highway 85 is the approximate border of the study area on the east. The Williams County boundaries form the north and west edges of the study area (fig. 2).

## Objectives and Scope

The primary objective of the investigation was to define the geohydrologic system in the greatest possible detail consistent with the time and funding available. Included were an assessment of the ground-water flow system and ground-water chemical characteristics and determination of surface-water low-flow magnitudes and surface-water chemistry. By defining the geohydrologic 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 assess potential effects resulting from surface mining of lignite. Management agencies, including the U.S. Bureau of Land Management, would then be able to use this projection to augment their decision-making processes. There currently (1984) are no mining activities in the study area, but in 1950 lignite was being mined near Hanks (Brant, 1953, p. 16). While working in the area, Brant (1953, p. 14) also located subsurface mines that were inactive. Effects on the geohydrologic system, if any, of prestudy mining have not been reported, and there were no effects observed during this study. As a result, all geohydrologic data are presumed to be similar to premining conditions, and potential effects resulting from lignite development are based on available data.

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

## Location-Numbering System

The location-numbering system used in this report (fig. 3) is based on the Federal system of rectangular surveys of the public lands. The first

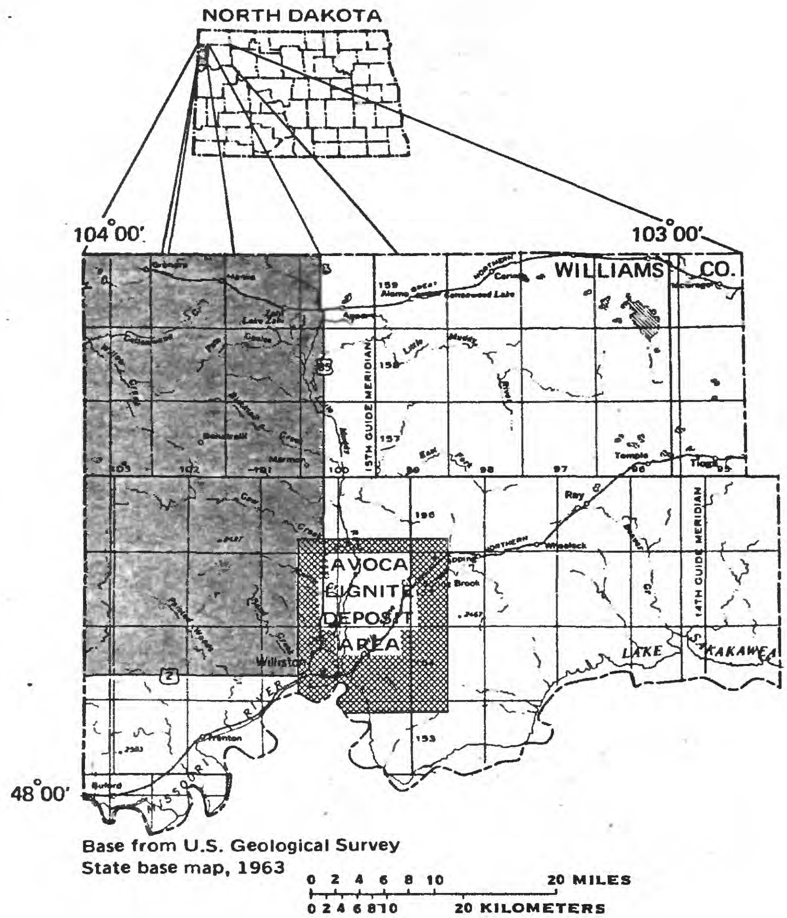


**Figure 1.—Location of the Sand Creek-Hanks lignite area (shaded) in North Dakota.**

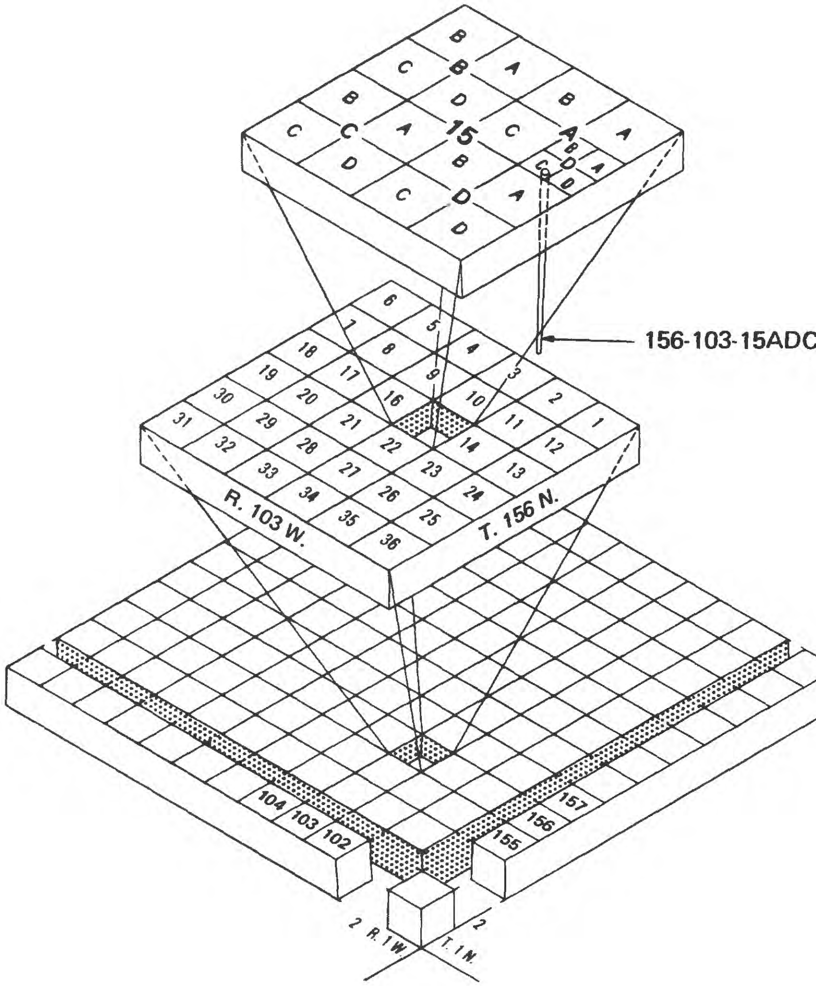


**Figure 3.—Location-numbering system.**

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 156-103-15ADC would be located in the SW1/4SE1/4NE1/4 sec. 15, T. 156 N., R. 103 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

Several investigators have studied the lignite deposits in Williams County. Wilder (1902) described the location of lignite exposures and the detailed lithology of some of the exposed sections. Wilder (1905) also described the location of lignite beds, one of which is in the Sand Creek-Hanks area. Herald (1913) described the geology and gave a fairly detailed account of the lignite resources of the Williston area. Dove and Eaton (1925) reported on the principal lignite beds and included a map showing mine location. Alden (1932) described the physiography of eastern Montana and adjacent areas, which includes the study area. Brant (1953) presented location, thickness, and reserve data for the major lignite beds in Williams County and listed the name and location of mines operating in 1950. Witkind (1959) reported on the Quaternary geology of the Smoke Creek-Medicine Lake-Grenora area of Montana and North Dakota and included a few paragraphs describing the Fort Union Formation. Howard (1960) studied the geology of northwestern North Dakota and northeastern Montana but concentrated almost entirely on the Pleistocene deposits. Schmid and Hoisveen (1961) studied the geology of the Little Muddy River valley to determine the availability of ground water for irrigation use. Armstrong (1967, 1969) studied the ground-water resources and Freers (1970) studied the geology of Williams County as part of the North Dakota Geological Survey, North Dakota State Water Commission, and U.S. Geological Survey cooperative county ground-water program. Spencer (1980) reported on the results of test drilling done in 1979 to determine the extent and thickness of lignite beds in Williams County. Most lithologic logs of wells and test holes used in this report that show more than 200 ft of the Fort Union Formation are from Spencer (1980). Wald and Norbeck (1983), as part of this study, inventoried the private wells in the study area. Data from their report are a primary source of information in this report. Horak and Crosby (1985) described four lignite beds in the Avoca deposit, which is located in south-central Williams County a few miles northeast of Williston.

## Topography

The study area is within the glaciated part of North Dakota. Local relief is subdued and the topography is low to moderately undulating. Altitudes range from about 1,850 ft at the mouth of Sand Creek to about 2,590 ft on the top of a butte in the northern part of the study area. The area generally is dissected by integrated drainage systems, but several undrained depressions that contain enough water to form lakes and sloughs are located in the northwest quarter of T. 159 N., R. 103 W.

## Climate

The climate is semiarid with a mean annual precipitation of 13.85 in. at Williston. About 75 percent of the precipitation falls during the April through September growing season. The mean annual temperature is 40.8°F at Williston (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service, 1982).

## Water Use and Supply

The principal uses of water in the Sand Creek-Hanks lignite 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 livestock watering.

Every farmstead in the area has at least one domestic well, 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 use have not been made.

# EFFECTS OF MINING ON AREA HYDROLOGY

Strip mining of lignite in the Sand Creek-Hanks lignite area will have an effect on the hydrology of the area. Mining will destroy all water-yielding zones in and above the mined lignite and all wells completed in the lignite or overlying beds. Small springs and seeps that are scattered along Painted Woods and Sand Creeks in the southern part of the area and Willow and Cottonwood Creeks in the northwestern part of the area also may be destroyed because the lignite or sandstone beds that are conduits for recharge and contain the stored water that sustain the springs would be destroyed.

When mining occurs, the overburden will be moved and sandstone lenses will be destroyed and mixed with clay. The mixed materials will be less compact than the original materials, and recharge from precipitation may increase. However, the destruction of the sandstone and lignite beds probably will retard the lateral movement of water toward the creeks. The result probably will be a small decrease in base flow in streams near the mined area.

As mining proceeds, a cone of depression will form around the mine and water levels in wells finished in the lignite or overlying beds will decline. Some of the wells may become unusable while mining is at some distance from the wells. However, the generally small transmissivity of most aquifers in the upper parts of the Sentinel Butte Member 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 the mining and the early reclamation stages probably can be supplied from the mine drainage. The final reclamation stage, however, is the planting of small grains or forage crops. Water needs for these crops will be dependent on precipitation or piped water because an adequate supply of ground or surface water that is chemically suitable for irrigation is not available near the areas that might be mined.

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, and possibly to some extent in the base flow of nearby streams.

After the area is reclaimed, wells can be drilled to sand lenses or lignite beds in the lower part of the Sentinel Butte Member or to the basal part of the Tongue River Member. If for any reason aquifers in these formations cannot be used, water can be obtained from deeper aquifers in the Hell Creek Formation or the Fox Hills Sandstone.

The beds beneath the lignite generally have very small hydraulic-conductivity values so recharge to aquifers in the Tongue River Member will be slow; probably so slow that dilution with water already in the basal part of the Tongue River Member 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 part of the Tongue River Member because of the very small hydraulic-conductivity values of the clayey beds separating each of the underlying aquifers.

## GEOLOGY

The study area is located near the center of the Williston sedimentary basin and is underlain by more than 13,000 ft of sedimentary rocks. Several thousand feet of predominantly sandstone, shale, carbonate rocks, and evaporite deposits comprises the stratigraphic section between the Precambrian and the top of the Upper Cretaceous Pierre Shale. The Pierre generally is considered the base of freshwater-yielding units in western North Dakota; therefore, in this report, it is considered the practical limit of test drilling for aquifer evaluation. The formations, members, maximum thicknesses, and lithologies discussed in this report are listed in table 1.

Data are few for the interval between the top of the Pierre Shale and the probable base of the Sentinel Butte Member of the Fort Union Formation. The data consist only of one well completed in the Fox Hills aquifer and geophysical logs of oil test holes in the Sand Creek-Hanks area. Tentative correlations were made by projecting formation contacts from adjacent counties. However, because of the similarity of lithologies and the distances to known contacts between the various formations and members, all contacts in the report area are considered questionable.

Table 1.--*Generalized stratigraphic column*

| System | Series | Formation | Member | Maximum thickness (feet) | Lithologic description |
|---|---|---|---|---|---|
| Quaternary | Pleistocene | | | 380 | Glacial drift-- Till, silt, sand, and gravel. |
| Tertiary | Paleocene | Fort Union Formation | Sentinel Butte Member | 520± | Claystone, bentonitic or carbonaceous; siltstone; silty very fine to medium sandstone; and lignite. |
| | | | Tongue River Member | 550± | Claystone, bentonitic or carbonaceous; siltstone; silty very fine to medium sandstone; and lignite. |
| | | | Ludlow and Cannonball Members | 580± | Ludlow--Claystone, siltstone, sandstone, and lignite. Cannonball--Marine claystone, siltstone, and silty sandstone. |
| Cretaceous | Upper Cretaceous | Hell Creek Formation | | 300± | Sandstone, claystone, siltstone, thin interbedded lignite and carbonaceous claystone. |
| | | Fox Hills Sandstone | | 300± | Sandstone, silty brown to gray; silty claystone; and siltstone. |
| | | Pierre Shale | | 2,100± | Shale, dark-gray, marine. |

## HYDROLOGY OF ROCKS OVERLYING THE PIERRE SHALE

### Fox Hills Sandstone

The Fox Hills Sandstone of Late Cretaceous age conformably overlies the Pierre Shale (table 1). The Fox Hills is the lowermost unit in a sequence of about 1,650 to 2,200 ft of rock strata that dips from north to south at about 25 to 30 ft/mi. Depths to the top of the Fox Hills range from about 1,200 ft in the topographically low areas in the north to about 2,000 ft beneath the topographically high areas in the south part of the study area. The Fox Hills Sandstone is of marine origin and consists largely of silty sandstone with silty claystone and siltstone. Geophysical logs of oil test holes indicate that the Fox Hills is about 300 ft thick in the southern part of the area and thins to about 200 ft in the northern part primarily because the sandstone beds thin as well as become more silty or clayey to the north. Sandstone beds in the upper part of the Fox Hills form an aquifer that may be as much as 120 ft thick, but the cleaner sandstone lenses, which readily yield water, generally range from about 30 to 60 ft in thickness.

Only one well (154-101-30BBA) is finished in the Fox Hills aquifer in western Williams County, so most hydrologic assumptions are based on data from northern McKenzie County and other areas in western North Dakota. Croft and Wesolowski (1970, p. B193) published a table showing the results of 38 aquifer tests made in Mercer and Oliver Counties. Of the 38 wells, 11 definitely were finished in the Fox Hills aquifer, and 1 additional well probably was finished in the aquifer. The table shows that the hydraulic conductivity (permeability) ranges from about 0.4 to 16 ft/d, and specific capacity ranges from 0.1 to 0.6 (gal/min)/ft of drawdown, but most wells had a specific capacity of 0.1 to 0.3 (gal/min)ft of drawdown. According to M. G. Croft (U.S. Geological Survey, oral commun., 1983), hydrologic conditions in the Fox Hills and Hell Creek aquifers in McKenzie County are similar to those in Mercer and Oliver Counties. If so, it is reasonable to assume that similar hydrologic conditions also exist in Williams County.

If the assumed hydrologic conditions are correct, well yields in the study area could range from 5 to 60 gal/min with 100 ft of drawdown. However, most wells probably would yield 10 to 30 gal/min. Water-level altitudes in three flowing wells in northern McKenzie County ranged from 2,067 to 2,108 ft above NGVD of 1929. Shut-in pressures for these wells probably would have resulted in somewhat higher static water levels. Water levels in the southern part of the study area probably would be similar to those in the northern part of McKenzie County. The water level in well 154-101-30BBA is not known, but in 1980 it did flow at an altitude of about 2,070 ft. Data are not sufficient to determine the direction or gradient of the potentiometric surface in the study area.

Analyses of water samples from Fox Hills wells in northern McKenzie County and from well 154-101-30BBA indicate that the water is soft, and is a sodium bicarbonate type. Hardeness generally is in the 9 to 30 mg/L range. Dissolved-solids concentrations in the samples ranged from 1,300 to about 2,100 mg/L. Chloride concentrations generally ranged from 150 to 420 mg/L, but, may increase in a northerly direction. Fluoride concentrations ranged from 2.4 to 5.9 mg/L, but most samples contained more than 4.0 mg/L.

## Hell Creek Formation

The continental Hell Creek Formation of Late Cretaceous age overlies the Fox Hills Sandstone. Depths to the top of the Hell Creek range from about 900 ft in the lower areas in northern Williams County to about 1,600 ft beneath some of the topographically higher areas in the south-central part of the study area. The Hell Creek in the southern part of the study area is composed of as much as 300 ft of interbedded claystone, siltstone, and fine-grained sandstone with thin interbedded lignite or carbonaceous claystone beds. The formation thins to about 200 ft in the northern part of the area. Generally individual sandstone lenses are less than 50 ft thick, but locally a sandstone interval as much as 60 ft thick is present at the top of the Hell Creek Formation. This sandstone may be in the lower part of the Ludlow Member of the Fort Union Formation, but it appears to be hydrologically associated with sandstone beds in the upper part of the Hell Creek Formation. In this study, it is considered as part of the Hell Creek aquifer.

The Hell Creek aquifer generally is concentrated in the upper one-half of the Hell Creek Formation. The aquifer consists of two or more saturated sand beds or lenses that are more than 900 ft below land surface and may or may not be hydraulically connected. Generally the hydraulic connection is poor at best. These beds yield water to wells; however, the quantity of water that could be produced is not known. By projecting data from Mercer and Oliver Counties (Croft and Wesolowski, 1970, p. B193) and allowing for differences in aquifer thickness, well yields would range from less than 10 to about 40 gal/min with 100 ft of drawdown. There are no measured water levels close enough to Williams County to make reasonable estimates in the study area.

Analyses of water samples collected from the Hell Creek aquifer in McKenzie County indicate that the water is soft and a sodium bicarbonate type. Dissolved-solids concentrations in the samples ranged from about 1,000 to 2,200 mg/L, and fluoride concentrations ranged from about 3 to 6 mg/L. Water in the Hell Creek aquifer in the study area probably is similar to that in McKenzie County.

## Fort Union Formation

The Tertiary system in the Sand Creek-Hanks lignite area is represented by the Fort Union Formation of Paleocene age. The formation has been divided into four members in western North Dakota: the Ludlow and its lateral equivalent the Cannonball, the overlying Tongue River, and the uppermost Sentinel Butte. The Cannonball is the only member of marine origin.

The Ludlow Member overlies the Hell Creek Formation. Depths to the top of the Ludlow range from about 650 to 1,000 ft. The Ludlow Member consists of alternating beds or lenses of claystone, siltstone, poorly consolidated sandstone, and thin beds of lignite. The Cannonball Member, which overlies the lower part of the Ludlow Member and is the lateral equivalent of parts of the Ludlow Member, also consists of claystone, siltstone, and, locally, some poorly consolidated silty sandstone, but it does not contain lignite beds.

Interpretations of geophysical logs indicate that the combined thicknesses of the Ludlow and Cannonball Members may be as great as 580 ft, but the thickness at most locations generally is somewhat less than 500 ft in the southern part of the area and may be as little as 250 ft in the northern part. Sandstone beds generally are less than 20 ft thick and appear to have comparatively little resistance on resistivity logs; therefore, the beds probably contain considerable interstitial clay. There are no other data available for these two members, so they are not considered further in this report.

The Tongue River and Sentinel Butte Members were deposited in early Tertiary time apparently under a similar environment--near the terminus of a fluvial system originating in Wyoming and Montana along the cordilleran highland. The alternating sandstone, siltstone, claystone, and lignite beds or lenses are discontinuous because of the meandering or distributary nature of the streams during the Paleocene. Some lignite beds or intervals containing interbedded lignite and siltstone or sandstone apparently extend throughout hundreds of square miles. The extent of these beds indicates that a vast quiescent swamp environment existed at the time of their deposition.

### Tongue River Member

The Tongue River Member underlies all of the study area. It consists of lenticular interbedded claystone, siltstone, sandstone, lignite, and, locally, thin ledges of cemented sandstone or sandy limestone. The member may be as much as 550 ft thick, and the base may be as much as 1,000 ft below land surface. Geophysical logs indicate that as much as 150 ft in the basal part of the member is either sandstone or siltstone with some interbedded claystone. The uppermost bed or interval in the member in western North Dakota commonly is a lignite bed. Where this lignite bed is not identified, the Tongue River Member and the overlying Sentinel Butte Member generally are not differentiated. The logs indicate that individual sandstone lenses may be as much as 65 ft thick but generally are less than 15 ft thick. There are no data from the study area to indicate the grain size within individual sandstone beds, but data from surrounding counties indicate that the size probably ranges from very fine to medium grain size within a particular bed. With the possible exception of the Fox Hills aquifer, the basal part of the Tongue River Member forms the most continuous aquifer in the study area.

Except for a few wells that may be finished in thin sand lenses in the upper part of the Tongue River Member in the northern part of the study area, there are no hydrologic data available concerning aquifers in the member. However, geophysical logs indicate that aquifers are present, especially in the basal part of the Tongue River Member. Aquifers in the basal part of the member may be as much as 150 ft thick (Armstrong, 1969, p. 25) and contain only a few thin siltstone or claystone beds. The quantity of water that could be obtained from wells finished in these aquifers in the study area cannot be estimated accurately; however, Armstrong (1969, p. 25) reported that as much as 40 gal/min has been obtained from wells in the eastern part of Williams County. (An analysis of well depths indicated that they were finished in a Tongue River aquifer.) Geophysical logs from the study area indicate that some sand lenses in the basal part of the Tongue River Member are as thick as some of the lenses in the eastern part of Williams County, so it is likely that as much as 40 gal/min also could be obtained from wells finished in the basal part of the Tongue River Member in the study area. There are no data available to make reliable estimates of the quality of water in the Tongue River Member.

The Tongue River Member also contains several lignite beds, some of which may be as much as 14 ft thick, but most are less than 10 ft thick. These lignite beds may be aquifers, but neither the quantity or quality of the water that could be produced from these beds is known.

### Sentinel Butte Member

The Sentinel Butte Member crops out in many scattered locations throughout the study area (Freers, 1970, p. 11). It is similar to the Tongue River Member in most respects and is composed of lenticular, interbedded claystone, siltstone, sandstone, lignite, and thin beds of cemented sandstone or sandy limestone. The color of the Sentinel Butte Member is somewhat darker than that of the Tongue River Member in weathered surface exposures. However, the color difference has not been reported in fresh test-hole cuttings. Except on the surface, the two members rarely are differentiated.

Geophysical and lithologic logs indicate that the Sentinel Butte Member may be as much as 520 ft thick, but correlations are tenuous and the combined thickness of the Tongue River and Sentinel Butte Members is not known to exceed 1,000 ft. However, thicknesses greater than 1,000 ft probably exist beneath some of the higher hills in the area. Individual sandstone lenses generally are composed of very fine to medium-grained sandstone. The sandstone lenses generally are less than 15 ft thick and are of limited extent; however, a bed 110 ft thick was penetrated in test hole 159-103-24CCC. The distribution of undifferentiated siltstone or claystone, sandstone, and lignite is illustrated on plate 1, sections A-A', B-B', and C-C'. Generally, individual lenses or beds of siltstone or claystone, and sandstone cannot be correlated from one test hole or well to another. Lignite beds, however, are more extensive and may be continuous between various test holes or wells.

Most test holes or wells that have been drilled as much as 100 ft into the Sentinel Butte Member in the study area have penetrated at least one lignite bed and most have penetrated more. Generally, the beds are less than 5 ft thick, but they may be as much as 20 ft thick. Correlation of the various lignite beds is tenuous. However, at least some of the beds between altitudes of 1,900 and 2,100 ft in section B-B' (pl. 1) probably are equivalent to some of the lignite beds comprising the Avoca deposit east of Little Muddy River (Horak and Crosby, 1985). The equivalent lignite beds appear to be somewhat higher in section A-A' than reported in the Avoca deposit. The lower lignite sequence in section B-B' possibly is equivalent to the Avoca bed, and the upper lignite sequence possibly is equivalent to the Williston bed. Individual lignite beds probably once were continuous between the study area and the Avoca deposit area to the east, but an ancestral course of the Yellowstone River eroded through the beds. Section B-B' (pl. 1) indicates at least two lignite beds that appear to be terminated by erosion. Correlation of individual lignite beds has not been made, but in the southeastern part of the study area comparable altitudes indicate some of the higher lignite beds in Painted Woods and Sand Creek valleys may be equivalent to beds in the area of the Avoca deposit. Sections A-A' and C-C' (pl. 1) indicate that the minable lignite beds in the Willow and Cottonwood Creeks drainage areas and the unnamed drainge area to the north probably are continuations of lignite beds comprising the Avoca deposit. Trends of these deposits shown in section A-A' indicate that the minable lignite in the Scorio Creek and Pats Coulee drainage areas also probably is a continuation of the Avoca deposits. Brant (1953, p. 16) referred to the bed in the Hank-Zahl district as the Hanks deposit. Lignite beds stratigraphically higher than the equivalent Avoca deposits exist beneath some of the topographically higher parts of the study area.

Aquifers in the Sentinel Butte Member are formed in sandstone beds and in fracture systems in lignite beds. These aquifers yield water to many of the domestic and stock wells in the study area. The quantity of water that can be obtained from the sandstone beds depends on the grain size and the thickness. Armstrong (1969, p. 25), using estimates based on laboratory data, postulated that the transmissivity of a 5-ft bed would range from 50 to 1,500 (gal/d)/ft or 6.5 to 200 $ft^2/d$. These transmissivities indicate that specific capacities of wells completed in one of these 5-ft lenses should range from about 0.025 to 0.75 (gal/min)/ft of drawdown. Wells finished in thicker lenses would have correspondingly greater specific capacities. Apparently wells with specific capacities greater than 0.4 (gal/min)/ft of drawdown are unusual because as of 1968 there were no wells finished in the Sentinel Butte aquifer in Williams County that would produce more than 40 gal/min. Most wells, however, were equipped with cylinder pumps and were limited to a pump capacity of 2 to 5 gal/min.

Lignite beds in the Sentinel Butte Member also will yield water. The quantity depends upon the degree of fracturing, the size and extent of the fractures in the lignite, and the transmissivity of the overlying or underlying beds. Yields from lignite beds are variable from place to place but commonly are somewhat more than 1 gal/min.

Water in the deeper parts of the Sentinel Butte aquifer generally has large concentrations of sodium and bicarbonate and small concentrations of calcium and magnesium. Water in the shallower parts, however, contains a larger proportion of calcium and magnesium, and the quantity of calcium may exceed the sodium. Chemical analyses (Wald and Norbeck, 1983, table 3) were made for water samples from 25 wells that are believed to be completed in the Fort Union Formation, and most if not all are completed in the Sentinel Butte Member. The sodium concentration exceeded 50 percent of the cations in 14 samples and exceeded 80 percent in 8 samples. Sulfate concentrations ranged from 150 to 2,200 mg/L and had a median value of 500 mg/L. Sulfate concentrations exceeded the recommended limit of 250 mg/L (U.S. Environmental Protection Agency, 1977) in 21 samples. Dissolved-solids concentrations in the samples ranged from about 800 to 4,100 mg/L and had a median value of 1,480 mg/L.

Standard analyses were made on water from three wells reportedly finished in lignite beds. Hardness concentrations in all three samples exceeded 500 mg/L, calcium concentrations exceeded sodium, and sulfate concentrations exceeded the recommended limits. In addition, water from lignite beds commonly is colored. The color ranges from a very light yellowish brown in some wells to brownish black in others. The color apparently is due to organic compounds.

## Glacial Drift

For the most part, the study area is covered by glacial drift of Quaternary age that ranges from a veneer in some of the high areas and on some hillsides to as much as 380 ft thick in some of the larger valleys. Most of the glacial drift, except in the valleys, is composed of till--a relatively impermeable mixture of clay, silt, sand, gravel, and some boulders. In the valleys and locally in isolated deposits within the till, the glacial drift consists of lenticular, stratified glaciofluvial deposits of sand, gravel, and silt. The relationship of the various landforms and the lithology of each is described by Freers (1970, pl. 1).

Except in areas of buried valleys, a considerable part of the study area is covered by relatively thin drift, and only very local aquifers, if any, exist above the Fort Union Formation. Water levels in these local aquifers compare with the regional water table or potentiometric surface, which parallels the land surface in a very general way. Ground-water divides are in the general areas of the surface-water divides. The potentiometric surface generally slopes toward the surface drainages, which are the principal areas of ground-water discharge in the study area.

The ability of smaller glaciofluvial deposits to yield water depends on the hydraulic conductivity of the material in the deposit, the size of the deposit, and the rate of recharge. If the deposit is relatively small and enclosed in till, it will receive recharge slowly; consequently, aquifers in such deposits will not yield large quantities of water for sustained periods. Well yields from small aquifers of this type in the study area commonly yield less than 10 gal/min. The thickest glaciofluvial deposits in the study area are in an ancestral valley of the Yellowstone River and in an ancestral course of the Missouri River.

### Little Muddy Aquifer

The largest of the buried-valley aquifers in the study area is the Little Muddy aquifer (Armstrong, 1969, p. 33). This aquifer is within a buried ancestral valley of the Yellowstone River and presently underlies the south-trending part of the Little Muddy River on the east side of the study area. The aquifer consists of two zones, each composed of sand and gravel. The zones are separated by 11 to 255 ft of till or clay. Armstrong (1969,

p. 33-34) reported that the upper zone has an average thickness of about 43 ft and generally does not extend more than 150 ft below land surface. The lower zone has an average thickness of about 28 ft and generally is more than 130 ft below land surface.

An aquifer test (Armstrong, 1969, p. 40) indicates that the upper zone of the aquifer in the vicinity of 158-100-17A has a transmissivity of about 130,000 (gal/d)/ft or 17,000 $ft^2/d$, and a storage coefficient of about 0.0004. The transmissivity value indicates that about 1,200 gal/min could be obtained from a properly constructed well in the area. However, the fact that the aquifer is confined to a valley with somewhat impermeable boundaries indicates that a continuous optimum pumping rate should be less than the maximum rate indicated by the test. The maximum pumping rate that has been permitted by the North Dakota State Water Commission is 900 gal/min. The storage coefficient indicates that the aquifer is confined. There are no data available to indicate transmissivity and storage values in the lower zone, so yields from this zone cannot be estimated.

Water levels in wells on the east side of the Little Muddy River indicate that the potentiometric surface in both zones slopes westward toward the river. There are insufficient data to determine the slope of the potentiometric surface on the west side of the river, but it too probably slopes toward the river. Water levels in a pair of observation wells at 158-100-08DAA indicate that the hydraulic head in the lower zone is about 4 ft higher than the hydraulic head in the upper zone. The fact that a few test wells near the Little Muddy River are finished in the lower zone and flow, whereas those finished in the upper zone do not flow, also indicates a higher hydraulic head in the lower zone. The difference in hydraulic head indicates that some leakage may occur from the lower to the upper zone.

Water in the upper zone of the Little Muddy aquifer in the study area differs in quality from place to place. Generally, the water is very hard, having hardness concentrations as calcium carbonate considerably greater than 180 mg/L. Sodium generally is the most abundant cation present, ranging from 34 to 68 percent of the total cations. However, calcium may be the most abundant cation and in T. 158 N., R. 100 W., magnesium may be the predominant cation. Sulfate concentrations ranged from 440 to 880 mg/L and exceeded bicarbonate concentrations in six of nine samples. Dissolved-solids concentrations ranged from 1,030 to 2,050 mg/L.

Well 158-100-08DAA1 is 160 ft deep and finished in the lower aquifer zone. Water from this well is a sodium sulfate type and contained 390 mg/L hardness and 360 mg/L sodium, which was 66 percent of the cations. The sulfate concentration was 560 mg/L, and the dissolved-solids concentration was 1,420 mg/L.

## Grenora Aquifer

The Grenora aquifer underlies about 22 $mi^2$ in the northwest corner of Williams County (Armstrong, 1969, p. 48). The aquifer is composed of a basal gravel and an upper predominantly fine to coarse sand and gravel. The aquifer materials were deposited in an ancestral valley of the Missouri

River (Alden, 1932, p. 45). Two test holes penetrated the full thickness of the aquifer in Williams County; test hole 159-103-06DDD contained 109 ft of saturated sand and gravel and test hole 159-103-10BBB contained 116 ft.

Wells completed in the Grenora aquifer generally yield only a few gallons per minute, but yields generally are limited by pump size or by wells that penetrate only a small section of the aquifer. Armstrong (1969, p. 49) estimated that the transmissivity of the thicker parts of the aquifer is more than 100,000 (gal/d)/ft or 13,400 $ft^2/d$. If the estimate is right, then wells with specific capacities as large as 50 (gal/min)/ft of drawdown could be developed in the more permeable zones. Yields of more than 1,000 gal/min could be obtained, but the quality of water in the basal gravel is not as desirable as the water in the upper part of the aquifer, so the basal gravel probably will not be developed. Estimations of the transmissivity of the Grenora aquifer, excluding the basal gravel, range from 4,000 to about 8,000 $ft^2/d$. Therefore, specific capacities of wells finished in the upper part of the aquifer should range from about 15 to 30 (gal/min)/ft of drawdown and well yields with 30 ft of drawdown would range from about 450 to 900 gal/min.

Three water samples have been collected from wells finished in the Grenora aquifer. Well 159-103-10BBB is finished in the basal gravel of the aquifer. The water was a sodium bicarbonate type and contained 430 mg/L hardness, 1,480 mg/L dissolved solids, and 400 mg/L sulfate. The sodium adsorption ratio was 8. Well 159-103-06DDD is finished in the upper part of the Genora aquifer. The water was a sodium bicarbonate type and contained 410 mg/L hardness, 1,090 mg/L dissolved solids, and 319 mg/L sulfate. The sodium-adsorption ratio was 5.1. Well 159-105-12CAD is a 38-foot well finished in the uppermost part of the aquifer. Water from this well was a calcium bicarbonate type and contained only 477 mg/L dissolved solids.

## SURFACE WATER

The Sand Creek-Hanks lignite area generally is drained by streams in the northern part of the Missouri River drainage basin. However, the area does include a few small, closed drainage basins in the northwestern part that do not contribute to the Missouri River. Painted Woods Creek, Sand Creek, and the Little Muddy River flow directly into the Missouri River, and Camp, Cow, Blacktail, and Scorio Creeks and Chinaman, Heideman, and Pats Coulees flow into the Little Muddy River (fig. 2). Cottonwood Creek and its tributary Willow Creek in the northwestern part of the area flow westward to Montana.

All of the streams in the lignite area except the Little Muddy River apparently are ephemeral or intermittent. The flow or conditions at several sites on each stream during visits in 1982 are shown in table 2. In addition, records of the U.S. Geological Survey show that flow measurements (supplements 1-4) were made between 1955 and 1974 at three stations on Painted Woods Creek and tributaries, sites 4, 5, and 7, and one station on Sand Creek, site 10 (fig. 4). Site 24 was discontinued in 1960 after a dam was constructed at the site. A continuous-record station, site 17, has been maintained on the Little Muddy River about a mile downstream from its junction with Cow Creek. Conditions at this station, although outside the study



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Table 2.--*Discharge in streams*

[$ft^3/s$, cubic feet per second; < indicates less than; E indicates estimated flow]

| Site number | Stream | Status of flow ($ft^3/s$) | Date | Remarks |
|---|---|---|---|---|
| 1 | Painted Woods Creek | 0.5E | 7/19/82 | Conditions good. |
| | | 0.66 | 11/09/82 | Measured. |
| 2 | Painted Woods Creek | Small flow | 7/19/82 | No estimate of flow. |
| 3 | Painted Woods Creek | Dry | 7/19/82 | |
| 4 | Painted Woods Creek | Ponds | 7/19/82 | No flow between ponds in channel. |
| | | 0.1 | 11/09/82 | Measured. |
| 5 | Painted Woods Creek Tributary No. 1 | Dry | 7/19/82 | |
| 6 | Painted Woods Creek | Ponds | 7/19/82 | No flow between ponds in channel. |
| 7 | Painted Woods Creek Tributary No. 2 | Ponds | 7/19/82 | No flow; few ponds in channel. |
| 8 | Painted Woods Creek Tributary No. 2 | Small flow | 7/19/92 | Small flow through culvert under road. Dry channel about 600 feet downstream. |
| 9 | Painted Woods Creek Tributary No. 2 | Dry | 7/19/82 | |
| 10 | Sand Creek | Trickle | 7/19/82 | |
| 11 | Sand Creek | 0.2E | 7/19/82 | Conditions poor; weeds in channel. |
| | | 0.33 | 11/09/82 | Measured. |
| 12 | Sand Creek | Ponds | 7/19/82 | No flow between ponds in channel. |
| 13 | Sand Creek | Ponds | 7/19/82 | Water in weeds in channel; no apparent flow. |
| 14 | Sand Creek | Ponds | 7/19/82 | No flow between ponds in channel. |
| 15 | Chinaman Coulee | Dry | 7/20/82 | |
| 16 | Camp Creek | Dry | 7/20/82 | |
| 17 | Little Muddy River | 12 | 7/20/82 | |
| | | 13 | 11/09/82 | Water-stage recorder; daily mean discharge. |
| 18 | Cow Creek | 0.3E | 7/20/82 | Average depth estimate poor. |
| 19 | Cow Creek | 0.05E | 7/20/82 | Flow through culvert. |
| 20 | Cow Creek | <0.01E | 7/20/82 | Flow considerably less than at site 19. |
| 21 | Cow Creek | <0.02 | 7/20/82 | Flow considerably less than at site 19. |
| 22 | Cow Creek Tributary | Dry | 7/20/82 | |
| 23 | Blacktail Creek | Small flow | 7/20/82 | Water in weeds in channel; slow downstream movement. |
| 24 | Blacktail Creek | Small flow | 7/20/82 | Water in weeds. |
| 25 | Heidemann Coulee | Dry | 7/20/82 | |
| 26 | Pats Coulee | Ponds | 7/20/82 | No flow between ponds in channel. |
| 27 | Scorio Creek | No flow | 7/20/82 | |
| 28 | Scorio Creek | No flow | 7/20/82 | Nearly continuous water in channel. |
| 29 | Willow Creek | Ponds | 7/20/82 | Depth and width too variable for estimate. |
| 30 | Willow Creek | 0.01E | 7/20/82 | Conditions good. |
| 31 | Cottonwood Creek | Small flow | 7/20/82 | Rate and area too variable for good estimate. |
| 32 | Cottonwood Creek | Ponds | 7/20/82 | No flow between ponds in channel. |

area, were used as an indicator of what was occurring at the various creeks within the study area.

Records show that the streamflows have large seasonal fluctuations. The largest flows occur in the spring as a result of snowmelt and rainfall. Other flows in most of the streams generally occur after intense thunderstorms or after a period when a few inches of rain falls within several days. The low flow is water that discharges from ground water through seeps and springs to form the base flow of the stream.

A study of the few records that are available for Painted Woods and Sand Creeks (table 2 and supplements 1-4) indicates that there is an approximate correlation between the duration of flows in the Little Muddy River and Sand Creek. The flow-duration curve for the Little Muddy River is shown in figure 5. Generally, when flows in the Little Muddy River exceeded 20 $ft^3/s$, there was flow in Sand Creek that exceeded a few tenths of a cubic foot per second. When flow in the Little Muddy River was between 8 and 20 $ft^3/s$, there generally was a few hundreths to a few tenths of a cubic foot per second flow in Sand Creek, although there were days of no flow. When flow in the Little Muddy River was less than 8 $ft^3/s$, there generally was no flow in Sand Creek. Generally, when there was no flow in Sand Creek, there also was no flow in Painted Woods Creek.

No measurements were made at the downstream ends of Cottonwood and Willow Creeks during this study. However, local residents reported that both creeks ceased to flow during most years. The residents also reported that some of the deeper holes in the creek channels contained water for long periods during most summers. This water probably can be attributed to the fact that the water table is near the level of the creek beds.

Three water samples have been obtained from the streams in the study area. The samples were obtained on November 9, 1982, at sites 1 and 4 on Painted Woods Creek and site 11 on Sand Creek (fig. 4). At the time of sampling, the flow at site 1 was 0.66 $ft^3/s$; at site 4, the flow was 0.10 $ft^3/s$; and at site 11, the flow was 0.32 $ft^3/s$. Hardness at the three sites ranged from 320 to 550 mg/L. The dominant cation at all sites was sodium, and the dominant anion was sulfate. Sulfate concentrations ranged from 450 to 990 mg/L and dissolved-solids concentrations ranged from 1,270 to 2,280 mg/L. The largest concentrations of sodium and of the common anions were in the sample from site 11 on Sand Creek. The analyses of water from Painted Woods and Sand Creeks indicate that most, if not all, of the water in the streams at the time of sampling was discharged from the ground water system.

## SUMMARY

Ground water in the Sand Creek-Hanks lignite area can be obtained from aquifers in the Fox Hills Sandstone and Hell Creek Formations of Cretaceous age, from aquifers in sandstone and lignite beds in the Tongue River and Sentinel Butte Members of the Fort Union Formation of Tertiary age, and from glacial-drift aquifers of Quaternary age.

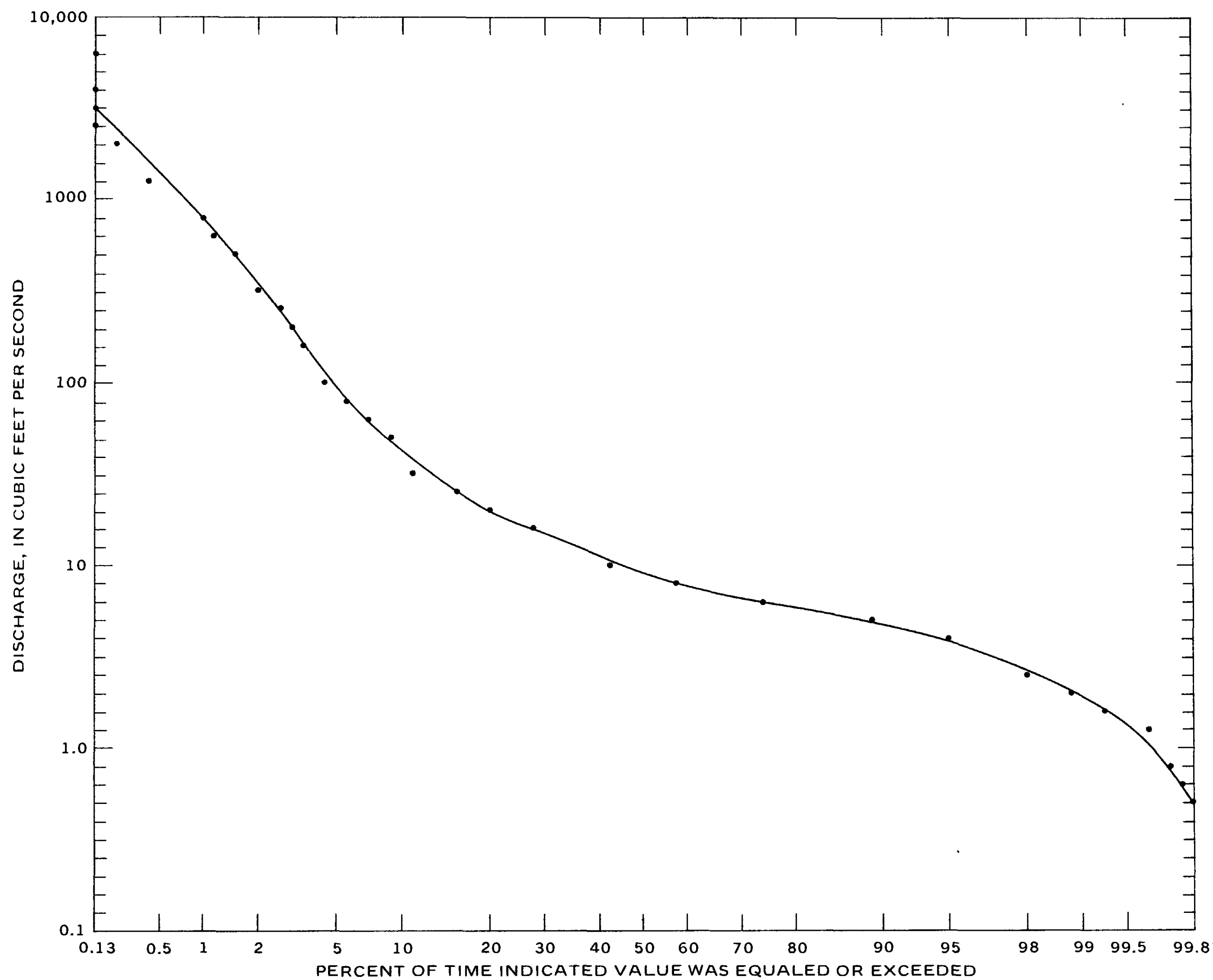


**Figure 5.—Flow-duration curve for the Little Muddy River at site 17.**

Depths to the top of the Fox Hills Sandstone ranges from about 1,200 ft in some of the topographically low areas in the north part of the area to about 2,000 ft beneath some of the topographically higher areas in the south. The thickness of individual sand lenses generally ranges from about 30 to 60 ft. Yields from the aquifer could range from about 5 to 60 gal/min with 100 ft of drawdown. Analyses of water samples from the Fox Hills aquifer indicate the water is soft and a sodium bicarbonate type. Water samples contained 1,300 to 2,100 mg/L dissolved solids and 2.4 to 5.9 mg/L fluoride.

Depths to the top of the Hell Creek Formation ranges from about 900 ft in the lower areas in northern Williams County to about 1,600 ft beneath some of the topographically higher areas in the south-central part of the study area. Individual sand lenses in the formation generally are less than 50 ft thick. Based on data from the surrounding area, well yields would range from less than 10 to about 40 gal/min with 100 ft of drawdown. The quality of water probably is similar to that in the Fox Hills aquifer, but dissolved-solids concentrations could range from about 1,000 to 2,200 mg/L.

The Tongue River and Sentinel Butte Members of the Fort Union Formation were deposited under similar environmental conditions and consist of interbedded lenses of sandstone, siltstone, claystone, and lignite. The Tongue River Member may be as much as 550 ft thick and the Sentinel Butte Member, which crops out in the area, may be as much as 520 ft thick. The total thickness is not known to exceed 1,000 ft. Individual sandstone beds may be as thick as 65 ft in the Tongue River Member and as much as 110 ft thick in the Sentinel Butte Member. However, individual sandstone beds in both members generally are less than 15 ft thick. Yields from wells finished in sandstone aquifers in the Fort Union Formation may be as much as 40 gal/min, but, generally, most wells yield from 2 to 5 gal/min. Lignite beds are as much as 20 ft thick but generally are less than 5 ft thick. Wells finished in lignite beds commonly yield more than 1 gal/min.

Analyses of water from wells in the Tongue River Member are not available. Analyses of water from 21 wells in the Sentinel Butte Member show that water from deeper wells generally contains comparatively large concentrations of sodium and bicarbonate and comparatively small concentrations of calcium and magnesium. Water from shallower wells contains a larger proportion of calcium and magnesium, and the calcium concentrations may exceed those of sodium. Sulfate concentrations ranged from 150 to 2,200 mg/L. The median value was 500 mg/L. Dissolved-solids concentrations ranged from about 800 to 4,100 mg/L and had a median value of 1,480 mg/L.

Glacial drift covers most of the Sand Creek-Hanks area. The thickness of the glacial drift ranges from a veneer in some topographically high areas to about 380 ft in some of the larger valleys. Individual sand and gravel lenses generally are thin to nonexistent in the higher areas but may be as much as 116 ft thick in valleys. Well yields from the glacial drift generally are a few gallons per minute except in the larger valleys where as much as 900 gal/min could be pumped. Water in the glacial drift generally contains more than 180 mg/L hardness. Either sodium or calcium may be the dominant cation, and either bicarbonate or sulfate may be the dominant anion. Dissolved-solids concentrations in samples generally ranged from 477 to 2,050 mg/L.

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 completed in the lignite or overlying beds in the mined area will be destroyed, but new wells can be finished in the deeper aquifers. The mining also will expose 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 aquifers will result. Because of the minimal permeability of the beds beneath the lignite to be mined and the dilution effect of water already in the underlying aquifers, increases in dissolved-solids and sulfate concentrations are expected to be minimal.

When mining occurs, the overburden will be moved and sand lenses will be destroyed and mixed with clay. The mixed materials will be less compact than the original materials, and recharge from precipitation may be increased. However, the destruction of the sand and lignite beds probably will retard the lateral movement of water so the movement of water toward the creeks will be retarded. The result probably will be a small decrease in base flow in streams near the mined area and the concentration of dissolved solids and sulfate in the water may undergo a small increase.

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Supplement 1.--*Miscellaneous streamflow measurements for Painted Woods Creek near Williston,* 154-103-01AB, *site* 4, 1955-74

[$ft^3/s$, cubic feet per second; E indicates estimated flow]

| Date | Flow ($ft^3/s$) | Date | Flow ($ft^3/s$) |
|---|---|---|---|
| 03/13/55 | 13.99 | 06/01/60 | 0 |
| 03/29/55 | Fast flow | 06/15/60 | 0 |
| 05/25/55 | 0 | 07/08/60 | 0 |
| 06/14/55 | 0 | 07/29/60 | 0 |
| 07/22/55 | 0 | 08/24/60 | 0 |
| 09/14/55 | 0 | 09/09/60 | 0 |
| 03/20/56 | 27.4 | 09/21/60 | 0 |
| 04/26/56 | 0 | 03/04/61 | 3.81 |
| 06/12/56 | 0 | 03/08/61 | 2E |
| 06/29/56 | 0 | 03/22/61 | .6 |
| 07/25/56 | 0 | 04/06/61 | 0 |
| 08/22/56 | 0 | 04/20/61 | 0 |
| 10/04/56 | 0 | 05/03/61 | 0 |
| 11/02/56 | 0 | 05/18/61 | 0 |
| 11/04/56 | 0 | 06/01/61 | 0 |
| 03/14/57 | .25E | 06/29/61 | 0 |
| 05/03/57 | 0 | 07/27/61 | 0 |
| 10/04/57 | 0 | 08/24/61 | 0 |
| 04/01/58 | 1.83 | 09/12/61 | 0 |
| 05/08/58 | 0 | 03/22/62 | 65.1 |
| 06/20/58 | 0 | 04/19/62 | 0 |
| 07/01/58 | 0 | 05/03/62 | 0 |
| 07/29/58 | 0 | 05/18/62 | 0 |
| 08/13/58 | 0 | 06/07/62 | 0 |
| 08/27/58 | 0 | 06/22/62 | 0 |
| 09/05/58 | 0 | 07/06/62 | 0 |
| 10/10/58 | 0 | 07/19/62 | 0 |
| 10/30/58 | 0 | 08/17/62 | 0 |
| 03/26/59 | 3.45 | 08/29/62 | 0 |
| 05/01/59 | 0 | 09/28/62 | 0 |
| 06/05/59 | 0 | 10/04/62 | 0 |
| 07/01/59 | 0 | 10/18/62 | 0 |
| 08/28/59 | 0 | 03/06/63 | 1E |
| 11/03/59 | 0 | 04/17/63 | .5E |
| 03/30/60 | 11.8 | 05/24/63 | 0 |

Supplement 1.--*Miscellaneous streamflow measurements for Painted Woods Creek near Williston,* 154-103-01AB, *site* 4, 1955-74--Continued

| Date | Flow ($ft^3/s$) | Date | Flow ($ft^3/s$) |
|---|---|---|---|
| 06/24/63 | 0 | 03/02/68 | 9E |
| 08/28/63 | 0 | 03/13/68 | .1E |
| 09/20/63 | 0 | 06/19/68 | .1 |
| 04/13/64 | 2E | 07/19/68 | 0 |
| 04/29/64 | 0 | 08/29/68 | .1 |
| 06/10/64 | 0 | 10/09/68 | .2 |
| 07/05/64 | 0 | 03/23/69 | 1E |
| 07/23/64 | 0 | 04/01/69 | 4E |
| 02/19/65 | 0 | 04/04/69 | 55 |
| 04/02/65 | 0 | 04/24/69 | .1 |
| 04/07/65 | 0 | 06/04/69 | 0 |
| 04/09/65 | 0 | 07/16/69 | .5 |
| 04/15/65 | 8.39 | 08/02/69 | 0 |
| 04/27/65 | 2E | 03/18/70 | 2.5E |
| 05/07/65 | 9.62 | 03/26/70 | .03E |
| 05/26/65 | 16.2 | 04/08/70 | 4E |
| 06/04/65 | 2 to 3E | 05/05/70 | .5E |
| 06/17/65 | 0 | 05/21/70 | 0.03E |
| 07/19/65 | 0 | 06/17/70 | 2E |
| 08/11/65 | 0 | 06/30/70 | 0 |
| 08/26/65 | 0 | 07/17/70 | 0 |
| 09/08/65 | 0 | 07/31/70 | 0 |
| 11/02/65 | 0 | 09/24/70 | .03E |
| 03/12/66 | .7E | 10/07/70 | .1E |
| 03/14/66 | 30E | 02/28/71 | 0 |
| 03/22/66 | 5 | 04/01/71 | 5 |
| 05/18/66 | 1.2 | 04/07/71 | 4.8 |
| 06/16/66 | .1 | 05/03/71 | 0 |
| 08/09/66 | 0 | 05/05/71 | .03E |
| 10/18/66 | .2 | 06/03/71 | .5E |
| 03/26/67 | 41.7 | 06/18/71 | .3E |
| 03/29/67 | 6 to 8E | 07/16/71 | .5E |
| 05/22/67 | .05E | 07/22/71 | .01E |
| 09/26/67 | 0 | 08/04/71 | 0 |
| 01/25/68 | 1E | 09/09/71 | 0 |

Supplement 1.--*Miscellaneous streamflow measurements for Painted Woods Creek near Williston,* 154-103-01AB, *site 4,* 1955-74--Continued

| Date | Flow ($ft^3/s$) | Date | Flow ($ft^3/s$) |
| --- | --- | --- | --- |
| 10/07/71 | .05 | 09/16/73 | .08 |
| 03/15/72 | 922 | 10/03/73 | .3 |
| 04/04/72 | 1.37 | 04/05/74 | 21.6 |
| 05/04/72 | 1.2E | 04/17/74 | 2.21 |
| 06/15/72 | 1.5E | 05/01/74 | .6 |
| 07/12/72 | .02E | 05/24/74 | 0 |
| 09/14/72 | 1 | | |
| 10/04/72 | .5E | | |
| 02/28/73 | .65 | | |
| 03/07/73 | 3.5E | | |
| 04/05/73 | 2.74 | | |
| 05/15/73 | .1E | | |
| 06/18/73 | .01E | | |
| 07/16/73 | 0 | | |
| 08/01/73 | 0 | | |

Supplement 2.-- *Miscellaneous streamflow measurements for Painted Woods Creek, Tributary No.* 1, 155-103-35AD, *site* 5, 1955-74

[$ft^3/s$, cubic feet per second; E indicates estimated flow]

| Date | Flow ($ft^3/s$) | Date | Flow ($ft^3/s$) |
|---|---|---|---|
| 03/14/55 | 0 | 07/29/60 | 0 |
| 03/29/55 | 686 | 08/24/60 | 0 |
| 05/25/55 | 0 | 09/09/60 | 0 |
| 06/14/55 | 0 | 09/21/60 | 0 |
| 07/22/55 | 0 | 03/04/61 | T |
| 03/20/56 | .5E | 03/22/61 | 0 |
| 04/26/56 | 0 | 04/06/61 | 0 |
| 06/12/56 | 0 | 04/20/61 | 0 |
| 06/29/56 | 0 | 05/03/61 | 0 |
| 07/25/56 | 0 | 06/01/61 | 0 |
| 08/22/56 | 0 | 06/29/61 | 0 |
| 10/04/56 | 0 | 07/27/61 | 0 |
| 11/02/56 | 0 | 08/24/61 | 0 |
| 03/14/57 | 0 | 09/12/61 | 0 |
| 05/03/57 | 0 | 03/22/62 | 1.2 |
| 10/04/57 | 0 | 04/19/62 | 0 |
| 04/01/58 | 0 | 05/03/62 | 0 |
| 04/24/58 | 0 | 06/07/62 | 0 |
| 06/20/58 | 0 | 07/06/62 | 0 |
| 07/01/58 | 0 | 08/17/62 | 0 |
| 07/29/58 | 0 | 08/29/62 | 0 |
| 08/13/58 | 0 | 09/28/62 | 0 |
| 09/05/58 | 0 | 10/18/62 | 0 |
| 10/10/58 | 0 | 03/06/63 | Trickle |
| 10/30/58 | 0 | 04/17/63 | 0 |
| 03/26/59 | 0 | 05/24/63 | 0 |
| 05/01/59 | 0 | 06/24/63 | 0 |
| 06/05/59 | 0 | 07/01/63 | 0 |
| 06/26/59 | 47.8 | 08/28/63 | 0 |
| 07/01/59 | 0 | 09/20/63 | 0 |
| 08/28/59 | 0 | 04/13/64 | 0 |
| 11/03/59 | 0 | 04/29/64 | 0 |
| 03/30/60 | 5E | 06/10/64 | 0 |
| 06/15/60 | 0 | 07/05/64 | 0 |
| 07/08/60 | 0 | 07/23/64 | 0 |

Supplement 2.-- *Miscellaneous streamflow measurements for Painted Woods Creek, Tributary No.* 1, 155-103-35AD, *site* 5, 1955-74--Continued

| Date | Flow ($ft^3/s$) | Date | Flow ($ft^3/s$) |
|---|---|---|---|
| 02/19/65 | 0 | 02/18/71 | 0 |
| 04/02/65 | 0 | 05/03/71 | 0 |
| 04/15/65 | 0 | 05/13/71 | .28 |
| 04/27/65 | 0 | 06/03/71 | 0 |
| 05/07/65 | 0 | 06/18/71 | 0 |
| 05/26/65 | .2E | 07/16/71 | 0 |
| 06/04/65 | 0 | 08/04/71 | 0 |
| 07/07/65 | 0 | 09/09/71 | 0 |
| 08/11/65 | 0 | 10/07/71 | 0 |
| 09/08/65 | 0 | 03/15/72 | 18.8 |
| 11/02/65 | 0 | 04/04/72 | 0 |
| 03/12/66 | .2E | 05/04/72 | 0 |
| 03/22/66 | 0 | 06/15/72 | 0 |
| 05/18/66 | 0 | 07/12/72 | 0 |
| 06/16/66 | 0 | 08/07/72 | 0 |
| 08/09/66 | 0 | 09/14/72 | 0 |
| 10/18/66 | 0 | 10/04/72 | 0 |
| 03/23/67 | 0 | 02/28/73 | 0 |
| 03/26/67 | 6E | 03/07/73 | .03E |
| 03/29/67 | .1E | 04/05/73 | 0 |
| 05/22/67 | 0 | 05/15/73 | 0 |
| 08/02/67 | 0 | 06/18/73 | 0 |
| 09/26/67 | 0 | 07/16/73 | 0 |
| 03/26/69 | .1E | 08/01/73 | 0 |
| 04/04/69 | .4E | 09/06/73 | 0 |
| 04/24/69 | 0 | 10/03/73 | 0 |
| 06/04/69 | 0 | 04/05/74 | .12 |
| 07/16/69 | 0 | 04/17/74 | 0 |
| 08/21/69 | 0 | 05/01/74 | 0 |
| 03/18/70 | .1E | | |
| 05/05/70 | 0 | | |
| 06/17/70 | 0 | | |
| 07/31/70 | 0 | | |
| 09/24/70 | 0 | | |
| 10/07/70 | 0 | | |

Supplement 3.--*Miscellaneous streamflow measurements for Painted Woods Creek, Tributary No. 2, 155-102-21CC, site 7, 1955-74*

[ft$^3$/s, cubic feet per second; E indicates estimated flow]

| Date | Flow (ft$^3$/s) | Date | Flow (ft$^3$/s) |
|---|---|---|---|
| 03/14/55 | 13.8 | 08/24/60 | 0 |
| 03/29/55 | 15.4 | 09/09/60 | 0 |
| 05/25/55 | 0 | 09/21/60 | 0 |
| 06/14/55 | 0 | 03/04/61 | .25E |
| 07/22/55 | 0 | 03/23/61 | 0 |
| 03/20/56 | 2E | 04/06/61 | 0 |
| 06/12/56 | 0 | 04/20/61 | 0 |
| 06/29/56 | 0 | 05/03/61 | 0.1 |
| 07/25/56 | 0 | 05/18/61 | 0 |
| 08/22/56 | 0 | 06/01/61 | 0 |
| 10/04/56 | 0 | 07/27/61 | 0 |
| 11/02/56 | 0 | 08/22/61 | 0 |
| 03/14/57 | 0 | 09/12/61 | 0 |
| 05/03/57 | 0 | 03/22/62 | 0 |
| 10/04/57 | 0 | 04/19/62 | 0 |
| 04/01/58 | 0 | 05/18/62 | 0 |
| 04/24/58 | 0 | 06/07/62 | 0 |
| 05/08/58 | 0 | 07/06/62 | 0 |
| 06/20/58 | 0 | 08/17/62 | 0 |
| 07/01/58 | 0 | 09/28/62 | 0 |
| 07/29/58 | 0 | 10/04/62 | 0 |
| 08/13/58 | 0 | 10/18/62 | 0 |
| 08/27/58 | 0 | 03/06/63 | .5 |
| 09/05/58 | 0 | 04/17/63 | 0 |
| 10/30/58 | 0 | 05/24/63 | 0 |
| 03/26/59 | .1E | 06/24/63 | 0 |
| 05/01/59 | 0 | 07/11/63 | 0 |
| 06/05/59 | 0 | 08/28/63 | 0 |
| 07/01/59 | 0 | 09/20/63 | 0 |
| 08/28/59 | 0 | 04/13/64 | 0 |
| 11/03/59 | 0 | 04/29/64 | 0 |
| 03/30/60 | 0 | 06/10/64 | 0 |
| 06/15/60 | 0 | 07/05/64 | 0 |
| 07/08/60 | 0 | 07/23/64 | 0 |
| 07/29/60 | 0 | 02/19/65 | 0 |

Supplement 3.--*Miscellaneous streamflow measurements for Painted Woods Creek, Tributary No. 2,* 155-102-21CC, *site* 7, 1955-74--Continued

| Date | Flow ($ft^3/s$) | Date | Flow ($ft^3/s$) |
|---|---|---|---|
| 04/07/65 | 0 | 04/24/69 | 0 |
| 04/09/65 | 6.2 | 06/04/69 | 0 |
| 04/15/65 | .1E | 07/16/69 | 0 |
| 04/27/65 | 0 | 08/21/69 | 0 |
| 05/07/65 | .4E | 03/26/70 | 0 |
| 05/26/65 | .5E | 04/08/70 | .02E |
| 06/04/65 | .4E | 05/05/70 | .1E |
| 06/17/65 | 2 | 05/21/70 | 0 |
| 07/07/65 | 0 | 06/17/70 | 0 |
| 07/19/65 | 0 | 07/17/70 | 0 |
| 08/11/65 | 0 | 08/06/70 | 0 |
| 09/08/65 | 0 | 09/24/70 | 0 |
| 11/02/65 | 0 | 10/07/70 | 0 |
| 03/14/66 | 6.8 | 03/03/71 | 0 |
| 03/22/66 | 0 | 04/01/71 | 1E |
| 05/18/66 | 0 | 04/07/71 | .03E |
| 06/16/66 | 0 | 05/05/71 | 0 |
| 08/09/66 | 0 | 05/13/71 | 23.2 |
| 10/18/66 | 0 | 06/03/71 | 0 |
| 03/23/67 | 0 | 06/18/71 | 0 |
| 03/26/67 | 31 | 07/16/71 | 0 |
| 03/29/67 | 3 to 5E | 09/09/71 | 0 |
| 05/22/67 | 0 | 10/07/71 | 0 |
| 08/02/67 | 0 | 03/15/72 | 150 |
| 09/26/67 | 0 | 04/04/72 | 0 |
| 01/25/68 | 1.5E | 05/04/72 | .2 |
| 03/02/68 | .05E | 06/15/72 | .05E |
| 03/13/68 | 0 | 07/12/72 | .01E |
| 06/19/68 | 0 | 08/07/72 | 0 |
| 07/19/68 | 0 | 10/04/72 | 0 |
| 08/29/68 | 0 | 02/28/73 | 0 |
| 10/09/68 | 0 | 03/07/73 | .01E |
| 03/26/69 | 0 | 04/05/73 | 0 |
| 04/01/69 | .1E | 05/15/73 | 0 |
| 04/04/69 | 18.2 | 06/18/73 | 0 |

Supplement 3.-- *Miscellaneous streamflow measurements for Painted Woods Creek, Tributary No.* 2, 155-102-21CC, *site* 7, 1955-74--Continued

| Date | Flow ($ft^3/s$) | Date | Flow ($ft^3/s$) |
|---|---|---|---|
| 07/16/73 | 0 | 04/17/74 | 0 |
| 08/01/73 | 0 | 05/01/74 | 0 |
| 09/16/73 | 0 | 05/24/74 | 0 |
| 10/03/73 | 0 | | |
| 04/05/74 | 15.74 | | |

Supplement 4.--*Miscellaneous streamflow measurements for Sand Creek near Williston,* 154-101-22DB, *site* 10, 1955-74

[ft³/s, cubic feet per second; E indicates estimated flow]

| Date | Flow (ft³/s) | Date | Flow (ft³/s) |
|---|---|---|---|
| 03/14/55 | 0 | 08/24/60 | 0 |
| 03/29/55 | 121 | 09/09/60 | 0 |
| 05/25/55 | .4 | 09/21/60 | T |
| 06/14/55 | .11 | 03/04/61 | 4.47 |
| 06/28/55 | .11 | 03/09/61 | 3 to 4E |
| 07/22/55 | 0 | 04/20/61 | .1E |
| 09/14/55 | 0 | 05/04/61 | .25E |
| 03/20/56 | 14.1 | 05/19/61 | 0 |
| 04/26/56 | .1 to .2E | 06/01/61 | 0 |
| 06/29/56 | .03E | 06/19/61 | 0 |
| 07/12/56 | .01 | 07/27/61 | 0 |
| 08/22/56 | 0 | 08/24/61 | 0 |
| 10/04/56 | .006 | 09/12/61 | .2 |
| 11/02/56 | 0 | 03/21/62 | 45.4 |
| 11/21/56 | .1E | 04/19/62 | .33 |
| 03/14/57 | 3.52 | 05/03/62 | 0 |
| 10/04/57 | 0 | 05/18/62 | .05E |
| 03/25/58 | 66 | 06/07/62 | .05E |
| 04/01/58 | 1.36 | 07/19/62 | .05E |
| 04/24/58 | .5 | 08/17/62 | 0 |
| 05/08/58 | 0 | 08/29/62 | 0 |
| 07/01/58 | 0 | 09/27/62 | 0 |
| 07/29/58 | 0 | 10/04/62 | 0 |
| 08/13/58 | 0 | 10/18/62 | .1 |
| 08/27/58 | 0 | 03/06/63 | 17 |
| 09/05/58 | 0 | 04/17/63 | .5 |
| 10/30/58 | 0 | 06/24/63 | 0 |
| 03/18/59 | 490 | 07/10/63 | 196 |
| 03/26/59 | 3.48 | 08/26/63 | 0 |
| 06/05/59 | 0 | 09/20/63 | 0 |
| 11/03/59 | T | 04/13/64 | 2E |
| 03/30/60 | 35.2 | 06/10/64 | 0 |
| 06/01/60 | T | 07/05/64 | 10 |
| 06/15/60 | T | 07/23/64 | 0 |
| 06/20/60 | T | 02/19/65 | 0 |

Supplement 4.-- *Miscellaneous streamflow measurements for Sand Creek near Williston,* 154-101-22DB, *site* 10, 1955-74--Continued

| Date | Flow ($ft^3/s$) | Date | Flow ($ft^3/s$) |
|---|---|---|---|
| 04/02/65 | 2.5E | 10/09/68 | 0.2E |
| 04/07/65 | 8E | 03/23/69 | 2.5E |
| 04/15/65 | 4E | 03/26/69 | 10E |
| 04/27/65 | 2.5E | 03/28/69 | 7E |
| 05/07/65 | 10E | 04/01/69 | 18E |
| 05/26/65 | 53.8 | 04/04/69 | 232 |
| 06/04/65 | 10E | 04/25/69 | .2E |
| 06/17/65 | 2.5E | 05/20/69 | .1E |
| 07/07/65 | 0 | 06/20/69 | 0 |
| 07/20/65 | .04E | 07/16/69 | .5E |
| 08/11/65 | 0 | 07/30/69 | .2E |
| 08/26/65 | 0 | 03/18/70 | 3E |
| 09/08/65 | .03E | 03/26/70 | 1.4 |
| 11/01/65 | .01E | 04/09/70 | 1.58 |
| 03/12/66 | 46.9 | 05/05/70 | 3E |
| 03/14/66 | 55E | 05/22/70 | 1.1E |
| 03/22/66 | 5E | 06/18/70 | 1E |
| 05/18/66 | 1E | 07/17/70 | 0 |
| 06/16/66 | .01 | 07/29/70 | .02E |
| 08/10/66 | 0 | 09/24/70 | .7E |
| 10/19/66 | 0 | 10/08/70 | 1E |
| 03/26/67 | 92 | 02/18/71 | 1E |
| 03/29/67 | 30 to 40E | 04/01/71 | 6E |
| 05/23/67 | .1E | 05/03/71 | 2.66 |
| 07/19/67 | 0 | 05/05/71 | .8E |
| 08/02/67 | 0 | 05/14/71 | 199 |
| 09/26/67 | 0 | 06/03/71 | .5E |
| 01/25/68 | .2E | 07/02/71 | 1.3E |
| 03/02/68 | 15.2 | 07/15/71 | 2E |
| 03/07/68 | 2E | 08/05/71 | 0 |
| 03/12/68 | .2E | 09/10/71 | .05E |
| 05/21/68 | .05E | 10/06/71 | .39 |
| 06/19/68 | .2E | 03/16/72 | 1,140 |
| 07/17/68 | .01E | 04/05/72 | 1.5E |
| 08/28/68 | .1 to .2E | 04/06/72 | 2.25 |

Supplement 4.-- *Miscellaneous streamflow measurements for Sand Creek near Williston,* 154-101-22DB, *site* 10, 1955-74--Continued

| Date | Flow (ft³/s) | Date | Flow (ft³/s) |
|---|---|---|---|
| 05/04/72 | 2 | 06/18/73 | .3E |
| 06/15/72 | 1.5E | 07/16/73 | 0 |
| 07/13/72 | .01E | 08/01/73 | 0 |
| 08/07/72 | 0 | 09/07/73 | .1E |
| 09/12/72 | .05E | 10/03/73 | .2E |
| 10/05/72 | .5E | 04/05/74 | 33.6 |
| 02/06/73 | 6E | 04/11/74 | 7.62 |
| 03/01/73 | 1.16 | 05/01/74 | 1E |
| 03/21/73 | 2.84 | | |
| 04/05/73 | .61 | | |