WATER RESOURCES AND POTENTIAL EFFECTS OF SURFACE COAL MINING IN THE AREA OF THE WOODSON PREFERENCE RIGHT LEASE APPLICATION, MONTANA

By M.R. Cannon

U.S. GEOLOGICAL SURVEY

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DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

The following factors can be used to convert inch-pound units in this report to the International System (SI) of units.

Multiply inch-pound unit	By	To obtain SI unit
	Length	
foot	0.3048	meter
inch	25.40	millimeter
mile	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
acre-foot	1,233	cubic meter
	Weight	
ton (short)	0.9072	megagram
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
	Gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$°C = 5/9\ (°F - 32)$$
$$°F = 9/5\ (°C) + 32$$

Sea level: In this report "sea level" refers to the 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 of 1929."

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ABSTRACT

Federal coal lands of the Woodson Preference Right Lease Application are located in Dawson and Richland Counties, northeastern Montana. A probable mine area, comprised of the lease area and adjacent coal lands, contains about 220 million tons of recoverable lignite coal in the 12- to 37-foot-thick Pust coal bed. A hydrologic study has been conducted in the area to describe the water resources and to evaluate potential effects of coal mining on the water resources.

Hydrogeologic data collected from wells and springs indicate that several aquifers exist in the area. Sandstone beds in the Tongue River Member of the Fort Union Formation (Paleocene age) are the most common aquifers and probably underlie the entire area. The Pust coal bed in the Tongue River Member is water saturated in part of the probable mine area and is dry in other parts of the probable mine area. Other aquifers, located mostly outside of the probable mine area, exist in gravel of the Flaxville Formation (Miocene or Pliocene age) and valley alluvium (Pleistocene and Holocene age). Chemical analyses of ground water indicate a range in dissolved-solids concentration of 240 to 2,280 milligrams per liter.

Surface-water resources are limited. Most streams in the area are ephemeral and flow only in response to rainfall or snowmelt. Small reaches of the North and Middle Forks of Burns Creek have intermittent flow. Water sampled from a small perennial reach of the Middle Fork had a dissolved-solids concentration of 700 milligrams per liter.

Mining of the Pust coal bed would destroy one spring and four stock wells, dewater areas of the Pust coal and sandstone aquifers, and probably lower water levels in seven stock and domestic wells. Mining in the valley of Middle Fork Burns Creek would intercept streamflow and alter flow characteristics of a small perennial reach of stream. Leaching of soluble minerals from mine spoils may cause a long-term degradation of the quality of water in the spoils and in aquifers downgradient from the spoils. Some of the effects on local water supplies could be mitigated by development of new wells in deeper sandstones of the Tongue River Member. Effects of mining on water resources would be minimized if only areas of dry coal were mined.

INTRODUCTION

The Woodson study area encompasses about 35 mi^2 of the Burns Creek basin in Dawson and Richland Counties of northeastern Montana. The study area is located about 25 miles southwest of Sidney and 30 miles north of Glendive, Montana (fig. 1). Boundaries of the study area were chosen to accommodate certain hydrologic and coal-lease boundaries. The study area includes a probable mine area of about 11.5 mi^2 and surrounding lands that could be affected by mining activities. The probable mine area (outlined in figs. 2 and 3) is the area likely to be mined if Federal coal reserves in the area of the Woodson Preference Right Lease Application are mined. Federal coal reserves of the probable mine area are in secs. 2, 4, 10, and 14 of T. 20 N., R. 56 E., and in secs. 30 and 32 of T. 21 N., R. 56 E. Coal in all other sections of the mine area is owned privately or by the State of Montana. Recoverable coal reserves of the mine area are estimated to be about 220 million tons, of which about 40 million tons are Federal coal (J.A. Kwiatkowski, U.S. Bureau of Land Management, written commun., 1986).

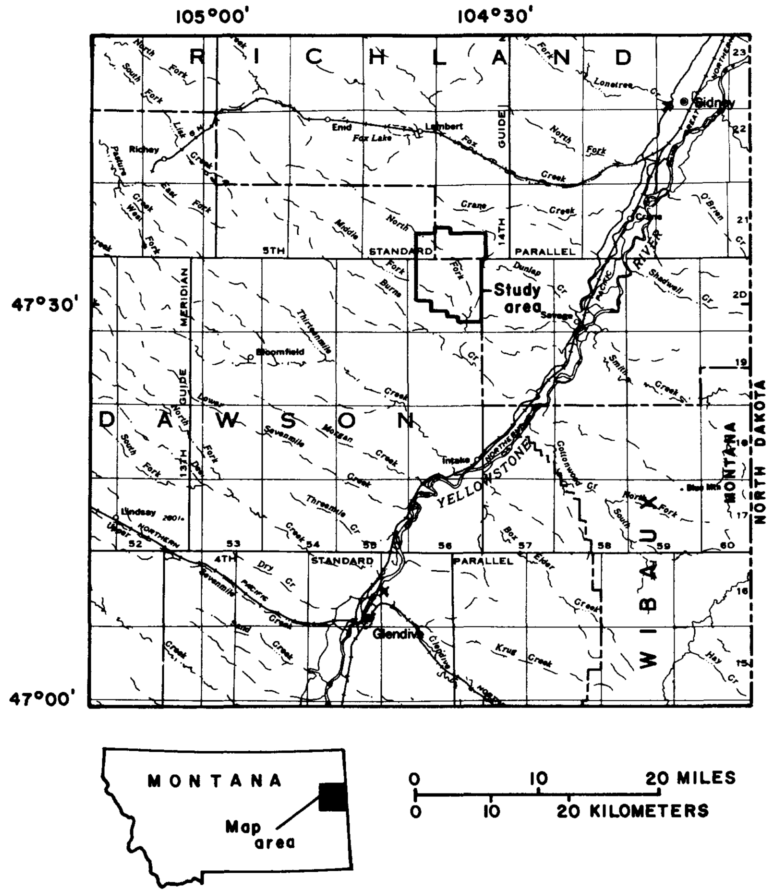


Figure 1.--Location of the Woodson study area.

Leasing of Federal coal in the Woodson Preference Right Lease Application probably would result in the mining of the Federal coal and adjacent private and State coal from an area of about 11.5 mi^2. Surface mining of the Pust coal bed from the area has the potential to affect water resources of the area during mining and for many years after reclamation. Effects of mining may include water-level declines, destruction of wells and springs, and degradation of water quality. Because of these potential effects, the U.S. Bureau of Land Management requested that the U.S. Geological Survey conduct a study to provide hydrologic information from the area that would aid them in coal-leasing decisions.

Purpose and Scope

The purpose of the study was to describe the water resources of the Woodson area and to evaluate the potential effects of mining on the water resources. Specific objectives were to: (1) Identify ground-water and surface-water resources; (2) describe chemical quality of the water resources; (3) describe probable effects of mining on wells, springs, and streams; and (4) evaluate the potential for reclamation of affected water resources.

To accomplish these objectives, an inventory was made of existing wells and springs. Hydrogeologic data from the inventory and from five observation wells installed during the study were used to identify aquifers, delineate areas of recharge and discharge, and map directions of ground-water flow. Channel geometry was measured on the North Fork and Middle Fork of Burns Creek to evaluate runoff characteristics of these streams. Water samples were collected from wells, springs, and Middle Fork Burns Creek and were analyzed for chemical quality.

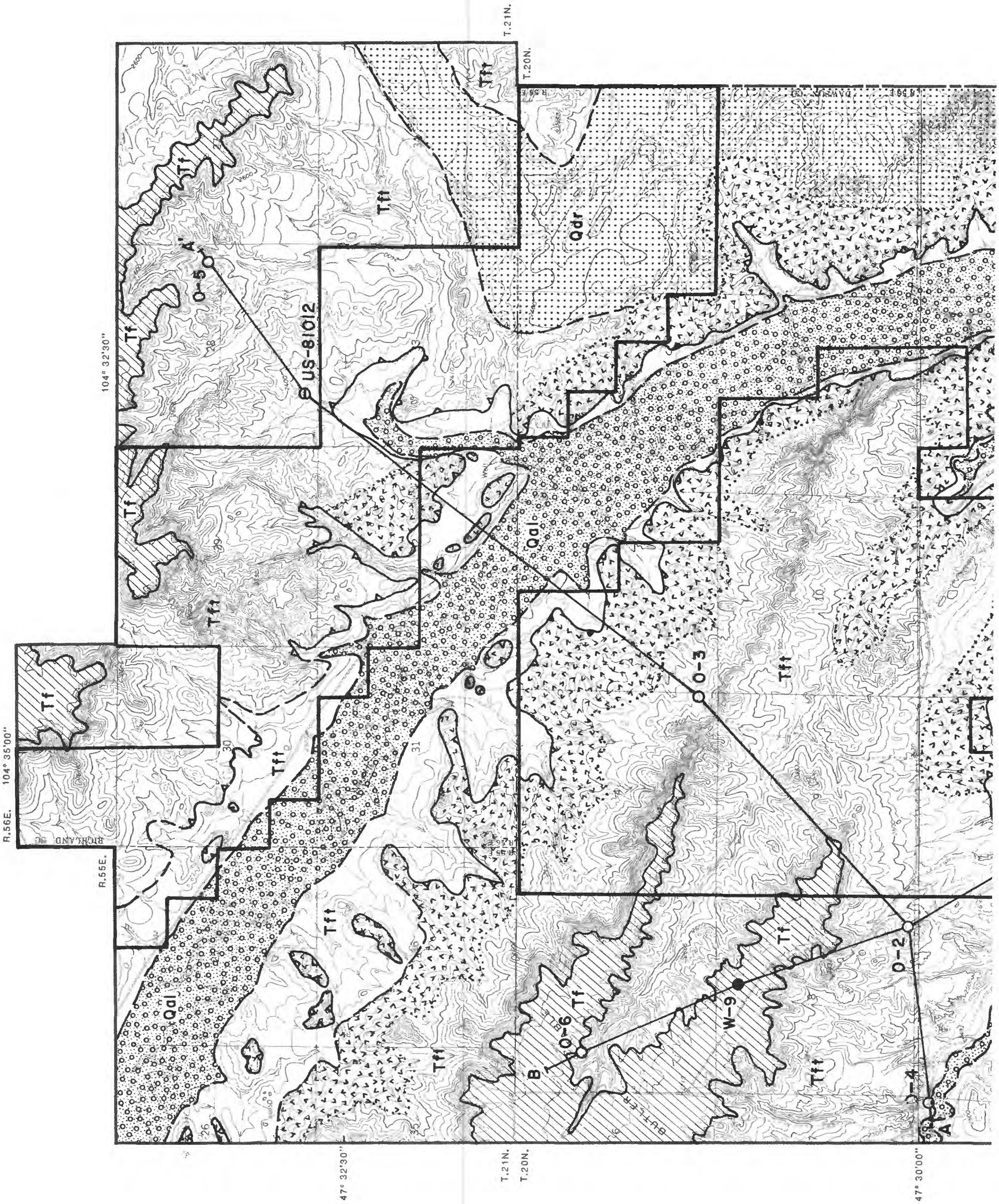
Climate and Topography

The climate in the Woodson area is typical of the northern Great Plains -- semiarid with warm summers, cold winters, moderate humidity, and generally little but variable rainfall. Average annual precipitation in the study area is about 14 inches. Monthly precipitation generally is largest during May, June, and July. Annual potential evaporation is much greater than precipitation and is about 38 inches. Temperatures in the area typically have an annual range of about -40 to 100 °F.

Topography is characterized by nearly level uplands in the northern and western parts of the study area, steep gulches and slopes at the margins of the uplands that grade into hilly or gently rolling slopes, and a broad alluvial valley along North Fork Burns Creek. Topography of the area is a result of erosion of an ancient gravel-capped plain overlying nearly horizontal sandstone, siltstone and shale of the Paleocene Fort Union Formation. Gradual erosion of the protective gravel from the surface of the plain has exposed the relatively soft rocks of the Fort Union Formation, which rapidly erode to form hills and steep gulches. The broad alluvial valley occupied by North Fork Burns Creek was largely formed by glacial meltwater during Pleistocene time. Altitudes in the study area range from about 2,220 feet in the valley of Burns Creek to 2,720 feet on the gravel-capped uplands.

Previous Investigations

Geology and coal deposits of the area have been the focus of several investigations. Coal resources of the Richey-Lambert coal field, which includes part of



T.21N.
T.20N.
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104° 35'00"
R.56E.
R.55E.
47° 32'30"
47° 30'00"
RICHLAND CO
DAWSON CO
Tf
Tft
Qal
Qdr
O-5
A'
US-81012
O-3
O-2
O-6
W-9
B
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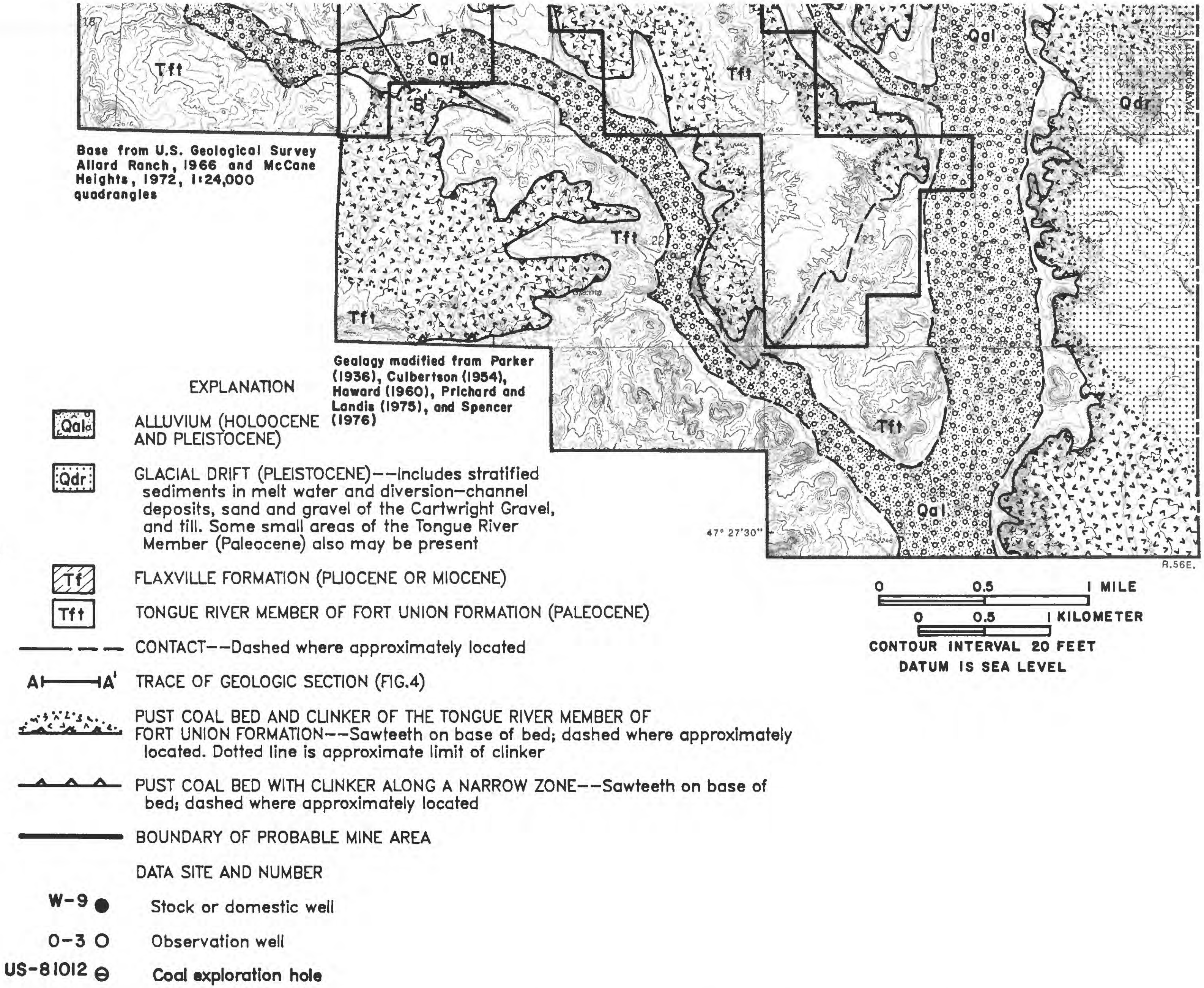
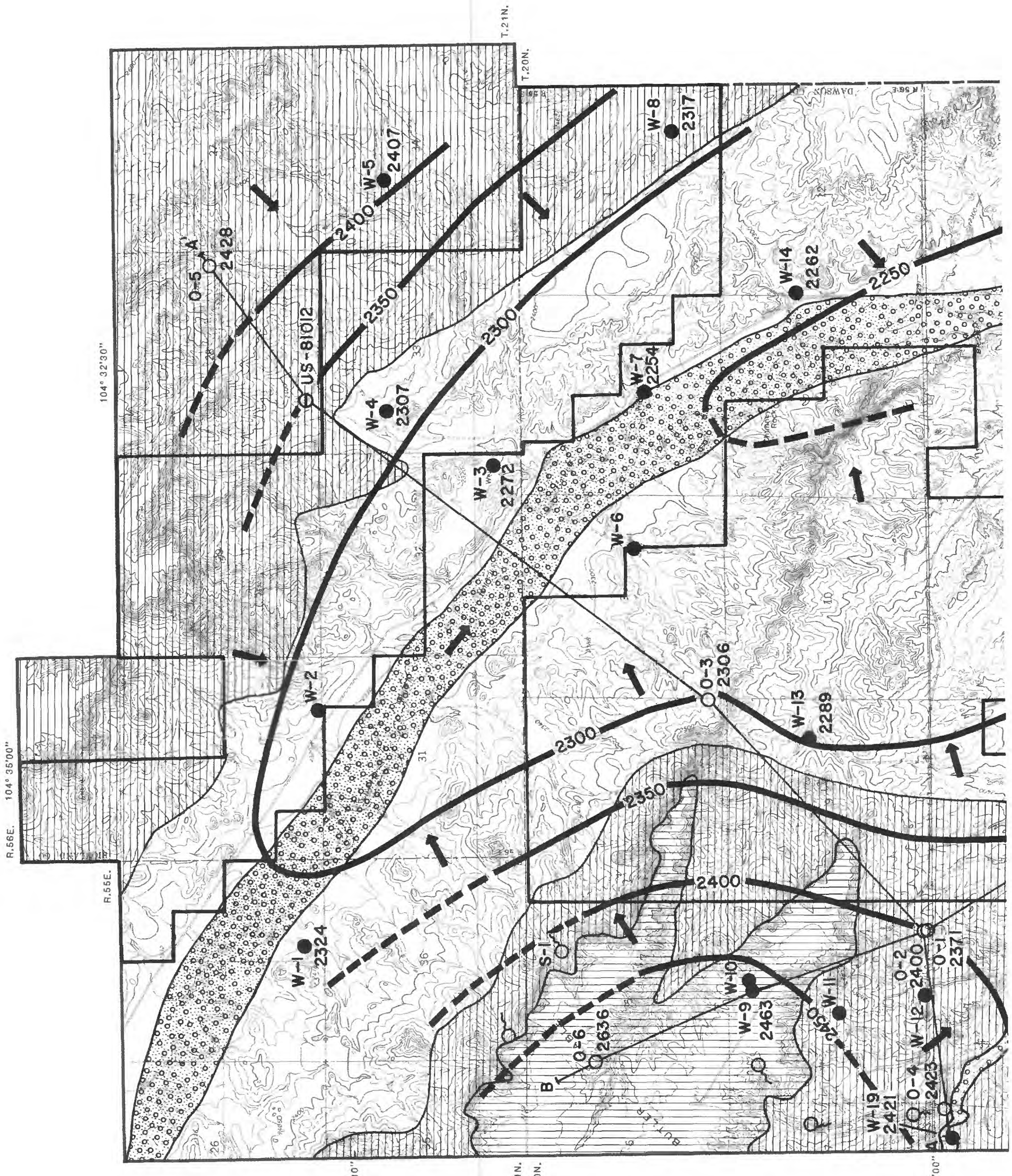


Figure 2.--Surficial geology and boundary of the Woodson probable mine area.



T.21N.
T.20N.
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R.56E.
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104° 35'00"
47° 32'30"
47° 30'00"
O-5 2428
A'
US-81012
W-5 2407
W-8 2317
W-4 2307
W-3 2272
W-7 2254
W-14 2262
W-6
W-2
O-3 2306
W-13 2289
W-1 2324
S-1
O-6 2636
B
W-10
W-9 2463
W-11
W-12 2423
O-2 2400
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W-19 2421
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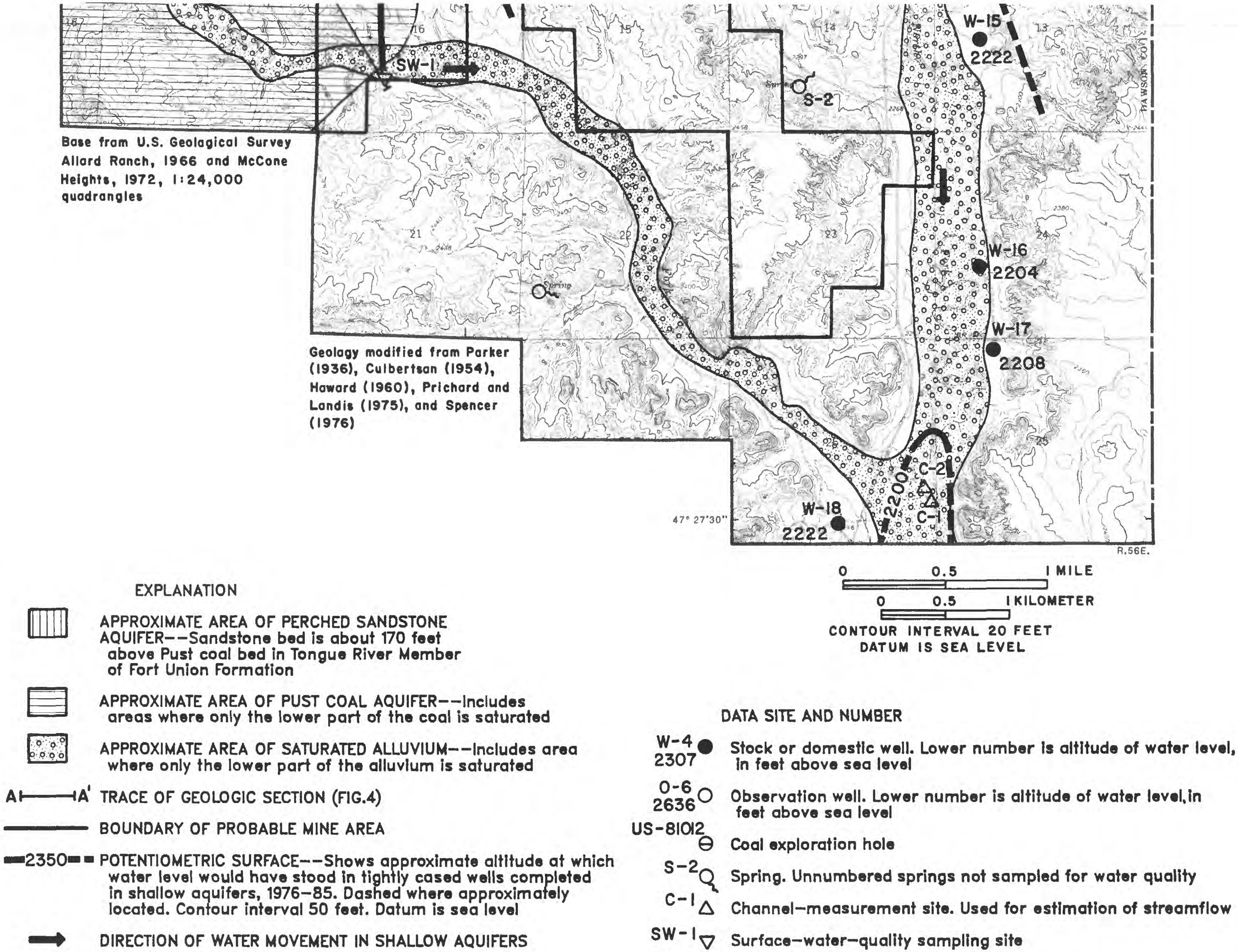

Figure 3.--Extent of aquifers, direction of shallow ground-water flow, and location of wells and springs.

the study area in T. 21 N., R. 55 E., were mapped and described in detail by the U.S. Geological Survey (Parker, 1936) as part of a systematic study and classification of public lands. A similar study of the Girard coal field, which includes the northeastern part of the study area in T. 21 N., R. 56 E., was made by Prichard and Landis (1975). Spencer (1976) mapped the extent, thickness, and structure of the Pust coal in the region, including the entire study area. Howard (1960) mapped the surficial deposits of the area in a comprehensive report of the Pleistocene history of northeastern Montana and northwestern North Dakota. Other coal deposits in and near the Woodson study area have been mapped by Culbertson (1954). Data on soils, overburden chemistry, and reclamation potential have been collected and compiled by the U.S. Bureau of Land Management and U.S. Bureau of Reclamation (Calcagno and Westman, 1983).

Ground-water resources and hydrogeologic characteristics of rocks in the area were reported by Perry (1931) and Stoner and Lewis (1980). Hydrogeologic data from wells in the region were compiled by Roberts (1980) and Slagle (1981). The quality of water in the mainstem of Burns Creek was described by McKinley (1979).

GEOLOGY

Rocks of the Tongue River Member of the Fort Union Formation are at land surface in most of the study area. About 420 feet of the Tongue River Member is exposed from the valley of Burns Creek to the upland areas along interstream divides. The Tongue River Member is composed predominantly of interbedded sandstone, siltstone, shale, and lignite coal. The Pust coal bed in the Tongue River Member, which ranges in thickness from about 12 to 37 ft, is the primary coal bed of the area and crops out along the valleys of the North and Middle Forks of Burns Creek. Thick beds of red clinker exist where the Pust coal bed has burned along its outcrop and baked the overlying rock (fig. 2). Strata of the Tongue River Member generally have an easterly dip of about 20 to 25 ft/mi (Prichard and Landis, 1975; Spencer, 1976).

The highest ridges and benches of the area are underlain by gravels of the Flaxville Formation of Miocene or Pliocene age. The Flaxville Formation consists of well-rounded pebbles and cobbles of chert, quartzite, and various igneous rocks in a matrix of fine gravel, sand, and silt. The gravel deposits seem to be from a few feet to 40 or 50 feet thick, based on logs of holes drilled in the area.

The valleys of North Fork and Middle Fork Burns Creek contain alluvium of Pleistocene and Holocene age. Alluvium in the Middle Fork occurs in a narrow band along the stream channel and consists of clay, silt, sand, and gravel. Gravel in the alluvium is comprised of clinker fragments and reworked gravel of the Flaxville Formation. Thickness of alluvium in the Middle Fork valley is unknown. The valley of North Fork Burns Creek was formed primarily during Pleistocene glaciation. The valley was an outlet channel for water draining from glacial Lake Lambert, located north of the study area (Howard, 1960). Flood waters draining from the lake widened and deepened the southeast-trending preglacial channel of Burns Creek. In the southern part of the study area, flood waters cut a new channel for Burns Creek where they flowed south-southwest along the margin of glacial ice. Alluvial deposits in North Fork Burns Creek consist of clay, silt, sand, and gravel. A large percentage of the gravel appears to be reworked Flaxville gravel. One well drilled in the North Fork valley (well W-16, fig. 3) penetrated 72 feet of alluvium overlying the Tongue River Member.

Glacial drift and gravel underlie the surface along the eastern margin of the study area (fig. 2). The drift marks the limit of advancement of glacial ice that covered much of northern Montana. The glacial drift contains stratified deposits of clay, silt, sand, and gravel that were sorted by glacial waters, and unstratified till, deposited directly by glacial ice. Patches of gravel, similar in lithology to the Flaxville gravel, underlie a rough terrace east of North Fork Burns Creek; the gravel is referred to as the Cartwright Gravel (Howard, 1960) and is of Pleistocene age.

GROUND-WATER RESOURCES

Ground-water resources of the area include shallow aquifers containing mostly local flow systems and deep aquifers with regional flow systems. Only shallow aquifers were investigated in this study because they are utilized for water supplies by local residents and are the only aquifers that could be affected directly by mining the Pust coal bed.

Sandstone beds within the Tongue River Member of the Fort Union Formation are the most common shallow aquifers and probably underlie the entire study area. The Pust coal bed in the Tongue River Member and clinker of the Pust coal bed are aquifers in parts of the area. Shallow aquifers also exist in some deposits of Flaxville gravel or colluvium derived from the Flaxville Formation, and valley alluvium. Hydrogeologic data for each of these aquifers were obtained from test drilling, well and spring inventories, or field evidence of recharge and discharge. Pertinent hydrogeologic data for wells in the area are listed in table 1 at back of report. The location of wells and springs is shown in figure 3.

Sandstone Aquifers

Sandstone aquifers exist both above and below the Pust coal bed. A fine- to medium-grained sandstone aquifer, located about 170 feet above the Pust coal bed, was penetrated by observation well O-6. This sandstone aquifer seems to be a perched aquifer that underlies the gravel-capped tableland in the west-central part of the study area (see fig. 3). A single-well aquifer test indicated a hydraulic conductivity of 670 ft/d for the sandstone. Recharge to the perched aquifer is from infiltration of precipitation on the gravel-capped table. Flaxville gravel that underlies this tableland appears to be very permeable, allowing precipitation to infiltrate rapidly. Discharge from the perched aquifer is by vertical leakage to lower aquifers and probably to seeps and by evapotranspiration where the sandstone crops out along the steep slopes below the table.

A very fine grained sandstone aquifer underlies the Pust coal bed. The sandstone is located 32 feet below the coal bed at well O-1 and 55 feet below the coal bed at well O-3. Single-well aquifer tests at these observation wells indicated respective hydraulic-conductivity values of 0.4 and 2 ft/d. It is not known if this sandstone is continuous between the two wells. Sandstone beds in the Tongue River Member typically are lenticular but are numerous and can form a rather continuous zone having a larger hydraulic conductivity than shales above and below the sandstone. Fine-grained sandstone aquifers probably exist throughout the study area within an interval of 30 to 200 feet below the level of the Pust coal bed. Recharge to sandstone aquifers underlying the Pust coal bed occurs as leakage from overlying aquifers in the upland areas north and west of the study area. Discharge primarily is to North Fork Burns Creek (see fig. 3), where water is removed by streamflow, evapotranspiration, and downvalley flow within the alluvium.

Coal and Clinker Aquifers

The Pust coal bed is an aquifer in some parts of the study area but is dry or absent in other parts. The areal extent of the Pust coal aquifer, or area containing saturated Pust coal, is shown in figure 3. Cross-sectional views of the study area, showing relations of the Pust coal aquifer to topography and potentiometric surface, are displayed in figure 4.

Single-well aquifer tests indicated hydraulic-conductivity values of 3 ft/d for the Pust coal aquifer at well O-2 and 24 ft/d at well O-4. The larger hydraulic conductivity at well O-4 is a result of a greater degree of fracturing of the coal at this location. The hydraulic conductivity of coal is largely dependent on the degree of fracturing, and in eastern Montana, coal beds near outcrops commonly are more fractured than those deeply buried.

Recharge to the Pust coal aquifer occurs as vertical leakage from overlying aquifers in the northern and western parts of the study area. The principal area of recharge seems to be the Flaxville gravel-capped tablelands (fig. 2). Discharge from the Pust coal aquifer is to underlying aquifers, to Middle Fork Burns Creek, and probably, in some areas, to clinker along the outcrop of the coal bed. Leakage to underlying aquifers probably is a major route for discharge. As shown in figure 3 and section A-A' in figure 4, the main direction of flow in shallow aquifers is toward North Fork Burns Creek; however, the Pust coal aquifer does not discharge directly to the North Fork valley, but discharges to underlying aquifers (sandstone), which discharge to the valley. In secs. 16 and 17, T. 20 N., R. 56 E., the coal aquifer discharges to alluvium of Middle Fork Burns Creek, as shown in figure 3 and section B-B' in figure 4. In part of sec. 16, discharge from the Pust coal aquifer and overlying aquifers maintains a small but perennial base flow of the Middle Fork.

Clinker, formed by burning of the Pust coal bed, appears to be dry in most of the area. However, in two locations the clinker discharges water to springs. Spring S-2 (fig. 3) had a discharge of about 2 gal/min on October 3, 1985, and an unnamed spring, located in the SW¼ sec. 22, T. 20 N., R. 56 E., had a measured discharge of 8.2 gal/min on April 1, 1981. The clinker aquifers that discharge at these springs appear to be of limited areal extent. Recharge to the very permeable clinker is from direct infiltration of precipitation and possibly by lateral flow from the Pust coal bed.

Aquifers in Flaxville Formation and Colluvium

Gravel in the Flaxville Formation underlies the high tables in the northern and western parts of the study area. Colluvium derived from the Flaxville has washed into many steep gulches that originate at the edge of the tablelands. Aquifers of small areal extent exist in the Flaxville gravel and colluvium of the gulches. These aquifers are perched on shale of the Tongue River Member of the Fort Union Formation.

Recharge to the Flaxville is from direct infiltration of precipitaton and snowmelt. Areas underlain by Flaxville gravel, or colluvium from the Flaxville, probably are the most important areas of recharge for almost all aquifers in the study area because rainfall rapidly infiltrates the gravels and the gulches accumulate large quantities of snow. Discharge from the Flaxville is downward to underlying aquifers and to springs in some of the steep gulches. The largest spring (S-1 in fig. 3) has a discharge of about 20 gal/min.

Alluvial Aquifers

Alluvial aquifers exist in the valleys of the North and Middle Forks of Burns Creek as shown in figure 3. Only one well (W-19) is known to be completed in alluvium. Another well (W-16) is cased through the alluvium and completed in the Tongue River Member. No aquifer tests were made on alluvial aquifers, but the alluvial sediments probably have a wide range of hydraulic conductivity, based on size of material ranging from clay to coarse gravel.

Recharge to alluvial aquifers is from several sources, including infiltration of precipitation, infiltration of streamflow during runoff, and leakage from adjacent aquifers. Discharge from alluvium is to evapotranspiration, streamflow in some reaches of the Middle Fork and North Fork, and downvalley flow within the alluvium. A substantial part of the alluvium in the North Fork and Middle Fork valleys appears to have a high water table and is subirrigated, based on areas of standing water and growth of vegetation. Because of subirrigation, evapotranspiration probably is a major means of discharge from the alluvial aquifers.

SURFACE-WATER RESOURCES

The Woodson study area is drained primarily by the North Fork and Middle Fork Burns Creek. A small part of the study area, along the eastern boundary, is drained by tributaries of Dunlap Creek. These streams primarily are ephemeral and flow only as a result of rainfall or snowmelt. Small reaches of the North and Middle Forks have intermittent flow, and one small reach of the Middle Fork in sec. 16, T. 20 N., R. 56 E. has perennial flow.

North Fork Burns Creek has a drainage area of 79.1 mi^2 from its headwaters to the confluence with Middle Fork, and Middle Fork Burns Creek has a drainage area of 36.4 mi^2. The mean annual discharge and the magnitude and frequency of floods for the North and Middle Forks were estimated indirectly. The method, which required measurements of channel geometry, was developed through regression analysis of streamflow and dimensions of the channel (Omang and others, 1983). Based on measurements of the stream channels (see fig. 3 for site locations), the mean annual discharge for North Fork upstream from Middle Fork is 1,120 acre-feet and the mean annual discharge for Middle Fork is 544 acre-feet.

Magnitudes of flood peaks for North Fork Burns Creek at the measurement site upstream from Middle Fork are 1,350 ft^3/s for the 100-year flood, 1,010 ft^3/s for the 50-year flood, and 96 ft^3/s for the 2-year flood. Magnitudes of flood peaks for Middle Fork at its mouth are 864 ft^3/s for the 100-year flood, 638 ft^3/s for the 50-year flood, and 54 ft^3/s for the 2-year flood.

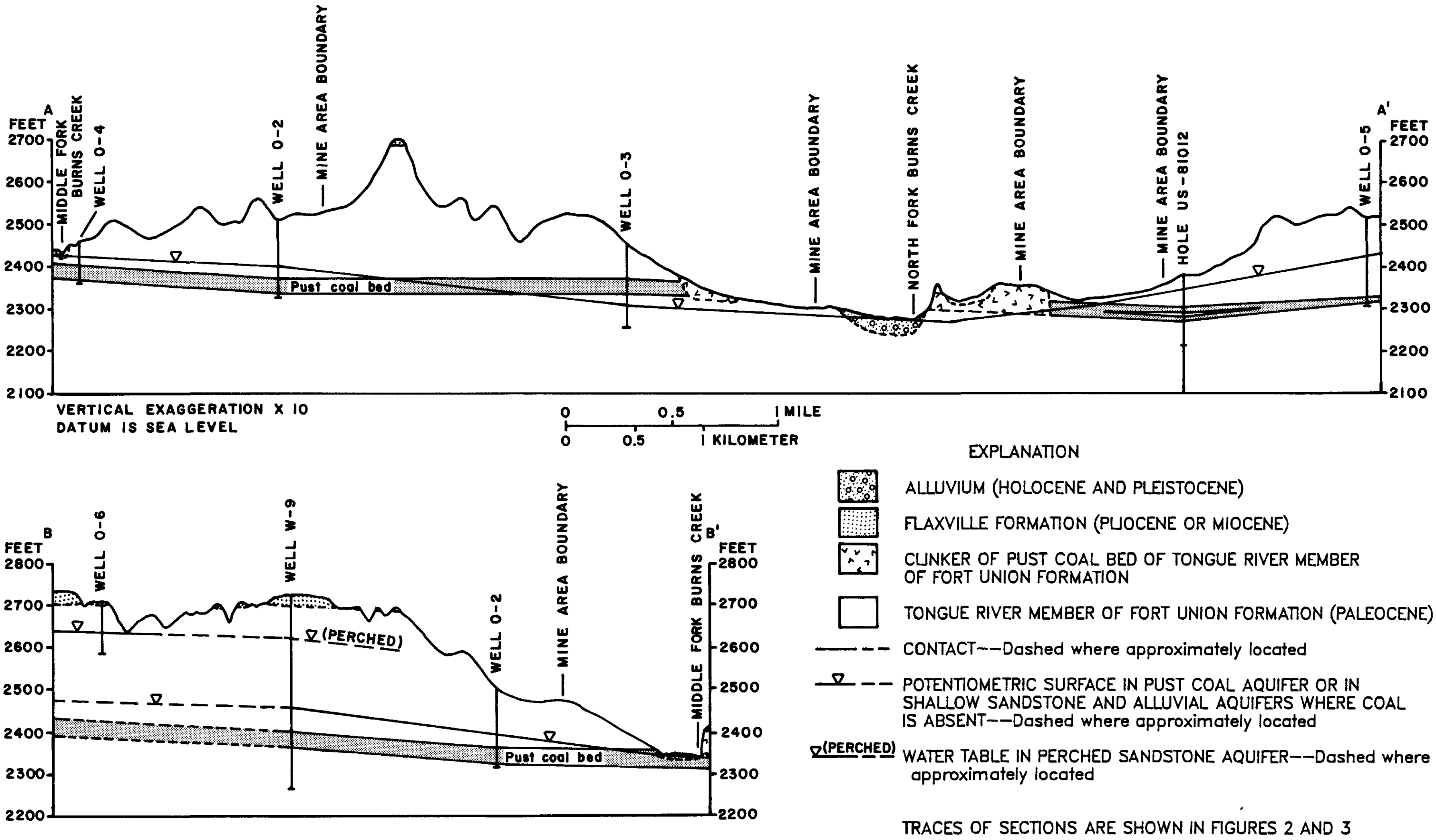

Figure 4.--Hydrogeologic sections A-A' and B-B' through the Woodson area.

WATER QUALITY

Ground Water

Quality of ground water was determined by analysis of nine water samples collected from seven wells and two springs (tables 2 and 3 at back of report). Of these samples, eight were from aquifers in the Tongue River Member and one was from colluvium derived from Flaxville gravel. Analysis of the samples indicated water of different chemical type from different aquifers.

Water from well O-6, completed in a perched sandstone aquifer above the Pust coal bed, was a calcium-magnesium bicarbonate type and had a dissolved-solids concentration of 240 mg/L (milligrams per liter). The dissolved-solids concentration of this water was the smallest analyzed in the study area. Wells completed in the Pust coal bed (wells O-2 and O-4) had water of a magnesium-calcium bicarbonate type and an average dissolved-solids concentration of 970 mg/L. Wells completed in a sandstone aquifer (wells O-1 and O-3), located 32 to 55 feet below the Pust coal bed, had water of a sodium bicarbonate type and an average dissolved-solids concentration of 1,010 mg/L. Two other wells (wells W-3 and W-16), completed in aquifers below the level of the Pust coal bed and in an area where the coal is absent because of erosion, had water of a sodium sulfate type and an average dissolved-solids concentration of 2,120 mg/L. These two wells (W-3 and W-16) are located near North Fork Burns Creek and had the largest concentrations of dissolved solids analyzed in the study area.

Water from spring S-1, which discharges from colluvium derived from Flaxville gravel, was a magnesium-calcium bicarbonate type and had a relatively small dissolved-solids concentration of 340 mg/L. Spring S-2, which discharges from the base of the Pust clinker bed, had a sodium bicarbonate type water and a dissolved-solids concentration of 1,360 mg/L.

Trace-element concentrations, determined for water samples collected from five observation wells and one spring (table 3), seem to be typical of ground water in the region. None of the analyses of trace elements indicate concentrations exceeding drinking-water regulations established by the U.S. Environmental Protection Agency (1977, 1979).

Ground water in the Woodson study area seems to increase in dissolved-solids concentration along the flow path and evolve from a calcium-magnesium bicarbonate water in recharge areas to a sodium sulfate-bicarbonate water in discharge areas. Water in aquifers at higher altitudes has the smallest concentrations of dissolved solids and contains predominantly calcium, magnesium, and bicarbonate ions. The higher-altitude aquifers mostly are in the recharge area for local ground-water flow systems. Water in aquifers near the valley of North Fork Burns Creek has the largest concentrations of dissolved solids; contains predominantly sodium, sulfate, and bicarbonate ions; and is near the discharge area for ground-water flow systems. Water in the Pust coal aquifer has an intermediate concentration of dissolved solids; contains predominantly magnesium, calcium, and bicarbonate ions; and is intermediate in the ground-water flow path from the upland areas to North Fork Burns Creek.

Geochemical processes presented by Moran and others (1978) seem to adequately explain the chemical evolution of ground water in the Woodson area. These geochemical processes include: (1) Generation of hydrogen ions through the production of carbon dioxide (CO_2) in the organic zone of the soil; (2) dissolution of calcite and dolomite, leaving calcium, magnesium, and bicarbonate ions in solution; (3) oxidation of pyrite; (4) dissolution of gypsum to produce calcium and sulfate ions; and (5) exchange of calcium and magnesium cations for sodium ions on sodium-rich clays.

Surface Water

Surface water was sampled at one site on the Middle Fork Burns Creek that maintains a small perennial flow (site SW-1 in fig. 3). Chemical analysis of the sample (tables 2 and 3) indicated a magnesium-calcium bicarbonate type water with a dissolved-solids concentration of 700 mg/L.

Twenty-two water samples, collected from Burns Creek near its mouth, had dissolved-solids concentrations ranging from 382 to 1,420 mg/L (McKinley, 1979). The water type generally was sodium sulfate during the spring and summer and sodium bicarbonate during the fall and winter. The sampling site was located about 10 miles southeast of the study area and the drainage area upstream from the site was 233 mi^2.

WATER USE

The largest use of ground and surface water is watering of livestock. The second largest use of ground water is for domestic water supply. Of the 19 water-supply wells inventoried in the study area (table 1 and fig. 3), 14 are used primarily for livestock and 5 for domestic water supply. At least one of these wells is used for both stock and domestic water supplies. All springs observed in the area (fig. 3) are used by livestock. Runoff from the largest spring (spring S-1) is collected in a small reservoir for watering of livestock.

Ground water in the valleys of North Fork and Middle Fork Burns Creek is used indirectly, through subirrigation of crops and forage for livestock. There is no known direct irrigation of crops from ground-water or surface-water sources.

All water sources sampled in the study area are classified as good for all livestock, based on measured concentrations of dissolved solids. McKee and Wolf (1971) indicate that water in Montana having a maximum dissolved-solids concentration of 2,500 mg/L is good for all livestock, and water having a dissolved-solids concentration of 3,500 mg/L is considered to be fair for livestock. The maximum dissolved-solids concentration measured from 10 samples was 2,280 mg/L at well W-3.

Most ground-water supplies in the area exceed or are near the maximum concentrations of 250 mg/L of sulfate and 500 mg/L of dissolved solids recommended by the U.S. Environmental Protection Agency (1979) for public supply. The recommended concentrations of sulfate and dissolved solids were established because of possible laxative effects on persons not accustomed to the water. These standards apply unless water of a better quality is unavailable. A relatively large concentration of dissolved solids is typical of most ground water in eastern Montana. Based on chemical analyses listed in table 2 and U.S. Environmental Protection Agency (1977, 1979) standards for drinking water, the best water supplies for domestic use are from the perched sandstone aquifer in the western part of the area (fig. 3) and the aquifer comprised of Flaxville gravel or colluvium derived from the Flaxville Formation.

POTENTIAL EFFECTS OF MINING ON WATER RESOURCES

Effects of surface coal mining on the water resources of the area are based on the assumption that the Pust coal bed would be mined from the entire probable mine area outlined in figure 2. Also, all mining regulations established by the U.S. Office of Surface Mining and the Montana Department of State Lands are assumed to be followed during mining and reclamation.

Effects During Mining

Mining of the Pust coal bed probably would start near the coal-clinker contact along both sides of the valley of North Fork Burns Creek (see fig. 2). The North Fork valley divides the Woodson probable mine area into northern and southern parts that, for the purpose of determining effects of mining on ground-water flow, could be treated as two separate mines.

In the northern part of the mine area (northeast of North Fork Burns Creek), mine pits excavated to the base of the Pust coal bed along the coal-clinker contact would almost immediately intercept some ground-water flow in the lower part of the Pust coal bed. As shown in figure 3, the Pust coal bed is an aquifer in much of this northern part. Near the coal-clinker contact, the coal probably is saturated only in the lower part of the bed. Near the northern boundary of the mine, the entire thickness of the coal bed is saturated and hydraulic heads within the coal probably are as much as 100 feet above the coal bed, based on the water level in well O-5.

In the southern part of the mine area (southwest of North Fork Burns Creek), the Pust coal bed is dry along most of the coal-clinker contact. In the area of spring S-2, there probably is a small area of the Pust coal bed containing a perched aquifer that discharges at the spring. Mine pits progressing from the coal-clinker contact to the west and southwest would not intercept any significant aquifers (except near spring S-2) until they were within about 0.5 mile of the western mine boundary. In the western 0.5 mile of the mine area, mine pits would intersect aquifers in the Pust coal bed and sandstone above the Pust coal bed (see fig. 3). Near the western boundary of the mine the entire thickness of the Pust coal bed is saturated and hydraulic heads within the coal bed probably are as much as 20 feet above the coal bed, based on the water level in well O-2.

The rates of ground-water discharge into the mine pits depend largely on configuration of the mine pits and rate of mining but likely would be small. Ground-water discharge to the mine pits could be drained to North Fork Burns Creek, because in most of the area the base of the Pust coal bed is at a higher altitude than the stream. Most of the water entering mine pits probably would be used for dust suppression and other water requirements at the mine site.

During mining, the most significant effects on water resources would be the destruction of several wells and a spring, dewatering of aquifers, and lowering of water levels in some wells outside the mine boundary. Water-supply wells that likely would be destroyed by mining are W-2, W-4, W-8, and W-13 (see fig. 3). Water-supply wells that probably would have water levels lowered by mining are W-3, W-5, W-6, W-7, W-9, W-11, and W-12; all but well W-6 are located outside the mine boundary. Most wells that would have lowered water levels are completed in the Pust coal aquifer or in sandstone aquifers that receive recharge from the Pust coal aquifer. Aquifers above the Pust coal bed, such as the perched sandstone aquifer (fig. 3) and aquifers in the Flaxville gravel or colluvium, receive recharge outside of the mine area and for the most part, would not be affected by mining. Small areas of Flaxville gravel exist within the mine boundary (fig. 2); these small areas may contain perched aquifers that would be destroyed by mining.

The only spring shown in figure 3 that would be destroyed by mining is spring S-2. The recharge area for this spring would be mined, thus drying the spring. Springs west of the mine area receive recharge from the Flaxville gravel, which underlies the high tableland. Because mining would not extend into the recharge area, these springs would not be affected.

Mining of the Pust coal bed from sec. 16 in the Middle Fork Burns Creek area would intercept streamflow and permanently change the flow characteristics. At sampling site SW-1 in sec. 16, the Middle Fork has a small perennial flow because of ground-water discharge from the Pust coal aquifer and overlying aquifers. Mining of the coal from this area could cause this reach of stream to stop flowing.

Long-Term Effects

After mining and reclamation, a potential exists for long-term degradation of the quality of ground water in the mine spoils and in aquifers downgradient from the spoils. At some time after reclamation, ground water would enter mine spoils, leach soluble minerals from the spoils, and discharge to downgradient aquifers, eventually reaching the valley of North Fork Burns Creek. Water would enter the mine spoils primarily by lateral flow from unmined Pust coal and sandstone aquifers. Mine spoils probably would become saturated only in areas that contained the Pust coal aquifer before mining (see fig. 3), based on the assumption that ground-water flow paths in the post-mining landscape would be similar to pre-mining flow paths.

Saturated-paste extracts prepared from overburden samples have been used by several investigators to evaluate the post-mining quality of spoils water (Van Voast and Hedges, 1975; Woessner and others, 1979; Van Voast and Thompson, 1982; Groenewold and others, 1983). Investigators have found that dissolved-solids concentrations in paste extracts generally are extremely variable within a mine site, but give an indication of post-mining quality of water in mine spoils. For the Woodson area, saturated-paste-extract data from coal overburden are available for only six samples from one drill hole in the SE¼ sec. 4, T. 20 N., R. 56 E. (Calcagno and Westman, 1983). The saturated-paste extracts indicate that the quantity of soluble minerals in mine spoils would be large and that mine-spoils water could attain an average dissolved-solids concentration of 5,200 mg/L. This concentration compares with pre-mining concentrations of about 1,000 mg/L in the Pust coal bed and about 2,000 mg/L in sandstone in the valley of North Fork Burns Creek. Actual concentrations of dissolved solids in mine-spoils water could vary considerably from the estimated concentration of 5,200 mg/L because of spatial variations in overburden geochemistry. Water in mine spoils of the Woodson area probably would attain dissolved-solids concentrations 2 to 3 times as large as concentrations in pre-mining ground water; increases of this magnitude were observed in mine spoils in western North Dakota (Groenewold and others, 1983). Additional overburden analysis would be needed in the study area to more accurately define the quality of post-mining ground water.

Water having a large concentration of dissolved solids would flow from the mine spoils, through undisturbed Tongue River Member and into alluvium along North Fork Burns Creek. The net effect would be a long-term increase in the quantity of dissolved solids entering the alluvial aquifer. Based on a detailed water-budget study of an alluvial aquifer in southeastern Montana (Cannon, 1985), coal and sandstone aquifers contribute a small part of total recharge to the alluvial valley but they contribute a large part of dissolved-solids load; with mine spoils replacing the coal aquifer, an even larger part of the dissolved-solids load entering the alluvial aquifer would come from ground water. The amount of increase in dissolved-solids concentration in the alluvial aquifer is unknown, but could be large enough to affect plant growth in subirrigated areas of the valley.

Shallow wells downgradient from mine spoils would be affected by an increase in dissolved-solids concentration. Wells W-3, W-6, and W-7 are completed in aquifers that receive recharge from within the mine boundary and would be affected by water from the mine spoils. Well W-2, if not destroyed by mining, also would be affected by an increase in dissolved-solids concentration. Wells affected by mining could be replaced with wells drilled to deeper sandstones in the Tongue River Member.

Mining probably would have no long-term effect on flow rates in North Fork Burns Creek. Most of the stream is ephemeral, with discharge controlled largely by rates of precipitation, snowmelt, and surface runoff. Streamflow in Middle Fork Burns Creek may be altered by decreasing or eliminating base flow from the perennial reach in sec. 16. With proper reclamation of the mined area, surface runoff to the North and Middle Forks would be similar to pre-mining runoff; magnitudes of floods would not be altered substantially.

POTENTIAL FOR RECLAMATION OF HYDROLOGIC SYSTEMS

No practicable method is available for restoring the shallow coal and sandstone aquifers that would be destroyed by mining. Likewise, spring S-2 which discharges from the Pust clinker probably could not be restored. Discharge of ground water having a large concentration of dissolved solids could be minimized by reclamation techniques that inhibit recharge to mine spoils. These techniques include proper grading to eliminate ponded water on the mine-spoils surface and adequate vegetation to minimize percolation past the root zone. Lateral flow from undisturbed aquifers into the mine-spoils probably could not be eliminated and would leach soluble minerals from mine spoils for many years after mining.

Effects of mining on water resources would be minimized if only areas of dry coal were mined. Water levels in the Pust coal aquifer would not decline from mine-pit dewatering and discharge of dissolved solids to North Fork Burns Creek would increase little. Also, the perennial reach of Middle Fork Burns Creek would be unaffected. The approximate limit of dry (and of saturated) coal in the mining unit is shown in figure 3. Most of the mine unit southwest of the North Fork contains dry coal. Northeast of the North Fork valley, dry coal occurs in a narrow band near the coal-clinker contact. At some places along this band, the coal at the coal-clinker contact may be saturated. A more detailed study would be required to more accurately delineate areas of dry coal.

CONCLUSIONS

Sandstone beds within the Tongue River Member of the Fort Union Formation are the most common shallow aquifers in the Woodson study area. Sandstone aquifers probably underlie the entire study area. The Pust coal bed and clinker of the Pust coal bed are aquifers in parts of the area; in other parts the Pust coal bed is dry. Shallow aquifers also exist in some gravel deposits of Flaxville Formation, or colluvium derived from the Flaxville Formation, and valley alluvium.

The primary areas of recharge to ground-water flow systems are the Flaxville gravel-capped tablelands in the northern and western parts of the study area. From the Flaxville gravel in the recharge area, water moves downward and laterally through sandstone and coal aquifers toward the valleys of North Fork and Middle Fork Burns Creek. The predominant direction of ground-water flow is to the North Fork.

Surface-water resources of the Woodson area are limited. For the most part, streams are ephemeral and flow only in response to rainfall or snowmelt. Small reaches of the North and Middle Forks of Burns Creek have intermittent flow, and one small reach of the Middle Fork in sec. 16, T. 20 N., R. 56 E., has perennial flow.

Quality of water in the study area was determined by analysis of water samples from seven wells, two springs, and one site on Middle Fork Burns Creek. Ground water in the Woodson study area seems to increase in dissolved solids along the flow path and evolve from a calcium-magnesium bicarbonate water in recharge areas to a sodium sulfate-bicarbonate water in discharge areas. Surface water from one site of perennial flow on the Middle Fork Burns Creek had a magnesium-calcium bicarbonate water with a dissolved-solids concentration of 700 mg/L.

The largest use of ground water and surface water is watering of livestock. The second largest use of ground water is for domestic water supply. All water sources sampled in the study area are classified as good for all livestock, based on measured concentrations of dissolved solids. Most ground-water supplies in the area exceed or are near the maximum concentrations of 250 mg/L of sulfate and 500 mg/L of dissolved solids recommended by the U.S. Environmental Protection Agency for public supply.

Effects of coal mining on water resources of the area are based on the assumption that the Pust coal bed would be mined from the entire probable mine area. During mining, the most significant effects on water resources would be the destruction of one spring and four stock wells, dewatering of aquifers, and lowering of water levels in seven stock or domestic wells. The wells and spring that would be destroyed are located within the mine boundary; wells that would have lowered water levels are completed in the Pust coal aquifer or in sandstone aquifers that receive recharge from the Pust coal aquifer. Aquifers above the Pust coal bed, such as the perched sandstone aquifer and aquifers in the Flaxville gravel or colluvium, receive recharge outside of the mine area and, for the most part, would not be affected by mining. Wells affected by mining could be replaced with wells drilled to deeper sandstones in the Tongue River Member. Mining of coal in the valley of Middle Fork Burns Creek in sec. 16, T. 20 N., R. 56 E., would intercept streamflow and permanently change the flow characteristics of this perennial reach of stream.

After mining and reclamation, a potential exists for long-term degradation of the quality of water in the mine spoils and in aquifers downgradient from the spoils. Ground water entering mine spoils would leach soluble minerals from the mine spoils and discharge to downgradient aquifers, eventually reaching the valley of North Fork Burns Creek. The quantity of increase in dissolved solids in the alluvial aquifer along the North Fork is unknown, but could be large enough to affect plant growth in subirrigated areas of the valley. Mining probably would have no long-term effect on flow rates in North Fork Burns Creek.

No practicable method is available for restoring the shallow coal and sandstone aquifers that would be destroyed by mining. Leaching of soluble minerals from mine spoils probably would occur for many years after mining. However, if only areas of dry coal were mined, effects of mining on water resources would be minimized. Water levels in the Pust coal aquifer would not decline from mine-pit dewatering and discharge of dissolved solids to North Fork Burns Creek would increase little. Also, the perennial reach of Middle Fork Burns Creek would be unaffected.

REFERENCES CITED

Calcagno, Frank, Jr., and Westman, G.H., 1983, eds., Resource and potential reclamation evaluation--Northeast Montana investigations: U.S. Bureau of Reclamation and U.S. Bureau of Land Management, BLM YA-533-1AO-3, 119 p.

Cannon, M.R., 1985, Effects of potential surface coal mining on dissolved solids in Otter Creek and in the Otter Creek alluvial aquifer, southeastern Montana: U.S. Geological Survey Water-Resources Investigations Report 85-4206, 52 p.

Culbertson, W.C., 1954, Three deposits of strippable lignite west of the Yellowstone River, Montana, *in* Contributions to Economic Geology 1953-54: U.S. Geological Survey Bulletin 995, p. 293-332.

Groenewold, G.H., Koob, R.D., McCarthy, G.J., Rehm, B.W., and Peterson, W.M., 1983, Geological and geochemical controls on the chemical evolution of subsurface water in undisturbed and surface-mined landscape in western North Dakota: North Dakota Geological Survey Report of Investigation 79, 276 p.

Howard, A.D., 1960, Cenozoic history of northeastern Montana and northwestern North Dakota with emphasis on the Pleistocene: U.S. Geological Survey Professional Paper 326, 107 p.

McKee, J.E., and Wolf, H.W., 1971, Water quality criteria (2d ed.): California State Water Quality Control Board Publication 3-A, 548 p.

McKinley, P.W., 1979, Water quality of selected streams in the coal area of east-central Montana: U.S. Geological Survey Water-Resources Investigations 78-142, 49 p.

Moran, S.R., Groenewold, G.H., and Cherry, J.A., 1978, Geologic, hydrologic, and geochemical concepts and techniques in overburden characterization for mined-land reclamation: North Dakota Geological Survey Report of Investigation 63, 152 p.

Omang, R.J., Parrett, Charles, and Hull, J.A., 1983, Mean annual runoff and peak flow estimates based on channel geometry of streams in southeastern Montana: U.S. Geological Survey Water-Resources Investigations 82-4092, 33 p.

Parker, F.S., 1936, The Richey-Lambert coal field, Richland and Dawson Counties, Montana: U.S. Geological Survey Bulletin 847-C, 174 p.

Perry, E.S., 1931, Ground water in eastern and central Montana: Montana Bureau of Mines and Geology Memoir 2, 59 p.

Prichard, G.E., and Landis, E.R., 1975, Coal resources and Cenozoic geology of the Girard coal field, Richland County, Montana: U.S. Geological Survey Bulletin 1310, 89 p.

Roberts, R.S., 1980, Hydrogeologic data for selected coal areas, east-central Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-329, 63 p.

Slagle, S.E., 1981, Hydrogeologic data for Dawson, McCone, Prairie, and Richland Counties, east-central Montana: U.S. Geological Survey Open-File Report 81-801, 101 p.

Spencer, J.M., 1976, Geology of the Pust lignite bed in the Burns Creek-Thirteenmile Creek known coal leasing area, Dawson and Richland Counties, Montana: U.S. Geological Survey Open-File Report 76-617, 6 p.

Stoner, J.D., and Lewis, B.D., 1980, Hydrogeology of the Fort Union coal region, eastern Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1236, 2 sheets.

U.S. Environmental Protection Agency, 1977, National interim primary drinking water regulations: Washington, D.C., U.S. Government Printing Office, EPA-570/9-76-003, 159 p.

______1979, National secondary drinking water regulations: Federal Register, v. 44, no. 140, July 19, p. 42195-42202.

Van Voast, W.A., and Hedges, R.B., 1975, Hydrogeologic aspects of existing and proposed strip coal mines near Decker, southeastern Montana: Montana Bureau of Mines and Geology Bulletin 97, 31 p.

Van Voast, W.A., and Thompson, K.S., 1982, Estimates of post-mining water quality for the upper Tongue River, Montana and Wyoming: Montana Bureau of Mines and Geology Hydrogeologic Map 5 (text), 10 p.

Woessner, W.W., Andrews, C.B., and Osborne, T.J., 1979, The impacts of coal strip mining on the hydrologic system of the Northern Great Plains--Case study of potential impacts on the Northern Cheyenne Reservation, *in* Back, William, and Stephenson, D.A., eds., Contemporary hydrogeology--The George Burke Maxey Memorial Volume: Journal of Hydrology, v. 43, p. 445-467.

SUPPLEMENTAL INFORMATION

Table 1.--*Hydrogeologic data from wells in and near the Woodson area*

[Site designation: O, observation well; W, water-supply well for stock or domestic use]

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of well (feet below land surface)	Principal aquifer[1]	Aquifer interval (feet below land surface)	Hydraulic conductivity of aquifer (feet per day)
O-1	SE¼SW¼SE¼SE¼ sec. 8, T. 20 N., R. 56 E.	2,510	223	Sandstone	210-220	0.4
O-2	SE¼SW¼SE¼SE¼ sec. 8, T. 20 N., R. 56 E.	2,510	180	Pust coal bed.	141-178	3
O-3	NE¼SE¼SE¼SE¼ sec. 4, T. 20 N., R. 56 E.	2,455	197	Sandstone	171-197	2
O-4	SE¼NE¼NE¼NE¼ sec. 18, T. 20 N., R. 56 E.	2,455	93	Pust coal bed.	53-89	24
O-5	SW¼SE¼SE¼NE¼ sec. 28, T. 21 N., R. 56 E.	2,515	220	Pust coal bed.	190-202	--
O-6	SE¼NE¼SW¼NW¼ sec. 5, T. 20 N., R. 56 E.	2,710	122	Sandstone	117-120	670
W-1	NE¼SW¼SW¼SE¼ sec. 25, T. 21 N., R. 55 E.	2,345	32	Tongue River Member.	--	--
W-2	SE¼SE¼SW¼SE¼ sec. 30, T. 21 N., R. 56 E.	2,350	--	Tongue River Member.	--	--
W-3	SW¼NE¼SE¼SE¼ sec. 32, T. 21 N., R. 56 E.	2,310	133	Tongue River Member.	--	--
W-4	SE¼NE¼SW¼NW¼ sec. 33, T. 21 N., R. 56 E.	2,330	--	Tongue River Member.	--	--
W-5	SE¼NW¼SE¼NW¼ sec. 34, T. 21 N., R. 56 E.	2,435	58	Tongue River Member.	--	--
W-6	NE¼NE¼NW¼SE¼ sec. 3, T. 21 N., R. 56 E.	2,305	--	Tongue River Member.	--	--
W-7	SW¼NW¼NW¼SE¼ sec. 2, T. 20 N., R. 56 E.	2,284	41	Tongue River Member.	--	--

Water level (feet below land surface)	Date of water-level measurement (month-day-year)	Hydraulic head (feet above sea level)	Well discharge (gallons per minute)	Date of discharge measurement (month-day-year)	Remarks
138.68	10-04-85	2,371	3.3	10-04-85	U.S. Geological Survey observation well BC85-1.
109.53	10-04-85	2,400	7.6	10-04-85	U.S. Geological Survey observation well BC85-2.
149.39	10-03-85	2,306	2.9	10-03-85	U.S. Geological Survey observation well BC85-3.
32.08	10-02-85	2,423	23	10-02-85	U.S. Geological Survey observation well BC85-4.
87.45	06-20-85	2,428	--	--	U.S. Geological Survey coal exploration hole US-75112.
74.37	10-02-85	2,636	16	10-02-85	U.S. Geological Survey observation well BC85-6.
21.10	06-20-85	2,324	--	--	Stock well.
--	--	--	--	--	Stock well.
38.23	06-20-85	2,272	2.5	06-20-85	Stock well.
23.37	06-20-85	2,307	2	06-20-85	Stock well.
27.95	08-15-85	2,407	--	--	Stock well.
--	--	--	3	06-20-85	Stock well.
29.50	06-20-85	2,254	--	--	Stock well.

Table 1.--*Hydrogeologic data from wells in and near the Woodson area*--Continued

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of well (feet below land surface)	Principal aquifer[1]	Aquifer interval (feet below land surface)	Hydraulic conductivity of aquifer (feet per day
W-8	SW¼SW¼NW¼SE¼ sec. 1, T. 20 N., R. 56 E.	2,370	72	Tongue River Member.	--	--
W-9	SW¼NW¼NW¼NE¼ sec. 8, T. 20 N., R. 56 E.	2,725	458	Coal and sandstone of Tongue River Member.	--	--
W-10	SE¼NW¼NW¼NE¼ sec. 8, T. 20 N., R. 56 E.	2,710	160	Tongue River Member.	--	--
W-11	NE¼NE¼NE¼SW¼ sec. 8, T. 20 N., R. 56 E.	2,565	260	Pust coal bed.	--	--
W-12	SW¼SW¼SW¼SE¼ sec. 8, T. 20 N., R. 56 E.	2,550	110	Pust coal bed.	--	--
W-13	NW¼SW¼SE¼NE¼ sec. 9, T. 20 N., R. 56 E.	2,450	257	Tongue River Member.	--	--
W-14	SW¼NW¼SW¼NW¼ sec. 12, T. 20 N., R. 56 E.	2,280	23	Tongue River Member.	--	--
W-15	NE¼NE¼NW¼SW¼ sec. 13, T. 20 N., R. 56 E.	2,260	121	Tongue River Member.	--	--
W-16	NW¼SE¼NW¼SW¼ sec. 24, T. 20 N., R. 56 E.	2,230	103	Sandstone of Tongue River Member.	92-103	--
W-17	NW¼NW¼NE¼NW¼ sec. 25, T. 20 N., R. 56 E.	2,230	90	Tongue River Member.	--	--
W-18	NW¼SW¼SW¼SE¼ sec. 26, T. 20 N., R. 56 E.	2,270	85	Tongue River Member.	--	--
W-19	NW¼NW¼SE¼NE¼ sec. 18, T. 20 N., R. 56 E.	2,430	26	Alluvium	0-26	--

[1] Pust coal bed occurs in Tongue River Member of Fort Union Formation.

Water level (feet below land surface)	Date of water-level measurement (month-day-year)	Hydraulic head (feet above sea level)	Well discharge (gallons per minute)	Date of discharge measurement (month-day-year)	' Remarks
53.20	09-11-76	2,317	4.7	09-11-76	Stock well.
261.62	10-04-85	2,463	2	02-11-75	Domestic well.
--	--	--	--	--	Stock well.
--	--	--	--	--	Domestic and stock well.
--	--	--	--	--	Stock well.
160.8	09-14-76	2,289	2.2	09-14-76	Stock well.
17.77	08-15-85	2,262	--	--	Domestic well.
37.55	08-15-85	2,222	10	09-11-76	Stock well.
26.10	09-11-76	2,204	8	09-11-76	Domestic well.
21.60	09-11-76	2,208	3	09-11-76	Stock well.
48.3	09-14-76	2,222	8.5	09-14-76	Domestic well.
9.2	09-14-76	2,421	1.9	09-14-76	Stock well.

Table 2.--*Major-constituent concentrations and physical properties of water from wells, springs, and a stream in and near the Woodson area*

[Unless indicated otherwise, constituents are dissolved and concentrations are reported in milligrams per liter. Analyses by Montana Bureau of Mines and Geology. Site designation: O, observation well; S, spring; SW, surface-water sampling site; W, water-supply well for stock or domestic use. Abbreviations: microsiemens, microsiemens per centimeter at 25 °C; °C, degrees Celsius; L, laboratory measurement]

Water source	Site designation	Location	Date of collection (month-day-year)	Onsite specific conductance (microsiemens)	Onsite pH, (standard units)	Onsite water temperature (°C)	Hardness (as $CaCO_3$)
Colluvium and gravel of Flaxville Formation.	S-1	NW¼SW¼NE¼NE¼ sec. 5, T. 20 N., R. 56 E.	08-15-85	630	7.8(L)	9.0	300
Sandstone of Tongue River Member[1] (above Pust coal bed).	O-6	SE¼NE¼SW¼NW¼ sec. 5, T. 20 N., R. 56 E.	10-02-85	420	7.6	9.0	230
Pust coal bed of Tongue River Member.	O-2	SE¼SW¼SE¼SE¼ sec. 8, T. 20 N., R. 56 E.	10-04-85	1,640	7.0	9.5	940
Pust coal bed of Tongue River Member.	O-4	SE¼NE¼NE¼NE¼ sec. 18, T. 20 N., R. 56 E.	10-02-85	1,250	7.3	8.5	600
Pust clinker bed of Tongue River Member.	S-2	NE¼NW¼SE¼SW¼ sec. 14, T. 20 N., R. 56 E.	10-03-85	2,020	7.6	7.0	470
Sandstone of Tongue River Member (below Pust coal bed).	O-1	SE¼SW¼SE¼SE¼ sec. 8, T. 20 N., R. 56 E.	10-04-85	1,670	8.2	11.0	53
Sandstone of Tongue River Member (below Pust coal bed).	O-3	NE¼SE¼SE¼SE¼ sec. 4, T. 20 N., R. 56 E.	10-03-85	1,640	8.8	11.0	14
Tongue River Member (below Pust coal bed).	W-3	SW¼NE¼SE¼SE¼ sec. 32, T. 21 N., R. 56 E.	08-15-85	3,300	8.7(L)	--	38
Sandstone of Tongue River Member (below Pust coal bed).	W-16	NW¼SE¼NW¼SW¼ sec. 24, T. 20 N., R. 56 E.	09-11-76	2,830(L)	7.6(L)	9.5	410
Middle Fork of Burns Creek.	SW-1	SW¼SW¼NE¼SW¼ sec. 16, T. 20 N., R. 56 E.	10-02-85	1,080	7.9	8.5	550

[1]Tongue River Member is in Fort Union Formation.

Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium adsorption ratio (SAR)	Potassium (K)	Bicarbonate (HCO_3)	Total alkalinity (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids, sum of constituents	Nitrate (as N)
56	39	14	0.4	3	360	290	31	2.0	0.5	20	340	0.36
52	24	4.2	.1	2	280	230	7.9	1.1	.2	15	240	.91
160	130	53	.8	6	850	700	350	2.9	.1	23	1,150	.31
100	85	56	1	5	560	460	250	2.6	.3	18	790	.13
55	82	320	6	9	820	670	470	3.0	.2	22	1,360	1.2
8.4	7.8	400	24	4	820	680	230	2.5	.8	10	1,070	.33
2.7	1.7	360	49	2	810	660	120	3.8	1.8	7.3	950	.19
7.1	4.9	820	58	2	1,060	870	900	6.7	2.0	7.2	2,280	.65
66	59	550	12	10	910	750	810	6.0	1.1	13	1,970	1.8
93	78	38	.7	6	510	420	200	4.6	.2	23	700	.28

Table 3.--*Trace-element concentrations of water from wells, springs, and a stream in and near the Woodson area*

[Constituents are dissolved and concentrations are reported in micrograms per liter. Analyses by Montana Bureau of Mines and Geology. Site designation: O, observation well; S, spring; SW, surface-water sampling site. Symbol: <, less than]

Site designation	Location	Date of collection (month-day-year)	Aluminum (Al)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)
O-1	SE¼SW¼SE¼SE¼ sec. 8, T. 20 N., R. 56 E.	10-04-85	<30	160	3	<2	<2
O-2	SE¼SW¼SE¼SE¼ sec. 8, T. 20 N., R. 56 E.	10-04-85	<30	240	<2	<2	6
O-3	NE¼SE¼SE¼SE¼ sec. 4, T. 20 N., R. 56 E.	10-03-85	150	120	<2	<2	<2
O-4	SE¼NE¼NE¼NE¼ sec. 18, T. 20 N., R. 56 E.	10-02-85	<30	210	<2	<2	5
O-6	SE¼NE¼SW¼NW¼ sec. 5, T. 20 N., R. 56 E.	10-02-85	<30	100	4	<2	10
S-2	NE¼NW¼SE¼SW¼ sec. 14, T. 20 N., R. 56 E.	10-03-85	<30	480	<2	<2	<2
SW-1	SW¼SW¼NE¼SW¼ sec. 16, T. 20 N., R. 56 E.	10-02-85	<30	170	5	<2	7

Iron (Fe)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Strontium (Sr)	Vanadium (V)	Zinc (Zn)
17	36	26	<20	<10	220	<1	16
610	40	200	30	10	2,930	<1	6
96	16	4	<20	<10	87	<1	3
<2	28	71	<20	<10	2,260	<1	<3
<2	6	16	30	20	220	6	4
<2	80	<1	<20	<10	2,090	1	15
<2	25	8	<20	20	1,540	5	<3