POTENTIAL EFFECTS OF SURFACE COAL MINING ON THE HYDROLOGY OF THE BLOOMFIELD COAL TRACT, DAWSON COUNTY, EASTERN MONTANA

By M. R. Cannon

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CONVERSION FACTORS

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

Multiply inch-pound unit	By	To obtain SI unit
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter 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 per year (ft/yr)	0.3048	meter per year
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.40	millimeter
micromho per centimeter at 25° Celsius (micromho)	100	microsiemens per meter at 25° Celsius
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram

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

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

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. NGVD of 1929 is referred to as sea level in this report.

POTENTIAL EFFECTS OF SURFACE COAL MINING ON THE HYDROLOGY OF THE BLOOMFIELD COAL TRACT, DAWSON COUNTY, EASTERN MONTANA

By M. R. Cannon

ABSTRACT

The Bloomfield coal tract in Dawson County, Montana, contains about 420 million tons of recoverable coal reserves within the Pust coal (lignite) bed of the Tongue River Member of the Fort Union Formation (Paleocene age). About 136 million tons of coal within the tract is Federally owned, of which 98 million tons has been identified for potential lease sale. A hydrologic study has been conducted in the potential lease area to describe existing hydrologic systems and to assess potential impacts of surface coal mining on local water resources.

Shallow ground-water resources in the tract are limited to sandstone and coal aquifers in the Tongue River Member. These shallow aquifers have small values of hydraulic conductivity; yields to wells generally range from 1 to 10 gallons per minute. Water from shallow sandstone and coal aquifers is used primarily for livestock watering and domestic supply. Chemical analyses indicate that water from most shallow aquifers is dominated by calcium and magnesium cations and sulfate and bicarbonate anions. Surface-water resources in the tract consist primarily of small reservoirs used for livestock watering. All streams in the tract are ephemeral, making them unreliable as a source of livestock water.

Mining of the Pust coal bed would cause certain impacts on local water resources. About 15 stock and domestic wells and 13 small stock reservoirs would be destroyed by mining. Shallow coal and sandstone aquifers would be permanently removed from parts of the tract. Leaching of soluble salts from mine spoils may cause a long-term degradation of the quality of water in shallow aquifers in and near the coal tract.

Impacts on the local water resources could be mitigated by development of alternative ground-water supplies from deeper aquifers in the Fort Union and in the Upper Cretaceous Hell Creek Formation and the underlying Fox Hills Sandstone. Reservoirs destroyed by mining could be reconstructed during mine reclamation.

INTRODUCTION

The Fort Union coal region of eastern Montana is an area of vast deposits of coal that contains little sulfur. The coal is both Federally and privately owned. Considerable interest exists in developing the coal reserves of the region to help meet the increased demand for domestically produced energy. To meet the demand for Federal coal and to ensure orderly leasing and development of Federal coal lands, a Federal Coal Management Program has been developed. Under this program, the U.S. Bureau of Land Management is required to identify tracts of coal for potential lease, analyze the tracts for potential environmental impacts, and schedule selected tracts of coal for lease sale.

One of the primary considerations in the selection of tracts for lease is potential adverse impacts to the water resources of the area during mining and reclamation operations, and after abandonment. To determine potential impacts and reclamation potential of coal tracts, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management, is conducting hydrologic studies on several potential coal lease tracts in the Fort Union coal region of eastern Montana. The Bloomfield area is in one of these tracts.

Purpose and scope

The purpose of this study was to describe existing hydrologic systems, to obtain data on the water quality in the area, and to assess potential impacts of surface coal mining on local water resources. Specific objectives of the study were to:

(1) Identify ground-water resources;
(2) identify surface-water resources and runoff characteristics;
(3) determine chemical quality of the water resources;
(4) determine probable impacts on existing water resources from mining operations, including changes in the quantity and quality of water; and
(5) evaluate the potential for reclamation of local water resources.

To accomplish these objectives, hydrogeologic data were collected from existing wells and drill holes. Additional test holes and observation wells were drilled and completed where data were lacking. Aquifer tests were made at suitable wells and a network of observation wells was established to measure long-term fluctuations of ground-water levels. Water samples were collected from ground-water and surface-water sources and analyzed for chemical quality. Channel-geometry measurements were made to predict runoff characteristics in small watersheds.

The information in this report emphasizes the potential effects of mining and the potential for reclamation of the hydrologic systems. Supporting technical information on geology, water resources, and water quality also is given for the interested reader.

Location and description of area

The Bloomfield coal tract occupies about 20 mi^2 and is located about 6 mi north of Bloomfield and 10 mi south of Richey in northern Dawson County, Montana (fig. 1). The tract contains about 420 million tons of recoverable coal reserves within the Pust coal (lignite) bed. About 136 million tons, or about 32 percent, of the recoverable coal is Federally owned. About 98 million tons of the Federal coal has been identified for potential lease sale.

The Bloomfield tract is located on the northeast-trending drainage divide between the Redwater and Yellowstone Rivers. Most of the tract is drained by North Fork Thirteenmile Creek, a tributary of Thirteenmile Creek, which flows southeast to

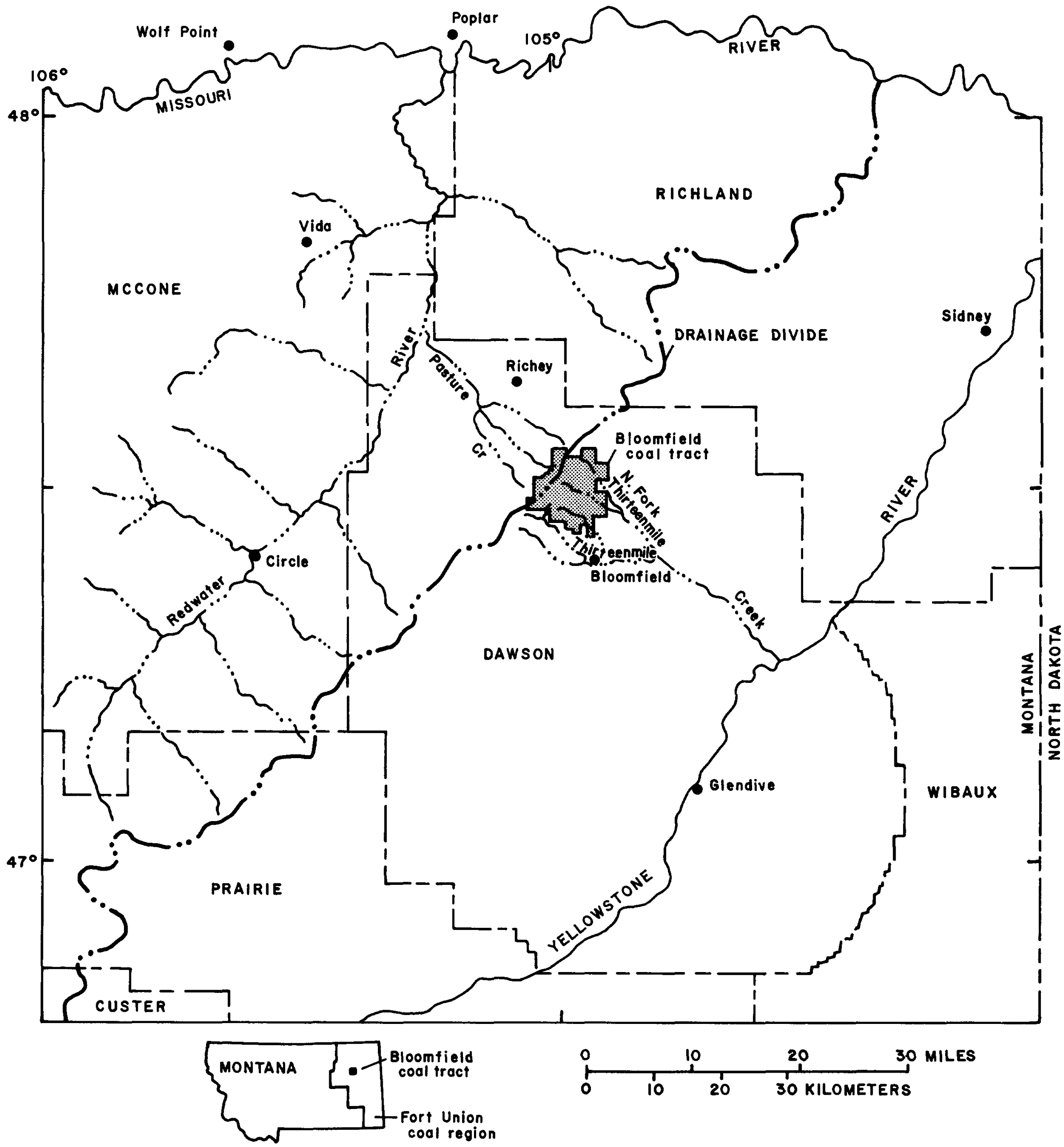

Figure 1.--Location of the Bloomfield coal tract. Boundary of Fort Union coal region from U.S. Bureau of Land Management (1983).

the Yellowstone River. The area northwest of the divide is drained by small tributaries of the Redwater River, which is a tributary of the Missouri River.

The drainage divide between the Redwater and Yellowstone Rivers separates the tract into two areas of vastly different topography. Southeast of the divide, the landscape is characterized by a gently undulating plain with a gradual southeasterly slope. Thirteenmile Creek and its tributaries have eroded broad, shallow valleys into the plain; gently rounded hills occupy the interstream divides. Northwest of the drainage divide, the landscape is characterized by a band of steeply sided badlands that merge with a hilly plain below. Headwaters of small northwesterly flowing streams are actively eroding the badlands and have created an escarpment along the Redwater-Yellowstone divide. Altitudes in the study area range from 3,121 ft above sea level on the drainage divide to about 2,700 ft along the lower stream courses.

Average annual precipitation on the coal tract is about 14 in. Greatest monthly precipitation generally occurs during May, June, and July. Annual potential evaporation is greater than precipitation and is about 38 in. (Kohler and others, 1959). Temperatures in the area typically have an annual range from about -40° to 100°F.

Previous investigations

The geology of the Bloomfield area has been mapped by several investigators. Most of the geologic maps were prepared during investigations of the coal, oil, and gas resources of the region. Parker (1936) mapped in detail the geology and coal resources of the Richey-Lambert coal field, which includes the northern part of the Bloomfield area. Culbertson (1954) mapped a strippable deposit of the Pust coal bed, located along North Fork Thirteenmile Creek. Maps showing thickness and structure of the Pust coal bed, and overburden thickness on the Pust coal, have been prepared by Spencer (1976). 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 areas east, south, and west of the Bloomfield area, have been mapped by Stebinger (1912), Hance (1912), Collier and Knechtel (1939), and Prichard and Landis (1975).

Ground-water resources and hydrogeologic characteristics of rocks in the area have been reported by Perry (1931), Montana Bureau of Mines and Geology and U.S. Geological Survey (1978), and Stoner and Lewis (1980). Hydrogeologic data from many wells in the Bloomfield and surrounding areas have been compiled by Roberts (1980) and Slagle (1981).

WATER USE AND SUPPLY

Ground-water resources of the Bloomfield area are used primarily for livestock watering and domestic supply. Use of ground water within the Bloomfield tract is estimated to be 2,500 gal/d. Ground water is obtained from shallow wells completed in sandstone and coal beds of the Tongue River Member of the Fort Union Formation. A well inventory conducted by the U.S. Geological Survey reported that at least eight wells within the tract are used for livestock or domestic water supplies. The well inventory of the area was not complete; an estimated seven additional wells exist within the tract and are regularly used for stock or domestic water supplies.

Wells in the Bloomfield area generally are completed in shallow aquifers and are less than 200 ft deep. Water levels in most of these wells are in the range of 25 to 150 ft below land surface, with the deeper wells having the lower water levels. The wells generally yield from 1 to 10 gal/min.

Surface-water resources in the Bloomfield tract consist primarily of small reservoirs used for watering of livestock. Most of these reservoirs are dry for part of the year and do not provide a long-term water supply for livestock. All surface-water drainages in the tract are ephemeral, making them unreliable as a source of livestock water. East of the tract, reaches of North Fork Thirteenmile Creek contain perennial ponds intermittently along the stream channel.

Chemical analyses of water samples from wells within the tract and from North Fork Thirteenmile Creek east of the tract indicate that concentrations of all constituents tested are less than the recommended maximum limits for use by livestock (McKee and Wolf, 1971). However, most water supplies in the area exceed the maximum concentrations of 250 mg/L (milligrams per liter) 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 and apply if water containing lesser concentrations of these constituents is available. However, the quality of the water sampled is typical of water quality in the Fort Union coal region and is not unique to the study area.

Aquifers underlying the Bloomfield tract could provide a long-term supply of ground water that is greater than the present (1982) use. Shallow aquifers within the Tongue River Member could sustain additional small-yield wells such as the existing stock and domestic wells. Deeper aquifers within the Tongue River Member or in the Fox Hills-lower Hell Creek aquifer could supply stock or domestic needs. However, wells completed in these deeper aquifers would have lower water levels than shallow wells and would require a greater pumping lift. Wells completed in the Fox Hills-lower Hell Creek aquifer would have water levels from 500 to 1,000 ft below land surface.

POTENTIAL EFFECTS OF MINING ON AREA HYDROLOGY

Assumptions

The effects of mining on local hydrologic systems can be predicted most accurately if a mine plan is available that details the timing and location of mine cuts, direction and rate of mine expansion, and duration of mining. The timing and location of mine cuts are particularly important for calculating transient ground-water flow into mine pits and for evaluating the temporal and spatial changes in the water table caused by excavation of the mine.

Detailed mine plans for the Bloomfield tract are not available. However, generic mine plans for the tract were developed by the U.S. Geological Survey and are outlined in the Bloomfield tract delineation report (U.S. Bureau of Land Management, 1981). Based on the generic mine plans, it is assumed that: (1) The Pust coal bed will be mined from the entire tract; (2) mining will commence along the outcrop of the Pust coal bed at the western boundary of the tract and will progress eastward; (3) the mine will have a 30-year duration and will produce 12.5 million tons per year and (4) all mining regulations established by the U.S. Office of Surface Mining Reclamation and Enforcement and the Montana Department of State Lands would be followed during mining and reclamation.

Effects during mining

Mining of the Pust coal would cause certain temporary effects on the local water resources. These effects include lowering of ground-water levels, dewatering of aquifers, and disruption of surface-water flows. In general, these effects would occur during the entire interval of mining.

Mining of the Pust coal would probably commence along its outcrop in the breaks terrain at the western boundary of the Bloomfield tract (fig. 2). In the area of the coal outcrop, the base of the mine pit would be above the water table and no dewatering of the pit would be required. However, during the spring of the year, small seeps might occur at the base of the coal and sandstone beds because of water discharge from small zones of perched water. These perched zones contain only small quantities of water and do not comprise usable aquifers.

The spatial relationship of the Pust coal to the water table is illustrated in figures 3 and 4. The base of the mine pit would intersect the water table after the pit has progressed about 1 mi eastward, toward the center of the tract. The central and north-central parts of the Bloomfield tract contain the greatest thickness of saturated overburden, with the water table ranging from 10 to almost 60 ft above the base of the Pust coal bed. As the mine pit progressed from the western part of the tract to the center, seepage of water into the mine pit would lower the water table in the vicinity of the mine and would dewater the coal and overburden that is presently saturated (fig. 2).

The volume of water that would enter the mine is dependent on the rate of mine-pit expansion as well as the saturated thickness and hydraulic characteristics of the aquifer. The maximum flow of ground water into the mine pit is estimated to be about 0.35 ft^3/d per lineal foot of mine pit. Mine pit inflow was estimated using the Stallman line sink, constant-discharge equation (Ferris and others, 1962, p. 126-131). The equation is based on certain assumptions, some of which were not met in the mine-pit application. However, the method is considered to provide a reliable estimate of expected inflow rates. The ground-water inflow rate was estimated using a hydraulic conductivity value of 0.3 ft/d, a storage coefficient of 10^{-3}, and a saturated thickness of 50 ft in the equation. A time factor of 100 days was used to compensate for the fact that the mine pit is not excavated instantaneously and is constantly expanding toward the highwall side of the pit. Also, inflow is assumed to occur only from the mine-pit highwall.

The estimated rate of inflow probably is a maximum value and would be less most of the time because the saturated thickness generally would be less than 50 ft. During the summer, a large part of the mine pit inflow would be lost to evaporation. Any water pumped from the mine pit probably would be used for mine needs such as dust suppression. There probably would be no need for offsite disposal of water from mine-pit inflow.

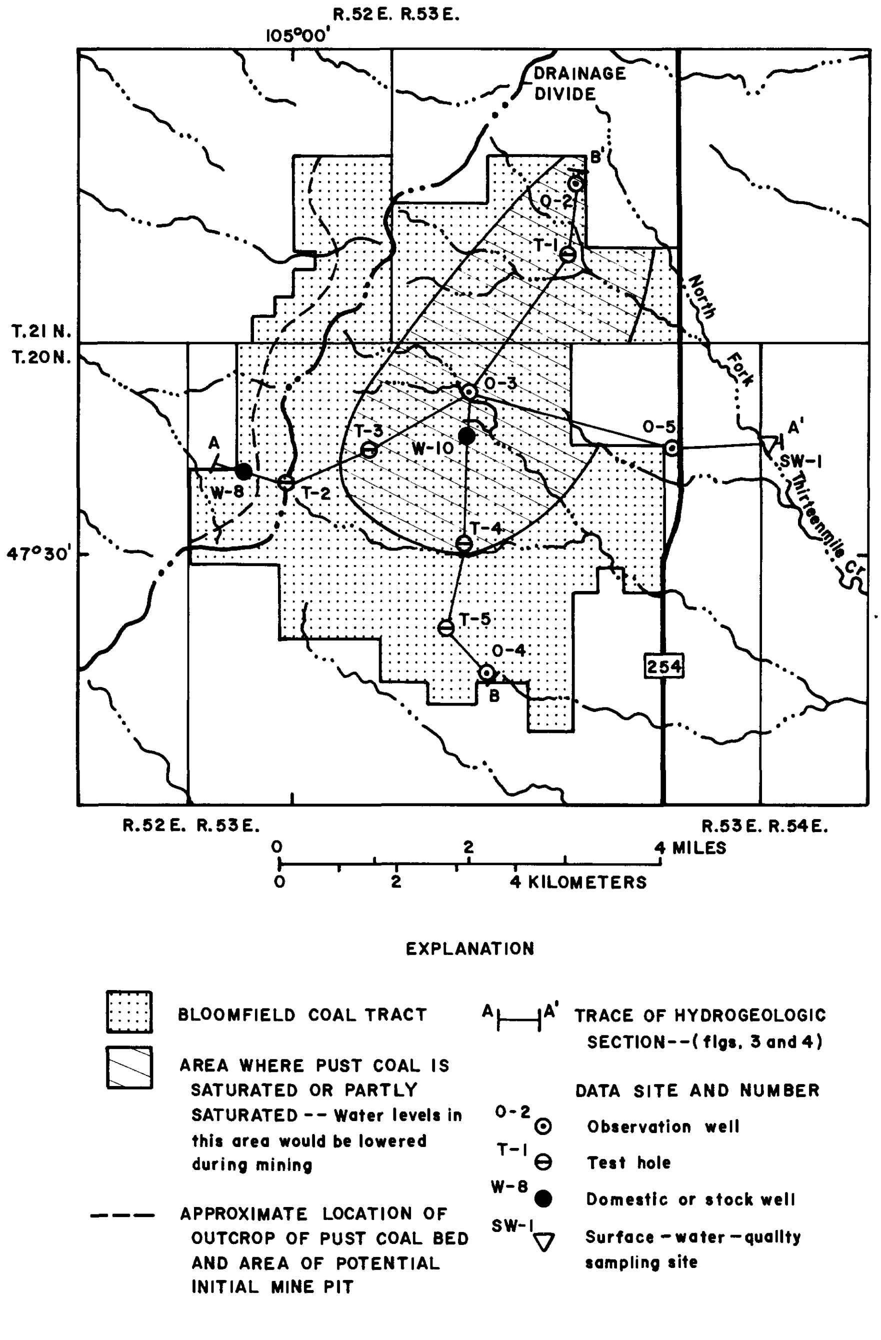

Figure 2.--Location of outcrop of Pust coal bed of the Tongue River Member of the Fort Union Formation, potential initial mine pit, and approximate area of saturated or partly saturated coal.

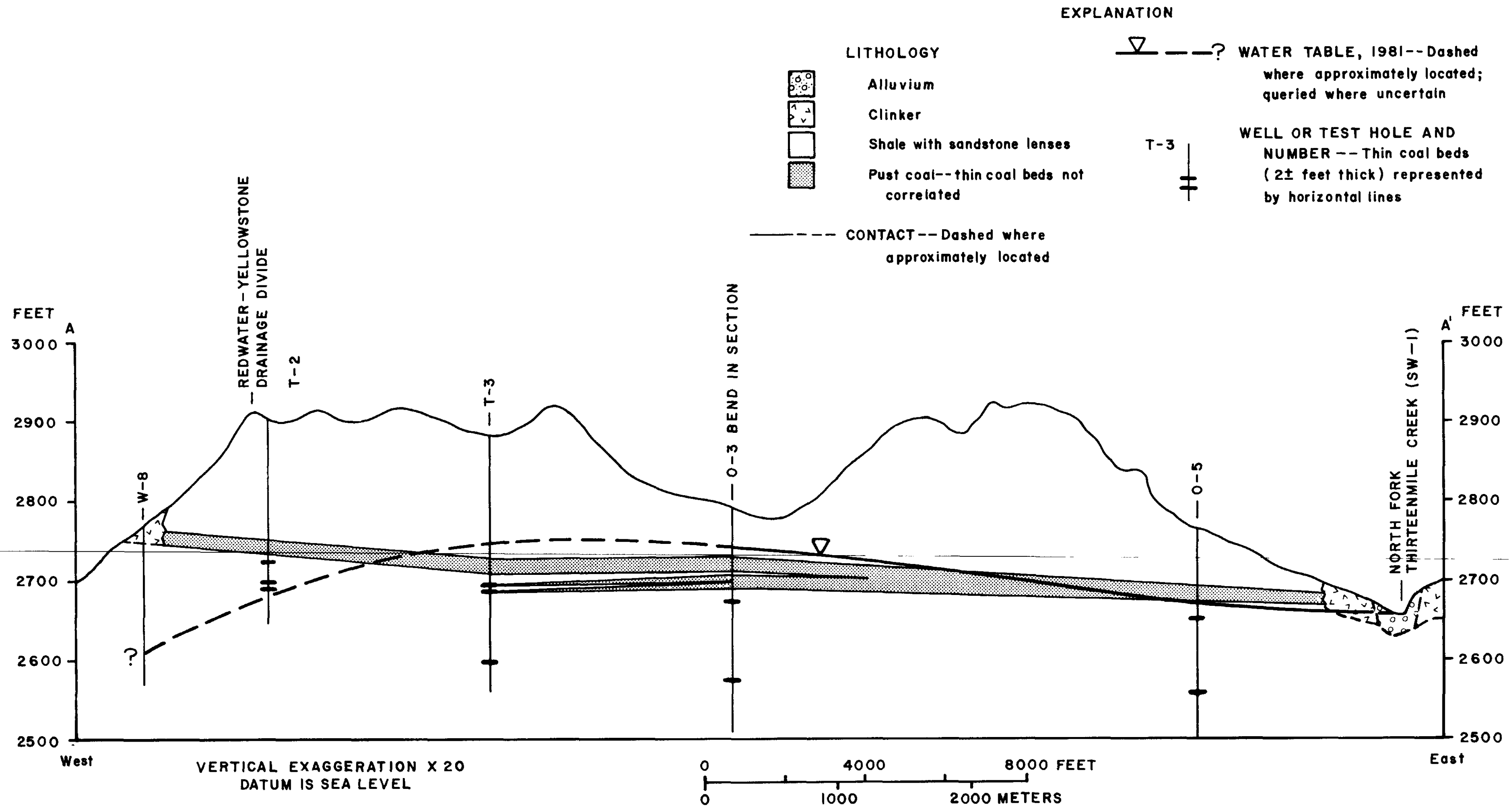

Figure 3.--West-east hydrogeologic section through the Bloomfield coal tract. Trace of section is shown in figure 2.

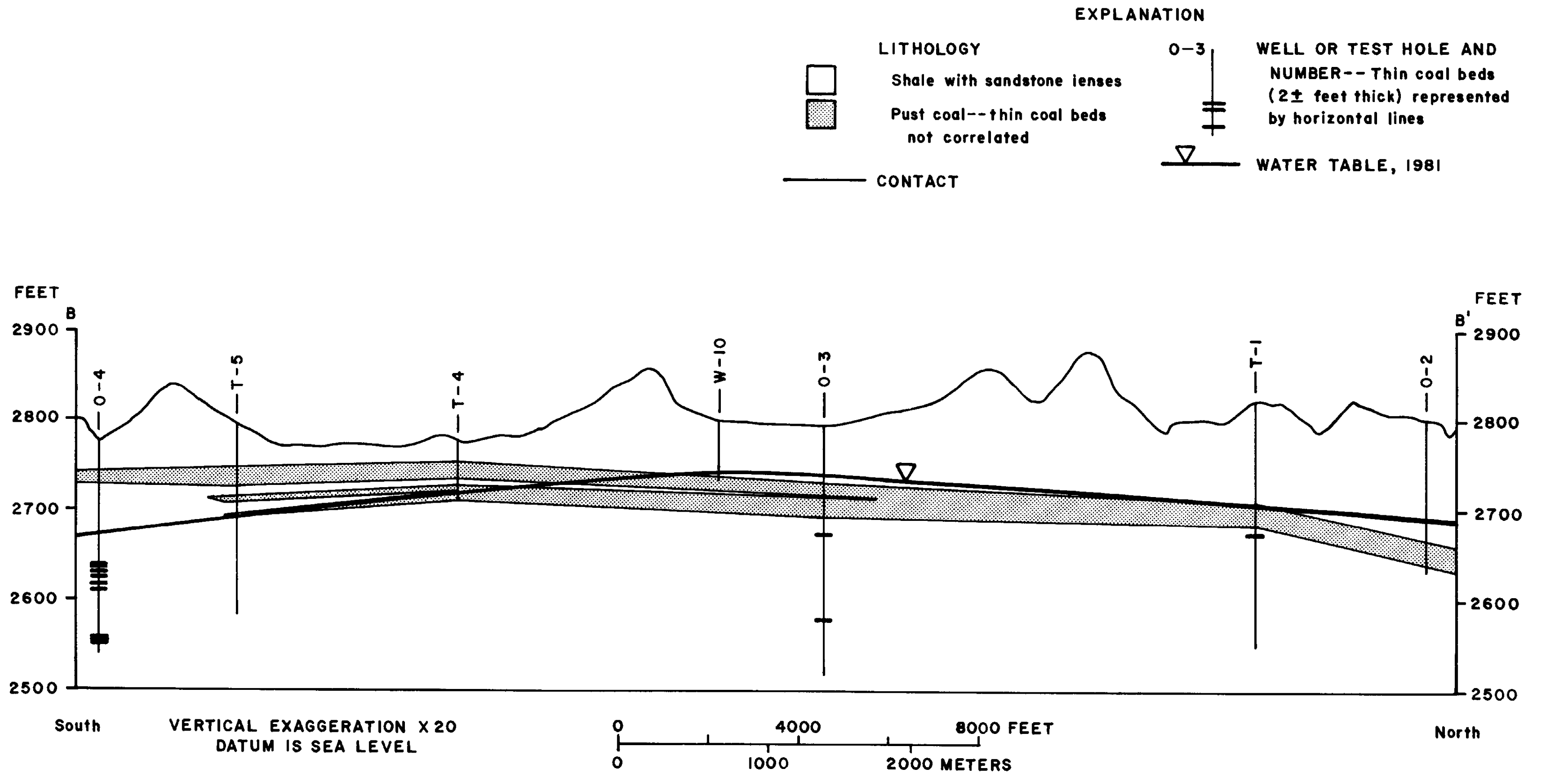

Figure 4.--South-north hydrogeologic section through the Bloomfield coal tract. Trace of section is shown in figure 2.

Lowering of water levels in sandstone and coal aquifers would be limited to the central and north-central parts of the tract, where present static water levels are above the base of the Pust coal. Areas likely to be affected by lowered water levels are shown in figure 2. Water levels in shallow aquifers east of the mine tract probably would not be affected because static water levels are near or below the base of the Pust coal, and the source of recharge in this area is primarily from vertical percolation rather than lateral flow from adjacent areas.

Water resources in deeper aquifers would need to be developed to meet the needs of the mine. Water requirements for dust suppression and other nonpotable uses are estimated to be 120,000 gal/d; water requirement for human consumption is estimated to be 15,000 gal/d (U.S. Bureau of Land Management, 1981). Water resources in the shallow aquifers of the Tongue River Member are inadequate to meet these water needs. An adequate supply of water for both potable and nonpotable uses probably could be obtained from deep wells completed in the Fox Hills-lower Hell Creek aquifer. This aquifer is presently (1982) undeveloped in the Bloomfield area and withdrawal from it would not affect shallow wells in the area.

Surface-water runoff in the Thirteenmile Creek drainage basin would be altered by mining. Surface runoff from the Bloomfield tract would likely be collected in holding ponds for sediment control, as required by surface-mining regulations. Interception of runoff from the Bloomfield tract would decrease the ephemeral flow of Thirteenmile Creek. However, the decrease in flow would likely be small because the mine tract occupies only about 8 percent of the Thirteenmile Creek drainage basin.

Long-term effects

Long-term effects on local water resources are those that are permanent or exist for many years after mining is completed. Long-term effects may include loss of water supplies or the degradation of water quality.

In the Bloomfield tract, about 15 stock and domestic wells would be destroyed by mining, along with about 13 livestock reservoirs. No known springs in or near the tract would be destroyed by mining.

Mining would permanently remove shallow coal and sandstone aquifers from the central and north-central parts of the Bloomfield tract. These aquifers presently support shallow stock and domestic wells.

A potential exists for the long-term degradation of the quality of water in shallow aquifers, through the leaching of soluble salts from mine spoils. After mining, spoil material used to backfill mine pits may become saturated as water levels rise to approximately pre-mining levels. Based on pre-mining water levels, areas of saturated spoils would be restricted to the central and north-central parts of the Bloomfield tract.

The mean dissolved-solids concentration of water in saturated spoils is estimated to be in the range of 2,460 to 3,170 mg/L. This range is 140 to 180 percent of the mean dissolved-solids concentration (1,760 mg/L) of all ground-water samples collected from the Bloomfield area and analyzed in this study (data in table 2). The magnitude of the increase in dissolved solids, between ground water in the natural environment and ground water in mine spoils, is based on geochemical studies at mine sites in the Powder River Basin of southeastern Montana (R. E. Davis, U.S. Geological Survey, written commun., 1982). The relationship between the quality of water in shallow undisturbed aquifers of the Fort Union Formation and the quality of spoils-derived water also has been investigated by Woods (1981). He reported that the median dissolved-solids concentration of spoils water could be estimated by applying a factor of 1.5 to the median dissolved-solids concentration of water in the shallow undisturbed aquifers.

Water in saturated mine spoils would contain magnesium, calcium, and sulfate as principal ions. Analysis of saturated-paste extracts, prepared from overburden samples from two test holes (T-1 and T-2 in fig. 2), showed that magnesium, calcium, and sulfate ions occur in the largest concentrations. Additionally, magnesium, calcium, and sulfate generally are the dominant ions in shallow ground water in the Bloomfield tract.

The large concentration of dissolved solids in water from mine spoils would restrict its use. Water from mine spoils would be nonpotable and generally unacceptable for domestic use. The water would be classified as having a very high salinity hazard, making it unsuitable for most irrigation (U.S. Salinity Laboratory Staff, 1954). McKee and Wolf (1971) indicate that Montana waters having a dissolved-solids concentration of as much as 3,500 mg/L are classified as fair or better for all livestock, indicating that the mine spoils water could be used for watering livestock.

POTENTIAL FOR RECLAMATION OF HYDROLOGIC SYSTEMS

No practical method is available for restoring the coal and sandstone aquifers that would be destroyed by mining. Aquifers present in the Fort Union and Hell Creek Formations and Fox Hills Sandstone could be used as alternative aquifers to replace ground-water supplies destroyed by mining. One disadvantage of using the deeper aquifers is that water levels are lower than in the shallow aquifers and greater pumping lift would be required.

Stock reservoirs destroyed by mining could be reconstructed during mine reclamation. Lining of livestock reservoirs with clay or some other relatively impermeable material would minimize seepage from the reservoir and decrease the leaching of soluble salts from the spoils beneath the reservoir.

Degradation of the quality of water in unmined shallow aquifers in and near the mine tract may occur because of leaching of soluble salts from mine spoils. However, the rate of water movement away from the tract would likely be very slow because of the small hydraulic conductivity of the extensive shale beds underlying the tract. The distance of lateral movement of degraded water may be short because of the predominantly downward hydraulic gradient in the area. Shallow wells near the mine tract would not be affected readily by mine-spoils water because of the slow rate of water movement; it would require nearly 1,000 years for water to move from the mine boundary to a point 0.5 mi downgradient.

SUPPORTING TECHNICAL DISCUSSION

Geology

Stratigraphy

Rocks of the Fort Union Formation of Paleocene age crop out throughout the area, except where overlain by alluvial deposits in some stream channels or isolated remnants of gravel terraces. Locally, the Fort Union Formation is represented by a lower, undivided section of rocks and by an upper section known as the Tongue River Member. Stratigraphic relationships of formations exposed in or underlying the Bloomfield area are shown in figure 5.

The lower section directly correlates with the Tullock Member and overlying Lebo Shale Member of the Fort Union Formation as mapped in McCone County (Collier and Knechtel, 1939) west of the study area. However, in the extreme eastern part of Montana, including the Bloomfield tract, the rocks of the lower section of the Fort Union Formation do not have distinct characteristics that justify dividing them into members. The undivided section is about 500 ft thick and is composed of dark shale, siltstone, and shaly sandstone, with lenticular sandstone and a few thin beds of lignite. As a whole, the section contains a larger percentage of shale than the Tullock Member, but a smaller percentage of shale than the Lebo Member.

All bedrock exposed in the Bloomfield area is of the Tongue River Member. The member is composed of interbedded fine-grained sandstone, siltstone, soft shale, coal of lignite grade, and a few thin beds of freshwater limestone. Beds of red clinker exist within the member, where coal beds have burned along their outcrops and baked the overlying sandstones and shales. The clinker is relatively hard and resistant to erosion and caps many small knolls and ridges. In the northern part of the Bloomfield area, the Tongue River Member is about 950 ft thick (Parker, 1936). The full thickness of the member is not present in the area; an estimated 150 ft has been removed by erosion.

The Tongue River Member contains many coal beds, most of them being relatively thin. Parker (1936) identified 11 coal beds within the member in the Richey-Lambert coal field. In the Bloomfield tract, drill-hole data indicate that at least four coal beds or benches of coal beds exist within 400 ft of the land surface. The Pust coal is the thickest of these coal beds and contains the only strippable reserves in the Bloomfield area. The Pust coal exists as two benches within most of the tract. In the northeastern part of the tract, near North Fork Thirteenmile Creek, the two benches merge into a single coal bed; in the extreme southern part of the tract the benches split into several thin beds (figs. 3 and 4). The thickest seam of Pust coal is in the northeastern part of the tract, where the upper and lower benches are merged; coal in this area is about 25 ft thick. The upper Pust bench ranges in thickness from 10 to 22 ft and the lower bench is from 4 to 10 ft thick. The maximum combined thickness of the upper and lower Pust benches is in the eastern part of the tract, where the combined thickness is about 30 ft.

Terrace gravel of Miocene or Pliocene age overlies the Tongue River Member in a few small areas along the Redwater River-Yellowstone River drainage divide. The gravel consists of rounded pebbles and cobbles of quartzite and chert, with interbedded sand. Howard (1960) speculated that these isolated patches of gravel are

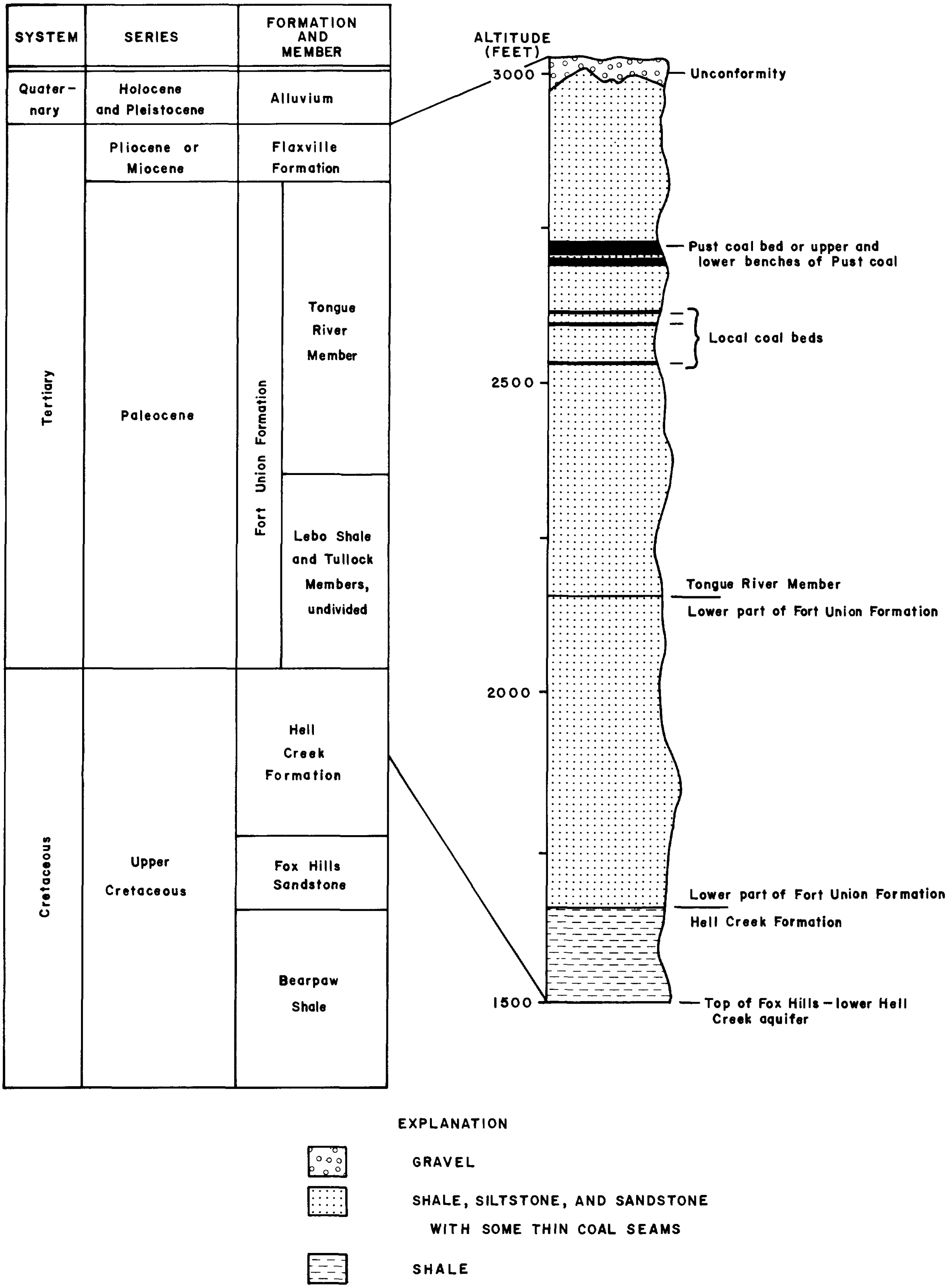

Figure 5.--Idealized stratigraphic section showing formations exposed in or underlying the Bloomfield area.

part of the widespread Flaxville Formation that caps many of the higher plateaus between Bloomfield and the Yellowstone River.

Alluvium of Quaternary age is found in the flood plain of Thirteenmile Creek, downstream from the Bloomfield tract. The alluvium is composed largely of silt but includes clay, sand, and gravel. Alluvium within the mine tract is limited to a few thin, narrow deposits in some stream channels.

Structure

The Bloomfield coal tract is situated on the west side of a broad synclinal depression known as the Williston Basin. The center of the basin is located near Williston, North Dakota, about 80 mi northeast of the Bloomfield area. Strata of the Bloomfield area dip gently to the east and northeast, toward the basin center. Structure contours drawn on top of the Pust, or first bench of the Pust coal bed (Spencer, 1976), show an easterly dip of 20 to 50 ft/mi in most of the Bloomfield tract. Small deviations from the general trend are found in the southern part of the tract where the Pust bed splits into several benches. No faults were observed in the area.

Ground-water resources

Shallow aquifers

The term "shallow aquifers" is used to characterize all aquifers that are located within about 200 or 300 ft of the land surface and that have local ground-water flow systems. In the Bloomfield tract, shallow aquifers exist almost exclusively within the more permeable beds of sandstone and coal in the Tongue River Member of the Fort Union Formation. Other geologic units, such as alluvium, Flaxville Formation, and clinker, are important water-bearing units of the region, but are not significant aquifers in the Bloomfield tract.

All shallow aquifers within the tract appear to be discontinuous. The sandstone aquifers are discontinuous because they pinch out or grade into siltstone and shale. The coal aquifers may be considered to be discontinuous because of their very small hydraulic conductivity in some locations. Alluvium is insignificant as an aquifer within the tract, because it is limited to small areas in a few drainage channels and is composed largely of silt. The Flaxville Formation is a very permeable formation, but does not appear to be an aquifer because of its limited areal extent and topographic position on the Redwater River-Yellowstone River drainage divide. These factors preclude the development of a saturated zone within the Flaxville. Small beds of clinker exist in the southern part of the tract and along the outcrop of the Pust coal bed on the western boundary of the tract. More massive deposits of clinker occur along North Fork Thirteenmile Creek, near the eastern boundary of the tract and south of the tract. The clinker of the Pust coal bed along North Fork Thirteenmile Creek has local ground-water flow; the small clinker beds within the tract appear to be unsaturated.

Hydrogeologic data from wells completed in shallow aquifers of the Bloomfield tract and adjacent areas are listed in table 1. The table does not include all wells in the area, but lists those where pertinent data were available. The location of wells listed in table 1 and water levels measured in these wells are shown in figure 6. Additional hydrogeologic data were derived from test-hole data. These test holes were drilled by various agencies for the purpose of obtaining data on coal beds and coal overburden.

Hydrogeologic properties

Hydrogeologic properties of the Tongue River Member were investigated by drilling and installing seven observation wells at selected locations within or near the tract. The wells were used for monitoring water levels, conducting aquifer tests, and collecting water samples. Two additional U.S. Geological Survey observation wells (0-1 and 0-8) are located near the tract and were monitored during this study. An inventory of many of the private wells in or near the tract was made to obtain additional hydrologic and geologic data, including water levels, well depths, well discharge, and principal aquifers (table 1 and fig. 6).

Aquifer tests conducted at observation wells indicate that the coal and sandstone beds of the Tongue River Member have small values of hydraulic conductivity. Hydraulic conductivities of coal or coal and rock aquifers ranged from about 0.01 to 2 ft/d. Both the largest and smallest values of hydraulic conductivity were measured in the Pust coal. The median value of hydraulic conductivity, from eight tests, was 0.3 ft/d. This median value is similar to the geometric mean hydraulic conductivity of 0.9 ft/d, calculated from 193 aquifer tests on Paleocene coal beds in the Northern Great Plains (Rehm and others, 1980).

Data for hydraulic conductivity of sandstone in the Bloomfield area are meager. An aquifer test conducted on a relatively thick sandstone at well 0-9 indicated a hydraulic conductivity of 10 ft/d. The sandstone penetrated in well 0-9 was the most productive aquifer tested during drilling of observation wells in the Bloomfield area. The hydraulic conductivity of the sandstone at this location probably is about the maximum of hydraulic-conductivity values for all local aquifers in the Tongue River Member, excluding clinker. Generally, sandstones in the Tongue River Member are fine grained, have a large percentage of silt, and have small values of hydraulic conductivity. The geometric-mean value of hydraulic conductivity, calculated from 70 aquifer tests of Paleocene sandstones in the Northern Great Plains, is about 0.3 ft/d (Rehm and others, 1980). It is reasonable to assume that Tongue River Member sandstones in the Bloomfield area have hydraulic-conductivity values similar to those reported by Rehm and others (1980).

Storage coefficients of coal and sandstone aquifers could not be reliably calculated from the single-well aquifer tests. Storage coefficients in the sandstone and coal are estimated to range from 10^{-4} to 10^{-3}, based on values at other sites in eastern Montana and western North Dakota (Rehm and others, 1980, p. 555).

Direction and velocity of flow

Ground water moves in response to the gradient of the hydraulic head or fluid potential. Hydraulic head is highest in topographically high areas, which are generally ground-water recharge areas, and lowest in ground-water discharge areas. The distribution of hydraulic heads between recharge and discharge areas is largely a function of the topography and the spatial distribution of zones of large hydraulic conductivity (aquifers) and small hydraulic conductivity (confining beds). In dynamic ground-water systems, hydraulic head varies from point to point in three-

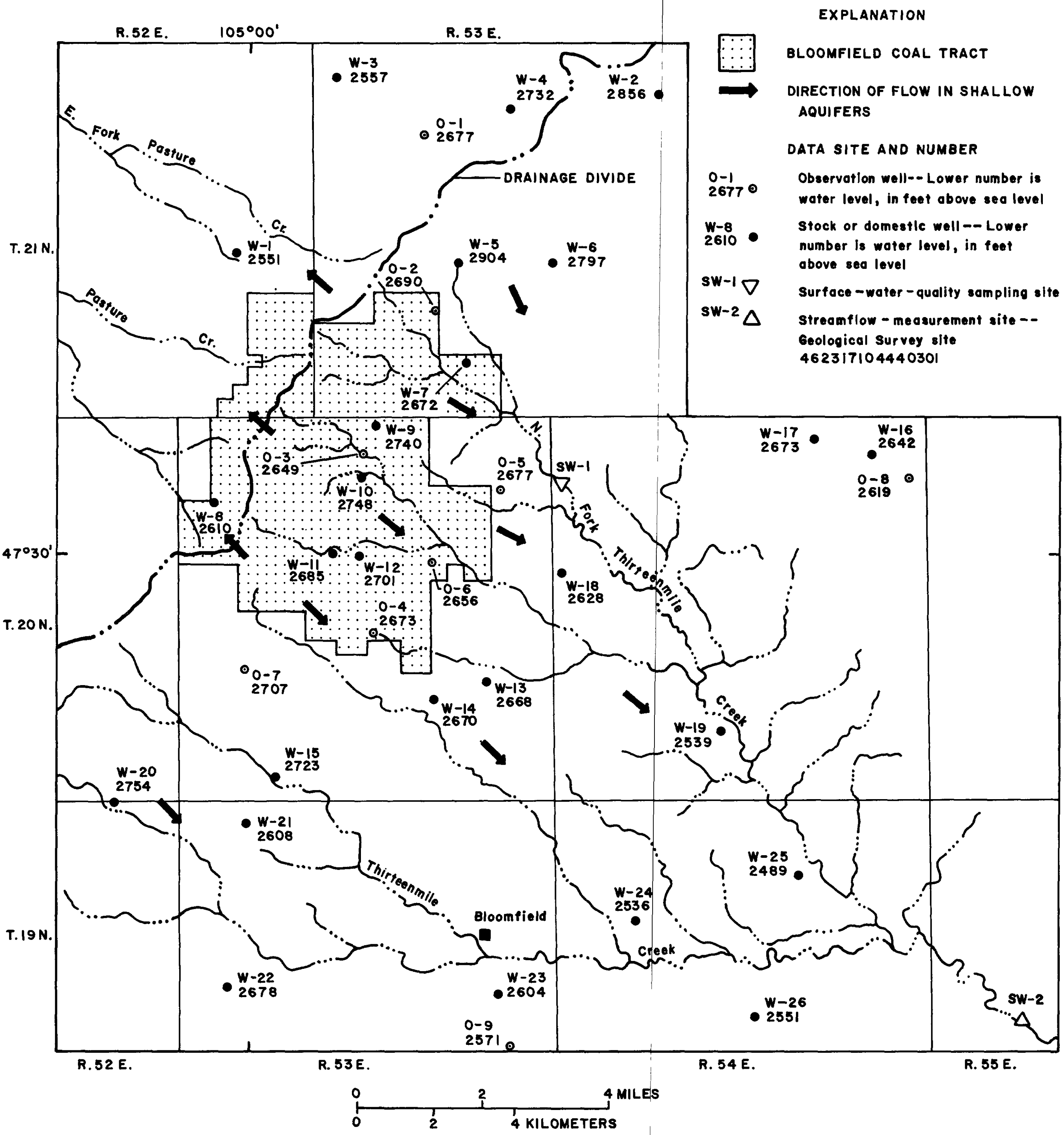

Figure 6.--Water levels in wells, direction of horizontal ground-water flow, and location of data sites in the Bloomfield coal tract and adjacent areas.

dimensional space. Hydraulic heads can be measured at points within ground-water flow systems by measuring water levels in potentiometers; water levels in wells indicate the hydraulic head at some point within the screened part of the well. The water levels measured in potentiometers and wells can be used to interpret the horizontal and vertical components of the hydraulic gradient and, thus, the direction of ground-water flow. Direction of ground-water flow generally is presented as a map of a potentiometric surface or in flow nets.

Directions of ground-water flow within the Bloomfield tract and adjacent areas were determined by measuring water levels (hydraulic heads) in wells throughout the area and applying the principles of ground-water flow to the observed hydrologic conditions. Location of wells and altitudes of measured water levels are shown in figure 6 and are listed in table 1. Water-level data from the area indicate that a northeast-trending ground-water divide occurs within the Bloomfield tract and parallels the escarpment, which forms the Redwater-Yellowstone drainage divide. The ground-water divide is located about 1 to 2 mi east of the surface-water divide (fig. 6). From the ground-water divide, horizontal components of flow are southeast toward North Fork Thirteenmile Creek and northwest toward tributaries of the Redwater River. From the ground-water divide and adjacent uplands, water also flows vertically downward toward deeper aquifers. Within the Bloomfield tract, the vertical component of hydraulic-head gradient is much larger than the horizontal component. In the central and eastern parts of the tract, vertical gradients are about 0.4 and horizontal gradients are about 0.005.

In general terms, ground-water flow in the Bloomfield tract is downward, especially near the ground-water divide. East of the Bloomfield tract and west of the escarpment, ground-water flow is predominantly downward through the zones of small hydraulic conductivity and horizontal in the zones of larger hydraulic conductivity.

Velocities of ground-water flow can be estimated if the porosity and hydraulic conductivity of the formation and the hydraulic gradient are known. Assuming that the soft shale and siltstone of the Tongue River Member have a porosity of 0.3 and a hydraulic conductivity of 10^{-3} ft/d, downward velocities would be about 0.5 ft/yr, where the gradient is 0.4. Horizontal velocity through sandstone and coal would be about 3 ft/yr, assuming a porosity of 0.2, a hydraulic conductivity of 0.3 ft/d, and a gradient of 0.005. Velocities of ground water have a large spatial variation and may vary from these estimates by an order of magnitude or more. However, it can be seen that velocities are generally very slow and thousands of years are required for ground water to flow from the center to the outside of the tract.

Recharge and discharge

The Bloomfield tract is located within the recharge area for ground-water flow systems. Evidence that the tract is predominantly a recharge area includes the location of the tract on the Redwater-Yellowstone drainage divide, the absence of springs in the tract, and the increase in depth to water in successively deeper wells.

Recharge to shallow aquifers occurs by infiltration of precipitation or ponded runoff and downward percolation of water through a thick unsaturated zone to the water table. Recharge from precipitation may occur throughout the tract, although the greatest rate of recharge probably occurs along drainages and small stock reservoirs, where runoff from precipitation and snowmelt can accumulate. Periods favorable for deep percolation and recharge to the water table occur infrequently. During the winter and early spring, the ground is frozen, preventing infiltration. From late spring to late autumn, evapotranspiration exceeds precipitation so that no significant quantity of percolation moves downward below the root zone. Recharge likely occurs only in the spring when snowmelt and rainfall accumulate in local depressions, which have favorable characteristics for infiltration and deep percolation of water. During years of less-than-average precipitation or antecedent soil-moisture deficiency the water table probably does not receive recharge from precipitation. Average yearly recharge is estimated to be less than 0.1 in.

Discharge of water from shallow aquifers within the Bloomfield tract occurs to domestic and livestock wells, vertical leakage to deeper aquifers, and lateral flow to adjacent aquifers outside of the tract. During the spring and early summer, ground water may discharge from coal and sandstone beds that crop out along the escarpment in the northwest part of the tract. The discharge is from temporary, perched water tables that develop in the coal and sandstone beds during seasons of ground-water recharge. Discharge of ground water to North Fork Thirteenmile Creek occurs in the SW1/4 sec. 6, T. 20 N., R. 54 E., about 1 mi east of the Bloomfield tract. Most of the ground water that discharges to North Fork Thirteenmile Creek at this site probably originates in the clinker adjacent to the stream.

The average rate of ground-water discharge for stock and domestic use is estimated to be 2,500 gal/d. The rates of discharge to vertical leakage and lateral flow to adjacent aquifers are small, although they account for most of the water discharging from shallow aquifers in the tract.

Deep aquifers

Deep aquifers are those that occur at depths greater than about 200 or 300 ft and have regional ground-water flow systems. Flow systems within the deep aquifers are characterized by long flow paths, small rates of flow, and stable water levels that generally are unaffected by dry or wet seasons. Waters from these deep aquifers typically have sodium, bicarbonate, and sulfate as the predominant ions. In the Bloomfield area, deep aquifers occur in the lower part of the Tongue River Member, the lower undivided section of the Fort Union Formation, and the sandstone of the Fox Hills Sandstone and Hell Creek Formation of Late Cretaceous age.

Aquifers in the lower part of the Tongue River Member are composed of fine-grained sandstones similar to the shallow aquifers in the member. Wells completed in these sandstones probably would yield from 1 to 20 gal/min; the water is likely a sodium bicarbonate or sodium sulfate type.

The lower undivided section of the Fort Union Formation is composed mostly of shale, siltstone, and shaly sandstone, locally interbedded with lenticular sandstone and a few thin beds of lignite coal. The sandstones are the principal water yielding units. Wells completed in these sandstones may yield as much as 12 gal/min.

The Fox Hills-lower Hell Creek aquifer includes the sandstone in the lower part of the Hell Creek Formation and the underlying Fox Hills Sandstone. The aquifer is a significant source of water in eastern Montana, yielding as much as 70 gal/min to domestic and stock wells and 200 gal/min to municipal or industrial wells (Stoner and Lewis, 1980). In the Bloomfield area, the thickness of the Fox Hills-lower

Hell Creek aquifer is 200 to 400 ft (Feltis, 1982a) and the top of the aquifer is at an altitude of about 1,500 ft (Feltis, 1982b). The potentiometric surface of this aquifer is at an altitude of about 2,150 to 2,200 ft in the Bloomfield area (Levings, 1982). Water from the Fox Hills-lower Hell Creek aquifer is almost invariably of the sodium bicarbonate type.

Surface-water resources

The Bloomfield tract is drained by Thirteenmile Creek, a southeast-flowing tributary of the Yellowstone River, and Pasture Creek, a northwest-flowing tributary of the Redwater River (fig. 1). The upstream reaches of Thirteenmile Creek and Pasture Creek, which includes the entire Bloomfield tract, are ephemeral and flow only in response to surface runoff from rainfall or snowmelt. Some runoff water is contained by small reservoirs for use by livestock. In general, surface-water resources within the tract are very limited.

Thirteenmile Creek has a drainage area of 207 mi^2. The Bloomfield coal tract occupies about 17 mi^2, or 8 percent of the area in the drainage basin. Stream channels in the tract are relatively straight, with gradients generally in the range of 40 to 120 ft/mi. Surface runoff is rapid where livestock reservoirs are not present to impede flow. Within the coal tract, North Fork Thirteenmile Creek and its small tributaries are all above the water table and have no base flow. Because of rapid surface runoff and no base flow, the stream channels are dry most of the year. East of the coal tract, in the SW1/4 sec. 6, T. 20 N., R. 54 E., the channel of North Fork Thirteenmile Creek contains water all year because the water table apparently intersects the stream channel in this area.

Pasture Creek has a drainage area of 110 mi^2. The Bloomfield coal tract occupies about 3 mi^2, or 3 percent of the area in the drainage basin. The part of tract drained by Pasture Creek is characterized by numerous steeply sided hills and gullies with many barren slopes. Stream channels are numerous, are relatively straight, have very steep gradients, and are deeply incised. Surface runoff is very rapid and causes severe erosion. All stream channels are above the water table and have no base flow.

The mean annual discharge of Thirteenmile Creek and the magnitude and frequency of floods on Thirteenmile and Pasture Creeks were estimated by indirect methods. The method used to estimate mean annual discharge requires measurements of channel geometry and was developed through regression analysis of streamflow and dimensions of the channel (Omang and others, 1983). Estimates of flood peaks for various recurrence intervals were made from regression equations that use the basin characteristics of drainage area and mean altitude, combined with a geographical factor that is dependent on the location of the basin within the State (Parrett and Omang, 1981).

Based on channel geometry, the mean annual discharge of Thirteenmile Creek at the streamflow-measurement site (SW-2 in fig. 6) in sec. 20, T. 19 N., R. 55 E., is about 4,270 acre-ft. About 490 of the 4,270 acre-ft of runoff originates in the Bloomfield coal tract. Magnitudes of flood peaks at site SW-2 on Thirteenmile Creek are 6,570 ft^3/s for the 100-year flood, 3,510 ft^3/s for the 25-year flood, and 1,170 ft^3/s for the 5-year flood. About 11 percent of the flood-flow volume would originate in the coal tract.

Magnitudes of flood peaks at the mouth of Pasture Creek are estimated to be 7,530 ft^3/s for the 100-year flood, 4,100 ft^3/s for the 25-year flood, and 1,390 ft^3/s for the 5-year flood. About 3 percent of the flood-flow volume would originate in the coal tract.

Runoff from the coal tract is attenuated by 13 small stock reservoirs. Eleven of these reservoirs are located in the Thirteenmile Creek basin; the other two are in the Pasture Creek drainage basin. Most of these reservoirs are less than 1 acre in size, although a few attain a size of 1 to 2.5 acres when full. All but one of these reservoirs are dry for part of the year. A reservoir in the NW1/4 sec. 29, T. 21 N., R. 53 E., is perennial most years, but became dry during the summer of 1981 after an extended interval of less-than-normal precipitation.

Water quality and geochemistry

Quality of ground water was determined by analysis of water samples from local stock, domestic, and observation wells. Quality of surface water was determined at only one site (SW-1) on North Fork Thirteenmile Creek. Analyses of surface-water samples are limited because of the ephemeral nature of Thirteenmile Creek and Pasture Creek, and general lack of water in the livestock reservoirs. Results of the water-quality analyses are listed in tables 2 and 3.

Shallow ground water in the Bloomfield tract and surrounding area contains principally magnesium, calcium, and sulfate, or principally magnesium, calcium, and bicarbonate ions. A sodium sulfate type water was sampled at two wells (O-4 and O-7). Dissolved-solids concentrations of ground water ranged from 867 to 2,830 mg/L, with a mean value of 1,760 mg/L.

The water sample collected from North Fork Thirteenmile Creek had a relatively small dissolved-solids concentration of 688 mg/L. Water from the creek was a calcium bicarbonate type.

The chemical composition and evolution of ground water in the area can be explained based on geologic, hydrologic, and geochemical factors. Moran and others (1978) outlined geochemical processes that account for the chemical evolution of water in the Tertiary sediments of North Dakota. Wallick (1981) has shown that the chemical composition and evolution of ground water is related to depth or distance along a ground-water flow path. The geochemical and hydrologic processes presented by these authors appear to adequately explain the chemical evolution of the ground water in the Bloomfield tract.

Geochemical processes that probably account for the observed chemical composition of ground water are: (1) The generation of hydrogen ions through the production of carbon dioxide (CO_2) in the organic zone of the soil; (2) the dissolution of calcite and dolomite, leaving calcium, magnesium, and bicarbonate ions in solution; (3) the oxidation of pyrite; (4) the dissolution of gypsum to produce calcium and sulfate ions; and (5) the exchange of calcium and magnesium cations for sodium ions on sodium-rich clays.

Hydrogeologic factors that affect the quality of ground water in the Bloomfield tract include the relatively large thickness of unsaturated fine-grained sediments and the location of the tract in a ground-water recharge area. All shallow ground water in the tract is relatively young because the tract is a recharge area. The presence of calcite, dolomite, and pyrite in the sediments, combined with infrequent recharge to the water table, are also important factors that affect the chemical evolution of the ground water.

A conceptual model of the evolution of shallow ground water in the Bloomfield tract is: typical infiltration from snowmelt or rainfall causes shallow percolation of water that does not pass the root zone. Carbonic acid, formed from CO_2 in the atmosphere and the root zone, dissolves calcite and dolomite, forming calcium and magnesium cations and bicarbonate anions. At the same time, oxidation of pyrite by dissolved oxygen produces sulfate ions. Alternate wet-dry conditions in the unsaturated zone leads to the formation of gypsum ($CaSO_4 \cdot 2H_2O$). Exceptionally intense rainfall causes deep percolation and dissolves gypsum. The resulting recharge water will contain predominantly calcium, magnesium, sulfate, and bicarbonate ions. Water of this type is typical of most ground water in the study area. If the sediments in the unsaturated or saturated zones contain sodium-enriched clays, cation exchange will take place and enrich the water in sodium. Water with a large percentage of sodium cations exists in relatively few wells in the area, indicating that shallow sediments do not have a large quantity of exchangeable sodium.

CONCLUSIONS

Ground-water resources of the Bloomfield area are used primarily for livestock watering and domestic supply. Ground water is obtained from shallow wells, generally less than 200 ft deep, completed in sandstone and coal beds of the Tongue River Member of the Fort Union Formation. Both the coal and sandstone aquifers have relatively small values of hydraulic conductivity, ranging from about 0.01 to 10 ft/d. Wells generally yield from 1 to 10 gal/min.

Surface-water resources in the area are meager. All streams in the area are ephemeral and most livestock reservoirs are dry for part of the year. Surface water that is available is used for watering livestock.

Chemical analyses indicate that most shallow ground water is dominated by calcium and magnesium cations and sulfate and bicarbonate anions. Some shallow ground water has a large percentage of sodium cations. One water sample from North Fork Thirteenmile Creek was a calcium bicarbonate type.

Mining of the Pust coal would destroy about 15 stock and domestic wells and 13 small livestock reservoirs. Shallow coal and sandstone aquifers would be permanently removed from parts of the tract. Water levels in shallow coal and sandstone aquifers would be lowered in the central and north-central parts of the tract. Water levels in shallow aquifers east of the tract probably would not be affected. After mining, a potential exists for the long-term degradation of the quality of water in shallow aquifers, caused by the leaching of soluble salts from mine spoils.

Impacts of mining on the local water resources could be mitigated during reclamation. Deeper aquifers in the Fort Union and Hell Creek Formations, and Fox Hills Sandstone, could be used as alternative aquifers to replace ground-water supplies destroyed by mining. The deep aquifers have lower water levels than existing shallow aquifers and would require a greater pumping lift. Stock reservoirs destroyed by mining could be replaced during reclamation. Migration of degraded water from mine spoils would be very slow, because of the small hydraulic conductivity of the extensive shale beds underlying the tract and the predominantly downward hydraulic gradient.

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DATA

Table 1.--*Hydrogeologic data from wells in the Bloomfield coal tract and adjacent areas*

[E, estimated from specific-capacity data; R, reported; USGS, U.S. Geological Survey; <, less than]

Site designation[1]	Location	Altitude of land surface (feet above sea level)	Depth of well (feet)	Principal aquifer[2]	Aquifer interval (feet)	Hydraulic conductivity of aquifer (feet per day)
0-1	SW¼SW¼SE¼NE¼ sec. 8, T. 21 N, R. 53 E.	2,703	70	Pust coal[3]	36-51	2.0 E
0-2	SE¼NE¼SE¼NE¼ sec. 29, T. 21 N., R. 53 E.	2,800	170	Pust coal[3]	136-160	< .01
0-3	NE¼NE¼NE¼SE¼ sec. 4, T. 20 N., R. 53 E.	2,790	280	Coal and sandstone	214-220 and 242-264	.2
0-4	SW¼SW¼SW¼NW¼ sec. 22, T. 20 N., R. 53 E.	2,780	240	Coal and shale	222-235	.04
0-5	NW¼NE¼NW¼NW¼ sec. 12, T. 20 N., R. 53 E.	2,765	118	Coal and sandstone	111-116	1
0-6	SW¼SW¼NW¼NW¼ sec. 14, T. 20 N., R. 53 E.	2,745	206	Coal and siltstone	195-203	.2
0-7	SW¼SW¼SW¼SW¼ sec. 20, T. 20 N., R. 53 E.	2,850	259	Coal	222-228	1
0-8	SE¼SE¼SW¼SE¼ sec. 1, T. 20 N., R. 54 E.	2,660	220	Coal of Tongue River Member	176-210	.4 E
0-9	SW¼SE¼SW¼SW¼ sec. 24, T. 19 N., R. 53 E.	2,715	220	Sandstone of Tongue River Member	190-220	10
W-1	SE¼NW¼SE¼NE¼ sec. 23, T. 21 N., R. 52 E.	2,610	66	Tongue River Member	--	--
W-2	NW¼SW¼SW¼SE¼ sec. 1, T. 21 N., R. 53 E.	2,890	65	Tongue River Member	--	--
W-3	NE¼NE¼NE¼SW¼ sec. 6, T. 21 N., R. 53 E.	2,610	103	Tongue River Member	--	--
W-4	SE¼NE¼NW¼NW¼ sec. 10, T. 21 N., R. 53 E.	2,760	77	Tongue River Member	--	--
W-5	NW¼NE¼NE¼SW¼ sec. 21, T. 21 N., R. 53 E.	2,950	93	Tongue River Member	--	--
W-6	NW¼NE¼NE¼SE¼ sec. 22, T. 21 N., R. 53 E.	2,870	128	Tongue River Member	--	--
W-7	SE¼SE¼NE¼NW¼ sec. 33, T. 21 N., R. 53 E.	2,790	170	Coal and sandstone	--	--
W-8	SE¼SE¼NE¼NW¼ sec. 7, T. 20 N., R. 53 E.	2,770	>200	Fort Union Formation	--	--

Water level (feet below land surface)	Date of water level measurement	Hydraulic head (feet above sea level)	Well discharge (gallons per minute)	Date of discharge measurement	Remarks
25.65	4-19-81	2,677	3	5-04-76	USGS observation well.
109.75	9-10-81	2,690	<1	9-10-81	Observation well installed by USGS.
141.40	9-11-81	2,649	3	9-11-81	Observation well installed by USGS.
107.15	9-12-81	2,673	1	9-13-81	Observation well installed by USGS.
87.99	9-12-81	2,677	1	9-12-81	Coal exploration hole US-81078. Drilled to 260 feet.
89.13	9-13-81	2,656	3	4-17-81	Coal exploration hole US-81086.
142.70	9-13-81	2,707	4	4-18-81	Coal exploration hole US-81087.
41.25	6-28-81	2,619	10	5-04-76	USGS observation well.
144.50	9-13-81	2,571	7	4-27-82	Maximum well discharge would be greater than measured discharge.
58.70	9-01-76	2,551	5	9-01-76	Stock well.
34.00	9-01-76	2,856	6R	9-01-76	Domestic well.
53.30	9-01-76	2,557	8	9-01-76	Domestic well.
27.70	9-01-76	2,732	--	--	Stock well.
46.40	9-01-76	2,904	--	--	Well is not used.
73.20	9-01-76	2,797	8	9-01-76	Domestic well.
117.96	6-25-81	2,672	--	--	Domestic well.
160.50	7-30-82	2,610	--	--	Stock well.

Table 1.--*Hydrogeologic data from wells in the Bloomfield coal tract and adjacent areas*--Continued

Site designation[1]	Location	Altitude of land surface (feet above sea level)	Depth of well (feet)	Principal aquifer[2]	Aquifer interval (feet)	Hydraulic conductivity of aquifer (feet per day)
W-9	NW¼NE¼NW¼NW¼ sec. 3, T. 20 N., R. 53 E.	2,830	110 R	Tongue River Member	--	--
W-10	SE¼SE¼SE¼SE¼ sec. 4, T. 20 N., R. 53 E.	2,800	66.5	Tongue River Member	--	--
W-11	NE¼NE¼NE¼NW¼ sec. 16, T. 20 N., R. 53 E.	2,775	216 R	Tongue River Member	--	--
W-12	NW¼SE¼NE¼NE¼ sec. 16, T. 20 N., R. 53 E.	2,785	115	Tongue River Member	--	--
W-13	SE¼NE¼NE¼NE¼ sec. 26, T. 20 N., R. 53 E.	2,685	81	Tongue River Member	--	--
W-14	NW¼SW¼SW¼NW¼ sec. 26, T. 20 N., R .53 E.	2,703	69	Tongue River Member	--	--
W-15	SE¼NW¼NW¼SE¼ sec. 32, T. 20 N., R. 53 E.	2,730	23	Alluvium	--	--
W-16	NW¼NW¼NW¼SW¼ sec. 1, T. 20 N., R. 54 E.	2,664	33	Alluvium	--	--
W-17	NE¼NE¼SW¼NW¼ sec. 2, T. 20 N., R. 54 E.	2,730	116	Tongue River Member	--	--
W-18	NE¼SW¼SW¼NW¼ sec. 18, T. 20 N., R. 54 E.	2,665	--	Fort Union Formation	--	--
W-19	NE¼SE¼SW¼SE¼ sec. 28, T. 20 N., R. 54 E.	2,550	15	Alluvium	--	--
W-20	NW¼NE¼NE¼NE¼ sec. 2, T. 19 N., R. 52 E.	2,820	110	Tongue River Member	--	--
W-21	SW¼NW¼SW¼NW¼ sec. 5, T. 19 N., R. 53 E.	2,760	250	Fort Union Formation	--	--
W-22	NW¼SE¼SE¼SE¼ sec. 18, T. 19 N., R. 53 E.	2,700	84	Tongue River Member	--	--
W-23	NW¼NW¼NW¼NW¼ sec. 24, T. 19 N., R. 53 E.	2,618	34	Alluvium	--	--
W-24	SE¼SW¼SE¼SW¼ sec. 8, T. 19 N., R. 54 E.	2,555	--	Fort Union Formation	--	--
W-25	NE¼NE¼SE¼NE¼ sec. 10, T. 19 N., R. 54 E.	2,518	79	Tongue River Member	--	--
W-26	SE¼SE¼SW¼NW¼ sec. 22, T. 19 N., R. 54 E.	2,585	160	Tongue River Member	--	--

[1] O, Observation well; W, stock, domestic, or irrigation well.
[2] Tongue River Member is a member of the Fort Union Formation.
[3] Pust coal is in Tongue River Member of Fort Union Formation.

Water level (feet below land surface)	Date of water level measurement	Hydraulic head (feet above sea level)	Well discharge (gallons per minute)	Date of discharge measurement	Remarks
90 R	--	2,740	3	--	Domestic well.
51.79	6-25-81	2,748	--	--	Dug well-no longer used.
90 R	--	2,685	--	--	Domestic well.
79.10	9-02-76	2,701	3	9-02-76	Domestic well.
17.40	9-02-76	2,668	20	9-02-76	Stock well.
32.80	9-02-76	2,670	--	--	Well is not used.
6.60	9-02-76	2,723	8	9-02-76	Stock well.
21.70	9-09-76	2,642	3	9-09-76	Stock well.
57.20	9-09-76	2,673	5	9-09-76	Stock and domestic well.
21.90	9-08-76	2,628	4	9-08-76	Stock and domestic well.
11.00	9-09-76	2,539	--	--	Well is not used.
66.01	10-17-77	2,754	--	--	Stock and domestic well.
152.00	10-04-77	2,608	--	--	Domestic well.
22.37	10-03-77	2,678	--	--	Stock well.
14.17	10-01-77	2,604	--	--	Stock and irrigation well.
18.99	10-03-77	2,536	--	--	Stock and domestic well.
28.57	10-01-77	2,489	--	--	Stock well.
34.12	9-07-77	2,551	29	9-07-77	Irrigation well.

Table 2.--*Major-constituent concentrations and physical properties of water from wells and streams in the Bloomfield coal tract and adjacent areas*

[Unless indicated otherwise, constituents are dissolved and concentrations are reported in milligrams per liter. Analyses by Montana Bureau of Mines and Geology. Abbreviations: micromhos, micromhos per centimeter at 25°C; °C, degrees Celsius; L, laboratory measurement]

Site designation[1]	Location	Date of collection	Geologic source	Onsite specific conductance (micromhos)	Onsite pH (standard units)	Onsite water temperature (°C)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)
0-1	SW¼SW¼SE¼NE¼ sec. 8, T. 21 N., R. 53 E.	5-04-76	Pust coal[2]	2,630 L	6.9 L	11.0	1,700	270	240
0-2	SE¼NE¼SE¼NE¼ sec. 29, T. 21 N., R. 53 E.	9-11-81	Pust coal[2]	1,320	7.5	12.0	630	100	92
0-3	NE¼NE¼NE¼SE¼ sec. 4, T. 20 N., R. 53 E.	9-11-81	Coal and sandstone	1,720	7.1	12.0	970	140	150
0-4	SW¼SW¼SW¼NW¼ sec. 22, T. 20 N., R. 53 E.	9-13-81	Coal and shale	2,400	7.4	12.0	140	24	20
0-5	NW¼NE¼NW¼NW¼ sec. 12, T. 20 N., R. 53 E.	9-12-81	Coal	1,420	7.0	10.5	--	--	--
0-6	SW¼SW¼NW¼NW¼ sec. 14, T. 20 N., R. 53 E.	4-17-81	Coal and sandstone	2,100	7.0	11.5	910	140	130
0-7	SW¼SW¼SW¼SW¼ sec. 20, T. 20 N., R. 53 E.	4-18-81	Coal	2,050	8.7	12.5	31	6.2	3.7
0-8	SE¼SE¼SW¼SE¼ sec. 1, T. 20 N., R. 54 E.	5-04-76	Pust coal[2]	1,830 L	7.0 L	9.0	1,100	210	150
0-9	SW¼SE¼SW¼SW¼ sec. 24, T. 19 N., R. 53 E.	9-13-81	Sandstone	3,100	6.9	11.5	1,090	160	170
SW-1	SE¼SW¼SW¼SW¼ sec. 6, T. 20 N., R. 54 E.	9-12-81	--	830	8.1	19.0	420	98	44
W-6	NW¼NE¼NE¼SE¼ sec. 22, T. 21 N., R. 53 E.	9-01-76	--	1,300 L	7.3 L	10.0	760	180	77
W-13	SE¼NE¼NE¼NE¼ sec. 26, T. 20 N., R. 53 E.	9-02-76	--	2,510 L	7.4 L	11.0	1,480	300	180
W-17	NE¼NE¼SW¼NW¼ sec. 2., T. 20 N., R. 54 E.	9-09-76	--	2,370 L	7.2 L	8.0	1,500	290	190

[1]O, observation well; SW, surface-water sampling site; W, stock or domestic well.
[2]Pust coal bed is in Tongue River Member of Fort Union Formation.

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)
67	0.7	8	650	540	1,200	6.4	0.1	16	2,130	--
78	1	6	610	500	280	3.1	.02	15	1,180	0.04
59	.8	9	730	600	470	4.2	.02	18	1,590	.04
530	20	6	700	570	680	4.6	.2	7.4	1,970	.12
--	--	--	--	--	--	--	--	--	--	--
160	2	9	750	610	580	3.4	.7	16	1,800	13
450	35	2	400	340	650	2.9	.8	7.3	1,520	.12
43	.6	8	570	470	770	2.9	.1	18	1,490	--
380	5	9	1,230	1,010	860	7.5	.2	15	2,830	.07
8	.2	20	320	260	180	7.6	.6	9.9	688	.01
12	.2	4	580	470	280	14	.2	14	867	3.1
97	1	5	420	340	1,200	22	.2	9.6	2,060	.27
50	.6	8	600	500	1,000	8.4	<.1	14	1,890	.22

Table 3.--*Trace-element concentrations of water from wells and streams in the Bloomfield coal tract and adjacent areas*

[Constituents are dissolved and concentrations are reported in micrograms per liter. Analyses by Montana Bureau of Mines and Geology. <, less than]

Site designation[1]	Location	Date of collection	Aluminum (Al)	Boron (B)	Cadmium (Cd)	Chromium (Cr)
0-2	SE¼NE¼SE¼NE¼ sec. 29, T. 21 N., R. 53 E.	9-11-81	<30	380	<2	<2
0-3	NE¼NE¼NE¼SE¼ sec. 4, T. 20 N., R. 53 E.	9-11-81	<30	260	<2	<2
0-4	SW¼SW¼SW¼NW¼ sec. 22, T. 20 N., R. 53 E.	9-13-81	<30	90	<2	<2
0-9	SW¼SE¼SW¼SW¼ sec. 24, T. 19 N., R. 53 E.	9-13-81	<30	220	<2	<2
SW-1	SE¼SW¼SW¼SW¼ sec. 6, T. 20 N., R. 54 E.	9-12-81	<30	130	<2	<2

[1]O, observation well; SW, surface-water sampling site.

Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Vanadium (V)	Zinc (Zn)
19	680	<40	88	<20	<10	<1	11
33	200	<40	38	<20	<10	<1	22
<2	<2	<40	58	<20	<10	2	65
9	1,920	<40	74	<20	<10	<1	6
20	40	<40	250	<20	<10	<1	<4