POTENTIAL EFFECTS OF SURFACE COAL MINING ON THE HYDROLOGY OF THE CIRCLE WEST COAL TRACTS, McCONE COUNTY, EASTERN MONTANA

By M. R. Cannon

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GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
428 Federal Building
301 S. Park
Drawer 10076
Helena, MT 59626-0076

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CONTENTS

ILLUSTRATIONS

TABLES

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-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
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
ton per square mile (ton/mi^2)	0.3503	tonne per square kilometer

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 CIRCLE WEST COAL TRACTS, McCONE COUNTY, EASTERN MONTANA

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ABSTRACT

The Circle West coal tracts in McCone County, Montana, contain about 460 million tons of recoverable coal reserves. Estimates of coal reserves for the tract are based predominantly on the S coal bed, which averages about 16 feet in thickness. About 175 million tons, or 38 percent, of the recoverable coal is Federally owned and 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 effects of surface coal mining on local water resources.

Hydrogeologic data collected from wells and drill holes indicate that shallow aquifers exist in sandstone and coal beds of the Tongue River Member of the Fort Union Formation (Paleocene age). These shallow aquifers generally have small values of hydraulic conductivity (0.1 to 380 feet per day) and typically yield from 2 to 20 gallons per minute to stock and domestic wells. Where coal is extremely fractured or the thickness of saturated sandstone is large, some wells can yield in excess of 70 gallons per minute. Chemical analyses indicate that most shallow aquifers contain a sodium sulfate or sodium bicarbonate type water.

Surface-water resources of the area consist of intermittent streamflow in parts of the Nelson and Timber Creek basins plus a large network of reservoirs. The reservoirs provide a large part of the water supply for area livestock. Two reservoirs in the Nelson Creek basin supply water for irrigation. Water-quality data for Nelson and Timber Creeks indicate that the water generally is a sodium sulfate type and has a large concentration (181 to 6,960 milligrams per liter) of dissolved solids.

Mining of the S coal bed in the Circle West coal tracts would permanently remove shallow coal and sandstone aquifers, resulting in the loss of shallow stock wells. Mining would destroy livestock reservoirs, alter runoff characteristics of Nelson Creek, and temporarily lower water levels in shallow aquifers near the mine. Leaching of soluble constituents from mine spoils may cause a long-term degradation of the quality of water in shallow aquifers in and near the coal tracts. Some of the effects on local water supplies could be mitigated by development of alternative water resources in deeper aquifers such as the Tullock aquifer of Paleocene age and the Fox Hills-lower Hell Creek aquifer of Late Cretaceous age.

INTRODUCTION

The Fort Union coal region of eastern Montana contains vast deposits of low sulfur coal that are under both Federal and private ownership. Considerable interest exists in developing the coal reserves of the region to help meet the increased demand for domestically produced energy. To satisfy 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 effects to the water resources of the area during mining and reclamation operations, and after abandonment. To determine potential effects 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. This report focuses on the hydrology of the Circle West coal 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 effects 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 effects 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 Circle West study area encompasses about 220 mi^2 in McCone County, eastern Montana. The study area is about 20 mi west of Circle, Mont., and 10 mi southeast of the Dry Arm of Fort Peck Lake (fig. 1).

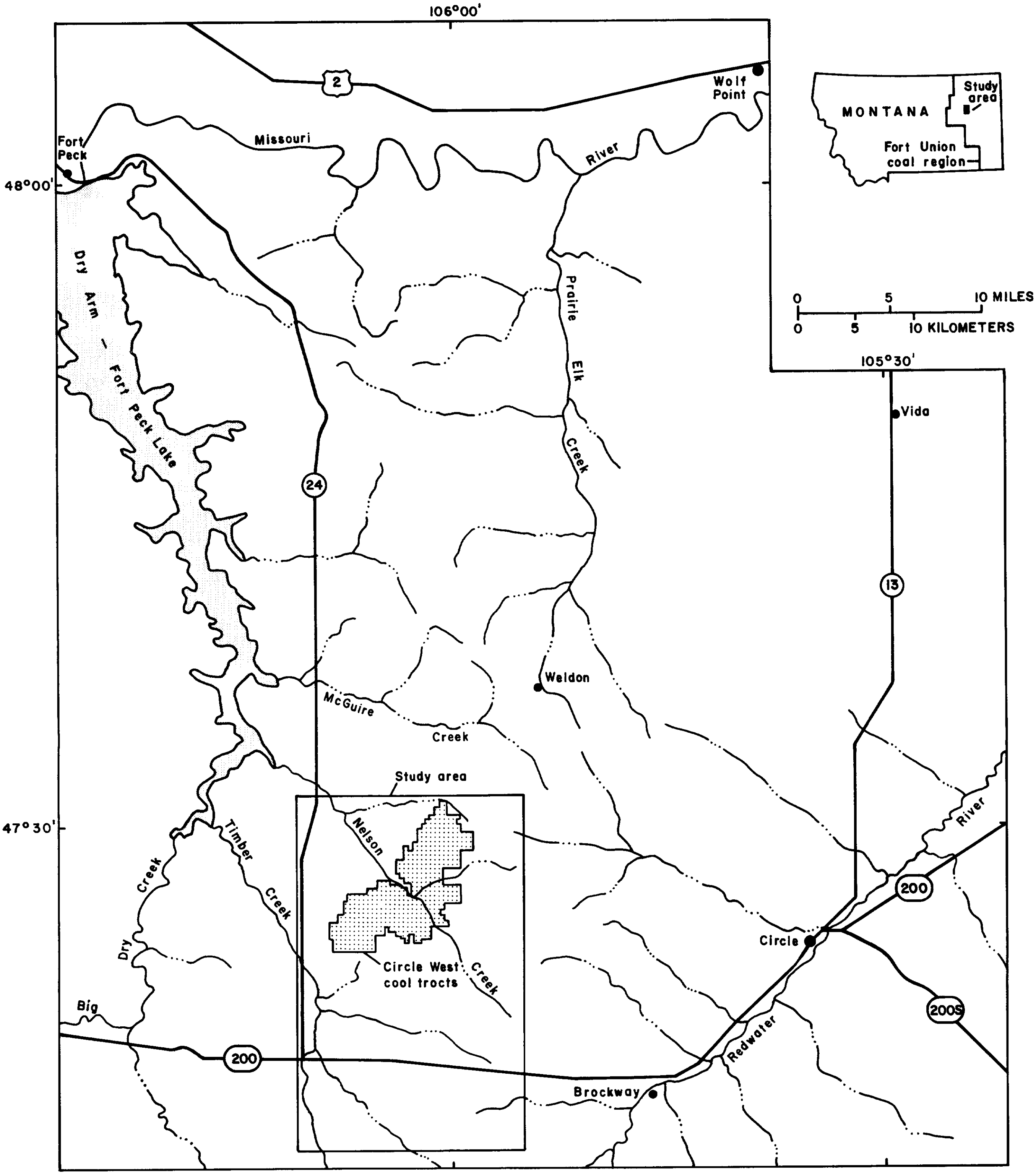

Figure 1.--Location of the Circle West study area. Boundary of Fort Union coal region from U.S. Bureau of Land Management (1983).

Boundaries of the study area were chosen to accommodate certain hydrologic and coal-tract boundaries. The study area includes three potential coal-lease tracts, identified by the U.S. Bureau of Land Management as Circle West Tracts I, II, and III. (Tract III is the combined area of tracts I and II, as shown in figure 2.) The study area also includes Federal coal south of the Circle West tracts that is part of a coal exchange between Meridian Land and Mineral Company and the U.S. Bureau of Land Management. The western boundary of the study area is the valley of Timber Creek, and the eastern boundary is near the drainage divide between Nelson or Timber Creek basin and the Redwater River basin.

The Circle West coal tracts occupy an area of about 33 mi^2 and contain about 460 million tons of recoverable coal reserves, mostly within the S coal bed. About 175 million tons, or 38 percent, of the recoverable coal is Federally owned. The quantity of Federal coal within the study area south of the Circle West tracts is large but undetermined.

Timber and Nelson Creeks and their small tributaries drain the study area. The valleys of Timber and Nelson Creeks are relatively broad and shallow throughout most of the study area. Slopes of these valleys predominantly are gentle and grass covered. Headwaters of Nelson Creek and Timber Creek tributaries have narrow channels moderately incised into the rolling uplands.

For the most part, the land surface is a moderately rolling plain with a general slope to the north-northwest. In the northwest part of the area, deformation and erosion have resulted in a more broken landscape, with numerous steep-sided hills and valleys. Altitudes of the land surface range from about 2,850 ft along the Nelson Creek-Redwater River divide to about 2,400 ft along the downstream reaches of Timber and Nelson Creeks.

Average annual precipitation in the Circle West area is about 14 in. based on precipitation records for 1941 to 1970 (U.S. Department of Agriculture, 1977). May, June, and July generally are the periods of greatest precipitation. Annual potential evaporation is greater than the annual precipitation and is about 38 in. (Farnsworth and others, 1982). Air temperatures in the area have large seasonal variations and typically have an annual range from about -35° to 102° F.

EXPLANATION FOR FIGURE 2

06131120 COMBINATION STREAMFLOW-GAGING AND WATER-QUALITY STATION AND NUMBER

OUTCROP OR LIMIT OF S COAL BED--Arrow shows direction of mine-pit advance

AREA OF DEWATERING--Mine pits may significantly lower water levels or decrease yields of existing shallow wells

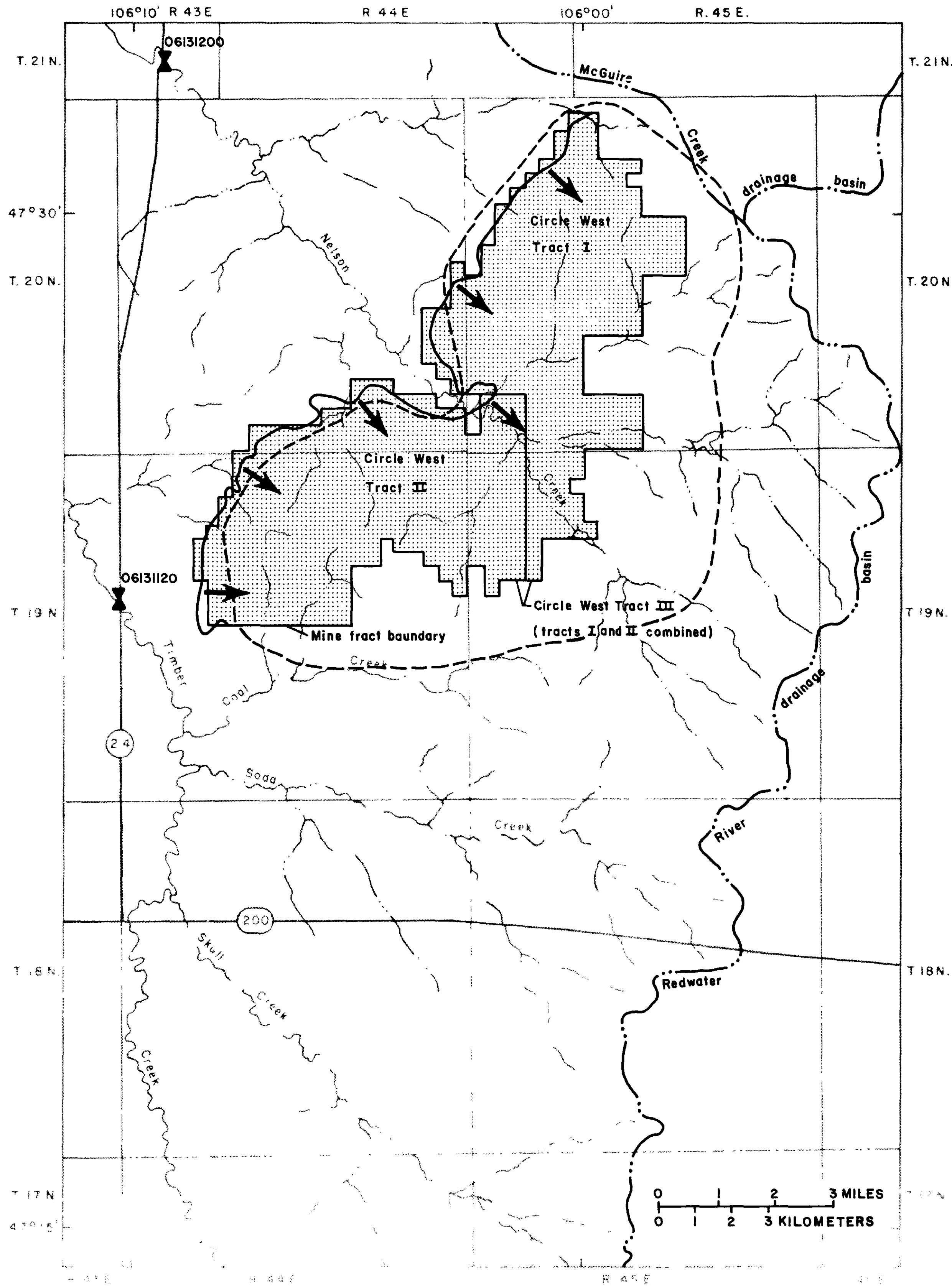

Figure 2.--Location of the Circle West coal tracts, outcrop of the S coal bed of the Tongue River Member of the Fort Union Formation, and area where water levels may be lowered during mining.

Previous investigations

Coal deposits of the region have been the focus of several investigations. Coal resources of McCone County were mapped and described in detail by the U.S. Geological Survey (Collier and Knechtel, 1939) as part of a systematic study and classification of public lands. Matson (1970) made a preliminary study of the strippable coal resources of McCone County and mapped a strippable coal deposit in the study area. Wincentsen (1978) used drill-hole data and surface data to map the thickness and extent of several coal beds in the Circle, Mont., area including the entire study area. Wincentsen (1979) later correlated the coal beds in the southern part of the study area with coal beds farther to the south.

Ground-water resources and hydrogeologic characteristics of rocks in the area have been reported by Perry (1931), the Montana Bureau of Mines and Geology and U.S. Geological Survey (1978), and Stoner and Lewis (1980). Van Lewen and King (1971) have reported on the water-yielding characteristics of rocks and development of stock-water supplies from wells in Garfield County. Hydrogeologic data from many wells in the Circle West and surrounding areas have been compiled by Roberts (1980) and Slagle (1981). Quality of water in certain streams of the area has been described by McKinley (1979). Potential effects of surface coal mining on the water resources in the Circle West tracts have been discussed in environmental impact statements by the U.S. Bureau of Land Management (1982, 1983).

WATER USE AND SUPPLY

Ground water in the Circle West area is used primarily for livestock. Several residences within the study area pump ground water for domestic uses; however, none of these residences are within the Circle West coal tracts. Use of ground water for irrigation is limited. Two wells within the study area are sometimes used to supplement the water supply in an irrigation reservoir on Nelson Creek.

Most ground water of the area is obtained from shallow wells, generally completed in sandstone or coal beds of the Tongue River Member of the Fort Union Formation. The Tongue River Member, which includes the S coal bed, is exposed at the surface in much of the area and most wells completed in the member are from 20 to 300 ft deep. Wells completed in the Tongue River Member generally yield from 2 to 20 gal/min.

The Lebo Shale Member of the Fort Union Formation underlies the Tongue River Member and is the source of water to several flowing wells in the southwestern part of the study area. The wells completed in the Lebo Shale Member are about 160-300 ft deep and flow about 2 gal/min. Alluvial deposits along some stream channels contain water, but seldom are used as a source of water because they are composed largely of silt and clay that yield small quantities of water to wells.

Surface-water resources of the Circle West study area are used primarily for livestock watering, although some have been developed for irrigation. Sources of surface water include intermittent and ephemeral streams, reservoirs, and a few small springs.

The larger streams in the area are intermittent and flow primarily during spring and early summer. During most years, the main channels of Nelson, Timber, Soda, and Skull Creeks (fig. 2) provide a large part of the water supply for area livestock. Numerous small reservoirs, constructed on ephemeral and intermittent drainages, retain runoff and provide a reliable source of water for livestock throughout the summer. Two larger reservoirs in the study area are used to irrigate crops along Nelson Creek. The few small springs and seeps that occur in the area provide a relatively small source of water for livestock.

Water samples collected from stock wells, streams, and a reservoir were analyzed for major chemical constituents. Analysis of the samples indicated that concentration of dissolved solids is less than the recommended maximum for use by livestock (McKee and Wolf, 1963). Generally, water with less than 5,000 mg/L (milligrams per liter) of dissolved solids can be used continuously by cattle, horses, and sheep. Most water supplies in the area exceed 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 water 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 of a better quality is available.

Aquifers underlying the study area could provide a long-term supply of water that is greater than the present (1983) use. Shallow sandstone and coal aquifers within the Tongue River Member could sustain additional small-yield wells for stock and domestic uses. Deeper sources of water, such as the Fox Hills-lower Hell Creek aquifer, are presently unused in the study area but could supply stock, domestic, or industrial wells. The city of Circle, Mont., about 20 mi east of the study area, uses water from the Fox Hills-lower Hell Creek aquifer for a large part of its supply. The disadvantages of obtaining water from this deep aquifer are the large drilling costs and deeper water levels, which require a greater pumping lift. The top of the Fox Hills-lower Hell Creek aquifer is at an altitude of about 1,500 to 1,800 ft within the study area (Feltis, 1982a) and the static water level (artesian) occurs at an altitude of about 2,350 ft (Levings, 1982). With the altitude of the land surface ranging from about 2,400 to 2,850 ft, the pumping lift would range from about 50 to 500 ft.

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 groundwater 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 Circle West tracts are not available. However, generic mine plans for Circle West tracts I, II, and III were developed by the U.S. Geological Survey and are outlined in the Circle West tract delineation reports published by the U.S. Bureau of Land Management (1981). Based on the generic mine plans for Circle West tract III (combination of coal tracts I and II), it is assumed that: (1) The S coal bed would be mined from the entire tract; (2) mining would commence along the northwestern boundary of the tract and would progress to the southeast; (3) mining would continue for 40 years; (4) all mining regulations established by the U.S. Office of Surface Mining and the Montana Department of State Lands would be followed during mining and reclamation.

Potential effects of mining on the local water resources were determined only for the 33 mi^2 within Circle West coal tracts, even though this study defines the hydrology of a much larger area. Analysis of potential hydrologic effects was limited to the coal tracts because they are the only areas presently (1983) considered for lease sale. Hydrology of lands adjacent to the tracts was investigated to provide a more complete understanding of local ground-water flow systems and because of the potential leasing of the adjacent Federal coal in the future.

Effects during mining

Construction of mine pits to the base of the S coal bed would stress the local hydrologic system and change the direction and rate of local ground-water flow for the duration of mining. The mine pits would become sinks, which would intercept ground water that currently flows through the coal tract, and would remove a large quantity of water that is currently stored within shallow aquifers. Surface-water flow in Nelson Creek would be intercepted by mining, which would alter downstream flows. Development of water supplies to meet the water requirements of the mine would affect aquifers that are not currently (1983) used in the local area.

Mine-pit inflow and water-level declines

According to the generic mine plans, mining of the S coal bed would commence at several locations along its outcrop on the northwestern boundary of the tract (fig. 2). In most of the tract, the outcrop of the coal bed is situated well above the water table and no dewatering of mine pits would be required at the start of mining. However, where the S coal bed crosses Nelson Creek, the water table is within the coal bed and local dewatering of the mine pit would be needed (pl. 1, section A-A'). As mining progresses to the southeast, a larger area of presently saturated coal and overburden will be intercepted by the mine pit, as shown on plate 1, sections B-B' and C-C'. Topography and structural configuration of the S coal bed are the primary factors causing the increase in saturated coal and overburden to the southeast. The maximum thickness of saturated coal and overburden is along the southeast boundary of the coal tract. In the vicinity of drill-hole H-15 (pl. 1, section B-B') about 180 ft of overburden and coal presently is saturated.

Ground-water flow equations for a potential mine pit in the valley of Nelson Creek are given to illustrate potential rates of ground-water inflow at the start of the mining operation. An approximately semicircular mine pit (fig. 3), excavated to the base of the S coal bed near its outcrop in the Nelson Creek valley, would have a maximum inflow rate of about 70,000 ft^3/d. This inflow rate was calculated by using an equation for flow to a large-diameter well with constant drawdown (Lohman, 1972, p. 23). A value of 45 ft/d for hydraulic conductivity of the S coal bed was used in the equation. This hydraulic conductivity was measured in well O-10 near the valley of Nelson Creek (data in table 1; all tables are in Supplemental Data section at back of report). A storage coefficient of 10^{-2}, a saturated thickness of 20 ft in the S coal bed, and a mine-pit depth of 30 ft below the water table were other values used in the equation. A time factor of 100 days was used in the equation to compensate for the fact that the mine pit is not excavated instantaneously. Finally, the computed inflow rate for a mine pit was decreased by 25 percent to compensate for the fact that downgradient from the mine (along Nelson Creek) the water table is below the base of the potential mine pit and the pit would not capture water from this area (see fig. 3).

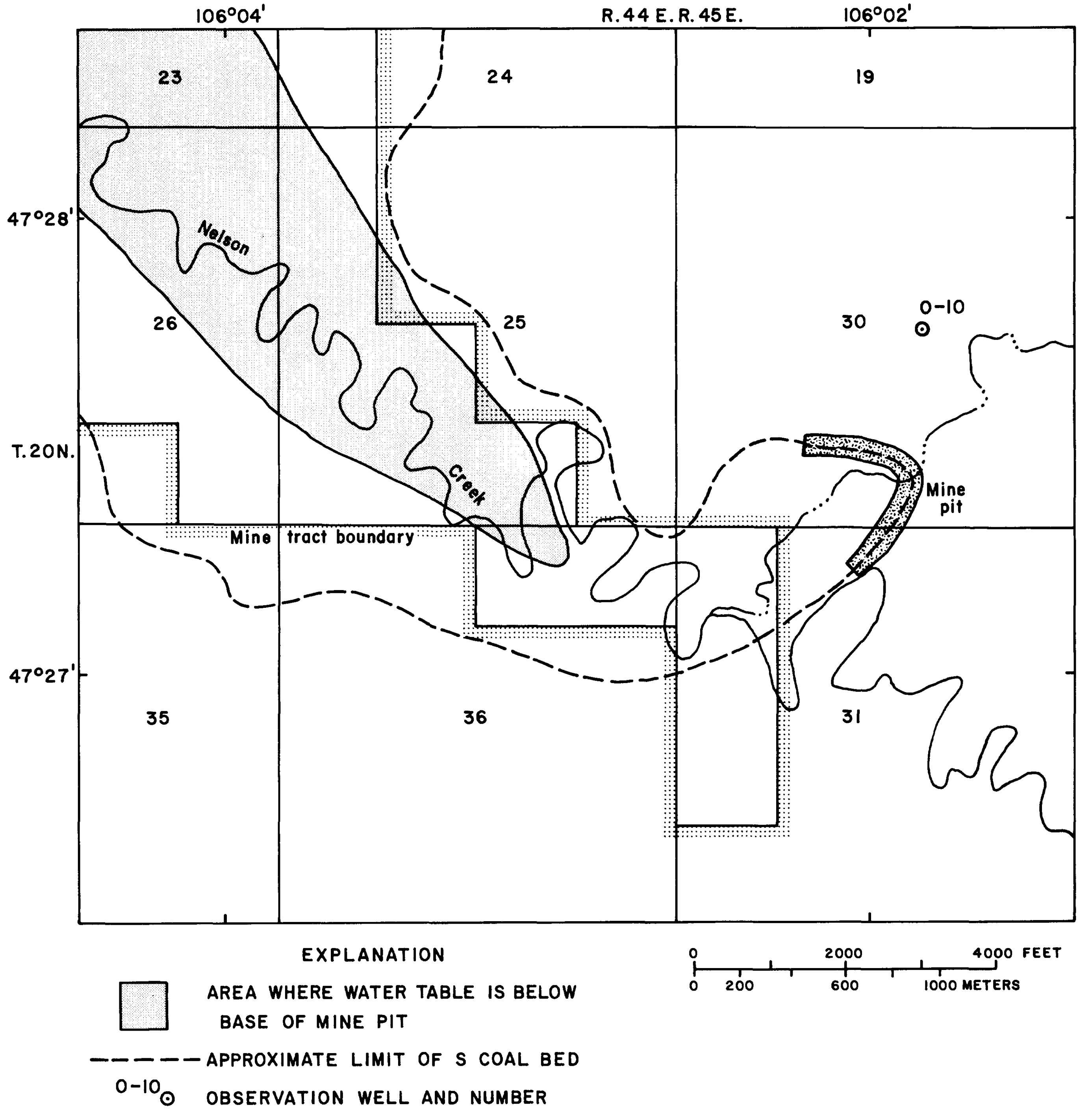

Figure 3.--Detail of potential mine pit in Nelson Creek valley. Radius of the mine pit is about 1,000 feet.

Water-level declines next to the mine pit would be as much as 180 ft, as the mine pits approached the eastern boundary of the mine tract near the end of the 40 years of mining. Water-level declines in the Nelson Creek basin might occur for 3 or more miles upgradient from the mine area, especially along the valley of Nelson

Creek where some relatively permeable beds of sandstone and coal are present. Water-level declines in several stock, domestic, and irrigation wells within the area shown in figure 2 are likely as a result of mine-pit dewatering. Lowered water levels in this area probably would recover after mining.

The calculated rate of mine-pit inflow is applicable only to the hypothetical mine pit on Nelson Creek for the early stages of mining. Because of the complex boundary conditions and extremely variable hydrogeologic conditions in the coal tract, simulations of ground-water levels and pit inflows during all stages of mining could best be made using digital-modeling techniques and a detailed plan of mine-pit excavation and expansion. Prediction of pit inflows and extent of water-level declines with a digital model is beyond the scope of this investigation.

Surface-water runoff

Surface-water runoff from the Nelson Creek basin would be largely altered by mining in the Circle West tracts. About 60 mi^2 of the upper Nelson Creek basin drains through the mine tract and about one-half of this area would be disturbed by mining. Many small stream channels within the tract as well as the main channel of Nelson Creek would be removed at some time during mining. Large-scale disturbance of the watershed could cause significant degradation of water quality, which would affect downstream use of the water for livestock. However, all surface runoff from the active mine area would be collected in holding ponds for sediment control as required by surface-mining regulations. Runoff in the main channel of Nelson Creek could be diverted around the active area of mining to minimize degradation of water quality.

Development of water supplies

Generic mine plans estimate that 120,000 gal/d of industrial water would be required for dust suppression and use in mine facilities, and 15,000 gal/d of potable water would be needed for human consumption. All requirements for industrial water probably could be met with water pumped from mine pits. If effluent from mine pits did not always meet the water requirement, additional water could be developed from shallow wells completed in the Tongue River Member of the Fort Union Formation. Pumping of shallow wells in the tract would not cause any significant lowering of area water levels, when compared to water-level declines that would be caused by the mine pits. Water for potable use could be obtained from one well drilled into the Fox Hills-lower Hell Creek aquifer. Water in this aquifer has a smaller concentration of dissolved solids and is considered to be more palatable than water from shallow aquifers in the Tongue River Member. Withdrawal of water from the Fox Hills-lower Hell Creek aquifer, for a potable water supply at the mine, would have no adverse impact on other users of this aquifer.

Long-term effects

Shallow coal and sandstone aquifers would be permanently removed from most of the Circle West tracts. At least 10 stock wells within the tract are completed in these shallow aquifers and would be destroyed by mining. Two spring areas that discharge from shallow aquifers along Nelson Creek also would be destroyed by mining. These spring areas are located within the coal tract in the SE1/4 NW1/4 sec.

25, T. 20 N., R. 44 E., and the NW1/4 NE1/4 sec. 8, T. 19 N., R. 45 E. One other spring, in the SW1/4 SW1/4 sec. 21, T. 19 N., R. 44 E., is located about three-fourths of a mile south of the tract and may have its recharge area decreased or eliminated by mining; if the recharge area were eliminated, the spring would be destroyed.

Runoff characteristics of Nelson Creek might be permanently changed from mining a large percentage of the basin. Mining likely would alter slopes, drainage patterns, and infiltration capacity of the soils. The removal of about nine reservoirs within the tract also would affect runoff characteristics and would decrease the quantity of surface water available for livestock.

A potential exists for the long-term degradation of the quality of water in shallow aquifers, caused by the leaching of soluble constituents from mine spoils. After mining, spoils used to backfill mine pits would become saturated as water levels recovered throughout the area. Saturated spoils would occur within most of the Circle West tracts, assuming that water levels recovered to approximately premining levels. Other water-quality problems, such as acid water and large concentrations of iron and other metals generally do not occur in coal-mine spoils in the Northern Great Plains. The natural buffering capacity of the overburden generally will prevent acid drainage (Groenewold and others, 1983).

The mean dissolved-solids concentration of water that would occur in saturated spoils is estimated to be in the range of 3,100 to 4,000 mg/L. This range of the mean dissolved-solids concentration is about 140 to 180 percent of the mean dissolved-solids concentration (2,213 mg/L) of 21 water samples collected from shallow wells completed in the Tongue River Member in the Circle West study area (data in table 3). The magnitude of the increase in dissolved solids, between ground water in the natural environment and water in mine spoils, is based on geochemical studies at mine sites in the Powder River Basin of southeastern Montana (Davis, 1983). 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 the saturated mine spoils would be predominantly a sodium sulfate or sodium bicarbonate type, based on the dominant water types in the undisturbed aquifers. Water types in the mine spoils would be similar to those in the undisturbed premining aquifers, except for a substantial increase in dissolved solids, because geochemical reactions within the two environments are similar (Groenewold and others, 1983).

POTENTIAL FOR RECLAMATION OF HYDROLOGIC SYSTEMS

No practicable method exists for restoring the shallow coal and sandstone aquifers that would be destroyed by mining. Likewise, the springs that discharge from the shallow aquifers could not be restored. Deeper aquifers such as the Tullock aquifer and the Fox Hills-lower Hell Creek aquifer could be used as alternative aquifers to replace ground-water supplies destroyed by mining. Well yields from and water quality in the Tullock aquifer would be adequate for use by livestock. Wells completed in the Fox Hills-lower Hell Creek aquifer would yield relatively large quantities of water suitable for livestock. Disadvantages of using the deep Fox Hills-lower Hell Creek aquifer are the large costs of drilling, maintaining, and pumping the deep wells.

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

SUPPORTING TECHNICAL DISCUSSION

Geology

Stratigraphy

The Fort Union Formation of Paleocene age is exposed throughout the study area, except for small areas of alluvium along the major stream channels and a small outcrop of the Hell Creek Formation (Cretaceous) in the extreme northwestern corner of the area (fig. 4). The Fort Union Formation is divided into the Tullock, the Lebo Shale, and the Tongue River Members.

EXPLANATION FOR FIGURE 4

Qal ALLUVIUM (QUATERNARY)

Tft TONGUE RIVER MEMBER OF FORT UNION FORMATION (PALEOCENE)

Tfl LEBO SHALE MEMBER OF FORT UNION FORMATION (PALEOCENE)

Tftu TULLOCK MEMBER OF FORT UNION FORMATION (PALEOCENE)

Khc HELL CREEK FORMATION (CRETACEOUS)

CONTACT--Dashed where approximately located

S OUTCROP OF S COAL BED--Dashed where approximately located

CLINKER FORMED BY BURNING OF S COAL BED--Dotted line is approximate limit of burning. Sawteeth show base of clinker bed

2450 STRUCTURE CONTOUR--Shows altitude of top of S coal bed. Dashed where approximately located. Contour interval 50 feet. Datum is sea level

U D WELDON MONOCLINE AND ASSOCIATED FAULT--U, upthrown side; D, downthrown side

AXIS OF SYNCLINE

A A' TRACE OF HYDROGEOLOGIC SECTION (pl. 1)

O-13 OBSERVATION WELL AND NUMBER

W-12 STOCK, DOMESTIC, OR IRRIGATION WELL AND NUMBER

H-14 DRILL HOLE AND NUMBER

06131200 COMBINATION STREAMFLOW-GAGING AND WATER-QUALITY STATION AND NUMBER

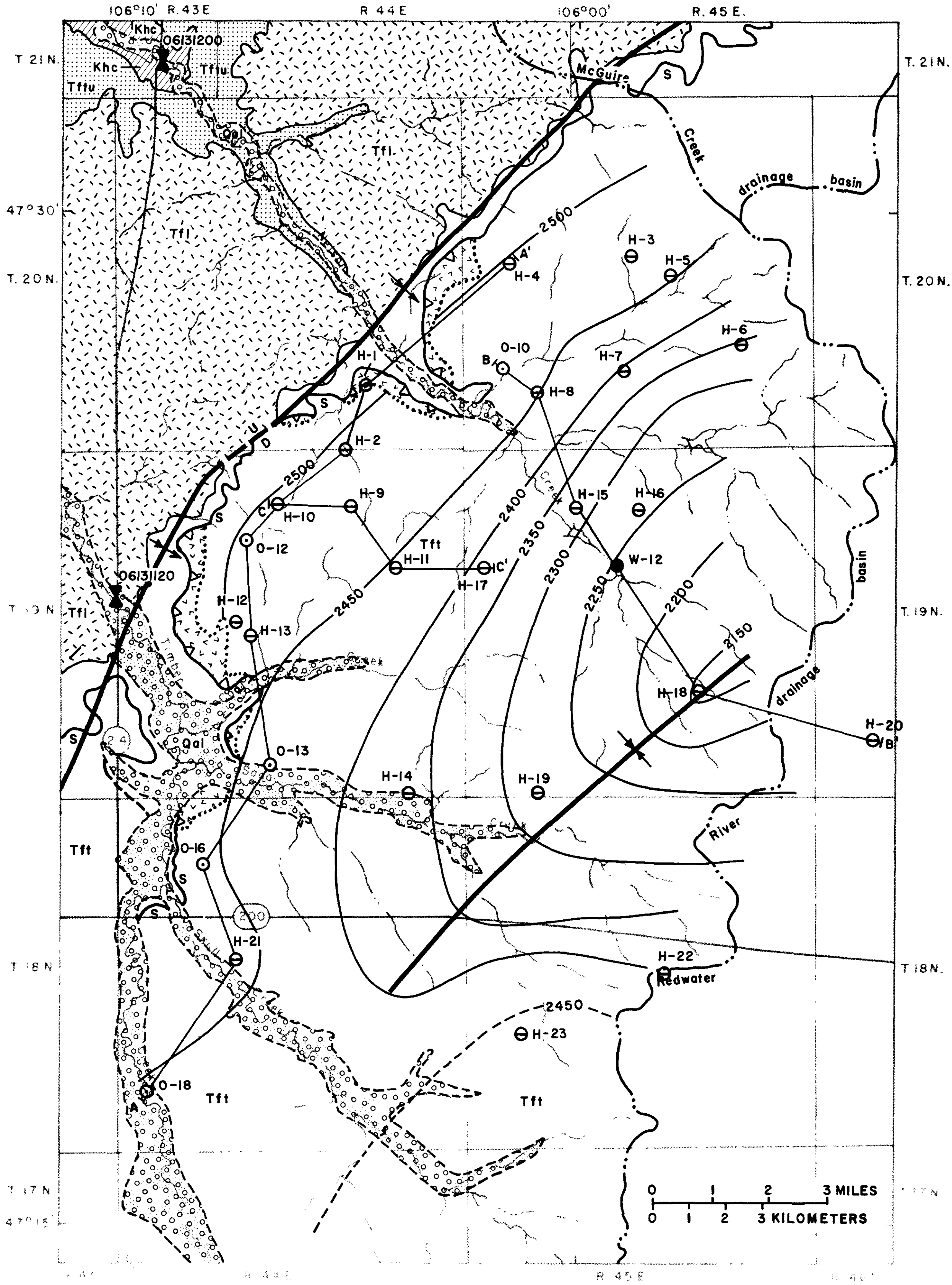

Figure 4.--Surficial geology, structure of the top of the S coal bed in the Tongue River Member of the Fort Union Formation, and location of drill holes.

The lowermost member, the Tullock, is exposed only in the northwestern part of the study area, along the valley of Nelson Creek. The Tullock is about 165 ft thick and is composed of dark carbonaceous shale and thin coal beds, separated by layers of light-colored sandstone, shale, and sandy shale (Collier and Knechtel, 1939).

The Lebo Shale Member overlies the Tullock Member and is exposed primarily in T. 20 N., R. 44 E., in the northwestern part of the study area (fig. 4). The member is about 400 ft thick and consists of thick beds of white sandy clay and brownish sandstone, alternating with nearly black clay shale. A fairly continuous, but impure, coal bed occurs at the base of the Lebo Shale Member, and is mapped as bed U (Big Dirty coal bed) by Collier and Knechtel (1939). Other lenses of coal are contained in the lower 100 ft of the member.

Rocks of the Tongue River Member are exposed in most of the Circle West study area. The Tongue River Member is about 700 ft thick and is composed of fine-grained sandstone, siltstone, and soft shale, with several extensive coal beds. Sandstone, claystone, and shale of the member are typically light gray on fresh exposures but are light yellow or tan when weathered. Coal beds of the Tongue River Member include, in ascending order, the S, R, Q, and P beds (fig. 5). Coal bed S, located about 50 ft above the base of the member, is the thickest coal bed of the area. The S coal bed ranges in thickness from about 0 to 23 ft and averages about 16 ft in the Circle West tracts. The R, Q, and P coal beds each range in thickness from about 0 to 7 or 8 ft.

Alluvium of Quaternary age occupies the channels and flood plains of Timber, Nelson, Soda, and Skull Creeks (fig. 4). The alluvium is composed predominantly of silt and fine sand.

Structure

Major structural features of the Circle West study area are a broad syncline, with its axis passing through the southeastern part of the area, and the Weldon monocline and associated fault in the northwestern part of the study area. Structural deformation occurred sometime after deposition of the coal beds in the Tongue River Member of the Fort Union Formation (Paleocene), for in no place is the depositional thickness of the coal related to the structural features (Wincentsen, 1978).

The axis of the broad syncline trends northeast from T. 18 N., R. 44 E., to T. 19 N., R. 45 E., as shown by the configuration of the top of the S coal bed (fig. 4, data in tables 1 and 2). The axis of the syncline represents a structural depression in the southeastern part of T. 19 N., R. 45 E. Dip of the coal bed toward the synclinal axis is less than 1°.

The Weldon monocline crosses the northwestern part of the study area, trending northeast from T. 19 N., R. 43 E., to T. 21 N., R. 45 E. Strata along the monocline dip from 1° to 3° southeast (Collier and Knechtel, 1939). The monocline is associated with the deeply seated Weldon fault, which offsets underlying Paleozoic rocks of the Madison Group (Feltis, 1981). About 5 mi northeast of the study area, the Weldon fault is exposed at the surface and has been traced to the northeast for a distance of about 8 mi. Beds on the southeast side of the Weldon fault have been displaced downward, with a throw of between 100 and 160 ft (Collier and Knechtel, 1939).

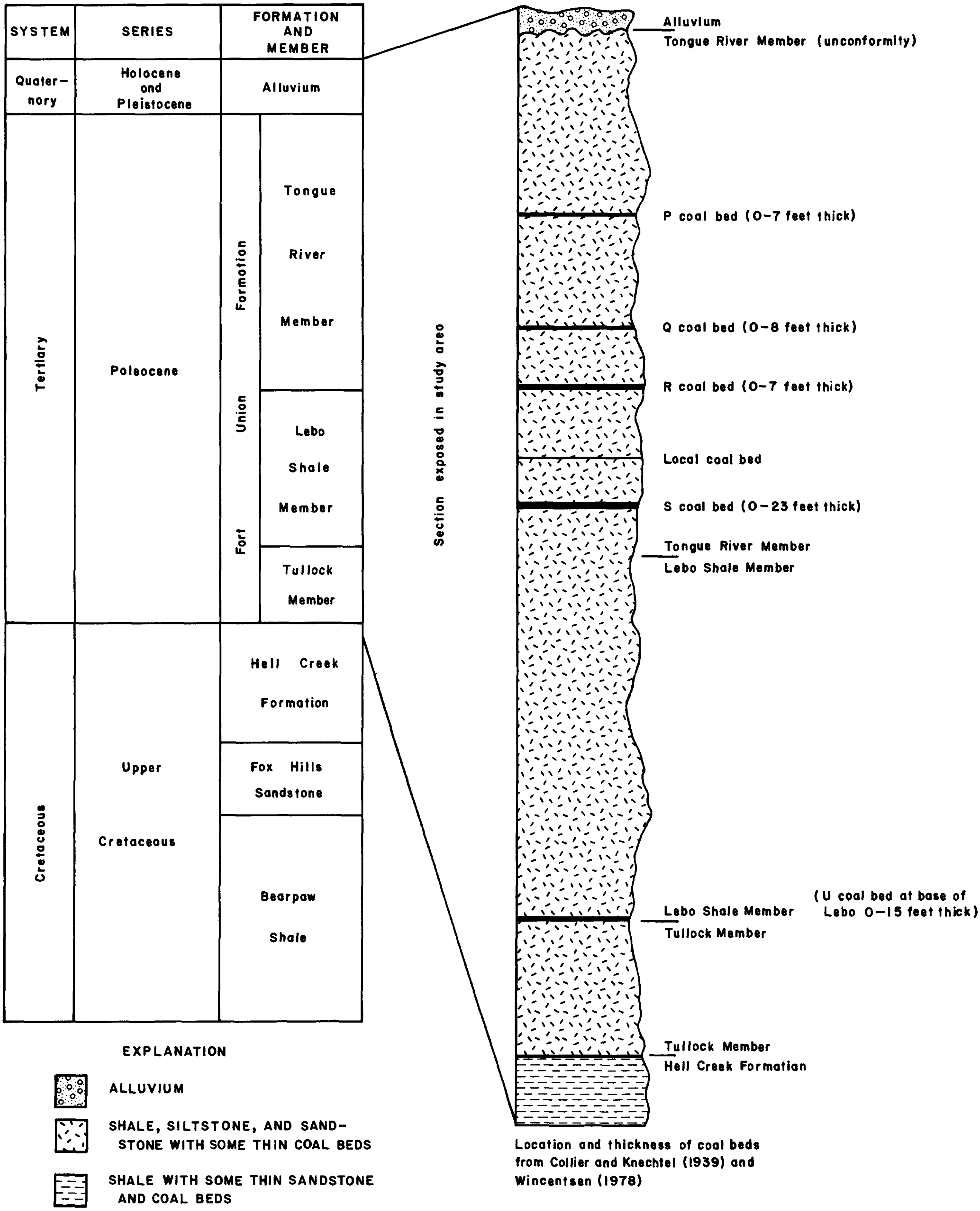

Figure 5.--Idealized stratigraphic section showing formations exposed in or underlying the Circle West study area.

Ground-water resources

Shallow aquifers

The term "shallow aquifers" is used to characterize all aquifers that are located within about 300 ft of the land surface and support local ground-water flow systems. In the Circle West area, shallow aquifers occur within sandstone lenses in the Lebo Shale Member, sandstone and coal beds in the Tongue River Member, and in valley alluvium. Thick beds of clinker, which occur at several locations in the Tongue River Member, also may contain water.

Sandstone and coal beds in the Tongue River Member are the most common shallow aquifers of the study area. None of the sandstone or coal beds can be considered as a single continuous aquifer throughout the study area, but as a whole they form a zone of hydraulic conductivity suitable for the development of small-yield wells. The sandstone aquifers are considered discontinuous because they occur as numerous beds or lenses that pinch out or grade into silt and clay. The coal beds are not considered as continuous aquifers because of their very small hydraulic conductivity in some locations.

Hydrogeologic properties

Hydrogeologic properties of shallow sandstone and coal aquifers were investigated by drilling and installing six observation wells at selected locations within the Circle West study area. The wells were used for monitoring water levels, conducting aquifer tests, and collecting water samples. Six other observation wells, installed by the U.S. Geological Survey during previous coal-exploration drilling in the area, also were monitored and tested where feasible. Many private wells in the area were inventoried to obtain additional hydrologic and geologic data, including water levels, well depths, well discharges, and principal aquifers. Pertinent hydrogeologic data for wells in the area are listed in table 1. Location of wells is shown in figure 6.

Single-well aquifer tests were conducted on seven wells completed in coal beds. Hydraulic conductivities of the coal beds ranged from 0.1 to 380 ft/d with a geometric mean of 4 ft/d. Both the smallest and largest values of hydraulic conductivity were measured in the S coal bed. Hydraulic conductivity of the coal appears to be related to depth of burial, which probably affects the degree of fracturing in the coal. The largest measured value of hydraulic conductivity occurred where the coal was under only 46 ft of overburden.

Single-well aquifer tests were conducted on two wells completed in fine-grained, soft sandstones of the Tongue River Member. Construction of these wells did not allow ideal test conditions because the wells continuously produced some fine sand. However, the tests indicated a hydraulic conductivity of about 4 to 5 ft/d, which appears to be a reasonable value, based on the lithologic characteristics of the sandstone.

Although hydraulic conductivity of sandstone and coal in the Tongue River Member generally is small, wells that withdraw water from a large saturated thickness of clean sandstone or extremely fractured coal beds are capable of fairly large yields. Irrigation wells W-12 and W-15 are completed in multiple zones of sandstone and coal and each produce more than 70 gal/min for extended periods of pumping.

Storage coefficients of coal and sandstone aquifers could not be reliably calculated from the single-well aquifer tests. Storage coefficients in the confined sandstone or coal aquifers are estimated to range from 10^{-5} to 10^{-3}, based on values at other sites in the Fort Union Formation in eastern Montana and western North Dakota (Rehm and others, 1980, p. 555).

No aquifer tests were conducted on the Lebo Shale Member, clinker, or alluvium. Sandstone lenses in the Lebo Shale Member generally will yield from 1 to 5 gal/min from properly constructed wells. Several flowing wells in the southwestern part of the study area yield 2 to 3 gal/min from the Lebo. Hydrogeologic properties of clinker appear to be favorable for the occurrence of ground water, but no wells in the area are known to be completed in clinker. Clinker of the area is extremely fractured and appears to have a large hydraulic conductivity, which would allow rapid infiltration of recharge water. Hydrogeologic properties of alluvium appear to be unfavorable for the production of water from small-diameter wells. Most alluvium in the study area is composed of fine-grained sediments having small values of hydraulic conductivity. A small number of wells in or near the study area yield water from the alluvium; some of these wells are large-diameter dug wells.

Specific yield of the aquifer and confining-layer materials is important for calculations of drainage of water into mine pits and estimates of rates of ground-water flow. Specific yield virtually is equivalent to the effective porosity of a material and is expressed as a percentage or a volume ratio (dimensionless). Loosely consolidated claystone and shale of the area are estimated to have a specific yield of about 0.02, siltstone about 0.08, and sandstone from 0.2 to 0.3, based on average values for nonindurated sediments (Johnson, 1967). Specific yield of coal is equivalent to the effective fracture porosity and probably is as variable as hydraulic conductivity. In general, the effective porosity of coal in the Fort Union area is small, and is commonly in the range of 10^{-2} to 10^{-3} (Moran and others, 1978). Tracer tests conducted on two coal beds in southeastern Montana indicated effective porosities of 3.0×10^{-3} and 3.5×10^{-2} (Davis, 1984). In the Circle West area, the effective porosity (specific yield) of the S coal bed probably is greatest where the coal is near the surface, such as in parts of Nelson and Soda Creeks, and smallest where the coal is deeply buried. The specific yield of the coal directly correlates with measured values of hydraulic conductivity.

Flow patterns and velocities

Ground water flows in response to the gradient of the hydraulic head or fluid potential. Hydraulic head generally is highest in topographically high areas or recharge areas, and lowest in topographically low areas or discharge areas. The distribution of hydraulic head between areas of recharge and discharge is largely a function of the topography and the spatial distribution of zones of large hydraulic conductivity (aquifers) and small hydraulic conductivity (confining layers). Hydraulic head 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. Directions of ground-water flow generally are presented as a map of a potentiometric surface or as flow nets.

Ground water in the Circle West area flows from topographically high areas, along interstream divides and other uplands, toward discharge areas along Timber,

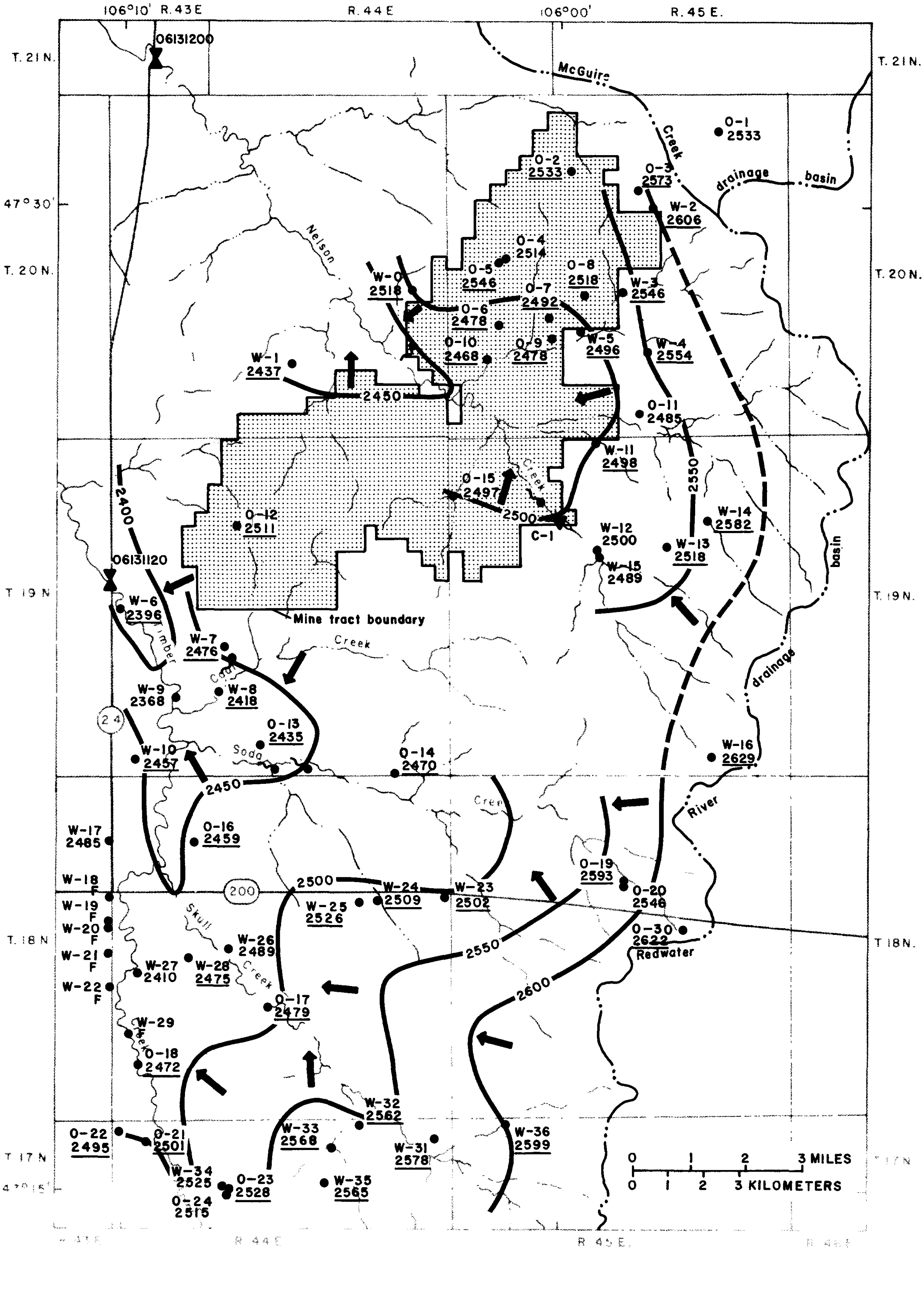

Figure 6.--Location of wells, altitude of water levels in wells, and direction of ground-water flow.

EXPLANATION FOR FIGURE 6

——2600— —	WATER-TABLE CONTOUR--Shows altitude of the water table, 1982. Dashed where approximately located. Contour interval 50 feet. Datum is sea level. Contours drawn using water levels in selected wells and position of water table at streams and springs
➡	GENERAL DIRECTION OF WATER FLOW IN SHALLOW AQUIFERS
O-2 2533 ●	DATA SITE AND NUMBER--O, observation well; W, stock, domestic, or irrigation well. Four-digit number is altitude of water level, in feet above sea level; underlined if used for contouring. F denotes flowing well
C-1 ▼	RESERVOIR SAMPLING SITE AND NUMBER
~●	SPRING OR SEEP
06131200 ⧗	COMBINATION STREAMFLOW-GAGING AND WATER-QUALITY STATION AND NUMBER

Skull, Soda, and Nelson Creeks. Direction of shallow ground-water flow predominantly is to the northwest, although many local deviations from this trend are observed, as shown in figure 6.

Directions of ground-water flow in the Circle West study area were determined by measuring water levels in wells, locating areas of ground-water discharge along stream channels, and applying the principles of ground-water flow to the observed hydrologic conditions. Horizontal directions of ground-water flow and approximate contours of the water table are shown in figure 6. Contours of the water table are only approximate because many of the wells used as data points are screened in an aquifer below the water table and measure a hydraulic head slightly different than would exist at the water table. Wells suspected of having a hydraulic head significantly different than the water table were not used to construct the water-table contours.

Velocity of ground-water flow is dependent on the hydraulic conductivity and effective porosity of the water-bearing strata, and the hydraulic gradient. Within the Circle West area, horizontal components of the gradient range from about 0.0002 to 0.01. Vertical components of the hydraulic gradient range from 0 to about 0.3. The largest hydraulic gradients are in the upland areas of interstream divides, where the terrain is steepest. The smallest hydraulic gradients appear to be along the major stream valleys. Hydraulic conductivity and effective porosity of the water-bearing strata each vary by several orders of magnitude, resulting in a wide range in velocity of ground-water flow.

Horizontal velocity through the S coal bed would range from about 25 ft/d where greatly fractured, to about 0.3 ft/d where slightly fractured, assuming respective values of 380 and 0.1 ft/d for hydraulic conductivity, 0.002 and 0.01 for gradient, and 0.03 and 0.003 for effective porosity. Vertical velocity through claystone and shale confining layers would range from 0 to about 0.02 ft/d, assuming a value of 0.001 ft/d for hydraulic conductivity, a gradient of 0.3 for the non-zero case, and an effective porosity of 0.02. Vertical velocities of zero are assumed to exist in areas with no vertical gradient.

True velocities of ground-water flow have a large spatial variation and may deviate from these estimates of average velocity by an order of magnitude or more. The average velocity computed from aquifer characteristics can vary significantly from true velocities because of measurement error in aquifer characteristics and the presence of preferred flow paths within the porous media.

Recharge and discharge

Recharge areas are characterized by downward movement of water away from the water table. Recharge areas can be detected by measurement of hydraulic heads in potentiometer nests like the one containing wells 0-19 and 0-20. Successively lower heads in potentiometers completed at successively greater depths indicate a downward component of the hydraulic gradient in an area of recharge. Recharge areas are evident on a map of the water table by closed contours in topographically high areas or by contours which show flow directions away from a ground-water basin divide. In most basins, the total area of recharge is much larger than the total area of discharge, with the topographic uplands and the upper valley slopes all contributing to recharge.

In the Circle West area, recharge to shallow aquifers occurs by infiltration of precipitation or ponded runoff and downward percolation to the water table through a large unsaturated zone. Recharge may occur in most of the study area, although the greatest rate of recharge probably occurs along small upland drainages, depressions, and reservoirs, where snowmelt and runoff from rainfall can accumulate. Conditions favorable for deep percolation and recharge to the water table occur infrequently, resulting in a slow rate of recharge. Unfavorable conditions of a thick unsaturated zone, large potential evapotranspiration, frozen soil during the winter, and relatively small quantity of precipitation all contribute to a slow rate of recharge. Recharge likely occurs only in the spring when snowmelt and rainfall are sufficient to accumulate in the small drainages and local depressions. During years of less than normal precipitation or antecedent soil-moisture deficiency, recharge to the water table probably does not occur. Average yearly recharge is estimated to be less than 0.1 in., based on calculated discharge from the Nelson Creek basin.

Discharge areas are characterized by upward movement of water toward the water table. Potentiometers installed in discharge areas exhibit an increase in hydraulic head with depth. Discharge areas usually are evident from springs and seeps, gain in base flow of a stream, or by vegetation that flourishes with an ample water supply. In most basins, discharge areas occupy only a small part of the basin and typically are located in the major stream valley, along lower valley slopes, and at abrupt breaks in topographic slope.

In the Circle West study area, shallow ground water discharges along the main stems of Timber, Skull, Soda, and Nelson Creeks. Discharge is to evapotranspiration and ponds along each of these creeks and to springs and seeps along Soda and Nelson Creeks. Small springs and seeps are found along Nelson Creek in the SE1/4 NW1/4 sec. 25, T. 20 N., R. 44 E., and in the NW1/4 NE1/4 sec. 8, T. 19 N., R. 45 E. In Soda Creek, seeps or small springs are located in the SE1/4 sec. 33, and S1/2 sec. 34, T. 19 N., R. 44 E. Additional ground-water discharge is to stock and domestic wells scattered throughout the area (fig. 6). Some of these wells, located along Timber Creek, flow at the land surface and indicate an area of natural ground-water discharge with an upward component of the hydraulic gradient.

Deep aquifers

The term "deep aquifers" is used to characterize all aquifers that are located at depths greater than about 300 ft and that have regional ground-water flow systems. Flow systems within the deep aquifers are characterized by long flow paths, slow rates of flow, and stable water levels that are generally unaffected by dry or wet seasons. Most recharge and discharge for these deep aquifers occur outside the study area.

Deep aquifers underlying the Circle West area include the Tullock aquifer and the Upper Cretaceous Fox Hills-lower Hell Creek aquifer. The Tullock aquifer comprises the entire thickness of the Tullock Member of the Fort Union Formation and locally includes the upper 10 to 80 ft of the Hell Creek Formation (Stoner and Lewis, 1980). The fine-grained sandstone and coal beds of the Tullock are the water-yielding units. Well yields may be as much as 40 gal/min, but generally average about 15 gal/min (Stoner and Lewis, 1980).

The Fox Hills-lower Hell Creek aquifer includes the Fox Hills Sandstone and the sandstone in the lower part of the Hell Creek Formation. The aquifer is a significant source of water in eastern Montana and yields 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 Circle West area, the total thickness of the Fox Hills-lower Hell Creek aquifer is 200 to 400 ft (Feltis, 1982b), and the top of the aquifer is at an altitude of 1,500 to 1,800 ft (Feltis, 1982a). The potentiometric surface of the aquifer in the Circle West area is at about 2,350 ft (Levings, 1982).

Surface-water resources

The Circle West study area is drained by Timber and Nelson Creeks, which flow northwestward to Fort Peck Lake on the Missouri River. Small streams that are tributary to Timber Creek and drain part of the area are Coal, Soda, and Skull Creeks (fig. 2). Surface-water resources of the area include intermittent flow in the main channels of Nelson, Timber, Soda, and Skull Creeks; ephemeral flow in most of the smaller tributaries; and a network of reservoirs throughout the area.

Nelson Creek drains the northern part of the study area and is the primary drainage in the Circle West coal tracts. Two relatively large reservoirs are located within the drainage and are used for sprinkler irrigation. One reservoir is located in the SE1/4 sec. 34 and the SW1/4 sec. 35, T. 20 N., R. 45 E.; the other is located in the E1/2 sec. 8, and the W1/2 sec. 9, T. 19 N., R. 45 E. Many other smaller stock reservoirs are located throughout the drainage.

Flow and continuous-stage measurements of Nelson Creek are made at the U.S. Geological Survey streamflow-gaging station (06131200) in sec. 36, T. 21 N., R. 43 E., at the upstream side of the bridge on State Highway 24 (fig. 2). Seven years of record at the station (October 1975 to October 1982) indicate a mean annual runoff of 1,770 acre-ft (2.45 ft^3/s) from a drainage area of 100 mi^2. Maximum discharge at the gage, for the period of record, was 1,750 ft^3/s on July 4, 1978. On many days of the year, there is no flow at the station. Magnitude and frequency of flood flows of Nelson Creek at the gaging station were estimated using the regression equations of Parrett and Omang (1981). Based on these equations, magnitudes of flood peaks are 1,120 ft^3/s for a 5-year flood, 3,380 ft^3/s for the 25-year flood, 4,900 ft^3/s for the 50-year flood, and 6,310 ft^3/s for the 100-year flood.

Timber Creek and its tributaries drain the southern part of the study area. Headwaters of the small tributaries have steep gradients, are above the water table, and flow only in response to snowmelt or storm runoff. The main channel of Timber Creek, as well as the downstream reaches of the tributaries Soda and Skull Creeks, support intermittent flow. The intermittent reaches of these creeks contain many perennial natural ponds, which receive recharge from ground water. Reservoirs scattered throughout the Timber Creek drainage decrease the rate of runoff from the basin and supply a large quantity of water for livestock.

Miscellaneous measurements of streamflow and water quality have been made on Timber Creek (station 06131120) for the interval October 1975 to September 1979 (fig. 2). These data were published and are available in the annual water-data reports by the U.S. Geological Survey. Since October 1982, flow and continuous-stage measurements have been made on Timber Creek at the same station. Mean annual runoff and the magnitude of flood flows were estimated by indirect methods because the short interval of flow record for Timber Creek does not allow a statistically valid direct computation. Mean annual runoff, based on the channel-geometry methods of Omang and others (1983), is 18,400 acre-feet (25.4 ft^3/s) at station 06131120 (see fig. 2). The drainage area of Timber Creek at this station is 287 mi^2. Magnitudes of flood peaks are 1,660 ft^3/s for the 5-year flood, 4,830 ft^3/s for the 25-year flood, 6,980 ft^3/s for the 50-year flood, and 8,850 ft^3/s for the 100-year flood. These flow estimates are based on the regression equations of Parrett and Omang (1981) and were computed for Timber Creek at station 06131120.

Water quality and geochemistry

Ground water

Quality of water from shallow aquifers in the Circle West area was determined by analysis of water samples from observation, stock, and domestic wells. All samples were analyzed for major ions and selected samples were analyzed for trace elements. Results of the analyses are listed in tables 3 and 4.

The water-quality analyses indicate that, in general, the ground water has a large concentration of dissolved solids, is alkaline, and is dominated by the sodium cation and bicarbonate and sulfate anions. Dissolved-solids concentrations of water from 22 wells ranged from 691 to 3,650 mg/L, with a mean of 2,170 mg/L. Values of pH for the 22 water samples ranged from 5.7 to 9.3, with all but 3 samples having a pH greater than 7. Most of the wells sampled had a sodium sulfate type water. The second most common water type was sodium bicarbonate. Only two of the wells sampled (W-16 and W-33) had a larger concentration (in milliequivalents per liter) of calcium plus magnesium cations than sodium cations.

Geochemical and hydrologic processes that probably account for the chemical composition of ground water have been outlined by several investigators. Moran and others (1978) have shown that certain geochemical processes account for the chemical evolution of water in Tertiary sediments (Sentinel Butte Member, the uppermost member of the Fort Union Formation) in North Dakota. These geochemical processes are: (1) The generation of hydrogen ions through the production of CO_2 (carbon dioxide) 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-enriched clays. Wallick (1981) has shown that the chemical composition and evolution of ground water are related to mineralogy and 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 water in the Fort Union Formation in the Circle West area.

Based on the geochemical concepts presented by these authors, a conceptual model of the evolution of shallow ground water in the Circle West area is as follows. A typical interval of infiltration 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 and atmospheric oxygen produces sulfate ions. Alternate wet-dry conditions in the unsaturated zone leads to the formation of gypsum ($CaSO_4 \cdot 2H_2O$). Exceptional intervals of recharge that cause deep percolation will then dissolve the gypsum. The resulting recharge water will contain predominantly calcium, magnesium, sulfate, and bicarbonate ions. If the sediments in the unsaturated or saturated zone contain sodium-enriched clays, cation exchange will take place and enrich the water with sodium. The resultant water type will be sodium sulfate or sodium bicarbonate.

In the Circle West area, water of the calcium magnesium bicarbonate or calcium magnesium sulfate type was sampled at only two wells. One of these wells (W-16) is located at a relatively high altitude, near the drainage divide in upper Nelson Creek; the other (W-33) is a shallow well in the upstream part of the Skull Creek basin. Both wells probably withdraw shallow ground water very near where recharge occurs to the saturated zone. Additionally, the soils in these areas may contain a relatively small quantity of clay with exchangeable sodium ions. All other wells sampled in the study area contained water of a sodium sulfate or sodium bicarbonate type, indicating that sodium-enriched clays exist in much of the area.

Quality of water from deeper aquifers in the Fort Union Formation and the Fox Hills-lower Hell Creek aquifer was determined by analysis of water-quality data from the region (Roberts, 1980; Slagle, 1981). Water from the Tullock Member of the Fort Union Formation is likely a sodium bicarbonate or sodium sulfate type and similar in quality to water in the Tongue River Member. Water from the Fox Hills-lower Hell Creek aquifer is almost invariably a sodium bicarbonate type, and dissolved-solids concentration of the water averages about 1,200 mg/L.

Surface water

Quality of surface water was monitored at one location on Nelson Creek (station 06131200) and one on Timber Creek (station 06131120) from October 1976 through September 1979 (fig. 2). Water-quality data for the two stations are summarized in tables 5 and 6. Water-quality data for these two streams indicate that the water generally is a sodium sulfate type and has a large concentration of dissolved solids. Sodium comprised 55 to 84 percent of the cations in water from Nelson Creek and 60 to 84 percent in Timber Creek. Sulfate ranged from 76 to 4,200 mg/L in Nelson Creek and 250 to 3,300 mg/L in Timber Creek. Dissolved solids in Nelson Creek ranged from 181 to 6,960 mg/L, with a mean of 2,640 mg/L. In Timber Creek, dissolved solids ranged from 468 to 5,530 mg/L, with a mean of 3,080 mg/L. In both streams, the smaller values of dissolved solids are measured during times of snowmelt and storm runoff and the larger values are measured during times of low flow.

Quality of water was analyzed for one large reservoir on Nelson Creek. Water-quality data from one sample (tables 3 and 4) indicate that water in the reservoir was a calcium magnesium sulfate type with calcium and magnesium comprising 62 percent of the cations. Concentration of dissolved solids in the reservoir water was relatively large at 1,990 mg/L. The concentration of dissolved solids probably fluctuates within a large range, with the smallest concentration occurring in the spring after runoff from snowmelt and the largest occurring in late summer when streamflow is small and evaporation rates are large.

Suspended-sediment concentrations in surface water were measured at the gaging stations on Nelson and Timber Creeks. In Nelson Creek, measured concentrations of suspended sediment ranged from 64 to 23,000 mg/L, with a mean of about 1,500 mg/L (table 5). Mean annual sediment yield of the Nelson Creek basin at the gaging station was computed to be 46.8 ton/mi^2 (John H. Lambing, U.S. Geological Survey, written commun., 1983). Suspended-sediment concentrations in Timber Creek ranged from 45 to 520 mg/L, with a mean of about 170 mg/L (table 6). Mean annual sediment yield from the basin could not be computed because of lack of flow data. It is reasonable to assume that sediment yields from the study area within the Timber Creek basin are similar to those in the Nelson Creek basin, because the physiography of the two parts of the study area is similar. However, mean concentrations of suspended sediment were almost nine times greater for Nelson than Timber Creek. Sediment concentrations in Nelson Creek are large possibly because of sediment runoff from badlands in the Lebo Shale Member, downstream from the study area. If the badlands are contributing a disproportionate quantity of sediment to the stream, then the computed value of sediment yield for the Nelson Creek basin would be too large for the upstream part of the basin that is within the study area and has no badlands.

SUMMARY

The Circle West study area encompasses about 220 mi^2 in McCone County of eastern Montana. The Circle West coal tracts occupy about 33 mi^2 of this area and contain about 460 million tons of recoverable coal reserves, mostly within the S coal bed of the Tongue River Member of the Fort Union Formation.

Shallow ground-water resources of the area include aquifers in sandstone and coal beds of the Tongue River Member and sandstone lenses in the Lebo Shale Member, both of the Fort Union Formation of Paleocene age. Deep aquifers are the Tullock aquifer of Paleocene age and the Fox Hills-lower Hell Creek aquifer of Late Cretaceous age. Most ground water used in the area is obtained from shallow wells completed in the Tongue River Member. These shallow wells typically yield from 2 to 20 gal/min; some wells are capable of producing in excess of 70 gal/min. Ground water is used predominantly for watering livestock and domestic supply. Some ground water is used for sprinkler irrigation.

Surface-water resources of the area include intermittent flow in the main channels of Nelson, Timber, Soda, and Skull Creeks; ephemeral flow in most of the smaller tributaries; and a network of reservoirs throughout the area. Water ponded in the main channels of the streams, plus the water stored in the numerous reservoirs, provide a large part of the water supply for area livestock. Two of the larger reservoirs on Nelson Creek are used to irrigate crops, as well as provide water for livestock.

Shallow ground water of the Circle West area generally has a large concentration of dissolved solids, is alkaline, and is dominated by the sodium cation and bicarbonate and sulfate anions. Dissolved-solids concentrations of water from 22 wells ranged from 691 to 3,650 mg/L, with a mean of 2,170 mg/L. The most predominant water type sampled from shallow wells was sodium sulfate. Water-quality data from two stations on Nelson and Timber Creeks indicate that surface water generally is a sodium sulfate type and has a large concentration (181 to 6,960 mg/L) of dissolved solids. Quality of both ground water and surface water generally is suitable for use by livestock.

Mining of the S coal bed from the Circle West tracts would cause certain temporary and permanent effects on the local water resources. Mine pits would cause temporary dewatering of shallow aquifers and water-level declines in area wells. Water levels near the mine pit would decline as much as 180 feet, and mine pits along Nelson Creek could have maximum inflow rates of about 70,000 ft^3/d. Lowered water levels in and adjacent to the mine area are expected to be temporary and probably would recover after mining. Surface-water runoff from the Nelson Creek basin would be largely altered by mining. About 60 mi^2 of the upper Nelson Creek basin drains through the mine tract and about one-half of this area would be disturbed by mining. Large-scale disturbance of the watershed could cause significant degradation of water quality and alteration of basin runoff characteristics. Shallow coal and sandstone aquifers would be permanently removed from the Circle West tracts. At least 10 stock wells, 2 spring areas, and 9 reservoirs would be destroyed by mining. A potential exists for the long-term degradation of the quality of water in shallow aquifers, caused by leaching of soluble constituents from mine spoils. The mean dissolved-solids concentration of water that would occur in saturated spoils is estimated to be in the range of 3,100 to 4,000 mg/L. Water in the saturated spoils would likely be a sodium sulfate or sodium bicarbonate type.

No practicable method exists for restoring the shallow aquifers and springs that would be destroyed by mining. Deeper aquifers such as the Tullock aquifer and the Fox Hills-lower Hell Creek aquifer could be used as alternative aquifers to replace ground-water supplies destroyed by mining. Reservoirs destroyed by mining could be reconstructed during mine reclamation.

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SUPPLEMENTAL DATA

Table 1.--*Hydrogeologic data from wells*

[Site designation: O, observation well; W, stock, domestic, or irrigation well. Principal aquifer: Tongue River and Lebo Shale are members of the Fort Union Formation; sandstone and coal are in the Tongue River Member. R, reported value. <, less than. >, greater than]

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of well (feet below land surface)	Principal aquifer	Aquifer interval (feet below land surface)	Hydraulic conductivity of aquifer (feet per day)
O-1	SW¼NW¼NE¼SE¼ sec. 2, T. 20 N., R. 45 E.	2,660	249	Coal - S bed	210-229	--
O-2	NE¼NE¼SW¼NW¼ sec. 9, T. 20 N., R. 45 E.	2,755	247	Coal - S bed	212-229	--
O-3	SW¼NE¼NE¼SW¼ sec. 10, T. 20 N., R. 45 E.	2,770	335	Coal - S bed	299-319	--
O-4	NW¼NW¼SW¼SW¼ sec. 17, T. 20 N., R. 45 E.	2,720	255	Coal - S bed	232-250	--
O-5	SW¼NE¼SE¼SE¼ sec. 18, T. 20 N., R. 45 E.	2,725	228	Coal - S bed	192-210	--
O-6	SE¼SE¼SE¼SE¼ sec. 19, T. 20 N., R. 45 E.	2,560	125	Coal - S bed	103-123	--
O-7	SW¼NW¼SE¼SE¼ sec. 20, T. 20 N., R. 45 E.	2,550	120	Coal - S bed	96-115	0.8
O-8	SW¼SE¼SE¼NW¼ sec. 21, T. 20 N., R. 45 E.	2,650	241	Coal - S bed	201-224	--
O-9	SE¼SW¼NE¼NE¼ sec. 29, T. 20 N., R. 45 E.	2,518	116	Coal - S bed	89-111	15R
O-10	NW¼NE¼NW¼SE¼ sec. 30, T. 20 N., R. 45 E.	2,495	57	Coal - S bed	32-52	45
O-11	NW¼NE¼NE¼SW¼ sec. 34, T. 20 N., R. 45 E.	2,530	280	Coal - S bed	234-256	.9
O-12	NE¼NE¼NW¼SW¼ sec. 9, T. 19 N., R. 44 E.	2,650	191	Coal - S bed	165-181	.1
O-13	SE¼SW¼SW¼NE¼ sec. 33, T. 19 N., R. 44 E.	2,460	60	Coal - S bed	46-57	380
O-14	SE¼SE¼SE¼SE¼ sec. 35, T. 19 N., R. 44 E.	2,510	140	Coal - S bed	128-134	60
O-15	SE¼SW¼SW¼SW¼ sec. 6, T. 19 N., R. 45 E.,	2,540	112	Coal (with parting of claystone).	83-106	--
O-16	NW¼NE¼NE¼NW¼ sec. 8, T. 18 N., R. 44 E.	2,520	78	Coal - S bed	62-65	--
O-17	SE¼SE¼SW¼SE¼ sec. 21, T. 18 N., R. 44 E.	2,510	92	Coal and sandstone.	80-92	--

Water level (feet below land surface)	Date of water level measurement	Well discharge (gallons per minute)	Date of discharge measurement	Remarks
126.7	11-16-82	--	--	Meridian Land and Mineral Company well LH20452-1(82).
222.4	11-16-82	--	--	Meridian Land and Mineral Company well LH20459-5(82).
197.3	11-16-82	--	--	Meridian Land and Mineral Company well LH204510-1(82).
206.0	11-16-82	3	--	Dreyer No. 1 test well.
179.0	11-16-82	--	--	Meridian Land and Mineral Company well LH204518-1(82).
82.0	11-16-82	<1	12-14-75	Dreyer No. 6 test well.
58.2	09-16-82	9	10-05-76	Coal exploration hole US-7616.
132.5	11-16-82	--	--	Meridian Land and Mineral Company well LH204521-5B(82).
40.0	11-16-82	11	12-10-75	Dreyer No. 7 test well.
27.0	09-16-81	23	05-07-82	Coal exploration hole US-7617.
45.4	09-16-81	8	08-10-79	Wesco hole 32.
138.9	09-16-81	1	09-16-81	U.S. Geological Survey observation well TC-1.
25.0	09-15-81	12	09-15-81	U.S. Geological Survey observation well TC-4; well capable of larger yield.
40.0	09-14-81	5	09-15-81	U.S. Geological Survey observation well TC-5; well capable of larger yield.
43.1	08-13-81	7.5	10-08-76	Coal exploration hole US-7638.
61.4	08-13-81	--	--	Coal exploration hole US-7635.
31.2	09-15-81	--	--	U.S. Geological Survey observation well TC-3.

Table 1.--*Hydrogeologic data from wells*--Continued

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of well (feet below land surface)	Principal aquifer	Aquifer interval (feet below land surface)	Hydraulic conductivity of aquifer (feet per day)
O-18	SW¼SE¼SE¼SW¼ sec. 30, T. 18 N., R. 44 E.	2,485	60	Alluvium and coal.	38-47	--
O-19	NW¼NW¼SW¼SW¼ sec. 10, T. 18 N., R. 45 E.	2,645	119	Sandstone of Tongue River Member.	110-116	5
O-20	NW¼NW¼SW¼SW¼ sec. 10, T. 18 N., R. 45 E.	2,645	310	Sandstone and coal.	290-306	4
O-21	NW¼NW¼SE¼NE¼ sec. 6, T. 17 N., R. 44 E.	2,505	32	Alluvium and coal.	--	--
O-22	NE¼SW¼NW¼NW¼ sec. 6, T. 17 N., R. 44 E.	2,535	160	Sandstone and coal.	128-152	--
O-23	NW¼SW¼NW¼NW¼ sec. 9, T. 17 N., R. 44 E.	2,590	111	Coal - R bed	94-103	--
O-24	NW¼SW¼NW¼NW¼ sec. 9, T. 17 N., R. 44 E.	2,590	185	Coal - S bed and sandstone.	150-176	--
W-0	SW¼NE¼SE¼NW¼ sec. 24, T. 20 N., R. 44 E.	2,561	107	Tongue River Member.	--	--
W-1	NE¼SE¼NW¼SW¼ sec. 27, T. 20 N., R. 44 E.	2,560	224	Sandstone of Fort Union Formation.	212-224	--
W-2	SW¼SE¼SW¼SE¼ sec. 10, T. 20 N., R. 45 E.	2,656	122	Tongue River Member.	--	--
W-3	NE¼SW¼SW¼NW¼ sec. 22, T. 20 N., R. 45 E.	2,560	21	Tongue River Member.	--	--
W-4	SW¼SW¼SW¼NE¼ sec. 27, T. 20 N., R. 45 E.	2,590	42	Tongue River Member.	--	--
W-5	SE¼NW¼NE¼NW¼ sec. 28, T. 20 N., R. 45 E.	2,520	56	Tongue River Member.	--	--
W-6	NW¼NE¼NW¼NW¼ sec. 19, T. 19 N., R. 44 E.	2,400	141	Tongue River Member.	--	--
W-7	SE¼SE¼NE¼SE¼ sec. 20, T. 19 N., R. 44 E.	2,480	26	Tongue River Member.	--	--
W-8	SE¼SW¼SE¼NE¼ sec. 29, T. 19 N., R. 44 E.	2,445	60	Tongue River Member.	--	--
W-9	SE¼NW¼NW¼SW¼ sec. 29, T. 19 N., R. 44 E.	2,428	90	Tongue River Member.	--	--
W-10	NW¼SE¼NE¼SW¼ sec. 31, T. 19 N., R. 44 E.	2,481	78	Tongue River Member.	--	--
W-11	NE¼NW¼NW¼NE¼ sec. 4, T. 19 N., R. 45 E.	2,517	28	Tongue River Member.	16-26	--

Water level (feet below land surface)	Date of water level measurement	Well discharge (gallons per minute)	Date of discharge measurement	Remarks
13.4	08-13-81	--	--	Coal exploration hole US-7653.
51.5	09-14-81	5	09-14-81	U.S. Geological Survey observation well TC-7.
98.8	09-14-81	4	09-14-81	U.S. Geological Survey observation well TC-6.
4.4	05-12-82	--	--	Well BNTC-8027.
39.8	05-12-82	--	--	Well BNTC-8024.
61.8	11-10-81	--	--	Well BNTC-8029.
74.6	11-10-81	>15	11-10-81	Well BNTC-8028.
42.8	08-19-75	--	--	Stock well.
122.6	08-20-75	--	--	Stock well.
50R	08-19-75	--	--	Stock well.
14.4	09-05-75	8	09-05-75	Stock well.
36.3	08-14-75	.8	08-14-75	Stock well.
24.5	09-05-75	--	--	Stock well.
4.2	07-17-75	3	07-17-75	Stock well.
3.7	07-15-75	12	07-15-75	Stock and domestic well.
26.6	07-15-75	3	07-15-75	Stock well.
60R	07-15-75	4	07-15-75	Stock well.
24.1	07-15-75	4	07-15-75	Stock well.
19.2	09-17-75	3	07-19-75	Unused well.

Table 1.--*Hydrogeologic data from wells*--Continued

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of well (feet below land surface)	Principal aquifer	Aquifer interval (feet below land surface)	Hydraulic conductivity of aquifer (feet per day)
W-12	SE¼SW¼SW¼SE¼ sec. 9, T. 19 N., R. 45 E.	2,540	324	Sandstone and coal.	multiple zone	--
W-13	NE¼SW¼SE¼SE¼ sec. 10, T. 19 N., R. 45 E.	2,618	189	Tongue River Member.	169-189	--
W-14	SE¼SW¼SW¼NE¼ sec. 11, T. 19 N., R. 45 E.	2,600	66	Tongue River Member.	--	--
W-15	NW¼NE¼NW¼NE¼ sec. 16, T. 19 N., R. 45 E.	2,550	326	Sandstone and coal.	multiple zone	--
W-16	NE¼SW¼NW¼SE¼ sec. 35, T. 19 N., R. 45 E.	2,720	128	Tongue River Member.	--	--
W-17	NW¼NE¼NE¼NE¼ sec. 12, T. 18 N., R. 43 E.	2,496	160	Tongue River or Lebo Shale Member.	100-160	--
W-18	NE¼NE¼NE¼NE¼ sec. 13, T. 18 N., R. 43 E.	2,470	300	Lebo Shale Member.	--	--
W-19	SW¼SE¼SE¼NE¼ sec. 13, T. 18 N., R. 43 E.	2,475	--	Lebo Shale Member.	--	--
W-20	NW¼NE¼NE¼SE¼ sec. 13, T. 18 N., R. 43 E.	2,475	--	Lebo Shale Member.	--	--
W-21	NW¼NE¼NE¼NE¼ sec. 24, T. 18 N., R. 43 E.	2,515	160	Lebo Shale Member.	--	--
W-22	NE¼SE¼NE¼SE¼ sec. 24, T. 18 N., R. 43 E.	2,470	--	Lebo Shale Member.	--	--
W-23	NW¼NE¼NE¼NE¼ sec. 13, T. 18 N., R. 44 E.	2,598	278	Coal	248-256	0.3
W-24	SW¼NE¼NW¼NE¼ sec. 14, T. 18 N., R. 44 E.	2,570	150	Tongue River Member.	--	--
W-25	SE¼NW¼NE¼NW¼ sec. 14, T. 18 N., R. 44 E.	2,565	133	Tongue River Member.	120-130	--
W-26	NW¼SW¼SW¼SW¼ sec. 16, T. 18 N., R. 44 E.	2,490	123	Tongue River Member.	83-123	--
W-27	SE¼NE¼SE¼NW¼ sec. 19, T. 18 N., R. 44 E.	2,460	100	Tongue River Member.	80-100	--
W-28	SW¼NW¼NE¼NW¼ sec. 20, T. 18 N., R. 44 E.	2,510	73	Tongue River Member.	--	--
W-29	NE¼SW¼SE¼NW¼ sec. 30, T. 18 N., R. 44 E.	2,476	140	Tongue River or Lebo Shale Member.	67-130	--
W-30	SW¼NW¼NW¼SW¼ sec. 14, T. 18 N., R. 45 E.	2,747	142	Tongue River Member.	--	--

Water level (feet below land surface)	Date of water level measurement	Well discharge (gallons per minute)	Date of discharge measurement	Remarks
40.5	07-27-82	>70	--	Irrigation well.
100R	07-15-75	5	07-17-75	Stock and domestic well.
17.6	07-19-75	3	07-19-75	Stock well.
60.7	07-27-82	>70	--	Irrigation well.
91.3	07-17-75	5	07-17-75	Stock well.
11.1	05-01-72	18	05-01-72	Domestic well.
Flowing	--	2	09-05-75	Public water-supply well.
Flowing	--	--	--	Stock well.
Flowing	--	--	--	Stock well.
Flowing	--	2	09-08-75	Stock well.
Flowing	--	--	--	Stock well.
96.3	06-29-81	3	05-05-76	Stock and observation well.
60.7	07-17-75	--	--	Stock well.
39.1	07-17-75	2	07-17-75	Stock well.
.6	07-16-75	8	07-16-75	Stock well.
50R	07-16-75	3	07-16-75	Stock well.
34.7	07-16-75	--	--	Stock well.
Flowing	--	1	07-17-75	Stock well.
125R	--	--	--	Stock well.

Table 1.--*Hydrogeologic data from wells*--Continued

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of well (feet below land surface)	Principal aquifer	Aquifer interval (feet below land surface)	Hydraulic conductivity of aquifer (feet per day)
W-31	NE¼NE¼SW¼NE¼ sec. 1, T. 17 N., R. 44 E.	2,608	72	Tongue River Member.	--	--
W-32	NE¼NW¼NE¼NW¼ sec. 2, T. 17 N., R. 44 E.	2,570	40	Alluvium	--	--
W-33	SE¼SW¼SE¼NE¼ sec. 3, T. 17 N., R. 44 E.	2,593	34	Tongue River Member.	--	--
W-34	SE¼NE¼NE¼NE¼ sec. 8, T. 17 N., R. 44 E.	2,620	100	Tongue River Member.	--	--
W-35	NE¼NE¼NW¼NE¼ sec. 10, T. 17 N., R. 44 E.	2,620	108	Tongue River Member.	96-104	--
W-36	NE¼NE¼NE¼NE¼ sec. 6, T. 17 N., R. 45 E.	2,640	120	Tongue River Member.	106-115	--

Water level (feet below land surface)	Date of water level measurement	Well discharge (gallons per minute)	Date of discharge measurement	Remarks
30R	07-22-75	--	--	Stock well.
7.8	07-23-75	--	--	Stock well.
24.6	07-23-75	2	07-23-75	Stock well.
95.0	07-24-75	--	--	Stock well.
55R	07-24-75	5	12-28-60	Stock well.
41.2	07-29-75	--	--	Stock well.

Table 2.--*Geologic data from drill holes*

[Site designation: H, drill hole. Available logs: D, density; E, resistivity; G, geologic; J, gamma; S, self-potential]

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of hole (feet below land surface)	Date drilled	Coal-bed thickness (feet) at depth (feet below land surface) of top of bed	Available logs	Remarks
H-1	NE¼SW¼SE¼SW¼ sec. 26, T. 20 N., R. 44 E.	2,550	80	05-02-76	2 at 28; 16 at 40	D, G, J	Coal exploration hole US-7618.
H-2	SE¼SE¼SE¼SE¼ sec. 34, T. 20 N., R. 44 E.	2,540	100	05-02-76	16 at 54	G, J	Coal exploration hole US-7619.
H-3	NW¼SE¼NE¼SE¼ sec. 16, T. 20 N., R. 45 E.	2,591	140	10-05-68	2 at 16; 20 at 118	G	Coal exploration hole S-Mc-10.
H-4	NE¼NE¼SE¼SE¼ sec. 18, T. 20 N., R. 45 E.	2,735	300	05-01-76	4 at 154; 14 at 261	D, E, G, J, S	Coal exploration hole US-7615.
H-5	NE¼NW¼NW¼NE¼ sec. 22, T. 20 N., R. 45 E.	2,650	240	04-30-76	4 at 80; 18 at 192	D, E, G, J, S	Coal exploration hole US-7613.
H-6	SW¼SW¼NE¼NE¼ sec. 26, T. 20 N., R. 45 E.	2,745	440	05-02-76	5 at 91: 4 at 279; 21 at 393	G, J	Coal exploration hole US-7621.
H-7	SW¼SW¼NE¼SE¼ sec. 28, T. 20 N., R. 45 E.	2,635	320	05-02-76	4 at 148; 20 at 280	D, E, G, J, S	Coal exploration hole US-7620.
H-8	NE¼NW¼NE¼NW¼ sec. 32, T. 20 N., R. 45 E.	2,580	160	05-04-76	20 at 118	E, G, J, S	Coal exploration hole US-7625.
H-9	SE¼SW¼SW¼SW¼ sec. 2, T. 19 N., R. 44 E.	2,690	260	05-14-76	5 at 71; 2 at 172; 15 at 217	D, E, G, J, S	Coal exploration hole US-7637.
H-10	SE¼SW¼SE¼SE¼ sec. 4, T. 19 N., R. 44 E.	2,720	255	05-12-76	6 at 80; 3 at 175; 14 at 228	D, E, G, J, S	Coal exploration hole US-7634.
H-11	NE¼NW¼NE¼NE¼ sec. 14, T. 19 N., R. 44 E.	2,740	340	05-13-76	3 at 97; 5 at 159; 4 at 256; 14 at 296	D, E, G, J, S	Coal exploration hole US-7636.
H-12	SW¼SW¼SW¼SW¼ sec. 16, T. 19 N., R. 44 E.	2,563	83	10-06-68	15 at 67	G	Coal exploration hole S-Mc-12.
H-13	SW¼SW¼NE¼NW¼ sec. 21, T. 19 N., R. 44 E.	2,520	81	10-15-80	15 at 44	G	Drill hole No. TC-2.

Table 2.--*Geologic data from drill holes*--Continued

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of hole (feet below land surface)	Date drilled	Coal-bed thickness (feet) at depth (feet below land surface) of top of bed	Available logs	Remarks
H-14	SW¼SW¼SW¼SW¼ sec. 36, T. 19 N., R. 44 E.	2,501	120	10-07-68	6 at 39; 8 at 97	G	Coal exploration hole S-Mc-13.
H-15	NE¼NE¼NE¼NE¼ sec. 8, T. 19 N., R. 45 E.	2,550	280	05-04-76	4 at 35; 4 at 100; 20 at 227	D, E, G, J, S	Coal exploration hole US-7624.
H-16	NW¼NW¼NW¼NW¼ sec. 10, T. 19 N., R. 45 E.	2,610	380	05-04-76	4 at 140; 5 at 204; 21 at 332	D, E, G, J, S	Coal exploration hole US-7626.
H-17	NE¼NW¼NE¼NW¼ sec. 18, T. 19 N., R. 45 E.	2,660	300	05-15-76	4 at 63; 6 at 144; 4 at 261; 16 at 271	D, E, G, J, S	Coal exploration hole US-7639.
H-18	NW¼SW¼NW¼NW¼ sec. 26, T. 19 N., R. 45 E.	2,650	520	05-03-76	3 at 59; 6 at 176; 5 at 305; 5 at 374; 3 at 462; 10 at 504	E, G, J, S	Coal exploration hole US-7623.
H-19	NW¼SW¼SE¼SW¼ sec. 32, T. 19 N., R. 45 E.	2,640	380	05-15-76	5 at 61; 6 at 165; 7 at 290; 8 at 351	E, G, J, S	Coal exploration hole US-7640.
H-20	NW¼NW¼NW¼NW¼ sec. 32, T. 19 N., R. 46 E.	2,690	500	05-28-76	2 at 76; 2 at 96; 4 at 100; 8 at 183; 5 at 290; 5 at 362; 2 at 437; 7 at 474	D, E, G, J, S	Coal exploration hole US-7655.
H-21	SW¼SW¼NW¼SW¼ sec. 16, T. 18 N., R. 44 E.	2,512	54	10-06-68	8 at 45	G	Coal exploration hole S-Mc-11.
H-22	NE¼NE¼NE¼NW¼ sec. 22, T. 18 N., R. 45 E.	2,857	300	11-05-77	8 at 231	D, G, J	Coal exploration hole US-77302.
H-23	NE¼NE¼NE¼NE¼ sec. 30, T. 18 N., R. 45 E.	2,750	320	05-27-76	9 at 175; 1 at 232; 7 at 274	D, E, G, J, S	Coal exploration hole US-7654.

Table 3.--*Major-constituent concentrations and physical properties of water from wells and a reservoir*

[Unless indicated otherwise, constituents are dissolved and constituent values are reported in milligrams per liter. Site designation: O, observation well; W, stock or domestic well; C, reservoir. Geologic source: Tongue River and Lebo Shale are members of the Fort Union Formation; coal and sand are in the Tongue River Member. Analysis by: MBMG, Montana Bureau of Mines and Geology; USGS, U.S. Geological Survey. Abbreviations: micromhos, micromhos per centimeter at 25° Celsius; °C, degrees Celsius. Symbol: <, less than]

Site designation	Location	Date of collection	Geologic source	Onsite specific conductance (micromhos)	Onsite pH (units)	Onsite water temperature (°C)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium adsorption ratio (SAR)
O-7	SE¼SE¼NW¼SW¼ sec. 20, T. 20 N., R. 45 E.	08-11-79	Coal-S bed.	2,980	[1]8.3	26.0	210	41	26	960	29
O-10	NW¼NE¼NW¼SE¼ sec. 30, T. 20 N., R. 45 E.	05-07-82	Coal-S bed.	2,400	5.7	10.0	550	95	77	340	6
O-12	NE¼NE¼NW¼SW¼ sec. 9, T. 19 N., R. 44 E.	09-16-81	Coal-S bed.	4,250	7.3	10.0	270	47	37	1,100	28
O-13	SE¼SW¼SW¼NE¼ sec. 33, T. 19 N., R. 44 E.	09-15-81	Coal-S bed.	4,250	7.8	10.0	120	24	16	1,100	43
O-14	SE¼SE¼SE¼SE¼ sec. 35, T. 19 N., R. 44 E.	09-15-81	Coal-S bed.	3,800	7.9	11.0	67	13	8.1	980	52
O-19	NW¼NW¼SW¼SW¼ sec. 10, T. 18 N., R. 45 E.	09-14-81	Sandstone of Tongue River Member.	3,200	7.0	10.5	680	110	99	520	9
O-20	NW¼NW¼SW¼SW¼ sec. 10, T. 18 N., R. 45 E.	09-14-81	Sandstone and coal.	3,100	8.0	12.0	52	11	6.0	690	42
W-6	NW¼NE¼NW¼NW¼ sec. 19, T. 19 N., R. 44 E.	07-17-75	Tongue River Member.	[1]2,230	[1]8.4	10.5	16	3.8	1.6	590	64
W-7	SE¼SE¼NE¼SE¼ sec. 20, T. 19 N., R. 44 E.	07-15-75	Tongue River Member.	[1]1,010	[1]7.7	10.0	170	30	24	180	6
W-9	SE¼NW¼NW¼SW¼ sec. 29, T. 19 N., R. 44 E.	07-15-75	Tongue River Member.	[1]2,090	[1]8.3	10.0	14	3.4	1.3	510	60
W-10	NW¼SE¼NE¼SW¼ sec. 31, T. 19 N., R. 44 E.	07-15-75	Tongue River Member.	[1]3,440	[1]7.4	9.5	470	78	66	700	14
W-13	NE¼SW¼SE¼SE¼ sec. 10, T. 19 N., R. 45 E.	07-17-75	Tongue River Member.	[1]3,280	[1]8.2	10.5	230	42	31	740	21
W-14	SE¼SW¼SW¼NE¼ sec. 11, T. 19 N., R. 45 E.	07-19-75	Tongue River Member.	[1]4,320	[1]7.3	11.0	1,500	230	230	610	7
W-16	NE¼SW¼NW¼SE¼ sec. 35, T. 19 N., R. 45 E.	07-17-75	Tongue River Member.	[1]1,500	[1]7.4	10.5	780	84	140	77	1
W-18	NE¼NE¼NE¼NE¼ sec. 13, T. 18 N., R. 43 E.	09-05-75	Lebo Shale Member.	[1]2,190	[1]6.6	11.0	17	4.2	1.6	500	53
W-23	NW¼NE¼NE¼NE¼ sec. 13, T. 18 N., R. 44 E.	05-05-76	Coal	2,850	8.5	13.0	44	8.4	5.5	720	47
W-25	SE¼NW¼NE¼NW¼ sec. 14, T. 18 N., R. 44 E.	07-17-75	Tongue River Member.	[1]2,880	[1]8.2	11.0	46	8.0	6.3	670	43
W-26	NW¼SW¼SW¼SW¼ sec. 16, T. 18 N., R. 44 E.	07-16-75	Tongue River Member.	[1]4,640	[1]9.3	10.0	140	9.4	28	1,100	39
W-27	SE¼NE¼SE¼NW¼ sec. 19, T. 18 N., R. 43 E.	07-16-75	Tongue River Member.	[1]2,650	[1]8.0	10.0	33	7.4	3.6	630	47

Potassium (K)	Bicarbonate (HCO_3)	Total alkalinity (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids, calculated sum	Nitrate (as N)	Nitrite plus nitrate (as N)	Analysis by
5	990	810	1,400	8.6	0.6	8.1	2,940	1.8	--	MBMG
5	290	240	1,000	10	.3	49	1,740	.50	--	MBMG
6	1,530	1,250	1,200	22	.5	9.2	3,120	.07	--	MBMG
3	1,330	1,090	1,300	21	1.6	7.1	3,090	.02	--	MBMG
2	1,190	980	1,000	7.8	1.2	7.4	2,610	.05	--	MBMG
9	920	760	990	8.0	.2	10	2,210	.05	--	MBMG
2	550	450	1,000	28	1.7	7.5	2,050	.07	--	MBMG
2	1,050	900	320	43	2.0	6.6	1,520	2.6	--	MBMG
4	320	260	290	2.2	.3	5.8	691	.45	--	MBMG
2	750	610	460	22	2.4	6.4	1,380	.97	--	MBMG
6	910	750	1,200	8.1	.3	7.1	2,540	.77	--	MBMG
6	730	600	1,200	18	.6	6.6	2,420	5.7	--	MBMG
15	870	710	2,100	9.6	<.1	9.4	3,650	4.5	--	MBMG
7	660	540	390	6.8	<.1	9.0	1,030	1.1	--	MBMG
2	640	530	480	25	2.3	6.8	1,350	1.9	--	MBMG
3	490	440	1,000	31	2.0	6.9	2,040	--	.03	USGS
3	620	510	910	24	1.3	7.1	1,940	.95	--	MBMG
5	310	340	2,000	21	.5	.9	3,340	4.5	--	MBMG
2	630	510	850	18	1.6	6.7	1,820	1.5	--	MBMG

Table 3.--*Major-constituent concentrations and physical properties of water from wells and a reservoir*--Continued

Site designation	Location	Date of collection	Geologic source	Onsite specific conductance (micromhos)	Onsite pH (units)	Onsite water temperature (°C)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium adsorption ratio (SAR)
W-29	NE¼SW¼SE¼NW¼ sec. 30, T. 18 N., R. 44 E.	07-17-75	Tongue River or Lebo Shale Member.	[1]3,270	[1]8.1	11.0	56	10	7.3	820	93
W-31	NE¼NE¼SE¼NE¼ sec. 1, T. 17 N., R. 44 E.	07-22-75	Tongue River Member.	[1]3,050	[1]7.1	15.0	1,000	180	140	440	6
W-33	SE¼SW¼SE¼NE¼ sec. 3, T. 17 N., R. 44 E.	07-23-75	Tongue River Member.	[1]2,140	[1]8.0	10.0	820	190	81	230	4
C-1	SE¼NW¼SE¼NE¼ sec. 8, T. 19 N., R. 45 E.	07-27-82	--	2,590	8.5	22.0	890	78	170	320	5

[1] Laboratory determination.

Potassium (K)	Bicarbonate (HCO_3)	Total alkalinity (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids, calculated sum	Nitrate (as N)	Nitrite plus nitrate (as N)	Analysis by
3	980	980	1,000	7.2	.6	6.9	2,380	1.4	--	MBMG
11	1,060	870	1,100	5.9	.1	10	2,410	1.7	--	MBMG
6	720	590	680	6.0	.1	9.4	1,560	1.8	--	MBMG
13	--	340	1,200	8.0	.2	2.9	1,990	--	<.10	USGS

Table 4.--*Trace-element concentrations of water from wells and a reservoir*

[Constituents are dissolved and concentrations are reported in micrograms per liter. Site designation: O, observation well; W, stock, irrigation, or domestic well; C, reservoir. Analysis by: MBMG, Montana Bureau of Mines and Geology; USGS, U.S. Geological Survey. Symbol: <, less than]

Site designation	Location	Date of collection	Aluminum (Al)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)
O-7	SE¼SE¼NW¼SW¼ sec. 20, T. 20 N., R. 45 E.	08-11-79	--	860	--	--	--	240	--
O-10	NW¼NE¼NW¼SE¼ sec. 30, T. 20 N., R. 45 E.	08-11-79	--	2,700	--	--	--	5,000	--
		05-07-82	--	--	--	--	--	4,200	--
O-12	NE¼NE¼NW¼SW¼ sec. 9, T. 19 N., R. 44 E.	09-16-81	<30	1,200	<2	<2	<2	10	<40
O-13	SE¼SW¼SW¼NE¼ sec. 33, T. 19 N. R. 44 E.	09-15-81	<30	840	<2	<2	<2	10	<40
O-14	SE¼SE¼SE¼SE¼ sec. 35, T. 19 N., R. 44 E.	09-15-81	<30	1,100	<2	<2	<2	10	<40
O-19	NW¼NW¼SW¼SW¼ sec. 10, T. 18 N., R. 44 E.	09-14-81	<3	1,600	<2	<2	<2	1,200	<40
O-20	NW¼NW¼SW¼SW¼ sec. 10, T. 18 N., R. 44 E.	09-14-81	<30	740	<2	<2	<2	100	<40
W-6	NW¼NE¼NW¼NW¼ sec. 19, T. 19 N., R. 44 E.	07-17-75	--	--	--	--	--	50	--
W-7	SE¼SE¼NE¼SE¼ sec. 20, T. 19 N., R. 44 E.	07-15-75	--	--	--	--	--	<10	--
W-9	SE¼NW¼NW¼SW¼ sec. 29, T. 19 N., R. 44 E.	07-15-75	--	--	--	--	--	10	--
W-10	NW¼SE¼NE¼SW¼ sec. 31, T. 19 N., R. 44 E.	07-15-75	--	--	--	--	--	30	--
W-13	NE¼SW¼SE¼SE¼ sec. 10, T. 19 N., R. 45 E.	07-17-75	--	--	--	--	--	<10	--
W-14	SE¼SW¼SW¼NE¼ sec. 11, T. 19 N. R. 45 E.	07-19-75	--	--	--	--	--	30	--
W-16	NE¼SW¼NW¼SE¼ sec. 35, T. 19 N., R. 45 E.	07-17-75	--	--	--	--	--	10	--
W-18	NE¼NE¼NE¼NE¼ sec. 13, T. 18 N., R. 45 E.	09-05-75	--	--	--	--	--	20	--
W-23	NW¼NE¼NE¼NE¼ sec. 13, T. 18 N., R. 44 E.	05-05-76	--	--	--	--	2	30	--
W-25	SE¼NW¼NE¼NW¼ sec. 14, T. 18 N., R. 44 E.	07-17-75	--	--	--	--	--	<10	--
W-26	NW¼SW¼SW¼SW¼ sec. 16, T. 18 N., R. 44 E.	07-16-75	--	--	--	--	--	10	--
W-27	SE¼NE¼SE¼NW¼ sec. 19, T. 18 N., R. 44 E.	07-16-75	--	--	--	--	--	10	--
W-29	NE¼SW¼SE¼NW¼ sec. 30, T. 18 N., R. 44 E.	07-17-75	--	--	--	--	--	10	--
W-31	NE¼NE¼SW¼NE¼ sec. 1, T. 17 N., R. 44 E.	07-22-75	--	--	--	--	--	10	--
W-33	SE¼SW¼SE¼NE¼ sec. 3, T. 17 N., R. 44 E.	07-23-75	--	--	--	--	--	40	--
C-1	SE¼NW¼SE¼NE¼ sec. 8, T. 19 N., R. 45 E.	07-27-82	--	--	--	--	--	20	--

Lithium (Li)	Manga-nese (Mn)	Molyb-denum (Mo)	Nickel (Ni)	Silver (Ag)	Stron-tium (Sr)	Vana-dium (V)	Zinc (Zn)	Analysis by
80	30	--	--	--	--	--	--	MBMG
90 --	240 220	--	--	--	--	--	--	MBMG
70	42	--	--	--	--	--	--	MBMG
30	30	<20	<10	<2	2,600	<1.0	20	MBMG
30	11	<20	<10	<2	1,200	<1.0	--	MBMG
40	74	<20	<10	<2	640	<1.0	--	MBMG
20	24	<20	<10	<3	4,500	<1.0	--	MBMG
--	<10	50	<10	<2	440	<1.0	--	MBMG
--	<10	--	--	--	--	--	--	MBMG
--	<10	--	--	--	--	--	--	MBMG
--	80	--	--	--	--	--	--	MBMG
--	50	--	--	--	--	--	--	MBMG
--	90	--	--	--	--	--	--	MBMG
--	140	--	--	--	--	--	--	MBMG
--	<10	--	--	--	--	--	--	MBMG
--	--	--	--	--	--	--	--	USGS
--	20	--	--	--	--	--	--	MBMG
--	10	--	--	--	--	--	--	MBMG
--	10	--	--	--	--	--	--	MBMG
--	10	--	--	--	--	--	--	MBMG
--	100	--	--	--	--	--	--	MBMG
--	1,400	--	--	--	--	--	--	MBMG
--	--	--	--	--	--	--	--	USGS

Table 5.--*Summary of water-quality data for Nelson Creek at U.S. Geological Survey station 06131200*

[Period of record: Water years 1976-79 (discontinued). Abbreviations: ft^3/s, cubic feet per second; micromhos, micromhos per centimeter at 25° Celsius; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter]

Variable	Number of samples	Minimum value	Maximum value	Mean	Standard deviation
Streamflow, instantaneous (ft^3/s)	27	0.03	125	16	34
Specific conductance (micromhos)	26	272	9,200	3,280	2,560
pH (units)	26	7.3	8.8	8.2	.35
Temperature (°C)	27	.0	23.0	9.7	7.8
Turbidity (NTU)	18	20	18,000	1,300	4,200
Oxygen, dissolved (mg/L)	24	6.2	11.0	9.0	1.6
Oxygen, dissolved (percent saturation)	24	54	99	81	10
Oxygen demand, biochemical, 5-day (mg/L)	18	1.1	6.4	3.4	1.5
Calcium, dissolved (mg/L as Ca)	25	16	140	55	33
Magnesium, dissolved (mg/L as Mg)	25	5.6	230	80	74
Sodium, dissolved (mg/L as Na)	25	37	2,000	680	570
Percent sodium	25	55	84	72	8
Sodium-adsorption ratio	25	2	26	12	7
Potassium, dissolved (mg/L as K)	25	3	20	8	4
Alkalinity (mg/L as $CaCO_3$)	26	63	1,160	370	280
Sulfate, dissolved (mg/L as SO_4)	25	76	4,200	1,540	1,320
Chloride, dissolved (mg/L as Cl)	25	1	37	10	8
Fluoride, dissolved (mg/L as F)	24	.1	1.2	.4	.2
Silica, dissolved (mg/L as SiO_2)	24	.1	25	5	5
Solids, sum of constituents, dissolved	24	181	6,960	2,640	2,180
Nitrogen, NO_2 + NO_3 total (mg/L as N)	26	.01	1.3	.27	.34
Nitrogen, ammonia total (mg/L as N)	26	.01	.12	.05	.03
Nitrogen, organic total (mg/L as N)	26	.69	3.8	1.4	.81
Nitrogen, total (mg/L as N)	26	.87	5.0	1.6	1.1
Phosphorus, total (mg/L as P)	26	.02	3.6	.35	.76
Sediment, suspended (mg/L)	24	64	23,000	1,500	4,700

Table 6.--*Summary of water-quality data for Timber Creek at U.S. Geological Survey station 06131120*

[Period of record: Water years 1976-79 (discontinued). Abbreviations: ft^3/s, cubic feet per second; micromhos, micromhos per centimeter at 25° Celsius; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter]

Variable	Number of samples	Minimum value	Maximum value	Mean	Standard deviation
Streamflow, instantaneous (ft^3/s)	22	0.10	128	14	30
Specific conductance (micromhos)	20	765	7,200	3,950	1,850
pH (units)	20	7.2	8.9	8.4	.38
Temperature (°C)	21	.0	23.5	11.8	8.3
Turbidity (NTU)	10	10	250	65	70
Oxygen, dissolved (mg/L)	19	6.5	12	9.4	1.6
Oxygen, dissolved (percent saturation)	19	74	123	90	13
Oxygen demand, biochemical, 5-day (mg/L)	7	1.2	4.2	2.7	1.0
Calcium, dissolved (mg/L as Ca)	20	14	84	51	19
Magnesium, dissolved (mg/L as Mg)	20	14	180	94	46
Sodium, dissolved (mg/L as Na)	20	120	1,600	790	440
Percent sodium	20	60	84	75	5
Sodium-adsorption ratio	20	5	27	14	6
Potassium, dissolved (mg/L as K)	20	4.5	17	10	2.9
Alkalinity (mg/L as $CaCO_3$)	20	98	960	500	240
Sulfate, dissolved (mg/L as SO_4)	19	250	3,300	1,700	890
Chloride, dissolved (mg/L as Cl)	19	1.3	50	12	12
Fluoride, dissolved (mg/L as F)	18	.1	1.0	.4	.2
Silica, dissolved (mg/L as SiO_2)	18	.2	21	4.4	4.6
Solids, sum of constituents, dissolved	18	468	5,530	3,080	1,510
Nitrogen, NO_2 + NO_3 total (mg/L as N)	19	.01	.26	.07	.08
Nitrogen, ammonia total (mg/L as N)	20	.01	.22	.06	.05
Nitrogen, organic total (mg/L as N)	20	.47	2.1	1.0	.36
Nitrogen, total (mg/L as N)	19	.59	2.1	1.1	.36
Phosphorus, total (mg/L as P)	20	.02	.27	.07	.06
Sediment, suspended (mg/L)	22	45	520	170	110