UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

POTENTIAL EFFECTS OF SURFACE COAL MINING ON THE HYDROLOGY OF THE COOK CREEK AREA, ASHLAND COAL FIELD, SOUTHEASTERN MONTANA

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METRIC CONVERSION TABLE

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	1233	cubic meter
cubic foot (ft^3)	0.02832	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	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon per minute (gal/min)	0.06309	liter per second
inch	25.40	millimeter
micromho per centimeter at 25° Celsius	100	microsiemens per meter at 25° Celsius
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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

$$°C = 0.556\ (°F - 32)$$

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 COOK CREEK AREA,
ASHLAND COAL FIELD, SOUTHEASTERN MONTANA

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ABSTRACT

The Cook Creek area of the Ashland coal field contains large reserves of Federally owned coal that have 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.

Hydrogeologic data collected from wells, springs, and drill holes indicate that shallow aquifers exist within the Tongue River Member of the Fort Union Formation (Paleocene age) and within valley alluvium (Pleistocene and Holocene age). Shallow aquifers within the Tongue River Member include coal beds, clinker, and lenses of sandstone and siltstone. The Knobloch coal bed, a principal shallow aquifer used for stockwatering in the area, averages about 55 feet in thickness and is completely saturated throughout most of its extent. Coarse alluvial deposits are the most productive aquifers and are a major source of stock water in the Cook Creek basin.

Surface-water resources are limited to the upstream reach of Cook Creek, which flows intermittently. The downstream reach of Cook Creek, plus all other small drainages that originate in the study area, are ephemeral.

Mining of the Knobloch and Sawyer coal beds would remove two alluvial springs, one bedrock spring, and two wells, which are all used for watering of livestock. The potentiometric surface within the Knobloch coal aquifer and the alluvial aquifer in the downstream part of the Cook Creek basin would be lowered during mining. Lowered water levels in these aquifers might substantially affect water levels in five wells outside the mine boundary. After mining, water in the alluvial aquifer downgradient from the mine area might show a long-term degradation in quality as a result of leaching of soluble salts from overburden materials used to backfill mine pits. Although mining would alter the existing hydrologic systems and remove several springs and shallow wells, alternative groundwater supplies are available that could be developed to replace those lost by mining.

INTRODUCTION

Development of western coal to meet national energy needs has recently received increased emphasis. A large part of the western coal is under Federal ownership; therefore, considerable demand exists for the leasing and development of Federal coal lands. To ensure orderly leasing and development of Federal coal, a Federal Coal Management Program was developed, which requires the U.S. Bureau of Land Management 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 is cooperating with the Bureau of Land Management under the EMRIA (Energy Minerals Rehabilitation Inventory and Analysis) program. As part of this program, the U.S. Geological Survey is conducting hydrologic studies on several potential coal-lease tracts in the Powder River structural basin of southeastern Montana. The Cook Creek area of the Ashland coal field is one of these tracts.

Purpose and scope

The purpose of the 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, springs, and drill holes. Eleven additional test holes and observation wells were drilled and completed where data were lacking. Aquifer tests were made at all 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 estimate runoff characteristics in small watersheds.

A major use of this report will be to provide information that can be used to rank various tracts of Federal coal for potential mining. The information for all tracts will be presented in a similar format, emphasizing 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 Cook Creek study area encompasses about 22 mi^2 in Rosebud and Powder River Counties, southeastern Montana. The town of Ashland, Mont., is about 1 mile southwest of the study area, and the Northern Cheyenne Indian Reservation is adjacent to the western boundary of the study area (fig. 1).

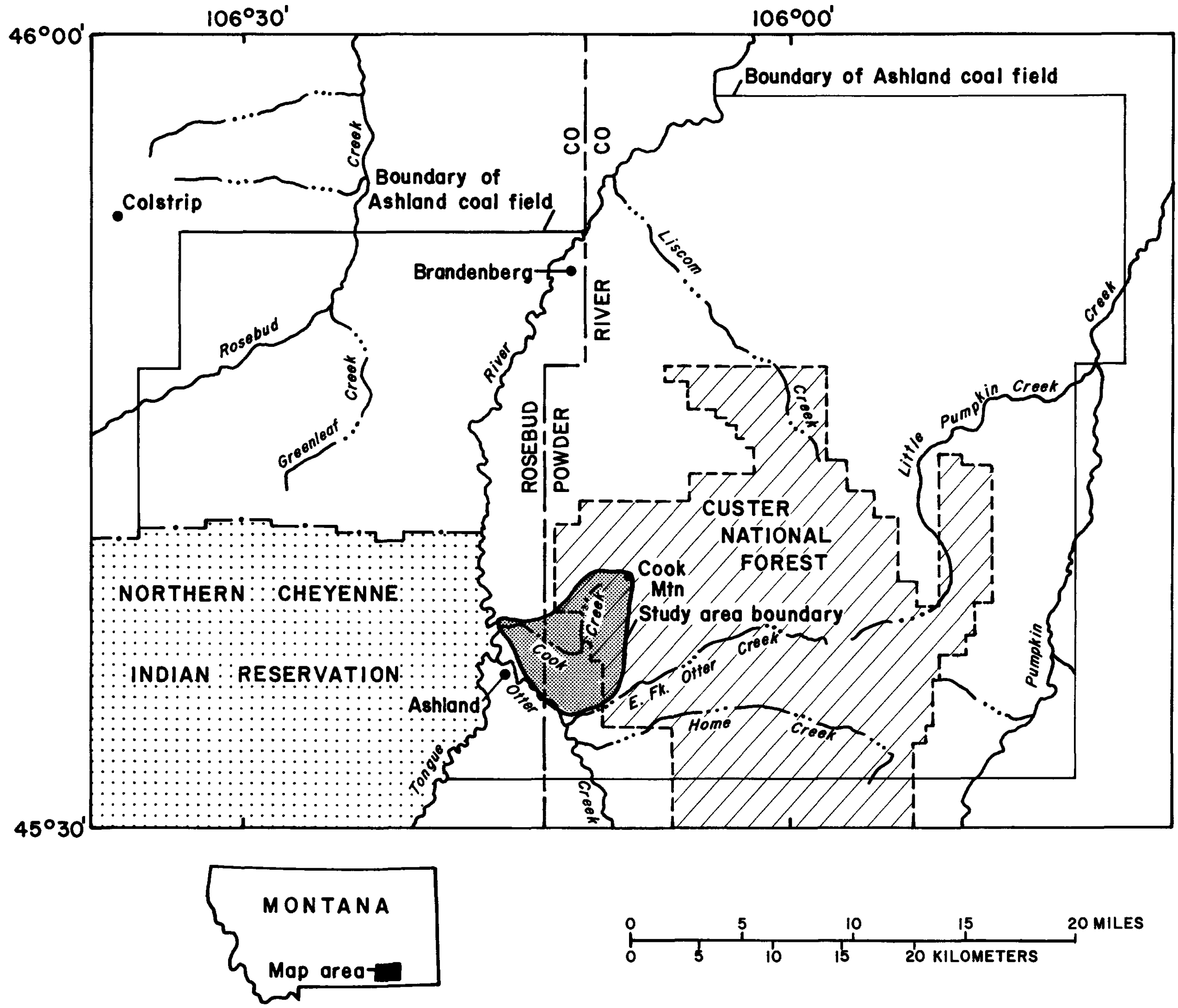

Figure 1.--Location of the Cook Creek study area.

Cook Creek and East Fork Otter Creek drain most of the study area. These small westward-flowing creeks are tributary to the northward-flowing Tongue River. Headwaters of small streams of the area typically are in steep, narrow, upland draws formed by the erosion of relatively soft and flat-lying sedimentary rocks. The streams have relatively straight and narrow channels in the upstream and middle reaches and narrow alluvial valleys in the downstream reaches. Almost all small streams in the area are ephemeral.

The land surface is a maturely dissected series of benches or plateaus that have been formed by the erosion of flat-lying strata of varying degrees of resistance. Hard clinker beds, formed by the burning of thick coal beds, are most resistant to erosion and cap many steep-sided buttes and narrow ridges. Maximum topographic relief in the area is about 1,450 feet, with altitudes ranging from 4,327 feet at Cook Mountain to about 2,900 feet along the Tongue River.

Average annual precipitation at Ashland is about 12.7 inches, based on 29 years of record (1951-79). Precipitation increases noticeably with altitude, and highland areas of interstream divides may receive an additional 3 to 4 inches of precipitation per year. April, May, and June generally are the periods of largest monthly precipitation. Annual potential evaporation is greater than precipitation and is estimated to be 36 inches. Air temperatures in the study area typically have an annual range from about -35° to 100°F.

Previous investigations

Geology and coal deposits within the area have been studied by several investigators. Wegemann (1908) made a reconnaissance of part of the area to describe coals of the Custer National Forest. Coal deposits of the Ashland coal field were studied and described in detail by the U.S. Geological Survey (Bass, 1932) as part of a systematic study and classification of western coal lands. Brown and others (1954) mapped reserves of strippable coal within the Cook Creek area. Matson and Blumer (1973) described the quality and quantity of strippable coal within the Ashland coal field in a comprehensive report on strippable coal deposits of southeastern Montana. The geology of part of the Cook Creek area was mapped in detail by McKay (1976).

Ground-water resources and hydrologic characteristics of rocks in the area have been studied by Renick (1929), Perry (1931), Hopkins (1973), Lewis and Roberts (1978), and Stoner and Lewis (1980). Slagle and Stimson (1979) have compiled ground-water data from 1,924 wells in the northern Powder River Basin.

Chemical quality of ground water and geochemical processes that control the quality of water in the Fort Union Formation have been investigated by Lee (1979, 1981) and by Dockins and others (1980). Studies have been made on the quality of surface water of the region (Knapton and McKinley, 1977; Knapton and Ferreira, 1980) and the quality of base flow of Otter Creek, the Tongue River, and Rosebud Creek (Lee and others, 1981).

Potential impacts of coal mining on water resources in the Tongue River drainage basin have been the focus of several studies. Effects of coal mining on water resources in the Decker, Mont., area (50 miles southwest of Ashland) have been studied by Van Voast (1974) and Van Voast and Hedges (1975). Woessner, Andrews, and Osborne (1979) investigated the potential impacts of coal mining on the quality of ground water and surface water on the Northern Cheyenne Indian Reservation. Woods (1981) has developed a computer model for assessing potential increases in dissolved solids of streams as a result of leaching of mine spoils and has modeled the impacts of surface coal mining on dissolved solids in the Tongue River.

WATER USE AND SUPPLY

Within the study area, ground-water and surface-water supplies are used primarily for livestock watering. Domestic water use is limited to residences near the southern and western boundaries of the study area and no irrigation uses exist at the present time (1981).

Wells and developed springs supply most of the water used by livestock within the study area. Four springs and seven wells (table 1) are known to be used for livestock watering. Two of the springs (S-1 and S-3) are developed in alluvium along Cook Creek. The other springs flow from bedrock sources--one from clinker (S-2) and one from fractured siltstone (S-4). All springs are considered to be perennial although spring S-4 may become dry during an extended drought. Three of the stock wells (W-3, W-11, and W-12) are completed in the Knobloch coal aquifer, one (W-16) is developed in alluvium along Cook Creek, and one (W-15) is completed in a sandstone lens (see pl. 1). Stock well W-13 probably is completed in alluvium of East Fork Otter Creek and stock well W-17 probably is completed in the Tongue River Member.

Surface-water supply is limited to the upstream reach of Cook Creek, which flows intermittently. Within the upper 2.5 river miles of Cook Creek are many small seeps and springs and several small stock reservoirs. These springs, seeps, and reservoirs supply all water used by livestock in the upstream part of the basin.

Water samples were collected from the four springs developed for livestock water, from well W-12, and from streamflow in the upstream part of the Cook Creek basin (see tables 2 and 3 and pl. 1). Chemical analyses of these samples indicated that concentrations of all constituents determined are less than the recommended maximum limits for use by livestock (McKee and Wolf, 1963). 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 (1977) for public supply. The recommended concentrations of sulfate and dissolved solids were established because of possible laxative effects on people not accustomed to the water and apply if less mineralized water is available. However, the quality of the water sampled is typical of water quality in the northern Powder River Basin and is not unique to the study area.

The water supply in the alluvium in the downstream part of the Cook Creek valley could support several additional livestock wells. Expected yield of alluvial wells is 10 to 20 gal/min. The Knobloch coal aquifer also could support additional livestock wells. Expected yield of coal-aquifer wells is about 2 to 10 gal/min. Deeper aquifers exist in the Tongue River and Tullock Members of the Fort Union Formation (Lewis and Hotchkiss, 1981). These aquifers presently are unused but could support many livestock wells in the area.

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 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 cuts and for evaluating the temporal and spatial changes in the potentiometric surface created by excavation of the mine pits.

Detailed mine plans for the Cook Creek area are not available. Therefore, predicted effects of mining on the local hydrologic systems are based on the assumptions that: (1) All mining of the Sawyer and Knobloch coal seams would take place within the mine boundaries as shown on plate 2; (2) mining would begin with the development of two long box cuts, with one of the cuts in the Cook Creek drainage and the other in the Otter Creek drainage (potential mine pits A and B on pl. 2); (3) the entire Sawyer coal bed and most of the Knobloch coal bed would be removed from the mine area; and (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.

Effects during mining

Potential mine pit A

Two aquifers currently transmit water through the site of potential mine pit A (see pl. 2)—the perched alluvial aquifer in the upstream reach of Cook Creek and the confined Knobloch coal aquifer. Downgradient from the mine pit site, water from the two aquifers mixes as the alluvium and clinker become hydraulically connected in the downstream part of the Cook Creek valley. The rate of natural ground-water flow through the mine pit site is estimated to be 4,000 ft^3/d in the Knobloch coal bed and 3,000 ft^3/d in the perched alluvial aquifer. These flow estimates are based on local aquifer characteristics and were determined using the Darcy equation.

Mine pit A would interrupt both the local ground-water flow and the surface-water flow, which supply a large proportion of the recharge to the alluvial aquifer in the downstream part of Cook Creek valley. Interception of recharge by the mine pit would cause a lowering of the water table within the alluvium downgradient from the mine pit as well as a decrease in basin runoff. The decrease in basin runoff would have an undetectable effect on the flow of the Tongue River, except during occasional periods of storm runoff.

Mine pit A would dewater an area of alluvium, clinker, and coal in the vicinity of the mine. A hydrogeologic section through the mine pit area (fig. 2) shows the spatial relationship of the coal, clinker, and alluvial aquifers to the existing potentiometric surface and the potential mine cut. From figure 2 it can be seen that a mine pit adjacent to the clinker in Cook Creek valley would dewater the combined alluvium-clinker aquifer as the existing hydraulic gradient becomes reversed and slopes towards the mine pit. An estimated 1.8×10^8 ft^3 of water would be removed from storage within the alluvium-clinker aquifer. All water entering the mine pit would probably be stored in a holding pond and used for mine needs such as dust suppression.

Average rate of ground-water flow into the mine pit during the first year of mining is estimated to be 370,000 ft^3/d. After 2 or 3 years of mining, the rate of flow will have decreased to less than 8,000 ft^3/d, as water in storage is

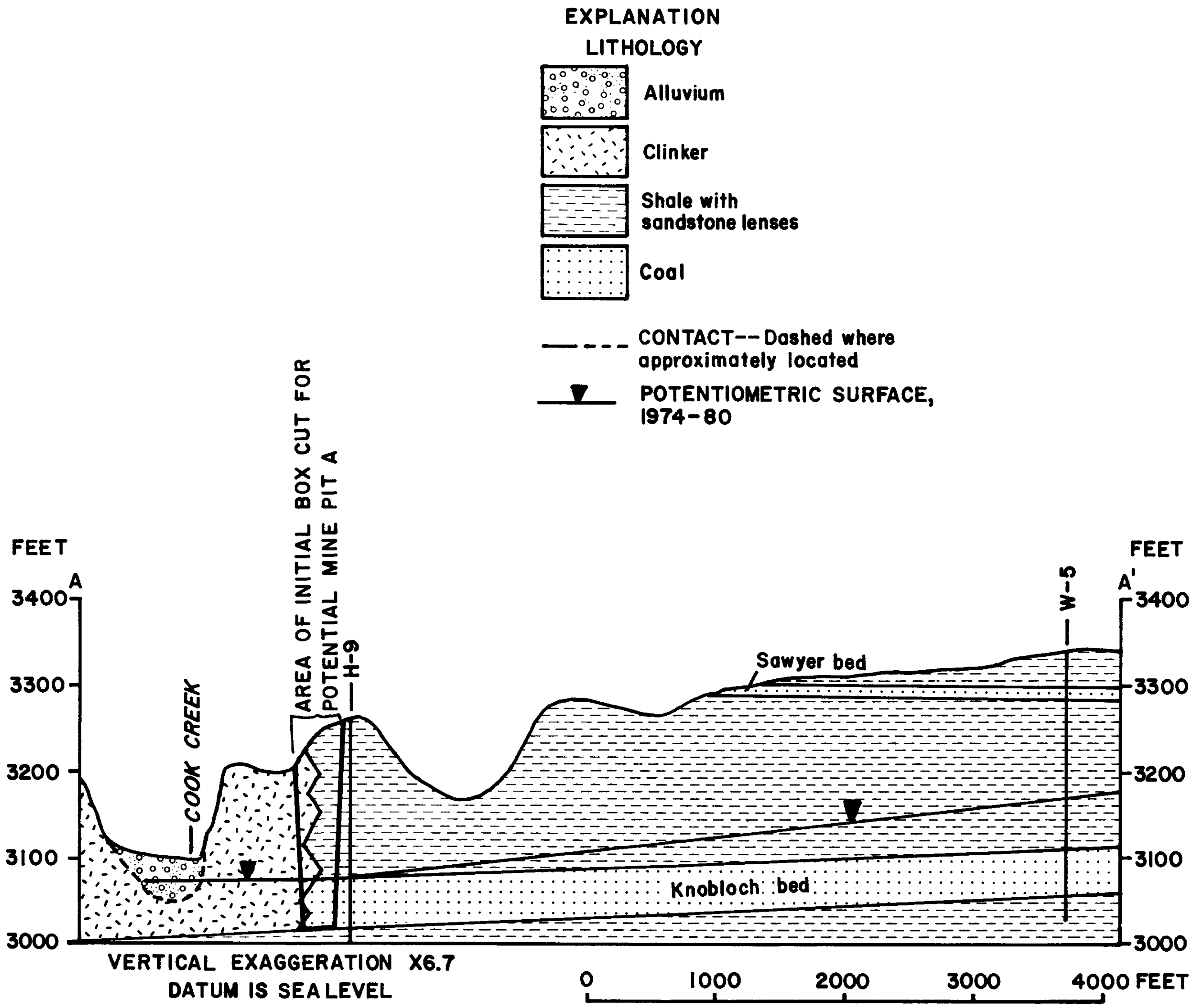

Figure 2.--Hydrogeologic section through the site of potential mine pit A. Trace of section is shown on plate 2.

depleted. These flow estimates are based on the assumption that the first mine cut would be made along the coal-clinker contact.

Decline of the potentiometric surface within the Knobloch coal bed is estimated to be from 40 to 100 feet near the mine pit. This decline is equal to the difference between the present static water level and the base of the Knobloch coal. To the north and east of the mine pit, water levels within the Knobloch coal might decline as much as 20 feet at a distance of 2 miles from the mine.

Downgradient (west) of the mine pit, water levels within clinker and alluvium would decline from the effects of mine-pit dewatering and interception of recharge. Mine-dewatering effects would cause water levels in nearby alluvium and clinker to decline from about 10 to 60 feet. Water levels in the alluvium along the downstream 2 miles of Cook Creek valley probably would decline only slightly. Water levels in this section of alluvium are below the base of the Knobloch coal; any decline in water levels would be from decreased aquifer recharge.

Flow rates into the mine pit and water-level declines within the Knobloch coal aquifer were derived using the finite-difference digital model developed by Trescott, Pinder, and Larson (1976). The distribution of hydrologic characteristics and the boundaries used in the model are shown in figure 3. This simplified

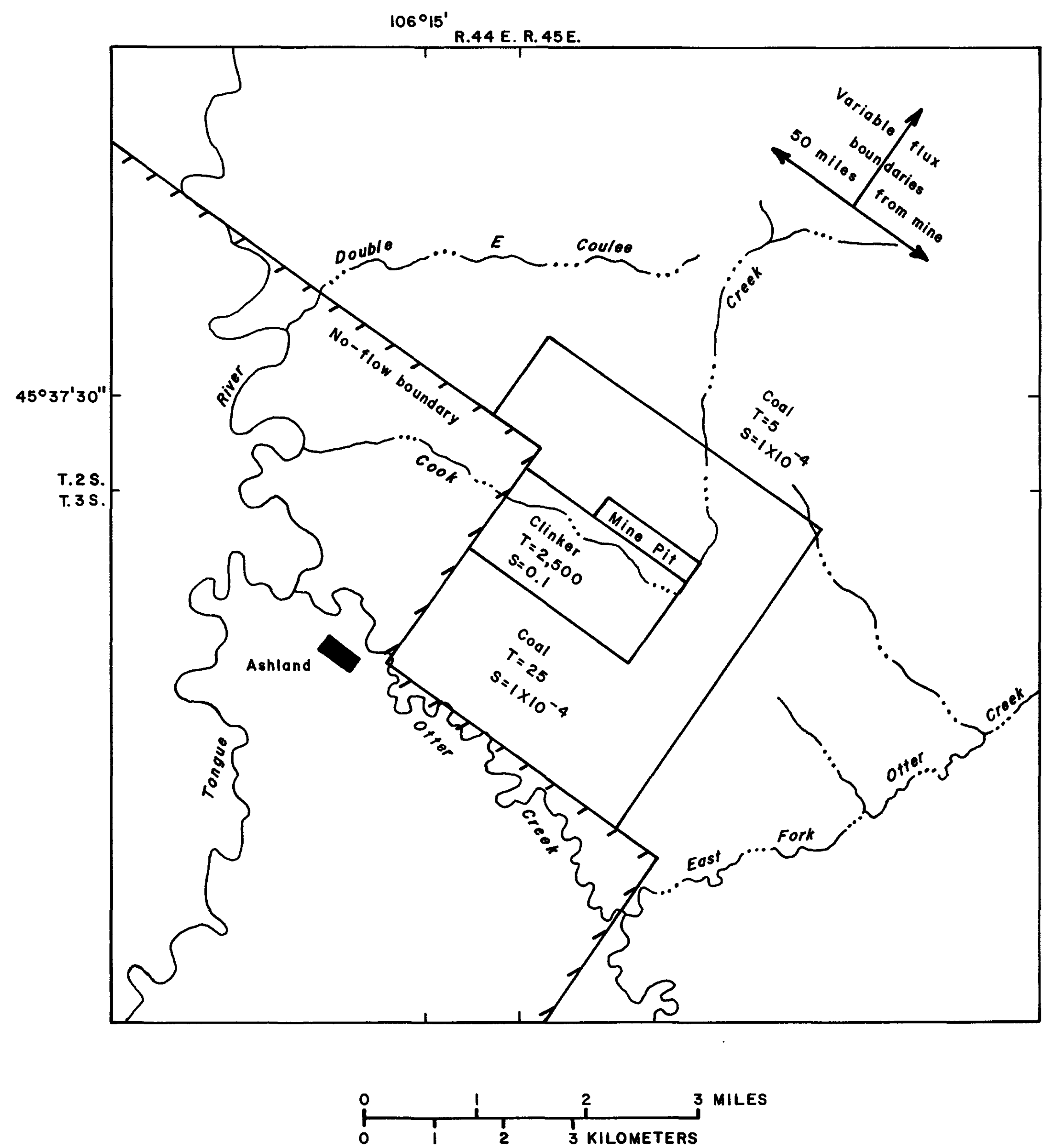

Figure 3.--Distribution of hydrologic characteristics and boundaries for model of potential mine pit A. *T* is transmissivity, in feet squared per day. *S* is storage coefficient, which is dimensionless.

model was designed only to estimate transient flow rates into the mine pit and water-level declines in the Knobloch coal. The model was not designed to simulate natural-flow conditions. Assumptions used in the model were: (1) The initial potentiometric surface is horizontal; (2) the mine pit is emplaced instantaneously; and (3) a no-flow boundary exists where water levels in the Knobloch coal, clinker, and alluvium are below the base of the mine pit.

Potential mine pit B

The Knobloch coal bed is the only known shallow aquifer that would be removed by mining in the area of potential mine pit B (pl. 2). Shallow ground-water flow through the mine-pit site is from near the Cook Creek-Otter Creek basin divide toward Otter Creek and East Fork Otter Creek (pl. 1). Rate of ground-water flow through the mine pit site is estimated to be less than 1,500 ft^3/d. Mine pit B would intercept the present ground-water flow and would eventually remove all water stored within the Knobloch coal in the vicinity of the mine. Water-level declines within the Knobloch coal aquifer would be greatest to the north. The potentiometric surface between mine pits A and B would be virtually coincident with the base of the Knobloch coal because of the combined dewatering effects of the two pits.

A hydrogeologic section through mine pit B is shown in figure 4. The base of

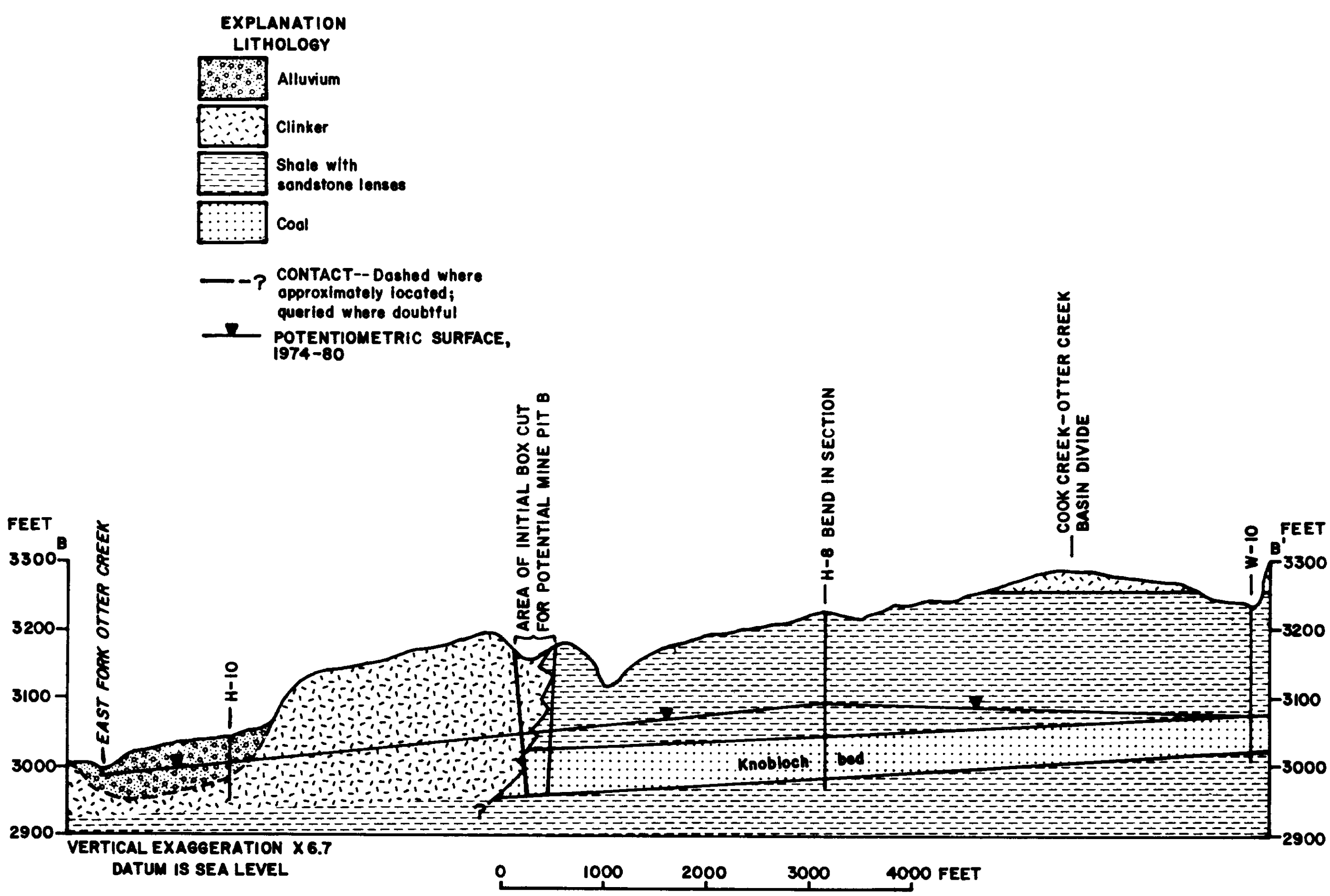

Figure 4.--Hydrogeologic section through the site of potential mine pit B. Trace of section is shown on plate 2.

the Knobloch coal bed is below the potentiometric surface of the alluvium-clinker aquifer in the valley of East Fork Otter Creek. If the first mine cut followed the coal-clinker contact, an estimated 5 x 10^7 ft^3 of water would be removed from storage within the clinker. This water would likely be removed within the first year of mining. The eastern end of the mine pit would receive greater inflow from clinker than the western end, because of a greater hydraulic gradient in this area.

Flow from the alluvium in East Fork to the mine pit could be as much as 150,000 ft^3/d under worst-case conditions. These conditions assume that: (1) The entire mine pit is excavated to the base of the Knobloch coal bed, (2) the mine-pit highwall is at the coal-clinker contact, (3) the clinker has a transmissivity of about 2,500 ft^3/d, and (4) East Fork Otter Creek is a constant hydraulic-head boundary. The rate of discharge from the clinker and alluvium into the mine pit could be decreased considerably by leaving a buffer zone of undisturbed coal and shale between the clinker and the mine pit or by excavating only part of the mine pit at one time.

In any case, as the mine advances northward, inflow from clinker and alluvium would be decreased from backfilling with mine spoils and from the increase in altitude of the base of the coal bed. In the vicinity of hole H-8 and well W-11, the base of the Knobloch coal bed is about equal in altitude to East Fork Otter Creek (fig. 4) and any flow from the alluvium of East Fork to the mine pit would cease by the time the mine pit advanced to this area.

Water-level decline within the alluvial aquifer in East Fork cannot be calculated because the rate of recharge to the aquifer from upstream sources is unknown. However, decline in water level is expected to be minimal, especially during later stages of mining when the mine pit advances northward, away from the valley floor.

Combined effects

Construction of potential mine pits A and B 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 mine-pit areas, and would remove water that currently is stored within shallow aquifers in the vicinity of the mine. Surface water from the upstream part of the Cook Creek basin also would be intercepted by the mine.

During early stages of mine-pit construction, ground-water inflow to mine pits would be predominantly from aquifer storage, with a resultant lowering of potentiometric surface (water levels) within the affected aquifers. During mid to late stages of mine life, the rate of ground-water flow into the mine pits would decrease as aquifer storage became depleted and the local hydrologic system adjusted toward a new equilibrium. The flow rate to mine pits during the late stages of mining would be approximately equal to current ground-water flow rates through the mine area.

The potentiometric surface within the alluvial and clinker aquifers in the downstream part of Cook Creek and in the Knobloch coal aquifer would be lowered during the life of the mine. Several livestock wells located outside of the mine boundary may have substantially lowered water levels as a result of mining (pl. 2). Lowered water levels in these wells are expected to be temporary and probably would recover after mining.

Surface-water supplies in the upstream area of Cook Creek basin, which are upgradient from the mine boundary, would not be affected by mining. The mines would likely have no measureable effect on the quantity of surface-water flow in the Tongue River and would likely have no measureable effect on the flow of Otter Creek.

Water might be discharged from the mine area if it is not needed for dust suppression or is not required to be stored in a holding pond. Quality of water discharged from the mine area would depend on the quality of ground water and surface water entering the mine pits and on any contamination caused by mining operations. During early stages of mine construction, discharge of water would be greatest as aquifers near the mine are dewatered. Dissolved-solids concentrations of this effluent probably would be less than 1,800 mg/L, based on the water-quality samples listed in table 2. Occasionally the mine effluent might have an increased concentration of nitrate as a result of blasting materials used in the mine. Abnormal concentrations of nitrate have been observed on occasion in effluent waters from the Decker Mine in Montana (Van Voast and Hedges, 1975). During mid to late stages of mine operation, ground-water inflow to mine pits will have decreased to the point that discharge of mine effluent is unlikely.

Long-term effects

Mining would remove the Knobloch coal aquifer from the area within the mine boundaries, resulting in the loss of all mine-area wells that are completed in this aquifer. The perched alluvial aquifer, along the Cook Creek channel in secs. 29 and 32, T. 2 S., R. 45 E., and sec. 5, T. 3 S., R. 45 E., also would be removed by mining. The two stock wells and three springs that would be destroyed by mining are shown on plate 2.

The potential exists for a long-term change in the quality of water in shallow aquifers downgradient from the mine area. After mining, ground-water flow systems would be re-established through the mine area. Water would enter the mine spoils from upgradient aquifers, flow through the mine spoils, and eventually discharge to downgradient aquifers. Additional flow through the mine spoils may come from vertical recharge directly into the spoils. Water flowing through the spoils would acquire a chemical quality dependent upon the mineralogy of the spoil material.

The quality of the water that would flow through mine spoils can be estimated by analyzing saturated-paste extracts of the overburden. Estimation of post-mining water quality, using saturated-paste-extract data, is based on the assumptions that: (1) During the mining process, the upper part of the overburden would become the lower part of the mine spoils; (2) after mining, water would saturate and flow through the lower part of the mine spoils; (3) water would leach soluble salts from the mine spoils; and (4) the dissolved-solids concentration in water from a saturated-paste extract is equal to the increase in dissolved-solids concentration of water flowing through the mine spoils.

Saturated-paste-extract data from two core holes (NW1/4 SW1/4 NW1/4 sec. 30, T. 2 S., R. 45 E., and NW1/4 SW1/4 SE 1/4 sec. 8, T. 3 S., R. 45 E.) were supplied by the firm Montco. Analysis of the data indicates that water passing through the mine spoils would attain a dissolved-solids concentration of 1,260 to 1,370 mg/L greater than present concentrations (W. A. Van Voast, Montana Bureau of Mines and Geology, written commun., 1981). The increase is 107 to 116 percent more than the mean dissolved-solids concentration of 1,180 mg/L for all water samples analyzed during this study (table 2). However, because overburden composition can be largely variable, determination of post-mining ground-water quality is tenuous when based on only two overburden cores. Aquifers most likely to be affected by a long-term change in water quality are the alluvium and clinker aquifers in the Cook Creek valley, which are directly downgradient from the proposed mine area. The alluvial aquifer in East Fork Otter Creek also might be affected; however, the effects would not be as evident because of the smaller mined area which drains into East Fork.

POTENTIAL FOR RECLAMATION OF HYDROLOGIC SYSTEMS

The existing hydrologic systems no doubt would be altered by the removal of shallow aquifers. Springs and shallow wells would be destroyed during mining and the chemical quality of shallow ground water may be degraded. However, alternative ground-water supplies at the site could be developed to replace livestock wells destroyed by mining. Alternative water supplies are sandstone and coal beds within the Tongue River and the Tullock Members of the Fort Union Formation, the lower part of the Hell Creek Formation, and the Fox Hills Sandstone. Data on the quality and quantity of water from these alternative sources (Lee, 1979; Slagle and Stimson, 1979) indicate that they are suitable sources for all present water uses. No evidence indicates that any of these alternative ground-water sources would be detrimentally affected by mining.

Impacts of mining and reclamation on the local water resources can be mitigated by proper planning. Reclamation techniques designed to minimize water flow through mine spoils would decrease the rate of leaching of soluble salts, thereby minimizing the change in water quality in downgradient aquifers. Techniques that could be used include proper surface contouring to eliminate ponding of precipitation in local depressions, planting of adequate vegetation to increase evapotranspiration, and diversion of surface water through the mined area in a manner that minimizes infiltration into mine spoils. Reconstruction of the Cook Creek channel through the mine area by forming a channel lined with well-compacted and relatively impermeable soil and filled with crushed clinker would rapidly transmit surface water through the area with minimum infiltration into spoils.

SUPPORTING TECHNICAL DISCUSSION

Geology

Stratigraphy

Rocks of the Fort Union Formation of Paleocene age crop out within the entire area, except for some stream valleys and terraces that contain alluvial deposits. Locally, the Fort Union Formation is divided into three members which, from oldest to youngest, are the Tullock, the Lebo Shale, and the Tongue River. Only the uppermost member, the Tongue River Member, is exposed in the study area.

The Tongue River Member is composed primarily of soft clay shale, sandy shale, sandstone, siltstone, and coal beds (fig. 5). The member also contains thick layers of hard, red clinker where coal beds have burned along their outcrops and

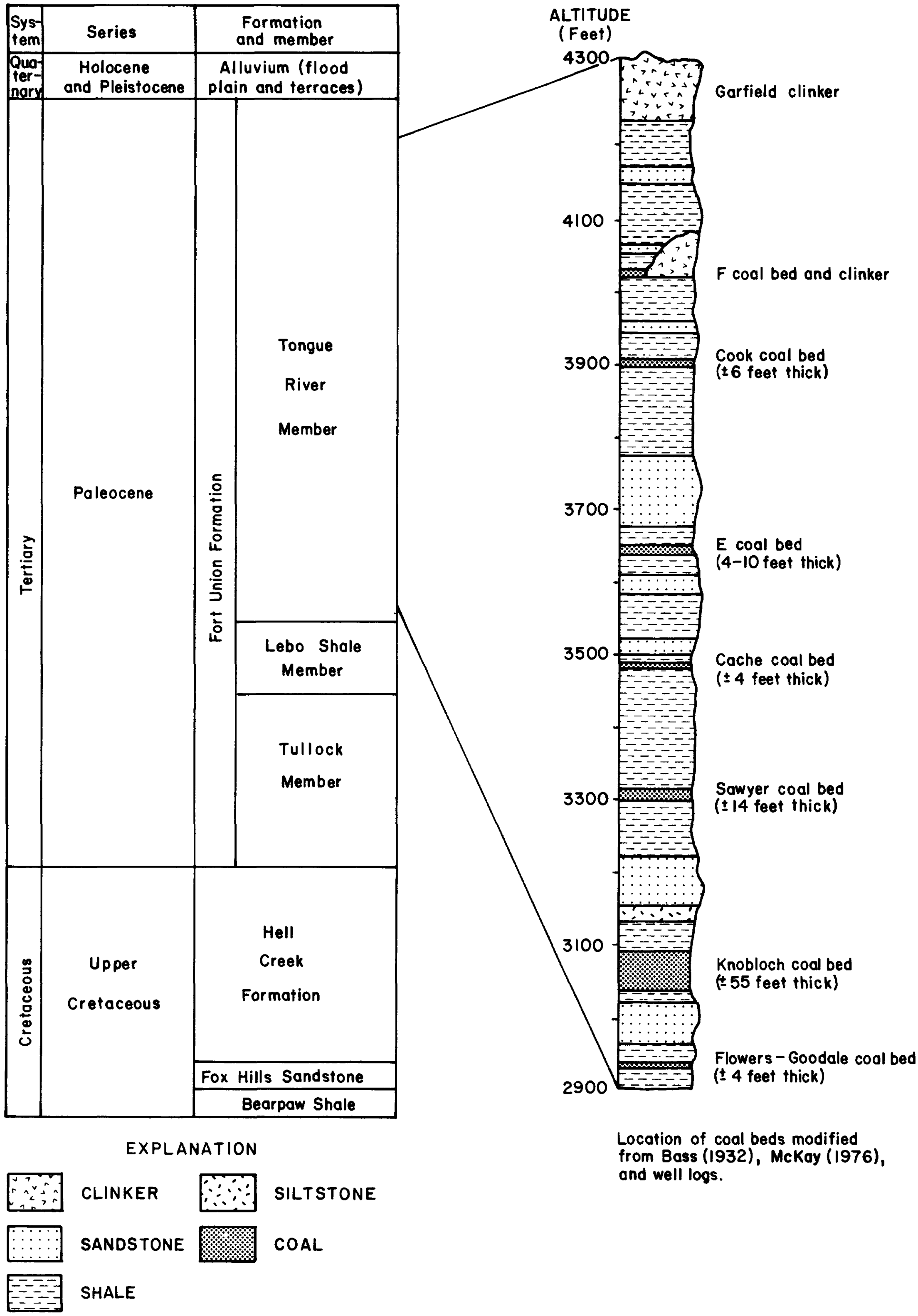

Figure 5.--Idealized stratigraphic section showing location of coal beds in the Cook Creek area.

baked the overlying rock. Thickness of the Tongue River Member in the Ashland coal field ranges from about 1,150 to 1,600 feet (Bass, 1932).

The Tongue River Member is exposed from the mouth of Cook Creek to the top of the mountains at the headwaters of Cook Creek, representing a vertical distance of about 1,450 feet. This interval of the Tongue River Member contains numerous beds of coal and clinker. Several of the coal beds are relatively thin and underlie only the highest part of these mountains; other coal beds, such as the Sawyer and Knobloch beds, are relatively thick and underlie a large part of the study area. Stratigraphic relationships of coal beds within the Tongue River Member are shown in figure 5.

Alluvium of Pleistocene age forms a gently sloping terrace west of Cook Creek in secs. 29 and 32, T. 2 S., R. 45 E. The alluvial terrace is situated about 450 feet above the Tongue River and is considered to be an ancient terrace of the river (Brown and others, 1954). The terrace alluvium is about 10 to 30 feet thick and is composed of silt, sand, and gravel. The gravel is largely composed of fragments of hard, red clinker.

Alluvium of Holocene age occupies the channels and flood plains of most small streams in the area. The alluvium is composed of clay, silt, and fine sand, with lenses of coarse sand, gravel, and cobbles. The sand and gravel are largely composed of angular fragments of clinker. Many of the cobbles are composed of hard siltstone and sandstone.

Local structure

Strata of the Tongue River Member are nearly horizontal throughout the study area. Locally, the top of the Knobloch coal forms a gently undulating surface with no definite trend in direction of dip. The undulations may be structural or depositional in origin. These undulations cause the top of the Knobloch coal bed to range in altitude by about 125 feet, as determined from logs of 23 wells and drill holes, which penetrated the coal bed. The relatively horizontal strata of the study area indicate no significant deformation from folds or faults.

Ground-water resources

Shallow aquifers

Shallow aquifers in the Cook Creek area occur in the Tongue River Member of the Fort Union Formation (Paleocene age). These aquifers include permeable units of fractured coal, sandstone and siltstone, and clinker. Shallow aquifers also are found within many alluvial deposits beneath small stream channels and larger stream valleys. The shallow aquifers, principally the alluvial and coal aquifers, are used for stockwatering purposes throughout the area. Hydrogeologic data pertinent to these shallow aquifers were obtained from wells, test holes, and springs (table 1).

Knobloch coal bed

The Knobloch coal bed is a relatively productive aquifer that underlies a large part of the study area. It extends from the margins of the Knobloch clinker beds along the valleys of East Fork Otter Creek, Otter Creek, and Cook Creek to the Cook Creek basin divide and northward (pl. 2). The Knobloch coal bed is partly or completely saturated at the sites of all observation wells completed in coal beds in the study area. Depth to the top of the Knobloch bed ranges from about 50 feet along a part of the Cook Creek valley in the NE1/4 sec. 6, T. 3 S., R. 45 E., to an estimated 1,200 feet along the Cook Creek basin divide at the headwaters. Thickness of the Knobloch coal bed averages about 55 feet.

Flow of water within the coal aquifer is from areas of high hydraulic head in the upstream part of the Cook Creek basin and along the basin divide towards areas of low hydraulic head along Cook Creek, Otter Creek, and East Fork Otter Creek. Gradient of the potentiometric surface ranges from about 0.01 to 0.03. Direction of flow within the Knobloch coal appears to be controlled largely by topography; thus, the potentiometric surface closely resembles the topographic surface (pl. 1). However, in secs. 5, 6, and 8, T. 3 S., R. 45 E., the direction of flow appears to be controlled more by geologic factors than by topographic slope. Clinker deposits in this area function as drains and transmit water from the Knobloch coal to the downstream part of the Cook Creek valley. Flow paths within the Knobloch coal generally do not cross basin divides and are of short length. Lengths of these flow paths range from about 0.5 to 4 miles, with most less than 2 miles.

Recharge to the Knobloch coal bed is from infiltration and percolation of precipitation through overlying fine-grained sediments. Rate of recharge is small because of the large silt and clay content of the overburden, small annual precipitation, and consumptive use of soil moisture by vegetation. Recharge to the coal bed from precipitation is estimated to be about 0.01 to 0.1 inch per year based on calculated discharge rates. Woessner, Andrews, and Osborne (1979) calculated a similar recharge rate of 0.12 inch per year to unconfined coal, sandstone, and shale at a site west of Ashland, Mont., on the Northern Cheyenne Indian Reservation. Their calculations were based on well hydrographs with 2 years of record.

Discharge of water from the Knobloch coal aquifer occurs as lateral flow to clinker zones along the valleys of Cook Creek, Otter Creek, and East Fork Otter Creek. No seeps or springs from the Knobloch coal were observed because of extensive clinker along the margins of the coal bed. Additional discharge from the coal aquifer is to local wells.

Aquifer properties of the Knobloch coal were determined from single-well aquifer tests at three locations (pl. 1). Transmissivity (T) values calculated from the tests are 110 ft^2/d at well W-7, 20 ft^2/d at well W-6, and 4 ft^2/d at well W-5. Corresponding values of hydraulic conductivity are 1.9 ft/d at well W-7, 0.34 ft/d at well W-6, and 0.07 ft/d at well W-5. Hydraulic conductivity of coal is directly related to fracture permeability, which in turn appears to be related to depth of burial and proximity to clinker beds. Hydraulic-conductivity tests indicate that the coal is fractured more at well W-7, where the coal bed is close to the surface and near clinker, than at wells W-6 and W-5, where the coal bed is at a greater depth and farther from the burned or clinker area.

Storage coefficients (S) for the Knobloch coal bed could not be reliably calculated from the single-well aquifer tests. Storage coefficient is estimated to range from 10^{-5} to 10^{-4}, based on values at other sites in southeastern Montana (Van Voast and Hedges, 1975, p. 7; U.S. Department of the Interior, 1977, p. 148).

Sandstone and siltstone

Sandstone and siltstone aquifers within the Tongue River Member of the Fort Union Formation typically are thin, lenticular, and of small areal extent. No thick sandstone layers were penetrated during test drilling; therefore, no wells were completed in sandstone. Typically, the thin sandstone and siltstone lenses yield enough water to wells for livestock use. Spring S-4 (see pl. 1) discharges from a thin, fractured siltstone lens and has been developed for livestock water. Flow of this spring, which is 0.3 gal/min, represents discharge from a small, localized flow system that is perched above the Knobloch coal aquifer. Well W-15 is completed in a sandstone bed and has a reported yield of 10 gal/min.

Sawyer coal bed

The Sawyer coal bed is about 14 feet thick and is stratigraphically about 180 feet above the Knobloch coal bed. The Sawyer coal bed appears to be dry in an area west of Cook Creek in secs. 29, 30, 31, and 32, T. 2 S., R. 45 E. (pl. 2), based on drill-hole data and the topographic location of the coal. However, on the east side of Cook Creek, in secs. 29 and 32, the Sawyer coal may contain a perched water table. Color-infrared photographs of this area indicate the possibility of seepage from the Sawyer coal bed where it crops out along the creek valley. In the upstream 2 miles of the Cook Creek basin, the Sawyer coal bed probably has a local ground-water flow system. The upstream part of the basin is within the Custer National Forest; therefore, no wells were drilled into the Sawyer coal bed to test the aquifer.

Clinker

Porous, fractured clinker, formed by the burning of coal seams, and consisting of baked shale, sandstone, and coal ash, exists in a large part of the study area. In the downstream areas of the Cook Creek, Otter Creek, and East Fork Otter Creek basins, hill slopes are composed primarily of clinker formed by burning of the Knobloch coal bed along its outcrop. The area between lower Cook Creek and the main stem of Otter Creek has particularly thick clinker deposits derived from both the Sawyer and the Knobloch coal beds. Thickness of clinker in this area exceeds 180 feet as determined by drill hole H-2.

The clinker is permeable and forms an aquifer where a sufficient saturated thickness exists. No aquifer tests were made on clinker aquifers because of the difficulty in drilling and casing a hole in the clinker; however, hydraulic conductivity of clinker can reasonably be expected to be similar to that of clean sand or sand and gravel, which is about 10 to 1,000 ft/d. The hydraulic conductivity of Knobloch clinker was calculated to be 36 ft/d by Woessner, Andrews, and Osborne (1979) for a nearby site in the Northern Cheyenne Indian Reservation. Those investigators calculated a storage coefficient of 0.1 for the clinker.

Recharge to clinker aquifers is primarily from infiltration and percolation of precipitation and lateral flow from adjacent coal and sandstone aquifers. In the Cook Creek valley, additional recharge to clinker is from infiltration of surface runoff, especially where the channel of Cook Creek crosses an outcrop of Knobloch clinker. Thin and permeable soils, which overlie many of the clinker areas, permit rapid infiltration of precipitation and eventual recharge to the ground-water system. Woessner, Andrews, and Osborne (1979) calculated a recharge rate of 1.2 inches per year for similar Knobloch clinker deposits in the Northern Cheyenne Indian Reservation near Ashland. The rate of recharge to clinker from infiltration of rainfall appears to be one to two orders of magnitude greater than recharge to coal-bed aquifers.

Ground-water gradients within the area are predominantly from coal and sandstone aquifers in the topographically high areas towards clinker and alluvium in the major drainages (pl. 1). Because clinker generally is downgradient from the Knobloch coal aquifer, part of the water moving through the clinker aquifer originates as discharge from the coal aquifer. However, the massive clinker deposit between the downstream part of Cook Creek and the main stem of Otter Creek receives almost all its water from direct infiltration of precipitation.

Discharge of water from clinker is predominantly to alluvium along Cook Creek, Otter Creek, and East Fork Otter Creek and to vegetation on lower hillsides of clinker. Spring S-2 (see pl. 1), which discharges directly from the Knobloch clinker at the base of a steep hillside, has been developed for livestock water. Measured discharge of this spring was 5.0 gal/min on September 13, 1979, and 3.3 gal/min on June 19, 1980.

Alluvium

Alluvium occupies the valleys of Cook Creek, Otter Creek, and East Fork Otter Creek. Coarse alluvial deposits compose the most productive aquifers in the study area, and within the Cook Creek basin alluvial aquifers are a major source of livestock water.

Seven holes were drilled through the alluvium in Cook Creek valley during the study. Four of these (W-1, W-2, W-8, W-9) were completed as wells and aquifer tests were conducted, one (W-6) was completed in the Knobloch coal bed, and two (H-4, H-5) were uncased exploration holes. Thickness of alluvium ranges from 16 feet at well W-6 to 77 feet at well W-1.

Aquifer tests were conducted at wells W-1, W-2, W-8, and W-9. Transmissivity of the alluvium is 9,000 ft^2/d at wells W-1 and W-2, 1,600 ft^2/d at well W-8, and 130 ft^2/d at well W-9. Corresponding values of hydraulic conductivity are 160 ft/d at wells W-1 and W-2, 140 ft/d at well W-8, and 4.5 ft/d at well W-9. The storage coefficient for the alluvium at wells W-1 and W-2 is estimated to be about 0.2.

The Cook Creek valley contains both perched and water-table alluvial aquifers (see pl. 2). Alluvial deposits from the headwaters of Cook Creek in sec. 22, T. 2 S., R. 45 E., downstream to the alluvium-clinker contact in sec. 5, T. 3 S., R. 45 E., appear to be a perched aquifer. At well W-6 the difference in hydraulic head between the alluvial aquifer and the Knobloch coal aquifer is more than 110 feet, with an unsaturated interval between the two aquifers. An unsaturated zone also exists between the alluvial and coal aquifers in the vicinity of well W-8. As Cook Creek traverses the Knobloch clinker, the perched zone no longer exists, and water-table conditions prevail within the alluvium and the clinker.

Recharge to the alluvium occurs as direct infiltration of precipitation, runoff, and discharge from adjacent clinker aquifers. Flow within the alluvium closely follows the gradient of the Cook Creek valley.

Discharge of water from the alluvium in the Cook Creek valley is by springs, wells, evapotranspiration, and subsurface flow to the Tongue River valley. Two alluvial springs in the upstream valley of Cook Creek (S-1 and S-3) have been developed for watering of livestock. Discharge rates of these springs fluctuate somewhat but are about 4 gal/min at spring S-1 and 10 gal/min at spring S-3. Evapotranspiration from alluvium is greatest in the upstream part of the valley where ground water is perched near the surface, as determined by color-infrared photography of the area. In the downstream part of Cook Creek valley, the depth of the water table precludes any significant discharge by evapotranspiration. Discharge from the alluvium in the downstream part of Cook Creek valley to the alluvium of the Tongue River valley probably accounts for most of the direct ground-water outflow from the basin. Rate of discharge from alluvium in Cook Creek valley to alluvium in the Tongue River valley is estimated to be 30,000 ft^3/d. This discharge rate is based on aquifer properties at wells W-1 and W-2, and was determined using the Darcy equation.

Deep aquifers

Several aquifers located stratigraphically below the Knobloch coal aquifer exist throughout the study area. These aquifers are coal and sandstone within the lower part of the Tongue River Member of the Fort Union Formation, the Tullock Member of the Fort Union Formation, and the combined Fox Hills Sandstone and lower part of the Hell Creek Formation (Lewis and Hotchkiss, 1981).

The base of the Tongue River Member occurs at an altitude of about 2,600 to 2,700 feet in the study area. From the base of the Knobloch coal aquifer to the base of the Tongue River Member is an interval of about 300 feet, which contains several coal beds and possibly several sandstone lenses. This interval is classified as an aquifer and is a local source of water for livestock and domestic uses. Well yields from this aquifer generally range from 2 to 25 gal/min.

The Tullock aquifer has a thickness of about 300 to 400 feet and its base is at an altitude of about 2,000 to 2,250 feet. The Tullock aquifer is confined above by the Lebo Shale Member of the Fort Union Formation and below by the upper part of the Hell Creek Formation. Many wells in the valleys of Otter Creek and the Tongue River are completed in the Tullock aquifer for livestock water. Some of these wells flow at the surface. Well yields may be as much as 40 gal/min, but generally average about 15 gal/min (Lewis and Roberts, 1978).

The Fox Hills-lower Hell Creek aquifer has a local thickness of about 500 feet and its base is at an altitude of about 1,300 to 1,400 feet. This aquifer yields as much as 200 gal/min to properly constructed wells, although yields generally are less than 100 gal/min.

Surface-water resources

Runoff

The study area is drained by Cook Creek and Otter Creek, which are both tributary to the Tongue River. Most of the area, 12.3 mi^2, is drained by Cook Creek. Approximately 9 mi^2 of the area is drained by Otter Creek and its principal tributary East Fork Otter Creek.

Cook Creek is intermittent in the upstream reaches and flows only where inflow from springs and seeps exceeds water losses from evapotranspiration and seepage; intermittent flow occurs mainly from the headwaters in sec. 22, T. 2 S., R. 45 E., to the SW1/4 sec. 5, T. 3 S., R. 45 E., where the channel crosses the Knobloch clinker. The rest of Cook Creek is ephemeral and flows only in response to surface runoff. The channel of the ephemeral reach of Cook Creek is above the water table at all times of the year.

From June 1979 to September 1980, flow occurred only once in the downstream reach of Cook Creek. The flow occurred during July 1979 in response to an intense thunderstorm. No flow measurements are available but duration of flow was less than 24 hours. During the spring and early summer of 1980, flows were observed in the intermittent reach of Cook Creek, but all observed flows were estimated to be less than 0.1 ft^3/s.

Cook Creek and East Fork Otter Creek are ungaged; therefore, mean annual discharge rates and the magnitude and frequencies of floods were estimated by indirect methods. The method used to estimate mean annual flow included measurements of channel geometry and was developed through regression analyses based on the correlation of flow characteristics with the dimensions of the channel (Hedman and Kastner, 1977). Flood-peak estimates were made from a regression equation using drainage area, percentage of forest cover within the drainage, and a geographical location factor (Parrett and Omang, 1981). Mean annual flow estimates are 213 acre-feet for Cook Creek and 2,790 acre-feet for East Fork Otter Creek. Estimated magnitude of the 100-year flood peak is 1,090 ft^3/s for Cook Creek and 2,210 ft^3/s for East Fork Otter Creek; estimated 25-year flood peaks are 580 ft^3/s for Cook Creek and 1,150 ft^3/s for East Fork Otter Creek.

Otter Creek is a perennial stream having a drainage area of 707 mi^2. A streamflow-gaging station is located on the downstream reach of Otter Creek near Ashland (station 06307740, pl. 1). Data collected at the station are record of stage, measurements of instantaneous stream discharge, and periodic suspended-sediment concentration, temperature, and chemical quality of water. The average discharge of Otter Creek, based on 7 years of record, is 8.71 ft^3/s or 6,310 acre-feet per year.

Suspended sediment

Discharge of suspended sediment from the Cook Creek basin could not be calculated with available data. Discharge from the basin is infrequent and records of water discharge and suspended-sediment concentration have never been obtained. Estimates of sediment yield could possibly be made by study of sediment accumulation in a reservoir in the NE1/4 sec. 29, T. 2 S., R. 45 E. However, the reservoir is in the upstream part of the basin, which is well vegetated and appears to be less eroded than the downstream part of the basin.

Water quality

Water samples were collected for chemical analysis from observation wells, springs, and streamflow of Cook Creek. All samples were analyzed for major ions and selected samples were analyzed for trace elements. Results of the analyses are listed in tables 2 and 3 and locations of sampling sites are shown on plate 1. Many additional water-quality samples have been collected from springs and wells in the general area. Water-quality data for these wells and springs are available in a report by Lee (1979).

Distinctive characteristics of almost all water from springs and shallow wells in the Cook Creek area are: pH values ranging from 7.2 to 7.8, relatively large dissolved-solids concentrations ranging from about 800 to 1,800 mg/L, sodium plus potassium ions typically composing 40 to 80 percent of the cations, and sulfate ions typically composing 40 to 70 percent of the anions. A notable exception to this average quality of water is indicated by the analysis for spring S-2. Water from this spring has a relatively small dissolved-solids concentration of about 310 mg/L and has much smaller concentrations of sodium and sulfate ions than most water in the area. The analysis represents water quality of a spring discharging from a local flow system within a massive clinker zone.

Trends are evident from examination of the water-quality data (pl. 1). The most apparent water-quality trend is the change in dominant cations with depth; calcium and magnesium are dominant in surface water and shallow ground water from alluvial wells and springs, whereas sodium plus potassium ions are dominant in the deeper coal aquifers. Concentrations of anions do not follow such a well-defined trend; sulfate ions increase with an increase of aquifer depth in some areas but decrease with depth in other areas. Bicarbonate-ion concentrations fluctuate similar to sulfate ions, and chloride concentrations are small in all water samples.

Changes in concentrations of dominant ions as water moves from recharge areas, to shallow aquifers, to deeper aquifers, and then to discharge areas can be attributed to aquifer mineralogy, the flow path, travel time along the flow path, and solution chemistry. Geochemistry of shallow flow systems and possible chemical reactions to explain the evolution of the quality of shallow water in the Fort Union Formation have been discussed by Lee (1981).

Based on a conceptual model developed by Lee (1981), the evolution of the major chemical characteristics of ground water in the Cook Creek area can be summarized as follows: (1) Recharge water that has entered a ground-water flow system and has traveled only a short distance is characterized by small concentrations of dissolved solids dominated by magnesium, calcium, and bicarbonate with lesser concentrations of sodium and sulfate; (2) these ions are derived through the dissolution of calcite, gypsum, and other minerals, combined with the exchange of calcium ions for sodium ions by clay minerals; water of this type occurs in the shallow alluvial wells W-1, W-2, W-8, and W-9 and in springs S-2 and S-3; (3) as ground water moves farther through the system, sodium and sulfate enrichment results in larger percentages of sodium, sulfate, and thus increased dissolved-solids concentrations; water of this type occurs in coal wells W-5, W-6, and W-7; and (4) by the time the water has moved farther along its flow path and into a deep coal aquifer, a sodium bicarbonate water may be produced, such as occurs in coal well W-12; sulfate ions likely have been reduced in this water by sulfate-reducing bacteria (Lee, 1981; Dockins and others, 1980).

CONCLUSIONS

Wells and developed springs supply most of the water used for livestock watering, the principal water use in the study area. The water supplies are obtained from shallow bedrock aquifers in the Tongue River Member of the Fort Union Formation and from alluvium. Alluvium in the downstream part of the Cook Creek Valley and the Knobloch coal aquifer could support additional livestock wells. Surface-water supply is limited to the upper 2.5 river miles of Cook Creek, where several small reservoirs, seeps, and springs supply water for livestock.

Mining of the Knobloch and Sawyer coal beds would remove two alluvial springs, one bedrock spring, and two wells, which are all used for livestock watering. The potentiometric surface within the alluvial and clinker aquifers in the downstream part of Cook Creek and in the Knobloch coal aquifer would be lowered during the life of the mine. Lowering of the potentiometric surface in these aquifers might substantially lower the water level in several wells located outside of the mine boundary. Surface-water supplies in the upstream area of the Cook Creek basin, which are upgradient from the mine boundary, would not be affected during mining. The mines would likely have no measureable effect on the quantity of flow in Otter Creek or the Tongue River.

After mining, water in the alluvial aquifer downgradient from the mine area might show a long-term degradation in quality, as a result of leaching of soluble salts from overburden materials used to backfill mine pits. Aquifers most likely to be affected by a long-term change in water quality are the alluvium and clinker aquifers in the Cook Creek valley, which are directly downgradient from the proposed mine area.

The existing hydrologic systems would be altered by the removal of shallow bedrock and alluvial aquifers, but alternative water supplies could be developed from deeper aquifers. Alternative sources are the Tongue River and Tullock Members of the Fort Union Formation and the Fox Hills-lower Hell Creek aquifer. These alternative ground-water sources probably would be unaffected by mining.

Impacts of mining and reclamation on local water resources can be mitigated by proper planning. Reclamation techniques designed to minimize water flow through mine spoils would decrease the rate of leaching of soluble salts, thereby minimizing the change in water quality in downgradient aquifers.

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Table 1.--*Hydrogeologic data from wells, test holes, and springs in the Cook Creek and adjacent areas*

Site designation[1]	Location	Altitude of land surface (feet above sea level)	Depth of well or drill hole (feet below land surface)	Hydrogeologic unit	Interval of hydrogeologic unit (feet below land surface)	Hydraulic conductivity of aquifer (feet per day)
W-1	NW1/4 NE1/4 NE1/4 SE1/4 sec. 35, T. 2 S., R. 44 E.	2,950	87	Alluvium	0-77	160
W-2	NW1/4 NE1/4 NE1/4 SE1/4 sec. 35, T. 2 S., R. 44 E.	2,950	73	Alluvium	0-72	160
W-3	NW1/4 NE1/4 NE1/4 NW1/4 sec. 29, T. 2 S., R. 45 E.	3,295	132 +	Knobloch coal	--	--
W-4	SW1/4 SE1/4 NW1/4 SW1/4 sec. 30, T. 2 S., R, 45 E.	3,261	220	Knobloch coal	156-209	--
W-5	NW1/4 NW1/4 NW1/4 NW1/4 sec. 32, T. 2 S., R. 45 E.	3,339	313	Knobloch coal	228-284	.07
W-6	SE1/4 NW1/4 NE1/4 SE1/4 sec. 32, T. 2 S., R. 45 E.	3,260	252	Knobloch coal	179-238	.34
W-7	NE1/4 NE1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	3,200	168	Knobloch coal	95-154	1.9
W-8	NW1/4 NW1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	3,170	24	Alluvium	0-17	140
W-9	NW1/4 NW1/4 NE1/4 NW1/4 sec. 6, T. 3 S., R. 45 E.	3,060	66	Alluvium	0-63	4.5
W-10	SE1/4 SW1/4 NE1/4 NE1/4 sec. 8, T. 3 S., R. 45 E.	3,241	235	Knobloch coal	170-224	--
W-11	NW1/4 SW1/4 SW1/4 SW1/4 sec. 9, T. 3 S., R. 45 E.	3,290	280	Knobloch coal	--	--
W-12	SE1/4 SW1/4 NE1/4 NW1/4 sec. 10, T. 3 S., R. 45 E.	3,210	193	Knobloch coal	--	--
W-13	NW1/4 SE1/4 SE1/4 SE1/4 sec. 16, T. 3 S., R. 45 E.	3,080	69	--	--	--
W-14	SE1/4 SE1/4 NE1/4 NW1/4 sec. 3, T. 3 S., R. 45 E.	3,300	280	Knobloch coal and sandstone.	--	--
W-15	NW1/4 NW1/4 SE1/4 SE1/4 sec. 29, T. 2 S., R. 45 E.	3,357	150	Sandstone	100-126	--
W-16	NW1/4 NW1/4 NW1/4 NW1/4 sec. 6, T. 3 S., R. 45 E.	3,045	58	Alluvium	--	--

Water level (feet below land surface)	Date of water-level measurement	Discharge (gallons per minute)	Date of discharge measurement	Remarks
21.8	8-19-80	32	9-13-79	Observation well. Hydrograph and aquifer-test data available.
21.9	8-19-80	32	9-13-79	Observation well. Hydrograph and aquifer-test data available.
75.1	4-11-80	--	--	U.S. Forest Service windmill well; exact depth unknown; used for stock watering.
163.8	8-19-80	--	--	Montco well 24530-3W
170.4	9-17-80	3.2	9-11-79	Observation well. Hydrograph and aquifer-test data available.
116.8	8-19-80	6.7	9-12-79	Observation well. Hydrograph and aquifer-test data available.
41.4	8-19-80	12	6-19-80	Observation well. Hydrograph and aquifer-test data available.
6.4	8-19-80	14	9-11-79	Observation well. Hydrograph and aquifer-test data available.
33.9	8-19-80	8.0	9-14-79	Observation well. Hydrograph and aquifer-test data available.
170.4	8-19-80	--	--	Montco well 3458-1W
147.3	6-19-80	--	--	Stock well with submersible pump. Would be removed by mining.
124.8	10-08-74	--	--	Stock well with submersible pump.
34.3	10-08-74	--	--	Stock well
120	10-08-64	15	--	Water level reported by driller.
90	--	10	--	Stock well. Water level and discharge reported by owner. Would be removed by mining.
--	--	--	--	Stock well

Table 1.--*Hydrogeologic data from wells, test holes, and springs in the Cook Creek and adjacent areas*--Continued

Site designation[1]	Location	Altitude of land surface (feet above sea level)	Depth of well or drill hole (feet below land surface)	Hydrogeologic unit	Interval of hydrogeologic unit (feet below land surface)	Hydraulic conductivity of aquifer (feet per day)
W-17	NW1/4 SE1/4 SE1/4 SE1/4 sec. 17, T. 3 S., R. 45 E.	3,080	103	--	--	--
H-1	SW1/4 SW1/4 SW1/4 SE1/4 sec. 31, T. 2 S., R. 45 E.	3,100	92	Knobloch coal and clinker.	25-81	--
H-2	SW1/4 SW1/4 SE1/4 NE1/4 sec. 32, T. 2 S., R. 45 E.	3,290	252	Knobloch coal	214-252 +	--
H-3	SE1/4 NW1/4 SE1/4 SW1/4 sec. 4, T. 3 S., R. 45 E.	3,340	320	Knobloch coal	240-295	--
H-4	SE1/4 NE1/4 NE1/4 SW1/4 sec. 5, T. 3 S., R. 45 E.	3,160	33	Alluvium and clinker.	33 +	--
H-5	NW1/4 NW1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	3,170	30	Alluvium	0-16	--
H-6	SW1/4 NE1/4 NE1/4 NE1/4 sec. 7, T. 3 S., R. 45 E.	3,280	180	Clinker	0-180	--
H-7	NE1/4 NW1/4 SW1/4 NW1/4 sec. 8, T. 3 S., R. 45 E.	3,265	228	Knobloch coal	163-217	--
H-8	SE1/4 SE1/4 SE1/4 SW1/4 sec. 8, T. 3 S., R. 45 E.	3,230	250	Knobloch coal	185-243	--
H-9	NW1/4 NW1/4 NE1/4 NE1/4 sec. 6, T. 3 S., R. 45 E.	3,251	260	Knobloch coal	176-233	--
H-10	NE1/4 SE1/4 NW1/4 NE1/4 sec. 20, T. 3 S., R. 45 E.	3,043	90	--	--	--
S-1	SE1/4 NW1/4 NE1/4 SE1/4 sec. 32, T. 2 S., R. 45 E.	3,260	--	Alluvium	--	--
S-2	NE1/4 SE1/4 SE1/4 NW1/4 sec. 12, T. 3 S., R. 44 E.	3,020	--	Clinker	--	--
S-3	NW1/4 NW1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	3,164	--	Alluvium	--	--
S-4	SE1/4 NE1/4 NE1/4 NE1/4 sec. 6, T. 3 S., R. 45 E.	3,140	--	Siltstone	--	--

[1]W, well; H, test hole, drilled and plugged; S, spring

Water level (feet below land surface)	Date of water-level measurement	Discharge (gallons per minute)	Date of discharge measurement	Remarks
--	--	--	--	Stock well
39.5	8-04-79	--	--	Water level measured 8 days after drilling.
--	--	--	--	Lost circulation while drilling in coal.
148	9-18-80	--	--	Coal exploration hole ASH-C-5. Water level measured 24 hours after drilling.
--	--	--	--	Dry hole
--	--	--	--	Dry hole
--	--	--	--	Coal exploration hole ASH-C-2
198	7-23-78	--	--	Montco hole 3458-2W
134	5-02-77	--	--	Coal exploration hole US-7716. Water level measured 24 hours after drilling.
--	--	--	--	Montco hole 3456-1
37	6-07-78	--	--	Montco hole 34520-1
0	--	4.0	4-09-80	Spring used for stock watering. Would be removed by mining.
0	--	3.3	6-19-80	Spring used for stock watering. Discharge was 5 gallons per minute on September 13, 1979.
0	--	10	8-19-80	Spring used for stock watering. Would be removed by mining.
0	--	.3	4-11-80	Spring used for stock watering. Would be removed by mining.

Table 2.--*Major chemical constituents and physical properties of water from wells, springs, and streams in the Cook Creek and adjacent areas*

[Unless indicated otherwise, constituents are dissolved and constituent values are reported in milligrams per liter. Abbreviations: micromhos, micromhos per centimeter at 25° Celsius; °C, degrees Celsius. Analysis by: BM, Montana Bureau of Mines and Geology; GS, U.S. Geological Survey]

Site designation[1]	Location	Date of collection	Geologic source	Onsite specific conductance (micromhos)	Onsite pH	Onsite water temperature (°C)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
W-1	NW1/4 NE1/4 NE1/4 SE1/4 sec. 35, T. 2 S., R. 44 E.	9-13-79	Alluvium	1,440	7.4	10.0	400	55	63	170
W-2	NW1/4 NE1/4 NE1/4 SE1/4 sec. 35, T. 2 S., R. 44 E.	9-13-79	Alluvium	1,460	7.5	10.0	420	55	68	180
W-2	do	6-18-80	Alluvium	1,460	7.5	10.5	420	59	65	180
W-5	NW1/4 NW1/4 NW1/4 NW1/4 sec. 32, T. 2 S., R. 45 E.	9-11-79	Coal	2,620	[2]7.5	12.0	460	72	68	430
W-6	SE1/4 NW1/4 NE1/4 SE1/4 sec. 32, T. 2 S., R. 45 E.	9-12-79	Coal	2,630	7.3	11.0	350	60	48	480
W-7	NE1/4 NE1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	9-12-79	Coal	2,630	7.4	11.0	410	52	67	460
W-7	do	6-19-80	Coal	2,500	7.2	10.5	420	59	67	460
W-8	NW1/4 NW1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	9-11-79	Alluvium	1,440	7.6	16.0	390	54	61	170
W-8	do	6-19-80	Alluvium	1,520	7.4	14.5	430	62	67	190
W-9	NW1/4 NW1/4 NE1/4 NW1/4 sec. 6, T. 3 S., R. 45 E.	9-14-79	Alluvium	1,510	7.5	10.0	400	48	69	190
W-12	SE1/4 SW1/4 NE1/4 NW1/4 sec. 10, T. 3 S., R. 45 E.	6-19-80	Coal	2,030	7.8	15.5	140	21	21	430
S-1	SE1/4 NW1/4 NE1/4 SE1/4 sec. 32, T. 2 S., R. 45 E.	9-12-79	Alluvium	1,270	7.2	13.0	240	43	33	200
S-2	NE1/4 SE1/4 SE1/4 NW1/4 sec. 12, T. 3 S., R. 44 E.	9-13-79	Knobloch clinker	500	7.3	7.5	200	34	27	22
S-2	do	6-19-80	Knobloch clinker	505	7.8	8.0	210	36	28	22
S-3	NW1/4 NW1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	9-11-79	Alluvium	1,520	7.6	10.5	420	62	65	150
S-4	SE1/4 NE1/4 NE1/4 NE1/4 sec. 6, T. 3 S., R. 45 E.	4-11-80	Siltstone	2,450	7.2	6.5	720	95	117	250
C-1	SW1/4 NW1/4 NE1/4 SW1/4 sec. 21, T. 2 S., R. 45 E.	4-11-80	--	1,870	8.5	7.5	850	96	147	118
C-2	SW1/4 NW1/4 NW1/4 SW1/4 sec. 22, T. 2 S., R. 45 E.	4-11-80	--	1,650	8.2	6.0	790	104	128	91

1 W, well; S, spring; C, creek.

2 Laboratory determination.

Site designation	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, calculated sum	Nitrate (as N)	Nitrite plus nitrate (as N)	Analysis by
W-1	4	12	450	370	380	5.9	0.9	26	950	--	3.2	GS
W-2	4	13	490	400	390	6.0	.9	26	980	--	.90	GS
W-2	4	13	510	420	370	6.2	1.5	27	970	0.26	--	BM
W-5	9	11	720	590	760	10	.5	14	1,720	--	.56	GS
W-6	11	8.7	510	420	930	5.4	.5	10	1,800	--	2.0	GS
W-7	10	8.6	660	540	890	6.9	.7	10	1,820	--	.66	GS
W-7	10	7.9	650	540	850	6.6	1.3	10	1,780	.02	--	BM
W-8	4	9.7	390	320	410	5.4	.7	17	920	--	.62	GS
W-8	4	11	580	480	380	6.1	1.3	19	1,020	.75	--	BM
W-9	4	13	480	390	440	5.9	.8	17	1,020	--	.21	GS
W-12	16	4.5	800	660	390	7.6	2.8	7.5	1,270	.52	--	BM
S-1	6	7.5	500	410	230	4.2	1.1	30	800	--	.22	GS
S-2	1	8.6	180	150	100	3.2	1.3	17	310	--	.83	GS
S-2	1	8.6	185	150	110	3.6	2.5	17	320	.80	--	BM
S-3	3	8.7	450	370	360	5.6	.6	21	910	--	2.2	GS
S-4	4	8.5	500	410	810	6.7	.5	12	1,540	.01	--	BM
C-1	2	8.9	510	420	670	6.1	.7	12	1,310	.01	--	BM
C-2	1	8.2	510	420	570	6.1	.7	16	1,170	.34	--	BM

Table 3.--*Trace-element concentrations of water from wells, springs, and streams in the Cook Creek and adjacent areas*

[Constituents are dissolved and concentrations are reported in micrograms per liter. Analysis by: BM, Montana Bureau of Mines and Geology; GS, U.S. Geological Survey]

Site designation[1]	Location	Date of collection	Aluminum	Arsenic	Boron	Cadmium	Chromium	Copper	Iron
W-1	NW1/4 NE1/4 NE1/4 SE1/4 sec. 35, T. 2 S., R. 44 E.	9-13-79	--	4	--	< 1	20	4	< 10
W-2	NW1/4 NE1/4 NE1/4 SE1/4 sec. 35, T. 2 S., R. 44 E.	6-18-80	< 20	--	380	< 2	3	4	< 10
W-6	SE1/4 NW1/4 NE1/4 SE1/4 sec. 32, T. 2 S., R. 45 E.	9-12-79	--	3	--	0	20	1	460
W-7	NE1/4 NE1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	6-19-80	< 20	--	350	< 2	< 2	< 2	490
W-8	NW1/4 NW1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	6-19-80	< 20	--	290	< 2	< 2	< 2	20
W-12	SE1/4 SW1/4 NE1/4 NW1/4 sec. 10, T. 3 S, R. 45 E.	6-19-80	< 20	--	210	< 2	< 2	4	20
S-2	NE1/4 SE1/4 SE1/4 NW1/4 sec. 12, T. 3 S., R. 44 E.	9-13-79	--	11	--	< 1	10	1	< 10
S-2	do	6-19-80	< 2	--	< 24	7	8	96	10
S-3	NW1/4 NW1/4 NW1/4 SE1/4 sec. 5, T. 3 S., R. 45 E.	9-11-79	--	3	--	< 1	20	2	< 10
S-4	SE1/4 NE1/4 NE1/4 NE1/4 sec. 6, T. 3 S., R. 45 E.	4-11-80	< 30	--	320	< 2	4	7	260
C-1	SW1/4 NW1/4 NE1/4 SW1/4 sec. 21, T. 2 S., R. 45 E.	4-11-80	< 30	--	250	< 2	7	8	< 10
C-2	SW1/4 NW1/4 NW1/4 SW1/4 sec. 22, T. 2 S., R. 45 E.	4-11-80	< 30	--	220	2	4	8	40

[1] W, well; S, spring; C, creek.

Site designation	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Vanadium	Zinc	Analysis by
W-1	0	< 1	0.0	--	0	2	--	20	GS
W-2	< 40	1	--	10	10	.1	4	4	BM
W-6	0	30	.2	--	0	0	--	40	GS
W-7	< 40	44	--	< 10	10	.4	< 1	< 3	BM
W-8	< 40	5	--	< 10	< 6	.4	< 1	< 3	BM
W-12	< 40	54	--	18	15	.1	< 1	120	BM
S-2	0	< 1	.0	--	0	4	--	10	GS
S-2	< 40	< 1	--	21	< 2	4	46	< 3	BM
S-3	0	< 1	.0	--	0	4	--	6	GS
S-4	< 40	45	--	20	< 10	.2	4	20	BM
C-1	< 40	120	--	20	10	2	6	4	BM
C-2	< 40	80	--	< 20	< 10	3	6	< 3	BM