POTENTIAL EFFECTS OF SURFACE COAL MINING ON THE HYDROLOGY OF THE GREENLEAF-MILLER AREA, ASHLAND COAL FIELD, SOUTHEASTERN MONTANA

by Gary W. Levings

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METRIC CONVERSION TABLE

The following factors can be used to convert the 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)	1233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared 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

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

$$°F = 1.8°C + 32$$

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.

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ABSTRACT

The Greenleaf-Miller area of the Ashland coal field contains reserves of Federal coal that have been identified for potential lease sale. A hydrologic study was conducted in the potential lease area in 1981 to describe the existing hydrologic system and to assess potential impacts of surface coal mining on local water resources.

The hydrologic data collected from wells, test holes, and springs were used to identify aquifers in the alluvium (Pleistocene and Holocene age) and Tongue River Member of the Fort Union Formation (Paleocene age). Coal, clinker, and sandstone beds comprise the aquifers in the Tongue River Member. The chemical quality of water from these aquifers is characterized by sulfate as the dominant anion, sodium and magnesium as the dominant cations, and extremely small concentrations of chloride.

Most streams are ephemeral and flow only as a result of precipitation. The only perennial surface-water flow in the study area is along short reaches downstream from springs.

A mine plan for the area is not available; thus, the location of mine cuts, direction and rate of mine expansion, and duration of mining are unknown. The mining of the Sawyer and Knobloch coal beds of the Tongue River Member would potentially effect ground-water flow in the area. Declines in the potentiometric surface would be caused by dewatering where the mine pits intersect the water table. Wells and springs would be removed in the mine area. The chemical quality of the ground water may change after moving through the spoils. The change probably would be an increase in the concentration of dissolved solids. Although mining would alter the existing hydrologic systems and remove several springs and shallow wells, alternative ground-water supplies are available that could be developed to replace those lost by mining.

INTRODUCTION

Development of western coal to meet national energy needs recently has received increased emphasis. A large part of the minerals ownership of western coal is Federal; 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, the U.S. Geological Survey, in cooperation with the Bureau of Land Management, is conducting hydrologic studies on several potential coal-lease tracts in the Powder River structural basin of southeastern Montana. The Greenleaf-Miller 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 and use;
(2) identify surface-water resources and runoff characteristics;
(3) determine chemical quality of the ground-water resources;
(4) identify probable impacts on existing water resources by mining operations; and
(5) evaluate the potential for reclamation of local water resources.

To accomplish these objectives, hydrogeologic data were collected from existing wells and springs. Three test holes were drilled and cased to measure long-term fluctuations of ground-water levels. Water samples were collected from ground-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 Greenleaf-Miller area encompasses about 80 mi^2 in south-central Rosebud County, southeastern Montana. The area is between Rosebud Creek and the Tongue River and within or north of the Northern Cheyenne Indian Reservation (fig. 1). Because of privately owned lands in the area, the study area is not defined by drainage basins but includes parts of Greenleaf, Miller, and Lay Creeks; Dobbs Coulee; Downey Coulee; and other smaller drainages.

Greenleaf and Miller Creeks drain most of the study area and are tributary to Rosebud Creek. Lay Creek, which drains the southeastern part of the area, is tributary to the Tongue River. The headwaters of these drainages originate between two prominent topographic features--Garfield and Badger Peaks. In the headwaters area, the flat-lying strata have been dissected into a series of benches or plateaus that are covered with sparse to fairly dense growths of western yellow pine and juniper. The lower areas support a sparse to fairly dense growth of native grasses.

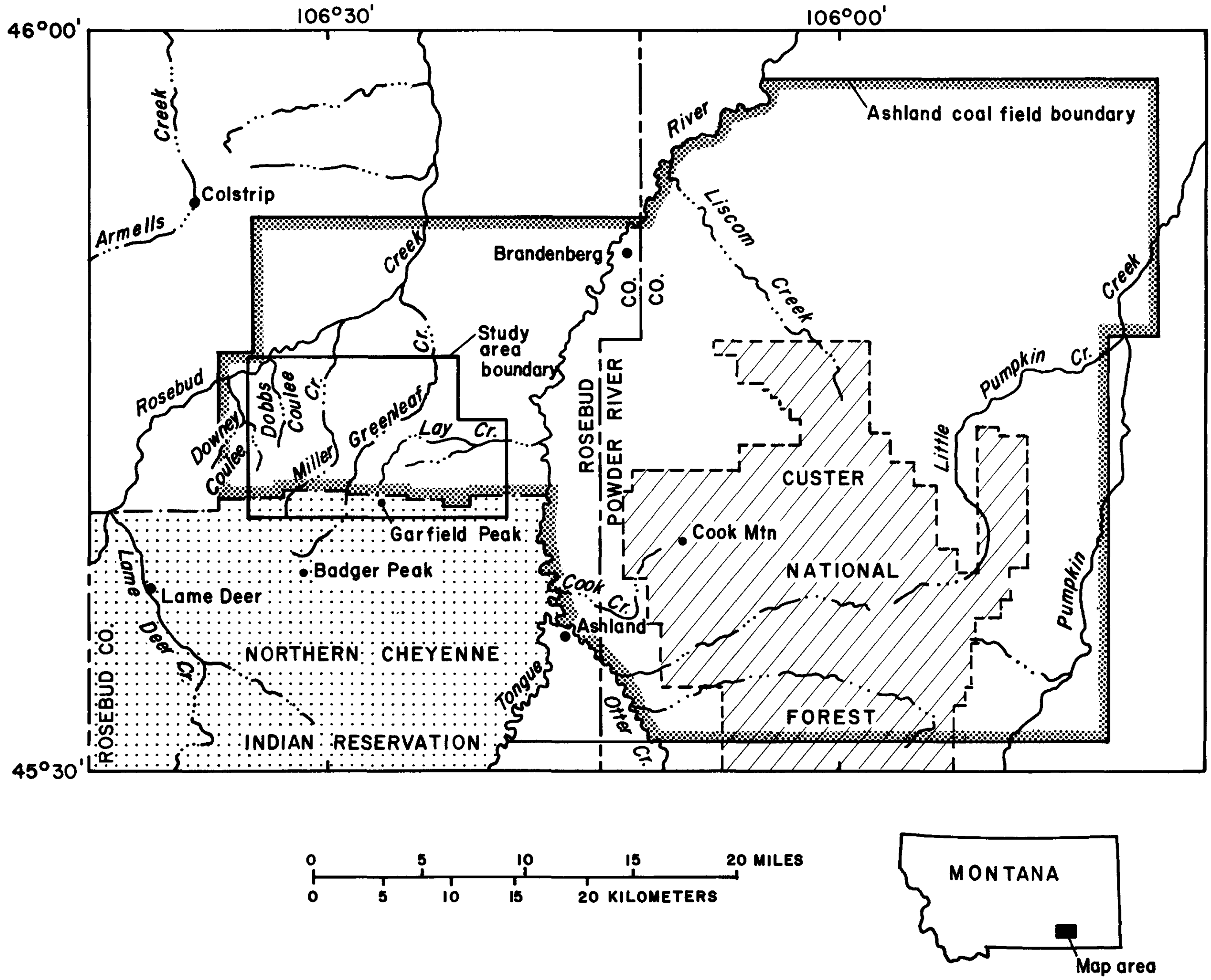


Figure 1.--Location of study area.

Average annual precipitation at the nearest measuring gages, all located outside the study area, is 15.8 in. at Colstrip for the period of record 1927-81, 16.1 in. at Brandenberg for the period of record 1956-81, and 16.2 in. at Lame Deer for the period of record 1938-81. The study area may receive 3 to 4 in. more precipitation per year in the higher altitudes than in the lowlands. The largest amount of precipitation generally occurs in April, May, and June.

Previous investigations

No detailed hydrologic studies have been made in the study area, but the area has been included in several areal studies. Renick (1929) discussed the geology and ground-water resources of Rosebud County and included limited data on a few wells and springs inventoried in 1923. Hopkins (1973) authored a map report of the water resources of the Northern Cheyenne Indian Reservation, south of the study area. Lewis and Roberts (1978) summarized the geology and water-yielding characteristics of rocks in the northern Powder River Basin. Stoner and Lewis (1980) prepared a map of the Fort Union coal region showing geology, structural features of eastern Montana, and water-yielding characteristics of shallow aquifers. Slagle and Stimson (1979) compiled ground-water data from 1,924 wells in the northern Powder River Basin.

The geology of the area, with emphasis on coal, has been mapped and described by Bass (1932) and Kepferle (1954). 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. Feltis and others (1981) have compiled selected subsurface data from oil and gas test holes.

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 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 investigations near the study area. Effects of coal mining on water resources in the Decker, Mont., area (50 mi 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

The primary use of ground-water and surface-water supplies in the study area is watering of livestock. Domestic use is restricted to two ranches located along Greenleaf Creek, and no irrigation uses are known at this time (1981). The location of wells and springs in the study area is shown in figure 2.

Wells and developed springs supply most of the water used by livestock within the study area. Ten springs and 20 wells (table 1) are known to be used for livestock watering. Two of the springs (S-1 and S-2) are developed at the base of the Knobloch coal bed and spring S-9 is developed in the Sawyer clinker outcrop; both the coal bed and the clinker are in the Tongue River Member. The other springs flow from sandstones in the Tongue River Member of the Fort Union Formation. All springs are considered to be perennial although springs S-5 and S-6 may cease flowing during an extended drought. Four of the stock wells (W-2, W-9, W-10, and W-13) are completed in the alluvium and the rest are completed in the Tongue River Member.

Surface-water supply is limited mainly to the three principal streams: Greenleaf Creek, Miller Creek, and Lay Creek. All streamflow in the study area is ephemeral, except for short reaches just downstream from springs or seeps. In August and October 1981, Lay Creek contained flowing or ponded water for at least 1 mi downstream from spring S-3.

Water samples have been collected from 12 wells and 4 springs developed for livestock water (see tables 2 and 3). Chemical analyses of these samples indicated that concentrations of all constituents tested 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 (1979) 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 water of a better quality is available. However, the quality of the water sampled is typical of water quality in the northern Powder River Basin.

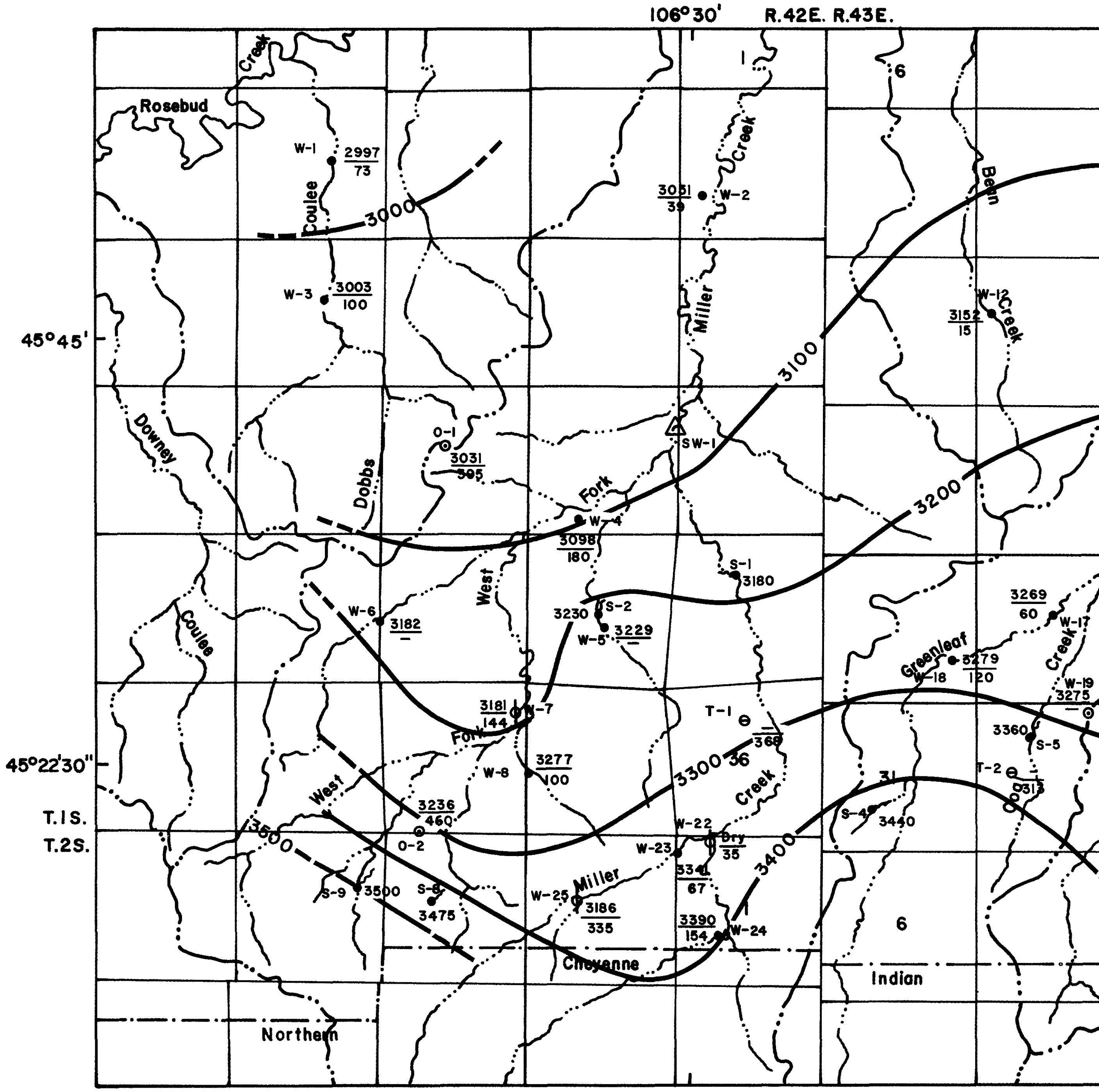
Current (1981) ground-water use in the study area is less than the sustained yield. The water supply in the alluvium could support several additional livestock wells. Expected yield of alluvial wells is 20 gal/min or less. The coal and sandstone aquifers also could support additional livestock wells. Expected yield of these aquifers is less than 25 gal/min. Deeper aquifers exist in the Tongue River and Tullock Members of the Fort Union Formation and the Fox Hills-lower Hell Creek aquifer (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

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.

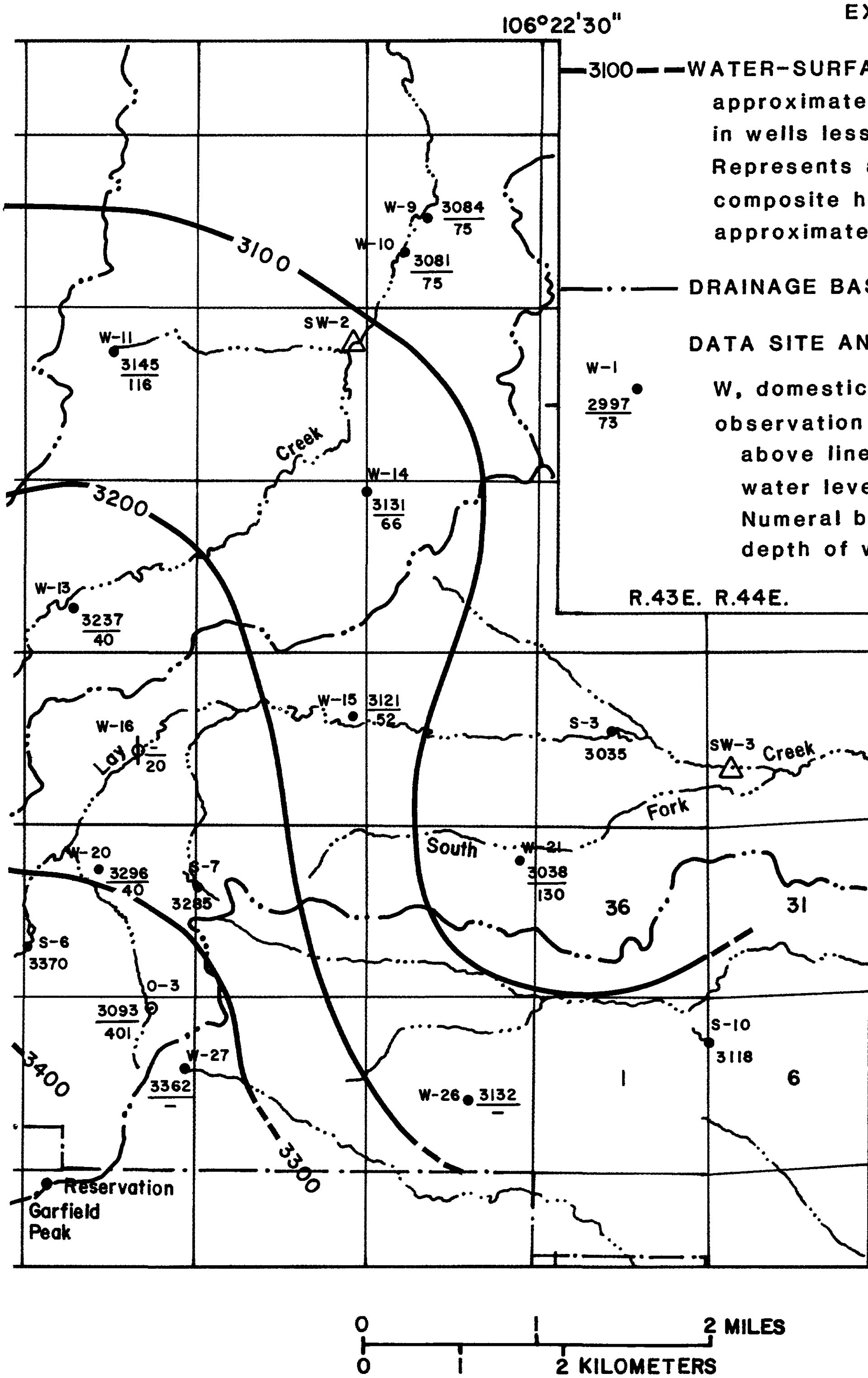
To date (1981), no Preliminary Logical Mining Unit plan for the Greenleaf-Miller area is available. Thus, the following assumptions will be used in discussing some general effects of mining on the hydrology of the area: (1) The Sawyer and Knobloch coal seams would be mined in the study area and (2) all 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.

The most obvious effect would be the disruption of ground-water flow through all units above and including the coal seams to be mined. The exact location and depth of the mine pits would determine the immediate and localized effects on the potentiometric surface. If the pits intersect the water table, water would flow into them and the potentiometric surface around the mined area would be lowered. This depression of the potentiometric surface would become larger with time, with the rate and distance of spread being a function of the aquifer characteristics and geometry of the mine pits. The depression would be greatest downgradient from the pits, because recharge to ground water would be intercepted. Wells and springs in mined areas would be destroyed.



Base from U.S.Geological Survey
Badger Peak, Garfield Peak, 1958;
Ashland NE, 1966; Colstrip SE,
Hammond Draw SW, 1971; Photo
revisions, 1978 1:24,000

Figure 2.--Altitude of water surface in wells less than 200 feet



EXPLANATION

3100 — WATER-SURFACE CONTOUR--Shows approximate altitude of the water surface in wells less than 200 feet deep, 1972-81. Represents an approximation of a composite hydraulic head. Dashed where approximately located. Datum is sea level

DRAINAGE BASIN DIVIDE

DATA SITE AND NUMBER

W, domestic, stock, or unused well; O, observation well; T, test hole--Numeral above line, where shown, is altitude of water level, in feet above sea level. Numeral below line, where shown, is depth of well or test hole, in feet below land surface

- ● Domestic or stock well
- ϕ Unused well
- ⊙ Observation well
- ⊙ Test hole

3180 S-1 Spring--Numeral is altitude, in feet above sea level

SW-1 △ Indirect streamflow-measurement site

deep and location of wells, test holes, and springs.

After mining and reclamation, the ground-water flow system would ultimately re-establish itself. The chemical quality of the ground water would undergo changes based on the mineralogy of the mine spoils and the distance and rate of flow through the spoils. The potential change would be an increase in dissolved-solids concentration, and individual cations or anions probably would vary from location to location depending on the mineralogical composition of the spoils.

Upstream from the mine boundary, surface-water supplies would not be affected by mining. Downstream from the mine, the magnitude of peak flow probably would be decreased because of runoff-control practices mandated in surface-mining regulations.

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 might 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, the Fox Hills Sandstone, and the Madison Group. 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 affected detrimentally 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 could 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 diverting surface water through the mined area in a manner that minimizes infiltration into mine spoils. Reconstruction of the surface-water drainages through the mine area by forming a channel lined with well-compacted and relatively impermeable soil and filled with crushed clinker would transmit surface water rapidly through the area with minimum infiltration into spoils.

SUPPORTING TECHNICAL DISCUSSION

Geology

Stratigraphy

The Fort Union Formation of Paleocene age crops out within the entire study area, except in some of the stream valleys that are underlain by alluvium. The three members of the Fort Union, from oldest to youngest, are the Tullock, Lebo Shale, and Tongue River Members (see table 4).

Table 4.--*Generalized section of geologic units*[1]

System	Series	Geologic unit	Thickness (feet)	General description	Water-yielding characteristics
QUATERNARY	Holocene and Pleistocene	Alluvium	0-75±	Sand, silt, clay, and local lenses of gravel. Gravel consists predominantly of clinker fragments on many smaller streams. Deposits are as much as 75 feet thick along the Tongue River and 40 feet thick along smaller streams. Unit includes many low-lying terraces adjacent to streams	Yields commonly are 20 gallons per minute or less to stock and domestic wells
TERTIARY	Paleocene	Fort Union Formation: Tongue River Member	0-1,600±	Light-yellow to light-gray fine- to medium-grained thick-bedded to massive locally crossbedded and lenticular sandstone and siltstone; weathers to a buff color. Commonly contains light-buff to light-gray shaly siltstone and shale, and brown to black carbonaceous shale. Contains numerous coal beds. Burning of the coal along outcrops has formed thick red and lavender clinker and baked shale beds. Base of unit is mapped as the change from predominantly siltstone and sandstone to predominantly shale of underlying unit	Sandstone and coal beds are the aquifers; the shales do not yield water to wells. Unit contains major aquifers in much of the study area; yields as large as 25 gallons per minute may be possible from wells penetrating large saturated thicknesses of aquifer material. Fractured clinker beds are very permeable and may yield as much as 15 gallons per minute
		Fort Union Formation: Lebo Shale Member	200±	Predominantly dark shale containing interbeds of light-gray and brown to black carbonaceous shale, siltstone, and locally thin coal beds. Shales contain altered and devitrified volcanic ash and brown ferruginous concretions. Base of unit is mapped as the change from predominantly shale to predominantly fine-grained sandstone and shale of underlying unit. Conformable contact with underlying unit; however, the Lebo exists locally as deposits in channels eroded deeply into the underlying Tullock Member	Not a reliable source of water although it yields small quantities of water to wells outside the study area
		Fort Union Formation: Tullock Member	300±	Lower part of member is interbedded medium-gray to light-gray shale, fine-grained light-gray sandstone and siltstone, and thin but persistent coal beds; grades upward to light-gray carbonaceous shale. Locally at the top is a resistant sandstone that forms a well-developed rimrock. Base of unit is mapped as the change from fine-grained thin-bedded sandstone, siltstone, shale, and coal beds to predominantly massive channel sandstone and dark-gray shale of underlying unit	Fine-grained sandstones and coal beds supply small quantities of water for domestic use. Well yields may be as much as 40 gallons per minute, but probably would average about 15 gallons per minute
CRETACEOUS	Upper Cretaceous	Hell Creek Formation	200±	Shale and siltstone, gray to yellowish-gray, silty, clayey, sandy, carbonaceous, and bentonitic; locally, a yellowish-gray to tan fine- to medium-grained silty sandstone containing thin coal beds predominates. Lower contact is gradational; mapped as the change from predominantly silty shale and siltstone to predominantly sandstone of underlying unit. Contact probably unconformable with underlying Fox Hills Sandstone or Bearpaw Shale	Upper part of Hell Creek--Limited as a water supply in study area; well yields may be as much as 12 gallons per minute, but probably would average about 5 gallons per minute
		Fox Hills Sandstone	280	Near-shore sand facies that is the uppermost marine deposit in the area. Very light gray fine- to medium-grained massive sandstone, and gray to brownish-gray fine-grained thin-bedded sandstone; interbedded with gray sandy shale and siltstone. Lower contact is gradational. Conformable contact with underlying shale unit	Lower part of Hell Creek and Fox Hills Sandstone--Considered to represent one aquifer (Fox Hills-lower Hell Creek aquifer) in the study area. Reliable source of water for artesian wells in adjacent areas; yields as much as 20 gallons per minute to flowing wells along the Tongue River valley. Yields as much as 70 gallons per minute to domestic and stock wells and 150 gallons per minute to industrial wells near the study area
		Bearpaw Shale	800±	Gray to black marine shaly claystone and shale. Contains some thin-bedded siltstone and silty sandstone and locally thin beds of bentonite. Base of unit is mapped as the change from shale and siltstone to sandstone of underlying unit. Disconformable contact with underlying unit	A confining bed; generally does not yield water to wells in study area

[1]Modified from Lewis and Roberts (1978)

Underlying the Fort Union Formation are the Hell Creek Formation and the Fox Hills Sandstone of Late Cretaceous age. With the exception of the Mississippian Madison Group, which lies about 5,700 ft stratigraphically beneath the Bearpaw Shale, the units underlying the Fox Hills Sandstone are not discussed in this report.

Local structure

The strata in the study area are almost horizontal; the area is near the northwest margin of the Powder River Basin and the rocks have a regional southwest dip that seldom exceeds 1°. However, the axis of the northwest-trending Ashland syncline crosses the southwestern corner of the area.

Two small faults have been mapped in secs. 32 and 33, T. 1 S., R. 43 E. (Bass, 1932). The southernmost fault, in sec. 33, is downthrown on the north about 75 ft; the fault plane dips steeply northward. The second fault, in the northern part of sec. 32, is downthrown on the south about 50 ft or less (Bass, 1932).

Ground-water resources

Shallow aquifers

In the Greenleaf-Miller area, the shallow aquifers consist of the alluvium along the larger streams and the clinker, coal, and sandstone beds of the Tongue River Member of the Fort Union Formation. Water from these units is used for stock and domestic use. Hydrologic data pertinent to these aquifers are given in table 1.

Alluvium

Alluvial deposits exist beneath the valleys of Miller, Greenleaf, and Lay Creeks as well as some of the smaller drainages. In the study area, five wells are reported to obtain water from the alluvium. A driller's log is available for only one well, W-2. The log indicates that the well penetrated 11 ft of clinker from 28 to 39 ft; however, the casing is reported to be perforated from 2 to 39 ft below land surface. Based on well depth, some of the wells possibly are completed in both alluvium and the Tongue River Member. Wells W-9 and W-10 are reported to be 75 ft deep; the thickness of alluvium penetrated by these wells is unknown, but the shallow water levels indicate that the alluvium contains water and probably is the primary aquifer. Well W-13 is reported to be 40 ft deep, with a water level about 13 ft below land surface. Well W-16 is an unused 20-ft well that is reported to have been dug in 1904. The water level, which could not be measured in August 1981, was reported to have been 18 ft when the well was completed. Well W-22, 35 ft deep, was dry in August 1981. The alluvium along other sections of the larger drainages probably is saturated and would yield water to wells.

No aquifer tests were conducted on alluvial wells in the study area. Four tests conducted in the Cook Creek area, about 15 mi to the southeast, had transmissivity values that ranged from 130 to 9,000 ft^2/d and hydraulic conductivity values that ranged from 4.5 to 160 ft/d (Cannon, 1982). Alluvium in the Greenleaf-Miller area probably has values similar to those for the alluvium of Cook Creek.

Tongue River Member of the Fort Union Formation

The Tongue River Member, the uppermost unit of the Fort Union Formation, crops out throughout the study area. Erosion has removed the upper part but 1,600 ft remain beneath Garfield Peak in secs. 4 and 9, T. 2 S., R. 43 E. (Bass, 1932). In oil test holes, 558 ft was penetrated in sec. 15, T. 1 S., R. 42 E., and 842 ft was penetrated in sec. 3, T. 2 S., R. 42 E. The Tongue River Member is composed of sandstone, shale, siltstone, coal beds, and clinker.

Many of the individual sandstone beds are lenticular and can be traced for only short distances. Groups of beds are more persistent and can be traced for several miles. The land surface formed by the unit is characterized by isolated buttes, mesa-like hills, and long narrow drainage divides.

Clinker

Extensive deposits of clinker, locally called scoria, are present in much of the higher ridges and hills in the study area (fig. 3). Clinker is derived from the extensive burning of coal beds. It includes several types of rock produced from the fusing and baking of the overlying sediments by the intense heat of the gases that rise from a burning coal bed. The clinker is resistant to weathering and erosion, so it forms caprock on many of the buttes, mesas, and ridges. In most places, the rock is very permeable, a factor that permits maximum recharge of precipitation to the ground-water system.

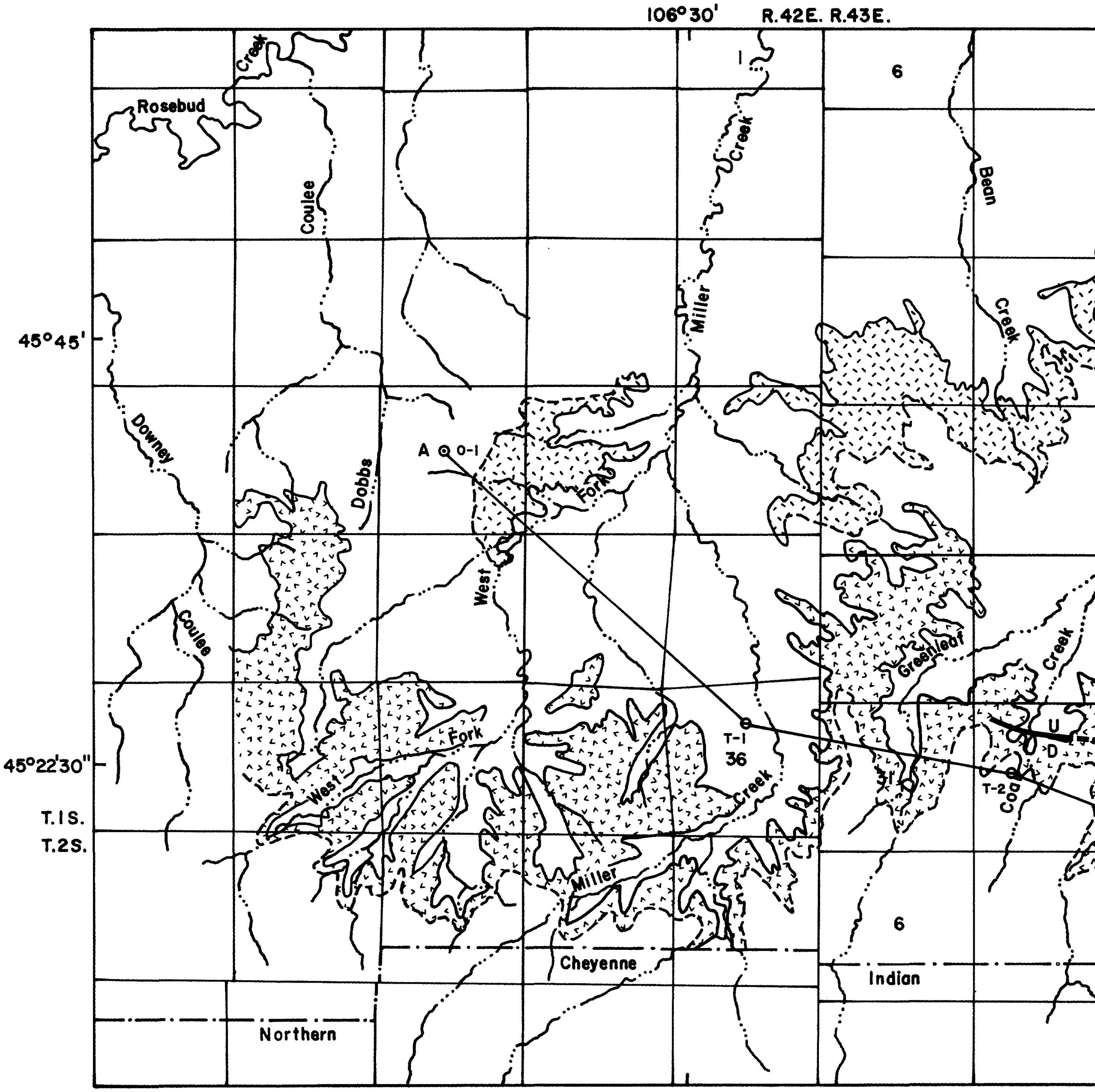
No wells are known to be completed solely in clinker deposits. Numerous seeps may exist at the base of the clinker where it overlies relatively impermeable shale or siltstone. Where the clinker overlies sandstone, it probably is an excellent conduit for ground-water recharge of precipitation. Woessner, Andrews, and Osborne (1979) calculated a recharge rate of 1.2 in. per year for Knobloch clinker deposits in the Northern Cheyenne Indian Reservation.

Coal beds

The major coal beds in the area are, from youngest to oldest, Sawyer, Knobloch, Rosebud, and McKay. In some areas, individual beds may be absent or additional localized coal beds such as the Burley or Terret may occur. The thickness and areal extent of the beds vary significantly throughout the area. For a detailed discussion of the coal resources of the area, the reader is referred to Bass (1932) or Kepferle (1954). A stratigraphic section (fig. 4) shows coal beds penetrated by observation wells and test holes near the central part of the study area.

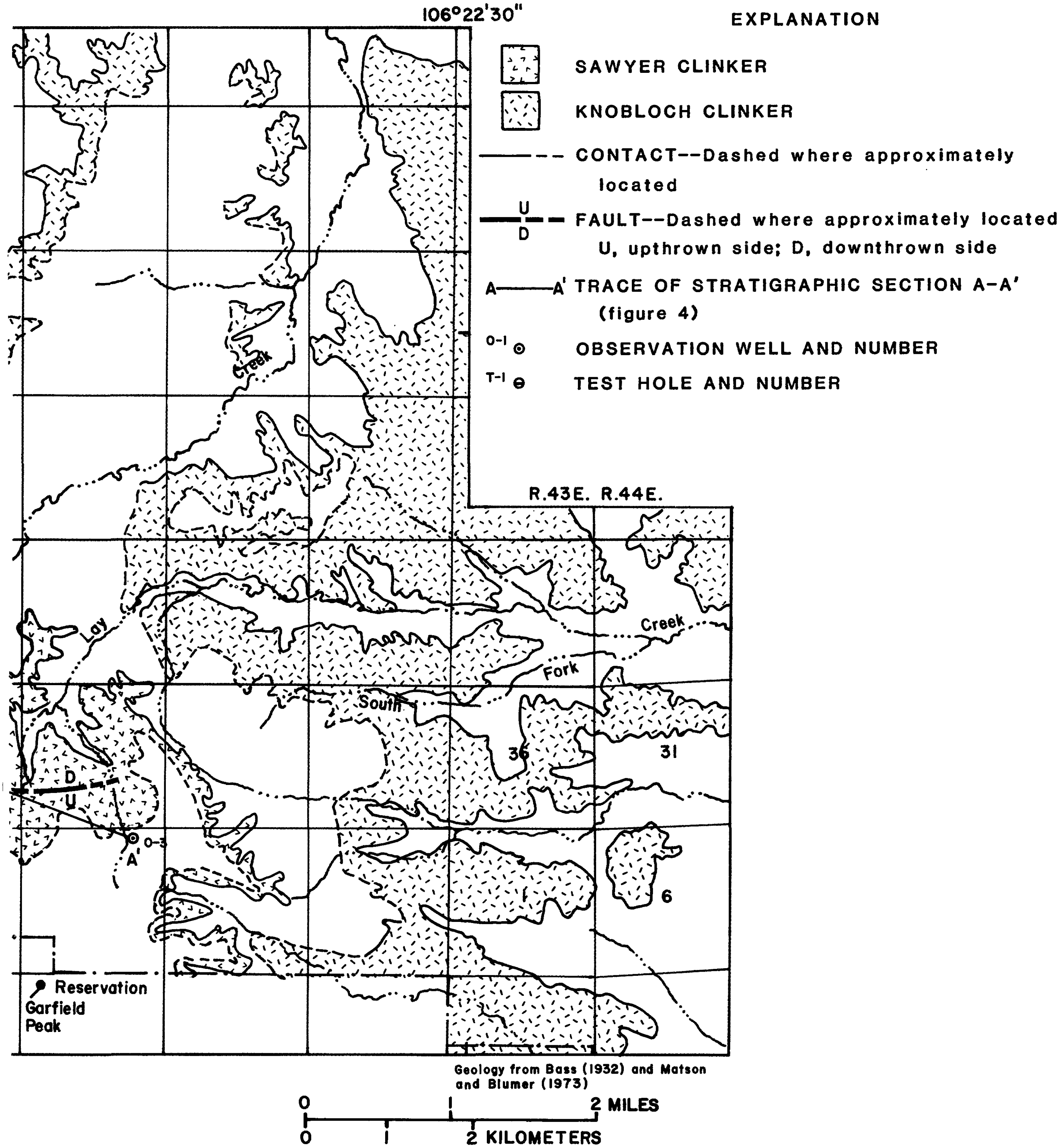
No stock wells are known to be completed solely in coal beds; however, drillers' logs from three wells indicate coal was penetrated. No indication was given as to the quantity of water, if any, in the coal beds. Data from other areas indicate that the coal beds commonly are aquifers if the coal has been fractured. If no facturing has occurred, the coal generally is dry or yields little water.

Cannon (1982) reported transmissivity values for three wells completed in the Knobloch coal bed in the Cook Creek area to range from 4 to 110 ft^2/d and hydraulic-conductivity values to range from 0.07 to 1.9 ft/d.



Base from U.S.Geological Survey Badger Peak, Garfield Peak, 1958; Ashland NE, 1986; Colstrip SE, Hammond Draw SW, 1971; Photo revisions, 1978 1:24,000

Figure 3.--Generalized outcrop area of the Sawyer and Knobloch clinker in the



Tongue River Member of the Fort Union Formation.

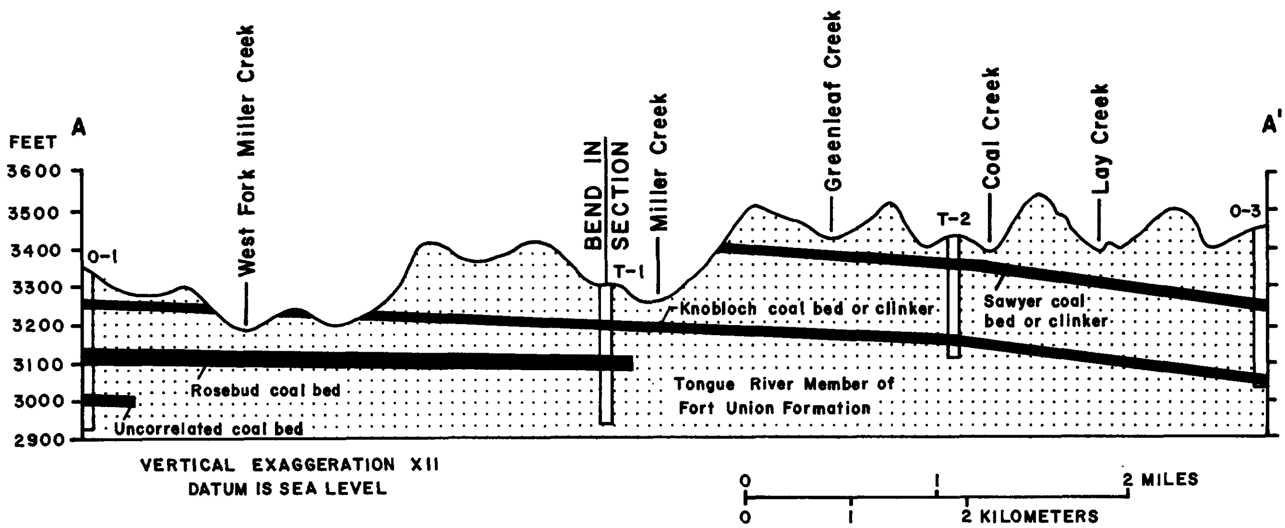


Figure 4.--Stratigraphic section showing coal beds penetrated in observation wells and test holes. Trace of section is shown in figure 3.

Sandstone beds

The massive sandstone beds in the Tongue River Member commonly weather into cliffs with cavernous faces below ledges of clinker or as large knobs or pinnacles. The thickness of the sandstone beds ranges from a few feet to 100 ft. The sandstone is composed primarily of fine-grained quartz but includes feldspar, mica, and minor quantities of other minerals. The sandstone beds are a source of water for most wells in the area. Few well-construction data exist, but most of the well casings probably are perforated opposite the first water-yielding sandstone bed that was penetrated during drilling.

Deep aquifers

Alternative sources of water can be obtained in the study area from deeper aquifers. The well depth will differ with location and aquifer. In some areas, the sandstones or coal beds in the Tongue River Member of the Fort Union Formation that are not disturbed by the mining operation will yield sufficient water for livestock wells. The depth of these wells could be as much as 800 ft. The static water level will differ from well to well, but probably will be a few hundred feet below land surface.

Underlying the Tongue River Member are several other potential aquifers: Lebo Shale and Tullock Members of the Fort Union Formation, Hell Creek Formation, Fox Hills-lower Hell Creek aquifer, and Madison Group. Projected drilling depths in the following discussion are based on formation tops determined from two oil-well test holes located in the area (Feltis and others, 1981).

The Lebo Shale Member is not considered to be a reliable aquifer, although it yields small quantities of water to some livestock wells outside the study area. The thickness of the Lebo averages about 200 ft.

The Tullock Member underlies the Lebo Shale Member. This unit averages about 300 ft thick and contains sufficient sandstone to be considered an aquifer. Depending on the location, it may be necessary to drill as deep as 1,300 ft to complete a well in this unit. Outside the study area, some wells completed in the Tullock Member flow but it is doubtful any wells in the study area will flow. Well yields probably would average 15 gal/min.

The Hell Creek Formation underlies the Tullock Member and is about 200 ft thick in the study area. An upper sandstone and shale section generally is referred to as the upper Hell Creek, and a lower sandstone is combined with the underlying Fox Hills Sandstone to form the Fox Hills-lower Hell Creek aquifer. The upper part of the Hell Creek Formation may yield as much as 12 gal/min, but probably would average about 5 gal/min.

The Fox Hills-lower Hell Creek aquifer is potentially the most prolific aquifer in the study area. It would be necessary to drill to a depth of about 2,000 ft to fully penetrate the aquifer. No wells are known to be completed in this unit in the study area. Based on projections from data to the north and east, the water level probably would vary from near land surface at the northern study-area boundary to 500 ft below land surface near the southern boundary. This aquifer might yield as much as 150 gal/min.

One additional aquifer, the Madison Group, underlies the study area but is extremely deep. The Madison has the potential for yielding about 10 to 500 gal/min of water to wells. An oil test hole in sec. 9, T. 1 S., R. 43 E., penetrated the top of the Madison at a depth of 7,688 ft below land surface. A water well drilled in the study area to this depth probably would flow, but the yield would depend on the permeability of the unit.

Ground-water movement and recharge

Alternating aquifers and confining zones coupled with complex intertonguing and interfingering within the Tongue River Member result in complicated patterns of ground-water flow. Water-quality distribution within the study area indicates that two general flow patterns are present above the Bearpaw Shale (Lee, 1981). An upper flow pattern occurs in aquifers at depths of less than about 200 ft and consists of localized flow that is controlled by topography. A lower, regional flow pattern is present in aquifers at depths of more than about 200 ft. The approximate altitude of the water surface in wells less than 200 ft deep is depicted in figure 2. The map, constructed from water levels in wells completed in sandstone lenses and coal beds having different potentiometric surfaces, approximates a single potentiometric surface that represents composite hydraulic heads.

Ground water moves from areas of recharge near Garfield Peak and Badger Peak (near the southern edge of the study area) generally toward Rosebud Creek to the north and the Tongue River to the east. Localized ground-water recharge occurs within each basin. Movement is from the basin divide toward the stream channel and toward the topographically low areas.

Recharge rates are estimated to be 0.01 to 0.1 in. per year. Woessner, Andrews, and Osborne (1979) calculated a recharge rate of 0.12 in. per year to unconfined coal, sandstone, and shale at a site west of Ashland, Mont., on the Northern Cheyenne Indian Reservation.

Surface-water resources

Most of the study area is drained by Greenleaf and Miller Creeks, which are tributaries to Rosebud Creek. Greenleaf and Miller Creeks originate on the Northern Cheyenne Indian Reservation and flow through the study area. Lay Creek originates in the study area and flows eastward where it joins the Tongue River. All three creeks are ephemeral except for short reaches of perennial flow just downstream from springs.

Three indirect streamflow-measurement sites were chosen on Greenleaf, Miller, and Lay Creeks (fig. 2) for computation of mean annual runoff and magnitude of peak flow. The mean annual runoff was calculated from the following equation (R. J. Omang, U.S. Geological Survey, written commun., 1982):

$$Q_A = 18.5 \, W_{AC}^{\;2.01} \qquad (1)$$

where: Q_A = mean annual runoff, in acre-feet, and
W_{AC} = active-channel width, in feet

The constants are derived from multiple-regression analysis of flow characteristics, channel features, and basin characteristics. Mean annual runoff for these sites was 36 acre-ft for Greenleaf Creek, 48 acre-ft for Miller Creek, and 330 acre-ft for Lay Creek.

Flood-peak estimates were made from regression equations using drainage area, percentage of forest cover within the drainage, and geographical location factor (Parrett and Omang, 1981). The magnitude of peak flow at different recurrence intervals for the three creeks is given in table 5.

Table 5.--*Magnitude of peak flow at ungaged sites*

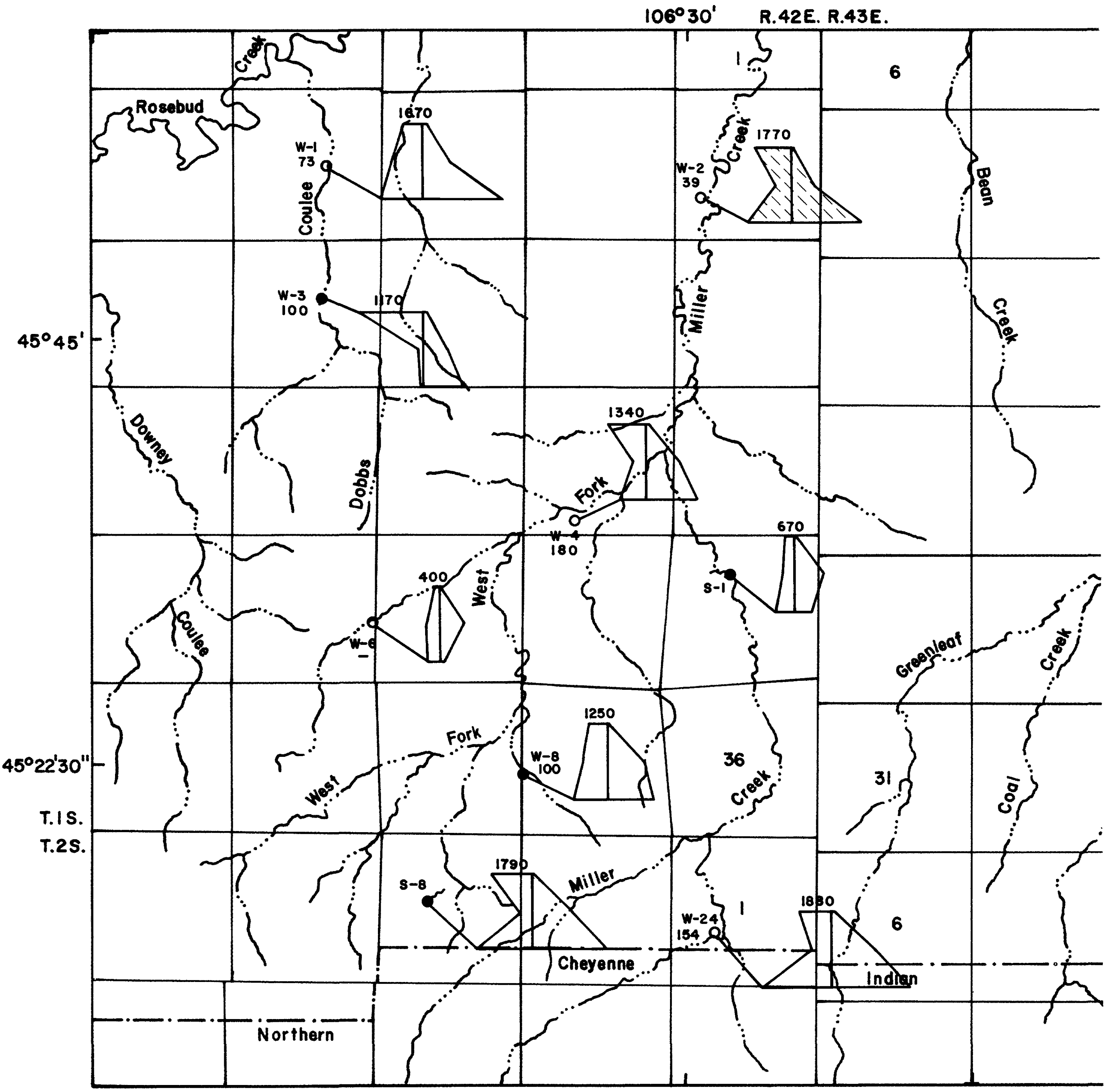
Recurrence interval (years)	Discharge, in cubic feet per second		
	Greenleaf Creek (drainage area 20.3 square miles)	Miller Creek (drainage area 16.9 square miles)	Lay Creek (drainage area 7.69 square miles)
2	25	20	25
5	65	60	70
10	110	100	110
25	190	170	190
50	280	240	280
100	390	340	380

Water quality

Water samples collected from 12 wells and 4 springs were analyzed for major ions. Selected samples also were analyzed for several trace elements. Results of the analyses are given in tables 2 and 3, and location of sampling sites and chemical-constituent diagrams are shown in figure 5. Many additional water-quality samples have been collected from wells and springs in the general area. Water-quality data for these wells and springs are given in a report by Lee (1979).

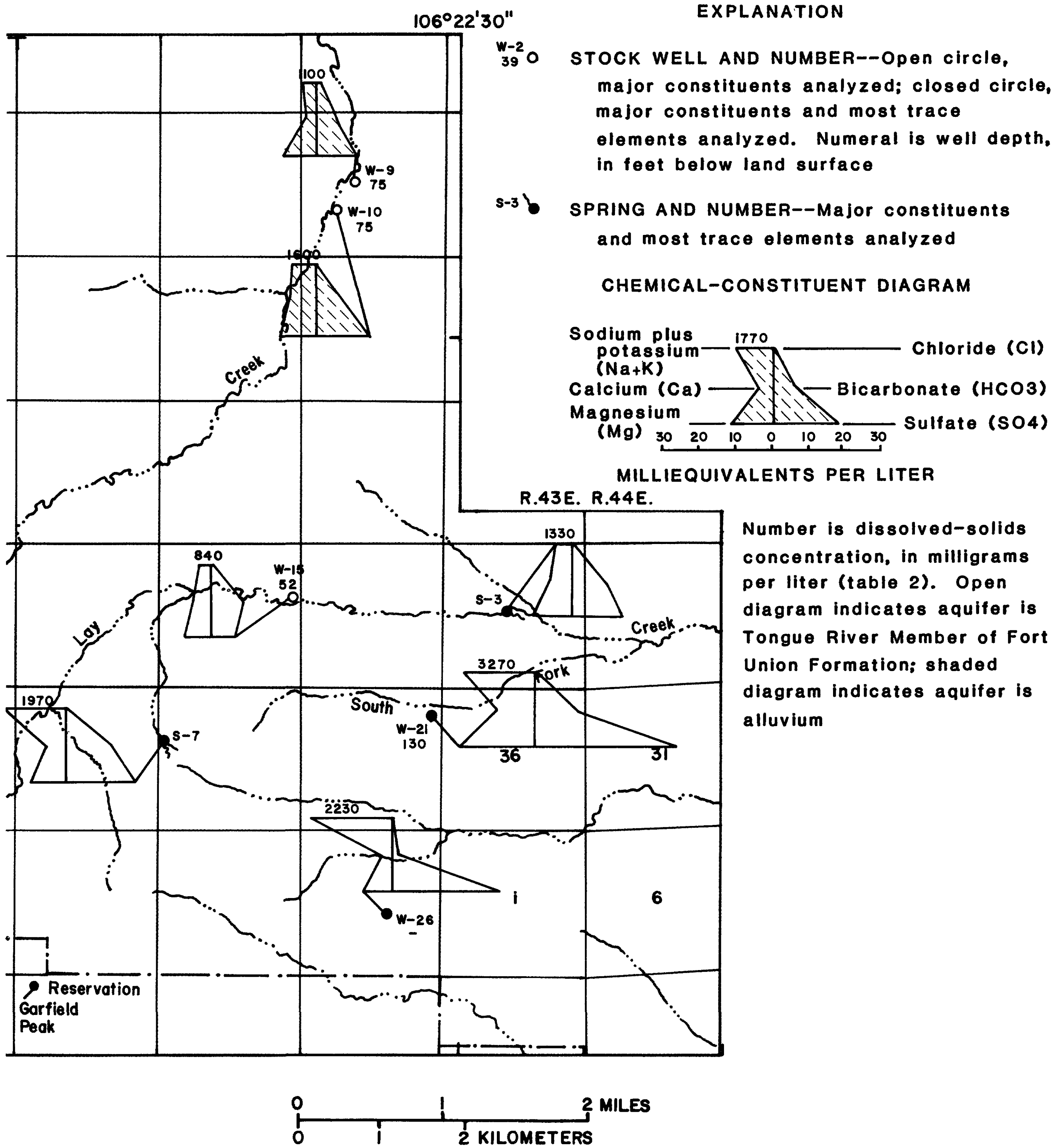
The water chemistry in the study area is variable. However, several generalizations can be made about the quality of water from wells and springs. The chloride concentration is extremely small--less than 16 mg/L for all samples. Sulfate, except for three samples, is the dominant anion. Sodium and magnesium generally are the dominant cations.

Lee (1981) concluded that water in the shallow aquifers (less than 200 ft deep) is chemically dynamic and the chemistry is variable. In contrast, water in the deeper aquifers forms chemically static regional systems characterized by sodium and bicarbonate as dominant ions.



Base from U.S.Geological Survey Badger Peak, Garfield Peak, 1958; Ashland NE, 1966; Colstrip SE, Hammond Draw SW, 1971; Photo revisions, 1978 1:24,000

Figure 5.--Chemical-constituent diagrams for



water samples from wells and springs.

CONCLUSIONS

In the Greenleaf-Miller area, the primary use of water from wells and springs is watering of livestock. Domestic use is restricted to two ranches located along Greenleaf Creek, and no irrigation uses are known at this time (1981). The alluvium and coal, clinker, and sandstone beds in the Tongue River Member of the Fort Union Formation are the only aquifers being used. Water in the coal, clinker, and sandstone aquifers moves from areas of recharge near Garfield Peak and Badger Peak (south of the study area) toward the topographically low areas to the north and east. The chemical quality of water from these aquifers is characterized by sulfate as the dominant anion, sodium and magnesium as the dominant cations, and extremely small concentrations of chloride.

All streamflow in the study area is ephemeral, except for short reaches of perennial flow just downstream from springs or seeps. Mean annual runoff and magnitude of peak flow were computed for three sites on Greenleaf, Miller, and Lay Creeks. The computed mean annual discharge was 36 acre-ft for Greenleaf Creek, 48 acre-ft for Miller Creek, and 330 acre-ft for Lay Creek. The magnitude of the peak flow at a recurrence interval of 100 years is 390 ft^3/s for Greenleaf Creek, 340 ft^3/s for Miller Creek, and 380 ft^3/s for Lay Creek.

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. To date (1981), no Preliminary Logical Mining Unit plan for the Greenleaf-Miller area is available. Based on the assumption that the Sawyer and Knobloch coal beds would be mined, some effects of the mining can be anticipated. The most obvious effect would be the disruption of ground-water flow through all units above and including the coal beds to be mined. If the pits intersect the water-table, water would flow into them and the potentiometric surface around the mined area would be lowered. This depression of the potentiometric surface would become larger with time--the rate and distance of spread being a function of the aquifer characteristics and geometry of the mine pits.

Another effect of the mining would be an increase in dissolved-solids concentrations as the ground-water flow system re-establishes itself through the mine spoils. The changes in water quality are dependent on the mineralogy of the mine spoils and the distance and rate of flow through the spoils.

Also, mining would decrease the magnitude of peak flow in Greenleaf, Miller, and Lay Creeks downstream from the mine. Upstream from the mine, surface-water supplies would not be affected by mining.

Alternative ground-water supplies could be developed to replace livestock wells destroyed by mining. Alternative water supplies are the undisturbed sandstone and coal beds within the Tongue River and Tullock Members of the Fort Union Formation, the lower part of the Hell Creek Formation, the Fox Hills Sandstone, and the Madison Group. Also, reclamation techniques to minimize water flow through the 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*

[Site designation: W, well; O, observation well; T, test hole; S, spring. Depth of well or test hole: R, reported; M, measured. Hydrogeologic unit: Tongue River, Tongue River Member of Fort Union Formation. Water level: S, steel tape; R, reported; T, electric tape. Discharge: R, reported; V, volumetric. Remarks: GS, U.S. Geological Survey; BM, Montana Bureau of Mines and Geology. Abbreviations: °C, degrees Celsius; micromhos, micromhos per centimeter at 25° Celsius]

Site desig- nation	Location	Altitude of land surface (feet above sea level)	Depth of well or test hole (feet below land surface)	Hydro- geologic unit	Perforated interval (feet below land surface)	Date of water-level measurement (month-day-year)
W-1	SW¼SE¼SW¼NE¼ sec. 9, T. 1 S., R. 42 E.	3,040	73R	Tongue River	----	8-02-73 8-25-81
W-2	SW¼SE¼NW¼SW¼ sec. 12, T. 1 S., R. 42 E.	3,052	39R	Alluvium	2-39	10-01-73
W-3	NE¼SW¼SW¼NE¼ sec. 16, T. 1 S., R. 42 E.	3,090	100R	Tongue River	----	3-24-76 8-25-81
W-4	NE¼SW¼SE¼SW¼ sec. 23, T. 1 S., R. 42 E.	3,178	180R	--do--	----	8-26-81
W-5	NE¼SE¼NW¼SE¼ sec. 26, T. 1 S., R. 42 E.	3,245	---	--do--	----	8-27-81
W-6	SW¼NW¼NW¼SW¼ sec. 27, T. 1 S., R. 42 E.	3,280	---	--do--	----	11-18-81
W-7	NE¼SE¼NE¼NE¼ sec. 34, T. 1 S., R. 42 E.	3,302	144M	--do--	----	8-26-81
W-8	SW¼NW¼NW¼SW¼ sec. 35, T. 1 S., R. 42 E.	3,335	100R	--do--	----	8-26-81
W-9	SW¼SE¼SE¼NW¼ sec. 11, T. 1 S., R. 43 E.	3,085	75R	Alluvium	----	10-01-73
W-10	NE¼SE¼NW¼SW¼ sec. 11, T. 1 S., R. 43 E.	3,105	75R	--do--	----	9-28-72
W-11	SW¼SW¼NW¼NE¼ sec. 16, T. 1 S., R. 43 E.	3,246	116R	Tongue River	----	10-01-73
W-12	SW¼NE¼SW¼NW¼ sec. 17, T. 1 S., R. 43 E.	3,160	15R	--do--	----	10-01-73
W-13	SE¼SW¼NE¼SW¼ sec. 21, T. 1 S., R. 43 E.	3,250	40R	Alluvium	----	8-25-81
W-14	NW¼NW¼NW¼NW¼ sec. 23, T. 1 S., R. 43 E.	3,170	66R	Tongue River	----	3-25-76
W-15	SE¼NE¼SE¼NE¼ sec. 27, T. 1 S., R. 43 E.	3,165	52R	--do--	----	3-24-76 8-25-81
W-16	NE¼NE¼NW¼SE¼ sec. 28, T. 1 S., R. 43 E.	3,240	20R	Alluvium	----	6- -04
W-17	SW¼SW¼SW¼NE¼ sec. 29, T. 1 S., R. 43 E.	3,310	60R	Tongue River	----	3-23-76
W-18	NE¼SW¼NE¼SE¼ sec. 30, T. 1 S., R. 43 E.	3,355	120R	--do--	85-120	3-22-76
W-19	SW¼NW¼NE¼NE¼ sec. 32, T. 1 S., R. 43 E.	3,430	---	--do--	----	11-17-81
W-20	NE¼NE¼SE¼NW¼ sec. 33, T. 1 S., R. 43 E.	3,325	40M	--do--	----	11-17-81
W-21	NW¼SE¼NE¼NE¼ sec. 35, T. 1 S., R. 43 E.	3,120	130R	--do--	----	3-24-76 8-25-81
W-22	SE¼NE¼NW¼NW¼ sec. 1, T. 2 S., R. 42 E.	3,358	35M	Alluvium	----	8-26-81
W-23	SW¼NW¼NW¼NW¼ sec. 1, T. 2 S., R. 42 E.	3,360	67M	Tongue River	----	11-18-81
W-24	NW¼SW¼NE¼SW¼ sec. 1, T. 2 S., R. 42 E.	3,415	154R	--do--	----	8-26-81
W-25	NE¼SW¼SE¼NW¼ sec. 2, T. 2 S., R. 42 E.	3,490	335R	--do--	----	8-26-81

Water level (feet below land surface)	Date of discharge measurement (month-day-year)	Discharge (gallons per minute)	Onsite water temperature (°C)	Onsite specific conductance (micromhos)	Onsite pH (standard units)	Remarks
44.12 S	8-02-73	8 R	---	---	---	Stock well.
42.79 S	----	--	10.5	1,860	7.3	
.85 S	----	--	9.5	2,400	---	Do.
86.50 S	----	--	11.5	1,720	8.4	Do.
87.07 S	----	--	---	---	---	
79.54 S	----	--	12.0	1,750	7.6	Do.
15.99 S	----	--	---	---	---	Water may be from Knobloch coal bed; hand pump.
97.50 S	----	--	10.5	630	7.6	Stock well.
121.14 S	----	--	---	---	---	Well originally 400 feet deep; unused.
57.97 S	----	--	10.5	1,450	7.2	Stock well.
1.10 S	----	--	10.5	1,700	---	Do.
24.45 S	----	--	9.5	1,750	7.4	Do.
101.49 S	----	--	---	---	---	Do.
8.01 S	----	--	---	---	---	Do.
13.31 S	----	--	---	---	---	Do.
39.00 S	3-25-76	5.5 V	10.0	1,210	---	Do.
44.90 S	----	--	---	---	---	Do.
44.47 S	----	--	12.0	1,080	7.4	
18 R	----	--	---	---	---	Unused.
40.90 S	----	--	---	---	---	Stock well.
75.60 S	5-19-69	15 R	---	---	---	
154.75 T	----	--	---	---	---	Observation well.
29.32 S	----	--	---	---	---	Stock well.
45.50 S	----	--	---	---	---	Do.
82.07 S	----	--	11.0	3,300	7.2	
Dry	----	--	---	---	---	Hand pump; unused.
19.29 S	----	--	---	---	---	Stock well
25.11 S	----	20 R	10.5	2,450	7.6	Do.
303.98 S	----	--	---	2,900	---	Unused.

Table 1.--*Hydrogeologic data from wells, springs, and test holes*--Continued

Site designation	Location	Altitude of land surface (feet above sea level)	Depth of well or drill hole (feet below land surface)	Hydro-geologic unit	Perforated interval (feet below land surface)	Date of water-level measurement (month-day-year)
W-26	SE¼NW¼NW¼SE¼ sec. 2, T. 2 S., R. 43 E.	3,270	---	--do--	----	11-19-81
W-27	NE¼SE¼SE¼NE¼ sec. 4, T. 2 S., R. 43 E.	3,435	---	--do--	----	11-17-81
O-1	NE¼SE¼SE¼NW¼ sec. 22, T. 1 S., R. 42 E.	3,335	395M	--do--	315-375	11-18-81
O-2	SW¼SW¼SE¼SW¼ sec. 34, T. 1 S., R. 42 E.	3,515	460M	--do--	440-460	10-10-81 11-18-81
O-3	NW¼NW¼NE¼NE¼ sec. 4, T. 2 S., R. 43 E.	3,450	401M	--do--	381-401	11-17-81
T-1	NW¼NW¼SW¼NE¼ sec. 36, T. 1 S., R. 42 E.	3,298	368M	----	----	----
T-2	SW¼SW¼SE¼NW¼ sec. 32, T. 1 S., R. 43 E.	3,425	313M	----	----	----
S-1	NW¼NE¼SE¼NW¼ sec. 25, T. 1 S., R. 42 E.	3,180	---	--do--	----	----
S-2	NW¼NE¼NW¼SE¼ sec. 26, T. 1 S., R. 42 E.	3,230	---	--do--	----	----
S-3	NE¼SE¼SE¼NW¼ sec. 25, T. 1 S., R. 43 E.	3,035	---	--do--	----	----
S-4	SE¼SW¼NE¼SW¼ sec. 31, T. 1 S., R. 43 E.	3,440	---	--do--	----	----
S-5	SW¼SE¼NE¼NW¼ sec. 32, T. 1 S., R. 43 E.	3,360	---	--do--	----	----
S-6	NW¼SW¼NW¼SW¼ sec. 33, T. 1 S., R. 43 E.	3,370	---	--do--	----	----
S-7	SW¼NW¼SW¼NW¼ sec. 34, T. 1 S., R. 43 E.	3,285	---	--do--	----	----
S-8	SE¼SW¼SE¼NW¼ sec. 3, T. 2 S., R. 42 E.	3,475	---	--do--	----	----
S-9	NW¼SW¼SE¼NE¼ sec. 4, T. 2 S., R. 42 E.	3,500	---	--do--	----	----
S-10	SW¼NW¼SW¼NW¼ sec. 6, T. 2 S., R. 44 E.	3,118	---	--do--	----	----

Water level (feet below land surface)	Date of discharge measurement (month-day-year)	Discharge (gallons per minute)	Onsite water temperature (°C)	Onsite specific conductance (micromhos)	Onsite pH (standard units)	Remarks
137.60 S	----	--	10.5	2,920	7.3	Stock well.
73.19 S	----	--	---	---	---	Do.
304.21 T	----	--	---	---	---	Observation well; GS test hole BP-10.
285.07 S 279.04 T	---- ----	-- --	--- ---	--- ---	--- ---	Observation well; GS test hole BP-4.
356.80 T	----	--	---	---	---	Observation well; GS test hole GP-7.
---	----	--	---	---	---	BM test hole SH-70100.
---	----	--	---	---	---	BM test hole SH-7098.
---	8-27-81 11-18-81	3.38 V 3.41 V	12.0	920	7.6	Spring at base of Knobloch coal bed.
---	----	--	---	---	---	Spring at base of Knobloch coal bed.
---	----	--	---	1,680	8.1	
---	-63	4 R	---	---	---	
---	----	--	---	---	---	Seep associated with fault; ponded pools of water in November 1981.
---	----	--	---	---	---	Seep associated with fault; ponded pools of water in November 1981.
---	-63	1.25 R	13.0	2,300	7.2	
---	8-26-81	.37 V	---	2,410	7.4	
---	----	--	---	---	---	Spring at Sawyer clinker outcrop.
---	7-24-68 11-19-81	.15 V .17 V	--- ---	1,060 1,000	7.2 7.4	

Table 2.--*Major chemical constituents and physical properties of water from wells and springs*

[Unless indicated otherwise, constituents are dissolved and constituent values are reported in milligrams per liter. Analyses by Montana Bureau of Mines and Geology. Site designation: W, well; S, spring. Hydrogeologic unit: Tongue River, Tongue River Member of Fort Union Formation]

Site designation	Date of collection (month-day-year)	Hydrogeologic unit	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium adsorption ratio (SAR)	Potassium (K)
W-1	8-25-81	Tongue River	1,020	180	140	130	1.8	6.1
W-2	10-01-73	Alluvium	280	76	140	220	3.5	9.0
W-3	8-25-81	Tongue River	22	5.7	1.9	400	37	2.4
W-4	8-27-81	--do--	550	76	87	240	4.4	7.8
W-6	11-18-81	--do--	370	78	42	6.6	0.15	2.1
W-8	8-26-81	--do--	820	130	120	110	1.7	6.6
W-9	10-01-73	Alluvium	240	67	100	85	1.5	8.2
W-10	11-29-72	--do--	390	130	120	140	2.1	5.0
W-15	8-25-81	Tongue River	590	92	88	66	1.2	6.4
W-21	8-27-81	--do--	1,500	200	250	450	5.0	11
W-24	8-26-81	--do--	1,200	100	220	180	2.3	12
W-26	11-19-81	--do--	490	53	87	520	10	18
S-1	8-27-81	--do--	460	68	70	65	1.3	6.1
S-3	11-17-81	--do--	870	120	140	99	1.5	11
S-7	8-25-81	--do--	750	110	120	390	6.1	8.8
S-8	8-26-81	--do--	870	67	170	250	3.7	19

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)
390	320	1,000	13	0.3	17	1,670	1.5
340	280	950	4.4	.1	25	1,770	1.2
450	370	520	9.5	1.0	8.1	1,170	.09
490	410	660	7.7	.6	14	1,340	.04
390	320	56	2.3	.2	16	400	.19
560	460	580	7.7	.4	12	1,250	.4
290	240	510	6.4	.2	29	1,100	.0
470	390	710	7.1	.3	22	1,600	2.8
520	420	310	6.1	.5	18	840	.10
720	590	2,000	12	.5	12	3,270	.07
680	560	1,000	12	.6	18	1,880	.41
120	98	1,500	15	.5	.8	2,230	<.01
490	400	200	2.8	.6	15	670	.02
540	450	660	6.2	.5	29	1,330	.01
760	620	960	9.6	.6	11	1,970	<.02
660	540	920	11	1.0	22	1,790	3.4

Table 3.--*Trace-element concentrations of water from wells and springs*

[Constituents are dissolved and concentrations are reported in micrograms per liter. Analyses by Montana Bureau of Mines and Geology. Site designation: W, well; S, spring. Symbol: <, less than.]

Site designation	Date of collection (month-day-year)	Aluminum (Al)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Lithium (Li)
W-1	8-25-81	--	--	--	--	--	570	--	20
W-2	10-01-73	--	--	--	--	--	--	--	--
W-3	8-25-81	<30	160	<2	<2	<2	120	<40	20
W-4	8-27-81	--	--	--	--	--	1,600	--	40
W-6	11-18-81	--	--	--	--	--	30	--	40
W-8	8-26-81	<30	450	<2	<2	14	400	<40	40
W-9	10-01-73	--	--	--	--	--	--	--	--
W-10	11-29-72	--	--	--	--	--	--	--	--
W-15	8-25-81	--	--	--	--	--	1,200	--	30
W-21	8-27-81	<30	1,200	<2	6	38	2,600	<40	120
W-24	8-26-81	--	--	--	--	--	50	--	80
W-26	11-19-81	<30	730	<2	4	2	80	<40	170
S-1	8-27-81	<30	260	<2	<2	6	50	<40	30
S-3	11-17-81	<30	510	<2	2	12	40	<40	60
S-7	8-25-81	<30	520	<2	<2	<2	720	<40	100
S-8	8-26-81	<30	960	<2	20	<2	40	<40	80

Manganese (Mn)	Molyb- denum (Mo)	Nickel (Ni)	Silver (Ag)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
40	--	--	--	--	--	--	--	--
20	--	--	--	--	--	--	--	--
9	<20	<10	<2	310	<1	<1	30	<3
31	--	--	--	--	--	--	--	--
79	--	--	--	--	--	--	--	--
220	60	<10	<2	2,500	8	<1	440	<3
10	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--
140	--	--	--	--	--	--	--	--
160	<20	--	<2	5,400	30	7	<4	<3
18	--	--	--	--	--	--	--	--
250	<30	<20	<2	2,600	10	3	540	<3
130	<20	<10	<2	1,500	<1	<1	<4	<3
19	<30	<20	<2	2,400	20	5	50	<4
290	30	<10	<2	2,900	1	<1	40	<3
4	<20	<10	<2	5,800	3	64	60	<3