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HYDROGEOLOGIC CONDITIONS AND PROJECTIONS RELATED TO MINING NEAR COLSTRIP, SOUTHEASTERN MONTANA

by

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HYDROGEOLOGIC CONDITIONS AND PROJECTIONS RELATED TO MINING NEAR COLSTRIP, SOUTHEASTERN MONTANA

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ABSTRACT

The Rosebud and McKay coal beds are important aquifers and are the objects of strip coal mining near Colstrip. They transmit about 5,000 cu. ft. of ground water per day across areas that will probably be mined.

Hydraulic conductivities and storage coefficients for mine spoils are similar to those of confined coal-bed aquifers. Implications are that spoils do not act as barriers to ground-water flow and that rubble zones along the mine floors contain water under pressure greater than atmospheric.

Ground-water quality near Colstrip is diverse. Dissolved-solids concentrations range between about 400 and 6,000 mg/l and are generally highest in waters from the oldest mine spoils. Sulfate is the predominant anion; no specific cation is predominant. Dissolved lead is detectable in most waters in the area; concentrations appear somewhat higher in waters associated with mine spoils than in other waters. Mine-cut effluents are chemical mixtures of ground waters normally discharging along outcrops and subcrops; they have not caused degradation of water quality.

Water-level measurements since 1974 have detected no mining-related changes around the Rosebud mine; within 1½ miles west of the Big Sky mine, declines have been 1 foot or more. Ultimately, active mine cuts may physically destroy five reservoirs, four springs, and twenty-six wells; in addition reliabilities of four reservoirs, three springs, and nine wells may be reduced. Where ground-water supplies are lost, new ones will be obtainable from wells completed in deeper aquifers.

After mining, ground-water-flow patterns will reestablish in the reclaimed areas and will not differ greatly from present patterns. Ground waters will be chemically diverse; principal constituents will probably be magnesium and sulfate, and dissolved lead concentrations may be generally higher than before.

INTRODUCTION

The probability of large-scale development of Fort Union coal has caused concern for all factors of southeastern Montana's environment. Concerns for water resources have been particularly great because of the extreme water dependency of the coal region's agricultural community. The Montana Bureau of Mines and Geology is conducting research at several mine sites in the region to determine hydrologic conditions before and during mining and to predict conditions after mining operations are completed. This report describes hydrologic research near Colstrip in southeastern Montana (Fig. 1), where strip coal mines are in operation and additional mines are planned.

Mining began near Colstrip in 1924 when Northwestern Improvement Company, then a subsidiary of

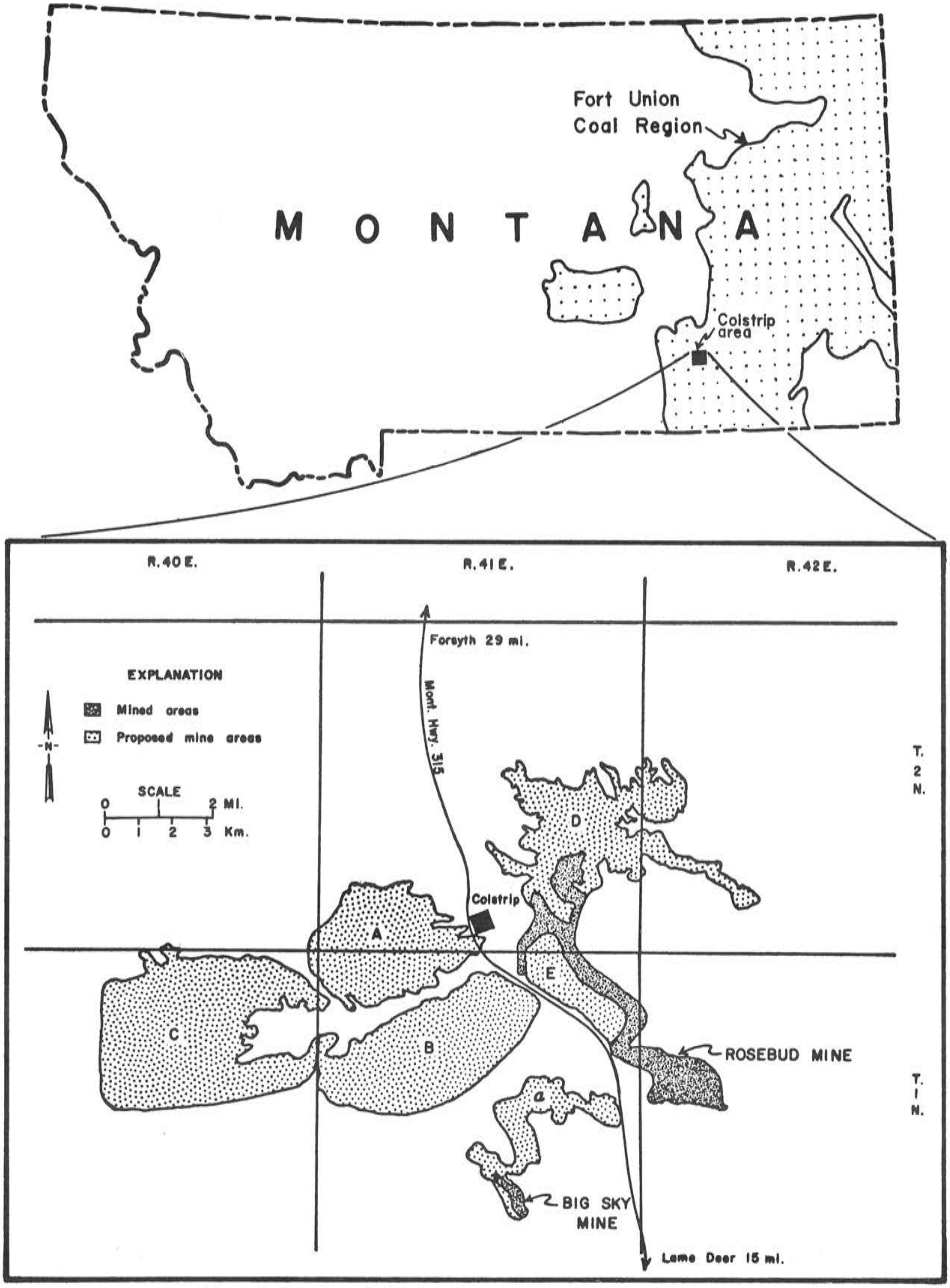

Figure 1.–Locations of Colstrip, mined areas, and proposed mine areas.

Northern Pacific Railway Company, opened the Rosebud mine (Fig. 1) and operated it until 1958; Western Energy Company, a subsidiary of Montana Power Company, reopened the mine in 1968 and completed its southern portion in 1974. By then, about 2,000 acres of land had been disturbed. Mine cuts have since been opened in areas A and E, and plans have been made for development of areas B, C, and D. Western Energy Company may disturb 10,000 acres in the Colstrip area. Another operator, Peabody Coal Company, opened the Big Sky mine, about 5 miles south of Colstrip, in 1969. Since then, the mine has gradually been expanded into Peabody Coal Company's development area *a*, which will eventually affect about 1,000 acres of surface. This report is a summary of hydrologic data and interpretations that have been generated in studies of the area since 1973. Hydrologic aspects of operations by both companies are described, and potential hydrologic changes are discussed.

PREVIOUS INVESTIGATIONS

Several studies have been conducted by the U. S. Geological Survey to define coal and water resources in the Colstrip area. From this work, Renick (1929) described the geology and ground-water resources of a large part of Rosebud County, including the areas of coal reserves currently proposed for mining. Renick's description of ground-water resources has special significance because his information predates any commercial mining near Colstrip.

Several other reports by the U. S. Geological Survey described the coal resources of the area (Dobbin, 1929; Bass, 1932; Pierce, 1936; and Kepferle, 1954). A more detailed study by the staff of Burlington Northern, Inc., under the direction of V. W. Carmichael (1964) generated a map of geologic structure and overburden thicknesses in the area. That photogeologic map provides the geologic framework for this hydrologic study.

Recent hydrologic data from the Colstrip area have been compiled by Westinghouse Electric Corporation in a locally distributed environmental analysis (1973), and by the Montana Bureau of Mines and Geology (Van Voast and Hedges, 1974) in an open-file report. Data from both of those reports were used extensively in the current study.

DATA-POINT NUMBERING SYSTEM

The system of numbering data points is based on the U. S. Bureau of Land Management system of subdivision of the public lands. The Colstrip area is in the Montana Principal Meridian system. The first segment of a data-point number indicates the township north or south of the baseline; the second, the range east of the principal meridian; and the third, the section in which the data point is located (Fig. 2). The letters A, B, C, and D, following the section number, locate the point within the section. The first letter denotes the 160-acre tract; the second, the 40-acre tract; the third, the 10-acre tract; and the fourth, the 2½-acre tract. The letters are assigned in a counterclockwise direction, beginning in the northeast quadrant. If two or more data points are located within the same 2½-acre tract, numbers are added as suffixes. It is important to note that the order of quarter-tract designations is exactly reversed from that commonly used by surveyors; here the order begins with the largest quarter and progresses to the smallest. Thus, in Figure 2, the designation 2 N. 41 E. 13 ABCD identifies the first data point in the SE¼ SW¼ NW¼ NE¼ sec. 13, T. 2 N., R. 41 E.

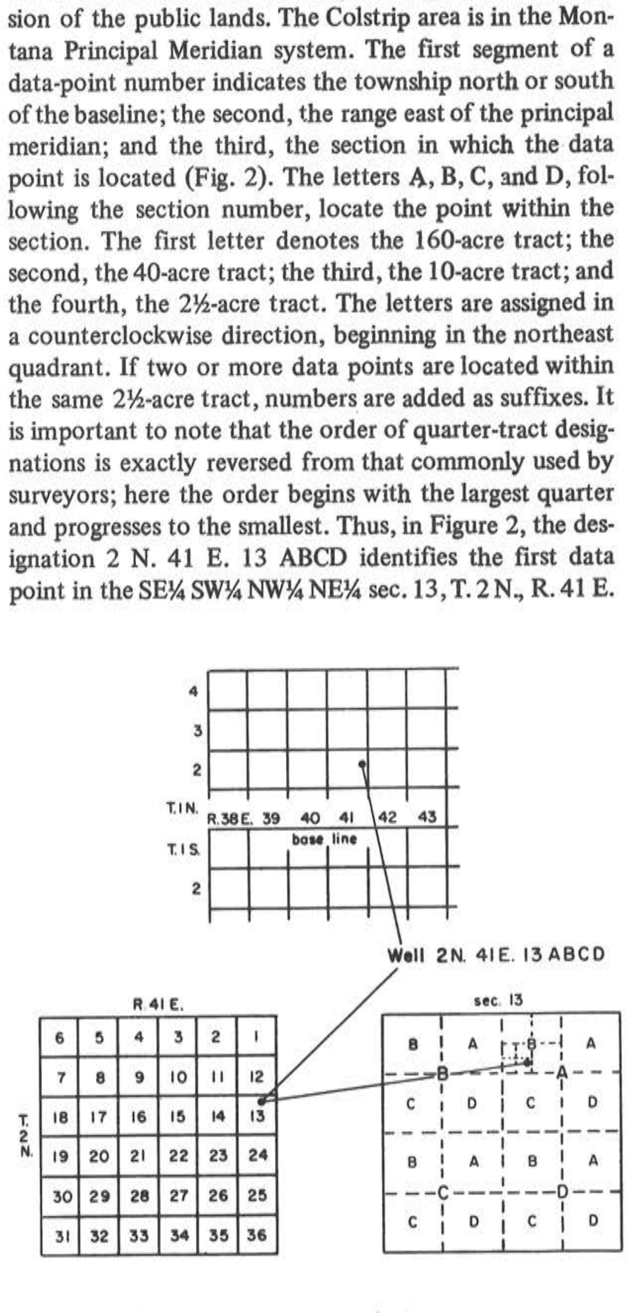

Figure 2.–Data-point numbering system.

Western Energy Company and Peabody Coal Company provided financial support, access, and important geologic data for the research. Additional funds for mine-spoils research were contributed by the Northern Great Plains Resource Program, the U. S. Environmental Protection Agency, the Old West Regional Commission, the Office of Water Resources Research, and the Montana Bureau of Mines and Geology. Many of the baseline hydrologic data included in this report were collected by the U. S. Geological Survey, Water Resources Division, in cooperation with the Montana Bureau of Mines and Geology. The Montana Highway Department, at the request of the Office of the Lieutenant Governor, contributed drilling equipment and personnel for construction of several shallow observation wells. Area residents and Burlington Northern, Inc., provided field access and data on wells and springs.

Special gratitude is owed to the usually innominate staff of the Montana Bureau of Mines and Geology, Billings office, for their labors in the collection of data and in the preparation of this report. Particularly, Michael R. Garverich and Judy L. McKeehan are acknowledged for their hard work.

PHYSIOGRAPHY

The climate of the Colstrip area can be classified as semiarid. From 1941 through 1970, the average annual precipitation was 15.79 inches (U. S. Weather Bureau, 1973), of which about 60 percent fell during the growing season (May through September). Average annual temperature for those years was 45.9°F. Most of the land surface is characterized by gentle slopes and subdued drainage divides; steep slopes and narrow ridges are present in the uplands in the western part of the area. The highest land-surface altitude (about 4,800 feet) occurs along the western drainage divide of East Fork Armells Creek (Fig. 3); the lowest altitude is about 3,000 feet and occurs along Rosebud Creek at the northeastern corner of the project area. Most mining will occur in the drainage basin of East Fork Armells Creek, which drains directly to the Yellowstone River approximately 30 miles north of Colstrip. Other drainages are tributary to Rosebud Creek, which also flows to the Yellowstone. Small areas have no apparent external surface drainage; these are the northern and southern ends of the Rosebud mine where natural drainages were obstructed by mining activities and were not restored when mining was completed.

Most streams flow only during periods of snowmelt and after infrequent events of high-intensity rainfall. Rosebud Creek and East Fork Armells Creek downstream from Colstrip have perennial flow generated by continuous ground-water discharge. Downstream from the project area, parts of the Armells Creek valley are reportedly "waterlogged" because of a high water table. Upstream from Colstrip, East Fork Armells Creek is generally dry except for water holes where its channel locally penetrates the water table.

Streamflow data are not available to derive direct values for flood peaks and average annual discharges in the Colstrip area. A method described by Johnson and Omang (1976) for estimating magnitudes and frequencies of floods in Montana was applied to predict peak flow rates having 10-, 25-, 50-, and 100-year recurrence intervals (Table 1). The method utilizes drainage area, channel

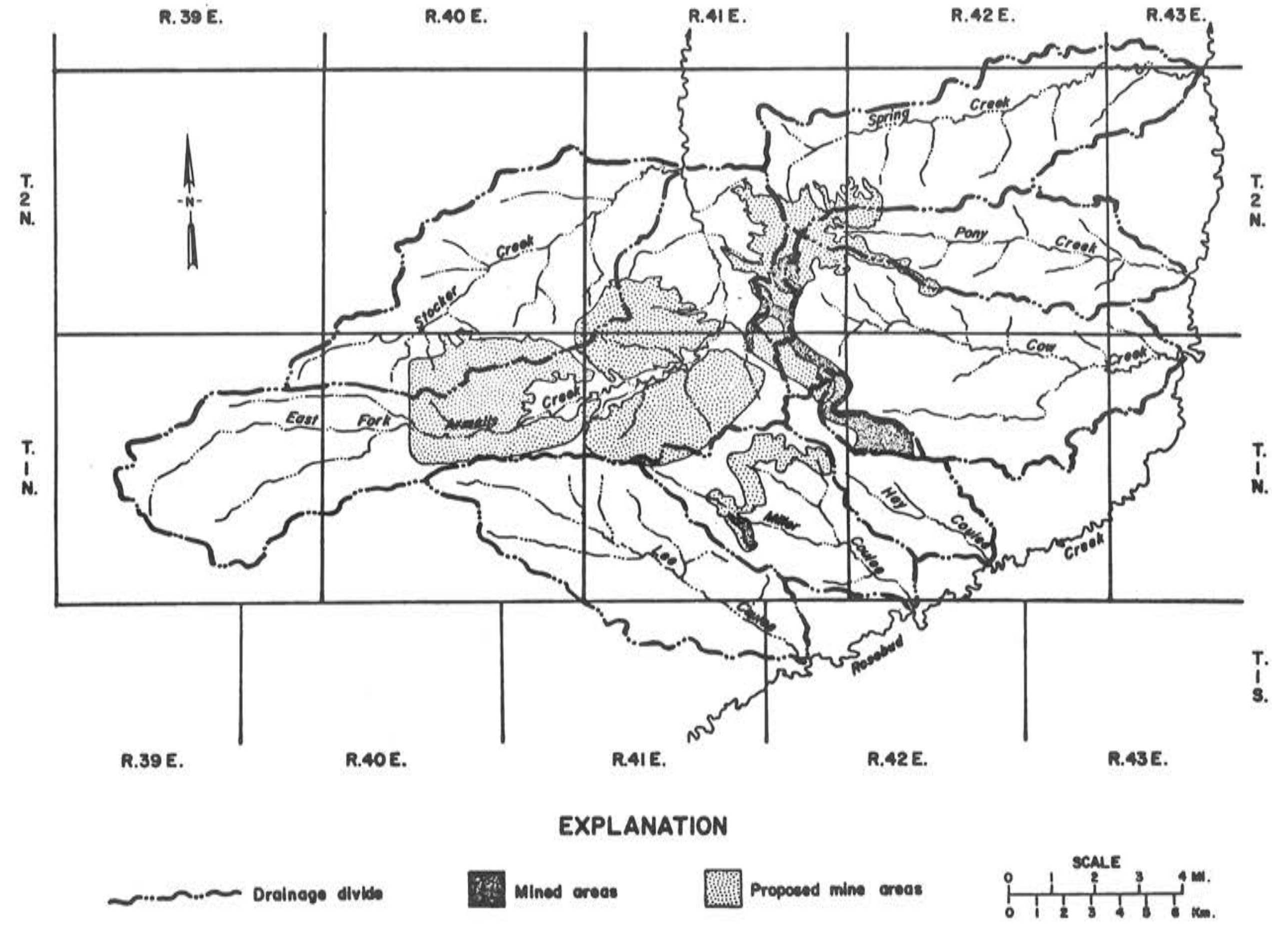

Figure 3.–Watercourses and drainage divides in the Colstrip area, southeastern Montana.

slope, channel length, and average annual precipitation, and was developed empirically through regression analyses of Montana streamflow records. The method is not very precise, and so the discharge rates in Table 1 are presented as theoretical ranges within which actual flows have a 68 percent likelihood of occurrence. Flood peaks thus predicted for the project area are surprisingly large considering the usually dry or ponded conditions of the streams. Average annual discharge rates were also estimated by indirect methods (Table 1). Analyses of data from Sarpy Creek near Hysham and from Pumpkin Creek near Miles City (U. S. Geol. Survey, 1974) indicate an average annual runoff rate of about 0.08 inch per year for each of those drainages; the same value seems applicable to drainages in the project area. Another estimate of average annual runoff was made by applying precipitation and evaporation data to water budgets for stock reservoirs that apparently have year-round storage and that lie at a wide range of altitudes in the area; an average runoff of 0.09 inch per year from contributing drainages was computed.

Less than a tenth of one percent of the area's average annual precipitation leaves the area directly as streamflow; almost all of the streamflow occurs during short-duration floods. Most precipitation returns to the atmosphere through processes of evaporation and transpiration, and a small remainder enters the geologic materials of the area to become ground water, a priceless resource and the subject of this report.

HYDROGEOLOGY, PRESENT CONDITIONS

GROUND-WATER TERMINOLOGY

The uppermost surface below which geologic materials are saturated under hydrostatic pressure is termed the "water table". Water is stored within spaces between grains or in fractures in the geologic material; the ratio of volume of pore space to total volume of material, expressed as a percentage, is known as "porosity". All geologic materials are porous to some degree. Their ability to transmit water under field conditions is termed "hydraulic conductivity" and depends upon the size of the pore spaces and the degree of their interconnection. Hydraulic conductivity as used in this report is defined as the flow of water in cubic feet per day through a cross-sectional area of geologic material 1 foot thick and 1 foot wide under a hydraulic gradient of 1 foot per foot. "Transmissivity" is used to indicate the ability of an aquifer to transmit water and is equivalent to the hydraulic conductivity multiplied by the aquifer thickness in feet. Transmissivity is defined as the flow of water in cubic feet per day through a section of aquifer 1 foot wide under a hydraulic gradient of 1 foot per foot. The volume of water that an aquifer can release from or take into storage per unit surface area of the aquifer per unit change in head, is known as "storage coefficient". Storage coefficient and transmissivity are the main characteristics that determine the worth of an aquifer as a source of water. Another term, "specific capacity", defined as the ratio of the rate of well discharge to the drawdown of water level, is used to describe well performance. Under certain assumptions the specific capacity of a well can be theoretically related to the transmissivity of the producing aquifer.

GROUND-WATER OCCURRENCE

Shallow aquifers that provide water in the Colstrip area are alluvium (unconsolidated deposits of silt, sand, and gravel) and consolidated beds of coal, silt, and sand of the Tongue River and Tullock Members of the Fort Union Formation (Fig. 4). The most significant deposits of alluvium occupy the floodplains of East Fork Armells Creek and Rosebud Creek; consolidated materials are present beneath the entire area. East Fork Armells Creek alluvium and the Rosebud and McKay coal beds are the only significant aquifers that will be disturbed by mining.

The East Fork Armells Creek alluvium has a total thickness as great as 40 feet and consists of beds of silt and clay overlying beds of sand and gravel. The sand and gravel beds have a maximum combined thickness of 20 feet and directly overlie consolidated Fort Union materials. Thinner deposits of alluvium occupy bottoms of the smaller drainages (Fig. 3); those in Miller Coulee and its tributaries will be disturbed by mining. Materials in them are probably much finer grained than those in alluvium along East Fork Armells Creek.

The Rosebud and McKay coal beds have thicknesses of about 25 feet and 10 feet, respectively, and are separated by clay, silt, and sand beds of extremely variable local thicknesses. Total thickness of materials, here termed Rosebud-McKay "interburden", ranges between about 3 and 60 feet. The interburden thickness is not predictable at any location and has no apparent areal trend. The thickest interburden strata seemingly contain the greatest thicknesses of sandstone; at these locales, the sandstone beds are aquifers of probably only local extent.

Table 1.–Peak-flood and average-annual discharges for watercourses near Colstrip, southeastern Montana.

Drainage name	Drainage area (square miles)	Calculated peak-flood discharge[1] (cubic feet per second) 10 year	25 year	50 year	100 year	Estimated average annual discharge[2] (cubic feet per second)
Rosebud tributaries						
Cow Creek	27.9	240 - (500) - 1040	380 - (810) - 1730	500 - (1110) - 2450	640 - (1460) - 3360	0.17
Hay Coulee	7.0	90 - (190) - 400	150 - (310) - 660	190 - (430) - 950	250 - (570) - 1310	0.04
Lee Coulee	20.8	230 - (480) - 1000	370 - (780) - 1660	490 - (1080) - 2390	630 - (1430) - 3290	0.12
Miller Coulee	13.3	120 - (250) - 520	190 - (410) - 870	250 - (560) - 1240	330 - (740) - 1700	0.08
Pony Creek	14.3	140 - (300) - 620	230 - (490) - 1040	310 - (680) - 1500	400 - (900) - 2070	0.09
Spring Creek	22.1	220 - (460) - 960	350 - (740) - 1580	460 - (1020) - 2250	590 - (1350) - 3100	0.13
Armells tributaries						
East Fork Armells[3]	47.8	330 - (680) - 1410	510 - (1090) - 2320	660 - (1470) - 3250	850 - (1930) - 4440	0.29
Stocker Creek	25.2	220 - (460) - 960	350 - (740) - 1580	450 - (1010) - 2230	590 - (1330) - 3060	0.15
Internal drainage[4]	3.5	–	–	–	–	0.02

[1] Calculation method by Johnson and Omang (1976); values in parentheses are means; others denote 68 percent confidence limits

[2] Based upon runoff rates transferred from gaged streams (0.08 inches per year)

[3] 0.1 mile upstream from Stocker Creek confluence

[4] Original drainages obstructed by mine spoils

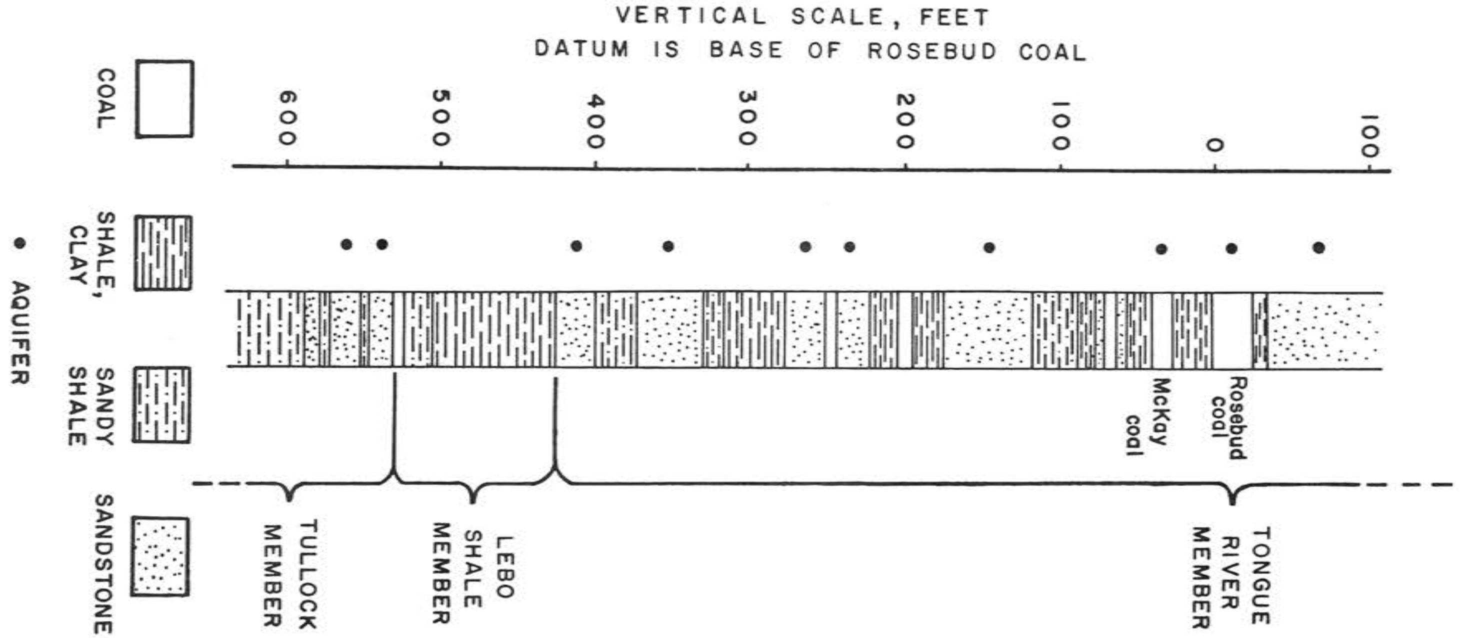

Figure 4.–Generalized stratigraphic column of part of Fort Union Formation near Colstrip, southeastern Montana.

GEOLOGIC STRUCTURE

The project area lies on the northeast flank of a broad shallow northwest-trending syncline or structural trough originally described by Dobbin (1929). The axis of the syncline plunges southeastward and crosses the western end of the area (Pl. 1). The syncline is a probable extension of one contoured by Rogers and Lee (1923, Pl. 10) in the Tullock Creek coal field, 20 miles west of Colstrip. Structural gradients of the Rosebud coal (Pl. 1) trend mostly southward, and are greatest in the western half of the area, where they locally exceed 100 feet per mile. In the area of current mining activity, attitude of the Rosebud coal bed is relatively subdued. There the predominant southward gradient is interrupted by a gentle anticline or structural ridge centered along Lee Coulee near the southern boundary of T. 1 N., R. 41 E. All of the active mine areas lie in a very shallow eastward-dipping geologic basin north of the Lee Coulee anticline.

Contours on Plate 1 are based upon subsurface data from drill holes and do not acknowledge the many faults mapped on the surface by Carmichael (1964). Faults of small stratigraphic displacement are certainly present in the area, and their cumulative displacements probably account for much of the generalized structural configuration.

WATER USE

Most water supplies for municipal and industrial uses at Colstrip are imported from the Yellowstone River, about 30 miles away; waters for rural-domestic and agricultural uses are obtained from within the project area.

Montana Power Company imports water from the Yellowstone River by way of a newly constructed 26-inch-diameter pipeline about 30 miles long. Most of the designed average inflow of 1.5 million cubic feet per day will be utilized by two coal-fired steam generation plants recently constructed at Colstrip. About 60 thousand cubic feet of river water per day is delivered by the pipeline to the town of Colstrip for municipal supply. Before completion of the pipeline, the municipal water supply was obtained from seven wells that drew water from sandstone aquifers 100 to 1,500 feet below the McKay coal bed and from one well completed in a limestone aquifer more than 7,500 feet below land surface. Outside of Colstrip, water users rely upon locally obtained surface water for stock and irrigation supplies and upon ground water for domestic, stock, and mining-related needs. Inventories conducted by the U. S. Geological Survey and the Montana Bureau of Mines and Geology have documented most of the existing water-use locations for the area (Pl. 2; Tables 2, 3).

Most supplies of surface water are obtained from small reservoirs impounded by earthen dams on intermittent watercourses. The reservoirs receive runoff during the spring and early summer months and store water for use during drier periods. The distribution of reservoirs believed to provide perennial storage within the area is fairly uniform (Pl. 2) and is about one reservoir per 5 square miles of area. Although perennial reservoirs provide very dependable water supplies, their distribution is too sparse to serve all of the ranching needs of the area.

Additional livestock water is obtained from springs. The discharges from many springs vary seasonally; some of them flow only during parts of each year. Geologic sources of the spring waters, interpreted in Table 2, are the surficial materials at each spring location and are referenced to the stratigraphic section to be disturbed by mining: from 150 feet above the Rosebud coal to the base of the McKay coal. Most springs in the project area occur above the 150 feet of overburden or below the McKay coal. Several of them discharge water from alluvium, probably recharged by subcrops of Fort Union aquifers. Most of the springs that discharge from coal or strippable overburden are in the western half of the project area along the beds' northern outcrops. Average density of springs is about one per 4 square miles. They are reported to be reliable sources for water supplies except during periods of extended drought.

Many wells have been drilled in the Colstrip area to obtain water for stock and rural-domestic needs. Most of the wells are less than about 200 feet deep (Table 3) and are drilled to the shallowest sources of ground water. When pumped, few of the wells produce more than about 1 cubic foot of water per minute; most of them are adequate for stock and domestic needs. Source aquifers for well waters have been interpreted on Table 3 wherever information was adequate. The diversity of well depths and stratigraphic positions of aquifers exemplify the number of sandstone beds in the Tongue River and Tullock Members of the Fort Union Formation. Significant coal beds, the Rosebud and McKay, are utilized only where they lie within about 200 feet below land surface. Logically, these areas nearly coincide with areas where the coal beds are economically mineable. Density of water wells in

Table 2.–Spring data for the Colstrip area, southeastern Montana.

Location: See text for explanation of well-numbering system.
Altitude: Altitude of land surface at spring, estimated from U.S. Geological Survey 7½-minute topographic maps; accurate to 10 feet.
Specific conductance: Field electrical conductance of water, in micromhos per centimeter 25°C; "L" indicates laboratory conductance.
Aquifer: Interpretations by MBMG. Coded sources – RO+, more than 150 feet above Rosebud coal; RO, overburden, 0-150 feet above Rosebud coal; Sub Mc, unspecified aquifers stratigraphically below McKay coal.
Water analysis: See water-quality table for chemical analyses of water.

Location	Altitude (feet)	Date examined	Specific conductance	Estimated discharge (gallons per minute)	Water use	Aquifer	Water analysis
2 N 38 E 03ABBB	3600	–	613	–	Stock	Rosebud coal	
2 N 38 E 03BAAA	3615	6-73	–	3	Stock	Rosebud coal	
2 N 38 E 03CCAD	3520	–	952	2	Stock	Rosebud coal	
2 N 38 E 10DCDC	3520	–	–	–	Stock	RO	
2 N 38 E 11ABBD	3520	–	–	–	Stock	RO	
2 N 38 E 11ADBC	3500	–	–	–	Stock	RO	
2 N 38 E 11DAAC	3480	–	–	–	Stock	RO	
2 N 38 E 11DCCA	3680	–	–	–	Stock	RO+	
2 N 38 E 12CADB	3460	6-73	–	6	Stock	Rosebud coal	
2 N 38 E 13ABBD	3400	–	–	3	Stock	Rosebud coal	
2 N 38 E 34ABBC	3630	7-73	–	1	Stock	RO+	
2 N 38 E 35ACAD	3700	–	–	–	Stock	RO+	
2 N 38 E 36BBBC	3670	7-73	–	–	Stock	RO+	
2 N 38 E 36DCDC	3760	7-73	–	0.5	Stock	RO+	
2 N 39 E 02CABB	3115	–	–	–	Stock	Sub Mc	
2 N 39 E 07BDCB	3380	7-73	–	–	Stock	Sub Mc	
2 N 39 E 08CBAD	3230	7-73	–	–	Stock	Sub Mc	
2 N 39 E 12CCCD	3140	–	–	–	Stock	Sub Mc	
2 N 39 E 14BDBB	3180	–	–	10	Stock	Alluvium	
2 N 39 E 18ABDC	3300	7-73	–	–	Stock	Sub Mc	
2 N 39 E 19DBDA	3435	7-73	–	–	Stock	Sub Mc	
2 N 39 E 24BDAB	3210	7-73	–	–	Stock	Sub Mc	
2 N 39 E 26DDAA	3295	–	–	–	Stock	Alluvium	
2 N 39 E 31ABAA	3500	10-72	3550	8	Stock	Rosebud coal	yes
2 N 39 E 31CBCD	3620	10-72	–	8	Stock	RO	
2 N 39 E 31CDCC	3620	10-72	–	–	Stock	RO+	
2 N 39 E 31CDCD	3620	10-72	–	–	Stock	RO+	
2 N 39 E 36CBAC	3395	–	–	–	Stock	McKay coal	
2 N 39 E 36CBBD	3390	–	–	–	Stock	McKay coal	
2 N 39 E 36CDDB	3400	7-73	–	0.5	Stock	McKay coal	
2 N 40 E 17CCBC	3255	–	–	–	Stock	Sub Mc	
2 N 40 E 17CDBA	3305	–	–	–	Stock	Sub Mc	
2 N 40 E 18DAAC	3235	–	–	–	Stock	Sub Mc	
2 N 40 E 18DADC	3240	10-72	3550	3.2	Stock	Sub Mc	yes
2 N 40 E 28CCBB	3420	7-75	–	5	Stock	Alluvium	
2 N 40 E 32BBAA	3380	–	–	–	Stock	Rosebud coal	
2 N 40 E 33CCDD	3415	–	–	–	Stock	Alluvium	
2 N 41 E 13BBCD	3200	–	–	–	Stock	Alluvium	
2 N 41 E 17ADAD	3120	10-73	2798L	–	Stock	Sub Mc	yes
2 N 42 E 30CCCA	3225	–	–	–	Stock	Rosebud clinker	
2 N 42 E 31CBDC	3160	–	–	–	Stock	Alluvium	
1 N 38 E 02DADD	3920	–	–	–	Stock	RO+	
1 N 38 E 03AACC	3710	–	–	–	Stock	RO+	
1 N 38 E 03ACDC	3660	8-73	4320	–	Stock	RO+	

Table 2.–Continued

Location	Altitude (feet)	Date examined	Specific conductance	Estimated discharge (gallons per minute)	Water use	Aquifer	Water analysis
1 N 38 E 03ADCC	3680	–	–	–	Stock	RO+	
1 N 38 E 10BBDC	3540	–	2050	1	Stock	RO	
1 N 38 E 11CCDD	3660	8-73	–	–	Stock	RO+	
1 N 38 E 11DBBC	3743	8-73	5840	0.1	Stock	RO+	
1 N 38 E 12CDCA	3850	–	–	–	Stock	RO+	
1 N 38 E 13AADA	3830	8-73	1860	0.5	Stock	RO+	
1 N 38 E 13BABB	3820	–	–	–	Stock	RO+	
1 N 38 E 13BCBA	3755	–	–	–	Stock	RO+	
1 N 38 E 14CBCB	3540	–	–	–	Stock	RO+	
1 N 38 E 15BBDA	3550	8-73	2830L	0.1	Stock	Rosebud coal	yes
1 N 38 E 15BCCD	3415	8-73	7320	–	Stock	Sub Mc	
1 N 38 E 15DAAD	3460	–	–	–	Stock	RO	
1 N 39 E 06ADDA	3690	7-73	–	–	Stock	RO+	
1 N 39 E 08CDDA	4160	7-73	–	–	Stock	RO+	
1 N 39 E 09DDAA	3920	7-73	–	–	Stock	RO+	
1 N 39 E 10BABB	3790	–	–	–	Stock	RO+	
1 N 39 E 11BBDD	3940	–	–	–	Stock	RO+	
1 N 39 E 14BBAB	3820	10-73	–	–	Stock	RO+	
1 N 39 E 17AACB	4260	10-73	–	–	Stock	RO+	
1 N 39 E 18ADCC	4175	10-73	–	–	Stock	RO+	
1 N 39 E 18ADDD	4330	10-73	–	–	Stock	RO+	
1 N 39 E 18BDBC	4020	–	–	–	Stock	RO+	
1 N 39 E 18BDCB	4000	8-73	–	2	Stock	RO+	
1 N 39 E 23CCBB	3990	–	–	–	Stock	RO+	
1 N 39 E 24ABCC	3780	–	–	–	Stock	RO+	
1 N 40 E 02BABD	3440	7-73	2930L	0.6	Stock	Rosebud coal	yes
1 N 40 E 02BBDD	3450	7-73	–	–	Stock	Rosebud coal	
1 N 40 E 02BDAB	3450	7-73	–	–	Stock	Rosebud coal	
1 N 40 E 04CAAA	3435	–	–	–	Stock	Rosebud coal	
1 N 40 E 19DCCD	3630	9-73	2090L	1	Stock	RO+	yes
1 N 40 E 20DADC	3515	9-73	–	0.3	Stock	RO	
1 N 40 E 27DCDD	3350	–	–	–	Stock	RO	
1 N 40 E 30ABBC	3610	9-73	–	3	Stock	RO+	
1 N 40 E 30ACDC	3610	9-73	–	3	Stock	RO+	
1 N 40 E 31DBDA	3610	7-73	–	1	Stock	RO+	
1 N 40 E 32ADDB	3490	–	–	–	Stock	RO+	
1 N 41 E 24CCAA	3130	–	–	–	Stock	Alluvium	
1 S 40 E 03BBAD	3510	–	–	–	Stock	RO+	
1 S 40 E 06BBDB	3890	9-73	1640	0.2	Stock	RO+	yes
1 S 40 E 07CBCD	3675	9-73	–	0.2	Stock	RO+	
1 S 40 E 08AADB	3600	9-73	2400	2	Stock	RO+	yes
1 S 40 E 09DADC	3475	–	–	–	Stock	RO+	
1 S 40 E 12DDDA	3480	7-73	692L	0.5	Stock	RO+	yes

Table 3.–Water-well data for the Colstrip area, southeastern Montana.

Location: See text for explanation of well-numbering system.

Altitude: Altitude of land surface at well, estimated from U.S. Geological Survey 7½-minute topographic maps; accurate to 10 feet.

Depth to water: Depths to nearest 0.1 foot measured; depths to nearest 1.0 foot reported; "F" indicates flowing well.

Specific conductance: Field electrical conductance of water, in micromhos per centimeter at 25°C; "L" indicates laboratory conductance.

Aquifer: Interpretations by MBMG. Coded sources–RO+, more than 150 feet above Rosebud coal; RO, overburden, 0-150 feet above Rosebud coal; Sub Mc, unspecified aquifers stratigraphically below McKay coal.

Water analysis: See water-quality table for chemical analysis of water.

Location	Altitude (feet)	Well depth (feet)	Depth to water (feet)	Date examined	Specific conductance	Temperature (°C)	Water use	Aquifer	Water analysis
2 N 38 E 15ADDA	3540	–	–	7-73	1840	–	Stock	Sub Mc	
2 N 38 E 15CCDC	3500	–	–	7-73	1232L	–	Stock	Sub Mc	yes
2 N 38 E 24BCBC	3530	–	–	–	1290	–	Stock	Alluvium	
2 N 38 E 25CDDC	3640	–	150	–	–	–	Stock	Rosebud coal	
2 N 38 E 26AABA	3650	226	166.8	10-73	–	–	Stock	Sub Mc	
2 N 38 E 36CDBD	3766	–	60	–	–	–	Stock	RO+	
2 N 39 E 03CDBB	3195	113	61.0	9-73	–	–	Stock	Sub Mc	
2 N 39 E 05BCBA	3205	57	–	9-73	2400	11.0	Stock	Sub Mc	yes
2 N 39 E 05DDDC	3170	16	15.2	9-73	6638L	13.3	Stock	Alluvium or Sub Mc	yes
2 N 39 E 06CBBB	3320	–	–	–	–	–	Stock	Sub Mc	
2 N 39 E 08AABB	3170	–	–	–	–	–	Stock	Sub Mc	
2 N 39 E 10BBCA	3245	130	75	–	–	–	Stock	Sub Mc	
2 N 39 E 12CCC$_1$	3160	555	–	11-72	1200	13.5	House	Tullock	yes
2 N 39 E 12CCC$_2$	3150	71	35	–	–	–	Stock	Sub Mc	
2 N 39 E 12CCDB	3130	20	17	–	–	–	Stock	Alluvium	
2 N 39 E 14BDBB	3180	240	–	7-75	3150	–	House	Sub Mc	
2 N 39 E 16ACDD	3260	100	35	–	–	–	Stock	Sub Mc	
2 N 39 E 17DCAA	3320	–	–	8-75	–	–	Stock	Sub Mc	
2 N 39 E 19CACB	3468	–	–	–	–	–	Stock	Unknown	
2 N 39 E 20DBCB	3457	–	–	8-75	–	–	Stock	Unknown	
2 N 39 E 23CAAB	3350	–	98.7	7-73	1450	27.0	Stock	Sub Mc	yes
2 N 39 E 24CDAB	3250	140	50	7-73	3030L	–	Stock	Sub Mc	yes
2 N 39 E 24CDDD	3240	46	18.1	7-73	–	–	Unused	Sub Mc	
2 N 39 E 25ACDC	3280	136	58	7-73	5060L	–	Stock	Sub Mc	yes
2 N 39 E 27CCCC	3430	262	127.6	7-73	–	–	Stock	Sub Mc	
2 N 39 E 28CABD	3375	–	–	8-75	–	–	Unused	Unknown	
2 N 39 E 29BCCC	3456	–	–	8-75	–	–	–	Unknown	
2 N 39 E 30CBAA	3555	–	–	–	–	–	Stock	Unknown	
2 N 39 E 31CBAA	3550	128	35.9	7-75	–	–	Stock	Rosebud coal or RO	
2 N 39 E 31CDBA	3625	220	73.1	7-75	–	–	Stock	Rosebud coal	
2 N 39 E 32DDDD	3520	–	–	7-73	3500	12.5	Stock	Unknown	yes
2 N 39 E 34ADBB	3435	60	27	11-72	2940L	–	House	Rosebud coal	yes
2 N 39 E 34DADB	3470	80	26.9	7-73	2050L	16.0	Stock	Rosebud coal	yes
2 N 40 E 01AAAA	3145	117	93	8-75	–	–	Stock	Tullock	
2 N 40 E 02DACB	3205	69	29.3	8-75	–	–	Unused	Sub Mc	
2 N 40 E 04BBAA	3270	84	30	–	–	–	Stock	Sub Mc	
2 N 40 E 06ABAB	3190	86	70	–	–	–	Stock	Sub Mc	
2 N 40 E 06ABAC	3200	143	84	–	–	–	Stock	Sub Mc	
2 N 40 E 06ABBA	3190	–	40	–	2400	–	House	Sub Mc	
2 N 40 E 06CBCB	3160	104	84	7-73	3000	10.5	Stock	Sub Mc	yes
2 N 40 E 07BDCC	3210	128	80	7-73	–	–	Stock	Sub Mc	
2 N 40 E 10BBCD	3282	210	145	–	–	–	Stock	Sub Mc	

Table 3.—Continued

Location	Altitude (feet)	Well depth (feet)	Depth to water (feet)	Date examined	Specific conductance	Tempera-ature (°C)	Water use	Aquifer	Water analysis
2 N 40 E 11AABA	3241	130	60	–	–	–	Stock	Sub Mc	
2 N 40 E 12AAAB	3260	165	30	–	–	–	House	Sub Mc	
2 N 40 E 17AACA	3440	184	165	–	–	–	Stock	Sub Mc	
2 N 40 E 17ABDD	3480	185	80	–	–	–	Stock	Sub Mc	
2 N 40 E 24DBDC	3220	85	60	–	–	–	House	Sub Mc	
2 N 40 E 24DCBA	3220	30	22	–	–	–	Stock	Alluvium	
2 N 40 E 25BABA	3245	80	60	–	–	–	Stock	Sub Mc	
2 N 40 E 26BADB	3274	–	–	–	–	–	Stock	Sub Mc	
2 N 40 E 28AADD	3370	146	75.7	7-75	3510	12.0	Stock	Sub Mc	
2 N 40 E 29CCDC	3380	–	F	7-75	2820	16.0	Stock	Sub Mc	
2 N 40 E 30BAAD	3275	246	72	7-73	3500	14.0	Stock	Sub Mc	yes
2 N 40 E 31DCCD	3530	165	113.6	11-72	1750	13.0	Stock	Rosebud coal and McKay coal	yes
2 N 40 E 32BBAB	3390	–	–	7-73	950	–	House	Sub Mc	yes
2 N 40 E 32BBDA	3430	67	23.3	7-73	–	–	Unused	Rosebud clinker	
2 N 40 E 33ADDD	3360	140	100	–	–	–	Stock	Sub Mc	
2 N 40 E 35DDCD	3425	250	148.2	7-73	2800	11.5	Stock	Sub Mc	yes
2 N 41 E 01DBBA	3140	–	61.7	8-73	878L	11.5	Stock	Sub Mc	yes
2 N 41 E 02ACDC	3160	10	3	8-73	–	–	Stock	Alluvium	
2 N 41 E 02DBBA	3170	220	–	11-72	3290L	–	House	Sub Mc	yes
2 N 41 E 08ACCD	3182	–	–	10-73	–	–	Stock	Sub Mc	
2 N 41 E 10BCBC	3175	150	100	7-73	182	13.0	Stock	Sub Mc	yes
2 N 41 E 12CCAD	3178	–	–	–	–	–	Stock	Sub Mc	
2 N 41 E 17ADAA	3121	110	–	10-73	239 L	12.0	House	Sub Mc	yes
2 N 41 E 20DDCD	3224	70	22.6	8-75	–	–	Stock	Sub Mc	
2 N 41 E 21CADA	3185	122	29.7	11-72	3460L	10.0	Public	Sub Mc	yes
2 N 41 E 21CDDD	3240	120	40.3	8-75	3830	11.0	Stock	Sub Mc	
2 N 41 E 22BAAB	3260	68	57	–	–	–	Stock	Sub Mc	
2 N 41 E 24CAAC	3450	27	23.6	7-73	–	–	Stock	RO	
2 N 41 E 24CABA	3460	18	–	7-73	–	–	House	RO	
2 N 41 E 27CCBC	3219	–	–	–	–	–	Stock	Alluvium or Sub Mc	
2 N 41 E 30DDAA	3360	–	–	10-73	307 L	13.0	Stock	Unknown	yes
2 N 41 E 32DABB	3420	300	140	–	–	–	Stock	Sub Mc	
2 N 41 E 33DAAA	3270	519	315	–	–	–	Public	Tullock	
2 N 41 E 33DAAD$_1$	3270	1520	60	–	–	–	Public	Hell Creek	
2 N 41 E 33DAAD$_2$	3270	596	203	–	–	–	Public	Tullock	
2 N 41 E 34BADC	3120	9336	–	–	–	–	Public	Madison	
2 N 41 E 34BCBB	3260	614	–	–	–	–	Public	Tullock	
2 N 42 E 04DACA	3003	102	60	8-73	205 L	11.5	Stock	Sub Mc	yes
2 N 42 E 05CABB	3077	–	56.5	8-73	207 L	11.0	Stock	Sub Mc	yes
2 N 42 E 06CBDC	3140	120	87.3	11-72	1850	12.0	Stock	Sub Mc	yes
2 N 42 E 07DCAD	3135	–	–	–	–	–	–	Sub Mc	
2 N 42 E 09CCBA	3087	–	–	–	–	–	–	Sub Mc	
2 N 42 E 20CDAD	3195	115	–	11-72	–	–	Stock	Sub Mc	
2 N 42 E 30CDCB	3245	200	–	–	–	–	Stock	Sub Mc	
2 N 42 E 32DBCC	3130	100	–	–	–	–	Stock	Sub Mc	
1 N 38 E 10ADCA	3679	–	–	–	–	–	Stock	RO+	
1 N 38 E 11BBCB	3740	–	34.7	8-73	5040	–	Stock	RO+	
1 N 38 E 13CDCC	3660	–	–	–	–	–	Stock	RO+	
1 N 39 E 01BBBA$_1$	3460	84	30	–	–	–	Stock	Sub Mc	
1 N 39 E 01BBBA$_2$	3476	96	39.9	7-73	–	–	Stock	Sub Mc	

Table 3.—Continued

Location	Altitude (feet)	Well depth (feet)	Depth to water (feet)	Date examined	Specific conductance	Temperature (°C)	Water use	Aquifer	Water analysis
1 N 39 E 02BBBB	3535	–	–	–	–	–	Stock	Unknown	
1 N 39 E 04AABC	3537	–	–	–	–	–	Stock	Unknown	
1 N 39 E 04DBCC	3643	–	–	–	–	–	Stock	Unknown	
1 N 39 E 05CBBA	3690	300	–	–	3000	12.0	Stock	RO+	yes
1 N 39 E 05CBBB	3745	–	–	–	–	–	Stock	Unknown	
1 N 39 E 10BBBB	3770	–	–	–	–	–	Stock	Unknown	
1 N 39 E 11ADAD	3860	–	–	–	–	11.0	Stock	Unknown	
1 N 39 E 12CCCC	3735	–	–	–	–	9.0	Stock	Unknown	
1 N 39 E 15BDAD	3910	–	–	–	–	–	Stock	Unknown	
1 N 39 E 23CAAA	3890	–	–	–	–	–	Stock	Unknown	
1 N 39 E 24BBBC	3826	122	62	9-73	242 L	12.0	Stock	RO+	yes
1 N 39 E 26ABBC	3978	375	–	–	–	–	Stock	RO+	
1 N 40 E 01CCCD	3418	80	34.1	7-73	–	–	Stock	RO	
1 N 40 E 02BBDC	3510	44	34.1	7-73	520	9.0	House	RO	yes
1 N 40 E 02CDCC	3512	100	42.2	10-73	125 L	11.0	Stock	Rosebud coal	yes
1 N 40 E 04DADD	3505	–	–	–	–	–	Stock	Unknown	
1 N 40 E 04DBBA	3440	200	75	–	–	–	Stock	Sub Mc	
1 N 40 E 05CCCB	3530	115	85.3	–	–	–	Stock	Rosebud coal or RO	
1 N 40 E 06ABBB	3520	128	40	–	–	–	Stock	Rosebud coal and McKay coal	
1 N 40 E 07BCBB	3720	143	84.3	–	–	–	Stock	RO+	
1 N 40 E 10DAAB	3470	132	50	–	–	–	Stock	McKay coal	
1 N 40 E 11ABBB	3558	–	–	10-73	–	–	–	Unknown	
1 N 40 E 12CBAA	3400	40	35.4	9-73	1700	10.5	Stock	Alluvium	yes
1 N 40 E 13ABAA	3426	–	–	10-73	229 L	11.0	Stock	Unknown	yes
1 N 40 E 14BBBB$_1$	3438	–	–	10-73	154 L	10.0	Stock	Unknown	yes
1 N 40 E 14BBBB$_2$	3438	–	–	10-73	134 L	–	House	Unknown	yes
1 N 40 E 15BBCB	3480	–	–	9-73	1520L	11.0	Stock	Unknown	yes
1 N 40 E 16DBAA	3520	–	42.8	9-73	–	–	Unused	Rosebud coal or RO	
1 N 40 E 17BAAA	3560	–	–	–	–	–	Stock	Unknown	
1 N 40 E 18ABBB	3640	–	–	7-73	–	–	House	Unknown	
1 N 40 E 18BABA	3630	–	–	–	–	–	Stock	Unknown	
1 N 40 E 18DDDC	3654	50	23	9-73	–	–	Unused	RO+	
1 N 40 E 21AAAD	3548	120	106.4	9-73	–	–	Unused	Rosebud coal	
1 N 40 E 23BDDB	3420	100	30	–	–	–	Stock	Rosebud coal	
1 N 40 E 24CACB	3380	66	35.3	9-73	–	–	Stock	Rosebud coal or RO	
1 N 40 E 26DABB	3423	–	–	–	–	–	Stock	Unknown	
1 N 40 E 28ADDD	3415	74	35.4	9-73	–	–	Stock	RO	
1 N 40 E 29ACBB	3550	232	80	9-73	275 L	10.5	Stock	Sub Mc	yes
1 N 40 E 34DCBB	3595	–	–	–	–	–	Stock	Unknown	
1 N 40 E 35CAAD	3298	–	–	–	–	–	Stock	Unknown	
1 N 40 E 36BACD	3440	104	85	9-73	–	–	Stock	RO	
1 N 41 E 02DACC	3330	141	76	–	–	–	Stock	Rosebud coal and McKay coal	
1 N 41 E 03BBBB	3240	55	45	–	–	–	Stock	McKay coal	
1 N 41 E 03CDDD	3330	86	67.4	8-73	1600	11.5	Stock	RO	yes
1 N 41 E 04DDBA	3330	–	–	–	–	–	Stock	Unknown	
1 N 41 E 06ACAB	3470	–	–	–	–	–	Stock	Unknown	
1 N 41 E 06DDDB	3365	–	–	–	–	–	Stock	Unknown	
1 N 41 E 07DBBA	3360	125	100	10-73	1160L	11.0	Stock	Sub Mc	yes
1 N 41 E 08BBDB	3320	50	–	–	–	–	Stock	Alluvium	

Table 3.—Continued

Location	Altitude (feet)	Well depth (feet)	Depth to water (feet)	Date examined	Specific conductance	Tempera-ature (°C)	Water use	Aquifer	Water analysis
1 N 41 E 08BBDC	3320	389	–	3-73	2610L	13.0	House	Sub Mc	yes
1 N 41 E 08BBDD	3320	50	–	–	–	–	Stock	Alluvium	
1 N 41 E 08CBAB$_1$	3357	100	–	10-73	776L	11.0	Stock	Rosebud coal	yes
1 N 41 E 08CBAB$_2$	3345	18	–	10-73	–	–	Unused	Alluvium	
1 N 41 E 12CBDB	3360	51+	–	8-73	3000	15.5	Stock	Unknown	yes
1 N 41 E 13CDCD	3290	200	108.9	11-72	2150	16.0	Irrigation	Sub Mc	yes
1 N 41 E 17BBBB	3390	–	–	–	–	–	Stock	Unknown	
1 N 41 E 23BCDC	3230	74+	44.9	8-73	254 L	19.0	Industrial	Sub Mc	yes
1 N 41 E 23CCAD	3260	300	190	-70	–	–	House	Sub Mc	
1 N 41 E 24DDBB	3150	30+	13.8	8-73	–	–	Stock	Sub Mc	
1 N 41 E 25DDBB	3085	60+	38.3	8-73	–	–	Stock	Sub Mc	
1 N 41 E 26BCAB	3190	195	23.5	8-73	–	–	Unused	Sub Mc	
1 N 41 E 30BBCD	3328	90	30	9-73	–	–	Stock	Rosebud coal	
1 N 41 E 31AADA	3255	153	83.3	9-73	–	–	Stock	Sub Mc	
1 N 41 E 33BCCB	3190	65	22.0	9-73	–	–	Stock	Sub Mc	
1 N 42 E 07CBBD	3260	940	–	2-72	–	–	Fire	Hell Creek	
1 N 42 E 19DBBA	3128	67	22.7	8-73	1600	11.0	Stock	McKay coal	yes
1 N 42 E 28BDDC	3010	53	17.8	8-73	190 L	10.0	Stock	Sub Mc	yes
1 N 42 E 31BBBC	3090	–	–	8-73	–	–	Stock	Sub Mc	
1 N 42 E 32DADD	2990	80	33.7	8-73	–	–	Stock	Sub Mc	
1 N 42 E 33ADBC	2970	42	24.2	9-72	3200	10.0	Stock	Sub Mc	yes
1 N 42 E 33BDCA	2990	91	57	8-73	–	–	Stock	Sub Mc	
1 S 40 E 02CACC	3415	–	–	–	–	–	Stock	Unknown	
1 S 40 E 03BACD	3500	–	–	–	–	–	Stock	Unknown	
1 S 40 E 05CDAD	3660	–	–	9-73	–	–	Stock	RO+	
1 S 40 E 06DADA	3757	150	120	9-73	–	–	Stock	RO+	
1 S 40 E 07DADA	3580	420	220	7-73	290 L	13.0	Stock	RO	yes
1 S 40 E 09DADB	3485	44	41.5	7-73	–	–	Stock	RO+	
1 S 40 E 14DCBD	3327	62	50.4	9-73	–	–	Stock	RO+	
1 S 40 E 16DABD	3410	65	60	7-73	–	–	Stock	RO+	
1 S 41 E 01DBBA	3105	54	38	9-73	–	–	Stock	Sub Mc	
1 S 41 E 02AABB	3150	81	26.5	7-73	234 L	–	Stock	Sub Mc	yes
1 S 41 E 05CADC	3220	150	105	–	–	–	Stock	Sub Mc	
1 S 41 E 06AAAC	3250	–	–	–	–	–	Stock	Unknown	
1 S 41 E 09CABC	3165	–	–	–	–	–	Stock	Unknown	
1 S 41 E 11DBCC	3130	–	–	–	–	–	Stock	Unknown	
1 S 41 E 13ACCB	3060	60	14	–	–	–	Stock	Sub Mc	
1 S 41 E 13BDDD	3060	80	14	–	–	–	House	Sub Mc	
1 S 41 E 14CCCB	3050	70	26.5	7-73	–	–	Stock	Sub Mc	
1 S 41 E 15DDCA	3091	71	–	–	–	–	Stock	Sub Mc	
1 S 41 E 17DAAD	3169	45	24	–	2450	10.5	Stock	Sub Mc	yes
1 S 42 E 03BBDC	2290	–	–	–	–	–	–	Alluvium or Sub Mc	
1 S 42 E 04DCA$_1$	3010	38	26.6	8-73	5250	11.5	Irrigation	Alluvium	yes
1 S 42 E 04DCA$_2$	3010	40	22.2	8-73	4500	13.0	Irrigation	Alluvium	yes
1 S 42 E 05ADBB	3070	–	–	–	–	–	–	Sub Mc	
1 S 42 E 07AACB	3040	–	–	–	–	–	–	Alluvium or Sub Mc	
1 S 42 E 08DAAC	3055	–	–	–	–	–	–	Sub Mc	
1 S 42 E 09ACDC	3040	–	–	–	–	–	–	Sub Mc	
1 S 42 E 16ACCA	3090	–	–	–	–	–	–	Sub Mc	
1 S 42 E 17DDDB	3196	–	–	–	–	–	–	Sub Mc	

the area is about one per 2 square miles. About eighty percent of them provide water for livestock; the others are utilized for rural-domestic, irrigation, municipal, and mining-related supplies.

OBSERVATION-WELL SYSTEM

Observation wells in and near existing and proposed mine areas (Pl. 3; Table 4) serve multiple objectives. Detailed maps of the well locations can be seen in Montana Bureau of Mines and Geology offices. Wells labeled with the prefix "P" (Table 4) form a system of three profiles installed across East Fork Armells Creek to determine and observe hydrologic conditions in alluvium along the stream. Well W-04 is one of six wells installed during a project by Westinghouse Electric Corporation (1973) to evaluate hydrologic characteristics of the oldest Rosebud mine spoils; the other five have since been destroyed during power-plant construction. Wells S-01 through S-13 and EPA-01 through EPA-12 provide data in and beneath Western Energy Company's mined area; wells S-18 through S-28 are more pertinent to their proposed mine area. Wells S-14 through S-17, and BS-15 through BS-25 relate to lands already mined by Peabody Coal Company; wells BS-01 through BS-14 relate to their existing and future operations. Because of the close proximity of the two companies' operations, observations at many of the wells will provide data pertinent to two or more mine areas.

Each well was constructed with 4-inch inside-diameter plastic casing and was designed with perforations and a seal so that data may be obtained for a specific depth. Selected wells were tested by pumping or bailing to determine aquifer characteristics. Water levels in all of them were measured approximately once a month and were plotted on hydrographs to distinguish trends of rise or decline. Water samples for chemical analysis were obtained from selected wells periodically in order to determine natural or mining-related changes in water quality. The observation program will continue as long as funding is available or as long as it remains practical.

Measurements in the wells have thus far shown a variety of trends. Water levels in a series of wells for observations in, beneath, and very close to the Rosebud mine area reacted strongly to recharge during spring and early summer in 1975 and again in 1976 (Fig. 5). Recharge to the water table, based upon estimated aquifer porosity of 25 percent, ranged between 2 inches and 9 inches in 1975. The aquifers, all shallow and all sensitive to surface hydrology, received little or no recharge during 1974. It is evident that optimum conditions are required to recharge the ground-water system and that they do not occur every year.

Water levels in observation wells (EPA-01 through EPA-12) near an experimental impoundment in the southern part of the Rosebud mine reacted very strongly to recharge during 1975 and 1976 (Fig. 6) as the impoundment filled with rainfall and snowmelt. Mine spoils beneath the impounded pond are very sandy and allow enough leakage that they temporarily become completely saturated. Hydrostatic pressure in the McKay coal bed there, about 10 feet below the spoils, also reacts to the leakage, and water levels have increased by more than 2 feet since January 1975. Details of the experimental pond and of further observation will be described in subsequent reports; it seems that impoundments can provide very substantial recharge to mine spoils and that some of the recharge can be transmitted through underlying geologic materials.

The water table in alluvium along East Fork Armells Creek received variable amounts of recharge in 1975 and 1976, partly natural and partly induced by construction activity. Downstream from Colstrip at well P-12, the water table rose more than a foot because of natural recharge in May 1975 (Pl. 4; Fig. 7), and then rose sharply again in July because of leakage from Montana Power Company's reservoir of imported cooling water. Leakage was at least partly controlled in August, and the water table then declined to relatively normal levels. One mile upstream from Colstrip, between proposed mine areas A and B, water levels in wells along the stream rose 2 to 4 feet each year, indicating 6 to 12 inches of late winter and spring recharge to alluvium there. Recharge to alluvium in area C, 7 miles upstream from Colstrip, was less pronounced; water levels in observation wells there rose less than 2 feet. At all monitoring locations along East Fork Armells Creek (Pl. 4; Fig. 7) water levels declined from spring and early summer recharge peaks until the end of the growing seasons, and then began gradual recoveries during fall and early winter months.

Hydrostatic-pressure changes in the Rosebud and McKay coal beds near Western Energy Company's proposed mine areas have been much less pronounced (Fig. 8) than those in the alluvium. Water levels in wells where the coal beds lie 130 to 250 feet below land surface changed very little during 1975 and 1976. No pressure or water-level reactions to activities at the Rosebud mine are evident thus far. Gradually rising water levels in wells completed in the McKay coal are unexplainable; there are no corresponding changes of

Table 4.–Observation wells near Colstrip, southeastern Montana.

Location	Altitude* (feet)	Designation	Well depth**	Date drilled	First measurement		Sept. 9, 1976 water-level measurement**	Aquifer	Relation of ground water to mining
					Date	Depth to water**			
2 N 41 E 28AAAC	3190	P-11	23	01-10-75	02-03-75	7.81	7.12	Alluvium	Along Armells Creek, downgradient from mined areas and proposed mine areas
"	3190	P-12	26	01-10-75	02-03-75	5.95	4.77	"	"
2 N 41 E 35DABD	3257s	S-12	45	09-21-73	10-23-73	26.63	27.12	McKay coal	Downgradient from mined areas
"	3255s	S-13	24	09-21-73	10-23-73	19.87	20.80	Rosebud coal	"
1 N 40 E 13CCDC	3480	S-22	225	12-11-74	01-10-75	100.42	99.99	McKay coal	Upgradient from mined areas and proposed mined areas
"	3480	S-23	195	12-12-74	01-10-75	100.07	100.25	Interburden sandstone	"
"	3480	S-24	149	12-13-74	01-10-75	105.72	105.28	Rosebud coal	"
1 N 40 E 15BBAB	3492	P-10	61	12-18-74	01-10-75	20.62	19.81	"	Near Armells Creek, upgradient from proposed mine areas
1 N 40 E 15BBDA	3477	P-09	40	12-18-74	01-10-75	8.80	8.65	"	"
1 N 40 E 15BDBB	3487	P-08	47	12-17-74	01-10-75	17.25	16.70	"	"
1 N 40 E 15BDBD	3489	P-07	60	12-17-74	01-10-75	20.89	20.00	"	"
1 N 41 E 01BCAB	3253s	S-10	38	09-20-73	10-23-73	dry	dry	Spoils	Within mined area
"	3254s	S-11	59	09-20-73	10-23-73	35.22	37.51	McKay coal	Beneath mined area
1 N 41 E 01DDAC	3245s	S-08	48	09-19-73	10-23-73	22.93	23.56	McKay coal	"
"	3244s	S-09	27	09-19-73	10-23-73	dry	dry	Spoils	Within mined area
1 N 41 E 03AABB	3264s	W-04	32	03-22-73	03-23-73	26.20	–	Spoils	"
1 N 41 E 04AABB	3274s	P-06	50	12-05-74	12-20-74	23.37	22.92	McKay coal	Near Armells Creek, between proposed mine areas
1 N 41 E 04AABD	3256s	P-05	33	12-05-74	12-20-74	8.34	7.56	Alluvium	"
1 N 41 E 04AADB	3262s	P-03	34	12-04-74	12-20-74	15.16	14.49	"	"
"	3254s	P-04	20	12-04-74	12-20-74	5.70	5.02	"	"
1 N 41 E 04AADD	3265s	P-02	36	12-03-74	12-20-74	17.83	17.08	"	"
1 N 41 E 04ADAA	3265	P-01	35	05-24-74	07-12-74	17.42	17.24	"	"
1 N 41 E 10AACD	3340	S-27	149	01-09-75	02-04-75	112.25	109.89	McKay coal	Downgradient from proposed mine areas
"	3340	S-28	130	01-09-75	02-04-75	82.54	82.54	Rosebud coal	"
1 N 41 E 12ADDD	3262s	S-06	50	09-18-73	10-23-73	37.47	37.61	McKay coal	Beneath mined area
"	3261s	S-07	22	09-18-73	10-23-73	dry	dry	Spoils	Within mined area
1 N 41 E 13CAC	3345	S-25	134	01-08-75	02-04-75	117.21	115.53	McKay coal	Between proposed mine areas
"	3345	S-26	119	01-08-75	02-04-75	81.05	80.69	Rosebud coal	"
1 N 41 E 16BAB	3410	S-18	248	05-16-74	07-12-74	126.23	128.49	McKay coal	Upgradient from proposed mine areas
"	3410	S-19	225	05-23-74	07-12-74	99.04	99.07	Rosebud coal	"
1 N 41 E 18ADC	3455	S-21	185	12-11-74	01-10-75	122.03	122.81	"	"
"	3455	S-20	209	12-10-74	01-10-75	141.39	140.01	McKay coal	"

*Altitude of land surface: Indicated "s", surveyed, accurate to ± 0.5 foot; otherwise estimated from U.S. Geological Survey topographic maps, altitudes generally accurate to ± 10 feet; datum is mean sea level.

**Depths measured in feet below land surface.

Table 4.–Continued

Location	Altitude* (feet)	Designation	Well depth**	Date drilled	First measurement		Sept. 9, 1976 water-level measurement**	Aquifer	Relation of ground water to mining
					Date	Depth to water**			
1 N 41 E 21DADC	3331s	BS-03	156	06-24-75	08-28-75	68.71	70.45	McKay coal	Upgradient from active mine pit
"	3331s	BS-04	121	06-25-75	08-28-75	63.58	69.59	Rosebud coal	"
1 N 41 E 24CAAD	3158s	BS-14	31	07-09-75	08-28-75	17.67	17.81	Alluvium	Downgradient from proposed mine area
1 N 41 E 24CABC	3146s	BS-12	23	07-08-75	08-28-75	11.71	12.49	"	"
1 N 41 E 24CBBC	3157s	BS-13	22	07-09-75	08-28-75	8.69	8.93	"	"
1 N 41 E 24CCBB	3151s	BS-11	22	07-08-75	08-28-75	12.21	12.22	"	"
1 N 41 E 26BBBB	3232s	BS-01	220	06-18-75	08-28-75	154.00	152.62	Sandstone below McKay coal	Downgradient from active mine pit
"	3231s	BS-02	108	06-23-75	08-28-75	44.15	39.65	"	"
1 N 41 E 27AADD	3220	S-16	40	09-24-73	10-23-73	24.07	24.09	"	"
"	3220	S-17	16	09-24-73	10-23-73	9.58	muddy	Alluvium	"
1 N 41 E 27ABCC	3273s	BS-20	97	07-22-75	10-03-75	48.67	51.31	McKay coal	Beneath mined area
"	3277s	BS-21	97	07-23-75	10-03-75	54.40	58.09	"	"
"	3276s	BS-22	58	07-23-75	10-03-75	50.30	51.15	Spoils	Within mined area
1 N 41 E 27BADC	3323s	BS-15	122	07-10-75	10-03-75	90.75	91.84	Rosebud coal	Upgradient from mined area
"	3323s	BS-24	63	07-24-75	10-03-75	56.98	57.24	Sandstone above Rosebud coal	"
"	3329s	BS-25	160	07-25-75	10-03-75	105.04	107.95	McKay coal	"
"	3307s	BS-18	107	07-17-75	10-03-75	76.10	77.12	Spoils	Within mined area
"	3284s	BS-19	83	07-21-75	10-03-75	54.73	55.43	"	"
1 N 41 E 27BDBA	3327s	BS-16	128	07-11-75	10-03-75	95.04	100.23	Rosebud coal	Upgradient from mined area
"	3336s	BS-17	134	07-15-75	08-28-75	101.77	102.85	"	"
"	3333s	BS-23	76	07-24-75	08-28-75	67.96	68.24	Sandstone above Rosebud coal	"
1 N 41 E 27DAAC	3230	S-15	34	09-24-73	10-23-73	dry	dry	Spoils	Within mined area
"	3230	S-14	51	09-21-73	10-23-73	46.35	41.32	McKay coal	Beneath mined area
1 N 41 E 28BDCB	3370	BS-07	168	07-01-75	08-28-75	86.64	88.29	"	Upgradient from active mine pit
"	3370	BS-08	131	07-02-75	08-28-75	72.27	74.03	Rosebud coal	"
1 N 41 E 29BBAA	3390	BS-05	209	07-27-75	08-28-75	120.47	120.76	McKay coal	"
"	3390	BS-06	177	07-30-75	08-28-75	92.60	93.06	Rosebud coal	"
1 N 41 E 35BCDB	3290	BS-09	105	07-07-75	08-28-75	dry	dry	McKay coal	Downgradient from mined area
"	3290	BS-10	72	07-08-75	08-28-75	dry	dry	Rosebud coal	"
1 N 42 E 07CBA	3252s	S-05	33	09-14-73	10-23-73	23.12	21.51	Alluvium	"
1 N 42 E 17BDDC	3224s	S-02	52	09-12-73	10-23-73	35.98	34.59	Spoils	Within mined area
1 N 42 E 17DBDA	3210	S-04	28	09-14-73	10-23-73	19.58	18.61	McKay coal	Beneath mined area
1 N 42 E 18AAAB	3240s	S-03	76	09-14-73	10-23-73	45.73	44.62	"	"
"	3240s	S-01	48	09-11-73	10-23-73	41.72	41.35	Spoils	Within mined area
1 N 42 E 18DAAB	3210s	EPA-11	57	12-02-74	12-11-74	27.11	20.80	McKay coal	Beneath mined area

1 N 42 E 18DAAB	3209s	EPA-12	33	12-03-74	12-11-74	28.49	20.87	Spoils	Within mined area
1 N 42 E 18DAAC	3208s	EPA-10	31	12-02-74	12-11-74	27.00	19.00	”	”
”	3209s	EPA-09	56	12-02-74	12-11-74	26.33	22.94	McKay coal	Beneath mined area
1 N 42 E 18DAAD	3201s	EPA-01	61	11-21-74	12-11-74	19.20	15.25	”	”
”	3201s	EPA-02	27	11-25-74	12-11-74	19.76	12.17	Spoils	Within mined area
”	3201s	EPA-03	28	11-25-74	12-11-74	19.49	11.60	”	”
”	3201s	EPA-04	29	11-26-74	12-11-74	19.85	11.90	”	”
1 N 42 E 18DABD	3201s	EPA-05	27	11-26-74	12-11-74	23.23	6.83	”	”
”	3201s	EPA-06	26	11-27-75	01-10-75	23.68	8.66	”	”
”	3202s	EPA-07	47	11-28-75	12-11-74	16.46	14.22	McKay coal	Beneath mined area
”	3201s	EPA-08	24	11-29-75	12-11-74	20.76	9.73	Spoils	Within mined area

* Altitude of land surface: Indicated “s”, surveyed, accurate to ± 0.5 foot; otherwise estimated from U.S. Geological Survey topographic maps, altitudes generally accurate to ± 10 feet; datum is mean sea level.

**Depths measured in feet below land surface.

water levels for the Rosebud coal. The generally consistent hydrostatic pressures in the relatively deep aquifers indicate their positions in a more regional flow system than that of the shallow aquifers. Pressures are maintained by long-term average recharge conditions; periods of many years of excessive or deficient recharge would be necessary to generate appreciable changes of hydrostatic pressures or water levels in wells.

Water levels in many wells near the Big Sky mine (Fig. 9) have been more erratic than those in other parts of the area. Alluvium along Coal Bank Coulee was recharged in 1976 similarly to shallow aquifers elsewhere. Water levels in overburden sandstone near the mine’s high wall did not vary greatly. Hydrostatic pressures in the Rosebud and McKay coal beds changed various amounts depending upon distances and directions from mining operations. The most dramatic changes were observed in wells BS-3 and -4 where water levels declined strongly as the active cut approached them. By the time the cut was within about ¼ mile of them, water levels had dropped about 6 feet. The wells are currently covered by mine spoils, so further observations have not been possible. About 1½ miles east of the mine, water levels in wells BS-5 and -6 have declined less than a foot since observations began.

Levels of shallow ground water in Miller Coulee, closely downstream from the Big Sky mine, have changed radically since 1973. Particularly dramatic changes occurred at well S-16 where the water table in shallow sandstone declined almost 10 feet in 1974, regained about 2 feet in 1975, and then rose 8 feet in 1976. The steady decline through 1974 must have been caused by a temporary interruption of flow by mining. The changes in 1975 and 1976 were probably due to combinations of mining activities and natural recharge. In spite of extreme fluctuations, the present Miller Coulee water table is approximately at its December 1973 level.

Water levels in wells within the Big Sky mined area (Fig. 10) have also changed since 1973. The McKay coal has been mined in some places and has been left behind in others, thus the Rosebud spoils, McKay spoils, and McKay coal are hydraulically interconnected. The active mine cut is moving progressively away from one well (S-14), and the water level has been rising as ground water reenters the system. A pass of the mine cut approached and passed the other wells; water levels declined as the cut approached, and then began to rise as active operations moved away.

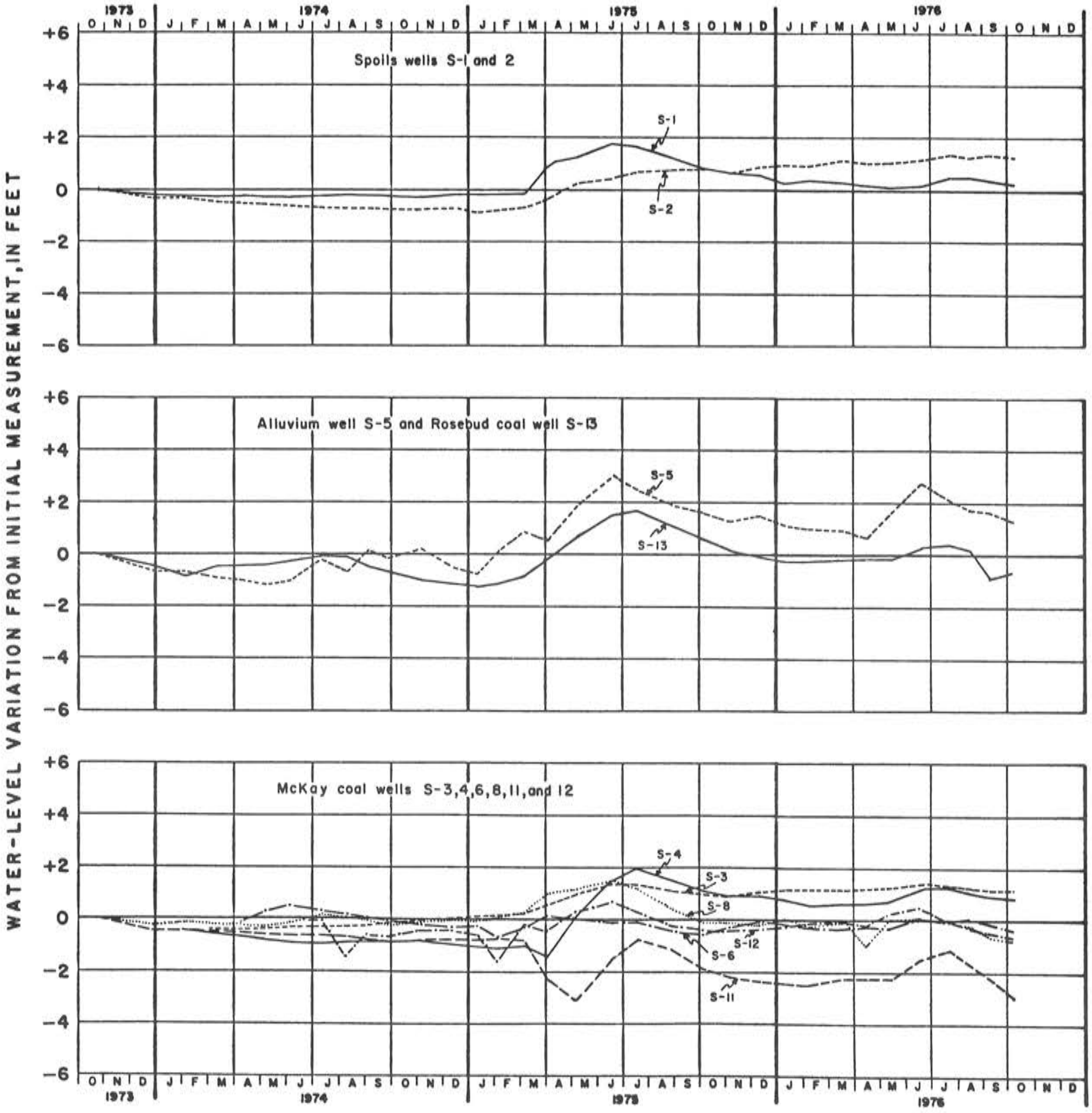

Figure 5.—Water-level changes in shallow wells in and near the Rosebud mine, southeastern Montana.

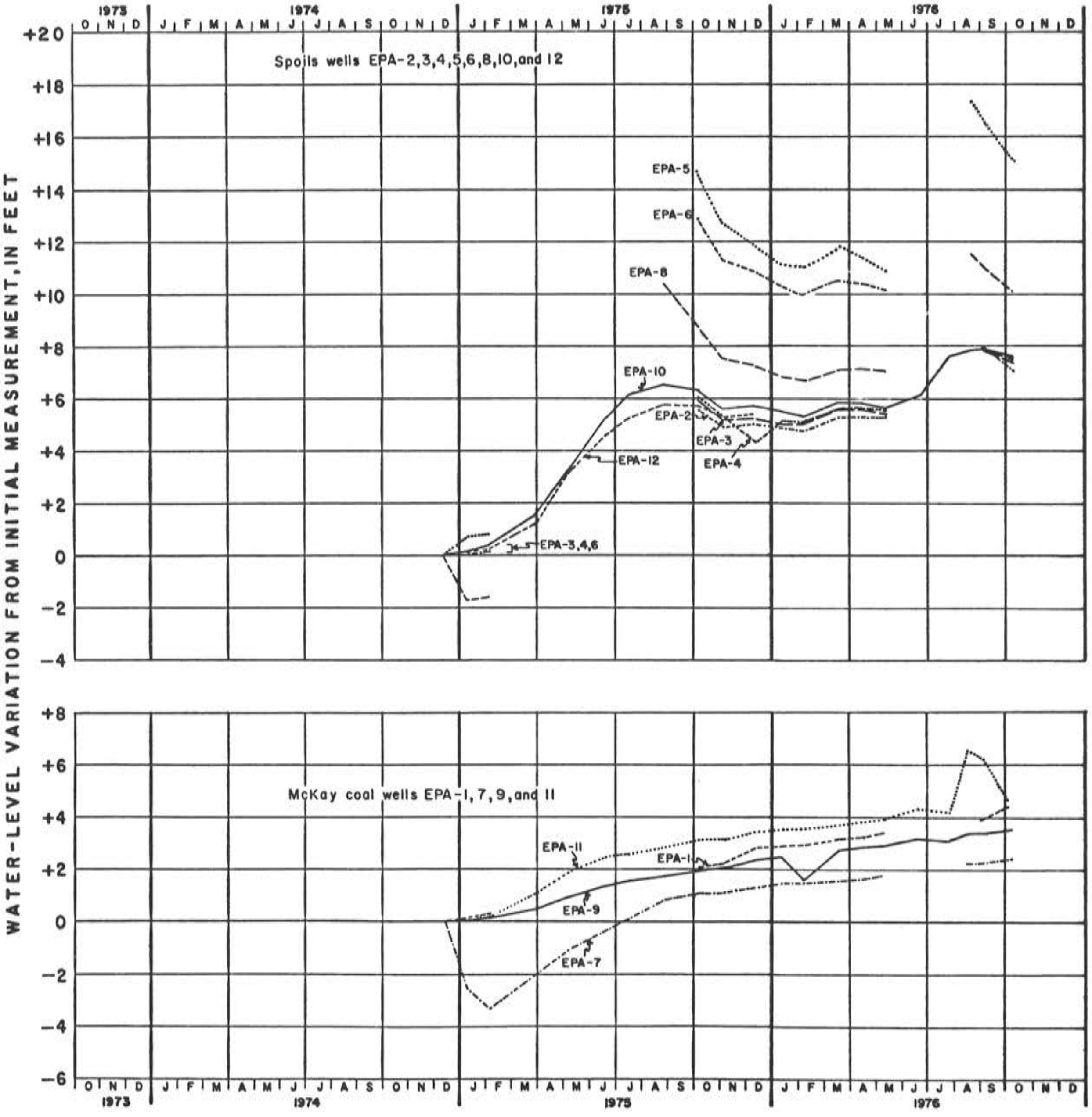

Figure 6.–Water-level changes in wells near an experimental impoundment in the southern end of the Rosebud mine, southeastern Montana.

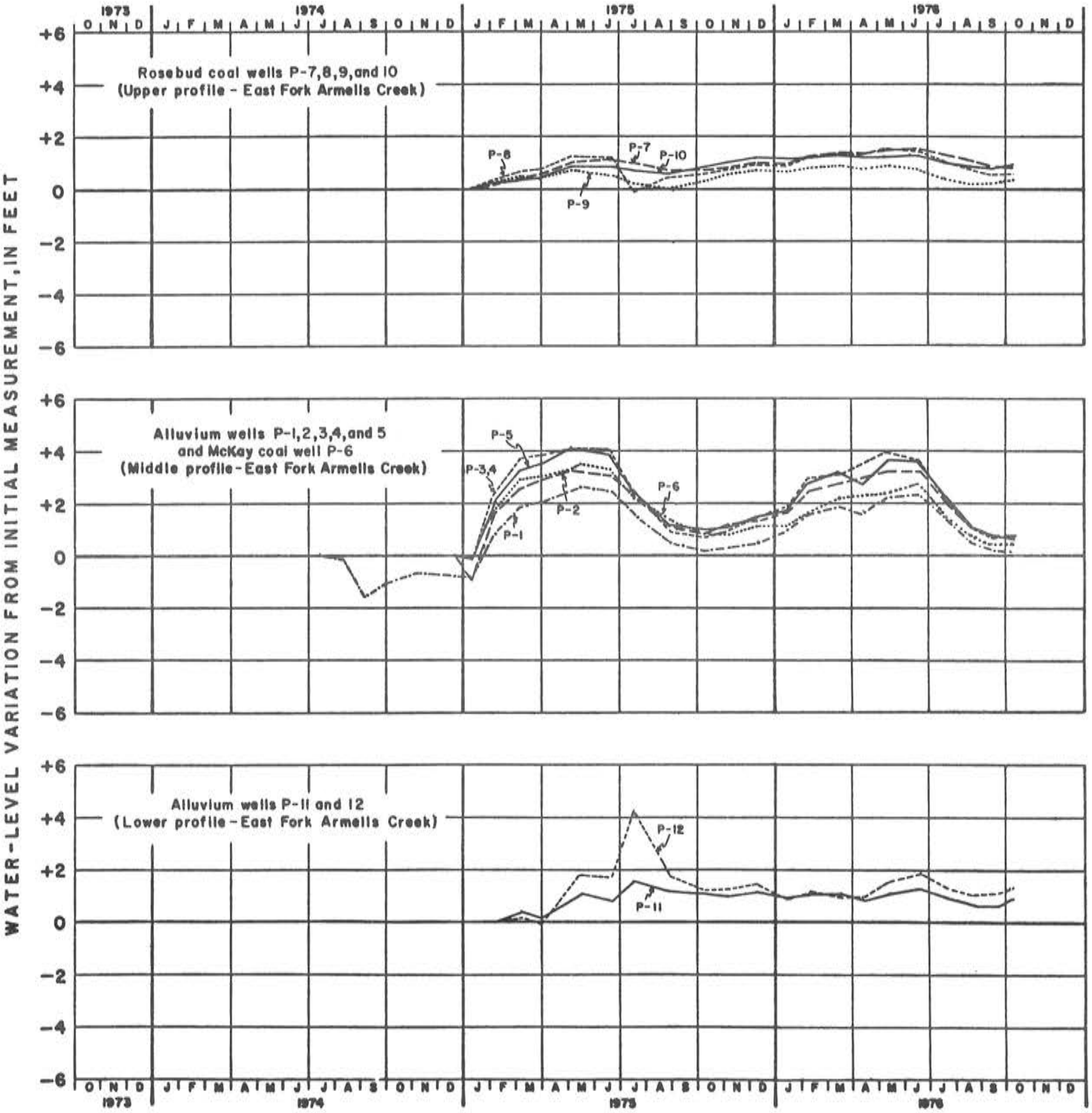

Figure 7.–Water-level changes in shallow wells near East Fork Armells Creek, southeastern Montana.

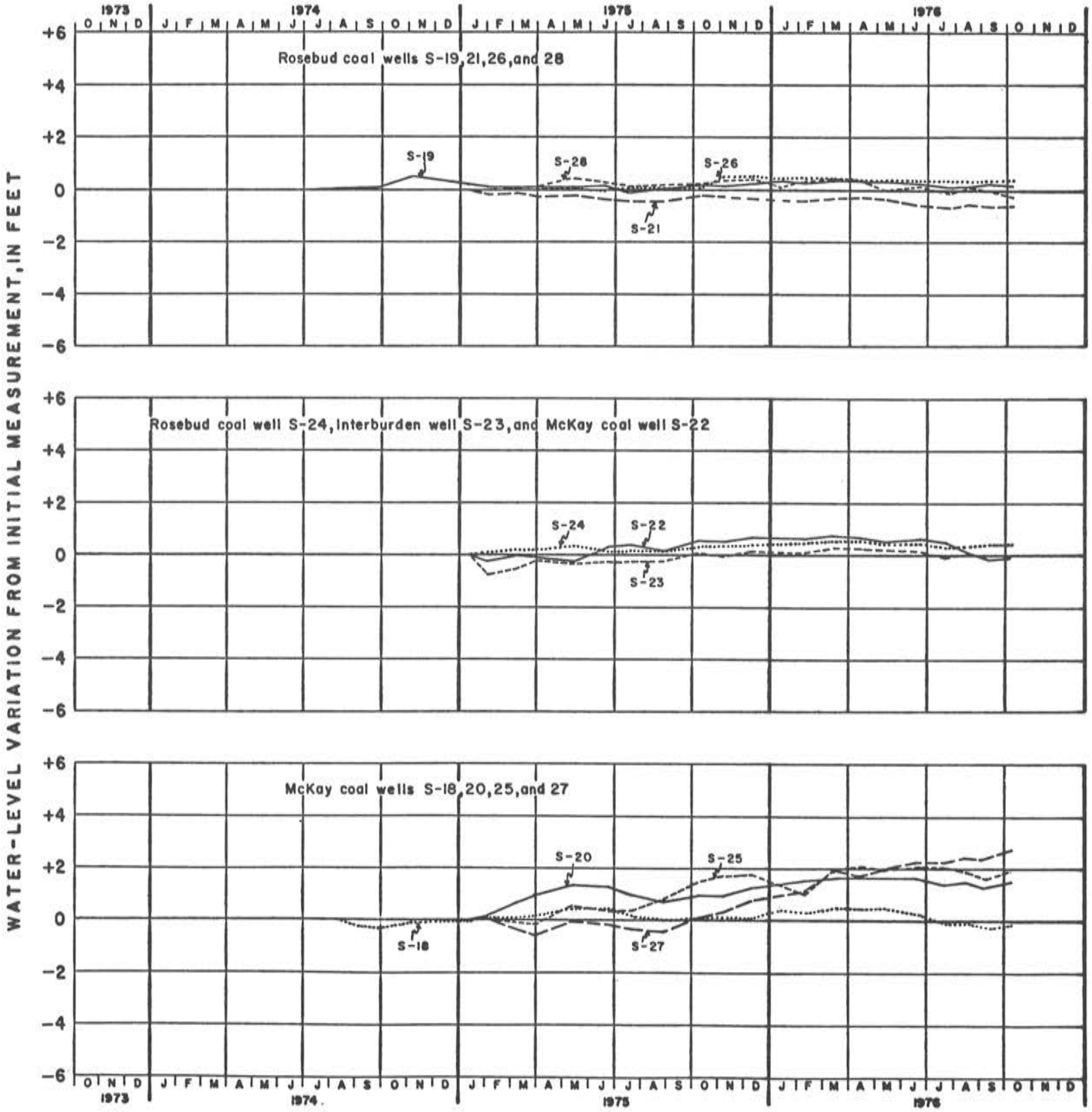

Figure 8.–Water-level changes in deep wells generally upgradient from the Rosebud mine, southeastern Montana.

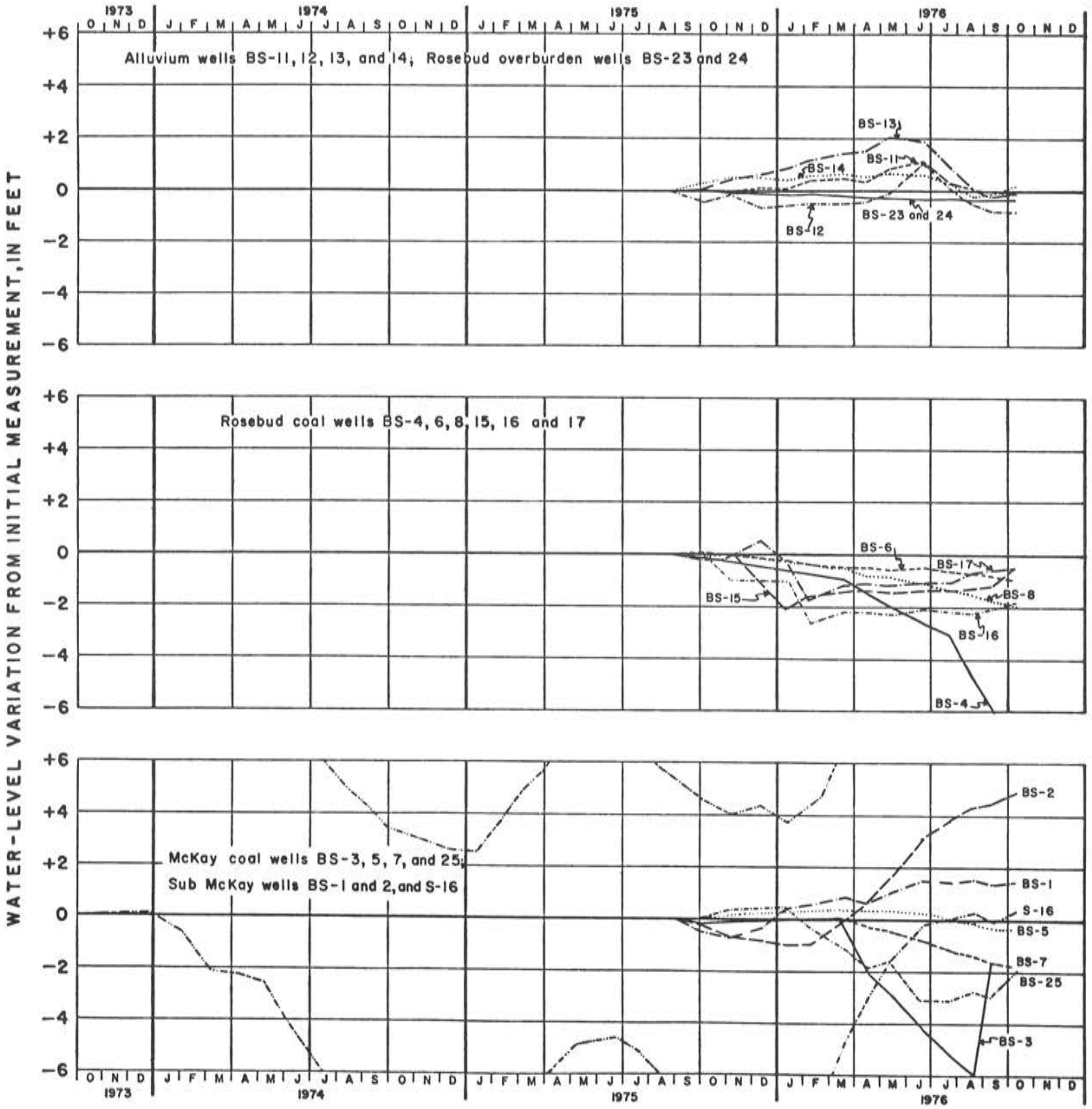

Figure 9.–Water-level changes in wells peripheral to the Big Sky mine, southeastern Montana.

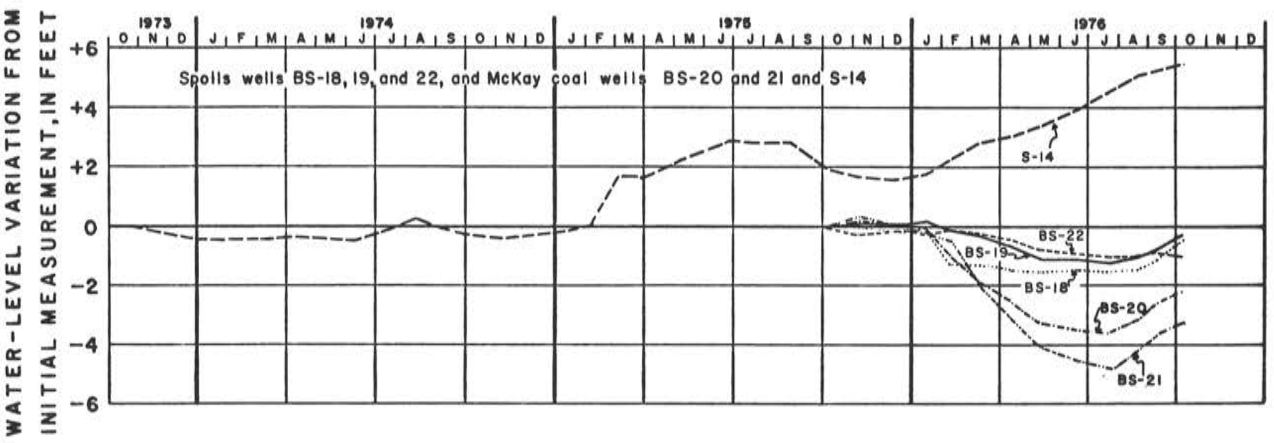

Figure 10.—Water-level changes in wells within the Big Sky mined area, southeastern Montana.

AQUIFER CHARACTERISTICS

Aquifers were tested by pumping or bailing water from selected wells in mine spoils and in undisturbed materials. Ranges of transmissivity- and hydraulic-conductivity values thus determined are very similar to those found by the Montana Bureau of Mines and Geology in other southeastern Montana coal fields (Van Voast, Hedges, and McDermott, 1976, p. 166). Transmissivities calculated from tests near Colstrip (Table 5) range from 0.1 sq. ft./day (square feet per day) to 1,900 sq. ft./day; hydraulic conductivities range from .04 ft./day (feet per day) to 160 ft./day. The highest values were found in tests of East Fork Armells Creek alluvium and are assumed to be representative along the entire reach of the creek; aquifer materials appeared similar in all wells constructed in the alluvium. Anomalous high values for Rosebud coal at well S-28 may be attributable to faulting and associated fractures at that location. Over most of the area, transmissivities and hydraulic conductivities of the Rosebud coal bed are probably less than 10 sq. ft./day and 0.5 ft./day, respectively. Values found for the McKay coal bed also have a very broad range and imply extreme variability in the areal distribution of fractures. In general, the McKay bed probably has about the same hydraulic conductivity as the Rosebud bed but has less transmissivity because it is thinner.

Eleven tests of mine spoils (Table 5) generated values in the same general ranges as those found for undisturbed coal-bed aquifers. The similar ranges of hydraulic conductivities imply that the spoils conduct ground water at about the same rates as did the Rosebud coal bed before it was removed by mining. All evidence indicates that conditions have not occurred at Colstrip that are feared for mined areas: that spoils would be conductive enough to act as ground-water sinks or that spoils would be so poorly conductive that they would seriously restrict ground-water flow.

Transmissivity and hydraulic conductivity are adequate parameters for calculations regarding steady-state or natural long-term flow conditions. An additional aquifer characteristic, storage coefficient (a dimensionless ratio), is needed for calculations predicting non-steady-state flows and water levels during relatively short periods such as during well production or inflow to mine pits. Storage coefficients for water-table aquifers (water surface at atmospheric pressure) are approximately equivalent to effective porosities expressed as decimals; they generally range between 0.1 and 0.3. In aquifers where water is confined under pressure greater than atmospheric pressure, storage coefficients are much less than effective porosities and commonly range between .01 and .000001. The alluvium along East Fork Armells Creek is probably a water-table aquifer having a range of storage coefficients between 0.1 and 0.3. Values for the confined sandstone and coal beds are estimated to be about .00001 by a method relating storage coefficient to aquifer thickness (Lohman, 1972, p. 53). Another method of estimation, based upon water-level responses to changes in atmospheric pressure (Jacob, 1940), also yielded storage-coefficient values of about .00001 at wells equipped with continuous water-level recorders. Examples of the barometric reactions (Fig. 11) show hydrologic similarities between mine spoils and undisturbed aquifers. Reactions are similar in both types of aquifers and lead to calculated storage coefficients indicative of confined conditions. The inference here is that water is at least partly confined in basal aquifers in spoils much the same as in coal-bed aquifers.

Table 5.–Transmissivity and hydraulic conductivity values for aquifers in the Colstrip area, southeastern Montana.

Well number	Location	Aquifer	Type of test*	Test discharge (cubic feet per minute)	Test duration (minutes)	Transmissivity (square feet per day)	Hydraulic conductivity (feet per day)
P-02	1 N 41 E 04AADD	Alluvium	Constant discharge	2.7	360	1900	160
S-02	1 N 42 E 17BDDC	Spoils	Bailer recovery	0.1	60	64	5.0
S-12	2 N 41 E 35DABD	McKay coal	"	.1	40	31	3.1
S-13	"	Rosebud coal	"	.1	160	1.3	0.1
S-19	1 N 41 E 16BAB	..	Constant discharge	.3	260	10	.4
S-23	1 N 40 E 13CCDC	Rosebud-McKay interburden	"	.6	360	28	.9
S-24	"	Rosebud coal	Bailer recovery	2.6	80	4.8	.2
S-27	1 N 41 E 10AACD	McKay coal	"	0.7	160	15	1.9
S-28	"	Rosebud coal	Constant discharge	1.7	360	1700	68
BS-04	1 N 41 E 21DADC	"	"	0.3	180	6.0	0.2
BS-19	1 N 41 E 27BADC	Spoils	Bailer recovery	.05	190	0.9	.04
BS-22	1 N 41 E 27ABCC	"	"	.1	155	.1	.05
EPA-01	1 N 42 E 18DAAD	McKay coal	"	.1	180	8.0	.8
EPA-02	"	Spoils	"	.05	150	0.3	.04
EPA-03	"	"	"	.05	45	28	3.4
EPA-04	"	"	"	.1	105	37	3.9
EPA-05	1 N 42 E 18DABD	"	"	.05	295	2.1	0.2
EPA-06	"	"	"	.05	212	1.7	.3
EPA-07	"	McKay coal	"	.1	160	0.7	.07
EPA-08	"	Spoils	"	.05	90	8.1	1.8
EPA-10	1 N 42 E 18DAAC	"	"	.05	50	24	5.7
EPA-12	1 N 42 E 18DAAB	"	"	.05	80	13	4.6

* Constant discharge: analysis with Jacob (1940) modification of Theis (1935) nonequilibrium equation. Bailer recovery: analysis with Skibitzke (1958) equation for residual drawdown after multicycle bailing.

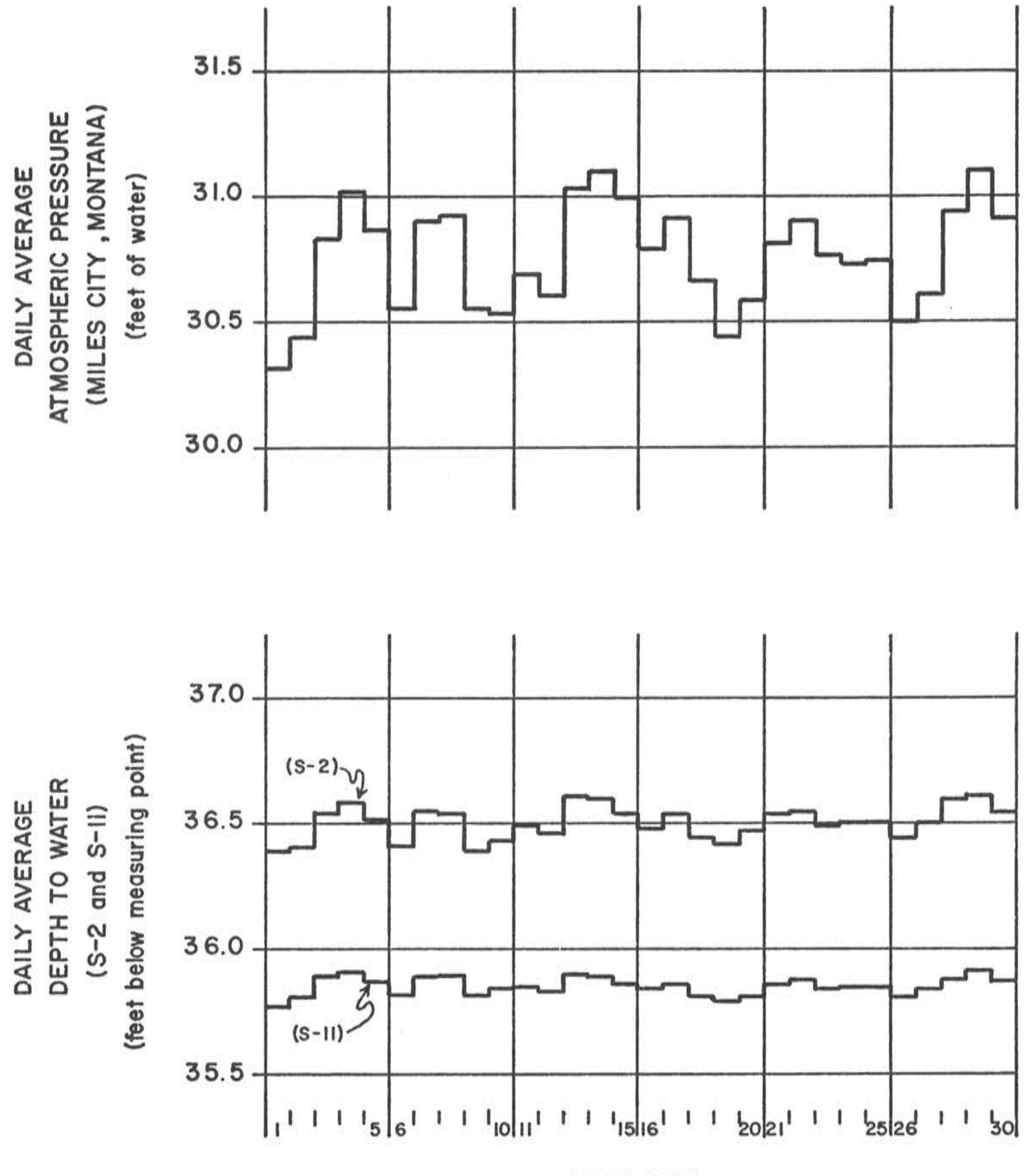

Figure 11.–Comparisons of barometric reactions of water levels in mine spoils and in undisturbed aquifers.

GROUND-WATER FLOW

The aquifer to be most disturbed by mining, the Rosebud coal bed, transmits water eastward across the project area (Pl. 5). The flow patterns are controlled by the structural gradient, variations in transmissivities, and the outcrop geometry of the aquifer. The aquifer receives most of its recharge from uplands west of the active mines. Discharge occurs to alluvium along East Fork Armells Creek and to eastern and northern outcrops. Discharge from coal and other bedrock aquifers also maintains shallow ground-water flow in thin alluvial deposits along watercourses such as Lee Coulee, Miller Coulee, and Coal Bank Coulee. Flow patterns for the Rosebud coal aquifer are generally applicable to shallower aquifers (excluding alluvium) and to deeper ones (as much as 200 feet below the Rosebud coal). Piezometric surfaces for shallower aquifers probably have similar trends but are more localized by outcrop patterns; piezometric surfaces of the deeper aquifers probably resemble the one illustrated in Plate 5 but are more subdued.

Calculations of ground-water flow rates are somewhat tenuous because of complex flow patterns and diverse transmissivities. Approximate natural flow rates into mined and proposed mine areas through the Rosebud and McKay beds, based upon estimated average transmissivities of 10 sq. ft./day and 5 sq. ft./day, respectively, and upon the flow gradients in Plate 5, are listed below:

Area	Rosebud coal (cu. ft./day)	McKay coal (cu. ft./day)
A*	450	700
B	600	300
C	2,000	1,000
D*	125	420
E	500	250
existing Rosebud mine	200	100
a	1,000	500
existing Big Sky mine	400	200

Flow of ground water in alluvium along East Fork Armells Creek is almost parallel to the watercourse. The alluvium is recharged vertically from precipitation and streamflow, and laterally from subcrops of bedrock aquifers. Most water in the alluvium is transmitted within the basal gravel beds. In proposed mine area C (profile A-A′, Pl. 4), the gravel overlies Rosebud coal and directly recharges the coal-bed aquifer. It has little apparent hydrologic relation to the stream channel. Between areas A and B (profile B-B′), the gravel is recharged directly by water from the McKay coal, and indirectly by water from the Rosebud coal subcrop and the stream channel. Downstream from any proposed mine areas, at profile C-C′, ground water discharges from gravel and bedrock to East Fork Armells Creek. Transmissivity of the gravel (about 2,000 sq. ft/day) is many times greater than that of the bedrock aquifers. The average hydrostatic-pressure gradient within the alluvium is about 25 feet per mile in the downstream direction of East Fork Armells Creek, and the implied rate of ground-water flow is about 10,000 cu. ft./day.

Calculations of ground-water flow rates show the relative efficiencies of the geologic materials as aquifers. The estimated average length of Rosebud and McKay coal outcrops and subcrops within the Rosebud Creek drainage (between tributaries Pony Creek and Richard Coulee, Pl. 5) is about 13 miles. Estimated total discharge along the outcrops and subcrops, based upon 10 sq. ft./day and 5 sq. ft./day coal-bed transmissivities and upon an average gradient of 25 ft./mi., is about 5,000 cu. ft./day from the two coal beds. This is about half the rate at which ground water leaves the area by way of East Fork Armells Creek alluvium. Altogether, the two coal beds and the alluvium transmit an estimated 15,000 cubic feet of water per day eastward across the project area.

WATER QUALITY; MAJOR CONSTITUENTS

Specific-conductance values for spring and well waters provide a general overview of the chemical quality of ground waters being used in the area. Specific conductance, a measure of electrical conductivity, is an indicator of degree of mineralization of water; near Colstrip, the dissolved-solids concentration in water, in mg/l (milligrams per liter), was found to be numerically equivalent to about 0.8 times the water's specific conductance in μmhos/cm (micromhos per centimeter). A wide range of specific-conductance values (520 to 7,320 μmhos/cm), indicating a wide range of dissolved-solids concentrations (420 to 5,860 mg/l), was found for waters from springs and wells (Tables 2 and 3). Median specific conductance (Fig. 12) was 2,100 μmhos/cm (1,700 mg/l); 50 percent of the well and spring waters had values between 1,600 and 3,300 μmhos/cm (1,280 and 2,640 mg/l). Comparisons of degree of ground-water mineralization with stratigraphic position of aquifers, position in the flow system, and areal distribution show no specific trends.

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*Rosebud coal only partly saturated in areas A and D.

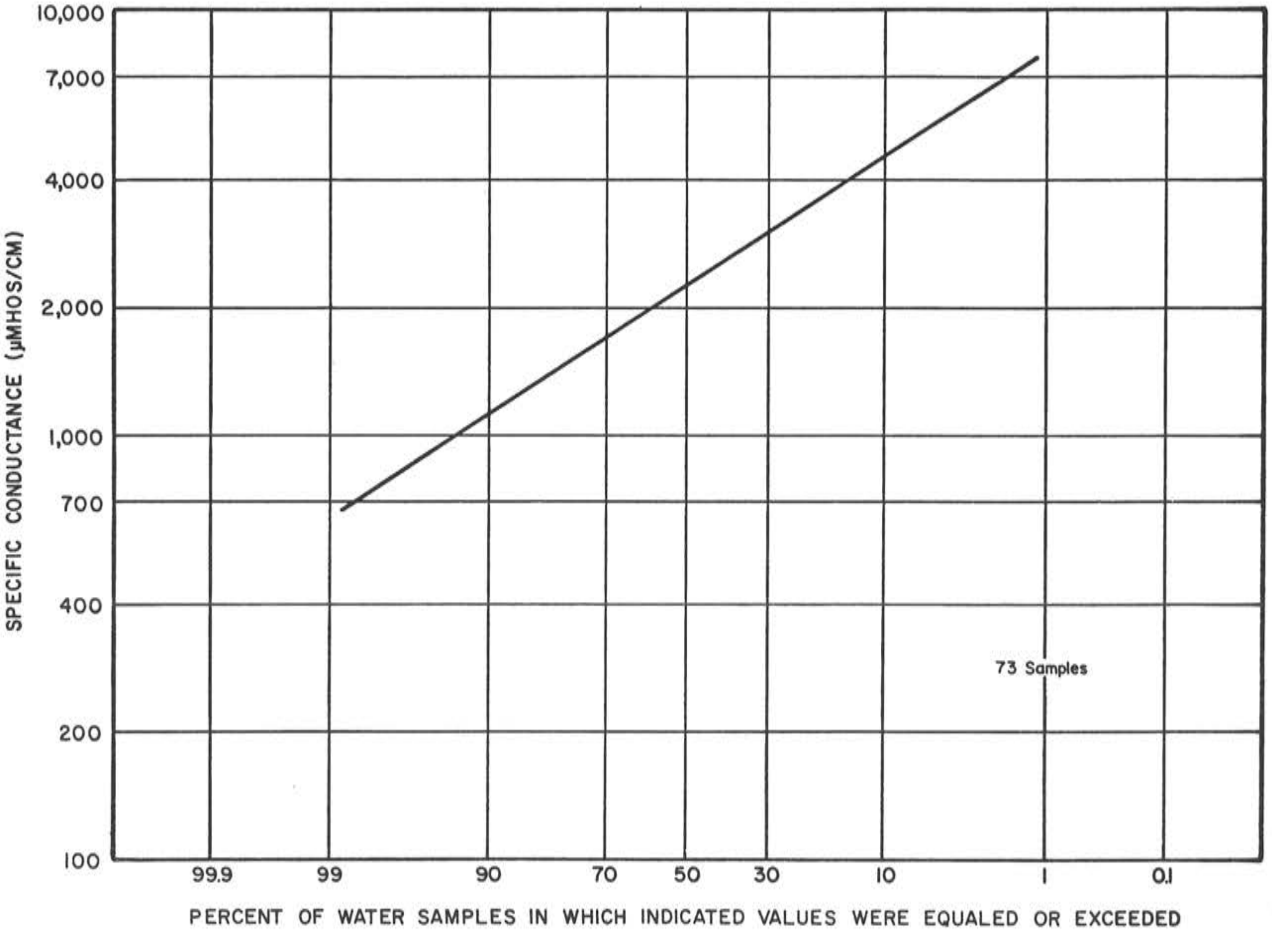

Figure 12.–Statistical distribution of specific-conductance values measured for spring and well waters near Colstrip, southeastern Montana.

Chemical analyses of waters collected from a wide variety of sources illustrate baseline conditions and enable comparisons of water quality in mined and unmined areas. Sources of waters that were sampled for analyses of major chemical constituents have three principal categories: springs and water wells (Table 6); observation wells (Table 7); and pits, ponds, and streams (Table 8). Sources and dissolved-solids concentrations of sampled waters are identified on Plate 6.

Waters from the springs and water wells vary greatly in degree and type of mineralization. No specific cation is predominant in water from any particular aquifer, depth, or locale; calcium, magnesium, and sodium occur in many different proportions regardless of the total concentrations of dissolved solids. The predominant anion in most waters is sulfate. Numerous exceptions are the waters containing less than 1,000 mg/l of dissolved solids; in these, bicarbonate concentrations approach or exceed those of sulfate.

Samples collected from observation wells (Table 7) represent waters from a large number of sources within and beneath existing and proposed mine areas. Data in Table 7 and sample-collection locations in Plate 6 illustrate some general aspects of ground-water quality:

(1) Dissolved-solids concentrations in water from the East Fork Armells Creek alluvium are about 50 percent greater downstream from Colstrip (wells P-11, -12) than upstream from Colstrip (wells P-01, -02, -03, -04, -05).

(2) Water in alluvium upstream from Colstrip (wells P-01, -02, -03, -04, -05) is chemically very similar to water in the adjacent McKay coal bed (well P-06).

(3) Chemical quality of water in the Rosebud coal differs greatly at different locations (wells S-19, -28).

Table 6.–Chemical analyses of waters from springs and water wells near Colstrip, southeastern Montana.

Location	Well depth (feet)	Date sampled	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrogen, nitrate (NO_3/N)	Dissolved solids (calc.)	Total hardness as $CaCO_3$ (calc.)	Alkalinity as $CaCO_3$	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH (laboratory)	Collecting agency a/	Aquifer b/
2 N 38 E 15CCDC	--	07-02-73	10.	16.	<.01	<.01	25.	126	64.	4.3	405	0.	385	4.7	0.1	.70	827	589	332	1.2	1230	8.3	MBMG	Sub Mc
2 N 39 E 05BCBA	57	09-13-73	11.	9.5	<.01	.06	54.	108	318	5.9	323	0.	980	7.5	5.9	.27	1650	585	265	5.7	2210	8.3	USGS	"
2 N 39 E 05DDDC	16	09-13-73	14.	11.	.01	.06	249	553	905	13.	703	0.	4180	27.	<.1	<.02	6290	2940	576	7.3	6640	7.9	"	Alluvium or Sub Mc
2 N 39 E 12CCC$_1$	555	11-10-72	14.	11.	.09	.01	2.4	0.8	330	1.0	739	15.	42.	30.	4.2	.07	800	9	631	47.	1250	8.6	"	Tullock
2 N 39 E 23CAAB	–	07-26-73	27.	14.	.01	.15	51.	97.	108	5.7	523	0.	330	4.3	0.2	.41	870	534	429	2.1	1240	8.0	"	Sub Mc
2 N 39 E 24CDAB	140	07-25-73	–	9.6	.02	<.01	144	162	450	7.9	508	0.	1550	9.6	.3	.05	2590	1040	417	6.1	3030	8.1	"	"
2 N 39 E 25ACDC	136	07-12-73	–	8.6	.04	.02	277	464	552	11.	673	0.	3130	22.	.4	.07	4800	2630	552	4.7	5060	7.8	"	"
2 N 39 E 31ABAA	Spring	10-04-72	12.	18.	.05	.02	196	387	330	13.	571	0.	2230	12.	.3	.77	3470	2110	468	3.1	3760	7.9	"	Rosebud coal
2 N 39 E 32DDDD	–	07-11-73	13.	19.	.14	.02	204	306	310	11.	514	0.	1950	11.	.3	.77	3060	1780	422	3.2	3990	8.0	"	Unknown
2 N 39 E 34ADBB	60	07-10-73	–	11.	0.2	0.5	157	327	179	8.5	721	0.	1480	12.	.2	.23	2530	1760	592	1.9	2940	7.9	"	Rosebud coal
2 N 39 E 34DADB	80	07-10-73	16.	14.	.93	.13	169	180	92.	5.3	484	0.	950	7.3	.1	.11	1660	1170	397	1.2	2050	7.9	"	"
2 N 40 E 06CBCB	104	07-25-73	11.	8.6	.08	.03	22.	14.	694	3.4	507	14.	1130	12.	.5	.09	2150	110	439	29.	2840	8.4	"	Sub Mc
2 N 40 E 18DADC	Spring	10-06-72	13.	11.	.12	.01	115	304	478	15.	734	0.	1880	19.	.1	.07	3190	1560	602	5.3	3700	8.0	"	"
2 N 40 E 30BAAD	246	07-13-73	14.	7.5	4.3	.09	77.	108	662	5.9	449	0.	1660	12.	.5	.05	2750	641	369	11.4	3360	8.1	"	"
2 N 40 E 31DCCD	165	11-09-72	13.	22.	.51	.05	162	136	78.	4.5	479	0.	703	7.8	.1	<.02	1350	968	393	1.1	1740	7.6	"	Rosebud and McKay coal
2 N 40 E 32BBAB	–	07-12-73	–	11.	.16	.02	83.	86.	24.	2.4	483	0.	209	3.1	.3	.07	658	565	396	0.4	991	7.9	"	Sub Mc
2 N 40 E 35DDCD	250	07-13-73	12.	14.	.83	.43	256	215	170	6.2	781	0.	1220	9.9	.3	.23	2270	1530	641	1.9	2670	7.9	"	"
2 N 41 E 01DBBA	–	08-30-73	12.	12.	<.01	.03	31.	92.	28.	3.7	220	19.	274	5.5	<.1	2.06	582	462	212	0.6	878	8.6	"	"
2 N 41 E 02DBBA	220	11-01-72	–	10.	3.0	.10	218	109	512	8.7	376	0.	1740	9.9	.3	.02	2790	995	309	7.1	3290	8.0	"	"
2 N 41 E 10BCBC	150	07-19-73	13.	11.	.50	.03	169	98.	55.	6.3	363	0.	620	6.5	.2	1.58	1150	826	298	0.8	1790	7.9	"	"
2 N 41 E 17ADAA	110	10-03-73	12.	12.	<.01	.02	138	200	178	9.2	398	0.	1160	29.	.2	.23	1920	1180	327	2.3	2400	8.0	MBMG	"
2 N 41 E 17ADAD	Spring	10-03-73	14.	16.	<.01	.01	169	250	218	24.	529	19.	1370	21.	.3	2.87	2360	1470	466	2.5	2800	8.5	"	"
2 N 41 E 21CADA	122	03-20-73*	10.	13.	1.3	.09	163	153	550	10.	547	0.	1700	13.	.5	.05	2880	1040	448	7.4	3460	7.4		"
2 N 41 E 30DDAA	–	10-02-73	13.	–	.03	.01	316	247	150	20.	350	0.	1770	22.	.3	.86	2700	1810	287	1.5	3080	7.7	MBMG	Unknown
2 N 42 E 04DACA	102	08-30-73	12.	11.	1.5	<.01	28.	35.	413	6.7	273	15.	832	8.8	<.1	.07	1490	217	249	12.	2060	8.5	USGS	Sub Mc
2 N 42 E 05CABB	–	08-30-73	11.	16.	<.01	.02	117	206	107	7.7	220	0.	1140	9.5	.1	.07	1710	1150	180	1.4	2070	8.3	"	"
2 N 42 E 06CBDC	120	11-01-72	12.	17.	1.45	.30	107	161	77.	5.2	429	0.	718	6.0	<.1	.16	1300	938	352	1.1	1680	7.7	"	"
1 N 38 E 15BBDA	Spring	08-13-73	3.	1.6	<.01	<.01	47.	65.	580	8.9	553	10.	1120	8.8	.2	1.36	2120	389	470	13.	2830	8.3	MBMG	Rosebud coal
1 N 39 E 05CBBA	300	07-05-73	12.	6.4	.08	.03	20.	8.2	745	4.1	258	0.	1400	13.	.5	.05	2320	84	211	35.	3140	8.2	USGS	RO+
1 N 39 E 24BBBC	122	09-27-73	12.	13.	.02	.05	130	182	213	11.	462	0.	1090	9.4	.2	.56	1870	1080	379	2.8	2420	7.8	MBMG	"
1 N 40 E 02BABD	Spring	07-27-73	17.	19.	.04	.02	380	270	65.	11.	352	0.	1850	13.	.3	.14	2780	2060	289	0.6	2930	7.5	USGS	Rosebud coal
1 N 40 E 02BBDC	44	07-19-73	9.0	11.	.02	.01	46.	34.	5.5	1.9	234	0.	58.	7.0	.1	3.39	294	256	192	.1	483	7.9	"	RO
1 N 40 E 02CDCC	100	10-02-73	11.	13.	<.01	<.01	110	107	37.	3.9	376	0.	463	3.7	.2	.16	924	721	309	.6	1260	8.1	MBMG	Rosebud coal
1 N 40 E 12CBAA	40	11-02-72	11.	29.	.08	.01	105	160	78.	5.8	447	0.	690	4.6	.2	.36	1290	930	367	1.1	1660	7.8	USGS	Alluvium
1 N 40 E 13ABAA	–	10-02-73	11.	18.	<.01	<.01	166	204	124	8.3	361	0.	1190	7.0	.1	1.06	1900	1260	296	1.5	2300	7.9	MBMG	Unknown
1 N 40 E 14BBBB$_1$	–	10-03-73	10.	13.	<.01	<.01	57.	145	94.	8.0	420	0.	585	3.8	.2	2.28	1120	749	344	1.5	1540	8.0	"	"
1 N 40 E 14BBBB$_2$	–	10-03-73	–	14.	<.01	<.01	33.	136	79.	7.6	354	0.	499	8.9	.2	4.18	969	651	290	1.4	1340	8.2	"	"
1 N 40 E 15BBCB	–	09-24-73	11.	20.	<.01	.01	91.	110	104	4.3	374	0.	586	4.2	.1	.16	1100	685	307	1.7	1520	7.7	"	"
1 N 40 E 19DCCD	Spring	09-24-73	12.	14.	<.01	<.01	80.	100	308	5.6	435	0.	870	5.9	.2	.50	1600	615	357	5.4	2090	8.0	"	RO+
1 N 40 E 29ACBB	232	09-24-73	11.	6.5	<.01	<.01	16.	5.2	650	3.6	462	0.	1050	7.4	.7	.54	1960	61	379	36.	2760	8.2	"	Sub Mc
1 N 41 E 03CDDD	86	08-20-73	12.	10.	2.7	.22	13.	145	63.	5.0	256	18.	490	8.6	<.1	.14	882	642	240	1.1	1240	8.5	USGS	RO
1 N 41 E 07DBBA	125	10-03-73	11.	40.	.06	.06	118	89.	27.	3.9	283	9.	427	6.1	.2	4.52	880	663	247	0.5	1160	8.5	MBMG	Sub Mc
1 N 41 E 08BBDC	389	03-19-73*	13.	7.1	0.65	0.02	14.	3.4	603	3.6	413	0.	978	7.9	0.4	0.02	1820	49	339	38.	2610	8.0		Sub Mc
1 N 41 E 08CBAB	100	10-02-73	11.	15.	<.01	<.01	35.	70.	27.	3.3	366	0.	118	4.3	.2	.52	455	381	300	0.6	776	8.2	MBMG	Rosebud coal
1 N 41 E 12CBDB	51+	08-02-73	16.	12.	.10	.05	62.	184	320	7.4	303	0.	1300	12.	<.1	.56	2030	925	249	4.6	2540	8.1	USGS	Unknown
1 N 41 E 13CDCD	200	07-18-73	16.	13.	2.9	.21	154	177	132	8.0	555	0.	926	6.0	.2	.05	1690	1120	456	1.7	2110	7.6	"	Sub Mc
1 N 41 E 23BCDC	74+	08-09-73	19.	16.	.26	.13	108	237	206	8.6	244	5.	1430	13.	<.1	.54	2140	1270	208	2.5	2540	8.4	"	"
1 N 42 E 19DBBA	67	08-02-73	11.	12.	.33	.08	45.	109	170	5.6	369	15.	568	8.5	.2	.07	1110	567	327	3.1	1510	8.4	"	McKay coal
1 N 42 E 28BDDC	53	08- -73	10.	12.	.70	.08	38.	145	202	7.0	321	15.	834	9.9	.2	.11	1420	704	288	3.3	1910	8.7	"	Sub Mc
1 N 42 E 33ADBC	42	09-28-72	10.	28.	3.1	.14	111	122	620	12.	515	0.	1640	16.	.5	.02	2810	786	422	9.7	3490	8.2	"	"
1 S 40 E 06BBDB	Spring	09-12-73	11.	20.	1.4	.03	15.	132	119	11.	350	30.	495	5.4	.1	<.02	1000	592	337	2.1	1420	8.8	"	RO+
1 S 40 E 07DADA	420	09-12-73	13.	12.	<.01	<.01	92.	122	435	7.6	235	0.	1440	5.5	<.1	.75	2230	735	193	7.0	2910	8.2	"	RO
1 S 40 E 08AADB	Spring	09-12-73	13.	18.	.33	.03	54.	215	180	12.	372	19.	1050	7.6	.1	.56	1740	1030	337	2.5	2230	8.4	"	RO+
1 S 40 E 12DDDA	Spring	07-24-73	14.	35.	<.01	<.01	73.	27.	33.	6.0	193	0.	197	5.0	1.5	.34	474	292	159	0.8	692	7.9	"	"
1 S 41 E 02AABB	81	09-07-73	–	17.	<.01	.10	143	195	159	10.	424	0.	1110	9.9	0.1	.36	1860	1170	347	2.0	2350	8.0	"	Sub Mc
1 S 41 E 17DAAD	45	12-01-72	11.	19.	.08	.01	120	161	295	4.8	404	0.	1210	10.	.1	.84	2030	970	331	4.1	2420	7.9	"	"
1 S 42 E 04DCA$_1$	38	08-01-73	12.	25.	.09	.18	87.	255	870	20.	557	20.	2540	33.	.5	9.04	4160	1290	490	10.6	4820	8.3	"	Alluvium
1 S 42 E 04DCA$_2$	40	08-01-73	13.	24.	.11	.29	53.	157	745	27.	438	24.	1920	27.	.4	6.33	3220	790	399	12.	3970	8.6	"	"

Samples analyzed by Montana Bureau of Mines and Geology water laboratory, Butte, except as noted

* Samples collected and analyzed by Westinghouse Electric Corporation (1973)

Concentrations in milligrams per liter

a/ Collecting agency: MBMG, Montana Bureau of Mines and Geology; USGS, U.S. Geological Survey.

b/ Interpretations by MBMG. Coded sources–RO+, more than 150 feet above Rosebud coal; RO, overburden, 150 feet above Rosebud coal; Sub Mc, unspecified aquifers stratigraphically below McKay coal.

(4) Strong differences in chemical type and degree of mineralization occur in waters from different depths at the same location (well pairs: S-27, -28; S-23, -24; and S-18, -19).

(5) Spoils in the oldest part of the Rosebud mined area (northwestern end) contain water that is generally more mineralized (wells W-02, -03, -04, -05) than waters in nearby undisturbed aquifers.

(6) Spoils in younger parts of the mined area (wells S-01, -02) contain waters that are chemically similar to waters from undisturbed aquifers.

(7) Temporal variations in chemical quality seem to occur in ground waters in and very close to mine spoils (wells S-01, -02, -04, -12, -13).

(8) In those wells where water quality changes are occurring, the greatest changes are in concentrations of calcium, magnesium, and sulfate.

The few local similarities and general relationships described above exemplify the striking lack of uniformity or predictability of ground-water quality in the Colstrip area.

Waters in pits, ponds, and streams (Table 8) have variable dependencies on precipitation, runoff, and ground-water discharge, so concentrations of their chemical constituents are probably changing constantly. Water in East Fork Armells Creek is less mineralized upstream from Colstrip than it is downstream from the town. The upstream water is chemically similar to ground water sampled from nearby wells and springs; the downstream water chemically resembles water from ponds in former Rosebud mine pits. The pits are in the oldest part of the mine and contain the most mineralized surface water in the area. The least mineralized waters were found in an impoundment at the Big Sky mine (probably snowmelt), and in an active pit at the Rosebud mine being fed by discharge from the Rosebud coal bed.

WATER QUALITY; TRACE ELEMENTS

Analyses of trace-element concentrations were conducted on selected water samples collected from streams, ponds, mine pits, and wells (Table 9). Samples were collected and preserved in accordance with U. S. Department of Interior (1972) recommended methods and were analyzed using procedures recommended by the U. S. Environmental Protection Agency (1974). A brief summary of the trace-element concentrations along with some general comments on their significance are outlined below:

Aluminum (Al)–Most concentrations were less than 0.05 mg/l. The maximum concentration was 0.23 mg/l, not enough to have significance. In a literature search, Gough and Shacklette (1976) found suggestions that at least 2 mg/l of aluminum is required to depress the most sensitive vegetation. No quantitative data are available regarding effects of human consumption.

Antimony (Sb)–Most concentrations were less than 0.20 mg/l. The maximum concentration was 0.60 mg/l. No information was found describing antimony toxicity to plants. There is no known effect on humans from antimony in drinking water (U. S. Environmental Protection Agency, 1973).

Arsenic (As)–One sample of ground water from mine spoils contained 4.4 μg/l; all other waters contained less than 2 μg/l. The U. S. Public Health Service (1962) has established a limit of 50 μg/l for arsenic permissible in public drinking water.

Beryllium (Be)–All concentrations were less than 5 μg/l. There are no known effects of beryllium in water; it is normally insoluble (U. S. Environmental Protection Agency, 1973).

Boron (B)–The maximum concentration was 2.04 mg/l. Of the ten samples containing more than 1.0 mg/l, all were associated with mined lands or were from streamflow downstream from Colstrip. Some plants such as citrus trees are sensitive to waters having concentrations greater than 1.0 mg/l (Wilcox, 1955), but crops such as alfalfa are far more tolerant.

Cadmium (Cd)–All concentrations were 0.01 mg/l or lower. Gough and Shacklette (1976) found reports in the literature describing depressed growth of plants receiving as little as 0.2 mg/l cadmium in nutrient solutions. The U. S. Public Health Service (1962) has established a limit of 0.01 mg/l cadmium allowable in public drinking water.

Chromium (Cr)–All concentrations were 0.04 mg/l or less. References listed by Gough and Shacklette indicated that chromium is one of the least toxic trace metals to man. The U. S. Public Health Service permissible limit is 0.05 mg/l chromium in drinking water.

Copper (Cu)–All concentrations were 0.03 mg/l or less except one anomalous value (0.13); little significance is attributed to the lone high concentration. The U. S. Public Health Service recommended limit

Table 7.—Chemical analyses of waters from observation wells near Colstrip, southeastern Montana.

Location	Designation	Well depth (feet)	Date sampled	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrogen, nitrate (NO_3/N)	Dissolved solids (calc.)	Total hardness as $CaCO_3$ (calc.)	Alkalinity as $CaCO_3$	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH (laboratory)	Aquifer
2 N 41 E 28AAAC	P-11	23	05-16-75	8.5	23.	0.01	0.47	229	300	255	13.	614	0.	1760	17.	0.3	0.23	2900	1820	504	2.6	3340	7.4	Alluvium
"	"	23	04-06-76	11.0	21.	.58	.57	221	295	274	14.	622	0.	1760	18.	.3	.05	2910	1770	510	2.8	3450	7.8	"
2 N 41 E 28AACA	P-12	26	05-16-75	7.0	19.	.03	.28	253	304	251	11.	571	0.	1850	19.	.2	1.13	2990	1900	469	2.5	3460	7.3	"
2 N 41 E 34DDAD	W-02^a	27	03-23-73*	–	17.	.3	4.7	481	748	23.	11.	697	0.	3640	3.2	.2	0.07	5270	4320	571	0.2	4860	7.3	Spoils
"	"	27	05-23-74	12.	14.	.03	0.37	497	731	170	16.	625	0.	3860	50.	.3	.09	5640	4290	512	1.1	5740	7.4	"
2 N 41 E 35BCDB	W-03^a	23	03-23-73*	–	24.	.4	.32	347	280	52.	15.	500	0.	1650	12.	.1	.11	2630	2020	410	0.5	2850	7.2	"
2 N 41 E 35CBAA	W-05^a	56	03-23-73*	–	19.	1.1	5.0	380	477	81.	14.	973	0.	2210	12.	.1	.25	3680	2930	798	.7	3860	7.0	"
2 N 41 E 35DABD$_1$	S-12	45	09-25-73	–	14.	0.26	0.07	53.	51.	190	8.1	553	0.	284	4.1	.1	.25	878	342	454	4.5	1370	7.9	McKay coal
"	"	45	02-04-74	–	15.	.01	.01	139	104	156	8.9	542	0.	652	5.9	<.1	.07	1350	776	445	2.4	1790	7.8	"
"	"	45	06-06-74	–	17.	<.01	.23	199	115	143	8.8	620	0.	745	7.3	.1	2.08	1550	969	508	2.0	2070	7.8	"
"	"	45	02-04-75	10.0	14.	<.01	<.01	138	111	140	8.9	439	0.	704	5.3	<.1	1.11	1340	804	360	2.2	1840	7.8	"
"	"	45	01-12-76	11.	15.	.02	.36	226	132	143	8.8	611	0.	830	7.0	.1	1.13	1670	1110	501	1.9	2140	7.3	"
2 N 41 E 35DABD$_2$	S-13	24	09-25-73	–	16.	1.8	1.3	467	351	114	9.0	483	0.	2420	16.	<.1	3.61	3650	2620	396	1.0	3770	7.9	Rosebud coal
"	"	24	02-04-74	–	17.	0.02	0.70	421	306	119	9.9	333	0.	2170	14.	<.1	2.26	3230	2320	273	1.1	3510	7.7	"
"	"	24	06-06-74	–	18.	.01	1.8	464	292	119	9.3	517	0.	2100	17.	.1	3.61	3290	2360	424	1.1	3640	7.1	"
"	"	24	02-04-75	9.0	11.	.01	0.01	333	199	77.	7.7	398	0.	1420	8.5	.2	1.22	2250	1980	326	0.8	2540	8.1	"
"	"	24	01-12-76	10.	17.	.05	1.69	509	366	119	9.6	566	0.	2390	15.	.1	1.04	3710	2780	464	1.0	3730	7.0	"
1 N 40 E 13CCDC$_1$	S-23	195	04-14-75	14.	19.	.02	0.02	265	277	138	7.9	673	0.	1470	6.5	<.1	0.23	2520	1810	552	1.4	2940	7.9	Interburden ss.
1 N 40 E 13CCDC$_2$	S-24	149	05-29-75	13.	16.	.02	.14	243	202	76.	7.4	601	0.	1040	5.7	.1	.29	1880	1450	493	0.9	2330	7.2	Rosebud coal
1 N 40 E 15BBAB	P-10	61	05-16-75	10.	19.	.06	.11	123	160	98.	8.3	518	0.	727	20.	.2	.23	1410	971	425	1.4	1880	7.4	"
1 N 40 E 15BBDA	P-09	40	05-16-75	6.0	14.	.05	.37	243	265	193	11.	707	0.	1420	25.	.3	.11	2520	1710	580	2.0	3110	7.4	"
1 N 40 E 15BDBB	P-08	47	05-16-75	7.0	20.	.07	.21	137	182	135	11.	645	0.	782	28.	.2	.34	1610	1100	529	1.8	2180	7.5	"
"	"	47	04-14-76	9.0	19.	.08	.45	160	205	152	11.	546	0.	1060	14.	.2	3.66	1890	1240	447	1.9	2440	7.9	"
1 N 40 E 15BDBD	P-07	60	05-16-75	9.0	36.	2.30	.06	60.	77.	118	12.	25	0.	664	18.		0.56	1000	469	21	2.4	1310	5.4	"
1 N 41 E 01BCAB	S-11	59	09-25-73	–	11.	0.34	.06	73.	72.	420	10.	597	0.	870	7.9	.2	.27	1760	483	490	8.3	2350	7.9	McKay coal
"	"	59	06-06-74	–	14.	<.01	<.01	112	65.	387	10.	714	0.	789	9.1	.2	.99	1740	549	586	7.2	2460	7.4	"
1 N 41 E 01DDAC	S-08	48	09-25-73	–	23.	.08	.08	349	246	127	25.	154	0.	2010	11.	.2	.16	2860	1890	126	1.3	3140	8.0	"
"	"	48	06-06-74	–	17.	<.01	.24	349	309	116	22.	402	0.	1960	12.	.3	1.40	2980	2150	330	1.1	3410	7.6	"
1 N 41 E 03AABB	W-04	32	03-23-73*	–	21.	.15	2.2	333	317	58.	12.	629	0.	1670	14.	.1	0.99	2740	2150	516	0.5	2990	6.9	Spoils
"	"	32	10-01-75	–	14.	.48	0.64	285	282	65.	–	817	0.	1230	17.	.2	11.9	2330	1880	670	.7	2940	7.9	"
"	"	32	01-12-76	10.	13.	.03	.86	356	347	70.	20.	916	0.	1490	28.	.2	2.55	2780	2320	752	.6	3060	7.3	"
"	"	32	04-06-76	12.5	11.	1.3	.06	315	307	63.	16.	697	0.	1520	26.	.2	1.24	2600	2050	572	.6	3320	7.9	"
1 N 41 E 04AABB	P-06	50	05-16-75	9.5	21.	0.01	.12	217	199	160	7.7	594	0.	1140	11.	.2	0.23	2050	1370	488	1.9	2540	7.5	McKay coal
1 N 41 E 04AABD	P-05	33	05-16-75	7.5	25.	.01	<.01	234	184	143	8.5	576	0.	1110	13.	.2	.27	2000	1350	472	1.7	2470	7.5	Alluvium
1 N 41 E 04AADB$_1$	P-03	34	05-16-75	10.	23.	<.01	.01	206	264	162	12.	664	0.	1370	12.	.2	.50	2380	1620	545	1.8	2820	7.5	"
"	"	34	04-06-76	11.5	24.	.04	.01	206	268	169	12.	678	0.	1380	15.	.2	.04	2410	1620	556	1.8	2900	7.9	"
1 N 41 E 04AADB$_2$	P-04	20	05-16-75	14.	24.	.01	.01	253	276	175	11.	605	0.	1550	17.	.2	.50	2600	1790	496	1.8	3040	7.7	"
1 N 41 E 04AADD	P-02	36	04-15-75	10.	23.	<.01	.02	165	268	152	11.	615	0.	1250	12.	.2	.84	2190	1530	504	1.7	2670	7.9	"
1 N 41 E 04ADAA	P-01	35	07-12-74	–	21.	<.01	<.01	134	216	116	9.0	484	0.	1040	12.	.1	.32	1790	1240	397	1.4	2220	8.1	"
"	"	35	05-16-75	10.	23.	.01	.03	183	233	121	9.1	600	0.	1110	12.	.2	.32	1990	1430	492	1.4	2460	7.6	"
1 N 41 E 10AACD$_1$	S-27	149	05-28-75	10.	11.	.01	.17	284	193	220	13.	815	0.	1280	8.9	<.1	.50	2410	1500	668	2.5	2930	7.7	McKay coal
1 N 41 E 10AACD$_2$	S-28	130	05-16-75	11.	12.	0.01	0.16	141	288	93.	6.1	923	0.	919	7.0	<.1	0.25	1920	1560	757	1.0	2490	7.6	Rosebud coal
"	"	130	09-30-75	–	12.	.18	.17	114	261	88.	5.7	781	0.	869	9.3	.1	.07	1740	1360	640	1.0	2220	7.7	"
1 N 41 E 12ADDD	S-06	50	09-25-73	–	15.	.06	.11	109	92.	59.	5.1	383	0.	444	6.6	.3	.14	918	653	314	1.0	1300	7.9	McKay coal
"	"	50	06-06-74	–	21.	<.01	.11	77.	58.	23.	3.4	364	0.	168	7.6	.3	.29	538	431	298	0.5	703	8.1	"
1 N 41 E 16BAB$_1$	S-18	248	07-12-74	–	10.	<.01	<.01	45.	41.	202	6.0	440	0.	344	5.0	.2	.63	873	282	361	5.2	1310	8.3	"
1 N 41 E 16BAB$_2$	S-19	225	07-12-74	–	12.	<.01	<.01	47.	83.	114	4.9	429	0.	335	6.4	.1	.05	814	464	352	2.3	1250	8.0	Rosebud coal
"	"	225	05-13-75	14.	14.	<.01	<.01	73.	68.	122	5.3	552	0.	269	4.1	.1	.14	827	466	453	2.5	1230	7.7	"
1 N 41 E 21DADC$_2$	BS-04	121	04-05-76	14.	16.	.54	.24	150	160	62.	5.0	589	0.	681	5.4	.2	.24	1370	1030	483	0.8	1790	7.7	"
1 N 41 E 21DADC$_1$	BS-03	156	10-01-75	–	12.	.02	.07	198	166	352	11.	625	0.	1440	11.	.3	<.02	2500	1180	513	4.5	3060	7.9	McKay coal
1 N 41 E 24CAAD	BS-14	31	08-28-75	10.	10.	.02	.01	262	246	416	10.	586	0.	2040	17.	.1	1.13	3290	1670	481	4.4	3660	8.1	Alluvium
1 N 41 E 24CABC	BS-12	23	08-28-75	11.	9.7	.01	<.01	132	246	174	6.	526	0.	1240	17.	.2	4.70	2090	1340	431	2.1	2620	7.9	"
1 N 41 E 24CBBC	BS-13	22	08-28-75	13.	18.	.05	.01	207	338	216	8.2	439	0.	1940	14.	.2	0.68	2960	1910	360	2.2	3280	8.1	"
1 N 41 E 24CCBB	BS-11	22	08-28-75	11.	7.9	.01	.02	144	221	278	8.4	461	0.	1440	11.	.2	1.81	2340	1270	378	4.4	2780	7.9	"
1 N 41 E 27AADD$_1$	S-16	40	09-25-73	–	13.	.05	.02	273	360	190	4.4	408	0.	2120	16.	.2	2.26	3190	2190	335	1.8	3550	7.8	Ss. below McKay coal
"	"	40	02-04-74	–	16.	.02	.02	302	384	209	4.2	437	0.	2320	13.	.2	4.52	3480	2350	358	1.9	3800	7.7	"
"	"	40	06-06-74	–	15.	.01	.01	328	345	193	4.4	477	3.	2110	18.	.2	4.52	3270	2250	396	1.8	3710	7.5	"
"	"	40	02-05-75	8.0	16.	.01	.01	273	407	206	5.1	458	0.	2300	15.	.2	4.74	3470	2390	375	1.8	3820	7.8	"
1 N 41 E 27AADD$_2$	S-17	16	02-04-74	–	15.	.07	.03	402	924	500	7.8	334	0.	5390	33.	.2	7.23	7470	4860	274	3.1	7240	8.2	Alluvium
1 N 41 E 27ABCC$_2$	BS-21	97	04-05-76	12.5	14.	1.5	.25	239	228	238	9.4	706	0.	1410	11.	.2	0.02	2500	1540	579	2.6	3060	7.8	McKay coal
1 N 41 E 27ABCC$_3$	BS-22	58	04-05-76	12.	11.	0.77	2.8	430	725	813	–	639	0.	4790	76.	.2	.04	7170	4060	524	5.6	7480	7.6	Spoils

1 N 41 E 27ABCC$_1$	BS-20	97	10-01-75	–	14.	.03	0.18	216	237	223	15.	580	0.	1520	12.	.2	<.02	2520	1520	476	2.5	2910	7.8	McKay coal
1 N 41 E 27BADC	BS-19	83	04-05-76	14.5	13.	.05	1.6	383	455	182	–	727	0.	2420	28.	.2	14.5	3880	2830	596	1.5	4390	7.7	Spoils
1 N 41 E 27DAAC	S-14	51	09-25-73	–	12.	.04	0.02	354	464	167	10.	541	0.	2660	24.	.2	0.23	3960	2820	444	1.4	4210	7.8	McKay coal
"	"	51	02-04-74	–	14.	.02	.06	346	426	173	9.0	530	0.	2460	23.	.2	.29	3710	2650	435	1.5	3950	7.7	"
"	"	51	05-23-74	12.	16.	.05	.33	415	421	169	9.1	708	0.	2380	25.	.4	.29	3780	2790	580	1.4	4140	7.4	"
"	"	51	03-26-75	9.0	13.	.01	.04	374	456	176	9.3	575	0.	2550	23.	.2	.09	3880	2830	472	1.4	4350	7.7	"
"	"	51	01-13-76	9.0	14.	.03	.20	437	476	176	9.2	765	0.	2570	23.	.3	.32	4080	3050	627	1.4	4280	7.3	"
"	"	51	04-05-76	12.5	14.	1.2	.26	428	452	172	9.0	738	0.	2530	25.	.3	.03	3990	2930	606	1.4	4300	7.6	"
1 N 41 E 27DACA	TW-1	74	04-13-76	10.5	9.6	0.03	1.6	405	358	116	–	859	0.	1960	27.	.1	.02	3320	2490	705	1.0	3770	7.8	Spoils
1 N 42 E 07CBA	S-05	33	09-25-73	–	21.	.85	0.05	429	553	346	4.0	655	0.	3310	63.	.2	.16	5050	2880	538	2.6	5300	7.6	Alluvium
"	"	33	02-04-74	–	22.	<.01	.02	341	486	325	3.5	377	0.	3110	56.	<.1	.05	4530	2880	309	2.6	4980	7.7	"
"	"	33	06-06-74	–	23	.01	.02	483	455	305	4.3	706	0.	3030	62.	.1	.09	4710	3100	579	2.4	5070	7.7	"
"	"	33	02-05-75	7.0	18.	.02	.01	431	466	305	4.8	507	0.	2990	58.	.1	.07	4520	3020	416	2.4	4840	7.9	"
1 N 42 E 17BDDC	S-02	52	09-25-73	–	18.	.18	.75	208	238	34.	6.2	618	0.	1060	7.0	<.1	.34	1880	1510	507	0.4	2300	7.6	Spoils
"	"	52	02-04-74	–	17.	<.01	.07	176	232	34.	5.5	601	0.	935	7.4	<.1	.27	1700	1410	493	.4	2170	7.8	"
"	"	52	06-06-74	–	19.	<.01	.16	221	218	32.	6.2	738	0.	874	10.	<.1	.27	1740	1460	605	0.4	2260	7.6	"
"	"	52	02-04-75	10.	16.	<.01	.15	216	212	33.	6.1	729	0.	838	7.5	<.1	.27	1690	1420	598	.4	2210	7.6	"
"	"	52	04-10-75	10.	17.	.01	.03	193	229	32.	6.2	749	0.	847	9.2	<.1	.38	1700	1440	614	.4	2250	7.5	"
"	"	52	09-30-75	–	16.	.15	1.0	299	269	37.	7.0	806	0.	1250	6.8	.1	<.02	2290	1860	661	.4	2660	7.6	"
"	"	52	01-12-76	10.	18.	.02	0.84	296	274	37.	6.5	819	0.	1160	7.9	.1	.07	2200	1870	672	.4	2640	7.2	"
"	"	52	03-17-76	12.	18.	.06	.59	288	296	37.	6.6	815	0.	1280	7.9	.1	.31	2330	1940	668	.4	2600	7.4	"
1 N 42 E 17BDDC	S-02	52	04-04-76	15.	18.	.03	1.6	216	250	35.	6.5	861	0.	882	8.6	.1	0.09	1840	1570	706	0.4	2530	7.6	Spoils
1 N 42 E 17DBDA	S-04	28	09-25-73	–	15.	.92	0.26	142	123	44.	5.5	383	0.	634	8.7	.2	.02	1160	863	314	.7	1520	7.9	McKay coal
"	"	28	06-06-74	–	23.	<.01	.28	149	121	105	6.0	450	0.	698	11.	.2	.18	1340	874	369	1.5	1570	8.1	"
"	"	28	09-30-75	–	13.	.07	.49	351	778	203	9.1	448	0.	3950	81.	.2	.54	5610	4080	367	1.4	5190	8.2	"
"	"	28	01-14-76	9.	14.	.03	.02	286	532	151	7.9	533	0.	2570	43.	.1	.45	3870	2910	437	1.2	4050	7.4	"
"	"	28	04-14-76	10.	11.	.07	.1	440	852	200	8.6	485	0.	4210	71.	.1	2.43	6030	4600	398	1.3	6050	7.5	"
"	"	28	06-23-76	10.	9.3	.05	.09	535	1530	332	10.	451	0.	7560	4.8	.1	2.15	10200	7630	370	1.7	9130	7.8	"
1 N 42 E 18AAAB$_1$	S-01	48	09-25-73	–	17.	3.0	1.1	317	269	60.	8.8	724	0.	1440	9.2	.1	.29	2480	1900	594	0.6	2920	7.7	Spoils
"	"	48	02-04-74	–	16.	0.04	0.03	250	281	57.	7.8	530	0.	1400	8.2	.1	.11	2280	1800	435	.6	2720	7.7	"
"	"	48	05-23-74	14.	16.	.01	.04	373	319	59.	7.9	778	0.	1630	11.	.2	.09	2800	2260	638	.5	3120	7.2	"
"	"	48	06-06-74	–	16.	.02	.40	366	283	57.	8.1	741	0.	1530	13.	.1	.16	2640	2090	608	.5	3110	7.5	"
"	"	48	02-04-75	11.	12.	.01	.01	283	288	58.	8.1	461	0.	1540	9.7	<.1	.11	2430	1900	378	.6	2670	7.7	"
"	"	48	04-10-75	12.	15.	.02	.02	360	289	52.	8.6	615	0.	1620	9.6	<.1	.47	2660	2100	505	.5	2980	7.7	"
"	"	48	09-30-75	–	15.	.43	1.2	400	324	59.	8.4	849	0.	1730	12.	<.1	.23	2970	2330	696	.5	3220	7.5	"
"	"	48	01-12-76	11.5	15.	.02	0.67	351	282	57.	7.7	826	0.	1350	9.5	.1	.07	2490	2040	677	.5	2860	7.2	"
"	"	48	03-17-76	13.	15.	.01	.78	320	270	59.	7.8	808	0.	1290	10.	.1	.10	2370	1910	662	.6	2920	7.8	"
"	"	48	04-04-76	12.5	15.	.10	.92	347	268	62.	7.6	805	0.	1410	11.	.1	.08	2520	1970	660	.6	2970	7.5	"
1 N 42 E 18AAAB$_2$	S-03	76	09-25-73	–	14.	.44	.17	136	101	137	6.8	203	0.	891	4.5	.2	.20	1390	760	166	2.2	1790	8.0	McKay coal
"	"	76	02-04-74	–	15.	.03	.04	112	87.	123	5.4	196	0.	739	3.8	.3	.02	1180	640	161	2.1	1560	8.2	"
"	"	76	06-06-74	–	17.	.01	.01	125	82.	111	5.9	229	0.	685	5.5	.3	1.06	1150	651	188	1.9	1540	7.9	"
"	"	76	02-04-75	10.	15.	<.01	<.01	117	81.	103	6.0	219	3.	625	3.4	.3	1.58	1070	625	185	1.8	1470	8.3	"
"	"	76	01-12-76	10.5	15.	.02	.01	123	81	106	5.9	229	0.	640	4.1	.3	.68	1090	643	188	1.8	1450	8.0	"
"	"	76	04-04-76	13.	15.	.05	.12	150	101	130	6.7	214	0.	846	6.6	.3	.79	1360	790	176	2.0	1790	7.7	"
1 N 42 E 18DAAD$_3$	EPA-03	28	04-14-76	9.5	11.	.03	.35	168	162	23.	8.7	637	0.	580	3.6	.2	1.77	1270	1090	523	0.3	1770	7.8	"

[a] Indicates well destroyed during power plant construction

Samples collected and analyzed by Montana Bureau of Mines and Geology

* Samples collected and analyzed by Westinghouse Electric Corporation (1973)

Concentrations in milligrams per liter

Table 8.–Chemical analyses of waters from pits, ponds, and streams near Colstrip, southeastern Montana.

Location	Date sampled	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrogen, nitrate (NO_3/N)	Dissolved solids (calc.)	Total hardness as $CaCO_3$ (calc.)	Alkalinity as $CaCO_3$	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH (laboratory)	
1 N 40 E 15BACB	07-25-73	26.	14.	0.23	2.5	40.	403	230	20.	584	0.	1720	12.	0.3	0.97	2740	1790	479	2.4	3130	8.3	East Fork Armells Creek 7 mi upstream from Colstrip; ponded
1 N 41 E 03BBBB	08-12-72	22.	20.	.03	0.01	110	218	145	13.	342	0.	1150	13.	.2	.27	1840	1180	280	1.8	2220	8.1	East Fork Armells Creek 1 mi upstream from Colstrip; ponded
"	03-20-73*	9.0	20.	.50	1.8	195	219	127	12.	598	0.	1130	12.	.2	.04	2010	1400	490	1.5	2370	7.5	East Fork Armells Creek 1 mi upstream from Colstrip; estimated flow 0.1 cfs
"	07-25-73	23.	19.	.29	0.78	188	270	180	17.	586	0.	1430	13.	.2	.50	2400	1590	481	2.0	2770	8.1	East Fork Armells Creek 1 mi upstream from Colstrip; ponded
1 N 42 E 17BC	03-24-73*	12.	21.	.10	.05	45.	47.	20.	2.8	244	0.	104	3.3	.2	10.6	411	308	200	0.5	624	8.2	Active mine pit; drainage from Rosebud coal bed
1 N 41 E 12ADAB	09-30-75	–	16.	.20	.10	183	241	95	8.2	400	0.	1280	14.	.1	3.34	2040	1450	328	1.1	2450	7.9	"
1 N 41 E 03AABD	03-20-73*	6.5	2.9	.15	.22	105	541	225	19.	285	0.	2630	23.	.1	0.09	3790	2530	234	2.0	3880	8.0	Pond in former mine pit; Colstrip "swimming hole"
"	04-06-76	11.	2.6	.04	.23	170	538	238	21.	454	0.	2560	32.	.1	.06	3780	2640	373	2.0	4290	8.0	"
2 N 41 E 35DBCD	07-24-73	24.	3.6	.08	.07	324	508	90.	24.	201	0.	2830	16.	<.1	<.01	3890	2920	165	0.7	3930	7.9	Pond in former mine pit
1 N 41 E 01DBCA	09-30-75	–	1.5	.11	.02	308	492	141	16.	299	0.	2800	15.	<.1	.27	3920	2790	245	1.2	4160	8.1	"
1 N 42 E 17BBDA	04-04-76	16.	1.1	.02	.02	156	140	17	9.6	266	0.	748	6.3	.2	.03	1210	966	218	0.2	1620	7.9	"Turtle pond" in former mine pit
2 N 41 E 34CAAD	03-20-73*	9.0	7.1	.10	.29	138	132	106	9.3	346	0.	795	10.	.2	.34	1370	891	284	1.5	1730	7.6	Drainage ditch 0.3 mi SE of Colstrip; estimated flow .05 cfs enters East Fork Armells Creek
2 N 41 E 34BDBD	08-12-72	18.	25.	.04	.01	335	319	286	5.6	499	0.	2210	29.	.2	4.29	3470	2160	409	2.7	3560	7.9	East Fork Armells Creek at downstream (north) edge of Colstrip; flow 0.1 cfs
"	07-24-73	26.	10.	.16	.09	136	308	211	9.9	472	0.	1610	13.	.2	0.07	2530	1630	387	2.3	2880	8.2	"
2 N 41 E 27BCCC	07-24-73	23.	3.0	.05	.02	228	378	310	16.	460	0.	2280	43.	.4	.14	3480	2150	377	2.9	3790	8.2	East Fork Armells Creek 1 mi downstream from Colstrip; estimated flow, 0.1 cfs
2 N 41 E 09BCBC	07-24-73	23.	1.1	.06	.02	162	395	471	27.	282	29.	2620	56.	.7	.27	3900	2060	280	4.5	4230	8.6	East Fork Armells Creek 4 mi downstream from Colstrip; estimated flow, 0.1 cfs
1 N 41 E 22ADAD	10-01-75	–	10.	.03	.09	161	132	138	9.1	308	0.	955	8.9	.5	4.16	1570	945	252	2.0	1950	8.0	Active mine pit; drainage from overburden, Rosebud coal, and McKay coal
1 N 41 E 22CCDC	06-04-76	19.	15.	.03	.05	129	205	111	7.7	517	0.	976	15.	.1	1.08	1715	1170	424	1.4	2210	7.8	"
1 N 41 E 22DCCD	03-18-76	14.	15.	<.01	.02	167	211	169	9.1	610	0.	1050	6.3	.2	3.73	1940	1290	500	2.0	2580	7.9	Effluent from active pits; pumped to nearby impoundment
1 N 41 E 27ABBA	04-05-76	15.	17.	.05	.24	261	272	154	8.2	631	0.	1510	14.	.2	0.69	2550	1770	518	1.6	3030	8.0	"
1 N 41 E 27DBAD	03-18-76	6.	1.9	.03	<.01	37.	20.	4.	3.8	58.	0.	127	0.	.2	.54	223	175	47.	0.1	378	7.5	Impoundment in mine spoils; fed by runoff, ground water, and mine effluent
"	04-05-76	15.	1.7	.03	.02	180	155	46	12.	257	0.	928	6.5	.2	3.34	1460	1090	211	.6	1880	8.0	"
"	06-04-76	18.5	1.0	<.01	.01	180	155	46	13.	190	0.	1000	11.	.1	2.34	1500	1090	156	.6	1940	7.8	"

Sampled and analyzed by the Montana Bureau of Mines and Geology, except as noted.

* Samples collected and analyzed by Westinghouse Electric Corporation (1973)

Concentrations in milligrams per liter

for copper in drinking water is 1.0 mg/l. Copper is far more toxic to fish than to human beings, and its toxicity depends upon other chemical characteristics of the water.

Lead (Pb)—Most concentrations listed in Table 9 exceed 0.05 mg/l, which is the mandatory public drinking-water limit established by the U. S. Public Health Service. Of the higher concentrations (0.1 mg/l to 0.21 mg/l), most are associable with shallow ground waters in or very near to mine spoils. Many additional lead analyses (not listed in Table 9) have been conducted since 1973 on waters from mined and non-mined areas near Colstrip. In all, 74 values of lead content have been determined for water samples from 23 locations in and near Rosebud and Big Sky mine spoils, and 33 values have been determined for waters from 27 locations not associable with mine spoils. Using mean values where multiple analyses had been done at single locations, the following statistical summaries of lead concentrations were made:

Mined areas	
Number of sample locations	23
Maximum concentration (mg/l)	0.21
Minimum concentration (mg/l)	<0.05
Number of samples containing 0.05 or more mg/l	18
Arithmetic mean of concentrations, 0.05 or more mg/l	0.12
Median of concentrations, 0.05 or more mg/l	0.12
Standard deviation (mg/l)	0.05

Non-mined areas	
Number of sample locations	27
Maximum concentration (mg/l)	0.11
Minimum concentration (mg/l)	<0.05
Number of samples containing 0.05 or more mg/l	14
Arithmetic mean of concentrations, 0.05 or more mg/l	0.07
Median of concentrations, 0.05 or more mg/l	0.06
Standard deviation (mg/l)	0.02

The summaries provide rough indications that there is detectable lead in most ground waters of the Colstrip area, that waters associated with Rosebud and Big Sky mine spoils do contain generally higher concentrations than do other waters, and that the lead concentrations are far more diverse in the mined-area waters.

Lithium (Li)—Concentrations ranged between 0.02 mg/l and 0.12 mg/l, and there were no apparent differences in concentrations between samples from mined and non-mined areas. The values seem to be far less than any that may be toxic (discussed by Gough and Shacklette, 1976) to vegetation or to animals.

Mercury (Hg)—Only one sample had a concentration greater than 0.4 μg/l. The one anomalous concentration (1.2 μg/l) was found in a sample from East Fork Armells Creek, downstream from Colstrip. Mercury, particularly in organic form, can be highly toxic to all animals. The U. S. Environmental Protection Agency (1975) has set a maximum permissible concentration of 2.0 μg/l for public drinking water.

Nickel (Ni)—The maximum concentration was 0.14 mg/l. A rough positive correlation between concentrations of nickel and lead is apparent. Nickel is not a very toxic trace element; there has been no known toxicity to human beings from nickel in drinking water (U. S. Environmental Protection Agency, 1973).

Selenium (Se)—Almost all concentrations were less than 2.0 μg/l. Relatively high selenium contents were found in the last two samples collected from well S-04 (8.0 and 28 μg/l, respectively). The apparent increases in selenium accompany strong increases in major constituents at that well (Table 7). A mandatory concentration limit of 10 μg/l selenium in public drinking water has been established by the U. S. Public Health Service (1962).

Silver (Ag)—Concentrations in all samples were 0.01 mg/l or less. The U. S. Public Health Service limit is 0.05 mg/l in drinking water.

Strontium (Sr)—Concentrations ranged between 1.77 and 12.2 mg/l. No strontium toxicity to animals or vegetation is mentioned in the literature.

Tin (Sn)—Tin was detectable in all samples; range of concentrations was 0.15 to 1.05 mg/l. There are no substantiated reports in the literature of tin toxicity of plants; animals are seemingly tolerant of high concentrations in food or water (Gough and Shacklette, 1976).

Zinc (Zn)—Most samples contained less than 0.10 mg/l. Higher values, as much as 0.86 mg/l, were found in waters from old mine spoils (wells W-02, -03, -04, and -05); concentrations are not so high in waters from newer spoils. The U. S. Public Health Service recommended limit for zinc content in drinking water is 5.0 mg/l.

Table 9.—Trace-element concentrations in surface waters and in ground waters in the Colstrip area, southeastern Montana.

Site designation	Location	Date of sample collection	Mine area	Aluminum (Al) mg/l	Antimony (Sb) mg/l	Arsenic (As) µg/l	Beryllium (Be) µg/l	Boron (B) mg/l	Cadmium (Cd) mg/l	Chromium (Cr) mg/l	Copper (Cu) mg/l	Lead (Pb) mg/l	Lithium (Li) mg/l	Mercury (Hg) µg/l	Nickel (Ni) mg/l	Selenium (Se) µg/l	Silver (Ag) mg/l	Strontium (Sr) mg/l	Tin (Sn) mg/l	Zinc (Zn) mg/l	Site description
Streamflow upstream from Colstrip and Rosebud mine[1]																					
15-BACB	1 N 40 E 15BACB	07-25-73						<.1	.01	.02	.01	.10		<.3	<.05					.01	E. Fk. Armells Crk. 7 mi. upstream from Colstrip; ponded
03-BBBB*	1 N 41 E 03BBBB	03-20-73				<2		.45	<.01	<.02	<.02	<.05		<.3	<.04	<5				.01	E. Fk. Armells Crk. 1 mi. upstream from Colstrip; ponded
"	"	07-25-73						.20	<.01	.02	.01	.10		<.3	<.05					.01	" ;flowing 0.1 cfs
34-CAAD*	2 N 41 E 34CAAD	03-20-73				<2		.29	<.01	<.02	<.02	<.05		<.3	<.04	<5				.01	Drainage ditch 0.3 mi. SE of Colstrip; flows to E. Fk. Armells Crk.
Streamflow downstream from Colstrip and Rosebud mine[1]																					
34-BDBD	2 N 41 E 34BDBD	07-24-73						.40	.01	<.02	<.01	.15		<.3	<.05					.02	E. Fk. Armells Crk. at downstream edge of Colstrip; flowing 0.1 cfs
27-BCCC	2 N 41 E 27BCCC	07-24-73						1.3	.01	.02	<.01	.15		1.2	<.05					.02	E. Fk. Armells Crk. 1 mi. downstream from Colstrip; flowing 0.1 cfs
09-BCBC	2 N 41 E 09BCBC	07-24-73						1.0	.01	.02	.01	.10		<.3	<.05					.02	E. Fk. Armells Crk. 4 mi. downstream from Colstrip; flowing 0.1 cfs
Ground waters from undisturbed aquifers[2]																					
P-8	1 N 40 E 15BDBB	04-14-76		<.05	<.2	<2	<5	.33	<.01	<.01	.01	.07	.06		.06	4.5	<.01	4.18	.33	.02	Alluvium along E. Fk. Armells Crk. 7 mi. upstream from Colstrip
P-3	1 N 41 E 04AADB	04-06-76		<.05	<.2	<2	<5	.50	<.01	<.01	<.01	.06	.06		.07	<2	<.01	4.85	.28	.01	Alluvium along E. Fk. Armells Crk. 1 mi. upstream from Colstrip
P-11	1 N 41 E 28AAAC	04-06-76		<.05	<.2		<5	.72	<.01	<.01	.01	<.08	.08		.06	<2	<.01	7.0	.33	.01	Alluvium along E. Fk. Armells Crk. 1 mi. downstream from Colstrip
08-CBAB	1 N 41 E 08CBAB	04-01-73				<2		<.1	<.01	<.02	<.02	<.05		<.3	<.04	<5				.10	Rosebud coal upgradient from Rosebud mine
S-28	1 N 41 E 10AACD	09-30-75		.05	<.2	<2	<5	.23	<.01	<.01	.01	<.05	.04	<.3	.03	<2	<.01	2.05	.25	.03	"
BS-04	1 N 41 E 21DADC	04-05-76		<.05	<.2	2.5	<5	.20	<.01	<.01	<.01	.10	.03		.04	<2	<.01	2.45	.21	.01	Rosebud coal upgradient from Big Sky mine
BS-03	1 N 41 E 21DADC	10-01-75		<.05	<.2	<2	<5	.46	<.01	<.01	.01	.07	.05	.4	.03	<2	<.01	12.30	.17	.13	McKay coal upgradient from Big Sky mine
08-BBDC*	1 N 41 E 08BBDC	03-19-73				<2		<.1	<.01	<.02	<.02	<.05		<.3	<.04	<5				.05	Sandstone 200 ft. below McKay coal
Influent to active mine pits[1]																					
17-BC*	1 N 42 E 17BC	03-24-73	Rosebud			<2		.21	<.01	<.02	<.02	<.05		<.3	<.04	<5				<.01	Seepage from Rosebud coal and overburden
12-ADAB	1 N 41 E 12ADAB	09-30-75	"	.05	.35	<2	<5	.65	<.01	<.01	.01	.07	.05	<.3	.04	2.8	<.01	8.30	.43	.02	"
22-ADAD	1 N 41 E 22ADAD	10-01-75	Big Sky	<.05	.30	<2	<5	.43	<.01	<.01	.01	<.05	.03	<.3	.03	2.0	<.01	6.50	.16	.02	Seepage from Rosebud coal, McKay coal, and overburden
27-ABBA	1 N 41 E 27ABBA	04-05-76	"	<.05	<.2	<2	<5	.66	<.01	<.01	.01	.08	.12		.07	<2	<.01	4.80	.32	.01	"
22-CCDC	1 N 41 E 22CCDC	06-04-76	"	.06	.20		<5	.40	.01	<.01	.01	.05	.04	<.3	.01	<2	.01	4.77	.23	.01	"
Storage in mined-land ponds and pits[1]																					
03-AABA*	1 N 41 E 03AABA	03-20-73	Rosebud			<2		.26	<.01	<.02	<.02	.16		<.3	.06	<5				.01	Colstrip "swimming hole" in former mine pit
"	"	04-06-76	"	<.05	<.2		<5	.78	.01	<.01	.01	.16	.07		.07	<2	<.01	2.75	.49	<.01	"
35-BDCD	2 N 41 E 35BDCD	07-24-73	"					.60	.01	.04	.02	.20		<.3	<.05					.02	Pond in former mine pit
01-DBCA	1 N 41 E 01DBCA	09-30-75	"	.05	.35	<2	<5	.97	<.01	.01	.01	.12	.07	.4	.06	<2	<.01	6.80	.46	.02	"
17-BBDA	1 N 42 E 17BBDA	04-04-76	"	<.05	<.2	<2	<5	.15	<.01	<.01	<.01	<.05	.02		.05	<2	<.01	1.77	.22	.03	" ; "turtle pond"
27-DBAD	1 N 41 E 27DBAD	04-05-76	Big Sky	<.05	<.2	<2	<5	.23	<.01	<.01	<.01	<.05	.03		.05	3.8	<.01	4.41	.16	.01	Experimental impoundment in former mine pit
"	"	06-04-76	"	<.05	<.2		<5	.30	.01	<.01	.01	<.05	.03	<.3	<.01		<.01	4.89	.30	.01	"

Ground waters from aquifers in and very near to mined lands[3]

S-01	1 N 42 E 18AAAB	09-25-73	Rosebud			<2		1.23	.01	<.02	.02	.06			<.05	<2				.04	Water from mine spoils
"	"	04-10-75	"			<2		.96	.01	.02	.03	.15			.04					.21	"
"	"	09-30-75	"	.08	.30	<2	<5	.83	<.01	<.01	.02	.09	.05	<.3	.06	<2	<.01	7.10	.31	.04	"
"	"	04-04-76	"	<.05	<.2		<5	.78	<.01	<.01	.01	.11	.05		.07	<2	<.01	8.60	.33	.03	"
S-02	1 N 42 E 17BDDC	09-25-73	"			<2		.82	.01	<.02	<.02	.06			<.05	<2				.02	"
"	"	09-30-75	"	.10	.20	<2	<5	.49	<.01	<.01	.01	.07	.02	<.3	.04	<2	<.01	3.18	.28	.11	"
"	"	04-04-76	"	<.05	<.2		<5	.49	<.01	<.01	.01	.07	.03		.06	<2	<.01	3.13	.30	.04	"
S-03	1 N 42 E 18AAAB	09-25-73	"			<2		.49				.02				<2					Water from McKay coal beneath mined area
"	"	04-04-76	"	<.05	<.2		<5	.50	<.01	<.01	<.01	<.05	.05		.04	<2	<.01	8.2	.15	.06	"
S-04	1 N 42 E 17DBDA	09-25-73	"			<2		2.04				<.02				<2					Water from McKay coal close to mined area
"	"	09-30-75	"	<.05	.60	<2	<5	1.50	.01	.02	.03	.21	.03	<.3	.08	8.0	.01	10.00	.95	.05	"
"	"	04-14-76	"	<.05	<.2	<2	<5	1.60	.01	.02	.02	.17	.04		.11	28	.01	11.3	1.05	.03	"
S-05	1 N 42 E 07CBA	09-25-73	"			<2		1.52				.13				2.0					Water from alluvium downgradient from mined area
S-06	1 N 41 E 12ADDD	09-25-73	"			<2		.58				.02				<2					Water from McKay coal beneath mined area
S-08	1 N 41 E 01DDAC	09-25-73	Rosebud			<2		1.17	.01	<.02	<.02	.06			<.05	<2				<.02	Water from McKay coal beneath mined area
S-11	1 N 41 E 01BCAB	09-25-73	"			<2		.54	.01	.02	<.02	<.02			<.05	<2				<.02	"
S-12	2 N 41 E 35DABD	09-25-73	"			<2		1.25	<.01	<.02	<.02	<.02			<.05	<2				<.02	"
S-13	2 N 41 E 35DABD	09-25-73	"			<2		1.14	<.01	<.02	.02	.20			<.05	<2				.06	Water from Rosebud coal downgradient from mined area
EPA-03	1 N 42 E 18DAAD	04-14-76	"	<.05	<.2	<2	<5	.31	<.01	<.01	<.01	<.05	.03		.06	<2	<.01	3.19	.23	.02	Water from mine spoils
W-02*	2 N 41 E 34DDAD	03-23-73	"			<2		.17	<.01	.02	.02	.19		<.3	.14	<5				.19	"
W-03*	2 N 41 E 35BCDB	03-23-73	"			<2		.96	<.01	<.02	.03	.13		<.3	.06	<5				.84	"
W-04*	1 N 41 E 03AABB	03-23-73	"			<2		1.20	<.01	<.02	<.02	.16		<.3	.08	<5				.27	"
"	"	10-01-75	"	.10	.30	4.4	<5	.34	<.01	<.01	.01	.06	.02	<.3	.04	<2	<.01	2.26	.35	.03	"
"	"	04-06-76	"	.23	<.2		<5	.34	.01	.01	.13	.12	.03		.07	<2	<.01	3.70	.33	.86	"
W-05*	2 N 41 E 35CBAA	03-23-73	"			<2		.46	<.01	.02	.03	.19		<.3	.10	<5				.45	"
S-14	1 N 41 E 27DAAC	04-05-76	Big Sky	<.05	<.2		<5	.38	<.01	.02	<.01	.13	.06		.09	<2	<.01	12.2	.40	.09	Water from McKay coal beneath mined area
BS-19	1 N 41 E 27BADC	04-05-76	"	<.05	<.2	<2	<5	.24	<.01	.01	.01	.13	.09		.12	<2	.01	6.60	.46	.03	Water from mine spoils
BS-20	1 N 41 E 27ABCC	10-01-75	"	.05	<.2	<2	<5	.55	<.01	<.01	.01	.06	.05	<.3	.04	<2	<.01	9.00	.35	.04	Water from McKay coal beneath mined area
BS-21	"	04-05-76	"	<.05	<.2		<5	.38	<.01	<.01	.01	.11	.06		.06	<2	<.01	7.20	.28	.01	"
BS-22	"	04-05-76	"	<.05	<.2	<2	<5	.95	.01	.02	.02	.20	.08		.11	<2	.01	6.50	.68	.04	Water from mine spoils

[1] See Table 8 for concentrations of major constituents

[2] See Tables 6 and 7 for concentrations of major constituents

[3] See Table 7 for concentrations of major constituents

Concentrations in mg/l (milligrams per liter) and μg/l (micrograms per liter) as noted.

Reported values are for dissolved constituents only.

Samples collected and analyzed by Montana Bureau of Mines and Geology except as noted.

*Samples collected and analyzed by Westinghouse Electric Corporation (1973).

Lead and nickel were the only trace elements found in generally higher concentrations in mined-area waters than in other waters. Measurable backgrounds of both metals were found in most waters of the area, indicating the presence of soluble lead and nickel minerals in geologic materials there. It would seem that the displacement of the geologic materials somehow has made the metals more available for dissolution. In the pre-mining environment, lead and nickel compounds may have been present mainly in dry overburden materials not subjected to leaching. Placement of the materials near the base of a mine cut would have made them eventually susceptible to leaching by reentering ground waters.

HYDROGEOLOGY, PRE-MINING CONDITIONS

A hydrologic reconnaissance of central and southern Rosebud County by the U. S. Geological Survey (Renick, 1929) documented some hydrologic data prior to mining activity near Colstrip. Although of very limited detail, Renick's report provides valuable pre-mining data and dialogue.

In 1923, the town of Colstrip did not exist. The Northern Pacific Railway was then engaged in building a short line from the Yellowstone River southward along Armells Creek to the present site of the town and Rosebud mine. Ground waters were not so extensively developed then. Most wells had been hand dug and were located in topographically low areas where water could be obtained at the shallowest possible depths. Locations of wells and springs examined in 1923 (Pl. 7) and corresponding water-quality data (Table 10) have been excerpted directly from Renick's report. The historical data indicate that ground-water conditions in 1923 were similar to those of the present. Long before the current study, Renick noted (p. 59) the diverse chemical character of the waters and the occurrence of less mineralized waters in some coal beds than in nearby inorganic geologic materials. The pre-mining data are not adequate for specific comparisons between past and present, but statistical tests of variances and means indicate that no significant changes in water quality have occurred since 1923. It is very likely that qualities of waters in materials disturbed by mining have changed, but there is no evidence of changes outside the mined areas.

HYDROGEOLOGY, CONDITIONS WITH FUTURE MINING

Capabilities of predicting mining and post-mining hydrologic conditions with much precision have not yet been developed. Predictions are currently made with hesitance because so much is yet to be learned about the effects of induced physical and chemical changes in the hydrologic system. Research observations have thus far established only one certainty: that water levels or hydrostatic pressures in aquifers penetrated by mining will decline because of increased, reversed, or interrupted hydraulic gradients. Such observations cause no astonishment; the principles of hydrology demand that they occur. It has also been shown without surprise that under certain vertical-flow conditions, hydrostatic pressures in aquifers below an active mine can decline because of reduced pressures in above-lying disturbed aquifers. The hydraulic reactions to mining are not difficult to understand or to predict but are difficult to quantify specifically, because of the inhomogeneities of geologic materials. They can, however, usually be estimated within ranges of accuracy that at least indicate degrees of significance.

The relation of mining and water quality or water chemistry is far more complicated. Because of the dependency of ground-water quality upon chemical character of host geologic materials, it seems likely that replacement of a coal-bed aquifer by other materials (clay, silt, and sand) would generate different chemical characteristics in post-mining waters. In 1973, Westinghouse Electric Corp. (p. 2-35, 2-36) reported the presence of abnormally high concentrations of major chemical constituents and several trace metals in waters from spoils in the oldest part of the Rosebud mine. In 1974, McWhorter, Skogerboe, and Skogerboe (p. 123-137) reported similar concentrations of major constituents in water from the Edna mine in northwestern Colorado, although no comparisons with other local ground waters were made. In April 1975, Rahn

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Since the writing of this report, some questions have arisen regarding the dependability of analytical methods for determining lead and other trace-metal concentrations in alkaline or saline waters. The values presented here were found by conventional flame atomic adsorption methods utilizing deuterium-arc background corrections. Other techniques such as plasma-emission spectrophotometry and chelation extractions have been indicating very different (generally lower) concentrations in Colstrip-area waters. Laboratories of the U. S. Environmental Protection Agency and the U. S. Geological Survey have also become aware of these discrepancies and are examining the analytical techniques. The values in this report are presented because they were determined by a currently recommended method even though its dependability has recently become suspect.

Table 10.–Chemical analyses of pre-mining (1923) waters in the Colstrip area, southeastern Montana (from Renick, 1929).

Number	Location	Depth of well (feet)	Water-bearing formation	Water level above (+) or below (–) surface (feet)	Date of collection	Total dissolved solids at 180°C	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrogen, nitrate (NO_3/N)	Total hardness as $CaCO_3$ (calc.)	Remarks
80	2 N 39 E 06B	340	Tullock Member of Lance Formation	–	08-24-23	884	12	Trace	8.0	2.6	342	24	764	76	16	Trace	31	Turbid when collected. Odor of hydrogen sulfide (H_2S).
81	2 N 39 E 12 C	220	Top sandstone of Lance Formation	- 85	07-30-23	732	9.2	.40	4.4	2.4	305	36	732	2.8	18	Trace	21	
83	2 N 39 E 06B	202	Lebo Member of Fort Formation	–	08-24-23	3266	12	2.4	134	177	618	0	683	1749	18	1.13	1061	
84	1 N 40 E 06B	48	Coal of Fort Union Formation	- 40	07-30-23	1351	28	5.3	144	135	92	0	517	634	11	0.34	914	
85	1 N 41 E 06C	50	"	+ 6	07-31-23	334	38	6.9	13	17	20	0	63	56	6.0	5.42	102	Color dark brown, due to organic matter.
86	1 N 41 E 12D	65	Fort Union Formation	- 54	07-22-23	366	14	Trace	54	45	16	19	320	49	3.0	Trace	220	
89	1 S 42 E 08C	170	Fort Union Formation and alluvial gravel	- 14	07-15-23	1884	13	1.2	104	92	346	0	300	1008	9.0	0.50	637	A mixture of hard shallow water and soft deeper water.
90	1 S 42 E 08D	200	Sandstone of Fort Union Formation	- 11	07-15-23	1160	10	Trace	14	9.1	380	19	371	531	8.0	.43	72	
91	1 S 41 E 14D	35	Alluvium	- 29	07-15-23	2488	18	8.0	194	172	296	0	547	1300	20	.23	1190	
118	2 N 41 E 17D	177	–	–	- -23	2029*	–	–	67	12	233	–	1210	1045	20	2.26	219	Analysis by Northern Pacific Railway Co.
119	2 N 41 E 27A	Spring	–	–	- -23	718*	–	–	114	51	38	–	357	268	5	–	494	"
120	2 N 41 E 34BC	–	–	–	- -23	1558*	–	–	136	103	244	–	337	684	–	5.42	762	Bored test hole; analysis by Northern Pacific Railway Co.
121	2 N 41 E 34BC	–	–	–	- -23	2446*	–	–	114	238	258	–	426	1343	35	8.13	1261	Test hole for coal; analysis by Northern Pacific Railway Co.
122	1 N 40 E 03BD	40	–	–	- -23	1102*	–	–	98	87	153	–	794	259	10	–	601	Coal shaft; analysis by Northern Pacific Railway Co.
123	1 N 41 E 08B	6	–	–	- -23	962*	–	–	106	35	146	–	497	295	7	–	408	Water hole in Armells Creek; analysis by Northern Pacific Railway Co.

* Calculated values of dissolved solids

Analyses by U.S. Geological Survey unless otherwise noted

Concentrations in parts per million (approximately equal to milligrams per liter)

(p. 351, 352) reported that his preliminary data from northeastern Wyoming and southeastern Montana indicate no significant differences between mined-area waters and waters from nearby undisturbed aquifers. In December 1975, Van Voast and Hedges (p. 18, 19) sampled ground water from Decker mine spoils and found much higher concentrations of dissolved solids than in waters from the coal-bed aquifers being mined. When Rahn (1976, p. 54) had completed his study, he concluded that concentrations of calcium, magnesium, sulfate, and total dissolved solids were significantly greater in spoils' waters than in those from undisturbed aquifers. And now, we see that spoils in parts of the Rosebud and Big Sky mines contain relatively highly mineralized ground water, that other spoils contain waters chemically similar to those in undisturbed materials, and that chemical concentrations in the mined-area waters have temporal variations. There can be little wonder that researchers and planners hesitate to make firm predictions and decisions.

Regardless of the current state of knowledge, administrators demand predictions of hydrologic changes that will occur during mining and after reclamation. Relative to future hydrologic conditions in and near Western Energy Company's proposed mine areas A through E, and Peabody Coal Company's area *a*, several very general assumptions must be made:

(1) The stratigraphic section to be displaced in all areas will extend from the base of the McKay coal bed upward, not exceeding 150 feet of overburden above the top of the Rosebud coal bed. It is assumed here that markets will be found for McKay coal, which is not being mined by Western Energy Company; Peabody Coal Company mines both coal beds.

(2) Outside the proposed mine areas, the only wells and springs to be affected obtain water from aquifers within the stratigraphic sequence being disturbed by mining. This assumption implies that vertical hydraulic conductivities of inter-aquifer beds are low enough and pressure differentials small enough that vertical flows will not be significantly changed.

(3) To be affected, wells and springs must be located within 2 miles of the mined area in the upgradient direction or within a greater but less-definite distance in the downgradient direction.

(4) Spoils produced by mining will have greater vertical hydraulic conductivities than the materials they replace and will have approximately the same horizontal hydraulic conductivities.

(5) The chemical qualities of spoils leachates will be comparable to those currently known for spoils waters of the existing mine areas.

GROUND-WATER FLOW

Mining of the Rosebud coal in area A will create little change in the ground-water system. The bed has a very small recharge area and is dry or only partly saturated in much of the proposed mine area. Mine influent from the Rosebud bed should be negligible; if the McKay bed is mined, influent rates will not be significantly greater. Mining of McKay coal along the southern edge of the area would cause reversal of hydraulic gradients and would induce ground-water flow from storage in the alluvium. It is doubtful that the induced flow would be great because of the McKay bed's low hydraulic conductivity. The influent rate would depend upon the mine's distance from the McKay subcrop and the degree of fracturing created by blasting of the coal. When mining is completed in Area A, previously interrupted ground-water flow would resume, probably at a slightly greater rate because of a greater recharge capacity of the mine spoils.

Mining of the Rosebud and McKay coal beds in area B will interrupt a probably negligible volume of ground water that normally flows to alluvium along East Fork Armells Creek. Flow eastward to the existing Rosebud mine and southeastward to Hay, Coal Bank, and Miller Coulees will also be partly interrupted during mining. Influent rates to active pits will be greatest at the eastern end of area B, where the Rosebud coal has anomalously high transmissivity and lies at relatively low altitudes. Inflow there would decrease rapidly, however, because of the small areal extent of Rosebud coal. A McKay pit at the bed's subcrop along East Fork Armells Creek can induce inflow from alluvium near the northern edge of area B. Actual rates would depend upon the pit length, its distance from the McKay subcrop, and the degree of fracturing caused by blasting. Under the assumptions that mine spoils will have hydraulic conductivities similar to those of undisturbed aquifers and that no mine cuts will remain open for permanent drainage, the post-mining flow system will closely resemble the pre-mining one.

Mining of area C will intercept eastward ground-water flow in the coal beds, in sandstone between them, and in East Fork Armells Creek alluvium. Significant inflow to mine cuts will also be induced from ground-water storage. The intercepted and induced flows cannot be estimated without some concept of pit locations and geometries. Most waters influent to mine cuts in area C would presumably be pumped into East Fork Armells Creek downstream from the mine and would either leave the area as streamflow or would reenter the ground-water system by way of the alluvium. When mining is completed, the resultant ground-water system will depend greatly upon the location and treatment of alluvium in the spoils. If gravel has been replaced in pre-mining locations without mixing with fine-grained materials, and if it is in good hydraulic connection with undisturbed gravel, the flow system will not have changed greatly. If hydraulic conductivity of the alluvium is decreased significantly, an abnormally high water table will become established within and upstream from the mined area.

Mining of area D will have little effect on ground-water flow. The coal beds are present over a very small and deeply dissected area. Part of the ground-water flow to the older Rosebud mine will be intercepted, but influent rates will probably be negligible in most cuts. Inflow may enter cuts in the southern end of area D, where the coal beds are structurally lowest and are bounded by old mine spoils containing relatively large volumes of ground water in transient storage. High inflow rates there will be temporary because of the small area to be dewatered. Post-mining ground-water flow in area D will follow the southward structural gradient as does the existing flow. Section 35, T. 2 N., R. 41 E., is an area of converging ground-water flow from areas D and E (Pl. 5), and there is a relatively high water table in the center of the section. After mining, both areas will likely accept greater recharge, which will ultimately raise the water table where the flow systems converge.

Mining of the Rosebud coal in the southern end of area E began in December 1974. Mine cuts have thus far encountered very little water, so little that no need to discharge the influent has arisen. Considerably more water would be encountered if the McKay bed is mined there, and influent would certainly have to be discharged from mine cuts. Because of the low transmissivity of the McKay coal, there is no reason to expect excessive volumes of mine influent and effluent.

Mining in Peabody Coal Company's area *a* will be an extension of current operations northward and eastward along the outcrops of Rosebud and McKay coal beds. Inflow rates to mine cuts have thus far been variable. The greatest rates occurred during 1976 when influent to a mine cut increased to a reported average rate of about 40,000 cu. ft./day as the existing operation approached the Miller Coulee watercourse. Inflow was induced from thin alluvial deposits, from other overburden, and from the coal beds. Similar inflow rates will probably be encountered as mine cuts cross Coal Bank Coulee. Effluents are now being pumped to sediment ponds downstream in Miller Coulee and to an experimental impoundment in the mined area. All effluents reenter the shallow ground-water system or are lost to evaporation and transpiration.

Effluents from active cuts in areas A, B, C, and E will likely be discharged to the East Fork Armells Creek drainage; effluent from area D will probably enter the North Fork Cow Creek drainage. That from area *a* will enter the Miller Coulee drainage. Addition of the mine waters will create increased but unpredictable rates of flow in water-table aquifers along the watercourses.

Some possibility exists of increased "water-logging" in already affected areas along Armells Creek downstream from the project area. No such condition is known, and no such possibility is expected in any of the other drainages.

WATER AVAILABILITY

Depending upon sizes of actual mine areas, as many as five perennial reservoirs, four springs, and twenty-six water wells might be physically destroyed during future operations (Table 11). Also, storage in four other reservoirs may be diminished because of reduced drainage areas; an additional three springs and nine wells are in positions where some diversions of ground-water flow patterns may diminish yields. The most obvious changes in water availability will be the physical losses of reservoirs, springs, and wells within the mine areas. These losses will probably be preceded by diminished water needs as land surface is gradually transferred from agricultural use to non-use prior to mining. The effects of mining on water supplies outside the probable mine areas are less obvious and are more difficult to predict; none of those listed in Table 11 is judged to be extremely vulnerable. They are listed because of theoretical possibilities that under certain conditions their reliability may be reduced during mining. The extensive ground-water observation system will provide advance notice if any of these water supplies are actually threatened.

Areas or locations of reduced ground-water availability will depend upon locations of drained mine

Table 11.—Reservoirs, springs, and wells that may be physically removed or otherwise affected by proposed mining operations near Colstrip, southeastern Montana.

Physical removal	Possible reduced storage or yield	Affecting mine area(s)*
	Reservoirs containing perennial storage	
	2 N 40 E 36AD	A
	2 N 41 E 15CA	D
2 N 41 E 29DC		A
	2 N 41 E 30CA	A
2 N 41 E 31AC		A
	2 N 42 E 19CA	D
1 N 41 E 10BA		B
1 N 41 E 24AB		*A*
1 N 41 E 24BA		*A*
	Springs	
	2 N 42 E 30CCCA	D
	2 N 42 E 31CBDC	D, E
1 N 40 E 02BABD		C
1 N 40 E 02BBDD		C
1 N 40 E 02BDAB		C
1 N 40 E 04CAAA		B
	1 N 41 E 24CCAA	B, *A*
	Wells	
2 N 41 E 24CAAC		D
2 N 41 E 24CABA		D
2 N 41 E 30DDAA		A
2 N 41 E 32DABB		A
1 N 40 E 01CCCD		C
1 N 40 E 02BBDC		C
1 N 40 E 02CDCC		C
1 N 40 E 04DADD		C
1 N 40 E 04DBBA		C
	1 N 40 E 05CCCB	C
1 N 40 E 10DAAB		C
1 N 40 E 11ABBB		C
	1 N 40 E 12CBAA	C
1 N 40 E 13ABAA		C
1 N 40 E 14BBBB$_1$		C
1 N 40 E 14BBBB$_2$		C
1 N 40 E 15BBCB		C
1 N 40 E 16DBAA		C
	1 N 40 E 21AAAD	C
	1 N 40 E 23BDDB	C
	1 N 40 E 24CACB	C
1 N 41 E 02DACC		E
1 N 41 E 03CDDD		B
	1 N 41 E 03BBBB	A, B
1 N 41 E 04DDBA		B
1 N 41 E 06ACAB		A
1 N 41 E 06DDDB		A
1 N 41 E 07DBBA		B
	1 N 41 E 08BBDB	B
	1 N 41 E 08BBDC	B
	1 N 41 E 08BBDD	B
1 N 41 E 08CBAB$_1$		B
1 N 41 E 08CBAB$_2$		B
1 N 41 E 13CDCD		*A*
1 N 41 E 17BBBB		B

* A, B, C, D, E, Western Energy areas; *A*, Peabody area A

cuts. As cuts are filled with spoils, flows will resume and will be augmented by rainfall and snowmelt, and productivities of wells and springs outside the mined areas should be restored. Within mined areas, it is likely that the final surface can be manipulated to recreate reservoirs to store surface water for livestock. Ground water will be obtainable from mine cuts left without external drainage (except in parts of areas A and D), and from wells drilled to aquifers below the disturbed materials. Wells completed in mine spoils will also produce some water, but completions may be considerably more difficult than in undisturbed aquifers because the spoils will be fine grained, poorly sorted, and unconsolidated.

WATER QUALITY

During mining, effluents from active cuts will be mixtures of waters from the disturbed aquifers. Under non-mining conditions these waters discharge naturally to the watercourses; at most places, discharge rates are less than evapotranspirative demands. No significant changes in the chemical system can be expected because natural ground-water discharge will be augmented by mine effluent having the same chemical quality. Dissolved-solids concentrations in effluents from most of the mine areas will be less than 2,000 mg/l. Concentrations may be greater in effluents from the northeast end of area B, the south end of area D, and the north end of area E because of induced flow from spoils of the old Rosebud mine; in these places the dissolved-solids concentrations may approach 3,000 mg/l. Effluents not used for dust control or other mining-related purposes will be discharged to watercourses and will be chemically similar to waters outside the mine areas.

Quality of ground water in spoils left by future operations will probably be as variable as the quality of water in the areas already mined. Based upon present conditions, it can be expected that post-mining waters will have dissolved-solids concentrations between 1,000 and 5,000 mg/l; that principal constituents will be magnesium and sulfate; and that concentrations of some trace elements will be higher than in pre-mining waters. The overall chemical differences between pre-mining and post-mining ground waters should ultimately be relatable to the final geochemical differences in aquifer materials. The coal beds and their waters will be stratigraphically replaced by inorganic spoils and by waters chemically more similar to waters in other non-coal aquifers.

SUMMARY

Approximately 2,000 acres of land has been subjected to strip mining of coal near Colstrip since 1924; Western Energy Company has mining plans that may involve 10,000 acres more; Peabody Coal Company has developed plans to mine an additional 1,000 acres. The area is semiarid and most streams are intermittent; average annual precipitation is about 15.8 inches, and average annual temperature is about 45.9°F. The scarcity of surface water necessitates heavy dependence upon ground water for livestock and domestic uses. The most significant aquifers to be disturbed by mining are the Rosebud and McKay coal beds and the hydrologically associated alluvium along East Fork Armells Creek.

The area of mining intent is part of a gentle southeastward-plunging structural trough compounded by numerous faults, most of which have less than 50 feet of displacement. In areas where the coal beds lie within about 200 feet below surface they are heavily used for water supplies; these are also areas where they are economically mineable.

An extensive system of observation wells has been installed to enable periodic measurements of water levels and periodic samplings for water-quality determinations. During 1974 the aquifers received little or no recharge. In 1975 and again in 1976 as much as 12 inches of recharge entered shallow, undisturbed aquifers at some locations, and even greater recharge entered mine spoils beneath an experimental impoundment at the Rosebud mine. No water-level changes in wells have been attributable to activities at the Rosebud mine, but strong water-level changes have occurred within about a quarter mile of the Big Sky mine. Beyond 1½ miles from the mine, water levels have dropped less than one foot.

Field tests of aquifer transmissivities and hydraulic conductivities generated similar ranges of values for undisturbed Fort Union aquifers and for mine spoils. The similarities imply that post-mining flow rates are not greatly different from those before mining began. Ground waters in the alluvium and the Rosebud and McKay coal beds flow generally eastward across the project area at an estimated rate of 15,000 cu. ft./day. Conductive alluvium along East Fork Armells Creek transmits about two-thirds of the total flow.

Chemical characteristics of the ground waters differ greatly between different locations and different depths. Dissolved-solids concentrations range from about 400 to 6,000 mg/l. In general, waters from coal beds are less mineralized than waters from inorganic materials. The cations calcium, magnesium, and sodium are present in a wide range of concentrations and proportions; no relations to aquifers, depth, or location are obvious. Sulfate is the predominant anion in most waters; those having less than about 1,000 mg/l of dissolved solids contain relatively more bicarbonate. Spoils in the oldest part of the Rosebud mine contain waters that are more mineralized than those in younger spoils or in nearby undisturbed aquifers. Occurrences and concentrations of trace elements are very diverse, but lead and nickel concentrations do appear somewhat greater in waters from mined areas. Data collected before mining began in 1924 give no indications that changes in water quality have occurred since then, but the data are too sparse for specific comparisons.

Future mining will induce ground-water flow temporarily to active mine cuts and permanently to any abandoned cuts having external drainage. Influent rates to most of them will be too insignificant to require pumping. Mine cuts near East Fork Armells Creek and near existing mine spoils will probably induce influent that must be discharged to surface water-courses. Such additions to East Fork Armells Creek may somewhat increase "waterlogging" downstream from Colstrip.

Depending upon sizes of actual mine areas, as many as five perennial reservoirs, four springs, and twenty-six wells may be physically destroyed during future operations. Also, storage in four other reservoirs may be reduced, and productions from three springs and nine wells may be reduced while mine cuts are active. Where ground-water supplies are lost, new ones can be obtained by drilling to deeper aquifers. Because of apparently similar aquifer coefficients of coal beds and mine spoils, it can be expected that future ground-water flow rates and patterns in reclaimed areas will not differ greatly from those now occurring in the coal beds.

Chemical qualities of active-mine effluents will be similar to those of other area waters; dissolved-solids concentrations will range between 500 and 3,000 mg/l. Leachates from spoils will probably have dissolved-solids concentrations ranging between 1,000 and 5,000 mg/l, of which the principal constituents will be magnesium and sulfate, and the general quality of ground water in the mined areas will ultimately alter to become more representative of waters in other non-coal aquifers.

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