POTENTIAL EFFECTS OF SURFACE COAL MINING ON THE HYDROLOGY OF THE UPPER OTTER CREEK-PASTURE CREEK AREA, MOORHEAD COAL FIELD, SOUTHEASTERN MONTANA

By Neal E. McClymonds and Joe A. Moreland

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CONVERSION FACTORS

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

Multiply inch-pound units	By	To obtain metric units
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per day (ft^3/d)	0.028317	cubic meter per day
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer

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

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

National Geodetic Vertical Datum of 1929 (NGVD of 1929)--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level."

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ABSTRACT

The combined upper Otter Creek-Pasture Creek area of the Moorhead coal field, located about 33 miles south of Ashland, Montana, contains large reserves of Federal coal that have been identified for potential lease sale. A hydrologic study has been conducted in the area to describe existing hydrologic systems and generalized ground-water quality, to assess potential effects of surface coal mining on local water resources, and to evaluate the potential for reclamation of those water resources.

The area is underlain by the Tongue River Member of the Fort Union Formation of Paleocene age and by alluvium of Pleistocene and Holocene age. The Tongue River Member consists of mostly shale, siltstone, sandstone, and extensive coal beds. The principal coal beds are: the Canyon, 18 to 25 feet thick in generally two or more beds; the Dietz, 5 to 12 feet thick in one or more beds; and the Anderson, 12 to 30 feet thick in generally two or more beds.

Sandstone, coal beds, and alluvial sand and gravel are the principal aquifers. Sandstone or coal aquifers in the upper Otter Creek area have hydraulic-conductivity values of 0.004 to 16 feet per day. Hydrologic characteristics of the alluvium vary considerably, depending on the location across the alluvial valley and the location upstream and downstream. The alluvial aquifers have hydraulic-conductivity values of 1 to 290 feet per day.

Quality of water in the sandstone and coal beds varies with distance from the point of recharge. In shallow bedrock aquifers in the upper Otter Creek area, dissolved-solids concentrations range from 1,160 to 4,390 milligrams per liter and the water contains principally calcium, magnesium, and sulfate. In deeper bedrock aquifers, the water is dominated by sodium and bicarbonate. Water in alluvial deposits has a dissolved-solids concentration ranging from 1,770 to 12,600 milligrams per liter. Major constituents in water from alluvial deposits are sodium, magnesium, and sulfate.

Surface-water resources are limited. Streamflow consists of the main streams of Otter Creek, with four principal tributaries, and Pasture Creek, in an area of 40.3 square miles. Most of the streamflow is intermittent. Flow is interrupted during most years in Otter Creek just upstream from the confluence with Pasture Creek and in the downstream 1.5 miles of Pasture Creek. Most of the stock ponds become dry by midsummer.

To allow prediction of the potential effects of mining on the hydrologic systems in the area, mine plans were postulated. Three mines,

occupying about one-third of the area, would excavate Anderson, Dietz, and Canyon coals. Mining would lower water levels in sandstone and coal aquifers outside the highwalls of the mines to the south, east, and west and would remove the alluvium beneath the valleys. After mining, water moving through replaced mine spoils would acquire a chemical quality dependent on mineralogy of spoils material and flow paths through the spoils.

Planned structuring of the spoils and reconstruction of the alluvial aquifers could minimize downstream changes in water quality. Although mining would alter the existing hydrologic systems and destroy several shallow wells, alternative ground-water supplies in reconstructed alluvium or at greater depths could be developed to replace those lost by mining. Stock ponds removed by mining could be replaced on the landscaped spoils surface.

INTRODUCTION

Development of western coal to meet national energy needs has been receiving increased emphasis. A large part of the western coal is under Federal ownership; therefore, considerable demand exists for leasing and development of Federal coal lands. To ensure orderly leasing and development of the Federal coal, a Federal Coal Management Program was developed, which requires the U.S. Bureau of Land Management to identify tracts of coal for potential lease, analyze the tracts for potential environmental effects, and schedule tracts of coal for lease sale.

One of the primary considerations in the selection of tracts for lease is potential adverse effects on the water resources of the area during mining and reclamation operations, and after abandonment. To determine potential effects on the hydrology of a coal tract during mining and after reclamation is completed, the U.S. Geological Survey, in cooperation with the Bureau of Land Management, has conducted hydrologic studies on several potential coal lease tracts in the Powder River structural basin of southeastern Montana. The upper Otter Creek-Pasture Creek area of the Moorhead coal field is one of these tracts.

Purpose and Scope

The purpose of this report is to describe the existing hydrologic systems, to describe the generalized ground-water quality of the area, and to assess potential effects of surface coal mining on local water resources. Specific objectives were to: (1) Identify ground-water resources of the area; (2) determine generalized chemical quality of the ground-water resources; (3) identify surface-water resources and runoff characteristics; (4) determine potential effects on existing water resources from surface-coal-mining operations, including possible changes in the quantity and quality of water; and (5) evaluate the potential for reclamation of local water resources.

To accomplish these objectives, all pertinent data on local geology and hydrology were compiled. Hydrogeologic data collection for existing domestic and livestock wells and observation wells was begun in March 1983 and continued through October 1984. Numerous test holes drilled within the upper Otter Creek and Pasture Creek basins and adjacent areas from about 1960 to 1983 provided information on the hydrogeology of the area. In 1974, American Metals Climax Corp. (now AMAX

Coal Co.) drilled and cased six observation wells within the basins. In 1975, Utah International Inc. completed two wells within the basins and the U.S. Bureau of Reclamation completed a series of wells in the Bear Creek basin to the west; data for three of the observation wells are included in this study. The U.S. Geological Survey in 1977 completed one observation well on the Otter Creek-Bear Creek divide, northwest of the area as part of another study, and in 1983 completed a network of 8 observation wells in the Tongue River Member of the Fort Union Formation and 19 observation wells in alluvium at 11 sites. Water levels in the wells were measured, most of the wells were tested by pumping or bailing to determine aquifer characteristics, and most wells and six springs were sampled for chemical analysis of the water. Surface-water data were collected from Otter and Pasture Creeks near their confluence.

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

Location and Description of Area

The area of principal study is the Otter Creek drainage basin upstream from the confluence with Pasture Creek, and the entire Pasture Creek drainage basin east of Otter Creek. For simplicity of reference in further discussion, the combined basins are referred to as the upper Otter Creek area. In addition, data from some wells and test holes near the area of principal study were used to evaluate the hydrology and the effects of mining.

The study area is in Powder River County, about 33 mi south of Ashland, Mont., and 22 mi southeast of Birney in the western part of the Moorhead coal field (fig. 1). The western boundary of the upper Otter Creek area, which generally is the divide between the Otter Creek and Bear Creek drainages, is about 31 mi east of the Tongue River near the West Decker and East Decker Mines. The eastern and southern boundaries generally are the divide between the Otter Creek and Powder River drainages. Otter Creek flows northward to join the Tongue River near Ashland.

The topography of the study area is characterized by broad, flat-topped uplands; deeply incised canyons eroded into the upland plains; broad, flat valley bottoms; and gently rounded hills between tributary stream valleys. Tributaries to Otter Creek include Billup, Boxelder, Long, and Cedar Creeks. Pasture Creek splits into west and east forks about 4 mi upstream from the confluence with Otter Creek. The west fork is the mainstem of the creek. The east fork is herein called "Bliss" creek.

The area of the drainage basins comprising the study area is 40.3 mi^2 (pl. 1). The altitude of Otter Creek valley at the confluence with Pasture Creek is 3,600 ft above the National Geodetic Vertical Datum of 1929 (NGVD of 1929). The flat uplands range in altitude from about 4,150 to 4,300 ft.

Climate

The climate in the area is typical of the northern Great Plains--semiarid, with warm summers, cold winters, moderate humidity, and generally little but variable precipitation. Winds are predominantly from the northwest to west.

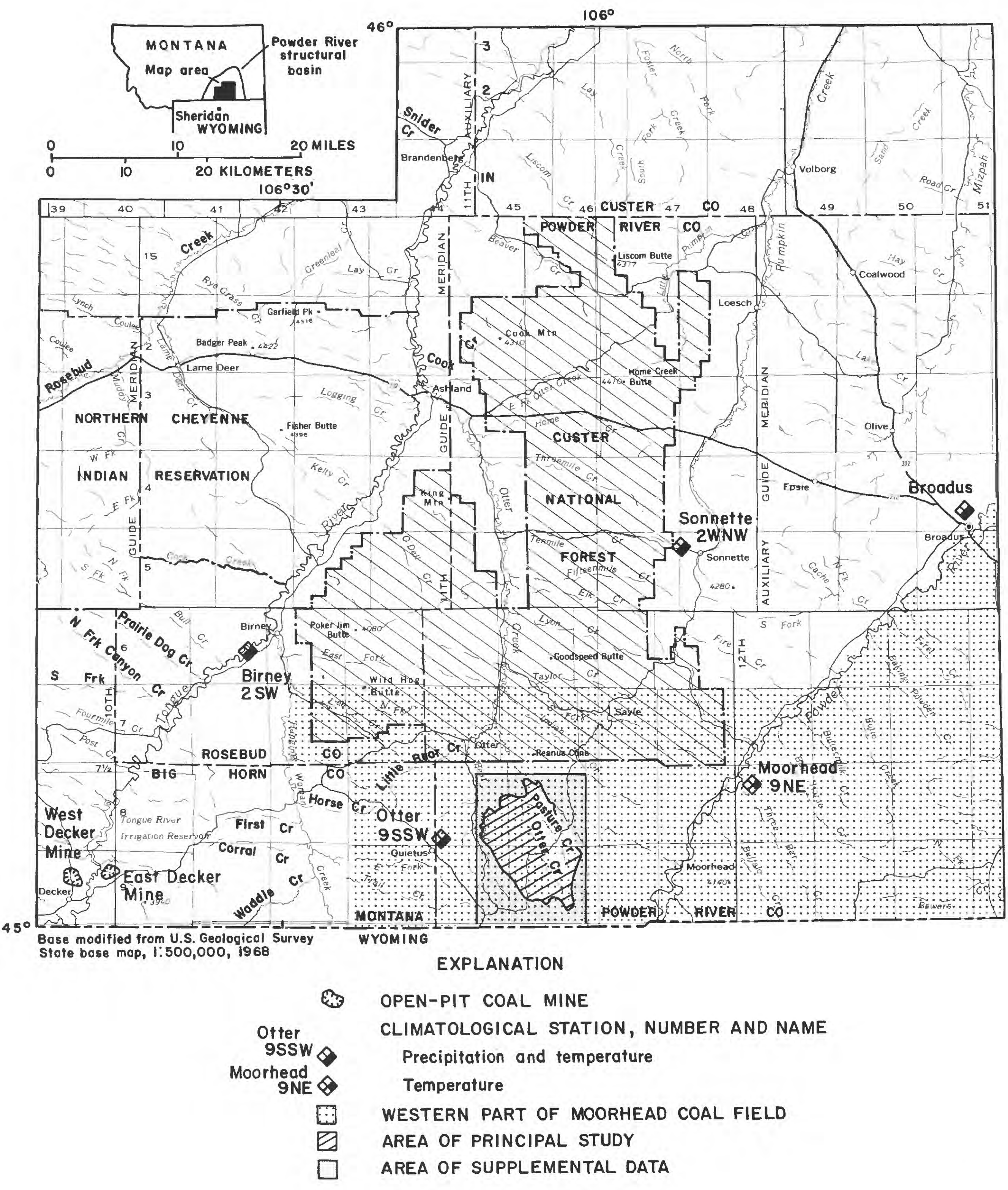


Figure 1.--Location of study area.

Air temperatures vary from a monthly average of 17 °F for January to 71 °F for July at Broadus, the nearest climatological station with long-term (50 years) temperature records. The 1983-84 monthly average temperatures at four climatological stations near the study area are shown in figure 2. Otter 9SSW and Sonnette 2WNW are at higher altitudes than most of the upper Otter Creek area, and Birney 2SW and Moorhead 9NE are at lower altitudes; the Birney station is on the flood plain of the Tongue River and the Moorhead station is near the Powder River (fig. 1). The temperatures in the study area are presumed to be within the range of the temperatures at the four stations--generally warmer at the lower altitudes (3,600 to 3,800 ft) and cooler at the higher altitudes (3,900 to 4,300 ft).

No precipitation stations are maintained in the upper Otter Creek area, but three climatological stations--Otter 9SSW, Sonnette 2WNW, and Birney 2SW--are close enough to reasonably define the quantity of precipitation, which is estimated to average 16 in. The quantity of precipitation at the three stations from January 1983 through October 1984 and the monthly average precipitation are shown in figure 3. Precipitation during 1983 was much less than average at all stations; in fact, it was the least annual precipitation for the 23 years of record at the Otter 9SSW station, which began operation in 1962. In 1984, a severe snowstorm in late April left as much as 3 ft of wet snow across much of southeastern Montana, increasing the total precipitation for April to much more than average at all stations.

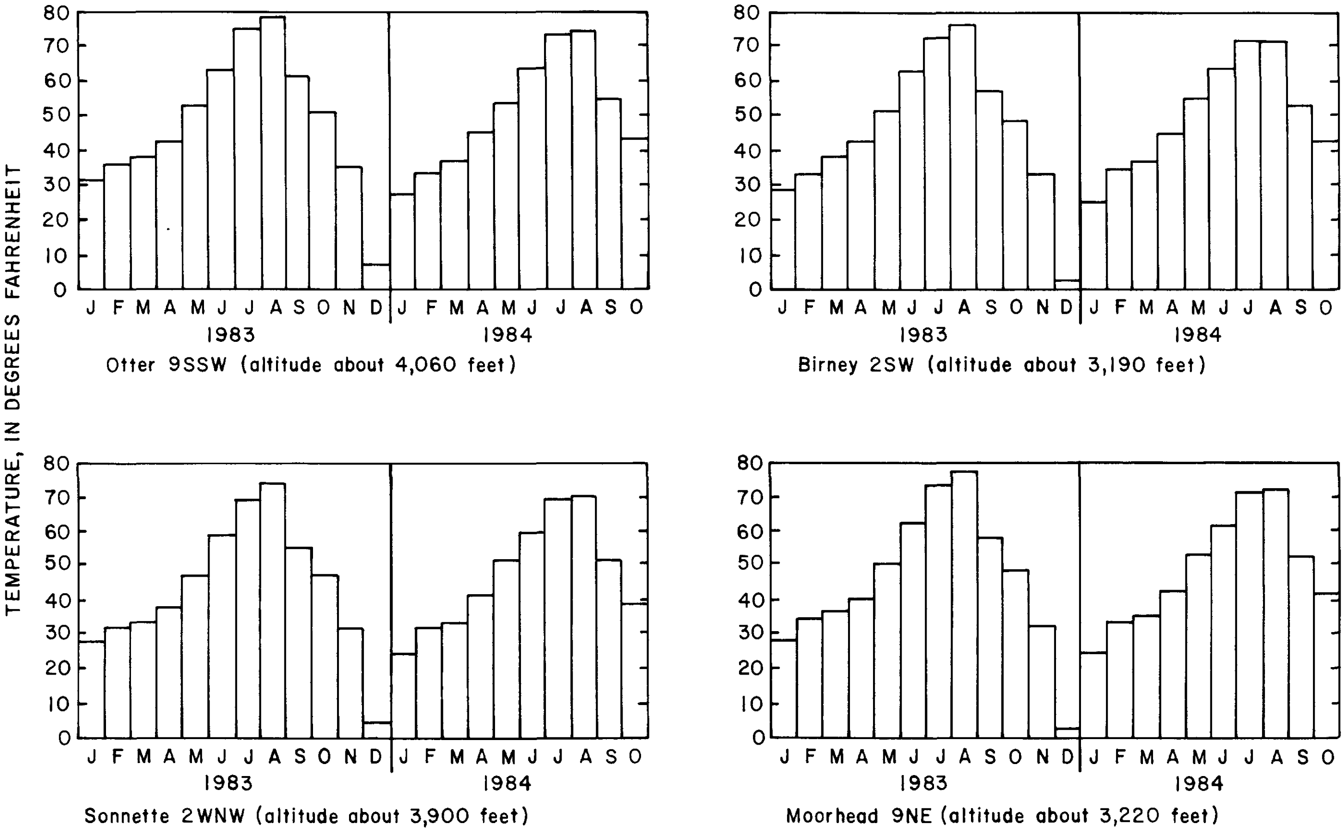


Figure 2.--Monthly average air temperatures during 1983 and most of 1984 at four climatological stations near the upper Otter Creek area. Stations are located in figure 1.

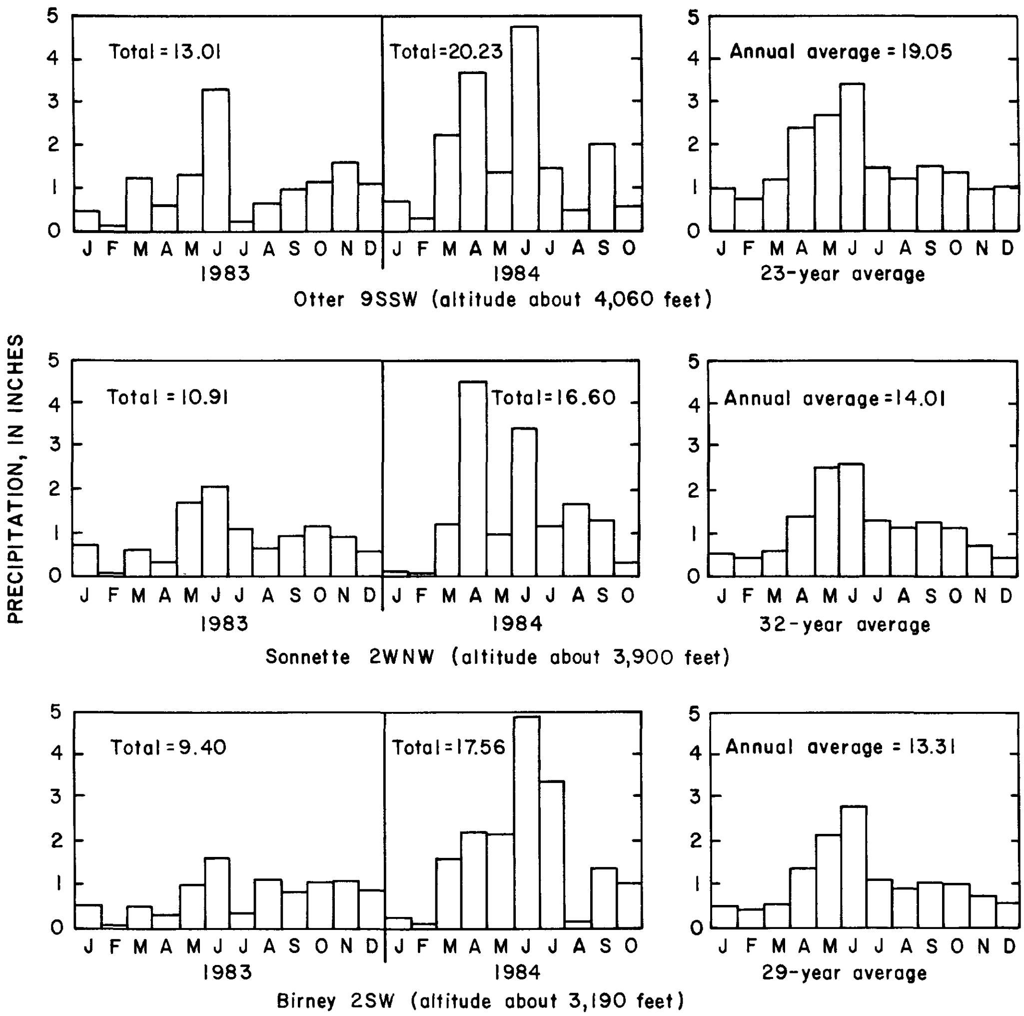


Figure 3.--Monthly precipitation during 1983 and most of 1984, average monthly precipitation for the period of record, and annual average precipitation for the period of record at three climatological stations near the upper Otter Creek area.

During a normal year, 45 to 50 percent of the precipitation falls during April, May, and June. November through March are usually driest, with about 20 percent of the annual precipitation falling during this time. The distribution of monthly average precipitation is characterized by large quantities of precipitation during the spring, some precipitation during the summer, and little precipitation during the winter.

Previous Investigations

The geology and coal deposits of the area have been studied by several investigators. R.P. Bryson conducted mapping studies in 1940, 1941, and 1946 of the area from Hanging Woman Creek eastward to the Powder River valley (Bryson and Bass, 1973), in what became known as the Moorhead coal field. That study correlated the coals, named by Taff (1909) and Baker (1929) in the Sheridan, Wyo., and Decker areas, eastward across the upper Otter Creek area. Matson and Blumer (1973) described the quality and quantity of strippable coal in the Tongue River Member of the Fort Union Formation in a comprehensive report on coal deposits of southeastern Montana. Cole (1981) investigated the Anderson and Dietz coal beds of southern Montana and correlation problems caused by splitting and merging of the coal beds.

Ground-water resources and hydrologic characteristics of the aquifers in the area have been studied on a regional scale by Perry (1931), Lewis and Roberts (1978), Slagle and Stimson (1979), and Lewis and Hotchkiss (1981). The hydrology has been studied in greater detail in the Bear Creek area (U.S. Department of the Interior, 1977), just west of the upper Otter Creek area.

Chemical quality of ground water and the chemical processes that control the quality in the Fort Union Formation have been investigated by Lee (1979) and Dockins and others (1980). The quality of surface water in the region was studied by Knapton and Ferreira (1980).

Potential effects of coal mining on water resources in the Tongue River drainage basin have been investigated by Van Voast (1974) and Van Voast and Hedges (1975) in the Decker area, and by Woessner and others (1979) on the Northern Cheyenne Indian Reservation. Woods (1981) developed a computer model for assessing potential increases in dissolved solids of streams as a result of leaching of mine spoils. McClymonds (1985) studied the hydrology and potential effects of surface coal mining near Little Bear Creek, about 5 mi northwest of the present study area.

WATER USE AND SUPPLY

Ground-water and surface-water supplies are used for domestic purposes and livestock watering within the upper Otter Creek area. Six ranches are operated in the area; most obtain domestic water from underground cisterns that receive precipitation from roof collectors. One ranch uses well water from an alluvial aquifer that is made potable by distillation. Another uses spring water from a clinker aquifer (burned coal and baked or vitrified overburden) north of the area.

Twenty-four of the 37 private wells inventoried (table 2 at back of report) were in operation or operable at the end of the study (October 1984). Of these 24 wells, 5 were domestic wells, 17 were livestock wells, and 2 were used for both domestic purposes and livestock watering. Ten domestic wells were unused; three livestock wells were abandoned (either destroyed, filled with sand, or had collapsed steel casing). The domestic wells were used for drinking or irrigating of lawns and gardens at the ranch houses. The yields of the wells range from about 1 to 20 gal/min. Most of the water from the wells is too mineralized for human consumption, but almost all the well water is usable for livestock watering.

Ground-water use is less than the potential yield from the sandstone and coal aquifers of the Tongue River Member of the Fort Union Formation and from the sand and gravel intervals at the base of the alluvium. However, in parts of the area, the sandstone aquifers have yields less than 1 gal/min; even wells drilled to depths of 300 ft may penetrate few water-yielding sandstone beds. In other parts of the area, a well drilled to the same stratigraphic interval has a chance of penetrating sandstone beds capable of yielding as much as 10 gal/min. The coal aquifers seem to be equally unpredictable from site to site. An ideally located well completed in the alluvium in most of the stream valleys probably could yield from 5 to 10 gal/min, although some of the observation wells completed in alluvium during this study yielded less than 1 gal/min.

.In most of the upper Otter Creek area, surface-water supplies are limited to intermittent streams, stock ponds, and a few springs. Otter Creek has interrupted flow from the confluence with Pasture Creek to about 1.2 mi upstream, except during extremely dry years when there is no flow upstream from the confluence. Pasture Creek has interrupted flow from its mouth to about 1.5 mi upstream, but during years of less than average rainfall, the reaches of flow shorten.

Few of the 48 stock ponds observed in the upper Otter Creek area retained water through the summers of the study (1983-84). One, near the southeast corner of sec. 19, T. 8 S., R. 46 E., is along Otter Creek near the upstream end of the reach with interrupted flow; this pond contained water throughout the dry summer of 1983, but the water level declined to near the bottom of the pond by September. Farther upstream along Otter Creek, a large pond in the northwest corner of sec. 4, T. 9 S., R. 46 E., had no visible water but was marshy on the broad flat bottom through the summer. Along Pasture Creek, two ponds retained water throughout the study, but both had little water (water depth of 1 to 2 ft) during late summer in 1983 and 1984. The downstream pond is in the north-central part of sec. 28, T. 8 S., R. 46 E., and receives water from alluvial seeps along the stream channel. The other pond, in the southeast corner of sec. 34, T. 8 S., R. 46 E., receives water from seeps in Anderson clinker. All ponds observed near the upstream ends of the drainage basins were dry by midsummer in 1983 and 1984.

Six springs were inventoried within the area. Three of the springs apparently issue from sandstone beds in the Tongue River Member of the Fort Union Formation in the upper part of tributary valleys. The other three springs--one along Billup Creek and two along Pasture Creek--issue from the alluvium; the source of the water probably is sandstone or coal beds draining into the alluvium.

Water samples were collected from 20 private wells to document the quality of water from wells in use in and near the upper Otter Creek area. The concentrations of all chemical constituents tested were less than the maximum limits recommended by McKee and Wolf (1971, p. 112) for use by livestock. Water from private wells in use in the area, however, exceeds the maximum concentrations of 250 mg/L (milligrams per liter) for sulfate and 500 mg/L for dissolved solids recommended by the U.S. Environmental Protection Agency (1986b, p. 588) for public supply. The quality of ground water of the upper Otter Creek area generally is typical of the quality of water in the Tongue River Member of the Fort Union Formation in the northern Powder River structural basin.

POTENTIAL EFFECTS OF SURFACE COAL MINING ON AREA HYDROLOGY

Assumptions

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

No mine plans are available for the upper Otter Creek area. Therefore, a postulated mine plan was drawn showing the potential location and configuration of open-pit mining, as well as potential directions of mining (pl. 1). Predicted effects of surface coal mining on the local hydrologic systems are based on the assumptions that:

1. All mining of the Anderson, Dietz, and Canyon coal beds would take place within the boundaries of the three postulated mines shown on plate 1.

2. Mining in the western mine would be along the Bear Creek-Otter Creek divide, with the Anderson coal bed being excavated. Mining in the central mine would be along the west side of Otter Creek, southeastward along Otter Creek into sec. 9, T. 9 S., R. 46 E., across the Otter Creek-Pasture Creek divide, and along the east side of Pasture Creek, with the Dietz and Canyon coal beds being excavated. Mining in the southeastern mine would be in the upstream area of Pasture Creek and westward across Cedar Creek, with the Anderson and Dietz coal beds being excavated.

3. In the three postulated mines, excavation would begin along the northern boundaries and move generally southward; in the central mine, which would have arms southwest of Otter Creek and northeast of Pasture Creek, mining would be commenced simultaneously at the north end of each arm. The mining would progress to where the thickness of overburden overlying the Canyon or Anderson coal bed is about 200 ft.

4. All mining regulations established by the U.S. Office of Surface Mining and the Montana Department of State Lands would be followed during mining and reclamation.

Effects During Mining

Bedrock Aquifers

Hydrologic systems are dissimilar in each of the areas to be mined. Consequently, the effects of mining on bedrock aquifers would differ in the three postulated mines.

Western Mine

Mining of the Anderson coal bed along the Bear Creek-Otter Creek divide would not affect any aquifers directly. The Anderson is dry, or has water only in the lowest parts, within the 2.2 mi^2 of the postulated mine, as outlined on plate 1. Mining would probably start at the north end of the mine just west of the Bear Creek-Otter Creek divide. Aquifers underlying the divide are sandstone beds, the Dietz coal bed, and the Canyon coal bed. The Dietz coal bed is 9 to 11 feet thick and is separated from the Anderson coal bed by about 70 to 120 ft of interburden; in this vicinity, the Dietz is presumed to be too deep to be mined with the Anderson coal bed. Perched aquifers in the overburden above the Anderson coal bed might drain small quantities of water into the mine for short periods, but the perched aquifers are not considered to be significant sources of water.

Central Mine

Multiple aquifers transmit water through the site of the potential central mine pit, at least along the southwest and south sides. Along the northeast arm, on the divide between Pasture and Bradshaw Creeks, the Canyon coal bed is the only aquifer that would be affected by mining. Toward the north end of the arm, (section C-C', pl. 1) the coal bed is probably mostly dry. The area of the postulated mine is about 10.8 mi^2.

Several sandstone beds and lenses above the Dietz coal bed and between the Dietz and Canyon coal beds, as well as the coal beds, would yield water to the postulated mine pit on the southwest, south, and southeast sides. In addition, alluvial sand and gravel along Billup, Boxelder, Long, Otter, Cedar, and Pasture Creeks would contribute water to the pit.

Mining would probably begin on the bench west of the Otter Creek-Pasture Creek confluence, which is at the north end of the southwest arm of the postulated mine pit, and at the north end of the northeast arm between the areas of clinker, burned coal, and scorched overburden that flank the divide between Pasture and Bradshaw Creeks, and progress southward and southeastward. In the middle part of Otter and Pasture Creek valleys, the central mine would become one broad pit and mining would proceed southward and southeastward up Boxelder, Long, Otter, and Pasture Creek valleys to the 200-ft overburden limit of the Canyon coal bed. The southwest edge of the postulated mine pit would be the approximate 200-ft overburden limit, and the northeast edge would be the limit of clinker, burned coal, and scorched overburden. The Canyon coal bed and overlying sandstone beds are probably dry at the north end of the southwest arm. As the mine progresses southward, the mine pit would intersect aquifers within the Canyon coal bed, sandstone beds, and, eventually, the Dietz coal bed.

Along the southwest and south sides of the central mine, sandstone and coal aquifers have a combined thickness of about 47 ft. Pre-mining water levels along the southwest and south sides of the central mine are as much as 120 ft above the base of the mine pit (base of the Canyon coal bed). In the eastern part of the central mine, sandstone and coal aquifers have a combined thickness of about 60 to 65 ft and water levels of 150 to 200 ft above the base of the mine pit. In the northernmost parts of the central mine, sandstone and coal aquifers contain less water because of natural discharge.

The central mine would cause water levels in sandstone and coal aquifers to decline as much as 200 ft near the highwall of the mine pit. Dewatering of the sandstone and coal aquifers at the mine pit would likely cause water-level declines in these aquifers for a distance of 1 to 3 mi to the west, south, and east of the mine. Water-supply wells completed in the affected aquifers could be dewatered or have substantially lowered water levels. Water levels in sandstone and coal aquifers to the north of the mine pit would not be as greatly affected by dewatering because of lower pre-mining water levels and less available drawdown between the top of the aquifers and the base of the mine pit.

The rate of inflow to the mine pit would be extremely variable and would depend on the transmissivity of exposed aquifers, the depth of the mine pit, and the potentiometric surface in the exposed aquifers. The rate of inflow would be fastest during the initial exposure of the aquifers and would decrease as the potentiometric surface declined. A detailed geohydrologic study of the mine area would be necessary to accurately determine the inflow rate.

Southeastern Mine

In the upstream reaches of Pasture Creek and extending westward into Cedar Creek valley, the Anderson coal bed is near the land surface and the Dietz coal bed is 40 to 60 ft below the base of the Anderson. Mining of both coal beds in the southeastern mine is presumed to be economical. In addition to the coal beds, aquifers include sandstone above and below the Anderson coal bed. Assuming that the size and outline of the postulated mine would be approximately as shown on plate 1, the area of the mine would be about 3.5 mi^2.

Mining of the Anderson and Dietz coal beds would probably be an extension of the central mine. Thus, mining would begin along the northern part of the mine, as outlined on plate 1, and proceed southeastward up Cedar Creek and Pasture Creek valleys, including "Bliss" creek valley. The northwestern limit of the mine would be the burned clinker of Anderson coal, and the southeastern limit would be the 200-foot overburden of the Anderson coal bed.

In the southeastern mine, sandstone and coal aquifers have a combined thickness of 50 to 70 ft. Pre-mining water levels in the area of the southeastern mine are as much as 170 to 180 ft above the base of the mine pit. Discharge of ground water to the mine pit would dewater sandstone and coal aquifers near the mine and lower water levels in the aquifers south and east of the mine. Water-level declines from the southeastern mine would merge with those from the central mine and together would simulate drawdown from a single, large mine pit.

Alluvium

The alluvium of Otter Creek valley would be removed from 2.4 to 5.7 mi upstream from the Otter Creek-Pasture Creek confluence by the central mine, as outlined on plate 1. The alluvium of Pasture Creek would be removed from 2.8 to 4.4 mi upstream from its mouth by the central mine, and from 5.1 to 6.8 mi upstream from its mouth by the southeastern mine. In addition, the central mine would remove a 1.8-mi stretch of alluvium in the valley of Billup Creek, beginning 0.9 mi upstream from its mouth; a 1.8-mi stretch of alluvium in the valley of Boxelder Creek, beginning at its mouth; and alluvium in the downstream one-half of the valleys of Long Creek and Cedar Creek. The southeastern mine would remove alluvium in the downstream 2.3 mi of the valley of "Bliss" creek.

Based on geohydrologic data from observation wells installed across Otter Creek and Pasture Creek valleys and assumptions about ground-water flow, the premining rate of underflow is about 6,000 ft^3/d through the alluvium in Otter Creek valley and 1,750 ft^3/d through the alluvium in Pasture Creek valley. This underflow would discharge into mine pits that intersect the valley floors. Although accurate estimates of underflow through alluvial deposits beneath tributary streams cannot be obtained with available data, proportional rates could be estimated on the basis of thickness of deposits and width of the valleys.

The effects of operating the central and southeastern mines in the upper Otter Creek area would be local disruption of the flow systems in aquifers in the Tongue River Member and a substantial decrease in the volume of underflow in alluvium in Otter Creek valley for several miles downstream from the confluence of Otter Creek and Pasture Creek. The entire underflow would be intercepted unless the mine plans include contingencies for replenishing the water in the removed alluvium.

Long-Term Effects

Assuming that the size and outline of the postulated mines are as shown on plate 1, an area of about 16.5 mi^2 would be mined. If all economically recoverable coal were removed, the altitude of the land surface would be lowered from 20 to about 35 ft. All sandstone, coal, and alluvial aquifers above the mined coal beds would be destroyed. The natural (pre-mining) flow of ground water in and near the mine pits would be disrupted.

Three ranch houses, 11 used and unused domestic wells, and 14 used and unused livestock wells would be destroyed. In addition, water levels in one used well (P-34) and one abandoned well (P-35) would probably decline when the postulated mine pit removed the aquifers about 1 mi north of the wells. Water quality in three wells completed in alluvial aquifers, one (P-3) in Otter Creek valley and two (P-2, P-5) in Pasture Creek valley, would probably be affected by mine-water effluent. The discharge capacity of these three wells also would be affected when the alluvium is removed upstream.

Otter Creek and Pasture Creek, which have interrupted flow in their northern reaches downstream from the postulated mines, would probably cease to flow during the mining operations when their source is destroyed by the mine pits upstream. All livestock ponds within the area of the mines would be destroyed.

Two springs, S-3 in Billup Creek valley and S-4 in Pasture Creek valley, would be destroyed in the central mine. Spring S-1 is near the western edge of the central mine, in a west-side tributary of Billup Creek. The spring outlet might be destroyed but the source of the water upstream in the tributary would be unaffected by the mining. Spring S-2, downstream from the central mine in Pasture Creek valley, is presumed to discharge water originating from the local coal bed above the Cook coal bed; however, the spring probably discharges some water originating from the alluvium. Water levels would decline during mining, thereby affecting the spring discharge.

The sandstone and coal-bed aquifers in the upstream part of Otter and Pasture Creeks dip generally southwest. The potential exists for a long-term change in the quality of water in these aquifers downgradient from the mined areas. In the western mine, there would be little effect, because the Anderson coal would be removed from the top of the ridges above the water table. Recharge water passing through the mine spoils would affect the quality of water under the talus slopes and eventually the water in alluvium in Bear and Otter Creek valleys unless a mine plan is formulated to minimize effluent discharge from the spoils. Along the northeast wall of the central and southeastern mines, the ground-water flow would be from the sandstone and coal aquifers to the spoils material. Discharge from the spoils would be to the surficial bedrock and alluvial aquifers in Pasture Creek valley.

On the northeast side of the southwest arm of the central mine and along the length of the northeast arm, water from rainfall and snowmelt on the mine spoils would percolate downward to the saturated zone and, when the ground-water level reached equilibrium, would move downgradient into Otter and Pasture Creek valleys. This water would eventually mix with the water in the alluvium. The quality of water in the alluvium would be degraded and become more like the quality of water in the mine spoils. The alluvial aquifers along Otter and Pasture Creek valleys would function as conduits for water flowing from the mine spoils.

The water moving through the mine spoils would acquire a chemical quality dependent on the mineralogy of the spoils material. The mean dissolved-solids concentration of water that would occur in saturated spoils is estimated to be in the range of 3,200 to 6,900 mg/L. This range is about 140 to 300 percent of the mean dissolved-solids concentration (2,300 mg/L) of 27 water samples collected from shallow wells completed in the Tongue River Member in the area of principal study. The magnitude of the increase in dissolved solids, between ground water in the natural environment and water in mine spoils, is based on geochemical studies at mine sites in the Powder River structural basin of southeastern Montana (Davis, 1984) and in western North Dakota (Groenewold and others, 1983). Water in the saturated mine spoils would be predominantly a sodium sulfate or sodium bicarbonate type, based on the dominant water types in the undisturbed aquifers.

POTENTIAL FOR RECLAMATION OF HYDROLOGIC SYSTEMS

Unlike other potential sites of surface coal mining in southeastern Montana where the hypothetical-mine outlines have an approximate geometric shape, the multiple coal layers in the upper Otter Creek area result in hypothetical-mine outlines having a complex configuration, restricted on one side by overburden thickness and on the other by clinker layers. The areal expansion of the postulated mines would make reclamation of the area particularly difficult. A mine plan would need to include not only the most economical extraction process, but also the final topographic conformation of land shapes--hills and ridges, terraces, and valleys.

The disruption of overburden and interburden shale, siltstone, and sandstone would expose soluble minerals that could be leached by surface and ground water. The planned reclamation could be successfully completed by containment of the mineralized materials in the spoils pit in compact, almost impermeable layers. Success in such containment would minimize the volume of water passing into and out of the chemically active spoils material. An almost impermeable wall of clayey material could be compacted along the southwest faces of the postulated mine pits, between the spoils in the pits and the permeable sandstone and coal beds of the highwall face, to restrict the movement of ground water into the aquifers toward the southwest. A similar almost impermeable wall of clayey materials could be compacted along the southwest face of the northeast arm and along the north face of the main part of the central mine, between the pit and clinker layers, to restrict the downgradient movement of water in the Otter and Pasture Creek valleys.

The alluvium along Otter and Pasture Creek valleys and main tributaries could be reconstructed by placing and compacting clayey layers to the grade of the original alluvial-aquifer base, then overlaying the previously stockpiled sand, gravel, and clinker, and finally replacing the alluvial mud and soil. If reconstruction of the alluvium were properly planned, degradation of the quality of water in the alluvium downgradient from the mined areas could be kept to a minimum.

After mining and reclamation, the wells destroyed by the mining operations could be replaced. Along Boxelder Creek valley, wells P-19, P-20, and P-21 could be replaced by new wells completed in the same sandstone aquifer underlying the Canyon coal bed that supplies the wells at the present time (1984). Other wells that could be replaced by drilling to the sandstone that generally occurs about 40 to 200 ft beneath the Canyon coal bed include well P-18 along Boxelder Creek valley; wells P-12, P-13, P-14, P-15, P-16, and P-23 along Otter Creek valley; well P-11 along Cedar Creek valley; wells P-10, P-25, P-26, P-27, P-28, P-29, P-30, P-31, and

P-32 along Pasture Creek valley; and well P-1 west of Billup Creek. Wells completed in alluvium that would be destroyed by mining include well P-17 along Boxelder Creek valley, wells P-7 and P-24 along Otter Creek valley, and well P-9 along Pasture Creek valley. These wells could be replaced by a collector system of wells installed when the alluvium is being reconstructed, by post-mining wells completed in the reconstructed alluvial aquifer, or by wells drilled to sandstone beds below the base of the Canyon coal bed.

Springs S-3 and S-4 in the postulated mines could not be reconstructed. However, they could be replaced by drilled wells or a collector system of wells.

All stock ponds destroyed in the mined area could be replaced at or near the present sites as part of the structured topography constructed during reclamation. The post-reclamation structured topography would appear generally like the topography of the present landscape, but likely would be more subdued, with gentle slopes and terraces. Steeper relief could exist near the highwall of the postulated mines along the southwest and south sides of the central mine, and the southwest and northeast sides of the southeastern mine.

SUPPORTING TECHNICAL DISCUSSION

Analysis of the potential effects of mining on the hydrology of the area was based on geologic information from previous studies and interpretation of drillers' logs of test wells, ground-water information from private wells and observation wells, and surface-water information estimated from indirect techniques. Drillers' logs and other information are on file in the U.S. Geological Survey office in Helena, Montana, and in other agencies' offices. A summary of the hydrologic information is contained in tables 2-5 at the back of this report for interested readers.

Geology

Stratigraphy

Outcrops in the upper Otter Creek area are mostly of the upper 750 ft of the Tongue River Member of the Fort Union Formation of Paleocene age (pl. 2). Overlying the Tongue River Member along the Otter Creek-Powder River divide, in the southern and southeastern parts of the area, is the Wasatch Formation of Eocene age. Alluvial deposits of Pleistocene and Holocene age overlie the Tongue River Member along stream valleys. Underlying the Tongue River Member are the Lebo Shale Member and the Tullock Member of the Fort Union Formation, which overlie the Hell Creek Formation and the Fox Hills Sandstone of Late Cretaceous age (fig. 4).

The Fox Hills Sandstone and the lower part of the Hell Creek Formation are mostly sandstone. The two units comprise the Fox Hills-lower Hell Creek aquifer, which is a major source of ground water in many areas. The upper part of the Hell Creek Formation is mostly shale and is considered to be a confining bed (Lewis and Hotchkiss, 1981).

The base of the Fort Union Formation is about 2,300 ft below land surface near the confluence of Otter and Pasture Creeks (Lewis and Hotchkiss, 1981). The lowest strata of the Fort Union Formation, the Tullock Member, is composed mostly of sandstone and sandy siltstone beds and is about 500 ft thick at the north end of the

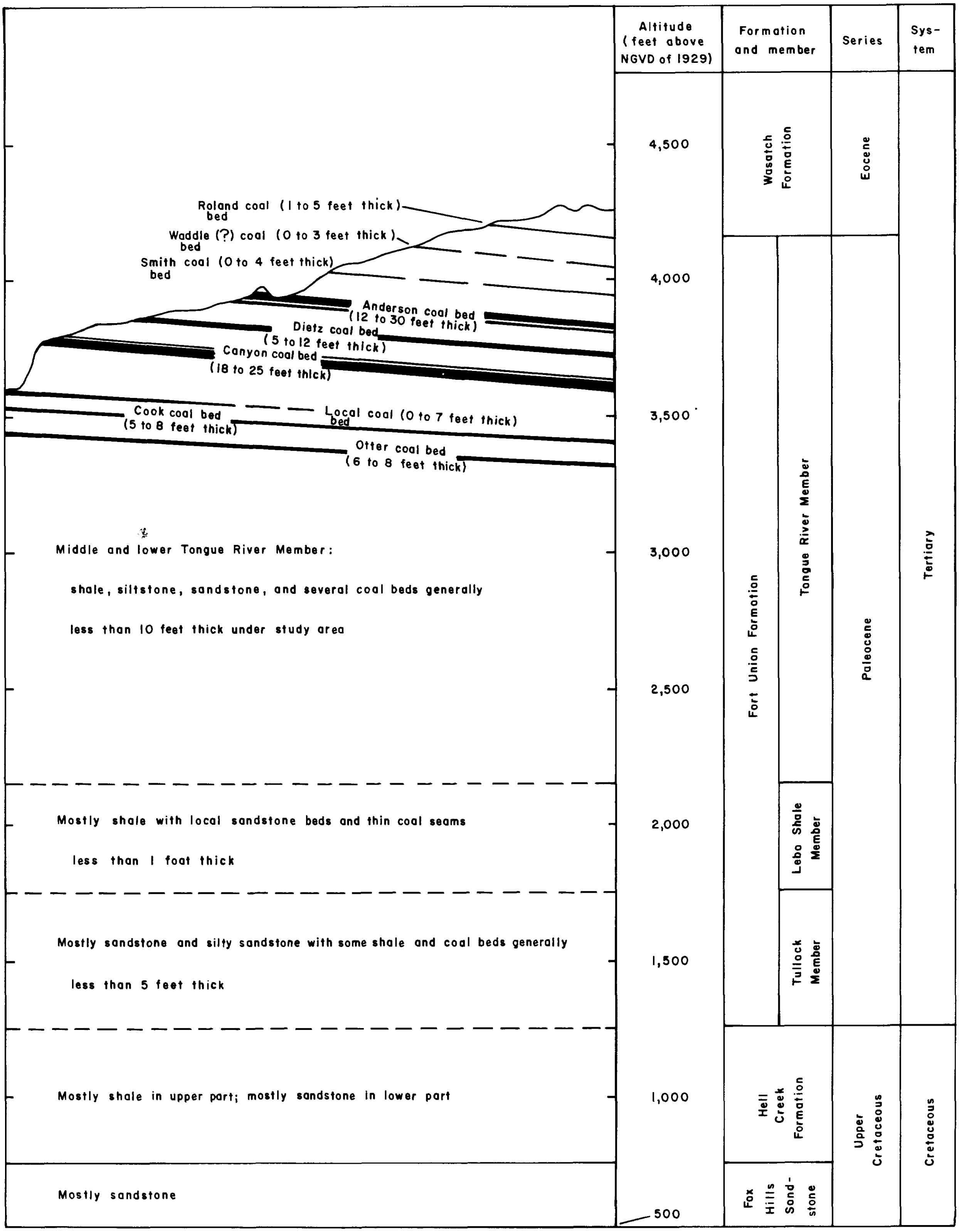


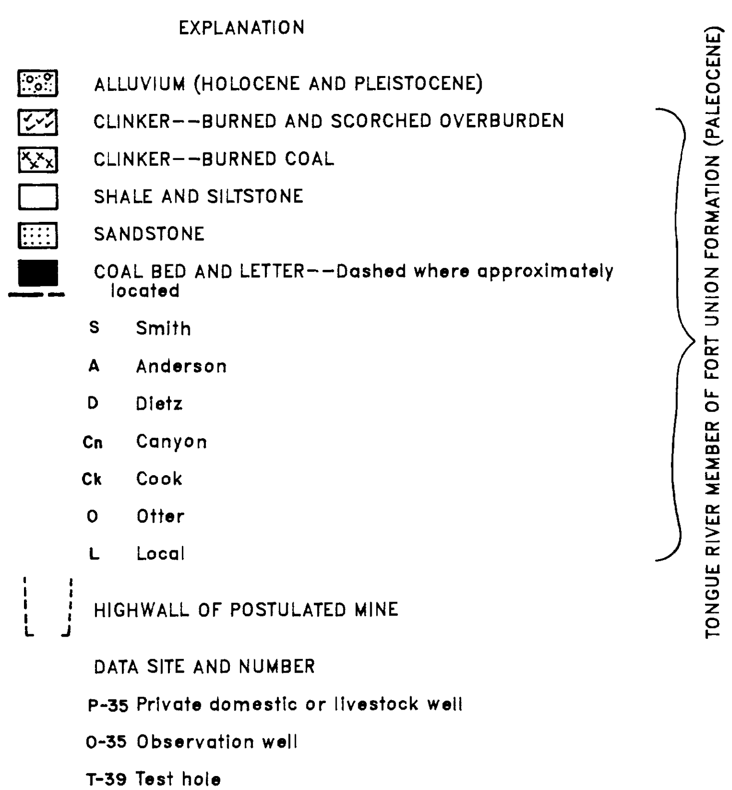
Figure 4.--Idealized section, from the Otter Creek-Pasture Creek confluence southeastward to the Otter Creek-Powder River divide, showing the stratigraphic sequence for the interval from the Eocene Wasatch Formation to the Upper Cretaceous Fox Hills Sandstone.

study area. In the upstream part of the Pasture Creek drainage, the Tullock thins to about 350 ft (Lewis and Hotchkiss, 1981). The Lebo Shale Member is about 200 ft thick under the northern part of the area, thickening to 550 ft along the western side. This member is mostly 300 to 400 ft thick under most of the central part of the study area.

The Tongue River Member, prior to erosion of the upper beds, was about 1,850 to 2,200 ft thick, generally thicker to the west and thinner to the east (Lewis and Hotchkiss, 1981). The rocks of the Tongue River Member are shale, siltstone, sandstone, and coal. The coal beds are the most laterally persistent layers, generally extending throughout the study area. At most places where the coal is at or near the land surface, the coal has been burned to clinker; massive clinker layers exist along the outcrop areas of the thicker coal beds. In the upper Otter Creek area, the main coal beds are the Canyon, Dietz, and Anderson, in ascending order. Only the upper 800 ft of the Tongue River Member is considered to be important to the discussion in this report. The hydrology of deeper strata will unlikely be affected by mining. Therefore, only the strata above the Cook coal bed are discussed in detail.

Cook Coal Bed and Overlying Strata

The Cook coal bed apparently underlies the entire study area. Only deep test holes in the northern part of the area and deep oil tests of the southern part penetrate the Cook coal bed. The Cook coal bed penetrated in these test holes is 5 to 8 ft thick (fig. 5). The Cook coal bed is 125 to 155 ft beneath the Canyon coal bed in most of the area, but the interburden thickens to as much as 220 ft



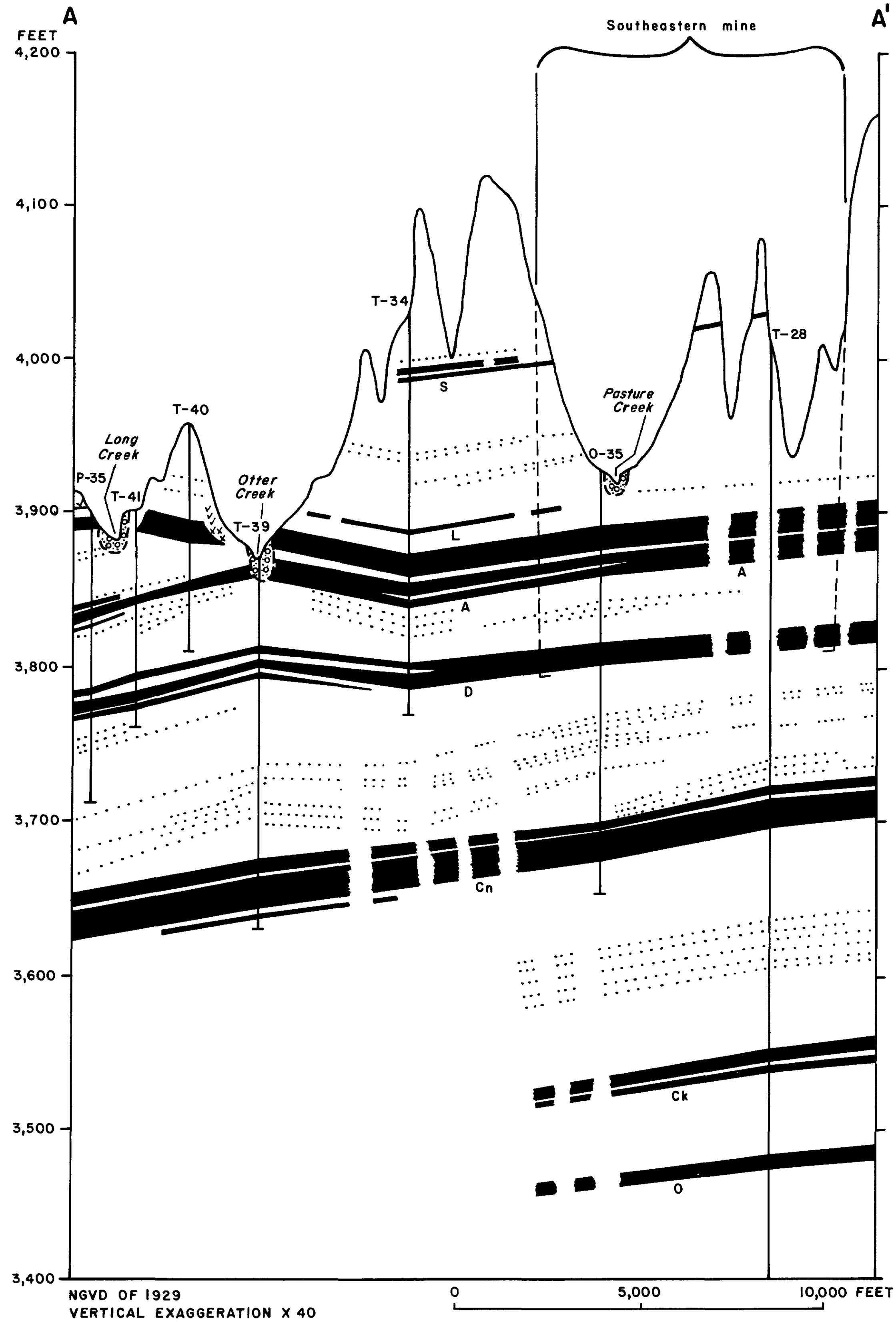


Figure 5.--Idealized stratigraphic section A-A', southwest to northeast across the southern part of area, showing relative positions of sandstone and coal beds. Trace of section is shown on plate 1. Explanation on facing page.

northwest of the Otter Creek-Pasture Creek confluence (W.C. Culbertson, U.S. Geological Survey, written commun., 1983). The interburden material is shale and sandstone. At most localities, potentially water-yielding sandstone composes about 25 percent of the interburden interval.

North of the Otter Creek-Pasture Creek confluence, along the sides of Otter Creek valley, a local coal bed that is 5 to 7 ft thick persists between the Cook and Canyon coal beds. The local coal bed is about 100 ft below the Canyon coal bed. At the confluence of Otter and Pasture Creeks, this local coal bed is just below the land surface. The local coal bed seems to extend southward for at least 3 to 4 mi.

Canyon Coal Bed and Overlying Strata

The Canyon coal bed generally is one massive bed 20 to 24 ft thick in the northwest corner of the area of principal study; this coal bed crops out in the northern part of the area and is predominantly clinker along the outcrops. Near the confluence of Otter and Pasture Creeks, the base of the Canyon coal bed is near the 3,700-ft topographic contour and the clinker crops out along the ridges on both sides of the valleys. The outcrop becomes lower to the southeast; the Canyon coal bed becomes covered by alluvial deposits about 2.3 mi to the south in Otter Creek valley and about 2.5 mi to the southeast in Pasture Creek valley.

Along the west side of the study area, the Canyon coal bed splits into two beds, an upper 2- to 4-ft bed and a lower massive 17- to 20-ft bed. The coal beds are separated by as much as 11 ft of shale. Test hole T-39, located in the upstream part of Otter Creek valley, penetrated the thickest part of the Canyon coal bed: three coal beds with a composite thickness of 25 ft (fig. 5). The Canyon coal bed is thinnest in test hole T-9 in the middle part of Billup Creek drainage. In this test hole, three coal beds have a composite thickness of about 18 ft. Under most of the area, the Canyon coal bed is 19 to 23 ft thick, generally in two beds, but sometimes in three or four beds.

The interburden between the Canyon and Dietz coal beds is predominantly shale and sandstone; however local coal beds 1 to 5 ft thick exist in the northern and northwestern parts of the area, and in isolated localities in the central and southern parts. Sandstone beds between the Canyon and Dietz coal beds exist throughout the area. In some localities, such as near observation well O-28, the sandstone is shaley. Along Boxelder Creek valley, the percentage of sandstone in the interburden interval ranges from 25 to 40. In the upstream part of Billup Creek drainage, several test holes penetrated more than 25 percent sandstone in the interburden interval. In the upstream part of Otter Creek drainage and northward through the central part of Pasture Creek drainage, the percentage of sandstone in the interburden interval ranges from 20 and 30 percent (fig. 6). The thickness of the interburden between the Canyon and Dietz coal beds ranges from 64 to about 140 ft; in most of the study area, the thickness is between 100 and 120 ft.

Dietz Coal Bed and Overlying Strata

The Dietz coal bed is, at most locations, a massive bed. Near the Otter Creek-Pasture Creek confluence, the Dietz coal bed crops out about midway up the slope to the Bear Creek-Otter Creek divide at about the 3,800-foot contour. On the Otter

Creek-Pasture Creek divide, the Dietz coal bed crops out along the 3,840-ft contour; on the western divide, between Pasture and Bradshaw Creeks, the Dietz coal bed crops out at about the 3,920-ft contour. The Dietz coal bed outcrop dips beneath the alluvial materials about 2.0 mi upstream from the mouth along the Billup Creek valley, about 3.5 mi upstream from the Otter Creek-Pasture Creek confluence along Otter Creek valley, and about 4.0 mi upstream along Pasture Creek valley. Along much of the outcrop, the Dietz coal bed has been burned to clinker (fig. 7).

The thickness of the Dietz coal bed is variable, ranging from 5 ft in the southern part of the area to 12 ft in the central part. In the southwest part of the area, the Dietz coal bed splits into an upper 6- to 8-ft bed and a lower 2- to 3-ft bed. In the south-central part of the area along Long and Otter Creeks, the coal splits again, into three beds (fig. 5).

The interburden between the Dietz and Anderson coal beds is interbedded shale and sandstone layers, and local coal beds 1 to 3 ft thick. Generally, the interburden thickness is more than 100 ft along the western and southwestern sides of the study area. The thickest sequence noted is at observation well O-23, where 181 ft of interburden separates the Dietz from the Anderson. Along the southeastern, eastern, and northwestern sides of the area, the interburden thickness is about 50 ft. The potentially water-yielding sandstone beds in the Dietz-Anderson interburden generally compose from 20 to 30 percent of the interval.

Anderson Coal Bed and Overlying Strata

The Anderson coal bed generally exists in two or more beds and is thickest along the northern part of the divide between the Bear Creek and Otter Creek valleys (test hole T-3), where the maximum thickness is about 30 ft. The coal bed thins to the south and southeast to a minimum thickness of 12 ft in observation well O-23, then thickens to 24 ft in several test holes and wells in the middle and upper parts of the Otter Creek and Pasture Creek valleys (fig. 7). The Anderson coal bed crops out on both sides of the Bear Creek-Otter Creek divide and north of the Otter Creek-Powder River divide. The coal bed forms a clinker cap on some hills between Otter and Pasture Creeks and between Pasture and Bradshaw Creeks. The Anderson coal bed dips below the alluvium about 2.8 mi upstream from the mouth of Billup Creek, about 2.9 mi upstream from the mouth of Boxelder Creek, about 6.0 mi upstream along Otter Creek from the confluence with Pasture Creek, and about 4.7 mi upstream along Pasture Creek.

Overlying the Anderson coal bed are shale and sandstone beds of the uppermost interval of the Tongue River Member. Where the Wasatch Formation crops out, along the southern to southeastern ridges and hilltops, the Tongue River Member above the Anderson is about 250 to 400 ft thick. The interval is thinnest in the central and southeastern parts of the study area and thickest in the southern part.

The Smith coal bed, which is as much as 4 ft thick, lies between 85 and 135 ft above the Anderson coal bed. At most places in the interval between the Anderson and Smith coal beds, sandstone layers compose 15 to 25 percent of the material. From 60 to 120 ft above the Smith coal bed, a local coal bed, which may be correlatable with the Waddle coal bed of Culbertson and Klett (1979), is present at most localities. This coal bed is as much as 3 ft thick in the study area. The sandstone beds compose about 10 to 30 percent of the interval between the Smith and Waddle(?) coal beds; the thickest sandstone beds are mostly along the southern and southeastern borders of the area.

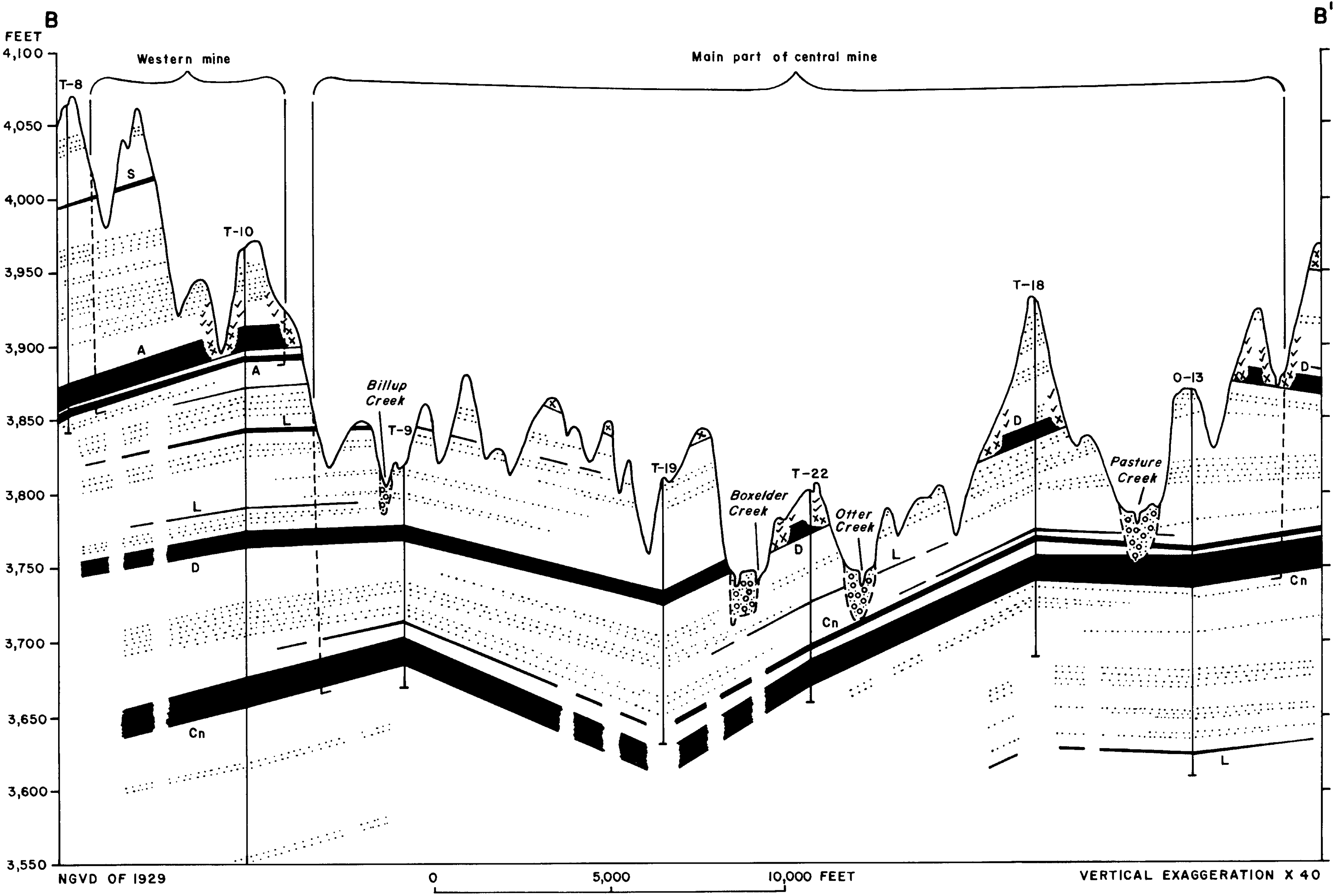


Figure 6.--Idealized stratigraphic section B-B', west to east across the central part of the area, showing relative positions of sandstone and coal beds. Trace of section is shown on plate 1. Explanation on following page.

EXPLANATION

ALLUVIUM (HOLOCENE AND PLEISTOCENE)

CLINKER--BURNED AND SCORCHED OVERBURDEN

CLINKER--BURNED COAL

SHALE AND SILTSTONE

SANDSTONE

COAL BED AND LETTER--Dashed where approximately located

S Smith

A Anderson

D Dietz

Cn Canyon

L Local

TONGUE RIVER MEMBER OF FORT UNION FORMATION (PALEOCENE)

HIGHWALL OF POSTULATED MINE

DATA SITE AND NUMBER

P-35 Private domestic or livestock well

O-35 Observation well

T-39 Test hole

The highest interval of the Tongue River Member, between the Waddle(?) and Roland coal beds, has a thickness of about 70 to 130 ft. In this interval, sandstone beds compose about 20 to 30 percent of the materials. The Roland coal bed, the top of which is considered to be the upper boundary of the Tongue River Member, and thus the Fort Union Formation (Baker, 1929, p. 24), is 2 to 3 ft thick at most places in the area. The Roland is fairly consistent at the 4,120-ft contour southwest of the study area. From sec. 29, T. 9 S., R. 46 E., and eastward, the Roland crops out at higher altitudes--at about 4,180 ft in section 27 and about 4,220 ft in section 26, then at lower altitudes across the upstream end of Pasture Creek, where it is near the 4,140-ft contour.

Wasatch Formation

Lithologically, the Wasatch Formation is indistinguishable from strata of the Tongue River Member. Shale is interbedded with sandstone and a few thin (1- to 4-ft thick) coal beds are present along the highest ridges in the study area. The Arvada coal bed (W.C. Culbertson, written commun., 1983) lies about 50 to 60 ft above the Roland coal bed in the southwestern part of the study area. No coal was observed at this horizon along the southeastern divide. The thickest part of the Wasatch Formation is in the upstream part of the Pasture Creek drainage, where it is about 180 ft thick. The upper strata of the Wasatch Formation have been eroded and removed throughout the area.

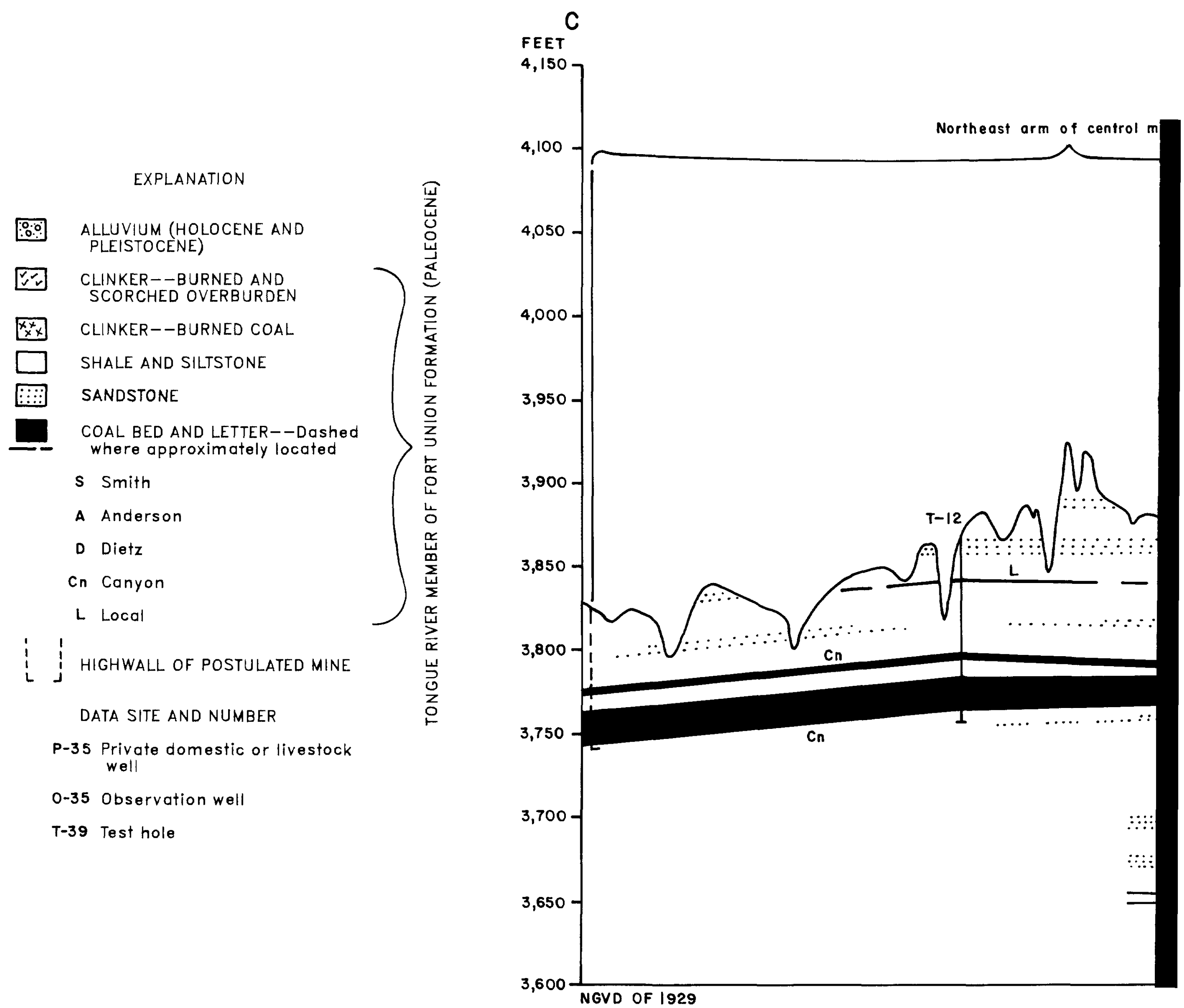
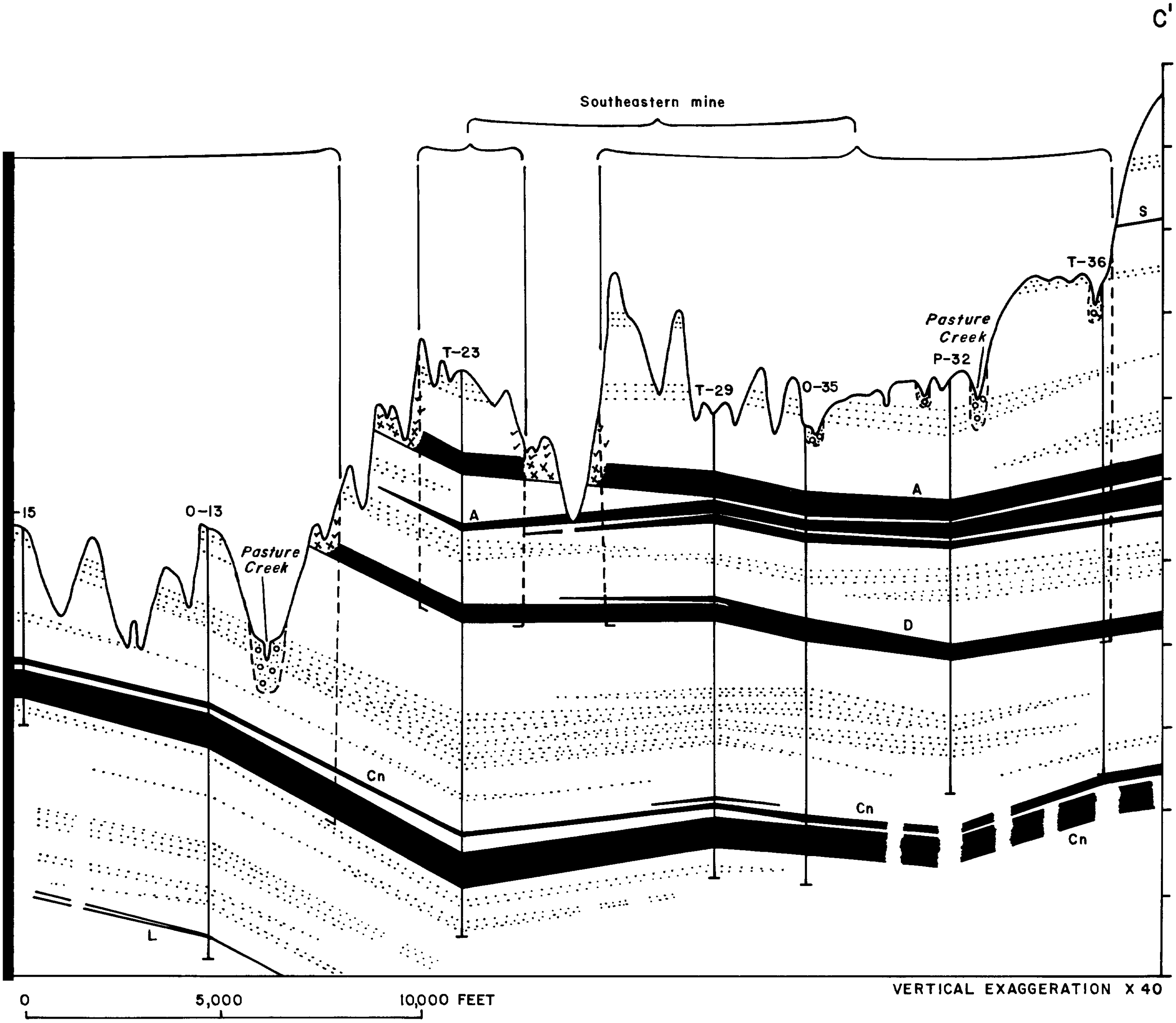


Figure 7.--Idealized stratigraphic section C-C', northwest to southeast across the shown on plate 1.



area, showing relative positions of sandstone and coal beds. Trace of section is

Alluvium

Pleistocene and Holocene alluvial material, derived by erosion of Tongue River Member sediments, was deposited in the valleys of the upper Otter Creek area. Early in the depositional period, sand and gravel from local sources were deposited in the deepest part of the valleys. During later depositional periods, alternately finer and coarser material was deposited over the earlier sand and gravel, forming a layered series of sand and gravel interbedded with mud. The thick layers of mud and sandy mud that compose the upper part of the alluvial deposits indicate that the most recent deposits have been primarily fine grained.

Local Structure

Generally, the beds of the Tongue River Member in the study area dip to the southwest (fig. 5). Because of probable local orogenic structures and the variable thinning and thickening of the intervals between the main coal beds, the general southwesterly dip is variable.

One northwest-trending fault (crossing sec. 24, T. 8 S., R. 45 E.), with the southwest side downthrown (pl. 2), is present in the northwest part of the study area (W.C. Culbertson, written commun., 1983). Other faults might be present. One probable fault was noted near the middle of sec. 1, T. 9 S., R. 45 E., where the outcrop of the Smith coal bed abruptly ends. Another fault may exist between observation well O-21 and test hole T-23, in the northern parts of secs. 3 and 4, T. 9 S., R. 46 E., based on the abrupt deepening of beds in observation well O-21. However, no surface evidence of a fault was observed.

Ground-Water Resources

Shallow Bedrock Aquifers

The term "shallow bedrock aquifers" is used to characterize the bedrock aquifers that are within about 500 feet of land surface and that are affected by local recharge or discharge. In the study area, the shallow bedrock aquifers are the permeable sandstone and coal beds in the Tongue River Member of the Fort Union Formation. Permeable sandstone beds and local coal beds in the overlying Wasatch Formation may contain perched water but are not considered to be significant sources of water owing to the limited areal extent of the saturated zones.

The coal beds in the Fort Union Formation are laterally extensive aquifers that can be traced throughout the study area except where they have been eroded or burned. The sandstone beds, however, are discontinuous and grade laterally into siltstone and shale. Wells drilled at any location in the study area will penetrate saturated sandstone and coal beds at various depths. Sufficient quantities of water to supply domestic or livestock needs can be obtained from properly developed wells throughout the area.

Hydrogeologic data from private wells completed in the shallow bedrock aquifers are listed in table 2; similar data for observation wells are listed in table 3. The location of wells and test holes is shown on plate 1. The test holes were drilled by various agencies and industries to obtain geologic information pertaining to coal resources and overburden. Data from these holes were used in this study to define the lateral and vertical extent of permeable sandstone and coal beds. Information on the depth to principal sandstone and coal beds is summarized in table 4.

Hydrogeologic Properties

Hydrogeologic properties of the shallow bedrock aquifers were determined from 18 observation wells drilled at selected locations in the area of principal study (table 3). The observation wells were used to monitor water levels, conduct aquifer tests, and collect water samples from various sandstone and coal aquifers. Private wells were inventoried to obtain additional information on water levels, well yields, and water quality.

Aquifer tests were conducted at 14 of the observation wells completed in bedrock aquifers to determine the hydraulic conductivity of representative sandstone beds and major coal beds. The hydraulic conductivity of the sandstone and coal beds ranged from 0.004 to 16 ft/d. One observation well (O-28) completed in a sandstone bed did not yield a sufficient quantity of water to provide valid data for analysis.

The hydraulic conductivity was 0.3 ft/d in both sandstone beds tested. The measured values equal the 0.3 ft/d reported by Rehm and others (1980, p. 552) as the geometric mean for hydraulic-conductivity values from 70 wells completed in Paleocene sandstone in the northern Great Plains.

The average hydraulic conductivity of coal beds in 9 wells was 4.1 ft/d. This value is similar to the geometric mean hydraulic conductivity of 0.9 ft/d reported by Rehm and others (1980) for 193 aquifer tests in coal aquifers in the northern Great Plains. The largest (16 ft/d) hydraulic-conductivity value for bedrock was measured in the Dietz coal bed; the smallest (0.004 ft/d) was for a local coal bed. Hydraulic conductivity in the Canyon coal bed ranged from 0.005 to 0.8 ft/d--the largest hydraulic-conductivity values were determined in the shallower wells and the smallest were determined in the deeper wells. Depth of burial affects the degree and openness of the fracture in the coal beds. Therefore, deeper coal aquifers are generally less permeable than those nearer to the land surface.

Storage coefficients of sandstone and coal beds could not be estimated from the single-well aquifer tests. Based on data from other sites in eastern Montana (Rehm and others, 1980), storage coefficients of the beds probably range from 10^{-4} to 10^{-3}.

Ground-Water Flow

Water in the shallow bedrock aquifers flows from areas of recharge to areas of discharge under the effect of pressure gradients. The direction of flow can be determined from potentiometric-surface maps constructed from water-level measurements in properly completed wells. Aquifers that are separated by confining layers of siltstone or shale can have distinctly different flow patterns depending on location of recharge and discharge, and on aquifer characteristics.

Only a few wells are available in the study area to document water-level altitudes in the various sandstone and coal beds. Many of the private wells are perforated at several depths or are gravel packed and open to several different aquifers, making them unreliable as indicators of the altitude of the potentiometric surface. Although the number of wells is inadequate to allow construction of potentiometric-surface maps, the general direction of flow can be discerned from the few water-level measurements and an understanding of the local conditions.

Water levels in the coal beds are highest near the outcrop areas in stream valleys and decrease toward the south and west. Water levels are progressively lower in deeper aquifers, corresponding to the lower altitude of outcrop of the lower coal beds. This pattern of increasing depth of water level with depth is characteristic of recharge areas. Water levels in wells completed in sandstone beds between coal beds appear to be intermediate between water levels in overlying and underlying coal beds. The data indicate that ground-water flow is vertically downward toward deeper zones and horizontally southward and westward toward discharge areas outside the study area. Exceptions to the general pattern probably occur near outcrop areas where local recharge and discharge control the flow patterns. Potentiometric gradients within specific coal beds appear to be slight. The slight gradients combined with the small values of hydraulic conductivity indicate that ground-water flow rates are slow.

On the basis of the foregoing information, recharge to the shallow bedrock aquifers occurs by infiltration of precipitation and downward percolation from streams and saturated alluvial aquifers. Most recharge to the aquifers probably occurs in the stream valleys where the aquifers crop out or where they are overlain by saturated alluvium. In the upland areas, recharge is limited to brief periods when rainfall or snowmelt infiltrates below the root zone of soils. Some recharge to deeper aquifers undoubtably occurs as downward percolation through confining zones from overlying aquifers with higher water levels.

Discharge from aquifers occurs locally as spring flow, as withdrawals from domestic and stock wells, and as vertical leakage to deeper aquifers. Most of the discharge apparently occurs as lateral flow to aquifers or discharge locations outside the study area.

Deep Bedrock Aquifers

Deep bedrock aquifers are those at depths of greater than about 500 feet that are not affected by local recharge or discharge. These aquifers include sandstone beds and thin coal beds in the middle and lower parts of the Tongue River Member of the Fort Union Formation, a few sandstone and coal beds in the Lebo Shale Member of the Fort Union Formation, and sandstone beds in the Tullock Member of the Fort Union Formation. Thick sandstone beds of the Fox Hills-lower Hell Creek aquifer are productive in other areas.

Although no water wells have been completed in the deep bedrock aquifers in the study area, results from other studies and data from test holes indicate that usable supplies of ground water could be obtained from deep wells. Yields of 1 to 20 gal/min could be expected from wells completed in deep sandstone beds of the Fort Union Formation. Sandstone beds of the Fox Hills-lower Hell Creek aquifer yield as much as 200 gal/min to wells in areas of eastern Montana (Stoner and Lewis, 1980).

The deep bedrock aquifers in the Fort Union Formation probably are sporadic from depths of 500 to 1,700 ft below land surface but more numerous from 1,700 to 2,400 ft below land surface. The top of the Fox Hills-lower Hell Creek aquifer is at an altitude of about 750 ft above NGVD of 1929 or at a depth of more than 3,000 ft below land surface (Feltis, 1982).

Alluvial Aquifers

Unconsolidated clay, silt, sand, and gravel underlie the stream valleys in the study area. In general, the material is coarsest near the base of the alluvial deposits and more fine grained at higher stratigraphic positions.

Twelve private wells are open to the alluvial deposits, obtaining all or part of their yield from the alluvial aquifers. Nineteen observation wells were completed in alluvial deposits to obtain information on hydrogeologic characteristics (table 3).

Observation wells were drilled and completed in the Billup, Boxelder, and Long Creek valleys to determine the total thickness of the unconsolidated alluvium and the thickness of permeable sand and gravel beds. Near the mouth, Billup Creek valley is underlain with more than 30 ft of alluvial material, with the lower 20 ft composed mostly of coarse sand and gravel. Boxelder Creek valley is underlain by as much as 30 ft of alluvial material but only a few thin sand and gravel beds are present near the base of unconsolidated deposits. Near the mouth of Long Creek valley, alluvial deposits are about 30 ft thick, with only the bottom 3 ft being permeable sand and gravel.

Three lines of observation wells were drilled across the Otter Creek valley--one in the upstream end, one near the middle reach, and one near the confluence with Pasture Creek. The upstream site is underlain by about 40 ft of unconsolidated material containing an aggregate total of about 12 ft of thin layers of coarse sand and gravel. Near the middle reach of the stream valley, the unconsolidated material is about 35 feet thick, with the lower 10 ft being coarse sand and gravel. Near the confluence with Pasture Creek, the Otter Creek valley contains about 20 ft of alluvium, with about 8 ft of coarse sand and gravel present in the deeper part of the section.

Observation wells were drilled in three areas of the Pasture Creek valley--one line of wells near the upstream end, one well near the middle reach of the valley, and one line of wells near the mouth of the valley. Near the upstream end, the alluvial deposits are about 20 ft thick and contain about 10 ft of sand and gravel. In the middle reach of the valley, the alluvial deposits are nearly 30 ft thick but the coarse-grained aquifer material remains about 10 ft thick. Near the mouth of the valley, the deposits thin to about 12 to 15 ft and contain less than 5 ft of coarse material.

Hydrogeologic Properties

Aquifer tests were conducted in the 19 observation wells completed in the alluvium to obtain estimates of hydraulic conductivity of the permeable sand and gravel layers. Aquifer tests in three wells in Billup Creek valley indicated hydraulic-conductivity values of 1, 50, and 65 ft/d. Aquifer tests in the two wells in the Boxelder Creek valley indicated hydraulic-conductivity values of 7 and 40 ft/d. An aquifer test in the one well in the Long Creek valley indicated a hydraulic-conductivity value of 4 ft/d. Aquifer tests in eight wells in Otter Creek valley indicated hydraulic-conductivity values ranging from 4 to 290 ft/d. Aquifer tests in five wells in Pasture Creek valley yielded hydraulic-conductivity values ranging from 20 to 170 ft/d.

Ground-Water Flow

The rate of flow through the alluvium varies, depending on the thickness of saturated sand and gravel layers and the potentiometric gradient. The flow rate can be calculated using the Darcy equation (as explained in Jacob and Lohman, 1952):

$$Q = KIA \qquad (1)$$

where Q = volume of water moving through a cross-sectional area, in cubic feet per day;
K = hydraulic conductivity of the aquifer, in feet per day;
I = gradient of the potentiometric surface, in feet per foot; and
A = cross-sectional area of the aquifer, in square feet.

Changes in water level in the alluvium alter the gradient of the potentiometric surface and also change the cross-sectional area of the aquifer. During periods of high water levels, the gradient is probably slighter, but the cross-sectional area is greater. Accurate calculation of the rate of flow through the alluvium requires determination of the gradient between observation wells upstream and downstream from the cross section. However, underflow also can be calculated by using reasonable estimates of gradients combined with cross-sectional areas obtained from lithologic logs of observation wells.

Near the confluence of Otter Creek and Pasture Creek, lithologic logs of observation wells O-8, O-9, and O-10 indicate that the 650-ft-wide valley of Otter Creek is underlain by an average thickness of 7 ft of sand and gravel. The hydraulic conductivity of the sand and gravel aquifer ranges from 7 to 290 ft/d (table 3). Assuming an average hydraulic conductivity of 120 ft/d for the 4,550 ft^2 of saturated sand and gravel and a gradient of 60 ft/mi (0.011 foot/foot), the underflow is:

$$\begin{aligned} Q &= KIA \\ &= (120 \text{ ft/d}) \cdot (0.011) \cdot (4{,}550 \text{ ft}^2) = \text{about } 6{,}000 \text{ ft}^3\text{/d} \end{aligned}$$

At the mouth of Pasture Creek, observation wells O-6 and O-7 indicate that the 250-ft-wide valley is underlain with about 5 ft of sand and gravel with an average hydraulic conductivity of about 100 ft/d. The potentiometric gradient is about 75 ft/mi or 0.014. The underflow is:

$$\begin{aligned} Q &= KIA \\ &= (100 \text{ ft/d}) \cdot (0.014) \cdot (1{,}250 \text{ ft}^2) = 1{,}750 \text{ ft}^3\text{/d} \end{aligned}$$

Surface-Water Resources

Streamflow characteristics, including average annual discharge and flows for 2-year, 10-year, and 100-year floods, were estimated for selected sites in the study area (table 1). Estimates for average annual discharge were based on a method developed by Omang and Parrett (1984) for an ungaged stream basin. Estimates for the magnitude of probable floods in the basin were based on techniques of Parrett and Omang (1981).

Table 1.--*Streamflow characteristics at selected sites*

Site	Drainage area (square miles)	Average annual discharge[1] (acre-feet)	Flood discharge, in cubic feet per second[2]		
			2-year flood	10-year flood	100-year flood
Billup Creek at mouth	6.0	130	60	260	850
Boxelder Creek at mouth	5.7	120	55	250	840
Long Creek at mouth	4.8	100	50	230	770
Cedar Creek at mouth	1.4	30	25	115	400
Otter Creek upstream from Long Creek	6.1	130	60	260	870
Otter Creek upstream from Pasture Creek	28.3	510	150	620	1,960
Pasture Creek upstream from "Bliss" creek	4.7	90	40	170	610
"Bliss" creek at mouth	2.1	35	20	90	340
Pasture Creek at mouth	12.0	220	90	380	1,250

[1]Based on method of Omang and Parrett (1984).
[2]Based on techniques of Parrett and Omang (1981).

Billup Creek

Billup Creek drains an area of 6.0 mi^2 in the northwestern part of the upper Otter Creek area. It has no perennial flow except for about 200 ft downstream from spring S-3. Nine stock ponds are in the valleys of the creek and its tributaries. None were observed to contain water after midsummer, and most were dry throughout 1983-84. During periodic visits to the area, Billup Creek had no flow in its channel, but evidence of flow along some reaches was observed in mid-May 1984, after the snowmelt of the severe storm in late April.

The discharge of Billup Creek was estimated from equations developed using basin characteristics because no streamflow-gaging stations are in the drainage basin. According to these equations, the average annual discharge from the Billup Creek basin is about 130 acre-ft based on a drainage area of 6.0 mi^2, an average annual precipitation of about 16 in., and a forest cover of about 20 percent. The probable magnitude of floods that could occur in the basin also was estimated. These estimates were determined from equations relating flood magnitude to drainage area, percentage of forest cover, and a factor for the geographic locality of the area. The probable flood flow from the basin is estimated to be about 60 ft^3/s for a 2-year flood (a flood having a 50-percent chance of being equaled or exceeded in any given year), 260 ft^3/s for a 10-year flood, and 850 ft^3/s for a 100-year flood.

Boxelder Creek

The Boxelder Creek basin (drainage area of 5.7 mi^2) is in the central and southwestern parts of the study area. No flow was observed along Boxelder Creek during 1983-84. In its middle reaches, the channel has been obliterated by leveling and a series of water-containment dams across the valley, where any flow from the upstream part of the basin is slowed or stopped to flood irrigate the pastures and alfalfa fields. Only one stock pond exists in the upstream part of the basin. It is at an altitude of about 4,120 ft, obtains water from a spring, and contains water during all but the driest years. Four small stock ponds in the tributaries of the downstream part of the basin contain water only after spring snowmelt and intense summer rainstorms.

The average annual discharge from Boxelder Creek basin is estimated to be about 120 acre-ft. The probable flood flow from the basin is estimated to be about 55 ft^3/s for a 2-year flood, 250 ft^3/s for a 10-year flood, and 840 ft^3/s for a 100-year flood. Water from a 2-year flood probably would not reach the mouth of Boxelder Creek because of the valley-wide containment dams in the middle reaches of the basin. These dams may even retain most of the water from a 10-year flood.

Long Creek

The Long Creek basin (drainage area of 4.8 mi^2) joins Otter Creek from the west side. No flow was observed along Long Creek during 1983-84, but flow passed observation well O-37 after the snowstorm of April 1984. The 0.5 mi of the channel nearest the mouth has been filled and the broad valley has been leveled and blocked by containment dams. Seven small stock ponds exist in the upstream parts of Long Creek and its tributaries. None were observed to contain water during 1983-84.

The average annual discharge is estimated to be about 100 acre-ft. The probable flood flow from the basin is estimated to be about 50 ft^3/s for a 2-year flood, 230 ft^3/s for a 10-year flood, and 770 ft^3/s for a 100-year flood. Like the Boxelder Creek basin, water from a 2-year flood, and possibly a 10-year flood, may not reach the mouth of Long Creek because much of this flow would be retained by containment dams along the downstream reaches.

Cedar Creek

The small (drainage area of 1.4 mi^2) basin of Cedar Creek, on the east side of Otter Creek valley, discharges little water. Most of any discharge in Cedar Creek could reach the Otter Creek channel, because the channel passes around the containment dams across Otter Creek valley. The average annual discharge for the small basin is estimated to be about 30 acre-ft. The probable flood flow from the basin is estimated to be about 25 ft^3/s for a 2-year flood, 115 ft^3/s for a 10-year flood, and 400 ft^3/s for a 100-year flood.

Otter Creek

The Otter Creek basin includes Billup, Boxelder, Long, and Cedar Creeks. Between the Long Creek-Otter Creek confluence and the north end of the study area at the Pasture Creek-Otter Creek confluence, Otter Creek valley is between 0.8 and 1.5 mi wide and contains numerous small east- and west-side tributaries.

Upstream from Long Creek, the Otter Creek basin has an area of 6.1 mi^2. No flow was observed during 1983-84, except for short distances downstream from springs S-5 and S-6. Six stock ponds along the mainstem and tributary valleys were dry after midsummer. The stream channel is well defined from the upstream reaches to Long Creek. Even though a containment dam was built 0.6 mi upstream from Long Creek, the land has not been leveled to absorb flood flow for irrigation in the vicinity of the dam.

The approximate average annual discharge from the upstream part of Otter Creek is estimated to be 130 acre-ft. Probable flood flow from the upstream part of the basin is estimated to be 60 ft^3/s for a 2-year flood, 260 ft^3/s for a 10-year flood, and 870 ft^3/s for a 100-year flood.

The hydrology of the middle and downstream parts of the Otter Creek valley is complicated by thickening alluvium and by outcrops of clinker, mostly of the Canyon coal bed, along the sides of the valley. At least three containment dams spread water across the flood plain and lower terraces, but the channel of Otter Creek is recognizable just downstream from the dams. For about 1.2 mi upstream from the Otter Creek-Pasture Creek confluence, the Otter Creek channel has interrupted flow along several long stretches. A weir was installed near observation well O-10, about 0.15 mi upstream from the confluence, to measure low flow. Measured flow varied from 0.03 ft^3/s in late October 1983 when the weir was installed, to a maximum of 0.04 ft^3/s in May 1984, to a minimum of 0.008 ft^3/s at the end of July 1984. Floods were not measured at the weir.

The average annual discharge from Otter Creek basin upstream from the confluence with Pasture Creek, an area of 28.3 mi^2 that includes all tributary areas, is estimated to be about 510 acre-ft. Because of the extensive clinker, which would absorb large quantities of precipitation, the calculated annual value of 510 acre-ft may be too large. Flood flows from Otter Creek upstream from the confluence with Pasture Creek is estimated to be about 150 ft^3/s for a 2-year flood, about 620 ft^3/s for a 10-year flood, and about 1,960 ft^3/s for a 100-year flood.

Pasture Creek

The Pasture Creek basin (drainage area of 12.0 mi^2) consists of the upstream mainstem (or west fork), "Bliss" creek (or east fork), and the middle and downstream parts of the basin. The upstream part of Pasture Creek was dry during periodic observations during 1983-84. Six small stock ponds were observed to be dry after midsummer. One large stock pond, 0.2 mi downstream from observation wells O-33 and O-34, was not observed to contain water during the study, but the ranchers reported that this pond occasionally fills. The earth-fill dam is reported to be placed on alluvial valley fill, so any water in the pond probably would leak rapidly into the underlying alluvium. This pond contained no water in May 1984, after the snowmelt of the large snowstorm in late April.

The estimated average annual discharge from the 4.7-mi^2 upstream mainstem basin is 90 acre-ft. The estimated flood flow from the basin is 40 ft^3/s for a 2-year flood, 170 ft^3/s for a 10-year flood, and 610 ft^3/s for a 100-year flood. Most flood flow probably would be retained by the dam near observation wells 0-33 and 0-34 before reaching the confluence with "Bliss" creek.

The "Bliss" creek basin drains the eastern-most corner of the upper Otter Creek area. One large stock pond, 1.2 mi upstream from the confluence with Pasture Creek, contained water from 1 to 5 ft deep during 1983-84. Apparently this pond receives water from seeps discharging from sandstone aquifers above the Anderson coal bed. The sandstone aquifers discharge water into the "Bliss" creek channel for a length of 300 ft, about 0.2 mi downstream from the pond. The large pond 700 ft upstream from the mouth of "Bliss" creek varied from full to one-half full during most of the study. This pond receives water from seeps discharging from the clinker formed by burned Anderson coal to the southwest and northeast, and from alluvium and the Anderson coal bed upstream.

The average annual discharge of the 2.1-mi^2 "Bliss" creek basin is estimated to be about 35 acre-ft. Without the two stock ponds, the estimated flood flow would be about 20 ft^3/s for a 2-year flood, about 90 ft^3/s for a 10-year flood, and about 340 ft^3/s for a 100-year flood. However, the stock ponds are effective water-storage structures that retain all but the largest floods.

The middle and downstream parts of the Pasture Creek valley become increasingly narrow downstream. However, 0.5 mi downstream from the confluence of Pasture and "Bliss" creeks, the flood plain of Pasture Creek and the lower terraces are as much as 1,500 ft wide. At observation well 0-15, the valley bottom is about 600 ft wide, and near observation wells 0-6 and 0-7, near the mouth, the valley bottom is about 260 ft wide.

Pasture Creek is blocked by a containment dam about 0.3 mi north of spring S-4 and a large stock pond 0.4 mi northwest of observation well 0-15. From a short distance upstream from the stock pond to the confluence of Pasture Creek and Otter Creek, flow in Pasture Creek is interrupted. The broad pond behind the containment dam contained water only during the early spring of 1983 and 1984. Most of this water, which was from spring runoff, was absorbed into the alluvium within a short time. Seeps discharging from the alluvium upstream from the stock pond maintained water in the pond during the study, although the depth of the water was only about 0.5 ft during late summer in 1984. Downstream from the stock pond, the channel of Pasture Creek is covered by sedge and reeds; the water was mostly stagnant, although, at a few places, it flowed for short distances. Between spring S-2 and well P-2, Pasture Creek has nearly continuous flow. The flow past observation wells 0-6 and 0-7 is intermittent, but parts of the channel have standing water almost perennially and these locations are effective watering areas for livestock.

The average annual discharge from the Pasture Creek basin is estimated to be about 220 acre-ft. At the mouth, the estimated flood flow would be about 90 ft^3/s for a 2-year flood, about 380 ft^3/s for a 10-year flood, and about 1,250 ft^3/s for a 100-year flood. These estimates may be slightly large, because the broad areas of clinker outcrops of the Anderson, Dietz, and Canyon coal beds, were not considered. In the downstream part of the basin, where the clinker outcrop of the Canyon coal bed is particularly extensive, even sudden and intense rainfall would be absorbed by the clinker terrane.

Water Quality and Geochemistry

The quality of ground water was determined by analysis of water samples from private wells, observation wells, and springs (table 5). The quality of surface water was determined by analysis of two samples of streamflow from Otter Creek and one sample of streamflow from Pasture Creek. All three surface-water samples were collected during low-flow conditions.

The quality of water in the shallow bedrock aquifers varies considerably, depending on the location of the sampling point within the flow system. In general, water in the shallow bedrock aquifers near the recharge areas contains larger concentrations of calcium, magnesium, and sulfate than water in deeper parts of the flow system. Deeper wells far from the recharge areas typically contain water dominated by sodium and bicarbonate. Dissolved-solids concentrations in water from shallow bedrock aquifers in the area of principal study ranged from 1,160 to 4,390 mg/L.

Water in alluvial aquifers typically contains large concentrations of sodium, magnesium, and sulfate. Dissolved-solids concentrations in samples ranged from 1,770 to 12,600 mg/L.

Water samples from Otter and Pasture Creek were similar to water samples from wells completed in the alluvium. The samples contained large concentrations of sodium, magnesium, and sulfate. Dissolved-solids concentrations in the Otter Creek samples were 3,600 and 4,080 mg/L. The dissolved-solids concentration in the Pasture Creek sample was 6,220 mg/L.

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

Geochemical processes that probably account for the chemical composition of ground water are: (1) The generation of hydrogen ions through the production of carbon dioxide in the organic zone of the soil; (2) the dissolution of calcite and dolomite, leaving calcium, magnesium, and bicarbonate in solution; (3) oxidation of pyrite; (4) the dissolution of gypsum to produce calcium and sulfate ions; (5) the exchange of calcium and magnesium cations for sodium ions on sodium-enriched clays; and (6) microbial-enhanced sulfate reduction to remove sulfate ions.

The quality of water in the alluvium is controlled to a large degree by evapotranspiration. Water is lost through the evapotranspiration process, which concentrates the remaining dissolved salts in the alluvial aquifers. Dissolved-solids concentrations in the alluvial ground water are generally smallest in the upstream reaches of the basin and largest in the downstream reaches. Recharge during occasional high flow dilutes the concentration of dissolved solids.

CONCLUSIONS

The combined upper Otter Creek-Pasture Creek area consists of 40.3 mi^2, about 33 mi south of Ashland, Montana. Water in the basins is available from wells, springs, stock ponds, and several reaches of the streams. The water is used for domestic supply at six ranches and for livestock watering throughout the basin.

The area is underlain principally by the upper part of the Tongue River Member of the Fort Union Formation (Paleocene age) and by alluvium (Pleistocene and Holocene age). The exposed section of the Tongue River Member is about 750 ft thick and is composed of alternating layers of shale, siltstone, sandstone, and coal. Before erosion, the Tongue River Member was about 1,850 to 2,200 ft thick in the study area. Overlying the Tongue River Member, along the southern and southeastern divides of the basin, is the Wasatch Formation (Eocene age). Underlying the Tongue River Member is the Lebo Shale Member, from 200 to 550 ft thick, and the Tullock Member of the Fort Union Formation, from 350 to 500 ft thick. The strata generally dip southwestward. The strata are broken by a northwest-trending fault in the northwest part of the study area.

Ground water is supplied from sandstone and coal beds of the Tongue River Member throughout the basin, and from alluvial sand and gravel along the principal stream valleys. Beds of water-yielding sandstone exist between each of the coal beds. Hydraulic conductivity of sandstone beds averages about 0.3 ft/d, based on two aquifer tests. Hydraulic conductivity of the coal beds varies with depth of burial but averages about 4.1 ft/d, based on 9 aquifer tests in the area of principal study. Water levels in observation wells indicate that potentiometric surfaces decrease with depth. Direction of ground-water flow is vertically downward and laterally toward the south and west.

Hydraulic conductivity of alluvial deposits ranges from 1 to 290 ft/d, based on 19 aquifer tests. Water flows through the Otter Creek alluvium at a rate of about 6,000 ft^3/d. Water flows through the Pasture Creek alluvium at a rate of about 1,750 ft^3/d.

Quality of water in sandstone and coal beds varies with distance from the point of recharge. In shallow bedrock aquifers in the upper Otter Creek area, dissolved-solids concentrations range from 1,160 to 4,390 mg/L and the water contains principally calcium, magnesium, and sulfate. In deeper bedrock aquifers, the water is dominated by sodium and bicarbonate. Water in alluvial deposits has a dissolved-solids concentration ranging from 1,770 to 12,600 mg/L. Major constituents in water from alluvial deposits are sodium, magnesium, and sulfate.

Surface-water resources are limited. Streams with flow include the mainstem of Otter Creek and its principal tributaries (Billup, Boxelder, Long, and Cedar Creeks) and Pasture Creek and its principal tributary ("Bliss" creek). The confluence of Otter Creek and Pasture Creek marks the northern end of the study area. Most of the streamflow in the area is intermittent. Otter Creek has interrupted flow from the confluence with Pasture Creek to about 1.2 mi upstream, except during extremely dry years. The flow in Pasture Creek is interrupted from about 1.5 mi upstream to the mouth, but during years of little precipitation, the reaches of flow shorten. Most of the stock ponds in the area become dry by midsummer.

To permit prediction of the potential effects of surface coal mining on the hydrologic system in the upper Otter Creek area, mine plans were postulated. The postulated mines, when completed, would occupy a total area of 16.5 mi^2--2.2 mi^2 for the western mine extracting the Anderson coal bed, 10.8 mi^2 for the central mine extracting the Dietz and Canyon coal beds, and 3.5 mi^2 for the southeastern mine extracting the Anderson and Dietz coal beds. Mining would probably start at the north end of the western mine, just west of the Bear Creek-Otter Creek divide, and proceed southward. In the central mine, mining would probably begin at the north ends of the southwest and northeast arms and progress southward. The southeastern mine would probably be an extension of the central mine in the Pasture Creek valley, starting at the north edge and moving southeastward along the Cedar Creek and Pasture Creek valleys, including "Bliss" creek valley.

Mining would lower water levels in the sandstone and coal aquifers to the south, east, and west of the mines. Outside the mined area, the lowered water levels probably would affect one ranch supply well and one abandoned well. Mining would destroy the alluvium as an aquifer along the downstream reaches of Billup, Boxelder, Long, and Cedar Creeks, and the middle reaches of Otter and Pasture Creeks. Water moving through the replaced mine spoils would acquire a chemical quality dependent on the mineralogy of the spoils material. The postulated mines would destroy 3 ranch houses and 25 private domestic and livestock wells, used and unused. Two springs would be destroyed in the central mine, and all stock ponds within the area of the mines would be destroyed.

To mitigate the effects of mining on the aquifers of the upper Otter Creek area, the alluvium could be reconstructed by first laying a base of clayey, almost impermeable spoils, overlaying with stockpiled sand, gravel, and clinker, and finally covering with alluvial mud and soil. The structuring of the spoils along the bottom of the mine and against the highwalls could be completed in such a manner to allow a minimum of water to flow through and from the mined area. The more impermeable the seal at the mine edges, the greater the success in containing water from flowing from the chemically active spoils materials to adjacent aquifers, and thereby affecting water quality. The destroyed wells could be re-drilled in reconstructed alluvium or to sandstone aquifers below the Canyon coal bed, which would be little affected by the mine or the post-mining recovery of the hydrologic system. The two springs destroyed in the potential mine area could be replaced by drilled wells or a collector system of wells. The stock ponds removed by the mine and mining operations could be replaced near their present sites on the landscaped spoils surface.

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SUPPLEMENTAL DATA

Table 2.--*Hydrogeologic data for private domestic or livestock wells in and near the upper Otter Creek area*

[Altitude of land surface: refers to distance above NGVD of 1929. Casing type: P, plastic; R, rock or stone; S, steel. Abbreviation: microsiemens, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Well No. (pl. 1)	Location	Date drilled or dug	Altitude of land surface (feet)	Depth of well (feet below land surface)	Aquifer material	Depth to top of aquifer (feet below land surface)	Aquifer thickness (feet)	Casing diameter (inches) and type
P-1	SW¼SW¼SW¼NW¼ sec. 36, T. 8 S., R. 45 E.	1949	3,900	250	Canyon coal bed.	210±	19	4(S)
					Sandstone	233	12±	
P-2	SE¼NW¼SE¼SW¼ sec. 17, T. 8 S., R. 46 E.	1920±	3,650	35	Alluvial sand and gravel.	20±	6±	48(R)
P-3	NW¼SW¼SW¼SW¼ sec. 20, T. 8 S., R. 46 E.	1958	3,675	33	Alluvial sand and gravel.	12	7±	4(S)
P-4	NW¼SW¼SE¼NE¼ sec. 28, T. 8 S., R. 46 E.	July 1949	3,770	75	Alluvial sand and gravel.	18	7	4(S)
					Local coal bed.	52	7	
P-5	NW¼SW¼SE¼NE¼ sec. 28, T. 8 S., R. 46 E.	September 1981	3,770	74	Alluvial sand and gravel.	18	7±	5(P)
					Local coal bed.	52	7	
P-6	SW¼NE¼NE¼SE¼ sec. 28, T. 8 S., R. 46 E.	October 1959	3,770	33	Alluvial sand and gravel.	11	4±	4(S)
					Local coal bed.	17	7±	
P-7	NW¼NE¼NW¼NE¼ sec. 32, T. 8 S., R. 46 E.	1920±	3,725	20	Alluvial sand and gravel.	12±	5±	48(R)
P-8	SW¼SW¼NW¼SW¼ sec. 12, T. 9 S., R. 45 E.	1958	3,930	293	Sandstone below Dietz coal bed.	232	20±	4(S)
P-9	NE¼NE¼NW¼NE¼ sec. 3, T. 9 S., R. 46 E.	November 1958	3,850	50	Alluvial sand and gravel.	22	5±	4(S)
P-10	NE¼SE¼SE¼SE¼ sec. 3, T. 9 S., R. 46 E.	1965±	3,945	200	Probably sandstone below Dietz coal bed.	180±	12±	4(S)
P-11	SW¼NW¼SW¼NE¼ sec. 4, T. 9 S., R. 46 E.	1949	3,820	160	Probably sandstone below Dietz coal bed.	100±	10±	4(S)
P-12	NE¼NE¼SE¼SE¼ sec. 5, T. 9 S., R. 46 E.	1916	3,810	41	Alluvial sand and gravel.	20±	5±	36(R)
					Dietz upper coal bed.	38	2	
P-13	NE¼NE¼SE¼SE¼ sec. 5, T. 9 S., R. 46 E.	September 1960	3,810	180	Canyon coal bed.	159	19	4(S)

Casing perforations (feet below land surface)	Date of hydrologic data	Static water level (feet below land surface)	Discharge (gallons per minute)	Onsite specific conductance (microsiemens)	Chemical analysis available (table 5)	Remarks
--	02/03/74	--	5±	--	No	Not used 1983-84. Driller's records omit data on perforated intervals.
--	06/28/84	10±	3.5	6,500	Yes	Used for domestic supply. No log available.
--	01/30/74	8.9	--	8,000±	Yes	Not used 1983-84.
--	10/10/84	17.3	--	--	No	Not used since 1981. Driller's records omit data on perforated intervals.
34 to 74	10/10/84	17.4	10±	--	No	Used for watering livestock.
--	01/31/74	13.2	--	--	No	Not used 1983-84; reportedly not used for "many years."
--	01/30/74	5.4	10±	7,000±	Yes	Used for watering livestock. No log available.
--	01/30/74	128	5±	1,690	Yes	Used for watering livestock. Driller's records omit data on perforated intervals.
--	06/29/84	15±	7	3,860	Yes	Used for domestic supply. Terse driller's log available.
--	06/29/84	108.7	5±	3,260	Yes	Used for watering livestock. No log available.
--	01/31/74	--	5±	2,700	Yes	Not used 1983-84. No log available.
--	06/27/84	6±	3±	5,050	Yes	Used for watering garden. No log available.
159 to 180	01/29/74	40±	10±	--	No	Not used since 1982. Driller's log available.

Table 2.--*Hydrogeologic data for private domestic or livestock wells in and near the upper Otter Creek area*--Continued

Well No. (pl. 1)	Location	Date drilled or dug	Altitude of land surface (feet)	Depth of well (feet below land surface)	Aquifer material	Depth to top of aquifer (feet below land surface)	Aquifer thickness (feet)	Casing diameter (inches) and type
P-14	NE¼NE¼SE¼SE¼ sec. 5, T. 9 S., R. 46 E.	December 1982	3,810	185	Upper Canyon coal bed. Canyon coal bed.	142 154	4 19	4(P)
P-15	NE¼NE¼SE¼SE¼ sec. 5, T. 9 S., R. 46 E.	December 1982	3,810	70	Alluvial sand and gravel. Dietz coal bed.	22 44	5± 10	4(P)
P-16	NE¼NE¼SE¼SE¼ sec. 5, T. 9 S., R. 46 E.	September 1984	3,810	65	Dietz coal bed.	46	10	5(P)
P-17	SW¼NW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	1908	3,805	53	Alluvial sand and gravel.	25±	5±	60(R)
P-18	SW¼NW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	1910	3,810	76	Probably sandstone below Dietz coal bed.	75	1+	60(R)
P-19	SW¼NW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	1949	3,810	330	Sandstone below Canyon coal bed.	240±	20±	4(S)
P-20	NW¼SW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	1958	3,810	300	Sandstone below Canyon coal bed.	230	20±	4(S)
P-21	SE¼NW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	May 1974	3,805	302	Sandstone below Canyon coal bed.	200	30±	4(S) 2.5(S)
P-22	SE¼SW¼SE¼SE¼ sec. 7, T. 9 S., R. 46 E.	1949	3,930	135	Sandstone above Dietz coal bed.	85	25±	4(S)
P-23	NW¼NW¼SE¼SE¼ sec. 9, T. 9 S., R. 46 E.	1961	3,910	360	Probably sandstone below Canyon coal bed.	--	--	4(S)
P-24	NW¼NW¼SE¼SE¼ sec. 9, T. 9 S., R. 46 E.	September 1977	3,855	40	Alluvial sand and gravel.	25±	5±	4(S)
P-25	NW¼SW¼SE¼NW¼ sec. 11, T. 9 S., R. 46 E.	August 1959	3,960	160	Dietz coal bed.	150±	10	4(S)
P-26	NW¼SW¼SE¼NW¼ sec. 11, T. 9 S., R. 46 E.	November 1974	3,960	147	Sandstone above Dietz coal bed.	112	15±	5(P)
P-27	SE¼SW¼SE¼NW¼ sec. 11, T. 9 S., R. 46 E.	May 1982	3,935	155	Sandstone Dietz coal bed.	94 137	8± 9	5(P)

Casing perforations (feet below land surface)	Date of hydrologic data	Static water level (feet below land surface)	Discharge (gallons per minute)	Onsite specific conductance (microsiemens)	Chemical analysis available (table 5)	Remarks
125 to 185	06/27/84	70±	4	7,200	Yes	Used for watering livestock. Driller's log available.
22 to 70	06/27/84	18±	10±	5,300	Yes	Used for watering livestock. Overpumping causes well to pump sand. Driller's log available.
45 to 65	09/10/84	25	20±	--	No	Used for watering livestock. Driller's log available. Well gravel packed from top to bottom.
--	06/28/84	25.9	2.5	4,800	Yes	Not used 1983-84. No log available.
--	06/28/84	23±	10	3,650	Yes	Used for watering livestock and yards and gardens. No log available.
--	01/30/74	110±	5±	2,200	Yes	Not used 1983-84. Reported to pump muddy water. Driller's log available.
--	06/30/84	116±	5±	1,950	Yes	Used for domestic water, but cannot be pumped for more than 10 minutes without discharge becoming muddy. Driller's log available.
220 to 260 260 to 302	06/28/84	112±	8	2,060	Yes	Used for domestic water. Driller's log available.
--	01/30/74	62	--	--	No	Used for watering livestock. Terse driller's log available.
--	--/--/61	260±	5±	--	No	Not used. Casing collapsed.
--	10/11/84	25.7	5±	--	No	Used for watering livestock. No log available.
140 to 160	02/03/74	94±	4±	2,640	Yes	Not used 1983-84. Terse driller's log and partial gamma logs available.
107 to 147	11/--/74	96±	6±	--	No	Used for watering livestock from 1974 to 1983; unused in 1984. Driller's log available. Well gravel packed from top to bottom.
95 to 155	05/--/82	95±	4±	--	No	Used for watering livestock. Driller's log available. Well gravel packed from top to bottom.

Table 2.--*Hydrogeologic data for private domestic or livestock wells in and near the upper Otter Creek area*--Continued

Well No. (pl. 1)	Location	Date drilled or dug	Altitude of land surface (feet)	Depth of well (feet below land surface)	Aquifer material	Depth to top of aquifer (feet below land surface)	Aquifer thickness (feet)	Casing diameter (inches) and type
P-28	SW¼SW¼SE¼NW¼ sec. 11, T. 9 S., R. 46 E.	1982	3,950	160	Probably sandstone above Dietz coal bed.	115±	10±	5(P)
P-29	SW¼SW¼SE¼NW¼ sec. 11, T. 9 S., R. 46 E.	May 1984	3,970	183	Anderson coal bed. Probably sandstone.	100 140±	24± 10±	5(P)
P-30	NE¼SE¼SW¼NW¼ sec. 11, T. 9 S., R. 46 E.	June 1984	3,965	215	Sandstone below Dietz coal bed.	195±	10±	5(P)
P-31	NE¼SW¼NE¼SW¼ sec. 11, T. 9 S., R. 46 E.	July 1949	3,955	175	Sandstone Dietz coal bed. Sandstone	105± 152 202	8± 10 20±	4(S)
P-32	SE¼SW¼NE¼SW¼ sec. 11, T. 9 S., R. 46 E.	1961	3,960	250	Sandstone Dietz coal bed. Sandstone	112 156 202	12± 10 20±	4(S)
P-33	NE¼NW¼NE¼SE¼ sec. 12, T. 9 S., R. 46 E.	1916	4,105	18	Alluvial sand and gravel.	10±	4±	48(R)
P-34	SE¼SE¼NW¼SW¼ sec. 15, T. 9 S., R. 46 E.	1957	3,925	260	Probably sandstone above Canyon coal bed.	200±	20±	4(S)
P-35	SE¼NE¼SE¼NE¼ sec. 17, T. 9 S., R. 46 E.	1950±	3,896	186	Dietz coal bed. Sandstone	121 142	8 9	4(S)
P-36	SE¼SE¼SW¼NW¼ sec. 28, T. 9 S., R. 46 E.	December 1963	4,170	320	Probably sandstone above Dietz coal bed.	310±	10±	4(S)
P-37	SW¼SW¼NW¼NE¼ sec. 29, T. 9 S., R. 46 E.	1917	4,175	56	Probably sandstone and Roland coal bed.	--	--	42(R)

Casing perforations (feet below land surface)	Date of hydrologic data	Static water level (feet below land surface)	Discharge (gallons per minute)	Onsite specific conductance (microsiemens)	Chemical analysis available (table 5)	Remarks
--	--	--	--	--	No	Used for watering livestock. No log available.
125 to 165	05/--/84	97	5±	--	No	Used for watering livestock. Driller's log available.
175 to 215	06/--/84	95±	5±	--	No	Used for watering livestock. Driller's log available. Well gravel packed from 10-ft depth to bottom.
--	06/29/84	108.4	2.4	3,900	Yes	Used for watering livestock. Driller's log available.
--	06/29/84	119.1	5±	--	No	Not used; filled to 201 ft. Driller's log available. Well abandoned in 1964.
--	06/30/84	4.0	2	5,100	Yes	Used for watering livestock 1983-84; once used for domestic water.
--	06/27/84	60±	4	3,800	Yes	Used for domestic and livestock water. No log available.
--	05/20/84	64.2	3±	--	No	Not used 1983-84. No driller's log. Gamma ray log available. Well removed from service because casing was corroding.
--	10/11/84	266	1±	--	No	Used for watering livestock. No log available.
52 to 56	01/29/74	52.5	1±	4,500	Yes	Not used 1983-84; operable hand pump installed.

Table 3.--*Hydrogeologic data for observation wells in and near the upper Otter Creek area*

[Altitude of land surface: refers to distance above NGVD of 1929. --, no data]

Well No. (pl. 1)	Location	Altitude of land surface (feet)	Depth drilled (feet below land surface)	Depth cased (feet below land surface)	Aquifer material	Aquifer interval (feet below land surface)
O-1	NE¼SE¼SE¼NE¼ sec. 11, T. 8 S., R. 45 E.	3,880	241	180	Sandstone above Canyon coal bed.	156-170
O-2	SE¼SW¼NE¼SE¼ sec. 25, T. 8 S., R. 45 E.	3,825	288	288	Local coal above Cook coal bed.	272-277
O-3	SE¼SW¼NE¼SE¼ sec. 25, T. 8 S., R. 45 E.	3,825	252	252	--	--
O-4	SW¼SW¼NW¼SW¼ sec. 34, T. 8 S., R. 45 E.	3,900	271	271	Canyon coal bed	243-262
O-5	NE¼NW¼SE¼NE¼ sec. 36, T. 8 S., R. 45 E.	3,798	20	19.7	Alluvial sand and gravel.	15-18.5
O-6	SE¼SW¼NW¼SW¼ sec. 17, T. 8 S., R. 46 E.	3,620	20	18.3	Alluvial sand and gravel.	7-12
O-7	SE¼SW¼NW¼SW¼ sec. 17, T. 8 S., R. 46 E.	3,619	12	11.5	Alluvial sand and gravel.	6-10
O-8	SW¼NE¼SE¼SE¼ sec. 18, T. 8 S., R. 46 E.	3,627	20	19.7	Alluvial sand and gravel.	12-19
O-9	SW¼NE¼SE¼SE¼ sec. 18, T. 8 S., R. 46 E.	3,620	20	18.4	Alluvial sand and gravel.	7-17.5
O-10	SE¼NE¼SE¼SE¼ sec. 18, T. 8 S., R. 46 E.	3,625	35	33.9	Alluvial sand and gravel. Local coal bed	12-16 16-22.5
O-11	SW¼NW¼SW¼SE¼ sec. 19, T. 8 S., R. 46 E.	3,678	20	18.9	Alluvial sand and gravel.	15-19
O-12	NE¼SW¼SW¼SE¼ sec. 19, T. 8 S., R. 46 E.	3,685	32	32.0	Alluvial sand and gravel.	25-30
O-13	NW¼NE¼SE¼SW¼ sec. 27, T. 8 S., R. 46 E.	3,870	260	233	Sandstone below Canyon coal bed.	160-230
O-14	NW¼NE¼SE¼SW¼ sec. 27, T. 8 S., R. 46 E.	3,870	138	138	Canyon coal bed	115-134
O-15	NW¼SW¼SE¼NE¼ sec. 28, T. 8 S., R. 46 E.	3,771	36	35.5	Alluvial sand and gravel.	20-30.5
O-16	NE¼NW¼SE¼NW¼ sec. 32, T. 8 S., R. 46 E.	3,745	31	30.1	Alluvial sand and gravel.	23-26.5

Hydraulic conductivity of aquifer (feet per day)	Water level (feet below land surface)	Date of water level measurement (month-day-year)	Well discharge (gallons per minute)	Chemical analysis available (table 5)	Remarks
--	156.1	10-21-83	--	No	Exploration hole U.S. 77-101.
0.004	232.0	05-18-84	0.12	Yes	U.S. Geological Survey observation well UOP-23.
--	--	--	--	No	Dry hole; blows methane gas. U.S. Geological Survey observation well UOP-24.
--	197.6	08-11-76	--	No	Exploration hole DH75-109.
1	15.6	06-26-84	.5	Yes	U.S. Geological Survey observation well UOP-22.
20	3.4	05-23-84	2.1	Yes	U.S. Geological Survey observation well UOP-01.
170	2.4	05-19-84	4.1	Yes	U.S. Geological Survey observation well UOP-02.
290	12.6	06-06-84	7.1	Yes	U.S. Geological Survey observation well UOP-05.
60	4.9	05-21-84	4.3	Yes	U.S. Geological Survey observation well UOP-04.
7	10.2	06-08-84	2.2	Yes	U.S. Geological Survey observation well UOP-03; aquifer characteristics are for combined alluvium and coal aquifer.
50	15.0	06-08-84	1.5	Yes	U.S. Geological Survey observation well UOP-25.
65	22.6	05-18-84	2.8	Yes	U.S. Geological Survey observation well UOP-26.
.3	125.8	07-24-83	3.8	Yes	U.S. Geological Survey observation well UOP-06.
.8	88.6	07-25-83	1.6	Yes	U.S. Geological Survey observation well UOP-07.
80	16.2	05-17-84	13.0	Yes	U.S. Geological Survey observation well UOP-08.
7	23.1	06-07-84	.9	Yes	U.S. Geological Survey observation well UOP-30.

Table 3.--*Hydrogeologic data for observation wells in and near the upper Otter Creek area*--Continued

Well No. (pl. 1)	Location	Altitude of land surface (feet)	Depth drilled (feet below land surface)	Depth of well (feet below land surface)	Aquifer material	Aquifer interval (feet below land surface)
0-17	SW¼NE¼SE¼SE¼ sec. 32, T. 8 S., R. 46 E.	3,765	34	30.2	Alluvial sand and gravel.	16-30
0-18	SW¼NE¼SE¼SE¼ sec. 32, T. 8 S., R. 46 E.	3,766	30	29.7	Alluvial sand and gravel.	19-28
0-19	SE¼NE¼NW¼SW¼ sec. 2, T. 9 S., R. 45 E.	3,970	312	299	Anderson coal bed Dietz coal bed	159-181 269-279
0-20	NW¼SE¼SE¼NE¼ sec. 11, T. 9 S., R. 45 E.	4,000	321	307	Dietz coal bed	284-296
0-21	SE¼SE¼SE¼NE¼ sec. 4, T. 9 S., R. 46 E.	3,940	340	340	Canyon coal bed	291-310
0-22	NW¼NE¼NW¼NE¼ sec. 5, T. 9 S., R. 46 E.	3,825	180	180	Canyon coal bed	148-167
0-23	NW¼NW¼SW¼SE¼ sec. 7, T. 9 S., R. 46 E.	4,027	430	419	Canyon coal bed	390-418
0-24	NE¼SE¼NE¼NE¼ sec. 7, T. 9 S., R. 46 E.	3,860	34	33.6	Alluvial sand and gravel.	28-32
0-25	SW¼SW¼NE¼NW¼ sec. 8, T. 9 S., R. 46 E.	3,965	240	240	Dietz coal bed	210-220
0-26	SW¼NW¼NW¼NE¼ sec. 9, T. 9 S., R. 46 E.	3,855	120	120	Dietz coal bed	94-104
0-27	NE¼NW¼NE¼SE¼ sec. 9, T. 9 S., R. 46 E.	3,875	220	209	Canyon coal bed	178-205
0-28	SE¼SW¼SE¼NE¼ sec. 9, T. 9 S., R. 46 E.	3,876	176	176	Sandstone above Canyon coal bed.	144-170
0-29	NE¼NW¼NE¼SE¼ sec. 9, T. 9 S., R. 46 E.	3,872	110	110	Dietz coal bed	95-101
0-30	NE¼NW¼NW¼SE¼ sec. 9, T. 9 S., R. 46 E.	3,841	36	35.7	Alluvial sand and gravel.	17-32.5

Hydraulic conductivity of aquifer (feet per day)	Water level (feet below land surface)	Date of water level measurement (month-day-year)	Well discharge (gallons per minute)	Chemical analysis available (table 5)	Remarks
260	16.1	05-20-84	12.8	Yes	U.S. Geological Survey observation well UOP-31.
50	16.7	05-22-84	3.8	Yes	U.S. Geological Survey observation well UOP-32.
.8	159.3	05-19-84	3.4	Yes	Exploration hole DH75-105; aquifer characteristics are for combined Anderson and Dietz coal beds.
.001	231.4	05-17-84	.12	Yes	Exploration hole DH75-104.
--	202.6	05-23-84	--	No	Exploration hole M75-35.
--	59	06-18-75	--	Yes	Exploration hole AMAX-112.
.005	277.1	07-20-83	.6	Yes	Exploration hole M75-38A.
40	28.2	06-27-84	1.2	Yes	U.S. Geological Survey observation well UOP-20.
4.0	169.6	07-22-83	1.5	Yes	Exploration hole AMAX-110.
15	73.7	05-15-84	9.3	Yes	Exploration hole AMAX-109.
.4	153.2	08-05-83	5.5	Yes	U.S. Geological Survey observation well UOP-13.
--	110.2	05-15-84	.005	Yes	U.S. Geological Survey observation well UOP-14.
16	94.9	08-05-83	3.3	Yes	Exploration hole AMAX-105.
10	17.1	06-06-84	2.6	Yes	U.S. Geological Survey observation well UOP-18.

Table 3.--*Hydrogeologic data for observation wells in and near the upper Otter Creek area*--Continued

Well No. (pl. 1)	Location	Altitude of land surface (feet)	Depth drilled (feet below land surface)	Depth of well (feet below land surface)	Aquifer material	Aquifer interval (feet below land surface)
O-31	NW¼NE¼NW¼SE¼ sec. 9, T. 9 S., R. 46 E.	3,840	37	34.2	Alluvial sand and gravel.	16-34
O-32	NW¼NE¼NW¼SE¼ sec. 9, T. 9 S., R. 46 E.	3,841	31	30.2	Alluvial sand and gravel.	19.5-29
O-33	SW¼SW¼NE¼NW¼ sec. 11, T. 9 S., R. 46 E.	3,927	18	17.8	Alluvial sand and gravel.	12-17.5
O-34	SW¼SW¼NE¼NW¼ sec. 11, T. 9 S., R. 46 E.	3,925	21	20.2	Alluvial sand and gravel.	11-16
O-35	NW¼NE¼NW¼NW¼ sec. 11, T. 9 S., R. 46 E.	3,929	275	262	Canyon coal bed	231-255
O-36	NW¼NE¼NW¼NW¼ sec. 11, T. 9 S., R. 46 E.	3,930	208	208	Sandstone above Canyon coal bed.	154-206
O-37	SW¼NW¼NW¼NW¼ sec. 16, T. 9 S., R. 46 E.	3,862	16	15.5	Alluvial sand and gravel.	11-13
O-38	SE¼NW¼NW¼NW¼ sec. 16, T. 9 S., R. 46 E.	3,881	31	30.3	Anderson coal bed	29-30
O-39	NE¼NE¼SW¼NW¼ sec. 20, T. 9 S., R. 46 E.	4,155	450	450	Dietz coal bed	426-433
O-40	SE¼SE¼NE¼NW¼ sec. 28, T. 9 S., R. 46 E.	4,165	435	430	Dietz coal bed	424-430

Hydraulic conductivity of aquifer (feet per day)	Water level (feet below land surface)	Date of water level measurement (month-day-year)	Well discharge (gallons per minute)	Chemical analysis available (table 5)	Remarks
120	16.3	05-22-84	4.0	Yes	U.S. Geological Survey observation well UOP-17.
4	17.1	05-16-84	1.9	Yes	U.S. Geological Survey observation well UOP-19.
30	11.9	05-20-84	3.4	Yes	U.S. Geological Survey observation well UOP-12.
60	10.4	05-17-84	15.5	Yes	U.S. Geological Survey observation well UOP-11.
.2	149.8	07-23-83	.8	Yes	U.S. Geological Survey observation well UOP-09.
.3	141.9	07-23-83	4.4	Yes	U.S. Geological Survey observation well UOP-10.
4	11.1	05-16-84	.3	Yes	U.S. Geological Survey observation well UOP-15.
--	29.9	05-16-84	--	No	U.S. Geological Survey observation well UOP-16; alluvial material dry.
.15	388.9	07-21-83	.4	Yes	Exploration hole AMAX-111.
--	171.5	07-22-83	--	No	Exploration hole AMAX-108.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*[1]

[Altitude of land surface: refers to distance above NGVD of 1929. --, no data]

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-1	M75-16	SW¼NE¼NW¼NE¼ sec. 13, T. 8 S., R. 45 E.	09-03-75	3,833	160
T-2	U.S.77-102	SW¼SE¼NE¼SW¼ sec. 14, T. 8 S., R. 45 E.	08-15-77	3,848	240
T-3	SM-18	SW¼NE¼SE¼SW¼ sec. 23, T. 8 S., R. 45 E.	07-02-68	3,925	100
T-4	SH70-43	NE¼NE¼NE¼NW¼ sec. 24, T. 8 S., R. 45 E.	07-20-70	3,853	214
T-5	U.S.80-099	SW¼NE¼SW¼NE¼ sec. 25, T. 8 S., R. 45 E.	11-05-80	3,805	200
T-6	U.S.77-108	SW¼SE¼NW¼NW¼ sec. 25, T. 8 S., R. 45 E.	08-17-77	3,910	242

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-1	Sandstone	91	96	Apparently massive. Probably contains water.
	Canyon coal bed.	112	135	Apparently massive coal.
T-2	Dietz coal bed.	76	86	Massive coal. Probably contains water; spring at this level in valley to northeast.
	Sandstone	182	200	Interbedded with shale layers.
	Canyon coal bed.	208	232	Massive coal.
T-3	Anderson coal bed.	52	78	Massive coal. Probably contains water only in lower part.
	Lower Anderson coal bed.	79	83	Probably contains water.
T-4	Dietz coal bed.	42	53	Shaly in middle part. Probably dry.
	Sandstone	66	81	Interbedded with shale layers. Probably dry.
	Canyon coal bed.	130	153	Mostly massive coal. Probably contains water.
	Sandstone	181	200	Interbedded with shale layers.
T-5	Dietz coal bed.	8	17	Massive coal. Probably dry.
	Sandstone	68	83	Interbedded with shale layers. Probably contains water.
	Canyon coal bed.	117	138	Massive coal.
	Sandstone	166	200	Interbedded with shale layers.
T-6	Anderson coal bed.	43	60	Massive coal. Probably contains water only in lower part.
	Lower Anderson coal bed.	65	69	Probably contains water.
	Sandstone	86	104	Interbedded with shale layers.
	Dietz coal bed.	175	185	Massive coal.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-7	U.S.77-103	SW¼NW¼SE¼NW¼ sec. 26, T. 8 S., R. 45 E.	08-15-77	3,880	301
T-8	U.S.77-107	SW¼SE¼SW¼SE¼ sec. 35, T. 8 S., R. 45 E.	08-15-77	4,063	220
T-9	SM-16	SW¼SE¼SE¼NE¼ sec. 36, T. 8 S., R. 45 E.	07-03-68	3,820	150
T-10	U.S.81-193	SE¼SW¼NW¼NW¼ sec. 36, T. 8 S., R. 45 E.	06-27-81	3,965	520

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-7	Anderson coal bed.	42	56	Massive coal. Probably dry.
	Lower Anderson coal bed.	63	69	Probably dry.
	Sandstone	86	94	With shale breaks.
	Dietz coal bed.	140	151	Massive coal. Probably contains water.
	Sandstone	224	239	Interbedded with shale layers.
	Canyon coal bed.	260	282	Massive coal.
	Sandstone	287	295	With shale breaks.
T-8	Smith coal bed.	66	68	Probably dry.
	Sandstone	129	163	Interbedded with shale layers. Probably contains water only in lower part.
	Anderson coal bed.	188	203	Massive coal. Probably contains water only in lower part.
	Lower Anderson coal bed.	207	211	Probably contains water.
T-9	Dietz coal bed.	40	51	Apparently massive coal. Probably contains water.
	Sandstone	77	106	Probably interbedded with shale layers.
	Canyon coal bed.	118	136	Apparently massive coal.
T-10	Anderson coal bed.	52	67	Massive coal. Probably dry.
	Lower Anderson coal bed.	72	75	Probably dry.
	Sandstone	88	112	Interbedded with shale layers. Probably contains water.
	Sandstone	130	156	Interbedded with shale layers. Probably contains water.
	Dietz coal bed.	191	200	Massive coal.
	Sandstone	235	263	Interbedded with shale layers.
	Canyon coal beds.	289	308	Massive coal.
	Sandstone	336	351	Interbedded with shale layers.
	Sandstone	410	446	Interbedded with shale layers.
	Cook coal bed.	459	465	Massive coal.
	Otter coal bed.	484	494	Massive coal.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-11	U.S.77-116	SE¼SW¼NW¼SW¼ sec. 14, T. 8 S., R. 46 E.	08-18-77	3,928	160
T-12	SM-13	SW¼SW¼SE¼SW¼ sec. 16, T. 8 S., R. 46 E.	07-07-68	3,867	110
T-13	U.S.80-098	NW¼SE¼SW¼SW¼ sec. 18, T. 8 S., R. 46 E.	10-30-80	3,782	140
T-14	U.S.77-110	SW¼NE¼SW¼SE¼ sec. 20, T. 8 S., R. 46 E.	08-17-77	3,855	150
T-15	U.S.77-115	SW¼SW¼SW¼SW¼ sec. 22, T. 8 S., R. 46 E.	08-18-77	3,870	120
T-16	U.S.77-114	SE¼SE¼NE¼SW¼ sec. 23, T. 8 S., R. 46 E.	08-18-77	3,900	140
T-17	SM-12	SE¼SW¼NE¼SW¼ sec. 27, T. 8 S., R. 46 E.	07-06-68	3,847	140

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-11	Dietz coal bed.	25	35	Massive coal. Probably dry.
	Sandstone	75	86	Interbedded with shale layers. Probably contains water only in lower part.
	Upper Canyon coal bed.	124	127	Probably contains water.
	Canyon coal bed.	132	150	Mostly massive coal.
T-12	Upper Canyon coal bed.	69	73	Probably dry.
	Canyon coal bed.	84	103	Apparently massive coal. Probably contains water only in in lower part.
T-13	Canyon coal bed.	78	100	Massive coal. Probably contains water only in lower part.
	Sandstone	108	117	Interbedded with shale layers. Probably contains water.
T-14	Upper Canyon coal bed.	60	63	Probably dry.
	Canyon coal bed.	72	90	Massive coal. Probably dry.
	Sandstone	114	145	Interbedded with shale layers. Probably contains water only in lower part.
T-15	Upper Canyon coal bed.	79	82	Probably dry.
	Canyon coal bed.	86	103	Massive coal. Probably contains water only in lower part.
T-16	Dietz coal bed.	37	48	Massive coal. Probably dry.
	Sandstone	70	83	Interbedded with shale layers. Probably contains water only in lower part.
	Upper Canyon coal bed.	107	110	Probably contains water.
	Canyon coal bed.	114	134	Massive coal.
T-17	Sandstone	75	90	Interbedded with shale layers. Probably contains water.
	Upper Canyon coal bed.	97	99	Probably contains water.
	Canyon coal bed.	103	122	Massive coal.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-18	U.S.80-100	SW¼SW¼SW¼SE¼ sec. 28, T. 8 S., R. 46 E.	11-05-80	3,930	240
T-19	U.S.77-117	SW¼NE¼SW¼SW¼ sec. 29, T. 8 S., R. 46 E.	08-18-77	3,810	180
T-20	U.S.77-109	NE¼SE¼SW¼NE¼ sec. 30, T. 8 S., R. 46 E.	08-17-77	3,838	140
T-21	UOP-27	SE¼NE¼SW¼SW¼ sec. 32, T. 8 S., R. 46 E.	06-25-83	3,770	15
T-22	M75-33	SW¼NW¼SE¼ sec. 32, T. 8 S., R. 46 E.	09-18-75	3,802	142

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-18	Dietz coal bed.	83	93	Massive coal. Probably dry.
	Sandstone	96	127	Interbedded with shale layers. Probably contains water only in lower part.
	Upper Canyon coal bed.	159	162	Probably contains water.
	Canyon coal bed.	171	189	Massive coal.
	Sandstone	191	204	Interbedded with shale layers.
T-19	Dietz coal bed.	76	85	Massive coal. Probably dry.
	Sandstone	106	129	Interbedded with shale layers. Probably contains water.
T-20	Dietz coal bed.	18	27	Shaly (or weathered) near top. Probably dry.
	Sandstone	46	70	Interbedded with shale layers. Probably dry.
	Upper Canyon coal bed.	91	94	Probably dry.
	Canyon coal bed.	105	123	Massive coal. Probably contains water only in lower part.
T-21	Alluvial sand and gravel.	10	11	Dry when drilled; possibly saturated during periods of greater than average rainfall and high water tables.
T-22	Dietz coal bed.	24	29	Incomplete section; upper part of Dietz bed eroded or burned. Probably dry.
	Upper Canyon coal bed.	104	107	Probably contains water.
	Middle Canyon coal bed.	114	117	--
	Canyon coal bed.	119	132	Massive coal.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-23	U.S.77-111	NE¼SE¼SE¼SE¼ sec. 33, T. 8 S., R. 46 E.	08-17-77	3,965	340
T-24	U.S.77-113	SE¼NW¼NW¼NW¼ sec. 35, T. 8 S., R. 46 E.	08-17-77	4,010	300
T-25	SM-10	NW¼SW¼SW¼NE¼ sec. 36, T. 8 S., R. 46 E.	07-07-68	3,995	160
T-26	U.S.80-093	NE¼SW¼NE¼SW¼ sec. 1, T. 9 S., R. 45 E.	10-28-80	3,990	300

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-23	Anderson coal bed.	50	63	Massive coal. Probably dry.
	Lower Anderson coal bed.	94	97	Probably dry.
	Sandstone	102	115	Interbedded with shale layers. Probably dry.
	Dietz coal bed.	142	152	Massive coal. Possibly contains water.
	Sandstone	207	240	Interbedded with shale layers. Probably contains water.
	Sandstone	255	270	Interbedded with shale layers.
	Upper Canyon coal bed.	278	281	--
	Canyon coal bed.	292	312	Massive coal.
T-24	Anderson coal bed.	66	80	Massive coal. Probably dry.
	Lower Anderson coal bed.	86	91	Probably dry.
	Sandstone	95	110	Interbedded with shale layers. Probably dry.
	Dietz coal bed.	137	147	Massive coal. Possibly contains water.
	Sandstone	217	236	Interbedded with shale layers. Probably contains water.
	Upper Canyon coal bed.	257	260	--
	Canyon coal bed.	263	283	Massive coal.
T-25	Anderson coal bed.	64	78	Apparently massive coal. Probably dry.
	Lower Anderson coal bed.	85±	90±	Possibly contains water.
	Dietz coal bed.	145	155	Apparently massive coal. Probably contains water.
T-26	Smith coal bed.	--	0	At ground surface.
	Anderson coal bed.	114	127	Massive coal. Probably contains water in lower part.
	Sandstone	150	164	Shaly sandstone in lower half. Probably contains water.
	Sandstone	175	223	Interbedded with shale layers.
	Dietz coal bed.	246	?	Log indicates broken Dietz coal beds at depths 246-260 ft and 277-296 ft -- may be in faulted zone.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-27	True Oil Co. Aztec-Federal No. 14-25	SW¼NE¼SW¼SW¼ sec. 25, T. 9 S., R. 45 E.	1970±	4,227	945+
T-28	Samuel, Gary, Ackman-Schulein and Associates No. 2-9 Federal-Elliott	SW¼NE¼NE¼SE¼ sec. 2, T. 9 S., R. 46 E.	10-17-68	4,006	8,110

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-27	Smith coal bed.	383	387	Apparently massive coal. Probably contains water.
	Sandstone	409	420	Apparently massive sandstone.
	Upper Anderson coal bed.	484	492	--
	Anderson coal bed.	495	509	Apparently massive coal.
	Sandstone	535	547	Apparently massive sandstone.
	Dietz coal bed.	621	628	Apparently massive coal.
	Sandstone	674	709	Probably interbedded with shale layers.
	Canyon coal bed.	724	738	Apparently massive coal.
	Lower Canyon coal bed.	740	743	--
	Sandstone	770	785	Probably interbedded with shale layers.
	Sandstone	795	828	Probably interbedded with shale layers.
	Cook coal bed.	878	884	Apparently massive coal.
	Sandstone	890	913	Probably interbedded with shale layers.
	Otter coal bed.	927	935	Apparently massive coal.
T-28	Anderson and Dietz coal beds.	--	--	No log 0-225 ft.
	Sandstone	264	279	Probably interbedded with shale layers. Probably contains water.
	Upper Canyon coal bed.	284	289	--
	Canyon coal bed.	293	310	Apparently massive coal.
	Sandstone	371	403	Probably interbedded with shale layers.
	Cook coal bed.	458	463	Apparently massive coal.
	Lower Cook coal bed.	467	470	--
	Otter coal bed.	525	532	Apparently massive coal.
	Sandstone	611	647	Probably interbedded with shale layers.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-29	AMAX-114	NE¼NW¼SE¼SE¼ sec. 3, T. 9 S., R. 46 E.	12-07-74	3,940	280
T-30	SM-14	NE¼SW¼SW¼NE¼ sec. 5, T. 9 S., R. 46 E.	07-05-68	3,825	197
T-31	U.S.80-092	NW¼SW¼SE¼NW¼ sec. 6, T. 9 S., R. 46 E.	10-29-80	3,935	330

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-29	Anderson coal bed.	37	51	Massive coal. Probably dry.
	Lower Anderson coal bed.	53	60	Possibly contains water.
	Basal Anderson coal bed.	63	66	Probably contains water.
	Dietz coal bed.	115	125	Massive coal. Probably contains water.
	Sandstone	167	201	Interbedded with shale layers.
	Upper Canyon coal bed.	236	239	--
	Canyon coal bed.	244	262	Massive coal.
T-30	Dietz coal bed.	53	62	Apparently massive coal. Probably contains water.
	Sandstone	77	109	Probably interbedded with shale.
	Upper Canyon coal bed.	165	169	--
	Canyon coal bed.	175	193	Apparently massive coal.
T-31	Anderson coal bed.	--	--	No log from 0-124 ft. Bottom of Anderson clinker projected to about 25-ft depth.
	Sandstone	124	133	Apparently massive sandstone. Probably contains water.
	Dietz coal bed.	174	183	Massive coal.
	Sandstone	224	235	With shale breaks.
	Upper Canyon coal bed.	282	286	--
	Canyon coal bed.	294	312±	Massive coal. Log ends at 304-ft depth, still in coal.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-32	U.S.80-094	NE¼NE¼SE¼NE¼ sec. 7, T. 9 S., R. 46 E.	10-29-80	3,880	360
T-33	U.S.80-097	NW¼NW¼SW¼NE¼ sec. 9, T. 9 S., R. 46 E.	10-29-80	3,838	280
T-34	AMAX-104	NE¼SW¼NE¼SW¼ sec. 10, T. 9 S., R. 46 E.	11-22-74	4,030	260

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-32	Sandstone	113	132	Interbedded with shale layers. Probably contains water.
	Dietz coal bed.	143	150	Massive coal.
	Lower Dietz coal bed.	158	161	--
	Sandstone	191	240	Interbedded with shale layers.
	Upper Canyon coal bed.	265	269	--
	Canyon coal bed.	276	294	Massive coal.
T-33	Sandstone	48	64	Interbedded with shale layers. Probably contains water.
	Dietz coal bed.	90	100	Massive coal.
	Sandstone	135	142	With shale breaks.
	Upper Canyon coal bed.	168	175	--
	Canyon coal bed.	182	198	Massive coal.
T-34	Smith coal bed.	36	41	Shale layer between two coal beds. Probably dry.
	Sandstone	93	106	Interbedded with shale layers. Probably dry.
	Anderson coal bed.	156	170	Massive coal. Probably contains water.
	Lower Anderson bed.	174	182	Massive coal.
	Basal Anderson coal bed.	185	187	--
	Sandstone	190	206	Interbedded with shale layers.
	Dietz coal bed.	235	244	Massive coal.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-35	Westrans Petroleum Inc. No. 14-11 Federal	NW¼SE¼SW¼SW¼ sec. 11, T. 9 S., R. 46 E.	06-13-70	4,070	7,787
T-36	Bliss test No. 6	SW¼SW¼SW¼SW¼ sec. 12, T. 9 S., R. 46 E.	11- -74	4,020	304
T-37	Bliss test No. 4	SW¼SE¼NE¼SE¼ sec. 12, T. 9 S., R. 46 E.	09- -69	4,250	400
T-38	Bliss test No. 1	NE¼SE¼NE¼SE¼ sec. 12, T. 9 S., R. 46 E.	09- -67	4,150	310

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-35	Anderson and Dietz coal beds.	--	--	No log 0-260 feet.
	Sandstone	316	330	Interbedded with shale layers. Probably contains water.
	Upper Canyon coal bed.	350	356	--
	Canyon coal bed.	360	375	Apparently massive coal.
	Sandstone	386	421	Interbedded with shale layers.
	Sandstone	445	467	Interbedded with shale layers.
	Cook coal bed.	530	537	Apparently massive coal.
	Sandstone	573	617	Interbedded with shale layers.
	Otter coal bed.	622	629	Apparently massive coal.
	Sandstone	666	724	Interbedded with shale layers.
T-36	Sandstone	84	100	Interbedded with shale layers. Probably contains water.
	Anderson coal bed.	112	140±	Probably with shale layer near middle.
	Sandstone	160	180	Probably with shale layers.
	Dietz coal bed.	205	215	Apparently massive coal.
	Canyon coal bed.	298	304	Top of Canyon bed; hole ended in coal.
T-37	Roland (?) coal bed.	138	141	Probably dry.
	Smith coal bed.	203	207	Possibly contains water.
	Anderson coal bed.	328	355±	Probably with shale layer near middle. Probably contains water.
T-38	Roland (?) coal bed.	25	28	Probably contains water.
	Smith coal bed.	105	109	Probably contains water.
	Anderson coal bed.	225	252	Probably with shale layer near middle.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-39	AMAX-113	SE¼SW¼NE¼NE¼ sec. 16, T. 9 S., R. 46 E.	12-07-74	3,870	240
T-40	SM-15	SE¼SE¼NE¼SW¼ sec. 16, T. 9 S., R. 46 E.	07-05-68	3,960	150
T-41	AMAX-101	SW¼SE¼NW¼NW¼ sec. 16, T. 9 S., R. 46 E.	11-22-74	3,900	140
T-42	True Oil Co. Wolter-Federal No. 13-18	SE¼NW¼NW¼SW¼ sec. 18, T. 9 S., R. 46 E.	1960±	4,047	304+

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-39	Dietz coal bed.	64	69	Massive coal. Probably contains water.
	Lower Dietz coal bed.	73	75	--
	Sandstone	133	172	Interbedded with shale layers.
	Upper Canyon coal bed.	196	203	--
	Canyon coal bed.	208	226	Massive coal; thin shale near base.
T-40	Anderson coal bed.	64	78	Apparently massive coal. Probably dry.
	Lower Anderson coal bed.	104	110	Apparently massive coal. Probably contains water.
T-41	Lower Anderson coal bed.	56	59	Main Anderson coal apparently eroded. Probably contains water.
	Sandstone	62	80	Interbedded with shale layers.
	Dietz coal bed.	117	123	Massive coal.
	Lower Dietz coal bed.	126	128	--
T-42	Smith coal bed.	106	108	Probably dry.
	Sandstone	135	169	Interbedded with shale layers. Probably contains water.
	Anderson coal bed.	206	220	Massive coal.
	Sandstone	230	241	Interbedded with shale layers.
	Sandstone	278	302	Interbedded with shale layers.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-43	AMAX-102	NE¼SW¼NW¼NE¼ sec. 21, T. 9 S., R. 46 E.	11-22-74	4,085	340
T-44	AMAX-103	SE¼NE¼NE¼SE¼ sec. 21, T. 9 S., R. 46 E.	11-22-74	4,165	440

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-43	Smith coal bed.	54	57	Probably dry.
	Sandstone	100	111	Interbedded with shale layers. Probably dry.
	Anderson coal bed.	159	171	Massive coal. Probably contains water only in lower part.
	Sandstone	213	223	Interbedded with shale layers. Probably contains water.
	Lower Anderson coal bed.	237	240	Massive coal.
	Basal Anderson coal bed.	243	245	--
	Sandstone	249	259	Interbedded with shale layers.
	Dietz coal bed.	305	312	Massive coal.
	Sandstone	315	327	Interbedded with shale layers.
T-44	Smith coal bed.	188	191	Probably dry.
	Sandstone	226	247	Interbedded with shale layers. Probably dry.
	Sandstone	266	274	Mostly massive sandstone. Probably contains water.
	Anderson coal bed.	289	302	Massive coal. Probably contains water.
	Sandstone	309	332	Interbedded with shale layers.
	Lower Anderson coal bed.	343	350	Massive coal.
	Basal Anderson coal bed.	352	355	--
	Sandstone	357	368	Interbedded with shale layers.
	Dietz coal bed.	406	411	Massive coal.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-45	AMAX-106	NE¼NE¼SE¼NW¼ sec. 22, T. 9 S., R. 46 E.	12-01-74	4,060	240
T-46	AMAX-100	SW¼NW¼SE¼SE¼ sec. 22, T. 9 S., R. 46 E.	11-21-74	4,150	440

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-45	Smith coal bed.	69	71	Probably dry.
	Sandstone	127	148	Interbedded with shale layers. Probably contains water.
	Sandstone	168	176	Mostly massive sandstone. Probably contains water.
	Anderson coal bed.	195	207	Massive coal.
	Lower Anderson coal bed.	210	218	Massive coal.
	Basal Anderson coal bed.	220	222	--
T-46	Smith coal bed.	195	197	Probably dry.
	Sandstone	214	228	Interbedded with shale layers. Probably contains water.
	Sandstone	269	276	Mostly massive sandstone.
	Anderson coal bed.	321	333	Massive coal.
	Lower Anderson coal bed.	336	344	Massive coal.
	Basal Anderson coal bed.	346	350	--
	Sandstone	353	363	Mostly massive sandstone; shale breaks in lower half.
	Dietz coal bed.	401	408	Massive coal.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-47	True Oil Co. Hope No. 41-27	SW¼NE¼NE¼NE¼ sec. 27, T. 9 S., R. 46 E.	1960±	4,146	1,020+
T-48	AMAX-107	SW¼NE¼NW¼SE¼ sec. 27, T. 9 S., R. 46 E.	12-01-74	4,140	380

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-47	Smith coal bed.	218	220	Probably dry.
	Sandstone	311	326	Interbedded with shale layers. Probably contains water.
	Anderson coal bed.	347	359	Apparently massive coal.
	Lower Anderson coal bed.	363	370	Apparently massive coal.
	Basal Anderson coal bed.	372	375	--
	Dietz coal bed.	422	428	Apparently massive coal.
	Sandstone	472	483	Mostly massive sandstone.
	Sandstone	502	528	Interbedded with shale layers.
	Upper Canyon coal bed.	544	549	--
	Canyon coal bed.	558	566	Apparently massive coal.
	Lower Canyon coal bed.	569	575	--
	Sandstone	634	646	Mostly massive sandstone.
	Sandstone	660	670	Interbedded with shale layers.
	Cook coal bed.	702	707	Apparently massive coal.
	Sandstone	718	732	Interbedded with shale layers.
	Otter coal bed.	783	790	Apparently massive coal.
	Sandstone	811	823	Interbedded with shale layers.
T-48	Smith coal bed.	212	214	Probably dry.
	Sandstone	232	241	Interbedded with shale layers. Probably contains water.
	Sandstone	259	274	Interbedded with shale layers.
	Anderson coal bed.	330	343	Massive coal.
	Lower Anderson coal bed.	346	354	Massive coal.
	Basal Anderson coal bed.	357	360	--
	Sandstone	362	376	Mostly massive sandstones, with shale layer in middle.

Table 4.--*Principal sandstone and coal beds penetrated in test holes in and near the upper Otter Creek area*--Continued

Test hole No. (pl. 1)	Local identification No.	Location	Date drilled (month-day-year)	Altitude of land surface (feet)	Depth drilled (feet below land surface)
T-49	Chandler and Associates, Inc., Line-Government No. 1	SE¼NW¼SW¼SW¼ sec. 30, T. 9 S., R. 47 E.	1960±	4,148	1,293+

Test hole No. (pl. 1)	Sandstone or coal bed	Depth to top of unit (feet below land surface)	Depth to bottom of unit (feet below land surface)	Remarks
T-49	Smith coal bed.	228	231	Probably dry.
	Sandstone	262	280	Interbedded with shale layers. Probably contains water in lower part.
	Anderson coal bed.	324	335	Massive coal. Probably contains water.
	Lower Anderson coal bed.	339	348	Massive coal.
	Basal Anderson coal bed.	349	353	--
	Dietz coal bed.	391	399	Massive coal.
	Sandstone	446	453	Apparently massive sandstone.
	Sandstone	489	500	Interbedded with shale layers.
	Upper Canyon coal bed.	519	523	--
	Canyon coal bed.	528	547	Massive coal.
	Sandstone	623	630	Mostly massive sandstone, with shale breaks.
	Cook coal bed.	672	678	Massive coal.
	Sandstone	716	723	Mostly massive sandstone, with shale breaks.
	Otter coal bed.	752	759	Massive coal.
	Sandstone	773	815	Interbedded shale layers.

[1]Minor subdivisions of units and minor sandstone and coal beds are not identified.

Table 5.--*Chemical quality of water from private wells, observation wells, springs, and streams in and near the upper Otter Creek area*

[Constituents are dissolved and concentrations are reported in milligrams per liter. Analyses by Montana Bureau of Mines and Geology, except as noted. Well or site designation: P, private domestic or livestock well; O, observation well; S, spring; SW, streamflow site. Abbreviations: microsiemens, microsiemens per centimeter at 25 °C; °C, degrees Celsius. Symbol: <, less than; --, no data]

Well or site designation (pl.1)	Location	Aquifer or source	Date sample collected (month-day-year)	Onsite specific conductance (microsiemens)	Onsite pH (units)	Onsite temperature (°C)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)
P-2	SE¼NW¼SE¼SW¼ sec. 17, T. 8 S., R. 46 E.	Alluvial sand and gravel.	06-28-84	6,500	7.2	10.0	2,200	230	390
P-3	NW¼SW¼SW¼SW¼ sec. 20, T. 8 S., R. 46 E.	Alluvial sand and gravel.	01-30-74	8,000±	7.9	8.0	2,700	300	470
P-7	NW¼NE¼NW¼NE¼ sec. 32, T. 8 S., R. 46 E.	Alluvial sand and gravel.	01-30-74	7,000±	8.0	--	2,400	280	410
P-8	SW¼SW¼NW¼SW¼ sec. 12, T. 9 S, R. 46 E.	Sandstone below Dietz coal bed.	01-30-74	1,690	8.1	10.0	36	6.5	4.8
P-9	NE¼NE¼NW¼NE¼ sec. 3, T. 9 S., R. 46 E.	Alluvial sand and gravel.	06-29-84	3,860	7.4	9.0	940	140	140
P-10	NE¼SE¼SE¼SE¼ sec. 3, T. 9 S., R. 46 E.	Probably sandstone below Dietz coal bed.	06-29-84	3,260	7.4	10.0	580	120	72
P-11	SW¼NW¼SW¼NE¼ sec. 4, T. 9 S., R. 46 E.	Probably sandstone below Dietz coal bed.	01-31-74	2,700	8.6	10.0	40	8.4	4.7
P-12	NE¼NE¼SE¼SE¼ sec. 5, T. 9 S., R. 46 E.	Alluvial sand and gravel and Dietz coal bed.	06-27-84	5,050	7.3	10.0	1,900	330	250
P-14	NE¼NE¼SE¼SE¼ sec. 5, T. 9 S., R. 46 E.	Canyon coal bed	06-27-84	7,200	7.4	10.0	740	150	90
P-15	NE¼NE¼SE¼SE¼ sec. 5, T. 9 S., R. 46 E.	Alluvial sand and gravel and Dietz coal bed.	06-27-84	5,300	7.1	7.5	2,900	490	400
P-17	SW¼NW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	Alluvial sand and gravel.	06-28-84	4,800	7.4	9.0	2,100	340	310
P-18	SW¼NW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	Probably sandstone below Dietz coal bed.	06-28-84	3,650	6.5	9.5	1,500	200	250
P-19	SW¼NW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	Sandstone below Canyon coal bed.	01-30-74	2,200	8.3	9.0	28	7.6	2.2
P-20	NW¼SW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	Sandstone below Canyon coal bed.	06-30-84	1,950	8.0	12.0	24	4.9	2.9

Sodium (Na)	Sodium adsorption ratio (SAR)	Potassium (K)	Bicarbonate (HCO_3)	Alkalinity (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids, sum of constituents	Remarks
840	8	17	691	567	3,300	28	0.1	17	5,150	--
950	8	15	653	536	4,200	20	.6	15	6,600	--
740	7	19	512	420	3,500	16	.6	21	5,510	--
450	32	3.2	1,220	1,000	2.5	16	2.0	8.0	1,090	--
580	8	5.6	662	543	1,600	13	.2	14	2,800	--
560	10	8.0	876	718	1,000	11	.1	11	2,260	No log available; water may be a mixture from sandstone and coal beds.
580	40	3.9	1,460	1,320	11	15	1.4	7.7	2,130	No log available; water may be a mixture from sandstone and coal beds.
670	7	8.9	676	554	2,600	9.6	.1	11	4,200	Mixture of water from alluvium and Dietz coal bed.
1,500	24	13	955	783	3,000	14	.1	8.0	5,270	May be mixture of water from alluvium and Canyon coal bed.
360	3	8.1	583	478	3,000	13	.2	16	4,560	Mixture of water from alluvium and Dietz coal bed.
470	4	9.4	947	777	2,600	26	.1	18	4,230	--
320	4	6.4	278	228	1,900	44	.1	16	2,850	--
510	42	3.8	1,360	1,110	2.9	15	2.2	--	1,900	--
510	45	3.2	1,380	1,130	<1	17	2.0	8.3	1,230	--

Table 5.--*Chemical quality of water from private wells, observation wells, springs, and streams in and near the upper Otter Creek area*--Continued

Well or site designation (pl.1)	Location	Aquifer or source	Date sample collected (month-day-year)	Onsite specific conductance (microsiemens)	On-site pH (units)	On-site temperature (°C)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)
P-21	SE¼NW¼SW¼NW¼ sec. 5, T. 9 S., R. 46 E.	Sandstone below Canyon coal bed.	06-28-84	2,060	8.0	12.0	25	5.1	2.9
P-25	NW¼SW¼SE¼NW¼ sec. 11, T. 9 S., R. 46 E.	Dietz coal bed	02-03-74	2,640	7.8	11.0	460	75	67
P-31	NE¼SW¼NE¼SW¼ sec. 11, T. 9 S., R. 46 E.	Sandstone and Dietz coal beds.	06-29-84	3,900	8.0	9.5	110	20	14
P-33	NE¼NW¼NE¼SE¼ sec. 12, T. 9 S., R. 46 E.	Alluvial sand and gravel.	06-30-84	5,100	7.3	7.0	3,100	420	490
P-34	SE¼SE¼NW¼SW¼ sec. 15, T. 9 S., R. 46 E.	Probably sandstone above Canyon coal bed.	06-27-84	3,800	7.3	9.5	400	70	56
P-37	SW¼SW¼NW¼NE¼ sec. 29, T. 9 S., R. 46 E.	Probably sandstone and Roland coal bed.	01-29-74	4,500	7.7	8.0	2,200	400	280
O-2	SE¼SW¼NE¼SE¼ sec. 25, T. 8 S., R. 45 E.	Local coal above Cook coal bed.	07-25-83	2,200	8.0	13.0	90	16	13
O-5	NE¼NW¼SE¼NE¼ sec. 36, T. 8 S., R. 45 E.	Alluvial sand and gravel.	06-26-84	2,350	7.4	8.0	1,100	200	160
O-6	SE¼SW¼NW¼SW¼ sec. 17, T. 8 S, R. 46 E.	Alluvial sand and gravel.	05-23-84	7,200	7.6	9.0	2,600	270	470
O-7	SE¼SW¼NW¼SW¼ sec. 17, T. 8 S., R. 46 E.	Alluvial sand and gravel.	05-19-84	7,200	7.4	8.5	2,700	280	490
O-8	SW¼NE¼SE¼SE¼ sec. 18, T. 8 S., R. 46 E.	Alluvial sand and gravel.	06-06-84	5,400	7.6	8.0	2,000	200	360
O-9	SW¼NE¼SE¼SE¼ sec. 18, T. 8 S., R. 46 E.	Alluvial sand and gravel.	05-21-84	5,200	7.7	9.0	2,000	210	350
O-10	SE¼NE¼SE¼SE¼ sec. 18, T. 8 S., R. 46 E.	Alluvial sand and gravel and local coal bed.	06-08-84	5,800	7.2	10.0	2,100	210	390
O-11	SW¼NW¼SW¼SE¼ sec. 19, T. 8 S., R. 46 E.	Alluvial sand and gravel.	06-08-84	2,950	7.6	9.0	1,300	200	210
O-12	NE¼SW¼SW¼SE¼ sec. 19, T. 8 S., R. 46 E.	Alluvial sand and gravel.	05-18-84	2,800	7.7	10.0	1,300	170	210
O-13	NW¼NE¼SE¼SW¼ sec. 27, T. 8 S., R. 46 E.	Sandstone below Canyon coal bed.	07-24-83	1,760	8.1	12.0	28	5.9	3.2

Sodium (Na)	Sodium adsorption ratio (SAR)	Potassium (K)	Bicarbonate (HCO_3)	Alkalinity (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids, sum of constituents	Remarks
520	45	3.2	1,380	1,130	<1	17	2.7	8.3	1,240	--
490	10	8.3	795	652	850	12	.4	9.4	2,310	--
910	38	5.3	1,470	1,200	830	4.5	.2	7.4	2,510	--
190	2	45	560	459	1,600	10	.8	14	2,570	--
780	17	7.3	1,490	1,220	860	12	.2	9.4	2,530	No log available; water may be a mixture from sandstone and coal beds.
310	3	14	473	388	2,300	7.7	.1	12	3,810	--
560	26	7.0	1,280	1,050	240	22	2.9	7.3	1,500	--
140	2	8.4	500	410	980	12	.2	16	1,770	--
990	8	21	697	572	4,000	32	1.0	15	6,100	--
960	8	24	706	579	4,100	33	.7	17	6,220	--
660	6	14	642	527	2,800	19	.1	16	4,360	--
660	6	15	678	556	2,700	17	.3	13	4,290	--
740	7	16	729	598	3,000	20	.1	16	4,800	Mixture of water from alluvium and coal aquifer.
230	3	10	569	467	1,300	8.3	1.6	24	2,280	--
220	3	8.9	534	438	1,200	10	1.0	23	2,160	--
510	42	3.3	1,340	1,100	3.5	18	2.1	8.8	1,220	--

Table 5.--*Chemical quality of water from private wells, observation wells, springs, and streams in and near the upper Otter Creek area*--Continued

Well or site designation (pl.1)	Location	Aquifer or source	Date sample collected (month-day-year)	Onsite specific conductance (microsiemens)	On-site pH (units)	On-site temperature (°C)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)
0-14	NW¼NE¼SE¼SW¼ sec. 27, T. 8 S., R. 46 E.	Canyon coal bed	07-25-83	3,350	7.7	11.0	130	24	18
0-15	NW¼SW¼SE¼NE¼ sec. 28, T. 8 S., R. 46 E.	Alluvial sand and gravel.	05-17-84	5,000	7.6	9.0	1,700	200	300
0-16	NE¼NW¼SE¼NW¼ sec. 32, T. 8 S., R. 46 E.	Alluvial sand and gravel.	06-07-84	4,400	7.4	10.0	2,400	330	380
0-17	SW¼NE¼SE¼SE¼ sec. 32, T. 8 S., R. 46 E.	Alluvial sand and gravel.	05-20-84	14,000	7.4	9.0	5,000	470	920
0-18	SW¼NE¼SE¼SE¼ sec. 32, T. 8 S., R. 46 E.	Alluvial sand and gravel.	05-22-84	14,000	7.4	9.0	4,600	450	840
0-19	SE¼NE¼NW¼SW¼ sec. 2, T. 9 S., R. 45 E.	Anderson and Dietz coal beds.	05-19-84	4,280	7.8	13.0	150	30	18
0-20	NW¼SE¼SE¼NE¼ sec. 11, T. 9 S., R. 45 E.	Dietz coal bed	05-21-84	3,900	7.7	13.0	170	35	21
0-22	NW¼NE¼NW¼NE¼ sec. 5, T. 9 S., R. 46 E.	Canyon coal bed	06-18-75	3,180	7.7	11.0	230	57	22
0-23	NW¼NW¼SW¼SE¼ sec. 7, T. 9 S., R. 46 E.	Canyon coal bed	08-06-83	2,860	8.1	13.0	54	10	6.8
0-24	NE¼SE¼NE¼NE¼ sec. 7, T. 9 S., R. 46 E.	Alluvial sand and gravel.	06-27-84	3,400	7.6	9.0	1,000	120	180
0-25	SW¼SW¼NE¼NW¼ sec. 8, T. 9 S., R. 46 E.	Dietz coal bed	07-22-83	3,700	7.5	13.0	130	27	16
0-26	SW¼NW¼NW¼NE¼ sec. 9, T. 9 S., R. 46 E.	Dietz coal bed	05-15-84	2,380	7.8	12.0	55	11	6.6
0-27	NE¼NW¼NE¼SE¼ sec. 9, T. 9 S., R. 46 E.	Canyon coal bed	08-05-83	1,980	7.9	13.0	35	6.9	4.2
0-28	SE¼SW¼SE¼NE¼ sec. 9, T. 9 S., R. 46 E.	Sandstone above Canyon coal bed.	06-05-84	2,080	8.1	12.0	41	8.0	5.1
0-29	NE¼NW¼NE¼SE¼ sec. 9, T. 9 S., R. 46 E.	Dietz coal bed	08-05-83	2,500	7.7	12.0	62	12	7.5

Sodium (Na)	Sodium adsorption ratio (SAR)	Potassium (K)	Bicarbonate (HCO_3)	Alkalinity (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids, sum of constituents	Remarks
840	32	5.8	1,960	1,610	320	12	1.2	9.2	2,200	--
700	7	9.0	680	558	2,600	18	.2	18	4,140	--
280	3	10	732	600	2,300	14	.1	19	3,740	--
2,100	13	17	690	566	8,700	32	.7	16	12,600	Mixture of water from alluvium and nearby weathered Dietz coal bed.
2,100	14	17	726	595	8,200	29	.8	16	12,000	Mixture of water from alluvium and nearby weathered Dietz coal bed.
990	35	6.6	1,460	1,200	1,100	13	<.1	7.8	2,840	Mixture of water from Anderson and Dietz coal beds.
950	31	7.1	1,720	1,410	770	6.6	<.1	8.9	2,650	--
720	21	7.2	1,640	1,350	280	16	1.3	8.1	1,920	Analysis by U.S. Geological Survey laboratory, Salt Lake City, Utah.
660	39	6.8	678	556	870	18	3.1	31	1,940	--
430	6	8.9	730	599	1,300	7.2	.2	16	2,460	--
850	32	6.3	1,170	960	940	14	1.2	7.6	2,440	--
610	35	4.5	1,650	1,350	.6	10	2.0	7.6	1,460	--
530	39	3.6	1,410	1,160	1.1	14	1.9	8.1	1,270	--
520	35	3.4	1,440	1,180	13	13	2.1	6.9	1,280	--
640	35	4.4	1,580	1,300	140	10	2.7	7.5	1,600	--

Table 5.--*Chemical quality of water from private wells, observation wells, springs, and streams in and near the upper Otter Creek area*--Continued

Well or site designation (pl. 1)	Location	Aquifer or source	Date sample collected (month-day-year)	Onsite specific conductance (microsiemens)	On-site pH (units)	On-site temperature (°C)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)
O-30	NE¼NW¼NW¼SE¼ sec. 9, T. 9 S., R. 46 E.	Alluvial sand and gravel.	06-06-84	4,800	7.2	10.0	1,900	440	190
O-31	NW¼NE¼NW¼SE¼ sec. 9, T. 9 S., R. 46 E.	Alluvial sand and gravel.	05-22-84	5,100	7.2	10.0	2,000	470	210
O-32	NW¼NE¼NW¼SE¼ sec. 9, T. 9 S., R. 46 E.	Alluvial sand and gravel.	05-16-84	4,380	6.5	10.0	1,400	340	140
O-33	SW¼SW¼NE¼NW¼ sec. 11, T. 9 S., R. 46 E.	Alluvial sand and gravel.	05-20-84	2,840	7.6	9.0	1,200	160	190
O-34	SW¼SW¼NE¼NW¼ sec. 11, T. 9 S., R. 46 E.	Alluvial sand and gravel.	05-17-84	4,550	7.5	7.5	990	170	140
O-35	NW¼NE¼NW¼NW¼ sec. 11, T. 9 S., R. 46 E.	Canyon coal bed	07-23-83	1,820	7.8	14.0	42	8.9	4.8
O-36	NW¼NE¼NW¼NW¼ sec. 11, T. 9 S., R. 46 E.	Sandstone above Canyon coal bed.	07-23-83	1,940	8.0	12.0	37	7.2	4.7
O-37	SW¼NW¼NW¼NW¼ sec. 16, T. 9 S., R. 46 E.	Alluvial sand and gravel.	05-16-84	3,080	7.5	7.5	1,700	290	230
O-39	NE¼NE¼SW¼NW¼ sec. 20, T. 9 S., R. 46 E.	Dietz coal bed	08-06-83	1,800	7.6	14.0	65	14	7.4
S-1	NE¼SW¼ sec. 24, T. 8 S., R. 45 E.	Spring discharge	06-28-84	5,900	6.9	10±	1,200	250	140
S-2	NW¼SW¼ sec. 21, T. 8 S., R. 46 E.	Spring discharge	02-04-74	4,700	7.7	10±	1,700	300	230
S-3	SE¼SE¼ sec. 25, T. 8 S., R. 45 E.	Spring discharge	08-02-84	3,220	7.6	9.0	1,900	280	280
S-4	NE¼SW¼ sec. 34, T. 8 S., R. 46 E.	Spring discharge	06-29-84	6,700	6.9	8.5	2,900	420	440
S-5	NW¼NW¼ sec. 23, T. 9 S., R. 46 E.	Spring discharge	06-30-84	5,300	7.3	10.0	1,300	200	190
S-6	SW¼NW¼ sec. 26, T. 9 S., R. 46 E.	Spring discharge	06-27-84	4,250	7.1	10±	2,700	440	390
SW-1	Pasture Creek at mouth	Pasture Creek streamflow.	05-19-84	7,200	7.8	16.0	2,600	260	480
SW-2	Otter Creek above Pasture Creek	Otter Creek streamflow.	10-21-83	4,280	8.1	4.0	1,700	180	300
			05-21-84	4,950	8.2	18.0	1,800	190	330

Sodium (Na)	Sodium adsorption ratio (SAR)	Potassium (K)	Bicarbonate (HCO_3)	Alkalinity (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids, sum of constituents	Remarks
580	6	8.6	727	596	2,400	12	.1	20	4,060	--
720	7	9.9	725	595	2,800	11	.3	18	4,650	--
570	7	11	458	376	2,200	8.9	<.1	6.3	3,500	--
300	4	3.5	530	435	1,300	12	1.0	14	2,280	--
770	11	6.5	716	587	2,000	14	.1	12	3,430	--
550	37	3.8	1,500	1,230	1.4	14	1.4	8.0	1,330	--
500	36	3.4	1,350	1,110	11	13	1.3	8.8	1,210	--
190	2	4.9	560	459	1,600	10	.8	14	2,570	--
470	25	5.2	1,270	1,040	11	15	1.6	7.4	1,160	--
990	12	14	837	686	2,600	12	.2	12	4,390	Spring discharge; mixture of water from sandstone and talus.
630	7	9.0	550	451	2,500	14	.7	18	4,000	Spring discharge; mixture of water from coal and alluvium.
240	2	7.3	566	464	1,800	14	.2	16	2,940	Spring discharge; mixture of water from sandstone and alluvium.
1,000	8	10	669	549	4,300	33	.1	14	6,540	Spring discharge; mixture of water from coal and alluvium.
870	11	9.9	767	629	2,400	12	.2	9.4	4,120	Spring discharge; mixture of water from sandstone and alluvium.
120	1	8.9	711	583	2,300	49	.1	17	3,640	Spring discharge; mixture of water from sandstone and alluvium.
990	8	26	709	582	4,100	31	.8	4.3	6,220	Flow about 0.02 cubic foot per second.
530	6	14	569	467	2,300	22	1.2	11	3,600	Flow about 0.03 cubic foot per second.
640	7	15	690	566	2,600	16	.2	5.5	4,080	Flow about 0.04 cubic foot per second.

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