POTENTIAL EFFECTS OF SURFACE COAL MINING ON THE HYDROLOGY OF THE WEST OTTER AREA, ASHLAND AND BIRNEY-BROADUS COAL FIELDS, SOUTHEASTERN MONTANA

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CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	2
Location and description of the area	3
Previous investigations	5
Water use and supply	5
Potential effects of mining on area hydrology	8
Assumptions	8
Effects during mining	8
Potential north mine pit	8
Potential south mine pit	12
Long-term effects	13
Potential for reclamation of hydrologic systems	13
Potential north mine pit	13
Potential south mine pit	16
Supporting technical discussion	16
Geology	16
Stratigraphy	16
Structure	18
Ground-water resources	18
Tullock Member of Fort Union Formation	20
Wells and yields	20
Quality of water	20
Lebo Shale Member of Fort Union Formation	20
Wells and yields	20
Quality of water	20
Tongue River Member of Fort Union Formation	21
Wells and yields	21
Aquifer characteristics	21
Middle sandstones	21
Knobloch coal bed	23
Water-level fluctuations	24
Middle sandstones	24
Knobloch coal bed	24
Ground-water movement	27
Quality of water	27
Lower sandstones	27
Middle sandstones	27
Knobloch coal bed	30
Alluvium	30
Wells and yields	30
Aquifer characteristics	32
Water-level fluctuations	32
Ground-water movement	34
Quality of water	34
Clinker	35
Surface-water resources	35
West-side drainages	35
Brian Creek	35

CONTENTS--Continued

Page

Supporting technical discussion--continued
Surface-water resources--continued
West-side drainages--continued
Chromo Creek 36
Gene Creek 37
Newell Creek 37
"Badgett" creek. 38
"South Shy" creek. 38
"North Shy" creek. 38
"Trusler" creek. 39
Between-creek drainages. 39
Otter Creek. 39
Quality of surface water 41
Springs. 41
Otter Creek. 41
Conclusions. 44
Selected references 45

PLATE

Plate 1. Geologic map showing potential north and south mine-pit boundaries in the West Otter area, southeastern Montana . . . . . in pocket

ILLUSTRATIONS

Figure 1. Map showing location of West Otter area 4
2. Map showing drainage basins and location of wells, test holes, springs, and streamflow-gaging stations 6
3. Idealized stratigraphic sections A-A' and B-B' across the potential north mine pit. 10
4. Idealized stratigraphic sections C-C', D-D', and E-E' across the potential south mine pit. 14
5. Idealized section from King Mountain eastward to Otter Creek showing coal intervals and relative thicknesses of members of the Fort Union Formation. 17
6. Idealized sketch showing lithology and relative thicknesses of members of the Fort Union Formation 19
7. Generalized section showing stratigraphic relationship between alluvium and the Tongue River Member of the Fort Union Formation at the south end of the West Otter area 22
8. Graphs showing water-level fluctuations from October 1979 through March 1981 in observation wells completed in the middle sandstone aquifers 25
9. Graphs showing water-level fluctuations from October 1979 through March 1981 in observation wells completed in the Knobloch coal bed aquifer 26

Page

Figure 10. Map showing general direction of water flow and approximate altitude of water level in the alluvium of Otter Creek valley and in the middle sandstones and Knobloch coal of the Tongue River Member of the Fort Union Formation 28
11. Generalized section showing stratigraphic relationship between alluvium and the Tongue River Member of the Fort Union Formation in the north-central part of West Otter area. 31
12-15. Graphs showing:
12. Water-level fluctuations from November 1979 through August 1981 in observation wells completed in the alluvial aquifer. 33
13. Monthly discharge of Otter Creek at the downstream station . . 42
14. Monthly precipitation at the U.S. Forest Service ranger station at Ashland, 3 miles northwest of the West Otter area. . 43
15. Measured instantaneous discharge in Otter Creek at the upstream and downstream stations 43

TABLES

Table 1. Construction and hydrologic data from private and public wells. . . 48
2. Construction and lithologic data from test holes. 52
3. Construction and hydrologic data from observation wells completed in the Tongue River Member of the Fort Union Formation. 54
4. Construction and hydrologic data from observation wells completed in alluvium 58
5. Aquifer characteristics of the coal and sandstone aquifers of the Tongue River Member of the Fort Union Formation 60
6. Aquifer characteristics of the Otter Creek valley alluvium. 62
7. Chemical quality of water from private, public, and observation wells 64
8. Calculated drainage-basin characteristics and stream discharges . . 36
9. Physical and flow characteristics of the between-creek drainages. . 40
10. Chemical quality of water from springs and Otter Creek. 68

CONVERSION FACTORS

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

Multiply inch-pound unit	By	To obtain SI unit
	Length	
foot	0.3048	meter
inch	25.40	millimeter
mile	1.609	kilometer

Area		
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
Volume		
acre-foot	1,233	cubic meter
Weight		
ton (short)	0.9072	megagram
Flow		
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
Gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer
Transmissivity		
foot squared per day (ft^2/d)	0.09290	meter squared per day
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day
Specific conductance		
micromho per centimeter at 25° Celsius (micromho)	100	microsiemens per meter at 25° Celsius

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. NGVD of 1929 is referred to as sea level in this report.

POTENTIAL EFFECTS OF SURFACE COAL MINING ON THE HYDROLOGY OF THE WEST OTTER AREA, ASHLAND AND BIRNEY-BROADUS COAL FIELDS, SOUTHEASTERN MONTANA

By

Neal E. McClymonds

ABSTRACT

The West Otter study area of the Ashland and Birney-Broadus coal fields extends from 2.5 to 14 miles south-southeast of Ashland, Montana. The area 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 to assess potential effects of surface coal mining on local water resources.

Hydrologic data collected from private wells, observation wells, test holes, and springs indicate that shallow aquifers exist primarily within the Tongue River Member of the Fort Union Formation (Paleocene age) and within valley alluvium (Pleistocene and Holocene age). Sandstone beds are the principal aquifers that are used in the area, with the Knobloch coal bed in the Tongue River Member being a secondary source of supply. The primary use of ground water is for domestic supply and livestock watering.

Surface-water resources consist principally of perennial flow in Otter Creek and intermittent flow in eight small basins sloping from the Tongue River-Otter Creek divide eastward to the Otter Creek valley. The west-side streams generally are dry at their mouth, except after intense rainfall or rapid snowmelt. Otter Creek is used for livestock watering and, during spring floods, for irrigating alfalfa fields.

The water supplied by wells generally is a sodium bicarbonate type, although some ground water has a large sulfate content. Dissolved-solids concentrations of water samples ranged from 480 to 3,460 milligrams per liter in sandstone beds of the Tongue River Member and from 910 to 6,260 milligrams per liter in the Knobloch coal bed. Water in Otter Creek contains principally sodium, magnesium, and sulfate ions. The dissolved-solids concentration ranged from 2,050 to 2,950 milligrams per liter in samples collected from 1977-80.

Mining of the Knobloch coal bed would remove three existing private wells and lessen the yield of two other wells; all five wells are used for watering livestock. During mining, the potentiometric surface within the Knobloch coal aquifer and the overlying sandstone aquifers along the western face of the mined area would be lowered; water levels also would be lowered in the alluvium of Otter Creek valley. After mining, water in the alluvium of Otter Creek might show long-term degradation in water quality as a result of waters leaching the soluble salts from the spoils material used to backfill the mine pits. This degradation could be lessened by structuring the spoils to permit minimum water flow through the spoils

material. Although mining would alter the existing hydrologic systems and remove several shallow wells, alternative ground-water supplies are available from deeper aquifers that could be developed to replace those lost by mining.

INTRODUCTION

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

One of the primary considerations in the selection of tracts for lease is potential adverse effects to the water resources of the area during mining and reclamation operations and after abandonment. To determine potential effects and reclamation potential, the U.S. Geological Survey, in cooperation with the Bureau of Land Management, is conducting hydrologic studies on several potential coal-lease tracts in the Powder River structural basin of southeastern Montana. The West Otter area of the Ashland and Birney-Broadus coal fields is one of these tracts.

Purpose and scope

The purpose of the study in the West Otter area was to describe existing hydrologic systems, to obtain data on the water quality, and to assess potential effects of surface coal mining on the local water resources. The specific objectives of the study were to:

1. Identify ground-water resources;
2. identify surface-water resources and runoff characteristics;
3. determine chemical quality of the water resources;
4. determine probable effects on existing water resources from mining operations; 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 was begun in July 1979 and continued through 1981. Four observation wells already had been completed at three sites in the Knobloch coal bed and sandstone beds in the Tongue River Member of the Fort Union Formation. Five observation wells were drilled and completed during late 1979 in coal or sandstone aquifers. Eleven alluvial wells along two lines across the Otter Creek flood plain also were completed during late 1979. Existing wells were monitored if they were accessible for measurement. Lithologic data from 24 test holes were utilized to construct geologic sections. Springs were minimally monitored. Mean annual-runoff estimates were made by R. J. Omang and J. A. Hull. Otter Creek streamflow and chemical-quality data were obtained from Geological Survey files. The hydrologic characteristics of the aquifers were determined by pumping the wells; these tests were conducted by the author, M. R. Cannon, T. E. Reed, A. R. Skerda, and W. A. Wood.

In 1980, Consolidation Coal Company drilled 58 test holes in Newell, "Badgett," and "South Shy" creek drainages. Thirteen of these holes were cased for hydrologic observation; data from these observation wells are included in this report.

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

Location and description of the area

The area studied is on the west side of Otter Creek valley, from 2.5 to 14 miles south-southeast of Ashland, Montana, in Powder River and Rosebud Counties (fig. 1). Access is via the Otter Road, which starts north of the area at U.S. Highway 212 about 3.5 miles east of Ashland. The study area is composed of eight small drainages and the Otter Creek flood plain. Small draws between these drainages channel all surface-water discharge directly to the Otter Creek flood plain. The study area is 41.3 mi^2 in extent.

The eight drainages from south to north are: Brian Creek, Chromo Creek, Gene Creek, Newell Creek, and four small drainages that are unnamed on 7 1/2-minute topographic maps. For convenience in identifying the unnamed drainages in this report, names of owners of the land through which the creeks flow have been assigned and are shown in quotation marks. Thus, the four drainages from south to north are herein termed "Badgett" creek, "South Shy" creek, "North Shy" creek, and "Trusler" creek (fig. 2).

Along the western border of the West Otter study area is the divide between the Tongue River and Otter Creek basins. The divide ranges in altitude from about 3,720 feet above sea level at the south end of the study area to about 4,175 feet at an unnamed peak at the headwaters of Chromo Creek. King Mountain is a prominent peak in the headwaters of Newell Creek drainage. North of the "Badgett" creek headwaters, the Tongue River-Otter Creek divide becomes lower, to about 3,200 feet above sea level at the north end of the West Otter area in the upper part of "Trusler" creek drainage.

All eight drainages flow eastward or northeastward to Otter Creek. At the south (upstream) end of the study area, Otter Creek is at an altitude of about 3,135 feet; at the north end, it is about 2,955 feet--a decrease of 180 feet in 12.6 miles of valley, or a slope of about 14 ft/mi. From the mouth of "Trusler" creek, Otter Creek flows about 4 miles northwestward to the Tongue River; the mouth of Otter Creek is at an altitude of about 2,900 feet.

The average annual precipitation at Ashland is about 13 inches, based on 29 years of record (1951-79). Precipitation increases with altitude. At the 4,000-foot level of the high hills along the western boundary of the West Otter area, the annual precipitation is as much as 17 inches. Most monthly precipitation generally occurs during April, May, and June; precipitation during these months is usually about 40 percent of the annual total. The annual potential evaporation, estimated to be about 36 inches, is greater than the annual precipitation.

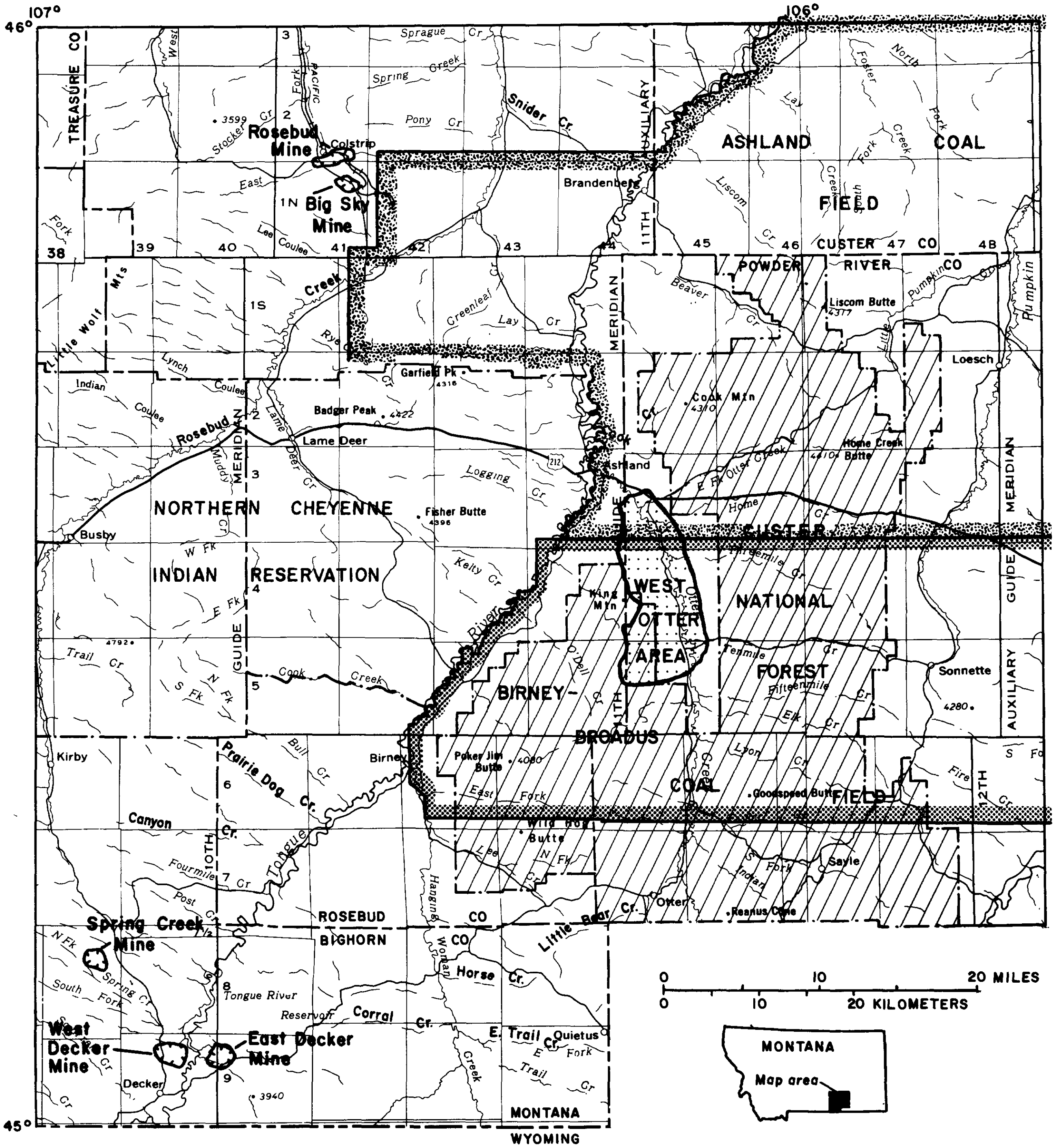


Figure 1.--Location of West Otter area.

Air temperatures in the West Otter area have an annual range from about -35° to +100°F. The average January temperature is about 18°F and the average July temperature is about 70°F.

Previous investigations

The geology and coal deposits of the Tongue River basin have attracted several investigators since near the turn of the century. Wegemann (1910) made a reconnaissance of part of the area and described the coal beds of the Custer National Forest. The coal deposits of the Ashland coal field were studied in more detail by the U.S. Geological Survey (Bass, 1932, and Warren, 1959) as part of a systematic investigation and classification of western coal lands. Brown and others (1954) and Matson and Blumer (1973) mapped the reserves of strippable coal in the West Otter and surrounding areas. The geology of the Willow Crossing and King Mountain quadrangles, which include the West Otter area, was mapped in detail by McKay (1976a, 1976b).

Hopkins (1973) and Stoner and Lewis (1980) investigated the ground-water resources and hydrologic characteristics of the Fort Union coal region. Slagle and Stimson (1979) compiled ground-water data from 1,924 wells in southeastern Montana. The U.S. Department of the Interior (1975) investigated the area east of Otter Creek, adjacent to part of the West Otter area.

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

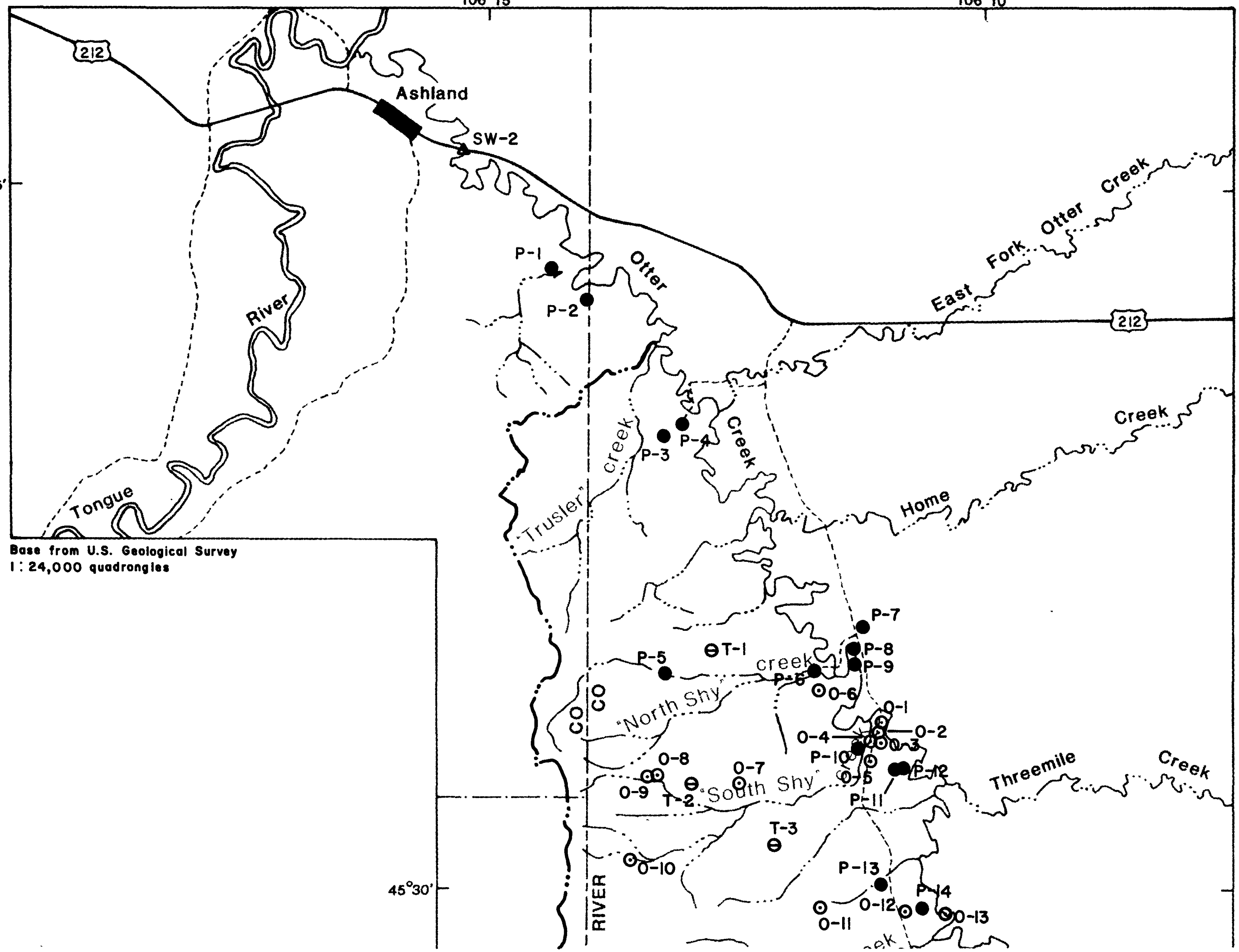
The potential effects of coal mining on water resources in the Tongue River drainage basin have been the focus of studies by Van Voast (1974) and Van Voast and Hedges (1975) in the West Decker Mine area (50 miles southwest of Ashland), and by Woessner and others (1979) on the Northern Cheyenne Indian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

WATER USE AND SUPPLY

The primary use of both ground water and surface water is for watering of livestock. Domestic water use is limited to nine ranch homes. Along the flood plain of Otter Creek valley, alfalfa crops are watered by subirrigation from alluvial ground water.

Wells are the most reliable source of water. Many wells, 34 of which were inventoried for this study, exist along the Otter Creek valley and in the hills to the west. Most wells are used for stock water; they are completed in sandstones of the Tullock, Lebo Shale, and Tongue River Members of the Fort Union Formation, and alluvial sands and gravels. Domestic water is obtained mostly from relatively shallow wells completed in sandstone aquifers of the Tongue River Member.

Springs occur mostly at altitudes above 3,300 feet on the hillsides and in valleys in the southwestern part of the area. Springs are used to maintain water in stock troughs and ponds.



106°15'
106°10'
45°35'
45°30'
212
212
Ashland
SW-2
Tongue
River
Otter
Creek
East Fork Otter Creek
Home Creek
Threemile Creek
"Trusler" creek
"North Shy" creek
"South Shy"
RIVER
CO
CO
P-1
P-2
P-3
P-4
P-5
P-6
P-7
P-8
P-9
P-10
P-11
P-12
P-13
P-14
O-1
O-2
O-3
O-4
O-5
O-6
O-7
O-8
O-9
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O-11
O-12
O-13
T-1
T-2
T-3
Base from U.S. Geological Survey
1:24,000 quadrangles

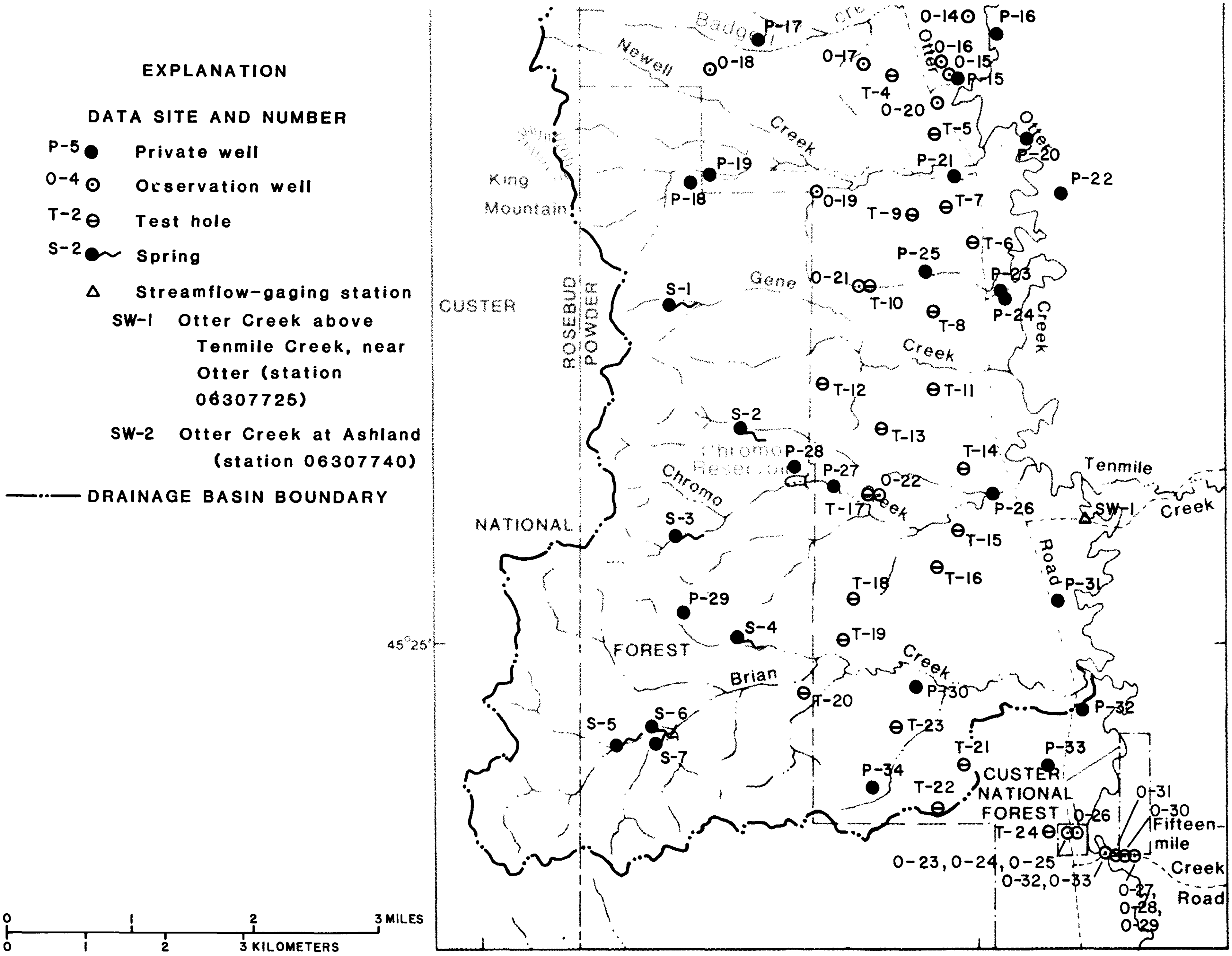


Figure 2.--Drainage basins and location of wells, test holes, springs, and streamflow-gaging stations.

The eight small streams draining most of the West Otter area have intermittent flow; during spring runoff they contribute water to small stock ponds, which are filled or partly filled.

Otter Creek is a perennial stream flowing along the length of the east side of West Otter area from south to north. The stream is a source for stock water and, during spring floods, for irrigating alfalfa fields on the Otter Creek flood plain.

POTENTIAL EFFECTS OF MINING ON AREA HYDROLOGY

Assumptions

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

A detailed mine plan is not available for the West Otter area. However, W. B. Hansen (Mining Engineer, U.S. Geological Survey, written commun., 1980) generally described the potential mining operation, the production rate, total coal that could be produced, and possible effects on the local economy for two mines--one 2.5 to 7 miles south-southeast of Ashland, and the other 7 to 10.5 miles south-southeast of Ashland. The assumed outlines of these two mines are shown on plate 1. The north mine would have an area, when completed, of about 4.3 mi^2. Assuming an average thickness of 60 feet for the Knobloch coal bed, about 290 million tons of coal could be extracted from this mine. The south mine, as outlined, would have an area of 4.2 mi^2; assuming an average thickness of 55 feet for the Knobloch coal bed, about 260 million tons of coal could be mined.

The predicted effects of mining on the local hydrologic systems are based on the assumptions that: (1) Mining of the Knobloch coal bed would take place within the mine boundaries shown on plate 1; (2) mining would begin in the southeast corner of the north mine and proceed westward and northwestward, and in the northeast corner of the south mine and proceed westward and southward; (3) the entire Knobloch coal bed and, where economical, the thinner local Sawyer "1" and Sawyer "2" coal beds would be removed from the mine area; and (4) all mining regulations established by the U.S. Office of Surface Mining and the Montana Department of State Lands would be followed during mining and reclamation.

The Geological Survey also is currently (1984) studying the probable cumulative impacts of coal mining on the hydrology of Otter Creek valley. In that project, primary emphasis is on defining changes in the quality of water in the alluvium and Otter Creek downgradient from the area to be mined.

Effects during mining

Potential north mine pit

The configuration of the outlined north mine pit (pl. 1) is based on the presumed southwestern edge of the burned coal and on a 200-foot overburden limit; the configuration of the actual mine probably would be different. Two main aquifers transmit water through the potential mine area: the Knobloch coal bed, from 55 to 70 feet thick in this area, and the Tongue River sandstones. The alluvial sand and gravel beneath the small stream channels probably are unimportant as ground-water conduits, although they transmit some water from their upstream reaches to the alluvial aquifer of Otter Creek.

The flow from the fully saturated Knobloch coal bed would be about 14,000 ft^3/d along a 1,000-foot-wide mine face, as determined by calculations using the constant drawdown formula of Jacob and Lohman (1952). In solving the formula, the values used were: an average transmissivity of 60 ft^2/d, a time of 100 days, an area of 250,000 ft^2, an assumed coefficient of storage of 0.01, and a drawdown of 60 feet. In the area where mining begins, about two-thirds of the coal is saturated; therefore, at a presumed hydraulic conductivity of 2 ft/d, about 9,000 ft^3/d of water would discharge into the pit from the east and west walls. An unknown in this calculation is the hydraulic characteristics of the coal under the clinker and burned coal (fig. 3). The fire that burned the coal is assumed to have been extinguished by ground water near the potentiometric surface, but the heat from the burning could have altered the hydraulic characteristics of this coal aquifer. None of the observation wells were drilled in or close to this zone. The coal beneath the burned coal could have a hydraulic conductivity that is greater than the average 2 ft/d.

The sandstones above the Knobloch coal bed are known to contain water; some stock wells in the area obtain water from these units. The sandstones affected by the north mine pit probably have perched water tables and are mostly drained at their outcrops in the sharply incised valleys of the small drainages. Few data were collected about the aquifer characteristics of the sandstone near the north mine area. Based on information from nearby areas, the hydraulic conductivity of the sandstone aquifer in the potential north mine area may be about 10 ft/d. The flow of water from a 10-foot-thick saturated sandstone bed along a 1,000-foot-wide face would be about 15,000 ft^3/d, as determined from the constant drawdown formula of Jacob and Lohman (1952). The values used to solve the formula were: an average transmissivity of 100 ft^2/d, a time of 100 days, an area of 100,000 ft^2, an assumed storage coefficient of 0.01, and a drawdown of 40 feet. Discharge from the sandstone aquifers overlying the Knobloch coal bed would decrease with time, as the perched water zones were dewatered. This dewatering would cause lower water levels in wells from 1 to 3 miles outside the area of the mine pit, including wells on the west side of the Tongue River-Otter Creek divide.

Although the deeper wells of the area--those wells completed in the lower sandstones in the Tongue River Member and in the Tullock Member--will be unaffected by water-level declines in and near the mine pit, they may be physically disrupted by nearby blasting or the vibration of heavy equipment movement. Specifically, the casing of well P-13 could be weakened enough to destroy this well.

Another factor affecting flow of water to the mine pit from the east wall of the initial cut, and the wall farther to the northwest, is the alluvial sand and gravel of Otter Creek valley. At the present time (1982), the potentiometric surface slopes toward the valley at a gradient of about 0.004 (a decline of 1 foot in a distance of 250 feet). After the box cut is excavated and all the water is pumped from the mine, the gradient would reverse--from the Otter Creek valley toward the mine at a gradient of about 0.017 (a decline of 1 foot in a distance of 60 feet). This reversal in gradient could increase the flow from the east wall (even at the

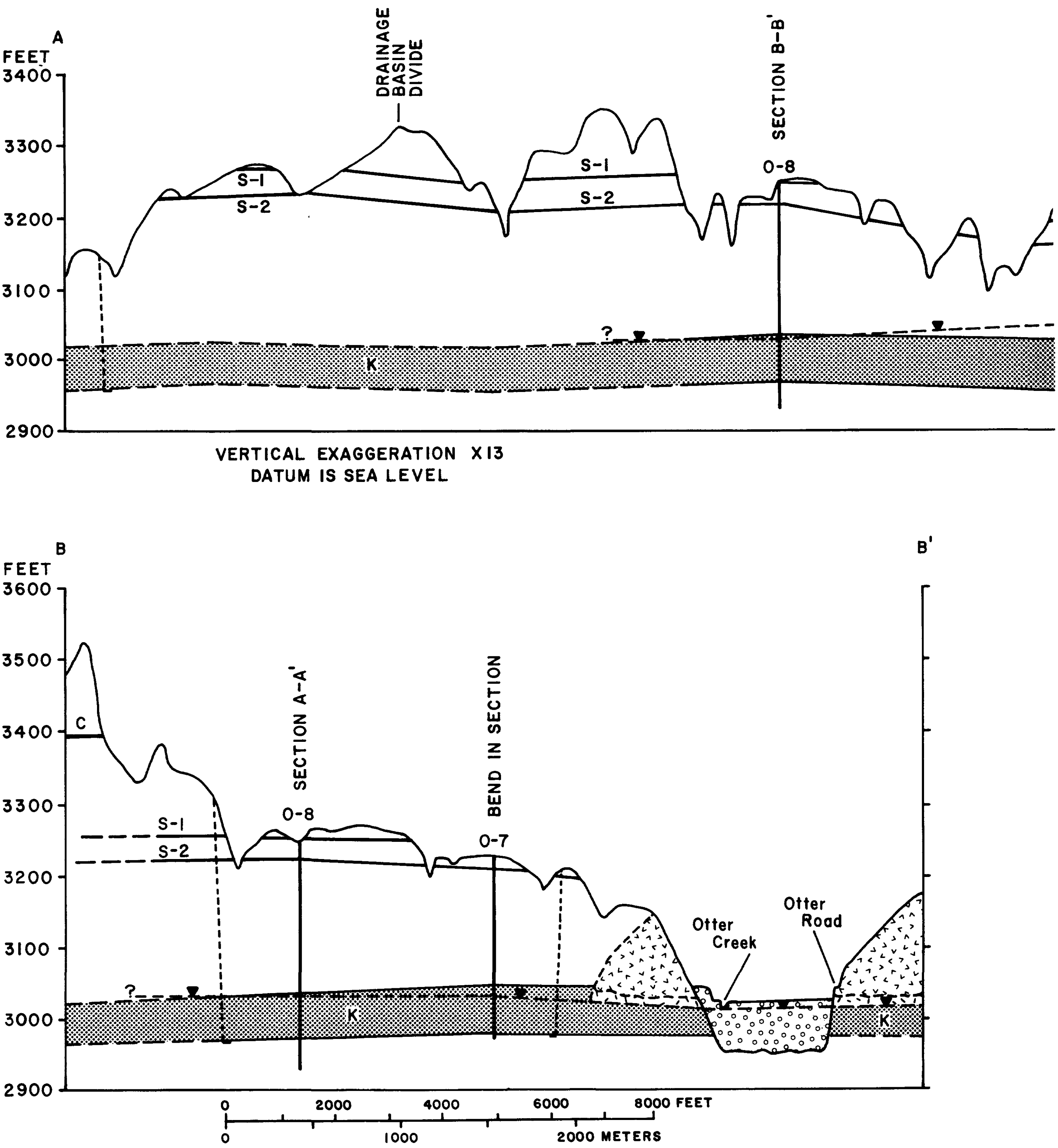
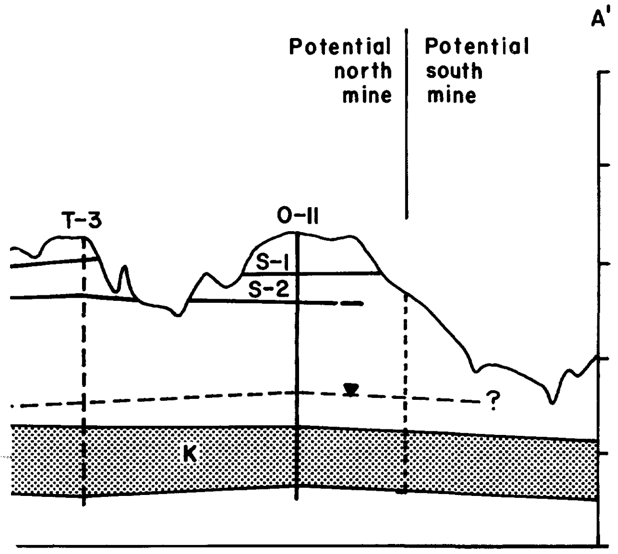


Figure 3.--Idealized stratigraphic sections A-A' and B-B' across the



EXPLANATION

ALLUVIAL SAND, GRAVEL, AND MUD (HOLOCENE AND PLEISTOCENE)

SHALE, SILTSTONE, AND SANDSTONE OF THE TONGUE RIVER MEMBER, FORT UNION FORMATION, UNDIFFERENTIATED (PALEOCENE)

CLINKER--Scorched overburden

CLINKER--Burned coal

CONTACT--Dashed where approximately located

COAL BED WITHIN TONGUE RIVER MEMBER AND LETTER--Dashed where approximately located

- C Cache coal bed
- S-1 Sawyer "1" coal bed
- S-2 Sawyer "2" coal bed
- K Knobloch coal bed

WATER-LEVEL SURFACE, 1980--Queried where uncertain

HIGHWALL OF POTENTIAL MINE

O-8 OBSERVATION WELL AND NUMBER ON TRACE OF SECTION

T-3 TEST HOLE AND NUMBER PROJECTED TO TRACE OF SECTION

potential north mine pit. Traces of the sections are shown on plate 1.

calculated average hydraulic conductivity of 2 ft/d) to about 35,000 ft^3/d. Inflow of 35,000 ft^3/d from the east wall would affect water levels in alluvium underlying the Otter Creek flood plain. The degree of decline would depend on several factors including the transmissivity of sand and gravel layers, rate of streamflow in Otter Creek, proximity of discharge of the removed inflow water, and geometry of the mine pit. Various engineering methods could be used to minimize the inflow and reduce water-level declines in the alluvium including selective replacement of mine spoils, emplacement of slurry cutoff walls, or installation of a hydraulic well barrier.

Potential south mine pit

The configuration of the south mine pit (pl. 1) is based on the presumed southern boundary of the north mine pit, and is restricted on the east by the Otter Creek alluvial valley, on the west by the Custer National Forest boundary, and on the south by the thinning and separating of the Knobloch coal bed. South of the south mine pit, the Knobloch is shallower than the 200-foot overburden limit, but is partly burned; with an irregular eastern border, the mine could be extended several miles farther south.

The same two main aquifers exist in the south mine as in the north mine: sandstone layers and lenses and the Knobloch coal bed of the Tongue River Member (fig. 4). Near the northern border of the potential south mine pit, the Knobloch includes shale partings and sandstone beds. Southward, the shale and sandstone interval increases in thickness and the total coal thickness decreases from about 70 feet near the northern border to about 40 feet at the southern border. The alluvial sand and gravel along the small stream channels become increasingly important as an aquifer southward, because the drainage areas are larger and the number of springs increase along the higher hills, contributing more recharge to the alluvial aquifer.

The hydraulic conductivity of the Knobloch coal in the potential south mine area, as calculated from three aquifer tests, is between 0.1 and 1.0 ft/d. Assuming an average transmissivity of about 30 ft^2/d, a time of 100 days, an area of 230,000 ft^2, an assumed storage coefficient of 0.01, and a drawdown of 55 feet, about 9,000 ft^3/d of water would be discharged from the Knobloch coal bed into the south mine pit along a 1,000-foot-wide mine face. More water probably would flow into the southern part of the mine pit than the northern part because the water-table gradient is steeper to the south. The quantity of water discharging through the coal near the Otter Creek valley would be about the same as in the north mine pit--about 14,000 ft^3/d along a 1,000-foot mine face. The base of the coal throughout the whole area of the south mine pit is below the level of Otter Creek valley, so water would flow continuously into the pit along the eastern mine wall. As in the north mine pit, engineering methods could be adapted to minimize the rate of inflow and decrease the degree of water-level decline in the alluvial material underlying the Otter Creek valley.

More saturated sandstone beds exist in the south mine pit area than in the north pit area. The contribution would be about the same as in the north mine pit, assuming that the hydraulic conductivity of the sandstone aquifer is about the same (10 ft/d) and the gradient is about 0.01. Thus, a saturated thickness of 10 feet of sandstone would yield about 15,000 ft^3/d from a mine face 1,000 feet long, using the same values as for the north mine pit in the constant drawdown formula.

The dewatering of the sandstone along the west wall of the mine would cause the water level in well P-19 to decline, and the partial dewatering of the Knobloch coal aquifer would cause the water level in P-18 to decline to a lesser extent. Wells P-18 and P-19 are on a south fork of Newell Creek about 1 mile west of the mine pit. Wells P-27 and P-28 are about 0.7 mile south of the mine pit. These wells probably would be affected only slightly by the mine, because of a small anticline between them and the south edge of the pit (section C-C; fig. 4), and because this would be the last part of the pit to be mined.

Long-term effects

In the area of the potential south mine pit, stock wells P-17, P-21, and P-25 would be destroyed by the excavation. In the area of the potential north mine pit, several observation wells would be destroyed, but these could be replaced as the mine progresses. The south mine pit would destroy observation wells O-17, O-19, and O-21; these wells could be replaced if necessary.

The possibility exists for a long-term change in the quality of water in the shallow aquifers of the mined area. After mining, ground-water flow systems would be re-established through the mined area. Water would enter the mine spoils from upgradient aquifers, seep through the mine spoils, and eventually discharge to downgradient aquifers. Additional flow from mine spoils would come from vertical recharge--rainfall and streamflow seeping into the top of the spoils and percolating downward. Water flowing through the spoils would acquire a chemical quality dependent on the mineralogy of the spoil materials.

POTENTIAL FOR RECLAMATION OF HYDROLOGIC SYSTEMS

Potential north mine pit

The removal of 55 to 70 feet of Knobloch coal would eliminate the shallow-aquifer system of the north mine area. If clayey spoils are packed tightly along the box cut and the remaining northeast margin of the mine pit, leakage of mineralized water from the spoils to the Otter Creek alluvium could be kept to a minimum. If the post-mining topography is graded so that there is little relief and grass is liberally seeded to withhold runoff water for evapotranspiration, then outflow of surface water could be decreased. If the new stream channels are restructured with a sand and gravel base to absorb runoff in the upstream ends and with a relatively impermeable clayey material under the gravels throughout the length, water in the alluvium would become less affected by mineralized water from the spoils material. Some water will infiltrate the spoils and leak downgradient to the Otter Creek valley alluvial aquifer. This water would be more mineralized than the water presently contributed, but if the volume could be kept small, the effects on the alluvial aquifer would be minimized.

Wells destroyed within the mine or nearby wells affected by the lowered water table could be replaced by wells drilled to deeper aquifers unaffected by the mining activity. Alternative water supplies are sandstone beds within the Tongue River and Tullock Members of the Fort Union Formation, the lower part of the Hell Creek Formation, and the Fox Hills Sandstone. There is no indication that any of these alternative ground-water sources would be detrimentally affected by mining.

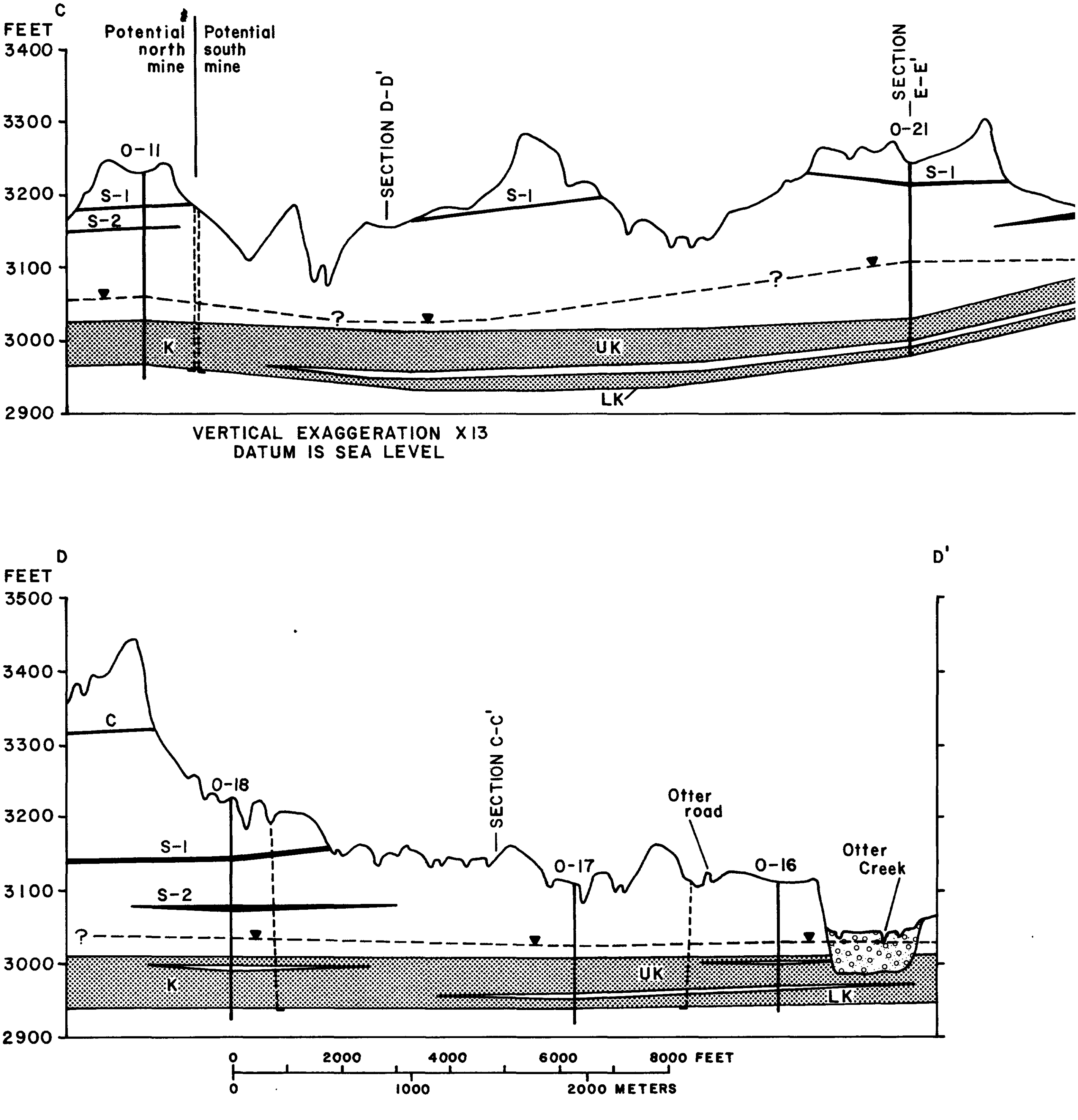
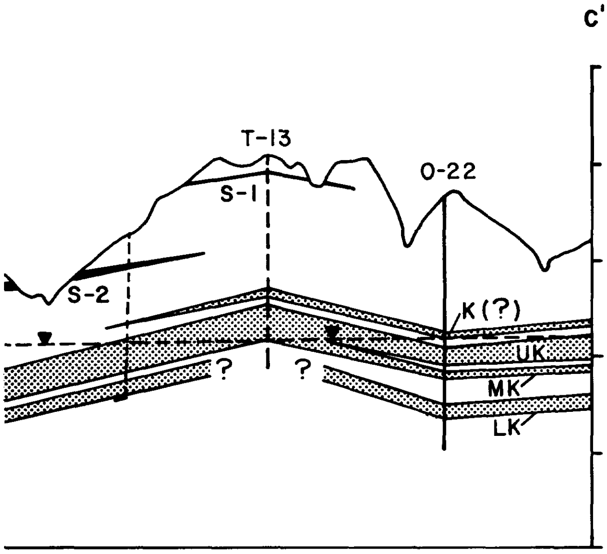


Figure 4.--Idealized stratigraphic sections C-C', D-D', and E-E' across the potential south mine pit. Traces of the sections are shown on plate 1.



EXPLANATION

ALLUVIAL SAND, GRAVEL, AND MUD (HOLOCENE AND PLEISTOCENE)

SHALE, SILTSTONE, AND SANDSTONE OF THE TONGUE RIVER MEMBER, FORT UNION FORMATION, UNDIFFERENTIATED (PALEOCENE)

CONTACT

COAL BED WITHIN TONGUE RIVER MEMBER AND LETTER--Dashed where approximately located:

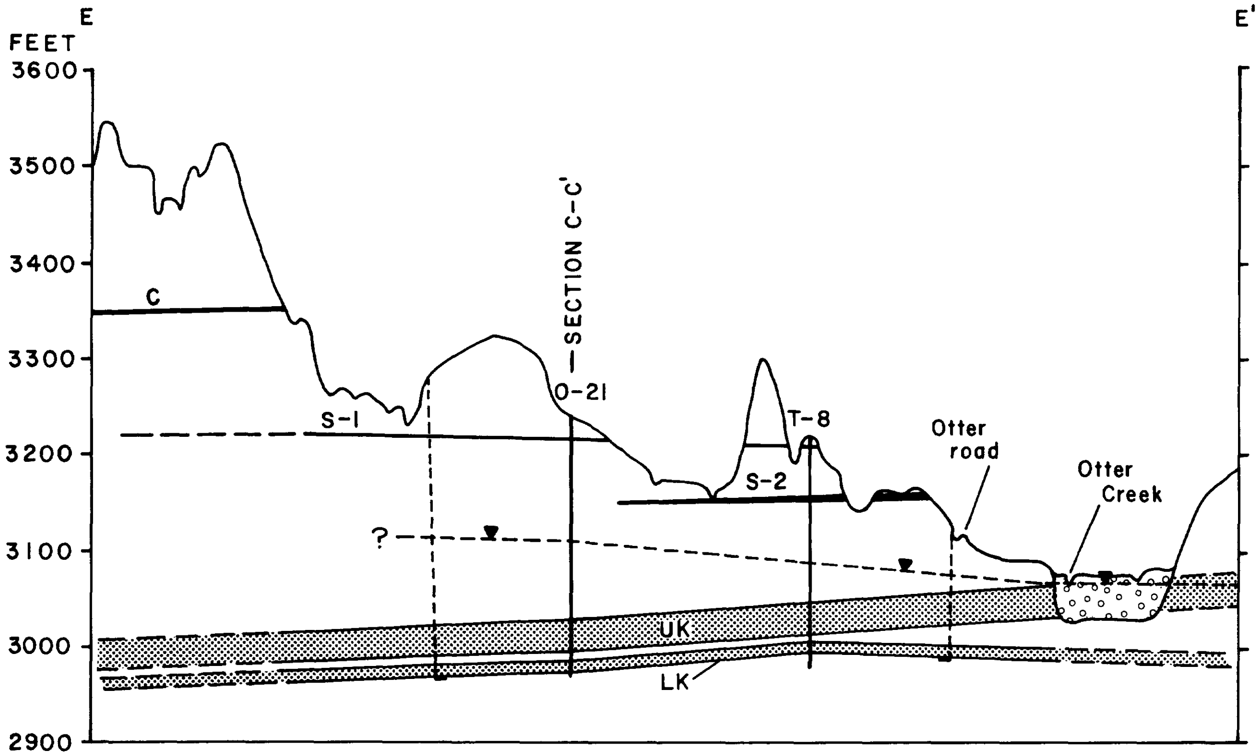
- C Cache coal bed
- S-1 Sawyer "1" coal bed
- S-2 Sawyer "2" coal bed
- K Knobloch coal bed
  - UK Upper Knobloch
  - MK Middle Knobloch
  - LK Lower Knobloch

WATER-LEVEL SURFACE, 1980--Queried where uncertain

HIGHWALL OF POTENTIAL MINE

0-21 OBSERVATION WELL OR TEST HOLE AND NUMBER ON TRACE OF SECTION

T-13 TEST HOLE AND NUMBER PROJECTED TO TRACE OF SECTION



Potential south mine pit

The methods of reclamation for the south mine pit would be about the same as for the north pit, except that greater care and planning would be needed to reconstruct the larger stream channels. The highwall would have to be removed in places to keep the stream gradients comparable to those existing today. The pit at the south border probably would need to be backfilled, eliminating the highwall, to stop or slow the leakage of water from the sandstone aquifers and to preserve the potentiometric surface under the areas farther southward.

SUPPORTING TECHNICAL DISCUSSION

Geology

Stratigraphy

More than 1,000 feet of stratigraphic section is present from the divide on the west side of the study area, including King Mountain, down to the Otter Creek flood plain. This rock interval includes almost all the upper and middle parts of the Tongue River Member of the Paleocene Fort Union Formation (fig. 5). A much thinned remnant of the Anderson coal bed, which is mined extensively in the West Decker, East Decker, and Spring Creek Mines (fig. 1), exists about 100 feet below the crest of the divide. The Dietz, Canyon, Wall, Pawnee, and Cache coal beds are all represented by about 2- to 9-foot-thick coal seams. The Cache coal bed crops out about the 3,330-foot contour; it is from 3 to 6 feet thick in the West Otter area.

The Sawyer "1" coal bed is 0 to 4 feet thick in the West Otter area. In the northern one-half of the area another coal bed, Sawyer "2," is located 20 to 40 feet beneath the Sawyer "1" bed; the Sawyer "2" coal bed is 0 to 3 feet thick. North of the West Otter area the two coal beds coalesce to form one Sawyer bed. All test holes and Tongue River Member observation wells were drilled through the Knobloch coal bed, which is 40 to 70 feet thick and the prime target for coal mining. The Knobloch is one massive coal layer in the northern part of the area, but southward and westward the layer is interbedded with increasingly thick shale and sandstone beds. At the south end of the West Otter area, the Knobloch consists of four distinct coal seams, each 10 to 20 feet thick.

In the West Otter area, the lower part of the Tongue River Member consists of sandstone, siltstone, shale, and coal beds. About 100 feet below the Knobloch coal bed is the Flowers-Goodale coal bed, which is 7 to 21 feet thick. A prominent sandstone bed, as much as 80 feet thick in some places, lies between the Flowers-Goodale bed and the next lower coal, which is 4 to 8 feet thick. This lower coal is about 120 feet below the Flowers-Goodale bed and probably correlates to the Terrett (or Rosebud) coal bed in the Brandenberg and Colstrip, Mont., areas to the north and northwest. The lowermost beds in the Tongue River Member, between the Terrett coal bed and the Lebo Shale Member of the Fort Union Formation, consist of about 110 feet of mostly sandstone, including a water-bearing basal sandstone as much as 60 feet thick.

The Lebo Shale Member, under the central part of the area, is nearly 300 feet thick and consists mostly of dark-gray shale interbedded with several sandstone lenses. Under the Lebo is the Tullock Member of the Fort Union Formation, which

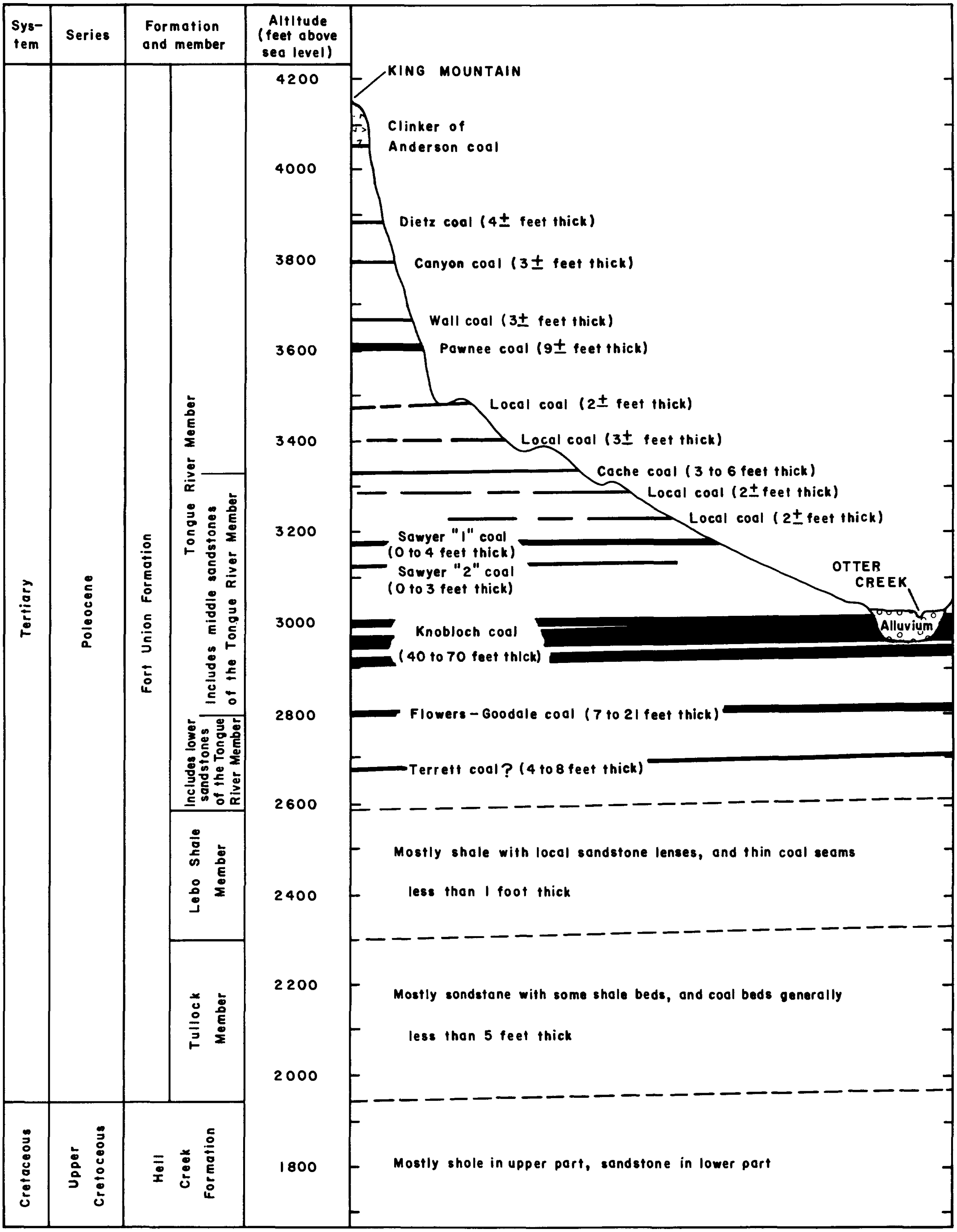


Figure 5.--Idealized section from King Mountain eastward to Otter Creek showing coal intervals and relative thicknesses of members of the Fort Union Formation.

has some 20- to 50-foot-thick sandstone beds alternating with thinner shale beds and a few coal beds generally less than 5 feet thick. An idealized sketch of the stratigraphic sequences that occur within the members of the Fort Union Formation along West Otter Creek is shown in figure 6.

Structure

The strata in the West Otter area generally are nearly flat-lying with a gentle, almost imperceptible dip to the northeast. A minor flexure exists near the south end of the area (fig. 6), which seems to be caused as much by thinning and thickening of the Tongue River Member as by earth movement. The result is a small anticline in sec. 33, T. 4 S., R. 45 E.

Ground-water resources

Ground water is present under the entire West Otter area. The presence of multiple springs originating from the higher coal and sandstone aquifers east of the Tongue River-Otter Creek divide, particularly in the southern one-half of the study area, indicates recharge to these aquifers on the divide and upper basin slopes. The coals and sandstones in the middle reaches of drainages also probably contain water; however, the water discharges through colluvial and alluvial deposits and does not reach the land surface. The sandstones above the Knobloch coal bed contain water, but are not everywhere completely saturated; they are drained partly by the incised valleys of each small drainage basin. The Knobloch coal bed is a major aquifer from "Badgett" creek southward, and northward where the coal is unburned. At the north end of the area and local places to the south, water exists only near the base of the clinker and is discharged readily to adjacent talus and alluvial materials, and finally to Otter Creek alluvium.

Below the Knobloch coal, almost any sandstone 20 or more feet thick will yield water to wells. Near the base of the Tongue River Member, a 60-foot-thick sandstone yields water to flowing artesian wells at the north end of the area. Below the Tongue River Member, the Lebo Shale Member in the central part of the area yields water to wells from a relatively clean sand lens, and the Tullock Member has sandstone beds that yield water to flowing artesian wells throughout the West Otter area.

Below the Fort Union Formation, other aquifers exist in formations of Mississippian through Cretaceous age, but they are too deep to be affected by surface coal mining. Therefore, they are not considered in this report.

In the following sections of the report, the ground-water resources are discussed by aquifer. If appropriate data are available, the discussion includes type of wells completed in the aquifer and well yields, aquifer characteristics, water-level fluctuations, and quality of the water. Corresponding tabular data are given at the end of the report. The data include construction and hydrologic data from private and public wells (table 1), test holes (table 2), observation wells completed in the Tongue River Member (table 3), and observation wells completed in alluvium (table 4). Aquifer-test data are given for the Tongue River Member (table 5) and the Otter Creek alluvium (table 6). Ground-water-quality data for wells are listed in table 7.

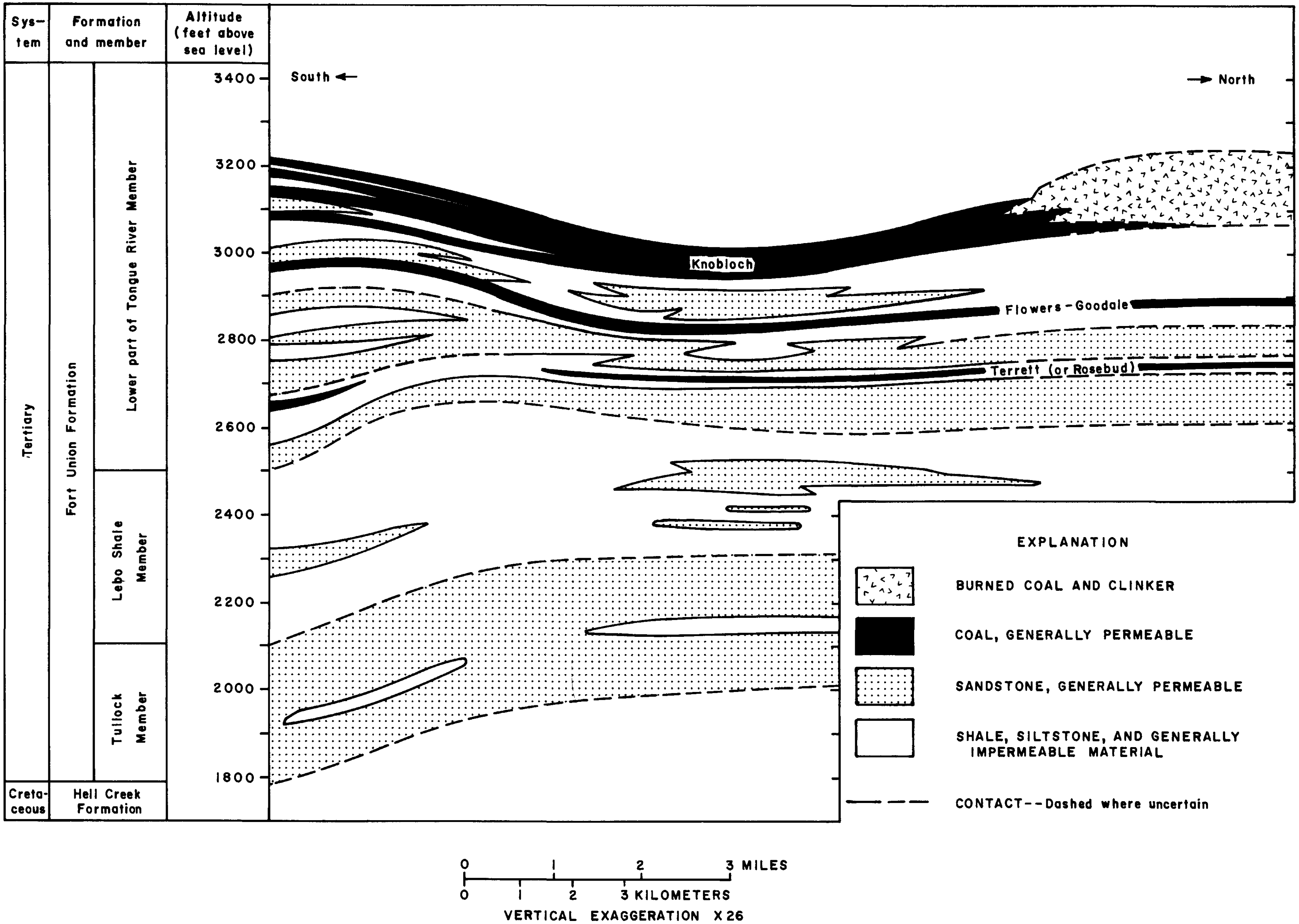


Figure 6.--Idealized sketch showing lithology and relative thicknesses of members of the Fort Union Formation. The sketch extends from near Fifteenmile Creek in the south part of the Otter Creek valley to near "Trusler" Creek in the north.

Tullock Member of Fort Union Formation

Wells and yields

Wells completed in the sandstones of the Tullock Member of the Fort Union Formation discharge 1.4 to 6 gal/min of water by artesian flow; the yield of these wells would be greater if pumps were installed. The wells were completed to depths of more than 1,000 feet at the south end of West Otter area and as little as 780 feet at the north end. The Tullock is too deep to be affected by surface coal mining and thus could be an alternative supply for any wells destroyed or drained by mining. Some of the wells completed in the Tullock are listed in table 1; location of the wells is shown in figure 2.

In the northern part of West Otter area from "Trusler" creek to Newell Creek drainage, all wells completed in the Tullock flow, where surface altitudes are less than about 3,060 feet. In the southern part of the area, wells completed in the Tullock are artesian, and the potentiometric surface is near but below land surface outside the Otter Creek flood plain, so the wells must be pumped. Almost all these wells have 2-inch casings; none were tested for aquifer characteristics. The artesian wells, many of which were drilled in the 1940's through the early 1960's, have had decreasing flow rates through 1981.

Quality of water

Water from sandstones of the Tullock Member contains principally sodium, bicarbonate, and chloride. The fluoride concentrations ranged from 4.5 to 7.0 mg/L (milligrams per liter), which is more than double the 2.2-mg/L standard established by the U.S. Environmental Protection Agency (1977) for drinking water. The average dissolved-solids concentration of Tullock water is about 1,600 mg/L (table 7).

Lebo Shale Member of Fort Union Formation

Wells and yields

The Lebo Shale Member of the Fort Union Formation normally is composed of shale and is a confining layer between the Tullock and Tongue River Members. In the West Otter area, the Lebo consists of shale beds, but in the central and southern parts it also contains thick lenses of permeable sandstone. Wells P-15, P-21, and P-26 apparently are completed in these sandstone lenses. The wells flowed between 1.3 and about 3 gal/min in 1973 (table 1). Well P-26 stopped flowing in 1979 and a pump was installed. The discharge of well P-21 decreased from 1.3 to 0.3 gal/min between 1973 and 1981.

Quality of water

One analysis is available for water from the Lebo. This water, from well P-15, is a sodium bicarbonate type, with a dissolved-solids concentration of 970 mg/L, and a fluoride concentration of 2.9 mg/L. An analysis of water from well P-26 is included with the Lebo in table 7, because the well originally was drilled and cased to the Lebo interval; however, the low water temperature and the large sulfate concentrations indicate that the water is contaminated with water from formations higher in the section, probably as a result of a broken casing.

Wells and yields

Most wells in the West Otter area are perforated opposite or open to sandstone beds of the Tongue River Member, and many of these are completed in the lower sandstones. The lower sandstones of the Tongue River Member are herein defined as those sandstones between the base of the Tongue River Member and the base of the Flowers-Goodale coal bed. Wells completed in the lower sandstones in the central and northern parts of the area flow 0.1 to 5 gal/min. One well, P-32, in the south part of the area can be pumped at about 20 gal/min. The existing wells have provided water for 20 years or longer, with slightly decreasing yields, so this aquifer is considered to be a reliable source of water. The potentiometric surface of wells completed in the lower sandstones is above the level of the Otter Creek flood plain from the central part of the area northward, so many of these artesian wells flow. Available data on the existing wells are listed in table 1.

The middle sandstones of the Tongue River Member are herein defined as the sandstones between the top of the Flowers-Goodale coal bed and the base of the Cache coal bed. The middle sandstones yield water to several wells at higher altitudes on the west side of Otter Creek valley. The sandstones yield from about 3 to 20 gal/min, which is sufficient for stock watering.

None of the existing stock wells were drilled to purposely obtain water from the Knobloch or other coal beds in the West Otter area. In many parts of the study area, water from coal has a large sulfate concentration and it is not fit to drink, even by cattle.

Three observation wells with 4-inch-diameter casings existed in the West Otter area when the study began in 1979. A test hole had been drilled at each observation-well site and one (0-9) had been cased with 2-inch casing at the site of well 0-8. General lithologic data were obtained from 24 test holes (table 2). During the study, five observation wells were drilled, cased, and completed in Tongue River Member sandstones or the Knobloch coal bed. Consolidation Coal Company drilled 53 test holes through the Knobloch coal in the central part of the area. Eight of these were cased and used as observation wells during the study (table 3).

Aquifer characteristics

Middle sandstones

None of the private wells were tested for aquifer characteristics because of inaccessibility, but three observation wells completed in the middle sandstones and a fourth (well 0-21) completed in sandstone and the underlying Knobloch coal bed were tested. However, the observation wells are limited to only two general locations within the basin.

The hydraulic conductivity of sandstones above and below the Knobloch coal bed ranges from 0.2 to 50 ft/d; the average of the four wells tested is about 20 ft/d (table 5). The sandstones at wells 0-21 (which was completed in both sandstone and the underlying Knobloch coal bed), 0-23, 0-25, and 0-27 probably are not representative of the sandstone in other parts of the area. Based on information from nearby areas, a sandstone hydraulic conductivity of 20 ft/d is considered to be too large; a value of 10 ft/d was used to calculate inflow during mining. The sandstone having the smallest hydraulic conductivity (0.2 ft/d) is at well 0-23; the perforated thickness of the partly penetrated sandstone is 12 feet. Eastward across the Otter Creek flood plain, well 0-27 is completed in this same sandstone interval. There, the contributing sandstone thickness is about 16 feet (fig. 7), but the hydraulic conductivity is about 25 ft/d.

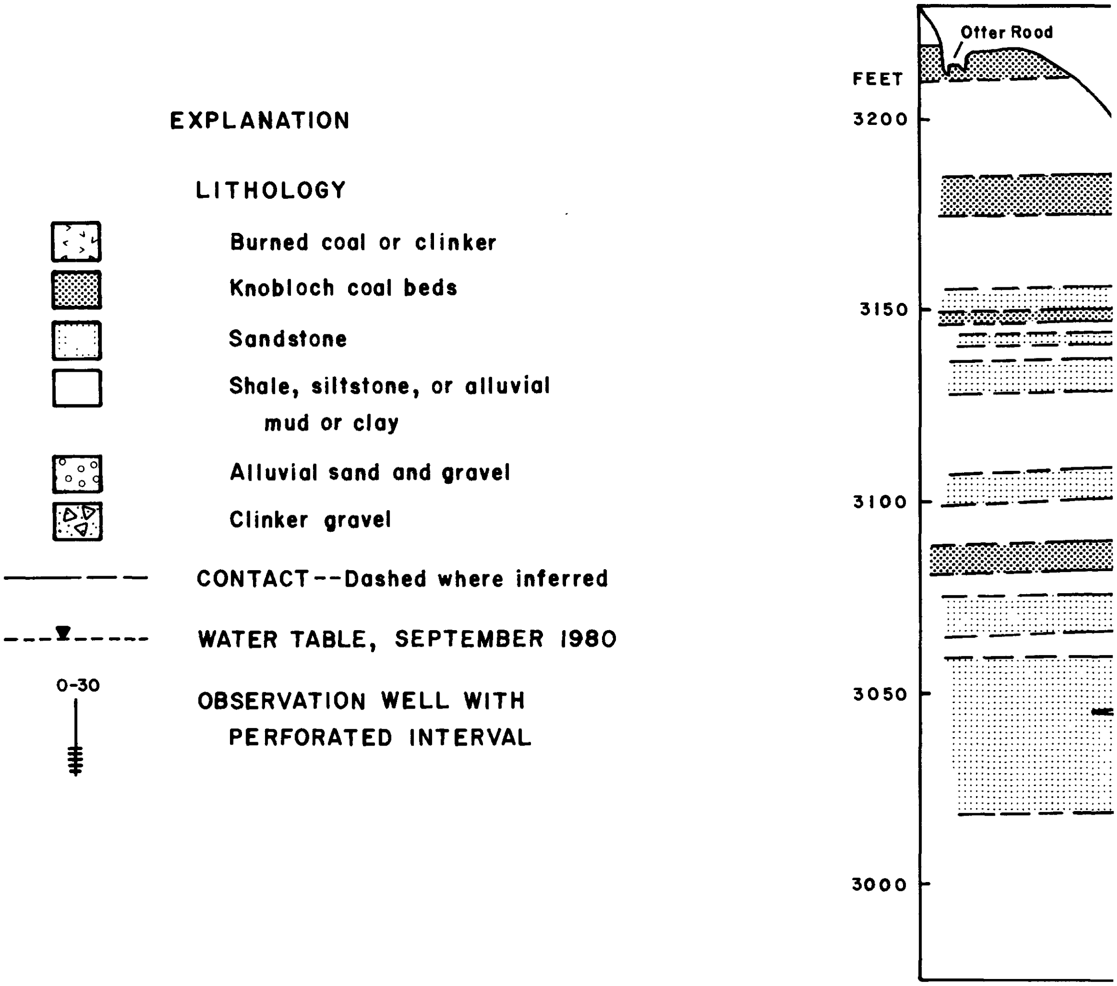
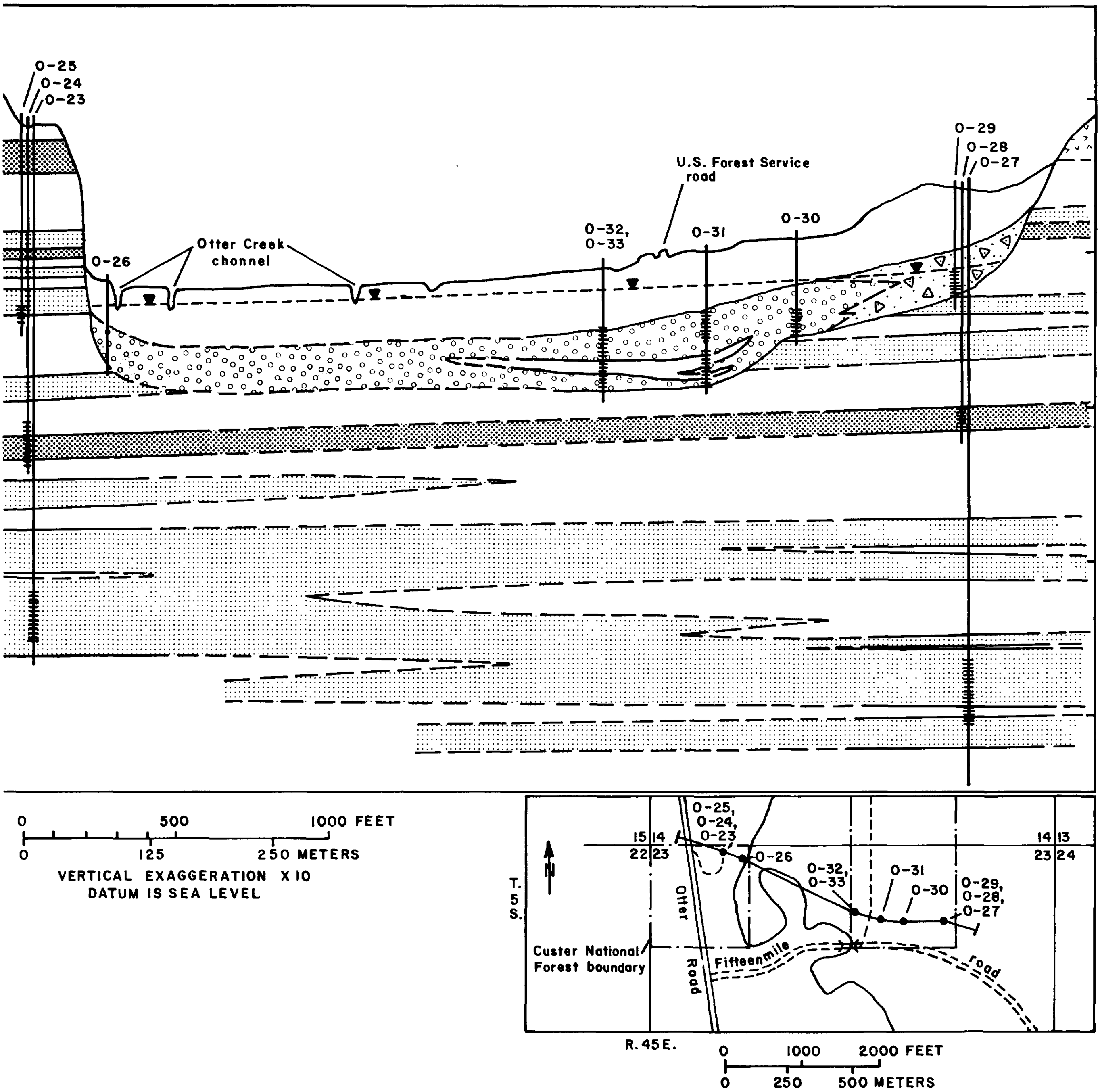


Figure 7.--Generalized section showing stratigraphic relationship between alluvium Otter area. Location of wells also is shown in figure 2.

Knobloch coal bed

Six wells completed solely in the Knobloch coal bed were tested by pumping for 2 to 3 hours (table 5). The wells tested (0-8, 0-10, 0-11, 0-22, 0-24, and 0-28) had hydraulic conductivities of 0.05 to 46 ft/d; excluding these two extremes, the other four wells have an average hydraulic conductivity of about 2 ft/d. The large



and the Tongue River Member of the Fort Union Formation at the south end of the West hydraulic conductivity at well 0-24 (46 ft/d), which is affected by leakage between well 0-24 and well 0-25, probably reflects the hydraulic conductivity of the sandstone of well 0-25, more than the less permeable Knobloch coal bed. The second largest hydraulic conductivity (6.5 ft/d) was at well 0-8. The wide range in hydraulic conductivities of the Knobloch coal is characteristic of coal aquifers throughout the Tongue River basin. The coal generally has the greatest transmissivities near outcrop areas. This condition is not particularly true in the West Otter area, where wells 0-8, 0-10, and 0-11 are all about equidistant to outcrop areas but have an extreme range in hydraulic conductivities. Well 0-8 seems to have penetrated wider fractures in the coal than did the other two wells; the well also is closer to altered shales and sandstones that have formed clinker above the burned Knobloch coal about 0.5 mile to the northeast.

Water-level fluctuations

Middle sandstones

Water-level records of observation wells completed in the middle sandstones of the Tongue River Member in the West Otter area are considered to be generally representative of water-level fluctuations in sandstone aquifers throughout the area. The general trend of water levels from October 1979 through March 1981 in four observation wells is shown in figure 8.

The water-level fluctuations in wells 0-21 and 0-27 are considered generally representative for the middle sandstone beds of the West Otter area. However, well 0-21 is perforated in both a sandstone aquifer and two beds of underlying Knobloch coal; therefore, the water levels in this well also reflect fluctuations in the coal beds. Generally, water levels in both wells rose from November 1979 to the spring and summer of 1980, then declined during the winter and early spring of 1981. In effect, the water level in these wells changed no more than about 0.5 foot from season to season. Well 0-23, which had a water-level recorder installed in April 1980, shows fluctuations of water level directly affected by barometric pressure; the water levels in other wells deeper than 100 feet would probably also reflect barometric changes in their water-level fluctuations. Also, in well 0-23, the water level dropped nearly 1 foot after the aquifer test was conducted in October 1980; this decline probably was caused by the pumping and cleaning of the slot perforations and the packer seal being more firmly set. Well 0-25, the shallowest well at the 0-23, 0-24, and 0-25 well complex, has water-level fluctuations similar to well 0-26, which is completed in the alluvial aquifer 250 feet to the east. This similarity indicates a direct hydraulic connection between the shallow sandstone aquifer and the alluvial aquifer in this vicinity.

Knobloch coal bed

Water levels were measured periodically in all observation wells completed in the Knobloch coal bed aquifer. Four observation wells (0-8, 0-22, 0-24, and 0-28) were selected to show the water-level fluctuations (table 3 and fig. 9). The water levels in well 0-8 changed very little (0.4 foot) from October 1979 through March 1981, with a general decline throughout this period, and a slight rise in mid-summer 1980. The overall gentle decline in water level in well 0-8 may indicate a decrease in recharge during the dry years of 1979 and 1980. Water levels in well 0-22 were beginning to show the same pattern, but after the aquifer test in October 1980,

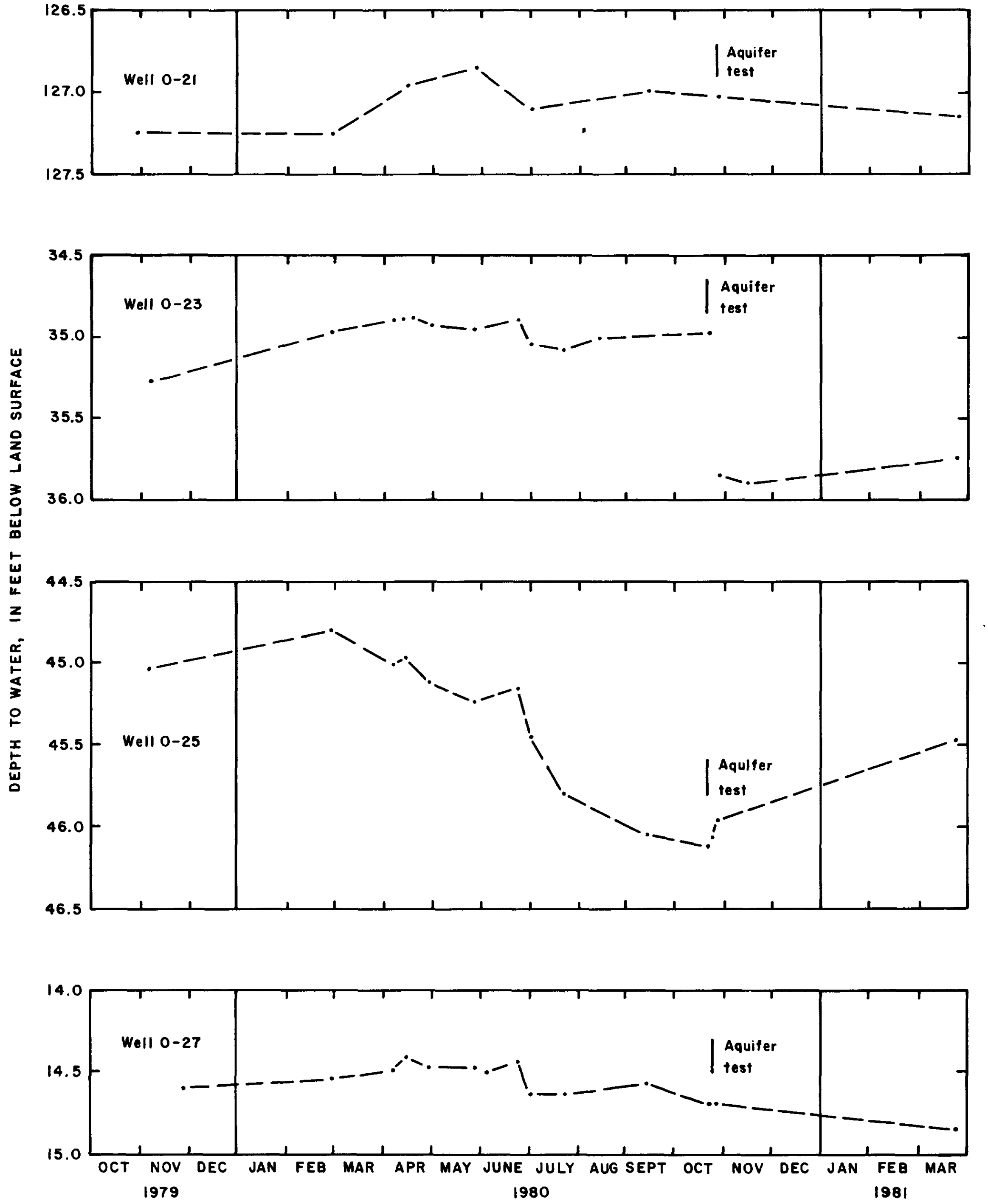


Figure 8.--Water-level fluctuations from October 1979 through March 1981 in observation wells completed in the middle sandstone aquifers.

the packer apparently sealed; the pre-test water levels of about 56 feet below land surface probably were a combination of Knobloch aquifer water levels and the water level of an overlying sandstone aquifer. The post-test level probably is more rep-

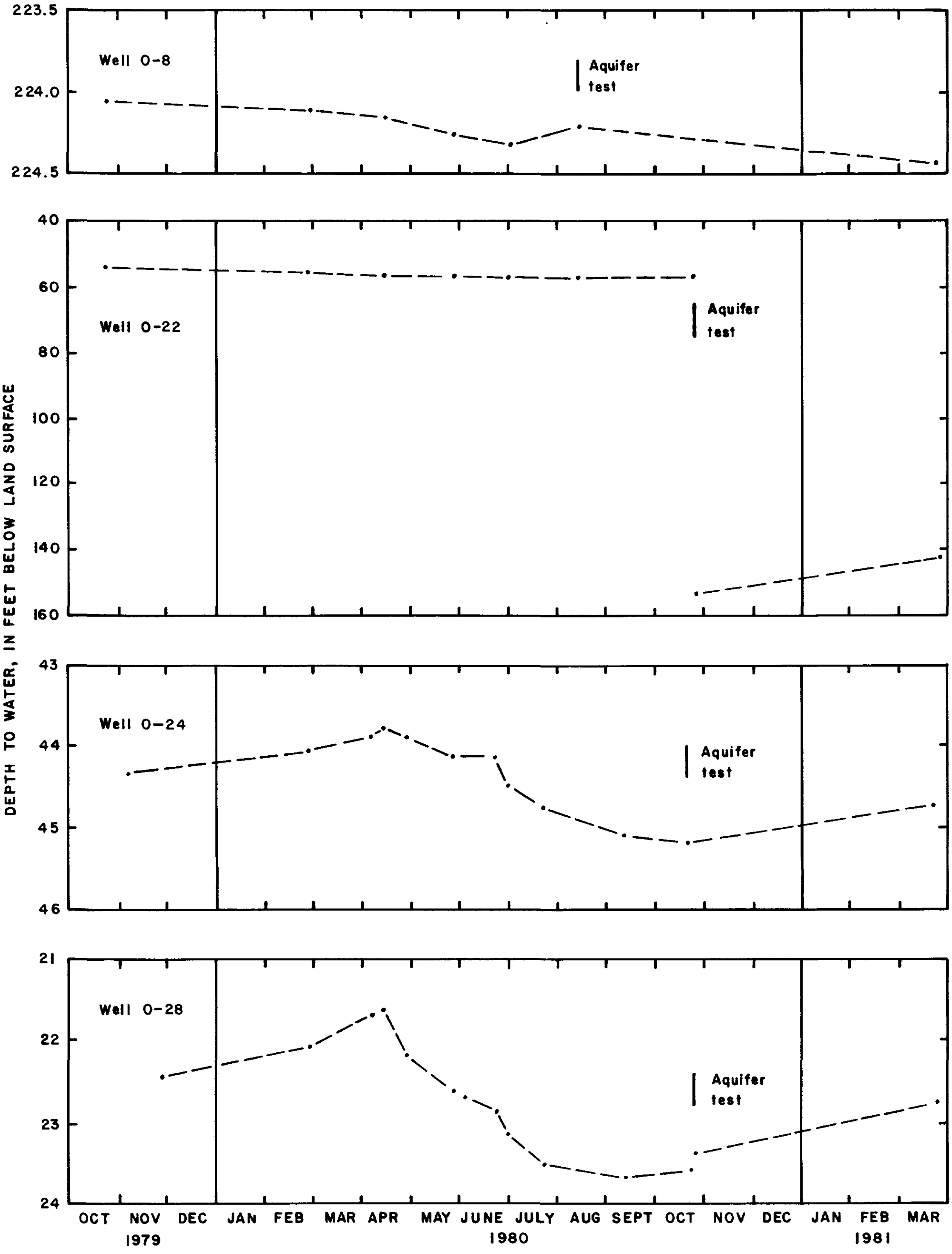


Figure 9.--Water-level fluctuations from October 1979 through March 1981 in observation wells completed in the Knobloch coal bed aquifer.

resentative of the actual Knobloch water level in this vicinity; that is, about 142 feet below land surface.

Wells 0-24 and 0-28, located on either side of the Otter Creek flood plain near the south end of the West Otter area, are completed only in the lowest Knobloch coal bed; they appear to be directly affected by water-level fluctuations in the alluvial aquifer of the valley. The hydrographs (fig. 9) of both of these wells show a seasonal trend in water levels--lowest during the late fall, rising during the winter and spring, and declining during the summer.

Ground-water movement

The general direction of water flow in the Knobloch coal bed or adjacent sandstone above or below the Knobloch is shown in figure 10. The contours are drawn from water-level measurements made during October 1980 and reflect only the general hydraulic gradient in all the individual aquifers. If wells were completed to each of these individual aquifers at one site, the water level would be different in each aquifer. The difference could be as much as 20 or 30 feet, with the deeper aquifers having the deeper water levels at most places. The flattening of the hydraulic gradient between the 3,050- and 3,025-foot contours in the north-central part of the West Otter area probably is caused by an increased volume of burned coal and clinker in this vicinity.

Quality of water

Lower sandstones

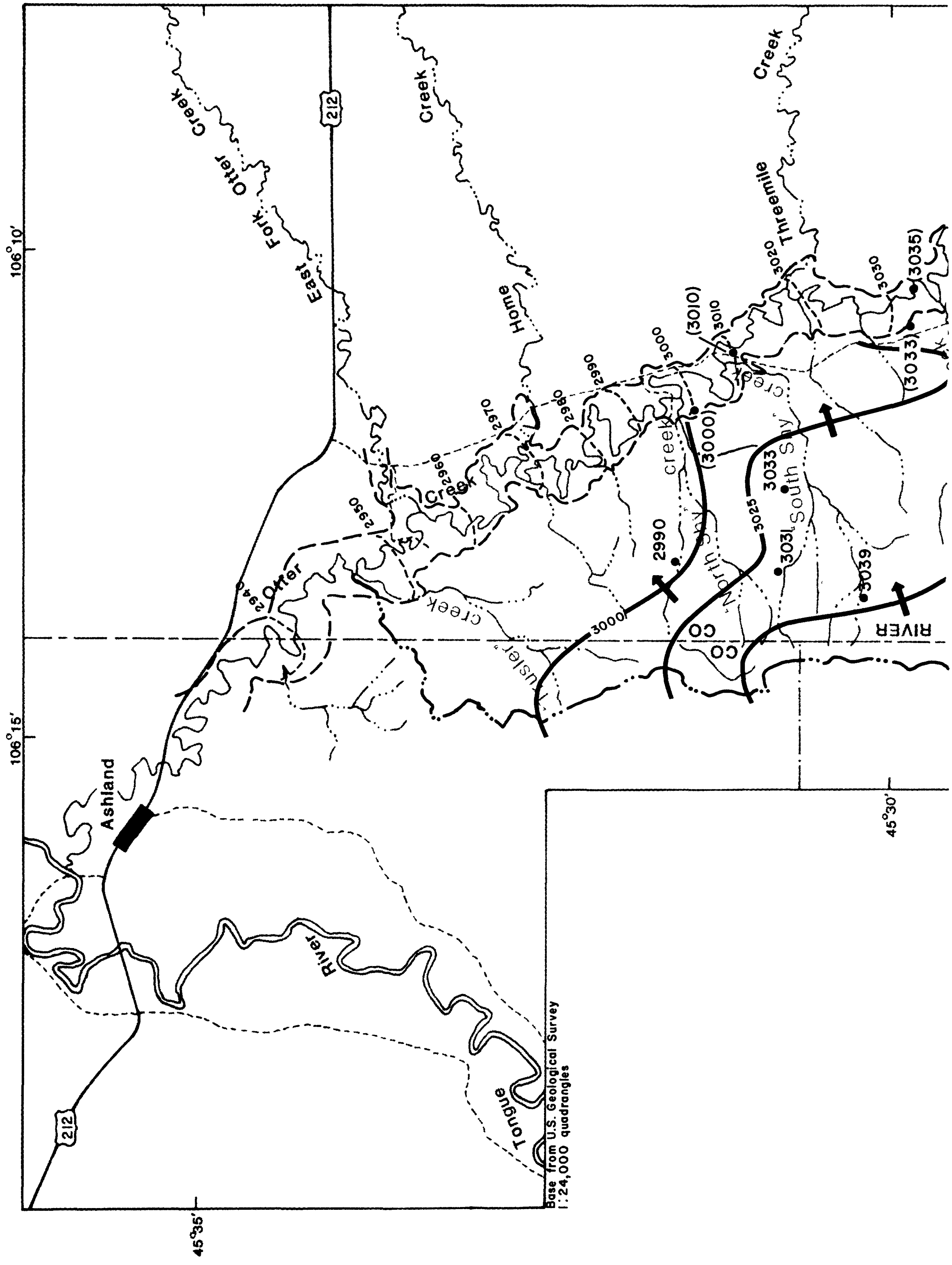
Analyses of water from nine wells, interpreted to be completed in the lower sandstone beds, are listed in table 7. Most of the water was of the sodium bicarbonate type, with relatively small concentrations of calcium, magnesium, potassium, sulfate, and silica. The sodium-adsorption ratio was large, ranging from 32 to 75. The chloride concentration was relatively large (20 to 150 mg/L). The fluoride concentration, which ranged from 0.7 to 4.4 mg/L, is marginal for human consumption (U.S. Environmental Protection Agency, 1977).

Water from well P-32 is listed with the lower sandstones because of the reported depth of the well; however, the water was a sodium sulfate type. This water probably leaks from coal beds higher in the stratigraphic section, as it is not typical of water from sandstone in the West Otter area. Excluding the analysis from well P-32, the average dissolved-solids concentration for the lower sandstones of the Tongue River Member was 890 mg/L.

Middle sandstones

The quality of water in the sandstone beds above or just below the Knobloch coal bed, and between the split coal beds in the southern part of the West Otter area, is more varied than the quality in the deeper sandstone beds. Analyses are available from nine wells (table 7). Water from all wells was either a sodium bicarbonate or a sodium sulfate type. When isolated from adjacent coal beds, water from the middle sandstones contained 480 to 3,460 mg/L of dissolved solids.

The water from the middle sandstones is least mineralized in wells P-27, 0-23, and 0-27 and most mineralized in wells P-5 and P-25. Wells P-27, 0-23, and 0-27 are completed in the sandstone below the lowest Knobloch coal bed near the south


106°10'
106°15'
45°35'
45°30'
East Fork Otter Creek
Home Creek
Threemile Creek
Otter Creek
212
Ashland
Tongue River
Base from U.S. Geological Survey
1:24,000 quadrangles
2940
2950
2960
2970
2980
2990
3000
3010
3020
3030
3025
(3010)
(3000)
(3035)
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3033
3031
3039
"North Sny" creek
"South Sny" creek
"Busler" creek
CO
RIVER

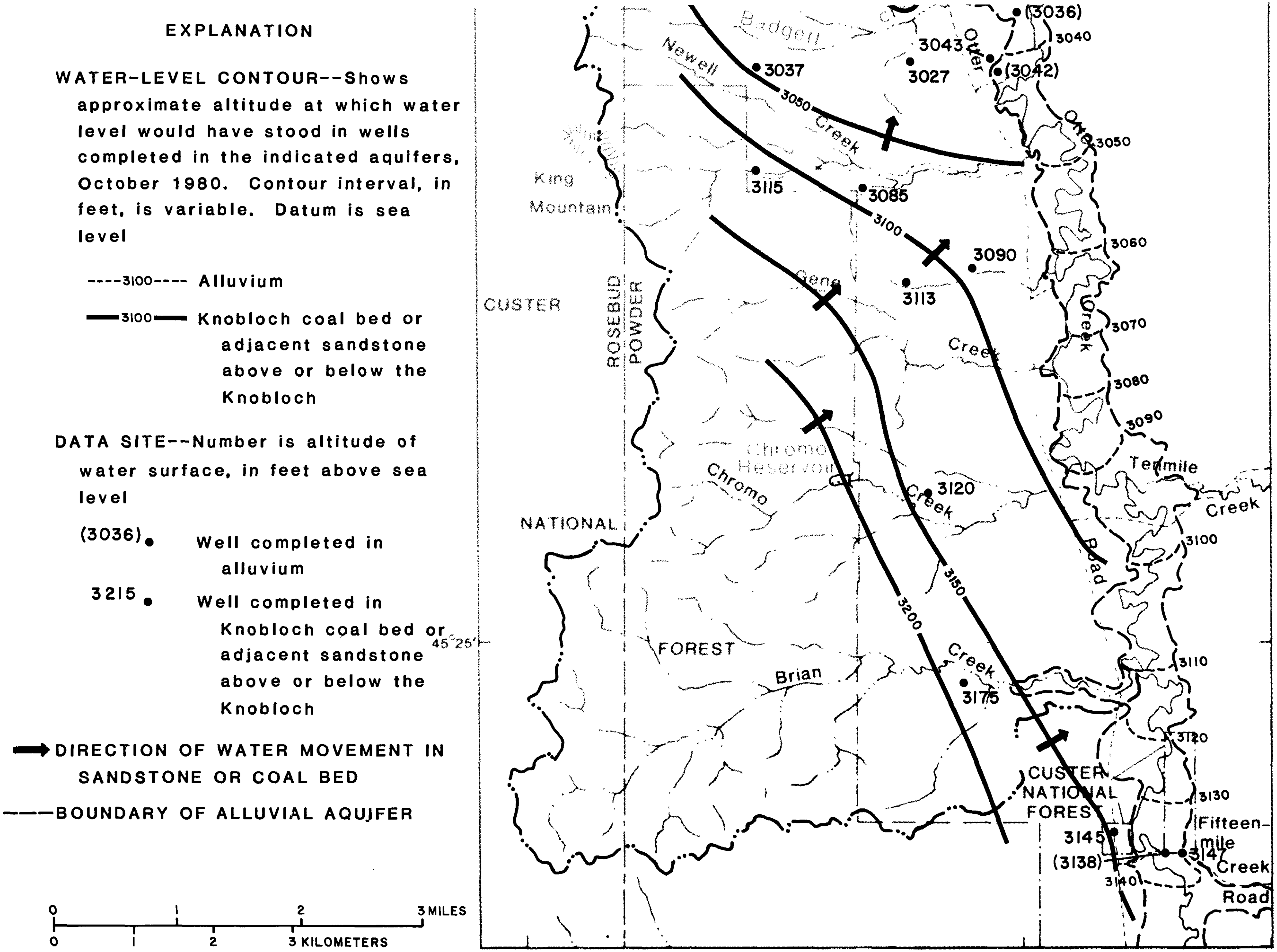

Figure 10.--General direction of water flow and approximate altitude of water level in the alluvium of Otter Creek valley and in the middle sandstones and Knobloch coal of the Tongue River Member of the Fort Union Formation.

end of the West Otter area. Water from this sandstone was a sodium bicarbonate type, and the dissolved-solids concentration ranged from 480 to 615 mg/L. Well P-5, in the "North Shy" creek drainage near the north end of the area, and P-25, in the central part of the area, are completed in a sandstone above the Knobloch coal. The water was a sodium sulfate type, and the dissolved-solids concentration was about 3,300 mg/L. Other wells yield water of quality between these extremes; dissolved-solids concentration ranged from 1,850 to 2,510 mg/L.

Fluoride concentration ranged from 0.4 to 1.9 mg/L and averaged 1.2 mg/L. The sulfate concentration was large (2,100 mg/L) in well P-5, and relatively large (average of 1,200 mg/L) in wells 0-25, P-19, P-25, and P-30. The average dissolved-solids concentration of all middle sandstone water was about 1,800 mg/L.

Knobloch coal bed

Samples were analyzed from six wells obtaining water solely or predominantly from the Knobloch coal bed (table 7). Most of the water was a sodium bicarbonate type, with a large concentration of sulfate; well 0-10 has water of a sodium sulfate type. The least mineralized water (except for water from well 0-24, which is mixed with water from sandstone well 0-25) was from well 0-8 in the north-central part of the West Otter area; there, the water contained about 930 mg/L of dissolved solids. The most mineralized water was from well 0-10, 0.8 mile south of 0-8; this well had water containing 6,260 mg/L of dissolved solids. Other water from the Knobloch coal bed ranged widely in dissolved-solids concentration--from 1,140 to 2,520 mg/L. The sodium-adsorption ratio was moderate to large (18 to 64). The fluoride concentration ranged from 0.7 to 2.6 mg/L. Concentrations of other constituents were about typical for Tongue River Member waters.

Alluvium

Wells and yields

Of the few private wells completed in alluvium that exist in the West Otter area, two were inventoried. The water from these wells is used primarily for watering lawns or small pastures. Although the alluvial gravels can yield as much as 100 gal/min of water to wells, the water has large concentrations of dissolved solids and an objectionable taste. The wells inventoried, P-12 and P-24, have small pumps; the greatest discharge measured was 15 gal/min from well P-24 (table 1).

During this study, 16 observation wells were drilled into the alluvial aquifer--11 by the U.S. Geological Survey and 5 by Consolidation Coal Company. Construction data for these wells are presented in table 4. The line of six wells (0-26, 0-29 to 0-33) at five sites at the south end of the area indicates a thickness of alluvium of 44 feet or less, and a range of contributing thickness of water-yielding sand and gravel of from 4 feet in well 0-29 to 15 feet in well 0-31 (fig. 7). The scattered wells completed in the alluvium in the middle reaches of Otter Creek (0-6, 0-12 to 0-15) indicate a depth to the bottom of the alluvium of 66 feet or less, with 15 to 20 feet of water-yielding sand and gravel. The line of five wells (0-1 to 0-5) at four sites in the north-middle reach of the area indicates a maximum thickness of the alluvium of about 70 feet, with as much as 36 feet of sand and gravel contributing water to the wells (fig. 11).

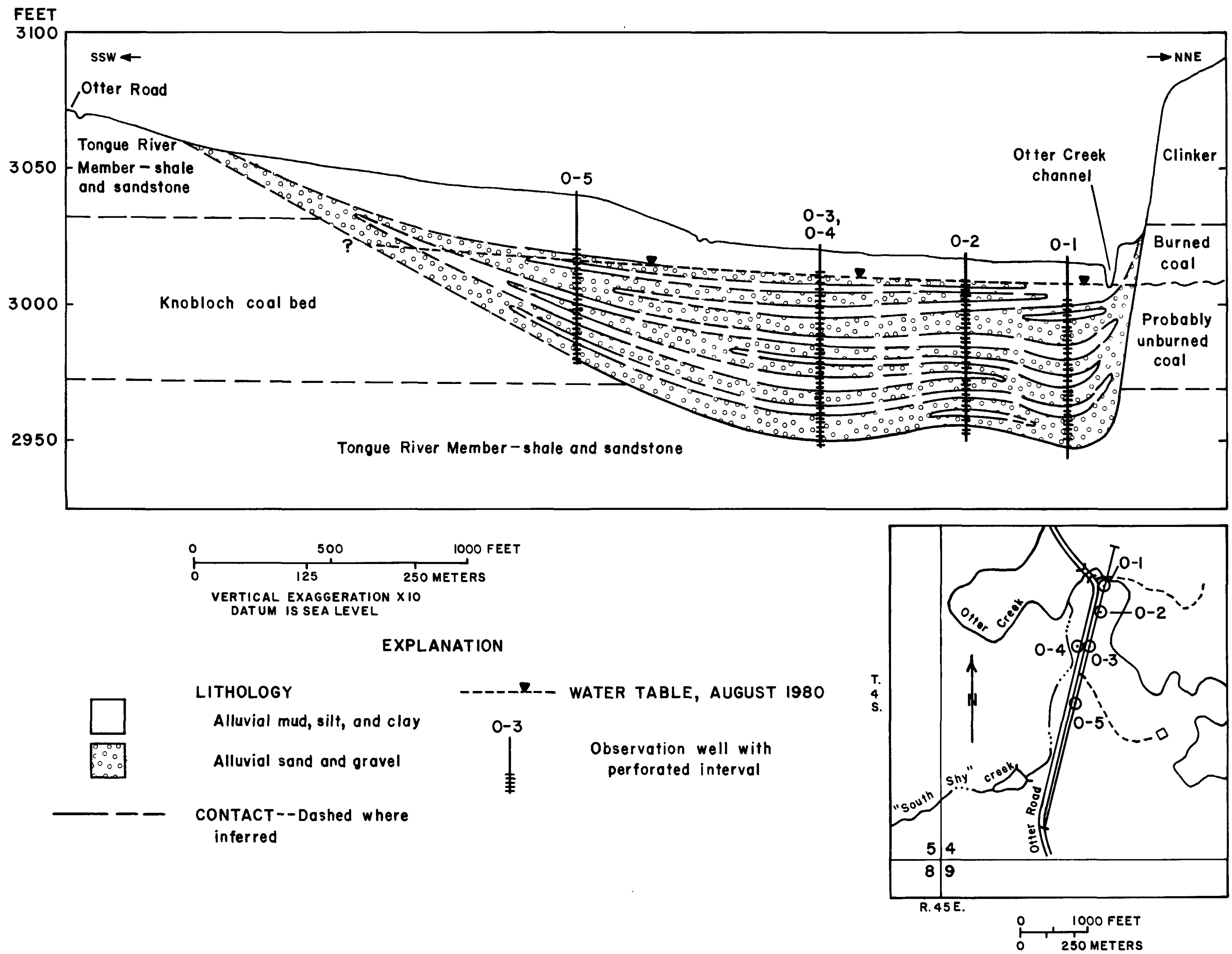

Figure 11.--Generalized section showing stratigraphic relationship between alluvium and the Tongue River Member of the Fort Union Formation in the north-central part of West Otter area. Location of wells also is shown in figure 2.

Aquifer characteristics

Twelve of the observation wells completed in the alluvium were pumped to determine the hydrologic characteristics of the aquifer (table 6). Discharge from the wells ranged from 2.8 gal/min in well O-29, drilled to clinker gravels beneath a high terrace, to 64 gal/min in wells O-1 and O-13 drilled on the flood plain. The discharges were determined using the largest pump available. Other wells that probably could have been pumped at a rate of at least 64 gal/min were O-3, O-4, O-12, O-31, and O-32.

The calculated hydraulic conductivities of wells at the south end of the Otter Creek valley ranged from 40 to 170 ft/d. The smallest value was at well O-30 near the east edge of the flood plain. The wells closest to the center of the valley had hydraulic conductivities of about 150 ft/d (O-32) and 170 ft/d (O-31).

Downstream to the middle reaches of the Otter Creek valley, two (O-12 and O-13) of the five Consolidation Coal Company wells completed in the alluvium were tested. Well O-12 is situated on a high terrace on the west side of the valley; a test at this well indicated a hydraulic conductivity of about 170 ft/d. The largest hydraulic conductivity (360 ft/d) was at well O-13, which has 18 feet of clean sand and gravel opposite the perforated interval of the well. The well is situated at a bend in the Otter valley where the gravels are likely to be coarsest and contain the least fine material.

Across the line along Otter Road (O-1 to O-5), hydraulic conductivity was fairly consistent in the middle three wells; all values were about 130 ft/d. At the well on the high terrace to the south (O-5), the hydraulic conductivity was about 40 ft/d.

Considering all wells completed in alluvium throughout the length of Otter Creek valley studied, the hydraulic conductivity ranged from 40 to 360 ft/d. The average hydraulic conductivity was about 120 ft/d.

Water-level fluctuations

The water table of the alluvial aquifer in Otter Creek valley is affected by runoff during the spring and evapotranspiration during the growing season. Water-level fluctuations in four wells completed in the alluvium (O-26 and O-31 at the southern end of the area and O-3 and O-5 in the north-central part) and one well completed in both clinker and terrace gravel (O-29) are shown by hydrographs (fig. 12). Four of the wells had a distinct peak water level in mid-April 1980 near the end of the winter season, and three showed a smaller peak in June 1980, which was caused by intense rains in May and June. Through the summer, the water levels declined as the growing plants on the flood plain and low terraces utilized the ground water. In September and October, the water levels stabilized as the plants used less water and little recharge was received. At the end of October the plants stopped using water and recharge from upvalley continued, causing water levels to rise. These fluctuations are shown best by the hydrograph for well O-3. Note that in all the wells, the November 1979 to November 1980 levels declined 1 to 2 feet. The most probable reason for the decline was the decreased snowpack in the basin upstream from the West Otter area during the winter of 1979-80 as compared with the winter of 1978-79. An additional decline is noted between August 1980 and August 1981.

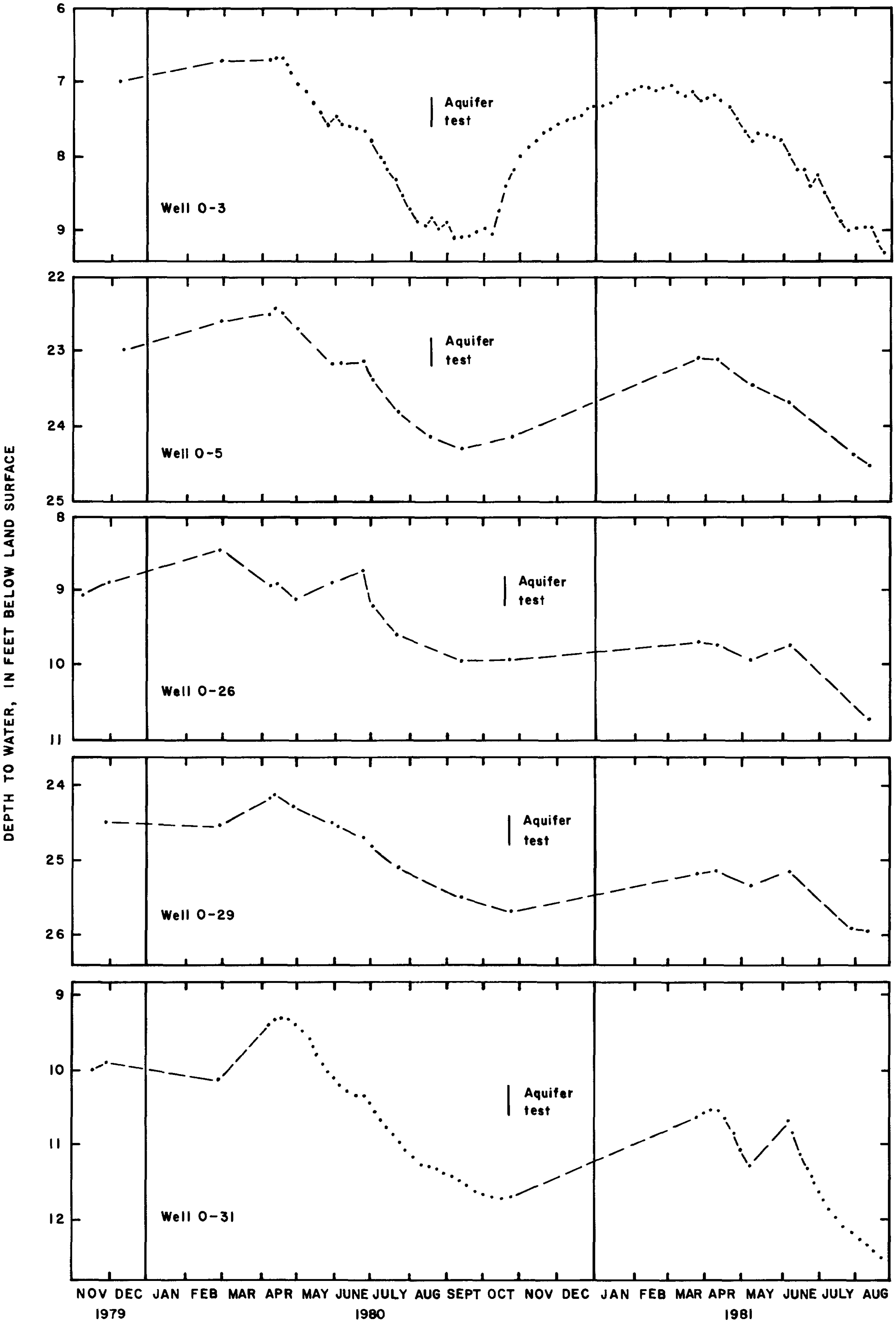

Figure 12.--Water-level fluctuations from November 1979 through August 1981 in observation wells completed in the alluvial aquifer.

Ground-water movement

Water moves down the Otter Creek valley through the alluvial aquifer. The gradient of the water table ranges from about 0.004 (10-foot decline in 0.5 mile) to about 0.002 (10-foot decline in 1 mile) from the south to north ends of the area (see fig. 10). The volume of water flowing downvalley through alluvium can be calculated using Darcy's law, Q = KIA (as explained in Jacob and Lohman, 1952). The volume entering the study area near wells O-26 and O-30 through O-33 is about 16,000 ft^3/d, as determined using the values of 100 ft/d for an average hydraulic conductivity (K), 0.004 for the gradient (I), and 40,000 ft^2 for an approximate area (A). The volume of water moving past the north-central part of the area near wells O-1 through O-5 is about 32,000 ft^3/d; using the values of 120 ft/d for an average hydraulic conductivity, 0.003 for the gradient, and 90,000 ft^2 for an approximate area. The volume of water passing out of the West Otter area probably exceeds 100,000 ft^3/d through the alluvial aquifer, greater than at the north-central well line, because of the broader valley downstream and the inflow from the east side streams reaching the Otter Creek alluvial valley downstream.

Quality of water

Fourteen analyses were made of water from wells completed in the alluvium (table 7). Water from alluvium had the largest average dissolved-solids concentration of all aquifers in the West Otter area, and it also had the most consistent quality--the range was from 1,940 to 4,440 mg/L, and the average was about 2,900 mg/L.

The water from the southern part of the area (wells O-26 and O-30 to O-32) was a sodium magnesium sulfate type with fairly large concentration of bicarbonate ions. The average dissolved-solids concentration of water from the four wells was about 3,800 mg/L. Well O-29, at the side of the valley, obtains water from alluvial terrace deposits containing much clinker gravel; the relatively small concentration of dissolved solids (2,480 mg/L) is not representative of water in the alluvium along Otter Creek.

Water from the north-central part of the West Otter area (wells O-1 to O-4) also was a sodium magnesium sulfate type with a fairly large average concentration of bicarbonate (about 680 mg/L). The average dissolved-solids concentration of water from the four wells was about 2,860 mg/L. The fifth well (O-5) is located on a terrace on the west side of the valley; it withdraws water partly from Otter Creek alluvium and partly from "South Shy" creek, which drains clinker-covered hills. The dissolved-solids concentration of water from well O-5 (2,260 mg/L) was much less than for water obtained solely from Otter Creek alluvium, and the water type was sodium sulfate.

Water in the alluvium along Otter Creek generally differs from water in the sandstone and coal aquifers of the Tongue River Member, mainly in the larger concentrations of calcium (average of about 120 mg/L) and magnesium (average of about 190 mg/L), and the much smaller sodium-adsorption ratio (average of about 7) and fluoride concentration (1.1 mg/L or less). The large sulfate concentration makes the water in the alluvium nonpotable for humans, but the water is adequate for irrigation.

Clinker

Burned coal and clinker crop out in large areas of the northern one-half of the West Otter area. These areas are important sources of recharge water, but, because of the difficulty in constructing a well in the material, none have been completed solely in clinker. Also, the clinker and burned-coal layers transmit water rapidly, similar to a clean, coarse gravel, so the water would be only in the lowest few feet and probably in buried channels that could be missed by a well laterally mislocated.

The clinker layers are conduits through which overland flow and snowmelt runoff easily are absorbed and transmitted but which retains water in only a few depressions or buried channels. Most of the water from the clinker layers passes into the colluvium of the hillsides and alluvium of the tributary valleys, then directly into the underlying coal and sandstone beds or into the alluvium along Otter Creek valley. Coal beds, which lie below the water table along Otter Creek valley, are not burned.

Surface-water resources

The West Otter area has eight small streams draining from the Tongue River-Otter Creek divide eastward to Otter Creek; none of the streams is perennial at its mouth, although several have interrupted flow in their upstream reaches. These streams contribute flow to Otter Creek generally only after intense storms; seldom does snowmelt runoff become large enough to cause temporary flow in the downstream reaches.

West-side drainages

Brian Creek

The southern-most stream of the West Otter area is Brian Creek, which drains from altitudes of 3,950 to 4,130 feet above sea level, eastward to Otter Creek, at an altitude of about 3,115 feet. Brian Creek has a drainage area of 8.1 mi^2, the largest in the area. The basin is 5.3 miles long, 2.7 miles wide along the divide, about 1.7 miles wide in the middle reaches, then narrows rapidly about 1 mile upstream from its mouth. The stream channel is steep in the upstream reaches--about 300 ft/mi below the 3,800-foot level. In the middle and downstream reaches (below the 3,400-foot level), the gradient gradually decreases from 100 to 50 ft/mi.

Numerous springs issue from coal and sandstone beds between the divide and the 3,400-foot level. However, there is no perennial flow in the main stream or tributaries below the 3,600-foot level; the water infiltrates the alluvial materials and reenters the ground-water system.

Flow was not observed during the study and no recording stations are operated on the stream. Using regional prediction equations (Omang and others, 1983) developed through regression analysis of streamflow and dimensions of the channel of streams in southeastern Montana, the mean discharge for the ungaged site is estimated to be 170 acre-feet during a year of average rainfall. From 1979 to 1981 rainfall was less than average, so the volume of water that reached Otter Creek during the study was less than average. Using regional prediction equations (Parrett and Omang, 1981), Brian Creek is calculated to have a maximum instantaneous flow at the mouth of about 45 ft^3/s once every 2 years, about 200 ft^3/s once every 10 years, and about 690 ft^3/s once every 100 years. The discharge characteristics of Brian Creek and other drainages in the West Otter area are listed in table 8.

Table 8.--*Calculated drainage-basin characteristics and stream discharges*

Drainage name	Drainage area (square miles)	Approximate altitude of divide (feet above sea level)	Approximate altitude of mouth (feet above) sea level)	Estimated mean annual discharge (acre-feet)	Estimated peak discharge, in cubic feet per second, for indicated recurrence interval, in years		
					2	10	100
Brian Creek	8.1	3,950-4,130	3,115	170	45	200	690
Chromo Creek	5.0	4,030-4,175	3,090	90	40	180	630
Gene Creek	2.6	4,050-4,160	3,075	40	30	140	490
Newell Creek	4.2	3,720-4,160	3,045	75	40	180	630
"Badgett" creek	2.3	3,770-4,020	3,030	45	65	280	880
"South Shy" creek	2.5	3,450-3,790	3,010	55	60	250	800
"North Shy" creek	2.0	3,290-3,610	3,000	40	60	260	820
"Trusler" creek	1.8	3,170-3,325	2,955	35	20	80	300
Total tributary	28.5						
		Upstream end	Downstream end				
Otter Creek flood plain (within West Otter area)	6.0	3,150	2,955	--	--	--	--

Chromo Creek

The Chromo Creek drainage, north of Brian Creek, has altitudes of about 4,030 to 4,175 feet (the highest point in the West Otter area) along the divide on the west to about 3,090 feet at Otter Creek. The basin, with an area of 5.0 mi^2, is 3.8 miles long and 2.0 miles wide at the upstream end, 1.5 miles wide through much of the middle reaches, and 0.2 mile wide near the mouth. After a precipitous descent from the divide to an altitude of 3,500 feet, the channel has a gradient of about 250 ft/mi in the upstream reaches, about 120 ft/mi in the middle reaches, and about 80 ft/mi near the mouth.

Like Brian Creek, numerous springs flow from coal and sandstone beds in the upstream reaches of Chromo Creek, but this area was not examined during this study.

Below the 3,400-foot level, no flow was observed in the channel, although the north fork had a marshy bottom from Chromo Reservoir for 0.8 mile downstream to the 3,180-foot level.

Mean annual discharge from Chromo Creek drainage area (during years of average rainfall) is estimated to be 90 acre-feet. The calculated maximum instantaneous flow at the mouth would be about 40 ft^3/s once every 2 years, about 180 ft^3/s once every 10 years, and about 630 ft^3/s once every 100 years.

Gene Creek

The third drainage north in the West Otter area is Gene Creek. It has altitudes of about 4,050 to 4,160 feet along the western divide to about 3,075 feet at Otter Creek. The basin, with a drainage area of 2.6 mi^2, is 3.3 miles long and about 1 mile wide, decreasing in width at the upstream and downstream ends. The stream-channel gradient is about 300 ft/mi at the 3,500-foot level, 130 ft/mi at the 3,250-foot level, and 50 ft/mi near the mouth.

Although the upstream reaches were not examined, several springs or seeps probably issue from the coal and sandstone beds between the divide and about the 3,400-foot level. No flow was observed in the downstream end of the basin during the study.

Mean annual discharge from the drainage basin is estimated to be about 40 acre-feet. The calculated maximum instantaneous flow at the mouth is about 30 ft^3/s once every 2 years, about 140 ft^3/s once every 10 years, and about 490 ft^3/s once every 100 years.

Newell Creek

The Newell Creek drainage, in the middle of the West Otter area, has an area of 4.2 mi^2. King Mountain, at an altitude of 4,161 feet, is one of the highest peaks along the Tongue River-Otter Creek divide. The lowest saddle in the Newell Creek drainage is about 3,720 feet in altitude. Newell Creek descends from the divide to Otter Creek, at an altitude of about 3,045 feet, in 3.8 miles; the basin is widest (2.3 miles) along the divide, narrows to 1.2 miles near the middle, and is 0.15 mile wide near the mouth. The gradient of the stream channel is about 150 ft/mi below the 3,400-foot level, about 100 ft/mi in the middle reach of the stream, and about 50 ft/mi near the mouth.

The uppermost reaches of the Newell Creek drainage basin were not examined, however, no springs have been reported. A few small springs probably occur above the 3,500-foot level, but the water apparently flows only short distances on the surface.

No flow was noted near the mouth of Newell Creek during the study and no surface-water recording stations were established. Using regional prediction equations, mean annual discharge from the basin is about 75 acre-feet. The calculated maximum instantaneous flow at the mouth will be about 40 ft^3/s once every 2 years, about 180 ft^3/s once every 10 years, and about 630 ft^3/s once every 100 years.

"Badgett" creek

The 2.3 mi^2 drainage north of Newell Creek is "Badgett" creek. "Badgett" creek drains from the western divide, at altitudes of 3,770 feet to 4,020 feet, to Otter Creek, at an altitude of about 3,030 feet. The length of the basin is 3.0 miles; the basin widens from 0.3 mile in the upstream reaches to 1.2 miles within 0.5 mile of the mouth. The gradient is steep from the divide to the 3,300-foot level, then becomes a more gentle 160 ft/mi; the gradient is 110 ft/mi in the middle reaches and 60 ft/mi near the mouth.

No springs are known to exist in the "Badgett" creek basin. However, small seeps probably occur in the upstream reaches.

The mean annual discharge from the basin is estimated to be about 45 acre-feet. The regional prediction equations indicate that the maximum instantaneous flow at the mouth would be about 65 ft^3/s once every 2 years, about 280 ft^3/s once every 10 years, and about 880 ft^3/s once every 100 years. These discharges are larger than those for Brian or Newell Creeks, because the forest cover is less in this smaller drainage basin.

"South Shy" creek

The drainage north of "Badgett" creek is "South Shy" creek; it drains from the Tongue River-Otter Creek divide, at altitudes of 3,450 feet to 3,790 feet, to Otter Creek, at an altitude of 3,010 feet. The drainage basin has an area of 2.5 mi^2, is 3.0 miles long, and trends northeastward instead of eastward as do the basins to the south. The width is 1.6 miles in the upstream reaches, and decreases to 0.5 mile near the mouth. The gradient of "South Shy" channel is about 120 ft/mi below the 3,200-foot level, and about 70 ft/mi in the downstream reaches.

One spring exists in the south fork of "South Shy" creek at the 3,190-foot level. This spring keeps a stock pond filled perennially and causes the stream channel to be marshy for about 1,200 feet downstream from the dam.

The approximate mean annual discharge at the mouth of "South Shy" creek is about 55 acre-feet. The calculated maximum instantaneous flow at the mouth will be about 60 ft^3/s once every 2 years, about 250 ft^3/s once every 10 years, and about 800 ft^3/s once every 100 years.

"North Shy" creek

The next northward drainage is "North Shy" creek. It has a drainage area of 2.0 mi^2, an altitude that ranges from 3,290 to 3,610 feet along the western divide, and an altitude of about 3,000 feet at the mouth. The basin is 2.5 miles long, 1.2 miles wide near the upstream reach, and 0.8 mile wide 0.5 mile upstream from the mouth. The stream gradient is 120 ft/mi downstream from the 3,200-foot level in the upstream reaches and about 75 ft/mi near the mouth.

No springs were observed or reported in the basin. The Knobloch coal is almost entirely burned in this basin, so the clinker would absorb and transmit any water underground.

The existence of the clinker in the "North Shy" creek drainage was considered in calculating the mean annual surface-water discharge by the regional prediction equations. This calculated discharge is about 40 acre-feet. Also, because of the clinker on the surface, precipitation will seep into the ground much faster than on the shales or sandstones of the Tongue River Member under most of the West Otter area and calculations for floods consider the effects of clinker. Calculated maximum instantaneous flow at the mouth is about 60 ft^3/s once every 2 years, about 260 ft^3/s once every 10 years, and about 820 ft^3/s once every 100 years.

"Trusler" creek

The northern-most small drainage in the West Otter area is "Trusler" creek. This drainage basin has an area of 1.8 mi^2 from the Tongue River-Otter Creek divide to the Otter Creek flood plain. The basin is aligned north-northeast, is 2.5 miles long and 1.4 miles wide in the middle part, and decreases in width at the upstream and downstream ends. The altitude of the divide ranges from 3,170 to 3,325 feet; at the mouth of "Trusler" creek the altitude is about 2,955 feet. The upstream reaches are rolling terrain, rather than the steep hillsides of the high ridge divide farther south. The gradient of "Trusler" channel is about 200 ft/mi upstream from the 3,100-foot level and 100 ft/mi downstream from this level. No springs are known to occur in the basin.

The existence of clinker, consisting of burned Knobloch coal and overburden, is extensive. The regional prediction equations used to calculate the discharge and flood estimates consider the effects of clinker on streamflow. The approximate mean annual discharge from the "Trusler" drainage at the edge of the Otter Creek flood plain is about 35 acre-feet. The calculated maximum instantaneous flow at the mouth will be about 20 ft^3/s once every 2 years, about 80 ft^3/s once every 10 years, and about 300 ft^3/s once every 100 years.

Between-creek drainages

Between each of the small basins of the West Otter area are smaller, short streams or coulees draining from the local divide directly to Otter Creek. Most of these drainages are eroded slightly into high terraces over most of their areas, with steeper slopes near the divide and slopes being about the same as the downstream terraces along Otter Creek on the eastern margins. The physical characteristics of these drainages are given in table 9.

Otter Creek

The entire Otter Creek drainage basin extends from near the Wyoming State line to Ashland, Mont., a distance of 46 miles; the basin has an area of about 700 mi^2. The area of Otter Creek upstream from the mouth of Fifteenmile Creek is about 420 mi^2, and the area on the east side of Otter Creek, from Fifteenmile Creek northward to the mouth of Otter Creek is about 240 mi^2; thus, the area within the West Otter study (41.3 mi^2) is a small part of the whole.

The valley of Otter Creek in the West Otter area covers 6.0 mi^2; the upstream end is at an altitude of about 3,150 feet and the downstream end is at about 2,995 feet. Otter Creek meanders back and forth across the flood plain, extending at

Table 9.--*Physical and flow characteristics of the between-creek drainages*

Location of drainage between:	Area from divide to Otter Creek flood plain (square miles)	Dominant gradient (feet per mile)	Estimated mean annual discharge to Otter Creek (acre-feet)
Study-area boundary and Brian Creek	1.0	120	20
Brian and Chromo Creeks	.9	100	18
Chromo and Gene Creeks	.5	200	10
Gene and Newell Creeks	1.3	200	26
Newell Creek and "Badgett" creek	.6	220	12
"Badgett" and "South Shy" creeks	1.1	220	22
"South Shy" and "North Shy" creeks	.2	300	4
"North Shy" and "Trusler" creeks	1.2	300	24
Total	6.8		136

least four times in stream miles the 12.7-mile length of the flood plain within the area.

In late October 1977, flow was measured and water-quality samples were collected on Otter Creek (Lee and others, 1981). The creek was measured at six sites within the West Otter area and at one site 2 miles upstream from the mouth of Fifteenmile Creek. The flow at that time was 0.9 ft^3/s at the upstream site, which decreased to no flow 6 miles downstream from Fifteenmile Creek. Flow began again near Threemile Creek, 8.5 miles downstream, and was 1.2 ft^3/s at the downstream end of the area. The increase in flow occurred along the stretch where the Knobloch clinker rises above the level of the flood plain. In late 1977, the Knobloch coal and clinker apparently were contributing water to the alluvial deposits and, therefore, the Otter Creek channel.

The discharge of Otter Creek was greater in October 1978 and October 1979 than in October 1977; no stretch of the channel was dry. The main reason for the increased flow was the much larger snowpack during the winters of 1977-78 and 1978-79. In 1980, the discharge in Otter Creek decreased (fig. 13); the decrease continued into 1981. Both years had preceding winters producing small snowpacks. The monthly precipitation during the same period is shown in figure 14.

The relative flow in Otter Creek at the upstream station (upstream from Tenmile Creek) and downstream station (at Ashland) is shown in figure 15. Most of each year, flow at the downstream station is greater than at the upstream station. This condition reflects the increased size of the drainage area between the stations, including the flow from several large tributaries from the east--Threemile Creek, Home Creek, and East Fork Otter Creek. It also reflects discharge from the Knobloch clinker in the downstream reaches of Otter Creek. A reversal of the relative flow occurs almost every October, when the upstream station has more flow than the downstream station.

Quality of surface water

Springs

Some of the springs in the upstream reaches of Brian, Chromo, and Gene Creeks were sampled for chemical analysis in 1974 and 1980. Most of the principal ions of the spring water were calcium, magnesium, bicarbonate, and sulfate, which are more characteristic of sandstone than coal aquifers (table 10). The dissolved-solids concentration ranged from 1,460 to 2,880 mg/L and averaged about 2,100 mg/L. As is typical of water from middle sandstones of the Tongue River Member, the concentration of chloride was very small, 16 mg/L or less for all samples. The concentration of fluoride also was relatively small, mostly less than 1.0 mg/L. Sodium was the most variable of the constituents, ranging from 38 to 330 mg/L. The sodium-adsorption ratio was very small, never more than 8, and always within the excellent category for crop irrigation. The other constituents were, in most samples, fairly close to the average for all these springs: calcium, about 140 mg/L; magnesium, about 240 mg/L; potassium, about 8 mg/L; bicarbonate, about 730 mg/L; sulfate, about 1,000 mg/L; and silica, about 16 mg/L. These average concentrations are based on eight samples from seven springs.

Otter Creek

Otter Creek has been sampled approximately monthly since 1977. The analyses represented in table 10 are only for low flow during November or December of each year from 1977 through 1980 at the upstream station Otter Creek above Tenmile Creek (station 06307725) and at the downstream station Otter Creek at Ashland (station 06307740). The flow in the creek ranged from about 2 to 4 ft^3/s at the upstream station and about 3 to 6 ft^3/s at the downstream station.

Most years, the quality of water in Otter Creek changed very little from the upstream to downstream stations. The hardness decreased slightly, from about 1,200 mg/L at the upstream station to about 1,050 mg/L at the downstream station. The water contained principally sodium, magnesium, and sulfate ions. The calcium, magnesium, sodium, and potassium concentrations were variable, some years larger at one station, other years larger at the other. Bicarbonate concentration increased slightly downstream, from an average of 660 mg/L to 720 mg/L. Sulfate was variable, but averaged about 1,400 mg/L. Chloride concentration increased slightly downstream, from about 13 to 15 mg/L. Concentration of fluoride was variable, almost always less than 1.0 mg/L. Silica concentration decreased downstream. The dissolved-solids concentration ranged from 2,380 to 2,950 mg/L at the upstream station and from 2,050 to 2,640 mg/L at the downstream station. Except for the rather large concentration of sulfate and the large hardness, the water of Otter Creek is acceptable for most uses.

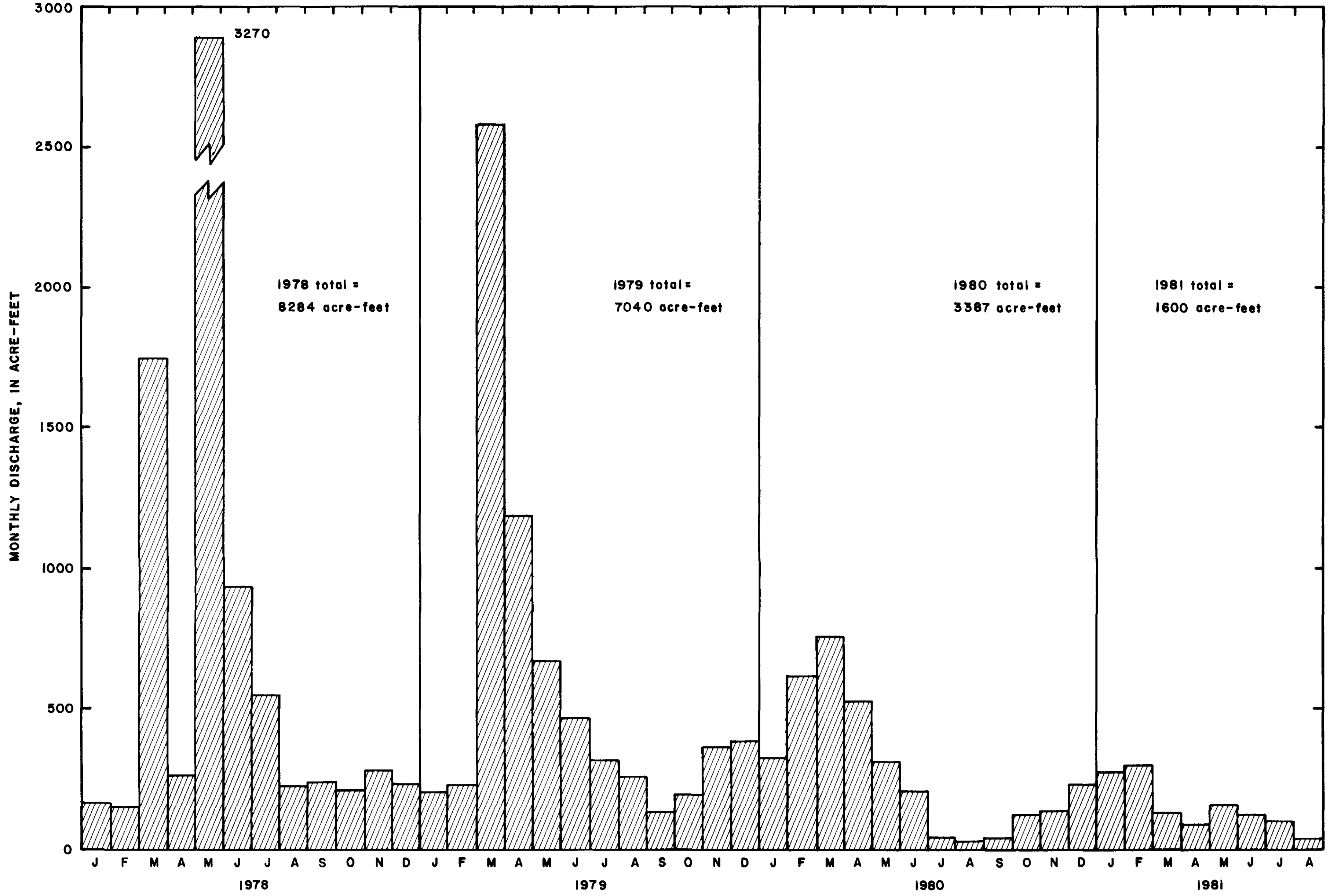

Figure 13.--Monthly discharge of Otter Creek at the downstream station. The graphs indicate a general decrease in discharge from 1978 to 1981 at the station, Otter Creek at Ashland (06307740).

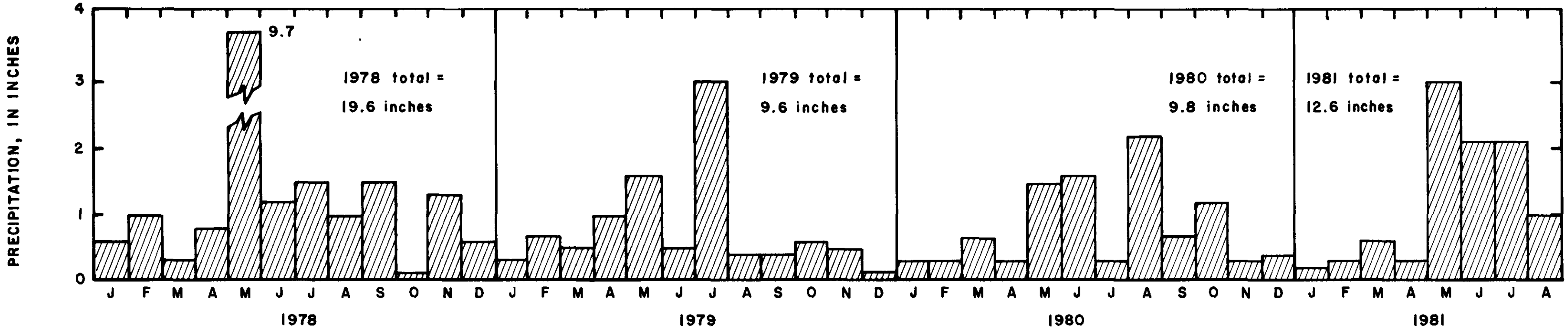

Figure 14.--Monthly precipitation at the U.S. Forest Service ranger station at Ashland, 3 miles northwest of the West Otter area.

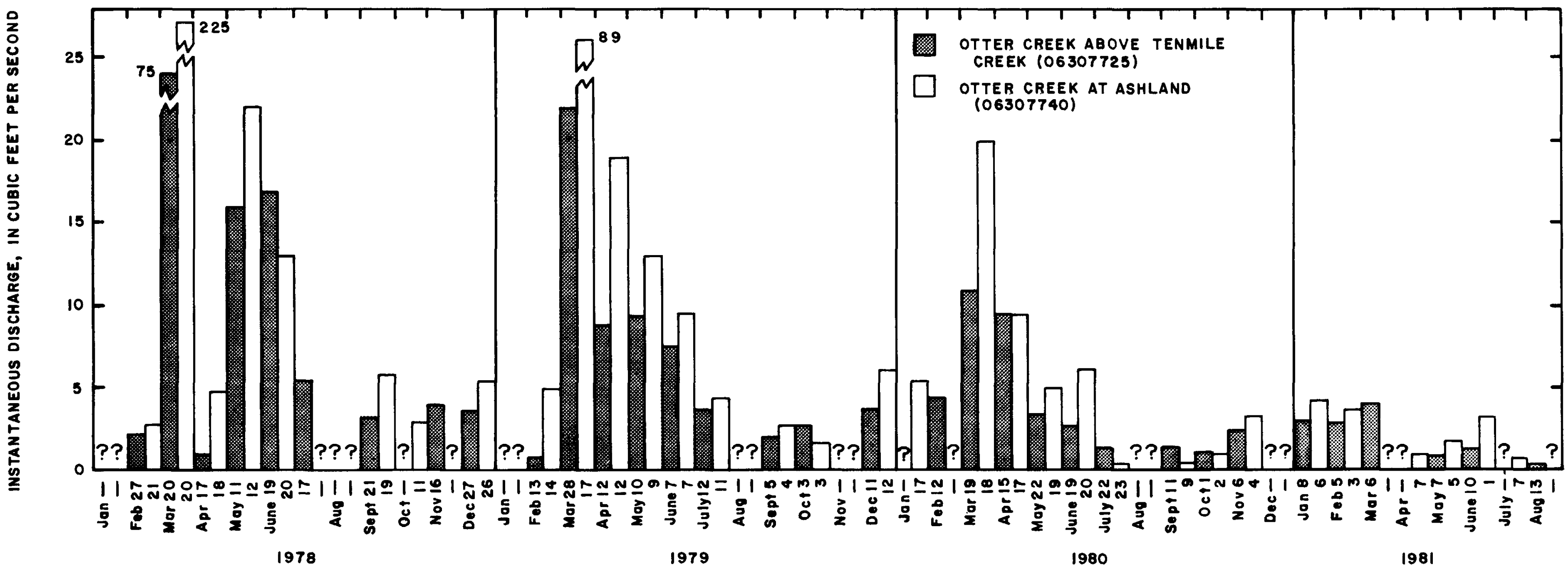

Figure 15.--Measured instantaneous discharge in Otter Creek at the upstream and downstream stations. The graphs indicate general losses or gains in flow through the West Otter area from 1978 to 1981. Query indicates flow was not measured.

CONCLUSIONS

Hydrogeologic data collected in 1979-80 from private wells, observation wells, test holes, and springs indicate that sandstone and coal beds within the Tongue River Member of the Fort Union Formation (Paleocene age) and alluvium (Pleistocene and Holocene age) beneath the Otter Creek valley are the principal aquifers in the West Otter area. Clinker layers are important infiltration conduits to the deeper aquifers, but no wells were completed in this material. The sandstone beds are the principal source for domestic and livestock water in the area. The sandstone aquifers are from a few feet to about 80 feet thick and have a hydraulic conductivity of about 10 ft/d. The Knobloch coal bed is 40 to 70 feet thick; the bed splits and becomes thinner southward through the West Otter area. The Knobloch coal aquifer has an average hydraulic conductivity of about 2 ft/d. Few existing wells obtained water from the Knobloch coal aquifer, but most of the observation wells constructed in the Tongue River Member were used to investigate the hydrologic characteristics of the coal aquifer. Wells completed in the alluvial aquifer along the Otter Creek flood plain are used for livestock water and small plot irrigation. The thickness of the alluvial aquifer contributing to the wells ranges from 4 to 36 feet, and the average hydraulic conductivity is about 120 ft/d.

Surface-water resources consist principally of Otter Creek and eight small streams that drain from the Tongue River-Otter Creek divide eastward to Otter Creek. During this investigation, Otter Creek was perennial throughout the study area but had dry reaches in 1977. The west-side tributaries flow only after spring snowmelt and occasional summer rainstorms. Otter Creek is a source for stock water. Springs located mostly on the higher hillsides and valleys are used to maintain water in stock troughs and ponds.

Water in the West Otter area generally has a large dissolved-solids concentration. Concentrations ranged from 590 to 1,580 mg/L in sandstones of the lower part of the Tongue River Member, 480 to 3,460 mg/L in sandstones above and below the Knobloch coal bed, 910 to 6,260 mg/L in the Knobloch coal, and 1,940 to 4,440 mg/L in alluvium of Otter Creek. The water supplied by wells completed in the Tongue River Member generally was a sodium bicarbonate type, although some ground water had a large sulfate content. Water in alluvium generally was a sodium-magnesium sulfate type with fairly large concentrations of bicarbonate. Water in Otter Creek had dissolved-solids concentrations ranging from 2,050 to 2,950 mg/L in samples collected from 1977-80 and contained principally sodium, magnesium, and sulfate ions.

Mining of the Knobloch coal bed would not affect the aquifers of the Tullock Member, Lebo Member, and lower part of the Tongue River Member. The wells completed in these aquifers, which are located near the potential mine pits, may be affected by vibrations caused by blasting during mining operations. Three bedrock wells that are within the area of the potential north and south mine pits would be destroyed by the mine. The water levels in two wells west of the potential south mine pit could be seriously lowered by the removal of aquifers in the mine. Two other wells south of the mine pit could have their water levels decline slightly. Also, inflow of water from the east wall would affect water levels in alluvium underlying the Otter Creek flood plain adjacent to the mine pit.

The potential exists for long-term change in the quality of water in the downstream part of the Otter Creek valley. Water leaching through recently disturbed spoils material could dissolve soluble salts as it seeps downgradient to the Otter Creek valley alluvium. The existing hydrologic system would be altered along the west and south walls of the potential mine pit as a result of the removal of the aquifers.

The effects of the mining and reclamation on the local water resources can be mitigated by proper planning. Any well affected by the mining operations could be replaced by a well drilled to a deeper, unaffected aquifer. Reclamation techniques designed to minimize water flow through the mine spoils would decrease the rate of leaching of soluble salts, thereby minimizing the change in water quality in downgradient aquifers.

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Table 1.--*Construction and hydrologic data from private and public wells*

[Aquifer material and unit: Qal, alluvium; Tft, Tongue River Member of Fort Union Formation; Tfl, Lebo Shale Member of Fort Union Formation; Tftu, Tullock Member of Fort Union Formation. Static water level: F, flowing. Discharge: R, reported when drilled. Abbreviations: °C, degrees Celsius; micromhos, micromhos per centimeter at 25°C]

Well No. (fig. 2)	Owner	Location	Date drilled (month-day-year)	Altitude of land surface (feet above sea level)	Depth drilled (feet below land surface)	Aquifer material and unit (in parentheses)	Depth to top of aquifer (feet below land surface)
P-1	Trusler	NE¼NW¼NW¼SE¼ sec. 13, T. 3 S., R. 44 E.	--	2,960	930	Sandstone (Tftu)	--
P-2	Trusler	NE¼SE¼SE¼SE¼ sec. 13, T. 3 S., R. 44 E.	1910	2,955	300	Probably sandstone (lower Tft)	--
P-3	Trusler	SE¼SW¼SW¼SE¼ sec. 19, T.3 S., R. 45 E.	--	2,990	1,000	Sandstone (Tftu)	--
P-4	Trusler	SW¼NW¼SE¼SE¼ sec. 19, T.3 S., R. 45 E.	1924	2,965	280	Probably sandstone (lower Tft)	--
P-5	Shy	NE¼SE¼SW¼SE¼ sec. 31, T. 3 S., R. 45 E.	12-22-44	3,130	168	Sandstone (middle Tft)	150
P-6	Shy	SW¼NE¼SE¼SE¼ sec. 32, T. 3 S., R. 45 E.	1934	3,010	372	Sandstone (lower Tft)	319
P-7	Trusler	NE¼SE¼SW¼NW¼ sec. 33, T. 3 S., R. 45 E.	--	3,022	900	Sandstone (Tftu)	--
P-8	Shy	NE¼SE¼NW¼SW¼ sec. 33, T. 3 S., R. 45 E.	1963	3,010	435	Probably sandstone (lower Tft)	--
P-9	Willow Crossing School	SW¼NW¼SE¼SW¼ sec. 33, T. 3 S., R. 45 E.	04-20-34	3,020	379	Sandstone (lower Tft)	352
P-10	Shy	SW¼SW¼SE¼NW¼ sec. 4., T. 4 S., R. 45 E.	1940	3,025	435	Probably sandstone (lower Tft)	--
P-11	Freestad	NE¼SW¼NW¼SE¼ sec. 4, T. 4 S., R. 45 E.	--	3,015	250	Probably sandstone (lower Tft)	--
P-12	Freestad	NW¼SE¼NW¼SE¼ sec. 4, T. 4 S., R. 45 E.	--	3,015	50	Sand and gravel (Qal)	--
P-13	Badgett	SW¼NW¼NW¼SE¼ sec. 9, T. 4 S., R. 45 E.	1956	3,045	800	Sandstone (Tftu)	--
P-14	Badgett	NE¼NW¼SE¼SE¼ sec. 9, T. 4 S., R. 45 E.	06-18-65	3,030	780	Sandstone (Tftu)	732
P-15	Badgett	SE¼SE¼SW¼SW¼ sec. 15, T. 4 S., R. 45 E.	--	3,050	700	Sandstone (Tfl)	--
P-16	Badgett	SW¼NW¼NW¼SE¼ sec. 15, T. 4 S., R. 45 E.	1960	3,070	450	Sandstone (lower Tft)	--
P-17	Badgett	SE¼SW¼NW¼SE¼ sec. 17, T. 4 S., R. 45 E.	--	3,150	--	--	--

Aquifer thickness (feet)	Casing diameter (inches)	Depth cased (feet below land surface)	Casing perforations (feet below land surface)	Date of hydrologic data (month-day-year)	Static water level (feet below land surface)	Discharge (gallons per minute)	Onsite water temperature (°C)	Onsite specific conductance (micromhos)	Onsite pH (units)	Chemical analysis available (table 7)
--	6.0	--	--	12-19-73	F	1.6	13.5	2,750	8.8	yes
--	6.0	--	--	12-19-73	F	3.2	12.5	1,600	--	no
--	6.0	--	--	12-18-73	F	1.6	14.0	2,800	--	no
--	2.5	--	--	08-13-75	F	1±	7.5	1,390	7.9	yes
15	4.0	150	open hole	08-13-75	140	3.5	--	4,400	7.5	yes
47	2.5	317	open hole	02-26-76	F	5 ±	--	1,400	8.2	yes
--	4.0	--	--	12-18-73 10-28-80	F F	2.0 1.7	16.0 14.5	-- 2,400	-- 8.1	no yes
--	2.0	--	--	12-21-73 10-28-80	F F	1.6 .9	12.5 12.0	1,750 1,480	8.5 8.4	no yes
24	4.0	--	--	09-06-67	F	.1	--	--	--	no
--	4.0	--	--	12-21-73	F	10 R	12.5	1,700	--	no
--	4.0	--	--	01-12-74	F	--	13.0	1,250	8.3	yes
--	4.0	--	--	01-12-74	11	6	10.0	3,000	8.2	yes
--	2.0	--	--	05-27-75 10-28-80	F F	3.1 2.0	16.0 15.5	2,300 2,350	8.2 8.1	yes yes
48	2.0	780	740-780	05-29-75	F	1.8	15.0	2,460	8.0	yes
--	2.0	--	--	12-19-73	F	3	14.0	1,540	8.4	yes
--	2.0	--	--	05-29-75	F	.1	11.5	2,330	8.1	yes
--	4.0	--	--	03-24-81	153.2	--	--	--	--	no

Table 1.--*Construction and hydrologic data from private and public wells*--Continued

Well No. (fig. 2)	Owner	Location	Date drilled (month-day-year)	Altitude of land surface (feet above sea level)	Depth drilled (feet below land surface)	Aquifer material and unit (in parentheses)	Depth to top of aquifer (feet below land surface)
P-18	U.S. Forest Service (Newell Creek well)	SW¼SE¼NE¼SE¼ sec. 19, T. 4 S., R. 45 E.	04-20-58	3,295	326	Sandstone and Knobloch coal (Tft)	255
P-19	Gaskill	SE¼NE¼SW¼SW¼ sec. 20, T. 4 S., R. 45 E.	06-50	3,245	180	Sandstone (middle Tft)	140
P-20	Badgett	SW¼SW¼SE¼NE¼ sec. 22, T. 4 S., R. 45 E.	--	3,055	440	Probably sandstone (lower Tft)	--
P-21	Capra	SW¼SE¼NW¼SW¼ sec. 22, T. 4 S., R. 45 E.	1956	3,080	700	Sandstone (Tfl)	--
P-22	Capra	NW¼SW¼SW¼SW¼ sec. 23, T. 4 S., R. 45 E.	12-73	3,080	454	Sandstone (lower Tft)	394
P-23	Capra	SE¼SW¼SW¼NE¼ sec. 27, T. 4 S., R. 45 E.	01-15-56	3,080	354	Sandstone (lower Tft)	300
P-24	Capra	NW¼NE¼NW¼SE¼ sec. 27, T. 4 S., R. 45 E.	1969	3,075	59	Sand and gravel (Qal)	22
P-25	Capra	NE¼SE¼SE¼NE¼ sec. 28, T. 4 S., R. 45 E.	1969	3,150	130	Probably sandstone (middle Tft)	--
P-26	Denson	NE¼NW¼SW¼NE¼ sec. 3, T. 5 S., R. 45 E.	--	3,120	700	Sandstone (Tfl)	--
P-27	Denson	SE¼SE¼NW¼NW¼ sec. 4, T. 5 S., R. 45 E.	1960	3,239	250	Probably sandstone (middle Tft)	--
P-28	U.S. Forest Service (Chromo Creek well)	NW¼NE¼NE¼NE¼ sec. 5, T. 5 S., R. 45 E.	05-02-62	3,300	270	Sandstone (middle Tft)	250
P-29	U.S. Forest Service (Brian Creek well)	SW¼SW¼NW¼NW¼ sec. 8,T. 5 S., R. 45 E.	--	3,555	150	Probably sandstone (middle Tft)	--
P-30	Denson	NE¼NE¼SE¼SE¼ sec. 9, T. 5 S., R. 45 E.	04-59	3,205	970	([1])	--
P-31	Denson	SW¼NE¼NW¼NW¼ sec. 11, T. 5 S., R. 45 E.	04-61	3,120	1,020	Sandstone (Tftu)	920
P-32	Denson	SE¼SW¼SE¼SW¼ sec. 11, T. 5 S., R. 45 E.	--	3,130	250	Probably sandstone (lower Tft)	--
P-33	Denson	SE¼SE¼SE¼NE¼ sec. 15, T. 5 S., R. 45 E.	--	3,145	1,243	Sandstone (Tftu)	1,052
P-34	Bull	NW¼SW¼NW¼SE¼ sec. 16, T. 5 S., R. 45 E.	1966	3,310	192	Sandstone (middle Tft)	175

[1]Well depth indicates Tullock sandstone aquifer. Chemical-quality data (table 7) indicate Tongue River middle sandstone aquifer.

Aquifer thickness (feet)	Casing diameter (inches)	Depth cased (feet below land surface)	Casing perforations (feet below land surface)	Date of hydrologic data (month-day-year)	Static water level (feet below land surface)	Discharge (gallons per minute)	Onsite water temperature (°C)	Onsite specific conductance (micromhos)	Onsite pH (units)	Chemical analysis available (table 7)
15	4.0	--	--	06-26-75	--	3	13.0	3,850	8.0	yes
30	4.0	125	open hole	12-19-73	130	5	10.0	2,600	7.5	yes
--	2.0	--	--	01-29-74	F	1.5	15.5	1,500	8.2	yes
--	2.5	--	--	12-19-73 03-25-81	F F	1.3 .3	13.0 12.0	1,060 1,020	8.6 --	no no
50	2.5	--	--	01-14-74	F	2.1	14.5	990	8.3	yes
42	4.0	--	--	12-17-73	F	2.0	11.0	950	8.4	yes
--	4.0	--	--	11-23-76	22	15	9.5	2,700	7.6	yes
--	4.0	--	--	06-26-75	60	4	12.0	4,100	7.0	yes
--	--	--	--	12-18-73	F	3±	7.0	1,700	8.3	yes
--	4.0	250	--	01-13-74	150	--	13.0	960	8.3	yes
20	4.0	270	240-270	09-20-67	--	20±	--	--	--	no
--	4.0	--	--	08-12-75	85	--	--	--	--	no
--	2.0	--	--	06-25-75	30	3±	11.5	3,480	7.5	yes
85	2.0	1,008	--	06-26-75	F	6	16.5	2,350	8.0	yes
--	2.0	--	--	06-25-75	--	20±	12.0	2,300	7.4	yes
100	2.0	1,239	--	12-18-73	F	1.4	13.5	2,400	8.2	yes
17	4.0	--	--	12-20-73	150	--	--	--	--	no

Table 2.--*Construction and lithologic data from test holes*

[ft, feet]

Test-hole No. (fig. 2)	Local identification	Location	Date drilled (month-day-year)	Altitude of land surface (feet above sea level)	Drilled depth (feet below land surface)	Aquifer material	Top of aquifer, (feet below land surface)	Aquifer thickness, (feet)	Remarks
T-1	US77-24	SE¼SW¼NW¼SW¼ sec. 32, T. 3 S., R. 45 E.	05-11-77	3,152	45	Clinker	--	--	Hole drilled into clinker from surface; did not reach water table.
T-2	SH70-55	SW¼SW¼NW¼SW¼ sec. 5, T. 4 S., R. 45 E.	1970	3,250	261	Knobloch coal bed	201	60	Assume hole penetrated entire thickness of coal.
T-3	US77-27	NW¼SW¼NE¼ sec. 8, T. 4 S., R. 45 E.	05-12-77	3,217	280	Sandstone	66	44	Upper part of sandstone may be dry. Well site approximately located.
						Knobloch coal bed	196	68	
T-4	SS-06	NW¼SE¼SW¼SE¼ sec. 16, T. 4 S., R. 45 E.	--	3,160	180	Knobloch coal bed	120	47	Hole not deep enough to reach lower Knobloch coal bed.
T-5	US77-21	NW¼SW¼SW¼NW¼ sec. 22, T. 4 S., R. 45 E.	05-04-77	3,095	200	Knobloch coal bed	76	68	Coal is 48 ft thick in upper bed and 20 ft thick in lower bed.
T-6	P-3555	NE¼NE¼NW¼ sec. 27, T. 4 S., R. 45 E.	--	3,120	200	Lower Knobloch coal bed	80	18	Upper Knobloch eroded from this site.
T-7	P-1060	NW¼NE¼NW¼NW¼ sec. 27, T. 4 S., R. 45 E.	--	3,140	220	Knobloch coal bed	127	68	Coal is 47 ft thick in upper bed and 21 ft thick in lower bed.
T-8	P-1009	SE¼SW¼NW¼SW¼ sec. 27, T. 4 S., R. 45 E.	--	3,220	240	Sawyer "2" coal bed	65	5	Sawyer "2" bed pinches in and out in this vicinity.
						Knobloch coal beds	172	45	Coal is 33 ft thick in upper bed and 12 ft thick in lower bed. Either upper Knobloch bed thins abruptly to south, or hole is not deep enough to reach lower Knobloch bed.
T-9	Hose-Austin Govt. No. 1	SW¼NE¼NE¼NE¼ sec. 28 ,T. 4 S., R. 45 E.	--	3,168	--	Knobloch coal bed	137	65	Coal is 47 ft thick in upper bed and 18 ft thick in lower bed.
T-10	Newell/ 28	SE¼SE¼SE¼NW¼ sec. 28, T. 4 S., R. 45 E.	06-12-78	3,240	281	Sandstone	127	67	Observation well 0-21 is about 30 ft west of this site.
						Knobloch coal bed	213	39	Coal is 30 ft thick in upper bed and 9 ft thick in lower bed. Either upper Knobloch bed thins abruptly to south or hole is not deep enough to reach lower Knobloch bed.
T-11	P-1390	SE¼NE¼SE¼NE¼ sec. 33, T. 4 S., R. 45 E.	--	3,190	120	Knobloch coal bed	54	44	Coal is 33 ft thick in upper bed and 11 ft thick in lower bed.
T-12	P-1387	NE¼NE¼SW¼NW¼ sec. 33, T. 4 S., R. 45 E.	--	3,210	180	Knobloch coal bed	115	42	Coal is 31 ft thick in upper bed and 11 ft thick in lower bed.
T-13	P-1455	NW¼NW¼SW¼SE¼ sec. 33, T. 4 S. R. 45 E.	--	3,300	220	Local coal bed	129	6	Coal bed is either a local bed or a split of the upper Knobloch coal bed.
						Knobloch coal bed	145	32	Coal is 24 ft thick in upper bed and 8 ft thick in lower bed. Apparently hole was not deep enough to reach lower Knobloch bed.
T-14	P-1052	NW¼NE¼NW¼ sec. 3, T. 5 S., R. 45 E.	--	3,230	180	Knobloch coal bed	75	30	Thin local coal bed exists above the Knobloch.
						Lower Knobloch coal bed	142	11	

Table 2.--*Construction and lithologic data from test holes*--Continued

Test-hole No. (fig. 2)	Local identification	Location	Date drilled (month-day-year)	Altitude of land surface (feet above sea level)	Drilled depth (feet below land surface)	Aquifer material	Top of aquifer, (feet below land surface)	Aquifer thickness, (feet)	Remarks
T-15	P-1039	SE¼SE¼SW¼NW¼ sec. 3, T. 5 S., R. 45 E.	--	3,160	160	Sand and gravel	20	23	Most of upper and middle Knobloch coal beds eroded from this site.
						Middle Knobloch coal bed	43	5	
						Lower Knobloch coal bed	100	10	--
T-16	P-1047	NW¼NW¼SW¼SW¼ sec. 3, T. 5 S., R. 45 E.,	--	3,190	180	Knobloch coal bed	54	31	Coal is 25 ft thick in upper bed and 6 ft thick in middle bed.
						Lower Knobloch coal bed	144	10	--
T-17	Chromo/04	SE¼SE¼NE¼NW¼ sec. 4, T. 5 S., R. 45 E.	12-02-77	3,265	232	Sandstone	60	17	Observation well 0-22 is about 90 ft east of this site. Another fairly permeable sandstone from 118 to 131 ft.
						Local coal bed	143	6	May be split of upper Knobloch.
						Knobloch coal bed	155	31	Coal with 1- to 2-ft-thick shale beds.
						Lower Knobloch coal bed	215	10	--
T-18	P-1026	SE¼NE¼NE¼NW¼ sec. 9, T. 5 S., R. 45 E.	--	3,290	280	Knobloch coal bed	139	31	3-ft-thick local coal bed lies above Knobloch. Coal is 25 ft thick in upper bed and 6 ft thick in middle bed.
						Lower Knobloch coal bed	239	10	--
T-19	P-1054	NW¼NE¼NE¼SW¼ sec. 9, T. 5 S., R. 45 E.	--	3,280	220	Knobloch coal bed	153	44	Coal is 33 ft thick in upper bed and 11 ft thick in middle bed; apparently hole was not deep enough to reach lower Knobloch bed.
T-20	P-1022	NW¼SW¼SW¼SW¼ sec. 9, T. 5 S., R. 45 E.	--	3,300	280	Knobloch coal bed	158	26	3-ft-thick local coal bed lies above Knobloch. Coal is 21 ft thick in upper bed and 5 ft thick in middle bed.
						Lower Knobloch coal bed	242	8	Lower coal is two beds, 2 and 6 ft thick.
T-21	P-1013	SW¼SE¼SE¼NW¼ sec. 15, T. 5 S., R. 45 E.	--	3,280	300	Knobloch coal bed	73	21	4-ft-thick local coal bed lies above Knobloch.
						Middle Knobloch coal bed	125	3	Middle Knobloch bed is separated from the main coal bed by an abruptly thickening shale wedge.
						Lower Knobloch coal bed	175	7	Lower coal bed is two beds, 1.5 and 5.5 ft thick.
T-22	P-1003	NW¼SW¼SW¼ sec. 15, T. 5 S., R. 45 E.	--	3,330	300	Knobloch coal bed	204	21	4-ft-thick local coal bed lies above Knobloch. Apparently hole was not deep enough to reach lower Knobloch bed.
T-23	SS-07	SE¼NW¼NE¼ sec. 16, T. 5 S., R. 45 E.	--	3,288	170	Knobloch coal bed	124	30	4-ft-thick local coal bed lies above Knobloch. Apparently hole was not deep enough to reach middle and lower Knobloch beds.
T-24	P-1005	NW¼NW¼NW¼NW¼ sec. 23, T. 5 S., R. 45 E.	--	3,200	200	Middle Knobloch coal bed	71	3	Upper Knobloch coal bed burned at this site.
						Lower Knobloch coal bed	128	9	

Table 3.--*Construction and hydrologic data from observation wells completed in the Tongue River Member of the Fort Union Formation*

[ft, feet; °C, degrees Celsius; micromhos, micromhos per centimeter at 25°C]

Well No. (fig. 2)	Local identification	Location	Date drilled (month-day-year)	Altitude of land surface (feet above sea level)	Drilled depth (feet below land surface)	Aquifer material
0-7	OC#39	SE¼SW¼NE¼SW¼ sec. 5, T. 4 S., R. 45 E.	07-11-80	3,230	257	Knobloch coal bed
0-8	US77-23	NW¼SE¼NW¼SE¼ sec. 6, T. 4 S., R. 45 E.	05-10-77	3,255	320	Knobloch coal bed
0-9	Shy/6	NW¼SE¼NW¼SE¼ sec. 6, T. 4 S., R. 45 E.	06-21-78	3,255	314	Knobloch coal bed
0-10	OC#30	NE¼NW¼NE¼SW¼ sec. 7, T. 4 S., R. 45 E.	06-22-80	3,225	292	Knobloch coal beds. Good coal from 222 to 255 ft; coal and shale partings from 258 to 287 ft
0-11	OC#13	SE¼NE¼SE¼SE¼ sec. 8, T. 4 S., R. 45 E.	05-27-80	3,230	276	Knobloch coal beds. Good coal from 203 to 229 ft; coal and shale partings from 239 to 267 ft
0-16	OC#03	NE¼NW¼SW¼SW¼ sec. 15, T. 4 S., R. 45 E.	05-22-80	3,115	170	Knobloch coal bed
0-17	OC#22	SW¼NE¼SE¼SW¼ sec. 16, T. 4 S., R. 45 E.	06-17-80	3,120	192	Knobloch coal beds. Good coal from 114 to 161 ft; coal and shale partings from 164 to 185 ft
0-18	OC#26	SW¼SE¼SW¼SW¼ sec. 17, T. 4 S., R. 45 E.	06-22-80	3,235	305	Knobloch coal beds; some shale partings
0-19	OC#28	NE¼SW¼SW¼SW¼ sec. 21, T. 4 S., R. 45 E.	06-20-80	3,160	230	Knobloch coal beds. Good coal from 145 to 194 ft; coal and shale partings from 208 to 228 ft
0-20	OC#55	SW¼SW¼NW¼NW¼ sec. 22, T. 4 S., R. 45 E.	07-26-80	3,125	296	Flowers-Goodale coal bed
0-21	US77-25	SE¼SE¼SE¼NW¼ sec. 28, T. 4 S., R. 45 E.	05-11-77	3,240	270	Sandstone and Knobloch coal beds. Sandstone from 146 to 158 ft and 172 to 200 ft. Good coal from 213 to 236 ft and 256 to 263 ft.
0-22	US77-26	SW¼SW¼NW¼NE¼ sec. 4, T. 5 S., R. 45 E.	05-11-77	3,260	260	Knobloch coal beds. Good coal from 152 to 174 ft and 212 to 216 ft. Some shale partings
0-23	WO#01	NE¼NE¼NW¼NW¼ sec. 23, T. 5 S., R. 45 E.	11-02-79	3,190	172	Sandstone, below Knobloch coal bed.
0-24	WO#02	NE¼NE¼NW¼NW¼ sec. 23, T. 5 S., R. 45 E.	11-06-79	3,188	112	Lowest Knobloch coal bed
0-25	WO#03	NE¼NE¼NW¼NW¼ sec. 23, T. 5 S., R. 45 E.	11-06-79	3,186	66	Sandstone, between Knobloch coal beds
0-27	WO#05	NE¼SE¼NW¼NE¼ sec. 23, T. 5 S., R. 45 E.	11-08-79	3,160	192	Sandstone, below Knobloch coal bed. Some shale partings
0-28	WO#06	NE¼SE¼NW¼NE¼ sec. 23, T. 5 S., R. 45 E.	11-08-79	3,160	82	Lowest Knobloch coal bed

Top of aquifer (feet below land surface)	Bottom of aquifer (feet below land surface)	Aquifer thickness (feet)	Casing diameter (inches)	Depth cased (feet below land surface)	Casing perforations (feet below land surface)	Packer setting (feet below land surface)	Date of hydrologic data (month-day-year)	Static water level (feet below land surface)	Pumping water level (feet below land surface)
183	249	66	4.5	257	187-257	177	08-25-80	192	--
221	286	65	4.0	295	219-289	180	08-14-80	224.2	232.6
221	287	66	2.0	314	220-280	--	08-14-80	223.8	--
222	288	52	4.5	287	217-287	217	08-17-80	190.8	244
203	268	45	4.5	268	198-268	198	08-20-80	166.5	217
99	164	48	4.5	151	73-151	72	10-28-80	80.6	--
114	185	62	4.5	192	120-192	112	09-13-80	92.3	--
226	295	55±	4.5	395	235-295	235	08-25-80	197.4	--
145	228	54	4.5	229	159-229	159	10-27-80	79.4	--
274	280	1	4.5	285	279-285	265	10-28-80	69.1	--
145	263	70	4.0	269	146-236 and 256-266	140	10-28-80	127.4	140
152	222	32	4.0	223	143-192 and 212-223	130	10-27-80	142	200
148	167	12	4.0	172	151-167	135	10-22-80	35.0	165
102	108	6	4.0	111	96-111	--	10-25-80	45.2	53
57	63	5	4.0	66	57-62	56	10-21-80	46.1	56
144	180	16	4.0	192	152-172	120	10-23-80	14.7	23
71	78	6	4.0	82	72-78.5	70	10-23-80	23.6	75

Discharge (gallons per minute)	Specific capacity (gallons per minute of drawdown)	Onsite water temperature (°C)	Onsite specific conductance (micromhos)	Onsite pH (units)	1980 water-level fluctuation (feet below land surface)	Remarks
1±	--	--	--	--	--	--
12.6	1.5	13	1,450	8.2	224.1-224.3	--
--	--	--	--	--	223.8-224.0	Used for observation during 0-8 aquifer test.
5.2	.1	14	8,800	7.7	190.4-191.1	--
2.1	.04	13	8,500	7.0	166.5-168.8	--
1±	--	--	--	--	79.3-80.6	Casing stopped 19 ft higher than planned.
--	--	--	--	--	92.3-92.8	Perforated interval does not include uppermost 6 ft of coal aquifer.
--	--	--	--	--	--	Perforated interval does not include uppermost 9 ft of coal aquifer. Measured depth was 244 ft in August 1980; thus, well is no longer open to lower part of Knobloch coal aquifer.
--	--	--	--	--	--	Perforated interval does not include uppermost 14 ft of coal aquifer.
--	--	--	--	--	--	Perforated interval does not match coal aquifer interval.
7.6	.6	13	2,100	8.0	126.8-127.4	Well perforated in 40 ft of sandstone and 30 ft of coal aquifers. No perforations opposite lower 7 ft of upper Knobloch, nor upper 4 ft of middle Knobloch coal bed.
3.6	.06	13	3,000	7.5	54.8-142	Apparently all intervals of Knobloch coal are penetrated.
8.5	.06	12	860	8.4	34.8-35.2	Recorder installed. Water level directly affected by atmospheric pressure
19	2.4	12	1,070	8.5	43.7-45.3	No packer. Water from coal and overlying sandstone flows freely along drill-hole column.
18	1.8	11.5	3,400	7.0	44.8-46.2	Well 0-25 is probably hydrologically connected with alluvial aquifer 250 ft to east.
20.4	2.4	11.5	760	8.6	14.4-14.7	Water level probably affected by atmospheric pressure.
7.0	.13	11	1,750	8.4	21.6-23.7	Well is tightly sealed from wells 0-27 and 0-29.

Table 4 begins on next page

Table 4.--*Construction and hydrologic data from observation wells completed in alluvium*

[ft, feet; °C, degrees Celsius; micromhos, micromhos per centimeter at 25°C]

Well No. (fig. 2)	Local identification	Location	Date drilled (month-day-year)	Altitude of land surface (feet above sea level)	Drilled depth (feet below land surface)	Aquifer material	Top of aquifer (feet below land surface)	Bottom of aquifer (feet below land surface)	Casing diameter (inches)	Depth cased (feet below land surface)	Casing perforations (feet below land surface)
O-1	WO#12	SE¼SE¼NE¼NW¼ sec. 4, T. 4 S., R. 45 E.	12-04-79	3,015	71	Sand and gravel, good gravel from 56 to 67 ft; alternating mud layers	15	67	4.0	71	14-65
O-2	WO#13	NE¼NE¼SE¼NW¼ sec. 4, T. 4 S., R. 45 E.	12-05-79	3,017	67	Sand and gravel, good gravel from 19 to 27 ft; alternating mud layers	8	62	4.0	67	8-63
O-3	WO#14	NW¼SE¼SE¼NW¼ sec. 4, T. 4 S., R. 45 E.	12-06-79	3,020	72	Sand and gravel, good gravel from 24 to 32 ft; alternating mud layers	9	69	4.0	72	7-70
O-4	WO#15	NW¼SE¼SE¼NW¼ sec. 4, T. 4 S., R. 45 E.	12-07-79	3,022	73	Sand and gravel, good gravel from 25 to 33 ft; alternating mud layers	10	70	4.0	73	8-72
O-5	WO#16	SW¼NE¼NE¼SW¼ sec. 4, T. 4 S., R. 45 E.	12-11-79	3,040	61	Sand and gravel, good gravel from 27 to 38 ft; alternating mud layers	24	60	4.0	61	21-61
O-6	OC#41	NW¼NE¼NE¼NE¼ sec. 5, T. 4 S., R. 45 E.	07-11-80	3,030	72	Sand and gravel, good gravel from 28 to 39 ft; alternating mud layers	29	66	4.5	60	30-60
O-12	OC#2A	NE¼NE¼SW¼SE¼ sec. 9, T. 4 S., R. 45 E.	05-21-80	3,040	70	Sand and gravel, good gravel from 43 to 64 ft; alternating mud layers	15	64	4.5	67	36.5-66.5
O-13	OC#08	SW¼NW¼SW¼SW¼ sec. 10, T. 4 S., R. 45 E.	05-22-80	3,030	55	Sand and gravel, good gravel from 21 to 33 ft; alternating mud layers	9	52	4.5	50	20-50
O-14	OC#06	SE¼SE¼SW¼NW¼ sec. 15, T. 4 S., R. 45 E.	05-21-80	3,035	65	Sand and gravel; alternating mud layers	18	57	4.5	60	30-60
O-15	OC#10	SE¼NE¼SW¼SW¼ sec. 15, T. 4 S., R. 45 E.	05-23-80	3,045	49	Sand and gravel; alternating mud layers	17	44	4.5	45	25-45
O-26	WO#04	NE¼NE¼NW¼NW¼ sec. 23, T. 5 S., R. 45 E.	11-07-79	3,145	31	Sand and gravel, good gravel from 19 to 27 ft; alternating mud layers	10	27	4.0	31	15-28
O-29	WO#07	NE¼SE¼NW¼NE¼ sec. 23, T. 5 S., R. 45 E.	11-09-79	3,160	40	Clinker and terrace gravels, good gravel from 25 to 29 ft and 32 to 34 ft; alternating mud layers	25	34	4.0	39	27-33
O-30	WO#08	NE¼SW¼NW¼NE¼ sec. 23, T. 5 S., R. 45 E.	11-14-79	3,155	34	Sand and gravel, good gravel from 13 to 20 ft and 26 to 32 ft, alternating mud layers	13	32	4.0	34	24-32
O-31	WO#09	NE¼SW¼NW¼NE¼ sec. 23, T. 5 S., R. 45 E.	11-15-79	3,150	45	Sand and gravel, good gravel from 19 to 28 ft and 31 to 39 ft; alternating mud layers	11	44	4.0	45	19-28 and 32-44
O-32	WO#10	NW¼SW¼NW¼NE¼ sec. 23, T. 5 S., R. 45 E.	11-27-79	3,145	43	Sand and gravel, good gravel from 19-33 ft and 37-40 ft; alternating mud layers	8	40	4.0	43	20-40
O-33	WO#11	NW¼SW¼NW¼NE¼ sec. 23, T. 5 S., R. 45 E.	11-28-79	3,145	40	Sand and gravel, good gravel from 21-27 ft and 36-39 ft; alternating mud layers	9	39	4.0	38	18-38

Packer setting (feet below land surface)	Date of hydrologic data (month-day-year)	Static water level (feet below land surface)	Pumping water level, (feet below land surface)	Discharge (gallons per minute)	Specific capacity (gallons per minute per foot of drawdown)	Onsite water temperature (°C)	Onsite specific conductance (micromhos)	Onsite pH (units)	1980 water-level fluctuation (feet below land surface)	Remarks
12	08-14-80	6.5	10.6	64	15	9.0	3,950	7.5	4.0 - 6.7	Well is 370 ft NNE of O-2, near east edge of Otter Creek flood plain.
6	08-19-80	7.4	9.6	9.9	4.5	9.0	3,450	7.5	4.4 - 7.4	Well is 530 ft NNE of O-3, on Otter Creek flood plain. Bottom filled back to 53 ft with mud.
5	08-18-80	8.9	11.5	26.6	10	9.0	4,400	7.6	6.6 - 9.1	Well is near west edge of Otter Creek flood plain. Recorder installed.
6	08-13-80	10.5	12.6	25	12	8.5	4,050	7.4	8.1 - 10.6	Well is 103 ft west of O-3, near west edge of Otter Creek flood plain. Bottom filled back to 63 ft with mud.
13	08-18-80	24.1	25.4	3.7	2.8	9.0	3,350	7.5	22.4 - 24.4	Well is 890 ft SSW of O-3, on terrace west of Otter Creek flood plain. Bottom filled back to 53 ft with mud.
--	08-25-80	30.6	--	30±	--	--	--	--	29.0 - 30.6	Well is on terrace west of Otter Creek flood plain.
none	08-19-80	15.2	17.4	24.6	11	10.0	3,700	7.5	14.5 - 15.6	Well is on lower terrace west of Otter Creek flood plain.
none	08-21-80	8.4	12.7	64	15	9.0	3,600	7.4	7.5 - 8.7	Well is near east edge of Otter Creek flood plain.
none	08-25-80	9.5	--	60±	--	--	--	--	8.3 - 9.6	Well is on lower terrace on west side of Otter Creek flood plain.
none	08-25-80	12.3	--	40±	--	--	--	--	10.3 - 12.3	Well is on lower terrace on west side of Otter Creek flood plain.
15	10-21-80	9.9	17.5	19	2.5	10.0	3,850	7.0	8.7 - 10.0	Well is about 1,500 ft WNW of O-32, near west edge of Otter Creek flood plain.
25	10-24-80	25.7	34	2.8	0.3	11.0	3,350	7.8	24.1 - 25.8	Well is 560 ft east of O-30, on terrace on east side of Otter Creek valley. Well is 20 ft SW of O-28. Water level in this well unaffected when O-28 was pumped.
22	10-24-80	15.0	26	20.4	1.8	10.0	4,600	7.3	12.7 - 15.2	Well is 290 ft ESE of O-31, on terrace on east side of Otter Creek flood plain.
18	10-25-80	11.7	14.7	21.8	7.2	9.5	5,400	7.2	9.3 - 11.8	Well is 290 ft WNW of O-30, on lower terrace on east side of Otter Creek flood plain. Recorder installed. Bottom filled back to 40 ft with mud and sand cavings.
12	10-26-80	8.8	18.4	56.5	5.8	9.0	4,600	7.3	6.5 - 8.9	Well is 340 ft west of O-31, on Otter Creek flood plain, about mid-valley.
13	10-25-80	9.0	11.2	23	10	9.0	4,400	6.9	6.7 - 9.1	Well is 18 ft north of O-32, on Otter Creek flood plain, about mid-valley.

Table 5.--*Aquifer characteristics of the coal and sandstone aquifers of the Tongue River Member of the Fort Union Formation*

[ft, feet; ss, sandstone]

Well No. (fig. 2)	Altitude of land surface (feet above sea level)	Aquifer material open to perforated casing	Contributing aquifer at water intake interval (feet below land surface)	Date of test (month-day-year)	Static water level (feet below land surface)	Drawdown (in feet)	Discharge (cubic feet per day)
0-8	3,255	Knobloch coal	221-286	08-14-80	224.2	8.4	2,400
0-10	3,225	Knobloch coal	222-255 258-264 274-287	08-17-80	190.8	53	1,000
0-11	3,230	Knobloch coal	203-229 239-245 254-267	08-20-80	166.5	50	400
0-21	3,240	Sandstone and underlying Knobloch coal	146-158 (ss) 172-200 (ss) 213-236 (coal) 256-263 (coal)	10-28-80	127.4	12.6	1,450
0-22	3,260	Knobloch coal	152-174 178-184 212-216	10-27-80	142	58	690
0-23	3,190	Sandstone below Knobloch coal	151-158 162-167	10-22-80	35.0	130	1,600
0-24	3,188	Lower Knobloch coal	102-107	10-25-80	45.2	8	3,600
0-25	3,186	Sandstone between middle and lower Knobloch coals	57-62	10-21-80	46.1	10	3,450
0-27	3,160	Sandstone below Knobloch coal	152-155 156-167 170-172	10-23-80	14.7	8.3	3,900
0-28	3,160	Lower Knobloch coal	72-78	10-23-80	23.6	51	1,300

Transmissivity (feet squared per day)	Hydraulic conductivity (feet per day)	Remarks
450	6.5	Well 0-9, 28 ft to the west, was used as an observation well. Calculated storage coefficient is about 1 x 10^{-3}. Test by M. R. Cannon.
3	.05	Single well test. Test by M. R. Cannon.
6	.1	Single well test. Test by M. R. Cannon.
200	2.5	Single well test. Sandstone is considered to be the major contributor of water.
8	.2	Single well test. Original static water level was 56 ft below surface. Early part of test apparently caused packer to seal, restricting higher level waters from entering well.
2.5	.2	Single well test. Wells 0-24 and 0-25 are nearby, but open to other aquifer intervals; they were unaffected by well 0-23 test.
230	46	Single well test. Apparently leakage occurs between wells 0-24 and 0-25, although they are perforated opposite separate aquifers; leakage seems to occur along the well column, not between aquifers.
250	50	Single well test. Leakage apparently occurs between well 0-25 and 0-24.
400	25	Single well test. Wells 0-28 and 0-29 are nearby, but open to other aquifer intervals; they were unaffected by well 0-27 test.
20	3.3	Single well test. Wells 0-27 and 0-29 are nearby, but open to other aquifer intervals; they were unaffected by well 0-28 test.

Table 6.--*Aquifer characteristics of the Otter Creek valley alluvium*

[ft, feet]

Well No. (fig. 2)	Altitude of land surface (feet above sea level)	Aquifer material open to perforated casing	Thickness of contributing aquifer (feet)	Date of test (month-day-year)	Static water level (feet below land surface)	Drawdown during test (feet below static water level)	Discharge (cubic feet per day)
O-1	3,015	Sand and gravel	31	08-14-80	6.5	4.1	12,300
O-2	3,017	Sand and gravel	26	08-19-80	7.4	2.2	1,900
O-3	3,020	Sand and gravel	36	08-18-80	8.9	2.6	5,100
O-4	3,022	Sand and gravel	34	08-13-80	10.5	2.1	4,800
O-5	3,040	Sand and gravel	25	08-18-80	24.1	1.3	700
O-12	3,040	Sand and gravel	17	08-19-80	15.2	2.2	4,700
O-13	3,030	Sand and gravel	18	08-21-80	8.4	4.3	12,300
O-26	3,145	Sand and gravel	8	10-21-80	9.9	7.6	3,600
O-29	3,160	Clinker and gravel	4	10-24-80	25.7	8	540
O-30	3,155	Sand and gravel	5	10-24-80	15.0	11	3,900
O-31	3,150	Sand and gravel	15	10-25-80	11.7	3.0	4,200
O-32	3,145	Sand and gravel	14	10-26-80	8.8	9.6	10,800

Transmissivity (feet squared per day)	Hydraulic conductivity (feet per day)	Remarks
2,500	80	Well 0-2, 370 ft to the SSW, was used as an observation well. Calculated storage coefficient of 3×10^{-4} indicates a confined aquifer. Test by M. R. Cannon.
3,500	130	Well 0-1, 370 ft to the NNW, was used as an observation well. Calculated storage coefficient is 3×10^{-4}. Test by M. R. Cannon.
4,900	130	Well 0-4, 103 ft to the west, was used as an observation well. Calculated storage coefficient is 0.01. Test by M. R. Cannon.
4,500	130	Well 0-3, 103 ft to the east, was used as an observation well. Calculated storage coefficient is 2×10^{-3}. Test by M. R. Cannon.
1,000	40	Single well test by M. R. Cannon.
3,000	170	Single well test by M. R. Cannon.
6,500	360	Single well test by M. R. Cannon.
500	60	Single well test.
250	60	Single well test. Wells 0-27 and 0-28 are nearby, but open to different aquifer intervals; they were unaffected during well 0-29 test.
200	40	Single well test; pumped well did not affect water levels in well 0-29, 560 ft to east, or well 0-31, 290 ft to WNW.
2,600	170	Single well test; pumped well did not affect water levels in well 0-30, 290 ft to ESE, or well 0-32, 340 ft to west.
2,200	150	Well 0-33, 18 ft to north, was used as an observation well. Calculated storage coefficient of 5×10^{-3}, indicates a confined aquifer.

Table 7.--*Chemical quality of water from private, public, and observation wells*

[Constituents are dissolved and constituent values are reported in milligrams per liter. Except as indicated, analyses are by Montana Bureau of Mines and Geology. Abbreviations: micromhos, micromhos per centimeter at 25°C; °C, degrees Celsius; <, less than]

Well No. (fig. 2)	Date sample collected (month-day-year)	Well depth (feet below land surface)	On-site specific conductance (micromhos)	On-site pH (units)	Onsite water temperature (°C)	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Sodium-adsorption ratio	Potassium	Bicarbonate
					Tullock Member							
P-1	12-19-73	930	2,750	8.8	13.5	18	4.2	1.7	580	60	2.5	1,300
P-7	10-28-80	900	2,400	8.1	14.5	14	3.6	1.1	590	70	2.4	1,290
P-13	05-27-75	800	2,300	8.2	16.0	12	2.5	1.3	580	75	2.9	1,390
	10-28-80	800	2,350	8.2	15.5	13	3.1	1.2	590	72	2.9	1,370
P-14	05-29-75	780	2,460	8.0	15.0	14	4.1	1.1	650	74	3.1	1,430
P-31	06-26-75	1,020	2,350	8.0	16.5	8	2.7	.2	690	110	3.4	1,550
P-33	12-18-73	1,243	2,400	8.2	13.5	12	3.4	.9	640	80	2.8	1,560
					Lebo Member							
P-15	12-19-73	700	1,540	8.4	14.0	14	3.4	1.4	390	46	1.8	960
P-26	12-18-73	700	1,700	8.3	7.0	32	7.4	3.3	380	29	3.0	420
					Tongue River Member - lower sandstones							
P-4	08-13-75	280	1,390	7.9	7.5	8	2.4	.5	350	53	1.7	820
P-6	02-26-76	372	1,400	8.2	--	8	.8	1.5	350	53	1.7	830
P-8	10-28-80	435	1,480	8.4	12.0	9	2.5	.6	360	53	1.6	865
P-11	01-12-74	250	1,250	8.3	13.0	10	3.0	.6	270	37	1.4	670
P-16	05-29-75	450	2,330	8.1	11.5	13	3.3	1.1	610	75	2.4	1,370
P-20	01-29-74	440	1,500	8.2	15.5	13	3.1	1.3	380	46	1.8	880
P-22	01-14-74	454	990	8.3	14.5	10	2.3	1.0	260	35	1.2	650
P-23	12-17-73	354	950	8.4	11.0	11	2.6	1.1	240	32	1.2	620
P-32	06-25-75	250	2,300	7.4	12.0	36	10	2.6	520	38	3.2	300
					Tongue River Member - middle sandstones							
P-5	08-13-75	168	4,400	7.5	--	990	91	190	740	10	34	550
P-19	12-19-73	180	2,600	7.5	10.0	750	91	160	320	5	8.4	910
P-25	06-26-75	130	4,100	7.0	12.0	1,000	180	140	640	8.6	12	910
O-21	11-07-77	269	1,980	8.5	13.5	29	7.1	2.6	550	45	3.6	1,460
	10-28-80	269	2,100	8.0	13.0	27	7.0	2.3	530	44	2.8	1,420
P-27	01-13-74	250	960	8.3	13.0	12	2.4	1.5	250	32	1.2	630
P-30	06-25-75	970	3,480	7.5	11.5	440	65	67	660	14	9.1	700

Carbonate	Alkalinity as $CaCO_3$	Sulfate	Chloride	Fluoride	Silica	Dissolved solids	Remarks
53	1,100	1.1	180	5.0	8.6	1,960	Sandstone
0	1,060	<.5	200	5.8	8.7	1,450	--Do.--
0	1,140	.9	110	5.5	8.8	1,410	--Do.--
0	1,120	5.3	130	4.5	9.1	1,410	--Do.--
0	1,170	2.6	160	--	8.8	1,550	--Do.--
0	1,270	.4	170	6.1	9.0	1,650	--Do.--
0	1,280	2.5	150	7.0	10	1,540	--Do.--
0	790	5.6	65	2.9	9.0	970	--Do.--
0	340	480	14	1.0	8.0	1,110	Low water temperature and large concentration of sulfate indicate casing may allow water from the Tongue River Member (probably coal) to enter well.
0	670	3.6	66	3.1	7.6	840	Sandstone, probably below Terrett coal bed.
0	680	.5	69	1.3	7.6	840	--Do.--
0	710	.8	69	4.4	8.0	870	Sandstone, basal Tongue River (or possibly Lebo) Member.
2	660	3.8	25	2.0	7.7	970	Sandstone, probably above Terrett coal bed.
0	1,120	3.8	150	1.6	9.3	1,470	Sandstone, basal Tongue River (or possibly Lebo) Member.
0	720	.5	77	2.9	8.3	920	Sandstone, basal Tongue River Member.
0	530	.5	23	2.0	9.1	620	Sandstone, probably below Terrett coal bed.
0	510	.3	20	1.8	8.3	590	Sandstone, probably above Terrett coal bed.
0	250	850	21	.7	8.2	1,580	Sandstone, probably below Flowers-Goodale coal bed. Well may receive leakage from coal beds.
0	450	2,100	15	1.4	14	3,460	Sandstone, directly overlying Knobloch coal bed.
0	750	780	11	.6	13	1,850	Sandstone, directly overlying Knobloch coal bed.
0	750	1,600	18	.4	13	3,070	Sandstone, directly overlying Knobloch coal bed; perforated casing may extend into top of Knobloch coal.
0	1,200	25	15	1.9	8.6	1,340	Well is perforated opposite 30 feet of Knobloch coal and 49 feet of overlying sandstone. Water is mixed. November 1977 sample analyzed by U.S. Geological Survey.
0	1,160	8.0	23	1.7	8.1	1,280	
5	530	1.7	22	1.5	10	615	Sandstone, directly underlying Knobloch coal bed.
0	580	1,200	11	.8	9.0	2,380	Well is deep enough to penetrate Tullock sandstone, but water is uncharacteristic of Tullock. No lithologic log available. Broken casing probably allows water from the Tongue River Member to enter well, or reported well depth is incorrect.

Table 7.--*Chemical quality of water from private, public, and observation wells*--Continued

Well No. (fig. 2)	Date sample collected (month-day-year)	Well depth (feet below land surface)	On-site specific conductance (micromhos)	On-site pH (units)	Onsite water temperature (°C)	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Sodium-adsorption ratio	Potassium	Bicarbonate
					Tongue River Member - middle sandstones--Continued							
O-23	10-22-80	172	860	8.4	12.0	7	2.0	.4	220	38	3.0	580
O-25	10-21-80	66	3,400	7.0	11.5	610	110	84	610	11	12	920
O-27	10-23-80	192	760	8.6	11.5	6	1.6	.5	200	35	1.2	510
					Tongue River Member - Knobloch coal bed							
P-18	06-26-75	326	3,850	8.0	13.0	49	9.1	6.3	1,000	64	5.7	2,500
O-8	11-10-77	295	1,470	8.3	15.0	9	2.1	.8	370	55	2.1	950
	08-14-80		1,450	8.2	13.0	10	2.2	1.0	370	53	1.8	960
O-10	08-17-80	287	8,800	7.7	15.5	260	62	25	2,000	54	11	1,040
O-22	11-09-77	223	3,400	7.5	12.5	270	59	29	820	22	11	1,190
	10-27-80		3,000	7.5	14.0	140	32	14	680	25	5.7	1,090
O-24	10-25-80	111	1,070	8.5	12.0	9	2.8	.6	280	39	1.5	710
O-28	10-23-80	82	1,750	8.4	11.0	98	17	14	400	18	3.8	780
					Alluvium							
O-1	08-14-80	71	3,950	7.5	9.0	990	110	170	480	7	16	630
O-2	08-19-80	67	3,450	7.5	9.0	960	120	160	400	6	20	570
O-3	08-18-80	72	4,400	7.6	9.0	1,200	120	220	640	8	25	760
P-12	01-12-74	50	3,000	8.2	10.0	500	90	130	360	6	23	610
P-24	11-23-76	59	2,700	7.6	9.5	660	88	110	420	7	20	670
O-4	08-13-80	73	4,050	7.4	8.5	1,100	110	200	580	8	28	740
O-5	08-18-80	61	3,350	7.5	9.0	640	76	110	520	9	22	740
O-12	08-19-80	67	3,700	7.5	10.0	820	100	140	560	8	25	810
O-13	08-21-80	50	3,600	7.4	9.0	980	110	170	450	6	20	750
O-26	10-21-80	31	3,850	7.0	10.0	1,300	140	230	520	6	19	830
O-29	10-24-80	39	3,350	7.8	10.0	1,000	130	170	450	6	14	800
O-30	10-24-80	34	4,600	7.3	10.0	1,600	180	290	630	7	19	540
O-31	10-25-80	45	5,400	7.2	9.5	1,900	210	340	740	7	22	960
O-32	10-26-80	43	4,600	7.3	9.0	1,600	160	290	610	7	23	860

Carbonate	Alkalinity as $CaCO_3$	Sulfate	Chloride	Fluoride	Silica	Dissolved solids	Remarks
0	480	1.5	13	1.9	8.1	540	Sandstone, 40 feet below lowest Knobloch coal bed.
0	760	1,200	25	1.2	8.8	2,510	Sandstone between lowest and next higher Knobloch coal beds. Leakage occurs between this well and coal aquifer in well 0-24 via the well column.
0	420	.9	12	1.4	8.4	480	Sandstone, 70 feet below lowest Knobloch coal bed.
0	2,050	200	11	1.2	7.4	2,520	Well presumed to be perforated opposite 15 feet of water-bearing sandstone and underlying 50-foot Knobloch coal bed.
0	780	30	27	2.1	8.7	910	Well perforated solely in Knobloch coal bed. November 1977 sample analyzed by U.S. Geological Survey.
0	790	52	31	2.1	8.4	950	
0	850	3,600	21	1.0	9.0	6,260	Well perforated solely in Knobloch coal bed.
0	980	1,100	14	.7	11	2,640	Well perforated solely in Knobloch coal bed, but water level changed about 70 feet during October 1980 pumping, indicating a break or resealing of the packer. November 1977 sample analyzed by U.S. Geological Survey.
0	890	720	24	1.0	10	2,020	
0	580	3.0	19	2.6	7.7	660	Well perforated in the lowest Knobloch coal bed. Leakage occurs between this well and sandstone aquifer in well 0-25, via the well column.
0	640	290	16	1.6	9.4	1,140	Well perforated in the lowest Knobloch coal bed.
0	520	1,500	12	1.0	22	2,590	One of five wells across valley, along Otter Road.
0	470	1,400	12	.7	27	2,400	--Do.--
0	620	1,900	24	.9	22	3,340	--Do.--
0	500	1,000	9.1	.8	30	2,280	--
0	550	940	17	.6	25	1,940	--
0	610	1,800	21	1.0	24	3,100	One of five wells across valley, along Otter Road.
0	610	1,100	20	1.1	24	2,260	--Do.--
0	660	1,300	12	.9	29	2,600	--
0	610	1,300	17	.8	40	2,460	--
0	680	1,700	23	1.1	23	3,080	One of five wells across valley, north of Fifteenmile Creek road.
0	650	1,300	22	.9	12	2,480	Clinker or talus material composed of clinker.
0	440	2,500	21	.9	20	3,890	One of five wells across valley, north of Fifteenmile Creek road.
0	790	2,600	14	.4	24	4,440	--Do.--
0	700	2,200	22	1.1	24	3,730	--Do.--

Table 10.--*Chemical quality of water from springs and Otter Creek*

[Except as indicated, constituents are dissolved and constituent values are reported in milligrams per liter. Analyses are by Montana Bureau of Mines and Geology. Abbreviations: micromhos, micromhos per centimeter at 25°C; °C, degrees Celsius]

Site No. (fig. 2)	Spring or station name and number	Location	Altitude of land surface at discharge point (feet above sea level)	Date sample collected (month-day-year)	Discharge: Gallons per minute	Discharge: Cubic feet per second	Onsite specific conductance (micromhos)	Onsite pH (units)	Onsite water temperature (°C)
S-1	Gene Creek Spring	NW¼NW¼SE¼SE¼ sec. 30, T. 4 S., R. 45 E.	3,450	01-14-74	0.5	--	1,900	8.0	3.0
S-2	North Fork Chromo Creek Spring	NW¼SE¼NE¼SW¼ sec. 32, T. 4 S., R. 45 E.	3,400	03-06-74	.2	--	2,600	7.9	5.5
S-3	Chromo Creek Spring	SE¼NE¼NE¼SE¼ sec. 6, T. 5 S., R. 45 E.	3,415	01-13-74	.5	--	1,600	7.8	4.5
S-4	Brian Spring No. 3A	NE¼SE¼SE¼NW¼ sec. 8, T. 5 S., R. 45 E.	3,390	01-13-74	1.0	--	1,800	7.7	8.0
S-5	Upper Brian Spring	SE¼NE¼SE¼NW¼ sec. 18, T. 5 S., R. 45 E.	3,490	10-28-80	.3	--	3,400	7.3	5.0
S-6	Little Brian Spring	SW¼SW¼NE¼NE¼ sec. 18, T. 5 S., R. 45 E.	3,440	10-28-80	.2	--	2,050	7.1	12.0
S-7	Brian Spring No. 2	SE¼SW¼NE¼NE¼ sec. 18, T. 5 S., R. 45 E.	3,435	01-12-74	.5	--	2,750	8.0	--
				10-28-80	.6	--	3,220	7.1	7.5
SW-1	Otter Creek above Tenmile Creek (06307725)	SW¼NW¼SE¼NW¼ sec. 2, T. 5 S., R. 45 E.	3,135	12-20-77	--	2.2	3,200	7.9	.0
				12-27-78	--	3.7	3,700	7.8	.0
				12-11-79	--	3.8	3,260	8.3	.5
				11-06-80	--	2.7	3,730	8.3	6.5
SW-2	Otter Creek at Ashland (06307740)	SE¼NE¼NE¼SE¼ sec. 11, T. 3 S., R. 44 E.	2,920	12-20-77	--	3.0	3,420	8.2	.0
				12-26-78	--	5.3	3,400	8.0	.0
				12-12-79	--	6.1	3,310	8.3	.0
				11-04-80	--	3.4	2,730	8.5	4.5

Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Sodium-adsorption ratio	Potassium	Bicarbonate	Carbonate	Alkalinity as $CaCO_3$	Sulfate	Chloride	Fluoride
510	110	160	95	1.3	6.3	620	0	510	650	5.1	0.4
690	160	240	180	2.1	7.1	840	0	690	1,000	10	.6
570	130	140	38	.5	4.9	690	0	570	430	5.9	.4
400	51	66	330	7.2	5.5	800	0	660	440	5.7	1.1
2,000	200	380	140	1.4	13	810	0	670	1,600	16	.3
1,100	130	200	83	1.1	7.8	660	0	540	750	10	.8
600	160	350	120	1.2	10	730	0	600	1,500	10	.6
1,900	160	370	120	1.2	10	660	0	540	1,600	14	.3
1,100	77	210	380	5.1	19	720	0	590	1,300	16	.7
1,300	190	210	410	4.9	20	720	0	590	1,500	15	.7
1,200	100	220	390	5.0	18	660	0	540	1,400	11	.7
1,200	130	220	540	6.7	23	560	0	680	1,600	11	1.0
1,100	95	200	470	6.3	23	740	0	610	1,400	18	.9
1,100	130	200	340	5.5	22	850	0	700	1,400	15	.7
1,100	89	210	450	5.9	18	690	0	570	1,400	14	.8
890	76	170	370	5.4	19	620	0	510	1,100	14	.7

Silica	Dis-solved solids	Nitrate, total (NO_3)	Formation or unit from which spring probably issues	Remarks
12	1,660	0.2	Sandstone between Pawnee and Cache coal beds.	Developed spring in valley; water probably from sandstone and alluvial sources.
18	2,500	.2	Sandstone above Cache coal bed.	Developed spring; horizontal pipe driven into sidewall of valley.
19	1,460	.1	Sandstone above Cache coal bed.	Developed spring in valley; water probably from sandstone and alluvial sources.
12	1,710	2.8	Sandstone below Cache coal; possibly partly from local coal bed.	Developed spring on hillside, about 1,000 ft east of Brian Spring No. 3.
19	2,800	--	Sandstone below Pawnee coal bed.	Developed spring in valley; water probably from sandstone and alluvial sources.
18	1,520	--	Sandstone between Pawnee and Cache coal beds.	Developed spring on hillside; same horizon as Brian Spring No. 2.
17	2,880	.8	Sandstone between Pawnee and Cache coal beds.	Developed spring in valley; water probably from coal bed and alluvial sources.
17	2,590	--		
18	2,380	.1	--	Near low-flow discharge. Geological Survey streamflow-gaging station 06307717.
19	2,720	.3		
15	2,480	.0		
17	2,950	--		
16	2,590	.4	--	Near low-flow discharge. Geological Survey streamflow-gaging station 06307740.
17	2,640	.5		
14	2,540	.2		
8.5	2,050	.2		