# EFFECTS OF POTENTIAL SURFACE COAL MINING ON DISSOLVED SOLIDS IN OTTER CREEK AND IN THE OTTER CREEK ALLUVIAL AQUIFER, SOUTHEASTERN MONTANA

by M. R. Cannon

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4206

Helena, Montana
October 1985

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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## 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** | |
| acre | 4,047 | 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 | 0.02832 | cubic meter per day |
| cubic foot per second | 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 |

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

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

# EFFECTS OF POTENTIAL SURFACE COAL MINING ON DISSOLVED SOLIDS IN OTTER CREEK AND IN THE OTTER CREEK ALLUVIAL AQUIFER, SOUTHEASTERN MONTANA

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## ABSTRACT

Otter Creek drains an area of 709 square miles in the coal-rich Powder River structural basin of southeastern Montana. The valley of Otter Creek is used extensively for the production of crops and livestock and contains a shallow alluvial aquifer that provides water for subirrigation. Shallow bedrock aquifers that discharge water to the Otter Creek valley include coal, sandstone, and clinker beds in the Tongue River Member of the Paleocene Fort Union Formation. Mining of the 40- to 70-foot-thick Knobloch coal bed in the downstream part of the basin would have the potential to increase the dissolved-solids load to Otter Creek and the alluvial aquifer through the leaching of soluble minerals from mine spoils.

A mass-balance model was developed to evaluate the pre-mining hydrologic system and to estimate the effects of potential large-scale surface mining on the dissolved-solids concentration in Otter Creek and the alluvial aquifer. The area modeled contains about 15 miles of the most downstream part of Otter Creek valley near Ashland, Montana. Model results are based on the assumption that all strippable reserves within the Knobloch coal beds would be mined from the study area.

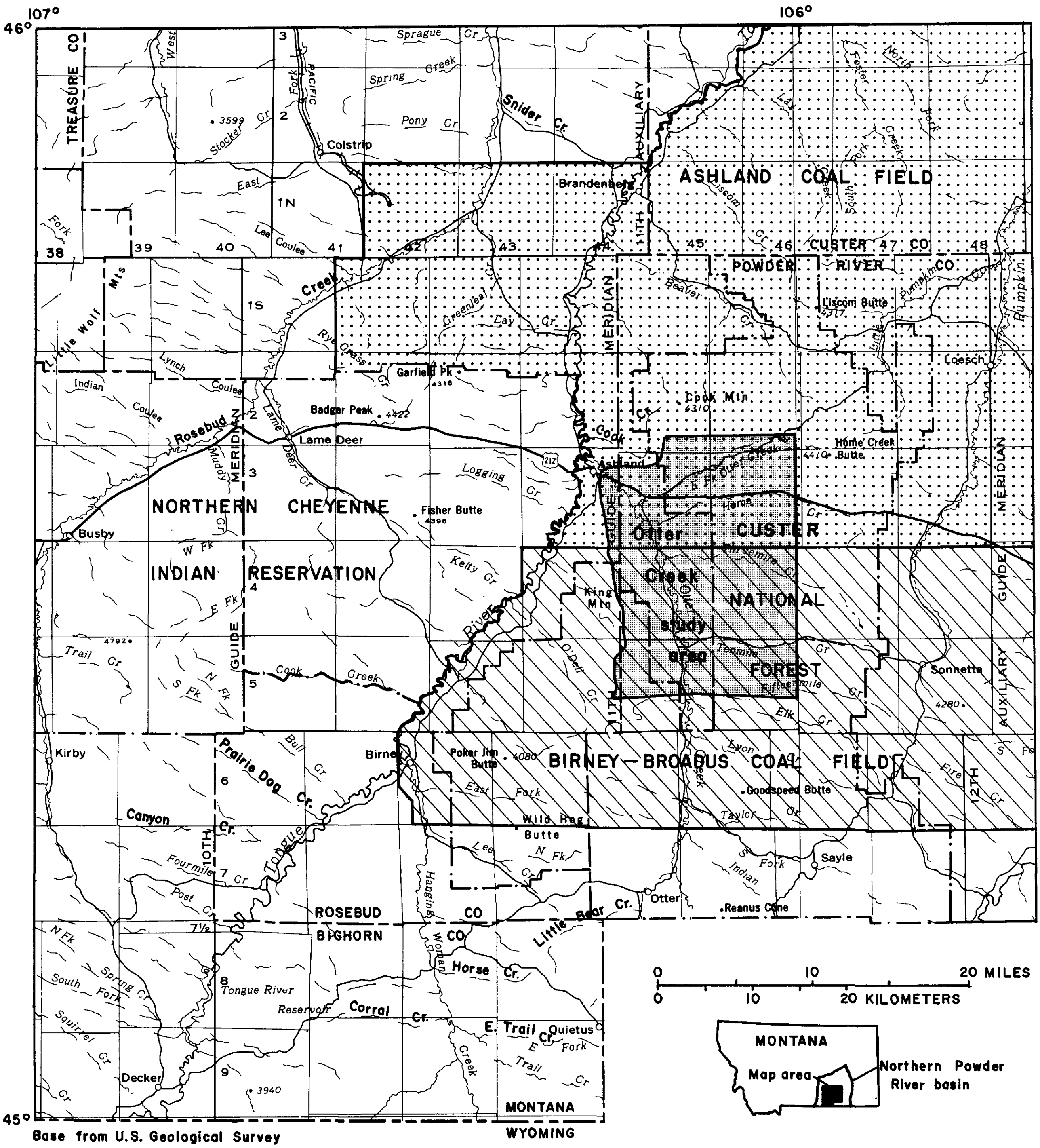
The annual post-mining load of dissolved solids to Otter Creek at Ashland at median streamflow could increase by 2,873 tons, or a 32-percent increase over the mean annual pre-mining load of 8,985 tons. Increased monthly loads of Otter Creek, at the median streamflow, could range from 15 percent in February to 208 percent in August. At the median streamflow, mean dissolved-solids concentrations of Otter Creek at Ashland could range from 1,970 mg/L (milligrams per liter) in March to 6,500 mg/L in August, an increase from the pre-mining range of 1,640 mg/L in March to 2,460 mg/L in December.

The annual post-mining dissolved-solids load to the subirrigated part of the Otter Creek alluvial valley could increase by 2,873 tons or 71 percent. The median dissolved-solids concentration in the subirrigated part of the alluvial valley could be 4,430 mg/L compared to the pre-mining median concentration of 2,590 mg/L.

Post-mining loads from the potentially mined landscape were calculated using saturated-paste-extract data from 506 overburden samples collected from 26 wells and test holes. Post-mining loads to the Otter Creek valley would likely continue at increased rates for many years (possibly hundreds) after mining. If the actual area of Knobloch coal beds disturbed by mining were less than that used in the model, post-mining loads to the Otter Creek valley would be proportionally smaller.

INTRODUCTION

Otter Creek is a small perennial stream in the northern part of the coal-rich Powder River structural basin in southeastern Montana (fig. 1). Within the Otter




Base from U.S. Geological Survey State base map, 1:500,000, 1968

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

Creek basin are vast reserves of low-sulfur strippable coal that have a good potential for development in the near future. Some of the thickest and most accessible coal deposits are located near or adjacent to the alluvial valley floor of Otter Creek.

Otter Creek is situated in a relatively flat alluvial valley that is used extensively for the production of crops and livestock. Crops in the valley are flood irrigated during times of high flow in Otter Creek and are subirrigated by the shallow water table during the growing season. Otter Creek and shallow wells in the Otter Creek valley are important sources of water for livestock.

Surface coal mining along the Otter Creek valley has the potential to conflict with the water needs of the agricultural users. Surface coal mining would remove coal and sandstone aquifers that discharge to the Otter Creek valley. After mining, ground water would flow through the backfilled mine pits and could transport large concentrations of dissolved solids into the alluvial aquifer and Otter Creek. Discharge of water having a large dissolved-solids load from the mined areas would increase the salinity of water in Otter Creek and the shallow alluvium, possibly decreasing the agricultural productivity of the valley.

## Purpose and scope

The purpose of this study was to describe the pre-mining hydrology of the Otter Creek stream-alluvial aquifer system and to assess the effects of potential surface coal mining on the dissolved solids of surface water and shallow ground water in the Otter Creek valley. Results of the study could be used by State and Federal agencies, residents of the Otter Creek area, and coal-mining interests to help evaluate cumulative effects of coal mining on the water resources of the area.

Existing data were used to characterize the hydraulic properties of aquifers, flow of Otter Creek, and water quality of surface and ground waters. During the 1983 water year (October 1982 through September 1983), many additional data were collected concerning streamflow, water quality, water levels in aquifers, and hydraulic properties of coal and sandstone aquifers. These data were used to calculate a pre-mining water budget and dissolved-solids-load budget for the Otter Creek stream-alluvial aquifer system. The budget equations are a mass-balance model where all inflows during a given time interval are equal to all outflows during the same time interval. The hydrologic data collected during the 1983 water year were used to evaluate components of the budget equations that have large temporal variations.

To evaluate the effects of potential surface coal mining on the dissolved-solids concentration in the Otter Creek stream-alluvial aquifer system, it was necessary to estimate the dissolved-solids load that mining would add to the system. Overburden samples from 26 wells and test holes were analyzed to estimate post-mining quality of water from mine spoils. For the purpose of assessing the cumulative effect of large-scale mining on the Otter Creek valley, all strippable coal within the Knobloch coal beds (as mapped by Matson and Blümer, 1973) was assumed to be mined eventually from the study area. The post-mining loads of dissolved solids were added to the median monthly flows of Otter Creek at Ashland to determine effects of mining on the stream. To evaluate the effects of mining on subirrigated alluvium in the valley, the estimated dissolved-solids load from mine spoils was added to the pre-mining load of the alluvium.

## Location and description of area

The Otter Creek study area consists of about 195 $mi^2$ of the Otter Creek basin in Powder River and Rosebud Counties, Montana (fig. 1). The study area includes about 15 miles of the Otter Creek valley and extends from Fifteenmile Creek at the southern boundary to Ashland at the northern end. The western boundary of the study area coincides with the drainage divide between the Tongue River and Otter Creek, and the eastern boundary is located from 7 to 11 miles east of the Otter Creek valley.

Boundaries of the study area were based on areas of Federal coal under consideration for lease, mine development plans, hydrologic boundaries, and potential effects on water quality in the basin. The study area contains coal lands that are adjacent to the alluvial valley floor of Otter Creek and probably have the greatest potential for development in the basin. Additional coal lands in the upstream reaches of the Otter Creek basin have the potential for large-scale surface mining, but were not included in this study because they are not located along an extensive alluvial valley floor such as those in the study area. A large part of the Otter Creek basin lies in the Custer National Forest (fig. 1). Most of the forest lands within the basin also contain vast coal deposits, but will not be mined, as stated in the "Surface Mining Control and Reclamation Act of 1977" (Public Law 95-87).

## Topography and drainage

Otter Creek and its tributaries drain the entire study area. Otter Creek is a perennial northward-flowing tributary to the Tongue River and has a drainage area of 709 $mi^2$. The reach of Otter Creek within the study area drains about 256 $mi^2$ or 36 percent of the basin. The basin of Otter Creek is asymmetrical with short, small drainages on the west side and longer drainages on the east side. Tributaries on the west side of Otter Creek typically have drainage areas of 2 to 8 $mi^2$, and the larger tributaries on the east side have drainage areas of about 46 to 60 $mi^2$. Headwaters of the tributaries typically are eroded into steep, narrow upland draws. The tributaries have relatively straight and narrow channels in the upstream and middle reaches and narrow alluvial valleys in the downstream reaches. Within the study area, almost all tributaries to Otter Creek are ephemeral.

The land surface ranges from rugged, steep-sided buttes and narrow ridges along the Tongue River-Otter Creek basin divide to the relatively flat alluvial valley of Otter Creek. The land surface was formed by erosion of flat-lying sedimentary rocks having various degrees of resistance. Hard red beds of clinker, formed where coal beds have burned along their outcrops and baked the overlying rock, are the most resistant to erosion and cap many of the steep buttes and ridges. Maximum topographic relief in the study area is about 1,270 feet, with altitudes ranging from 4,175 feet on the Tongue River-Otter Creek divide to about 2,905 feet at the mouth of Otter Creek.

Otter Creek meanders within a 1,500- to 3,000-foot-wide alluvial valley. The valley slopes about 14 ft/mi from an altitude of 3,135 feet at the upstream end of the study area near Fifteenmile Creek to 2,920 feet at the downstream end near Ashland.

## Climate

Average annual precipitation at Ashland is about 13 inches based on 25 years of record (1956-80). Precipitation increases significantly with altitude, and highland areas on interstream divides may receive an additional 3 to 4 inches of precipitation per year. April, May, and June generally have the greatest monthly precipitation and together receive about 40 percent of the annual precipitation. The average annual lake evaporation is about 40 inches or about 3 times as large as precipitation (Farnsworth and others, 1982). Air temperatures in the study 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.

## General geology

Strata of the Tongue River Member of the Paleocene Fort Union Formation and Holocene and Pleistocene alluvium, consisting of reworked material from the Tongue River Member, compose the surface of the study area (pl. 1). More than 1,000 feet of the upper and middle parts of the Tongue River Member is exposed from King Mountain, on the west side of the Otter Creek basin, to the Otter Creek flood plain (fig. 2). The Tongue River Member attains a thickness of about 1,500 feet in the study area and is composed of shale, sandstone, siltstone, and coal beds. The Knobloch coal bed, which is 40 to 70 feet thick, is the thickest coal bed in the area and is the prime target for coal mining (McClymonds, 1984). In the northern part of the study area, the Knobloch is one massive bed (fig. 3), but southward and westward it is interbedded with increasingly thicker shale and sandstone beds. At the south end of the study area, the Knobloch consists of four distinct coal seams, each 5 to 20 feet thick (fig. 3). Massive beds of fractured, red clinker exist in the northern part of the study area where the Knobloch coal bed has burned along its outcrop (pl. 1).

The Tongue River Member contains several massive beds of sandstone. In the middle part of the Tongue River Member, thick extensive sandstone beds exist between the Sawyer and Knobloch coal beds and below the Knobloch coal bed (fig. 2). In the lower part of the member, thick beds of sandstone exist below the Flowers-Goodale coal bed and near the base of the member (McClymonds, 1984). In places, the sandstone beds attain a thickness of 100 feet or more and extend throughout many square miles. In general, the thick sandstone beds are not lenticular bodies of local extent, such as river channel deposits, but rather have an extensive sheetlike occurrence (Bass, 1932). The sandstone beds are composed mostly of friable, fine-grained quartz, but also contain a comparatively large percentage of clay, which with calcium carbonate, forms a weak cementing material.

The Lebo Shale and Tullock Members of the Fort Union Formation underlie the entire study area, but are not exposed at the surface. The Lebo Shale Member is nearly 300 feet thick and consists mostly of dark-gray shale. The Tullock Member consists of interbedded sandstone and shale with thin coal beds.

Alluvium underlies the valley of Otter Creek and many of its tributary valleys (pl. 1). Alluvium in the Otter Creek valley is as much as 70 feet thick and is composed of silt, clay, sand, and gravel. In many locations in the Otter Creek valley, the alluvium contains a large thickness of well-sorted, coarse sand and gravel derived from fragments of clinker.

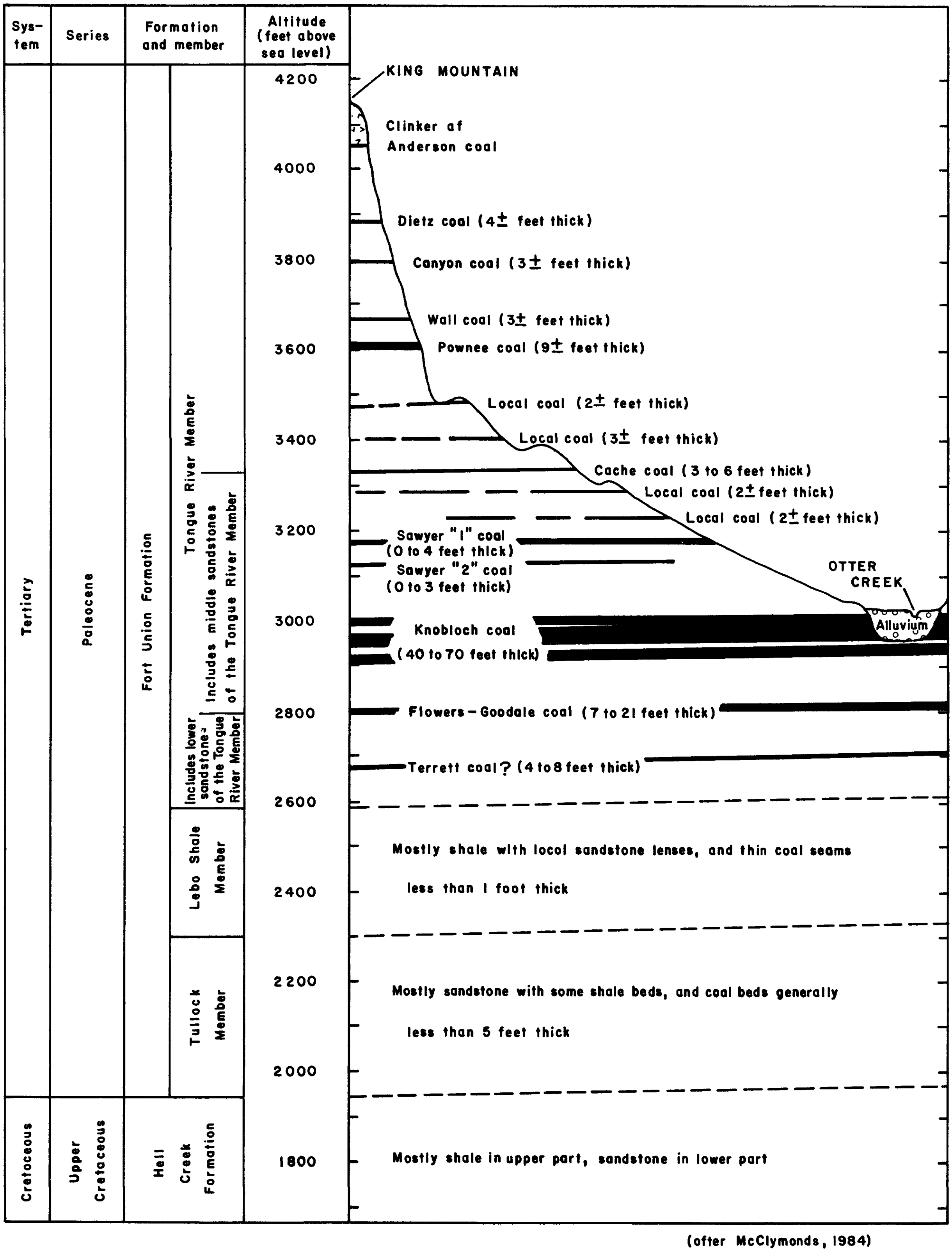



Figure 2.--Idealized section from King Mountain eastward to Otter Creek showing coal intervals and relative thicknesses of members of the Fort Union Formation.

## Ground water

The primary shallow aquifers in the Otter Creek study area are the Knobloch coal bed, Knobloch clinker, sandstone beds above and below the Knobloch coal bed, and alluvium. The average rate of recharge to the shallow aquifers is very small because of the small annual precipitation relative to evapotranspiration and the generally small permeability of the fine-grained sediments of the Tongue River Member. Mean annual recharge to shallow aquifers in the Tongue River Member is estimated to be in the range of 0.01 to 0.1 inch, based on calculated discharge rates. A large percentage of recharge probably occurs at outcrops of permeable clinker and sandstone and throughout the extent of the alluvial deposits. Mean annual recharge to clinker and alluvium probably is in the range of 1 to 3 inches, based on a study by Woessner and others (1981).

Water in shallow aquifers of the study area moves from the upper basin slopes toward Otter Creek and the Otter Creek alluvial valley, as shown by the water-level contours on plate 2. Water-level contours shown on the map are only approximate because many of the wells used as data points are open to the aquifer in a zone below the water table and have a hydraulic head slightly different than would exist at the water table. Water-level data for the map (table 1; all tables are in the Supplemental Information section at the back of the report) were collected in various years between 1959 and 1983. Water levels during the time of data collection are assumed to represent almost steady-state conditions.

In the northern part of the study area, downstream from East Fork Otter Creek, a large percentage of the ground water that discharges to the alluvium along Otter Creek originates from the Knobloch clinker. Between East Fork Otter Creek and Threemile Creek, shallow aquifers that discharge toward Otter Creek are the Knobloch coal bed, Knobloch clinker, and alluvium in the tributary valleys. In this reach, the Knobloch coal aquifer discharges to the alluvium via the Knobloch clinker or discharges directly to the alluvium where the coal subcrops in the alluvial valley (fig. 3, section A-A'). Between Threemile Creek and the upstream end of the study area near Fifteenmile Creek, the Knobloch coal aquifer, clinker, sandstone, and alluvium in tributaries all discharge water to alluvium in the Otter Creek valley. Water within the alluvium discharges primarily to Otter Creek and by evapotranspiration; only a small percentage discharges downvalley through the alluvial aquifer.

Deeper aquifers exist in sandstone beds of the Lebo Shale and Tullock Members of the Fort Union Formation. These aquifers are part of the regional ground-water flow system and have no significant discharge to the Otter Creek valley. A sandstone aquifer in the Tullock Member has a hydraulic head above parts of the Otter Creek valley, but the thick shale beds in the Lebo Shale Member effectively retard upward discharge to the Otter Creek valley. Deep wells (780 to about 1,000 feet) drilled from the valley floor to the Tullock aquifer discharge 1.4 to 6 gal/min by artesian flow (McClymonds, 1984).

## Previous investigations

Otter Creek and the surrounding areas have been the focus of many investigations, primarily because of the vast coal reserves of the region. Wegemann (1910) made a reconnaissance of part of the area to describe coals of the Custer National Forest. Coal deposits of the Ashland and the Birney-Broadus coal fields were

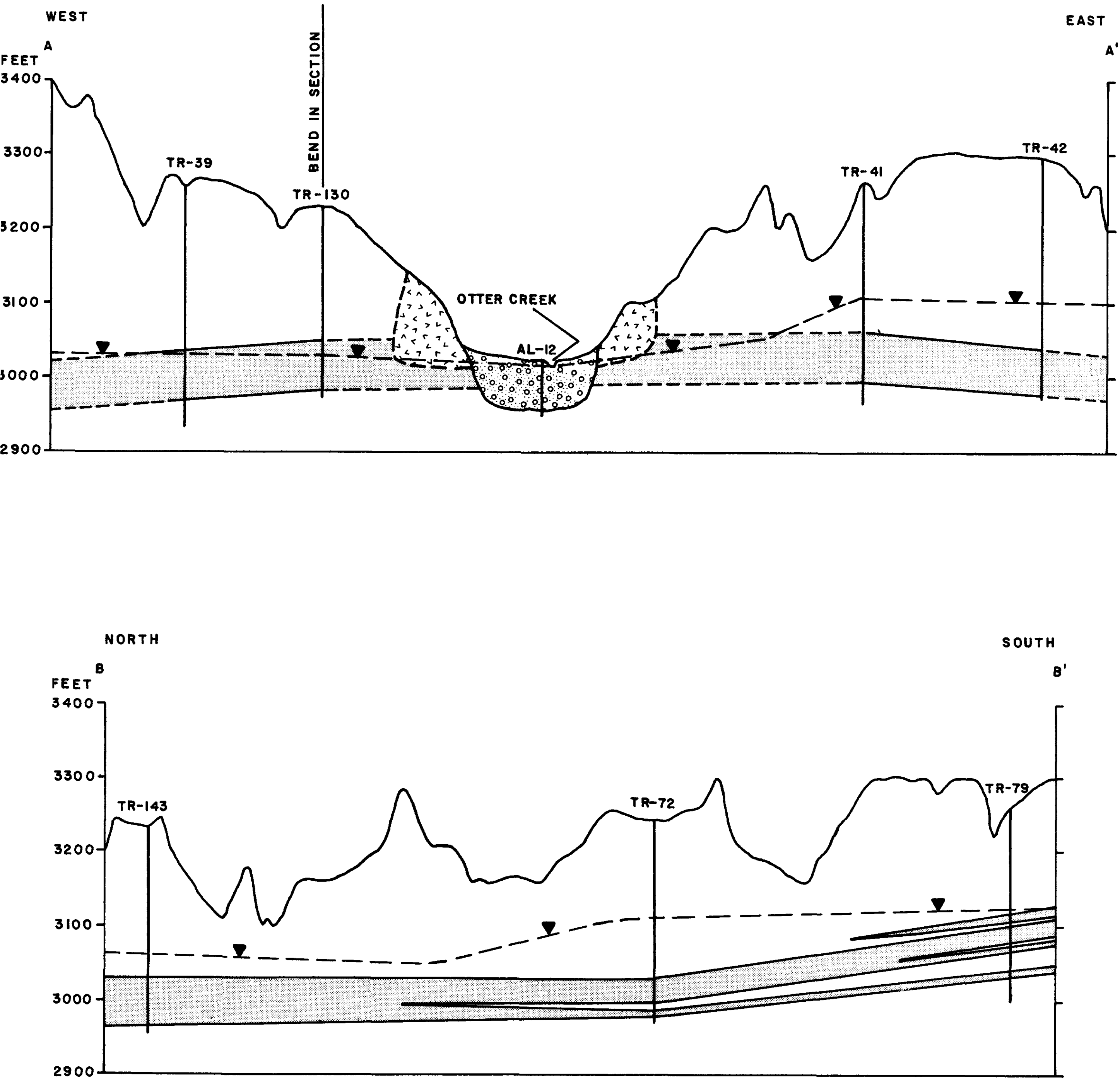
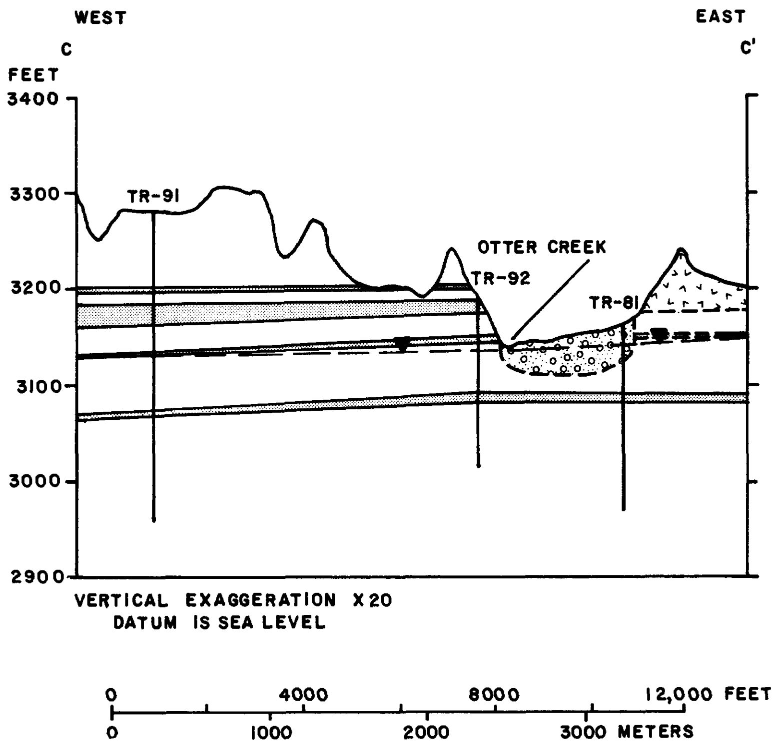



Figure 3.--Idealized stratigraphic sections A-A', B-B', and C-C'.




EXPLANATION

ALLUVIAL SAND, GRAVEL, SILT, AND CLAY (HOLOCENE AND PLEISTOCENE)

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

CLINKER

KNOBLOCH COAL BED(S) WITHIN THE TONGUE RIVER MEMBER

CONTACT--Dashed where approximately located

WATER-LEVEL SURFACE, 1983

TR-39

OBSERVATION WELL OR TEST HOLE AND NUMBER

Trace of sections is shown on plate 1.

studied and described in detail by the U.S. Geological Survey (Bass, 1932; Warren, 1959) as part of a systemmatic study and classification of western coal lands. Matson and Blumer (1973) described the quality and quantity of strippable coal within the Otter Creek area in a comprehensive report on strippable coal deposits of southeastern Montana. The geology of the Willow Crossing and King Mountain quadrangles, which include much of the Otter Creek study area, was mapped in detail by McKay (1976a, 1976b).

Ground-water resources and hydrologic characteristics of rocks in the area have been studied by Renick (1929), Perry (1931), Hopkins (1973), Lewis and Roberts (1978), and Stoner and Lewis (1980). Slagle and Stimson (1979) have compiled ground-water data from many wells in the Otter Creek basin.

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

Potential effects of coal mining on water resources in the Tongue River drainage basin have been the focus of several studies. Van Voast (1974) and Van Voast and Hedges (1975) studied the effects of coal mining on water resources in the Decker area (50 miles southwest of Ashland). Woessner and others (1979) investigated the potential effects of coal mining on the quality of ground water and surface water on the Northern Cheyenne Indian Reservation. Woods (1981) developed a computer model to assess potential increases in dissolved solids in the Tongue River as a result of leaching of mine spoils. Cannon (1982) investigated the potential effects of surface coal mining on the hydrology of the Cook Creek area near Ashland. McClymonds (1984) studied the potential effects of surface coal mining on the hydrology of the West Otter area, which includes most of the study area west of Otter Creek.

## Acknowledgments

Appreciation is expressed to the residents of the area who provided information about their wells and springs, and allowed access to their land for the drilling of observation wells and collection of hydrologic data. Thanks are extended to the Montana Bureau of Mines and Geology, Consolidation Coal Company, and Peabody Coal Company for providing data and support.

# MASS-BALANCE MODEL OF THE PRE-MINING OTTER CREEK HYDROLOGIC SYSTEM

A mass-balance model was developed to evaluate the pre-mining hydrologic system in Otter Creek and its alluvial aquifer. Mass-balance equations were developed to quantify all pre-mining inflows and outflows of water and dissolved solids in the stream-alluvial aquifer system. Boundaries of the modeled stream-alluvial aquifer system were placed at the upstream end of the study area near Fifteenmile Creek and at the downstream end near Ashland (pl. 2). Lateral boundaries of the modeled stream-alluvial aquifer system were placed at the boundary between the subirrigated and non-subirrigated areas of the Otter Creek alluvial valley (pl. 2). Lateral boundaries were placed at the edge of the subirrigated valley because all inflows and outflows of water and dissolved solids ultimately occur within Otter Creek and the subirrigated part of the valley. Boundaries of the subirrigated valley were delineated from color infrared aerial photographs of the valley and from maps of the alluvial valley floor (Malde and Boyles, 1976).

The study area was divided into 10 subareas (pl. 1), because of spatial variations in the hydrologic characteristics of the area. Inflows and outflows of each subarea were entered into the mass-balance equations. A conceptual model of the Otter Creek hydrologic system (fig. 4) shows all inflows and outflows of water and dissolved solids to Otter Creek and the subirrigated alluvium.

## Water budget

The annual water-budget equation for the Otter Creek stream-alluvial aquifer system is:

$$Q_{so} + Q_{ao} = Q_{sio} + Q_{sit} + Q_{ai} + Q_{bi} + R - ET_a - E_{fws} + \Delta\text{storage} \qquad (1)$$

where

$Q_{so}$ = surface-water outflow from Otter Creek at the downstream end of the modeled reach (all volumes in acre-feet),

$Q_{ao}$ = ground-water outflow from the alluvial aquifer at the downstream end of the model reach,

$Q_{sio}$ = surface-water inflow from Otter Creek at the upstream end of the modeled reach,

$Q_{sit}$ = surface-water inflow from tributaries along the modeled reach of Otter Creek,

$Q_{ai}$ = ground-water inflow from the alluvial aquifer at the upstream end of the modeled reach,

$Q_{bi}$ = ground-water inflow from bedrock (coal and sandstone) aquifers along the modeled reach,

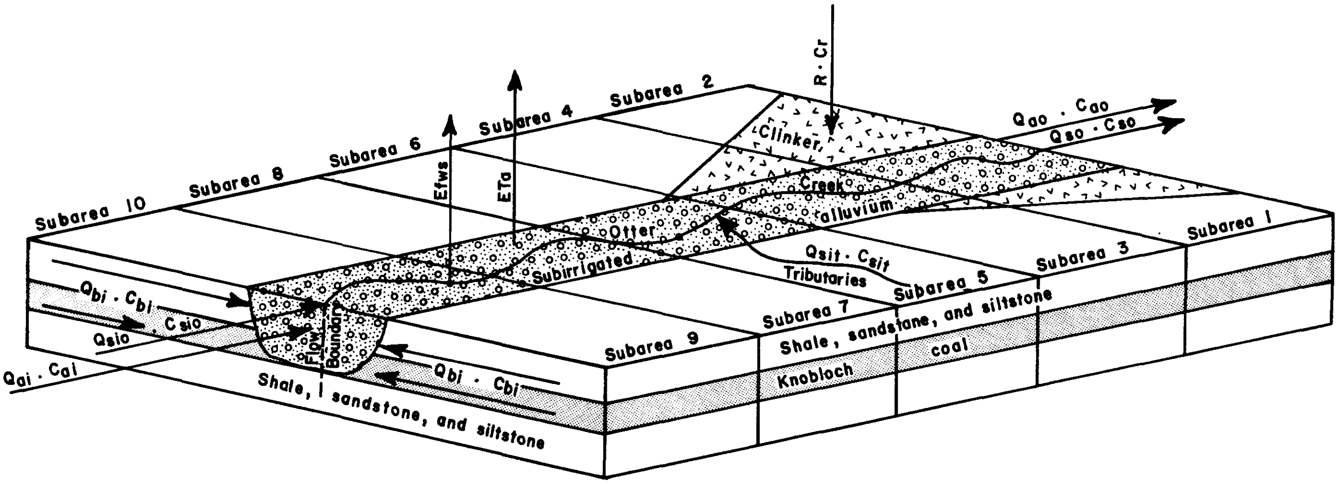
$R$ = additional recharge to ground-water system that occurs in areas of clinker and non-subirrigated alluvium along the reach,

$ET_a$ = net discharge from the subirrigated part of the alluvial aquifer by evapotranspiration,

$E_{fws}$ = net evaporation from the surface of Otter Creek, and

$\Delta$storage = change in ground-water storage within the study area.

Values for all components of the water-budget equation, except recharge, evapotranspiration, and evaporation rates, were determined from data collected in the study area. Recharge to clinker and non-subirrigated alluvium was calculated as a remainder in the water-budget equation, but was checked for validity against




EXPLANATION

$Q_{so}$ = surface-water outflow from Otter Creek

$Q_{ao}$ = ground-water outflow from the alluvial aquifer

$Q_{sio}$ = surface-water inflow from Otter Creek

$Q_{sit}$ = surface-water inflow from tributaries

$Q_{ai}$ = ground-water inflow from the alluvial aquifer

$Q_{bi}$ = ground-water inflow from bedrock aquifers

$R$ = additional recharge in areas of clinker and non-subirrigated alluvium

$ET_a$ = net discharge by evapotranspiration

$E_{fws}$ = net evaporation from Otter Creek

$C_{so}$ = dissolved-solids concentration of outflow from Otter Creek

$C_{ao}$ = dissolved-solids concentration of outflow from the alluvial aquifer

$C_{sio}$ = dissolved-solids concentration of inflow from Otter Creek

$C_{sit}$ = dissolved-solids concentration of inflow from tributaries

$C_{ai}$ = dissolved-solids concentration of inflow from the alluvial aquifer

$C_{bi}$ = dissolved-solids concentration of inflow from bedrock aquifers

$C_r$ = dissolved-solids concentration of recharge water percolating through clinker and alluvium

Figure 4.--Conceptual model of the Otter Creek hydrologic system including all inflows and outflows of water and dissolved solids.

recharge values reported in other studies conducted in the region. Evapotranspiration and evaporation rates were determined from regional data (Farnsworth and others, 1982). Data used in the mass-balance equations are from the 1983 water year (Oct. 1, 1982, to Sept. 30, 1983), except for precipitation and evaporation data, which are from long-term records. Precipitation enters the mass-balance equation in the net values for evapotranspiration and evaporation and in the ground-water and surface-water runoff values.

### Surface water

Upstream inflow of water from Otter Creek ($Q_{sio}$) was determined at the U.S. Geological Survey streamflow gaging station 06307717, located on Otter Creek downstream from the confluence with Fifteenmile Creek (pl. 2). Total annual discharge (1983 water year) at the gaging station was 2,530 acre-feet. Daily discharge data for the station are listed in table 2.

Surface-water inflow from small tributaries along the modeled reach of Otter Creek ($Q_{sit}$) was minimal. Home Creek is the only perennial stream that enters Otter Creek within the modeled reach. Total annual discharge of Home Creek was estimated to be 43 acre-feet, based on the mean of nine measurements made between November 1982 and October 1983. All other tributaries along the reach are ephemeral and were inspected on a regular basis during the year. In most years these tributaries have small flows during spring snowmelt or early summer rainstorms; however, no flows were detected during the 1983 water year. Therefore, total tributary inflow was 43 acre-feet.

Outflow of surface water from the modeled reach ($Q_{so}$) was determined at the U.S. Geological Survey gaging station on Otter Creek at Ashland (station 06307740, pl. 2). Total discharge for the 1983 water year was 3,440 acre-feet. Daily discharge data for this station are listed in table 3.

### Flow through alluvium

A line of test wells was installed across the alluvial valley at each end of the modeled reach to determine the thickness and hydraulic properties of the alluvial aquifer (data in table 4). Hydraulic data obtained from aquifer tests at the wells were used in the Darcy (1856) equation to determine flow rates through the alluvial aquifer.

At the upstream end of the reach, five wells (AL-20, AL-21, AL-22, AL-23, and AL-27) (pl. 1) were installed in the alluvium. Thickness of the alluvium ranged from 28 to 44 feet and transmissivity values obtained from aquifer tests at these wells ranged from 200 to 2,600 $ft^2/d$. The gradient of the water table within the alluvial aquifer in the vicinity of the wells was 0.0027. The calculated rate of annual inflow from the alluvial aquifer into the modeled reach ($Q_{ai}$) was 85 acre-feet.

At the downstream end of the modeled reach near Ashland, three test wells (AL-1, AL-2, AL-3)(pl. 1) were installed across the alluvial valley. Thickness of the alluvium ranged from 36 to 72 feet, and transmissivity values ranged from 1,100 to 2,900 $ft^2/d$. The hydraulic gradient of the water table within the alluvium in the vicinity of the wells was 0.0035. Using the Darcy equation for ground-water flow, the calculated rate of annual discharge from the alluvial aquifer ($Q_{ao}$) was 130 acre-feet.

### Bedrock inflow

Ground-water inflow from bedrock aquifers to the modeled stream-alluvial aquifer system ($Q_{bi}$) is through shallow coal and sandstone aquifers. These aquifers discharge directly to valley alluvium or discharge indirectly to the alluvium through clinker beds. Deeper sandstone and coal aquifers, those that do not crop out along the Otter Creek valley or intersect valley alluvium, are assumed to contribute little or no water to the modeled reach of the Otter Creek valley. This assumption is supported by the presence of thick beds of relatively impermeable shale underlying the entire valley and by small upward potentiometric gradients in deeper aquifers.

The rate of water flow through the shallow aquifers was estimated using the Darcy equation. Transmissivity values for the coal and sandstone aquifers were determined from single-well aquifer tests at 13 sites (table 5). The potentiometric gradient was determined from water levels in shallow bedrock wells distributed throughout the study area (pl. 2). Bedrock components of inflow to the modeled reach were computed for the 10 subareas and are summarized in table 6. Total annual inflow from the bedrock aquifers was 1,175 acre-feet (table 6).

### Precipitation and evapotranspiration

Precipitation and evapotranspiration rates are applied only to the modeled reach; that is, to the area containing the subirrigated part of the alluvial valley and the surface of Otter Creek. Precipitation and evapotranspiration are not applied to the areas outside the modeled reach because they are reflected in the ground-water or surface-water inflows to the modeled reach. For example, the rate of water flow from a coal aquifer to the modeled reach is controlled, in part, by precipitation and evapotranspiration in the recharge zone.

Precipitation for the area is based on precipitation records at Ashland for the 25 years 1956-80. Mean annual precipitation for this period of record is 13.05 inches. Monthly distribution of precipitation, used for calculating precipitation and net evapotranspiration during the growing season, is given in table 7.

Precipitation during the 1983 water year was less than normal and was 8.8 inches (8.6 inches for the calendar year); precipitation was greater than normal the preceding year and was 15.0 inches (15.5 inches for the calendar year). The mean annual precipitation of 13.05 inches was used in the model, rather than the 8.8 inches for the 1983 water year, because of lag time associated with ground-water flow and antecedent soil moisture conditions from the preceding wet year. Using the mean annual precipitation in the model, instead of the 1983 precipitation, would not introduce significant error because surface-water runoff, a primary model component related to precipitation, is measured directly.

Evaporation data for the area were obtained from a report by Farnsworth and others (1982). Mean annual free-water-surface evaporation for the Otter Creek valley is about 40 inches. Free-water-surface evaporation for the growing season (May-October) is about 33 inches. Monthly distribution of free-water-surface evaporation was calculated by a method of Farnsworth and Thompson (1982, p. A-1) and is given in table 8.

Free-water-surface-evaporation data were used to determine evaporation rates from the surface of Otter Creek and potential evapotranspiration from the subirrigated part of the valley. Free-water-surface evaporation is considered to be approximately equivalent to evaporation from a shallow water surface and to potential evapotranspiration from a vegetative surface having an unlimited supply of water (Farnsworth and others, 1982). Based on annual precipitation of about 13 inches and free-water-surface evaporation of 40 inches, the net annual evaporation rate from the surface of Otter Creek is about 27 inches. Annual evaporation loss from the surface of Otter Creek ($E_{fws}$), along the entire modeled reach, is 181 acre-feet (calculations in table 9).

Actual evapotranspiration from the subirrigated area within the modeled reach was estimated from published consumptive use rates for alfalfa and grass crops of the region (U.S. Department of Agriculture, 1974) and from water-budget studies of alfalfa and native range near Colstrip, Montana (Dollhopf and others, 1979; Dollhopf and others, 1981). Evapotranspiration during the growing season is reported to be 26.0 inches for alfalfa and 23.8 inches for grass (U.S. Department of Agriculture, 1974). For subirrigated alfalfa near Colstrip, evapotranspiration during the growing season was about 23.6 inches (Dollhopf and others, 1981). Average evapotranspiration for alfalfa and grass in the Otter Creek area, based on the above values, was assumed to be 24.5 inches.

Evapotranspiration of 24.5 inches and an average May through October precipitation of 8.8 inches result in a water deficit of 15.7 inches, which is supplied to plants from stored soil moisture and subirrigation. In water-budget studies near Colstrip, Montana (Dollhopf and others, 1979), subirrigated crops satisfied from 31 to 55 percent of their evapotranspiration requirement from subirrigation. Based on these studies, subirrigated crops in the Otter Creek valley extract about 11.5 inches of water from the water table and about 4.2 inches from soil moisture. Soil moisture accumulates in the root zone of the soil during the winter and spring and is depleted during the growing season.

On an annual basis, the net loss of water from the subirrigated alluvial system is equivalent to evapotranspiration (24.5 inches) minus precipitation (13.05 inches), or about 11.5 inches. The total annual volume of ground water consumed by subirrigated plants within the modeled reach of Otter Creek ($ET_a$) is 3,423 acre-feet, based on the rate of 11.5 inches for the growing season, which is also the rate for the year. Evapotranspiration calculations are given in table 10.

## Recharge

A recharge value is applied to clinker and non-subirrigated alluvium to account for the ground-water flow that comes from these sources. As water flows from the coal and sandstone aquifers toward Otter Creek, much of it passes through clinker and alluvium before reaching the Otter Creek stream-alluvial aquifer system (pl. 1). Ground-water discharge increases downgradient from the clinker and alluvium because of recharge that readily percolates into the clinker and alluvium from rainfall and snowmelt.

The quantity of water entering the modeled reach, originating from recharge to clinker and non-subirrigated alluvium, was calculated as a remainder in the water-balance equation. Total annual volume of recharge (*R*) was calculated to be 2,016 acre-feet, which is equivalent to an annual rate of 1.54 inches over the total area of clinker and non-subirrigated alluvium in the Otter Creek valley and major tributaries (calculations in table 11). The calculated annual recharge rate of 1.54 inches appears to be reasonable. In a hydrologic study conducted on the Northern Cheyenne Indian Reservation 4 miles southwest of Ashland, Woessner and others (1981) calculated mean annual recharge rates of 1.2 inches in clinker and 2.8 inches in valley alluvium.

### Storage

During the 1983 water year, water levels in the Otter Creek alluvial valley declined, reflecting a decrease in ground-water storage. Water-level data from six wells completed in the valley alluvium indicated an average decline of 0.83 foot from September 1982 to September 1983 (data in table 12). Assuming that the average specific yield of the alluvial materials is 0.22 (Johnson, 1967), the decrease in ground-water storage was 0.18 foot within the affected area. The decrease in storage occurred primarily within alluvium of the Otter Creek valley and its major tributaries, based on water-level data from the network of observation wells. The calculated decrease in ground-water storage (Δstorage) along the modeled reach of the Otter Creek valley was 1,325 acre-feet for the 1983 water year.

### Dissolved-solids-load budget

The annual dissolved-solids-load budget for the Otter Creek stream-alluvial aquifer system is expressed by the equation:

$$[(Q_{so} \cdot C_{so}) + (Q_{ao} \cdot C_{ao})]\, cf = [(Q_{sio} \cdot C_{sio}) + (Q_{sit} \cdot C_{sit}) (Q_{ai} \cdot C_{ai}) + (Q_{bi} \cdot C_{bi}) + (R \cdot C_r)]\, cf - \Delta\text{storage} \quad (2)$$

where

$C_{so}$ = dissolved-solids concentration of outflow from Otter Creek at the downstream end of the modeled reach (concentrations in milligrams per liter; loads in tons),

$C_{ao}$ = dissolved-solids concentration of outflow from the alluvial aquifer at the downstream end of the modeled reach,

$cf$ = a conversion factor (0.001359) to convert (acre-feet • milligrams per liter) to tons,

$C_{sio}$ = dissolved-solids concentration of inflow from Otter Creek at the upstream end of the modeled reach,

$C_{sit}$ = dissolved-solids concentration of inflow from tributaries (Home Creek) along the modeled reach of Otter Creek,

$C_{ai}$ = dissolved-solids concentration of inflow from the alluvial aquifer at the upstream end of the modeled reach,

$C_{bi}$ = dissolved-solids concentration of inflow from bedrock (coal and sandstone) aquifers along the modeled reach,

$C_r$ = dissolved-solids concentration of recharge water percolating through clinker and alluvium,

$\Delta$storage = change in soluble material stored within the soils and alluvial aquifer of the modeled reach, and

other parameters are as previously defined for the annual water-budget equation. In the dissolved-solids load budget, precipitation and evapotranspiration are assumed to not have a dissolved-solids load; therefore, they are not included in the equation.

### Surface-water load

Dissolved-solids loads in Otter Creek for the 1983 water year were computed using a computer program developed by the U.S. Geological Survey (Wilson, 1977). Input data for the program were daily mean streamflow, daily mean specific conductance (once daily values were used to represent the mean for the day), and a linear regression equation to relate dissolved solids to specific conductance. The program retrieves the daily values, calculates daily loads, and sums the daily loads to determine the monthly load. Specific-conductance samples were collected at U.S. Geological Survey gaging stations at the upstream end of the modeled reach (station 06307717) and at the downstream end near Ashland (station 06307740). Specific-conductance data for the stations are listed in tables 13 and 14. Missing values of specific conductance were interpolated from adjacent values for the load calculations. Data for the linear regression equations are from water-quality analyses for water years 1981, 1982, and 1983 (regression equations are given in table 15). The calculated annual load at the upstream gage ($Q_{sio} \cdot C_{sio}$) was 7,311 tons and the load at the downstream gage ($Q_{so} \cdot C_{so}$) was 8,836 tons. Monthly and annual loads at these stations are given in table 16.

Annual dissolved-solids load from Home Creek to the modeled reach of Otter Creek was calculated using the estimated annual streamflow value and the mean dissolved-solids concentration. Mean dissolved-solids concentration in Home Creek was determined from analysis of water samples collected during the streamflow measurements. The calculated annual load from Home Creek ($Q_{sit} \cdot C_{sit}$) was 162 tons.

### Load from alluvium

The annual dissolved-solids load entering the upstream end of the modeled reach from the Otter Creek alluvial aquifer ($Q_{ai} \cdot C_{ai}$) is 438 tons. The annual dissolved-solids load leaving the downstream end of the modeled reach through the alluvial aquifer ($Q_{ao} \cdot C_{ao}$) is 286 tons. The loads were determined from the mean dissolved-solids concentration of alluvial water at the upstream and downstream boundaries of the reach, and from flow rates through the alluvium. The mean dissolved-solids concentration at the upstream end, measured at four alluvial wells (AL-21, AL-22, AL-23, and AL-27), was 3,790 mg/L (milligrams per liter). The mean dissolved-solids concentration at the downstream end, measured at three alluvial wells (AL-1, AL-2, and AL-3), was 1,620 mg/L. Data from the wells are listed in table 17.

### Load from bedrock aquifers

Bedrock aquifers, composed of sandstone and coal beds, contribute a large dissolved-solids load to the alluvial aquifer and Otter Creek. The load contribution varies greatly from place to place along the valley because of the considerable range in hydraulic properties of the aquifers and the quality of ground water. Because of this variability, loads were calculated for each of the 10 subareas. The loads were calculated using the water discharge rate and dissolved-solids concentration of ground water in each subarea. The dissolved-solids concentration of ground water in each subarea (data in table 18) was assumed to be equal to the log mean of dissolved solids in all coal and sandstone wells sampled in the subarea. The log mean value was used because dissolved-solids concentrations of samples from the Tongue River Member were close to a log-normal distribution; the log mean value of dissolved solids was very similar to the median value for each subarea. The total annual load from the bedrock aquifers ($Q_{bi} \cdot C_{bi}$) was 2,732 tons per year. Loads from each subarea are listed in table 19.

### Recharge

Recharge water that enters the clinker and non-subirrigated alluvium from precipitation percolates downward to the water table, dissolves minerals in the soil and rock before reaching the water table, and acquires a dissolved-solids load that eventually discharges to the Otter Creek stream-alluvial aquifer system. The dissolved-solids concentration of percolating recharge water is 315 mg/L, based on the quality of water from clinker in sec. 12, T. 3 S., R. 44 E. For non-subirrigated alluvium, the concentration of 315 mg/L represents the quality of recharge water in the unsaturated zone and not the quality of water in the aquifer, which is derived from several sources. No data are available on the quality of recharge water from the unsaturated zone in alluvium. The quality was assumed to be similar to that in clinker because a large part of the alluvium in the Otter Creek area consists of reworked clinker fragments. Based on the concentration of 315 mg/L, the total annual dissolved-solids load entering the modeled reach of the Otter Creek valley from clinker and non-subirrigated areas of alluvium ($R \cdot Cr$) is 863 tons.

### Storage

The change in storage ($\Delta$ storage) is the change in soluble material stored in the soils and alluvial aquifer within the modeled reach. Change in storage was determined by the difference between inflows and outflows of dissolved-solids loads in the modeled reach. For the 1983 water year, 2,384 tons of dissolved material was stored within the modeled reach of the Otter Creek valley.

Water levels within the alluvial aquifer declined during the 1983 water year; a large part of the water deficit went to evapotranspiration in the subirrigated part of the valley. Because water that is transpired by plants has little or no dissolved solids, the dissolved solids that were contained in the ground water remain within the root zone of the soil. The soluble material remains within the soils until sufficient recharge or ground-water flow flushes it from the root zone. After a long time, under natural hydrologic conditions, there would be no net change in storage of soluble material within the alluvium. However, during years when inflows do not equal outflows (such as 1983 water year), change in storage is a significant component of the budget.

## Budget summary

The water budget for the Otter Creek stream alluvial aquifer system is represented by equation 1:

$$Q_{so} + Q_{ao} = Q_{sio} + Q_{sit} + Q_{ai} + Q_{bi} + R - ET_a - E_{fws} + \Delta storage$$

For the 1983 water year, the water budget equation has the values:

$$3{,}440 + 130 = 2{,}530 + 43 + 85 + 1{,}175 + 2{,}016 - 3{,}423 - 181 + 1{,}325$$

where all values are in acre-feet.

The load budget for the Otter Creek stream-alluvial aquifer system is represented by equation 2:

$$[(Q_{so} \cdot C_{so}) + (Q_{ao} \cdot C_{ao})]\, cf = [(Q_{sio} \cdot C_{sio}) + (Q_{sit} \cdot C_{sit})$$

$$(Q_{ai} \cdot C_{ai}) + (Q_{bi} \cdot C_{bi}) + (R \cdot C_r)]\, cf - \Delta storage$$

For the 1983 water year, the load equation reduces to:

$$8{,}836 + 286 = 7{,}311 + 162 + 438 + 2{,}732 + 863 - 2{,}384$$

where all values are in tons.

## INITIAL POST-MINING DISSOLVED SOLIDS IN THE MINE SPOILS

After mining of coal beds and placement of spoils in the mine pits, ground-water flow systems would become established within the spoils material. Water would enter the spoils from adjacent coal and sandstone aquifers, and in some areas from vertical recharge by precipitation. Within the spoils, water would react chemically with the spoils material, generally resulting in an increase in dissolved-solids concentrations of the ground water. Variables that would affect the quality of spoils water include recharge to the spoils, spoil porosity and permeability, availability of readily soluble material within spoils, and chemical reactivity of the spoils.

Studies at existing coal mines in southeastern Montana have indicated that water in mine spoils contains greater concentrations of dissolved solids than does water in undisturbed aquifers of the area. In a study at the West Decker Mine at Decker, Montana, Davis (1984) reported that the concentration of dissolved solids in water from the mine spoils was about 2,500 mg/L, and from coal aquifers it was about 1,400 mg/L. At the Big Sky Mine near Colstrip, Montana, dissolved-solids concentration of water from spoils was about 3,700 mg/L and from coal aquifers it was about 2,700 mg/L (Davis, 1984). Van Voast and others (1978) reported that in the Colstrip, Montana, area, theoretical mean dissolved-solids concentrations in spoils waters are 820 mg/L to 1,800 mg/L greater than those in nearby stock and domestic supplies. For surface coal-mine sites in western North Dakota, Groenewold and others (1983) reported that ground water in spoils at the study sites typically was two to three times as mineralized as ground water in undisturbed settings at these sites.

## Methods and load calculations

Saturated-paste-extract (saturation extract) data for 506 overburden samples from 26 wells and test holes (see pl. 2 for locations) and batch-mixing-test data for overburden samples from 3 wells were used to predict post-mining concentrations of dissolved solids in mine spoils water. Of the two methods used, the saturated-paste-extract method probably best represents initial post-mining quality of water from the mine spoils because it is based on a large number of samples and represents the first pore volumes of water from the mined area.

An additional method of predicting post-mining quality of spoils water, using saturation-extract data, was investigated for possible future use. Post-mining dissolved-solids concentration and loads to the Otter Creek modeled area were calculated with this method, for comparison with results of the other methods.

### Saturated-paste-extract method

The saturated-paste-extract method is a laboratory procedure used to measure the content of salts in a soil or sediment sample (U.S. Salinity Laboratory Staff, 1954). Samples for the tests are mixed to a saturated paste with distilled water and allowed to stand for a given time. The quantity of water required to saturate a dry sample varies with the texture and composition of the sample. Saturation percentage, calculated from the weight of oven-dry soil and water required for saturation, ranged from about 25 percent for sandy samples to 130 percent for some silty-clay samples from the Otter Creek area. Saturation extracts were recovered from the pastes by vacuum filtration and were analyzed for specific conductance and major cations.

Saturation extracts have been used by Van Voast and Hedges (1975) and Van Voast and Thompson (1982) to evaluate the post-mining quality of spoils water in Montana and Wyoming. For predicting post-mining quality of spoils water in the upper Tongue River area in Montana and Wyoming, Van Voast and Thompson (1982) assumed that dissolved-solids concentrations of saturation extracts were potential additions to concentrations in ground waters that would enter and eventually discharge from the mine spoils. In the method used by Van Voast and Thompson, log-normal mean concentrations of cations were determined from analyses of saturation extracts; dissolved-solids concentrations were computed from the ion concentrations and these concentrations were used in conjunction with ground-water flow rates to compute the added dissolved-solids load from mining. Dissolved-solids concentrations indicated by saturation extracts were assumed to be potential additions to the premining concentrations, based on actual quality of aquifer and spoils water at mine sites in southeastern Montana. At the Big Sky and West Decker Mines in Montana, log-normal mean concentrations of cations in spoils water were consistently greater than log-normal mean concentrations of cations in saturation extracts (Van Voast and others, 1978). Log-normal mean concentrations of cations typically were two to three times greater in the spoils water than in saturation extracts. Studies of spoils waters, saturation extracts of spoils and overburden, and quality of water in undisturbed aquifers in southeastern Montana indicate an empirical relation between the dissolved-solids concentration of water in mine spoils and the sum of dissolved-solids concentrations in aquifer water and saturation extracts.

Saturation extracts also have been used to evaluate spoils water quality in Montana by Woessner and others (1979), in North Dakota by Groenewold and others (1983), and in Colorado by McWhorter and others (1975). In a publication of procedures for predictive analysis of hydrologic impacts of surface mining, McWhorter (1982, p. 12) states that "... probably the most reasonable estimate of concentration of dissolved solids in subsurface runoff from mined land can be made from a judicious study of the quality of spoil water from nearby mines in a similar geochemical environment." He further adds that the dissolved-solids concentration in extracts from saturated drill cuttings will provide a reasonable lower limit for dissolved-solids concentration in subsurface runoff from mined land; however, if the dissolved solids derive mainly from readily soluble sodium salts, concentrations in spoils water can be expected to be greater than the saturation-extract value, perhaps by as much as a factor of three.

For the Otter Creek area, dissolved-solids concentrations derived from the saturation-extract data were assumed to be potential additions to the dissolved-solids concentration in undisturbed aquifers, similar to the method used by Van Voast and Thompson (1982). For each of the 26 sampling sites, a weighted mean value of specific conductance was calculated from the specific-conductance values of the saturation extracts. The mean specific-conductance value was weighted, based on the depth interval of each overburden sample. The weighted specific-conductance value for each sampling site was then equated to dissolved-solids concentration by the regression equation:

$$DS = 0.762\ (SC) - 222 \qquad (3)$$

where

DS = dissolved-solids concentration, in milligrams per liter, and
SC = specific conductance, in microsiemens per centimeter at 25° Celsius.

Specific conductance, calculated dissolved solids, and other sample data are presented in table 20. The dissolved-solids values obtained from the saturation extracts were assumed to result from the dissolution of the readily soluble minerals in the overburden, which would also be present in the post-mining spoils.

The log-mean concentration of dissolved solids from all saturated-paste data sites was 1,970 mg/L. To estimate the maximum post-mining load of dissolved solids from the mined area, 1,970 mg/L was added to the dissolved-solids concentration of ground water in each of the 10 subareas. In subareas 1, 2, and 3 the additional load was applied to only a fraction of the subareas because parts of these areas do not contain strippable coal in the Knobloch bed. The rate of ground-water flow from the subareas was not changed from the pre-mining rate because there is no evidence to indicate that mining would cause a significant change in the rate of ground-water recharge. The calculated maximum increase in annual dissolved-solids load to the Otter Creek stream-alluvial aquifer system is 2,873 tons (load calculations are given in table 21). Because the rate of movement of ground water through the mined area would be very slow, the Otter Creek valley would receive this increased load for many years (possibly hundreds) after the completion of mining.

## Batch-mixing-test method

Batch-mixing tests involved the mixing of local aquifer water with the overburden sample to simulate possible chemical changes in the water as it moves through mine spoils. The method was used by Davis (1984) to determine potential changes in the quality of ground water at the West Decker Mine at Decker, Montana, and at the Big Sky Mine near Colstrip, Montana. In the tests, aquifer water was mixed with granular overburden samples in a ratio of 2:1 (water, soil) by weight. After thorough mixing, the mixtures were allowed to settle and were filtered after a total contact time of about 24 hours. The filtrates were then analyzed for concentrations of common ions, dissolved-solids concentration, and specific conductance.

In a mixing ratio of 2:1, many pore volumes (50 to 1,000) of water are exposed to the overburden sample. In the batch-mixing tests, overburden samples are mixed with about 2 to 10 times as much water as in a saturated paste. Because samples are exposed to many pore volumes of water, the batch-mixing test may reflect the long-term quality of water that would discharge from the mine spoils.

Data from batch-mixing tests indicated that water in spoils would have an average increase in dissolved-solids concentration of 840 mg/L over the pre-mining concentration (data and calculations in table 22). Based on the increase of 840 mg/L, the annual dissolved-solids load contributed from the mine spoils would be 1,225 tons.

## Possible direct method using saturation-extract data

Saturation extracts, prepared from overburden samples and distilled water, give a reliable indication of the quantity of soluble minerals available in the overburden and thus, probably give a direct means of estimating the post-mining quality of water in mine spoils. Theoretically, the dissolved-solids concentration in a saturation extract for a given soil is governed by the quantity of soluble minerals in the soil, if the quantity is small, or by the kinematics of the chemical reactions if the quantity of the soluble material is large. In soils with a large quantity of soluble minerals, leaching of the sample with distilled water or with ground water from the sampling site, probably produces the same type and concentration of leachate, for the first pore volumes.

Many horizons within the Tongue River Member of the Fort Union Formation appear to contain abundant soluble minerals, based on similar leachates derived from various tests such as saturated-paste extract, batch mixing, and column leaching. Other horizons may not contain abundant soluble minerals; based on dissimilar leachates from different tests. It is reasonable to assume that recharge water moving through mine spoils would react with horizons that contained abundant soluble minerals until the water reached an equilibrium concentration dependent on the kinematics of the involved reactions. If recharge water does attain a dissolved-solids concentration dependent on soil horizons with abundant soluble minerals, then saturation extracts from these soil horizons may give a good estimate of dissolved-solids concentration in post-mining spoils water. A mean or log mean of saturation extracts from all soil horizons at a sampling site produces too small a value for dissolved-solids concentration because it gives equal weight to all soil horizons, even those with limited soluble minerals. Using just the 75th percentile or even the 90th percentile of samples appears to emphasize the soil horizons with abundant soluble minerals--those which govern the dissolved-solids concentration of spoils water.

Dissolved-solids concentrations in mine spoils and loads to the Otter Creek modeled area were calculated by a direct method using saturation-extract data, and compared with the results of other methods. In this method, the 75th- and 90th-percentile values of specific conductance were calculated for each of the 26 data sites (506 overburden samples). Means were then calculated for the 26 values representing the 75th percentile and the 26 values representing the 90th percentile of specific conductance. The mean values of specific conductance were converted to dissolved-solids concentrations using equation 3. With this method, dissolved-solids concentration of water in mine spoils would be 3,400 mg/L, based on the 75th percentile, and 4,410 mg/L based on the 90th percentile. Annual loads to the Otter Creek stream-alluvial aquifer system are 4,960 tons for the 75th-percentile value of dissolved solids and 6,430 tons for the 90th-percentile value. Loads were calculated directly using ground-water flow rates and dissolved-solids concentration of spoils water; loads from spoils were not added to pre-mining loads as in the other two methods. For comparison, annual loads were 3,990 tons for the batch-mixing method and 5,600 tons for the original saturation-extract method. Loads computed with the 75th- and 90th-percentile values bracket the load computed using the original saturation-extract method. The dissolved-solids concentrations of spoils water calculated by this direct method are in the range of two to three times as large as pre-mining concentrations in ground water, which is in the range reported by several investigators. Further study is needed to determine the value of this method for directly estimating the dissolved-solids concentration of spoils water from saturation-extract data.

## LONG-TERM POST-MINING DISSOLVED SOLIDS IN THE HYDROLOGIC SYSTEM

After ground-water flow systems have developed in the post-mining landscape, water would flow from the mine spoils, through clinker and alluvium, and discharge to Otter Creek. Dissolved-solids concentrations in Otter Creek would increase as a result of the increased dissolved-solids load originating in the mine spoils. Dissolved-solids concentrations in the shallow alluvial aquifer downgradient from the mine spoils also would increase. With complete mining development of the Knobloch coal in the study area, the annual dissolved-solids load to the Otter Creek stream-alluvial aquifer system could increase by 1,225 to 2,873 tons. The larger load figure is based on saturated-paste data and likely represents the increased load for many years (possibly hundreds) after mining; the smaller figure is based on batch-mixing data and likely represents the increased load after many (50 to 1,000) pore volumes of water have passed through the mine spoils. With less than complete mining of the Knobloch coal along the Otter Creek valley, post-mining dissolved-solids load to the valley would be proportionally smaller. Calculations of dissolved-solids concentrations in Otter Creek and the alluvial aquifer assume that dissolved solids from the mined area would move through the alluvial aquifer and discharge to Otter Creek at a steady rate; inflows of dissolved solids to the alluvial aquifer would equal outflows, averaged over a long time.

### Otter Creek

Increases in dissolved-solids loads and concentrations in Otter Creek were calculated for the downstream end of the modeled reach where dissolved-solids increases from mining would be the greatest. To most accurately represent the general increase in dissolved-solids concentrations in Otter Creek, the additional dissolved-solids load was added to the mean monthly loads of Otter Creek at the Ashland gaging station (station 06307740). The mean monthly loads of Otter Creek at Ashland were calculated from the median (50th percentile) monthly flows and the mean monthly dissolved-solids concentrations, using almost 9 years of data (data and calculations in table 23). The mean annual load of Otter Creek at Ashland is 8,985 tons, based on the long-term data. This calculated mean annual load is only slightly larger than the load for the 1983 water year, which was 8,863 tons.

The monthly loads of Otter Creek showed a maximum post-mining increase of 15 to 208 percent, based on the annual addition of 2,873 tons of dissolved solids (paste-extract method) to the Otter Creek valley. Monthly loads of Otter Creek showed a minimum increase of 6 to 89 percent, based on the additional annual load of 1,225 tons (batch-mixing method) to the Otter Creek valley. Otter Creek would have the smallest concentrations of dissolved solids in March, with mean post-mining concentrations ranging from 1,780 to 1,970 mg/L. In August, post-mining concentrations of dissolved solids would be the greatest, with mean concentrations ranging from 3,980 to 6,500 mg/L. Post-mining concentrations of dissolved solids in Otter Creek would be greater than these monthly figures for streamflows less than the median flow, and would be smaller for streamflows greater than the median flow.

Annual loads of Otter Creek at Ashland (at median streamflow) would have a post-mining increase of 14 percent for the added load of 1,225 tons and an increase of 32 percent for the added load of 2,873 tons (see table 23). At the median streamflow, the annual post-mining load of Otter Creek at Ashland (station 06307740) would range from 10,210 to 11,858 tons.

## Alluvial aquifer

Post-mining concentrations of dissolved solids would increase within the alluvial aquifer in the Otter Creek valley as a result of the additional dissolved-solids load from mine spoils. Post-mining quality of the ground water was estimated by assuming that the ratio of pre-mining dissolved-solids load to pre-mining dissolved-solids concentration is proportional to the ratio of post-mining dissolved-solids load to dissolved-solids concentrations, which in equation form is:

$$\frac{\textit{Pre-mining dissolved-solids load to subirrigated part of alluvial aquifer}}{\textit{Median pre-mining concentration of dissolved solids in subirrigated part of alluvial aquifer}} = \frac{\textit{Post-mining dissolved-solids load to subirrigated part of alluvial aquifer}}{\textit{Median post-mining concentration of dissolved solids in subirrigated part of alluvial aquifer}}$$

The equation should give a reasonable estimate of post-mining water quality, because the only factor affecting the dissolved-solids concentration in the subirrigated part of the valley, which would be changed after mining, is the additional dissolved-solids load to the alluvium from mine spoils.

Pre-mining dissolved-solids load to the subirrigated part of the alluvial valley is equal to the sum of annual loads from ground-water inflow at the upstream end of the alluvial aquifer (438 tons), from bedrock aquifers (2,732 tons), and from clinker and non-subirrigated alluvium (863 tons). The total annual pre-mining load to the subirrigated alluvium is 4,033 tons. The median pre-mining concentration of dissolved solids in the subirrigated alluvium is 2,590 mg/L. The median was obtained from 17 wells completed in the subirrigated part of the valley (table 17). The post-mining load to the subirrigated part of the alluvial aquifer was obtained by summing the annual pre-mining load (4,033 tons) and the additional load from mine spoils (1,225 to 2,873 tons). The total annual post-mining load to the subirrigated alluvium would be 5,258 to 6,906 tons.

Substituting the above values into the water-quality equation yields a post-mining dissolved-solids concentration with a median ranging from 3,380 to 4,430 mg/L. Based on these calculations, the median post-mining concentration of dissolved solids in the subirrigated part of the valley would increase by 31 to 71 percent over the pre-mining concentration. However, because of incomplete mixing of water from mine spoils with water in the alluvial aquifer, a large range of dissolved-solids concentrations could be expected. Some locations within the alluvial aquifer, such as just downgradient of a massive clinker bed or at the mouth of a tributary, might show no increase in dissolved solids, whereas other locations might have an increase in dissolved solids that is much greater than 71 percent.

## CONCLUSIONS

The primary shallow aquifers in the Otter Creek study area are the Knobloch coal beds, Knobloch clinker, sandstone beds above and below the Knobloch coal beds, and alluvium along Otter Creek and its major tributaries. The Knobloch coal beds and clinker, sandstone beds, and alluvium in the tributary valleys all discharge water to Otter Creek through the valley alluvium.

Large-scale surface mining of the Knobloch coal bed along the Otter Creek valley would remove large sections of the Knobloch coal and sandstone aquifers and replace them with mine spoils. After mining, ground-water flow systems would develop in the mine spoils, dissolve soluble materials, transport them to the Otter Creek valley, and increase the dissolved-solids concentrations in Otter Creek and the Otter Creek alluvial aquifer.

A mass-balance model was developed to evaluate the pre-mining hydrologic system in Otter Creek and its alluvial aquifer. Data from the mass-balance model were used in conjunction with calculated dissolved-solids concentrations in mine spoils to estimate the concentrations of dissolved solids that might exist in Otter Creek and the subirrigated part of the Otter Creek valley once mining was completed. If the Knobloch coal is completely mined along both sides of the Otter Creek valley, annual dissolved-solids load to Otter Creek at Ashland (at median streamflow) could increase by 2,873 tons, or a 32 percent increase over the mean annual pre-mining load of 8,985 tons. With the additional annual load of 2,873 tons, monthly loads of Otter Creek, at the median streamflow, could increase from 15 percent in February to 208 percent in August. At the median streamflow, mean dissolved-solids concentrations of Otter Creek at Ashland could range from 1,970 mg/L in March to 6,500 mg/L in August, an increase from the pre-mining range of 1,640 mg/L in March to 2,460 mg/L in December. The annual post-mining dissolved-solids load to the subirrigated part of the Otter Creek alluvial valley could increase by 2,873 tons or 71 percent. The median dissolved-solids concentration in the subirrigated part of the valley could be 4,430 mg/L, a 71-percent increase from the pre-mining median concentration of 2,590 mg/L. Actual increases in concentrations of dissolved solids in the alluvium could vary significantly from the calculated increase, because of incomplete mixing of water in the alluvium.

The estimate of additional dissolved-solids load from the mined landscape was derived from saturated-paste-extract data for 506 overburden samples from 26 wells and test holes. The paste-extract data represent the soluble material available to the initial pore volume of water moving through the mine spoils. The post-mining loads calculated using the saturated-paste-extract data likely would continue for many years (possibly hundreds) after mining.

Post-mining loads of dissolved solids also were estimated using data from batch-mixing tests. The batch-mixing tests represent the passing of many (50 to 1,000) pore volumes of water through the spoils and may reflect the long-term quality of water that could discharge from the mine spoils. Post-mining loads calculated from the batch-mixing tests were smaller than those calculated from saturated-paste-extract data.

Of the two methods used to estimate post-mining loads of dissolved solids, loads calculated from the saturated-paste-extract data probably best represent initial post-mining loads from the mine spoils. The paste-extract results were based on a larger number of samples and represent the first pore volumes of water from the mined area. Results of the batch-mixing tests show that concentrations of dissolved solids would not decrease rapidly after the initial saturation and flushing of mine spoils, but would continue at increased concentrations for many pore volumes of water.

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SUPPLEMENTAL INFORMATION

Table 1.--*Water-level data for wells, test holes, or springs*

| Well, test-hole, or spring No. | Location No.[1] | Date of water-level measurement (mo-day-yr) | Water level (feet below land surface) | Altitude of water level (feet above sea level) | Remarks |
|---|---|---|---|---|---|
| AL-1 | 03S44E11DAAA01 | 06-10-83 | 6.59 | 2,915 | Observation well OC83-2 |
| AL-4 | 03S45E16DDDC01 | 06-08-83 | 40.1 | 3,022 | Observation well OC83-5 |
| AL-8 | 03S46E14CBCD01 | 01-17-74 | 17.0 | 3,291 | |
| AL-9 | 04S45E10CCBC01 | 05-29-80 | 7.5 | 3,027 | Observation well OC-8 |
| AL-10 | 04S45E04BADD01 | 12-05-79 | 3.6 | 3,011 | Observation well WO-12 |
| AL-12 | 04S45E04BDDB01 | 12-07-79 | 5.8 | 3,014 | Observation well WO-14 |
| AL-16 | 04S45E09DCAA01 | 06-23-80 | 14.5 | 3,020 | Observation well OC-2A |
| AL-17 | 04S45E15BCDD01 | 08-25-80 | 9.5 | 3,026 | Observation well OC-6 |
| AL-18 | 05S46E04DACA01 | 01-16-74 | 45.0 | 3,257 | |
| AL-19 | 04S45E27DBAB01 | 12-17-73 | 22.0 | 3,053 | |
| AL-22 | 05S45E23ABCA02 | 10-25-80 | 11.7 | 3,138 | Observation well WO-09 |
| AL-27 | 05S45E23BBAA04 | 06-08-83 | 9.9 | 3,130 | Observation well WO-04 |
| AL-29 | 03S44E13AACD01 | 12-13-73 | 16.0 | 2,924 | |
| AL-30 | 03S45E33BBBB01 | 10-08-74 | 10.1 | 3,000 | |
| AL-31 | 05S46E20CBCC01 | 01-15-74 | 12.0 | 3,243 | |
| AL-32 | 05S46E23CBDD01 | 01-18-74 | 30.0 | 3,375 | |
| AL-33 | 05S46E28BBAB01 | 01-15-74 | 3.0 | 3,279 | |
| SP-1 | 03S44E12BDDA01 | -- | -- | 3,020 | Spring from clinker |
| TR-2 | 03S45E19DDBD01 | 12-18-73 | 9.0 | 2,954 | |
| TR-3 | 03S44E36DACA01 | 06-08-83 | 233.9 | 3,036 | Observation well OC83-1 |
| TR-4 | 03S45E03BADD01 | 10-08-64 | 120.0 | 3,180 | Water level reported by driller |
| TR-5 | 03S45E10BACD01 | 10-08-74 | 124.8 | 3,085 | |
| TR-6 | 03S45E22BBBA01 | 12-20-73 | 50.0 | 3,026 | |
| TR-7 | 03S45E22BAAB01 | 01-12-74 | 91.0 | 3,026 | |
| TR-8 | 03S45E15DDDA01 | 12-17-73 | 132.0 | 3,048 | |
| TR-9 | 03S45E14CCAB01 | 01-14-74 | 143.3 | 3,060 | Well for Red Shale Campground |
| TR-11 | 03S45E26ADAC01 | 10-17-74 | 134.9 | 3,069 | Observation well DH74-104 |
| TR-12 | 03S45E26DBCB01 | 11-06-74 | 120.2 | 3,071 | Observation well DH74-102 |
| TR-14 | 03S45E34CACD01 | 08-09-74 | 229.6 | 3,030 | Observation well DH74-101 |
| TR-15 | 03S45E34AACD01 | 10-17-74 | 123.4 | 3,071 | Observation well DH74-103 |
| TR-24 | 03S45E12BDCB01 | 08-07-74 | 11.9 | 3,168 | |
| TR-25 | 03S46E07ADBB01 | 01-18-74 | 44.9 | 3,224 | |
| TR-26 | 03S45E13DCBC01 | 01-14-74 | 119.0 | 3,081 | |
| TR-28 | 03S46E17DBDC01 | 01-17-74 | 55.0 | 3,153 | |
| TR-30 | 03S46E15CAAA01 | 01-17-74 | 110.0 | 3,177 | |
| TR-35 | 03S46E19ACBA01 | 01-11-74 | 47.4 | 3,163 | Stock well |
| TR-36 | 03S46E30BCCC01 | 01-13-74 | 95.0 | 3,158 | Stock well |
| TR-37 | 03S45E31DCDA01 | 08-13-75 | 140.0 | 2,990 | Stock well |
| TR-39 | 04S45E06DBDB01 | 08-14-80 | 224.2 | 3,031 | Observation well US77-23 |
| TR-40 | 04S45E07CABA01 | 08-17-80 | 190.8 | 3,034 | Observation well OC-30 |
| TR-41 | 03S45E34DDDA01 | 12-12-74 | 156.0 | 3,106 | Observation well DH74-105 |
| TR-42 | 03S45E35DABA01 | 03-18-75 | 193.4 | 3,100 | |

Table 1.--*Water-level data for wells, test holes, or springs*--Continued

| Well, test-hole, or spring No. | Location No.[1] | Date of water-level measurement (mo-day-yr) | Water level (feet below land surface) | Altitude of water level (feet above sea level) | Remarks |
|---|---|---|---|---|---|
| TR-43 | 04S45E02BDDD01 | 01-09-75 | 157.0 | 3,071 | Observation well DH74-106 |
| TR-44 | 04S45E02DACD01 | 01-22-75 | 43.2 | 3,062 | Observation well DH74-107 |
| TR-45 | 04S45E02CDDB01 | 12-21-73 | 56.0 | 3,024 | |
| TR-48 | 04S46E05BCBC01 | 12-12-74 | 84.0 | 3,131 | Stock well |
| TR-51 | 04S46E11BBBA01 | 01-13-74 | 58.0 | 3,299 | |
| TR-53 | 04S45E14CDCC01 | 06-09-83 | 117.6 | 3,037 | Observation well OC83-4 |
| TR-54 | 04S46E08CBCC01 | 06-12-62 | 60.0 | 3,185 | |
| TR-55 | 04S46E10DABC01 | 01-12-74 | 44.0 | 3,281 | Stock well |
| TR-58 | 04S45E20CCAD01 | 12-19-73 | 130.0 | 3,115 | |
| TR-65 | 04S46E31DDBC01 | 01-16-74 | 10.0 | 3,202 | |
| TR-66 | 04S46E32DCDC01 | 01-16-74 | 35.0 | 3,207 | |
| TR-68 | 05S46E05BDCB01 | 01-12-74 | 42.0 | 3,213 | |
| TR-69 | 05S46E04DDAB01 | 01-16-74 | 41.0 | 3,269 | |
| TR-72 | 04S45E28BDDD01 | 05-11-77 | 128.6 | 3,112 | Observation well US77-25 |
| TR-73 | 04S45E28ADDA01 | 12-17-73 | 60.0 | 3,100 | |
| TR-79 | 05S45E04BADD01 | 10-27-80 | 142.0 | 3,120 | Observation well US77-26 |
| TR-91 | 05S45E16ADDD01 | 06-10-83 | 144.5 | 3,134 | Observation well OC83-7 |
| TR-93 | 05S45E23BBAA02 | 10-25-80 | 45.2 | 3,145 | Observation well WO-02 |
| TR-95 | 05S45E28BBBA01 | 06-01-62 | 163.0 | 3,162 | |
| TR-103 | 05S45E12BDBA01 | 06-10-76 | 93.5 | 3,186 | Coal exploration hole DH76-101 |
| TR-104 | 04S45E26BDCD01 | 06-03-76 | 119.7 | 3,075 | Coal exploration hole DH76-101 |
| TR-118 | 03S45E08AACD01 | 08-19-80 | 170.4 | 3,071 | Montco well 3458-1W |
| TR-119 | 03S45E09CCCB01 | 06-19-80 | 147.3 | 3,143 | Stock well |
| TR-120 | 03S45E18BBBA01 | 08-13-75 | 78.6 | 2,936 | |
| TR-122 | 03S45E16DDDB01 | 10-08-74 | 34.3 | 3,046 | Stock well |
| TR-123 | 03S45E15DBBB01 | 12-17-73 | 27.0 | 3,067 | |
| TR-124 | 03S45E14BCCB01 | 12-17-73 | 41.0 | 3,077 | |
| TR-126 | 03S45E21ABCD01 | 12-17-73 | 38.0 | 3,002 | |
| TR-127 | 03S45E23DCBA01 | 12-21-73 | 54.0 | 3,050 | |
| TR-128 | 03S45E27ACBB01 | 12-20-73 | 41.0 | 3,021 | |
| TR-129 | 03S45E32DDAC02 | 12-21-73 | 15.0 | 2,995 | |
| TR-130 | 04S45E05CACD01 | 08-25-80 | 191.9 | 3,033 | Observation well OC-39 |
| TR-131 | 04S45E03DDDA01 | 08-13-75 | 42.4 | 3,018 | |
| TR-132 | 04S44E12BBDA01 | 10-01-59 | 260.0 | 3,040 | |
| TR-133 | 03S45E01CDCC01 | 08-07-74 | 55.7 | 3,174 | |
| TR-134 | 03S46E06AADD01 | 08-07-74 | 28.1 | 3,252 | |
| TR-135 | 03S46E04BBBB01 | 08-08-74 | 17.5 | 3,342 | |
| TR-136 | 03S46E17ADBC01 | 05-05-65 | 48.0 | 3,192 | |
| TR-137 | 03S46E20DBAB01 | 01-17-74 | 97.0 | 3,208 | Stock well |
| TR-138 | 03S46E21CDBA01 | 01-13-74 | 132.0 | 3,215 | Stock well |
| TR-139 | 03S46E22CBBA01 | 01-17-74 | 99.0 | 3,251 | Stock well |
| TR-140 | 04S46E04DCDC01 | 01-16-74 | 48.0 | 3,226 | Stock well |

Table 1.--*Water-level data for wells, test holes, or springs*--Continued

| Well, test-hole, or spring No. | Location No.[1] | Date of water-level measurement (mo-day-yr) | Water level (feet below land surface) | Altitude of water level (feet above sea level) | Remarks |
|---|---|---|---|---|---|
| TR-141 | 04S45E12ABBC01 | 01-01-74 | 25.0 | 3,092 | |
| TR-142 | 04S46E10BCBA01 | 01-16-74 | 24.0 | 3,258 | |
| TR-143 | 04S45E08DDAD01 | 03-24-81 | 169.0 | 3,061 | Observation well OC-13 |
| TR-144 | 04S45E17CCDC01 | 08-25-80 | 197.4 | 3,037 | Observation well OC-26 |
| TR-145 | 04S45E16CDAC01 | 09-13-80 | 92.3 | 3,028 | Observation well OC-22 |
| TR-146 | 04S45E21CCCA01 | 02-24-81 | 79.9 | 3,093 | Observation well OC-28 |
| TR-147 | 05S45E08BBCC01 | 08-12-75 | 85.0 | 3,465 | |
| TR-149 | 05S45E16DBCB01 | 12-20-73 | 150.0 | 3,160 | |
| TR-150 | 04S46E15CBDC01 | 01-12-74 | 102.0 | 3,514 | Stock well |
| TR-151 | 04S46E33CBAC01 | 05-22-75 | 27.0 | 3,272 | Stock well |
| TR-152 | 03S45E04CDBD01 | 09-18-80 | 148.0 | 3,192 | Coal exploration hole US80-069 |
| TR-153 | 03S45E08BCBA01 | 07-23-78 | 198.0 | 3,067 | Montco hole 3458-2W |
| TR-154 | 03S45E08CDDD01 | 05-02-77 | 134.0 | 3,096 | Coal exploration hole US77-16 |

[1]Location number based on Federal system of land subdivision. The first set of numerals indicates the township; the second, the range; and the third, the section. The first letter following the section denotes the 160-acre tract; the second, the 40-acre tract; the third, the 10-acre tract; and the fourth, the 2.5-acre tract. Letters are assigned in a counterclockwise direction, beginning with "A" in the northeast quadrant. Two-digit numerals at the end of the location number are assigned sequentially. For example, well 03S45E08CDDD01 is the first well inventoried in the SE1/4SE1/4SE1/4SW1/4 sec. 8, T. 3 S., R. 45 E.

Table 2.--*Daily discharge records for Otter Creek below Fifteenmile Creek (station 06307717), 1983 water year*

YELLOWSTONE RIVER BASIN

06307717 OTTER CREEK BELOW FIFTEENMILE CREEK, NEAR OTTER, MT

LOCATION.--Lat 45°24'11", long 106°08'31" in SW¼SW¼NE¼ sec. 14, T. 5 S., R. 45 E., Powder River County, Hydrologic Unit 10090102, Custer National Forest, on right bank, 2.8 miles downstream from Fifteenmile Creek, 9.0 miles north of Fort Howes Ranger Station, 16.5 miles northeast of Otter, and at mile 39.2.

DRAINAGE AREA.--453 square miles.

WATER-DISCHARGE RECORDS

PERIOD OF RECORD.--June 1982 to current year.

GAGE.--Water-stage recorder. Altitude of gage is 3,140 feet, from topographic map.

REMARKS.--Water-discharge records fair except those for winter period, which are poor. Numerous diversions for irrigation above station.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge unknown; maximum gage height, 6.96 feet, revised, July 26, 1982; minimum discharge, 0.07 cubic foot per second Aug. 13, 17, 18, 1983.

EXTREMES FOR CURRENT YEAR.--Maximum discharge unknown; maximum gage height, 2.80 feet Jan. 12 (backwater from ice); minimum discharge, 0.07 cubic foot per second Aug. 13, 17, 18.

MEAN DISCHARGE, IN CUBIC FEET PER SECOND, OCTOBER 1982 THROUGH SEPTEMBER 1983

| Day | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.8 | 2.6 | 2.2 | 2.2 | 7.0 | 4.6 | 4.0 | 2.8 | 1.7 | 1.0 | 0.35 | 0.22 |
| 2 | 2.3 | 2.8 | 2.2 | 1.9 | 5.0 | 4.4 | 3.9 | 2.3 | 1.6 | .88 | .24 | .20 |
| 3 | 2.6 | 2.3 | 2.0 | 1.8 | 3.0 | 4.2 | 3.9 | 2.1 | 1.6 | .82 | .20 | .18 |
| 4 | 2.3 | 2.5 | 1.9 | 1.8 | 2.4 | 4.4 | 3.7 | 2.0 | 1.6 | 1.1 | .16 | .20 |
| 5 | 2.3 | 2.5 | 1.9 | 1.9 | 2.5 | 4.0 | 3.7 | 2.0 | 1.5 | 1.1 | .18 | .22 |
| 6 | 1.6 | 2.3 | 1.8 | 3.0 | 3.0 | 3.9 | 3.6 | 2.0 | 1.5 | 1.1 | .20 | .22 |
| 7 | 2.9 | 2.3 | 1.7 | 7.0 | 3.5 | 4.4 | 3.7 | 2.1 | 1.4 | 1.1 | .23 | .22 |
| 8 | 2.8 | 2.6 | 1.6 | 12 | 4.5 | 4.4 | 3.4 | 2.3 | 1.6 | .94 | .22 | .27 |
| 9 | 3.3 | 2.6 | 1.5 | 15 | 5.0 | 4.2 | 3.6 | 2.4 | 1.7 | .82 | .20 | .24 |
| 10 | 3.1 | 2.6 | 1.6 | 20 | 6.0 | 3.9 | 3.7 | 2.5 | 1.5 | .82 | .14 | .30 |
| 11 | 2.5 | 2.5 | 1.5 | 30 | 7.0 | 3.9 | 4.0 | 3.1 | 1.2 | .62 | .12 | .30 |
| 12 | 2.8 | 2.0 | 1.5 | 40 | 7.0 | 3.9 | 3.4 | 4.7 | 1.1 | .66 | .09 | .30 |
| 13 | 2.3 | 1.8 | 1.9 | 60 | 8.0 | 3.9 | 3.1 | 3.4 | 1.1 | .57 | .07 | .30 |
| 14 | 2.2 | 1.8 | 2.4 | 35 | 8.0 | 3.9 | 2.9 | 3.4 | 1.4 | .49 | .10 | .27 |
| 15 | 2.4 | 1.8 | 2.0 | 20 | 9.0 | 3.4 | 2.6 | 2.6 | 1.4 | .49 | .12 | .33 |
| 16 | 2.5 | 2.0 | 3.6 | 9.0 | 10 | 3.7 | 3.4 | 3.0 | 1.4 | .49 | .09 | .30 |
| 17 | 2.4 | 2.5 | 3.5 | 8.0 | 15 | 3.9 | 3.1 | 2.6 | 1.5 | .49 | .07 | .42 |
| 18 | 2.3 | 2.6 | 3.0 | 7.0 | 15 | 4.6 | 3.1 | 2.6 | 1.4 | .45 | .08 | .38 |
| 19 | 2.2 | 2.6 | 2.5 | 6.0 | 25 | 4.7 | 3.3 | 2.5 | 1.4 | .45 | .09 | .49 |
| 20 | 2.3 | 2.4 | 2.0 | 5.5 | 40 | 4.6 | 3.7 | 2.4 | 1.3 | .53 | .09 | .62 |
| 21 | 2.2 | 2.2 | 1.8 | 5.0 | 32 | 4.9 | 3.1 | 2.3 | 1.2 | .53 | .11 | .62 |
| 22 | 1.9 | 2.1 | 2.0 | 4.5 | 38 | 4.7 | 2.6 | 2.4 | 1.1 | .49 | .35 | .62 |
| 23 | 1.8 | 2.0 | 2.0 | 4.0 | 30 | 4.4 | 2.5 | 2.3 | 1.1 | .57 | .45 | .76 |
| 24 | 1.9 | 2.0 | 1.8 | 3.5 | 20 | 4.4 | 2.2 | 2.3 | 1.0 | .57 | .38 | .88 |
| 25 | 2.1 | 2.0 | 1.4 | 3.0 | 12 | 4.7 | 2.1 | 2.3 | 1.0 | .53 | .35 | .82 |
| 26 | 2.0 | 2.0 | 1.6 | 2.5 | 9.0 | 4.6 | 2.3 | 2.2 | .94 | .53 | .33 | .82 |
| 27 | 2.1 | 2.0 | 1.6 | 3.0 | 9.0 | 3.9 | 2.5 | 2.2 | .88 | .66 | .30 | .71 |
| 28 | 2.1 | 2.1 | 1.3 | 5.5 | 7.5 | 3.4 | 2.4 | 1.9 | .94 | .57 | .27 | .71 |
| 29 | 2.4 | 2.2 | 1.6 | 9.0 | --- | 3.6 | 2.8 | 1.7 | 1.5 | .53 | .24 | .88 |
| 30 | 2.5 | 2.2 | 2.0 | 12 | --- | 3.6 | 2.8 | 1.7 | 1.1 | .57 | .24 | 1.5 |
| 31 | 2.8 | --- | 2.7 | 10 | --- | 3.9 | --- | 1.7 | --- | .49 | .22 | --- |
| Total | 73.7 | 67.9 | 62.1 | 349.1 | 343.4 | 129.0 | 95.1 | 75.8 | 39.66 | 20.96 | 6.28 | 14.30 |
| Mean | 2.38 | 2.26 | 2.00 | 11.3 | 12.3 | 4.16 | 3.17 | 2.45 | 1.32 | .68 | .20 | .48 |
| Maximum | 3.3 | 2.8 | 3.6 | 60 | 40 | 4.9 | 4.0 | 4.7 | 1.7 | 1.1 | .45 | 1.5 |
| Minimum | 1.6 | 1.8 | 1.3 | 1.8 | 2.4 | 3.4 | 2.1 | 1.7 | .88 | .45 | .07 | .18 |
| Acre-feet | 146 | 135 | 123 | 692 | 681 | 256 | 189 | 150 | 79 | 42 | 12 | 28 |

Water year 1983 Total = 1,277.30 Mean = 3.50 Maximum = 60 Minimum = 0.07 Acre-feet 2,530

Table 3.--*Daily discharge records for Otter Creek at Ashland (station 06307740), 1983 water year*

## YELLOWSTONE RIVER BASIN

## 06307740 OTTER CREEK AT ASHLAND, MT

LOCATION.--Lat 45°35'18", long 106°15'17", in NE¼NE¼SE¼ sec. 11, T. 3 S., R. 44 E., Rosebud County, Hydrologic Unit 10090102, on left bank 200 feet downstream from bridge on U.S. Highway 212, 0.3 mile southeast of Ashland, and at mile 2.7.

DRAINAGE AREA.--707 square miles.

### WATER-DISCHARGE RECORDS

PERIOD OF RECORD.--October 1972 to current year.

GAGE.--Water-stage recorder. Datum of gage is 2,916.57 feet above sea level.

REMARKS.--Water-discharge records poor. Diversions for irrigation of about 4,200 acres above station.

AVERAGE DISCHARGE.--11 years, 7.03 cubic feet per second, 5,090 acre-feet per year.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 425 cubic feet per second Mar. 21, 1978, gage height, 8.65 feet, backwater from beaver dam; no flow on many days in 1977 and 1982.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 75 cubic foot per second Feb. 21, gage height, 5.24 feet, only peak above base of 50 cubic feet per second; minimum daily, 0.29 cubic foot per second, on many days in August and September.

MEAN DISCHARGE, IN CUBIC FEET PER SECOND, OCTOBER 1982 THROUGH SEPTEMBER 1983

| Day | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.9 | 3.3 | 3.1 | 3.1 | 9.0 | 12 | 6.3 | 5.1 | 3.0 | 0.82 | 0.50 | 0.29 |
| 2 | 2.0 | 3.3 | 3.2 | 3.1 | 8.2 | 12 | 6.9 | 5.1 | 4.6 | .93 | .40 | .29 |
| 3 | 2.2 | 3.3 | 3.3 | 3.3 | 8.0 | 9.7 | 6.8 | 5.1 | 3.0 | .71 | .40 | .29 |
| 4 | 2.1 | 3.3 | 3.3 | 3.4 | 9.0 | 9.7 | 6.8 | 5.0 | 2.5 | .71 | .40 | .29 |
| 5 | 2.1 | 3.5 | 3.5 | 3.4 | 8.5 | 10 | 6.3 | 5.1 | 2.6 | .71 | .40 | .29 |
| 6 | 2.6 | 3.6 | 3.3 | 3.5 | 9.0 | 9.0 | 6.1 | 5.4 | 2.4 | .71 | .40 | .29 |
| 7 | 2.8 | 3.6 | 3.3 | 3.4 | 9.0 | 8.7 | 6.3 | 5.1 | 2.4 | .71 | .40 | .29 |
| 8 | 2.5 | 3.3 | 3.2 | 3.4 | 7.8 | 11 | 6.3 | 5.0 | 2.4 | .71 | .40 | .29 |
| 9 | 3.2 | 4.1 | 3.3 | 3.4 | 7.0 | 9.5 | 6.1 | 4.8 | 2.8 | .61 | .40 | .29 |
| 10 | 3.6 | 4.4 | 3.3 | 3.4 | 7.6 | 10 | 6.1 | 4.8 | 2.9 | .61 | .40 | .29 |
| 11 | 3.6 | 3.9 | 3.2 | 4.0 | 8.0 | 10 | 5.9 | 5.0 | 2.9 | .61 | .29 | .29 |
| 12 | 4.1 | 3.0 | 3.3 | 5.0 | 8.5 | 10 | 5.9 | 5.1 | 3.2 | 1.0 | .29 | .29 |
| 13 | 4.1 | 2.7 | 3.3 | 8.0 | 13 | 9.5 | 5.7 | 5.4 | 3.3 | 1.0 | .29 | .29 |
| 14 | 4.2 | 2.8 | 3.4 | 15 | 14 | 9.5 | 5.6 | 5.6 | 3.3 | 1.0 | .29 | .29 |
| 15 | 3.6 | 2.9 | 3.4 | 13 | 19 | 9.5 | 5.9 | 5.6 | 3.0 | .71 | .29 | .29 |
| 16 | 3.8 | 3.0 | 3.5 | 10 | 27 | 9.0 | 6.3 | 5.1 | 2.6 | .71 | .29 | .29 |
| 17 | 3.5 | 3.1 | 3.3 | 8.5 | 19 | 8.7 | 6.1 | 5.0 | 2.8 | .61 | .29 | .29 |
| 18 | 3.3 | 3.2 | 3.2 | 8.0 | 36 | 8.5 | 5.7 | 4.6 | 2.2 | .61 | .29 | .29 |
| 19 | 3.6 | 3.6 | 3.2 | 7.2 | 29 | 8.0 | 5.6 | 4.4 | 1.5 | .61 | .29 | .29 |
| 20 | 3.6 | 4.4 | 3.3 | 6.9 | 35 | 7.4 | 5.4 | 4.0 | 1.0 | .50 | .40 | .40 |
| 21 | 3.6 | 4.2 | 3.2 | 6.6 | 51 | 7.2 | 5.3 | 3.6 | 1.4 | .50 | .50 | .40 |
| 22 | 3.6 | 3.9 | 3.2 | 6.3 | 40 | 7.4 | 5.3 | 3.2 | 1.7 | .50 | .40 | .40 |
| 23 | 3.6 | 3.5 | 3.2 | 5.9 | 42 | 7.8 | 5.3 | 2.9 | 1.4 | .50 | .40 | .40 |
| 24 | 3.6 | 3.4 | 3.1 | 5.6 | 39 | 7.6 | 5.3 | 3.0 | 1.0 | .50 | .40 | .40 |
| 25 | 4.1 | 3.3 | 3.0 | 5.3 | 27 | 7.8 | 5.1 | 3.2 | .71 | .50 | .40 | .40 |
| 26 | 3.5 | 3.0 | 3.1 | 5.0 | 20 | 8.0 | 5.0 | 3.6 | .71 | .40 | .40 | .40 |
| 27 | 3.6 | 3.0 | 3.1 | 5.2 | 16 | 7.8 | 5.0 | 3.8 | .71 | .50 | .40 | .50 |
| 28 | 3.6 | 2.9 | 3.0 | 5.7 | 14 | 7.4 | 5.0 | 2.9 | .71 | .50 | .40 | .50 |
| 29 | 3.3 | 3.1 | 3.1 | 7.6 | --- | 7.6 | 5.0 | 1.5 | .71 | .50 | .29 | .50 |
| 30 | 3.2 | 3.1 | 3.2 | 16 | --- | 7.6 | 5.0 | 1.7 | .71 | .50 | .29 | .50 |
| 31 | 3.5 | --- | 3.2 | 14 | --- | 7.4 | --- | 2.8 | --- | .50 | .29 | --- |
| Total | 101.6 | 101.7 | 100.3 | 202.2 | 540.6 | 275.3 | 173.4 | 132.5 | 64.16 | 19.99 | 11.28 | 10.31 |
| Mean | 3.28 | 3.39 | 3.24 | 6.52 | 19.3 | 8.88 | 5.78 | 4.27 | 2.14 | .64 | .36 | .34 |
| Maximum | 4.2 | 4.4 | 3.5 | 16 | 51 | 12 | 6.9 | 5.6 | 4.6 | 1.0 | .50 | .50 |
| Minimum | 1.9 | 2.7 | 3.0 | 3.1 | 7.0 | 7.2 | 5.0 | 1.5 | .71 | .40 | .29 | .29 |
| Acre-feet | 202 | 202 | 199 | 401 | 1070 | 546 | 344 | 263 | 127 | 40 | 22 | 20 |

Water year 1983 Total 1,733.34 Mean = 4.75 Maximum = 51 Minimum = 0.29 Acre-feet = 3,440

Table 4.--*Hydraulic data for wells completed in alluvium*

| Well No. | Location No. | Other identi-fication No. | Subarea No. | Pumping rate (gallons per minute) | Trans-missivity[1] (feet squared per day) | Storage[2] coeffi-cient |
|---|---|---|---|---|---|---|
| AL- 1 | 03S44E11DAAA01 | OC83-2 | 2 | 27.4 | 1,100 | 0.004 |
| AL- 2 | 03S44E11DAAC01 | OC83-3 | 2 | 27.4 | 2,400 | -- |
| AL- 3 | 03S44E11DACB01 | OC83-6 | 2 | 26.7 | 2,900 | -- |
| AL- 4 | 03S45E16DDDC01 | OC83-5 | 3 | 26.0 | 9,200 | -- |
| AL- 9 | 04S45E10CCBC01 | OC-8 | 5 | 64.0 | 6,500 | -- |
| AL-10 | 04S45E04BADD01 | WO-12 | 6 | 64.0 | 2,500 | .0003 |
| AL-11 | 04S45E04BDAA01 | WO-13 | 6 | 10.0 | 3,500 | .0003 |
| AL-12 | 04S45E04BDDB01 | WO-14 | 6 | 26.6 | 5,800 | .01 |
| AL-13 | 04S45E04BDDB02 | WO-15 | 6 | 25.0 | 4,500 | .002 |
| AL-14 | 04S45E04CAAC01 | WO-16 | 6 | 3.7 | 1,000 | -- |
| AL-16 | 04S45E09DCAA01 | OC-2A | 6 | 24.6 | 3,000 | -- |
| AL-20 | 05S45E23ABDA03 | WO-7 | 9 | 2.8 | 250 | -- |
| AL-21 | 05S45E23ABCA01 | WO-8 | 9 | 20.4 | 200 | -- |
| AL-22 | 05S45E23ABCA02 | WO-9 | 9 | 21.8 | 2,600 | -- |
| AL-23 | 05S45E23ABCB01 | WO-10 | 9 | 56.5 | 2,200 | .003 |
| AL-27 | 05S45E23BBAA04 | WO-4 | 10 | 19.0 | 500 | -- |

[1]Transmissivity values were computed from aquifer tests using either the non-equilibrium method of Theis (1935), or the straight-line solution method of Cooper and Jacob (1946).

[2]Storage coefficient was calculated only for multiple-well sites. Values reflect early-time storage coefficient before delayed yield from storage is complete.

Table 5.--*Hydraulic data for wells completed in the Tongue River Member of the Fort Union Formation*

| Well No. | Location No. | Other identification No. | Subarea No. | Aquifer | Pumping rate (gallons per minute) | Transmissivity[1] (feet squared per day) | Storage[2] coefficient |
|---|---|---|---|---|---|---|---|
| TR- 3 | 03S44E36DACA01 | OC83-1 | 2 | Knobloch coal bed | 3.8 | 60 | -- |
| TR- 39 | 04S45E06DBDB01 | US77-23 | 4 | Knobloch coal bed | 12.5 | 440 | 0.001 |
| TR- 40 | 04S45E07CABA01 | OC-30 | 4 | Knobloch coal bed | 5.2 | 3.0 | -- |
| TR- 53 | 04S45E14CDCC01 | OC83-4 | 5 | Knobloch coal bed | 13.7 | 230 | -- |
| TR- 72 | 04S45E28BDDD01 | US77-25 | 8 | Sandstone and coal | 7.6 | 200 | -- |
| TR- 79 | 05S45E04ABCC01 | US77-26 | 8 | Knobloch coal bed | 3.6 | 8.0 | -- |
| TR- 81 | 05S45E23ABDA01 | WO-5 | 9 | Sandstone | 20.4 | 400 | -- |
| TR- 82 | 05S45E23ABDA02 | WO-6 | 9 | Lower Knobloch coal bed | 7.0 | 20 | -- |
| TR- 91 | 05S45E16ADDD01 | OC83-7 | 10 | Sandstone bed | 6.0 | 130 | -- |
| TR- 92 | 05S45E23BBAA01 | WO-1 | 10 | Sandstone bed | 8.5 | 2.5 | -- |
| TR- 93 | 05S45E23BBAA02 | WO-2 | 10 | Lower Knobloch coal bed | 19.0 | 230 | -- |
| TR- 94 | 05S45E23BBAA03 | WO-3 | 10 | Sandstone and coal | 18.0 | 250 | -- |
| TR-143 | 04S45E08DDAD01 | OC-13 | 6 | Knobloch coal bed | 2.1 | 6.0 | -- |

[1]Transmissivity values were computed from aquifer tests using either the nonequilibrium method of Theis (1935), or the straight-line solution method of Cooper and Jacob (1946).

[2]Storage coefficient was calculated only for multiple-well sites.

Table 6.--*Rates of water inflow from bedrock aquifers*

| Subarea No. | Transmissivity[1] (feet squared per day) | Gradient | Width of area (feet) | Discharge (cubic feet per day) |
|---|---|---|---|---|
| 1 | 30 | 0.016 | 15,200 | 7,300 |
| 2 | 60 | .008 | 15,200 | 7,300 |
| 3 | 152 | .005 | 15,500 | 11,780 |
| 4 | 222 | .005 | 15,500 | 17,200 |
| 5 | 230 | .005 | 15,000 | 17,250 |
| 6 | 152 | .007 | 15,000 | 15,960 |
| 7 | 152 | .007 | 18,000 | 19,150 |
| 8 | 104 | .007 | 18,000 | 13,100 |
| 9 | 210 | .007 | 15,000 | 22,050 |
| 10 | 153 | .004 | 15,000 | 9,180 |
| | | | Total | [2]140,270 |

[1]Transmissivity from aquifer tests in subarea or nearby area. In subareas where more than one test was done, the reported value is a simple mean.

[2]Equivalent to annual rate of 1,175 acre-feet.

Table 7.--*Average monthly precipitation at Ashland, Mont., for 1956-80*

| Period | Precipitation (inches) | Period | Precipitation (inches) |
|---|---|---|---|
| January | 0.62 | August | 1.03 |
| February | .56 | September | 1.00 |
| March | .60 | October | .86 |
| April | 1.30 | November | .66 |
| May | 2.37 | December | .56 |
| June | 2.46 | Annual | 13.05 |
| July | 1.03 | | |

Source: U.S. Department of Commerce,
National Oceanic and Atmospheric Administration

Table 8.--*Monthly distribution*[1] *of free-water-surface evaporation for the Otter Creek valley for 1956-70*

| Period | Evaporation (inches) | Period | Evaporation (inches) |
|---|---|---|---|
| January | 0.61 | August | 6.83 |
| February | .71 | September | 4.29 |
| March | 1.48 | October | 2.97 |
| April | 2.51 | November | .97 |
| May | 5.38 | December | .74 |
| June | 6.04 | Total (annual) | 40 |
| July | 7.46 | Total (May-Oct.) | 33 |

[1]Based on free-water-surface evaporation for Huntley, Mont. (about 100 miles west of Ashland); Terry, Mont. (about 115 miles north-northeast of Ashland); and Sheridan, Wyo. (about 65 miles southwest of Ashland) using method of Farnsworth and Thompson (1982).

Table 9.--*Average annual net evaporation*[1] *from the surface of Otter Creek*

| Subarea No. | Stream length (miles) | Stream area (acres) | Annual evaporation rate (inches) | Evaporated volume (acre-feet) |
|---|---|---|---|---|
| 1+2 | 7.28 | 14.12 | 26.95 | 31.7 |
| 3+4 | 9.87 | 19.14 | 26.95 | 42.9 |
| 5+6 | 6.95 | 13.48 | 26.95 | 30.3 |
| 7+8 | 9.81 | 19.02 | 26.95 | 42.7 |
| 9+10 | 7.76 | 15.05 | 26.95 | 33.8 |
| | | | Total | 181.4 |

[1]Calculations assume: Width of stream channel = 16 feet (from Omang and others, 1983), and

Net evaporation = free-water-surface evaporation minus precipitation (40 inches -13.05 inches = 26.95 inches)

Table 10.--*Annual volume*[1] *of ground-water loss to evapotranspiration in areas of subirrigated alluvium, 1983 water year*

| Area No. | Area (square miles) | Water from subirrigation (inches) | Volume removed by subirrigation (acre-feet) |
|---|---|---|---|
| 1+2 | 1.30 | 11.5 | 797 |
| 3+4 | 1.26 | 11.5 | 773 |
| 5+6 | .82 | 11.5 | 491 |
| 7+8 | 1.27 | 11.5 | 779 |
| 9+10 | .95 | 11.5 | 583 |
| | | | Total 3,423 |

[1]Calculations assume: Consumptive use for year = 24.46 inches, precipitation during growing season = 8.75 inches, water deficit = 15.7 inches, and crops satisfied 11.5 inches of water requirement from water table and 4.2 inches from soil moisture.

Table 11.--*Calculations of average annual recharge rate for clinker and alluvium*

Area of clinker and non-subirrigated alluvium = 24.54 square miles.

Volume of annual recharge calculated as a remainder in the water-budget equation = 2,016 acre-feet

$$\text{Annual recharge rate} = \frac{(2{,}016 \text{ acre-feet})}{(24.54 \text{ square miles})} \frac{(\text{square mile})}{(640 \text{ acres})} \frac{(12 \text{ inches})}{(1 \text{ foot})} = 1.54 \text{ inches}$$

Table 12.--*Change in water storage in the Otter Creek alluvial aquifer, 1983 water year*

| Well No. | Other identi-fication No. | Date (mo-day-yr) | Water level (feet below land surface) | Change in water level (feet) | Change in storage during water-year (acre-feet) |
|---|---|---|---|---|---|
| AL-10 | WO-12 | 09-20-82 | 5.69 | | |
| | | 09-30-83 | [1] 6.21 | -0.52 | -- |
| AL-12 | WO-14 | 10-16-82 | 7.89 | | |
| | | 09-30-83 | 8.92 | -1.03 | -- |
| AL-21 | WO-08 | 09-20-82 | 15.56 | | |
| | | 09-30-83 | [1]16.12 | -0.56 | -- |
| AL-22 | WO-09 | 09-20-82 | 11.57 | | |
| | | 09-30-83 | 12.92 | -1.35 | -- |
| AL-23 | WO-10 | 09-20-82 | 9.33 | | |
| | | 09-30-82 | [1]10.15 | -0.82 | -- |
| AL-27 | WO-04 | 09-20-82 | 10.13 | | |
| | | 09-30-83 | [1]10.85 | -0.72 | -- |
| | | | Average change | -0.83 | [2]1,325 |

[1]Water levels for these days were interpolated from measurements close to these days.

[2]Calculated as follows: Assume specific yield = 0.22; then average change in water = (-0.83) (0.22) = -0.18 foot.

Area of alluvium in main valley of Otter Creek plus in downstream parts of major tributaries = 11.5 square miles.

Therefore, change in storage for water year = (11.5 square miles) (640 acres per square mile) (0.18 foot) = 1,325 acre-feet.

Table 13.--*Daily specific-conductance values for Otter Creek below Fifteenmile Creek (station 06307717)*[1], *1983 water year*[2]

YELLOWSTONE RIVER BASIN

06307717 OTTER CREEK BELOW FIFTEENMILE CREEK, NEAR OTTER, MT

WATER-QUALITY RECORDS

PERIOD OF RECORD.--Water years 1982 to current year.

PERIOD OF DAILY RECORD.--
SPECIFIC CONDUCTANCE: October 1982 to September 1983.

REMARKS.--Once-daily water temperatures are available in the Helena district office.

ONCE-DAILY SPECIFIC CONDUCTANCE, IN MICROSIEMENS PER CENTIMETER AT 25° CELSIUS, OCTOBER 1982 THROUGH SEPTEMBER 1983

| Day | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | --- | 3230 | 3290 | 3310 | 2920 | 2530 | 3460 | 3410 | --- | 3120 | --- | --- |
| 2 | --- | 3260 | 3380 | 3360 | 2910 | 2610 | 3460 | 3480 | --- | 3140 | 3550 | --- |
| 3 | --- | 3250 | 3370 | 3290 | 3140 | 2790 | 3440 | 3480 | --- | 3200 | 3580 | --- |
| 4 | --- | 3260 | 3370 | 3330 | 3290 | 2790 | 3430 | 3490 | --- | 3170 | --- | --- |
| 5 | 3170 | 3240 | 3330 | 3090 | 3290 | --- | 3440 | 3520 | --- | 3120 | --- | --- |
| 6 | 3220 | 3250 | 3270 | 3330 | 3250 | 2900 | 3410 | 3490 | 3250 | 3080 | --- | --- |
| 7 | 3170 | 3180 | 3360 | 2570 | 3270 | 3020 | 3430 | 3440 | 3290 | --- | --- | --- |
| 8 | 3170 | 3170 | 3310 | 2220 | 3130 | 3020 | 3440 | 3450 | 3300 | 3380 | 3660 | --- |
| 9 | 3090 | 3190 | 3410 | 1490 | 3140 | 3170 | --- | 3400 | --- | 3260 | 3650 | --- |
| 10 | 3160 | 3210 | 3430 | 2280 | 2870 | 3290 | 3430 | 3440 | 3290 | 3340 | 3740 | --- |
| 11 | 3100 | 3250 | --- | 2250 | 2870 | 3320 | 3420 | 3450 | 3230 | 3280 | 3830 | --- |
| 12 | 3190 | 3370 | 3450 | 1250 | --- | 3370 | 3410 | 3190 | 3300 | --- | 3990 | --- |
| 13 | 3260 | 3320 | 3470 | 1750 | 2620 | 3370 | 3410 | 3180 | 3250 | 3390 | 4010 | --- |
| 14 | 3280 | 3500 | 3370 | 2250 | 2600 | 3380 | 3450 | 3410 | 3250 | 3470 | --- | --- |
| 15 | 3270 | 3520 | 3360 | 2730 | 2570 | 3400 | 3430 | 3240 | 3200 | 3410 | --- | --- |
| 16 | 3240 | 3450 | 3300 | 2980 | --- | 3400 | 3460 | 3380 | 3250 | --- | 4000 | --- |
| 17 | 3230 | 3450 | 3360 | 2620 | --- | 3430 | 3460 | --- | 3250 | 3480 | 3980 | --- |
| 18 | 3220 | 3300 | 3360 | 2950 | --- | 3440 | 3490 | 3320 | 3250 | 3460 | 4010 | --- |
| 19 | 3230 | 3220 | 3300 | 3430 | --- | 3420 | 3480 | 3320 | 3280 | 3160 | 3930 | --- |
| 20 | 3230 | 3330 | 3310 | 3030 | --- | 3420 | 3480 | --- | --- | 3480 | 3930 | --- |
| 21 | 3250 | 3330 | 3330 | 2770 | 1360 | 3400 | 3480 | --- | --- | 3470 | 3660 | --- |
| 22 | 3280 | 3510 | 3280 | 2650 | 1350 | 3430 | 3490 | --- | 3280 | 3520 | 3650 | --- |
| 23 | 3290 | 3640 | 3350 | 3250 | 1640 | 3440 | 3480 | --- | 3320 | 3390 | 3510 | --- |
| 24 | 3270 | 3670 | 3320 | 3240 | --- | 3420 | --- | --- | 3330 | 3440 | 3620 | --- |
| 25 | 3250 | 3800 | 3190 | 3350 | 1810 | 3420 | 3560 | --- | 3330 | 3400 | 3600 | --- |
| 26 | 3260 | 3800 | 3250 | --- | 2450 | --- | 3490 | --- | 3370 | 3390 | 3660 | --- |
| 27 | 3150 | 3480 | 3260 | --- | 2170 | 3400 | 3500 | --- | 3360 | --- | 3740 | --- |
| 28 | 3200 | 3890 | 3320 | 2630 | 2170 | 3430 | 3440 | --- | 3170 | --- | 3740 | --- |
| 29 | 3150 | 3560 | 3270 | 2630 | --- | 3450 | 3460 | --- | --- | --- | 3760 | --- |
| 30 | 3170 | 3530 | 3210 | 2990 | --- | 3440 | 3450 | --- | --- | --- | 3750 | --- |
| 31 | 3230 | --- | 3280 | 3060 | --- | 3470 | --- | --- | --- | --- | 3850 | --- |
| Mean | 3210 | 3410 | 3330 | 2760 | 2610 | 3250 | 3460 | 3390 | 3280 | 3330 | 3770 | |

Water year 1983 Mean 3260 Maximum 4010 Minimum 1250

[1]Latitude 45°24'11", longitude 106°08'31"; drainage area 453 square miles.

[2]Number of missing days of record exceeded 20 percent of year.

Table 14.--*Daily specific-conductance values for Otter Creek at Ashland (station 06307740)*[1], *1983 water year*

YELLOWSTONE RIVER BASIN

06307740 OTTER CREEK AT ASHLAND, MT

WATER-QUALITY RECORDS

PERIOD OF RECORD.--Water years 1975 to current year.

PERIOD OF DAILY RECORD.--
SPECIFIC CONDUCTANCE: November 1980 to current year.

REMARKS.--Once-daily temperatures are available in the Helena district office.

EXTREMES FOR PERIOD OF DAILY RECORD.--
SPECIFIC CONDUCTANCE: Maximum daily, 3,440 microsiemens Dec. 16, 1982; minimum daily, 942 microsiemens Feb. 19, 1982.

EXTREMES FOR CURRENT YEAR.--
SPECIFIC CONDUCTANCE: Maximum daily, 3,440 microsiemens Dec. 16; minimum daily, 1,090 microsiemens Feb. 18.

ONCE-DAILY SPECIFIC CONDUCTANCE IN MICROSIEMENS PER CENTIMETER AT 25° CELSIUS, OCTOBER 1982 THROUGH SEPTEMBER 1983

| Day | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2100 | 2810 | 3250 | 3300 | 1550 | 1650 | 3290 | 3340 | 3310 | 3090 | 3100 | 3100 |
| 2 | 2180 | 2820 | 3280 | 3310 | 1850 | 1700 | 3290 | 3360 | 3400 | 3100 | 3100 | 3090 |
| 3 | 2210 | 2830 | 3210 | 3270 | 1850 | 1760 | 3300 | 3340 | 3330 | 3110 | 3120 | 3070 |
| 4 | 2230 | 2870 | 3280 | 3230 | 2170 | 1840 | 3280 | 3340 | 3310 | 3100 | 3120 | 3070 |
| 5 | 2290 | 2830 | 3300 | 3220 | 2600 | 1960 | 3300 | 3350 | 3300 | 3100 | 3080 | 3060 |
| 6 | 2390 | 2840 | 3290 | 3150 | 2590 | 1960 | 3290 | 3370 | 3230 | 3120 | 3070 | 3060 |
| 7 | 2470 | 2860 | 3300 | 3150 | 2910 | 2020 | 3300 | 3360 | 3170 | 3110 | 3060 | 3050 |
| 8 | 2500 | 2860 | 3330 | 3180 | 3180 | 2070 | 3290 | 3350 | 3140 | 3090 | 3120 | 3040 |
| 9 | 2470 | 2840 | 3330 | 3150 | 3270 | 2110 | 3280 | 3310 | 3130 | 3090 | 3120 | 3050 |
| 10 | 2530 | 2880 | 3320 | 3150 | 2830 | 2200 | 3270 | 3380 | 3110 | 3090 | 3100 | 3030 |
| 11 | 2590 | 2880 | 3330 | 3130 | 2850 | 2280 | 3270 | 3380 | 3110 | 3110 | 3110 | 3020 |
| 12 | 2640 | 2910 | 3360 | 3120 | 2860 | 2460 | 3270 | 3280 | 3020 | 3100 | 3120 | 3000 |
| 13 | 2640 | 2960 | 3400 | 2790 | 2850 | 2460 | 3280 | 3220 | 2980 | 3090 | 3130 | 2980 |
| 14 | 2670 | 3020 | 3410 | 2120 | 2440 | 2710 | 3290 | 3220 | 2930 | 3090 | 3120 | 2970 |
| 15 | 2710 | 3110 | 3430 | 1360 | 1980 | 2760 | 3280 | 3230 | 2920 | 3090 | 3130 | 2950 |
| 16 | 2750 | 3070 | 3440 | 1570 | 1630 | 2820 | 3300 | 3230 | 2940 | 3070 | 3110 | 2950 |
| 17 | 2750 | 3070 | 3430 | 1590 | 1130 | 2850 | 3310 | 3250 | 2920 | 3070 | 3100 | 2950 |
| 18 | 2780 | 3130 | 3390 | 1610 | 1090 | 2880 | 3300 | 3220 | 2950 | 3050 | 3110 | 2960 |
| 19 | 2860 | 3170 | 3400 | 1880 | 1250 | 2920 | 3330 | 3220 | 2950 | 3030 | 3110 | 2830 |
| 20 | 2930 | 3070 | 3310 | 1880 | 1140 | 3000 | 3330 | 3280 | 3000 | 3050 | 3090 | 2810 |
| 21 | 2930 | 3020 | 3300 | 1830 | 1450 | 3050 | 3340 | 3290 | 3030 | 3040 | 3030 | 2830 |
| 22 | 2900 | 3110 | 3310 | 1860 | 1710 | 3060 | 3330 | 3280 | 3110 | 3050 | 2980 | 2800 |
| 23 | 2830 | 3170 | 3270 | 2170 | 1650 | 3050 | 3320 | 3290 | 3130 | 3040 | 2970 | 2790 |
| 24 | 2720 | 3190 | 3240 | 2180 | 1400 | 3090 | 3330 | 3300 | 3130 | 3050 | 2950 | 2790 |
| 25 | 2710 | 3300 | 3250 | 2290 | 1350 | 3150 | 3320 | 3310 | 3140 | 3070 | 3000 | 2780 |
| 26 | 2810 | 3290 | 3230 | 2550 | 1380 | 3170 | 3330 | 3320 | 3130 | 3090 | 3030 | 2750 |
| 27 | 2800 | 3370 | 3280 | 2700 | 1380 | 3170 | 3330 | 3300 | 3140 | 3070 | 3080 | 2750 |
| 28 | 2820 | 3360 | 3260 | 2650 | 1570 | 3260 | 3340 | 3320 | 3140 | 3060 | 3090 | 2710 |
| 29 | 2840 | 3360 | 3240 | 2770 | --- | 3260 | 3330 | 3310 | 3110 | 3070 | 3090 | 2680 |
| 30 | 2830 | 3250 | 3360 | 2900 | --- | 3280 | 3310 | 3310 | 3110 | 3070 | 3060 | 2680 |
| 31 | 2820 | --- | 3360 | 2140 | --- | 3310 | --- | 3300 | --- | 3100 | 3070 | --- |
| Mean | 2640 | 3040 | 3320 | 2550 | 2000 | 2620 | 3300 | 3300 | 3110 | 3080 | 3080 | 2920 |

Water year 1983 Mean 2920 Maximum 3440 Minimum 1090

[1]Latitude 45°35'18", longitude 106°15'17"; drainage area 707 square miles.

Table 15.--*Regression equations relating dissolved-solids concentration*[1] *to specific conductance*[2]

Otter Creek below Fifteenmile Creek near Otter (06307717)
Dissolved solids = 0.775 (specific conductance) + 34.6
Number of samples = 11
Coefficient of determination = 0.91

Otter Creek at Ashland (06307740)
Dissolved solids = 0.784 (specific conductance) - 76.6
Number of samples = 28
Coefficient of determination = 0.92

Home Creek near Ashland (06307735)
Dissolved solids = 0.714 (specific conductance) + 233
Number of samples = 18
Coefficient of determination = 0.88

Wells completed in the Tongue River Member of the Fort Union Formation
Dissolved solids = 0.835 (specific conductance) - 281
Number of samples = 95
Coefficient of determination = 0.95

Wells completed in alluvium
Dissolved solids = 0.889 (specific conductance) - 393
Number of samples = 26
Coefficient of determination = 0.98

[1]In milligrams per liter.
[2]In microsiemens per centimeter at 25° Celsius.

Table 16.--*Monthly and annual dissolved-solids loads in Otter Creek below Fifteenmile Creek (station 06307717)*[1] *and Otter Creek at Ashland (station 06307740)*[2]*, 1983 water year*

| Dissolved-solids load, in tons | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Annual |
| Otter Creek below Fifteenmile Creek | | | | | | | | | | | | |
| 503.00 | 494.00 | 437.60 | 1712.00 | 1462.00 | 888.00 | 694.00 | 538.00 | 277.40 | 148.30 | 48.92 | 108.20 | 7311.42 |
| Otter Creek at Ashland | | | | | | | | | | | | |
| 549.00 | 631.00 | 684.00 | 967.00 | 1833.00 | 1432.00 | 1174.00 | 896.00 | 412.00 | 125.90 | 71.80 | 60.70 | 8836.40 |

[1]Drainage area 453 square miles.

[2]Drainage area 707 square miles.

Table 17.--*Specific-conductance and dissolved-solids data for alluvial wells and springs*

[mg/L, milligrams per liter; microsiemens, microsiemens per centimeter at 25° Celsius]

| Well No.[1] | Location No. | Other identification No. | Subarea No. | Specific conductance (microsiemens) | Dissolved-solids concentration (mg/L) |
|---|---|---|---|---|---|
| *AL- 1 | 03S44E11DAAA01 | OC83-2 | 2 | 1,540 | 1,003 |
| *AL- 2 | 03S44E11DAAC01 | OC83-3 | 2 | 2,320 | 1,650 |
| *AL- 3 | 03S44E11DACB01 | OC83-6 | 2 | 2,860 | 2,200 |
| AL- 4 | 03S45E16DDDC01 | OC83-5 | 3 | 2,100 | 1,410 |
| AL- 5 | 02S46E32ABCC01 | Spring | 3 | 2,390 | 1,670 |
| AL- 6 | 03S45E12BDCB02 | PRIV-12 | 3 | 1,880 | 1,410 |
| AL- 7 | 03S45E12BDCD01 | Spring | 3 | 1,450 | 984 |
| AL- 8 | 03S46E14CBCD01 | PRIV-14 | 3 | 1,940 | 1,410 |
| *AL- 9 | 04S45E10CCBC01 | OC-8 | 5 | 3,260 | 2,460 |
| *AL-10 | 04S45E04BADD01 | WO-12 | 6 | 3,340 | 2,590 |
| *AL-11 | 04S45E04BDAA01 | WO-13 | 6 | 3,100 | 2,400 |
| *AL-12 | 04S45E04BDDB01 | WO-14 | 6 | 4,200 | 3,340 |
| *AL-13 | 04S45E04BDDB02 | WO-15 | 6 | 4,010 | 3,100 |
| *AL-14 | 04S45E04CAAC01 | WO-16 | 6 | 3,100 | 2,260 |
| *AL-15 | 04S45E04DBDB01 | PRIV-4 | 6 | 3,000 | 1,950 |
| *AL-16 | 04S45E09DCAA01 | OC-2A | 6 | 3,420 | 2,600 |
| *AL-17 | 04S45E15BCDD01 | OC-6 | 6 | 4,050 | 3,110 |
| AL-18 | 05S46E04DACA01 | PRIV-4 | 7 | 2,560 | 1,670 |
| *AL-19 | 04S45E27DBAB01 | PRIV-27 | 8 | 2,700 | 1,960 |
| AL-20 | 05S45E23ABDA03 | WO-7 | 9 | 3,350 | 2,510 |
| *AL-21 | 05S45E23ABCA01 | WO-8 | 9 | 4,720 | 4,020 |
| *AL-22 | 05S45E23ABCA02 | WO-9 | 9 | 5,400 | 4,430 |
| *AL-23 | 05S45E23ABCB01 | WO-10 | 9 | 4,600 | 3,760 |
| AL-24 | 05S46E20CDAB01 | PRIV-20 | 9 | 3,640 | 2,940 |
| AL-25 | 05S46E24BCCB01 | PRIV-24 | 9 | 2,360 | 1,890 |
| AL-26 | 05S46E29ABAA01 | PRIV-29 | 9 | 2,650 | 2,080 |
| *AL-27 | 05S45E23BBAA04 | WO-4 | 10 | 3,800 | 2,960 |

[1]An asterisk denotes wells completed in the subirrigated part of the alluvial aquifer. The median dissolved-solids concentration in these wells is 2,590 milligrams per liter.

Table 18.--*Specific-conductance and dissolved-solids data for wells and springs in the Tongue River Member of the Fort Union Formation*

[mg/L, milligrams per liter; microsiemens, microsiemens per centimeter at 25° Celsius]

| Well or spring No. | Location No. | Other identification No. | Subarea No. | Specific conductance (microsiemens) | Dissolved-solids concentration (mg/L) |
|---|---|---|---|---|---|
| TR- 1 | 03S45E19DDBC02 | PRIV-19 | 2 | 1,600 | 834 |
| TR- 2 | 03S45E19DDBD01 | PRIV-19 | 2 | 1,600 | 866 |
| TR- 3 | 03S44E36DACA01 | OC83-1 | 2 | 5,000 | 3,530 |
| TR- 4 | 03S45E03BADD01 | Coal Creek Mine well | 3 | 4,600 | 3,540 |
| TR- 5 | 03S45E10BACD01 | Coal Creek well | 3 | 2,030 | 1,280 |
| TR- 6 | 03S45E22BBBA01 | PRIV-22 | 3 | 1,900 | 1,130 |
| TR- 7 | 03S45E22BAAB01 | PRIV-22 | 3 | 2,400 | 1,490 |
| TR- 8 | 03S45E15DDDA01 | PRIV-15 | 3 | 2,400 | 1,360 |
| TR- 9 | 03S45E14CCAB01 | Red Shale Camp well | 3 | 1,650 | 1,150 |
| TR-10 | 03S45E23DADA01 | PRIV-23 | 3 | 1,400 | 737 |
| TR-11 | 03S45E26ADAC01 | DH74-104 | 3 | 4,720 | 3,630 |
| TR-12 | 03S45E26DBCB01 | DH74-102 | 3 | 4,170 | 3,430 |
| TR-13 | 03S45E33CBDA01 | Shy flowing well | 3 | 1,480 | 882 |
| TR-14 | 03S45E34CACD01 | DH74-101 | 3 | 6,160 | 5,500 |
| TR-15 | 03S45E34AACD01 | DH74-103 | 3 | 5,600 | 4,230 |
| TR-16 | 02S45E36ACBA01 | Spring | 3 | 1,960 | 1,340 |
| TR-17 | 02S46E33CCBA01 | Spring | 3 | 1,700 | 1,160 |
| TR-18 | 02S46E34BCCB01 | PRIV-34 | 3 | 3,450 | 2,900 |
| TR-19 | 03S45E01ABDD01 | Spring | 3 | 2,300 | 1,790 |
| TR-20 | 03S46E06CCBD01 | PRIV-6 | 3 | 1,210 | 875 |
| TR-21 | 03S46E05AABB01 | PRIV-5 | 3 | 1,460 | 949 |
| TR-22 | 03S46E05AABB02 | PRIV-5 | 3 | 1,235 | 852 |
| TR-23 | 03S46E04CDBB01 | Spring | 3 | 5,400 | 4,190 |
| TR-24 | 03S45E12BDCB01 | PRIV-12 | 3 | 1,790 | 1,320 |
| TR-25 | 03S46E07ADBB01 | Coal mine project well | 3 | 5,200 | 3,030 |
| TR-26 | 03S45E13DCBC01 | PRIV-13 | 3 | 4,000 | 2,690 |
| TR-27 | 03S46E18BDAC01 | Coal Bank Spring | 3 | 4,510 | 3,460 |
| TR-28 | 03S46E17DBDC01 | PRIV-17 | 3 | 3,000 | 2,030 |
| TR-29 | 03S46E16ADCC01 | Wiechman well | 3 | 5,370 | 4,140 |
| TR-30 | 03S46E15CAAA01 | PRIV-15 | 3 | 2,400 | 1,730 |
| TR-31 | 03S46E14DBBD01 | Spring | 3 | 2,870 | 2,060 |
| TR-32 | 03S45E24ACDA01 | PRIV-24 | 3 | 3,700 | 2,700 |
| TR-33 | 03S46E19BBBB01 | PRIV-19 | 3 | 5,000 | 4,260 |
| TR-34 | 03S46E19BBAB01 | PRIV-19 | 3 | 4,940 | 4,210 |
| TR-35 | 03S46E19ACBA01 | Coleman well | 3 | 2,870 | 2,210 |
| TR-36 | 03S46E30BCCC01 | Thomas Draw well | 3 | 5,250 | 4,500 |
| TR-37 | 03S45E31DCDA01 | PRIV-31 | 4 | 4,400 | 3,480 |
| TR-38 | 03S45E32DDAC01 | PRIV-32 | 4 | 1,400 | 846 |

Table 18.--*Specific-conductance and dissolved-solids data for wells and springs in the Tongue River Member of the Fort Union Formation*--Continued

| Well or spring No. | Location No. | Other identification No. | Subarea No. | Specific conductance (microsiemens) | Dissolved-solids concentration (mg/L) |
|---|---|---|---|---|---|
| TR-39 | 04S45E06DBDB01 | US77-23 | 4 | 1,560 | 930 |
| TR-40 | 04S45E07CABA01 | OC-30 | 4 | 8,600 | 6,240 |
| TR-41 | 03S45E34DDDA01 | DH74-105 | 5 | 5,600 | 3,890 |
| TR-42 | 03S45E35DABA01 | DH75-108 | 5 | 3,300 | 2,260 |
| TR-43 | 04S45E02BDDD01 | DH74-106 | 5 | 2,820 | 1,840 |
| TR-44 | 04S45E02DACD01 | DH74-107 | 5 | 1,930 | 1,250 |
| TR-45 | 04S45E02CDDB01 | PRIV-2 | 5 | 2,470 | 1,860 |
| TR-46 | 03S46E33CBDA01 | Spring | 5 | 1,750 | 893 |
| TR-47 | 03S46E34DDCD01 | Stafford Spring | 5 | 3,900 | 2,940 |
| TR-48 | 04S46E05BCBC01 | Threemile well | 5 | 1,780 | 1,210 |
| TR-49 | 04S46E05CCAA01 | PRIV-5 | 5 | 2,500 | 1,980 |
| TR-50 | 04S46E09BBCA01 | Middle Pasture well | 5 | 1,580 | 1,010 |
| TR-51 | 04S46E11BBBA01 | Stafford well | 5 | 2,390 | 1,770 |
| TR-52 | 04S45E15DBBC01 | PRIV-15 | 5 | 2,300 | 1,460 |
| TR-53 | 04S45E14CDCC01 | OC83-4 | 5 | 1,060 | 662 |
| TR-54 | 04S46E08CBCC01 | McLatchy Draw well | 5 | 5,150 | 3,770 |
| TR-55 | 04S46E10DABC01 | Nutter well | 5 | 2,660 | 1,960 |
| TR-56 | 04S45E04DBCA01 | PRIV-4 | 6 | 1,250 | 669 |
| TR-57 | 04S45E19DADC01 | Newell Creek well | 6 | 4,250 | 3,000 |
| TR-58 | 04S45E20CCAD01 | PRIV-20 | 6 | 2,600 | 1,840 |
| TR-59 | 04S45E22ADCC01 | PRIV-22 | 7 | 1,520 | 910 |
| TR-60 | 04S45E23CCCB01 | PRIV-23 | 7 | 1,010 | 613 |
| TR-61 | 04S46E29CBBA01 | Coal Creek Spring | 7 | 5,670 | 5,010 |
| TR-62 | 04S46E28DABC01 | Mineral Yager Spring | 7 | 5,720 | 5,250 |
| TR-63 | 04S46E28DADC01 | Spring | 7 | 5,500 | 5,210 |
| TR-64 | 04S46E31CCCC01 | PRIV-31 | 7 | 2,210 | 1,520 |
| TR-65 | 04S46E31DDBC01 | PRIV-31 | 7 | 5,550 | 3,300 |
| TR-66 | 04S46E32DCDC01 | PRIV-32 | 7 | 2,240 | 1,470 |
| TR-67 | 04S46E34ABDB01 | Newcomer Spring | 7 | 5,400 | 4,760 |
| TR-68 | 05S46E05BDCB01 | PRIV-5 | 7 | 2,060 | 1,500 |
| TR-69 | 05S46E04DDAB01 | PRIV-4 | 7 | 2,200 | 1,700 |
| TR-70 | 05S46E09DADD01 | Coombe Spring | 7 | 2,320 | 1,680 |
| TR-71 | 04S45E30DDBB01 | Gene Creek Spring | 8 | 1,790 | 1,350 |
| TR-72 | 04S45E28BDDD01 | US77-25 | 8 | 2,290 | 1,310 |
| TR-73 | 04S45E28ADDA01 | PRIV-28 | 8 | 4,100 | 3,070 |
| TR-74 | 04S45E27DBBA02 | PRIV-27 | 8 | 988 | 582 |
| TR-75 | 04S45E27ACCD01 | PRIV-27 | 8 | 890 | 596 |
| TR-76 | 04S45E32CADC01 | Spring | 8 | 2,600 | 2,070 |
| TR-77 | 05S45E06DAAD01 | Chromo Spring | 8 | 1,590 | 1,280 |
| TR-78 | 05S45E04BBDD01 | PRIV-4 | 8 | 960 | 610 |
| TR-79 | 05S45E04ABCC01 | US77-26 | 8 | 3,000 | 2,020 |
| TR-80 | 05S45E03ACBA01 | PRIV-3 | 8 | 1,630 | 1,110 |

Table 18.--*Specific-conductance and dissolved-solids data for wells and springs in the Tongue River Member of the Fort Union Formation*--Continued

| Well or spring No. | Location No. | Other identification No. | Subarea No. | Specific conductance (microsiemens) | Dissolved-solids concentration (mg/L) |
|---|---|---|---|---|---|
| TR-81 | 05S45E23ABDA01 | WO-5 | 9 | 760 | 477 |
| TR-82 | 05S45E23ABDA02 | WO-6 | 9 | 1,780 | 1,150 |
| TR-83 | 05S46E20ABCA01 | Willey Use Spring | 9 | 3,000 | 2,470 |
| TR-84 | 05S46E21DDAA01 | PRIV-21 | 9 | 2,300 | 1,770 |
| TR-85 | 05S46E27BAAA01 | Smith Spring | 9 | 4,300 | 3,970 |
| TR-86 | 05S45E08BDDD01 | Brian Spring No 3 | 10 | 1,820 | 1,310 |
| TR-87 | 05S45E11CDCD01 | PRIV-11 | 10 | 2,300 | 1,430 |
| TR-88 | 05S45E18BDAD01 | Upper Brian Spring | 10 | 3,400 | 2,770 |
| TR-89 | 05S45E18AACC01 | Little Brian Spring | 10 | 2,050 | 1,530 |
| TR-90 | 05S45E18AACD01 | Brian Spring No. 2 | 10 | 3,220 | 2,620 |
| TR-91 | 05S45E16ADDD01 | OC83-7 | 10 | 900 | 581 |
| TR-92 | 05S45E23BBAA01 | WO-1 | 10 | 860 | 535 |
| TR-93 | 05S45E23BBAA02 | WO-2 | 10 | 1,070 | 667 |
| TR-94 | 05S45E23BBAA03 | WO-3 | 10 | 3,400 | 2,510 |
| TR-95 | 05S45E28BBBA01 | Upper Paget well | 10 | 1,950 | 1,100 |

Table 19.--*Annual pre-mining dissolved-solids load from bedrock aquifers*

| Subarea No. | Discharge (cubic feet per day) | Annual discharge (acre-feet) | Dissolved-solids concentration (milligrams per liter) | Annual load (tons) |
|---|---|---|---|---|
| 1 | 7,300 | 61 | [1]1,750 | 145 |
| 2 | 7,300 | 61 | 1,360 | 113 |
| 3 | 11,780 | 99 | 2,070 | 278 |
| 4 | 17,200 | 144 | 2,030 | 397 |
| 5 | 17,250 | 144 | 1,710 | 335 |
| 6 | 15,960 | 134 | 1,540 | 280 |
| 7 | 19,150 | 160 | 2,180 | 474 |
| 8 | 13,100 | 110 | 1,210 | 181 |
| 9 | 22,050 | 185 | 1,570 | 395 |
| 10 | 9,180 | 77 | 1,280 | 134 |
| | | | Total | 2,732 |

[1]Used area log mean value.

Table 20.--*Saturated-paste-extract data*[1]

[mg/L, milligrams per liter; microsiemens, microsiemens per centimeter at 25° Celsius]

| Well No. | Location No. | Other identification No. | Sub-area No. | Interval (feet below land surface) | Number of samples | Specific conductance[2] (microsiemens | Dissolved-solids[3] concentrations (mg/L) |
|---|---|---|---|---|---|---|---|
| TR- 3 | 03S44E36DACA01 | OC-83-1 | 2 | 0-60 | 2 | 5,900 | 4,270 |
| TR- 14 | 03S45E34CACD01 | DH74-101 | 3 | 0-98 | 5 | 4,175 | 2,960 |
| TR- 15 | 03S45E34AACD01 | DH74-103 | 3 | 0-50 | 4 | 6,040 | 4,380 |
| TR- 53 | 04S45E14CDCC01 | OC-83-4 | 5 | 0-150 | 4 | 5,770 | 4,170 |
| TR- 91 | 05S45E16ADDD01 | OC-83-7 | 10 | 0-175 | 6 | 3,660 | 2,570 |
| TR- 97 | 04S45E09CDAC01 | 80-OC-1 | 6 | 3-137 | 25 | 4,670 | 3,340 |
| TR- 98 | 04S45E21DDCC01 | 80-OC-31 | 8 | 0-120 | 22 | 2,410 | 1,610 |
| TR- 99 | 04S45E07BCAA01 | 80-OC-35 | 4 | 13-316 | 59 | 4,580 | 3,270 |
| TR-100 | 04S45E22BBCB01 | 80-OC-55 | 6 | 0-101 | 16 | 4,360 | 3,100 |
| TR-101 | 04S45E21ACDA01 | 80-OC-33 | 6 | 42-216 | 27 | 2,960 | 2,030 |
| TR-102 | 03S45E08DCB 01 | Montco 3458-3C | 3 | 15-79 | 9 | 1,960 | 1,270 |
| TR-103 | 05S45E12BDB 01 | DH76-101 (Dam Creek) | 9 | 0-50 | 4 | 2,745 | 1,870 |
| TR-104 | 04S45E26BDCD01 | DH76-101 | 7 | 0-62<br>157-212 | 5 | 2,050 | 1,340 |
| TR-105 | 05S45E04BADD01 | DH77-101 (Chromo 4) | 8 | 0-50 | 4 | 7,375 | 5,400 |
| TR-106 | 04S45E28BDDD02 | DH78-101 (Newell 28) | 8 | 0-113 | 7 | 2,085 | 1,370 |
| TR-107 | 04S45E06DBDA01 | DH78-101 (Shy 6) | 4 | 0-121 | 6 | 3,050 | 2,100 |
| TR-108 | 03S45E09CDDA01 | State 30 | 3 | 0-245 | 46 | 2,250 | 1,490 |
| TR-109 | 03S44E25BDCC01 | State 55 | 2 | 0-170 | 34 | 1,510 | 930 |
| TR-110 | 03S44E36DBCD01 | State 31 | 2 | 0-245 | 49 | 2,860 | 1,960 |
| TR-111 | 03S45E26DBCC01 | State 140 (A-1) | 3 | 0-145 | 22 | 4,570 | 3,260 |
| TR-112 | 03S45E34DBDC01 | State 141 | 3 | 0-205 | 40 | 2,710 | 1,840 |
| TR-113 | 04S45E03BDBD01 | State 142 | 5 | 0-170 | 33 | 1,970 | 1,280 |
| TR-114 | 04S45E26CCAD01 | State 62 | 7 | 0-65 | 10 | 560 | 205 |
| TR-115 | 05S45E04BBDC01 | State 61 | 8 | 0-135 | 26 | 1,600 | 997 |
| TR-116 | 05S45E12ACCC01 | State 60 | 9 | 0-95 | 19 | 2,740 | 1,860 |
| TR-117 | 05S45E16ACDA01 | State 36 | 10 | 0-125 | 22 | 2,580 | 1,740 |

[1]Saturated-paste extract data from Montana Department of State Lands, Montana Bureau of Mines and Geology, and U.S. Geological Survey.

[2]All specific-conductance values are weighted means (by thickness of overburden sample).

[3]Dissolved solids calculated by equation: Dissolved solids = 0.762 (specific conductance) -222. The regression equation was derived from 15 samples of overburden leachate water from the Otter Creek area. Coefficient of determination for the equation is 0.998.

Table 21.--*Annual post-mining dissolved-solids loads from mine spoils*

| Sub-area No. | Width of mined area (percent of total width) | Annual discharge from mine spoils (acre-feet) | Additional post-mining concentration[1] of dissolved solids from mine spoils (milligrams per liter) | | Additional post-mining annual load[2] from mine spoils (tons) | |
|---|---|---|---|---|---|---|
| | | | Minimum | Maximum | Minimum | Maximum |
| 1 | 66 | 40 | 840 | 1,970 | 46 | 107 |
| 2 | 36 | 22 | 840 | 1,970 | 25 | 59 |
| 3 | 58 | 57 | 840 | 1,970 | 65 | 153 |
| 4 | 100 | 144 | 840 | 1,970 | 164 | 386 |
| 5 | 100 | 144 | 840 | 1,970 | 164 | 386 |
| 6 | 100 | 134 | 840 | 1,970 | 153 | 359 |
| 7 | 100 | 160 | 840 | 1,970 | 183 | 428 |
| 8 | 100 | 110 | 840 | 1,970 | 126 | 294 |
| 9 | 100 | 185 | 840 | 1,970 | 211 | 495 |
| 10 | 100 | 77 | 840 | 1,970 | 88 | 206 |
| | | | | Totals | 1,225 | 2,873 |

[1]Post-mining concentrations: minimum values from batch-mixing data and maximum values from saturated-paste-extract data.

[2]The factor for converting the product of acre-feet and milligrams per liter to tons is 0.001359.

Table 22.--*Specific-conductance and dissolved-solids data from batch-mixing tests* [1]

[mg/L, milligrams per liter; microsiemens, microsiemens per centimeter at 25° Celsius]

| Well No. | Location No. | Other identification No. | Sample interval (feet below land surface) | Specific conductance (microsiemens) | Dissolved solids concentration (mg/L)[2] |
|---|---|---|---|---|---|
| TR-3[3] | 03S44E36DACA01 | OC83-1 | 0-60 | 5,990 | 4,360 |
| | | | | [5]5,025 | [5]3,610 |
| TR-53[3] | 04S45E14CDCC01 | OC83-4 | 0-60 | 3,375 | 2,360 |
| | | | 60-150 | 2,050 | 1,300 |
| | | | | [5]1,375 | [5]642 |
| TR-91[4] | 05S45E16ADDD01 | OC83-7 | 0-60 | 2,480 | 1,630 |
| | | | 60-115 | 1,820 | 1,240 |
| | | | 115-175 | 1,460 | 894 |
| | | | | [5]935 | [5]559 |

[1]Mixing ratio for samples was 2:1 by weight (water:material).

[2]Dissolved-solids concentrations of water from the batch-mixing tests were greater than those from the aquifer water. Weighted-mean concentrations increased by: 750 milligrams per liter for TR-3, 1,080 milligrams per liter for TR-53, and 700 milligrams per liter for TR-91 (average increase 840 milligrams per liter).

[3]Water from Knobloch coal aquifer.

[4]Water from sandstone aquifer.

[5]Denotes values from aquifer water.

Table 23.--*Annual and monthly post-mining dissolved-solids loads in Otter Creek at Ashland (station 06307740)*

[mg/L, milligrams per liter]

| Month | Median discharge[1] (acre-feet) | Mean dissolved solids concentration[2] (mg/L) | Mean load (tons) | Additional load from mining (tons) | | Mean post-mining load (tons)[3] | | Post-mining dissolved-solids concentration at median flow (milligrams per liter) | | Percent increase in dissolved solids load at median flow | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Minimum | Maximum | Minimum[4] | Maximum[4] | Minimum | Maximum | Minimum | Maximum |
| Jan. | 262 | 2,130 | 758 | 104.0 | 244.0 | 862 | 1,002 | 2,420 | 2,810 | 14 | 32 |
| Feb. | 550 | 1,940 | 1,450 | 94.0 | 220.4 | 1,544 | 1,670 | 2,060 | 2,230 | 6 | 15 |
| Mar. | 546 | 1,640 | 1,217 | 104.0 | 244.0 | 1,321 | 1,461 | 1,780 | 1,970 | 9 | 20 |
| Apr. | 440 | 2,200 | 1,316 | 100.7 | 236.1 | 1,417 | 1,552 | 2,370 | 2,600 | 8 | 18 |
| May | 337 | 2,220 | 1,017 | 104.0 | 244.0 | 1,121 | 1,261 | 2,450 | 2,750 | 10 | 24 |
| June | 298 | 2,300 | 931 | 100.7 | 236.1 | 1,032 | 1,167 | 2,550 | 2,880 | 11 | 25 |
| July | 136 | 2,230 | 412 | 104.0 | 244.0 | 516 | 656 | 2,790 | 3,550 | 25 | 59 |
| Aug. | 41 | 2,110 | 118 | 104.0 | 244.0 | 222 | 362 | 3,980 | 6,500 | 89 | 208 |
| Sept. | 48 | 2,040 | 133 | 100.7 | 236.1 | 234 | 369 | 3,590 | 5,660 | 76 | 177 |
| Oct. | 133 | 1,990 | 360 | 104.0 | 244.0 | 464 | 604 | 2,570 | 3,340 | 29 | 68 |
| Nov. | 195 | 2,130 | 564 | 100.7 | 236.1 | 665 | 800 | 2,510 | 3,020 | 18 | 42 |
| Dec. | 212 | 2,460 | 709 | 104.0 | 244.0 | 813 | 953 | 2,820 | 3,310 | 15 | 35 |
| Totals | 3,198 | | 8,985 | 1,225 | 2,873 | 10,210 | 11,858 | | | | |

[1]Period of record for discharge values is Oct. 1975 through Feb. 1984.

[2]Calculated from mean monthly specific conductance, in microsiemens per centimeter at 25° Celsius; period of record for specific-conductance values is Oct. 1975 through July 1984 (regression equation in table 15).

[3]The factor for converting the product of acre-feet and milligrams per liter to tons is 0.001359.

[4]Values do not exactly sum to total because of rounding.