SIMULATED EFFECTS OF SURFACE COAL MINING AND AGRICULTURE ON DISSOLVED SOLIDS IN ROSEBUD CREEK, SOUTHEASTERN MONTANA

By Rodger F. Ferreira

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4101

Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

Helena, Montana
August 1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

To convert inch-pound units in this report to the International System of units (SI), multiply by the following factors:

Multiply inch-pound unit	By	To obtain SI unit
acre	4,047	square meter
acre-foot	1,233	cubic meter
acre-foot per acre	0.3048	cubic meter per square meter
acre-foot per day per river mile	766.3	cubic meter per day per kilometer
cubic foot per second (ft^3/s)	28.32	liter per second
foot	0.3048	meter
inch	25.40	millimeter
inch per acre	0.006276	millimeter per square meter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram
ton per acre	0.0002241	megagram per square meter

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

$$°C = 5/9\ (°F - 32)$$

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ABSTRACT

Dissolved-solids concentrations in five reaches of Rosebud Creek in southeastern Montana were simulated to assist in evaluating the effects of surface coal mining and agriculture on the dissolved-solids concentration. A mass balance of streamflow and dissolved-solids load was used. Mined acreage, dissolved-solids concentrations in mined spoils, and irrigated acreage were varied in the model to study relative changes in the dissolved-solids concentration of each reach of Rosebud Creek.

Both simulated monthly streamflow and dissolved-solids load generally are within the 95-percent confidence limits of the mean monthly values calculated for Rosebud Creek at the mouth near Rosebud, Montana. From May through September, the simulated mean monthly streamflows vary by no more than 15 percent of the historical mean values. Except for January, May, and December, the simulated mean monthly dissolved-solids loads vary by no more than 13 percent of the historical mean values.

Simulations based on present mining show irrigation accounting for a larger cumulative percentage of dissolved-solids concentration (3.05 percent in reach 5) than mining (0.38 percent in reach 5). However, with full-scale mining, the cumulative percentage resulting from irrigation in reach 5 (2.50 percent) will be smaller than that resulting from mining (14.69 percent). By not simulating mining of the Kirby coal deposit in reach 1, because of its large dissolved-solids load, the cumulative percentage of dissolved-solids concentration resulting from mining in all reaches will be decreased to less than 6.00 percent.

INTRODUCTION

Passage of air pollution laws, rapid population increase in the West, increased use of coal as an energy source, and the economics of surface coal mining have shifted emphasis of coal production in the United States from the East to the West (Woessner and others, 1979). In 1978 the U.S. Department of Energy (1978) had projected that western coal production would equal 50 percent of the total production in the United States by 1990, with the Fort Union coal region (fig. 1) possibly being one of the largest coal producing areas in the country. Eastern Montana alone is underlain by 43 billion tons of economically strippable coal (Struck, 1975; Montana Bureau of Mines and Geology and U.S. Geological Survey, 1978).

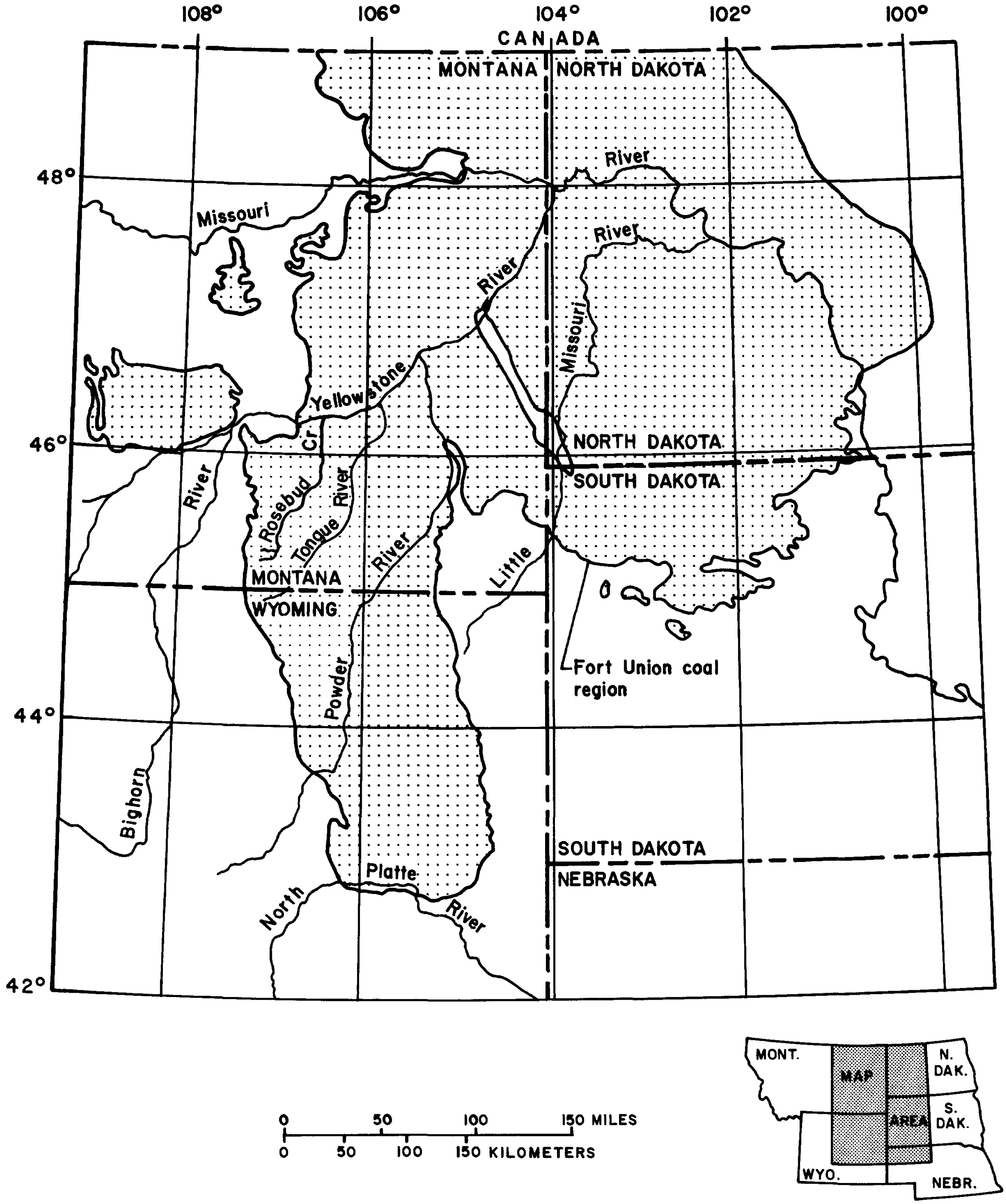

Figure 1.--Location of Fort Union coal region. Modified from Northern Great Plains Resource Program, Water Work Group-Ground Water Subgroup (1974).

Several studies have shown that water in mine spoils of southeastern Montana generally has larger dissolved-solids concentrations than water in coal aquifers that have not been mined (Davis, 1984; Van Voast, 1974; Van Voast and others, 1978a,b). The concentrations are increased as a result of water leaching dissolved solids as it flows through the mine spoils. Water from coal beds and sandstone aquifers downgradient from the spoils could become degraded for use as domestic and livestock supply. Where this ground water discharges to streams, the dissolved-solids load in the streams could be increased.

Agriculture is southeastern Montana's largest water use (Klarich and Thomas, 1977), and much of the water used is derived from surface-water resources. Dissolved-solids concentrations ranging from 500 to 1,000 mg/L (milligrams per liter) can have detrimental effects on sensitive crops in southeastern Montana (U.S. Environmental Protection Agency, 1978). Generally, 3,150 mg/L is about the maximum concentration of dissolved solids tolerated by most plants (McKee and Wolf, 1963). Dissolved-solids concentrations less than 3,000 mg/L are satisfactory for all livestock under most conditions (National Academy of Sciences and National Academy of Engineering, 1973). A concern among agricultural users in southeastern Montana is that dissolved-solids loads from mine spoils will increase dissolved-solids concentrations resulting in detrimental effects on crops.

In addition to the change created by surface coal mining, agricultural use of water has been shown to be responsible for varying degrees of change on the quality and quantity of water (Bondurant, 1971). Water loss through evapotranspiration can be a major factor that increases dissolved-solids concentrations in water used for irrigation.

In an effort to evaluate the potential impacts of strip mining on the dissolved-solids concentration of surface water, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management, developed a computer model for water quality in the Tongue River (Woods, 1981). The Tongue River model is capable of temporal and spatial simulation of dissolved-solids concentration in the Tongue River for various land-use plans of surface coal mining and agriculture. The purpose of this report is to describe simulations of dissolved-solids concentrations in Rosebud Creek that can be used to evaluate the effects of surface coal mining and agriculture on dissolved-solids concentration.

This report discusses the model development, describes the sources of data, lists the FORTRAN program, and provides input instructions for the dissolved-solids model of Rosebud Creek. Model output is discussed for present conditions of mining and agricultural development and comparisons are made between model output and historical streamflow and dissolved-solids concentrations that occur at the mouth of Rosebud Creek near Rosebud, Montana. Discussion also is included of output for model simulations with no development, partial development, and full development of surface coal mining.

STUDY AREA

Rosebud Creek originates about 20 river miles south of Kirby, Mont., and flows north approximately 200 river miles to its confluence with the Yellowstone River near Rosebud, Mont. (fig. 2). The total drainage area of Rosebud Creek is about 1,300 mi^2. The headwaters of Rosebud Creek drain the eastern slopes of the Wolf and Rosebud Mountains, which generally are steep and tree covered. The middle and downstream reaches of Rosebud Creek drain irregularly dissected slopes that merge into a broad grass-covered valley.

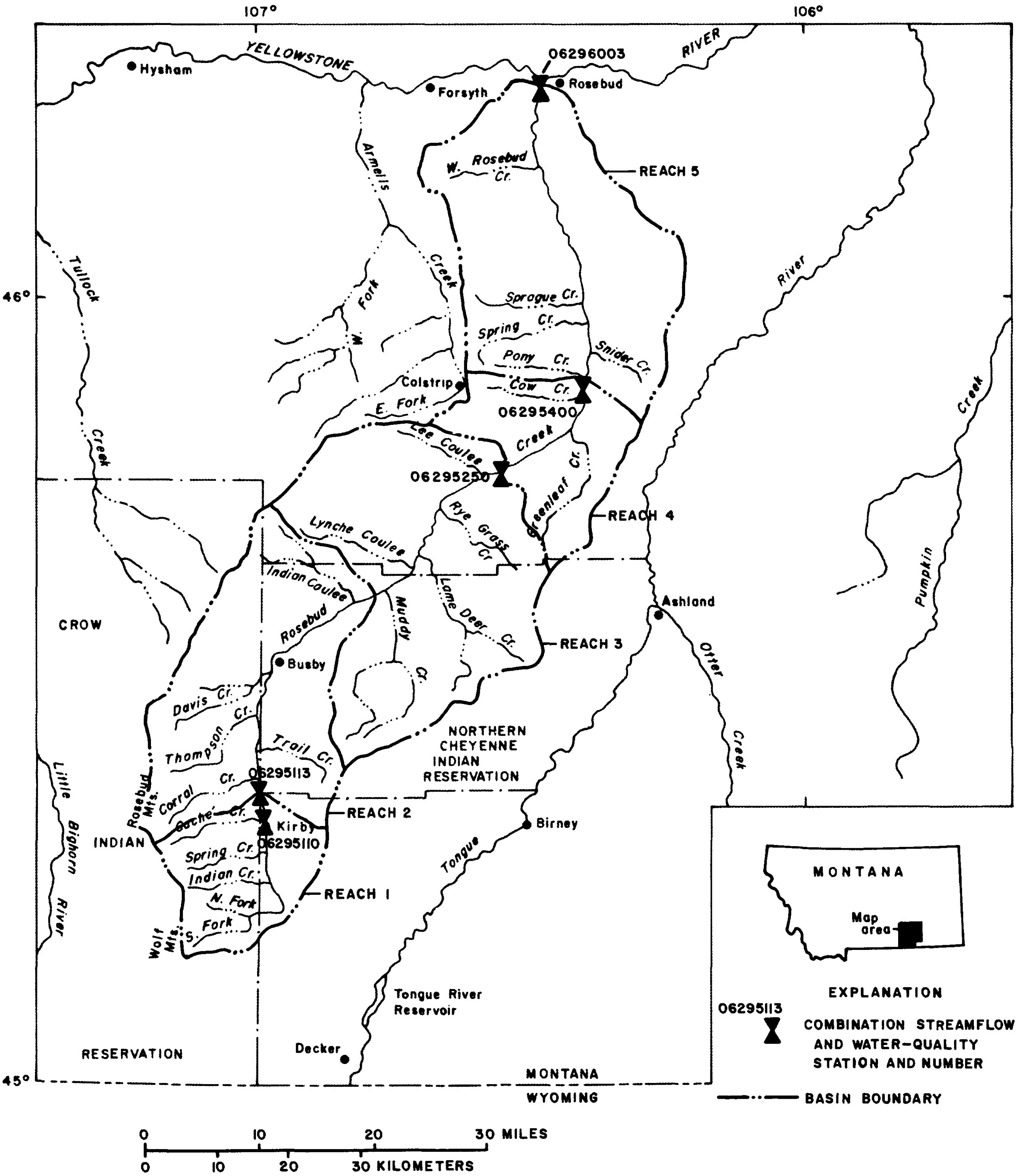

Figure 2.--Location of Rosebud Creek and reaches simulated by the model.

The Pleistocene and Holocene valley alluvium of Rosebud Creek ranges in width from 300 to 600 feet and is 100 feet thick in some areas (Lewis and Roberts, 1978). In the upstream reaches of Rosebud Creek, the valley alluvium intersects the Tongue River, Lebo Shale, and Tullock Members of the Paleocene Fort Union Formation. Near the mouth of Rosebud Creek the alluvium intersects the Upper Cretaceous Hell Creek Formation (Knapton and McKinley, 1977; Lee and others, 1981).

The quality of water in the upstream reaches of Rosebud Creek differs from that in the downstream reaches. The mean dissolved-solids concentration from measurements at the mouth of Rosebud Creek is 876 mg/L, which is about 60 percent larger than in the upstream drainage near Kirby, Mont. (Knapton and Ferreira, 1980). There also is a downstream increase in percentage of annual mean sodium and sulfate concentrations. However, these differences are not consistent throughout the flow cycle, most likely because of differing effects of the base-flow and direct-runoff components of streamflow.

Rosebud Creek is considered to be a perennial stream, with the largest volume of streamflow generally occurring during snowmelt in March or April. High flows may shift to May or June during years of large spring precipitation (Holnbeck, 1982). Smaller peaks occur during the summer in response to local rainstorms. During base-flow conditions in late summer, the upstream reaches gain flow from the ground-water system, whereas the downstream reaches lose flow to ground water (Lee and others, 1981).

Lame Deer Creek and Muddy Creek are the principal tributaries to Rosebud Creek. The tributaries and the headwaters of Rosebud Creek generally have intermittent flow patterns.

The climate in the Rosebud Creek drainage basin is semiarid, with a mean annual precipitation of about 14 inches, which is measured at Busby, Mont. Snowfall ranges from 35 to 50 inches annually (Knapton and McKinley, 1977). Most precipitation occurs in April, May, and June, which accounts for 45 percent of the annual total. Mean monthly temperatures at the Busby station range from 17.6°F in January to 69.9°F in July (U.S. Department of Commerce, issued annually).

Agriculture is an important industry in the Rosebud Creek drainage. Timber is harvested in parts of the upper drainage and the area along the middle and downstream reaches of the main stem is irrigated for hay and alfalfa. Livestock are grazed in selected areas throughout the drainage. A total of 1,887 acres were being irrigated in 1982 by means of pumping, gravity flow, or overbank-flooding (Griffith and Holnbeck, 1982).

MODEL DESCRIPTION

The dissolved-solids model is a monthly mass-balance routing of streamflow and dissolved-solids load down the main stem of Rosebud Creek. The model divides Rosebud Creek into five reaches (fig. 2). A description of the stations at the downstream end of each reach is given in table 1. All the model variables are listed and defined in table 23 (Supplemental Information section at back of report). The model is a FORTRAN computer program (table 24, Supplemental Information at back of report), which adapts many of the theoretical aspects used in the Tongue River model (Woods, 1981).

Table 1.--*Description of the stations at the downstream end of each reach of Rosebud Creek*

REACH 1

Station[1]: Rosebud Creek at reservation boundary, near Kirby, Mont. (06295113)
River mile[2]: 182.1
Reach drainage area: 123 square miles

REACH 2

Station: Rosebud Creek 0.1 mile upstream from Muddy Creek, near Busby, Mont.
River mile: 120.2
Reach drainage area: 305 square miles

REACH 3

Station: Rosebud Creek near Colstrip, Mont. (06295250)
River mile: 85.6
Reach drainage area: 371 square miles

REACH 4

Station: Rosebud Creek above Pony Creek, near Colstrip, Mont. (06295400)
River mile: 55.6
Reach drainage area: 162 square miles

REACH

Station: Rosebud Creek at mouth, near Rosebud, Mont. (06296003)
River mile: 0.8
Reach drainage area: 341 square miles

[1] For a more complete description of the stations having a station number, see U.S. Geological Survey (issued annually).

[2] River mileage obtained from Montana Department of Natural Resources and Conservation (1976a).

Initial streamflow and dissolved-solids concentrations are input at the downstream end of reach 1. These values are affected directly by input of dissolved solids from mining and water losses from irrigation if acreage involved in these two activities is larger than what presently exists in the drainage of reach 1. The resulting values at the downstream end of reach 1 are then used as input for the upstream end of reach 2.

Within reach 2 and each successive reach, gains and losses to streamflow and dissolved-solids load are accounted for algebraically. The model step is monthly and each simulation is for 1 calendar year (fig. 3). In the model, monthly travel

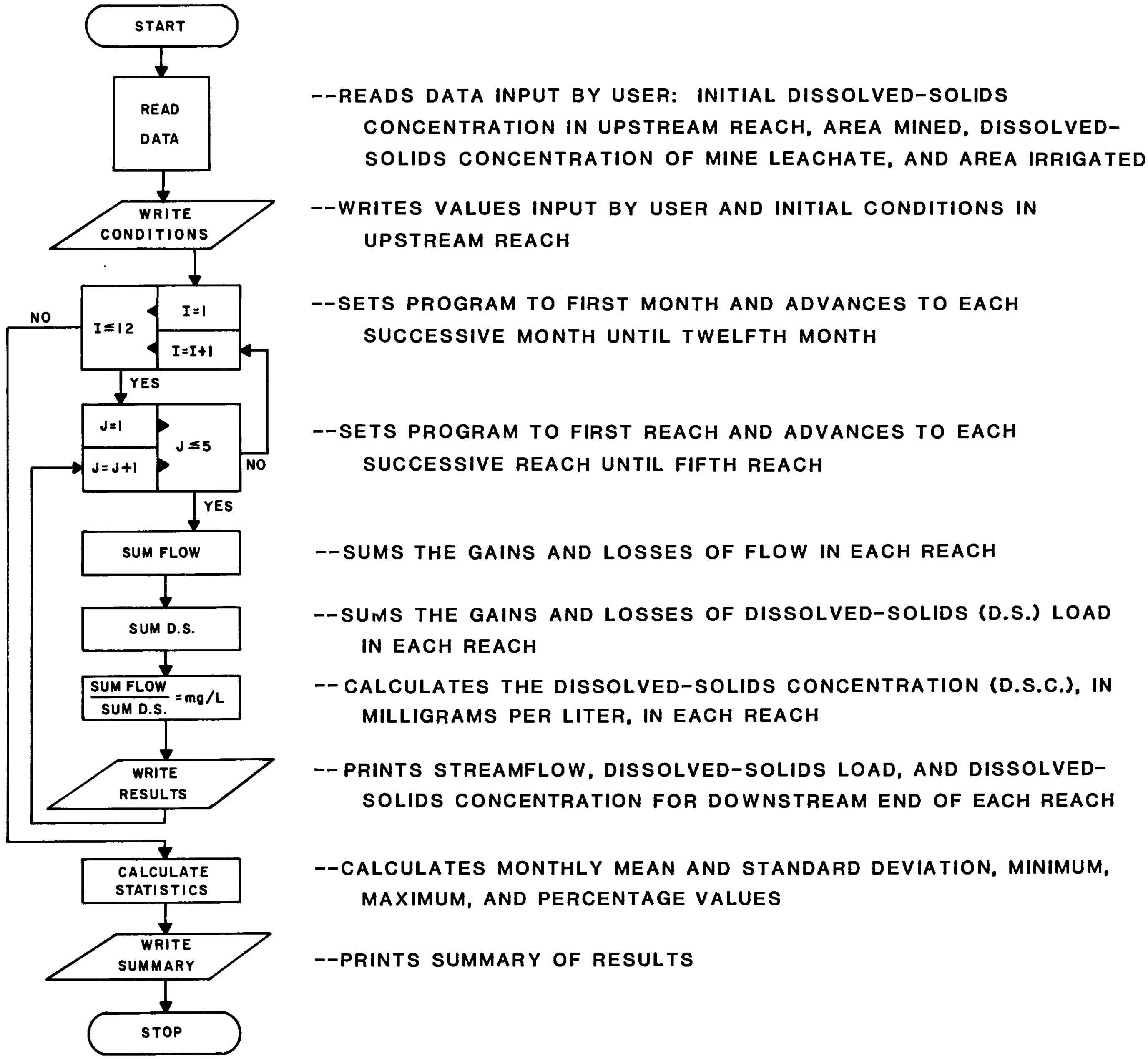

Figure 3.--Simplified flow chart of model for calculating monthly dissolved-solids concentration in five reaches of Rosebud Creek.

time of streamflow and dissolved-solids concentration within each reach and from the headwaters to the mouth are instantaneous.

The mass balance of streamflow between the upstream and downstream ends of each reach is computed by the equation:

$$Q_{OUT} = Q_{IN} + Q_P - Q_E - Q_{ET} + Q_{GW} + Q_T - Q_{SI} + Q_{RI} - Q_{DI} + Q_{IRF} - Q_{OL} \qquad (1)$$

where all units are in acre-feet per month, and

Q_{OUT} is streamflow at downstream end of reach,
Q_{IN} is streamflow at upstream end of reach,
Q_P is precipitation received on stream surface,
Q_E is evaporation loss from stream surface,
Q_{ET} is evapotranspiration from riparian vegetation,
Q_{GW} is ground-water inflow or outflow,
Q_T is streamflow from tributaries,
Q_{SI} is volume of streamflow stored as ice,
Q_{RI} is volume of streamflow released from ice,
Q_{DI} is volume of streamflow diverted for irrigation,
Q_{IRF} is volume of irrigation return flow, and
Q_{OL} is volume of other water losses.

The mass balance of dissolved solids between the upstream and downstream ends of each reach is computed by the equation:

$$DSL_{OUT} = DSL_{IN} + DSL_{GW} + DSL_T - DSL_{DI} + DSL_{IRF} + DSL_M - DSL_{OL} \tag{2}$$

where all units are in tons per month, and

DSL_{OUT} is dissolved-solids load at downstream end of reach,
DSL_{IN} is dissolved-solids load at upstream end of reach,
DSL_{GW} is dissolved-solids load in ground-water inflow or outflow,
DSL_T is dissolved-solids load input by tributary streams,
DSL_{DI} is dissolved-solids load diverted by irrigation flow,
DSL_{IRF} is dissolved-solids load returned by irrigation flow,
DSL_M is dissolved-solids load input by mining, and
DSL_{OL} is dissolved-solids load removed with other water losses.

The dissolved-solids concentration at the downstream end of the reach is calculated using the following equation:

$$DSC_{OUT} = \frac{DSL_{OUT}}{Q_{OUT} \times f} \tag{3}$$

where DSC_{OUT} is dissolved-solids concentration, in milligrams per liter,
DSL_{OUT} is dissolved-solids load, in tons per month,
Q_{OUT} is streamflow, in acre-feet per month, and
f is a factor (0.00136) that converts the product of acre-feet and milligrams per liter to tons.

Other equations and factors used to obtain values for variables contained in equations 1, 2, and 3 are explained in the following sections. Some of these equations are incorporated in the model, whereas others are used to calculate constant values used in the model as block data.

Hydrologic components

The model simulates dissolved-solids concentrations for six discrete hydrologic flow conditions: mean, 50th percentile, 25th percentile, 75th percentile, historic maximum, and historic minimum. Any one of these conditions can be used for any given month during a simulation. Using discrete hydrologic flow conditions rather than stochastic methods to generate hydrologic conditions for each simulation allows direct comparisons of effects on dissolved solids by various mining and agricultural plans.

Gage-based streamflow

Streamflow records for Rosebud Creek cover a short period of time. Yevjevich (1972) indicates that less than 20 years of streamflow data is a small sample. With a small number of samples the mean is greatly affected by extreme values, whereas the median is not. Holnbeck (1981) used a stochastic time-series hydrology model (U.S. Army Corps of Engineers' HEC-4) to reconstitute streamflow records for Rosebud Creek.

Holnbeck (1982) reconstituted missing streamflow records for Rosebud Creek near Colstrip, Mont., (5 years of record) and Rosebud Creek at mouth, near Rosebud, Mont., (17 years of record; see Holnbeck, 1981) to obtain estimated monthly mean streamflows from 1938 to 1981. Concurrent streamflow measurements from Rosebud Creek near Kirby and near Colstrip were used to obtain an average monthly discharge coefficient that represents flow near Kirby as a percentage of the flow near Colstrip. Multiplying the reconstituted flows at Colstrip by the appropriate discharge coefficient yields monthly streamflows for Rosebud Creek near Kirby from 1938 to 1981 (Holnbeck, 1981). Estimated streamflows for the six modeled hydrologic conditions of Rosebud Creek near Kirby, Mont., were then calculated from these monthly streamflows (table 2) and are used as the initial streamflow conditions in the model.

Table 2.--*Gage-based streamflow for six modeled hydrologic conditions of Rosebud Creek at reservation boundary, near Kirby, Mont.*

Hydrologic condition[1]	Streamflow, in acre-feet per month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	346	675	1,399	2,390	2,027	1,540	816	456	391	361	395	291
50th percentile	246	666	1,045	1,785	1,599	1,012	738	307	268	178	268	212
25th percentile	123	555	738	952	805	595	369	130	60	123	179	61
75th percentile	400	778	1,599	3,064	2,367	1,696	1,076	738	536	553	589	400
Maximum	1,783	1,388	5,780	11,068	9,408	8,450	2,521	1,968	1,785	1,599	1,131	1,045
Minimum[2]	61	259	369	357	.0	179	123	.0	.0	.0	60	.0

[1]Simulated values.
[2]0.0 values are entered as 0.001 in the model to avoid division by zero.

Ungaged streamflow

Modeled streamflow from ungaged tributaries in reaches 2 through 5 of Rosebud Creek is simulated by runoff coefficients, in acre-feet per acre per month (table 3). Runoff coefficients are not needed in reach 1 because streamflow from tribu-

Table 3.--*Runoff coefficients for six modeled hydrologic conditions for ungaged streamflow in four reaches of Rosebud Creek*

Hydrologic condition	Runoff coefficient, in acre-feet per acre per month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
					Rosebud Creek reach 2							
Mean	0.00632	0.01077	0.02017	0.03385	0.02667	0.02650	0.01265	0.00769	0.00632	0.00752	0.00701	0.00547
50th percentile	.00364	.01016	.01539	.02532	.02133	.01751	.01102	.00542	.00422	.00366	.00555	.00422
25th percentile	.00185	.00880	.01025	.01357	.01080	.01031	.00581	.00220	.00132	.00255	.00278	.00138
75th percentile	.00632	.01157	.02318	.04292	.03139	.02920	.01646	.01236	.00865	.01152	.00952	.00776
Maximum	.05273	.02209	.08369	.15593	.12554	.14628	.03890	.03248	.02787	.03319	.02128	.02167
Minimum	.00041	.00653	.00533	.00525	.00000	.00323	.00191	.00000	.00000	.00000	.00046	.00000
					Rosebud Creek reach 3							
Mean	.00113	.00158	.00230	.00321	.00405	.00363	.00211	.00120	.00086	.00084	.00091	.00062
50th percentile	.00065	.00150	.00176	.00240	.00324	.00241	.00184	.00085	.00057	.00041	.00072	.00047
25th percentile	.00033	.00129	.00117	.00129	.00165	.00141	.00097	.00034	.00018	.00029	.00036	.00016
75th percentile	.00113	.00170	.00264	.00407	.00477	.00401	.00274	.00193	.00118	.00129	.00124	.00086
Maximum	.00945	.00325	.00953	.01479	.01907	.02007	.00648	.00506	.00380	.00371	.00277	.00239
Minimum	.00007	.00096	.00061	.00050	.00000	.00044	.00031	.00000	.00000	.00000	.00006	.00000
					Rosebud Creek reach 4							
Mean	.00040	.00072	.00128	.00178	.00169	.00165	.00088	.00046	.00036	.00038	.00038	.00031
50th percentile	.00023	.00068	.00097	.00133	.00135	.00109	.00076	.00033	.00024	.00019	.00030	.00023
25th percentle	.00012	.00059	.00065	.00072	.00069	.00064	.00040	.00013	.00008	.00013	.00015	.00008
75th percentile	.00040	.00078	.00147	.00226	.00199	.00182	.00114	.00074	.00049	.00058	.00051	.00042
Maximum	.00337	.00148	.00530	.00822	.00796	.00910	.00269	.00195	.00159	.00169	.00115	.00118
Minimum	.00003	.00044	.00034	.00028	.00000	.00020	.00013	.00000	.00000	.00000	.00003	.00000
					Rosebud Creek reach 5							
Mean	.00066	.00240	.00424	.00322	.00283	.00302	.00126	.00054	.00058	.00064	.00070	.00058
50th percentile	.00041	.00149	.00295	.00260	.00174	.00184	.00075	.00035	.00020	.00037	.00036	.00035
25th percentile	.00021	.00076	.00146	.00112	.00070	.00112	.00030	.00014	.00004	.00014	.00016	.00019
75th percentile	.00078	.00354	.00661	.00439	.00253	.00339	.00163	.00078	.00055	.00075	.00087	.00077
Maximum	.00333	.01144	.01745	.01000	.02217	.01935	.00802	.00221	.00434	.00389	.00527	.00291
Minimum	.00000	.00000	.00033	.00000	.00014	.00031	.00008	.00000	.00000	.00000	.00000	.00000

taries in reach 1 is embodied in the initial streamflow conditions at the downstream end of the reach (Rosebud Creek near Kirby). However, a runoff coefficient, in inches per year, was calculated for reach 1 to be used for mining calculations as explained later in the report. Tributary streams used for estimating runoff coefficients for reaches 1 through 5 are listed in table 4.

Table 4.--*Tributary streams used for calculating runoff coefficients for five reaches of Rosebud Creek*

Reach				
1	2	3	4	5
Cache Creek Spring Creek Indian Creek Rosebud Creek at river mile 186.1.	Corral Creek Thompson Creek Davis Creek	Muddy Creek Lame Deer Creek	Greenleaf Creek. Snider Creek	Snider Creek

No continuous streamflow records are available for the tributaries in reaches 2 through 5. Mean annual streamflow estimates based on channel geometry were obtained from Robert Omang (U.S. Geological Survey, written commun., 1982) for tributaries in reaches 2, 4, and 5. In reach 2 the "mean" hydrologic condition was obtained by calculating a drainage-area-weighted mean of the tributary mean annual streamflows and partitioning this mean among 12 months in proportion to the mean monthly flows at Rosebud Creek near Busby. Streamflow for Rosebud Creek near Busby, Mont., was calculated by the same procedure used for Rosebud Creek near Kirby (Holnbeck, 1981). The remaining hydrologic conditions for each month were estimated from the same percentage of the mean monthly streamflow that occurs at the Busby station.

The same procedure was used for reaches 4 and 5; however, proportioned streamflows for each month were based on Rosebud Creek near Colstrip for reach 4 and Rosebud Creek near Rosebud for reach 5. The six modeled hydrologic conditions for reach 3 were calculated by drainage-area weighting estimated mean monthly streamflows of Lame Deer Creek and Muddy Creek obtained from Holnbeck (1981).

Precipitation and evaporation

In the model, precipitation and evaporation are applied only to the stream surface area of Rosebud Creek. Only stream surface is utilized because the effects that precipitation and evaporation have in the rest of the drainage are embodied in the runoff coefficients for each reach. Because sample sizes for precipitation and evaporation data are sufficiently large for statistical purposes, the 75th percentile is replaced by plus one standard deviation from the mean and the 25th percentile is replaced by minus one standard deviation from the mean (tables 5 and 6).

Mean annual values of precipitation in the Rosebud Creek area indicate that data at the Busby weather station is representative of average precipitation for

Table 5.--*Precipitation for various modeled hydrologic conditions throughout Rosebud Creek drainage*

Hydrologic condition	Precipitation, in acre-feet per acre per month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	0.051	0.041	0.055	0.113	0.201	0.223	0.096	0.093	0.102	0.085	0.052	0.048
Minus one standard deviation	.008	.017	.023	.044	.078	.106	.024	.000	.013	.016	.016	.016
Plus one standard deviation	.093	.065	.087	.181	.324	.339	.168	.188	.190	.154	.088	.079
Maximum	.198	.121	.138	.243	.684	.557	.308	.373	.343	.377	.158	.125
Minimum	.004	.008	.003	.000	.053	.063	.003	.000	.000	.000	.005	.003

Table 6.--*Evaporation from the stream surface of Rosebud Creek for various modeled hydrologic conditions*

Hydrologic condition	Evaporation, in acre-feet per acre per month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	0.058	0.058	0.117	0.217	0.358	0.450	0.575	0.550	0.358	0.258	0.117	0.058
Minus one standard deviation	.067	.067	.142	.258	.433	.567	.667	.650	.425	.308	.142	.067
Plus one standard deviation	.050	.050	.092	.175	.283	.333	.475	.450	.292	.208	.092	.050
Maximum	.042	.042	.083	.150	.242	.275	.408	.425	.233	.183	.083	.042
Minimum	.092	.092	.175	.325	.533	.842	.808	.775	.508	.383	.175	.092

the Rosebud Creek drainage. Precipitation data for various modeled hydrologic conditions throughout Rosebud Creek drainage are given in table 5. Although precipitation data for Busby extend to 1903, only records from 1938 to 1981 are used, to coincide with the time frame used to calculate the hydrologic flow conditions.

Evaporation data for various modeled hydrologic conditions were calculated from records collected at Sheridan, Wyo., from 1951 to 1979 (table 6). This is the closest weather station to the Rosebud Creek drainage that has evaporation data. Evaporation data were collected with a National Weather Service class A pan. To estimate lake evaporation (evaporation from a water surface) from class A-pan data, a coefficient of 0.70 commonly is used (Winter, 1981). Because evaporation is only modeled for the stream surface area of Rosebud Creek (evaporation from a water surface), a coefficient of 0.70 has been applied to pan-evaporation data to obtain the values in table 6.

Depending on the quantity of flow occurring in Rosebud Creek, the water surface area, which is affected by precipitation and evaporation, will vary. Average widths of the stream were obtained for each month from discharge-measurement notes. These widths were distance weighted to obtain an average width for each reach. River lengths and areas that are used for calculations of precipitation and evaporation from the water surface in each reach are given in table 7.

Table 7.--*Area and length for each reach of Rosebud Creek*

Reach		Stream surface area, in acres											
Number	Length (miles)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2	61.9	98	98	120	150	143	128	113	98	98	98	98	98
3	34.6	71	71	88	96	96	92	80	71	71	71	71	71
4	30.0	73	73	87	98	95	91	84	73	73	73	73	73
5	46.0	123	123	156	195	178	167	151	123	123	123	123	123

Transpiration

Transpiration from riparian vegetation along the main stem of Rosebud Creek is modeled as a loss of water in each reach. Effects of transpiration from vegetation in the ungaged tributaries of Rosebud Creek are embodied in the runoff coefficients for each reach or accounted for as water losses by irrigation. Because actual measurements of transpiration are not available for riparian vegetation along Rosebud Creek, potential evapotranspiration values are used as a best estimate. Lake evaporation is approximately equal to potential evapotranspiration (Cruff and Thompson, 1967); therefore, the coefficient of 0.70, which was used with pan evaporation to calculate surface-water evaporation, also was used to calculate transpiration. In the model, the area on each bank affected by transpiration is equal to the surface area of Rosebud Creek. The area affected approximately equals the area along the bank of Rosebud Creek that was observed by the author to support a pronounced growth of vegetation. The vegetation indicates an abundant supply of water that could be obtained from bank storage.

Ice formation and breakup

During ice formation and breakup, streamflow either decreases or increases. On Rosebud Creek ice generally forms in December, with melting and breakup occurring in February or March. Between these times, the volume of water stored as ice changes with varying air temperature; however, these changes are small and do not significantly affect the net volume of water stored as ice during this period. The volume of water stored as ice in the model is calculated from ice depths obtained during streamflow measurements. The depths were distance-weighted to give average depths of ice for each reach. The model assumes that complete ice formation occurs in December and complete ice breakup occurs in March (table 8).

Table 8.--*Change in depth of ice in four reaches of Rosebud Creek during each month*

	Change in depth of ice, in feet											
Reach	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2	0.0	0.0	-0.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.35
3	.0	.0	-.35	.0	.0	.0	.0	.0	.0	.0	.0	.35
4	.0	.0	-.35	.0	.0	.0	.0	.0	.0	.0	.0	.30
5	.0	.0	-.35	.0	.0	.0	.0	.0	.0	.0	.0	.25

Irrigation withdrawal and return flow

The Montana Department of Natural Resources and Conservation (1976b) reported that 1,810 acres are irrigated in Rosebud Creek drainage with 10,860 acre-feet of water diverted annually. Of the total volume, 5,755 acre-feet per year, or 53 percent, return as streamflow in Rosebud Creek.

A more recent survey by Griffith and Holnbeck (1982) indicates about 1,880 acres receiving at least one irrigation application, with some of the acreage receiving two applications. Irrigation water use, as described by the users, depends on crop needs and flow conditions. Irrigation consists of three different forms: pump diversion and some flooding, gravity diversion and some flooding, and overbank flooding with pumping as a second application (Griffith and Holnbeck, 1982).

Overbank flooding used for irrigation is virtually uncontrolled by the irrigator and is not given any particular treatment in the model. Any affect that overbank flooding has on streamflow at the downstream end of each reach is assumed to be included in the flow statistics for ungaged tributary runoff or ground-water inflow.

By only including the principal parcels of acreage irrigated in Rosebud Creek, about 120 acres in reach 2 and about 1,660 acres in reach 5 annually receive about 2,220 acre-feet of diverted water. Water diversion for irrigation does not occur in reaches 1, 3, and 4; however, some areas benefit from overbank flooding and sub-irrigation from a high water table (E. F. Griffith, Montana Department of Natural Resources and Conservations, written commun., 1982).

The Rosebud Creek model utilizes an irrigation withdrawal rate, in acre-feet per acre, to calculate the volume of water withdrawn for irrigation in each reach (table 9). Irrigated acreage in reach 2 is for alfalfa crops and is serviced by

Table 9.--*Monthly rates of irrigation withdrawal*

	Withdrawal[1], in acre-feet per acre, for indicated reach				
Month Reach	1	2	3	4	5
Jan	0	0	0	0	0
Feb	0	0	0	0	0
Mar	0	0	0	0	0
Apr	0	0	0	0	.21
May	0	.28	0	0	.27
June	0	.41	0	0	.55
July	0	.74	0	0	.13
Aug	0	.61	0	0	0
Sept	0	.26	0	0	0
Oct	0	0	0	0	0
Nov	0	0	0	0	0
Dec	0	0	0	0	0

[1]Irrigation rate during low-streamflow years (25 percentile and minimum flows) are assigned 50 percent of the rates given in this table.

two 60-acre pivot sprinklers, which theoretically are operated from May to September (E. F. Griffith, written commun., 1982). The irrigation withdrawal rate in reach 2 was calculated from consumptive-use tables prepared by the U.S. Soil Conservation Service, (1974). In determining an irrigation withdrawal rate for reach 2, a 70-percent system efficiency was assumed for the sprinklers resulting in a diversion requirement based on the monthly consumptive use divided by 0.70.

Because of varying crop needs and streamflow conditions in reach 5, different combinations of plots at any given time are irrigated by about 10 different irrigators. Irrigation in reach 5, which occurs from April to July, is considered to be partial service and is limited to about three irrigators operating simultaneously. This situation results in less acreage than the total irrigated acreage in reach 5 being irrigated each month (Griffith and Holnbeck, 1982). However, the irrigation rate for each month is calculated by dividing the actual volume of water diverted by the total irrigated acreage in reach 5. If water is available during low-streamflow years, the quantity of water diverted for irrigation is assumed to equal 50 percent of the quantity diverted during normal streamflow years.

Because water is not diverted for irrigation in reaches 1, 3, and 4, irrigation-withdrawal rates internally in the model are set to zero (table 9). Irrigation operations are presently in relative equilibrium with the water supply along the downstream reach of Rosebud Creek (Griffith and Holnbeck, 1982). Any water diversions imposed upstream may be disruptive to irrigation practices in reach 5. If irrigation practices change in the future, irrigation-withdrawal rates can be calculated for appropriate reaches upstream and added internally to the model.

Irrigation return flow occurs from water applied in excess of the consumptive water use of plants, the quantity held by the soil, and the quantity percolating beneath the shallow aquifers that discharge to Rosebud Creek. Water losses from irrigation in the Rosebud Creek model are based on agricultural-engineering estimates. These estimates indicate that about 65 percent of water applied for irrigation is left after consumptive use and, after other losses, 85 percent of the 65 percent is available for irrigation return flow (Woessner and others, 1981). Of the water available for irrigation return flow, 65 percent returns during the same month of application and the remainder returns in equal quantities during the following 8 months. In addition to irrigation return flow that results from the current years' application, some return flow occurs from the antecedent years' application (table 10). Irrigation return flow from the antecedent year is calculated with the assumption that the rate of irrigation withdrawal during that year was commensurate with mean streamflow.

Table 10.--*Monthly rates of irrigation return flow from previous year*

	Return flow[1], in acre-feet per acre, for indicated reach				
Month Reach	1	2	3	4	5
Jan	0.0	0.0556	0	0	0.0229
Feb	0	.0488	0	0	.0164
Mar	0	.0389	0	0	.0031
Apr	0	.0210	0	0	0
May	0	.0063	0	0	0
June	0	0	0	0	0
July	0	0	0	0	0
Aug	0	0	0	0	0
Sept	0	0	0	0	0
Oct	0	0	0	0	0
Nov	0	0	0	0	0
Dec	0	0	0	0	0

[1]Irrigation return flow from antecedent year assumes rate of irrigation withdrawal during that year was commensurate with mean streamflow.

Ground-water flow

Estimates of ground-water flow, in acre-feet per river mile, were calculated from base streamflow in Rosebud Creek from October 26 to November 5, 1977 (Lee and others, 1981). The calculations show reaches 2 and 3 gaining streamflow and reaches 4 and 5 losing streamflow. Muddy Creek and Lame Deer Creek were the only tributaries reported to have streamflow during the study of Lee and others (1981). Mean monthly streamflow of 2.6 ft^3/s for October and November 1977 was estimated for Muddy Creek using data from Holnbeck (1981, 1982). A mean daily streamflow of 1.8 ft^3/s was reported for Lame Deer Creek November 1, 1977 (Andrews and others, 1981). These streamflows were subtracted from total streamflow in Rosebud Creek in the calculations of ground-water flow for the model. Assuming that irrigation return flow to Rosebud Creek occurs with ground water, ground-water inflow rates calculated from the base-streamflow study were corrected for irrigation return flow in reaches 2 and 5. The average irrigation return flow rate for October and November, the months of the base-flow study, was 0.0556 acre-foot per acre per month in reach 2 and 0.0280 acre-foot per acre per month in reach 5. Based on 120 irrigated acres in reach 2, the ground-water flow correction is 0.2224 acre-foot per day, which equals a daily correction of 0.0036 acre-foot per river mile. Based on 1,662 irrigated acres in reach 5, the ground-water flow correction is 1.5512 acre-feet per day, which equals a daily correction of 0.0283 acre-foot per river mile. Ground-water flow rates, in acre-feet per day per river mile, are given in table 11.

Table 11.--*Daily ground-water inflow rate per river mile for each reach of Rosebud Creek*

Reach	Inflow rate, in acre-feet per day
2	0.13
3	.06
4	- .22
5	- .08

Other water losses

The model can account for other water losses resulting from water requirements of industries, such as coal gasification plants and coal-fired electric generating plants. Input to the model for these losses would be on an annual basis; the model will partition this loss equally among each month. None of the streamflow withdrawn for these losses is returned to Rosebud Creek in the model.

Dissolved-solids components

In each reach of Rosebud Creek, dissolved-solids loads are calculated from the dissolved-solids concentration and volume of each hydrologic component. The model then routes dissolved-solids loads downstream, detached from streamflow, from reach to reach. The derivation of dissolved-solids loads for each component is discussed in the following sections. Precipitation, evaporation, evapotranspiration, and ice storage and breakup are processes that increase or decrease water but not dissolved solids. Therefore, the dissolved-solids concentrations in each reach will be affected by these processes but the dissolved-solids loads will not.

Mining

If the total quantity of dissolved solids added to Rosebud Creek from mining could be accurately determined, the algebraic calculations to estimate changes in dissolved-solids concentrations could be made. Unfortunately, the effects of a mine are dependent on numerous complex relationships including proximity of the mine to the creek, geochemistry of coal and overburden at the site, rate and direction of ground-water flow, orientation of the mine, method of mining and spoils handling, and method and success of reclamation practices. Because of the many variables involved and the uncertainties of future mine development, each potential mine needs to be evaluated individually to estimate probable hydrologic consequences. However, for this study, a technique used by Woods (1981) was used to simulate the dissolved-solids load resulting from mining.

The model simulates the movement of dissolved solids that are leached from backfilled mined spoils and transported to Rosebud Creek by ground water. The dissolved solids leached from spoils is calculated using the following equation (Woods, 1981):

$$DSLMR = DSCMR \times AMR \times RCARR \times f \tag{4}$$

where *DSLMR* is the dissolved-solids load, in tons per year from a mined area;
DSCMR is dissolved-solids concentration, in milligrams per liter, of spoil leachate in mined area;
AMR is area of surface coal mine, in acres;
RCARR is runoff coefficient, in inches per year, for a mined drainage basin; and
f is a factor (0.0001133) to convert equation units into tons.

The runoff coefficients for each reach of Rosebud Creek are given in table 12. These values were calculated from mean annual flow estimates of the streams that were used for the calculation of ungaged tributary flow.

Table 12.--*Runoff coefficients for mined acreages in each reach of Rosebud Creek*

Reach	Runoff coefficient, in inches per year
1	2.203
2	2.051
3	.269
4	.123
5	.248

Woods (1981) reviewed studies that compared the dissolved-solids concentration of water from undisturbed shallow aquifers with water from mine spoils (Rahn, 1975; Van Voast and others, 1978b) and water from saturated paste extracts of overburden materials (Wayne A. Van Voast, Montana Bureau of Mines and Geology, written commun., 1981). From these studies Woods determined that a coefficient of 1.5 applied to the dissolved-solids concentration of water samples from the undisturbed shallow aquifers in most instances would approximate the dissolved-solids concentration of mine spoils and saturated-paste extracts of overburden material. Woods (1981) also showed that using a factor of 1.5 with equation 4 for four tracts of Federally owned coal in or near Otter Creek, Montana, gave dissolved-solids loads that were similar to loads calculated using aquifer characteristics. Therefore, the dissolved-solids concentration for mined areas in the model are estimated by applying a coefficient of 1.5 to the dissolved-solids concentration of water from nearby springs and wells. Qualifying criteria are that the springs and wells derive water from the Tongue River Member of the Fort Union Formation and the well depth is less than 300 feet below land surface (Woods, 1981).

Aquifer characteristics in the coal area of southeastern Montana indicate that the production of leachates from mine spoils could occur for hundreds of years after spoils emplacement (Woessner and others, 1979). Thus, the production of leachates from mine spoils of several mines would reach a steady-state discharge to Rosebud Creek at some common future time. From whatever mined acreage is specified, the model simulates the steady-state input of dissolved solids to Rosebud Creek at this common future time.

Because of possible interactions of spoil-derived water with differing aquifer mineralogy while enroute to discharge into a stream, dissolved-solids concentrations of spoil-derived water might be decreased. The model assumes that such a decrease does not occur. Therefore, the model is considered to simulate worst-case conditions for dissolved-solids loads resulting from mining.

Gage-based and ungaged streamflow

Dissolved-solids loads for Rosebud Creek near Kirby are determined by linear regression analysis. Concurrent measurements of streamflow and dissolved-solids concentration at Rosebud Creek at Kirby, Mont. (station 06295110) and Rosebud Creek at reservation boundary near Kirby, Mont. (station 06295113) were used to develop the following linear regression equation:

$$Y = (685.6) + (-100.3) \cdot (\log_{10} X) \qquad (5)$$

where Y is the dissolved-solids concentration, in milligrams per liter; and
X is instantaneous streamflow, in cubic feet per second.

Equation 5 is based on 46 samples that were collected monthly from October 1977 to May 1982, and explains 65 percent ($r^2 = 0.65$) of the variation in dissolved-solids concentration, a correlation that is significant at the 0.01 level ($p \leq 0.0001$). The model calculates the initial dissolved-solids concentration at Rosebud Creek at reservation boundary near Kirby using equation 5 and a streamflow value consistent with the user-selected monthly hydrologic condition (table 2).

Estimates for dissolved-solids concentrations from ungaged tributaries are based on few data. Most of the miscellaneous water-quality measurements for tributary streams on Rosebud Creek do not have concurrent streamflow measurements for developing regressions. For those samples having concurrent streamflow measurements, the sample size was too small to develop a meaningful regression. Consequently, estimates of mean annual dissolved-solids concentration for ungaged tributaries in each reach (fig. 2) were obtained by averaging the dissolved-solids concentration of available samples from individual tributaries, weighting each of these averages according to drainage area, and summing the weighted averages for each reach (table 13). Dissolved-solids concentrations for Thompson Creek, Trail

Table 13.--*Estimates of mean annual dissolved-solids concentration for ungaged tributaries in reaches 2 through 5 during simulations*

Reach	Dissolved-solids concentration, in milligrams per liter
2	633
3	883
4	1,814
5	1,814

Creek, Davis Creek, and Corral Creek in reach 2 and Muddy Creek and Lame Deer Creek in reach 3 were obtained from Andrews and others (1981). Dissolved-solids concentration from Cow Creek, Greenleaf Creek, and Snider Creek for reaches 4 and 5 were obtained from the U.S. Geological Survey (issued annually) and Skogerboe and others (1980). In the model, the mean annual dissolved-solids concentration for ungaged tributaries is used with every monthly hydrologic condition.

Irrigation withdrawal and return flow

The dissolved-solids load diverted with irrigation withdrawal is calculated in the model by multiplying the dissolved-solids concentration at the upstream end of each reach by the volume of streamflow withdrawn in each reach. Two processes can result from the application of irrigation water to soil: salts remaining after evaporation can accumulate in the soil, and salts can be leached from the soil and geologic units during deep percolation. The first process would decrease the dissolved-solids load in irrigation return flow and the second process would increase the dissolved-solids load in irrigation return flow. Both processes are difficult to quantify and have a canceling effect. Therefore, the model assumes a salt balance, with 100 percent of the load that was diverted during irrigation withdrawal being returned to Rosebud Creek. The return rate of dissolved-solids load is based on irrigation return flow, but because of salt balance, 65 percent of the total load diverted returns during the same month of application and the rest occurs in equal parts during the following 8 months. Therefore, for any given month, dissolved-solids load applied during the month plus some from previous months will be in irrigation return flow.

In addition to dissolved-solids loads returning during the year of application, dissolved-solids loads that were diverted the previous year, within 8 months of the current month, also return. As with irrigation return flow during the year of application, only reaches 2 and 5 receive dissolved solids returning from the previous year. The dissolved-solids load available for irrigation return from the previous year is based on the load diverted during mean hydrologic flow conditions. Dissolved-solids concentrations during water withdrawal the previous year are estimated from equation 5 for reach 2. The following regression equation was developed from 75 samples at Rosebud Creek at mouth, near Rosebud (station 06296003) and is used to calculate dissolved-solids concentrations for water withdrawal the previous year from reach 5:

$$\text{Log } Y = 3.0218 + (-0.0009) \cdot X \qquad (6)$$

where
Y is dissolved-solids concentration, in milligrams per liter; and
X is instantaneous streamflow, in cubic feet per second.

The coefficient of determination (r^2) is 0.535, a correlation that is significant at the 0.01 level ($p \leq 0.0001$).

The dissolved-solids loads returning in each month for the previous year are determined by the same calculations for load returning in the current year. In the model the dissolved-solids loads for the previous year (table 14) are summed with the loads for the current year for each month.

Table 14.--*Monthly rates of dissolved solids input by return flow from irrigation in year prior to simulation*

Month	Reach	Dissolved solids returned[1], in tons per acre, for indicated reach				
		1	2	3	4	5
Jan		0	0.07841	0	0	0.05271
Feb		0	.06953	0	0	.03777
Mar		0	.05626	0	0	.00770
Apr		0	.03103	0	0	0
May		0	.00933	0	0	0
June		0	0	0	0	0
July		0	0	0	0	0
Aug		0	0	0	0	0
Sept		0	0	0	0	0
Oct		0	0	0	0	0
Nov		0	0	0	0	0
Dec		0	0	0	0	0

[1]Dissolved solids returning from antecedent year assumes that there was full irrigation service during that year.

Ground-water flow

Dissolved-solids loads gained or lost in each reach were calculated from base-flow data for Rosebud Creek in the same manner that gain and loss of ground-water flow were calculated (Lee and others, 1981). During the base-flow study, Muddy Creek and Lame Deer Creek were reported to contribute streamflow, and therefore dissolved solids, to Rosebud Creek (Lee and others, 1981). Estimates of dissolved-solids concentration in Muddy and Lame Deer Creeks were obtained by averaging the dissolved-solids concentrations reported by Andrews and others (1981). Resulting dissolved-solids loads from Muddy and Lame Deer Creeks were subtracted from loads in Rosebud Creek to obtain corrected ground-water loads.

Because irrigation return flow is assumed to occur with ground-water flow, the dissolved-solids load in ground water was corrected for dissolved-solids load returning with irrigation flow. Assuming mean flow conditions and irrigation withdrawal, dissolved-solids loads returning with irrigation flow were calculated based on 120 acres in reach 2 and 1,662 acres in reach 5. The result was a November correction of 0.314 ton per day returning in reach 2 and 3.550 tons per day returning in reach 5. The resulting dissolved-solids concentrations for the ground-water component of streamflow in each reach are given in table 15.

Table 15.--*Dissolved-solids concentration for the ground-water component of streamflow in each reach of Rosebud Creek*

Reach	Dissolved-solids concentration, in milligrams per liter
2	1,133
3	798
4	211
5	1,172

Reaches 4 and 5 are indicated as losing streamflow, and therefore dissolved-solids load, to ground water. If the streams were losing water and dissolved-solids load in proportion to their occurrence in the streams, the streamflow lost to ground water would have the same dissolved-solids concentrations as the streams. Because there can be several ground-water inflow and outflow areas along a reach, possibly with each inflow having a different dissolved-solids concentration, the net loss in dissolved-solids load and streamflow can result in a dissolved-solids concentration that is different from the average dissolved-solids concentration of the reach. Therefore all dissolved-solids concentrations in table 15 represent a net change in dissolved-solids load and flow and satisfy mass balancing of both quantities. Differences in dissolved-solids concentration in ground-water flow among the reaches are the result of differences in the quantity of dissolved solids contributed by the mineralogical contacts of the contributing aquifers.

Other dissolved-solids losses

Dissolved-solids loads removed by other water losses from Rosebud Creek are calculated from the product of the specified volume of streamflow removed and the current dissolved-solids concentration in the affected reach. The loads removed in each reach are not returned to Rosebud Creek in the model.

Model input and output

Initial conditions for each model run are specified by the user. Input includes specification of either regression-derived or user-input values of monthly dissolved-solids concentration and hydrologic flow condition at Rosebud Creek near Kirby (station 06295113), mined acreage, dissolved-solids concentration of mine-spoils water, and irrigated acreage, in each of five reaches in Rosebud Creek (table 16). Other data used in the computations for streamflow and dissolved-sol-

Table 16.--*Input data-card instructions*

Card	Columns	Format	Variable	Description
1	1-5	A5	SN	Simulation number
	10-33	12I2	MHC	Monthly hydrologic flow condition (in acre-feet per month); enter 1 for mean, 2 for 50th percentile, 3 for 25th percentile, 4 for 75th percentile, 5 for maximum, and 6 for minimum.
2	1	I1	DDSCRK	Designator for dissolved-solids concentration in Rosebud Creek near Kirby; enter 0 for regression-derived values, 1 for user-defined values.
	6-65	12F5.0	DSCRKU	Dissolved-solids concentration (in milligrams per liter) at Rosebud Creek near Kirby; user defined.
3	1-30	5F6.0	AIR	Area (in acres) irrigated on each of five reaches of Rosebud Creek.
4	1-30	5F6.0	AMR	Area (in acres) mined in each of five reaches of Rosebud Creek.
5	1-30	5F6.0	DSCMR	Dissolved-solids concentration (in milligrams per liter) of leachate from surface coal mines on each of five reaches of Rosebud Creek.
6	1-30	5F6.0	QOLR	Other losses of streamflow (in acre-feet per year) from each reach of Rosebud Creek.

ids load for each reach are contained in the model and will be selected for use depending on the hydrologic flow conditions specified by the user. A different hydrologic flow condition can be specified for each month, which allows avoidance of the improbable occurrence of minimum flow for 12 successive months in a given year. The model could be adapted for other hydrologic conditions in Rosebud Creek by replacing the internal data statements with data statements describing the new conditions.

Presently the model includes irrigation rates of 0.0 for reaches 1, 3, and 4, because irrigation practices that withdraw water are not known to occur for these reaches of Rosebud Creek. The irrigation rates for these reaches will have to be changed internally in the model before the hydrologic effect of irrigated acreage can be modeled. Because the quantity of water used for irrigation in Rosebud Creek drainage basin is considered to be in balance with water availability, it is unlikely that water withdrawal for irrigation will be started in reaches 1, 3, and 4; however, irrigated acreage might be shifted to other reaches but continue as the same total.

Output from the model consists of a description of initial conditions specified by the user; a results section which gives the monthly volume of streamflow (in acre-feet), dissolved-solids load (in tons), and dissolved-solids concentration (in milligrams per liter) for each reach of Rosebud Creek; and a section giving a statistical summary of the results. Because initial hydrologic flow conditions for Rosebud Creek at reservation boundary near Kirby and precipitation data for the study area were computed from records extending from 1938 to 1981, and ungaged tributary flow was estimated from channel geometry, model output is considered to estimate long-term conditions. Varying mining or agricultural development from what presently exists would result in model output representing long-term conditions that would occur sometime in the future. An example of model output is presented in table 25 in the Supplemental Information section at the back of the report.

For each month, the model provides a single value for each of the output variables. These values are characterized by the monthly hydrologic flow condition specified by the user. Therefore, specifying mean flow would result in a model output value that would estimate a mean monthly flow; specifying median flow would result in a model output value that would estimate a median monthly mean flow; and specifying a maximum flow would result in a model output value that would estimate the maximum monthly mean flow. Generally, a range of values are associated with each monthly mean value. As a longer period of record for daily specific conductance becomes available for Rosebud Creek at the mouth, near Rosebud, Montana, it will be possible to predict, through regression analysis, monthly maximum and minimum values for each monthly mean value.

Because mining and agriculture are two important industries of concern in Rosebud Creek drainage, their effect on dissolved solids is expressed in the results section as a percentage of the dissolved-solids concentration at the downstream end of each reach. For mining, the dissolved-solids concentration at the downstream end of each reach is affected directly by the load input by mining and is calculated by the following equation:

$$PDSMR = \frac{DSLMR}{DSLD} \times 100 \qquad (7)$$

where *PDSMR* is the percentage of dissolved-solids concentration in Rosebud Creek resulting from mining;

DSLMR is the dissolved-solids load, in tons, leached from coal mines in each reach; and

DSLD is the dissolved-solids load, in tons, at the downstream end of each reach.

For irrigation, the model assumes a salt balance in that the dissolved-solids load added to the river with irrigation return flow is nearly equal to the dissolved-solids load removed by irrigation withdrawal. Dissolved-solids loads returning by irrigation the previous year would cause some differences between irrigation inflow and outflow for a given year. However, over many years these differences would be equal.

In the model the greatest effect that irrigation return flow has in changing the dissolved-solids concentration of Rosebud Creek results from a loss of water through evapotranspiration. The following equation describes the percentage change in dissolved-solids concentration resulting from irrigation:

$$PDSIR = 1 - \left[\left(\frac{\left(\dfrac{DSLD - (DSLRIR - DSLDIR)}{QD - (QRFIR - QDIR)} \right) \div C}{DSCD} \right) \right] \times 100 \qquad (8)$$

where *PDSIR* is the percentage of dissolved-solids concentration in Rosebud Creek resulting from irrigation;

DSLD is the dissolved-solids load, in tons, at the downstream end of each reach;

DSLRIR is the dissolved-solids load, in tons, returning with irrigation to Rosebud Creek;

DSLDIR is the dissolved-solids load, in tons, diverted with irrigation to Rosebud Creek;

QD is the streamflow, in acre-feet, at the downstream end of each reach of Rosebud Creek,

QRFIR is the return flow, in acre-feet, from irrigation in each reach of Rosebud Creek;

QDIR is streamflow, in acre-feet, diverted for irrigation along Rosebud Creek;

C is a factor, 0.00136, that converts the product of acre-feet and milligrams per liter to tons; and

DSCD is the dissolved-solids concentration, in milligrams per liter, at the downstream end of each reach.

Changes in streamflow and dissolved-solids load resulting from mining and irrigation are cumulatively summed in each successive reach to give a cumulative percentage of each of their effects on the dissolved-solids concentration.

In the summary of simulation results, monthly streamflow (in acre-feet), dissolved-solids load (in tons), and dissolved-solids concentration (in milligrams per liter) are given for the downstream station of reach 1, Rosebud Creek at reservation boundary near Kirby, and for the downstream station of reach 5, Rosebud Creek at mouth, near Rosebud. A statistical summary also is presented for each reach. Calculations are based on the monthly values of dissolved-solids concentration generated for each reach.

MODEL VALIDATION

The validity of the Rosebud Creek model was determined by comparing simulated monthly streamflows and dissolved-solids loads with historical data collected at the downstream end of reach 5, Rosebud Creek at mouth, near Rosebud. The simulated conditions during the comparison were for mean hydrologic flow conditions. Input data include presently irrigated acreage on Rosebud Creek drainage. However, input for mined acreage was set at zero on the assumption that dissolved solids derived from spoils water has not reached Rosebud Creek (Davis, 1984).

Monthly mean streamflow estimates (from 1938 to 1980) for Rosebud Creek at the mouth were determined by the same methods used for Rosebud Creek near Kirby (Holnbeck, 1982). Monthly mean streamflow for the 1981 water year were combined with Holnbeck's estimates to obtain 44 years of data, which herein will be referred to as historical streamflow data. These data were used to calculate the mean and upper and lower 95-percent confidence limits of streamflow, in acre-feet, for each month (table 17). Mean monthly streamflow from 1975 to 1981 was calculated from

Table 17.--*Mean monthly flow at Rosebud Creek at the mouth, near Rosebud estimated by a streamflow model (1938-81), calculated from streamflow records (1975-81), and calculated by the model*

Month	Mean monthly streamflow, in acre-feet					
	Lower 95-percent confidence limit	Streamflow-model derived mean monthly 1938-81[1]	Upper 95-percent confidence limit	Streamflow-records derived mean monthly 1975-81[2]	Simulated mean monthly	Percentage simulated is of historic mean (1938-81)
Jan	564	890	1,215	1,832	1,146	129
Feb	2,135	3,177	4,218	2,665	2,197	69
Mar	4,051	5,613	7,175	7,009	4,102	73
Apr	3,215	4,278	5,340	5,266	5,409	126
May	2,060	3,753	5,445	10,329	4,331	115
June	2,542	3,999	5,455	6,366	3,385	85
July	1,043	1,662	2,280	2,416	1,446	87
Aug	486	716	945	1,242	712	99
Sept	363	778	1,193	1,184	741	95
Oct	514	840	1,165	1,383	1,092	130
Nov	551	937	1,323	1,529	1,170	125
Dec	495	758	1,021	1,604	797	105
Total		27,401		42,825	26,528	

[1]Obtained from Holnbeck (1982) plus 1981 water year for a total of 44 samples.
[2]Calculated from U.S. Geological Survey streamflow records.

U.S. Geological Survey streamflow records and is included in table 17 for comparison. In all months except February, mean monthly flows from 1975 to 1981 were larger than mean monthly flows from 1938 to 1981.

Except for April, the mean monthly streamflows simulated by the dissolved-solids model are within the 95-percent confidence limits of the historical mean monthly streamflows. From May through September, the simulated mean monthly streamflows vary by no more than 15 percent of the historical means. The total flows for the simulated mean monthly flows and historical mean monthly flows are quite similar. The large mean monthly and total flows for 1975-81, compared to the simulated and historical flows, indicate the variability of flow in Rosebud Creek.

Historical dissolved-solids loads, in tons, were estimated by use of two separate regressions to obtain two sets of data. One set of data was obtained by regressing dissolved-solids concentration, in milligrams per liter, on streamflow, in cubic feet per second. The other set of data was obtained by regressing dissolved-solids concentration, in milligrams per liter, on specific conductance, in microsiemens per centimeter at 25° Celsius. The dissolved-solids concentrations, streamflow, and specific-conductance values were obtained from reports of the U.S. Geological Survey (issued annually).

The form of the equation to predict dissolved-solids concentration from streamflow is:

$$DSC = 1504.8 - 349.15\ (\log_{10} Q) \tag{9}$$

where DSC is the dissolved-solids concentration, in milligrams per liter; and
Q is streamflow, in cubic feet per second.

Equation 9 is based on a sample size of 85, has a coefficient of determination, r^2, equal to 0.503, and is a significant correlation at the 0.01 level ($p \leq 0.0001$). The form of the equation to predict dissolved-solids concentration from specific conductance is:

$$DSC = -43.57 + 0.722\ (SC) \tag{10}$$

where DSC is the dissolved-solids concentration, in milligrams per liter; and
SC is specific conductance, in microsiemens per centimeter at 25° Celsius.

Equation 10 also is based on 85 samples, has a coefficient of determination, r^2, equal to 0.968, and is a significant correlation at the 0.01 level ($p \leq 0.0001$).

Using daily streamflow and specific conductance obtained from the U.S. Geological Survey annual reports, and the appropriate regressions, monthly dissolved-solids loads were calculated for Rosebud Creek at the mouth (table 18). There was sufficient streamflow period of record (eight samples) to calculate 95-percent confidence limits about the mean monthly dissolved-solids loads calculated from equation 9 and streamflow in table 17. The resulting values herein are referred to as historical dissolved-solids loads. Because only three samples are available for each month using the specific-conductance regression, confidence limits about the mean were not calculated.

The simulated mean monthly dissolved-solids loads for each month are within the 95-percent confidence limits for the historical dissolved-solids loads (table

Table 18.--*Mean monthly dissolved-solids load at Rosebud Creek at the mouth, near Rosebud, calculated by streamflow-derived regression, calculated by a specific conductance derived regression (1978-81), and simulated by the model*

	Mean monthly dissolved-solids load, in tons					
Month	Lower 95-percent confidence limit	Streamflow regression derived mean monthly 1974-82	Upper 95-percent confidence limit	Specific conductance-regression derived mean monthly 1978-81	Simulated mean monthly	Percentage simulated is of historic mean 1974-82 [1]
Jan	991	2,093	3,195	2,152	1,656	79
Feb	1,795	3,612	5,428	2,193	3,194	88
Mar	2,566	6,229	9,892	5,145	5,432	87
Apr	2,700	5,335	7,970	6,027	6,390	120
May	2,064	8,000	13,936	4,714	5,806	73
June	2,217	5,958	9,699	3,568	5,251	88
July	499	2,599	4,699	1,236	2,861	110
Aug	395	1,514	2,633	884	1,755	116
Sept	0	1,311	2,697	561	1,551	118
Oct	718	1,653	2,587	2,111	1,630	99
Nov	921	1,822	2,723	2,392	1,678	92
Dec	1,130	1,970	2,810	2,695	1,373	70
Total		42,096		33,678	38,577	

[1] Historic mean as calculated from streamflow-derived regression.

18). Except for January, May, and December, the simulated mean monthly dissolved-solids loads vary by no more than 13 percent of the historic mean value. The total of the simulated monthly dissolved-solids loads is between the total of the monthly dissolved-solids loads calculated from streamflow and the total of the monthly dissolved-solids loads calculated from specific conductance.

The major sources of streamflow in the model are ground-water flow and ungaged tributary flow. Evapotranspiration by riparian vegetation and evaporation from the water surface have minor effects on streamflow. Their greatest percentage effect as loss of streamflow occurs during June, July, and August when ungaged tributary flow is at a minimum and water is being withdrawn for irrigation. Ungaged tributary flow on a monthly basis increases at the same time that precipitation increases. Consequently, precipitation on the water surface of Rosebud Creek always accounts for only a small percentage of the total streamflow. Ice effects on streamflow are minimal and a net change occurs only twice a year--once during ice formation and once during ice melt. In the model ice effects occur in December and March and account for less than 5 percent of the total flow in Rosebud Creek.

Because ground-water flow and ungaged-tributary flow account for large volumes of streamflow in Rosebud Creek, these two factors could account for the largest errors in the model. Errors in their estimation not only introduce errors in volume of water, but also errors in the dissolved-solids loads modeled for each reach. Ground-water-flow and dissolved-solids-load estimates might be improved by synoptic flow studies in conjunction with alluvial-aquifer studies. Synoptic flow studies throughout the year might identify seasonal variation in ground-water flow rates as river stage changes (Rorabaugh, 1964; Daniel and others, 1970). Alluvial-aquifer studies might characterize more precisely the dissolved-solids load input into each reach that results from a mixture of subsurface flow moving parallel to the stream and ground-water flow, which approaches the stream from a perpendicular aspect.

Ungaged-tributary-flow estimates could be improved by collecting continuous streamflow data from at least one representative drainage basin in each reach. A comparison of mean annual-streamflow estimates for drainage basins in reach 2 obtained from channel-geometry estimates and the difference in streamflow that occurs between Rosebud Creek near Kirby and Rosebud Creek near Busby indicates that the runoff coefficient for reach 2 needs to be decreased by 75 percent. Therefore, Corral Creek, Thompson Creek, and Davis Creek, which were used to estimate the runoff coefficients for reach 2, either have overestimated mean annual streamflows, or are not representative of all the drainages in reach 2. In addition, more accurate estimates of dissolved-solids load from ungaged tributaries can be obtained by complementing monthly dissolved-solids measurements with daily specific-conductance measurements.

Errors in the model that involve mining and irrigation can result from an inaccurate representation of the processes that actually occur. Mining, as modeled for Rosebud Creek, affects only dissolved-solids load. Errors could be introduced by using the runoff coefficient equation in predicting the load from mining. Using aquifer characteristics is an alternative approach. However, this approach would require data on aquifer characteristics for each mine area in addition to predicted aquifer characteristics of the mine spoils. The user can affect the outcome of the model in choosing various dissolved-solids concentrations of leachate from specified mined areas.

With irrigation, the main affect in the model is a loss of water. Irrigation withdrawal and return-flow volumes may need further refinement because different parcels of land are irrigated at different times. Errors in dissolved-solids load could be introduced because of the salt balance assumption in the model, when in fact a significant degree of dissolved solids leaching or adsorption could occur in the study area.

Both streamflow and dissolved-solids components of the model are considered to be satisfactory in describing present conditions in Rosebud Creek. The model is based on data that are considered to provide the best estimates available. As additional information becomes available, data that are internal to the program can be updated to produce a more accurate simulation of streamflow and dissolved-solids load. In its present form, the model can be used to evaluate the relative magnitude and effects of surface coal mining and agriculture on the dissolved-solids concentration of Rosebud Creek by comparing simulations of present-state conditions to simulations of coal-mining and irrigation-development plans.

SIMULATED EFFECTS OF MINING AND AGRICULTURAL DEVELOPMENT

Both mining and irrigation have the potential to affect the dissolved-solids concentration in Rosebud Creek. The model incorporates several hydrologic flow conditions in the Rosebud Creek drainage basin that can be subjected to various mined and irrigated acreage. If all other conditions remain the same, comparisons of different simulations can indicate the relative effect that mining and irrigation have on the dissolved-solids load in Rosebud Creek. The following simulations in this section for mining and agricultural development were run under mean hydrologic flow conditions.

Mining development

Selected dissolved-solids concentrations used in the simulations for mining are based on estimates. Dissolved-solids concentrations that result at the downstream end of each reach are for relative comparisons. Dissolved-solids concentrations judged to be more realistic for mining would result in more realistic concentrations at the downstream end of each reach.

Three areas of Federal coal are potentially available for leasing in the Rosebud Creek drainage and vicinity: Sweeney Creek-Snider Creek coal deposit, Greenleaf Creek-Miller Creek coal deposit, and Kirby coal deposit (fig. 4). The Big Sky and Rosebud Mines presently are operating in the Colstrip coal deposit. The Big Sky Mine, which is operated by Peabody Coal Co., is mining the Rosebud coal bed. About 633 acres have been mined in the Rosebud Creek drainage. The Rosebud Mine, which is operated by Western Energy Co., is mining the Rosebud coal bed, and, in some places, the McKay coal bed. About 1,467 acres have been mined in the Rosebud Creek drainage.

The average dissolved-solids concentration of water in the coal aquifers in the Big Sky Mine area is 2,700 mg/L (Davis, 1984). The average dissolved-solids concentration in the spoils aquifer of the Big Sky Mine is about 3,700 mg/L, which represents a 37-percent increase in dissolved-solids concentration compared to that of water in the coal aquifer.

The model was run with present (1982) irrigation conditions and the sum of mined acreages for the Big Sky and Rosebud Mines (2,100 acres), with a spoils-water dissolved-solids concentration of 3,700 mg/L. All present mining occurs in reach 4, with the result that only reaches 4 and 5 are simulated to receive increased dissolved-solids load. The resulting changes in dissolved-solids concentration are given in table 19.

The monthly increase in dissolved-solids concentration as a result of present mining in the Colstrip coal deposit ranges from 1 mg/L in April and May to 9 mg/L in December in reach 4. The greatest affect on dissolved-solids concentration of Rosebud Creek occurs during low streamflow from August through January. The monthly dissolved-solids load from present mining in reach 4 is 9 tons added to Rosebud Creek, which equals an annual load of 108 tons. The annual load simulated by the model is less than the annual load (980 tons) calculated by Davis (1984) using hydrologic properties of the coal and spoils aquifers. However, the dissolved-solids load simulated by the model will increase as the acreage mined is increased, whereas the dissolved-solids load calculated by Davis represents complete mining.

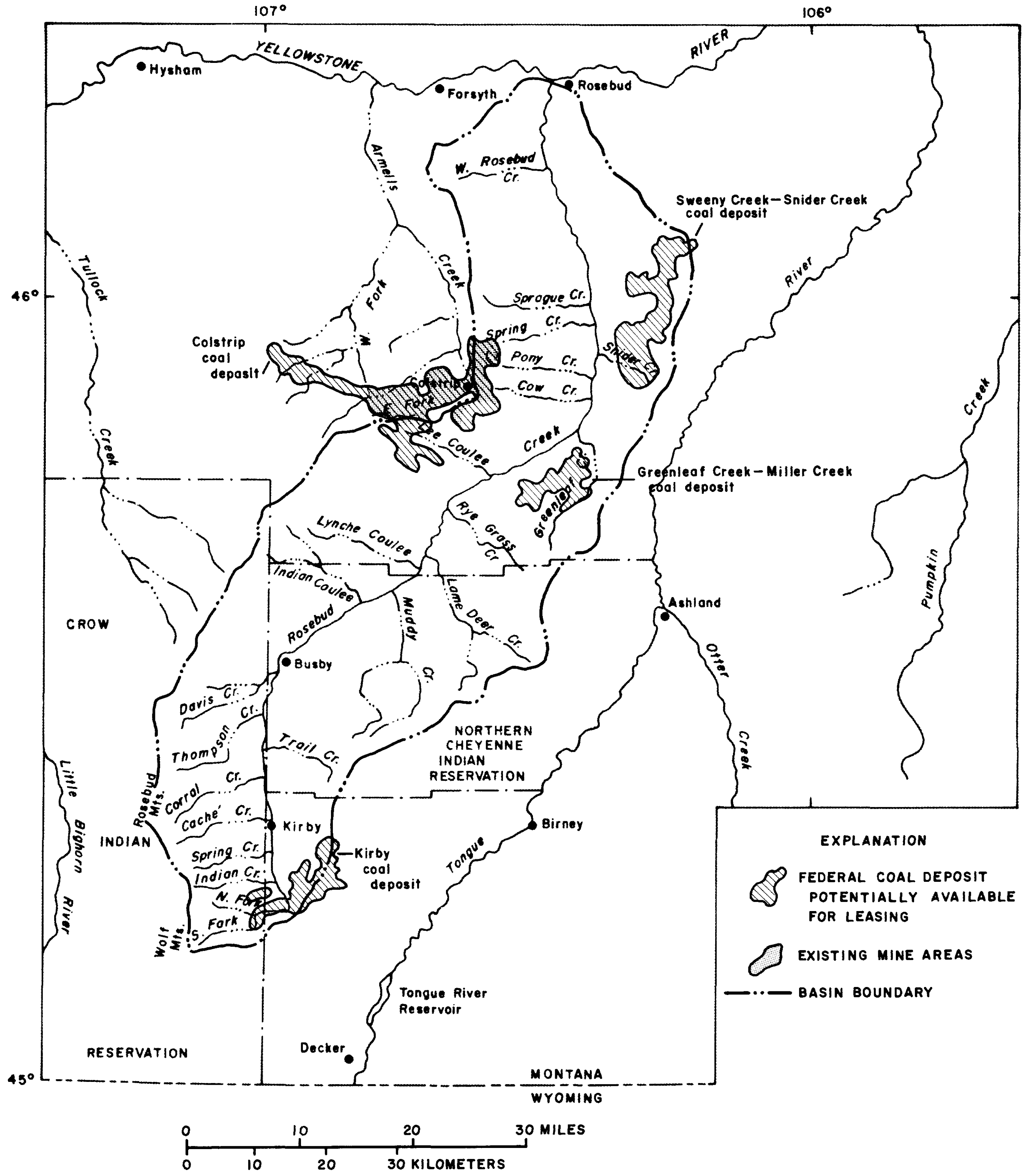

Figure 4.--Location of existing mine areas and Federal coal potentially available for leasing in the Rosebud Creek drainage and vicinity (after Matson and Blumer, 1973, and U.S. Geological Survey, 1974).

Table 19.--*Simulated monthly dissolved-solids concentration at the downstream end of each reach of Rosebud Creek with present irrigated acreage*[1] *and different mining conditions*[2]

Reach	1				2				3				4				5			
	Dissolved-solids concentration, in milligrams per liter, at downstream end of indicated reach																			
Month	No mining	Present mining[3]	Full mining[4]	Partial mining[5]	No mining	Present mining	Full mining	Partial mining	No mining	Present mining	Full mining	Partial mining	No mining	Present mining	Full mining	Partial mining	No mining	Present mining	Full mining	Partial mining
Jan	610	610	1,192	610	775	775	996	775	800	800	983	821	951	957	1,196	1,009	1,063	1,069	1,332	1,156
Feb	577	577	875	577	699	699	840	699	739	739	862	754	842	845	992	877	1,069	1,072	1,210	1,118
Mar	550	550	694	550	640	640	715	640	678	678	747	686	749	751	830	769	974	975	1,049	1,000
Apr	525	525	609	525	615	615	662	615	659	659	703	664	720	721	772	732	869	870	925	888
May	533	533	633	533	647	647	705	647	714	714	765	720	797	798	859	812	986	987	1,055	1,010
June	544	544	675	544	676	676	745	676	745	745	805	752	846	848	919	864	1,141	1,143	1,225	1,171
July	573	573	820	573	792	792	927	792	871	871	989	886	1,080	1,085	1,238	1,119	1,454	1,459	1,658	1,527
Aug	598	598	1,040	598	896	896	1,112	896	975	975	1,169	999	1,335	1,343	1,633	1,409	1,811	1,821	2,239	1,964
Sept	604	604	1,119	604	858	858	1,097	858	917	917	1,136	943	1,216	1,224	1,544	1,295	1,540	1,549	1,961	1,687
Oct	609	609	1,166	609	778	778	990	778	804	804	994	826	969	975	1,226	1,029	1,098	1,104	1,390	1,198
Nov	603	603	1,113	603	762	762	971	762	787	787	972	808	933	939	1,178	990	1,055	1,060	1,327	1,148
Dec	618	618	1,310	618	830	830	1,093	830	858	858	1,098	885	1,095	1,104	1,443	1,177	1,267	1,275	1,667	1,403

[1]Present irrigated acreage consists of 120 acres in reach 2 and 1,662 acres in reach 5.

[2]All simulations were run under mean hydrologic flow conditions.

[3]Present mining consists of 2,100 acres with a spoils water dissolved-solids concentration of 3,700 milligrams per liter in reach 4.

[4]Full mining consists of acreage and dissolved-solids concentration as given in table 20.

[5]Partial mining consists of mining all coal deposits except Kirby coal deposit.

Full-scale mining and dissolved-solids concentrations were simulated for each of the coal deposits in Rosebud Creek drainage to simulate worst-case dissolved-solids concentrations resulting from mining. Estimates of mined acreage for simulation were obtained from acreage estimates of selected strippable coal deposits (Matson and Blumer, 1973). The total acreage for each coal deposit and the coal-deposit acreage simulated for each reach are given in table 20.

Estimates of dissolved-solids concentration for each coal aquifer were obtained by calculating the mean dissolved-solids concentration of water sampled from several wells and springs within or near each coal deposit (Lee, 1979; Levings, 1983; Cannon, 1983; and Van Voast and others, 1978a). To estimate the dissolved-solids concentration of the mine spoils, the mean dissolved-solids concentration of water in the coal aquifers was multiplied by a factor of 1.5 (see Dissolved-Solids Components, Mining). For reaches that contained more than one coal deposit, a mean dissolved-solids concentration for spoils water was calculated by area weighting the dissolved-solids concentrations of water in each coal aquifer.

The simulation of full-scale mining indicates that the greatest effect will be from the Kirby coal deposit in reach 1, where the monthly dissolved-solids concentrations in Rosebud Creek will be nearly doubled during low streamflow from August through January (table 19). Although the dissolved-solids concentration of spoils water for the Kirby coal deposit is about one-half that of the other coal deposits, a large simulated dissolved-solids load results from the larger runoff coefficient for reach 1 than the other reaches with coal deposits (table 12). The runoff coefficient for reach 1 is about 10 times larger than that for reaches 3 and 5 and about 20 times larger than that for reach 4. The increased load in reach 1 is then transported downstream through the remaining reaches; however, the flow volumes and dissolved-solids loads contributed in these reaches prevent the same percentage increases in dissolved-solids concentration that will occur in

Table 20.--*Mined acreage and spoil leachate dissolved-solids concentrations for known strippable coal deposits in each reach of Rosebud Creek for full-scale mining*

Reach			Strippable coal deposit			
No.	Mined acreage[1]	Spoil leachate dissolved-solids concentration[2] (milligrams per liter)	Coal deposit	Acreage used for simulation	Number of wells and springs sampled	Mean dissolved-solids concentration (milligrams per liter)
1	11,950	1,102	Kirby	[3]33,189	38	735
2	0	--	--	--	--	--
3	5,340	2,649	Colstrip	33,379	14	1,776
4	4,000	--	Colstrip	33,379	14	1,776
	12,700	--	Greenleaf-Miller Creek	14,918	17	1,684
Subtotal (reach 4)	16,700	2,554		--	--	--
5	4,000	--	Colstrip	33,379	14	1,766
	6,000	--	Sweeney-Snider Creek	10,921	16	1,886
Subtotal (reach 5)	10,000	2,757		--	--	--

[1]Surface area of disturbed watershed
[2]Surface-area weighted mean for each coal deposit x 1.5
[3]Composite surface acreage of major coal beds in Kirby coal deposit (from Matson and Blumer, 1973).

reach 1. As in reach 1, the largest increases in dissolved-solids concentration for reaches 2 through 5 will occur during low streamflow from about August through January.

By not simulating the dissolved-solids concentration from the Kirby coal deposit, the effect of mining on dissolved-solids concentration in Rosebud Creek will be greatly decreased. Reaches 1 and 2 have no mining effect, and the increase in dissolved-solids concentration is small.

For each reach of Rosebud Creek the mean cumulative percentage of dissolved-solids concentration resulting from mining under different mining conditions is given in table 21. Simulations with present mining show irrigation accounting for a larger cumulative percentage of dissolved-solids concentration than mining. However, with full-scale mining, the cumulative percentages of the dissolved-solids concentration resulting from mining will be increased greatly, averaging about 15

Table 21.--*Mean cumulative percentage of the dissolved-solids concentration for all months in each reach of Rosebud Creek resulting from irrigation return flow and mining under different mining conditions*[1]

Condition	Reach	Percentage of dissolved-solids concentration: Irrigation return flow	Percentage of dissolved-solids concentration: Mining
No mining	1	0.0	0.0
	2	.79	.0
	3	.	.0
	4	.76	.0
	5	3.07	.0
Present mining[2]	1	.0	.0
	2	.79	.0
	3	.63	.0
	4	.76	.47
	5	3.05	.38
Full mining [3]	1	.0	34.81
	2	.68	16.48
	3	.56	14.25
	4	.69	15.51
	5	2.50	14.69
Partial mining [4]	1	.0	.0
	2	.79	.0
	3	.63	1.93
	4	.75	4.28
	5	2.84	5.78

[1]All simulations were run under mean hydrologic flow conditions.
[2]Present mining consists of 2,100 acres disturbed, with a spoils water dissolved-solids concentration of 3,700 mg/L.
[3]Full mining consists of acreage and dissolved-solids concentration as listed in table 20.
[4]Partial mining consists of all coal deposits except Kirby coal deposit.

percent in reaches 2, 3, 4, and 5, and about 35 percent in reach 1. Because mining was not simulated as occurring in reach 2, the cumulative percentage of dissolved-solids concentration resulting from mining in reach 2 will be from the dissolved-solids load transferred from reach 1. The incoming dissolved-solids load occurring with flows from ground water and ungaged tributaries in reach 2 will decrease the cumulative percentage of dissolved-solids concentration resulting from mining in reach 1. By not simulating mining in reach 1, because of its large dissolved-solids load, the cumulative percentage of dissolved-solids concentration resulting from mining in all reaches will be decreased to less than 6.00 percent.

For most of the different mining conditions in each reach, there will be a decrease in the percentage of dissolved-solids concentration resulting from irrigation as the percentage is increased from mining. However, for reach 4 between no mining and present mining and for reach 3 among no mining, present mining, and partial mining the cumulative percentage of dissolved solids resulting from irrigation does not change. This lack of change results from zero or very small increases in the mean cumulative percentage of dissolved-solids concentration resulting from mining.

Agricultural development

Irrigation along Rosebud Creek provides water for one or two alfalfa crops per year to supplement cattle operations in the basin. In some areas the second growth of alfalfa is allowed to produce seed, which is harvested as a cash crop (Griffith and Holnbeck, 1982). Agricultural crops have a wide range of tolerances to dissolved-solids concentration, making dissolved solids a critical factor in judging the suitability of water for irrigation (McKee and Wolf, 1963). For long-term irrigation, the International Joint Commission (1981) concluded that a maximum dissolved-solids concentration of 1,300 mg/L would afford completed protection for alfalfa crops.

Because the irrigated acreage in Rosebud Creek is considered to be in balance with water availability, additional irrigated acreage was not simulated in reaches 2 and 5. Irrigation rates are set to zero in the model for reaches 1, 3, and 4 so that user designated irrigated acreage for these reaches will show no affect on dissolved solids. If necessary, irrigation rates calculated for reach 2 or 5 can be used internally in the model as a gross estimate of irrigation rates for reaches 1, 3, and 4. However, because of the variability in existing irrigation rates, updating the model when data become available would be the most accurate method for estimating the effects of irrigation on dissolved-solids concentration in reaches 1, 3, and 4.

The monthly dissolved-solids concentration for each reach of Rosebud Creek, using 120 acres irrigated in reach 2, 1,662 acres irrigated in reach 5, and no mining is given in table 22. Each month the dissolved-solids concentration increased from reach 1 downstream to reach 5. The annual mean concentrations of dissolved solids in reach 1 was 579 mg/L and increased to 747 mg/L in reach 2, 796 mg/L in reach 3, 961 mg/L in reach 4, and 1,194 mg/L in reach 5. The smallest monthly dissolved-solids concentration occurred in April for each reach, and the largest occurred in August of each reach except reach 1. The dissolved-solids concentration in reach 1 did not vary as much as other reaches; however, it was generally larger from August through January than from February through July.

The percentage of dissolved-solids concentration resulting from irrigation was largest in August for reach 2 and in June for reach 5 (table 22). The mean percentage of dissolved-solids concentration resulting from agriculture in reach 2 (0.79) is less than the mean percentage of reach 5 (2.20), mainly as a result of more acreage irrigated in reach 5. Negative August and September percentages for reach 5 in table 22 indicate that the model simulated a decrease in dissolved-solids concentration in Rosebud Creek as a result of irrigation. This condition results from a net gain in flow from antecedent irrigation return flow, which is in greater proportion than the net gain in dissolved-solids load from antecedent flow. Water from irrigation return flow had a smaller dissolved-solids concentra-

Table 22.--*Simulated dissolved-solids concentration at the downstream end of each reach of Rosebud Creek and percentage and cumulative percentage of dissolved-solids concentration that result from irrigation without mining*[1]

[mg/L, milligrams per liter]

Reach	Dissolved solids at downstream end of indicated reach														
	1			2			3			4			5		
Month	Concentration (mg/L)	Percent	Cumulative percent	Concentration (mg/L)	Percent	Cumulative percent	Concentration (mg/L)	Percent	Cumulative percent	Concentration (mg/L)	Percent	Cumulative percent	Concentration (mg/L)	Percent	Cumulative percent
Jan	610	0.0	0.0	775	0.25	0.25	800	0.0	0.16	951	0.0	0.06	1,063	2.04	2.03
Feb	577	.0	.0	699	.21	.21	739	.0	.13	842	.0	.08	1,069	.73	.73
Mar	550	.0	.0	640	.12	.12	678	.0	.08	749	.0	.06	974	.11	.12
Apr	525	.0	.0	615	.05	.05	659	.0	.03	720	.0	.03	869	2.17	2.19
May	533	.0	.0	647	.36	.36	714	.0	.30	797	.0	.33	986	3.54	3.86
June	544	.0	.0	676	.62	.62	745	.0	.51	846	.0	.57	1,141	8.92	9.44
July	573	.0	.0	792	2.33	2.33	871	.0	1.90	1,080	.0	2.39	1,454	5.34	7.91
Aug	598	.0	.0	896	3.27	3.27	975	.0	2.69	1,335	.0	3.84	1,811	-1.14	4.10
Sept	604	.0	.0	858	1.60	1.60	917	.0	1.30	1,216	.0	1.68	1,540	-.10	1.85
Oct	609	.0	.0	778	.23	.23	804	.0	.16	969	.0	.05	1,098	1.70	1.68
Nov	603	.0	.0	762	.25	.25	787	.0	.17	933	.0	.07	1,055	1.82	1.82
Dec	618	.0	.0	830	.22	.22	858	.0	.15	1,095	.0	-.05	1,267	1.23	1.08

[1]All simulations were run under mean hydrologic flow conditions

tion than Rosebud Creek, thereby diluting water in Rosebud Creek. The positive cumulative percentage in reach 5 for August and September indicates that the cumulative net effect of irrigation is to increase the dissolved-solids concentration. The increase results partly from the net gain of water that occurs from irrigation in reach 5 being cancelled by the net loss of water that occurs in reach 2. Although there is also a loss of dissolved-solids load in reach 2 from irrigation, it is small compared to the gain of dissolved-solids load in reach 5. The result is a cumulative net gain in dissolved solids in reach 5, which is proportionally much larger than the cumulative net gain in flow. Compared to the dissolved-solids concentration at the downstream end of reach 5, which also is affected by load and flow changes from other hydrologic factors, the cumulative changes in load and flow caused by irrigation in reaches 2 and 5 increase the dissolved-solids concentration.

In December a negative cumulative percentage, from irrigation return flow in reach 2, is shown for reach 4. The cumulative percentage in reach 2 was positive but became negative in reach 4 because the dissolved-solids concentration of irrigation return flow was smaller than the dissolved-solids concentration of Rosebud Creek. The larger dissolved-solids concentration in reach 4 compared to reach 2 resulted mainly from dissolved-solids load input from tributary streams.

Monthly hydrologic flow conditions

The effects that mining and irrigation have on the dissolved-solids concentration of Rosebud Creek can be altered by different monthly hydrologic flow conditions. With present mining and agricultural conditions, dissolved-solids concentrations calculated with median and mean streamflows at the downstream end of each reach of Rosebud Creek are similar. With increasing monthly hydrologic flow conditions (75th percentile and maximum flows) the dissolved-solids concentrations at the downstream ends of each reach decrease because of dilution. However, because the total load at the downstream end of each reach increases with increasing hydrologic flow conditions, the mean percentage of the dissolved-solids concentration resulting from mining and irrigation is decreased. Conversely, decreasing the hydrologic flow conditions causes an increase in dissolved-solids concentrations at the downstream end of each reach. However, the total load decreases and results in an increase in the mean cumulative percentage of dissolved solids resulting from mining and agriculture.

Because very small flows, and sometimes zero flows, occur with ungaged tributary flow when 25th percentile and minimum hydrologic conditions are specified, the program can self terminate at a given month because of a less-than-zero or zero flow at the downstream end of a reach. When this occurs the program can be run again either with an increased hydrologic flow condition during the terminated month or with decreased "other water losses" or irrigated acreage. If the user needs flows other than those that occur with the 25th percentile or minimum hydrologic flow conditions of ungaged tributaries, the runoff coefficients for select months in each reach can be increased in the program internally. However, the user needs to remember that the hydrologic flow condition specified by the model output for the altered month no longer applies.

SUMMARY

Dissolved-solids concentrations in five reaches of Rosebud Creek were simulated to assist in evaluating the effects of surface coal mining and agriculture on dissolved-solids concentration. Mined acreage, dissolved-solids concentrations in mined spoils, and irrigated acreage can be varied in the model to study relative changes in the dissolved-solids concentration of each reach of Rosebud Creek.

Rosebud Creek originates in the eastern slopes of the Wolf and Rosebud Mountains and flows northeast about 200 miles to its mouth at the Yellowstone River near Rosebud, Mont. Flow is perennial, with the largest volume of streamflow generally occurring during snowmelt in March or April. Rosebud Creek drains an area of about 1,300 mi^2 and flows through irregularly dissected slopes that merge into a broad grass-covered valley. The valley alluvium of Rosebud Creek intersects the Tongue River, Lebo Shale, and Tullock Members of the Fort Union Formation and the Hell Creek Formation.

The model uses a mass balance of streamflow and dissolved-solids load. Initial streamflow and dissolved-solids concentrations are specified by the user for the downstream end of reach 1, which is located near Kirby, Mont. These values are affected directly by input of dissolved solids from mining and water losses from irrigation if acreage involved in these activities is larger than what presently exists in the drainage area of reach 1. The mass balance of streamflow and dissolved-solids load between each subsequent reach is accomplished by the algebraic summation of precipitation and evaporation on the water surface, evapotranspiration from riparian vegetation, ground-water flow, tributary flow, changes in ice formation, irrigation diversion and return flow, and other water losses. Output from the model consists of a description of initial conditions specified by the user; a results section which gives the monthly volume of streamflow, dissolved-solids load, and dissolved-solids concentration for each reach of Rosebud Creek; and a section giving a statistical summary of the results.

At the mouth of Rosebud Creek near Rosebud, Mont., monthly streamflows simulated by the model with mean hydrologic flow conditions are within the 95-percent confidence limits of historical mean monthly streamflows for all months except April. From May through September, the simulated mean monthly streamflows vary by no more than 15 percent of the historical mean values. Simulated mean dissolved-solids loads for each month are within the 95-percent confidence limits for the historical mean monthly dissolved-solids loads. Except for January, May, and December, the simulated mean monthly dissolved-solids loads vary by no more than 13 percent of the historic mean value.

Water diverted for irrigation, which occurs only in reaches 2 and 5 of Rosebud Creek, is considered to be in balance with water availability. With no mining and present irrigated acreage simulated, the smallest monthly dissolved-solids concentrations occurred in April for each reach (525 to 869 mg/L) and the largest dissolved-solids concentrations occurred in August for each reach except reach 1 (896 to 1,811 mg/L). In reach 1 the largest concentrations of dissolved solids occurred from August through January (598 to 610 mg/L). The mean percentage of dissolved-solids concentration resulting from agriculture in reach 2 (0.79 percent) is less than the mean percentage of reach 5 (2.20 percent), mainly as a result of more acreage irrigated in reach 5.

The simulated monthly increase in dissolved-solids concentration as a result of present (1982) mining in the Colstrip coal deposit ranges from 1 mg/L in April and May to 9 mg/L in December in reach 4. The greatest effect on dissolved-solids concentration of Rosebud Creek occurs during low streamflow from August through January. Simulation of full-scale mining indicates the largest effect will be in the Kirby coal deposit in reach 1, where the monthly dissolved-solids concentrations in Rosebud Creek are nearly doubled during low streamflow from August through January.

Simulations with present mining show irrigation accounting for a larger cumulative percentage of dissolved-solids concentration (3.05 percent in reach 5) than mining (0.38 percent in reach 5). However, with full-scale mining, the cumulative percentage resulting from irrigation in reach 5 (2.50 percent) will be smaller than from mining (14.69 percent). By not simulating mining of the Kirby coal deposit in reach 1, because of its large dissolved-solids load, the cumulative percentage of dissolved-solids concentration resulting from mining in all reaches will be decreased to less than 6.00 percent.

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SUPPLEMENTAL INFORMATION

Table 23.--*Definition of model variables*

AIR	Area (in acres) irrigated in each of five reaches of Rosebud Creek
AIRFS	Distribution of water (in acre-feet per acre) for complete service irrigation
AIRPS	Distribution of water (in acre-feet per acre) for partial service irrigation
AIRS	Distribution of water (in acre-feet per acre) for irrigation on each reach of Rosebud Creek
AMR	Area (in acres) mined in each of five reaches of Rosebud Creek
AUT	Area (in acres) of ungaged tributaries in each of five reaches of Rosebud Creek
B	Temporary variable used to calculate cumulative percentage of dissolved solids
C	Factor (0.00136) that converts the product of acre-feet and milligrams per liter to tons
CPDSIR	Cumulative percentage of dissolved-solids concentration due to irrigation return flow
CPDSMR	Cumulative percentage of dissolved solids due to mining
CV	Divisor to convert monthly discharge (in acre-feet) to mean daily streamflow (in cubic feet per second)
DDSCRK	Designator for dissolved-solids concentration in Rosebud Creek near Kirby
DICER	Depth (in feet) of ice change in each reach
DSARIR	Dissolved solids (in tons per acre) in antecedent return flow from irrigation in Rosebud Creek during the previous year
DSCD	Dissolved-solids concentration (in milligrams per liter) at the downstream end of each reach
DSCDMA	Maximum dissolved-solids concentration (in milligrams per liter) at the downstream end of each reach
DSCDMI	Minimum dissolved-solids concentration (in milligrams per liter) at the downstream end of each reach
DSCGW	Dissolved-solids concentration (in milligrams per liter) of ground water
DSCMR	Dissolved-solids concentration (in milligrams per liter) of leachate from surface coal mines on each of five reaches of Rosebud Creek

Table 23.--*Definition of model variables*--Continued

DSCRK	Dissolved-solids concentration (in milligrams per liter) at Rosebud Creek near Kirby
DSCRKU	Designator for dissolved-solids concentration of Rosebud Creek near Kirby
DSCUT	Dissolved-solids concentrations (in milligrams per liter) from ungaged tributaries
DSLD	Dissolved-solids load (in tons) at downstream end of reach
DSLDIR	Dissolved-solids load (in tons) diverted by irrigation from Rosebud Creek
DSLGW	Dissolved-solids load (in tons) in ground-water flow
DSLMR	Dissolved-solids load (in tons) from coal mines on each of five reaches of Rosebud Creek
DSLOL	Dissolved-solids load (in tons) in other water losses
DSLRIR	Dissolved-solids load (in tons) returning with irrigation to Rosebud Creek
DSLRK	Dissolved-solids load (in tons) in Rosebud Creek near Kirby
DSLUT	Dissolved-solids load (in tons) from ungaged tributaries
DSLU	Dissolved-solids load (in tons) at upstream end of reach
ET	Monthly evaporation rate (in acre-feet per acre)
I	Counter for months
J	Counter for reaches
M	Month name
MHC	Monthly hydrologic-flow conditions (in acre-feet per month)
MHCI	Hydrologic-flow conditions (in acre-feet per month) for a given month
MND	Number of days in the month
PDSIR	Percentage of dissolved-solids concentration in Rosebud Creek resulting from irrigation
PDSMR	Percentage of dissolved-solids concentration in Rosebud Creek resulting from mining
PT	Monthly distribution of precipitation (in acre-feet per acre) on the surface of Rosebud Creek

Table 23.--*Definition of model variables*--Continued

QARFIR	Antecedent return flow (in acre-feet per acre) from irrigated acreage along Rosebud Creek
QD	Monthly streamflow (in acre-feet) at downstream end of each reach of Rosebud Creek
QDIR	Streamflow (in acre-feet) diverted for irrigation along Rosebud Creek
QET	Monthly evaporation (in acre-feet) from the stream surface of Rosebud Creek
QEVTR	Monthly evapotranspiration (in acre-feet) from riparian vegetation along Rosebud Creek
QGW	Flow of ground water (in acre-feet per mile per day) to Rosebud Creek
QGWRR	Flow of ground water (in acre-feet) for each reach of Rosebud Creek
QICER	Gain or loss of streamflow (in acre-feet) as ice from Rosebud Creek
QOL	Other monthly losses of streamflow (in acre-feet) from Rosebud Creek
QOLR	Other annual losses of streamflow (in acre-feet) from Rosebud Creek
QPT	Monthly precipitation (in acre-feet) received in each reach of Rosebud Creek
QRFIR	Return flow (in acre-feet) from irrigation in each reach of Rosebud Creek
QRK	Monthly streamflow (in acre-feet) at upstream end of each reach of Rosebud Creek near Kirby
QU	Monthly streamflow (in acre-feet) at upstream end of each reach of Rosebud Creek
QUT	Streamflow (in acre-feet) to Rosebud Creek from ungaged tributaries
RA	Surface area (in acres) of each reach of Rosebud Creek
RC	Monthly runoff coefficients (in acre-feet per acre) for ungaged tributaries to each reach of Rosebud Creek
RCARR	Annual runoff coefficients (in inches) for each reach of Rosebud Creek
RCK	Initial conditions of streamflow (in acre-feet) and dissolved solids (concentration in milligrams per liter and load in tons) at Rosebud Creek near Kirby
RCRR 2-5	Monthly runoff coefficients (in acre-feet) for reaches 2 through 5 of Rosebud Creek
RL	Reach length (in miles)

Table 23.--*Definition of model variables*--Continued

S	Temporary variable used to calculate cumulative percentages of dissolved-solids concentrations
SCPDSI	Sum of cumulative percentages of dissolved-solids concentrations from irrigation return flow
SCPDSM	Sum of cumulative percentages of dissolved-solids concentrations from mined areas
SDSCD	Sum of dissolved-solids concentrations (in milligrams per liter) in the downstream end of each reach
SN	Simulation number which identifies the computer run
SPDSIR	Sum of the percentages of dissolved-solids concentrations from irrigation return flow
SPDSMR	Sum of the percentages of dissolved-solids concentrations from mined areas
SSDSCD	Sum of the squares of the dissolved-solids concentrations in the downstream end of each reach
U MEAN	Mean of cumulative percentages of dissolved-solids concentrations from irrigation return flow.
V MEAN	Mean of cumulative percentages of dissolved-solids concentrations from mined areas
X MEAN	Mean of the dissolved-solids concentrations at the downstream end of each reach
XSD	Standard deviation of the dissolved-solids concentration of the downstream end of each reach
Y MEAN	Mean of the percentages of dissolved-solids concentrations from irrigation return flows
Z MEAN	Mean of the percentages of dissolved-solids concentrations from mined areas

Table 24.--*Listing of computer program*

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                                                                          *
C                    ROSEBUD CREEK DISSOLVED SOLIDS MODEL                  *
C                                                                          *
C    PROGRAM TO COMPUTE DISSOLVED SOLIDS (SALINITY) CONDITIONS FOR FIVE    *
C    REACHES IN ROSEBUD CREEK, MONTANA FROM THE HEADWATERS TO              *
C    ROSEBUD CREEK NR THE MOUTH.                                           *
C    COMPUTATIONAL SCHEME IS MASS BALANCE OF HYDROLOGIC INPUTS AND OUTPUTS  *
C    IN ASSOCIATION WITH THEIR RESPECTIVE DISSOLVED SOLIDS CONCENTRATIONS.  *
C    TIME STEP IS MONTHLY. EACH SIMULATION RUN IS FOR ONE YEAR TIME PERIOD. *
C                                                                          *
C    DEFINITION OF INPUT VARIABLES                                         *
C      SN = SIMULATION NUMBER, USE FOR IDENTIFICATION PURPOSES             *
C      MHC = MONTHLY HYDROLOGIC CONDITION, ENTER 1 FOR MEAN, 2 FOR FOR 50TH *
C            PERCENTILE, 3 FOR 25TH PERCENTILE,4 FOR 75TH PERCENTILE       *
C            5 FOR MAXIMUM, 6 FOR MINIMUM                                  *
C      DDSCRK = DESIGNATOR FOR DISSOLVED SOLIDS CONCENTRATTON AT ROSEBUD   *
C             CREEK NEAR KIRBY                                             *
C             ENTER 0 FOR REGRESSION-DERIVED VALUES OR ENTER 1 FOR         *
C             USER-DEFINED VALUES                                          *
C      DSCRKU = USER-DEFINED MONTHLY VALUE FOR DISSOLVED SOLIDS            *
C              CONCENTRATION AT ROSEBUD CREEK NEAR KIRBY                   *
C      AIR = AREA (ACRES) IRRIGATED ON EACH OF FIVE REACHES ON ROSEBUD CREEK *
C      AMR = ACREAGE OF SURFACE COAL MINES ON EACH OF FIVE REACHES ON      *
C            ROSEBUD CREEK                                                 *
C      DSCMR = DISSOLVED SOLIDS CONCENTRATION (MG/L) OF LEACHATE FROM      *
C             SURFACE COAL MINES ON EACH OF FIVE REACHES ON ROSEBUD CREEK  *
C      QOLR = OTHER WATER LOSSES FROM EACH OF FIVE REACHES ON ROSEBUD CREEK *
C             (ACRE-FEET/YEAR)                                             *
C                                                                          *
C    INPUT DATA CARD INSTRUCTIONS, SIX CARDS REQUIRED                      *
C      CARD 1 = SN,MHC                  FORMAT(A5,4X,12I2)                 *
C      CARD 2 = DDSCRK,DSCRKU           FORMAT(I1,4X,12F5.0)               *
C      CARD 3 = AIR                     FORMAT(5F6.0)                      *
C      CARD 4 = AMR                     FORMAT(5F6.0)                      *
C      CARD 5 = DSCMR                   FORMAT(5F6.0)                      *
C      CARD 6 = QOLR                    FORMAT(5F6.0)                      *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
CCCCC     MAIN PROGRAM --- READS INPUT DATA, WRITES SIMULATION CONDITIONS,
CCCCC     CALLS APPROPRIATE SUBROUTINES FOR PASSAGE OF DATA TO SUBROUTINE
CCCCC     SALINE, WRITES HEADINGS FOR OUTPUT OF MONTHLY RESULTS, PERFORMS
CCCCC     STATISTICAL ANALYSES OF MONTHLY RESULTS, WRITES HEADINGS AND
CCCCC     RESULTS FOR SIMULATION SUMMARY
      DIMENSION MHC(12),MX(12)
      COMMON AIR(5),AMR(5),DSCMR(5),QOLR(5),M(12),SN,I,J,
     *CPDSIR(12,5),CPDSMR(12,5),QU(12,5),QD(12,5),DSLDIR(12,5)
     *,PDSIR(12,5),PDSMR(12,5),DDSCRK,DSCRKU(12),DSLRK(12),DSCRK
     *(12),QDIR(12,5),DSLD(12,5),DSLU(12,5),DSCD(12,5),JJ
      DATA MX / 'JAN','FEB','MAR','APR','MAY','JUNE','JULY','AUG','SEPT'
     *,'OCT','NOV','DEC'/
      DO 1 I=1,12
    1 M(I)=MX(I)
CCCCC     READ INPUT DATA FROM CARDS
      READ(5,5)SN,MHC
      READ(5,7)DDSCRK,DSCRKU
      READ(5,10)AIR
      READ(5,10)AMR
      READ(5,10)DSCMR
```

```
      READ(5,10)QOLR
    5 FORMAT(A5,4X,12I2)
    7 FORMAT(I1,4X,12F5.0)
   10 FORMAT(5F6.0)
CCCCC      WRITE DESCRIPTION OF SIMULATION CONDITIONS
      WRITE(6,15) SN
   15 FORMAT('1ROSEBUD CREEK DISSOLVED SOLIDS MODEL --- SIMULATION NUMBE
     *R ',A5//)
      IF(DDSCRK.EQ.0) WRITE(6,18)
      IF(DDSCRK.EQ.1) WRITE(6,20)
   18 FORMAT(' DESIGNATOR FOR DISSOLVED-SOLIDS INPUT AT ROSEBUD CREEK NE
     *AR KIRBY SET TO REGRESSION-DEFINED STATUS')
   20 FORMAT(' DESIGNATOR FOR DISSOLVED-SOLIDS INPUT AT ROSEBUD CREEK NE
     *AR KIRBY SET TO USER-DEFINED STATUS')
      WRITE(6,76)
      WRITE(6,78)
      WRITE(6,80)
      WRITE(6,82)
      WRITE(6,84)
      WRITE(6,86)
      WRITE(6,88)
      WRITE(6,89)
      WRITE(6,22)
   22 FORMAT('0STREAMFLOW STATUS DURING SIMULATION')
      WRITE(6,24)
   24 FORMAT(' ***********************************')
      WRITE(6,30)MHC(1),MHC(2)
      WRITE(6,32)MHC(3),MHC(4)
      WRITE(6,34)MHC(5),MHC(6)
      WRITE(6,36)MHC(7),MHC(8)
      WRITE(6,38)MHC(9),MHC(10)
      WRITE(6,40)MHC(11),MHC(12)
   30 FORMAT('0JAN   = ',I1,T13,'FEB   = ',I1,T30,'1 = MEAN')
   32 FORMAT(' MARCH = ',I1,T13,'APRIL = ',I1,T30,'2 = 50TH PERCENTILE')
   34 FORMAT(' MAY   = ',I1,T13,'JUNE  = ',I1,T30,'3 = 25TH PERCENTILE')
   36 FORMAT(' JULY  = ',I1,T13,'AUG   = ',I1,T30,'4 = 75TH PERCENTILE')
   38 FORMAT(' SEPT  = ',I1,T13,'OCT   = ',I1,T30,'5 = MAXIMUM')
   40 FORMAT(' NOV   = ',I1,T13,'DEC   = ',I1,T30,'6 = MINIMUM')
      WRITE(6,42)
      WRITE(6,44)
   42 FORMAT('0IRRIGATED ACREAGE STATUS DURING SIMULATION')
   44 FORMAT(' ******************************************')
      WRITE(6,46)AIR(1),AIR(2),AIR(3)
      WRITE(6,48)AIR(4),AIR(5)
      WRITE(6,49)
   46 FORMAT('0REACH 1 = ',F6.0,T19,'REACH 2 = ',F6.0,T36,'REACH 3 = '
     *,F6.0)
   48 FORMAT(' REACH 4 = ',F6.0,T19,'REACH 5 = ',F6.0)
   49 FORMAT('    NOTE - IRRIGATED ACRES IN REACH 1 ARE THOSE IN '/,
     *'+   EXCESS OF PRESENTLY IRRIGATED ACRES (0 ACRES)')
      WRITE(6,50)
      WRITE(6,52)
   50 FORMAT('0SURFACE COAL MINING STATUS DURING SIMULATION')
   52 FORMAT(' ********************************************')
      WRITE(6,54)
      WRITE(6,56)
      WRITE(6,58)
   54 FORMAT('0                       DISSOLVED SOLIDS                     DI
```

Table 24.--*Listing of computer program*--Continued

```
     *SSOLVED SOLIDS')
  56 FORMAT(' REACH  ACREAGE  (MG/L) OF LEACHATE    REACH  ACREAGE  (MG
     */L) OF LEACHATE')
  58 FORMAT(' -----  -------  -----------------    -----  -------  ---
     *---------------')
      WRITE(6,60)AMR(1),DSCMR(1),AMR(2),DSCMR(2)
      WRITE(6,62)AMR(3),DSCMR(3),AMR(4),DSCMR(4)
      WRITE(6,64)AMR(5),DSCMR(5)
  60 FORMAT('   1',T8,F7.0,T25,F5.0,T42,'2',T46,F7.0,T63,F5.0)
  62 FORMAT('   3',T8,F7.0,T25,F5.0,T42,'4',T46,F7.0,T63,F5.0)
  64 FORMAT('   5',T8,F7.0,T25,F5.0)
      WRITE(6,68)
      WRITE(6,70)
  68 FORMAT('0OTHER WATER LOSSES (ACRE-FEET PER YEAR) DURING SIMULATION
     *')
  70 FORMAT(' ***********************************************************
     *')
      WRITE(6,72)QOLR(1),QOLR(2),QOLR(3)
      WRITE(6,74)QOLR(4),QOLR(5)
  72 FORMAT('0REACH 1 = ',F6.0,T19,'REACH 2 = ',F6.0,T36,'REACH 3 =
     *',F6.0)
  74 FORMAT(' REACH 4 = ',F6.0,T19,'REACH 5 = ',F6.0)
  76 FORMAT('0REACH DESCRIPTIONS')
  78 FORMAT(' ******************')
  80 FORMAT('0 1  = HEADWATER REACH UPSTREAM FROM RIVER MILE 182.1')
  82 FORMAT('  2  = RIVER MILE 182.1 TO RIVER MILE 120.2 (INCLUDES CORR
     *AL,THOMSON, AND DAVIS CREEKS)')
  84 FORMAT('  3  = RIVER MILE 120.2 TO RIVER MILE  85.6 (INCLUDES MUDD
     *Y, AND LAME DEER CREEKS)')
  86 FORMAT('  4  = RIVER MILE  85.6 TO RIVER MILE  55.6 (INCLUDES GREE
     *N LEAF CREEK)')
  88 FORMAT('  5  = RIVER MILE  55.6 TO RIVER MILE 0.8 AT THE MOUTH (IN
     *CLUDES SNIDER CREEK)'//)
  89 FORMAT(' RCK = INITIAL CONDITIONS AT ROSEBUD CREEK NEAR KIRBY')
CCCCC      WRITE HEADINGS FOR MONTHLY RESULTS OF SIMULATION. RESULTS WILL BE
CCCCC      WRITTEN BY SUBROUTINE SALINE
      WRITE(6,100)SN
 100 FORMAT('1SIMULATION RESULTS -- SIMULATION NUMBER',A5/,'+***********
     ************************************'/,'+',T17,'STREAMFLOW',T33,'DI
     *SSOLVED SOLIDS',T63,'PERCENT',T88,'CUMULATIVE PERCENT'/,'+',T17,
     *'(ACRE-FEET)',T34,'LOAD',T44,'CONC',T57,'CONCENTRATION DUE TO',T8
     *7,'CONCENTRATION DUE TO'/,'+MONTH  REACH',T33,
     *'(TONS)',T43,'(MG/L)',T56,                                    'RE
     *TURN FLOW    MINING           RETURN FLOW    MINING'/,'+-----  -----
     *   -----------  ---------  ----------    -----------  --------
     *        -----------   --------')
CCCCC      ZERO OUT ARRAYS FOR COMPUTATIONS OF IRRIGATION RETURN FLOW
      DO 112 I = 1,12
      DO 111 J = 1,5
      QDIR(I,J)=0.0
      DSLDIR(I,J)=0.0
 111 CONTINUE
 112 CONTINUE
CCCCC      BASED ON VALUE OF MONTHLY HYDROLOGIC CONDITION (MHC),
CCCCC      SUBROUTINE SALINE OBTAINS APPROPRIATE DATA
CCCCC      FROM SUBROUTINE BLOCK DATA
      DO 145 I = 1,12
C  TEST FOR VALID MONTHLY HYDROLOGIC CONDITION
```

Table 24.--*Listing of computer program*--Continued

```
      IF(MHC(I).LT.1.OR.MHC(I).GT.6) GO TO 1000
  115 CALL SALINE(MHC(I))
  145 CONTINUE
CCCCC     WRITE FIRST SET OF HEADINGS FOR SIMULATION SUMMARY
      WRITE(6,300) SN
  300 FORMAT('1SIMULATION SUMMARY -- SIMULATION NUMBER ',A5)
      WRITE(6,305)
  305 FORMAT(' ********************************************'////)
      WRITE(6,310)
  310 FORMAT('0',T20,'STREAMFLOW',T56,'DISSOLVED SOLIDS'/,'+',T20,'(ACRE
     *-FEET)',T44,'------------------------------------'/,'+',T4
     *4,'ROSEBUD CR NEAR KIRBY',T67,'ROSEBUD CR NR ROSEBUD'/,'+',T9,'---
     *---------------------  -------------------  -----------
     *----------'/,'+MONTH  ROSEBUD CR KIRBY  RSBD CR ROSEBUD  LOAD(TON)
     *  CONC(MG/L)  LOAD(TON)  CONC(MG/L)'/'+-----  ----------------  --
     *------------  ---------  ----------  ---------  ----------')
CCCCC     WRITE RESULTS FOR SIMULATION SUMMARY
      DO 390 I=1,12
      WRITE(6,385) M(I),QD(I,1),QD(I,5),DSLD(I,1),DSCD(I,1),DSLD(I,5),
     *DSCD(I,5)
  385 FORMAT(1X,A5,T11,F10.0,T28,F10.0,T42,F10.0,T56,F7.0,T65,F10.0,T79,
     *F7.0)
  390 CONTINUE
CCCCC     WRITE SECOND SET OF HEADINGS FOR SIMULATION SUMMARY
      WRITE(6,400)
      WRITE(6,410)
      WRITE(6,420)
      WRITE(6,430)
  400 FORMAT('0',T10,'MONTHLY DISSOLVED SOLIDS CONC (MG/L)',T58,'MEAN PE
     *RCENT',T83,'MEAN CUMULATIVE PERCENT')
  410 FORMAT(' ',T10,'------------------------------------',T54,
     *'CONCENTRATION DUE TO',T85,'CONCENTRATION DUE TO')
  420 FORMAT(' ',T2,'REACH',T12,'MEAN',T20,'STD DEV',T31,'MIN',T40,'MAX'
     *,T53,'RETURN FLOW',T68,'MINING',T84,'RETURN FLOW',T99,'MINING')
  430 FORMAT(' ',T2,'-----',T11,'-------  -------  -------  -------',T53
     *,'-----------   --------',T84,'-----------   --------')
CCCCC     PERFORM STATISTICAL ANALYSIS OF DATA OUTPUT BY MONTHLY COMPUTATIONS
CCCCC     FOR FIVE REACHES OF ROSEBUD CREEK, WRITE RESULTS OF STATISTICAL
CCCCC     ANALYSES
      DO 500 J=1,5
      SDSCD = 0
      SSDSCD = 0
      SPDSIR = 0
      SPDSMR = 0
      DSCDMI = 1.E20
      DSCDMA = -1.E20
      SCPDSI=0
      SCPDSM=0
      DO 470 I=1,12
      SDSCD = SDSCD + DSCD(I,J)
      SSDSCD = SSDSCD + DSCD(I,J) ** 2
      SPDSIR = SPDSIR + PDSIR(I,J)
      SPDSMR = SPDSMR + PDSMR(I,J)
      DSCDMI = AMIN1(DSCDMI,DSCD(I,J))
      DSCDMA = AMAX1(DSCDMA,DSCD(I,J))
      SCPDSI=SCPDSI+CPDSIR(I,J)
      SCPDSM=SCPDSM+CPDSMR(I,J)
  470 CONTINUE
```

Table 24.--*Listing of computer program*--Continued

```
      XMEAN = SDSCD/12
      XSD = SQRT((SSDSCD - (SDSCD ** 2)/12)/11)
      YMEAN = SPDSIR/12
      ZMEAN = SPDSMR/12
      UMEAN=SCPDSI/12
      VMEAN=SCPDSM/12
      WRITE(6,480) J,XMEAN,XSD,DSCDMI,DSCDMA,YMEAN,ZMEAN,
     *UMEAN,VMEAN
  480 FORMAT(' ',T4,I1,T10,F6.0,T20,F6.0,T29,F6.0,T38,F6.0,T55,F7.4,T67,
     *F7.4,T87,F7.4,T98,F7.4)
  500 CONTINUE
      WRITE(6,670)
  670 FORMAT('0    NOTE -- MEAN AND CUMULATIVE PERCENT VALUES DERIVED FR
     *OM 12 MONTHLY VALUES')
      GO TO 1020
CCCCC     WRITE ERROR MESSAGE FOR INVALID MONTHLY HYDROLOGIC
CCCCC     CONDITION(MHC)
 1000 WRITE(6,1010) SN,I
 1010 FORMAT('0SIMULATION NUMBER ',A5,' TERMINATED DUE TO INVALID MONTHL
     *Y HYDROLOGIC CONDITION IN MONTH NUMBER ',I2)
      GO TO 1020
 1020 STOP
      END
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
CCCCC     SUBROUTINE BLOCK DATA --- CONTAINS DATA FOR SIX STREAMFLOW
CCCCC     CONDITIONS USED IN THE MODEL
      BLOCK DATA
      COMMON / DATA / QRK(6,12),PT(6,12),ET(6,12),RCRR2(6,12),RCRR3
     *(6,12),RCRR4(6,12),RCRR5(6,12)
      DATA QRK /
     *346.,   246.,   123.,   400.,   1783.,  61.,
     *675.,   666.,   555.,   778.,   1388.,  259.,
     *1399.,  1045.,  738.,   1599.,  5780.,  369.,
     *2390.,  1785.,  952.,   3064.,  11068., 357.,
     *2027.,  1599.,  805.,   2367.,  9408.,  .001,
     *1540.,  1012.,  595.,   1696.,  8450.,  179.,
     *816.,   738.,   369.,   1076.,  2521.,  123.,
     *456.,   307.,   130.,   738.,   1968.,  .001,
     *391.,   268.,   60.,    536.,   1785.,  .001,
     *361.,   178.,   123.,   553.,   1599.,  .001,
     *395.,   268.,   179.,   589.,   1131.,  60.,
     *291.,   212.,   61.,    400.,   1045.,  .001/
      DATA PT /
     *.051,   .051,   .008,   .093,   .198,   .004,
     *.041,   .041,   .017,   .065,   .121,   .008,
     *.055,   .055,   .023,   .087,   .138,   .003,
     *.113,   .113,   .044,   .181,   .243,   .0,
     *.201,   .201,   .078,   .324,   .684,   .053,
     *.223,   .223,   .106,   .339,   .557,   .063,
     *.096,   .096,   .024,   .168,   .308,   .003,
     *.093,   .093,   .0,     .188,   .373,   .0,
     *.102,   .102,   .013,   .190,   .343,   .0,
     *.085,   .085,   .016,   .154,   .337,   .0,
     *.052,   .052,   .016,   .088,   .158,   .005,
     *.048,   .048,   .016,   .079,   .125,   .003/
      DATA ET /
     *.058,   .058,   .067,   .050,   .042,   .092,
     *.058,   .058,   .067,   .050,   .042,   .092,
```

```
     *.117,   .117,   .142,   .092,   .083,   .175,
     *.217,   .217,   .258,   .175,   .150,   .325,
     *.358,   .358,   .433,   .283,   .242,   .533,
     *.450,   .450,   .567,   .333,   .275,   .842,
     *.575,   .575,   .667,   .475,   .408,   .808,
     *.550,   .550,   .650,   .450,   .425,   .775,
     *.358,   .358,   .425,   .292,   .233,   .508,
     *.258,   .258,   .308,   .208,   .183,   .383,
     *.117,   .117,   .142,   .092,   .083,   .175,
     *.058,   .058,   .067,   .050,   .042,   .092/
      DATA RCRR2 /
     *6.32,   3.64,   1.85,   6.32,   52.73,  .41,
     *10.77,  10.16,  8.8,    11.57,  22.09,  6.53,
     *20.17,  15.39,  10.25,  23.18,  83.69,  5.33,
     *33.85,  25.32,  13.57,  42.92,  155.93, 5.25,
     *26.67,  21.33,  10.80,  31.39,  125.54, 0.,
     *26.50,  17.51,  10.31,  29.20,  146.28, 3.23,
     *12.65,  11.02,  5.81,   16.46,  38.90,  1.91,
     *7.69,   5.42,   2.20,   12.36,  32.48,  0.,
     *6.32,   4.22,   1.32,   8.65,   27.87,  0.,
     *7.52,   3.66,   2.55,   11.52,  33.19,  0.,
     *7.01,   5.55,   2.78,   9.52,   21.28,  .46,
     *5.47,   4.22,   1.38,   7.76,   21.67,  0./
      DATA RCRR3 /
     *1.13,   .65,    .33,    1.13,   9.45,   .07,
     *1.58,   1.50,   1.29,   1.70,   3.25,   .96,
     *2.30,   1.76,   1.17,   2.64,   9.53,   .61,
     *3.21,   2.40,   1.29,   4.07,   14.79,  .50,
     *4.05,   3.24,   1.65,   4.77,   19.07,  .0,
     *3.63,   2.41,   1.41,   4.01,   20.07,  .44,
     *2.11,   1.34,   .97,    2.74,   6.48,   .31,
     *1.20,   .85,    .34,    1.93,   5.06,   .0,
     *.86,    .57,    .18,    1.18,   3.80,   .0,
     *.84,    .41,    .29,    1.29,   3.71,   .0,
     *.91,    .72,    .36,    1.24,   2.77,   .06,
     *.62,    .47,    .16,    .86,    2.39,   .0/
      DATA RCRR4 /
     *.40,    .23,    .12,    .40,    3.37,   .03,
     *.72,    .63,    .59,    .78,    1.48,   .44,
     *1.28,   .97,    .65,    1.47,   5.30,   .34,
     *1.78,   1.33,   .72,    2.26,   8.22,   .28,
     *1.69,   1.35,   .69,    1.99,   7.96,   .0,
     *1.65,   1.09,   .64,    1.82,   9.10,   .20,
     *.88,    .76,    .40,    1.14,   2.69,   .13,
     *.46,    .33,    .13,    .74,    1.95,   .0,
     *.36,    .24,    .08,    .49,    1.59,   .0,
     *.38,    .19,    .13,    .58,    1.69,   .0,
     *.38,    .30,    .15,    .51,    1.15,   .03,
     *.31,    .23,    .08,    .42,    1.18,   .0/
      DATA RCRR5/
     *.66,    .41,    .21,    .78,    3.33,   .0,
     *2.4,    1.49,   .76,    3.54,   11.44,  .0,
     *4.24,   2.95,   1.46,   6.61,   17.45,  .33,
     *3.22,   2.60,   1.12,   4.39,   10.,    .0,
     *2.83,   1.74,   .70,    2.53,   22.17,  .14,
     *3.02,   1.84,   1.12,   3.39,   19.35,  .31,
     *1.26,   .75,    .30,    1.63,   8.02,   .08,
     *.54,    .35,    .14,    .78,    2.21,   .0,
```

```
      *.58,    .20,    .04,    .55,    4.34,   .0,
      *.64,    .37,    .14,    .75,    3.89,   .0,
      *.70,    .36,    .16,    .87,    5.27,   .0,
      *.58,    .35,    .19,    .77,    2.91,   .0/
       END
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
CCCCC     SUBROUTINE SALINE --- CALCULATES HYDROLOGIC AND DISSOLVED SOLIDS
CCCCC     MASS BALANCES FOR FIVE REACHES OF ROSEBUD CREEK AND WRITES
CCCCC     RESULTS OF MONTHLY COMPUTATIONS
       SUBROUTINE SALINE (MHC)
       COMMON / DATA / QRK(6,12),PT(6,12),ET(6,12),RCRR2(6,12),RCRR3
      *(6,12),RCRR4(6,12),RCRR5(6,12)
       COMMON AIR(5),AMR(5),DSCMR(5),QOLR(5),M(12),
      *SN,I,J,CPDSIR(12,5),CPDSMR(12,5),QU(12,5),QD(12,5),
      *DSLDIR(12,5),PDSIR(12,5),PDSMR(12,5),DDSCRK,DSCRKU(12),
      *DSLRK(12),DSCRK(12),QDIR(12,5),DSLD(12,5),DSLU(12,5),DSCD(12,5),JJ
       DIMENSION DSCGW(5),RA(5,12),RL(5),AUT(5),QGW(5),MND(12),
      *DICER(5,12),QICER(5),RCARR(5),QPT(5),QET(5),QGWRR(5),
      *QRFIR(5),QUT(5),QSI(5),QOL(5),DSLGW(5),
      *DSLRIR(5),DSCUT(5),DSLUT(5),DSLMR(5),DSLOL(5),
      *DSARIR(5,12),AIRFS(5,12),AIRPS(5,12),QARFIR(5,12),QEVTR(5)
       DATA DSCGW / .01, 1133., 798., 211., 1172. /
       DATA DSCUT / .01, 663., 883., 1814., 1814. /
       DATA RA /
      *.1, 98., 71., 73.,123.,
      *.1, 98., 71., 73.,123.,
      *.1,120., 88., 37.,156.,
      *.1,150., 96., 98.,195.,
      *.1,143., 96., 95.,178.,
      *.1,128., 92., 91.,167.,
      *.1,113., 80., 34.,151.,
      *.1, 98., 71., 73.,123.,
      *.1, 98., 71., 73.,123.,
      *.1, 98., 71., 73.,123.,
      *.1, 98., 71., 73.,123.,
      *.1, 98., 71., 73.,123. /
       DATA RL / .01,61.9,34.6,30.0,46.0 /
       DATA AUT / 78720.,195200.,237440.,103680.,218240. /
       DATA QGW / .01,.13,.06,-.22,-.08/
       DATA MND / 31,28,31,30,31,30,31,31,30,31,30,31/
       DATA DICER /
      *.1,  .0,  .0,  .0,  .0,
      *.1,  .0,  .0,  .0,  .0,
      *.1,+.35,+.35,+.30,+.25,
      *.1,  .0,  .0,  .0,  .0,
      *.1,  .0,  .0,  .0,  .0,
      *.1,  .0,  .0,  .0,  .0,
      *.1,  .0,  .0,  .0,  .0,
      *.1,  .0,  .0,  .0,  .0,
      *.1,  .0,  .0,  .0,  .0,
      *.1,  .0,  .0,  .0,  .0,
      *.1,  .0,  .0,  .0,  .0,
      *.1,-.35,-.35,-.30,-.25 /
       DATA RCARR / 2.203,2.051,.269,.123,.248 /
       DATA DSARIR /
      *  .0, .07841, .0, .0, .05271,
      *  .0, .06953, .0, .0, .03777,
      *  .0, .05626, .0, .0, .03770,
```

Table 24.--*Listing of computer program*--Continued

```
     *  .0, .03103, .0, .0,     .0,
     *  .0, .00933, .0, .0,     .0,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0./
      DATA AIRFS /
     *5*0.,
     *5*0.,
     *5*0.,
     * .0, .0, .0, .0,.21,
     * .0,.28, .0, .0,.27,
     * .0,.41, .0, .0,.55,
     * .0,.74, .0, .0,.13,
     * .0,.61, .0, .0, .0,
     * .0,.26, .0, .0, .0,
     *5*0.,
     *5*0.,
     *5*0./
      DATA AIRPS /
     *5*0.,
     *5*0.,
     *5*0.,
     * .0, .0, .0, .0,.11,
     * .0,.14, .0, .0,.14,
     * .0,.21, .0, .0,.28,
     * .0,.37, .0, .0,.07,
     * .0,.31, .0, .0, .0,
     * .0,.13, .0, .0, .0,
     *5*0.,
     *5*0.,
     *5*0./
      DATA QARFIR /
     *  .0, .0556, .0, .0, .0229,
     *  .0, .0488, .0, .0, .0164,
     *  .0, .0389, .0, .0, .0031,
     *  .0, .0210, .0, .0,    .0,
     *  .0, .0063, .0, .0,    .0,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0./
CCCCC      CALCULATE HYDROLOGIC MASS BALANCE
      DO 1500 J = 1,5
      IF(MND(I).EQ.31) CV = 61.488
      IF(MND(I).EQ.30) CV = 59.504
      IF(MND(I).EQ.28) CV = 55.537
      IF(J.EQ.1) QU(I,J)=QRK(MHC,I)
      IF(J.EQ.1) GO TO 1
      IF(J.GT.1) QU(I,J)=QD(I,J-1)
      QPT(J)=RA(J,I)*PT(MHC,I)
      QET(J)=RA(J,I)*ET(MHC,I)
```

Table 24.--*Listing of computer program*--Continued

```
      QEVTR(J)=2.0*QET(J)
      IF(I.LT.5.OR.I.GT.9) QEVTR(J)=0
      QGWRR(J)=RL(J)*QGW(J)*MND(I)
    1 IF(MHC.EQ.1.OR.MHC.EQ.2.OR.MHC.EQ.4.OR.MHC.EQ.5) AIRS=AIRFS(J,I)
      IF(MHC.EQ.3.OR.MHC.EQ.6) AIRS=AIRPS(J,I)
      QDIR(I,J)=AIR(J)*AIRS
      QRFIR(J)=((QDIR(I,J)*.65)*.85)*
     *.65+(((QDIR(1,J)+QDIR(2,J)+QDIR(3,J)+QDIR
     *(4,J)+QDIR(5,J)+QDIR(6,J)+QDIR(7,J)
     *+QDIR(8,J)+QDIR(9,J)+QDIR(10,J)
     *+QDIR(11,J)+QDIR(12,J)
     *-QDIR(I,J))*.65)*.85)*.35/8+QARFIR(J,I)*AIR(J)
      IF(J.EQ.1) GO TO 60
      IF(J.EQ.2) RC=RCRR2(MHC,I) * .001 * .25
      IF(J.EQ.3) RC=RCRR3(MHC,I) * .001
      IF(J.EQ.4) RC=RCRR4(MHC,I) * .001
      IF(J.EQ.5) RC=RCRR5(MHC,I) * .001
      QUT(J)=AUT(J)*RC
   20 QICER(J)=RA(J,I)*DICER(J,I)
   60 QOL(J)=QOLR(J)/12
CCCCC      COMPUTE DISSOLVED SOLIDS MASS BALANCE
      C=.00136
      IF(J.EQ.1.AND.QRK(MHC,I).EQ.0) DSLU(I,J)=0
      IF(J.EQ.1.AND.QRK(MHC,I).EQ.0) GO TO 65
      IF(J.EQ.1.AND.DDSCRK.EQ.0) DSLU(I,J) = C*QRK(MHC,I)*
     *(685.587-100.253*(ALOG10((QRK(MHC,I))/CV)))
      IF(J.EQ.1.AND.DDSCRK.EQ.1) DSLU(I,J) = DSCRKU(I)*QRK(MHC,I)*C
   65 DSLRK(I)=DSLU(I,1)
      DSCRK(I)=(DSLU(I,1)/QRK(MHC,I))/C
      IF(J.EQ.1) GO TO 70
      DSLU(I,J)=DSLD(I,J-1)
      DSLGW(J)=QGWRR(J)*DSCGW(J)*C
   70 DSLDIR(I,J)=QDIR(I,J)*(DSLU(I,J)/QU(I,J))
      DSLRIR(J) = DSLDIR(I,J)*.65+(DSLDIR(1,J)+DSLDIR(2,J)
     *+DSLDIR(3,J)+DSLDIR(4,J)+DSLDIR(5,J)
     *+DSLDIR(6,J)+DSLDIR(7,J)+DSLDIR(8,J)
     *+DSLDIR(9,J)+DSLDIR(10,J)+DSLDIR(11,J)
     *+DSLDIR(12,J)-DSLDIR(I,J))*.04375+DSARIR(J,I)*AIR(J)
      IF(J.EQ.1) GO TO 75
      DSLUT(J)=QUT(J)*DSCUT(J)*C
   75 DSLMR(J)=DSCMR(J)*.0001133*AMR(J)*(RCARR(J)/12)
      DSLOL(J)=QOL(J)*(DSLU(I,J)/QU(I,J))
CCCCC      COMPUTE DISSOLVED SOLIDS MASS BALANCE AT DOWNSTREAM END OF REACH
  400 DSLUT(1)=0
      DSLGW(1)=0
      DSLD(I,J)=DSLU(I,J)+DSLGW(J)-DSLDIR(I,J)+DSLRIR(J)
     *+DSLUT(J)-DSLOL(J)+DSLMR(J)
CCCCC      COMPUTE MASS BALANCE OF FLOW AT DOWNSTREAM END OF REACH
      QPT(1)=0
      QET(1)=0
      QGWRR(1)=0
      QUT(1)=0
      QICER(1)=0
      QEVTR(1)=0
      QD(I,J)=QU(I,J)+QPT(J)-QET(J)+QGWRR(J)-QDIR(I,J)+QRFIR(J)
     *+QUT(J)+QICER(J)-QOL(J)-QEVTR(J)
C   TEST FOR ZERO OR NEGATIVE STREAMFLOW
      IF(QD(I,J).LE.0) GO TO 2000
```

```
CCCCC      COMPUTE DISSOLVED SOLIDS CONCENTRATIONS, COMPUTE PERCENTAGE OF
CCCCC      DISSOLVED SOLIDS LOAD DUE TO MINING OR RETURN FLOW, COMPUTE
CCCCC      CUMULATIVE PERCENTAGE OF DISSOLVED SOLIDS LOAD DUE TO MINING
CCCCC      OR RETURN FLOW
      DSCD(I,J)=DSLD(I,J)/QD(I,J)/C
      PDSIR(I,J)=(1-((((DSLD(I,J)-(DSLRIR(J)-DSLDIR(I,J)))/
     *(QD(I,J)-(QRFIR(J)-QDIR(I,J))))/C)/DSCD(I,J)))*100
      PDSMR(I,J)=DSLMR(J)/DSLD(I,J)*100
      B=0
      DO 405 JJ = 1,J
  405 B=B+DSLMR(JJ)
      CPDSMR(I,J)=B/DSLD(I,J)*100
      S=0
      B=0
      DO 410 JJ = 1,J
      S=S+(DSLRIR(JJ)-DSLDIR(I,JJ))
  410 B=B+(QRFIR(JJ)-QDIR(I,JJ))
      CPDSIR(I,J)=(1-((((DSLD(I,J)-S)/(QD(I,J)-B))/C)/
     *DSCD(I,J)))*100
CCCCC      WRITE RESULTS OF REACH COMPUTATIONS FOR MONTH
      IF(J.EQ.1) WRITE(6,1000) M(I),QRK(MHC,I),DSLRK(I),DSCRK(I)
      WRITE(6,1100) J,QD(I,J),DSLD(I,J),DSCD(I,J),PDSIR(I,J),
     *PDSMR(I,J),CPDSIR(I,J),CPDSMR(I,J)
 1000 FORMAT(1X,A5,3X,'RCK',5X,F8.0,5X,F8.0,2X,F8.0)
 1100 FORMAT(10X,I1,6X,F8.0,5X,F8.0,2X,F8.0,T58,F7.4,T70,
     *F7.4,T88,F7.4,T100,F7.4)
 1399 IF(I.EQ.6.AND.J.EQ.5) WRITE(6,1400)SN
 1400 FORMAT('1SIMULATION RESULTS -- SIMULATION NUMBER',A5/,'***********
     ************************************'/,'+',T17,'STREAMFLOW',T33,'DI
     *SSOLVED SOLIDS',T63,'PERCENT',T88,'CUMULATION PRECENT'/,'+',T17,
     *'(ACRE-FEET)',T34,'LOAD',T44,'CONC',T57,'CONCENTRATION DUE TO',T8
     *7,'CONCENTRATION DUE TO'/,'+MONTH  REACH',T33,
     *'(TONS)',T43,'(MG/L)',T56,                                     'RE
     *TURN FLOW    MINING          RETURN FLOW    MINING'/,'+-----  -----
     *  -----------  ---------  ----------    -----------   --------
     *      -----------  --------')
 1500 CONTINUE
 1550 RETURN
CCCCC      WRITE ERROR MESSAGE FOR ZERO OR NEGATIVE STREAMFLOW
 2000 WRITE(6,2100) SN,J,I
 2100 FORMAT('OSIMULATION NUMBER ',A5,' TERMINATED DUE TO ZERO OR NEGATI
     *VE STREAMFLOW IN REACH NUMBER ',I1,' DURING MONTH NUMBER ',I2)
      STOP
```

Table 25.--*Example of model output*

```
ROSEBUD CREEK DISSOLVED SOLIDS MODEL --- SIMULATION NUMBER      1


DESIGNATOR FOR DISSOLVED-SOLIDS INPUT AT ROSEBUD CREEK NEAR KIRBY SET TO REGRESSION-DEFINED STATUS

REACH DESCRIPTIONS
******************

 1  = HEADWATER REACH UPSTREAM FROM RIVER MILE 182.1
 2  = RIVER MILE 182.1 TO RIVER MILE 120.2 (INCLUDES CORRAL,THOMSON, AND DAVIS CREEKS)
 3  = RIVER MILE 120.2 TO RIVER MILE  85.6 (INCLUDES MUDDY, AND LAME DEER CREEKS)
 4  = RIVER MILE  85.6 TO RIVER MILE  55.6 (INCLUDES GREEN LEAF CREEK)
 5  = RIVER MILE  55.6 TO RIVER MILE 0.8 AT THE MOUTH (INCLUDES SNIDER CREEK)


RCK = INITIAL CONDITIONS AT ROSEBUD CREEK NEAR KIRBY

STREAMFLOW STATUS DURING SIMULATION
***********************************

JAN   = 1  FEB   = 1         1 = MEAN
MARCH = 1  APRIL = 1         2 = 50TH PERCENTILE
MAY   = 1  JUNE  = 1         3 = 25TH PERCENTILE
JULY  = 1  AUG   = 1         4 = 75TH PERCENTILE
SEPT  = 1  OCT   = 1         5 = MAXIMUM
NOV   = 1  DEC   = 1         6 = MINIMUM

IRRIGATED ACREAGE STATUS DURING SIMULATION
******************************************

REACH 1 =      0. REACH 2 =   120. REACH 3 =      0.
REACH 4 =      0. REACH 5 =  1662.
   NOTE - IRRIGATED ACRES IN REACH 1 ARE THOSE IN
   EXCESS OF PRESENTLY IRRIGATED ACRES (0 ACRES)

SURFACE COAL MINING STATUS DURING SIMULATION
********************************************

                 DISSOLVED SOLIDS                            DISSOLVED SOLIDS
REACH  ACREAGE  (MG/L) OF LEACHATE     REACH  ACREAGE  (MG/L) OF LEACHATE
-----  -------  ------------------     -----  -------  ------------------
  1       0.            0.               2       0.             0.
  3       0.            0.               4     2100.          3700.
  5       0.            0.

OTHER WATER LOSSES (ACRE-FEET PER YEAR) DURING SIMULATION
*********************************************************

REACH 1 =      0. REACH 2 =      0. REACH 3 =         0.
REACH 4 =      0. REACH 5 =      0.
```

Table 25.--*Example of model output*--Continued

SIMULATION RESULTS -- SIMULATION NUMBER 1

****

MONTH	REACH	STREAMFLOW (ACRE-FEET)	DISSOLVED SOLIDS LOAD (TONS)	DISSOLVED SOLIDS CONC (MG/L)	PERCENT CONCENTRATION DUE TO RETURN FLOW	PERCENT CONCENTRATION DUE TO MINING	CUMULATIVE PERCENT CONCENTRATION DUE TO RETURN FLOW	CUMULATIVE PERCENT CONCENTRATION DUE TO MINING
JAN	RCK	346.	287.	610.				
	1	346.	287.	610.	0.0	0.0	0.0	0.0
	2	910.	959.	775.	0.2496	0.0	0.2496	0.0
	3	1242.	1351.	800.	0.0	0.0	0.1600	0.0
	4	1078.	1404.	957.	0.0	0.6428	0.0519	0.6428
	5	1146.	1665.	1069.	2.0061	0.0	2.0003	0.5420
FEB	RCK	675.	530.	577.				
	1	675.	530.	577.	0.0	0.0	0.0	0.0
	2	1430.	1359.	699.	0.2053	0.0	0.2053	0.0
	3	1862.	1873.	739.	0.0	0.0	0.1315	0.0
	4	1751.	2013.	845.	0.0	0.4483	0.0803	0.4483
	5	2197.	3203.	1072.	0.7278	0.0	0.7235	0.2817
MAR	RCK	1399.	1046.	550.				
	1	1399.	1046.	550.	0.0	0.0	0.0	0.0
	2	2672.	2324.	640.	0.1160	0.0	0.1160	0.0
	3	3308.	3050.	678.	0.0	0.0	0.0803	0.0
	4	3257.	3328.	751.	0.0	0.2712	0.0597	0.2712
	5	4102.	5441.	975.	0.1098	0.0	0.1201	0.1658
APR	RCK	2390.	1706.	525.				
	1	2390.	1706.	525.	0.0	0.0	0.0	0.0
	2	4270.	3571.	615.	0.0452	0.0	0.0452	0.0
	3	5085.	4554.	659.	0.0	0.0	0.0322	0.0
	4	5061.	4961.	721.	0.0	0.1819	0.0253	0.1819
	5	5409.	6399.	870.	2.1738	0.0	2.1860	0.1410
MAY	RCK	2027.	1470.	533.				
	1	2027.	1470.	533.	0.0	0.0	0.0	0.0
	2	3432.	3021.	647.	0.3579	0.0	0.3579	0.0
	3	4375.	4246.	714.	0.0	0.0	0.2990	0.0
	4	4262.	4628.	798.	0.0	0.1950	0.3258	0.1950
	5	4331.	5814.	987.	3.5412	0.0	3.8548	0.1552
JUNE	RCK	1540.	1139.	544.				
	1	1540.	1139.	544.	0.0	0.0	0.0	0.0
	2	2900.	2666.	676.	0.6150	0.0	0.6150	0.0
	3	3720.	3768.	745.	0.0	0.0	0.5117	0.0
	4	3591.	4142.	848.	0.0	0.2178	0.5689	0.2178
	5	3385.	5260.	1143.	8.9184	0.0	9.4324	0.1716

Table 25.--*Example of model output*--Continued

SIMULATION RESULTS -- SIMULATION NUMBER 1

****

MONTH	REACH	STREAMFLOW (ACRE-FEET)	DISSOLVED SOLIDS LOAD (TONS)	DISSOLVED SOLIDS CONC (MG/L)	PERCENT CONCENTRATION DUE TO RETURN FLOW	PERCENT CONCENTRATION DUE TO MINING	CUMULATION PRECENT CONCENTRATION DUE TO RETURN FLOW	CUMULATION PRECENT CONCENTRATION DUE TO MINING
JULY	RCK	816.	636.	573.				
	1	816.	636.	573.	0.0	0.0	0.0	0.0
	2	1444.	1555.	792.	2.3282	0.0	2.3282	0.0
	3	1879.	2227.	871.	0.0	0.0	1.8987	0.0
	4	1629.	2402.	1085.	0.0	0.3756	2.3932	0.3756
	5	1446.	2870.	1459.	5.3391	0.0	7.9109	0.3144
AUG	RCK	456.	371.	598.				
	1	456.	371.	598.	0.0	0.0	0.0	0.0
	2	885.	1079.	896.	3.2666	0.0	3.2666	0.0
	3	1124.	1491.	975.	0.0	0.0	2.6850	0.0
	4	854.	1559.	1343.	0.0	0.5789	3.8448	0.5789
	5	712.	1764.	1821.	-1.1536	0.0	4.0870	0.5116
SEPT	RCK	391.	321.	604.				
	1	391.	321.	604.	0.0	0.0	0.0	0.0
	2	831.	970.	858.	1.5969	0.0	1.5969	0.0
	3	1029.	1283.	917.	0.0	0.0	1.2980	0.0
	4	797.	1327.	1224.	0.0	0.6797	1.6853	0.6797
	5	741.	1560.	1549.	-0.1238	0.0	1.8219	0.5784
OCT	RCK	361.	299.	609.				
	1	361.	299.	609.	0.0	0.0	0.0	0.0
	2	967.	1023.	778.	0.2314	0.0	0.2314	0.0
	3	1219.	1333.	804.	0.0	0.0	0.1597	0.0
	4	1041.	1380.	975.	0.0	0.6537	0.0412	0.6537
	5	1092.	1639.	1104.	1.6814	0.0	1.6534	0.5504
NOV	RCK	395.	324.	603.				
	1	395.	324.	603.	0.0	0.0	0.0	0.0
	2	979.	1014.	762.	0.2485	0.0	0.2485	0.0
	3	1253.	1341.	787.	0.0	0.0	0.1702	0.0
	4	1089.	1390.	939.	0.0	0.6490	0.0648	0.6490
	5	1170.	1688.	1060.	1.7993	0.0	1.7972	0.5347
DEC	RCK	291.	245.	618.				
	1	291.	245.	618.	0.0	0.0	0.0	0.0
	2	779.	879.	830.	0.2160	0.0	0.2160	0.0
	3	965.	1126.	858.	0.0	0.0	0.1457	0.0
	4	770.	1155.	1104.	0.0	0.7811	-0.0524	0.7811
	5	797.	1382.	1275.	1.1941	0.0	1.0375	0.6529

Table 25.--*Example of model output*--Continued

SIMULATION SUMMARY -- SIMULATION NUMBER 1
****

MONTH	STREAMFLOW (ACRE-FEET) ROSEBUD CR KIRBY	STREAMFLOW (ACRE-FEET) RSBD CR ROSEBUD	DISSOLVED SOLIDS ROSEBUD CR NEAR KIRBY LOAD(TON)	DISSOLVED SOLIDS ROSEBUD CR NEAR KIRBY CONC(MG/L)	DISSOLVED SOLIDS ROSEBUD CR NR ROSEBUD LOAD(TON)	DISSOLVED SOLIDS ROSEBUD CR NR ROSEBUD CONC(MG/L)
JAN	346.	1146.	287.	610.	1665.	1069.
FEB	675.	2197.	530.	577.	3203.	1072.
MAR	1399.	4102.	1046.	550.	5441.	975.
APR	2390.	5409.	1706.	525.	6399.	870.
MAY	2027.	4331.	1470.	533.	5814.	987.
JUNE	1540.	3385.	1139.	544.	5260.	1143.
JULY	816.	1446.	636.	573.	2870.	1459.
AUG	456.	712.	371.	598.	1764.	1821.
SEPT	391.	741.	321.	604.	1560.	1549.
OCT	361.	1092.	299.	609.	1639.	1104.
NOV	395.	1170.	324.	603.	1688.	1060.
DEC	291.	797.	245.	618.	1382.	1275.

REACH	MONTHLY DISSOLVED SOLIDS CONC (MG/L) MEAN	STD DEV	MIN	MAX	MEAN PERCENT CONCENTRATION DUE TO RETURN FLOW	MEAN PERCENT CONCENTRATION DUE TO MINING	MEAN CUMULATIVE PERCENT CONCENTRATION DUE TO RETURN FLOW	MEAN CUMULATIVE PERCENT CONCENTRATION DUE TO MINING
1	579.	33.	525.	618.	0.0	0.0	0.0	0.0
2	747.	91.	615.	896.	0.7897	0.0	0.7897	0.0
3	796.	96.	659.	975.	0.0	0.0	0.6310	0.0
4	966.	192.	721.	1343.	0.0	0.4729	0.7574	0.4729
5	1199.	278.	870.	1821.	2.1845	0.0	3.0521	0.3833

NOTE -- MEAN AND CUMULATIVE PERCENT VALUES DERIVED FROM 12 MONTHLY VALUES