SIMULATED EFFECTS OF SURFACE COAL MINING AND AGRICULTURE ON DISSOLVED SOLIDS IN THE REDWATER RIVER, EAST-CENTRAL MONTANA

By Rodger F. Ferreira and John H. Lambing

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4180

Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

Helena, Montana
September 1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S Geological Survey
428 Federal Building
301 South Park, Drawer 10076
Helena, MT 59626-0076

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225-0425

CONTENTS

ILLUSTRATIONS

TABLES

Page

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 mile per day	766.3	cubic meter per kilometer per day
cubic foot per second (ft^3/s)	28.32	liter per second
foot	0.3048	meter
inch	25.40	millimeter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram
ton per day (ton/d)	0.9072	megagram per day
ton per acre	0.0002241	megagram per square meter

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

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

SIMULATED EFFECTS OF SURFACE COAL MINING AND AGRICULTURE ON DISSOLVED SOLIDS IN THE REDWATER RIVER, EAST-CENTRAL MONTANA

By

Rodger F. Ferreira and John H. Lambing

ABSTRACT

Dissolved-solids concentrations in five reaches of the Redwater River in east-central Montana were simulated to assist in evaluating the effects of surface coal mining and agriculture on dissolved-solids concentrations. A mass-balance model of streamflow and dissolved-solids load developed for the Tongue River in southeastern Montana was modified and applied to the Redwater River. The model is designed so that 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 in consecutive reaches of a river.

Because of the limited amount and extreme variability of available data, the model was not conclusively validated, as indicated by comparison of simulated streamflow to streamflow calculated from records for the Redwater River near Vida. Thus, this modeling effort is considered to be an exploratory assessment that indicates where additional data collection would be beneficial. Simulated mean and median monthly mean streamflows are consistently larger than those calculated from streamflow records. Similarly, simulated mean and median monthly mean dissolved-solids loads are consistently larger than streamflow regression-derived values calculated for the Redwater River near Vida. These discrepancies probably result from extremely variable streamflow of the Redwater River at Circle, overestimates of streamflow from ungaged tributaries to the Redwater River, and weak correlations between streamflow and dissolved-solids concentrations that were developed for use in the model.

Under conditions of no mining, the mean percentage of simulated dissolved-solids concentration resulting from agriculture was larger in reach 2 (1.1 percent) than in reach 5 (0.3 percent). The largest increase in simulated dissolved-solids concentration as a result of mining occurs in reach 2 when both mining tracts are developed concurrently. The largest increases in simulated dissolved-solids concentration from mining and agriculture occur from September through January because of smaller streamflows and dissolved-solids loads existing in the Redwater River. Different combinations of agriculture and mining under mean flow conditions resulted in cumulative increases of dissolved-solids concentrations in each reach that are less than 5 percent for mining and less than 2 percent for agriculture.

INTRODUCTION

Interest has been expressed in developing the extensive coal resources in the western United States to help meet demand for domestically produced energy. Depending on the course of development, the Fort Union coal region (fig. 1) could be one of the larger coal producing areas in the country (Woessner and others, 1979; U.S. Department of Energy, 1978). 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; U.S. Geological Survey, 1974).

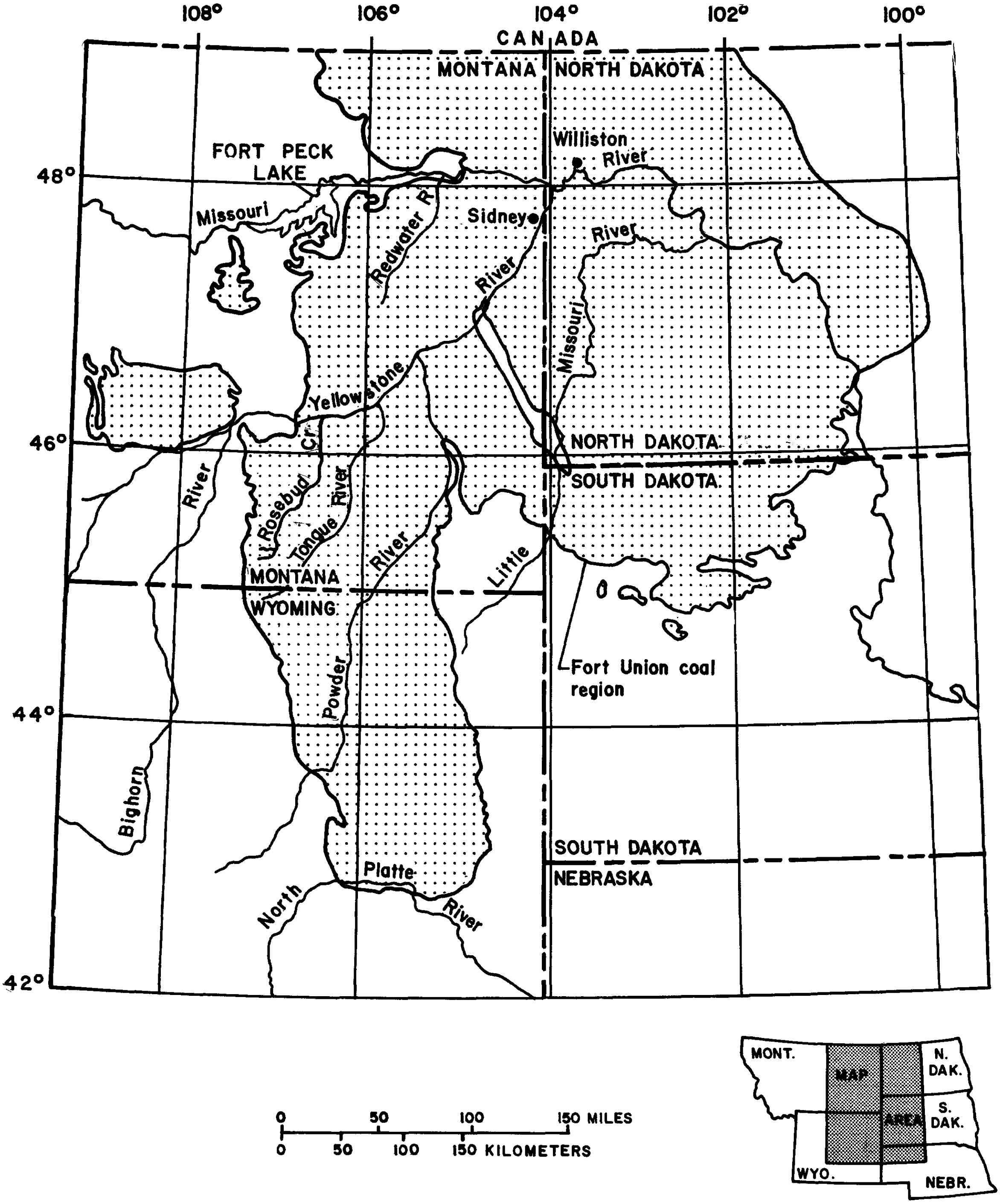

Figure 1.--Location of Fort Union coal region. Modified from Northern Great Plains Resource Program, Water Work Group-Ground Water Subgroup (1974).

Several studies have indicated that water in mine spoils of eastern 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. Thus, 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.

In addition to the change in dissolved-solids concentration created by surface coal mining, agricultural use of water has been shown to be responsible for varying degrees of change in the quality and quantity of water (Bondurant, 1971). Water loss through evapotranspiration can be a major factor that increases dissolved-solids concentrations in water that has been used for irrigation. In addition, residues of applied fertilizers can be leached from the soil and transported with irrigation return flow to the receiving stream.

Surface water is an important source of water for agriculture in eastern Montana. Dissolved-solids concentrations ranging from 500 to 1,000 mg/L (milligrams per liter) can have detrimental effects on sensitive crops (U.S. Environmental Protection Agency, 1978). Generally, 3,150 mg/L is near 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 east-central Montana is that dissolved-solids loads from mine spoils will increase dissolved-solids concentrations to detrimental levels.

In an effort to evaluate the potential effects of surface coal 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 dissolved solids 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 Tongue River model was modified to enable simulations of dissolved-solids concentrations in the Redwater River of east-central Montana. However, because less data are available for the Redwater River compared to the Tongue River, more estimation is required, thus weakening the results somewhat.

The purpose of this report is to describe the model approach and results of simulations of dissolved-solids concentrations in the Redwater River with varied acreages of surface coal mining and agriculture. Because of the paucity of data for the Redwater drainage, the modeling effort is considered to be an exploratory assessment that indicates areas where additional data collection would be beneficial.

This report discusses model development, describes the sources of data, lists the FORTRAN program, and provides instructions for entering input data to the dissolved-solids model of the Redwater River. Model input data are similar to input data for the Tongue River model. These data incorporate the best available single estimates for the Redwater River drainage. Model output is discussed for present conditions of agricultural development and comparisons are made between model output and historical streamflow and dissolved-solids concentrations that occur near the mouth of the Redwater River near Vida, Montana. Discussion also is included of output for model simulations with partial development and full development of surface coal mining.

STUDY AREA

The Redwater River is the major north-flowing tributary to the Missouri River between Fort Peck Lake and the Yellowstone River (fig. 1). The Redwater River originates in the Big Sheep Mountains about 15 miles south of Brockway, Montana (fig. 2). From Brockway, the river flows about 130 miles north to its confluence with the Missouri River. The total drainage area of the Redwater River is 2,113 mi^2.

Land-surface altitudes in the Redwater River drainage range from 3,625 to 2,000 feet above sea level. The drainage consists of long gentle slopes and rolling grasslands that are moderately incised in the central reaches. Near the mouth, the river channel is 10 to 20 feet deep and about 60 feet wide.

The river alluvium and soils in the drainage, south of the North Fork and South Fork of Lisk Creek near Vida, overlie the Tongue River Member of the Fort Union Formation (Paleocene). Downstream from Lisk Creek, the alluvium and soils overlie the Lebo and Tullock Members of the Fort Union Formation. Near the mouth, the Redwater River intercepts the Upper Cretaceous Hell Creek Formation, Fox Hills Sandstone, and Bearpaw Shale. Detailed hydrogeology of the Redwater River drainage area is described by Slagle (1983), Roberts (1980), Stoner and Lewis (1980), and Collier and Knechtel (1939).

The climate is semiarid continental. Minimum winter temperatures of about -30°F may occur; January normally is the coldest month with a mean daily temperature of 12.9°F. Maximum summer temperatures in excess of 100°F are common. July is generally the warmest month, with a mean daily temperature of 71.1°F. Mean annual temperature for the study area is 44.1°F (U.S. Department of Commerce, issued annually). Most precipitation occurs in late spring and early summer in response to dominating Pacific or Gulf Coast frontal systems. June is normally the wettest month, with a mean precipitation of about 3 inches. Mean annual precipitation ranges from 11 to 15 inches throughout the study area (U.S. Department of Commerce, issued annually). Seasonal snowfall varies from 30 to 50 inches, but seldom accumulates owing to frequent thaws caused by "chinook" winds. Localized thunderstorms commonly cause intense rainfall of short duration during the summer and autumn.

The Redwater River is generally perennial near the mouth and intermittent in the middle and upstream reaches, with the largest sustained volume of streamflow generally occurring during snowmelt in March. Large streamflows may also occur in February or April in response to early or late snowmelts. Small streamflow peaks occur during the summer in response to local rainstorms, and minimum streamflows generally occur from August to January. At the Redwater River at Circle (station 06177500), from 1929 to 1982, the maximum mean monthly streamflow was 84.8 ft^3/s in March and the minimum mean monthly streamflow was 0.24 ft^3/s in November and January. At the Redwater River near Vida (station 06177825), from 1976 to 1982, the maximum mean monthly streamflow was 177 ft^3/s in April, mainly as a result of runoff extremes in 1979. The minimum mean monthly streamflow at the Redwater River near Vida from 1976 to 1982 was 1.8 ft^3/s in January. During some years the river has periods of no flow.

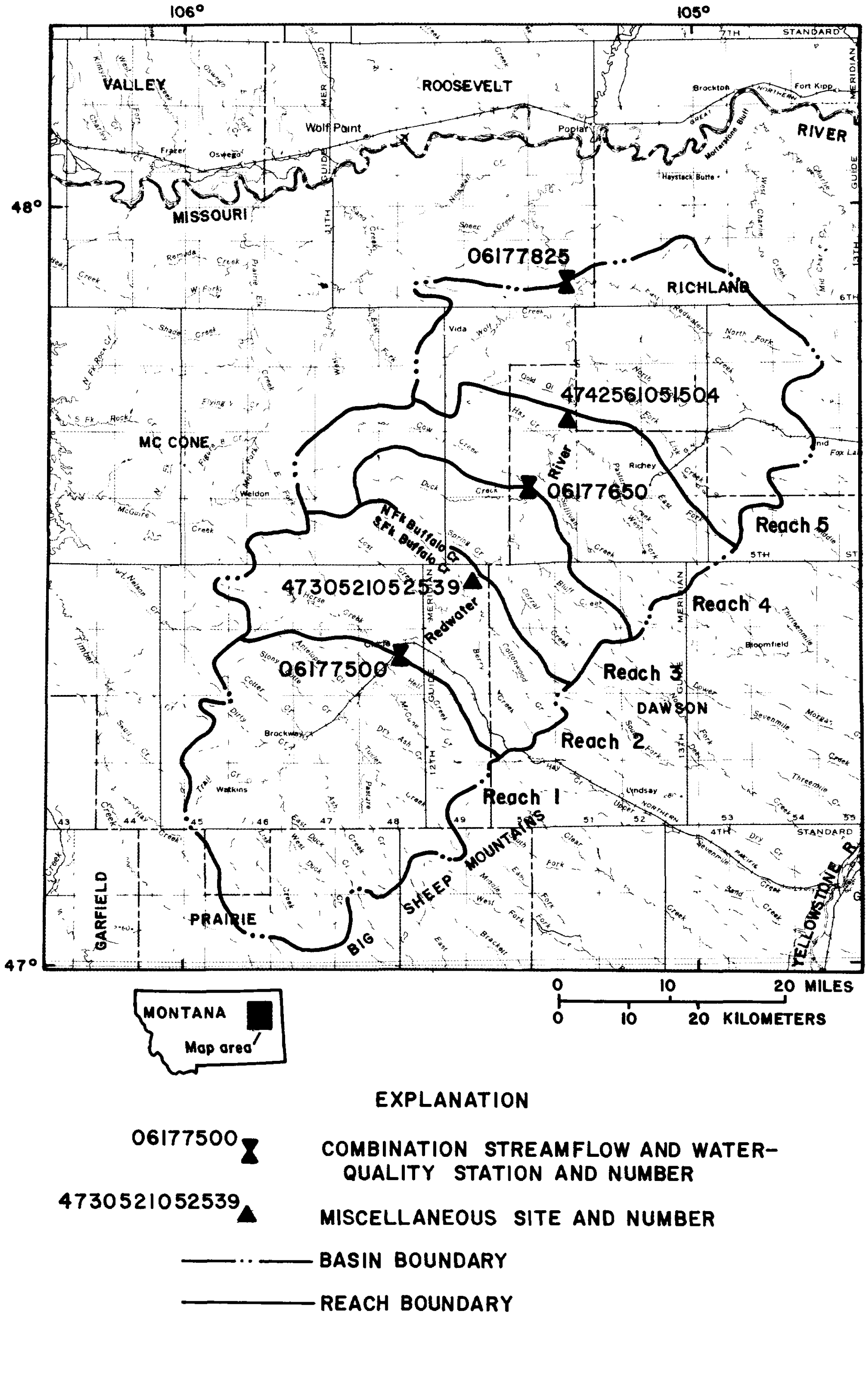

Figure 2.--Location of the Redwater River and five reaches simulated in the model.

The Redwater River is characterized by sodium sulfate water (McKinley, 1979), with the largest dissolved-solids concentrations occurring during low flow. Measured dissolved sodium concentrations in the Redwater River at Circle ranged from 23 to 1,100 mg/L from 1975 to 1981; near Vida they ranged from 49 to 900 mg/L from

1976 to 1981 (Lambing, 1983). During these periods, dissolved sulfate concentrations ranged from 91 to 2,700 mg/L at Circle and from 110 to 1,800 mg/L near Vida. Mean dissolved-solids concentrations were 2,840 mg/L at Circle and 2,160 mg/L near Vida (Lambing, 1983).

The large dissolved-solids concentrations in the Redwater River result in a high salinity hazard for use of the water in agriculture (McKinley, 1979). Although the Redwater River is mainly used for irrigation and stockwatering, irrigation is limited to periods when streamflow consists primarily of direct runoff. Generally, the water is suitable for stock consumption; however, dissolved-solids concentrations are greater than the maximum concentration of 500 mg/L (milligrams per liter) recommended by the U.S. Environmental Protection Agency (1979) for human consumption.

MODEL DESCRIPTION

The dissolved-solids model calculates a monthly mass-balance routing of streamflow and dissolved-solids load down the main stem of the Redwater River. The model divides the Redwater River into five reaches (fig. 2). A description of the stations at the downstream end of each reach is given in table 1. The model variables are listed and defined in table 28 (Supplemental Information section at back of report). The model, formulated in a FORTRAN computer program (table 29, Supplemental Information at back of report), adapts many of the theoretical aspects used in the Tongue River model (Woods, 1981).

Initial streamflow and dissolved-solids concentrations are input internally in the model at the downstream end of reach 1. These values incorporate input of dissolved solids from mining and water losses from irrigation based on acreages currently devoted to these two activities in reach 1. Simulation of mined or irrigated acres in excess of what presently exists in the drainage of reach 1 will cause a change in the initial input values of streamflow or dissolved-solids concentration. 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 summed algebraically. The model time-step is monthly and each simulation is for 1 calendar year (fig. 3). In the model, travel of streamflow and dissolved solids within each reach and from the headwaters to the mouth is instantaneous for each month.

Table 1.--*Description of stations at the downstream end of each simulated reach of the Redwater River*

[Number in parentheses is formal Geological Survey station number (06177500) or station number based on latitude and longitude (4730521052539)]

REACH 1

Station[1]: Redwater River at Circle, Mont. (06177500)
River mile[2]: 110.2
Reach drainage area: 547 square miles
Reach length: 50.4 miles

REACH 2

Station: Redwater River below Buffalo Creek, near Circle, Mont. (4730521052539)
River mile: 90.8
Reach drainage area: 335 square miles
Reach length: 19.4 miles

REACH 3

Station: Redwater River near Richey, Mont. (06177650)
River mile: 69.5
Reach drainage area: 189 square miles
Reach length: 21.3 miles

REACH 4

Station: Redwater River below Pasture Creek, near Richey, Mont. (4742561051504)
River mile: 57.2
Reach drainage area: 346 square miles
Reach length: 12.3 miles

REACH 5

Station: Redwater River near Vida, Mont. (06177825)
River mile: 30.6
Reach drainage area: 557 square miles
Reach length: 26.6 miles

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

[2] River mileage obtained from Montana Department of Natural Resources and Conservation (1979).

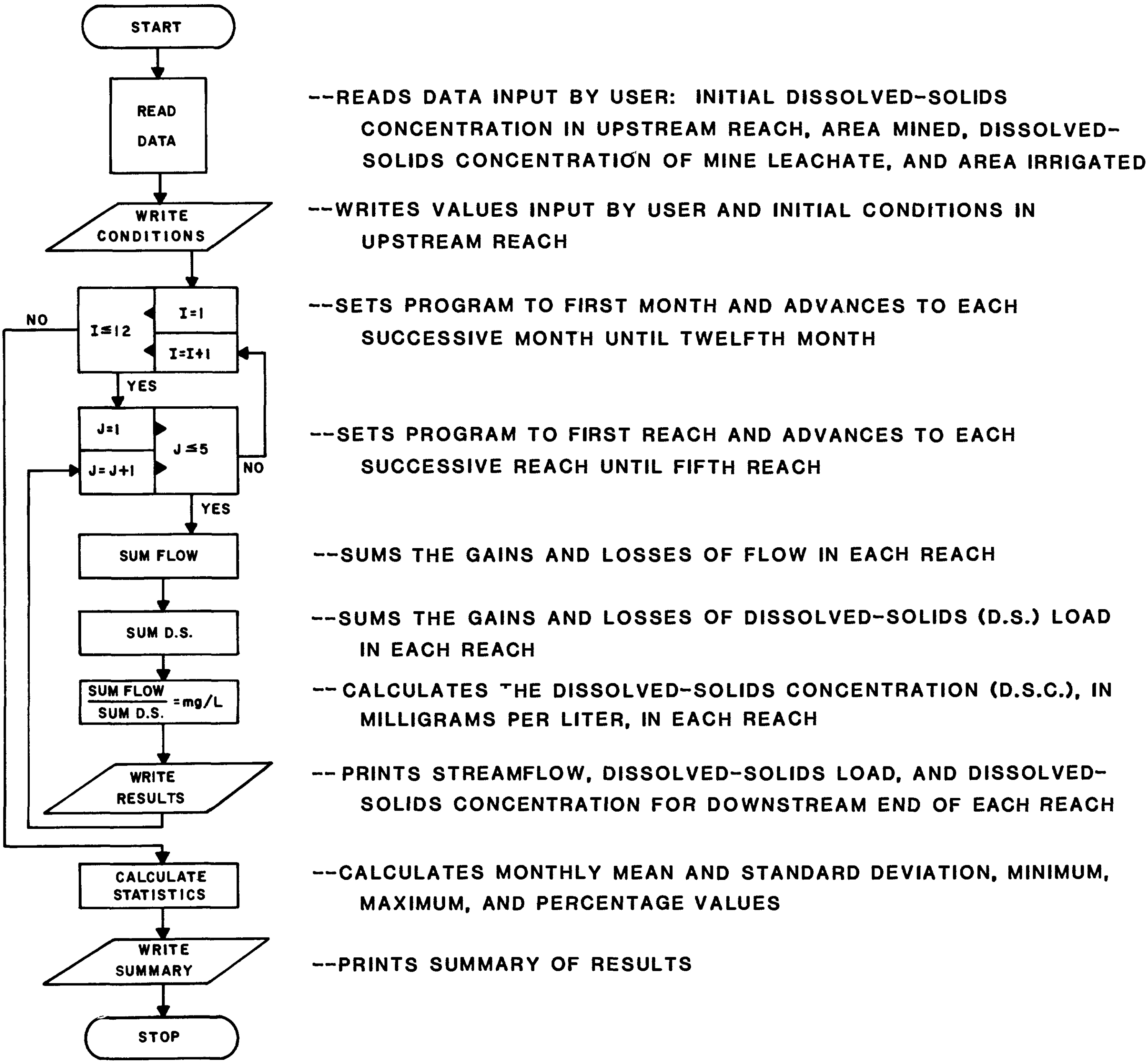

Figure 3.--Simplified flow chart of model for calculating monthly dissolved-solids concentration in five reaches of the Redwater River.

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

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

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:

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

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 carried by 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 carried by irrigation return 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:

$$DSC_{OUT} = \frac{DSL_{OUT}}{Q_{OUT} \times f} \quad (3)$$

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.

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 as block data in the model.

Hydrologic components

The model simulates dissolved-solids concentrations for six discrete hydrologic flow conditions: mean, median (50th percentile), 25th percentile, 75th percentile, historic maximum, and historic minimum. Any 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

Estimated initial streamflow for the six modeled hydrologic conditions of the Redwater River at Circle (station 06177500) were obtained from U.S. Geological Survey streamflow records from 1929 to 1982 (U.S. Geological Survey, issued annually). However, streamflow data for the Redwater River near Richey (station 06177650) and near Vida (station 06177825) are not extensive. Streamflow records for the Redwater River near Richey are available for May to September 1982; streamflow records for the Redwater River near Vida are available for October 1975 to September 1982. 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. Because most of the water-quality and streamflow data obtained from other stations is based on fewer than 20 samples, percentiles, in addition to the mean, are used to specify hydrologic conditions of streamflow in the model. Initial streamflow values for the downstream end of reach 1 (Redwater River at Circle) are presented in table 2 for each of the six hydrologic flow conditions specified in the model.

Table 2.--*Gage-based streamflow for six modeled hydrologic flow conditions of the Redwater River at Circle, Montana*

[based on period of record from 1929 to 1982]

Hydrologic flow condition	Streamflow, in acre-feet per month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	15	983	5,210	1,330	247	958	849	150	24	14	14	23
Median	2.5	26	1,780	211	98	164	17	3.7	4.2	7.4	6.6	4.9
25th percentile.	.0	.56	282	67	38	36	3.7	.61	.0	1.2	1.2	.0
75th percentile.	8.6	605	6,830	613	295	1,190	478	62	15	14.8	13	12
Maximum	377	7,830	23,900	24,900	1,970	9,940	7,130	2,280	331	166	161	528
Minimum [1]	.0	.0	3.1	4.2	1.2	.0	.0	.0	.0	.0	.0	.0

[1] 0.0 values are 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 the Redwater River 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

Table 3.--*Runoff coefficients for six modeled hydrologic conditions for ungaged tributary streamflow in four reaches of the Redwater River*

Hydrologic condition	Runoff coefficient, in acre-feet per acre per month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
						Redwater River reach 2						
Mean	0.00009	0.00670	0.03209	0.00842	0.00151	0.00609	0.00521	0.00092	0.00015	0.00009	0.00009	0.00014
Median	.00002	.00020	.01091	.00135	.00060	.00104	.00010	.00002	.00003	.00005	.00004	.00003
25th percentile.	.00000	.00001	.00160	.00042	.00023	.00024	.00002	.00000	.00000	.00001	.00001	.00000
75th percentile.	.00005	.00415	.04204	.00387	.00180	.00755	.00292	.00038	.00009	.00009	.00008	.00008
Maximum	.00230	.05340	.14697	.15779	.01205	.06315	.04382	.01395	.00203	.00106	.00101	.00325
Minimum	.00000	.00000	.00003	.00003	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000
						Redwater River reach 3						
Mean	.00016	.00840	.02537	.01365	.00284	.00636	.00620	.00116	.00049	.00035	.00037	.00030
Median	.00009	.00025	.01218	.00246	.00116	.00204	.00043	.00036	.00014	.00023	.00026	.00018
25th percentile.	.00001	.00008	.00203	.00096	.00051	.00045	.00006	.00005	.00004	.00011	.00011	.00009
75th percentile.	.00020	.01033	.03526	.00683	.00383	.01068	.01054	.00089	.00036	.00042	.00043	.00029
Maximum	.00224	.05418	.10402	.17185	.01724	.04357	.03732	.01133	.00449	.00250	.00244	.00377
Minimum	.00000	.00000	.00076	.00027	.00011	.00013	.00003	.00000	.00003	.00005	.00006	.00002
						Redwater River reach 4						
Mean	.00015	.00783	.02363	.01272	.00264	.00592	.00577	.00108	.00045	.00033	.00034	.00028
Median	.00008	.00023	.01134	.00229	.00108	.00189	.00040	.00033	.00013	.00021	.00023	.00017
25th percentile.	.00001	.00008	.00189	.00089	.00048	.00041	.00006	.00004	.00004	.00010	.00011	.00008
75th percentile.	.00019	.00963	.03285	.00636	.00356	.00995	.00981	.00083	.00033	.00039	.00039	.00027
Maximum	.00210	.05050	.09688	.16014	.01602	.04055	.03474	.01055	.00412	.00236	.00224	.00351
Minimum	.00000	.00000	.00071	.00025	.00011	.00012	.00003	.00000	.00003	.00005	.00006	.00001
						Redwater River reach 5						
Mean	.00017	.00792	.01353	.01504	.00333	.00510	.00560	.00108	.00066	.00050	.00052	.00037
Median	.00016	.00024	.00825	.00286	.00140	.00240	.00067	.00064	.00026	.00039	.00048	.00036
25th percentile.	.00003	.00016	.00149	.00135	.00067	.00051	.00006	.00009	.00012	.00026	.00028	.00022
75th percentile.	.00033	.01449	.01975	.00797	.00503	.01076	.01590	.00121	.00055	.00067	.00073	.00052
Maximum	.00041	.03897	.04884	.09686	.01382	.01698	.02027	.00473	.00314	.00128	.00100	.00071
Minimum	.00000	.00000	.00081	.00060	.00027	.00020	.00006	.00000	.00009	.00014	.00017	.00004

tributaries in reach 1 is embodied in the initial streamflow conditions at the downstream end of the reach (Redwater River at Circle). Tributary streams and mean annual streamflow estimates used for estimating runoff coefficients for reaches 2 through 5 are listed in table 4.

No continuous streamflow records are available for tributaries in reaches 2 through 5. Mean annual streamflow estimates for tributaries in each reach were based on channel geometry, obtained from Robert J. Omang (U.S. Geological Survey, written commun., 1983). The regression equation for estimating mean annual streamflow of ephemeral and intermittent streams has a standard error of 58 percent (Omang and others, 1983). As the best available estimate for each reach, runoff coefficients representing the "mean" hydrologic condition were obtained by calculating a drainage-area-weighted mean of the tributary mean annual streamflows and partitioning the mean among the 12 months in proportion to the gage-based mean monthly streamflows at the Redwater River at Circle and near Vida. Runoff coefficients for reach 2 were based on proportional streamflows at Circle, for reach 5 they were based on proportional streamflows at Vida, and for reaches 3 and 4 they were based on proportional streamflows averaged between Circle and Vida. Runoff coefficients for hydrologic conditions other than the mean for each month were estimated from the same percentage of the mean monthly streamflow that occurs at Redwater River at Circle and near Vida. Because streamflow data do not exist for tributaries of the Redwater River, the validity of these estimates cannot be determined until continuous streamflow stations are established in the drainage.

Table 4.--*Drainage area and mean annual streamflow estimates of tributaries used for calculating runoff coefficients for four reaches of the Redwater River*

Redwater River reach No.	Tributary stream	Drainage area (square miles)	Estimated mean annual flow (acre-feet)
2	Corral Creek	36.4	3,210
	Duck Creek	54.0	1,710
	Horse Creek	104	2,730
3	Corral Creek	36.4	3,210
	Cow Creek	117	4,870
	Horse Creek	104	2,730
4	Corral Creek	36.4	3,210
	Cow Creek	117	4,870
	East Redwater Creek	268	8,410
5	Cow Creek	117	4,870
	East Redwater Creek	268	8,410

Precipitation and evaporation

In the model, precipitation and evaporation are applied only to the stream surface area of the Redwater River. Stream surface area is utilized because the effects of precipitation and evaporation in the rest of the drainage are embodied in the runoff coefficients for each reach.

Estimates for precipitation were obtained from weather stations at Circle and Vida. Data for 1929-81 for both stations were averaged to give the same values for all the reaches of the Redwater River (table 5). These years coincide with the period of time used to calculate the hydrologic flow conditions for the Redwater River at Circle.

Table 5.--*Estimated precipitation on the surface of the Redwater River for six modeled hydrologic flow conditions*

Hydrologic flow condition	Precipitation,[1] in acre-feet per acre per month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	0.048	0.036	0.052	0.104	0.158	0.261	0.157	0.109	0.096	0.065	0.041	0.041
Median	.038	.028	.043	.080	.135	.247	.134	.093	.055	.049	.035	.038
25th percentile.	.020	.016	.028	.049	.076	.144	.085	.039	.036	.024	.017	.018
75th percentile.	.074	.048	.065	.140	.198	.331	.219	.161	.128	.097	.060	.057
Maximum	.163	.136	.128	.361	.567	.576	.460	.383	.384	.282	.115	.169
Minimum	.005	.002	.005	.004	.015	.036	.015	.002	.003	.000	.001	.003

[1] Calculated from precipitation data collected from 1929 to 1981.

Evaporation data for various modeled hydrologic conditions were calculated from records collected at Sidney, Mont. (fig. 1), from 1957 to 1981 (U.S. Department of Commerce, issued annually). This is the closest weather station to the Redwater River drainage that has evaporation data. Data were not available for November through March at Sidney; therefore, estimates for these months were obtained from data for Williston, N. Dak., which is the next closest weather station (Farnsworth and Thompson, 1982).

Evaporation data were collected with a National Weather Service class A pan. A coefficient commonly is used to convert evaporation from a class A pan to evaporation from a free-water surface, such as a lake (Winter, 1981). For the Redwater River drainage, a coefficient of 0.72 was applied to the pan evaporation data to convert the values to evaporation from a free-water surface (Farnsworth and Thompson, 1982). These values were then multiplied by a factor of 1.08 to obtain values of evaporation from a flowing free-water surface in table 6 (Sleight, 1917).

Depending on the amount of flow in the Redwater River, the water surface area, which is affected by precipitation and evaporation, will vary. Average widths of the stream for each month were based on measured active-channel widths of the Redwater River at the downstream ends of reaches 1, 3, and 5. Active-channel widths for the downstream ends of reaches 2 and 3 were estimated by distance weighting the measured values. Assuming that these active-channel widths represented widths during maximum mean monthly flow, active-channel widths for other months were proportioned, for lack of other data, according to the ratio of mean monthly flow to maximum monthly flow that occurs at the Redwater River at Circle and near Vida. Estimated channel widths were multiplied by the reach lengths to obtain estimated stream surface areas for each reach (table 7).

Table 6.--*Estimated evaporation from the surface of the Redwater River for six modeled hydrologic flow conditions*

Hydrologic flow condition	Evaporation[1], in acre-feet per acre per month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	0.0	0.065	0.099	0.269	0.406	0.436	0.492	0.420	0.247	0.162	0.065	0.065
Median	.0	.059	.091	.246	.414	.444	.487	.427	.230	.153	.062	.062
25th percentile.	.0	.079	.121	.328	.465	.471	.534	.471	.294	.198	.079	.079
75th percentile.	.0	.054	.082	.222	.330	.406	.437	.365	.201	.114	.046	.046
Maximum	.0	.048	.073	.198	.248	.311	.364	.274	.134	.068	.027	.027
Minimum	.0	.082	.125	.338	.567	.610	.626	.558	.402	.296	.119	.119

[1]Calculated from evaporation data collected from 1957 to 1981.

Transpiration

Transpiration from riparian vegetation along the main stem of the Redwater River is modeled as a loss of water in each reach. Effects of transpiration from vegetation in the ungaged tributaries of the Redwater River are embodied in the runoff coefficients for each reach or accounted for as water losses by irrigation.

Table 7.--*Estimated water-surface area for each reach of the Redwater River*

Reach	Stream surface area, in acres											
Number	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2	0.2	14.7	70.5	18.6	3.3	13.4	11.5	2.0	0.4	0.2	0.2	0.3
3	.7	35.6	92.0	61.2	13.0	25.7	25.9	4.9	2.3	1.7	1.8	1.5
4	.7	34.3	58.5	65.1	14.4	22.1	24.2	4.7	2.8	2.1	2.2	1.6
5	2.0	96.9	165.2	183.8	40.6	62.3	68.4	13.2	7.9	6.1	6.2	4.6

Because actual measurements of transpiration are not available for riparian vegetation along the Redwater River, potential evapotranspiration values are used as a best estimate. Free-water-surface evaporation is approximately equal to potential evapotranspiration (Cruff and Thompson, 1967); therefore, the coefficient of 0.72, which was used with pan evaporation to calculate free-water-surface evaporation, is also used to calculate transpiration. In the model, the area on each bank affected by transpiration is assumed to be equal to the surface area of the Redwater River. The area affected approximately equals the area 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 streamflow decreases and during breakup streamflow generally increases. On the Redwater River, ice generally forms in December, with melting and breakup occurring in February or March (John J. French, U.S. Geological Survey, oral commun., 1983). Between these times, the volume of water stored as ice changes with ambient 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 observed during streamflow measurements. Maximum depths of ice in pools can vary from 2 to 3 feet in contrast to riffle areas, which often contain no ice (John J. French, oral commun., 1983). An overall mean ice depth for the Redwater River model is estimated to be 0.5 foot (J. Roger Knapton, U.S. Geological Survey, oral commun., 1982). Assumptions used in the model are that complete ice formation with a depth of 0.5 foot occurs in December, is maintained throughout the winter, and breaks up in March.

Irrigation withdrawal and return flow

Estimates of the volume of water withdrawn from the Redwater River, acreage irrigated, and frequency of irrigation were obtained from ranchers in the study area and from records filed at the Montana Department of Natural Resources and Conservation. Irrigation water use, as described by 10 known users, depends mainly on flow conditions. Irrigation consists primarily of pump diversion and overbank flooding.

Overbank flooding used for irrigation is virtually uncontrolled by the irrigator and is not given any particular treatment in the model. Any effect 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.

Pump diversion generally consists of withdrawing as much water as possible with a 16-in. pump during spring snowmelt, or whenever streamflows in the Redwater River are large. Pump diversion can occur from February through June (table 8).

Table 8.--*Estimated monthly rates of irrigation withdrawal used in the model*

Month	Withdrawal[1], in acre-feet per acre, for indicated reach				
	Reach 1	2	3	4	5
Jan	0.0	0.0	0.0	0.0	0.0
Feb	.04	0	0	0	0
Mar	.16	.24	0	0	0
Apr	.43	0	0	0	0
May	.14	0	0	0	.67
June	.06	.24	0	0	.33
July-Dec	0	0	0	0	0

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

Frozen soil conditions during winter withdrawals can result in standing water on the fields. However, this practice is necessary to avoid water with large dissolved-solids concentrations that occurs in late spring and summer. Some irrigators pump water from spring runoff into a holding reservoir for later distribution.

Because of the lack of suitable water, the amount of acreage irrigated is limited. Major crops presently irrigated are alfalfa, hay, and oats. However, only reaches 1, 2, and 5 are irrigated with water from the Redwater River. Because of varying crop needs and streamflow conditions, different combinations of plots may be irrigated at any given time. This situation results in less than the total available acreage in each reach being simultaneously irrigated. However, the irrigation rate for each month is calculated for the model by dividing the estimated total volume of water diverted by the total available irrigated acreage in each reach. If water is available during years of low streamflow, the amount of water diverted for irrigation is assumed to equal 50 percent of the amount diverted during years of normal streamflow. Because data describing the amount of actual irrigation do not exist, these values are not verifiable, and could have large errors.

Because water is not diverted for irrigation in reaches 3 and 4 (table 8), irrigation withdrawal rates are set to zero internally in the model. Irrigation operations are probably in relative equilibrium with the water supply along the course of the Redwater River. Any additional water diversions imposed may be disruptive to irrigation practices in downstream reaches. If irrigation practices change in the future, irrigation withdrawal rates can be recalculated for appropriate reaches and added internally to the model.

Irrigation return flow occurs from water applied in excess of the consumptive water use of plants, the amount held by the soil, and the amount percolating beneath the shallow aquifers that discharge to the Redwater River. Water losses from irrigation in the Redwater River 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 amounts during the following 8 months. In addition to irrigation return flow that results from the current year's application, some return flow occurs from the antecedent year's application (table 9). 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 9.--*Estimated monthly rates of irrigation return flow from the previous year*

Month	Return flow[1], in acre-feet per acre, for indicated reach: Reach 1	2	3	4	5
Jan	0.0049	0.0029	0.0	0.0	0.0242
Feb	.0015	.0029	0	0	.0080
Mar-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

Ground-water inflow rates were estimated from base-flow studies conducted in June, August, and October of 1982 at 10 sites on the Redwater River. The location of measurement sites and site descriptions for base-flow measurements are given in figure 4 and table 10.

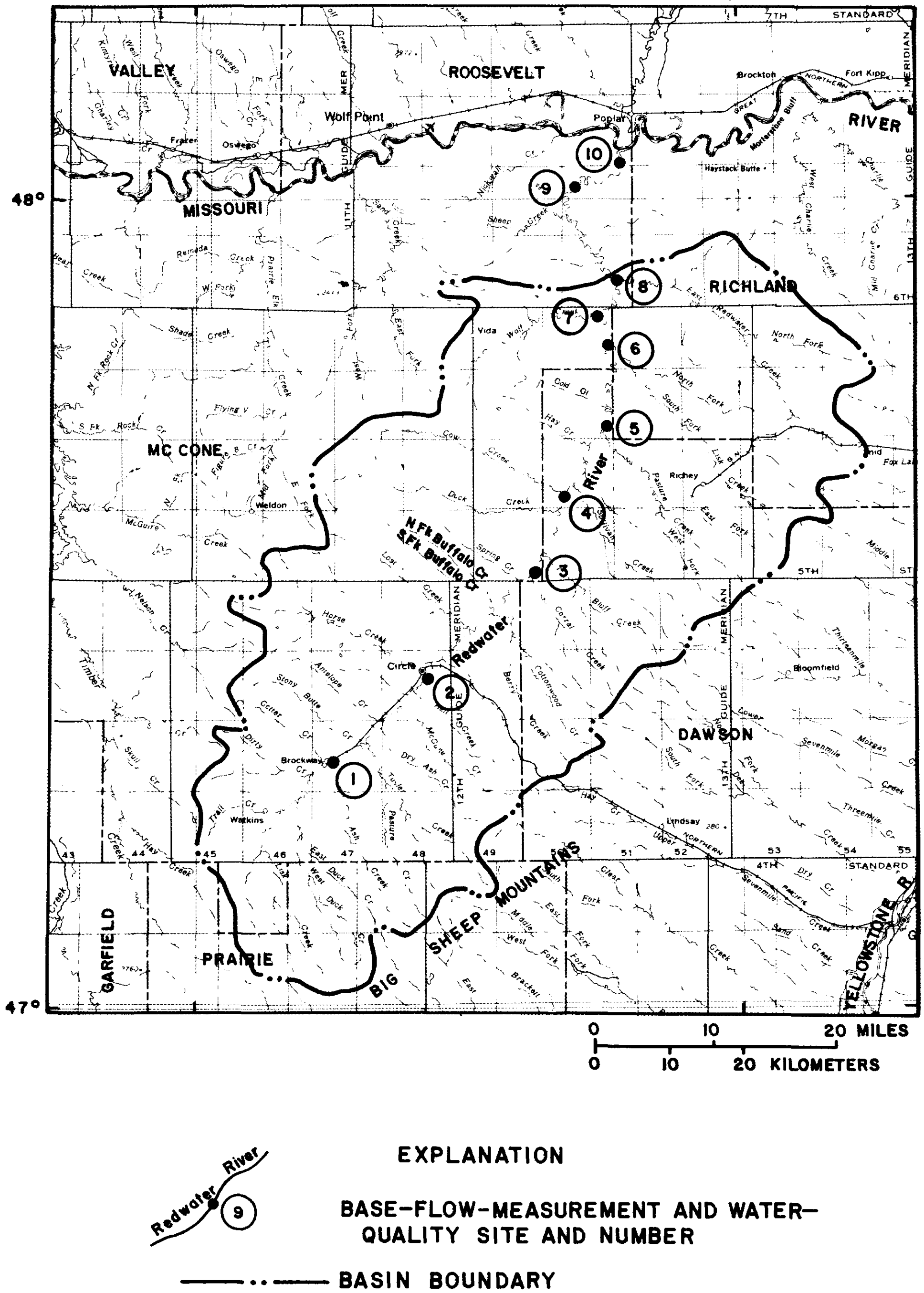

Figure 4.--Location of measurement sites for base-flow measurements during 1982.

Table 10.--*Site descriptions for base-flow measurements during 1982*

[Number in parentheses is formal Geological Survey station number (06177150) or miscellaneous site number based on latitude and longitude (473036105253101)]

Site No. (fig. 4)	Stream	Location and station number
1	Redwater River at Brockway.	NW¼ sec. 20, T. 18 N., R. 47 E., McCone County, at bridge on county road, one-quarter mile northeast of Brockway (06177150).
2	Redwater River at Circle.	SW¼SW¼ sec. 11, T. 19 N., R. 48 E., McCone County, on left bank at Circle, 1 mile upstream from Horse Creek, and at mile 79.6 (06177500).
3	Redwater River 10 miles from Circle.	SE¼SE¼ sec. 2, T. 20 N., R. 49 E., McCone County, at county bridge crossing, 10 miles northeast of Circle (473052105253901).
4	Redwater River near Richey.	SE¼ sec. 29, T. 22 N., R. 50 E., Dawson County, at county road bridge crossing, just upstream from Cow Creek tributary, and 12 miles due west of Richey (06177650).
5	Redwater River 10 miles northwest of Richey.	NW¼NW¼ sec. 36, T. 23 N., R. 50 E., Dawson County, 150 feet upstream from county road (474256105150401).
6	Redwater River east of Vida.	NW¼ sec. 24, T. 24 N., R. 50 E., McCone County, along county road, southeast of "T" in road from community of Vida, in vicinity of old log cabin, 11 miles due east of Vida (474947105150401).
7	Wolf Creek at mouth, near Vida.	SE¼ sec. 11, T. 24 N., R. 50 E., McCone County, at mouth near county road bridge crossing, 1.3 miles north of "T" located 10 miles east of Vida (475101105153101).
8	Redwater River near Vida.	SW¼ sec. 24, T. 25 N., R. 50 E., McCone County, on right bank at downstream side of bridge on FAS Highway 201, 400 feet downstream from East Redwater Creek and 13.7 miles northeast of Vida post office (06177825).
9	Redwater River 27 miles north of Vida.	NW¼NE¼SE¼ sec. 7, T. 26 N., R. 50 E., McCone County, behind barnyard at ranch, 2 miles due south of Nickwall, and 27 road miles north of Vida (480111105182001).

Table 10.--*Site descriptions for base-flow measurements during 1982*--Continued

Site No. (fig. 4)	Stream	Location and station number
10	Redwater River at mouth, near Poplar.	NW¼NW¼ sec. 36, T. 27 N., R. 50 E., McCone County, at first county road bridge crossing upstream from mouth, about 4 miles south of Poplar Poplar (480315105125001).

Three studies were made in an effort to define the variability in base discharge occurring throughout the year. The study months were selected to represent assumed conditions of maximum ground-water inflow (June), maximum evapotranspiration (August), and dry-weather base flow with negligible evapotranspiration (October). Ground-water inflow rates measured for each reach during the three base-flow studies are given in tables 11, 12, and 13. Although the base-flow studies included measurements for the entire length of the Redwater River, the model is programmed to simulate salinity only from sites 1 to 8. Overall ground-water inflow rates, in acre-feet per mile per day, for the 101.5-mile length of the modeled river are 0.26 for June, 0.04 for August, and 0.09 for October. Values for June and August include the effect of evapotranspiration.

Monthly ground-water inflow rates for each reach (table 14) were estimated from streamflow differences measured during the three base-flow studies. To estimate monthly variation in inflow rates, months were segregated into a recharge period (March to June), a recession period (July to October), and a period of uniform discharge (November to February). Long-term mean precipitation is generally constant from October through February; therefore, October inflow rates were maintained throughout this period to represent uniform ground-water discharge to the Redwater River. Ground-water recharge is assumed to occur from March through June as a result of snowmelt and rainfall; consequently, ground-water inflow rates to the streams for March, April, and May were also derived by linear interpolation between February and June. Limited recharge occurs after June and the subsequent recession through October was assumed to be linear if the effect of evapotranspiration is discounted. Therefore, linear interpolation from June through October is considered to result in reasonable monthly flow rates for July, August, and September.

Because the model is internally programmed to subtract evapotranspiration, the June, July, and August ground-water inflow rates were increased by adding an estimated evapotranspiration rate (0.113 acre-foot per river mile per day). This evapotranspiration rate represents the difference between the measured base flows of October and August. The maximum value was applied uniformly to June, July, and August because of maximum air temperature and riparian plant production. Zero evapotranspiration losses were assumed for October through February. Evapotranspiration rates for March, April, May, and September were calculated by linear interpolation between zero and the maximum rate of evapotranspiration.

Table 11.--*Measured discharges and gains or losses of flow between Redwater River sites, June 1982*

[ft^3/s, cubic feet per second]

Site No. (fig. 4)	Stream	Date (mo-day)	Measured discharge (ft^3/s)	Net gain (+) or loss (-) of streamflow between Redwater River sites (ft^3/s)	Sum of tributary inflow between Redwater River sites (ft^3/s)	Net gain (+) or loss (-) of ground-water between Redwater River sites (ft^3/s)
1	Redwater River	06-22	0.34	--	--	--
2	Redwater River	06-22	2.99	+2.65	0	+2.65
	Horse Creek	06-22	.52	--	--	--
	Lost Creek	06-22	.06	--	--	--
	Cottonwood Creek	06-22	.02	--	--	--
3	Redwater River	06-22	7.73	+4.74	.60	+4.14
	Duck Creek	06-22	.11	--	--	--
4	Redwater River	06-22	10.4	+2.67	.11	+2.56
	Cow Creek	06-22	.51	--	--	--
	Sullivan Creek	06-22	.04	--	--	--
	Pasture Creek	06-22	.48	--	--	--
5	Redwater River	06-23	14.3	+3.90	1.03	+2.87
	Lisk Creek	06-22	.02	--	--	--
6	Redwater River	06-22	16.0	+1.70	.02	+1.68
7	Wolf Creek	06-23	.62	--	--	--
	East Redwater Creek.	06-23	1.03	--	--	--
8	Redwater River	06-23	17.2	+1.20	1.65	-.45
	Sheep Creek	06-23	.15	--	--	--
9	Redwater River	06-23	24.7	+7.50	.15	+7.35
10	Redwater River	06-23	28.6	+3.90	0	+3.90

Table 12.--*Measured discharges and gains or losses of flow between Redwater River sites, August 1982*

[ft³/s, cubic feet per second]

Site No. (fig. 4)	Stream	Date (mo-day)	Measured discharge (ft^3/s)	Net gain (+) or loss (-) of streamflow between Redwater River sites (ft^3/s)	Sum of tributary inflow between Redwater River sites (ft^3/s)	Net gain (+) or loss (-) of ground-water between Redwater River sites (ft^3/s)
1	Redwater River	08-24	0.0	--	--	--
2	Redwater River	08-24	.05	+0.05	0	+0.05
	Horse Creek	08-24	0	--	--	--
	Lost Creek	08-24	0	--	--	--
	Cottonwood Creek	08-24	0	--	--	--
3	Redwater River	08-24	.41	+.36	0	+.36
	Duck Creek	08-24	0	--	--	--
4	Redwater River	08-24	1.10	+.69	0	+.69
	Cow Creek	08-24	0	--	--	--
	Sullivan Creek	08-24	0	--	--	--
	Pasture Creek	08-24	0	--	--	--
5	Redwater River	08-24	1.15	+.05	0	+.05
	Lisk Creek	08-24	.01	--	--	--
6	Redwater River	08-24	1.16	+.01	.01	0
7	Wolf Creek	08-24	0	--	--	--
	East Redwater Creek.	08-24	0	--	--	--
8	Redwater River	08-24	2.12	+.96	0	+.96
	Sheep Creek	08-24	0	--	--	--
9	Redwater River	08-24	2.21	+.09	0	+.09
10	Redwater River	08-24	2.31	+.10	0	+.10

Table 13.--*Measured discharges and gains or losses of flow between Redwater River sites, October 1982*

[ft^3/s, cubic feet per second]

Site No. (fig. 4)	Stream	Date (mo-day)	Measured discharge (ft^3/s)	Net gain (+) or loss (-) of streamflow between Redwater River sites (ft^3/s)	Sum of tributary inflow between Redwater River sites (ft^3/s)	Net gain (+) or loss (-) of ground-water between Redwater River sites (ft^3/s)
1	Redwater River	10-19	0.04	--	--	--
2	Redwater River	10-19	.06	+0.02	0.0	+0.02
	Horse Creek	10-19	.28	--	--	--
	Lost Creek	10-19	0	--	--	--
	Cottonwood Creek	10-19	0	--	--	--
3	Redwater River	10-19	1.05	+.99	.28	+.71
	Duck Creek	10-19	.01	--	--	--
4	Redwater River	10-19	2.73	+1.68	.01	+1.67
	Cow Creek	10-19	.15	--	--	--
	Sullivan Creek	10-19	.01	--	--	--
	Pasture Creek	10-19	.25	--	--	--
5	Redwater River	10-19	4.89	+2.16	.41	+1.75
	Lisk Creek	10-19	.02	--	--	--
6	Redwater River	10-19	5.40	+.51	.02	+.49
7	Wolf Creek	10-19	.19	--	--	--
	East Redwater Creek.	10-19	.14	--	--	--
8	Redwater River	10-19	5.60	+.20	.33	-.13
	Sheep Creek	10-20	.09	--	--	--
9	Redwater River	10-19	7.65	+2.05	.09	+1.96
10	Redwater River	10-20	7.43	-.22	0	-.22

Table 14.--*Estimated daily ground-water inflow rate per river mile for each reach of the Redwater River*

Month	Reach	Inflow rate [1], in acre-feet per river mile per day, for indicated reach				
		1	2	3	4	5
Jan		0.0017	0.0717	0.1555	0.2822	0.0228
Feb		-.0004	.0716	.1555	.2822	.0253
Mar		.0716	.1758	.2046	.3558	.0714
Apr		.1728	.3038	.2537	.4292	.1159
May		.2626	.4197	.3027	.5027	.1211
Jun		.3517	.5225	.3518	.5762	.1823
Jul		.2339	.3417	.2648	.3488	.1910
Aug		.1162	.1485	.1777	.1215	.1810
Sep		.0582	.1096	.1666	.2019	.1018
Oct		.0001	.0709	.1555	.2822	.0228
Nov		.0002	.0708	.1555	.2822	.0227
Dec		.0015	.0717	.1555	.2822	.0228

[1]All values are corrected for irrigation return flow and evapotranspiration losses

Assuming that irrigation return flow to the Redwater River occurs as ground water, ground-water inflow rates were corrected for irrigation return flow in reaches 1, 2, and 5. The model correction for irrigation return flow, in acre-feet per river mile per day, is calculated from the amount of irrigation return flow occurring during mean flow conditions. Irrigation return flow values are based on 48 acres irrigated in reach 1 from Brockway to Circle, 180 acres irrigated in reach 2, and 135 acres irrigated in reach 3.

The seasonal trends for resultant ground-water inflow rates correspond reasonably well to long-term mean precipitation and hydrograph records available for the Redwater River at Circle and near Vida (tables 2, 5, and 14). Although the estimated monthly ground-water-inflow rates may contain significant error, their use is an improvement to the Tongue River model in that they are considered to represent actual inflow rates more reliably than one constant rate throughout the year. The lack of data precludes calculation of the magnitude of error associated with these estimates. More detailed analysis of aquifer water levels and evapotranspiration rates or a series of base-flow studies during several years would enable a more accurate quantification of monthly ground-water-inflow rates or the magnitude of existing error.

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. In the model no amount of streamflow withdrawn for these losses is returned to the Redwater River.

Dissolved-solids components

In each reach of the Redwater River, dissolved-solids loads are calculated from the dissolved-solids concentration and the volume of each hydrologic component. The model then routes dissolved-solids loads downstream, 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 the volume of water but not the dissolved-solids load. Therefore, the dissolved-solids concentrations in each reach will be affected by these processes, but not the dissolved-solids loads.

Mining

If the total quantity of dissolved solids added to the Redwater River from surface coal mining could be determined accurately, algebraic calculations could be made to estimate changes in dissolved-solids concentrations. Unfortunately, the effects of a mine are dependent on numerous complex relationships, including proximity of the mine to the river, 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 must be evaluated individually to estimate probable hydrologic consequences. However, for this study, a technique used by Woods (1981) was employed to simulate the dissolved-solids load resulting from mining.

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

$$DSLMR = DSCMR \times AMR \times RCARR \times f \qquad (4)$$

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 the surface coal mine, in acres;
- $RCARR$ is infiltration rate, in inches per year, for a mined drainage basin; and
- f is a factor (0.0001133) to convert equation units into tons.

The infiltration rate for the study area is estimated to be about 0.1 inch per year (Cannon, 1983).

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 water from mine spoils and saturated paste extracts of overburden material. Therefore, the dissolved-solids load from mined areas in the model that is additional to the load already accounted for in ground-water flow is estimated in equation 4 by applying a coefficient of 0.5 to the dissolved-solids concentration of water from nearby springs and wells. Only dissolved-solids concentrations from springs and wells that derive water from the aquifers disturbed during mining are used as input to the model.

Aquifer characteristics in the coal area of eastern 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 the Redwater River at some common future time. From whatever mined acreage is specified, the model simulates the steady-state input of dissolved solids to the Redwater River at this common future time.

Because of possible interactions of spoil-derived water with various aquifer minerals 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 with regard to dissolved-solids loads derived from mining.

Gage-based and ungaged streamflow

Dissolved-solids loads for the Redwater River at Circle were determined by linear regression analysis. Concurrent measurements of streamflow and dissolved-solids concentration were used to develop the following linear regression equation:

$$\log_{10} Y = 3.46068 - 0.00109\, X \qquad (5)$$

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 86 samples that were collected monthly from October 1974 to January 1983, and explains 55 percent ($r^2 = 0.55$) of the variation in dissolved-solids concentration, a correlation that is significant at the 0.01 level ($[p > F] = 0.0001$). The model uses equation 5 to calculate the initial dissolved-solids concentration at the Redwater River at Circle from a streamflow value consistent with the user-selected monthly hydrologic condition (table 2).

Estimates of dissolved-solids concentrations from ungaged tributaries are based on sparse data. Samples of dissolved-solids concentration and concurrent streamflow measurements are insufficient to develop meaningful regressions for the tributary streams. Therefore, estimates of mean annual dissolved-solids concentration for the tributaries were obtained by applying estimates of tributary mean annual streamflow to equation 5. The mean annual dissolved-solids concentration for each reach was estimated by weighting the mean annual dissolved-solids concentration of tributary streams by drainage area, as indicated in table 4. Mean annual dissolved-solids concentrations for ungaged tributaries in each reach (table 15) are used with every monthly hydrologic condition.

Table 15.--*Estimated mean annual dissolved-solids concentration for ungaged tributaries*

Reach No.	Dissolved-solids concentration, in milligrams per liter
2	2,863
3	2,851
4	2,820
5	2,816

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 load. Both processes are difficult to quantify and may 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 the Redwater River. The return rate of dissolved-solids load is based on the assumed rate of irrigation return flow, with 65 percent of the total load diverted returning during the same month of application and the rest returning in equal parts during the following 8 months. Therefore, for any given month, part of the 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 1, 2, and 5 receive dissolved solids returning from the previous year. The dissolved-solids load available for irrigation return flow from the previous year is estimated from the load diverted during mean hydrologic flow conditions. Dissolved-solids concentrations during water withdrawal the previous year are estimated from equation 5 for reaches 1 and 2. The following regression equation was developed from 79 samples at Redwater River near Vida, Mont. (station 06177825), and is used to calculate dissolved-solids concentrations for water withdrawal the previous year from reach 5:

$$Y = 2751.7824 - 619.8557 (\log_{10} X) \qquad (6)$$

where

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

Equation 6 explains 57 percent ($r^2 = 0.57$) of the variation in dissolved-solids concentration. This correlation is significant at the 0.01 level ($[p > F] = 0.0001$).

The mean monthly dissolved-solids concentrations for reaches 1 and 5 were calculated by using the regression equations with daily mean streamflow obtained from historical records (U.S. Geological Survey, issued annually). However, mean monthly streamflow for reach 2 was estimated by partitioning mean annual streamflow (Robert J. Omang, written commun., 1983) for the Redwater River below Buffalo Creek, near Circle, Mont. (station 4730521052539), proportionally to mean monthly streamflows that occur at Redwater River at Circle. The mean monthly streamflows for Redwater River below Buffalo Creek, near Circle then were used in equation 5 to obtain estimates of mean monthly dissolved-solids concentrations in reach 2.

The dissolved-solids loads returning in each month from 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 16) are summed with the loads for the current year for each month.

Table 16.--*Estimated monthly dissolved-solids loads in irrigation return flow from the year prior to simulation*

	Dissolved solids returned [1], in tons per acre, for indicated reach				
Month Reach	1	2	3	4	5
Jan	0.02657	0.01920	0.0	0.0	0.09849
Feb	.00432	.01920	0	0	.03491
Mar-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 concentrations for ground-water inflow to the five Redwater River reaches are based on streamflow loads and ground-water inflow rates computed from 1982 base-flow measurements (tables 17, 18, and 19). Concentrations were calculated using the following equation:

$$C = \frac{L_d - L_u - L_t}{(Q_d - Q_u - Q_t) \times f} \qquad (7)$$

where

C is dissolved-solids concentration, in milligrams per liter;
L_d is dissolved-solids load, in tons per day, at downstream end of reach;
L_u is dissolved-solids load, in tons per day, at upstream end of reach;
L_t is dissolved-solids load, in tons per day, input to reach by tributaries;
Q_d is streamflow, in cubic feet per second, at downstream end of reach;
Q_u is streamflow, in cubic feet per second, at upstream end of reach;
Q_t is streamflow, in cubic feet per second, input to reach by tributaries; and
f is a factor (0.0027) to convert equation units into milligrams per liter.

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 streamflow conditions and irrigation withdrawal, dissolved-solids loads returning with irrigation flow were calculated based on 48 acres in reach 1 (Brockway to Circle), 180 acres in reach 2, and 135 acres in reach 5. In addition, the ground-water inflow rates in each reach were corrected for losses of water by evapotranspiration (see Hydrologic components, Ground-water flow). Calculations for each reach are based on mean dissolved-solids loads and ground-water flows calculated for June, August, and October 1982. The resulting dissolved-solids concentrations for the ground-water component of streamflow in each reach are given in table 20.

The dissolved-solids loads contributed by ground-water inflow in each reach are used to derive effective concentrations calculated on the basis of mass balance and do not necessarily represent actual dissolved-solids concentrations of ground-water inflow. Complicating factors such as the exchange of water between the surface-water and ground-water systems at various points make determination of actual concentrations difficult. In addition, the method of computation is dependent on accurate measurements of small stream discharges and dissolved-solids concentrations to prevent anomalous results; for example, gaining flow but losing load. Such anomalies were omitted from calculations of average effective concentrations. Because of the variability inherent in indirect estimates of ground-water dissolved-solids concentrations, a single average concentration for the entire year for each reach was considered to be the most reasonable estimate available.

Other dissolved-solids losses

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

Model input and output

Initial conditions for each model run are specified by the user. Input includes specification of monthly hydrologic flow condition, either regression-derived or user-input values of monthly dissolved-solids concentration in the Redwater River at Circle (station 06177500), irrigated acreage, mined acreage, and dissolved-

Table 17.--*Changes in dissolved-solids loads between Redwater River sites, June 1982*

[ft^3/s, cubic feet per second; microsiemens, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; ton/d, tons per day]

Site No. (fig. 4)	Stream	Date (mo-day)	Measured discharge (ft^3/s)	Onsite specific conductance (microsiemens)	Dissolved-solids concentration (mg/L)	Dissolved-solids load (ton/d)	Net gain (+) or loss (-) of dissolved-solids load between Redwater River sites (ton/d)	Sum of tributary loads between Redwater River sites (ton/d)	Net gain (+) or loss (-) of ground-water load between Redwater River sites (ton/d)
1	Redwater River	06-22	0.34	6,200	5,630	5.17	--	--	--
2	Redwater River	06-22	2.99	4,600	3,760	30.4	+25.2	0.0	+25.2
	Horse Creek	06-22	.52	7,250	[1]6,370	8.94	--	--	--
	Lost Creek	06-22	.06	7,300	[1]6,420	1.04	--	--	--
	Cottonwood Creek.	06-22	.02	1,290	[1]431	.02	--	--	--
3	Redwater River	06-22	7.73	3,750	3,030	63.2	+32.8	10.0	+22.8
	Duck Creek	06-22	.11	3,900	[1]3,030	.90	--	--	--
4	Redwater River	06-22	10.4	3,700	2,910	81.7	+18.5	.90	+17.6
	Cow Creek	06-22	.51	4,900	[1]4,030	5.55	--	--	--
	Sullivan Creek.	06-22	.04	2,950	[1]2,080	.22	--	--	--
	Pasture Creek.	06-23	.48	4,820	[1]3,950	5.12	--	--	--
5	Redwater River	06-23	14.3	3,350	2,660	103	+21.3	10.9	+10.4
	Lisk Creek	06-22	.02	6,350	[1]5,470	.30	--	--	--
6	Redwater River	06-22	16.0	3,580	2,640	114	+11.0	.30	+10.7
7	Wolf Creek	06-23	.62	3,150	2,350	3.93	--	--	--
	East Redwater Creek.	06-23	1.03	4,780	[1]3,910	10.9	--	--	--
8	Redwater River	06-23	17.2	3,850	2,760	128	+14.0	14.8	-.83
	Sheep Creek	06-23	.15	3,410	[1]2,540	1.03	--	--	--
9	Redwater River	06-23	24.7	3,120	2,420	161	+33.0	1.03	+32.0
10	Redwater River	06-23	28.6	3,310	2,430	188	+27.0	0	+27.0

[1]Dissolved-solids concentration estimated from regression between specific conductance and dissolved solids at sites 1-10.

Table 18.- *Changes in dissolved-solids loads between Redwater River sites, August 1982*

[ft^3/s, cubic feet per second; microsiemens, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; ton/d, tons per day]

Site No. (fig. 4)	Stream	Date (mo-day)	Measured discharge (ft^3/s)	Onsite specific conductance (microsiemens)	Dissolved-solids concentration (mg/L)	Dissolved-solids load (ton/d)	Net gain (+) or loss (-) of dissolved-solids load between Redwater River sites (ton/d)	Sum of tributary loads between Redwater River sites (ton/d)	Net gain (+) or loss (-) of ground-water load between Redwater River sites (ton/d)
1	Redwater River	08-24	0.0	--	--	0.0	--	--	--
2	Redwater River	08-24	.05	5,030	3,910	.53	+0.53	0.0	+0.53
	Horse Creek	08-24	0	--	--	0	--	--	--
	Lost Creek	08-24	0	--	--	0	--	--	--
	Cottonwood Creek.	08-24	0	--	--	0	--	--	--
3	Redwater River	08-24	.41	4,500	3,390	3.75	+3.22	0	+3.22
	Duck Creek	08-24	0	--	--	0	--	--	--
4	Redwater River	08-24	1.10	4,020	2,840	8.43	+4.68	0	+4.68
	Cow Creek	08-24	0	--	--	0	--	--	--
	Sullivan Creek	08-24	0	--	--	0	--	--	--
	Pasture Creek	08-24	0	--	--	0	--	--	--
5	Redwater River	08-24	1.15	3,400	2,560	7.95	-.48	0	-.48
	Lisk Creek	08-24	.01	5,020	[1]4,150	.11	--	--	--
6	Redwater River	08-24	1.16	3,500	2,410	7.55	-.40	.11	-.51
7	Wolf Creek	08-24	0	--	--	0	--	--	--
	East Redwater Creek.	08-24	0	--	--	0	--	--	--
8	Redwater River	08-24	2.12	3,620	2,700	15.4	+7.85	0	+7.85
	Sheep Creek	08-24	0	--	--	0	--	--	--
9	Redwater River	08-24	2.21	3,200	2,290	13.7	-1.70	0	-1.70
10	Redwater River	08-24	2.31	3,400	2,470	15.4	+1.70	0	+1.70

[1]Dissolved-solids concentration estimated from regression between specific conductance and dissolved solids at sites 1-10.

Table 19.--*Changes in dissolved-solids loads between Redwater River sites, October 1982*

[ft^3/s, cubic feet per second; microsiemens, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; ton/d, tons per day]

Site No. (fig. 4)	Stream	Date (mo-day)	Measured discharge (ft^3/s)	Onsite specific conductance (microsiemens)	Dissolved-solids concentration (mg/L)	Dissolved-solids load (ton/d)	Net gain (+) or loss (-) of dissolved-solids load between Redwater River sites (ton/d)	Sum of tributary loads between Redwater River sites (ton/d)	Net gain (+) or loss (-) of ground-water load between Redwater River sites (ton/d)
1	Redwater River	10-19	0.04	7,200	7,000	0.76	--	--	--
2	Redwater River	10-19	.06	4,250	3,250	.53	-0.23	0.0	-0.23
	Horse Creek	10-19	.28	8,900	[1]8,010	6.06	--	--	--
	Lost Creek	10-19	0	--	--	0	--	--	--
	Cottonwood Creek.	10-19	0	--	--	0	--	--	--
3	Redwater River	10-19	1.05	3,800	2,910	8.25	+7.72	6.06	+1.66
	Duck Creek	10-19	.01	6,250	[1]5,370	.14	--	--	--
4	Redwater River	10-19	2.73	3,380	2,450	17.1	+8.85	.14	+8.71
	Cow Creek	10-19	.15	4,850	[1]3,980	1.61	--	--	--
	Sullivan Creek	10-19	.01	3,940	[1]3,070	.08	--	--	--
	Pasture Creek	10-19	.25	3,800	[1]2,930	1.98	--	--	--
5	Redwater River	10-19	4.89	3,200	2,330	30.8	+13.7	3.67	+10.0
	Lisk Creek	10-19	.02	5,500	[1]4,620	.25	--	--	--
6	Redwater River	10-19	5.40	3,160	2,290	33.4	+2.60	.25	+2.35
7	Wolf Creek	10-19	.19	4,890	3,780	1.94	--	--	--
	East Redwater Creek.	10-19	.14	3,680	[1]2,810	1.06	--	--	--
8	Redwater River	10-19	5.60	3,030	2,250	34.1	+.70	3.00	-2.30
	Sheep Creek	10-20	.09	2,500	[1]1,640	.40	--	--	--
9	Redwater River	10-19	7.65	2,700	1,930	39.9	+5.80	.40	+5.40
10	Redwater River	10-20	7.43	2,890	2,130	42.7	+2.80	0	+2.80

[1]Dissolved-solids concentration estimated from regression between specific conductance and dissolved solids at sites 1-10.

Table 20.--*Estimated dissolved-solids concentration of ground-water inflow in each reach of the Redwater River*

Reach No.	Dissolved-solids concentration, in milligrams per liter
1	1,804
2	1,300
3	1,562
4	1,219
5	983

solids concentration of mine-spoils water in each of five reaches of the Redwater River (table 21). Other data used in the computations for streamflow and dissolved-solids 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 consecutive months in a given year. The model could be adapted for other hydrologic conditions in the Redwater River by replacing the internal data statements with data statements describing the new conditions.

Presently the model includes an irrigation rate of 0.0 for reaches 3 and 4, because irrigation withdrawal from the Redwater River is not known to occur for these reaches. The irrigation rates for these reaches would have to be changed internally in the model before the hydrologic effect of irrigated acreage in reaches 3 and 4 could be modeled. Because the amount of water used for irrigation in the Redwater River drainage basin is considered to be in equilibrium with water availability, it is unlikely that water withdrawal for irrigation will be initiated in reaches 3 and 4; however, irrigated acreage might be shifted to other reaches but continue with the same total volume of water withdrawn.

Output from the model consists of a description of initial conditions specified by the user; a results section giving 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 the Redwater River; and a section giving a statistical summary of the results. Because initial hydrologic flow conditions for the Redwater River at Circle and precipitation data for the study area were computed from records extending from 1929 to 1981, and ungaged tributary flow was estimated from channel geometry, model output is considered to estimate long-term conditions. Varying agricultural or mining 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 30 (Supplemental Information section at back of 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. For example, specifying a mean hydrologic flow condition would result in a mean monthly value for each of the output variables; specifying a minimum hydrologic flow condition would result in a minimum monthly mean for each

Table 21.--*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 median, 3 for 25th percentile, 4 for 75th percentile, 5 for maximum, and 6 for minimum.
2	1	I1	DDSCRC	Designator for monthly dissolved-solids concentration in the Redwater River at Circle; enter 0 for regression-derived values, 1 for user-defined values.
	6-65	12F5.0	DSCRCU	Monthly dissolved-solids concentration (in milligrams per liter) in Redwater River at Circle; user defined.
3	1-30	5F6.0	AIR	Area (in acres) irrigated in each of five reaches of the Redwater River.
4	1-30	5F6.0	AMR	Area (in acres) mined in each of five reaches of the Redwater River.
5	1-30	5F6.0	DSCMR	Dissolved-solids concentration (in milligrams per liter) of leachate from surface coal mine spoils in each of five reaches of the Redwater River.
6	1-30	5F6.0	QOLR	Other losses of streamflow (in acre-feet per year) from each reach of the Redwater River.

of the output variables; and so forth. Generally, a range of values is associated with each monthly mean value. As a longer period of record for daily specific conductance becomes available for the Redwater River near Vida, it will be possible to predict, through regression analysis, monthly maximum and minimum values associated with each monthly mean dissolved-solids concentration.

Because agriculture and mining are two important industries of concern in the Redwater River 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 percentage of dissolved-solids concentration at the downstream end of each reach attributed to the load input by mining is calculated by the following equation:

$$PDSMR = \frac{DSLMR}{DSLD} \times 100 \qquad (8)$$

where

PDSMR is the percentage of dissolved-solids concentration in the Redwater River resulting from mining;

DSLMR is the dissolved-solids load, in tons, leached from mined areas 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 wherein 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 has in changing the dissolved-solids concentration of the Redwater River results from a loss of water through evapotranspiration. The following equation describes the percentage of dissolved-solids concentration resulting from irrigation:

$$PDSIR = \left[1 - \left(\frac{\left(\frac{DSLD - (DSLRIR - DSLDIR)}{QD - (QRFIR - QDIR)}\right)}{DSCD \times C}\right)\right] \times 100 \qquad (9)$$

where

PDSIR is the percentage of dissolved-solids concentration in the Redwater River 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 water to the Redwater River;
DSLDIR is the dissolved-solids load, in tons, diverted by irrigation from the Redwater River;
QD is the streamflow, in acre-feet, at the downstream end of each reach of the Redwater River;
QRFIR is the return flow, in acre-feet, from irrigation in each reach of the Redwater River;
QDIR is streamflow, in acre-feet, diverted for irrigation from the Redwater River;
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 irrigation and mining 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 (Redwater River at Circle) and for the downstream station of reach 5 (Redwater River near Vida). A statistical summary is also presented for each reach. Calculations are based on monthly values of dissolved-solids concentration generated for each reach.

MODEL VALIDATION

The validity of the Redwater River model was examined by comparing simulated monthly mean streamflows and dissolved-solids loads with historical data collected at the downstream end of reach 5 (Redwater River near Vida) from 1976 to 1982. The simulated conditions for the comparison were set to mean and median hydrologic flow conditions. Input data include presently irrigated acreage within the Redwater River drainage. As there is no active mining in the Redwater River drainage, input for mined acreage was set at zero.

A statistical validation of the model was not possible because of the small number of monthly mean streamflow values for the Redwater River near Vida. A statistical summary of monthly mean streamflows is presented in table 22 to show the range of monthly mean streamflows during the period of record and to provide a comparison between historical and simulated values. The large difference between minimum and maximum and between mean and median values of monthly mean streamflows for the Redwater River near Vida indicates that streamflows for the period of record were extremely variable. Because of the limited amount and extreme variability of available data, comparison of simulated streamflow with streamflow calculated from historical records does not conclusively validate the model.

Table 22.--*Statistical summary of monthly mean streamflow at Redwater River near Vida, calculated from streamflow records (1976-82) and simulated by the model*

	Monthly mean streamflow, in acre-feet					
	Historical				Simulated	
Month	Minimum	Mean	Median	Maximum	Mean	Median
Jan	0.0	111	105	271	424	369
Feb	0	4,623	149	22,715	8,237	479
Mar	521	9,556	7,870	31,482	25,797	11,627
Apr	329	10,549	2,101	60,575	13,501	2,861
May	168	2,297	744	8,916	3,302	1,718
June	140	3,184	1,488	10,592	6,875	2,616
July	33	3,619	438	13,097	6,504	931
Aug	0	697	412	3,044	1,492	732
Sept	58	409	161	1,946	774	472
Oct	85	322	248	824	603	507
Nov	105	323	299	625	607	537
Dec	25	240	231	459	557	472

Comparison of the mean and median monthly mean streamflows in table 22 consistently shows simulated streamflows larger than calculated historical streamflows. The simulated mean and median monthly mean streamflows are within the calculated minimum and maximum monthly mean streamflows for all months except January and December. However, a model simulation specifying maximum-streamflow hydrologic condition shows simulated maximum monthly mean streamflows almost three times larger than calculated maximum monthly mean streamflows for the Redwater River near Vida.

Examination of internal model values indicates that ungaged tributary flow and ground-water inflow account for the large streamflows simulated by the model during the low streamflow months of September to January. From February to August, the large simulated flows are a direct result of large tributary flows.

Using daily streamflow records obtained from U.S. Geological Survey (issued annually) and equation 6, monthly mean dissolved-solids loads were calculated by regression and simulated for the Redwater River near Vida. A statistical summary of regression-derived and simulated monthly mean dissolved-solids loads is presented in table 23. Simulated mean and median monthly mean dissolved-solids loads, in tons, are consistently larger than corresponding streamflow-regression-derived values. Unlike simulated streamflow, simulated mean monthly mean dissolved-solids concentrations generally are nearly as large or larger than regression-derived maximum monthly mean concentrations. In contrast, simulated median monthly mean dissolved-solids concentrations generally are smaller than regression-derived maximum

Table 23.--*Statistical summary of monthly mean dissolved-solids load at Redwater River near Vida, calculated by streamflow-derived regression (1976-82) and simulated by the model*

	Monthly mean dissolved-solids load, in tons					
	Streamflow-regression-derived				Simulated	
Month	Minimum	Mean	Median	Maximum	Mean	Median
Jan	0.0	370	371	867	1,083	870
Feb	0	6,106	473	22,777	31,150	1,369
Mar	1,543	14,052	15,031	37,044	94,516	42,941
Apr	1,017	13,295	5,089	63,176	50,757	10,002
May	568	4,916	2,101	16,943	11,565	5,494
June	478	5,678	3,791	14,078	25,140	8,819
July	126	5,852	1,322	20,239	24,224	2,804
Aug	.04	1,650	1,242	6,127	5,006	2,070
Sept	211	1,065	538	4,423	2,337	1,176
Oct	310	984	728	2,286	1,787	1,418
Nov	372	1,002	951	1,788	1,816	1,545
Dec	100	763	782	1,379	1,622	1,294

monthly mean concentrations. Examination of internal model values indicates that ungaged tributary flow accounts for the large dissolved-solids loads to each reach. Large loads from tributary streams are expected because of the large simulated tributary streamflows.

Simulations with minimum, 25th percentile, median, 75th percentile, and maximum hydrologic flow conditions demonstrate the weak correlation between dissolved-solids concentration and streamflow. Without mining, dissolved-solids concentrations for each month decrease with increasing streamflow in reach 1; however, in reaches 2, 3, 4, and 5, dissolved-solids concentrations for each month generally increase with increasing streamflow. This relationship indicates that ungaged tributary flow or possibly ground-water inflow estimates are too large, thereby resulting in an overestimation of dissolved-solids load contributed to the Redwater River.

Evapotranspiration by riparian vegetation and evaporation from the water surface affect streamflow to only a minor extent. Their greatest percentage effect is as loss of streamflow during June, July, and August when ungaged tributary flow is at a minimum and riparian production is at a maximum. Ungaged tributary flow on a monthly basis increases at the same time that precipitation increases. Consequently, precipitation on the water surface of the Redwater River 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. During large streamflows in March, ice effects account for less than 1 percent of the total flow in the Redwater River. However, during small streamflow in December, the model simulates as much as 30 percent water loss due to ice formation in reach 3.

Because ground-water flow and particularly ungaged-tributary flow account for large volumes of streamflow in the Redwater River, these two factors probably 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. Estimates of ground-water flow and dissolved-solids load 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 that approaches the stream from a perpendicular aspect.

Ungaged tributary flow estimates are indicated to be the main source of error in the Redwater River model. More accurate estimates could be obtained by collecting continuous streamflow data from at least one representative drainage basin in each reach. Even though the large error in dissolved-solids loads from ungaged tributaries would be caused by erroneously large estimated streamflows, overestimation of dissolved-solids concentrations would also contribute to the error. Error in predicting the dissolved-solids concentration from streamflow (equation 5) may be a source of significant error in the model. Although the regression is statistically significant, the percentage of variation explained is small ($r^2 = 0.55$) and the standard error is large (28.8 percent). A plot of the data includes only a few points for large streamflows; therefore, the regression relationship is not sensitive to small streamflow changes as represented by monthly means rather than daily means. Consequently, the model shows little variation in dissolved-solids concentration each month. More accurate estimates of dissolved-solids load from ungaged tributaries could be obtained by collecting monthly dissolved-solids measurements complemented with daily specific-conductance measurements to obtain better regressions.

Errors in the model that involve irrigation and mining can result from an inaccurate representation of the processes that actually occur. With irrigation, the main effect 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, and the ranchers from whom information was obtained have no way of measuring the amount of water diverted. Errors in dissolved-solids load could be introduced because of the salt balance assumption in the model, when in fact a significant amount of dissolved-solids leaching or adsorption could occur in the study area.

Mining, as modeled for the Redwater River, affects only dissolved-solids load. Errors could be introduced by using only the infiltration rate 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 for a given mined acreage by choosing various dissolved-solids concentrations of leachate from specified mined areas.

Both the streamflow and dissolved-solids components of the model are considered to be unsatisfactory in describing present conditions in the Redwater River. Although the model is based on data that are considered to provide the best estimates available, considerable improvement could be made with additional information on tributary runoff and ground-water flow. Data that are internal to the program could be updated to produce a more accurate simulation of streamflow and dissolved-solids load. In its present form, the model can be used to explore possible effects of surface coal mining and agriculture on the dissolved-solids concentration in the Redwater River. However, the ability of the model to predict realistic magnitudes of dissolved solids is questionable in view of the potentially large error associated with many of the estimates of input variables.

SIMULATION OF MINING AND AGRICULTURAL DEVELOPMENT

Both mining and irrigation have the potential to affect the dissolved-solids concentration in the Redwater River. The model incorporates several hydrologic flow conditions in the Redwater River drainage basin that can be subjected to various amounts of 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 as portrayed by the present form of the model for the Redwater River. The following simulations in this section for mining and agricultural development were run under mean hydrologic flow conditions.

Mining development

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 representative of mine-spoils leachate would result in more realistic concentration estimates at the downstream end of each reach.

Two areas of Federal, State, and private coal are designated as being potentially available for leasing: Redwater Tract I and Redwater Tract II. Together, these tracts contain recoverable coal in the Redwater River drainage between Horse Creek and Buffalo Creek (fig. 5). Tract I encompasses 22,786 acres, with an economically recoverable coal seam that averages 14.8 feet in thickness and with overburden ranging from about 150 to 200 feet in depth (U.S. Bureau of Land Management, 1981a). Tract II encompasses 20,246 acres, with an economically strippable coal seam 10.5 feet in thickness and with overburden ranging from about 150 to 200 feet in depth (U.S. Bureau of Land Management, 1981b).

The amount of potentially mineable acreage in each tract and the amount included in each reach of the Redwater River drainage are listed in table 24. Esti-

Table 24.--*Mineable acreage and spoil leachate dissolved-solids concentrations for coal reserves potentially available for leasing in each reach of the Redwater River*

Reach No.	Potentially mineable area [1] (acres)	Spoil leachate dissolved-solids concentration (milligrams per liter)[2]	Tracts included in each reach	Area of strippable coal from each tract (acres)
1	0.0	--	--	--
2	29,535	2,880	Tract I Tract II	22,786 6,749
3	13,497	2,880	Tract II	13,497
4	0	--	--	--
5	0	--	--	--

[1]Surface area of disturbed watershed.
[2]Mean dissolved-solids concentration of ground water in study area x 1.5.

mates of spoil leachate dissolved-solids concentrations given in table 24 were calculated by multiplying the mean dissolved-solids concentrations of ground water in the study area (Roberts, 1980) by 1.5 (see Dissolved-solids components, Mining). Consequently, simulations were run with spoil leachate dissolved-solids concentration set at 2,880 mg/L.

The model was run with present (1982) irrigated acreage under four different mining conditions: no mining, mining Tract I only, mining Tract II only, and mining

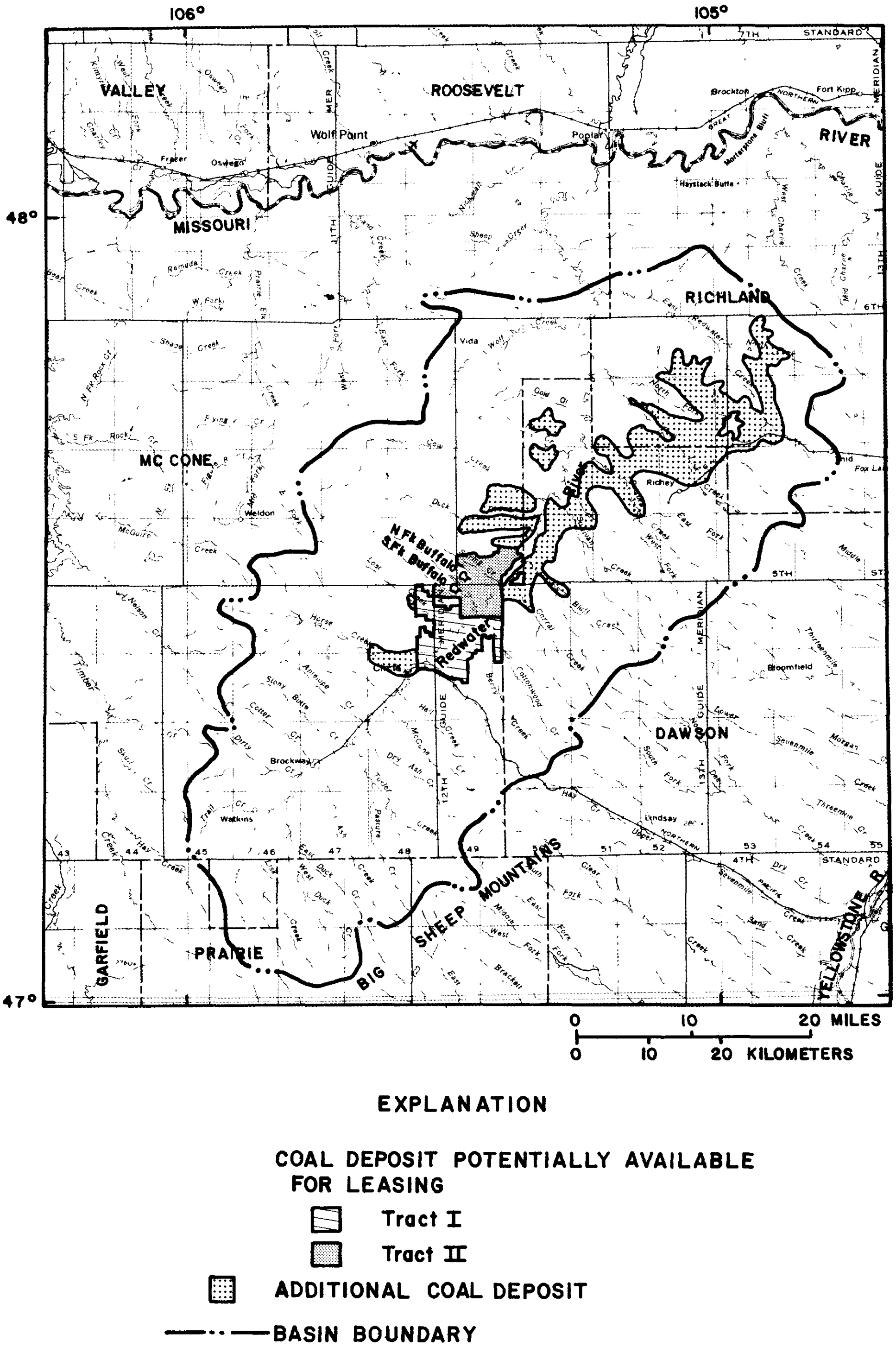

Figure 5.--Location of strippable lignite coal deposit in the Redwater River drainage (after U.S. Geological Survey, 1974).

both Tracts I and II concurrently (table 25). Irrigation in reach 2 was set to zero when Tract I was mined. However, when only Tract II was mined, irrigation was assumed to continue in reach 2. Irrigation in reach 5 was assumed to continue during all simulations of mining development.

Table 25.--*Simulated monthly dissolved-solids concentration at the downstream end of each reach of the Redwater River 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	Mining Tract I	Mining Tract II	Mining Tracts I and II	No mining	Mining Tract I	Mining Tract II	Mining Tracts I and II	No mining	Mining Tract I	Mining Tract II	Mining Tracts I and II	No mining	Mining Tract I	Mining Tract II	Mining Tracts I and II	No mining	Mining Tract I	Mining Tract II	Mining Tracts I and II
Jan	2,887	2,887	2,887	2,887	2,016	2,193	2,074	2,251	1,863	1,932	1,931	1,999	1,753	1,793	1,793	1,832	1,880	1,912	1,912	1,944
Feb	2,763	2,763	2,763	2,763	2,799	2,805	2,801	2,807	2,783	2,787	2,787	2,790	2,767	2,770	2,770	2,772	2,781	2,782	2,782	2,784
Mar	2,337	2,337	2,337	2,337	2,621	2,619	2,621	2,619	2,650	2,649	2,651	2,650	2,680	2,679	2,681	2,680	2,694	2,693	2,694	2,694
Apr	2,732	2,732	2,732	2,732	2,730	2,734	2,731	2,735	2,737	2,740	2,740	2,743	2,740	2,742	2,742	2,743	2,764	2,765	2,765	2,766
May	2,860	2,860	2,860	2,860	2,395	2,411	2,400	2,416	2,411	2,420	2,421	2,430	2,432	2,438	2,439	2,445	2,516	2,580	2,580	2,584
June	2,775	2,775	2,775	2,775	2,672	2,664	2,673	2,666	2,659	2,654	2,662	2,658	2,652	2,648	2,654	2,651	2,689	2,686	2,691	2,688
July	2,791	2,791	2,791	2,791	2,706	2,712	2,709	2,714	2,705	2,709	2,709	2,713	2,712	2,715	2,715	2,718	2,738	2,740	2,741	2,742
Aug	2,871	2,871	2,871	2,871	2,569	2,594	2,579	2,604	2,475	2,490	2,494	2,510	2,513	2,525	2,527	2,538	2,467	2,474	2,476	2,483
Sept	2,886	2,886	2,886	2,886	2,085	2,167	2,122	2,205	2,059	2,094	2,106	2,141	2,096	2,117	2,125	2,147	2,221	2,234	2,239	2,252
Oct	2,887	2,887	2,887	2,887	2,061	2,190	2,118	2,250	1,983	2,026	2,043	2,088	1,932	1,955	1,965	1,989	2,179	2,196	2,202	2,219
Nov	2,887	2,887	2,887	2,887	2,075	2,207	2,133	2,267	2,002	2,046	2,063	2,108	1,952	1,976	1,986	2,010	2,202	2,218	2,224	2,241
Dec	2,886	2,886	2,886	2,886	2,223	2,329	2,269	2,376	2,040	2,081	2,097	2,139	1,945	1,969	1,979	2,003	2,143	2,161	2,167	2,185

[1] Present irrigated acreage consists of 647 acres in reach 1, 180 acres in reach 2, and 135 acres in reach 5.

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

The largest increase in simulated dissolved-solids concentration as a result of mining occurs in reach 2 when both tracts are mined concurrently. As the dissolved-solids load is transported downstream, the effect of mining becomes less apparent, primarily as a result of additional dissolved solids from tributary streams and ground-water inflow composing a larger proportion of the total load. The largest increase in simulated dissolved-solids concentration of reach 2 occurs from September through January in response to smaller streamflows and dissolved-solids loads existing in the Redwater River. Slightly larger dissolved-solids concentrations occur in reaches 2, 3, 4, and 5 during March and June if only Tract II is mined, compared to mining Tracts I and II concurrently. This difference in dissolved-solids concentration results from no irrigation occurring in reach 2 when Tract I is mined.

In reach 2, mining of Tract I generally would create a larger increase in dissolved-solids concentration than mining of Tract II, because all the acreage of Tract I is located in reach 2. However, mining of either Tract I or Tract II results in essentially the same increase of dissolved-solids concentrations in reaches 3, 4, and 5 in that both tracts have about the same acreage of mine spoils. Simulations made with different dissolved-solids concentrations of leachate or with variable mined acreages would show differences in dissolved-solids concentrations in reaches 3, 4, and 5.

For each reach of the Redwater River, the mean monthly cumulative percentage of dissolved-solids concentration resulting from agriculture and mining under different mining conditions is given in table 26. Simulation of different combinations of agriculture and mining under mean flow conditions resulted in cumulative percentages of dissolved-solids concentrations in each reach that are less than 5 percent for mining and less than 2 percent for agriculture. The mean cumulative

Table 26.--*Mean monthly cumulative percentage of simulated dissolved-solids concentration in each reach of the Redwater River resulting from irrigation return flow and different mining conditions*[1]

Condition	Reach No.	Percentage of dissolved-solids concentration[2]	
		Irrigation return flow	Mining
No mining	1	0.0	0.0
	2	1.12	.0
	3	.49	.0
	4	.30	.0
	5	.50	.0
Mining[3] Tract I	1	.0	.0
	2	.0	3.58
	3	.0	1.53
	4	.0	.93
	5	.33	.60
Mining Tract II	1	.0	.0
	2	1.08	1.07
	3	.46	1.34
	4	.29	.82
	5	.50	.53
Mining[3] Tracts I and II	1	.0	.0
	2	.0	4.54
	3	.0	2.82
	4	.0	1.73
	5	.32	1.12

[1] Present irrigated acreage consists of 647 acres in reach 1, 180 acres in reach 2 and 135 acres in reach 5; all simulations were run under mean hydrologic flow conditions.

[2] Values for reach 1 indicate percentage in excess of what presently exists in the reach.

[3] Irrigation in reach 2 is set to zero when Tract I is mined.

percentage increase in dissolved solids shows the effect of Tract I having larger acreage in reach 2 than Tract II. The differences in mean cumulative percentage between mining Tract I or Tract II for each of the reaches also result from not including irrigation in reach 2 while Tract I is mined.

Monthly percentage increases of dissolved-solids concentrations in reach 2 resulting from Tracts I and II being mined concurrently under mean flow conditions vary from about 0.1 percent in March to about 12 percent in November. Generally, percentage increases in dissolved-solids concentration are largest from September through January for each mining plan simulated. This condition exists because the dissolved-solids load from mining is constant for each month and composes a larger proportion of the total load during months of minimum streamflow (September through January).

Agricultural development

Agricultural crops have a wide range of tolerance 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 complete protection for alfalfa crops. In the Redwater River, dissolved-solids concentrations for monthly mean streamflows are generally larger than 1,300 mg/L. However, there are periods of large streamflow during spring runoff when the dissolved-solids concentrations are less than 1,300 mg/L. During these periods, water users in the Redwater River drainage divert as much water as possible for irrigation. This method is used by some water users as early as February, if streamflow is large, even though the ground might still be frozen.

Essentially, large dissolved-solids concentrations in the Redwater River prevent expansion of irrigated agriculture in the Redwater River drainage. Unless additional water is imported, irrigation in the drainage probably will not be changed from present operations.

Water is diverted for irrigation in reaches 1, 2, and 5. Because the irrigated acreage along the Redwater River is unlikely to change, additional irrigated acreage was not simulated in any of the reaches. Irrigation rates are set to zero in the model for reaches 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 reaches 1, 2, or 5 can be used internally in the model as a gross estimate of irrigation rates for reaches 3 and 4. However, owing to 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 3 and 4.

The monthly dissolved-solids concentrations for each reach of the Redwater River, using 180 acres irrigated in reach 2 and 135 acres irrigated in reach 5, are given in table 27. Reach 1 is not shown because initial dissolved-solids concentrations at the downstream end are internally programmed in the model based on presently irrigated acres (647 acres).

The mean monthly dissolved-solids concentrations in each reach did not show large variations. In contrast to the inverse relationship between streamflow and dissolved-solids concentration generally observed with instantaneous samples, the mean monthly simulated values showed smaller concentrations during the months with smaller streamflows (September through January).

Table 27.--*Simulated mean monthly dissolved-solids concentration at the downstream end of each reach of the Redwater River and percentage and cumulative percentage of dissolved-solids concentration that result from irrigation without mining*[1,2]

[mg/L, milligrams per liter]

Reach	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
Jan	2,016	0.95	0.95	1,863	0.0	0.42	1,753	0.0	0.27	1,880	0.46	0.65
Feb	2,799	.02	.02	2,783	.0	.01	2,767	.0	<.01	2,781	<.01	<.01
Mar	2,621	.12	.12	2,650	.0	.09	2,680	.0	.07	2,694	.0	.06
Apr	2,730	.02	.02	2,737	.0	.01	2,740	.0	.01	2,764	.0	<.01
May	2,395	.10	.10	2,411	.0	.06	2,432	.0	.04	2,576	.84	.86
June	2,672	.49	.49	2,659	.0	.34	2,652	.0	.25	2,689	.21	.39
July	2,706	.07	.07	2,705	.0	.05	2,712	.0	.03	2,738	.03	.06
Aug	2,569	.39	.39	2,475	.0	.26	2,513	.0	.18	2,467	.18	.31
Sept	2,085	2.13	2.13	2,059	.0	.92	2,096	.0	.55	2,221	.44	.74
Oct	2,061	3.42	3.42	1,983	.0	1.26	1,932	.0	.73	2,179	.59	.98
Nov	2,075	3.45	3.45	2,002	.0	1.25	1,952	.0	.72	2,202	.57	.95
Dec	2,223	2.35	2.35	2,040	.0	1.13	1,945	.0	.71	2,143	.66	1.10

[1]All simulations were run under mean hydrologic flow conditions.
[2]Present irrigated acreage consists of 180 acres in reach 2 and 135 acres in reach 5.

The mean percentage of dissolved-solids concentration resulting from agriculture was larger in reach 2 (1.1 percent) than in reach 5 (0.3 percent). The larger mean percentage in reach 2 probably is affected by the streamflows and dissolved-solids loads in reach 2 than in reach 5. The largest percentage increase in dissolved-solids concentration resulting from agriculture occurred from September to December in reach 2 (table 27). These large percentages arise from maximum irrigation return flow occurring during months of small streamflow and small dissolved-solids load.

SUMMARY

Dissolved-solids concentrations in five reaches of the Redwater River were simulated to assist in evaluating the effects of surface coal mining and agriculture on dissolved-solids concentration. Simulation was performed through use of a mathematical model developed for the Tongue River. Mined acreage, dissolved-solids concentrations in mine spoils, and irrigated acreage can be varied in the model to study relative changes in the dissolved-solids concentration in consecutive reaches of a river. Because of the limited amount of data for the Redwater River drainage, this modeling effort is considered to be an exploratory assessment that indicates areas where more study would be beneficial.

The Redwater River originates in the Big Sheep Mountains about 15 miles south of Brockway, Mont., and flows northward about 130 miles to its confluence with the Missouri River. Flow is perennial in the middle and downstream reaches of the

Redwater River, with the largest volume of sustained streamflow generally occurring during snowmelt in March. Maximum recorded mean monthly streamflows range from 84.8 ft^3/s at Circle to 177 ft^3/s near Vida. Minimum mean monthly streamflows range from 0.24 ft^3/s at Circle to 1.8 ft^3/s near Vida. The mean of measured dissolved-solids concentrations was 2,840 mg/L at Circle and 2,160 mg/L near Vida.

The model calculates a monthly mass-balance routing of streamflow and dissolved-solids load down the main stem of the Redwater River, which is divided into five reaches. Initial streamflow and dissolved-solids concentrations are specified by the user for the downstream end of reach 1, which is located at Circle. These values are affected directly by estimated 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 estimated gains and losses to streamflow and dissolved-solids load from numerous hydrologic components. Output from the model consists of a description of initial conditions specified by the user; a results section giving the monthly volume of streamflow, dissolved-solids load, and dissolved-solids concentration for each reach of the Redwater River; and a section giving a statistical summary of the results.

Because of the limited amount and extreme variability of available data, the model was not conclusively validated as indicated by comparison of simulated streamflow to streamflow calculated from historical records for the Redwater River near Vida. Simulated mean and median monthly mean streamflows are consistently larger than those calculated from actual monthly mean streamflows. Although mean and median monthly mean streamflows are generally within calculated minimum and maximum monthly streamflows, simulated maximum monthly mean streamflows are almost three times larger than calculated maximum monthly mean streamflows. These discrepancies are probably a result of extremely variable streamflow for the Redwater River at Circle, which is used for initial conditions, and overestimation of streamflow from ungaged tributaries to the Redwater River.

Simulated mean and median monthly mean dissolved-solids loads are consistently larger than streamflow-regression-derived values calculated for the Redwater River near Vida. Examination of internal model values indicates that ungaged tributary flow accounts for the large dissolved-solids loads to each reach, which occur in conjunction with the large tributary streamflows. In part, the errors in dissolved-solids loads result from weak correlations between streamflow and dissolved-solids concentration that were developed for use in the model. The weak correlations are manifested in the simulations of minimum, 25th percentile, median, 75th percentile, and maximum hydrologic flow conditions. Without mining, dissolved-solids concentrations for each month decrease with increasing streamflow in reach 1; however, in reaches 2, 3, 4, and 5 dissolved-solids concentrations for each month generally increase with increasing streamflow.

Redwater River reaches 2 and 3 contain acreage designated as being potentially available for leasing. Redwater Tract I is composed of 22,786 acres and Redwater Tract II is composed of 20,246 acres. Simulations were run with spoil leachate dissolved-solids concentration set at 2,880 mg/L.

The largest increase in simulated dissolved-solids concentration as a result of mining occurs in reach 2 when both tracts are mined concurrently. As dissolved-solids load is transported downstream, the effect of mining becomes less apparent, primarily as a result of additional dissolved solids from tributary streams and ground-water inflow composing a larger proportion of the total load. The largest increase in dissolved solids of reach 2 occurs from September through January in response to smaller streamflows and dissolved-solids loads existing in the Redwater River. Simulation of different combinations of agriculture and mining under mean flow conditions resulted in cumulative percentages of dissolved-solids concentrations in each reach that are less than 5 percent for mining and less than 2 percent for agriculture.

Monthly percentage increases of dissolved-solids concentrations in reach 2 resulting from Tracts I and II mined concurrently under mean flow conditions vary from about 0.1 percent in March to about 12 percent in November. Generally, percentage increases in dissolved-solids concentrations are larger from September through January for each mining plan simulated. This condition exists because the dissolved-solids load from mining is constant for each month and composes a larger proportion of the total load during months of minimum streamflow (September through January).

Water is diverted for irrigation in reaches 1, 2, and 5. Because the dissolved-solids concentrations generally are larger than 1,300 mg/L, water is commonly diverted for irrigation during spring runoff when the dissolved-solids concentration is at a minimum. Unless additional water is imported, irrigation in the Redwater River drainage probably will not be changed from present operations.

The mean percentage of dissolved-solids concentration resulting from agriculture was larger in reach 2 (1.1 percent) than in reach 5 (0.3 percent). The largest percentage increase in dissolved-solids concentration resulting from agriculture occurred from September to December in reach 2. These large percentages arise from maximum irrigation return flow occurring during months of small streamflow and small dissolved-solids loads.

REFERENCES CITED

Bondurant, J. A., 1971, Quality of surface irrigation runoff: American Society of Agricultural Engineers Transactions, v. 14, no. 6, p. 1001-1003.

Cannon, M. R., 1983, Potential effects of surface coal mining on the hydrology of the Bloomfield coal tract, Dawson County, eastern Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4229, 33 p.

Collier, A. J., and Knechtel, M. M., 1939, The coal resources of McCone County, Montana: U.S. Geological Survey Bulletin 905, 80 p.

Cruff, R. W., and Thompson, T. H., 1967, A comparison of methods of estimating potential evapotranspiration from climatological data in arid and subhumid environments: U.S. Geological Survey Water-Supply Paper 1839-M, 28 p.

Daniel, J. F., Cable, L. W., and Wolf, R. J., 1970, Ground water-surface water relation during periods of overland flow: U.S. Geological Survey Professional Paper 700-B, p. B219-B223.

Davis, R. E., 1984, Geochemistry and geohydrology of the West Decker and Big Sky coal-mining areas, southeastern Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4225, 109 p.

Farnsworth, R. K., and Thompson, E. S., 1982, Mean monthly, seasonal, and annual pan evaporation for the United States: U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Report NWS 34, 85 p.

International Joint Commission, 1981, Water quality in the Poplar River Basin: 268 p.

Lambing, J. H., 1983, Statistical analysis and evaluation of water-quality data for selected streams in the coal area of east-central Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4224, 89 p.

McKee, J. E., and Wolf, H. W., 1963, Water quality criteria (2d ed): California Water Resources Control Board Publication 3-A, 548 p. (reprinted 1974).

McKinley, P. W., 1979, Water quality of selected streams in the coal area of east-central Montana: U.S. Geological Survey Water-Resources Investigations 78-142, 49 p.

Montana Bureau of Mines and Geology and U.S. Geological Survey, 1978, Ground water of the Fort Union Coal Region, eastern Montana: Montana Bureau of Mines and Geology Special Publication 80, 47 p.

Montana Department of Natural Resources and Conservation, 1979, River mile index of the Yellowstone River: 61 p.

National Academy of Sciences and National Academy of Engineering, 1973 [1974], Water quality criteria, 1972: Washington, D.C., U.S. Government Printing Office, 594 p.

Northern Great Plains Resource Program, Water Work Group-Ground Water Subgroup, 1974, Shallow ground water in selected areas in the Fort Union coal region: U.S. Geological Survey Open-File Report 74-371, 132 p.

Omang, R. J., Parrett, Charles, and Hull, J. A., 1983, Mean annual runoff and peak flow estimates based on channel geometry of streams in southeastern Montana: U.S. Geological Survey Water-Resources Investigations 82-4092, 33 p.

Rahn, P. H., 1975, Ground water in coal strip-mine spoils, Powder River Basin: Montana Academy of Sciences, Proceedings of Fort Union Coal Field Symposium, v. 3, Reclamation Section, p. 348-361.

Roberts, R. S., 1980, Hydrogeologic data for selected coal areas, east-central Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-329, 63 p.

Rorabaugh, M. I., 1964, Estimating changes in bank storage and ground-water contribution to streamflow: International Association of Scientific Hydrology Publication 63, p. 432-441.

Slagle, S. E., 1983, Water resources of the Fort Union coal region, east-central Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4151, 39 p.

Sleight, R. B., 1917, Evaporation from surfaces of water and river bed materials: Journal of Agricultural Research, v. 10, no. 5, p. 209-261.

Stoner, J. D., and Lewis, B. D., 1980, Hydrogeology of the Fort Union coal region, eastern Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1236, 2 sheets.

Struck, D. G., 1975, Conflictive land use; Coal strip mining and agriculture: Western Interstate Commission of Higher Education, 1 sheet.

U.S. Bureau of Land Management, 1981a, Fort Union Coal Region, Redwater I Tract Analysis: Preliminary Facility Evaluation Report 777-116/15, 53 p.

______1981b, Fort Union Coal Region, Redwater II Tract Analysis: Preliminary Facility Evaluation Report, 777-116/15, 53 p.

U.S. Department of Commerce, issued annually, Climatological data, Montana.

U.S. Department of Energy, 1978, Federal coal leasing and 1985 and 1990 coal production forecasts: 26 p.

U.S. Environmental Protection Agency, 1978, Quality criteria for water, July 1976: Washington, D.C., U.S. Government Printing Office, 0-278-727, 256 p.

______1979, National secondary drinking water regulations: Federal Register, v. 44, no. 140, July 19, p. 42195-42202.

U.S. Geological Survey, issued annually, Water resources data for Montana: U.S. Geological Survey Water-Data Report.

______1974, Stripping coal deposits of the Northern Great Plains, Montana, Wyoming, North Dakota, and South Dakota: U.S. Geological Survey Miscellaneous Field Studies Map MF-590, 1 sheet.

Van Voast, W. A., 1974, Hydrologic effects of strip coal mining in southeastern Montana--Emphasis, one year of mining near Decker: Montana Bureau of Mines and Geology Bulletin 93, 24 p.

Van Voast, W. A., Hedges, R. B., and McDermott, J. J., 1978a, Strip coal mining and mined-land reclamation in the hydrologic system, southeastern Montana: Billings, Mont., Old West Regional Commission, Project completion report of OWRC grant 10570165, 122 p.

______1978b, Hydrologic characteristics of coal-mine spoils, southeastern Montana: Bozeman, Montana University Joint Water Resources Research Center Report 94, 34 p.

Winter, T. C., 1981, Uncertainties in estimating the water balance of lakes: Water Resources Bulletin, v. 17, no. 1, p. 82-115.

Woessner, W. W., Andrews, C. B., and Osborne, T. J., 1979, The impacts of coal strip mining on the hydrogeologic system of the Northern Great Plains--Case study of potential impacts on the Northern Cheyenne Reservation, *in* Back, William, and Stephenson, D. A., eds., Contemporary hydrogeology--The George Burke Maxey Memorial Volume: Journal of Hydrology, v. 43, p. 445-467.

Woessner, W. W., Osborne, T. J., Heffern, E. L., Andrews, Charles, Whiteman, Jason, Spotted Elk, Wesley, and Morales-Brink, Daniel, 1981, Hydrologic impacts from potential coal strip mining--Northern Cheyenne Reservation, Volume I: U.S. Environmental Protection Agency, EPA-600/781-004a, 302 p.

Woods, P. F., 1981, Modeled impacts of surface coal mining on dissolved solids in the Tongue River, southeastern Montana: U.S. Geological Survey Water-Resources Investigations 81-64, 73 p.

Yevjevich, Vujica, 1972, Probability and statistics in hydrology: Fort Collins, Colo., Water Resources Publications, 302 p.

SUPPLEMENTAL INFORMATION

Table 28.--*Definition of model variables*

AIR	Area (in acres) irrigated in each of five reaches of the Redwater River
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 in each reach of the Redwater River
AMR	Area (in acres) mined in each of five reaches of the Redwater River
AUT	Area (in acres) of ungaged tributaries in each of five reaches of the Redwater River
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 in each reach due to irrigation return flow
CPDSMR	Cumulative percentage of dissolved-solids concentration in each reach due to mining
CV	Divisor to convert monthly discharge (in acre-feet) to mean daily streamflow (in cubic feet per second)
DDSCRC	Designator for dissolved-solids concentration in the Redwater River at Circle
DICER	Depth (in feet) of ice change in each reach
DSARIR	Dissolved solids (in tons per acre) in antecedent return flow from irrigation in the Redwater River 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 in each of five reaches of the Redwater River

DSCRC	Dissolved-solids concentration (in milligrams per liter) at the Redwater River at Circle
DSCRCU	Designator for dissolved-solids concentration of the Redwater River at Circle
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 with irrigation from the Redwater River
DSLGW	Dissolved-solids load (in tons) in ground-water flow
DSLMR	Dissolved-solids load (in tons) from coal mines in each of five reaches of the Redwater River
DSLOL	Dissolved-solids load (in tons) in other water losses
DSLRIR	Dissolved-solids load (in tons) returning with irrigation to the Redwater River
DSLRC	Dissolved-solids load (in tons) in the Redwater River at Circle
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) from the surface of the Redwater River
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 the Redwater River resulting from irrigation
PDSMR	Percentage of dissolved-solids concentration in the Redwater River resulting from mining

PT	Monthly distribution of precipitation (in acre-feet per acre) on the surface of the Redwater River
QARFIR	Antecedent return flow (in acre-feet per acre) from irrigated acreage in each reach of the Redwater River
QD	Monthly streamflow (in acre-feet) at downstream end of each reach of the Redwater River
QDIR	Streamflow (in acre-feet) diverted for irrigation from the Redwater River
QET	Monthly evaporation (in acre-feet) from the stream surface of the Redwater River
QEVTR	Monthly evapotranspiration (in acre-feet) from riparian vegetation along the Redwater River
QGW	Flow of ground water (in acre-feet per mile per day) to the Redwater River
QGWRR	Flow of ground water (in acre-feet) for each reach of the Redwater River
QICER	Gain or loss of streamflow (in acre-feet) as ice from the Redwater River
QOL	Other monthly losses of streamflow (in acre-feet) from the Redwater River
QOLR	Other annual losses of streamflow (in acre-feet) from the Redwater River
QPT	Monthly precipitation (in acre-feet) received in each reach of the Redwater River
QRFIR	Return flow (in acre-feet) from irrigation in each reach of the Redwater River
QRC	Monthly streamflow (in acre-feet) for the Redwater River at Circle
QU	Monthly streamflow (in acre-feet) at upstream end of each reach of the Redwater River
QUT	Streamflow (in acre-feet) to the Redwater River from ungaged tributaries in each reach
RA	Surface area (in acres) of each reach of the Redwater River
RC	Monthly runoff coefficients (in acre-feet per acre) for ungaged tributaries to each reach of the Redwater River
RCARR	Annual runoff coefficients (in inches) for each reach of the Redwater River
RCRR 2-5	Monthly runoff coefficients (in acre-feet) for reaches 2 through 5 of the Redwater River

Table 28.--*Definition of model variables*--Continued

RL	Reach length (in miles)
RRC	Initial streamflow (in acre-feet) and dissolved solids (tons and milligrams per liter) conditions at Redwater River at Circle
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 at 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 29.--*Listing of computer program*

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                                                                               *
C                    REDWATER RIVER DISSOLVED SOLIDS MODEL                      *
C                                                                               *
C    PROGRAM TO COMPUTE DISSOLVED SOLIDS (SALINITY) CONDITIONS FOR FIVE         *
C    REACHES IN REDWATER RIVER, MONTANA FROM THE HEADWATERS TO                  *
C    REDWATER RIVER NEAR VIDA.                                                  *
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      DDSCRC = DESIGNATOR FOR DISSOLVED SOLIDS CONCENTRATION AT REDWATER       *
C             RIVER AT CIRCLE                                                   *
C             ENTER 0 FOR REGRESSION-DERIVED VALUES OR ENTER 1 FOR              *
C             USER-DEFINED VALUES                                               *
C      DSCRCU = USER-DEFINED MONTHLY VALUE FOR DISSOLVED SOLIDS                 *
C              CONCENTRATION AT REDWATER RIVER AT CIRCLE                        *
C      AIR = AREA (ACRES) IRRIGATED ON EACH OF FIVE REACHES ON REDWATER RIVER*
C      AMR = ACREAGE OF SURFACE COAL MINES ON EACH OF FIVE REACHES ON           *
C            REDWATER RIVER                                                     *
C      DSCMR = DISSOLVED SOLIDS CONCENTRATION (MG/L) OF LEACHATE FROM           *
C             SURFACE COAL MINES ON EACH OF FIVE REACHES ON REDWATER RIVER      *
C      QOLR = OTHER WATER LOSSES FROM EACH OF FIVE REACHES ON REDWATER RIVER *
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 = DDSCRC,DSCRCU             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),DDSCRC,DSCRCU(12),DSLRC(12),DSCRC
     *(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'/
      OPEN (5,FILE='REDIN',STATUS='OLD')
      OPEN (6,FILE='OUTRED',STATUS='NEW')
      DO 1 I=1,12
    1 M(I)=MX(I)
CCCCC     READ INPUT DATA FROM CARDS
      READ(5,5)SN,MHC
      READ(5,7)DDSCRC,DSCRCU
      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('1REDWATER RIVER DISSOLVED SOLIDS MODEL--- SIMULATION NUMBE
     *R ',A5,//)
      IF(DDSCRC.EQ.0) WRITE(6,18)
      IF(DDSCRC.EQ.1) WRITE(6,20)
   18 FORMAT(' DESIGNATOR FOR DISSOLVED-SOLIDS INPUT AT REDWATER RIVER A
     *T CIRCLE SET TO REGRESSION-DEFINED STATUS')
   20 FORMAT(' DESIGNATOR FOR DISSOLVED-SOLIDS INPUT AT REDWATER RIVER A
     *T CIRCLE 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 ',//,
     *'0   EXCESS OF PRESENTLY IRRIGATED ACRES (647 ACRES)')
      WRITE(6,50)
      WRITE(6,52)
   50 FORMAT('0SURFACE COAL MINING STATUS DURING SIMULATION')
   52 FORMAT(' ********************************************')
      WRITE(6,54)
      WRITE(6,56)
```

Table 29.--*Listing of computer program*--Continued

```
      WRITE(6,58)
   54 FORMAT('0                     DISSOLVED SOLIDS                          DI
     *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 110.2')
   82 FORMAT('  2  = RIVER MILE 110.2 TO RIVER MILE 90.8 (INCLUDES DUCK,
     *TUSLER, AND MCCUNE CREEKS)')
   84 FORMAT('  3  = RIVER MILE 90.8 TO RIVER MILE  69.5 (INCLUDES LOST,
     *HORSE, AND COTTON WOOD CREEKS)')
   86 FORMAT('  4  = RIVER MILE  69.5 TO RIVER MILE  57.2 (INCLUDES COW,
     *PASTURE, AND SULLIVAN CREEKS)')
   88 FORMAT('  5  = RIVER MILE  57.2 TO RIVER MILE 30.6 (INCLUDES WOLF
     *CREEK AND EAST REDWATER RIVER)'//)
   89 FORMAT(' RRC = INITIAL CONDITIONS AT REDWATER RIVER AT CIRCLE')
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
      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,'REDWATER R. AT CIRCLE',T67,'REDWATER R. NEAR VIDA'/,' ',T9,'---
     *---------------------------  --------------------  -----------
     *-----------'/,' MONTH  REDWATER  CIRCLE  REDWATER R. VIDA  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 REDWATER RIVER, 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
          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('OSIMULATION NUMBER ',A5,' TERMINATED DUE TO INVALID MONTHL
         *Y HYDROLOGIC CONDITION IN MONTH NUMBER ',I2)
          GO TO 1020
     1020 CLOSE (5)
          CLOSE (6)
          STOP
          END
    C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
    CCCCC     SUBROUTINE BLOCK DATA --- CONTAINS DATA FOR SIX STREAMFLOW
    CCCCC     CONDITIONS USED IN THE MODEL
          BLOCK DATA
          COMMON / DATA / QRC(6,12),PT(6,12),ET(6,12),RCRR2(6,12),RCRR3
         *(6,12),RCRR4(6,12),RCRR5(6,12)
          DATA QRC /
         *15.,    2.5,    .001,   8.6,    377.,   .001,
         *983.,   26.,    .56,    605.,   7830.,  .001,
         *5210.,  1780.,  282.,   6830.,  23900., 3.1,
         *1330.,  211.,   67.,    613.,   24900., 4.2,
         *247.,   98.,    38.,    295.,   1970.,  1.2,
         *958.,   164.,   36.,    1190.,  9940.,  .001,
         *849.,   17.,    3.7,    478.,   7130.,  .001,
         *150.,   3.7,    .61,    62.,    2280.,  .001,
         *24.,    4.2,    .001,    15.,    331.,   .001,
         *14.,    7.4,    1.2,    14.8,   166.,   .001,
         *14.,    6.6,    1.2,    13.,    161.,   .001,
         *23.,    4.9,    .001,   12.,    528.,   .001/
          DATA PT /
         *.048,   .038,   .020,   .074,   .163,   .005,
         *.036,   .028,   .016,   .048,   .136,   .002,
         *.052,   .043,   .028,   .065,   .128,   .005,
         *.104,   .080,   .049,   .140,   .361,   .004,
         *.158,   .135,   .076,   .198,   .567,   .015,
         *.261,   .247,   .144,   .331,   .576,   .036,
         *.157,   .134,   .085,   .219,   .460,   .015,
         *.109,   .093,   .039,   .161,   .383,   .002,
         *.096,   .055,   .036,   .128,   .384,   .003,
         *.065,   .049,   .024,   .097,   .282,   .0,
         *.041,   .035,   .017,   .060,   .115,   .001,
```

```
     *.041,    .038,    .018,    .057,    .169,    .003/
      DATA ET /
     *.0,      .0,      .0,      .0,      .0,      .0,
     *.065,    .059,    .079,    .054,    .048,    .082,
     *.099,    .091,    .121,    .082,    .073,    .125,
     *.269,    .246,    .328,    .222,    .198,    .338,
     *.406,    .414,    .465,    .330,    .248,    .567,
     *.436,    .444,    .471,    .406,    .311,    .610,
     *.492,    .487,    .534,    .437,    .364,    .626,
     *.420,    .427,    .471,    .365,    .274,    .558,
     *.247,    .230,    .294,    .201,    .134,    .402,
     *.162,    .153,    .198,    .114,    .068,    .296,
     *.065,    .062,    .079,    .046,    .027,    .119,
     *.065,    .062,    .079,    .046,    .027,    .119/
      DATA RCRR2 /
     *.09,     .02,     .0,      .05,     2.30,    .0,
     *6.70,    .20,     .01,     4.15,    53.40,   .0,
     *32.09,   10.91,   1.60,    42.04,   146.97,  .03,
     *8.42,    1.35,    .42,     3.87,    157.79,  .03,
     *1.51,    .60,     .23,     1.80,    12.05,   .01,
     *6.09,    1.04,    .24,     7.55,    63.15,   .0,
     *5.21,    .10,     .02,     2.92,    43.82,   .0,
     *.92,     .02,     .0,      .38,     13.95,   .0,
     *.15,     .03,     .0,      .09,     2.03,    .0,
     *.09,     .05,     .01,     .09,     1.06,    .0,
     *.09,     .04,     .01,     .08,     1.01,    .0,
     *.14,     .03,     .0,      .08,     3.25,    .0/
      DATA RCRR3 /
     *.16,     .09,     .01,     .20,     2.24,    .0,
     *8.40,    .25,     .08,     10.33,   54.18,   .0,
     *25.37,   12.18,   2.03,    35.26,   104.02,  .76,
     *13.65,   2.46,    .96,     6.83,    171.85,  .27,
     *2.84,    1.16,    .51,     3.83,    17.24,   .11,
     *6.36,    2.04,    .45,     10.68,   43.57,   .13,
     *6.20,    .43,     .06,     10.54,   37.32,   .03,
     *1.16,    .36,     .05,     .89,     11.33,   .0,
     *.49,     .14,     .04,     .36,     4.49,    .03,
     *.35,     .23,     .11,     .42,     2.50,    .05,
     *.37,     .26,     .11,     .43,     2.44,    .06,
     *.30,     .18,     .09,     .29,     3.77,    .02/
      DATA RCRR4 /
     *.15,     .08,     .01,     .19,     2.10,    .0,
     *7.83,    .23,     .08,     9.63,    50.50,   .0,
     *23.63,   11.34,   1.89,    32.85,   96.88,   .71,
     *12.72,   2.29,    .89,     6.36,    160.14,  .25,
     *2.64,    1.08,    .48,     3.56,    16.02,   .11,
     *5.92,    1.89,    .41,     9.95,    40.55,   .12,
     *5.77,    .40,     .06,     9.81,    34.74,   .03,
     *1.08,    .33,     .04,     .83,     10.55,   .0,
     *.45,     .13,     .04,     .33,     4.12,    .03,
     *.33,     .21,     .10,     .39,     2.36,    .05,
     *.34,     .23,     .11,     .39,     2.24,    .06,
     *.28,     .17,     .08,     .27,     3.51,    .01/
      DATA RCRR5/
     *.17,     .16,     .03,     .33,     .41,     .0,
     *7.92,    .24,     .16,     14.49,   38.97,   .0,
     *13.53,   8.25,    1.49,    19.75,   48.84,   .81,
     *15.04,   2.86,    1.35,    7.97,    96.86,   .60,
```

Table 29.--*Listing of computer program*--Continued

```
      *3.33,   1.40,   .67,    5.03,   13.82,  .27,
      *5.10,   2.40,   .51,    10.76,  16.98,  .20,
      *5.60,   .67,    .06,    15.90,  20.27,  .06,
      *1.08,   .64,    .09,    1.21,   4.73,   .0,
      *.66,    .26,    .12,    .55,    3.14,   .09,
      *.50,    .39,    .26,    .67,    1.28,   .14,
      *.52,    .48,    .28,    .73,    1.0,    .17,
      *.37,    .36,    .22,    .52,    .71,    .04/
       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 / QRC(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),DDSCRC,DSCRCU(12),
      *DSLRC(12),DSCRC(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(5,12),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 / 1804., 1300., 1562., 1219., 983. /
       DATA DSCUT / .01, 2863., 2851., 2820., 2816. /
       DATA RA /
      *.1,   .2,   .7,   .7,   2.0,
      *.1, 14.7, 35.6, 34.3,  96.9,
      *.1, 70.5, 92.0, 58.5, 165.2,
      *.1, 18.6, 61.2, 65.1, 183.8,
      *.1,  3.3, 13.0, 14.4,  40.6,
      *.1, 13.4, 25.7, 22.1,  62.3,
      *.1, 11.5, 25.9, 24.2,  68.4,
      *.1,  2.0,  4.9,  4.7,  13.2,
      *.1,   .4,  2.3,  2.8,   7.9,
      *.1,   .2,  1.7,  2.1,   6.1,
      *.1,   .2,  1.8,  2.2,   6.2,
      *.1,   .3,  1.5,  1.6,   4.6 /
       DATA RL / .01, 19.4, 21.3, 12.3, 26.6 /
       DATA AUT / 350080.,214400.,120960.,221440.,356480./
       DATA QGW /
      *.0017, .0717, .1555, .2822, .0228,
      *-.0004,.0716, .1555, .2822, .0253,
      *.0716, .1758, .2046, .3558, .0714,
      *.1728, .3038, .2537, .4292, .1159,
      *.2626, .4197, .3027, .5027, .1211,
      *.3517, .5225, .3518, .5762, .1823,
      *.2339, .3417, .2648, .3488, .1910,
      *.1162, .1485, .1777, .1215, .1810,
      *.0582, .1096, .1666, .2019, .1018,
      *.0001, .0709, .1555, .2822, .0228,
      *.0002, .0708, .1555, .2822, .0227,
      *.0015, .0717, .1555, .2822, .0228/
       DATA MND / 31,28,31,30,31,30,31,31,30,31,30,31/
       DATA DICER /
      *.1,  .0,  .0,  .0,  .0,
```

Table 29.--*Listing of computer program*--Continued

```
     *.1,  .0,  .0,  .0,  .0,
     *.1, +.5, +.5, +.5, +.5,
     *.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, -.5, -.5, -.5, -.5/
      DATA RCARR / .100, .100 , .100, .100, .100 /
      DATA DSARIR /
     *.02657, .01920, .0, .0, .09849,
     *.00432, .01920, .0, .0, .03491,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0./
      DATA AIRFS /
     *.0,   .0,   .0,   .0,   .0,
     *.04,  .0,   .0,   .0,   .0,
     *.16,   .24, .0,   .0,   .0,
     *.43,  .0,   .0,   .0,   .0,
     *.14,  .0,   .0,   .0,   .67,
     *.06,   .24, .0,   .0,   .33,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0.,
     *5*0./
      DATA AIRPS /
     *.0,   .0,   .0,   .0,   .0,
     *.02,  .0,   .0,   .0,   .0,
     *.08,  .12,  .0,   .0,   .0,
     *.22,  .0,   .0,   .0,   .0,
     *.07,  .0,   .0,   .0,   .34,
     *.03,  .12,  .0,   .0,   .16,
     *5*0.,
     *5*.0,
     *5*.0,
     *5*.0,
     *5*.0,
     *5*.0/
      DATA QARFIR /
     *.0049, .0029, .0,    .0,    .0242,
     *.0015, .0029, .0,    .0,    .0080,
     *5*.0,
     *5*.0,
     *5*.0,
     *5*.0,
```

Table 29.--*Listing of computer program*--Continued

```
     *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)=QRC(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)
      QEVTR(J)=(2.0*QET(J))/1.08
      IF(I.LT.5.OR.I.GT.9) QEVTR(J)=0
      QGWRR(J)=RL(J)*QGW(J,I)*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
      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.QRC(MHC,I).EQ.0) DSLU(I,J)=0
      IF(J.EQ.1.AND.QRC(MHC,I).EQ.0) GO TO 65
      IF(J.EQ.1.AND.DDSCRC.EQ.0) DSLU(I,J) = C*QRC(MHC,I)*
     *(10**(3.46068140-(.00108614*((QRC(MHC,I))/CV))))
      IF(J.EQ.1.AND.DDSCRC.EQ.1) DSLU(I,J) = DSCRCU(I)*QRC(MHC,I)*C
   65 DSLRC(I)=DSLU(I,1)
      DSCRC(I)=(DSLU(I,1)/QRC(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)*(.3333)
      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),QRC(MHC,I),DSLRC(I),DSCRC(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,'RRC',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('0SIMULATION NUMBER ',A5,' TERMINATED DUE TO ZERO OR NEGATI
     *VE STREAMFLOW IN REACH NUMBER ',I1,' DURING MONTH NUMBER ',I2)
       CLOSE (5)
       CLOSE (6)
       STOP
       END
```

Table 30.--*Example of model output*

```
REDWATER RIVER DISSOLVED SOLIDS MODEL--- SIMULATION NUMBER     1

DESIGNATOR FOR DISSOLVED-SOLIDS INPUT AT REDWATER RIVER AT CIRCLE SET TO REGRESSION-DEFINED STATUS

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

 1  = HEADWATER REACH UPSTREAM FROM RIVER MILE 110.2
 2  = RIVER MILE 110.2 TO RIVER MILE 90.8 (INCLUDES DUCK,TUSLER, AND MCCUNE CREEKS)
 3  = RIVER MILE 90.8 TO RIVER MILE  69.5 (INCLUDES LOST,HORSE, AND COTTON WOOD CREEKS)
 4  = RIVER MILE  69.5 TO RIVER MILE  57.2 (INCLUDES COW,PASTURE, AND SULLIVAN CREEKS)
 5  = RIVER MILE  57.2 TO RIVER MILE 30.6 (INCLUDES WOLF CREEK AND EAST REDWATER RIVER)


RRC = INITIAL CONDITIONS AT REDWATER RIVER AT CIRCLE

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 =   180. REACH 3 =      0.
REACH 4 =      0. REACH 5 =   135.
   NOTE - IRRIGATED ACRES IN REACH 1 ARE THOSE IN

   EXCESS OF PRESENTLY IRRIGATED ACRES (647 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       0.             0.
  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.
```

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	RRC	15.	59.	2887.				
	1	15.	59.	2887.	0.0000	0.0000	0.0000	0.0000
	2	78.	214.	2016.	0.9538	0.0000	0.9538	0.0000
	3	200.	507.	1863.	0.0000	0.0000	0.4220	0.0000
	4	341.	813.	1753.	0.0000	0.0000	0.2725	0.0000
	5	424.	1083.	1880.	0.4599	0.0000	0.6581	0.0000
FEB	RRC	983.	3694.	2763.				
	1	983.	3694.	2763.	0.0000	0.0000	0.0000	0.0000
	2	2458.	9360.	2799.	0.0157	0.0000	0.0157	0.0000
	3	3566.	13497.	2783.	0.0000	0.0000	0.0110	0.0000
	4	5396.	20307.	2767.	0.0000	0.0000	0.0073	0.0000
	5	8237.	31150.	2781.	0.0020	0.0000	0.0068	0.0000
MAR	RRC	5210.	16559.	2337.				
	1	5210.	16559.	2337.	0.0000	0.0000	0.0000	0.0000
	2	12200.	43486.	2621.	0.1161	0.0000	0.1161	0.0000
	3	15446.	55672.	2650.	0.0000	0.0000	0.0928	0.0000
	4	20840.	75965.	2680.	0.0000	0.0000	0.0695	0.0000
	5	25797.	94516.	2694.	0.0000	0.0000	0.0564	0.0000
APR	RRC	1330.	4941.	2732.				
	1	1330.	4941.	2732.	0.0000	0.0000	0.0000	0.0000
	2	3310.	12288.	2730.	0.0173	0.0000	0.0173	0.0000
	3	5113.	19035.	2737.	0.0000	0.0000	0.0111	0.0000
	4	8078.	30100.	2740.	0.0000	0.0000	0.0070	0.0000
	5	13501.	50757.	2764.	0.0000	0.0000	0.0041	0.0000
MAY	RRC	247.	961.	2860.				
	1	247.	961.	2860.	0.0000	0.0000	0.0000	0.0000
	2	821.	2673.	2395.	0.0976	0.0000	0.0976	0.0000
	3	1351.	4430.	2411.	0.0000	0.0000	0.0584	0.0000
	4	2113.	6990.	2432.	0.0000	0.0000	0.0365	0.0000
	5	3302.	11565.	2576.	0.8356	0.0000	0.8559	0.0000
JUNE	RRC	958.	3615.	2775.				
	1	958.	3615.	2775.	0.0000	0.0000	0.0000	0.0000
	2	2528.	9185.	2672.	0.4929	0.0000	0.4929	0.0000
	3	3497.	12646.	2659.	0.0000	0.0000	0.3555	0.0000
	4	4999.	18026.	2652.	0.0000	0.0000	0.2484	0.0000
	5	6875.	25140.	2689.	0.2111	0.0000	0.3934	0.0000

Table 30.--*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	RRC	849.	3222.	2791.				
	1	849.	3222.	2791.	0.0000	0.0000	0.0000	0.0000
	2	2159.	7948.	2706.	0.0686	0.0000	0.0686	0.0000
	3	3052.	11227.	2705.	0.0000	0.0000	0.0486	0.0000
	4	4432.	16348.	2712.	0.0000	0.0000	0.0332	0.0000
	5	6504.	24224.	2738.	0.0329	0.0000	0.0550	0.0000
AUG	RRC	150.	586.	2871.				
	1	150.	586.	2871.	0.0000	0.0000	0.0000	0.0000
	2	436.	1525.	2569.	0.3850	0.0000	0.3850	0.0000
	3	689.	2318.	2475.	0.0000	0.0000	0.2644	0.0000
	4	969.	3312.	2513.	0.0000	0.0000	0.1816	0.0000
	5	1492.	5006.	2467.	0.1836	0.0000	0.3068	0.0000
SEPT	RRC	24.	94.	2886.				
	1	24.	94.	2886.	0.0000	0.0000	0.0000	0.0000
	2	122.	345.	2085.	2.1264	0.0000	2.1264	0.0000
	3	286.	801.	2059.	0.0000	0.0000	0.9164	0.0000
	4	459.	1307.	2096.	0.0000	0.0000	0.5524	0.0000
	5	774.	2337.	2221.	0.4409	0.0000	0.7365	0.0000
OCT	RRC	14.	55.	2887.				
	1	14.	55.	2887.	0.0000	0.0000	0.0000	0.0000
	2	78.	219.	2061.	3.4240	0.0000	3.4240	0.0000
	3	223.	601.	1983.	0.0000	0.0000	1.2612	0.0000
	4	403.	1060.	1932.	0.0000	0.0000	0.7260	0.0000
	5	603.	1787.	2179.	0.5876	0.0000	0.9819	0.0000
NOV	RRC	14.	55.	2887.				
	1	14.	55.	2887.	0.0000	0.0000	0.0000	0.0000
	2	77.	216.	2075.	3.4473	0.0000	3.4473	0.0000
	3	221.	601.	2002.	0.0000	0.0000	1.2526	0.0000
	4	400.	1062.	1952.	0.0000	0.0000	0.7187	0.0000
	5	607.	1816.	2202.	0.5728	0.0000	0.9572	0.0000
DEC	RRC	23.	90.	2886.				
	1	23.	90.	2886.	0.0000	0.0000	0.0000	0.0000
	2	98.	297.	2223.	2.3515	0.0000	2.3515	0.0000
	3	236.	655.	2040.	0.0000	0.0000	1.1308	0.0000
	4	405.	1072.	1945.	0.0000	0.0000	0.7142	0.0000
	5	557.	1622.	2143.	0.6579	0.0000	1.0995	0.0000

SIMULATION SUMMARY -- SIMULATION NUMBER 1
****

MONTH	STREAMFLOW (ACRE-FEET) REDWATER CIRCLE	REDWATER R. VIDA	DISSOLVED SOLIDS REDWATER R. AT CIRCLE LOAD(TON	CONC(MG/L)	REDWATER R. NEAR VIDA LOAD(TON)	CONC(MG/L)
JAN	15.	424.	59.	2887.	1083.	1880.
FEB	983.	8237.	3694.	2763.	31150.	2781.
MAR	5210.	25797.	16559.	2337.	94516.	2694.
APR	1330.	13501.	4941.	2732.	50757.	2764.
MAY	247.	3302.	961.	2860.	11565.	2576.
JUNE	958.	6875.	3615.	2775.	25140.	2689.
JULY	849.	6504.	3222.	2791.	24224.	2738.
AUG	150.	1492.	586.	2871.	5006.	2467.
SEPT	24.	774.	94.	2886.	2337.	2221.
OCT	14.	603.	55.	2887.	1787.	2179.
NOV	14.	607.	55.	2887.	1816.	2202.
DEC	23.	557.	90.	2886.	1622.	2143.

REACH	MONTHLY DISSOLVED SOLIDS CONC (MG/L) MEAN	STD DEV	MIN	MAX	MEAN PERCENT CONCENTRATION DUE TO RETURN FLOW	MINING	MEAN CUMULATIVE PERCENT CONCENTRATION DUE TO RETURN FLOW	MINING
1	2797.	156.	2337.	2887.	0.0000	0.0000	0.0000	0.0000
2	2413.	303.	2016.	2799.	1.1247	0.0000	1.1247	0.0000
3	2364.	349.	1863.	2783.	0.0000	0.0000	0.4854	0.0000
4	2348.	382.	1753.	2767.	0.0000	0.0000	0.2973	0.0000
5	2444.	306.	1880.	2781.	0.3320	0.0000	0.5093	0.0000

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