MODELED IMPACTS OF SURFACE COAL MINING ON DISSOLVED SOLIDS IN THE TONGUE RIVER, SOUTHEASTERN MONTANA

U.S GEOLOGICAL SURVEY

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16. Abstract (Limit: 200 words)

A computer model has been developed for spatial and temporal simulation of streamflow and dissolved solids in the Tongue River from the Tongue River Dam to Miles City, Montana. User-defined plans of surface coal mining and agricultural development permit evaluation of potential changes in dissolved solids resulting from leaching of overburden material used to backfill mine pits and from withdrawal and return flow of irrigation water. Provision is made for simulation runs using increased streamflow from a proposed larger reservoir intended to replace the present Tongue River Reservoir.

Simulations at mean streamflow indicated that mining 119,600 acres of Federally leased coal tracts may increase by 4.8 percent the present annual dissolved-solids concentration in the Tongue River at Miles City. Simulations using the proposed Tongue River Reservoir show substantial reductions in dissolved-solids concentration when paired with similar simulations using the present Tongue River Reservoir. When compared on a per-acre basis for the study area, the dewatering caused by irrigation increases dissolved-solids concentration more than the input of leachates from surface coal-mining operations.

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Front cover: Photograph showing the Tongue River in the vicinity of Birney Day School Bridge, about 6.5 miles downstream from Birney. View is upstream

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UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

WATER RESOURCES DIVISION
428 Federal Building 301 South Park
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December 15, 1981

To: Recipients of report, "Modeled impacts of surface coal mining on dissolved solids in the Tongue River, southeastern Montana," by Paul F. Woods

The report was recently released as U.S. Geological Survey report Water-Resources Investigations 81-64, and is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

Lines 588 and 589 of table 2 (page 61) have been modified to the wording shown below. The modifications do not affect any data, tables, or results in the report other than just the listing of the computer program.

```
588.        IF(IRD.EQ.0.OR.IRD.EQ.1.AND.INDEX.EQ.6)QIRD(INDEX,I)=QIRD(INDEX,I)
589.        IF(IRD.EQ.1.AND.INDEX.EQ.1)QIRD(INDEX,I)=QIRD(INDEX,I)*2.05
```

The modifications can be made to your copy by pen and ink or the modified lines taped over the original printed copy.

For the District Chief

Robert S. Roberts
Robert S. Roberts

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METRIC CONVERSION TABLE

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

Multiply inch-pound unit	by	To obtain SI unit
acre	4047	square meter
acre-foot	1233	cubic meter
acre-foot per acre	0.3048	cubic meter per square meter
acre-foot per river mile per day	766.3	cubic meter per kilometer per day
cubic feet per day	0.0003278	liter per second
cubic foot per second	28.32	liter per second
foot	0.3048	meter
inch	25.40	millimeter
inch per acre	0.006276	millimeter per square meter
mile	1.609	kilometer
square foot	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram
ton per acre	0.0002241	megagram per square meter
ton per acre-foot	0.0007357	megagram per cubic meter

MODELED IMPACTS OF SURFACE COAL MINING ON DISSOLVED SOLIDS IN THE TONGUE RIVER, SOUTHEASTERN MONTANA

By

Paul F. Woods

ABSTRACT

A computer model has been developed for assessing potential increases in dissolved solids of streams as a result of leaching of overburden materials used to backfill pits in surface coal-mining operations in southeastern Montana. The model allows spatial and temporal simulation of streamflow and dissolved-solids loads and concentrations for user-defined plans of surface coal mining and agricultural development. The model specifically addresses the Tongue River from the Tongue River Dam to Miles City, Montana, and its three major tributaries, Hanging Woman, Otter, and Pumpkin Creeks. Provision is made to simulate releases from the present Tongue River Reservoir or the increased releases expected from a larger dam and reservoir proposed as a replacement for the present Tongue River Reservoir.

The model routes an input quantity of streamflow and dissolved solids from the upstream end to the downstream end of a stream reach while algebraically accounting for gains and losses of streamflow and dissolved solids within the stream reach. Data used to program the computational routines of the model are evaluated in terms of the model's predictive capability.

A hypothetical plan was formulated for the mining of all Federally owned coal judged potentially available for mining. Under this plan, a simulation using mean streamflow from the present Tongue River Reservoir indicates that the mean annual dissolved-solids concentration of 646 milligrams per liter with no mining is increased by mining to 677 milligrams per liter. When the proposed Tongue River Reservoir is used in the simulation, the shift in dissolved-solids concentration is from 436 to 451 milligrams per liter, which is illustrative of the dilutional effect of increased streamflow on concentration. Calculations were performed with data representative of the study area to determine the relative impacts of irrigation and surface coal mining on unit area basis in a hypothetical stream. The dissolved-solids concentration of the hypothetical stream was determined to increase annually by 2.94 percent as a result of withdrawal and return flow of irrigation water and by 0.22 percent as a result of leachates from surface coal mines.

The computer program is written in FORTRAN language. A listing of the computer program, input data requirements, definitions of all variables in the model, and an example output will permit use of the model by interested persons. Input data needed to operate the model include the following: simulation number, designation of hydrologic conditions for each simulated month, designation of present or proposed Tongue River Reservoir, either user-defined or regression-defined concentrations of dissolved solids input by the Tongue River Reservoir, number of irrigated acres, number of mined acres, dissolved-solids concentration of mine leachates, and quantity of other water losses.

INTRODUCTION

The U.S. Department of Energy (1978) has projected that by 1990 about one-half of the coal production in the United States will be from the Western States. Surface coal mining, the predominant method of coal extraction in the Western States, has rapidly increased in recent years with much of the increase occurring in Wyoming and Montana. The economically strippable coal resources of Montana are estimated to be 50 billion tons (Clack, 1976) with about 75 percent of such resources located in southeastern Montana. Strippable coal deposits in southeastern Montana are the object of currently operating and proposed surface coal mines.

Water-quality impacts from surface coal mining are a major concern along the Tongue River in semiarid southeastern Montana (fig. 1), where many of the coal beds are important aquifers. The quality of the water obtainable from these aquifers may be degraded by mining. Surface mining involves removal and stockpiling of overburden materials (spoils) in strips adjacent to the pit containing the coal. Following extraction of the coal, the pit is backfilled with the spoils. Dissolved solids may be leached from the backfilled spoils as ground water and recharge water move through the materials. Pagenkopf, Whiteworth, and Van Voast (1977) determined that spoils from the Decker and Rosebud Mines (fig. 1) yielded large quantities of soluble salts when subjected to column leaching experiments. Van Voast, Hedges, and McDermott (1978a) compared the dissolved-solids concentration of water from spoils at the Rosebud and Decker Mines to the dissolved-solids concentration of water from nearby observation wells completed in coal aquifers. At the Rosebud Mine, the mean dissolved-solids concentration of water from spoils was significantly larger than in coal aquifers. At the Decker Mine, the mean dissolved-solids concentration of water from spoils was not significantly different from that in the coal aquifers. Van Voast, Hedges, and McDermott (1978b) emphasized the variability in dissolved-solids concentration of water from spoils and hypothesized that it was due to variability in saturated thickness in the spoils, lack of complete circulation of water within the spoils, and complexity of the salt distribution within the spoils.

Some ground water discharges to streams, adding its load of spoils-derived dissolved solids to streams. If such loads are large enough, streamflow will show an increase in dissolved-solids concentration.

Increased dissolved-solids concentrations resulting from surface coal mining may conflict with the water needs of the agricultural industry downstream from the mined areas. Agriculture is Montana's principal industry and accounts for much of the consumptive use of water in southeastern Montana (Koch and others, 1977). Water used for irrigating crops in southeastern Montana is derived primarily from surface sources, not from ground water. The amount of dissolved solids, commonly referred to as salinity in agricultural usage, in irrigation water has important implications to the success of irrigated crops.

Irrigation water used in arid to semiarid regions may have some detrimental effects on salinity-sensitive crops if the dissolved-solids concentration ranges from 500 to 1,000 mg/L (milligrams per liter); concentrations in excess of 1,000 mg/L may adversely affect many crops (U.S. Environmental Protection Agency, 1976). Dissolved-solids concentrations at four U.S. Geological Survey study sites on the Tongue River ranged from 176 to 912 mg/L during 1975-76; concentrations in the three major tributaries, Hanging Woman, Otter, and Pumpkin Creeks, had a much wider range (Knapton and McKinley, 1977). Klarich and Thomas (1977) considered Tongue River

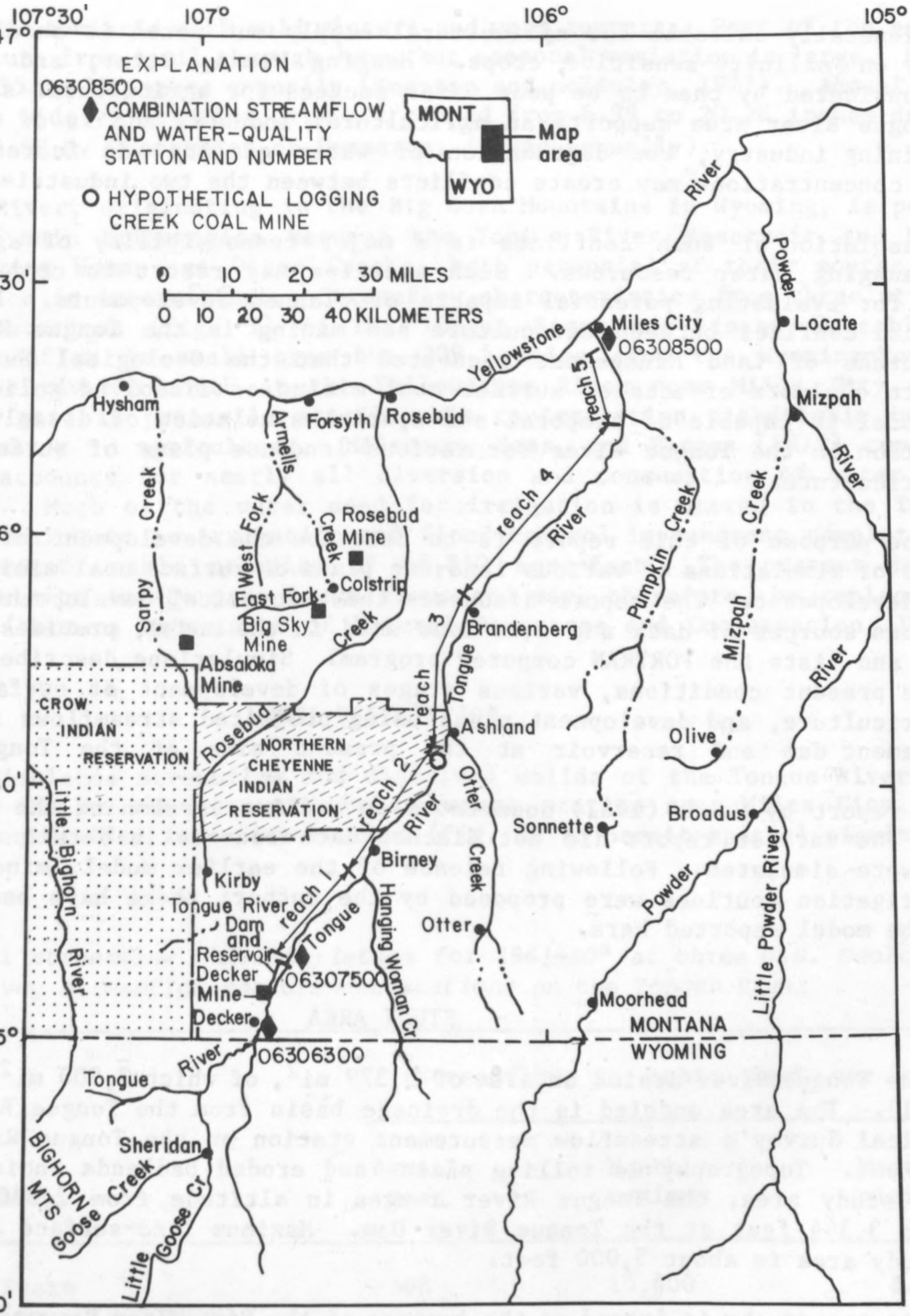

Figure 1.--Location of the Tongue River, selected surface coal mines, and reaches simulated by the model.

water generally suitable for agricultural supply but noted it should be used cautiously on salinity-sensitive crops. Hanging Woman, Otter, and Pumpkin Creeks were considered by them to be poor water sources for agricultural supply. Because the Tongue River area supports an agricultural industry and is of interest to the coal-mining industry, the degradation of water quality via increased dissolved-solids concentrations may create conflicts between the two industries.

Resolution of such conflicts is a major responsibility of agencies charged with managing water resources. Such agencies may resort to computer simulation models for evaluating potential impacts of planned developments. Recognizing the potential conflict between agriculture and mining in the Tongue River area, the U.S. Bureau of Land Management requested that the Geological Survey develop a model to evaluate effects of surface coal mining on dissolved solids. The resultant model is capable of temporal and spatial simulation of dissolved-solids concentration in the Tongue River for various land-use plans of surface coal mining and agriculture.

The purpose of this report is to describe the development of the model and results of simulations of various land-use plans of surface coal mining and agricultural development. The report discusses the theoretical development of the model, describes sources of data and equations used in the model, provides input instructions, and lists the FORTRAN computer program. Simulations described in the report include present conditions, various stages of development of surface coal mining and agriculture, and development plans using projected streamflows from a proposed replacement dam and reservoir at the present site of the Tongue River Dam.

A report by Woods (1981) documented an earlier version of the model discussed here. The earlier report did not discuss data sources in detail and no land-use plans were simulated. Following release of the earlier model, minor revisions to its irrigation routines were proposed by the author; these have been incorporated into the model reported here.

STUDY AREA

The Tongue River drains an area of 5,379 mi^2, of which 3,900 mi^2 are in Montana (fig. 1). The area modeled is the drainage basin from the Tongue River Dam to the Geological Survey's streamflow measurement station on the Tongue River near Miles City, Mont. Topography is rolling plains and eroded badlands incised by streams. In the study area, the Tongue River ranges in altitude from 2,330 feet at Miles City to 3,344 feet at the Tongue River Dam. Maximum land-surface altitude within the study area is about 5,000 feet.

The topography is formed on the surface of the Fort Union Formation of Paleocene age. This geologic unit is comprised of flat-lying sedimentary beds of sandstone, shale, and coal that have been described by Lewis and Roberts (1978). The Fort Union Formation consists of three members: the basal Tullock Member, the Lebo Shale Member, and the overlying Tongue River Member. The Tongue River Member contains numerous sub-bituminous coal beds that are economically attractive because of their shallow depth, large thickness, large areal coverage, and small-sulfur content. The Tongue River Member is also the principal shallow aquifer of the study area (Lee, 1980).

The climate is semiarid with cold winters and warm summers. Most of the annual precipitation occurs from April through June, but seasonal variation is large. Snowfall ranges from 35 to 50 inches annually (Knapton and McKinley, 1977). Annual precipitation varies widely; at Miles City, it ranged from 6.99 to 20.28 inches during 1947 through 1978 (U.S. Department of Commerce, issued annually).

The Tongue River, originating in the Big Horn Mountains in Wyoming, is perennial. The three main tributaries between the Tongue River Reservoir and Miles City include Hanging Woman and Otter Creeks, both perennial at their mouths, and Pumpkin Creek which is intermittent. Streamflow characteristics from three streamflow-measurement stations (fig. 1) on the Tongue River are listed in table 1. The gain in streamflow is small over the 209.5 miles from the Wyoming-Montana State line to the river's mouth at the Yellowstone River near Miles City. The smallness of the gain is primarily attributable to irrigation withdrawals by the area's major industry -- agriculture. Melancon, Hess, and Thomas (1979) reported that irrigation accounts for nearly all diversion and consumption of water from the Tongue River. Much of the water used for irrigation is stored in the Tongue River Reservoir, which is an irrigation and flood-control impoundment completed in 1939, with a present usable capacity of 68,040 acre-feet. The present dam is considered unlikely to safely pass large flows and may, therefore, be replaced by a new structure (Montana Department of Natural Resources and Conservation, 1980).

MODEL DESCRIPTION

The model simulates streamflow and dissolved solids of the Tongue River from the Tongue River Dam to the streamflow-measurement station near Miles City. The Tongue River is subdivided into five reaches (fig. 1) to permit spatial simulation.

Table 1.--*Annual streamflow characteristics for 1961-80*[a] *at three U.S. Geological Survey streamflow-measurement stations on the Tongue River*

	Streamflow, in cubic feet per second		
Station and number	Annual mean	Monthly maximum	Monthly minimum
Tongue River at State near Decker, Montana (06306300)	508	15,400	5.4
Tongue River at Tongue River Dam, near Decker, Montana (06307500)	512	9,580	3.0
Tongue River at Miles City, Montana (06308500)	526	9,290	3.6

[a] Longest concurrent period of record for the three stations.

River mileages are based on a report of the Montana Department of Natural Resources and Conservation (1976). Model time step is monthly and each simulation is for a calendar year. The FORTRAN computer program (table 2) is composed of nine subroutines linked as shown in figure 2 and described in table 3. Model variables are defined in table 4.

Theoretical development

Streamflow and dissolved solids at the downstream end of a reach are simulated by routing an input quantity of streamflow and dissolved solids from the upstream end of the reach. Gains and losses to streamflow and dissolved solids within the reach are accounted for algebraically during routing. Although the model assumes a travel time of 1 month, the actual travel time from the Tongue River Dam to Miles City is largely dependent on streamflow magnitude. Using empirical equations presented by Boning (1974), the travel time for the mean annual streamflow was estimated to be 10 days. Conceptually, the monthly streamflow from the Tongue River Reservoir is instantaneously routed to Miles City; gains and losses to this routed streamflow occur simultaneously. Routing of streamflow and dissolved solids is accomplished by two primary equations.

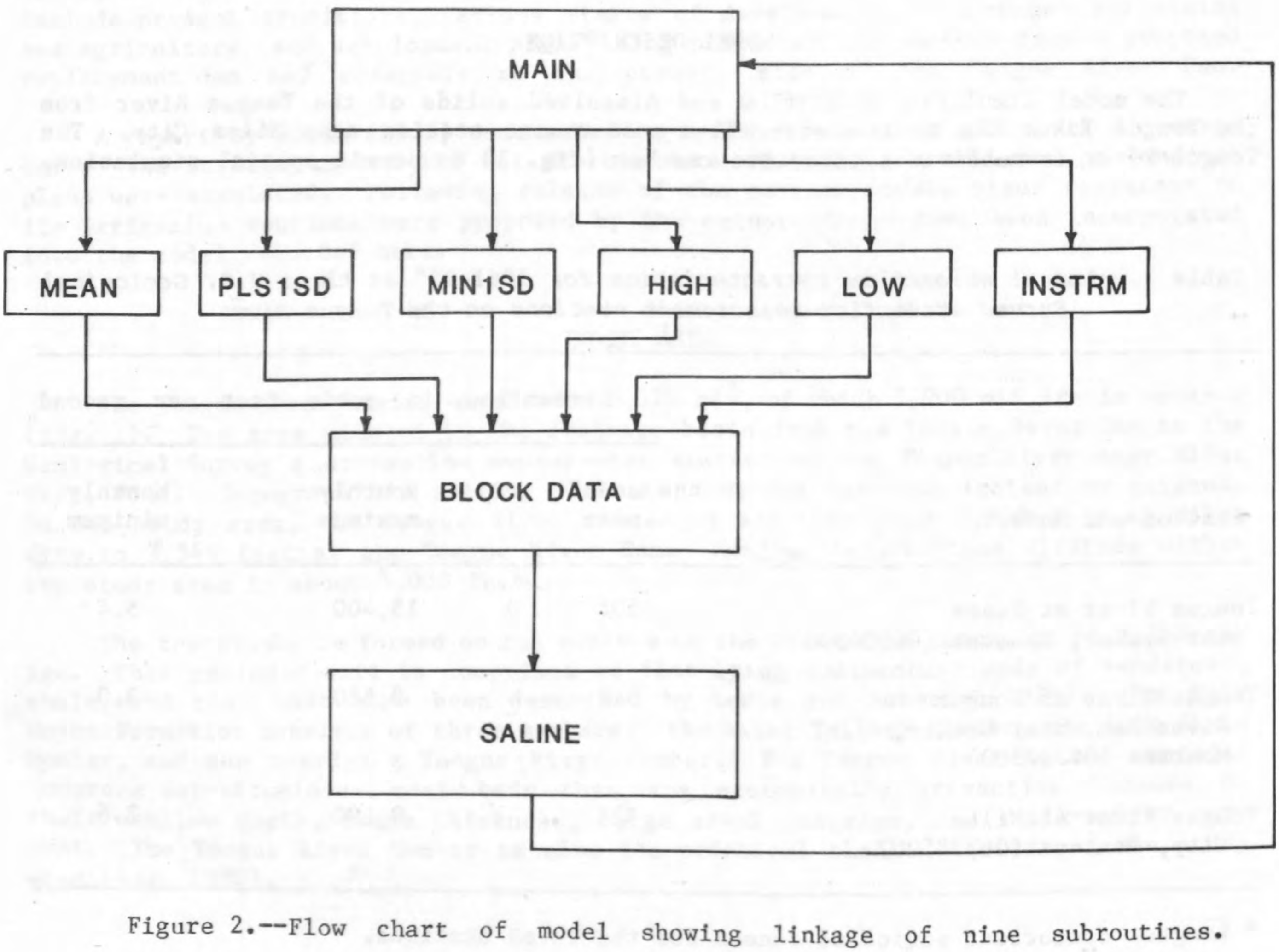

Figure 2.--Flow chart of model showing linkage of nine subroutines.

Table 3.--*Description of model subroutines*

Subroutine name	Subroutine description
MAIN	Reads input data, writes simulation conditions, calls appropriate subroutines for passage of data to subroutine SALINE, writes headings for output of monthly results, performs statistical analyses of monthly results, and writes headings and results for simulation summary
BLOCK DATA	Contains data for six streamflow conditions used in the model
MEAN	Passes data associated with mean streamflow to subroutine SALINE
PLS1SD	Passes data associated with plus one standard deviation streamflow to subroutine SALINE
MIN1SD	Passes data associated with minus one standard deviation streamflow to subroutine SALINE
HIGH	Passes data associated with historic maximum streamflow to subroutine SALINE
LOW	Passes data associated with historic minimum streamflow to subroutine SALINE
INSTRM	Passes data associated with instream flow requirements to subroutine SALINE
SALINE	Calculates hydrologic and dissolved solids mass balances for five reaches of the Tongue River plus Hanging Woman, Otter, and Pumpkin Creeks and writes results of monthly computations

The streamflow balance of a reach is computed by the first primary equation:

$$Q_{OUT} = Q_{IN} + Q_P - Q_E + Q_{GW} + Q_{GA} + Q_{UGA} - Q_{IR} + Q_{IB} + Q_{IRF} - Q_{ID} - Q_{OL} \qquad (1)$$

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

Q_{OUT} is streamflow at downstream end of reach,
Q_{IN} is streamflow at upstream end of reach,
Q_P is precipitation received on stream surface,
Q_E is evaporation loss from stream surface,
Q_{GW} is ground-water inflow,
Q_{GA} is streamflow from gaged tributaries,
Q_{UGA} is streamflow from ungaged tributaries,
Q_{IR} is volume of streamflow stored as ice,
Q_{IB} is volume of streamflow input by ice breakup,
Q_{IRF} is volume of irrigation return flow,
Q_{ID} is volume of irrigation water removed, and
Q_{OL} is volume of other water losses.

The dissolved-solids balance of a reach is computed by the second primary equation:

$$S_{OUT} = [(S_{IN} \times Q_{IN}) + (S_{GW} \times Q_{GW}) + (S_{GA} \times Q_{GA}) + (S_{UGA} \times Q_{UGA}) + (S_{IRF} \times Q_{IRF}) - (S_{ID} \times Q_{ID}) - (S_{OL} \times Q_{OL})] \times f \tag{2}$$

where all concentrations are in milligrams per liter, and
S_{OUT} is dissolved-solids load (in tons per month) at downstream end of reach,
S_{IN} is dissolved-solids concentration at upstream end of reach,
S_{GW} is dissolved-solids concentration of ground water,
S_{GA} is dissolved-solids concentration of gaged tributaries,
S_{UGA} is dissolved-solids concentration of ungaged tributaries,
S_{IRF} is dissolved-solids concentration of irrigation return flow,
S_{ID} is dissolved-solids concentration of irrigation water removed,
S_{OL} is dissolved-solids concentration of other water losses,
f is a factor (0.00136) to convert streamflow in acre-feet per month and dissolved-solids concentration in milligrams per liter into dissolved-solids load in tons per month, and
the remaining variables are as defined for equation 1.

Streamflow and dissolved-solids load at the downstream end of the reach are used to compute dissolved-solids concentration in milligrams per liter as follows:

$$DS_{OUT} = \frac{S_{OUT}}{Q_{OUT} \times f} \tag{3}$$

where DS_{OUT} is dissolved-solids concentration, in milligrams per liter;
S_{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) to convert streamflow in acre-feet per month and dissolved-solids load in tons per month to dissolved-solids concentration in milligrams per liter.

Numerous peripheral equations are used to compute values for input to the two primary equations. Development of these peripheral equations is described in the following sections.

Hydrologic components

Comparison of the impacts on dissolved solids caused by various plans for surface coal mining is the major intended use of this model. To facilitate comparability, simulated hydrologic conditions were restricted to a discrete number (six) instead of using stochastic methods to generate hydrologic conditions. The six hydrologic conditions are based on streamflow data because dissolved solids and streamflow are highly correlated. Hydrologic conditions, on a monthly basis, include the mean, plus one and minus one standard deviation from the mean, historic maximum and minimum flows, and instream flows. Instream flows are the minimum flows necessary for maintenance of the existing physical and biological stream environment. In the instance of streamflow and runoff coefficients for Hanging Woman, Otter, and Pumpkin Creeks, the mean is replaced by the 50th percentile, the plus one standard deviation from the mean is replaced with the 75th percentile, and the minus one standard deviation from the mean is replaced by the 25th percentile.

Gaged streamflow

Releases from the Tongue River Reservoir provide the initial input for each month of simulation (table 5). Except for instream flows, the six hydrologic conditions were developed from a statistical analysis of streamflow records spanning 1948 to 1980 for a Geological Survey streamflow-measurement station downstream from and near the Tongue River Dam. Instream-flow conditions were obtained from the Missouri River Basin Commission (1978). Changes in bank storage during a simulated month are assumed to equal zero or to be a negligible amount; therefore, no component for bank storage is included in the model.

The period of record at the Tongue River Dam greatly exceeds that available for Hanging Woman, Otter, and Pumpkin Creeks, each of which had 8 years of record or less. For small samples of hydrologic data, Yevjevich (1972) cautions that the 50th percentile, rather than the mean, is a better estimator of central tendency, especially when the data contain extreme values. Because the three tributaries have such extreme values, the 50th percentile is used to estimate their most likely streamflow, and standard deviations are replaced by the 25th and 75th percentiles (table 5).

The Montana Department of Natural Resources and Conservation (1980) has concluded that the present Tongue River Dam would likely fail in a moderately large flood. Their recommendation is to enlarge the spillway and raise the dam to increase reservoir capacity. The present reservoir has a usable capacity of 68,040 acre-feet and provides 40,000 acre-feet of firm annual yield. The proposed reservoir would have a usable capacity of 130,000 acre-feet and would provide 82,000 acre-feet of firm annual yield. This increased capacity is simulated in this report because the additional streamflow would be available to the Tongue River within the study area. Monthly releases from the proposed reservoir have not been calculated, but the ratio of firm annual yields for the present and proposed reservoir is 2.05. Therefore, the monthly releases from the proposed reservoir are simulated as 205 percent of the mean monthly releases from the present reservoir. Mean releases are simulated because no data are yet available for statistical estimation of variations from the mean. Instream flows listed in table 5 are simulated as the minimum streamflows that would be released from the proposed reservoir. If construction of the proposed dam is authorized, and project planning and construction proceed as scheduled, the Montana Department of Natural Resources and Conservation (1980) estimates the project could be in place as early as October 1990.

Ungaged streamflow

Streamflow from ungaged tributaries is estimated by using runoff coefficients based on unit area. These coefficients were calculated from gaged streamflow data for Hanging Woman, Otter, and Pumpkin Creeks. Runoff coefficients for Hanging Woman Creek are applied to ungaged tributaries in Tongue River reach 1, those from Otter Creek are applied to Tongue River reaches 2 and 3, and those from Pumpkin Creek are applied to Tongue River reaches 4 and 5 (table 6).

Table 5.--*Gaged streamflow for six modeled hydrologic conditions for releases from present and proposed Tongue River Reservoirs and Hanging Woman, Otter, and Pumpkin Creeks*

Hydrologic condition	Streamflow, in acre-feet per month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Tongue River Reservoir						
Mean[a]	10,800	10,580	15,390	24,770	63,390	90,450	35,170	22,560	18,130	16,730	15,120	12,120
Plus one standard deviation	13,350	15,520	24,560	37,490	95,550	145,350	57,010	31,220	25,480	24,580	22,820	15,770
Minus one standard deviation	8,250	5,640	6,220	12,050	31,230	35,550	13,330	13,900	10,780	8,880	7,430	8,470
Historic maximum	15,060	32,880	41,550	57,020	166,900	223,300	128,100	47,190	40,850	31,320	30,110	19,680
Historic minimum	4,910	3,160	1,400	6,830	11,970	13,980	10,390	6,700	7,740	4,740	2,420	5,320
Instream[b]	9,220	8,330	9,220	8,920	23,700	41,640	12,790	9,220	8,920	11,680	11,300	9,220
						Hanging Woman Creek						
50th percentile	175	150	413	225	210	183	225	85	45	75	95	115
75th percentile	825	525	544	325	375	762	262	116	76	92	162	191
25th percentile	88	138	262	158	105	125	88	38	34	49	64	74
Historic maximum	1,300	1,220	5,730	1,030	6,060	769	390	129	139	186	182	194
Historic minimum	62	64	133	117	67	88	27	10	16	46	54	58
Instream	175	150	413	225	210	183	225	85	45	75	95	115
						Otter Creek						
50th percentile	300	550	750	500	525	300	167	80	80	133	233	233
75th percentile	400	650	1,800	600	900	500	350	200	150	200	300	300
25th percentile	233	300	500	433	375	233	100	40	40	67	167	167
Historic maximum	1,850	1,940	6,550	1,670	3,270	936	549	259	243	272	364	432
Historic minimum	162	154	413	270	263	138	17	5	8	25	121	165
Instream	300	550	750	500	525	300	167	80	80	133	233	233
						Pumpkin Creek						
50th percentile	172	600	800	900	800	300	200	16	200	16	16	16
75th percentile	257	900	6,000	2,100	2,000	2,100	300	30	300	30	30	30
25th percentile	86	200	400	300	400	150	100	8	100	8	8	8
Historic maximum	1,120	6,770	18,400	5,000	12,580	3,820	1,100	344	3,560	72	158	45
Historic minimum	1	1	25	12	1	1	1	1	1	1	1	1
Instream	172	600	800	900	800	300	200	16	200	16	16	16

[a]Monthly mean releases from proposed Tongue River Reservoir are 205 percent of monthly mean releases from present Tongue River Reservoir.

[b]Monthly minimum releases from proposed Tongue River Reservoir are equal to monthly instream flows for present Tongue River Reservoir.

Table 6.--*Runoff coefficients for six modeled hydrologic conditions for ungaged streamflow from five Tongue River reaches*

Hydrologic condition	Runoff coefficient, in acre-feet per acre per month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Tongue River reach 1						
50th percentile	0.00058	0.00050	0.00137	0.00075	0.00070	0.00061	0.00075	0.00028	0.00015	0.00025	0.00032	0.00038
75th percentile	.00274	.00175	.00181	.00108	.00125	.00253	.00087	.00039	.00025	.00031	.00054	.00063
25th percentile	.00029	.00046	.00087	.00053	.00035	.00042	.00029	.00013	.00011	.00016	.00021	.00025
Historic maximum	.00274	.00175	.00181	.00108	.00125	.00253	.00087	.00039	.00025	.00031	.00054	.00063
Historic minimum	.00029	.00046	.00087	.00053	.00035	.00042	.00029	.00013	.00011	.00016	.00021	.00025
Instream	.00058	.00050	.00137	.00075	.00070	.00061	.00075	.00028	.00015	.00025	.00032	.00038
						Tongue River reaches 2 and 3						
50th percentile	.00066	.00122	.00166	.00111	.00116	.00066	.00037	.00018	.00018	.00029	.00051	.00051
75th percentile	.00088	.00144	.00398	.00133	.00199	.00111	.00077	.00044	.00033	.00044	.00061	.00066
25th percentile	.00051	.00066	.00111	.00096	.00083	.00051	.00022	.00009	.00009	.00015	.00037	.00037
Historic maximum	.00088	.00144	.00398	.00133	.00199	.00111	.00077	.00044	.00033	.00044	.00066	.00066
Historic minimum	.00051	.00066	.00111	.00096	.00083	.00051	.00022	.00009	.00009	.00015	.00037	.00037
Instream	.00066	.00122	.00166	.00111	.00116	.00066	.00037	.00018	.00018	.00029	.00051	.00051
						Tongue River reaches 4 and 5						
50th percentile	.00039	.00135	.00179	.00202	.00179	.00067	.00045	.00004	.00045	.00004	.00004	.00004
75th percentile	.00058	.00202	.01345	.00471	.00448	.00471	.00067	.00007	.00067	.00007	.00007	.00007
25th percentile	.00019	.00045	.00090	.00067	.00090	.00034	.00022	.00002	.00022	.00002	.00002	.00002
Historic maximum	.00058	.00202	.01345	.00471	.00448	.00471	.00067	.00007	.00067	.00007	.00007	.00007
Historic minimum	.00019	.00045	.00090	.00067	.00090	.00034	.00022	.00002	.00022	.00002	.00002	.00002
Instream	.00039	.00135	.00179	.00202	.00179	.00067	.00045	.00004	.00045	.00004	.00004	.00004

Precipitation and evaporation

Precipitation records are available for a number of stations within or near the study area; however, most are of short duration or are incomplete. The longest and most complete record is for Miles City FAA Airport (near Miles City, Mont., fig. 1). Based on 41 years of record, the mean annual precipitation at that station is 13.93 inches. The monthly precipitation data for the model were statistically derived from the 1949-78 records for the Miles City station so they would correspond to the 1948-80 streamflow data used in the model.

Evaporation data applicable to the study area are available for Sheridan Field Station (20 miles south of Decker, Mont., fig. 1), which has a period of record of 1951-79. The data were recorded with a National Weather Service Class A pan and were, therefore, converted to corrected evaporation by application of a 0.7 coefficient as suggested by Hewlett and Nutter (1969). The mean annual corrected evaporation at the Sheridan station is 37.9 inches.

In the model, monthly amounts of precipitation and corrected evaporation (table 7) are applied only to the stream surface areas of the Tongue River. This approach is used because inflows to the Tongue River from gaged and ungaged tributaries are not computed by hydrologic mass balance but are derived from analysis of historic streamflow records, which include the effects of precipitation and evaporation.

Table 7.--*Precipitation and corrected evaporation (in acre-feet per acre per month) for six modeled hydrologic conditions*

[P, precipitation; E, evaporation]

	Hydrologic condition											
	Mean		Plus one standard deviation		Minus one standard deviation		Historic maximum		Historic minimum		Instream flow	
Month	P	E	P	E	P	E	P	E	P	E	P	E
Jan.	0.049	0.058	0.081	0.050	0.018	0.067	0.148	0.042	0.007	0.092	0.049	0.058
Feb.	.047	.058	.073	.050	.020	.067	.108	.042	.007	.092	.047	.058
Mar.	.054	.117	.090	.092	.018	.142	.153	.083	.006	.175	.054	.117
Apr.	.114	.217	.196	.175	.033	.258	.352	.150	.008	.325	.114	.217
May	.194	.358	.323	.283	.066	.433	.568	.242	.020	.533	.194	.358
June	.232	.450	.341	.333	.123	.567	.436	.275	.070	.842	.232	.450
July	.123	.575	.217	.475	.030	.667	.376	.408	.008	.808	.123	.575
Aug.	.099	.550	.192	.450	.007	.650	.333	.425	.001	.775	.099	.550
Sept.	.095	.358	.180	.292	.010	.425	.335	.233	.001	.508	.095	.358
Oct.	.078	.258	.178	.208	.001	.308	.526	.183	.001	.383	.078	.258
Nov.	.050	.117	.093	.092	.008	.142	.180	.083	.002	.175	.050	.117
Dec.	.050	.058	.088	.050	.013	.067	.148	.042	.002	.092	.050	.058

Irrigation withdrawal and return flow

Irrigation withdrawals and return flows are important components of the model, because agriculture accounts for much of the consumptive use of water in the study area. Unfortunately, data are not available for actual volumes of irrigation withdrawals and return flows in the study area. These volumes were estimated by applying agricultural engineering practices to estimates of irrigated acreages (Woessner and others, 1981).

Irrigation withdrawal rates for the Tongue River are patterned after those measured from 1945 through 1967 at the Huntley Project, an irrigation diversion on the Yellowstone River near Billings, Mont. (77 miles southwest of Hysham, fig. 1). These historic data were also used in a water planning model developed for Montana by Boyd and Williams (1974). The Huntley Project data represent the only long-term information available and were judged likely to be applicable for the Tongue River. When the model's hydrologic condition is set to mean, plus one standard deviation, or historic maximum the model provides complete service irrigation (table 8) for the five Tongue River reaches. Partial service irrigation (table 8) is provided the Tongue River reaches when the hydrologic condition is set to minus one standard deviation, historic minimum, or instream flow. Hanging Woman, Otter, and Pumpkin Creeks receive partial irrigation service under all six hydrologic conditions. Complete and partial service irrigation provides water from April through October, but only one-half of the volume is provided by partial service from July through October.

Table 8.--*Monthly rates of irrigation withdrawal for complete and partial service irrigation*

Month	Withdrawal, in acre-feet per acre per month	
	Complete service irrigation	Partial service irrigation
Jan.	0	0
Feb.	0	0
Mar.	0	0
Apr.	.06	.06
May	.94	.94
June	1.14	1.14
July	1.52	.76
Aug.	1.41	.70
Sept.	1.06	.53
Oct.	.27	.13
Nov.	0	0
Dec.	0	0

Tributary irrigation in the model is handled differently than Tongue River irrigation. Tributary streamflow is derived from statistical analysis of historic streamflow data and, as such, integrates all hydrologic components, including irrigation withdrawals, within the tributary drainage basin. Therefore, irrigation withdrawal rates for the three major tributaries are applied only to acreages in excess of those presently (1980) irrigated in that particular drainage basin.

Return flow occurs when irrigation water is applied in excess of the evapotranspiration requirements (consumptive use) of plants. Some of the applied water may percolate beneath shallow aquifers and be lost from the return-flow system. The remaining water returns to the stream via surface or shallow-subsurface flow. No quantitative data on actual return-flow rates were found for the study area. However, agricultural engineering estimates for the Tongue River (Woessner and others, 1981) indicate that about one-half of the water applied for irrigation returns to the stream--65 percent returns during the month of application, and 35 percent returns in equal increments during the next 8 months. Modeled return flow for a month includes the return flow component of that month's irrigation withdrawal and the return flows emanating during prior months. In addition, some return flow from the previous year's irrigation lags into the simulated year and, therefore, is added to modeled return flow. These antecedent return flows are computed with the assumption that the previous year's irrigation was done under mean hydrologic conditions. On an acre-foot per acre basis, the antecedent return flows are of the following magnitudes per month: January, 0.1532; February, 0.1306; March, 0.103; April, 0.0662; May, 0.0321; June, 0.0065; and July through September, 0.0. Only the Tongue River reaches receive antecedent return flows because such flows to the three tributaries are insignificant.

About 22,000 acres of irrigated and potentially irrigable land are within the Tongue River basin of Montana (Old West Regional Commission, 1979). This acreage is defined as land with soils, topography, and drainage characteristics suitable for gravity or sprinkler irrigation. Another estimate of irrigated and potentially irrigable land within the study area (table 9) was provided by Glen Smith (Montana Department of Natural Resources and Conservation, Helena, Mont., written commun., 1980). These data are a 1975 update of those compiled by the Montana State Engineer's Office (1947, 1948a, b, 1961). The estimates of potentially irrigable land provided by Glen Smith were derived from a land-classification survey that neglected water availability or economic feasibility for irrigation. The ratio between the Old West Regional Commission's and Glen Smith's estimates of irrigable land is 0.8; therefore, values in table 9 were obtained by multiplication of Glen Smith's values by 0.8 to arrive at the upper limit of potentially irrigable land within each reach of the study area.

Table 9.--*Acreage of irrigated and additional potentially irrigable land*

Location	Irrigated acres	Additional potentially irrigable acres
Tongue River		
Reach 1	1,250	1,500
Reach 2	3,400	2,650
Reach 3	3,550	3,800
Reach 4	5,100	4,850
Reach 5	1,700	2,150
Hanging Woman Creek	1,225	1,000
Otter Creek	785	2,400
Pumpkin Creek	2,875	4,000

Ground water

Ground-water inflow was estimated from base-flow studies conducted November 2-5, 1977, on the Tongue River as reported by Lee, Slagle, and Stimson (1981). Analysis of their data indicated an overall ground-water inflow rate of 0.82 acre-foot per river mile per day, which equals 4,453 acre-feet of inflow in November for the 181-mile length of modeled river. Correcting for irrigation return flow that comprised part of the measured ground-water inflow, the volume of irrigation return flow in November for the modeled river distance was calculated to be 2,248 acre-feet. This value is based on an irrigated acreage of 14,500 acres and an irrigation return flow rate of 0.155 acre-foot per acre. Accordingly, the overall ground-water inflow rate measured by Lee, Slagle, and Stimson (1981) was reduced by 50 percent, to 0.41 acre-foot per river mile per day. In the model, each reach has a ground-water inflow rate (table 10), which is 50 percent of the rate measured by Lee, Slagle, and Stimson (1981) for that particular reach.

Table 10.--*Daily ground-water inflow rate per river mile and per each reach of the Tongue River*

Tongue River reach	Reach length (miles)	Inflow, in acre-feet per day: Per river mile	Per reach
1	32.4	0.09	2.92
2	44.0	.67	29.48
3	35.1	.37	12.99
4	57.6	.41	23.62
5	11.9	.35	4.16

Ground-water inflow may be approximated by the dry-weather streamflow in exceedence of 90 percent flow duration (W. T. Stuart, U.S. Geological Survey, written commun., 1965). The 90-percent flow duration reported for the Tongue River at Miles City is 43,439 acre-feet (Moore and Shields, 1980). This annual flow, divided by a model river distance of 181 miles and a year length of 365 days, yields a daily ground-water inflow rate of 0.66 acre-foot per river mile. This rate is bracketed by the daily rate determined from the study of Lee, Slagle, and Stimson (1981), and the reduced daily rate calculated in this study.

Ice storage and breakup

Part of Tongue River streamflow is stored as ice during winter. Process-oriented models of ice storage and breakup are complex and beyond the scope of this model; therefore, ice storage for the model is estimated from ice-thickness data obtained by the Geological Survey during streamflow measurements on the Tongue River at the Tongue River Dam, near Ashland, near Brandenberg Bridge (Brandenberg, fig. 1), and at Miles City. Analysis of 9 years of that data indicated that ice generally occurred from December through February. During a simulation, streamflow is converted to ice based on surface area and average ice thickness of the reach being computed. In March, the quantity of streamflow removed as ice in the preceding 3 months is converted back to streamflow. Ice storage in reach 1 is reduced by 50 percent because records show that ice formation is partly inhibited by releases from the Tongue River Dam. Owing to lack of correlation between ice thickness and streamflow conditions, the same ice formation and breakup values (table 11) are used in all simulations.

Other water losses

Provision is made for the model user to designate additional water losses. These losses could be due to the water requirements of specific industries, such as coal gasification plants, coal-fired electrical generating plants, or others. Hanging Woman, Otter, and Pumpkin Creeks are assumed to have insufficient streamflow for such industries. If these facilities are sited on the three tributaries, the water supply is drawn from the Tongue River. Other water losses for Hanging Woman Creek

Table 11.--*Ice thickness and monthly ice storage for Tongue River reaches*

Reach	Stream reach area (acres)	January Thickness (feet)	January Storage (acre-feet)	February Thickness (feet)	February Storage (acre-feet)	December Thickness (feet)	December Storage (acre-feet)
1[a]	471	0.75	176.6	0.75	176.6	0.5	117.8
2	640	.75	480.0	.75	480.0	.5	320.0
3	511	.75	383.2	.75	383.2	.5	255.5
4	838	.75	628.5	1.00	838.0	.5	419.0
5	173	1.00	173.0	1.00	173.0	.5	86.5

[a]Ice storage value has been reduced 50 percent to account for suppression of ice formation in upstream part of reach affected by releases from Tongue River Reservoir.

are withdrawn from Tongue River reach 1, Otter Creek withdrawals are from Tongue River reach 2, and Tongue River reach 4 supplies Pumpkin Creek.

Dissolved-solids components

Most of the dissolved-solids loads are computed by multiplying the volume of a hydrologic component by its associated dissolved-solids concentration. These concentrations are derived by various means described in the following sections. The hydrologic components of precipitation, evaporation, ice storage, and ice breakup are not associated with a dissolved-solids concentration but they do affect dissolved-solids concentrations by addition or removal of streamflow.

Gaged and ungaged streamflow

Where streamflow and dissolved-solids concentrations have been measured concurrently, linear regression equations were derived. Regression equations are used to estimate dissolved-solids concentration from streamflow input by the Tongue River Reservoir and Hanging Woman, Otter, and Pumpkin Creeks (table 12). Provision is made for the model user to input alternate concentrations at the Tongue River Dam in place of regression-derived values. The regression-derived dissolved-solids concentrations for Hanging Woman, Otter, and Pumpkin Creeks are used to compute dissolved-solids loads from ungaged tributaries.

Irrigation withdrawal and return flow

Dissolved-solids load removed by irrigation withdrawal is computed as the product of the volume of streamflow withdrawn in the reach and the current dissolved-solids concentration in the reach of withdrawal. Dissolved-solids load from irrigation return flow is based on an assumption of salt balance. That is, the dissolved-solids load removed by irrigation withdrawal is returned to the stream in full

Table 12.--*Linear regression equations for predicting dissolved-solids concentrations from streamflow for releases from Tongue River Reservoir and Hanging Woman, Otter, and Pumpkin Creeks*

Tongue River Reservoir

All months: $Y = (13{,}412.07) \times (X)^{-.03498}$, $r^2 = 0.473$, $p \leq 0.0001$, $n = 51$

Hanging Woman Creek

January: $Y = (2{,}056.07) + (-22.885) \times (Z)$, $r^2 = 0.832$, $p \leq 0.0310$, $n = 5$

February: $Y = (1{,}874.24) + (-67.916) \times (Z)$, $r^2 = 0.896$, $p \leq 0.0534$, $n = 4$

March: $Y = (1{,}779) + (-13.293) \times (Z)$, $r^2 = 0.722$, $p \leq 0.0076$, $n = 8$

Other months[a]: $Y = (2{,}006.14) + (-16.13) \times (Z)$, $r^2 = 0.337$, $p \leq 0.0001$, $n = 63$

Otter Creek

January: $Y = (2{,}678.99) + (-24.409) \times (Z)$, $r^2 = 0.980$, $p \leq 0.0012$, $n = 5$

March: $Y = (1{,}829.06) + (-6.336) \times (Z)$, $r^2 = 0.881$, $p \leq 0.0056$, $n = 6$

September: $Y = (2{,}195.16) + (-94.326) \times (Z)$, $r^2 = 0.582$, $p \leq 0.0776$, $n = 6$

Other months[b]: $Y = (2{,}237.49) + (-8.831) \times (Z)$, $r^2 = 0.590$, $p \leq 0.0001$, $n = 6$

Pumpkin Creek

October: $Y = (42) + (5{,}172.22) \times (Z)$, $r^2 = 0.855$, $p \leq 0.075$, $n = 4$

Other months[c]: $Y = (1{,}610.64) \times (Z)^{-0.2543}$, $r^2 = 0.489$, $p \leq 0.0001$, $n = 35$

where X is total monthly streamflow, in acre-feet;

Y is dissolved-solids concentration, in milligrams per liter;

Z is instantaneous streamflow, in cubic feet per second;

r^2 is coefficient of determination;

p is probability that regression was derived from a population with a regression coefficient equal to zero; and

n is number of data pairs used to develop regression equation.

[a]This equation predicts dissolved-solids concentration in streamflow from ungaged tributaries on Tongue River reach 1.

[b]This equation predicts dissolved-solids concentration in streamflow from ungaged tributaries on Tongue River reaches 2 and 3.

[c]This equation predicts dissolved-solids concentration in streamflow from ungaged tributaries on Tongue River reaches 4 and 5.

with return flow. Return flows occur in the month of withdrawal and for 8 months thereafter. Monthly loads of dissolved solids from return flow were, therefore, a summation of that month's return flow load and loads returning from prior months.

Additionally, some dissolved-solids load is input by antecedent return flow from irrigation in the year prior to simulation. Antecedent return-flow loads were computed with the assumption that the antecedent year received complete service irrigation. On a per-acre basis, the dissolved-solids load removed by irrigation withdrawal was the product of the irrigation withdrawal rate and the dissolved-solids concentration of the reach of withdrawal. The dissolved-solids concentration per reach was the distanced-weighted mean, derived from monthly values for the Tongue River at the Tongue River Dam and Miles City. The distribution of monthly loads was calculated on the same basis used for simulated year loads. The antecedent loads that lagged into the simulated year (table 13) are added to return flow loads produced in the simulated year. Only the Tongue River receives such loads, because antecedent return flows to the three tributaries are insignificant.

Table 13.--*Antecedent return-flow loads of dissolved solids to Tongue River reaches*

Month	Load, in tons per acre per month				
	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Jan.	0.120	0.137	0.154	0.171	0.189
Feb.	.093	.109	.125	.141	.158
Mar.	.075	.090	.105	.120	.135
Apr.	.055	.064	.074	.084	.093
May	.033	.036	.040	.044	.048
June	.008	.008	.009	.009	.010
July through December	0	0	0	0	0

Ground water

Dissolved-solids concentrations for ground-water inflow to the five Tongue River reaches are based on values calculated from a 1978 base-flow study of the Tongue River (W. R. Hotchkiss, U.S. Geological Survey, written commun., 1981). Concentrations were calculated with the following equation:

$$C = \frac{L_d - L_u - L_t}{(Q_d - Q_u - Q_t) \times f} \tag{4}$$

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.

Reaches sampled in the 1978 base flow study do not coincide with reaches in the model; therefore, concentrations were distance-weighted to achieve conformity with model reaches. In downstream order, the dissolved-solids concentration, in milligrams per liter, input by ground water to Tongue River reaches 1 to 5 is as follows: 1,150, 1,125, 1,100, 950, and 800.

Dissolved solids leached from backfilled spoils are transported via ground water. In the model, the dissolved-solids load leached from spoils is calculated using methods developed by McWhorter and others (1979). The model equation is as follows:

$$L = A \times D \times R \times f \tag{5}$$

where L is dissolved-solids load, in tons per year;
A is area of surface coal mine, in acres;
D is dissolved-solids concentration of spoil leachate, in milligrams per liter;
R is runoff coefficient for the mined drainage basin, in inches per year (table 14); and
f is a factor (0.0001133) to convert equation units into tons.

Table 14.--*Runoff coefficients for mined drainages for Tongue River reaches 1 to 5 and Hanging Woman, Otter, and Pumpkin Creeks*

Location	Runoff coefficient (inches per year)
Tongue River	
Reach 1	0.186
Reach 2	.167
Reach 3	.167
Reach 4	.409
Reach 5	.409
Hanging Woman Creek	.186
Otter Creek	.167
Pumpkin Creek	.409

The dissolved-solids concentration of spoil leachate from a particular mine is calculated by applying a coefficient of 1.5 to the mean dissolved-solids concentration of water sampled from wells and springs which meet the following criteria: The well or spring is within or near the mine site, the aquifer sampled is the Tongue River Member of the Fort Union Formation, and the well depth is less than 300 feet. This procedure was developed from a review of water-quality data for undisturbed aquifers and spoil water samples. Rahn (1975) compared a small number of samples of spoil-derived water and undisturbed shallow ground water from the Powder River Basin of Montana and Wyoming. He reported the dissolved-solids concentration of spoil water was 160 percent of that from the undisturbed aquifers. A more extensive data base was utilized by Van Voast, Hedges, and McDermott (1978b). They analyzed 505 water samples from stock and domestic wells in the Fort Union Formation of southeastern Montana, as well as 81 water samples from spoils at the Absaloka, Rosebud, Big Sky, and Decker coal mines (fig. 1). Water from the stock and domestic wells had a median dissolved-solids concentration of 1,500 mg/L, whereas the median spoil-water concentration was 2,597 mg/L. The spoils, therefore, had a median dissolved-solids concentration 173 percent of that in the stock and domestic wells.

McWhorter, Skogerboe, and Skogerboe (1975) reported that the dissolved-solids concentration of spoil leachates can be estimated with saturated paste extract analyses of overburden materials. Wayne A. Van Voast (Montana Bureau of Mines and Geology, Billings, Mont., written commun., 1981) has used this methodology. For nine core samples of overburden taken near Otter Creek, Van Voast calculated a mean dissolved-solids concentration of 2,634 mg/L. This is 128 percent of the mean dissolved-solids concentration of 2,056 mg/L determined for 49 wells and springs in the same area. The wells and springs were selected for analysis if their source was the Tongue River Member of the Fort Union Formation and the wells were less than 300 feet deep.

The saturated paste extracts provide data at specific sites for estimating spoil leachate concentrations; however, such data are of limited availability in the study area. Therefore, the dissolved-solids concentration of spoil leachate is estimated with the coefficient method discussed previously. The coefficient of 1.5 is a compromise value that accounts for the three percentages (160, 173, 128) discussed in relation to studies by Rahn (1975), McWhorter, Skogerboe, and Skogerboe (1975), and Wayne A. Van Voast (written commun., 1981).

The dissolved solids leached from mine spoils are modeled as the quantity entering streams after such leachates reach steady-state input rates. Based on aquifer characteristics in the study area, the production of leachates may occur for hundreds of years (Woessner and others, 1979). Therefore, all coal mines in the study area are assumed to discharge at a steady-state rate for a long time period, and they all will be discharging to streams at some common, but undetermined, time in the future. The model simulates this common future time.

Spoils-derived loads of dissolved solids are important components of the model; therefore, it is desirable to compare results from equation 5, an empirical equation, with loads calculated from aquifer characteristics. This comparison was made for four tracts of Federally owned coal in or near Otter Creek that are being considered by the U.S. Bureau of Land Management for leasing. The Bureau of Land Management estimates that 33,731 acres will be made available for mining. Of this, 4,577 acres will discharge leachates to the Tongue River; the remaining 29,154 acres will discharge to Otter Creek. The dissolved-solids concentration of leachates expected from these four tracts is 2,634 mg/L, the mean of nine paste-extract analyses from core holes taken in or near the four tracts (Wayne A. Van Voast, written commun., 1981). Aquifer characteristics obtained from test-well data in or near the four tracts were used to compute the dissolved-solids load from the tracts (M. R. Cannon, U.S. Geological Survey, written commun., 1981). Total ground-water discharge from an area is computed from:

$$Q = T \times I \times W \tag{6}$$

where Q is ground-water discharge, in cubic feet per day;
T is transmissivity, in feet squared per day;
I is gradient, unitless; and
W is width of area, in feet.

The dissolved-solids load from an area is computed from:

$$L = Q \times C \times f \tag{7}$$

where L is dissolved-solids load, in tons per year;
Q is ground-water discharge, in cubic feet per day;
C is dissolved-solids concentration, in milligrams per liter; and
f is a factor (0.00001139) to convert equation units into tons per year.

The lease tracts were subdivided so each core hole with a paste-extract analysis was computed as a subunit. The annual dissolved-solids load from summing the nine subareas is 1,849 tons. Using equation 5, the annual dissolved-solids load from the four tracts would be 1,681.3 tons. Equation 5 is therefore considered a reasonable method for calculating dissolved-solids loads.

Other water losses

Dissolved-solids loads removed by other water losses from Tongue River reaches are computed as the product of the monthly volume of loss and the current dissolved-solids concentration in the reach of withdrawal. Hanging Woman, Otter, and Pumpkin Creeks are computed in a similar manner, except that the Tongue River is the source of water.

Model input and output

Most of the data used to compute streamflow and dissolved-solids loads are contained in the computer program, mostly in subroutine BLOCK DATA. The model could be adapted to other hydrologic conditions for the Tongue River by replacing the internal data statements with data statements representing the new conditions. No provision is made for simulation of the extra day in a leap year, but leap-year computations could be made by resetting variable ND in subroutine SALINE.

The model user selects the hydrologic condition for each month of simulation by inputting values for the monthly flow designator (model variable MFD). These values determine the hydrologic condition of streamflow releases from the Tongue River Reservoir. The model releases are internally programmed to select appropriate hydrologic conditions for the other hydrologic components of the model (table 15). Input data for a simulation are read into the computer program via subroutine MAIN with six data cards described in table 16.

Table 15.--*Condition of hydrologic components during a simulation as selected by monthly flow designator variable*

[Hydrologic conditions: A = mean, B = plus one standard deviation, C = minus one standard deviation, D = historic maximum, E = historic minimum, F = instream flow. Monthly flow designator: 1 = mean, 2= plus one standard deviation, 3 = minus one standard deviation, 4 = historic maximum, 5 = historic minimum, 6 = instream flow]

Hydrologic component	Hydrologic condition based on status of monthly flow designator					
	1	2	3	4	5	6
Initial streamflow from Tongue River Dam	A	B	C	D	E	F
Precipitation rate	A	B	C	D	E	F
Evaporation rate	A	C	B	E	D	A
Initial streamflow of Hanging Woman Creek	A[a]	B[b]	C[c]	D	E	A[a]
Initial streamflow of Otter Creek	A[a]	B[b]	C[c]	D	E	A[a]
Initial streamflow of Pumpkin Creek	A[a]	B[b]	C[c]	D	E	A[a]
Runoff coefficient for Hanging Woman Creek	A[a]	B[b]	C[c]	B[b]	C[c]	A[a]
Runoff coefficient for Otter Creek	A[a]	B[b]	C[c]	B[b]	C[c]	A[a]
Runoff coefficient for Pumpkin Creek	A[a]	B[b]	C[c]	B[b]	C[c]	A[a]
Irrigation water diversion rate for Tongue River reaches	d	d	e	d	e	e
Irrigation water diversion rate for Hanging Woman, Otter, and Pumpkin Creeks	e	e	e	e	e	e

[a]50th percentile in place of mean.
[b]75th percentile in place of plus one standard deviation
[c]25th percentile in place of minus one standard deviation
[d]Complete service irrigation
[e]Partial service irrigation

Table 16.--*Input data card instructions*

Card	Columns	Format	Variable	Description
1	1-5	A5	SN	Simulation number
	10	I1	IRD	Designator for reservoir; enter 0 for present Tongue River Reservoir, enter 1 for proposed Tongue River Reservoir
	11-34	12I2	MFD	Monthly flow designator; enter 1 for mean, 2 for plus one standard deviation, 3 for minus one standard deviation, 4 for historic maximum, 5 for historic minimum, 6 for instream flow
2	1	I1	INDS	Designator for dissolved-solids input by Tongue River Dam; enter 0 for regression-defined, 1 for user-defined
	6-65	12F5.0	TRDTDS	User-defined monthly concentration (in milligrams per liter) of dissolved solids input by Tongue River Dam
3	1-30	5F6.0	AIT	Acreage irrigated on each of five reaches of Tongue River
	31-36	F6.0	AIHW	Acreage irrigated on Hanging Woman Creek (enter acres in excess of 1,225 acres presently irrigated)
	37-42	F6.0	AIO	Acreage irrigated on Otter Creek (enter acres in excess of 785 acres presently irrigated)
	43-48	F6.0	AIP	Acreage irrigated on Pumpkin Creek (enter acres in excess of 2,875 acres presently irrigated)
4	1-20	5F6.0	AMT	Acreage of surface coal mines on each of five reaches of Tongue River
	31-36	F6.0	AMHW	Acreage of surface coal mines on Hanging Woman Creek
	37-42	F6.0	AMO	Acreage of surface coal mines on Otter Creek
	43-48	F6.0	AMP	Acreage of surface coal mines on Pumpkin Creek

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

Card	Columns	Format	Variable	Description
5	1-30	5F6.0	DST	Dissolved-solids concentration (in milligrams per liter) of leachate from surface coal mines on each of five reaches of Tongue River
	31-36	F6.0	DSHW	Dissolved-solids concentration (in milligrams per liter) of leachate from surface coal mines on Hanging Woman Creek
	37-42	F6.0	DSO	Dissolved-solids concentration (in milligrams per liter) of leachate from surface coal mines on Otter Creek
	43-48	F6.0	DSP	Dissolved-solids concentration (in milligrams per liter) of leachate from surface coal mines on Pumpkin Creek
6	1-30	5F6.0	QOLT	Other water losses (in acre-feet per year) from each of five reaches of Tongue River
	31-36	F6.0	QOLHW	Other water losses (in acre-feet per year) from Hanging Woman Creek
	37-42	F6.0	QOLO	Other water losses (in acre-feet per year) from Otter Creek
	43-48	F6.0	QOLP	Other water losses (in acre-feet per year) from Pumpkin Creek

Model output consists of a description of simulation conditions input by the model user, monthly results of the simulation, and a summary of simulation results. Under simulation results, the output for each month consists of the streamflow, the dissolved-solids load and concentration for each reach, and the initial streamflow from the Tongue River Reservoir. In addition, the contribution of dissolved-solids load due to return flow or mining along each reach is tabulated as a percentage of the current dissolved-solids load. During routing the model computes the components of the total load of dissolved solids and prints the percentage of the cumulative dissolved-solids load due to return flow or mining. In the simulation summary, tabulations for each month consist of the dissolved-solids load and the dissolved-solids concentration discharged from the Tongue River Reservoir and at Miles City. A statistical summary of monthly dissolved-solids concentrations and percentage loads due to return flow or mining then is listed for each reach. An example of model output is given in table 17.

MODEL VALIDATION

Prior to simulating agricultural development and mining plans, the model was tested to determine its accuracy in simulating existing hydrologic and dissolved-solids budgets of the Tongue River study area. Existing conditions were simulated and then compared to historic streamflow and dissolved-solids data.

Comparisons of existing and simulated streamflow are based on the percentage difference between streamflow measured at the Tongue River Dam and Miles City. These comparisons represent mean hydrologic conditions; therefore, those months in which streamflow at the Tongue River Dam was at or near its mean value were located in historic records. Then the streamflow historically measured at Miles City during such months was used to derive the historic percentage difference. The resulting percentages were statistically analyzed for the mean and upper and lower 95-percent confidence limits (table 18). In the simulation of existing conditions, surface coal-mining acreage and other water losses were set to zero; irrigated acreages were set to values listed under "irrigated acres" in table 9, and hydrologic conditions were at mean values.

The simulated percentage difference in annual streamflow agrees closely with historic conditions (table 18). Half of the simulated months (February, April, June, July, August, and September) are within their historic 95-percent confidence interval. Five months (January, May, October, November, and December) exceed the upper limit of their confidence interval and March is less than the lower limit of its confidence interval. It is important to note that streamflow was accurately simulated for June through September, months of large irrigation withdrawals. These four months are those in which water-quality conflicts are most likely to occur between surface coal-mining and agricultural industries in the study area.

Comparisons of historic and simulated dissolved-solids loads were for the same simulated conditions used for hydrologic comparisons in table 18. In addition, simulated dissolved-solids concentrations in streamflow released from the Tongue River Reservoir were historic monthly means, not regression-derived concentrations. Historic dissolved-solids loads were calculated for months in which streamflow at Miles City was at or near that expected at Miles City when releases from the Tongue River Reservoir were monthly means. For example, if 10,800 acre-feet were released from the Tongue River Reservoir in January, the flow historically expected at Miles City in January (table 18) would be 11,988 acre-feet (111 percent of the 10,800 acre-feet). The month and year in which these expected streamflows historically occurred at Miles City then were located in Geological Survey streamflow records. Dissolved-solids loads were calculated with the following equation:

$$L = Q \times C \times f \qquad (8)$$

where L is dissolved-solids load, in tons;
Q is streamflow, in acre-feet;
C is dissolved-solids concentration, in milligrams per liter; and
f is a factor (0.00136) to convert equation units into tons.

Table 18.--*Historical and simulated percentages of streamflow measured at Miles City in relation to streamflow released from the Tongue River Reservoir*

Month	Historic percentage difference[a] Lower 95-percent confidence limit	Mean	Upper 95-percent confidence limit	Number of samples	Simulated percentage difference[b]
Jan.	94	111	128	12	135.3
Feb.	109	149	189	16	141.5
Mar.	183	287	391	12	180.9
Apr.	98	113	128	6	122.4
May	69	79	89	9	94.9
June	88	99	110	10	92.5
July	58	77	98	10	69.0
Aug.	38	49	60	11	54.9
Sept.	48	66	84	7	68.2
Oct.	75	88	101	8	111.1
Nov.	97	111	125	9	132.3
Dec.	97	106	115	14	132.5
Annual	92	98	104	34	100.0

[a]Percentages based on months with at, or near, mean streamflow at Tongue River at Tongue River Dam. Moore and Shields (1980) list mean monthly streamflow of the station.

[b]Percentages based on mean hydrologic conditions (variable MFD set to 1).

Dissolved-solids concentrations input to equation 8 were developed from analysis of daily measurements of specific conductance at Miles City and simultaneous measurements of specific conductance and dissolved-solids concentration at Miles City. The simultaneous measurements were regressed to obtain the following prediction equation:

$$\log C = (-0.4072) \times (1.0768) \times (\log S) \qquad (9)$$

where C is dissolved-solids concentration, in milligrams per liter, and
S is specific conductance, in micromhos per centimeter at 25 degrees Celsius.

The correlation coefficient of equation 9 is 0.98 (number of samples is 137). The monthly mean specific conductance was computed from daily values and then converted to monthly mean dissolved-solids concentration by equation 9. Finally, the monthly dissolved-solids loads obtained with equation 8 were statistically analyzed for the mean and the 95-percent confidence interval.

The simulated and historic annual dissolved-solids loads in table 19 are in close agreement; however, this is true only for two of the monthly comparisons in table 19. Simulated loads for June and July are reasonably close to the historic mean load. The simulated load for March is 70 percent of the historic mean load; the remaining 9 months exceed historic mean dissolved-solids loads by 27 to 45 percent.

Table 19.--*Historical and simulated dissolved-solids loads of the Tongue River at Miles City*

Month	Historic dissolved-solids load, in tons [a] Lower 95-percent confidence limit	Mean	Upper 95-percent confidence limit	Number of samples	Simulated dissolved-solids load, in tons [b]	Percentage simulated is of historic mean
Jan.	10,556	11,433	12,310	7	16,574	145
Feb.	9,921	12,570	15,219	4	18,188	145
Mar.	c	34,500	c	2	24,321	70
Apr.	19,408	22,159	24,910	5	28,723	130
May	27,730	36,122	44,515	4	48,305	134
June	c	34,426	c	2	37,170	108
July	10,945	13,954	16,963	4	14,122	101
Aug.	7,198	7,535	7,873	7	9,768	130
Sept.	7,203	8,727	10,252	5	12,067	138
Oct.	10,402	11,466	12,530	10	16,393	143
Nov.	12,246	13,648	15,050	5	17,304	127
Dec.	10,621	12,053	13,485	9	16,631	138
Annual	183,070	246,170	309,270	3	259,566	105

[a]Loads based on months at or near streamflow expected at Miles City when releases from present Tongue River Reservoir were at their mean value.

[b]Loads based on mean hydrologic conditions (variable MFD set to 1).

[c]Insufficient sample size for meaningful calculation.

Annual simulated streamflow and dissolved-solids loads agree well with historic values, probably largely due to compensating monthly errors. If only annual simulations had been required, the model could be deemed suitably accurate. However, monthly simulations are necessary because of concerns over water-quality degradation during the irrigation season. The discrepancies between historic and simulated streamflow and dissolved-solids loads can be ascribed to a number of sources. The following evaluation of errors serves to identify model components in need of additional data.

Monthly errors in streamflow simulation are due partly to assignment of one hydrologic condition to all hydrologic components during the simulated month. For example, all gaged and ungaged tributary streams are unlikely to concurrently flow at their mean value. Accurate estimation of gaged tributary streamflow is difficult because of the short period of record available. These estimates are, in turn, used to calculate streamflow from ungaged tributaries. The ice-related components of the model are set to the same values for the six hydrologic conditions. This procedure is inaccurate, but data limitations necessitate such an assumption.

Agriculture-related components of the model are other error sources because only estimates are available for irrigation withdrawal and return flow volumes and irrigated acreages. Yearly variations in amount and types of crops will affect volume of irrigation withdrawals and return flows.

Ground-water inflow was estimated from a single low-flow investigation; additional data would have permitted improved estimates of this important hydrologic component. A constant rate of ground-water inflow per reach is used during simulation because data are not yet available for reasonable estimation of monthly rates. Determination of monthly rates is influenced by irrigation withdrawals and return flows, storage of streamflow as ice, and the predominating influence of releases from the Tongue River Reservoir. The effect of increased river stage on ground-water inflow is neglected in the model although such increases are known to impede ground-water inflow by causing it to be stored temporarily in the aquifer (Rorabaugh, 1964). Streamflow may actually migrate into the streambank as temporary storage if sufficient increases in river stage occur (Daniel and others, 1970). This phenomena could introduce model error by depleting streamflow in a month of increasing river stage and then, if river stage declined in the following month, augment streamflow as bank storage was released.

The foregoing identifies parts of the model in which additional data might improve the simulation capability of the hydrologic components of the model. These errors notwithstanding, the hydrologic part of the model is considered to be satisfactory, especially for the months of irrigation withdrawal.

The monthly errors in dissolved-solids loads are generally of larger magnitude than monthly errors in streamflow. Much of this error probably is due to the dissolved-solids load input initially from the Tongue River Reservoir. Under mean hydrologic conditions, 69.2 percent of the load at Miles City had been input by the reservoir. The dissolved-solids concentration used to calculate the reservoir-derived load can be obtained from a regression equation or input by the model user. The regression equation (table 12) is based on 51 pairs of data for dissolved-solids concentration and total monthly streamflow that encompass the entire period of record available for such data. The coefficient of determination of the regression equation is 0.473; the correlation coefficient is 0.688. Monthly based regression equations were also developed in hopes of increasing prediction accuracy; unfortunately, none had a regression coefficient significantly different than zero and, hence, had no predictive capability. Because the regression equation in table 12 has a relatively small coefficient of determination, the model user may elect to input monthly values for dissolved-solids concentration. Monthly means were derived from data on dissolved-solids concentration measured in the Tongue River at the Tongue River Dam (table 20). These means have been used in most simulation runs of the model. Obviously, additional data for dissolved-solids concentration are needed for the Tongue River Dam station; such data are presently being obtained by the Geological Survey.

Dissolved-solids load is the product of streamflow and dissolved-solids concentration; hence, errors in streamflow simulation will produce errors in load simulation. The accuracy of simulation for streamflow and dissolved-solids loads under mean hydrologic conditions can be compared in table 21. Five months with excess load also had excess streamflow; March had both deficient load and streamflow. Of the remaining 6 months, 2 had correctly simulated load and streamflow, and the others had correct streamflow but excess load.

Table 20.--*Statistical summary of dissolved-solids concentrations measured in the Tongue River at the Tongue River Dam*

	Dissolved-solids concentration, in milligrams per liter				
Month	Mean	Standard deviation	Minimum	Maximum	Number of samples
Jan.	530.0	a	511	549	2
Feb.	565.2	37.7	511	613	4
Mar.	577.0	68.3	522	671	5
Apr.	558.6	64.8	489	650	5
May	487.0	32.2	247	654	3
June	262.2	90.3	173	443	6
July	222.8	21.0	190	247	5
Aug.	262.0	a	232	292	2
Sept.	394.0	45.3	323	425	5
Oct.	479.8	34.0	421	523	5
Nov.	489.8	34.3	448	540	4
Dec.	558.8	57.0	502	637	5
Annual	446.9	120.1	173	671	51

[a]Insufficient sample size for computation.

Regression equations are used to predict dissolved-solids concentration of gaged and ungaged tributaries and, as with releases from the Tongue River Reservoir, are based on small sample sizes. Some monthly based regressions are significant for Hanging Woman, Otter, and Pumpkin Creeks and are used in the model. However, such instances are limited; most concentrations are predicted with regression equations derived from the entire data base for that tributary and have relatively small coefficients of determination.

The dissolved-solids concentration of ground-water inflow was estimated from a single low-flow investigation. Concentrations derived from such investigations are not true representations of ground-water dissolved-solids concentrations because ground water moving downgradient and roughly perpendicular to surface streamflow will mix with subsurface flow moving beneath and parallel to surface streamflow. The resultant concentration is a mix of the two volumes. Intensive studies of alluvial aquifers would be required to provide accurate data on the interaction of these flow components.

The salt balance assumption used in the model is an additional source of error. Dissolved-solids loads will be inaccurate if leaching of salts from irrigated acreages occurs in the study area. Variations in agricultural practices may cause such errors to fluctuate both temporally and spatially. The accuracy of irrigation-based loads also is largely dependent upon the accuracy of irrigation withdrawal and return-flow volumes.

Table 21.--*Simulation accuracy for streamflow and dissolved-solids loads for mean hydrologic conditions*

[0 is within historic 95 percent confidence interval; + is in excess of historic 95 percent upper confidence limit; - is less than historic 95 percent lower confidence limit]

Month	Streamflow	Dissolved-solids load
Jan	+	+
Feb.	0	+
Mar.	-	-
Apr.	0	+
May	+	+
June	0	0
July	0	0
Aug.	0	+
Sept.	0	+
Oct.	+	+
Nov.	+	+
Dec.	+	+
Annual	0	0

The simulation errors in the model may be compensated for by using calibration techniques. A correction variable could be added to the model to adjust the simulated values to closely match historic values. This procedure was rejected because model error is likely to fluctuate under different hydrologic conditions; therefore, the correction variable would be adequate in some simulations and inadequate in others. Models are also calibrated by internal adjustment of parameters. This option was also rejected because this model was developed, for the most part, using data collected within or near the study area. Instead of adjusting such data it was deemed more realistic to accept the data as the best estimates yet available. As additional data become available, the model may be progressively updated to achieve more accurate simulation of streamflow and dissolved-solids loads.

The major objective of this model is assessment of impacts on dissolved-solids caused by surface coal mining in part of the Tongue River basin. This objective may still be met because the relative magnitude of impacts may be assessed by comparing simulations of present-state conditions to simulations of surface coal-mining plans. This approach is used because the model is considered to be a realistic analog of streamflow and dissolved-solids budgets of the study area. Although the model contains errors, many of these errors are traceable to lack of long-term data, and not to an inaccurate theoretical basis.

SIMULATION OF AGRICULTURAL DEVELOPMENT AND MINING PLANS

The number of different plans that could be simulated with this model is theoretically unlimited; only a small number are discussed here. These plans are separated into four categories: Otter Creek mining plans, agricultural development plans, intensive mining plans, and intensive mining and agricultural development plans. Simulations within the categories are presented for various hydrologic conditions as well as for two conditions of reservoir releases--one for the present Tongue River Reservoir and one for the proposed Tongue River Reservoir.

Streamflow from the proposed reservoir is simulated because evidence indicates the proposed reservoir will be in place prior to the arrival to the Tongue River of spoil leachates discharged from surface coal mines. Actual travel times of spoil leachates have not been measured, but estimates were made for a hypothetical coal mine within the study area. Woessner, Andrews, and Osborne (1979) obtained hydrologic and water-quality data from the site of a hypothetical mine at Logging Creek on the Northern Cheyenne Indian Reservation. The centroid of the spoils pit was 13,731 feet from the Tongue River. They determined that 183 years would be required for spoil leachates to reach the Tongue River once the spoils had been resaturated.

An important objective of this report is to evaluate impacts of surface coal mining on the dissolved-solids concentration of water used for irrigation in the study area. Hence, a discussion of dissolved-solids concentrations that may adversely affect plant growth is important. The sensitivity of plants to dissolved solids has been cited in numerous publications. The National Academy of Sciences, National Academy of Engineering (1973) concluded that water in excess of 5,000 mg/L dissolved-solids concentration is of little value for irrigation. References cited in McKee and Wolf (1971) considered water permissible for irrigation if the dissolved-solids concentrations ranged from 525 to 1,400 mg/L, but it was of doubtful usage if in excess of 1,400 mg/L. The International Joint Commission (1981) recently researched the toxicity of irrigation water for use in the Poplar River basin of northeastern Montana. They concluded that for long-term irrigation a maximum dissolved-solids concentration of 1,300 mg/L for alfalfa and 4,000 mg/L for wheat and barley would afford complete protection to these crops.

The variability in recommended dissolved-solids concentration is due, in part, to the influence of factors on the suitability of water for irrigation. These factors include the chemical composition of irrigation water, the drainage and leaching requirements of the soil, and the tolerance of specific plants to dissolved solids.

Relative tolerances of crop plants to dissolved solids are discussed in National Academy of Sciences and National Academy of Engineering (1973). The crop plants irrigated in the study area include alfalfa, corn, sugar beets, oats, barley, and wheat (Missouri River Basin Commission, 1978). Barley and sugar beets have a large tolerance to dissolved solids, whereas alfalfa, wheat, oats, and corn have a medium tolerance. For arid to semiarid regions, the U.S. Environmental Protection Agency (1976) lists dissolved-solids concentrations for the following four categories of dissolved-solids hazards for irrigation water.

Dissolved-solids hazard for irrigation water	Dissolved-solids concentration, in milligrams per liter
Water from which no detrimental effects will usually be noticed	500
Water which can have detrimental effects on sensitive crops.	500 - 1,000
Water that may have adverse effects on many crops and requires careful management practices.	1,000 - 2,000
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000 - 5,000

These values provide some guidance for judging the relative impact of dissolved solids in irrigation water; however, these values may not accurately represent the actual dissolved-solids impacts on crops irrigated within the study area.

The dissolved-solids data in the following discussion of simulation results represent monthly based concentrations calculated with equation 3 using monthly loads and streamflow. The concentration within a month may vary widely in response to temporal fluctuations in dissolved-solids load and streamflow. To simulate daily concentrations, the model would need to simulate model components on a daily basis. Because data were not available for daily simulation, the model has been designed for monthly simulation. A later section of this report discusses regression equations for predicting minimum and maximum dissolved-solids concentrations within a particular month.

Otter Creek mining plans

The Bureau of Land Management is responsible for determining if tracts of Federally owned coal are suitable for leasing for surface mining. If tracts pass initial screening against numerous unsuitability criteria, then they can be considered for leasing under the Federal Coal Management Program. Tracts of Federal coal (fig. 3) are being considered by the Bureau of Land Management for lease in 1982. The tracts, Ashland (Coalwood), Ashland (Decker-Birney), and Otter Creek, are within an area alleged to be unsuitable for surface mining of coal. The allegations are contained in a petition submitted on December 29, 1980, by the Northern Plains Resource Council and others to the U.S. Office of Surface Mining and the Montana Department of State Lands. The following discussion addresses impacts on dissolved solids that may occur if these tracts are mined.

Within the tracts, the Bureau of Land Management has identified 33,731 acres that are acceptable for lease consideration. If the total acreage is leased, mining would disturb those 33,731 acres during a 40-year span of operation. Leachates from 4,577 acres would be discharged to reach 3 of the Tongue River; the remaining 29,154 acres would discharge leachates to Otter Creek. The dissolved-solids concentration leached from the mine spoils is estimated to be 3,000 mg/L, which was derived

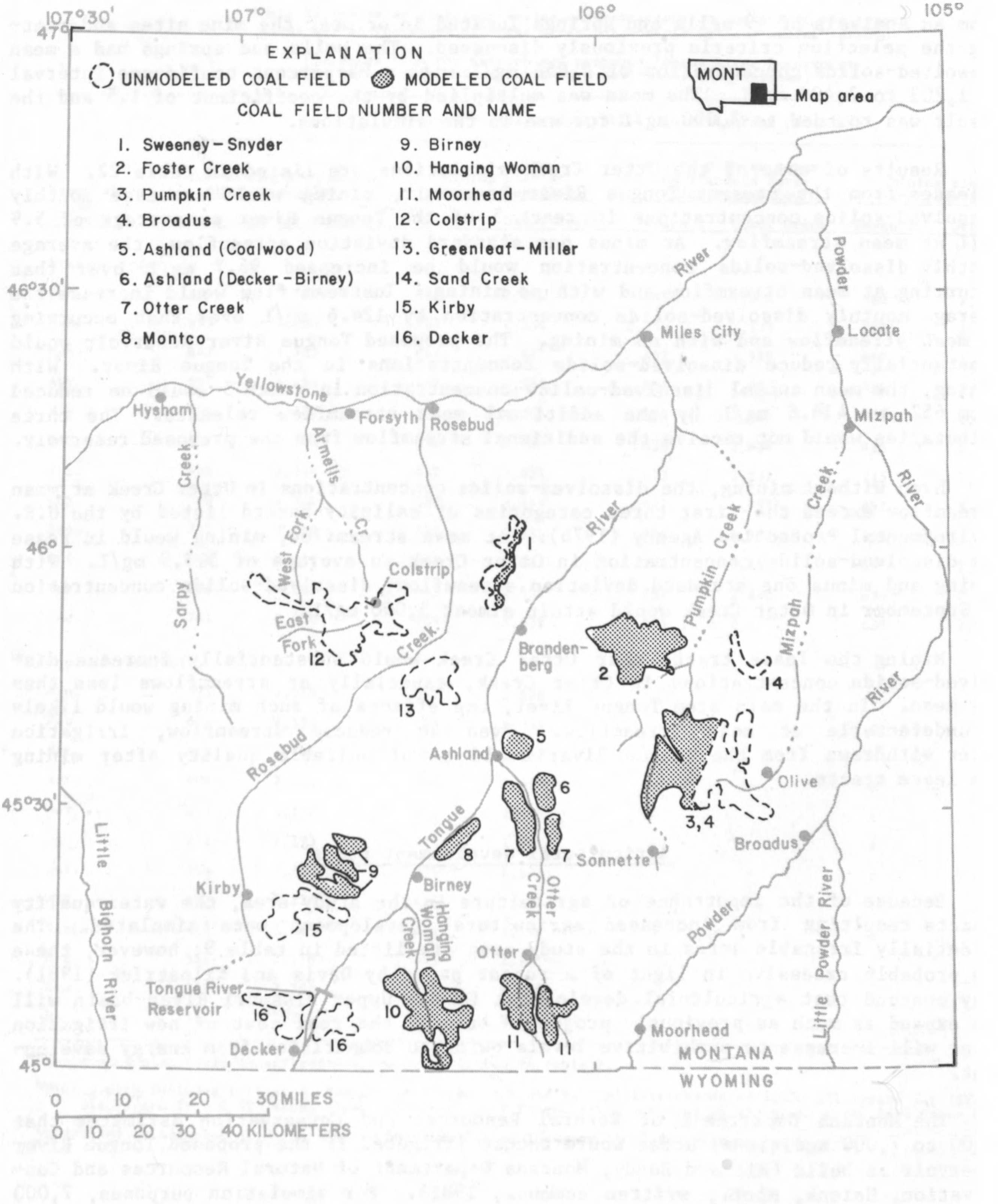

Figure 3.--Location of Federal coal potentially available for leasing.

from an analysis of 49 wells and springs located in or near the mine sites and meeting the selection criteria previously discussed. The wells and springs had a mean dissolved-solids concentration of 2,056 mg/L with a 95-percent confidence interval of 1,703 to 2,409 mg/L. The mean was multiplied by the coefficient of 1.5 and the result was rounded to 3,000 mg/L for use in the simulations.

Results of some of the Otter Creek simulations are listed in table 22. With releases from the present Tongue River Reservoir, mining would increase monthly dissolved-solids concentrations in reach 5 of the Tongue River an average of 5.9 mg/L at mean streamflow. At minus one standard deviation streamflow, the average monthly dissolved-solids concentration would be increased 96.7 mg/L over that occurring at mean streamflow and with no mining. Instream flow would increase the average monthly dissolved-solids concentration by 124.6 mg/L over that occurring at mean streamflow and with no mining. The proposed Tongue River Reservoir would substantially reduce dissolved-solids concentrations in the Tongue River. With mining, the mean annual dissolved-solids concentration in reach 5 would be reduced from 652 to 438.8 mg/L by the additional mean streamflow releases. The three tributaries would not receive the additional streamflow from the proposed reservoir.

Even without mining, the dissolved-solids concentrations in Otter Creek at mean streamflow exceed the first three categories of salinity hazard listed by the U.S. Environmental Protection Agency (1976). At mean streamflow, mining would increase the dissolved-solids concentration in Otter Creek an average of 513.9 mg/L. With mining and minus one standard deviation streamflow, dissolved-solids concentration in September in Otter Creek would attain almost 5,000 mg/L.

Mining the lease tracts near Otter Creek would substantially increase dissolved-solids concentrations in Otter Creek, especially at streamflows less than the mean. In the main stem Tongue River, the effects of such mining would likely be undetectable at mean streamflow. Even at reduced streamflow, irrigation water withdrawn from the Tongue River would be of suitable quality after mining the lease tracts.

Agricultural development plans

Because of the importance of agriculture in the study area, the water-quality impacts resulting from increased agricultural development were simulated. The potentially irrigable acres in the study area are listed in table 9; however, these are probably excessive in light of a recent paper by Davis and Kilpatrick (1981). They contend that agricultural development in the Upper Missouri River basin will not expand as much as previously projected because the real cost of new irrigation water will increase to prohibitive levels owing to competition from energy development.

The Montana Department of Natural Resources and Conservation estimates that 6,000 to 7,000 additional acres would become irrigated if the proposed Tongue River Reservoir is built (Richard Bondy, Montana Department of Natural Resources and Conservation, Helena, Mont., written commun., 1981). For simulation purposes, 7,000 acres are allocated to the five Tongue River reaches based on the present distribution of irrigated acres among the five reaches. No additional irrigated acreages were assigned to the three tributaries.

Table 22.--*Modeled dissolved-solids concentrations in reach 5 of the Tongue River and at the mouth of Otter Creek for non-mining[a] and mining[b] plans.*

[Releases from the present and proposed Tongue River Reservoirs set at mean, minus 1 standard deviation, and instream]

Reservoir and month	Dissolved-solids concentration, in milligrams per liter							
	Non-mining plan at mean streamflow		Mining plan at mean streamflow		Mining plan at minus one standard deviation streamflow		Mining plan at instream flow	
	Reach 5	Otter Creek	Reach 5	Otter Creek	Reach 5	Otter Creek	Reach 5	Otter Creek
Present reservoir								
Jan.	834	2,560	842	2,898	885	3,022	880	2,898
Feb.	893	2,150	901	2,334	1,046	2,528	961	2,334
Mar.	642	1,752	647	1,887	637	1,980	667	1,887
Apr.	697	2,163	702	2,366	811	2,407	856	2,366
May	590	2,162	592	2,355	698	2,454	778	2,355
Jun.	327	2,193	328	2,531	438	2,638	416	2,531
Jul.	428	2,214	432	2,821	673	3,237	715	2,821
Aug.	580	2,226	587	3,494	632	4,767	892	3,494
Sept.	717	2,068	726	3,336	782	4,667	858	3,336
Oct.	648	2,218	655	2,981	740	3,741	697	2,981
Nov.	636	2,203	643	2,638	737	2,820	690	2,638
Dec.	761	2,204	769	2,639	834	2,821	838	2,639
Proposed reservoir								
Jan.	595	2,560	599	2,898	-	-	c	c
Feb.	623	2,150	628	2,334	-	-	c	c
Mar.	461	1,752	464	1,887	-	-	c	c
Apr.	404	2,163	406	2,366	-	-	c	c
May	271	2,162	272	2,355	-	-	c	c
Jun.	222	2,193	223	2,531	-	-	c	c
Jul.	354	2,214	355	2,821	-	-	c	c
Aug.	433	2,226	436	3,494	-	-	c	c
Sept.	468	2,068	471	3,336	-	-	c	c
Oct.	438	2,218	441	2,981	-	-	c	c
Nov.	449	2,203	453	2,638	-	-	c	c
Dec.	513	2,204	517	2,639	-	-	c	c

[a]Non-mining plan includes irrigated acreages as listed in table 9.

[b]Mining plan includes irrigated acreages as listed in table 9. Spoil leachates of 3,000 milligrams per liter discharged from 4,577 mined acres into reach 3 of Tongue River and from 29,154 mined acres into Otter Creek.

[c]Dissolved-solids concentration same as "mining plan at instream flow" for present reservoir.

Simulations were run with mean streamflow under present and increased irrigated acreage (table 23). For releases from the present reservoir, the increased irrigated acreage causes an increase in dissolved-solids concentrations from March through December. The maximum increase in dissolved-solids concentration is from 580 mg/L to 867 mg/L in reach 5 during August. Dissolved-solids concentrations decline slightly in January and February under increased irrigation, as a consequence of larger return flow volumes from the previous year's irrigation. Dissolved-solids concentrations are substantially reduced by simulated increases in streamflow from the proposed reservoir. During June through September in reach 5 the maximum dissolved-solids concentration under present irrigated acreage is 468 mg/L; it increases to 511 mg/L with increased irrigation.

The simulations at mean streamflow do not quantify the impacts of increased irrigated acreage that would occur at streamflow less than the mean. Therefore, simulations were run at instream flow. It is assumed here that such streamflow will be representative of the minimum monthly releases from the proposed Tongue River Reservoir. For comparability, the present irrigated acreage was simulated with instream flows released from the present reservoir. Note that the instream flows from each reservoir are identical, but those from the present reservoir are not likely to be the minimum monthly releases. The results of these two simulations are presented in table 24. The simulated values represent the largest monthly dissolved-solids concentrations expected with the proposed reservoir and an increased level of irrigation. Under these two conditions, monthly dissolved-solids concentrations range from 456 to 1,435 mg/L; the range is 413 to 952 mg/L for present irrigation. When contrasted with simulated concentrations in table 23, the effect of reduced streamflow is readily seen. For example, with releases from the proposed reservoir the dissolved-solids concentration in August under increased irrigation is 478 mg/L at mean streamflow; at instream flow the concentration increases to 1,435 mg/L.

Intensive mining plans

Mining development plans for the study area are, as yet, largely undetermined. The Bureau of Land Management has identified potential tracts for leasing to coal mining interests (fig. 3), but only preliminary analyses have been made for most. For purposes of this report, the maximum development plan envisioned by the Bureau of Land Management has been simulated. The mined acreage and dissolved-solids concentration of spoil leachates from these tracts are listed in table 25. Parts of some tracts will not discharge spoil leachates to the study area; the acres listed are those expected to impact the study area. Multiple mines are planned for some reaches; in such instances, the dissolved-solids concentration of leachate for the reach is an area-weighted average based on mined acres.

Simulated dissolved-solids concentrations in reach 5 for non-mining and intensive mining plans under various releases from the two reservoirs can be compared in table 26. With the proposed reservoir releasing mean streamflow, the range of dissolved-solids concentrations is 225 to 647 mg/L with mining and 222 to 623 mg/L without mining. With releases at instream flow, the dissolved-solids concentration for mining ranges from 494 to 1,307 mg/L, again illustrating the rapid increase in concentration due to lessened streamflow.

Table 23.--*Modeled dissolved-solids concentrations in the Tongue River for present and increased levels of agricultural development for mean releases from the present and proposed Tongue River Reservoirs*

Reservoir and month	Dissolved-solids concentration, in milligrams per liter									
	Present level[a] of agricultural development for Tongue River reaches					Increased level[b] of agricultural development for Tongue River reaches				
	1	2	3	4	5	1	2	3	4	5
Present reservoir										
Jan.	559	668	765	817	834	559	667	762	812	829
Feb.	591	703	828	884	893	590	700	822	874	884
Mar.	585	627	675	643	642	585	627	675	645	646
Apr.	570	619	673	690	697	571	621	676	696	703
May	494	523	558	581	590	495	528	569	601	614
Jun.	267	286	305	320	327	267	289	310	331	339
Jul.	237	293	341	403	428	239	305	370	474	521
Aug.	279	354	423	538	580	282	375	482	734	867
Sept.	411	487	560	672	717	415	511	620	832	928
Oct.	493	551	597	637	648	495	557	610	663	682
Nov.	501	558	607	630	636	502	559	609	637	648
Dec.	577	654	718	753	761	577	653	716	755	768
Proposed reservoir										
Jan.	420	484	544	581	595	421	486	547	587	601
Feb.	422	488	567	608	623	422	489	569	611	627
Mar.	368	411	455	454	461	368	412	457	459	466
Apr.	310	342	376	394	404	310	343	378	398	409
May	221	236	254	265	271	222	238	257	270	277
Jun.	195	204	212	219	222	195	205	214	222	226
Jul.	275	301	321	345	354	276	305	331	363	376
Aug.	321	355	383	421	433	323	363	400	458	478
Sept.	346	381	411	452	468	347	389	428	487	511
Oct.	354	386	411	433	438	355	389	417	443	450
Nov.	366	400	430	445	449	367	401	432	449	454
Dec.	399	446	485	507	513	399	446	486	510	516

[a]Present level irrigated acreage: reach 1 = 1,000, reach 2 = 3,000, reach 3 = 3,500, reach 4 = 5,000, reach 5 = 1,700, Hanging Woman Creek = 1,225, Otter Creek = 785, Pumpkin Creek = 2,875

[b]Increased level irrigated acreage: reach 1 = 1,490, reach 2 = 4,470, reach 3 = 5,250, reach 4 = 7,450, reach 5 = 2,540, Hanging Woman Creek = 1,225, Otter Creek = 785, Pumpkin Creek = 2,875

Table 24.--*Modeled dissolved-solids concentrations in the Tongue River for present and increased levels of agricultural development for instream releases*[a] *from the present and proposed Tongue River Reservoirs*

Month	Dissolved-solids concentration, in milligrams per liter									
	Present level[b] of agricultural development for Tongue River reaches					Increased level[c] of agricultural development for Tongue River reaches				
	1	2	3	4	5	1	2	3	4	5
Jan.	563	688	797	853	871	564	687	792	845	862
Feb.	598	735	883	945	952	597	731	873	929	937
Mar.	590	650	712	663	661	590	649	711	666	665
Apr.	590	711	829	848	848	591	713	833	855	857
May	506	584	682	749	773	509	602	725	837	875
Jun.	272	315	358	397	413	273	322	375	431	456
Jul.	259	396	509	649	703	263	421	575	833	947
Aug.	297	453	588	798	874	302	490	694	1,175	1,435
Sept.	421	546	650	792	844	426	573	718	956	1,052
Oct.	497	572	629	676	688	498	577	641	701	723
Nov.	505	579	643	673	682	506	580	646	685	700
Dec.	583	683	766	815	828	583	682	766	823	843

[a]Instream releases from present and proposed Tongue River Reservoir are of equal magnitude

[b]Present level irrigated acreage: reach 1 = 1,000, reach 2 = 3,000, reach 3 = 3,500, reach 4 = 5,000, reach 5 = 1,700, Hanging Woman Creek = 1,225, Otter Creek = 785, Pumpkin Creek = 2,875

[c]Increased level irrigated acreage: reach 1 = 1,490, reach 2 = 4,470, reach 3 = 5,250, reach 4 = 7,450, reach 5 = 2,540, Hanging Woman Creek = 1,225, Otter Creek = 785, Pumpkin Creek = 2,875

Table 25.--*Mined acreage and spoil leachate dissolved-solids concentrations for intensive mining plans*

Reach			Potential lease tracts			
Name	Mined acreage[a]	Dissolved-solids concentration of leachate[a] (milligrams per liter)	Tract name	Acreage	Number of wells and springs sampled	Mean dissolved-solids concentration (milligrams per liter)
Tongue River, 1	10,000	1,600	Birney	10,024	49	1,048
Tongue River, 2	4,200	4,500	Montco	4,200	2	2,990
Tongue River, 3	4,600	2,350	Ashland (Coalwood)	4,577	15	1,570
Tongue River, 4	18,000	2,900	Sweeney-Snyder,	1,062	12	2,317
			Foster Creek	16,904	30	1,906
Tongue River, 5	0	0	--	--	--	--
Hanging Woman Creek	21,600	4,000	Hanging Woman	21,620	30	2,654
Otter Creek	52,300	3,850	Ashland (Decker-Birney),	6,240	34	2,270
			Otter Creek,	20,626	34	2,270
			Ashland(Coalwood),	1,288	15	1,570
			Moorhead	24,132	57	2,967
Pumpkin Creek	8,900	3,000	Pumpkin Creek	8,900	29	2,012

[a]These values used in simulations of intensive mining plans.

Table 26.--*Modeled dissolved-solids concentrations in reach 5 of the Tongue River for non-mining and intensive mining plans*[a],[b].

[Releases from the present and proposed Tongue River Reservoirs set at mean, minus 1 standard deviation, and instream]

Reservoir and month	Dissolved-solids concentration, in milligrams per liter: Non-mining plan at mean streamflow	Mining plan at mean streamflow	Mining plan at minus one standard deviation streamflow	Mining plan at instream flow
Present reservoir				
Jan.	834	876	929	933
Feb.	893	935	1,105	1,004
Mar.	642	665	667	679
Apr.	697	718	843	890
May	590	601	716	715
Jun.	327	334	456	494
Jul.	428	451	728	1,040
Aug.	580	623	683	1,307
Sept.	717	763	837	1,091
Oct.	648	683	789	777
Nov.	636	669	786	762
Dec.	761	803	882	900
Proposed reservoir				
Jan.	595	619	--	c
Feb.	623	647	--	c
Mar.	461	475	--	c
Apr.	404	415	--	c
May	271	276	--	c
Jun.	222	225	--	c
Jul.	354	363	--	c
Aug.	433	449	--	c
Sept.	468	487	--	c
Oct.	438	455	--	c
Nov.	449	467	--	c
Dec.	513	535	--	c

[a]Mining plan conditions listed in table 25.

[b]Irrigated acreages as listed in table 9.

[c]Dissolved-solids concentrations same as "mining plan at instream flow" for present reservoir.

Dissolved-solids concentrations are listed in table 27 for the five Tongue River reaches and the three tributaries under mean streamflow releases from the proposed Tongue River Reservoir. At mean streamflow, intensive mining does not increase dissolved-solids concentrations in the Tongue River to levels unfit for irrigation usage. In the instance of the three tributaries, the dissolved-solids concentration of water withdrawn from them ranges from 891 to 7,007 mg/L and generally would be unsuitable for irrigation; however, such is true at present based on the salinity-hazard criteria previously discussed. In practice, some irrigation water used in the tributaries is impounded during the spring when dissolved-solids concentrations are reduced by dilution with surface runoff of small dissolved-solids concentration.

Intensive mining and agricultural development plans

The most serious impacts would result from simultaneous increases in agricultural development and intensive mining. The results for reach 5 of such simulations are listed in table 28 and include various streamflow releases from the two reservoirs. With the present reservoir and mean streamflow, the dissolved-solids concentrations in reach 5 for present irrigation are increased an average of 90 mg/L per month by mining and additional irrigated acreage. The largest monthly increase is 355 mg/L in August. The additional streamflow releases from the proposed reservoir again substantially reduce dissolved-solids concentrations. With mining and increased irrigation, dissolved-solids concentrations in reach 5 range from 229 to 650 mg/L at mean streamflow, whereas the range is 347 to 989 mg/L with the present reservoir. The simulated dissolved-solids concentrations for instream flow represent a worst case example for the proposed reservoir. Under this simulation, dissolved-solids concentration attains 2,057 mg/L during August.

Table 27.--*Modeled dissolved-solids concentrations for intensive mining and mean releases from the proposed Tongue River Reservoir*[a,b]

Month	Dissolved-solids concentration, in milligrams per liter							
	Tongue River reaches					Hanging Woman Creek	Otter Creek	Pumpkin Creek
	1	2	3	4	5			
Jan.	421	490	560	603	619	2,629	3,338	1,681
Feb.	423	495	584	630	647	2,435	2,574	1,006
Mar.	369	415	465	467	475	1,960	2,063	934
Apr.	310	345	384	404	415	2,441	2,630	891
May	221	238	257	269	276	2,482	2,607	934
Jun.	195	205	215	222	225	2,566	2,971	1,320
Jul.	275	303	327	353	363	2,443	3,611	1,572
Aug.	322	358	393	435	449	3,297	5,144	7,007
Sept.	346	385	422	468	487	4,474	4,986	1,562
Oct.	355	391	423	448	455	3,474	3,974	6,126
Nov.	367	405	442	461	467	3,155	3,205	6,988
Dec.	400	451	499	527	535	2,946	3,206	7,007

[a]Mining plan conditions listed in table 25.

[b]Irrigated acreages as listed in table 9.

Table 28.--*Modeled dissolved-solids concentrations in reach 5 of the Tongue River for non-mining with present irrigation plans*[a] *and intensive mining with increased irrigation plans*[b].

[Releases from the present and proposed Tongue River Reservoir set at mean, minus 1 standard deviation, and instream]

Reservoir and month	Non-mining, present agriculture plan at mean streamflow	Mining, increased agriculture plan at mean streamflow	Mining, increased agriculture plan at minus one standard deviation streamflow	Mining, increased agriculture plan at instream flow
	Dissolved-solids concentration, in milligrams per liter			
Present reservoir				
Jan.	834	868	915	920
Feb.	893	923	1,069	986
Mar.	642	668	671	682
Apr.	697	724	851	897
May	590	624	787	815
Jun.	327	347	517	542
Jul.	428	551	1,009	1,353
Aug.	580	935	884	2,057
Sept.	717	989	1,008	1,353
Oct.	648	717	826	824
Nov.	636	681	799	790
Dec.	761	809	890	927
Proposed reservoir				
Jan.	595	624	--	c
Feb.	623	650	--	c
Mar.	461	480	--	c
Apr.	404	420	--	c
May	271	282	--	c
Jun.	222	229	--	c
Jul.	354	387	--	c
Aug.	433	497	--	c
Sept.	468	532	--	c
Oct.	438	467	--	c
Nov.	449	471	--	c
Dec.	513	538	--	c

[a]Irrigated acreages as listed in table 9.

[b]Mining plan conditions listed in table 25. Increased level irrigated acreage: reach 1 = 1,490, reach 2 = 4,470, reach 3 = 5,250, reach 4 = 7,450, reach 5 = 2,540, Hanging Woman Creek = 1,225, Otter Creek = 785, Pumpkin Creek = 2,875.

[c]Dissolved-solids concentrations same as "mining, increased agriculture plan at instream flow."

The dissolved-solids concentrations in all reaches for the complete development plan and mean streamflow releases from the proposed reservoir are listed in table 29. The five Tongue River reaches have water suitable for irrigation. Similar to the intensive mining plan previously discussed, the three tributaries have dissolved-solids concentrations considered unsuitable for irrigation of salinity-sensitive crops.

Within-month variation of dissolved-solids concentrations

Dissolved-solids concentrations in tables 22-24 and 26-29 are monthly means. Variations within the month are of interest but were not simulated by the model. Estimates of the maximum and minimum concentrations may be derived with the regression equations listed in table 30. These are applicable only to reach 5 of the Tongue River because they were derived from data obtained at the Geological Survey's streamflow-measurement station on the Tongue River at Miles City. As an example, if the dissolved-solids concentration for July is 500 mg/L, the predicted maximum concentration is 748.6 mg/L and the minimum concentration is 320.2 mg/L. The duration of the maximum or minimum concentration within a month was not determined.

The following procedure was used to calculate the equations. The mean, maximum, and minimum specific conductances for each month were obtained from daily values measured since January 1951. Then, the mean, maximum, and minimum dissolved-solids concentrations for each month were calculated from equation 9, which relates dissolved-solids concentration to specific conductance. Finally, the equations in table 30 were determined by linear regression. These regressions should be used with caution because they were developed with historic data and, therefore, may not be accurate for all simulated plans.

Dissolved-solids loads from irrigation return flow and spoil leachates

The model contains routines that calculate the percentages of the dissolved-solids loads due to irrigation return flow or spoil leachates. Such calculations indicate that even for the intensive mining and agricultural development plan, mining-related loads of dissolved solids are much smaller than those from irrigation return flow (table 31). With mean releases from the present Tongue River Reservoir, an average of 4.70 percent of the dissolved-solids load arriving at the downstream end of the study area has emanated from mining for the intensive mining and agricultural development plan; the percentage declines to 3.23 with the additional streamflow from the proposed Tongue River Reservoir. Instream releases from the proposed reservoir, in conjunction with intensive mining and agricultural development, represent a potential worst case example. The results of such a simulation for each reach and month are listed in table 32. The cumulative percentage of dissolved-solids load due to spoil leachates ranges from 3.85 to 11.62 percent in reach 5 of the Tongue River. Cumulative percentage loads due to irrigation return flow are substantially larger than those for spoil leachates.

Although irrigation return flow appears to contribute substantial loads of dissolved solids, these results require further explanation. Because the model assumes a salt balance, the dissolved-solids load added to the river with irrigation return flow is nearly equal to the dissolved-solids load removed from the river as irrigation withdrawal. The inequality results from some return flow lagging into the following year and antecedent return flow from the previous year. Under the salt

Table 29.--*Modeled dissolved-solids concentrations for intensive mining with increased irrigation and mean releases from the proposed Tongue River Reservoir*[a,b]

Month	Dissolved-solids concentration, in milligrams per liter: Tongue River reaches 1	2	3	4	5	Hanging Woman Creek	Otter Creek	Pumpkin Creek
Jan.	422	492	563	607	624	2,629	3,338	1,681
Feb.	423	496	585	632	650	2,435	2,574	1,006
Mar.	369	416	467	471	480	1,960	2,063	934
Apr.	310	346	386	408	420	2,441	2,630	891
May	222	239	260	274	282	2,482	2,607	934
Jun.	195	206	216	225	229	2,566	2,971	1,320
Jul.	276	307	337	372	387	2,443	3,611	1,572
Aug.	323	366	411	474	497	3,297	5,144	7,007
Sept.	348	393	440	505	532	4,474	4,986	1,562
Oct.	355	394	428	458	467	3,474	3,974	6,126
Nov.	367	406	444	465	471	3,155	3,205	6,988
Dec.	400	452	500	529	538	2,946	3,206	7,007

[a]Mining plan conditions listed in table 25.

[b]Irrigated acreages: reach 1 = 1,490, reach 2 = 4,470, reach 3 = 5,250, reach 4 = 7,450, reach 5 = 2,540, Hanging Woman Creek = 1,225, Otter Creek = 785, Pumpkin Creek = 2,875

Table 30.--*Regression equations for predicting maximum and minimum monthly dissolved-solids concentrations from monthly mean dissolved-solids concentrations (in milligrams per liter)*[a]

Month	Maximum concentration, in milligrams per liter: b_o	b_1	r^2	n	Minimum concentration, in milligrams per liter: b_o	b_1	r^2	n
Jan.	120.2	0.976	0.606	25	-660.5	1.757	0.724	25
Feb.	341.5	.588	.481	25	-644.5	1.803	.600	25
Mar.	463.3	.431	.340	26	-532.4	1.610	.723	26
Apr.	269.8	.727	.508	26	-193.5	1.146	.661	26
May	276.2	.787	.430	26	-227.4	1.119	.817	26
Jun.	77.7	1.185	.790	26	-8.8	.788	.891	26
Jul.	-112.4	1.722	.715	25	119.7	.401	.697	25
Aug.	-332.8	1.939	.841	24	57.6	.274	.097[b]	24
Sept.	-170.0	1.453	.853	25	123.3	.620	.673	25
Oct.	-56.2	1.275	.483	26	-16.9	.870	.561	26
Nov.	163.1	.918	.854	26	-88.9	1.006	.669	26
Dec.	-185.2	1.426	.882	25	-15.7	.870	.791	25

[a]General form of regression equation is $Y = b_o + (b_1 \times X)$
where Y is the maximum or minimum monthly concentration,
b_o is the intercept,
b_1 is the regression coefficient,
X is the monthly mean concentration,
r^2 is the coefficient of determination, and
n is number of samples

[b]Regression coefficient not significantly different than 0 at probability level of 0.05.

Table 31.--*Cumulative percentage of loads of dissolved solids in reach 5 of the Tongue River due to irrigation return flow or mine spoil leachates for mean releases from the present and proposed Tongue River Reservoirs*

Plan and reservoir	Cumulative load[a], in percent					
	Irrigation return flow			Mine spoil leachates		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Present conditions						
Present reservoir	25.69	5.43	80.04	0	0	0
Proposed reservoir	13.26	4.36	33.99	0	0	0
Otter Creek mining						
Present reservoir	25.56	5.41	79.57	.89	.33	1.61
Proposed reservoir	13.21	4.34	33.87	.63	.30	.79
Agricultural development						
Present reservoir	45.18	8.01	100.00	0	0	0
Proposed reservoir	20.62	6.42	56.34	0	0	0
Intensive mining						
Present reservoir	24.89	5.30	77.00	4.53	1.73	8.08
Proposed reservoir	12.96	4.25	33.27	3.24	1.55	4.08
Intensive mining and agricultural development						
Present reservoir	43.76	7.81	100.00	4.70	1.78	9.97
Proposed reservoir	20.16	6.27	55.12	3.23	1.57	4.27

[a]Mean, maximum, and minimum cumulative percentages derived from 12 monthly values.

balance assumption, one may say that agriculture does not add dissolved solids to the Tongue River. However, withdrawal of irrigation water partly dewaters the river and creates an increase in dissolved-solids concentration. Such dewatering does not occur with mining, but dissolved solids are added to the river by ground-water inflow transporting spoil leachates.

To better illustrate the relative magnitude of agricultural and mining impacts on dissolved-solids concentration, the calculations outlined in table 33 were performed. The plan assumes two hypothetical areas--a 100-acre irrigated field and a 100-acre surface coal mine, both adjacent to a stream having an annual flow of 10,000 acre-feet and having a dissolved-solids concentration of 500 mg/L. The mine adds dissolved solids to the stream, but does not withdraw water from it. The irrigated field requires an annual withdrawal of 6.40 acre-feet of irrigation water per acre, 3.54 acre-feet per acre of which is returned to the stream. The dissolved-solids load removed by irrigation withdrawal returns in full with irrigation return flow. As indicated in table 33, agriculture increases the stream's annual dissolved-solids concentration 2.94 percent; mining increases it 0.22 percent. Obviously, changes in the input values would shift the percentages; however, the values used approximate the conditions in the study area.

Table 32.--*Percentage loading of dissolved solids due to irrigation return flow or mine spoil leachates for instream releases from the proposed Tongue River Reservoir and with the intensive mining and increased irrigation plan*[a]

		Load per reach, in percent		Cumulative load, in percent	
Month	Reach[b]	Return flow	Leachate	Return flow	Leachate
Jan.	1	2.37	0.37	2.37	0.37
	2	5.75	.28	7.43	1.97
	3	5.81	.12	11.49	3.91
	4	7.68	1.22	17.33	4.50
	5	2.72	.00	19.00	4.81
	HWC	--	24.26	--	--
	OC	--	23.31	--	--
	PC	--	26.23	--	--
Feb.	1	1.98	.40	1.98	.40
	2	4.84	.30	6.21	2.08
	3	4.65	.12	9.09	3.86
	4	6.26	1.20	13.90	4.44
	5	2.20	.00	14.96	4.65
	HWC	--	30.56	--	--
	OC	--	16.49	--	--
	PC	--	12.56	--	--
Mar.	1	1.42	.36	1.42	.36
	2	3.40	.25	4.34	1.77
	3	3.38	.10	6.53	3.34
	4	4.68	1.06	10.27	3.91
	5	1.65	.00	11.09	4.09
	HWC	--	13.79	--	--
	OC	--	15.09	--	--
	PC	--	10.15	--	--
Apr.	1	1.71	.38	1.71	.38
	2	4.09	.29	5.30	2.01
	3	4.25	.12	8.22	3.92
	4	5.96	1.24	12.99	4.59
	5	2.00	.00	13.84	4.76
	HWC	--	20.32	--	--
	OC	--	17.75	--	--
	PC	--	9.45	--	--
May	1	4.15	.22	4.15	.22
	2	11.26	.20	14.80	1.37
	3	14.08	.10	26.91	3.09
	4	24.82	1.14	51.66	4.22
	5	9.62	.00	59.63	4.65
	HWC	--	21.41	--	--
	OC	--	17.06	--	--
	PC	--	10.15	--	--
June	1	2.87	.15	2.87	.15
	2	8.16	.15	10.78	1.03
	3	10.39	.08	20.48	2.49
	4	17.11	.92	37.58	3.41
	5	6.62	.00	43.87	3.85
	HWC	--	23.76	--	--
	OC	--	26.19	--	--
	PC	--	19.14	--	--
July	1	6.30	0.32	6.30	.32
	2	17.17	.28	22.42	1.97
	3	24.55	.15	45.62	4.80
	4	46.21	1.86	93.89	6.87
	5	21.59	.00	100.00	8.03
	HWC	--	20.30	--	--
	OC	--	38.71	--	--
	PC	--	24.11	--	--

Table 32.--*Percentage loading of dissolved solids due to irrigation return flow or mine spoil leachates for instream releases from the proposed Tongue River Reservoir and with the intensive mining and increased irrigation plan*[a]--Continued

		Load per reach, in percent		Cumulative load, in percent	
Month	Reach[b]	Return flow	Leachate	Return flow	Leachate
Aug.	1	8.65	.40	8.65	.40
	2	23.72	.36	30.98	2.50
	3	35.29	.19	64.95	6.21
	4	71.84	2.49	100.00	9.21
	5	41.29	.00	100.00	11.62
	HWC	--	39.82	--	--
	OC	--	56.73	--	--
	PC	--	67.63	--	--
Sept.	1	7.58	.41	7.58	.41
	2	19.91	.35	26.11	2.48
	3	26.78	.18	50.33	5.80
	4	44.19	1.99	90.80	7.36
	5	19.04	.00	100.00	8.09
	HWC	--	55.43	--	--
	OC	--	58.52	--	--
	PC	--	24.26	--	--
Oct.	1	2.94	.33	2.94	.33
	2	7.33	.28	9.63	1.94
	3	8.88	.13	16.93	4.21
	4	13.12	1.33	27.55	4.91
	5	5.36	.00	31.55	5.32
	HWC	--	42.83	--	--
	OC	--	44.17	--	--
	PC	--	77.35	--	--
Nov.	1	2.01	.34	2.01	.34
	2	4.88	.27	6.40	1.90
	3	5.77	.12	10.88	3.93
	4	8.68	1.23	17.85	4.54
	5	3.69	.00	20.57	4.89
	HWC	--	37.23	--	--
	OC	--	31.26	--	--
	PC	--	67.81	--	--
Dec.	1	2.26	.38	2.26	.38
	2	5.29	.29	6.93	2.06
	3	6.14	.13	11.57	4.18
	4	9.12	1.29	18.75	4.77
	5	3.86	.00	21.55	5.12
	HWC	--	32.94	--	--
	OC	--	31.25	--	--
	PC	--	67.63	--	--

[a]Mining plan conditions listed in table 25. Irrigated acreages: reach 1 = 1,490, reach 2 = 4,470, reach 3 = 5,250, reach 4 = 7,450, reach 5 = 2,540, Hanging Woman Creek = 1,225, Otter Creek = 785, Pumpkin Creek = 2,875
[b]HWC = Hanging Woman Creek, OC = Otter Creek, PC = Pumpkin Creek

Table 33.--*Annual impact on dissolved-solids concentrations of a hypothetical stream due to a 100-acre irrigated field and a 100-acre surface coal mine.*

[acre-ft, acre-feet; mg/L, milligrams per liter]

Initial conditions

1. Annual streamflow of 10,000 acre-ft with dissolved-solids concentration of 500 mg/L which equals an annual dissolved-solids load of 6,800 tons (10,000 acre-ft x 500 mg/L x 0.00136).
2. Mine area = 100 acres; irrigated field area = 100 acres.

Agriculture-related impacts

1. Water removed for irrigaton: 100 acres x 6.40 acre-ft per acre = 640 acre-ft.
2. Water added by irrigation return flow: 100 acres x 3.54 acre-ft per acre = 354 acre-ft.
3. Dissolved-solids load removed by irrigation withdrawal: 640 acre-ft x 500 mg/L x 0.00136 = 435.2 tons.
4. Dissolved-solids load added by irrigation return flow: 435.2 tons, by assumption of salt balance.
5. Stream concentration with irrigation:

$$\frac{6{,}800 \text{ tons} + 435.2 \text{ tons} - 435.2 \text{ tons}}{(10{,}000 \text{ acre-ft} - 640 \text{ acre-ft} + 354 \text{ acre-ft}) \times 0.00136} = 514.7 \text{ mg/L}$$

Mining-related impacts

1. Leachate dissolved-solids concentration of 3,171 mg/L, the mean of values listed in table 25.
2. Annual runoff coefficient of 0.409 inch per acre, from table 14.
3. Dissolved-solids load from mining: 100 acres x 0.409 inch per acre x 3,171 mg/L x 0.0001133 = 14.69 tons
4. Stream concentration with mining:

$$\frac{6{,}800 \text{ tons} + 14.69 \text{ tons}}{10{,}000 \text{ acre-ft} \times 0.00136} = 501.08 \text{ mg/L}$$

Comparison of impacts

Agriculture

$$\frac{514.7 \text{ mg/L}}{500.0 \text{ mg/L}} = 1.0294 \text{ or a 2.94 percent increase}$$

Mining

$$\frac{501.08 \text{ mg/L}}{500.0 \text{ mg/L}} = 1.0022 \text{ or a 0.22 percent increase}$$

SUMMARY

The Bureau of Land Management's request for a dissolved-solids model of the Tongue River arose from their need to predict water-quality impacts expected from surface coal mines planned within the study area. Prior to developing the model, the water-quality impacts from agriculture were judged to be significant within the study area. Thus, the model is designed to simulate impacts on dissolved solids from both surface coal mines and agriculture.

Input data requirements of the model permit simulation of numerous plans associated with spoil leachates from surface coal mines, irrigation withdrawals and return flows, and additional withdrawals of water for industries such as coal gasification plants. The model is able to simulate the larger monthly releases planned for the proposed Tongue River Reservoir. Model output permits assessing the relative magnitude of mining-related and agriculture-related impacts on dissolved solids during each month and in the five reaches of the Tongue River and at the mouths of Hanging Woman, Otter, and Pumpkin Creeks.

The model simulates the present-state hydrologic budget more accurately than it does the dissolved-solids budget. The majority of model error is attributable to a lack of long-term data necessary for accurate representation of the numerous hydrologic and dissolved-solids components in the model. These errors do not necessarily negate the model's usefulness for impact assessment in that the errors are common to all simulations. One can assess the relative changes in dissolved-solids concentrations among plans and thereby determine whether or not surface coal mining significantly degrades water quality in the Tongue River or the three tributaries. The severity of such impacts, taken as increases in dissolved-solids concentration, may be judged respective to irrigation salinity hazard criteria. However, such judgments may be biased by the generality inherent in these criteria and, therefore, may not accurately predict effects on irrigated crops specific to the study area.

Simulations were run for plans expected to be of interest relative to the study area. These simulations indicate that even with intensive mining the dissolved-solids concentrations in the Tongue River do not increase substantially, nor does Tongue River water reach dissolved-solids concentrations unfit for irrigation supply. The three tributaries, however, do show significant increases in dissolved-solids concentration with mining; the concentrations are in excess of those considered suitable for irrigation. However, the three tributaries presently contain water generally considered unsuitable for irrigation.

Based on comparisons of simulations using the present or proposed Tongue River Reservoir, it is apparent that the larger monthly streamflows available with the proposed reservoir would substantially reduce the dissolved-solids concentrations in the Tongue River. This is not true for Hanging Woman, Otter, and Pumpkin Creeks, which do not receive the larger streamflows.

Because of a lack of data, no attempt was made to model either the time required for spoil leachates to reach streams in the study area, or the duration of their impacts on streams. However, such impacts likely will occur after completion of the proposed reservoir.

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SUPPLEMENTAL INFORMATION

Table 2.--*Listing of computer program*

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                                                                               *
C                    TONGUE RIVER DISSOLVED SOLIDS MODEL                        *
C                                                                               *
C    PROGRAM TO COMPUTE DISSOLVED SOLIDS (SALINITY) CONDITIONS FOR FIVE         *
C    REACHES ON THE TONGUE RIVER, MONTANA FROM THE TONGUE RIVER DAM TO MILES *
C    CITY, IN ADDITION TO HANGING WOMAN, OTTER, AND PUMPKIN CREEKS.             *
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      IRD = DESIGNATOR FOR RESERVOIR, ENTER 0 FOR PRESENT TONGUE RIVER         *
C            RESERVOIR, ENTER 1 FOR PROPOSED TONGUE RIVER RESERVOIR             *
C      MFD = MONTHLY FLOW DESIGNATOR , ENTER 1 FOR MEAN, 2 FOR PLUS ONE         *
C             STANDARD DEVIATION, 3 FOR MINUS ONE STANDARD DEVIATION, 4 FOR     *
C             HISTORIC HIGH, 5 FOR HISTORIC LOW, 6 FOR INSTREAM FLOW            *
C      INTDS = DESIGNATOR FOR DISSOLVED SOLIDS INPUT BY TONGUE RIVER DAM,       *
C               ENTER 0 FOR REGRESSION-DERIVED VALUES OR ENTER 1 FOR            *
C               USER-DEFINED VALUES                                             *
C      TRDTDS = USER-DEFINED MONTHLY VALUE FOR DISSOLVED SOLIDS INPUT BY        *
C                TONGUE RIVER DAM                                               *
C      AIT = AREA (ACRES) IRRIGATED ON EACH OF FIVE REACHES ON TONGUE RIVER     *
C      AIHW = AREA (ACRES) IRRIGATED ON HANGING WOMAN CREEK (ENTER ACRES        *
C              IN EXCESS OF 1225 ACRES PRESENTLY IRRIGATED)                     *
C      AIO = AREA (ACRES) IRRIGATED ON OTTER CREEK (ENTER ACRES IN EXCESS       *
C             OF 785 ACRES PRESENTLY IRRIGATED)                                 *
C      AIP = AREA (ACRES) IRRIGATED ON PUMPKIN CREEK (ENTER ACRES IN            *
C             EXCESS OF 2875 ACRES PRESENTLY IRRIGATED)                         *
C      AMT = ACREAGE OF SURFACE COAL MINES ON EACH OF FIVE REACHES ON           *
C             TONGUE RIVER                                                      *
C      AMHW = ACREAGE OF SURFACE COAL MINES ON HANGING WOMAN CREEK              *
C      AMO = ACREAGE OF SURFACE COAL MINES ON OTTER CREEK                        *
C      AMP = ACREAGE OF SURFACE COAL MINES ON PUMPKIN CREEK                      *
C      DST = DISSOLVED SOLIDS CONCENTRATION (MG/L) OF LEACHATE FROM             *
C             SURFACE COAL MINES ON EACH OF FIVE REACHES ON TONGUE RIVER        *
C      DSHW = DISSOLVED SOLIDS CONCENTRATION (MG/L) OF LEACHATE FROM            *
C              SURFACE COAL MINES ON HANGING WOMAN CREEK                        *
C      DSO = DISSOLVED SOLIDS CONCENTRATION (MG/L) OF LEACHATE FROM             *
C             SURFACE COAL MINES ON OTTER CREEK                                 *
C      DSP = DISSOLVED SOLIDS CONCENTRATION (MG/L) OF LEACHATE FROM             *
C             SURFACE COAL MINES ON PUMPKIN CREEK                               *
C      QOLT = OTHER WATER LOSSES FROM EACH OF FIVE REACHES ON TONGUE RIVER      *
C              (ACRE-FEET/YEAR)                                                 *
C      QOLHW = OTHER WATER LOSSES FROM HANGING WOMAN CREEK (ACRE-FEET/YEAR)     *
C      QOLO = OTHER WATER LOSSES FROM OTTER CREEK (ACRE-FEET/YEAR)              *
C      QOLP = OTHER WATER LOSSES FROM PUMPKIN CREEK (ACRE-FEET/YEAR)            *
C                                                                               *
C     INPUT DATA CARD INSTRUCTIONS, SIX CARDS REQUIRED                          *
C       CARD 1 = SN,IRD,MFD                      FORMAT(A5,4X,I1,12I2)          *
C       CARD 2 = INTDS,TRDTDS                    FORMAT(I1,4X,12F5.0)           *
C       CARD 3 = AIT,AIHW,AIO,AIP                FORMAT(8F6.0)                  *
C       CARD 4 = AMT,AMHW,AMO,AMP                FORMAT(8F6.0)                  *
C       CARD 5 = DST,DSHW,DSO,DSP                FORMAT(8F6.0)                  *
C       CARD 6 = QOLT,QOLHW,QOLO,QOLP            FORMAT(8F6.0)                  *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *




CCCCC        SUBROUTINE MAIN --- 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 MFD(12),X(12),Y(12),M(12),Z(12),YMEAN(5),ZMEAN(5),
```

```
     *YMEANT(3)
      COMMON AIT(5),AMT(5),DST(5),QOLT(5),CT(12,5),PTA(12,5),PTM(12,5),C
     *H(12),CO(12),CP(12),PHM(12),POM(12),PPM(12),SN,AIHW,AIO,AIP,IRD,A
     *MHW,AMO,AMP,DSHW,DSO,DSP,QOLHW,QOLO,QOLP,YQMC(12),YSLMC(12),I,J,CP
     *TA(12,5),CPTM(12,5),QD(12),SADX(12,5),SLADH(12),SLADO(12),SLADP(12
     *),INTDS,TRDTDS(12),SD(12),CD(12),QADX(12,5),QADXH(12),QADXO(12),
     *QADXP(12)
      DATA M / 'JAN','FEB','MAR','APR','MAY','JUNE','JULY','AUG','SEPT',
     *'OCT','NOV','DEC'/

CCCCC     READ INPUT DATA FROM CARDS

      READ(5,5)SN,IRD,MFD
      READ(5,7)INTDS,TRDTDS
      READ(5,10)AIT,AIHW,AIO,AIP
      READ(5,10)AMT,AMHW,AMO,AMP
      READ(5,10)DST,DSHW,DSO,DSP
      READ(5,10)QOLT,QOLHW,QOLO,QOLP
    5 FORMAT(A5,4X,I1,12I2)
    7 FORMAT(I1,4X,12F5.0)
   10 FORMAT(8F6.0)
CCCCC     WRITE DESCRIPTION OF SIMULATION CONDITIONS
      WRITE(6,15) SN
   15 FORMAT('1TONGUE RIVER DISSOLVED SOLIDS MODEL --- SIMULATION NUMBER
     * ',A5//)
      IF(IRD.EQ.0) WRITE(6,16)
      IF(IRD.EQ.1) WRITE(6,17)
   16 FORMAT(' RESERVOIR RELEASES FROM PRESENT TONGUE RIVER RESERVOIR')
   17 FORMAT(' RESERVOIR RELEASES FROM PROPOSED TONGUE RIVER RESERVOIR')
      IF(INTDS.EQ.0) WRITE(6,18)
      IF(INTDS.EQ.1) WRITE(6,20)
   18 FORMAT(' DESIGNATOR FOR DISSOLVED-SOLIDS INPUT BY TONGUE RIVER DAM
     * SET TO REGRESSION-DEFINED STATUS')
   20 FORMAT(' DESIGNATOR FOR DISSOLVED-SOLIDS INPUT BY TONGUE RIVER DAM
     * 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(6,90)
      WRITE(6,92)
      WRITE(6,94)
      WRITE(6,96)
      WRITE(6,22)
   22 FORMAT('0STREAMFLOW STATUS DURING SIMULATION')
      WRITE(6,24)
   24 FORMAT(' ************************************')
      WRITE(6,30)MFD(1),MFD(2)
      WRITE(6,32)MFD(3),MFD(4)
      WRITE(6,34)MFD(5),MFD(6)
      WRITE(6,36)MFD(7),MFD(8)
      WRITE(6,38)MFD(9),MFD(10)
      WRITE(6,40)MFD(11),MFD(12)
   30 FORMAT('0JAN   = ',I1,T13,'FEB   = ',I1,T30,'1 = MEAN')
   32 FORMAT(' MARCH = ',I1,T13,'APRIL = ',I1,T30,'2 = PLUS ONE STANDARD
     * DEVIATION')
   34 FORMAT(' MAY   = ',I1,T13,'JUNE  = ',I1,T30,'3 = MINUS ONE STANDAR
     *D DEVIATION')
   36 FORMAT(' JULY  = ',I1,T13,'AUG   = ',I1,T30,'4 = HISTORIC HIGH')
   38 FORMAT(' SEPT  = ',I1,T13,'OCT   = ',I1,T30,'5 = HISTORIC LOW')
   40 FORMAT(' NOV   = ',I1,T13,'DEC   = ',I1,T30,'6 = INSTREAM FLOW REQ
     *UIREMENTS')
      WRITE(6,42)
      WRITE(6,44)
   42 FORMAT('0IRRIGATED ACREAGE STATUS DURING SIMULATION')
```

```
      44 FORMAT(' ***********************************************')
         WRITE(6,46)AIT(1),AIT(2),AIT(3),AIT(4)
         WRITE(6,48)AIT(5),AIHW,AIO,AIP
         WRITE(6,49)
      46 FORMAT('0REACH 1 = ',F6.0,T19,'REACH  2  = ',F6.0,T38,'REACH  3 =
        *',F6.0,T56,'REACH  4 = ',F6.0)
      48 FORMAT(' REACH 5 = ',F6.0,T19,'REACH HWC = ',F6.0,T38,'REACH OC =
        *',F6.0,T56,'REACH PC = ',F6.0)
      49 FORMAT('    NOTE - IRRIGATED ACRES ON REACHES HWC, OC, AND PC ARE
        *THOSE IN '/,'+   EXCESS OF PRESENTLY IRRIGATED ACRES (1225 ACRES O
        *N HWC, '/,'+   785 ACRES ON OC, 2875 ACRES ON PC)')
         WRITE(6,50)
         WRITE(6,52)
      50 FORMAT('0SURFACE COAL MINING STATUS DURING SIMULATION')
      52 FORMAT(' ********************************************')
         WRITE(6,54)
         WRITE(6,56)
         WRITE(6,58)
      54 FORMAT('0                          DISSOLVED SOLIDS                 DI
        *SSOLVED SOLIDS')
      56 FORMAT(' REACH  ACREAGE  (MG/L) OF LEACHATE   REACH  ACREAGE  (MG
        */L) OF LEACHATE')
      58 FORMAT(' -----  -------  ------------------   -----  -------  ---
        *---------------')
         WRITE(6,60)AMT(1),DST(1),AMT(2),DST(2)
         WRITE(6,62)AMT(3),DST(3),AMT(4),DST(4)
         WRITE(6,64)AMT(5),DST(5),AMHW,DSHW
         WRITE(6,66)AMO,DSO,AMP,DSP
      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,T41,'HWC',T46,F7.0,T63,F5.0)
      66 FORMAT('  OC',T8,F7.0,T25,F5.0,T42,'PC',T46,F7.0,T63,F5.0)
         WRITE(6,68)
         WRITE(6,70)
      68 FORMAT('0OTHER WATER LOSSES (ACRE-FEET PER YEAR) DURING SIMULATION
        *')
      70 FORMAT(' ***********************************************************
        *')
         WRITE(6,72)QOLT(1),QOLT(2),QOLT(3),QOLT(4)
         WRITE(6,74)QOLT(5),QOLHW,QOLO,QOLP
      72 FORMAT('0REACH 1 = ',F6.0,T19,'REACH  2  = ',F6.0,T38,'REACH  3 =
        *',F6.0,T56,'REACH  4 = ',F6.0)
      74 FORMAT(' REACH 5 = ',F6.0,T19,'REACH HWC = ',F6.0,T38,'REACH OC =
        *',F6.0,T56,'REACH PC = ',F6.0)
      76 FORMAT('0REACH DESCRIPTIONS')
      78 FORMAT(' ******************')
      80 FORMAT('0 1  = TONGUE RIVER DAM (RIVER MILE 189.1) TO RIVER MILE 1
        *56.7')
      82 FORMAT('  2  = RIVER MILE 156.7 TO RIVER MILE 112.7 (INCLUDES HANG
        *ING WOMAN CREEK)')
      84 FORMAT('  3  = RIVER MILE 112.7 TO RIVER MILE  77.6 (INCLUDES OTTE
        *R CREEK)')
      86 FORMAT('  4  = RIVER MILE  77.6 TO RIVER MILE  20.0')
      88 FORMAT('  5  = RIVER MILE  20.0 TO RIVER MILE 8.1 AT MILES CITY GA
        *GE (INCLUDES PUMPKIN CREEK)')
      90 FORMAT(' HWC = HANGING WOMAN CREEK')
      92 FORMAT(' OC  = OTTER CREEK')
      94 FORMAT(' PC  = PUMPKIN CREEK')
      96 FORMAT(' TRD = TONGUE RIVER DAM DISCHARGE'//)

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',T58,'PERCENT LOAD (PER',T88,'CUMULATIVE PERCENT'/,
        *'+',T17,'(ACRE-FEET)',T34,'LOAD',T44,'CONC',T60,'REACH) DUE TO',T9
```

```
     *1,'LOAD 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
      QADXH(I)=0.0
      QADXO(I)=0.0
      QADXP(I)=0.0
      SLADH(I)=0.0
      SLADO(I)=0.0
      SLADP(I)=0.0
      DO 111 J = 1,5
      QADX(I,J)=0.0
      SADX(I,J)=0.0
  111 CONTINUE
  112 CONTINUE

CCCCC     BASED ON VALUE OF MONTHLY FLOW DESIGNATOR(MFD), SUBROUTINE MAIN
CCCCC     CALLS APPROPRIATE SUBROUTINE FOR PASSING DATA TO SUBROUTINE SALINE

      DO 145 I = 1,12
      IMFD=MFD(I)
C   TEST FOR VALID HYDROLOGIC CONDITION USED WITH PROPOSED RESERVOIR
      IF((IRD.EQ.1).AND.((IMFD.EQ.2).OR.(IMFD.EQ.3).OR.(IMFD.EQ.4)
     *.OR.(IMFD.EQ.5))) GO TO 1015
C   TEST FOR VALID MONTHLY FLOW DESIGNATOR
      IF(IMFD.LT.1.OR.IMFD.GT.6) GO TO 1000
      GO TO(115,120,125,130,135,140),IMFD
  115 CALL MEAN
      GO TO 145
  120 CALL PLS1SD
      GO TO 145
  125 CALL MIN1SD
      GO TO 145
  130 CALL HIGH
      GO TO 145
  135 CALL LOW
      GO TO 145
  140 CALL INSTRM
  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
     *6,'TONGUE RIVER DAM',T70,'MILES CITY GAGE'/,'+',T9,'--------------
     *-------------------  --------------------  --------------------'
     */,'+MONTH  TONGUE RIVER DAM  MILES CITY GAGE  LOAD(TON)  CONC(MG/L
     *)  LOAD(TON)  CONC(MG/L)'/,'+-----  ---------------  -----------
     *---  ---------  ----------  ---------  ----------')

CCCCC     WRITE RESULTS FOR SIMULATION SUMMARY

      DO 390 I=1,12
      Z(I)=YSLMC(I)/YQMC(I)/.00136
      WRITE(6,385) M(I),QD(I),YQMC(I),SD(I),CD(I),YSLMC(I),Z(I)
  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)',T55,'MEAN PE
     *RCENT LOAD',T83,'MEAN CUMULATIVE PERCENT')
  410 FORMAT(' ',T10,'------------------------------------',T55,'PER REA
     *CH DUE TO',T89,'LOAD 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 TONGUE RIVER, WRITE RESULTS OF STATISTICAL
CCCCC      ANALYSES

      DO 500 J=1,5
      SUMX = 0
      SUMXSQ = 0
      SUMY = 0
      SUMZ = 0
      XMIN = 1.E20
      XMAX = -1.E20
      SUMU=0
      SUMV=0
      DO 470 I=1,12
      SUMX = SUMX + CT(I,J)
      SUMXSQ = SUMXSQ + CT(I,J) ** 2
      SUMY = SUMY + PTA(I,J)
      SUMZ = SUMZ + PTM(I,J)
      XMIN = AMIN1(XMIN,CT(I,J))
      XMAX = AMAX1(XMAX,CT(I,J))
      SUMU=SUMU+CPTA(I,J)
      SUMV=SUMV+CPTM(I,J)
  470 CONTINUE
      XMEAN = SUMX/12
      XSD = SQRT(12 * SUMXSQ - SUMX ** 2)/12
      YMEAN(J) = SUMY/12
      ZMEAN(J) = SUMZ/12
      UMEAN=SUMU/12
      VMEAN=SUMV/12
      WRITE(6,480) J,XMEAN,XSD,XMIN,XMAX,YMEAN(J),ZMEAN(J),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

CCCCC      PERFORM STATISTICAL ANALYSIS OF DATA OUTPUT BY MONTHLY COMPUTATIONS
CCCCC      FOR HANGING WOMAN, OTTER, AND PUMPKIN CREEKS, WRITE RESULTS OF
CCCCC      STATISTICAL ANALYSES

      DO 650 K=1,3
      SUMX = 0
      SUMXSQ = 0
      SUMY = 0
      XMIN = 1.E20
      XMAX = -1.E20
      DO 610 I=1,12
      IF(K.EQ.1) X(I) = CH(I)
      IF(K.EQ.2) X(I) = CO(I)
      IF(K.EQ.3) X(I) = CP(I)
      IF(K.EQ.1) Y(I) = PHM(I)
      IF(K.EQ.2) Y(I) = POM(I)
      IF(K.EQ.3) Y(I) = PPM(I)
      SUMX = SUMX + X(I)
      SUMXSQ = SUMXSQ + X(I)**2
```

```
          SUMY = SUMY + Y(I)
          XMIN = AMIN1(XMIN,X(I))
          XMAX = AMAX1(XMAX,X(I))
    610 CONTINUE
          XMEAN = SUMX/12
          XSD = SQRT(12 * SUMXSQ - SUMX ** 2)/12
          YMEANT(K) = SUMY/12
          GO TO(620,625,630),K
    620 WRITE(6,635)XMEAN,XSD,XMIN,XMAX,YMEANT(1)
          GO TO 650
    625 WRITE(6,640)XMEAN,XSD,XMIN,XMAX,YMEANT(2)
          GO TO 650
    630 WRITE(6,645)XMEAN,XSD,XMIN,XMAX,YMEANT(3)
    635 FORMAT('  HWC',T9,F7.0,T19,F7.0,T28,F7.0,T37,F7.0,T67,F7.4)
    640 FORMAT('  OC ',T9,F7.0,T19,F7.0,T28,F7.0,T37,F7.0,T67,F7.4)
    645 FORMAT('  PC ',T9,F7.0,T19,F7.0,T28,F7.0,T37,F7.0,T67,F7.4)
    650 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 FLOW DESIGNATOR(MFD)

   1000 WRITE(6,1010) SN,I
   1010 FORMAT('0SIMULATION NUMBER ',A5,' TERMINATED DUE TO INVALID MONTHL
         *Y FLOW DESIGNATOR IN MONTH NUMBER ',I2)
          GO TO 1020
   1015 WRITE(6,1017) SN
   1017 FORMAT('0SIMULATION NUMBER ',A5,' TERMINATED DUE TO INVALID HYDROL
         *OGIC CONDITION USED WITH PROPOSED TONGUE RIVER RESERVOIR.')
   1020 STOP
          END

 C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 CCCCC     SUBROUTINE BLOCK DATA --- CONTAINS DATA FOR SIX STREAMFLOW
 CCCCC     CONDITIONS USED IN THE MODEL

          BLOCK DATA
          COMMON / DATA / QTRD(6,12),PT(6,12),ET(6,12),QHW(6,12),QO(6,12),QP
         *(6,12),YHW(6,12),YO(6,12),YP(6,12)
          DATA QTRD / 10800.,13350.,8250.,15060.,4910.,9220.,10580.,15520.,5
         *640.,32880.,3160.,8330.,15390.,24560.,6220.,41550.,1400.,9220.,247
         *70.,37490.,12050.,57020.,6830.,8920.,63390.,95550.,31230.,166900.,
         *11970.,23700.,90450.,145350.,35550.,223300.,13980.,41640.,35170.,5
         *7010.,13330.,128100.,10390.,12790.,22560.,31220.,13900.,47190.,670
         *0.,9220.,18130.,25480.,10780.,40850.,7740.,8920.,16730.,24580.,888
         *0.,31320.,4740.,11680.,15120.,22820.,7430.,30110.,2420.,11300.,121
         *20.,15770.,8470.,19680.,5320.,9220./
          DATA PT/.049,.081,.018,.148;.007,.049,.047,.073,.02,.108,.007,.047
         *,.054,.09,.018,.153,.006,.054,.114,.196,.033,.352,.008,.114,.194,.
         *323,.066,.568,.02,.194,.232,.341,.123,.436,.07,.232,.123,.217,.03,
         *.376,.008,.123,.099,.192,.007,.333,.001,.099,.095,.18,.01,.335,.00
         *1,.095,.078,.178,.001,.526,.001,.078,.05,.093,.008,.18,.002,.05,.0
         *5,.088,.013,.148,.002,.05/
          DATA ET/.058,.05,.067,.042,.092,.058,.058,.05,.067,.042,.092,.058,
         *.117,.092,.142,.083,.175,.117,.217,.175,.258,.15,.325,.217,.358,.2
         *83,.433,.242,.533,.358,.45,.333,.567,.275,.842,.45,.575,.475,.667,
         *.408,.808,.575,.55,.45,.65,.425,.775,.55,.358,.292,.425,.233,.508,
         *.358,.258,.208,.308,.183,.383,.258,.117,.092,.142,.083,.175,.117,.
         *058,.05,.067,.042,.092,.058/
          DATA QHW / 175.,825.,88.,1300.,62.,175.,150.,525.,138.,1220.,64.,1
         *50.,413.,544.,262.,5730.,133.,413.,225.,325.,158.,1030.,117.,225.,
         *210.,375.,105.,6060.,67.,210.,183.,762.,125.,769.,88.,183.,225.,26
         *2.,88.,390.,27.,225.,85.,116.,38.,129.,10.,85.,45.,76.,34.,139.,16
         *.,45.,75.,92.,49.,186.,46.,75.,95.,162.,64.,182.,54.,95.,115.,191.
         *,74.,194.,58.,115./
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      DATA QO / 300.,400.,233.,1850.,162.,300.,550.,650.,300.,1940.,154.
     *,550.,750.,1800.,500.,6550.,413.,750.,500.,600.,433.,1670.,270.,50
     *0.,525.,900.,375.,3270.,263.,525.,300.,500.,233.,936.,138.,300.,16
     *7.,350.,100.,549.,17.,167.,80.,200.,40.,259.,5.,80.,80.,150.,40.,2
     *43.,8.,80.,133.,200.,67.,272.,25.,133.,233.,300.,167.,364.,121.,23
     *3.,233.,300.,167.,432.,165.,233./
      DATA QP / 172.,257.,86.,1120.,1.,172.,600.,900.,200.,6770.,1.,600.
     *,800.,6000.,400.,18400.,25.,800.,900.,2100.,300.,5000.,12.,900.,80
     *0.,2000.,400.,12580.,1.,800.,300.,2100.,150.,3820.,1.,300.,200.,30
     *0.,100.,1110.,1.,200.,16.,30.,8.,344.,1.,16.,200.,300.,100.,3560.,
     *1.,200.,16.,30.,8.,72.,1.,16.,16.,30.,8.,158.,1.,16.,16.,30.,8.,45
     *.,1.,16./
      DATA YHW / .58,2.74,.29,2.74,.29,.58,.5,1.75,.46,1.75,.46,.5,1.37,
     *1.81,.87,1.81,.87,1.37,.75,1.08,.53,1.08,.53,.75,.7,1.25,.35,1.25,
     *.35,.7,.61,2.53,.42,2.53,.42,.61,.75,.87,.29,.87,.29,.75,.28,.39,.
     *13,.39,.13,.28,.15,.25,.11,.25,.11,.15,.25,.31,.16,.31,.16,.25,.32
     *,.54,.21,.54,.21,.32,.38,.63,.25,.63,.25,.38/
      DATA YO /.66,.88,.51,.88,.51,.66,1.22,1.44,.66,1.44,.66,1.22,1.66,
     *3.98,1.11,3.98,1.11,1.66,1.11,1.33,.96,1.33,.96,1.11,1.16,1.99,.83
     *,1.99,.83,1.16,.66,1.11,.51,1.11,.51,.66,.37,.77,.22,.77,.22,.37,.
     *18,.44,.09,.44,.09,.18,.18,.33,.09,.33,.09,.18,.29,.44,.15,.44,.15
     *,.29,.51,.66,.37,.66,.37,.51,.51,.66,.37,.66,.37,.51/
      DATA YP / .39,.58,.19,.58,.19,.39,1.35,2.02,.45,2.02,.45,1.35,1.79
     *,13.45,.9,13.45,.9,1.79,2.02,4.71,.67,4.71,.67,2.02,1.79,4.48,.9,4
     *.48,.9,1.79,.67,4.71,.34,4.71,.34,.67,.45,.67,.22,.67,.22,.45,.04,
     *.07,.02,.07,.02,.04,.45,.67,.22,.67,.22,.45,.04,.07,.02,.07,.02,.0
     *4,.04,.07,.02,.07,.02,.04,.04,.07,.02,.07,.02,.04/
      END

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

CCCCC      SUBROUTINE MEAN --- PASSES DATA ASSOCIATED WITH MEAN STREAMFLOW
CCCCC      TO SUBROUTINE SALINE

      SUBROUTINE MEAN
      COMMON / DATA / QTRD(6,12),PT(6,12),ET(6,12),QHW(6,12),QO(6,12),QP
     *(6,12),YHW(6,12),YO(6,12),YP(6,12)
      COMMON AIT(5),AMT(5),DST(5),QOLT(5),CT(12,5),PTA(12,5),PTM(12,5),C
     *H(12),CO(12),CP(12),PHM(12),POM(12),PPM(12),SN,AIHW,AIO,AIP,IRD,A
     *MHW,AMO,AMP,DSHW,DSO,DSP,QOLHW,QOLO,QOLP,YQMC(12),YSLMC(12),I,J,CP
     *TA(12,5),CPTM(12,5),QD(12),SADX(12,5),SLADH(12),SLADO(12),SLADP(12
     *),INTDS,TRDTDS(12),SD(12),CD(12),QADX(12,5),QADXH(12),QADXO(12)
     *,QADXP(12)
      CALL SALINE (1)
      RETURN
      END

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

CCCCC      SUBROUTINE PLS1SD --- PASSES DATA ASSOCIATED WITH PLUS ONE
CCCCC      STANDARD DEVIATION STREAMFLOW TO SUBROUTINE SALINE

      SUBROUTINE PLS1SD
      COMMON / DATA / QTRD(6,12),PT(6,12),ET(6,12),QHW(6,12),QO(6,12),QP
     *(6,12),YHW(6,12),YO(6,12),YP(6,12)
      COMMON AIT(5),AMT(5),DST(5),QOLT(5),CT(12,5),PTA(12,5),PTM(12,5),C
     *H(12),CO(12),CP(12),PHM(12),POM(12),PPM(12),SN,AIHW,AIO,AIP,IRD,A
     *MHW,AMO,AMP,DSHW,DSO,DSP,QOLHW,QOLO,QOLP,YQMC(12),YSLMC(12),I,J,CP
     *TA(12,5),CPTM(12,5),QD(12),SADX(12,5),SLADH(12),SLADO(12),SLADP(12
     *),INTDS,TRDTDS(12),SD(12),CD(12),QADX(12,5),QADXH(12),QADXO(12),
     *QADXP(12)
      CALL SALINE (2)
      RETURN
      END

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

CCCCC      SUBROUTINE MIN1SD --- PASSES DATA ASSOCIATED WITH MINUS ONE
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CCCCC      STANDARD DEVIATION STREAMFLOW TO SUBROUTINE SALINE

      SUBROUTINE MIN1SD
      COMMON / DATA / QTRD(6,12),PT(6,12),ET(6,12),QHW(6,12),QO(6,12),QP
     *(6,12),YHW(6,12),YO(6,12),YP(6,12)
      COMMON AIT(5),AMT(5),DST(5),QOLT(5),CT(12,5),PTA(12,5),PTM(12,5),C
     *H(12),CO(12),CP(12),PHM(12),POM(12),PPM(12),SN,AIHW,AIO,AIP,IRD,A
     *MHW,AMO,AMP,DSHW,DSO,DSP,QOLHW,QOLO,QOLP,YQMC(12),YSLMC(12),I,J,CP
     *TA(12,5),CPTM(12,5),QD(12),SADX(12,5),SLADH(12),SLADO(12),SLADP(12
     *),INTDS,TRDTDS(12),SD(12),CD(12),QADX(12,5),QADXH(12),QADXO(12)
     *,QADXP(12)
      CALL SALINE (3)
      RETURN
      END

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

CCCCC      SUBROUTINE HIGH --- PASSES DATA ASSOCIATED WITH HISTORIC HIGH
CCCCC      STREAMFLOW TO SUBROUTINE SALINE

      SUBROUTINE HIGH
      COMMON / DATA / QTRD(6,12),PT(6,12),ET(6,12),QHW(6,12),QO(6,12),QP
     *(6,12),YHW(6,12),YO(6,12),YP(6,12)
      COMMON AIT(5),AMT(5),DST(5),QOLT(5),CT(12,5),PTA(12,5),PTM(12,5),C
     *H(12),CO(12),CP(12),PHM(12),POM(12),PPM(12),SN,AIHW,AIO,AIP,IRD,A
     *MHW,AMO,AMP,DSHW,DSO,DSP,QOLHW,QOLO,QOLP,YQMC(12),YSLMC(12),I,J,CP
     *TA(12,5),CPTM(12,5),QD(12),SADX(12,5),SLADH(12),SLADO(12),SLADP(12
     *),INTDS,TRDTDS(12),SD(12),CD(12),QADX(12,5),QADXH(12),QADXO(12),
     *QADXP(12)
      CALL SALINE (4)
      RETURN
      END

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

CCCCC      SUBROUTINE LOW --- PASSES DATA ASSOCIATED WITH HISTORIC LOW
CCCCC      STREAMFLOW TO SUBROUTINE SALINE

      SUBROUTINE LOW
      COMMON / DATA / QTRD(6,12),PT(6,12),ET(6,12),QHW(6,12),QO(6,12),QP
     *(6,12),YHW(6,12),YO(6,12),YP(6,12)
      COMMON AIT(5),AMT(5),DST(5),QOLT(5),CT(12,5),PTA(12,5),PTM(12,5),C
     *H(12),CO(12),CP(12),PHM(12),POM(12),PPM(12),SN,AIHW,AIO,AIP,IRD,A
     *MHW,AMO,AMP,DSHW,DSO,DSP,QOLHW,QOLO,QOLP,YQMC(12),YSLMC(12),I,J,CP
     *TA(12,5),CPTM(12,5),QD(12),SADX(12,5),SLADH(12),SLADO(12),SLADP(12
     *),INTDS,TRDTDS(12),SD(12),CD(12),QADX(12,5),QADXH(12),QADXO(12),
     *QADXP(12)
      CALL SALINE (5)
      RETURN
      END

C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

CCCCC      SUBROUTINE INSTRM --- PASSES DATA ASSOCIATED WITH INSTREAM
CCCCC      STREAMFLOW REQUIREMENTS TO SUBROUTINE SALINE

      SUBROUTINE INSTRM
      COMMON / DATA / QTRD(6,12),PT(6,12),ET(6,12),QHW(6,12),QO(6,12),QP
     *(6,12),YHW(6,12),YO(6,12),YP(6,12)
      COMMON AIT(5),AMT(5),DST(5),QOLT(5),CT(12,5),PTA(12,5),PTM(12,5),C
     *H(12),CO(12),CP(12),PHM(12),POM(12),PPM(12),SN,AIHW,AIO,AIP,IRD,A
     *MHW,AMO,AMP,DSHW,DSO,DSP,QOLHW,QOLO,QOLP,YQMC(12),YSLMC(12),I,J,CP
     *TA(12,5),CPTM(12,5),QD(12),SADX(12,5),SLADH(12),SLADO(12),SLADP(12
     *),INTDS,TRDTDS(12),SD(12),CD(12),QADX(12,5),QADXH(12),QADXO(12),
     *QADXP(12)
      CALL SALINE (6)
      RETURN
      END
```

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C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

CCCCC     SUBROUTINE SALINE --- CALCULATES HYDROLOGIC AND DISSOLVED SOLIDS
CCCCC     MASS BALANCES FOR FIVE REACHES OF THE TONGUE RIVER INCLUDING
CCCCC     HANGING WOMAN, OTTER, AND PUMPKIN CREEKS AND WRITES RESULTS
CCCCC     OF MONTHLY COMPUTATIONS

      SUBROUTINE SALINE (INDEX)
      COMMON / DATA / QTRD(6,12),PT(6,12),ET(6,12),QHW(6,12),QO(6,12),QP
     *(6,12),YHW(6,12),YO(6,12),YP(6,12)
      COMMON AIT(5),AMT(5),DST(5),QOLT(5),CT(12,5),PTA(12,5),PTM(12,5),C
     *H(12),CO(12),CP(12),PHM(12),POM(12),PPM(12),SN,AIHW,AIO,AIP,IRD,A
     *MHW,AMO,AMP,DSHW,DSO,DSP,QOLHW,QOLO,QOLP,YQMC(12),YSLMC(12),I,J,CP
     *TA(12,5),CPTM(12,5),QD(12),SADX(12,5),SLADH(12),SLADO(12),SLADP(12
     *),INTDS,TRDTDS(12),SD(12),CD(12),QADX(12,5),QADXH(12),QADXO(12),
     *QADXP(12)
      DIMENSION SCGW(5),RA(5),RL(5),AUT(5),GW(5),M(12),ND(12),QIR123(12)
     *,QIR4(12),QIR5(12),QIM(5)
      DIMENSION Q(5),QC(5),QPT(5),QET(5),QGW(5),QAD(5),QRF(5),QUT(5),QGT
     *(5),QI(5),QOL(5),SL(5),SLC(5),SGW(5),SAD(5),SRF(5),S(5),SUT(5),SGT
     *(5),SLMT(5),SOL(5),SC(5),SADP(12,5),ADFS(12),ADPS(12),QADP1(12)
      DATA SCGW / 1150.,1125.,1100.,950.,800./
      DATA RA / 471.,640.,511.,838.,173./
      DATA RL / 32.4,44.,35.1,57.6,11.9/
      DATA AUT / 187520.,223360.,247680.,355200.,84480./
      DATA GW / .09,.67,.37,.41,.35/
      DATA M / 'JAN','FEB','MAR','APR','MAY','JUNE','JULY','AUG','SEPT',
     *'OCT','NOV','DEC'/
      DATA ND / 31,28,31,30,31,30,31,31,30,31,30,31/
      DATA QIR123 / .75,.75,9*0.,.5/
      DATA QIR4 / .75,1.,9*0.,.5/
      DATA QIR5 / 1.,1.,9*0.,.5/
      DATA QIM / 471.,1280.,1022.,1886.,433./
      DATA SADP / .12,.093,.075,.055,.033,.008,6*0.,.137,.109,.09,.064,
     *.036,.008,6*0.,.154,.125,.105,.074,.04,.009,6*0.,.171,.141,.12,
     *.084,.044,.009,6*0.,.189,.158,.135,.093,.048,.01,6*0./
      DATA ADFS / 0.,0.,0.,.06,.94,1.14,1.52,1.41,1.06,.27,0.,0./
      DATA ADPS / 0.,0.,0.,.06,.94,1.14,.76,.70,.53,.13,0.,0./
      DATA QADP1 / .1532,.1306,.103,.0662,.0321,.0065,6*0./

CCCCC      CALCULATE HYDROLOGIC MASS BALANCE

      IF(IRD.EQ.0) QTRD(INDEX,I) = QTRD(INDEX,I)
      IF(IRD.EQ.1) QTRD(INDEX,I) = QTRD(INDEX,I) * 2.05
      QD(I) = QTRD(INDEX,I)
      DO 1500 J = 1,5
      IF(ND(I).EQ.31) CV = 61.491
      IF(ND(I).EQ.30) CV = 59.504
      IF(ND(I).EQ.28) CV = 55.547
      IF(J.EQ.1) Q(J)=QTRD(INDEX,I)
      IF(J.GT.1) Q(J)=QC(J-1)
      QPT(J)=RA(J)*PT(INDEX,I)
      QET(J)=RA(J)*ET(INDEX,I)
      QGW(J)=RL(J)*GW(J)*ND(I)
      IF(INDEX.EQ.1.OR.INDEX.EQ.2.OR.INDEX.EQ.4) AD=ADFS(I)
      IF(INDEX.EQ.3.OR.INDEX.EQ.5.OR.INDEX.EQ.6) AD=ADPS(I)
      QAD(J)=AIT(J)*AD
      QADX(I,J)=QAD(J)
      QRF(J)=((QAD(J)*.65)*.85)*.65+(((QADX(1,J)+QADX(2,J)+QADX(3,J)+QAD
     *X(4,J)+QADX(5,J)+QADX(6,J)+QADX(7,J)+QADX(8,J)+QADX(9,J)+QADX(10,J
     *)+QADX(11,J)+QADX(12,J)-QADX(I,J))*.65)*.85)*.35/8+QADP1(I)*AIT(J)
      IF(J.EQ.1) YC=YHW(INDEX,I) * .001
      IF(J.EQ.2.OR.J.EQ.3) YC=YO(INDEX,I) * .001
      IF(J.EQ.4.OR.J.EQ.5) YC=YP(INDEX,I) * .001
      QUT(J)=AUT(J)*YC
      QGT(J)=0
      IF(J.EQ.2) QGT(J)=QHW(INDEX,I)
```

```
      IF(J.EQ.3) QGT(J)=QO(INDEX,I)
      IF(J.EQ.5) QGT(J)=QP(INDEX,I)
      GO TO (20,30,30,40,50),J
   20 QI(J)=RA(J)*.5*QIR123(I)
      GO TO 60
   30 QI(J)=RA(J)*QIR123(I)
      GO TO 60
   40 QI(J)=RA(J)*QIR4(I)
      GO TO 60
   50 QI(J)=RA(J)*QIR5(I)
   60 QOL(J)=QOLT(J)/12
      QOLTR=0
      IF(J.EQ.1) QOLTR=QOLHW/12
      IF(J.EQ.2) QOLTR=QOLO/12
      IF(J.EQ.4) QOLTR=QOLP/12
CCCCC      COMPUTE DISSOLVED SOLIDS MASS BALANCE
      C=.00136
      IF(J.EQ.1) ROCT=.186
      IF(J.EQ.2.OR.J.EQ.3) ROCT=.167
      IF(J.EQ.4.OR.J.EQ.5) ROCT=.409
      ROCH=.186
      ROCO=.167
      ROCP=.409
      IF(J.EQ.1.AND.INTDS.EQ.0) SL(J) = C*QTRD(INDEX,I)*13412.07*(QTRD(I
     *NDEX,I)**(-.3498))
      IF(J.EQ.1.AND.INTDS.EQ.1) SL(J) = TRDTDS(I)*QTRD(INDEX,I)*C
      SD(I)=SL(1)
      CD(I)=SL(1)/QD(I)/C
      IF(J.GT.1) SL(J)=SLC(J-1)
      SGW(J)=QGW(J)*SCGW(J)*C
      SAD(J)=QAD(J)*(SL(J)/Q(J))
      SADX(I,J) = SAD(J)
      SRF(J) = SAD(J)*.65+(SADX(1,J)+SADX(2,J)+SADX(3,J)+SADX(4,J)+SADX(
     *5,J)+SADX(6,J)+SADX(7,J)+SADX(8,J)+SADX(9,J)+SADX(10,J)+SADX(11,J)
     *+SADX(12,J)-SADX(I,J))*.04375+SADP(I,J)*AIT(J)
      IF(J.EQ.1) S(J)=2006.14-16.13*(QHW(INDEX,I)/CV)
      IF(J.EQ.2.OR.J.EQ.3) S(J)=2237.49-8.831*(QO(INDEX,I)/CV)
      IF(J.EQ.4.OR.J.EQ.5) S(J)=1610.64*(QP(INDEX,I)/CV)**(-.2543)
      SUT(J)=QUT(J)*S(J)*C
      SLMT(J)=DST(J)*.0001133*AMT(J)*(ROCT/12)
      SOL(J)=QOL(J)*(SL(J)/Q(J))
      SOLTR=0
      IF(J.EQ.1) SOLTR=QOLTR*(SL(J)/Q(J))
      IF(J.EQ.2) SOLTR=QOLTR*(SL(J)/Q(J))
      IF(J.EQ.4) SOLTR=QOLTR*(SL(J)/Q(J))
CCCCC      COMPUTE DISSOLVED SOLIDS MASS BALANCES FOR THREE TRIBUTARIES
      SGT(J)=0
      GO TO (400,100,200,400,300),J
CCCCC      COMPUTE DISSOLVED SOLIDS MASS BALANCE FOR HANGING WOMAN CREEK
  100 GO TO(110,120,130,140,140,140,140,140,140,140,140,140),I
  110 SGT(J)=C*QGT(J)*(-22.885*(QHW(INDEX,I)/CV)+2056.07)
      GO TO 150
  120 SGT(J)=C*QGT(J)*(-67.916*(QHW(INDEX,I)/CV)+1874.24)
      GO TO 150
  130 SGT(J)=C*QGT(J)*(-13.293*(QHW(INDEX,I)/CV)+1779)
      GO TO 150
  140 SGT(J)=C*QGT(J)*(-16.13*(QHW(INDEX,I)/CV)+2006.14)
  150 SLAD=AIHW*ADPS(I)*SGT(J)/QGT(J)
      SLADH(I) = SLAD
      SLA = SLAD*.65+(SLADH(1)+SLADH(2)+SLADH(3)+SLADH(4)+SLADH(5)+SLADH
     *(6)+SLADH(7)+SLADH(8)+SLADH(9)+SLADH(10)+SLADH(11)+SLADH(12)-SLADH
     *(I))*.04375
```

```
      SLMH=DSHW*.00011333*AMHW*(ROCH/12)
      QADH=AIHW*ADPS(I)
      QADXH(I)=QADH
      QRFH=((QADH*.65)*.85)*.65+(((QADXH(1)+QADXH(2)+QADXH(3)+QADXH(4)+Q
     *ADXH(5)+QADXH(6)+QADXH(7)+QADXH(8)+QADXH(9)+QADXH(10)+QADXH(11)+QA
     *DXH(12)-QADH)*.65)*.85)*.35/8
      QGT(J)=QGT(J)-QADH+QRFH
C   TEST FOR CALCULATED ZERO OR NEGATIVE STREAMFLOW
      IF(QGT(J).LE.0) QGT(J)=1.0
      SGT(J)=SLA-SLAD+SLMH+SGT(J)
      SCHW=SGT(J)/QGT(J)/C
      PSHM=SLMH/SGT(J)*100
      PHM(I)=PSHM
      CH(I)=SCHW
  180 FORMAT('                  Q IN HWC LESS THAN OR EQUAL TO ZERO')
  190 FORMAT('                  LOAD IN HWC LESS THAN OR EQUAL TO ZERO')
      GO TO 400

CCCCC      COMPUTE DISSOLVED SOLIDS MASS BALANCE FOR OTTER CREEK

  200 GO TO(210,220,230,220,220,220,220,220,240,220,220,220),I
  210 SGT(J)=C*QGT(J)*(-24.409*(QO(INDEX,I)/CV)+2678.99)
      GO TO 250
  220 SGT(J)=C*QGT(J)*(-8.831*(QO(INDEX,I)/CV)+2237.49)
      GO TO 250
  230 SGT(J)=C*QGT(J)*(-6.336*(QO(INDEX,I)/CV)+1829.06)
      GO TO 250
  240 SGT(J)=C*QGT(J)*(-94.326*(QO(INDEX,I)/CV)+2195.16)
  250 SLAD=AIO*ADPS(I)*SGT(J)/QGT(J)
      SLADO(I) = SLAD
      SLA = SLAD*.65+(SLADO(1)+SLADO(2)+SLADO(3)+SLADO(4)+SLADO(5)+SLADO
     *(6)+SLADO(7)+SLADO(8)+SLADO(9)+SLADO(10)+SLADO(11)+SLADO(12)-SLADO
     *(I))*.04375
      SLMO=DSO*.0001133*AMO*(ROCO/12)
      QADO=AIO*ADPS(I)
      QADXO(I)=QADO
      QRFO=((QADO*.65)*.85)*.65+(((QADXO(1)+QADXO(2)+QADXO(3)+QADXO(4)+Q
     *ADXO(5)+QADXO(6)+QADXO(7)+QADXO(8)+QADXO(9)+QADXO(10)+QADXO(11)+QA
     *DXO(12)-QADO)*.65)*.85)*.35/8
      QGT(J)=QGT(J)-QADO+QRFO
C     TEST FOR CALCULATED ZERO OR NEGATIVE STREAMFLOW
      IF(QGT(J).LE.0) QGT(J)=1.0
      SGT(J)=SLA-SLAD+SLMO+SGT(J)
      SCO =SGT(J)/QGT(J)/C
      PSOM=SLMO/SGT(J)*100
      POM(I)=PSOM
      CO(I)=SCO
  280 FORMAT('                  Q IN OC LESS THAN OR EQUAL TO ZERO')
  290 FORMAT('                  LOAD IN OC LESS THAN OR EQUAL TO ZERO')
      GO TO 400

CCCCC      COMPUTE DISSOLVED SOLIDS MASS BALANCE FOR PUMPKIN CREEK

  300 GO TO(310,310,310,310,310,310,310,310,310,320,310,310),I
  310 SGT(J)=C*QGT(J)*(1610.64*(QP(INDEX,I)/CV)**(-.2543))
      GO TO 350
  320 SGT(J)=C*QGT(J)*(5172.22*(QP(INDEX,I)/CV)+42)
  350 SLAD=AIP*ADPS(I)*SGT(J)/QGT(J)
      SLADP(I) = SLAD
      SLA = SLAD*.65+(SLADP(1)+SLADP(2)+SLADP(3)+SLADP(4)+SLADP(5)+SLADP
     *(6)+SLADP(7)+SLADP(8)+SLADP(9)+SLADP(10)+SLADP(11)+SLADP(12)-SLADP
     *(I))*.04375
      SLMP=DSP*.0001133*AMP*(ROCP/12)
      QADP=AIP*ADPS(I)
      QADXP(I)=QADP
      QRFP=((QADP*.65)*.85)*.65+(((QADXP(1)+QADXP(2)+QADXP(3)+QADXP(4)+Q
     *ADXP(5)+QADXP(6)+QADXP(7)+QADXP(8)+QADXP(9)+QADXP(10)+QADXP(11)+QA
     *DXP(12)-QADP)*.65)*.85)*.35/8
```

```
      QGT(J)=QGT(J)-QADP+QRFP
C   TEST FOR CALCULATED ZERO OR NEGATIVE STREAMFLOW
      IF(QGT(J).LE.0) QGT(J)=1.0
      SGT(J)=SLA-SLAD+SLMP+SGT(J)
      SCP=SGT(J)/QGT(J)/C
      PSPM=SLMP/SGT(J)*100
      PPM(I)=PSPM
      CP(I)=SCP
  380 FORMAT('                  Q IN PC LESS THAN OR EQUAL TO ZERO')
  390 FORMAT('                  LOAD IN PC LESS THAN OR EQUAL TO ZERO')

CCCCC     COMPUTE DISSOLVED SOLIDS MASS BALANCE AT DOWNSTREAM END OF REACH

  400 SLC(J)=SL(J)+SGW(J)-SAD(J)+SRF(J)+SUT(J)+SGT(J)-SOL(J)
     *+SLMT(J)-SOLTR

CCCCC     COMPUTE MASS BALANCE OF FLOW AT DOWNSTREAM END OF REACH

      QC(J)=Q(J)+QPT(J)-QET(J)+QGW(J)-QAD(J)+QRF(J)+QUT(J)+QGT(J)-QI(J)-
     *QOL(J)-QOLTR
      IF(I.EQ.3) QC(J)=QC(J)+QIM(J)
C   TEST FOR ZERO OR NEGATIVE STREAMFLOW
      IF(QC(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

      SC(J)=SLC(J)/QC(J)/C
      PSTA=SRF(J)/SLC(J)*100
      PSTM=SLMT(J)/SLC(J)*100
      IF(J.EQ.1) CSLM=SLMT(1)/SLC(1)
      IF(J.EQ.2) CSLM=(SLMT(1)+SLMT(2)+SLMH)/SLC(2)
      IF(J.EQ.3) CSLM=(SLMT(1)+SLMT(2)+SLMT(3)+SLMH+SLMO)/SLC(3)
      IF(J.EQ.4) CSLM=(SLMT(1)+SLMT(2)+SLMT(3)+SLMT(4)+SLMH+SLMO)/SLC(4)
      IF(J.EQ.5) CSLM=(SLMT(1)+SLMT(2)+SLMT(3)+SLMT(4)+SLMT(5)+SLMH+SLMO
     *+SLMP)/SLC(5)
      IF(J.EQ.1) CSRF=SRF(1)/SLC(1)
      IF(J.EQ.2) CSRF=(SRF(1)+SRF(2))/SLC(2)
      IF(J.EQ.3) CSRF=(SRF(1)+SRF(2)+SRF(3))/SLC(3)
      IF(J.EQ.4) CSRF=(SRF(1)+SRF(2)+SRF(3)+SRF(4))/SLC(4)
      IF(J.EQ.5) CSRF=(SRF(1)+SRF(2)+SRF(3)+SRF(4)+SRF(5))/SLC(5)

CCCCC     BUILD ARRAYS FOR LATER STATISTICAL ANALYSIS BY SUBROUTINE MAIN

      PTA(I,J)=PSTA
      PTM(I,J)=PSTM
      CT(I,J)=SC(J)
      CPSTA=CSRF*100
      CPSTM=CSLM*100
      CPTA(I,J)=CPSTA
      CPTM(I,J)=CPSTM

CCCCC     WRITE RESULTS OF REACH COMPUTATIONS FOR MONTH

      IF(J.EQ.5) YQMC(I)=QC(J)
      IF(J.EQ.5) YSLMC(I)=SLC(J)
      GO TO(500,600,700,800,900),J
  500 IF(INTDS.EQ.0) X=C*QTRD(INDEX,I)*13412.07*(QTRD(INDEX,I)**
     *(-.3498))
      IF(INTDS.EQ.0) Y=QTRD(INDEX,I)**(-.3498)*13412.07
      IF(INTDS.EQ.1) X=TRDTDS(I)*QTRD(INDEX,I)*C
      IF(INTDS.EQ.1) Y=TRDTDS(I)
      WRITE(6,1000) M(I),QTRD(INDEX,I),X,Y
      WRITE(6,1100) J,QC(1),SLC(1),SC(1),PSTA,PSTM,CPSTA,CPSTM
      GO TO 1500
  600 WRITE(6,1100) J,QC(2),SLC(2),SC(2),PSTA,PSTM,CPSTA,CPSTM
```

```
      WRITE(6,1200) QGT(2),SGT(2),SCHW,PSHM
      IF(QGT(2).LE.0) WRITE(6,180)
      IF(SGT(2).LE.0) WRITE(6,190)
      GO TO 1500
  700 WRITE(6,1100) J,QC(3),SLC(3),SC(3),PSTA,PSTM,CPSTA,CPSTM
      WRITE(6,1300) QGT(3),SGT(3),SCO,PSOM
      IF(QGT(3).LE.0) WRITE(6,280)
      IF(SGT(3).LE.0) WRITE(6,290)
      GO TO 1500
  800 WRITE(6,1100) J,QC(4),SLC(4),SC(4),PSTA,PSTM,CPSTA,CPSTM
      GO TO 1500
  900 WRITE(6,1100) J,QC(5),SLC(5),SC(5),PSTA,PSTM,CPSTA,CPSTM
      WRITE(6,1400) QGT(5),SGT(5),SCP,PSPM
      IF(QGT(5).LE.0) WRITE(6,380)
      IF(SGT(5).LE.0) WRITE(6,390)
      IF(I.EQ.6) WRITE(6,1450) SN
 1000 FORMAT(1X,A5,3X,'TRD',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)
 1200 FORMAT(9X,'HWC',5X,F8.0,5X,F8.0,2X,F8.0,T70,F7.4)
 1300 FORMAT(9X,'OC',6X,F8.0,5X,F8.0,2X,F8.0,T70,F7.4)
 1400 FORMAT(9X,'PC',6X,F8.0,5X,F8.0,2X,F8.0,T70,F7.4)
 1450 FORMAT('1SIMULATION RESULTS -- SIMULATION NUMBER', A5/,'+*********
     ***********************************'/,'+',T17,'STREAMFLOW',T33,'DI
     *SSOLVED SOLIDS',T58,'PERCENT LOAD (PER',T88,'CUMULATIVE PERCENT'/,
     *'+',T17,'(ACRE-FEET)',T34,'LOAD',T44,'CONC',T60,'REACH) DUE TO',T9
     *1,'LOAD 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)
      STOP
      END
```

Table 4.--*Definition of model variables*

ADFS	Water diversion rate (in acre-feet per acre) for complete service irrigation
ADPS	Water diversion rate (in acre-feet per acre) for partial service irrigation
AIHW	Area (in acres) irrigated on Hanging Woman Creek
AIO	Area (in acres) irrigated on Otter Creek
AIP	Area (in acres) irrigated on Pumpkin Creek
AIT	Area (in acres) irrigated on Tongue River reaches
AMHW	Area (in acres) mined on Hanging Woman Creek
AMO	Area (in acres) mined on Otter Creek
AMP	Area (in acres) mined on Pumpkin Creek
AMT	Area (in acres) mined on Tongue River reaches
AUT	Area (in acres) of ungaged tributaries
C	Factor to convert dissolved-solids load (in tons per acre-foot) of streamflow into concentration (in milligrams per liter)
CD	Dissolved-solids load (in tons) input by Tongue River Reservoir
CH	Matrix of SCHW values
CO	Matrix of SCO values
CP	Matrix of SCP values
CPSTA	Cumulative percentage of dissolved-solids load in the Tongue River due to irrigation return flow
CPSTM	Cumulative percentage of dissolved-solids load in the Tongue River due to mining
CPTA	Matrix of CPSTA values
CPTM	Matrix of CPSTM values
CSLM	Cumulative ratio of dissolved-solids load (in tons) due to mining versus total load (in tons) of dissolved solids in the Tongue River
CSRF	Cumulative ratio of dissolved-solids load (in tons) due to irrigation return flow versus total load (in tons) of dissolved solids in the Tongue River
CT	Matrix of SC values
CV	Factor to convert monthly streamflow (in acre-feet) to mean daily streamflow (in cubic feet per second)
DSHW	Dissolved-solids concentration (in milligrams per liter) of mine-spoil leachates from Hanging Woman Creek
DSO	Dissolved-solids concentration (in milligrams per liter) of mine-spoil leachates from Otter Creek
DSP	Dissolved-solids concentration (in milligrams per liter) of mine-spoil leachates from Pumpkin Creek
DST	Dissolved-solids concentraton (in miligrams per liter) of mine spoil leachates from Tongue River reaches
ET	Evaporation rate (in feet)
GW	Ground-water inflow rate (in acre-feet per river mile per day)
I	Counter for monthly loop
IMFD	Monthly flow designator
INTDS	Option variable for initial input of dissolved solids
IRD	Option variable for designation of reservoir releases from present or proposed Tongue River Reservoir
J	Counter for Tongue River reaches loop
M	Name of month
MFD	Monthly flow designator
ND	Number of days in month
PHM	Matrix of PSHM values

Table 4.--*Definition of model variables*--Continued

POM	Matrix of PSOM values
PPM	Matrix of PSPM values
PSHM	Percentage of dissolved-solids load in Hanging Woman Creek due to mining
PSOM	Percentage of dissolved-solids load in Otter Creek due to mining
PSPM	Percentage of dissolved-solids load in Pumpkin Creek due to mining
PSTA	Percentage of dissolved-solids load in the Tongue River due to irrigation return flow
PSTM	Percentage of dissolved-solids load in the Tongue River due to mining
PT	Precipitation rate (in feet)
PTA	Matrix of PSTA values
PTM	Matrix of PSTM values
Q	Streamflow (in acre-feet) input to upstream end of reach
QAD	Volume (in acre-feet) of irrigation diversion for Tongue River reaches
QADH	Volume (in acre-feet) of irrigation diversion for Hanging Woman Creek
QADO	Volume (in acre-feet) of irrigation diversion for Otter Creek
QADP	Volume (in acre-feet) of irrigation diversion for Pumpkin Creek
QADP1	Irrigation water return-flow rate (in acre-feet per acre) for antecedent return flow to Tongue River reaches
QADX	Matrix of QAD values
QADXH	Matrix of QADH values
QADXO	Matrix of QADO values
QADXP	Matrix of QADP values
QRFH	Volume (in acre-feet) of irrigation return flow for Hanging Woman Creek
QRFO	Volume (in acre-feet) of irrigation return flow for Otter Creek
QRFP	Volume (in acre-feet) of irrigation return flow for Pumpkin Creek
QC	Streamflow (in acre-feet) at downstream end of reach
QD	Streamflow (in acre-feet) input by Tongue River Reservoir
QET	Volume (in acre-feet) of evaporation
QGT	Volume (in acre-feet) of streamflow input to the Tongue River by Hanging Woman, Otter, and Pumpkin Creeks
QGW	Volume (in acre-feet) of ground water
QHW	Initial streamflow (in acre-feet) of Hanging Woman Creek
QI	Volume (in acre-feet) of ice removed from streamflow
QIM	Volume (in acre-feet) of streamflow input by ice breakup
QIR123	Ice removal rate (in feet) for Tongue River reaches 1 through 3
QIR4	Ice removal rate (in feet) for Tongue River reach 4
QIR5	Ice removal rate (in feet) for Tongue River reach 5
QO	Initial streamflow (in acre-feet) of Otter Creek
QOL	Volume (in acre-feet) of other water losses for Tongue River reaches
QOLHW	Other water losses rate (in acre-feet per year) for Hanging Woman Creek
QOLO	Other water losses rate (in acre-feet per year) for Otter Creek
QOLP	Other water losses rate (in acre-feet per year) for Pumpkin Creek
QOLT	Other water losses rate (in acre-feet per year) for Tongue River reaches
QOLTR	Volume (in acre-feet) of other water losses from Hanging Woman, Otter, and Pumpkin Creeks
QP	Initial streamflow (in acre-feet) of Pumpkin Creek
QPT	Volume (in acre-feet) of precipitation
QRF	Volume (in acre-feet) of irrigation return flow for Tongue River reaches
QTRD	Initial streamflow (in acre-feet) input by Tongue River Reservoir
QUT	Volume (in acre-feet) of streamflow from ungaged tributaries

Table 4.--*Definition of model variables*--Continued

RA	Reach area (in acres)
RL	Reach length (in miles)
ROCT	Runoff coefficient (in inches per year) for Tongue River reaches
ROCH	Runoff coefficient (in inches per year) for Hanging Woman Creek
ROCO	Runoff coefficient (in inches per year) for Pumpkin Creek
S	Dissolved-solids concentration (in milligrams per liter) for ungaged tributaries
SAD	Dissolved-solids load (in tons) removed by irrigation water diversion
SADP	Dissolved-solids loading rate (in tons per acre) from previous year's irrigation
SADX	Matrix of SAD values
SC	Dissolved-solids concentration (in milligrams per liter) at downstream end of reach
SCGW	Dissolved-solids concentration (in milligrams per liter) of ground water
SCHW	Dissolved-solids concentration (in milligrams per liter) of Hanging Woman Creek
SCO	Dissolved-solids concentration (in milligrams per liter) of Otter Creek
SD	Dissolved-solids concentration (in milligrams per liter) input by Tongue River Reservoir
SCP	Dissolved-solids concentration (in milligrams per liter) of Pumpkin Creek
SGT	Dissolved-solids load (in tons) of Hanging Woman, Otter, and Pumpkin Creeks
SGW	Dissolved-solids load (in tons) from ground water
SL	Dissolved-solids load (in tons) due to irrigation water return flow in Hanging Woman, Otter, and Pumpkin Creeks
SLA	Dissolved-solids load (in tons) due to irrigation water return flow in Hanging Woman, Otter, and Pumpkin Creeks
SLAD	Dissolved-solids load (in tons) removed by irrigation water diversion from Hanging Woman, Otter, and Pumpkin Creeks
SLADH	Matrix of SLAD values for Hanging Woman Creek
SLADO	Matrix of SLAD values for Otter Creek
SLADP	Matrix of SLAD values for Pumpkin Creek
SLC	Dissolved-solids load (in tons) at downstream end of reach
SLMH	Dissolved-solids load (in tons) due to mining on Hanging Woman Creek
SLMO	Dissolved-solids load (in tons) due to mining on Otter Creek
SLMP	Dissolved-solids load (in tons) due to mining on Pumpkin Creek
SLMT	Dissolved-solids load (in tons) due to mining on Tongue River reaches
SN	Simulation number
SOL	Dissolved-solids load (in tons) removed by other water losses from Tongue River reaches
SOLTR	Dissolved-solids load (in tons) removed by other water losses from Hanging Woman, Otter, and Pumpkin Creeks
SRF	Dissolved-solids load (in tons) due to irrigation water return flow on Tongue River reaches
SUMU	Summation of CPTA values
SUMV	Summation of CPTM values
SUMX	Summation of CT values or X values
SUMXSQ	Summation of CT values squared or X values squared
SUMY	Summation of PTA values or Y values
SUMZ	Summation of PTM values
SUT	Dissolved-solids load (in tons) from ungaged tributaries

TRDTS	User-defined dissolved-solids concentrations (in milligrams per liter) input by Tongue River Reservoir
UMEAN	Mean of CPTA values
VMEAN	Mean of CPTM values
X	Matrix of CH or CO or CP values or dissolved-solids load (in tons) input by Tongue River Reservoir
XMAX	Maximum of CT values or X values
XMEAN	Mean of CT values or X values
XMIN	Minimum of CT values of X values
XSD	Standard deviation of CT values of X values
Y	Matrix of PHM or POM or PPM values or dissolved-solids concentration (in milligrams per liter) input by Tongue River Reservoir
YC	Runoff coefficient (in feet) for ungaged tributaries
YHW	Runoff coefficient (in feet) for Hanging Woman Creek
YMEAN	Mean of PTA values
YMEANT	Mean of PHM or POM or PPM values
YO	Runoff coefficient (in feet) for Otter Creek
YP	Runoff coefficient (in feet) for Pumpkin Creek
YQMC	Streamflow (in acre-feet) at Miles City
YSLMC	Dissolved-solids load (in tons) at Miles City
Z	Dissolved-solids concentration (in milligrams per liter) at Miles City
ZMEAN	Mean of PTM values

Table 17.--*Example of model output*

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TONGUE RIVER DISSOLVED SOLIDS MODEL --- SIMULATION NUMBER   500

RESERVOIR RELEASES FROM PROPOSED TONGUE RIVER RESERVOIR
DESIGNATOR FOR DISSOLVED-SOLIDS INPUT BY TONGUE RIVER DAM SET TO REGRESSION-DEFINED STATUS

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

  1  = TONGUE RIVER DAM (RIVER MILE 189.1) TO RIVER MILE 156.7
  2  = RIVER MILE 156.7 TO RIVER MILE 112.7 (INCLUDES HANGING WOMAN CREEK)
  3  = RIVER MILE 112.7 TO RIVER MILE  77.6 (INCLUDES OTTER CREEK)
  4  = RIVER MILE  77.6 TO RIVER MILE  20.0
  5  = RIVER MILE  20.0 TO RIVER MILE 8.1 AT MILES CITY GAGE (INCLUDES PUMPKIN CREEK)
HWC = HANGING WOMAN CREEK
OC  = OTTER CREEK
PC  = PUMPKIN CREEK
TRD = TONGUE RIVER DAM DISCHARGE


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

JAN    = 1  FEB    = 1      1 = MEAN
MARCH  = 1  APRIL  = 1      2 = PLUS ONE STANDARD DEVIATION
MAY    = 1  JUNE   = 1      3 = MINUS ONE STANDARD DEVIATION
JULY   = 1  AUG    = 1      4 = HISTORIC HIGH
SEPT   = 1  OCT    = 1      5 = HISTORIC LOW
NOV    = 1  DEC    = 1      6 = INSTREAM FLOW REQUIREMENTS

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

REACH 1 =  1490. REACH  2  =  4470. REACH  3 =  5250. REACH  4 =  7450.
REACH 5 =  2540. REACH HWC =     0. REACH OC =     0. REACH PC =     0.
   NOTE - IRRIGATED ACRES ON REACHES HWC, OC, AND PC ARE THOSE IN
   EXCESS OF PRESENTLY IRRIGATED ACRES (1225 ACRES ON HWC,
   785 ACRES ON OC, 2875 ACRES ON PC)

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

                DISSOLVED SOLIDS                          DISSOLVED SOLIDS
REACH  ACREAGE  (MG/L) OF LEACHATE     REACH  ACREAGE   (MG/L) OF LEACHATE
-----  -------  ------------------     -----  -------   ------------------
  1    10000.         1600.              2     4200.          4500.
  3     4600.         2350.              4    18000.          2900.
  5        0.            0.             HWC   21600.          4000.
 OC    52300.         3850.              PC    8900.          3000.

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

REACH 1 =     0. REACH  2  =     0. REACH  3 =     0. REACH  4 =     0.
REACH 5 =     0. REACH HWC =     0. REACH OC =     0. REACH PC =     0.
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Table 17.--*Example of model output*--Continued

SIMULATION RESULTS -- SIMULATION NUMBER 500

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MONTH	REACH	STREAMFLOW (ACRE-FEET)	DISSOLVED SOLIDS LOAD (TONS)	DISSOLVED SOLIDS CONC (MG/L)	PERCENT LOAD (PER REACH) DUE TO RETURN FLOW	PERCENT LOAD (PER REACH) DUE TO MINING	CUMULATIVE PERCENT LOAD DUE TO RETURN FLOW	CUMULATIVE PERCENT LOAD DUE TO MINING
JAN	TRD	22140.	12197.	405.				
	1	22387.	12836.	422.	1.3930	0.2189	1.3930	0.2189
	2	23822.	15942.	492.	3.8414	0.1869	4.9630	1.3152
	HWC	175.	626.	2629.		24.2596		
	3	25104.	19219.	563.	4.2067	0.0887	8.3234	2.8316
	OC	300.	1362.	3338.		23.3116		
	4	26480.	21874.	607.	5.8240	0.9215	13.1371	3.4094
	5	27029.	22943.	624.	2.0924	0.0	14.6172	3.6999
	PC	172.	393.	1681.		26.2255		
FEB	TRD	21689.	12035.	408.				
	1	21877.	12580.	423.	1.1015	0.2234	1.1015	0.2234
	2	23222.	15653.	496.	3.1126	0.1904	3.9979	1.3395
	HWC	150.	497.	2435.		30.5558		
	3	24734.	19680.	585.	3.3346	0.0866	6.5145	2.7653
	OC	550.	1926.	2574.		16.4867		
	4	26001.	22360.	632.	4.6979	0.9015	10.4317	3.3354
	5	26988.	23845.	650.	1.6830	0.0	11.4649	3.5600
	PC	600.	821.	1006.		12.5633		
MAR	TRD	31550.	15356.	358.				
	1	32492.	16300.	369.	0.6856	0.1724	0.6856	0.1724
	2	35889.	20305.	416.	1.9812	0.1468	2.5316	1.0326
	HWC	413.	1101.	1960.		13.7867		
	3	38984.	24771.	467.	2.2254	0.0688	4.3005	2.1969
	OC	750.	2104.	2063.		15.0876		
	4	42952.	27538.	471.	3.2464	0.7320	7.1149	2.7082
	5	44716.	29210.	480.	1.1739	0.0	7.8817	2.9062
	PC	800.	1016.	934.		10.1515		
APR	TRD	50779.	20925.	303.				
	1	50999.	21531.	310.	0.4918	0.1305	0.4918	0.1305
	2	52415.	24637.	346.	1.4599	0.1210	1.8897	0.8510
	HWC	225.	747.	2441.		20.3178		
	3	53672.	28171.	386.	1.7207	0.0605	3.3734	1.9318
	OC	500.	1789.	2630.		17.7514		
	4	55219.	30619.	408.	2.5419	0.6583	5.6455	2.4357
	5	56467.	32240.	420.	0.9031	0.0	6.2647	2.6330
	PC	900.	1091.	891.		9.4491		
MAY	TRD	129950.	38549.	218.				
	1	129246.	38972.	222.	0.8233	0.0721	0.8233	0.0721
	2	127981.	41593.	239.	2.3788	0.0716	3.1502	0.5041
	HWC	210.	709.	2482.		21.4066		
	3	126126.	44574.	260.	2.8245	0.0382	5.7640	1.2209
	OC	525.	1861.	2607.		17.0580		
	4	123118.	45918.	274.	4.2396	0.4390	9.8348	1.6241
	5	122725.	47061.	282.	1.4969	0.0	11.0929	1.8038
	PC	800.	1016.	934.		10.1515		
JUNE	TRD	185423.	48573.	193.				
	1	184479.	48918.	195.	0.6561	0.0574	0.6561	0.0574
	2	182425.	51003.	206.	1.9106	0.0584	2.5398	0.4111
	HWC	183.	639.	2566.		23.7621		
	3	179492.	52841.	216.	2.2928	0.0323	4.7443	1.0299
	OC	300.	1212.	2971.		26.1907		
	4	175041.	53613.	225.	3.3774	0.3760	8.0534	1.3910
	5	173707.	54128.	229.	1.1908	0.0	9.1676	1.5683
	PC	300.	539.	1320.		19.1429		

Table 17.--*Example of model output*--Continued

SIMULATION RESULTS -- SIMULATION NUMBER 500

MONTH	REACH	STREAMFLOW (ACRE-FEET)	DISSOLVED SOLIDS LOAD (TONS)	DISSOLVED SOLIDS CONC (MG/L)	PERCENT LOAD (PER REACH) DUE TO RETURN FLOW	PERCENT LOAD (PER REACH) DUE TO MINING	CUMULATIVE PERCENT LOAD DUE TO RETURN FLOW	CUMULATIVE PERCENT LOAD DUE TO MINING
JULY	TRD	72099.	26282.	268.				
	1	70742.	26574.	276.	2.1671	0.1057	2.1671	0.1057
	2	67551.	28225.	307.	6.3012	0.1056	8.3416	0.7429
	HWC	225.	748.	2443.		20.3014		
	3	63139.	28923.	337.	8.0114	0.0589	16.1515	1.8816
	OC	167.	820.	3611.		38.7077		
	4	56780.	28742.	372.	12.5242	0.7013	28.7773	2.5947
	5	54726.	28770.	387.	4.6987	0.0	33.4487	2.9506
	PC	200.	428.	1572.		24.1083		
AUG	TRD	46248.	19691.	313.				
	1	44964.	19765.	323.	3.3231	0.1422	3.3231	0.1422
	2	42071.	20957.	366.	9.6959	0.1422	12.8299	1.0005
	HWC	85.	381.	3297.		39.8242		
	3	38088.	21276.	411.	12.6555	0.0801	25.2930	2.5578
	OC	80.	560.	5144.		56.7270		
	4	32383.	20869.	474.	20.4567	0.9659	46.2438	3.5737
	5	30383.	20531.	497.	8.1200	0.0	55.1239	4.1346
	PC	16.	152.	7007.		67.6271		
SEPT	TRD	37167.	17082.	338.				
	1	36329.	17184.	348.	3.4122	0.1635	3.4122	0.1635
	2	34641.	18530.	393.	9.7633	0.1608	12.9276	1.1315
	HWC	45.	274.	4474.		55.4314		
	3	32098.	19223.	440.	12.4436	0.0887	24.9055	2.8310
	OC	80.	543.	4986.		58.5206		
	4	28598.	19653.	505.	19.2623	1.0257	43.6223	3.7947
	5	27501.	19896.	532.	7.3917	0.0	50.4824	4.2667
	PC	200.	425.	1562.		24.2615		
OCT	TRD	34297.	16213.	348.				
	1	34312.	16588.	355.	1.6269	0.1694	1.6269	0.1694
	2	35139.	18813.	394.	4.4103	0.1584	5.8449	1.1145
	HWC	75.	354.	3474.		42.8260		
	3	35524.	20689.	428.	5.2229	0.0824	10.5377	2.6304
	OC	133.	719.	3974.		44.1722		
	4	35934.	22389.	458.	7.5036	0.9004	17.2413	3.3311
	5	35989.	22872.	467.	2.7396	0.0	19.6165	3.7114
	PC	16.	133.	6126.		77.3460		
NOV	TRD	30996.	15180.	360.				
	1	31342.	15661.	367.	0.9871	0.1794	0.9871	0.1794
	2	33084.	18269.	406.	2.6052	0.1631	3.4514	1.1477
	HWC	95.	408.	3155.		37.2320		
	3	34611.	20884.	444.	2.9712	0.0816	5.9905	2.6059
	OC	233.	1016.	3205.		31.2628		
	4	36430.	23014.	465.	4.2138	0.8759	9.6499	3.2406
	5	36956.	23680.	471.	1.5523	0.0	10.9308	3.5849
	PC	16.	152.	6988.		67.8097		
DEC	TRD	24846.	13147.	389.				
	1	25117.	13663.	400.	1.1315	0.2057	1.1315	0.2057
	2	26626.	16369.	452.	2.9077	0.1821	3.8521	1.2809
	HWC	115.	461.	2946.		32.9355		
	3	27940.	19003.	500.	3.2652	0.0897	6.5833	2.8637
	OC	233.	1016.	3206.		31.2519		
	4	29413.	21164.	529.	4.5821	0.9524	10.4931	3.5238
	5	29867.	21835.	538.	1.6834	0.0	11.8541	3.8877
	PC	16.	152.	7007.		67.6271		

SIMULATION SUMMARY -- SIMULATION NUMBER 500
****

	STREAMFLOW (ACRE-FEET)		DISSOLVED SOLIDS			
			TONGUE RIVER DAM		MILES CITY GAGE	
MONTH	TONGUE RIVER DAM	MILES CITY GAGE	LOAD(TON)	CONC(MG/L)	LOAD(TON)	CONC(MG/L)
JAN	22140.	27029.	12197.	405.	22943.	624.
FEB	21689.	26988.	12035.	408.	23845.	650.
MAR	31550.	44716.	15356.	358.	29210.	480.
APR	50779.	56467.	20925.	303.	32240.	420.
MAY	129950.	122725.	38549.	218.	47061.	282.
JUNE	185423.	173707.	48573.	193.	54128.	229.
JULY	72099.	54726.	26282.	268.	28770.	387.
AUG	46248.	30383.	19691.	313.	20531.	497.
SEPT	37167.	27501.	17082.	338.	19896.	532.
OCT	34297.	35989.	16213.	348.	22872.	467.
NOV	30996.	36956.	15180.	360.	23680.	471.
DEC	24846.	29867.	13147.	389.	21835.	538.

	MONTHLY DISSOLVED SOLIDS CONC (MG/L)				MEAN PERCENT LOAD PER REACH DUE TO		MEAN CUMULATIVE PERCENT LOAD DUE TO	
REACH	MEAN	STD DEV	MIN	MAX	RETURN FLOW	MINING	RETURN FLOW	MINING
1	334.	70.	195.	423.	1.4833	0.1534	1.4833	0.1534
2	376.	87.	206.	496.	4.1973	0.1406	5.5266	0.9893
3	420.	105.	216.	585.	5.0979	0.0714	10.2068	2.2789
4	452.	115.	225.	632.	7.7058	0.7875	17.5204	2.9135
5	465.	118.	229.	650.	2.8938	0.0	20.1621	3.2256
HWC	2859.	638.	1960.	4474.		30.2199		
OC	3359.	907.	2063.	5144.		31.3773		
PC	3086.	2635.	891.	7007.		34.7052		

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