SIMULATED EFFECTS OF ANTICIPATED COAL MINING ON DISSOLVED SOLIDS IN SELECTED TRIBUTARIES OF THE YAMPA RIVER, NORTHWESTERN COLORADO

By Randolph S. Parker and J. Michael Norris

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METRIC CONVERSIONS

Multiply inch-pound units	*By*	*To obtain SI units*
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
square mile	2.590	square kilometer
ton per month	0.9072	megagram per month
ton per year	0.9072	megagram per year

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

Identifying cumulative effects of mining on dissolved solids downstream from multiple coal-mining operations is particularly important in western basins. The problem of identifying cumulative effects is evident in the Trout Creek drainage, a tributary to the Yampa River in northwestern Colorado, where a number of mines are active and expansions planned. As an evaluation tool, a model was developed and calibrated for the Trout Creek drainage and a reach of the Yampa River main stem.

In the model a series of nodes on the stream network is used to sum water quantity and quality through the network. The model is operated on a monthly time step and was based on data from water years 1976 to 1981. Output is mean monthly discharge, dissolved-solids concentration, and dissolved-solids load. Observed data are needed to initiate the model and for model calibration. Some data were extrapolated from records of nearby streamflow-gaging stations.

Some nodes within the stream network were inputs from anticipated mining and were inactive during calibration. After calibration, these nodes were used to input water discharge at a given dissolved-solids concentration to reflect various future mine configurations.

INTRODUCTION

The demand for energy in this Nation has fostered increased needs for coal. In response to this demand, one area of increased coal-mining activity is the Yampa River basin in northwestern Colorado. Many coal mines are now active in the basin, and many of the mining companies have proposed expansion of active coal mines or have identified sites for new mines.

The Yampa River basin is hydrologically typical of many coal regions in Colorado. Much of the streamflow of the main stem of the Yampa River is derived from high-altitude mountain snowpacks. The geology of these high-altitude areas is very different from the geology of the coal areas in the basin. The basic rock types in the high-altitude areas are igneous and metamorphic and result in streamflow with low dissolved-solids concentration. Coal mines are located in sedimentary-rock areas which may yield higher dissolved solids.

The Yampa River main stem serves as a conduit of water through the coal region. The streams within the active coal area can be classified into two groups--small tributaries and major tributaries. The small tributaries draining sedimentary-rock basins may contain naturally occurring large concentrations of dissolved solids. In general, most mining activity takes place in these small basins. The major tributaries, which receive water from the small tributaries and carry it to the Yampa River, similarly drain basins underlain by sedimentary rock.

Numerous mines are active, proposed, or mine expansions are contemplated in the vicinity of Trout Creek (fig. 1), a major tributary to the Yampa River. In reviewing proposed mine plans, the Mined Land Reclamation Division must evaluate the cumulative impacts to the small tributaries, to the major tributaries, and ultimately to the Yampa River main stem. A cumulative evaluation is difficult because each mine plan is prepared and evaluated independently with no standardized method available to combine the effects of various plans.

This difficulty is particularly evident in an evaluation of changes in the dissolved solids of the stream system which can be attributed to mining activity. The changes in dissolved solids may be dramatic--both in small tributaries and in major tributaries. In addition, any increase in dissolved solids in the Yampa River main stem could have serious consequences on the continuing problem of dissolved solids in the Colorado River.

A modeling study of the area was made by the U.S. Geological Survey for the Mined Land Reclamation Division of the Colorado Department of Natural Resources. This study is an initial attempt to construct a dissolved-solids model of surface water in the Yampa River basin. The model will be used by the Mined Land Reclamation Division to evaluate proposed mine development. To meet planning needs, severe time constraints on model development and evaluation were imposed upon the U.S. Geological Survey. Because of the time limitations, assumptions were made where needed data were not available. Also, the area to be modeled was reduced and focused only on the Trout Creek basin because this area was of immediate concern to the State. Therefore, using this particular model in the Yampa River basin is the first effort at combining mine plans with water-resource information.

The overall objective of this report is to determine the cumulative effects of mining on dissolved solids in the Yampa River basin. More specifically the approach is:

1. To develop a model of streamflow and dissolved solids focused on the Trout Creek drainage and a reach of the Yampa River main stem.

2. To calibrate this model with existing data.

3. To insert into the model future mine plans as given by the Mined Land Reclamation Division to determine cumulative effects of mining on dissolved solids in the streamflow.

In this paper the model is described, data needs for the model are identified, methods used to extrapolate missing data needed by the model are shown, model calibration is explained, and anticipated mining activity provided by the Mined Land Reclamation Division is analyzed. These plans are compared with the existing conditions from the calibrated model. The model is to be used by the Division to help in the assessment of cumulative effects of multiple coal mines in a drainage system.

Although the model is focused on the Trout Creek drainage, the State also is interested in changes in dissolved solids resulting from mining activity in Dry Creek (fig. 1). Insufficient water-quantity and water-quality data are available from this drainage system for inclusion in the model. Therefore, streamflow and dissolved solids were computed manually for Dry Creek following the model algorithm. In this report, an analysis of Dry Creek is given after the description of the model.

THE MODEL

The model, which routes streamflow and dissolved solids through the stream network, was written by A. W. Burns (U.S. Geological Survey, written commun., 1983) and has been used for other major stream systems in Colorado. The algorithm is an accounting procedure that sums water quantity and quality in monthly time steps from one or more upstream points to a downstream point. The addition of water quantity and quality is done at individual points called nodes. A reach is defined as the stream segment between nodes. In the stream network examined in this report, there are 27 nodes. Data can be entered, modified, or outputted at each node. Although the data are manipulated at these nodes, the changes in quantity and chemical composition of the water are attributed to the reach upstream from any particular node. As an example, a simple stream network with a series of nodes is shown in figure 2. If the concentration in dissolved solids is increased at node 5, this increase is not necessarily due to a point source at node 5 but may be due to diffused sources of increased salinity in the reach bounded by nodes 1 to 5 and 4 to 5.

There are three kinds of nodes (fig. 2): input nodes, internal nodes, and output nodes. Input nodes are the upstream nodes (nodes 1, 2, and 3 in fig. 2) in the stream network. Because the summation process of water downstream starts at these nodes, the ideal case is to have streamflow-gaging stations for the input nodes. This is not always possible, and some estimated data must be used.

Water and dissolved solids from upstream nodes are accumulated by the model at internal nodes (nodes 4, 5, and 6 in fig. 2). As such, some internal nodes will not be shown in the stream network under analysis in this paper. Internal nodes also are used to input proposed changes in water quantity and quality at individual coal mines (fig. 1). These input changes at a node can be point sources of water from dewatering activities or diffused sources of water such as drainage from a coal spoil pile within the reach upstream from the node. For brevity, there are instances when proposed changes of water quantity and quality for several mines are combined at a single node. Thus, there may not be an internal node for every mine in the watershed.

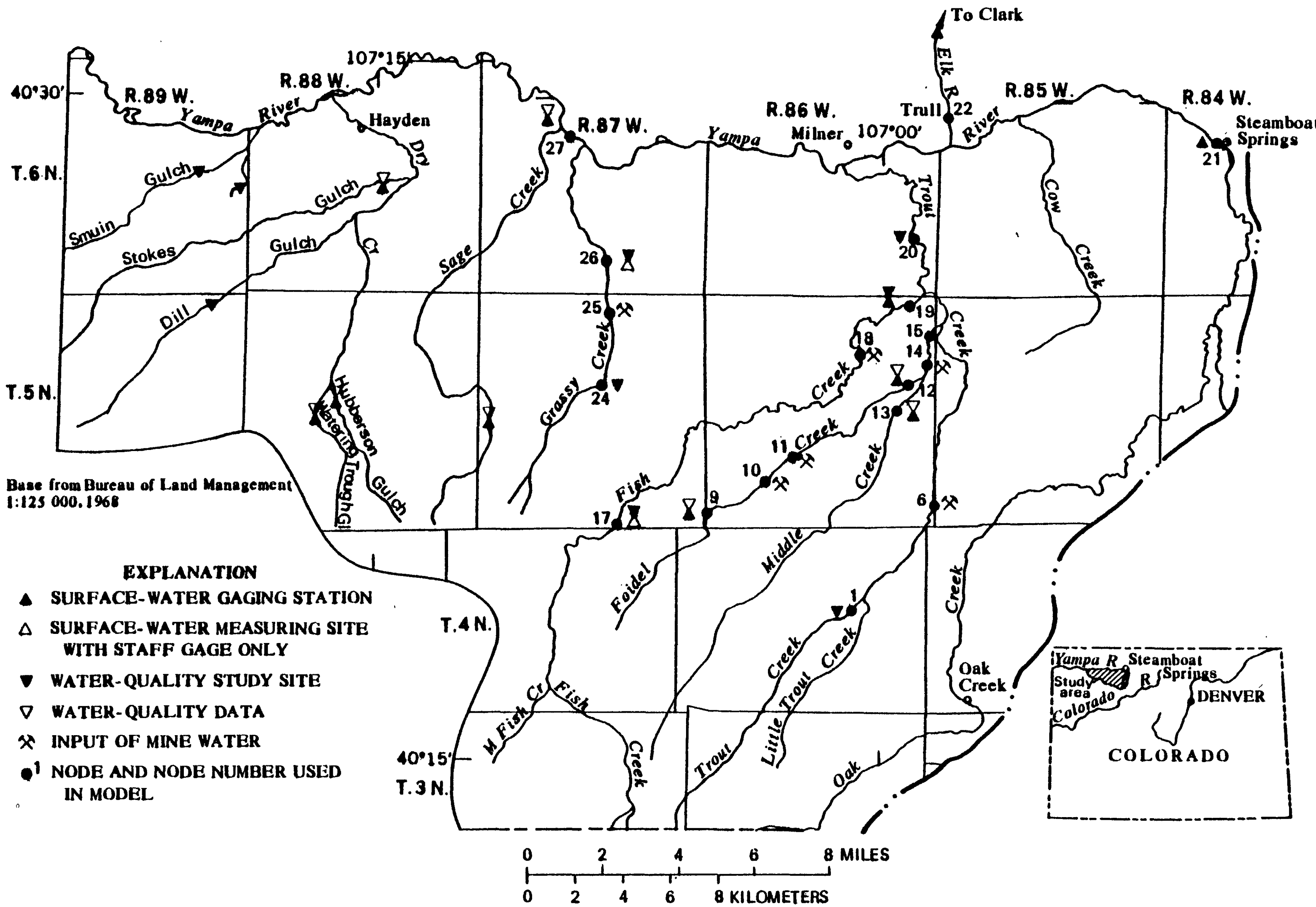

Figure 1.--Location map showing the model node system, gaging stations, and miscellaneous measuring sites.

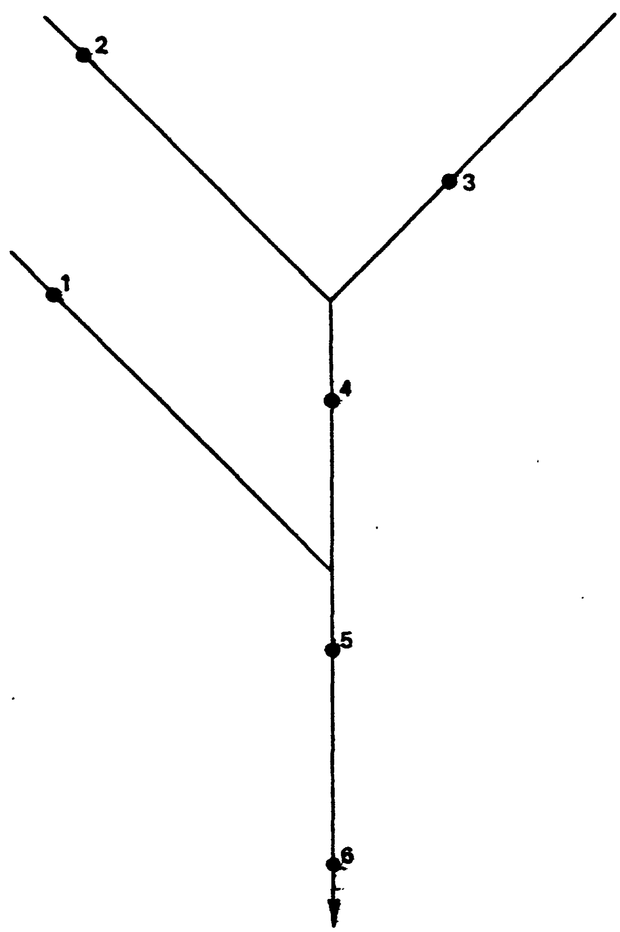

Figure 2.--Diagram of a simple stream network with nodes and node numbers for the model.

An output node is any node at which there is an interest in observing the model estimates through time and examining differences in these estimates with various anticipated mining activities. The most downstream node (node 6 in fig. 2) usually would be an output node. If the cumulative effects of coal mining in the area upstream from node 4 (fig. 2) are of interest, node 4 also could be an output node.

At any node, the surface-water quantity component, which is mean monthly discharge in cubic feet per second, is calculated by the equation:

$$Q_i=(\sum_{u=1}^{n} Q_u)+Q_r, \tag{1}$$

where: Q_i=discharge at node i,

Q_u=discharge at adjacent nodes immediately upstream from node i,

n=number of adjacent nodes immediately upstream from node i, and

Q_r=incremental discharge (increase or decrease) within the reach between node i and adjacent nodes immediately upstream.

The estimate of incremental discharge within the reach can be obtained by reading observed data or by estimating the data by the equation:

$$Q_r=a+bQ_s, \tag{2}$$

where: Q_r=incremental discharge (increase or decrease) within the reach,

and b=the regression coefficients from simple linear regression, and

Q_s=discharge at some nearby streamflow-gaging stations.

In the model several stream reaches have both an upstream and a downstream node with a streamflow-gaging station. In these situations, Q_r could be measured directly and observed discharge data were used. In those situations where observed data were not available, Q_r was initially set to zero and modified by altering the regression coefficients in equation 2 during calibration.

For each anticipated mining activity the Mined Land Reclamation Division estimated the quantity of water discharging to the stream. This discharge input was made at nodes identified in figure 1. If the estimated water discharge was runoff discharged from sediment ponds or from water migrating through spoil material from a surface mine, this water was not considered "new" water to the system but rather part of the water present in the observed data. If the estimated discharge was from dewatering activities, it was considered new water. It may be argued that surface mining increases the streamflow by reducing evapotranspiration and by the addition of a new ground-water storage zone (the reclaimed area). If this increase in discharge was included in the model, an estimate of the increased amount of water would be needed. At present, these numbers would be difficult to obtain. Therefore, it was assumed that the amount of water moving through the system during existing conditions was the same amount moving through the system with an anticipated mining activity except for dewatering activities.

At each node the surface-water quality component, mean monthly dissolved-solids concentration in milligrams per liter, is calculated by the mass balance equation:

$$C_i=[(\sum_{u=1}^{n} Q_uC_u)+Q_rC_r]/[(\sum_{u=1}^{n} Q_u)+Q_r], \quad (3)$$

where: C_i=dissolved-solids concentration at node i,

n=number of nodes immediately upstream from node i,

Q_u=discharge at nodes immediately upstream from node i,

C_u=dissolved-solids concentration at nodes immediately upstream from node i, and

C_r=dissolved-solids concentration associated with the incremental discharge (Q_r) within the reach.

The dissolved-solids concentration within the reach (C_r) is obtained from the linear-regression equation:

$$C_r=aQ_r^b, \quad (4)$$

where: a and b=the regression coefficients from simple linear regression.

Initial estimates of C_r are obtained from observed data at each node. For input nodes, the observed data reflect the actual value of C_r because it is the integrated dissolved-solids concentration for the total reach above that node. However, for internal and output nodes, observed data do reflect integrated dissolved-solids concentration for the total length of stream above the node and do not reflect the reach between nodes. Thus, the observed data are not an estimate of C_r. Because data are not available to estimate C_r directly, final estimates of the regression coefficients in equation 4 were obtained in the calibration process.

For each anticipated mining activity, the Mined Land Reclamation Division estimated dissolved-solids concentration for water discharging to the stream from the mining activity. During mining operations, the concentration value of dissolved solids was 2,860 mg/L (milligrams per liter) for combined surface- and ground-water discharge. For postmining situations, no discharge from a surface-water source was assumed, and the dissolved-solids concentration was estimated at 3,200 mg/L from a ground-water source only.

One special case must be discussed. In several stream segments in the area of analysis, water is lost between the upstream and downstream nodes during certain periods of the year. If the discharge at the upstream node or nodes is greater than the discharge at the next node downstream (that is, if $Q_r<0$), then the quantity of dissolved solids is reduced in proportion to the water quantity lost. Reducing the quantity of dissolved solids in this manner assumes that water lost in the reach is lost to ground water and, therefore, the water that is lost takes with it the associated dissolved solids. Unfortunately, some of the dissolved solids assumed lost to ground water may remain on the bed and banks of the stream channel to be removed with the next high flow. In addition, water lost to evapotranspiration leaves the associated dissolved solids in the streamflow. To accommodate these problems, a calibration factor was added to increase the dissolved-solids concentration in this situation. This factor was adjusted during the model calibration. Thus, in a losing reach, C_i is reduced to the minimum value and adjusted upward by:

$$C_i=C_i \cdot \frac{Q_i}{\sum_{u=1}^{n} Q_u} \cdot E_i, \tag{5}$$

where: E_i=calibration coefficient ≥ 1.0.

AVAILABLE DATA

Data are necessary for all the input nodes because these nodes initiate streamflow in the network. Streamflow-data collection for several small basins in the area was begun in water year 1976 (October 1975) in a cooperative effort with the U.S. Bureau of Land Management. These data (water years 1976 through 1981) provided 6 years of data, which included a mix of dry, wet, and average years, for model calibration.

Two different types of station numbers are shown in table 1. If the number has eight digits, continuous streamflow record is obtained at the site as part of the U.S. Geological Survey streamflow-gaging program; in addition, some water-quality information may be available. If the station number has 15 digits, the site only has data on instantaneous discharge with associated water-quality data. One exception to this numbering system--node 19--is noted in table 1.

Node numbers associated with the streamflow-gaging stations in the stream network are listed in table 1. Node numbers were assigned consecutively in a downstream direction beginning with the input node on Trout Creek. The node numbers associated with streamflow-gaging stations listed in table 1 and shown in figure 1 will be used to identify stations in this report.

Table 1.--*Water-resource information available for nodes in the model*

Node No.	Type of node	Station No.	Station name	Latitude	Longitude	Period of discharge record	Drainage area (square miles)
1	INPUT	401816107011000	Trout Creek near Oak Creek	40°18'47"	107°01'10"	-------	31.1
9	INPUT	09243800	Foidel Creek near Oak Creek	40°20'45"	107°05'04"	1975-	8.61
12	INTERNAL	09243900	Foidel Creek at mouth, near Oak Creek	40°23'25"	106°59'39"	1975-	17.5
13	INPUT	09243700	Middle Creek near Oak Creek	40°23'08"	106°59'33"	1975-	23.5
15	OUTPUT	--------	Middle Creek at mouth	---------	----------	-------	--------
17	INPUT	[1]09244100	Fish Creek near Milner	40°20'03"	107°08'19"	1977-80	34.5
19	OUTPUT	[1]402530106585700	Fish Creek at mouth, near Milner	40°25'30"	106°58'57"	1977-80	77.9
20	OUTPUT	402720106591200	Trout Creek above Milner	40°27'20"	106°59'12"	-------	110
21	INPUT	09239500	Yampa River at Steamboat Springs	40°29'01"	106°49'54"	1909-	604
22	INPUT	09241000	Elk River at Clark	40°43'03"	106°54'55"	1930-	206
24	INPUT	402330107082000	Grassy Creek at Grassy Gap	40°23'30"	107°08'20"	-------	5.52
26	INTERNAL	09244300	Grassy Creek near Mount Harris	40°26'49"	107°08'42"	1959-67	25.8
27	OUTPUT	09244410	Yampa River below diversion, near Hayden	40°29'18"	107°09'33"	1965-	1,430

[1]Continuous streamflow-gaging site operated by the U.S. Department of Agriculture, Science and Education Administration.

For the 6-year period in which the model is operated, mean monthly discharges were required for seven input nodes (fig. 1). Of these, observed data for the entire period were available for four input nodes (table 1): Yampa River at Steamboat Springs (09239500), Foidel Creek near Oak Creek (09243800), Middle Creek near Oak Creek (09243700), and Fish Creek near Milner (09244100). Partial record was available for Fish Creek near Milner from 1977 to 1980, so missing records were estimated by correlation with node 13 and the record extended. In addition, data for the Elk River station required only an extrapolation from the data for station Elk River near Clark to the outlet. This leaves only the input nodes on Trout Creek and Grassy Creek for which no streamflow information is available and must be estimated (fig. 1).

As part of the calibration process, streamflow data also must be available for output nodes: Middle Creek at mouth, Fish Creek at mouth, near Milner (402530106585700), Trout Creek above Milner (402720106591200), and Yampa River below diversion, near Hayden (09244410). As shown in table 1, gaged data are available in the period for Fish Creek at mouth, near Milner (402530106585700) and Yampa River below diversion, near Hayden (09244410). In addition, the location of the output node for Middle Creek at mouth (node 15) is directly downstream from the two streamflow gages, Middle Creek near Oak Creek (09243700) and Foidel Creek at mouth, near Oak Creek (09243900). Thus, data for output node 15 is assumed to be a direct summation of these two gages.

DATA ESTIMATION

Surface Water

No continuous discharge data were available for input node 1, Trout Creek near Oak Creek (401816107011000). In 1981, several instantaneous-discharge measurements were made at this site in conjunction with a water-quality sampling program (Maura, 1983). These discharge values were used to develop a linear relationship with the streamflow-gaging station, Bear River near Toponas (09236000) to estimate mean monthly discharge at Trout Creek (node 1). The Bear River drainage is the next drainage to the south of Trout Creek and has elevations, drainage areas, and geology similar to Trout Creek near Oak Creek. The equation to predict mean daily discharge at Trout Creek (node 1) from the gaged data for Bear River is:

$$Q_p=0.55Q_o+1.8, \qquad (6)$$

where: Q_p=predicted discharge in cubic feet per second, and

Q_o=observed discharge in cubic feet per second,

and the standard error of estimate is 5.046 ft^3/s. These mean daily values were summed, and mean monthly discharge was determined for each month for Trout Creek (node 1).

Partial record is available for input node 17, Fish Creek near Milner from 1977 to 1980 (Science and Education Administration, Agriculture Research, written commun., 1981). Discharge data missing from this partial record and data for water years 1976 and 1981 were estimated from data for Middle Creek near Oak Creek. Middle Creek is the second basin to the east of Fish Creek; the elevation and drainage area for the streamflow gage at Middle Creek near Oak Creek are similar to Fish Creek near Milner. The equation to estimate missing mean monthly discharge data at Fish Creek from Middle Creek is:

$$Q_p=1.57Q_o+6.56, \tag{7}$$

and the standard error of estimate is 10.979 ft^3/s.

Gaged data are available for input node 22, Elk River at Clark (09241000). However, this streamflow gage monitors discharge for less than one-half the Elk River drainage area (206 square miles). Because of this, data for Elk River near Clark were adjusted using a period of concurrent record from the discontinued streamflow-gaging station Elk River near Trull (09242500), where discharge was measured for over three-fourths the total Elk River drainage area (415 square miles). Mean monthly increases in Elk River discharge from the station at Clark to the station near Trull were added to the discharge data for the station Elk River near Clark to account for more drainage area and to give a better estimate of the discharge at the mouth of the Elk River.

Data for input node 24, Grassy Creek at Grassy Gap (402330107082000), included instantaneous-discharge measurements made in 1981 and 1982 (Maura, 1983). Input-discharge data for this station were estimated from the downstream station, Grassy Creek near Mount Harris (09244300), from the equation:

$$Q_p=0.16Q_o+0.18. \tag{8}$$

The standard error of estimate is 0.500 ft^3/s.

The data for output node 15, Middle Creek at mouth, is determined from data at a site just below the confluence of Foidel and Middle Creeks--both gaged streams. Discharge data at this node are the sum of the discharges for node 12, Foidel Creek at mouth, near Oak Creek and node 13, Middle Creek near Oak Creek.

Partial-discharge record was available for output node 19, Fish Creek at mouth, near Milner, for the period 1977 to 1980 (U.S. Department of Agriculture, Science and Education Administration, Agriculture Research, written commun., 1981). Missing record was estimated from the next stream to the east, Foidel Creek at mouth, near Oak Creek, from the equation:

$$Q_p=7.53Q_o+3.24. \tag{9}$$

The standard error of estimate is 8.35 ft^3/s.

No continuous-discharge data were available for output node 20, Trout Creek above Milner, but instantaneous-discharge measurements made in 1981 and 1982 were included (Maura, 1983). These measurements were made concurrently with instantaneous-discharge measurements at Trout Creek near Oak Creek. The regression equation of these concurrent measurements is:

$$Q_p=1.05Q_o+5.57, \qquad (10)$$

which was used to estimate discharge at Trout Creek above Milner. The standard error of estimate is 8.997 ft^3/s.

All major tributaries of Trout Creek have streamflow-gaging stations (fig. 1). Therefore, the data estimated for node 20, Trout Creek above Milner, were compared to the streamflow records from these tributaries. A satisfactory estimate of discharge was obtained from equation 10, except during the peak-flow months of March, April, and May. To improve timing for data for node 20, mean monthly discharge for March, April, and May was estimated for Trout Creek from data for Foidel Creek at mouth, near Oak Creek from the equation:

$$Q_p=9.32Q_o+26.23. \qquad (11)$$

The standard error of estimate is 18.55 ft^3/s. Gaged data for the entire period of record was available for the last output node, node 27, Yampa River below diversion, near Hayden.

Water Quality

Analyses of instantaneous water-quality samples of dissolved-solids concentration are available for most streamflow-gaging stations in the study area. In addition, instantaneous measurements of discharge and associated dissolved-solids concentration are available from a previous study for a number of miscellaneous sites in the stream system (Maura, 1983). Data were analyzed in the same way for both streamflow-gaging stations and miscellaneous sites.

For each input node, a linear-regression equation was obtained between the logarithm of instantaneous discharge and the logarithm of dissolved-solids concentration. These equations are of the form of equation 4, and the regression equations are given in table 2. These equations were placed directly into the model for each input node.

For each output node with mean monthly discharge data (either observed or extrapolated), a linear-regression equation between the logarithm of instantaneous discharge (cubic foot per second) and dissolved-solids concentration (milligram per liter) was obtained from data available at the sites. These equations are of the form of equation 4, and are given in table 3.

Table 2.--*Linear-regression equations of the logarithm of instantaneous discharge and dissolved-solids concentrations for input nodes*

Node No.	Station No.	Equation	Number of observations	Standard error (percent)
1	401816107011000	$283\ Q^{-0.336}$	6	17
9	09243800	$411\ Q^{-0.206}$	32	70
13	09243700	$383\ Q^{-0.098}$	50	21
17	09244100	$501\ Q^{-0.238}$	8	24
21	09239500	[1]$956\ Q^{-0.38}$	([1])	([1])
22	09241000	[1]$109\ Q^{-0.15}$	([1])	([1])
24	402330107082000	$324\ Q^{-0.205}$	7	28

[1]Equations are estimated from the linear-regression equations of the discharge and the logarithm of specific conductance. See text for further discussion.

Table 3.--*Linear-regression equations of the logarithm of instantaneous discharge and dissolved-solids concentrations for output nodes*

Node No.	Station No.	Equation	Number of observations	Standard error (percent)
15	Middle Creek at mouth	-----------	--	--
12	09243900 (tributary)[1]	$721\ Q^{-0.172}$	35	80
13	09243700 (tributary)[1]	$383\ Q^{-0.098}$	50	21
19	402530106585700-------	$434\ Q^{-0.012}$	7	34
20	402720106591200-------	$416\ Q^{-0.101}$	9	57
27	09244410-------	$862\ Q^{-0.296}$	70	40

[1]Node 15 is a direct summation of nodes 12 and 13, which are immediately upstream.

Using these equations, a dissolved-solids concentration was obtained for each mean monthly discharge. Calculation of the load of dissolved solids (tons per month) was obtained from:

$$L=Q \cdot C \cdot 0.0027 \cdot N_m, \qquad (12)$$

where: L=dissolved-solids load (in tons per month),
Q=mean monthly discharge (in cubic feet per second),
C=dissolved-solids concentration (in milligrams per liter) at the mean monthly discharge, and
N_m=number of days in the month.

The calculated values for the period of record are used as the observed values and are compared to modeled values for calibration and error analysis.

No measurements of dissolved-solids concentration are available for input node 21, Yampa River at Steamboat Springs, and node 22 on the Elk River; data for node 22 is extrapolated from Elk River at Clark (09241000). This lack of data is unfortunate as these nodes input an average of nearly 90 percent of the total volume of water observed at the outlet (node 27).

However, specific-conductance values are available for both stations. For the Elk River at Clark (09241000), there are 41 values for specific conductance and instantaneous discharge. These values in a regression yield:

$$C_s=188Q^{-0.152}, \qquad (13)$$

where: C_s=specific conductance (in micromhos per centimeter at 25° Celsius), and
Q=instantaneous discharge (in cubic feet per second), with a standard error of 35 percent.

For node 21, there are 44 observations of specific conductance and discharge. The regression equation for these data is:

$$C_s=1,648Q^{-0.383}, \qquad (14)$$

with a standard error of 27 percent.

Hem (1970) suggests that the relation between dissolved-solids concentration and specific conductance is of the form:

$$C=b \cdot C_s, \qquad (15)$$

where: C=dissolved-solids concentration (in milligrams per liter),
C_s=specific conductance (in micromhos per centimeter at 25° Celsius), and
b=regression coefficient.

With the equation in this form, Hem (1970) states that the coefficient b should be about 0.60. From observed data for node 27 the coefficient b for equation 15 is 0.58. Using a coefficient b of 0.58 and assuming the slopes of the relations do not change in equations 13 and 14, the resulting equation for Elk River at Clark (09241000) used in the model for node 22 is:

$$C=109Q^{-0.152}. \qquad (16)$$

The equation used in the model for node 21 is:

$$C=956Q^{-0.383}. \qquad (17)$$

MODEL CALIBRATION

Observed or estimated data were entered into the model at each of the input nodes. In order to calibrate the model, observed or estimated data were computed for several internal nodes and all output nodes. These observed data were compared against the model output for the particular nodes. Calibration was done for nodes 15, 19, 20, and 27 (table 1). Calibration was performed by changing parameters in the model in order that modeled output of discharge, dissolved-solids concentration, and dissolved-solids load closely matched observed data at the output nodes. Model parameters which were altered were the regression coefficients in equations 2 and 4 and the coefficient E_i in equation 5.

The objective function that was considered during calibration was the mean square error over the total 72 months the model was run for each variable. The error function uses the logarithms of the differences between observed and predicted values. The mean square error is:

$$MSE=\bar{x}^2+s^2, \qquad (18)$$

where:

MSE=mean square error,

$\bar{x}$=mean of the differences between the logarithms (base e) of observed and model prediction for each model variable for each month, and

s^2=variance of the differences of the logarithms (base e) between the observed and model prediction for each model variable for each month.

In this equation, the first term is the bias from the true mean zero and the second term is the variance. During calibration, the attempt is to reduce the bias ($\bar{x}$) to zero with a minimum variance (s^2).

Hydrographs of observed variables and predicted variables for nodes 15, 19, 20, and 27 are shown in figures 3 through 14. An examination of these figures gives a qualitative evaluation of the calibration of the variables. The bias, variance, and mean square error of each variable for the same nodes are given in table 4.

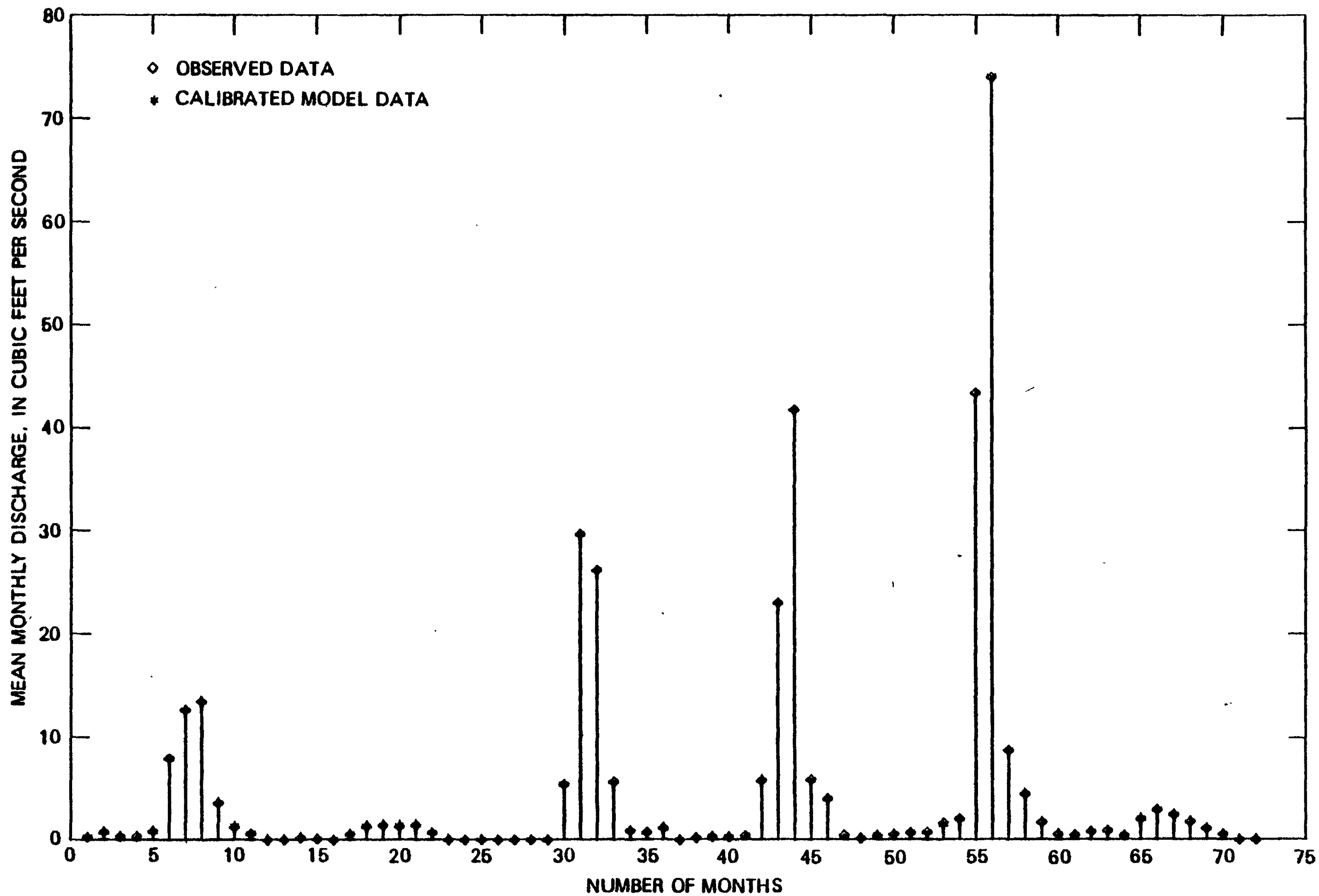

Figure 3.--A comparison of calibrated model output and observed mean monthly discharge at node 15, Middle Creek at mouth.

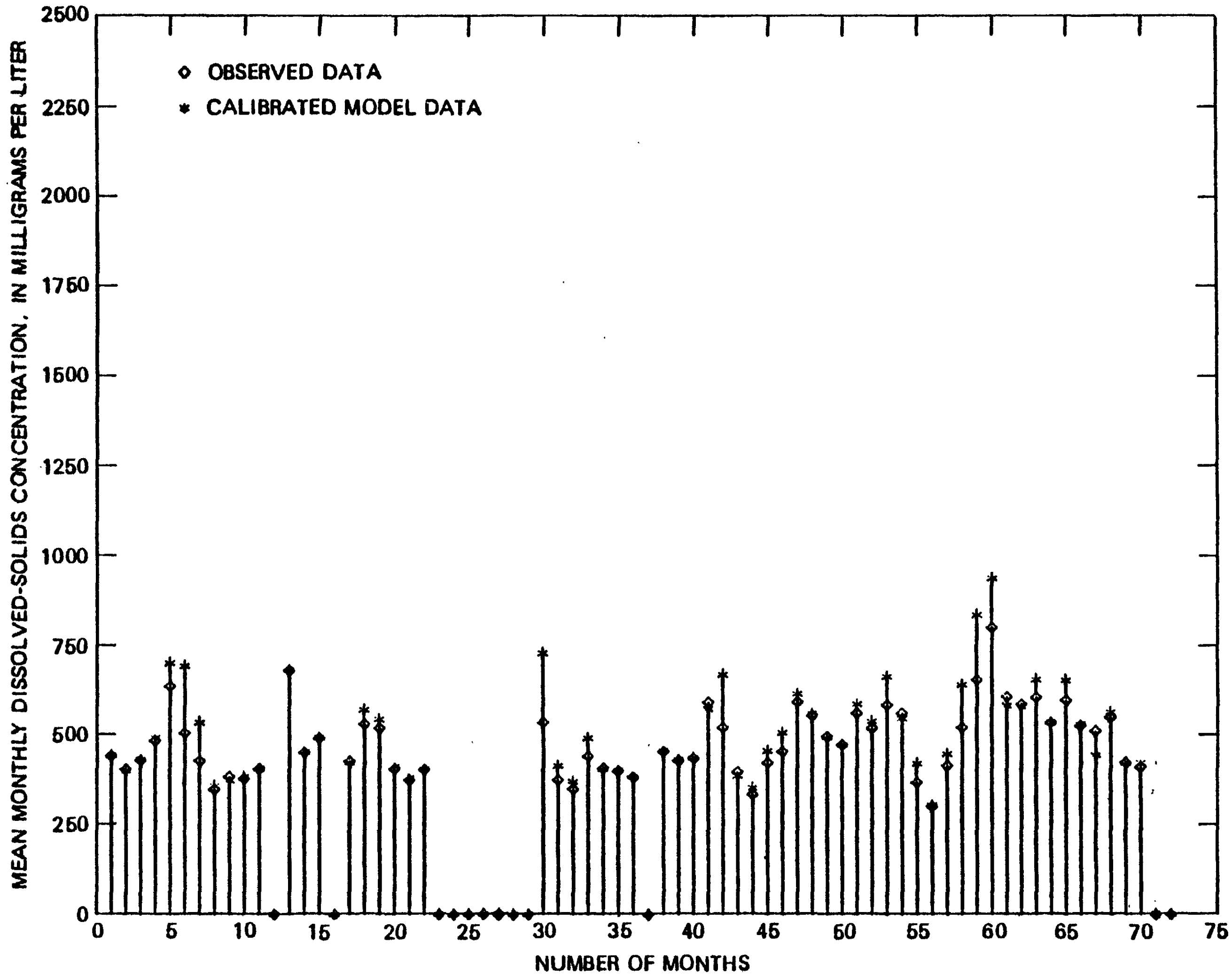

Figure 4.--A comparison of calibrated model output and observed mean monthly dissolved-solids concentration at node 15, Middle Creek at mouth.

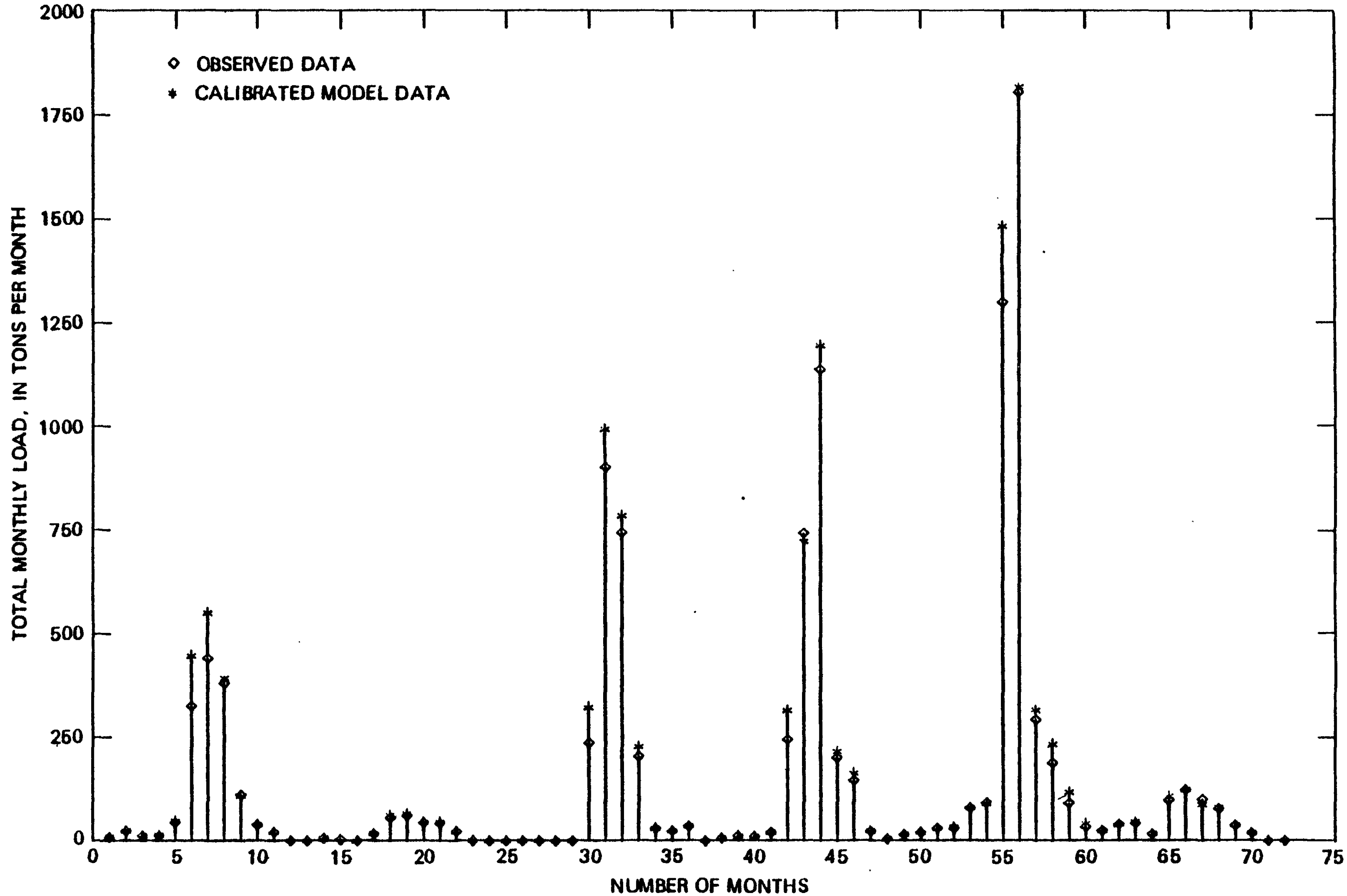

Figure 5.--A comparison of calibrated model output and observed total monthly load at node 15, Middle Creek at mouth.

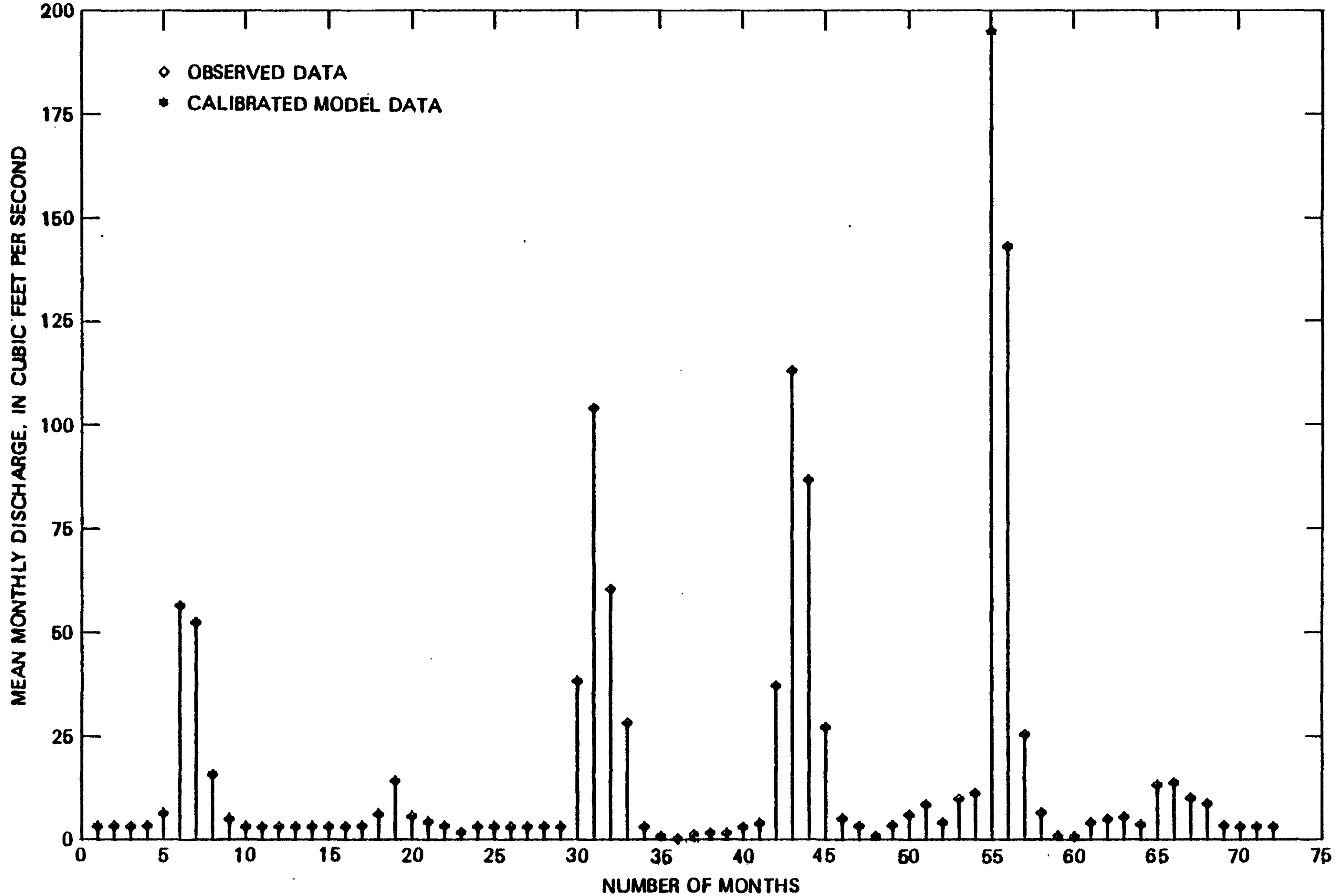

Figure 6.--A comparison of calibrated model output and observed mean monthly discharge at node 19, Fish Creek at mouth, near Milner.

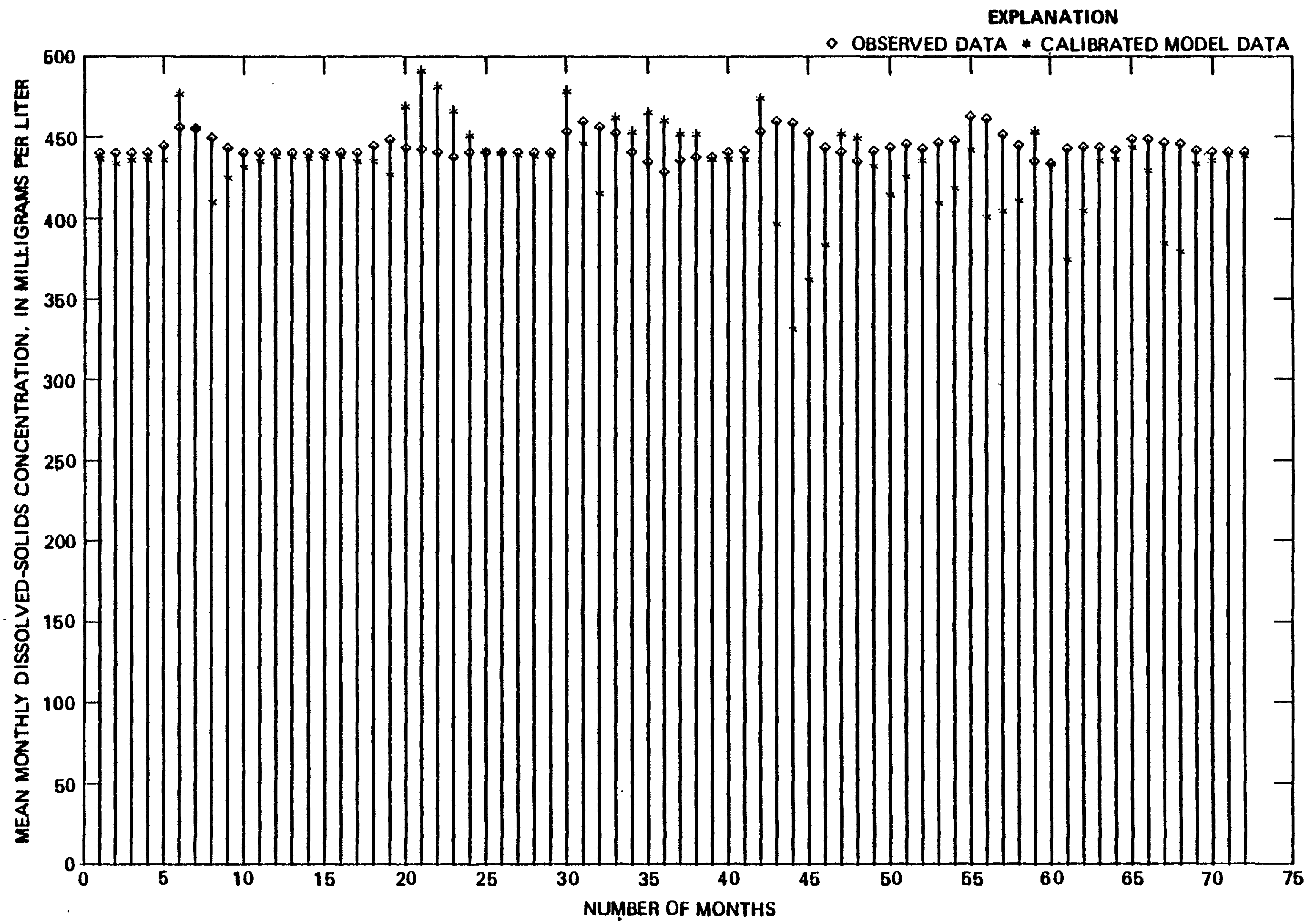

Figure 7.--A comparison of calibrated model output and observed mean monthly dissolved-solids concentration at node 19, Fish Creek at mouth, near Milner.

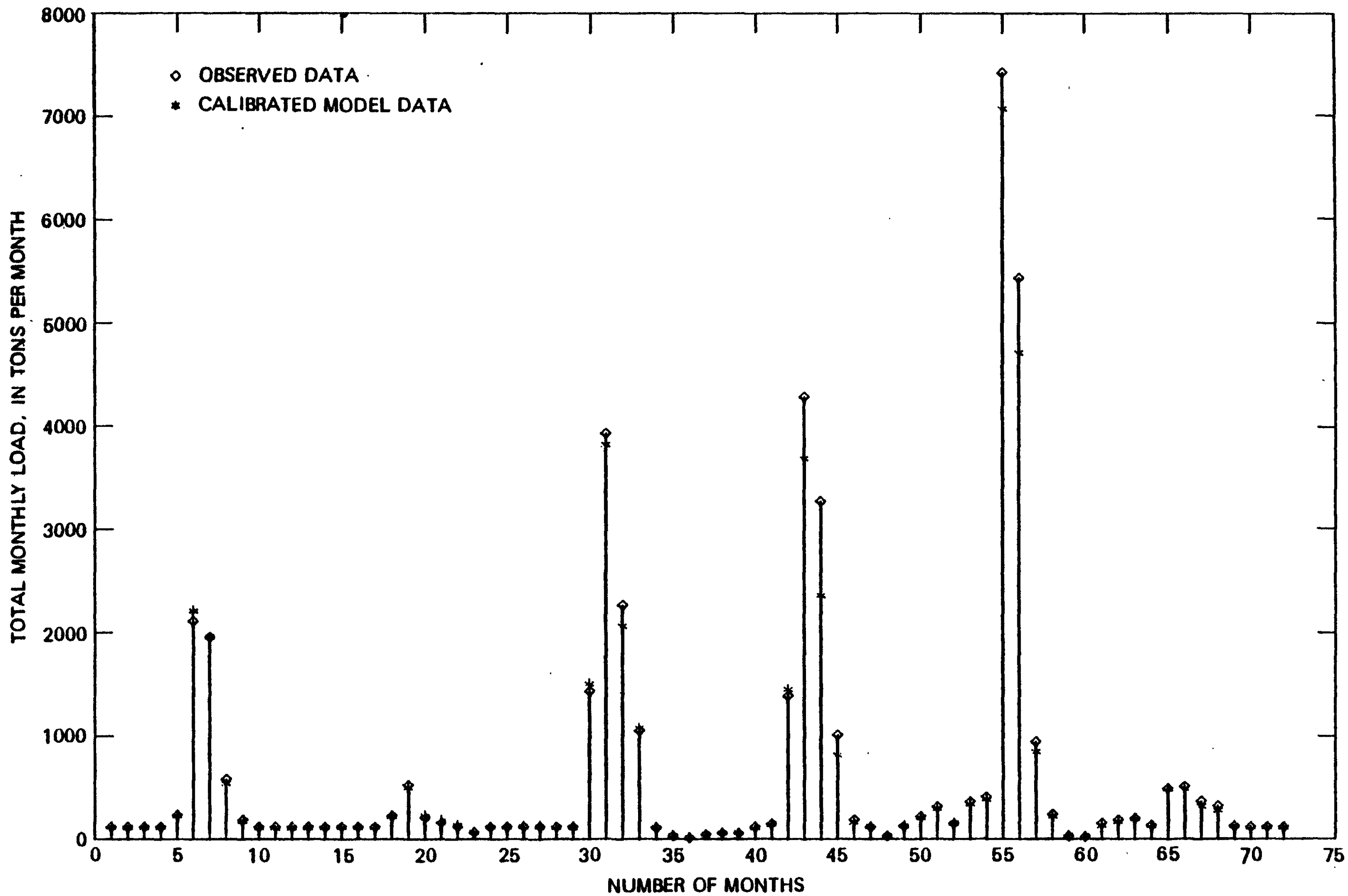

Figure 8.--A comparison of calibrated model output and observed total monthly load at node 19, Fish Creek at mouth, near Milner.

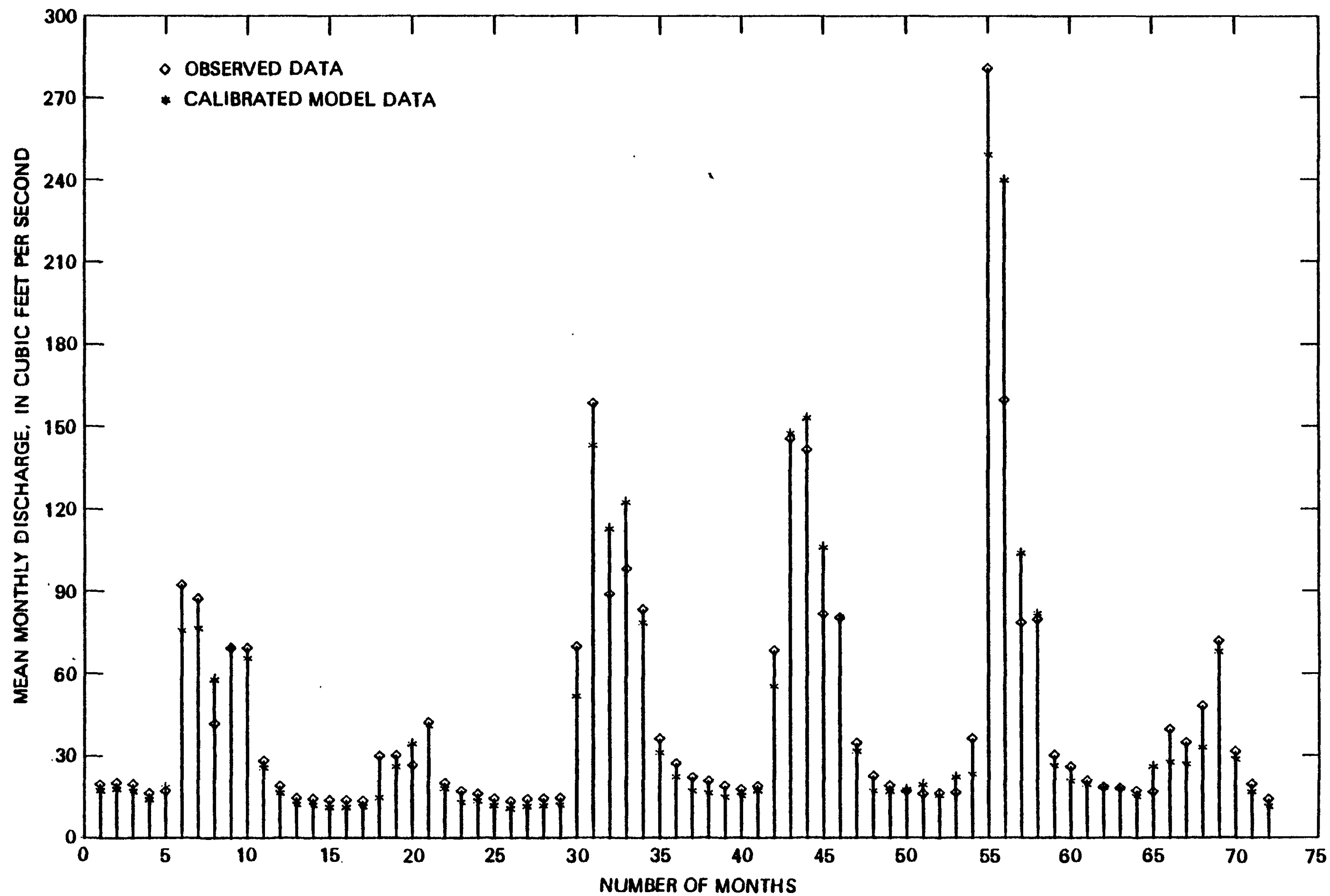

Figure 9.--A comparison of calibrated model output and observed mean monthly discharge at node 20, Trout Creek above Milner.

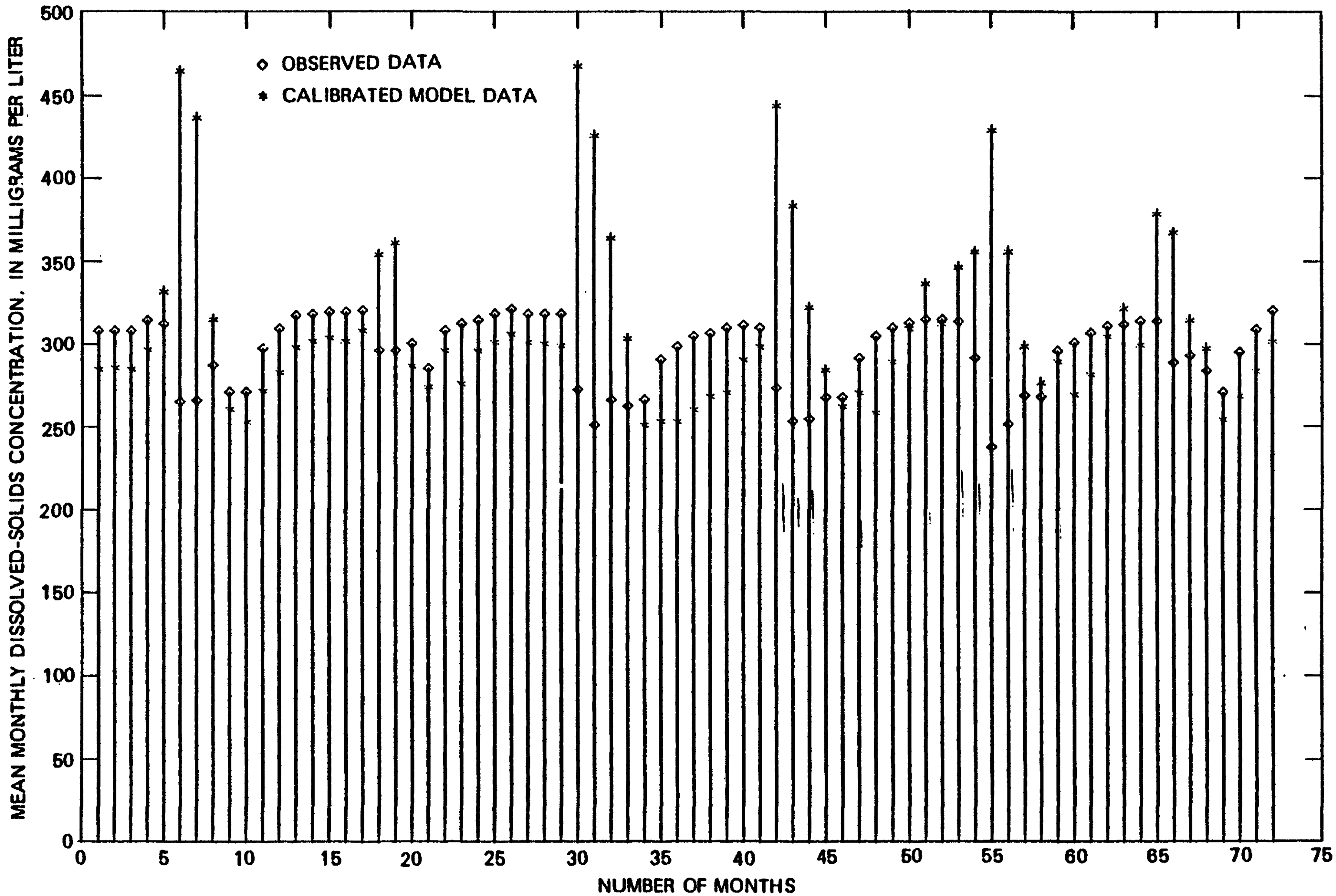

Figure 10.--A comparison of calibrated model output and observed mean monthly dissolved-solids concentration at node 20, Trout Creek above Milner.

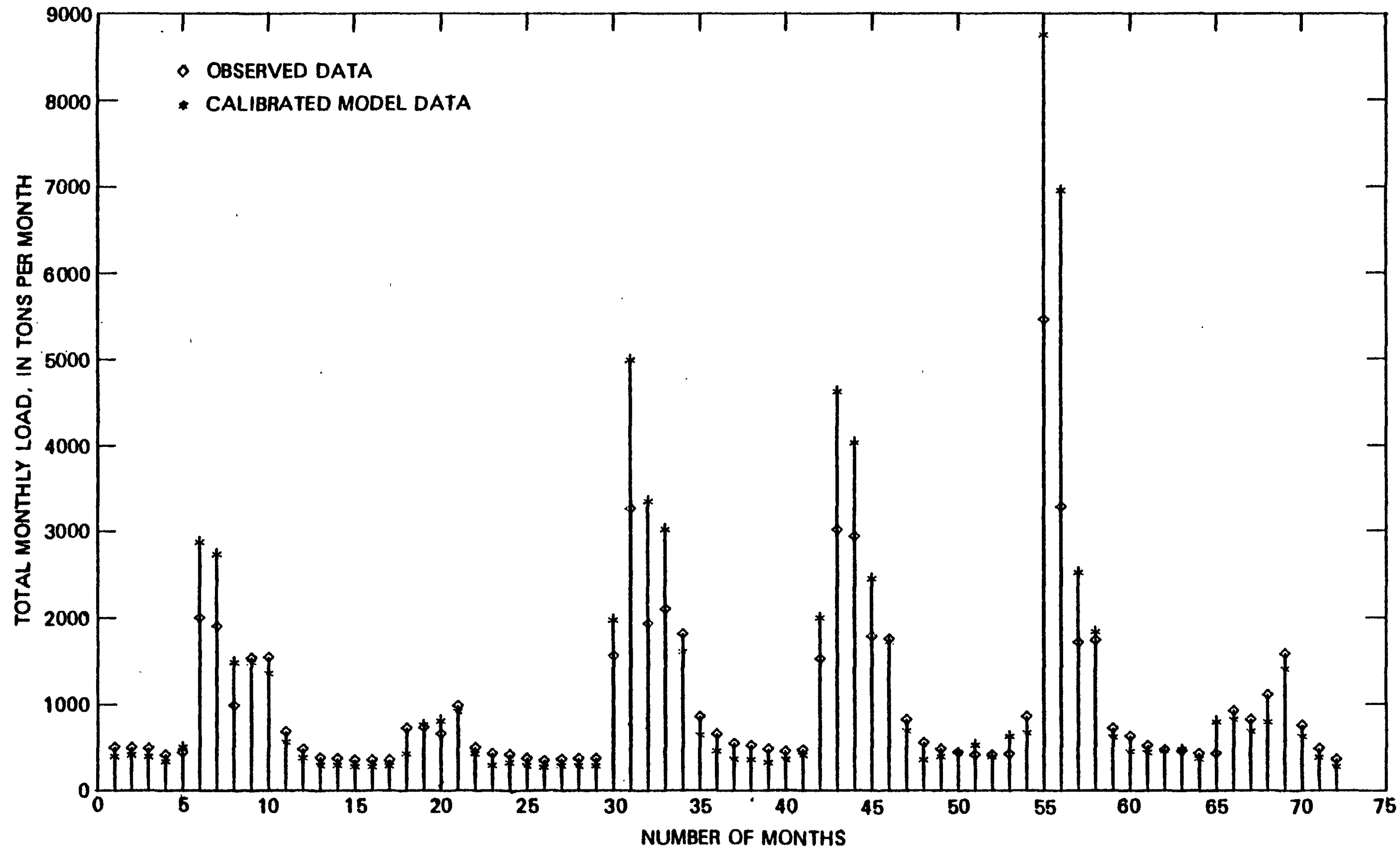

Figure 11.--A comparison of calibrated model output and observed total monthly load at node 20, Trout Creek above Milner.

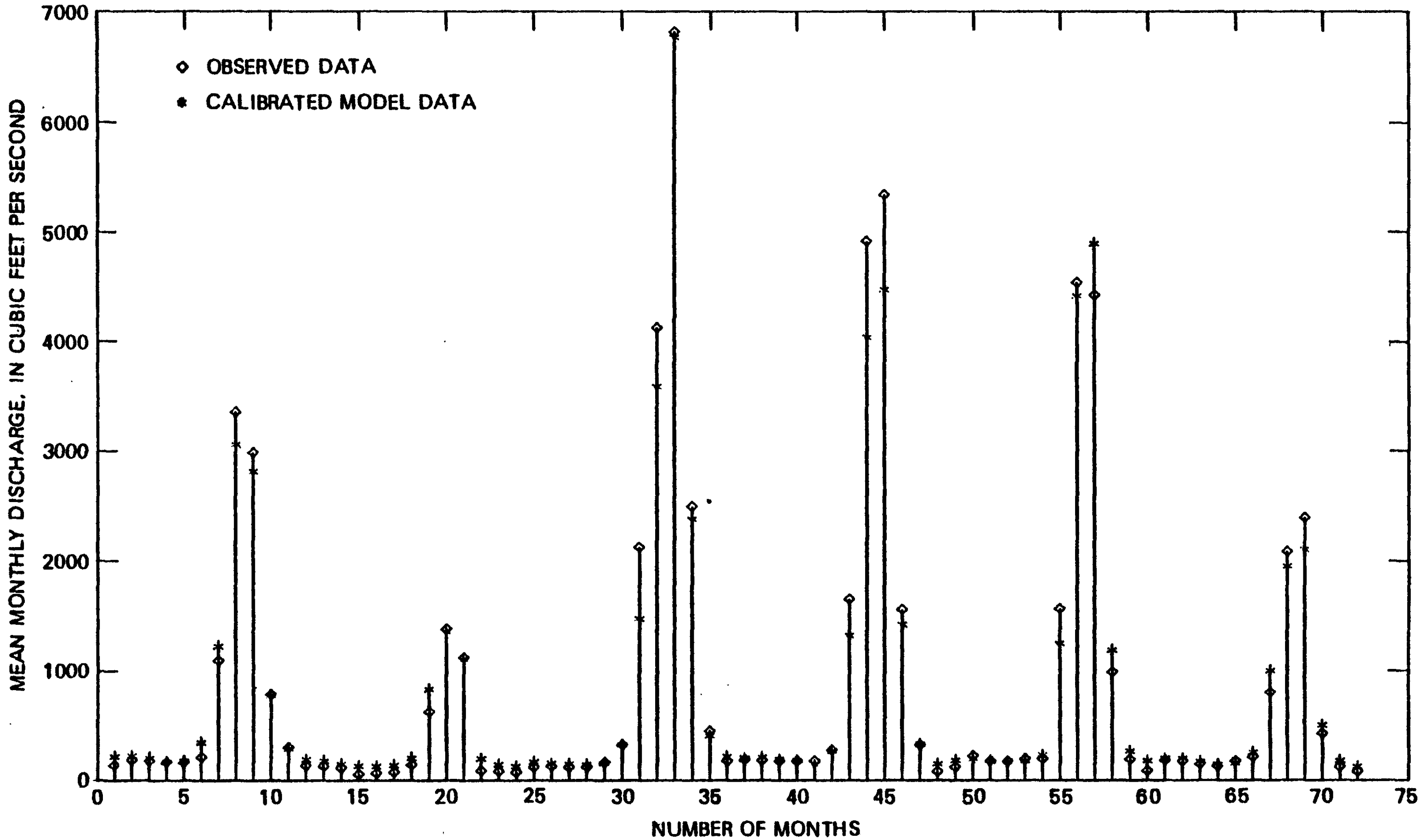

Figure 12.--A comparison of calibrated model output and observed mean monthly discharge at node 27, Yampa River below diversion, near Hayden.

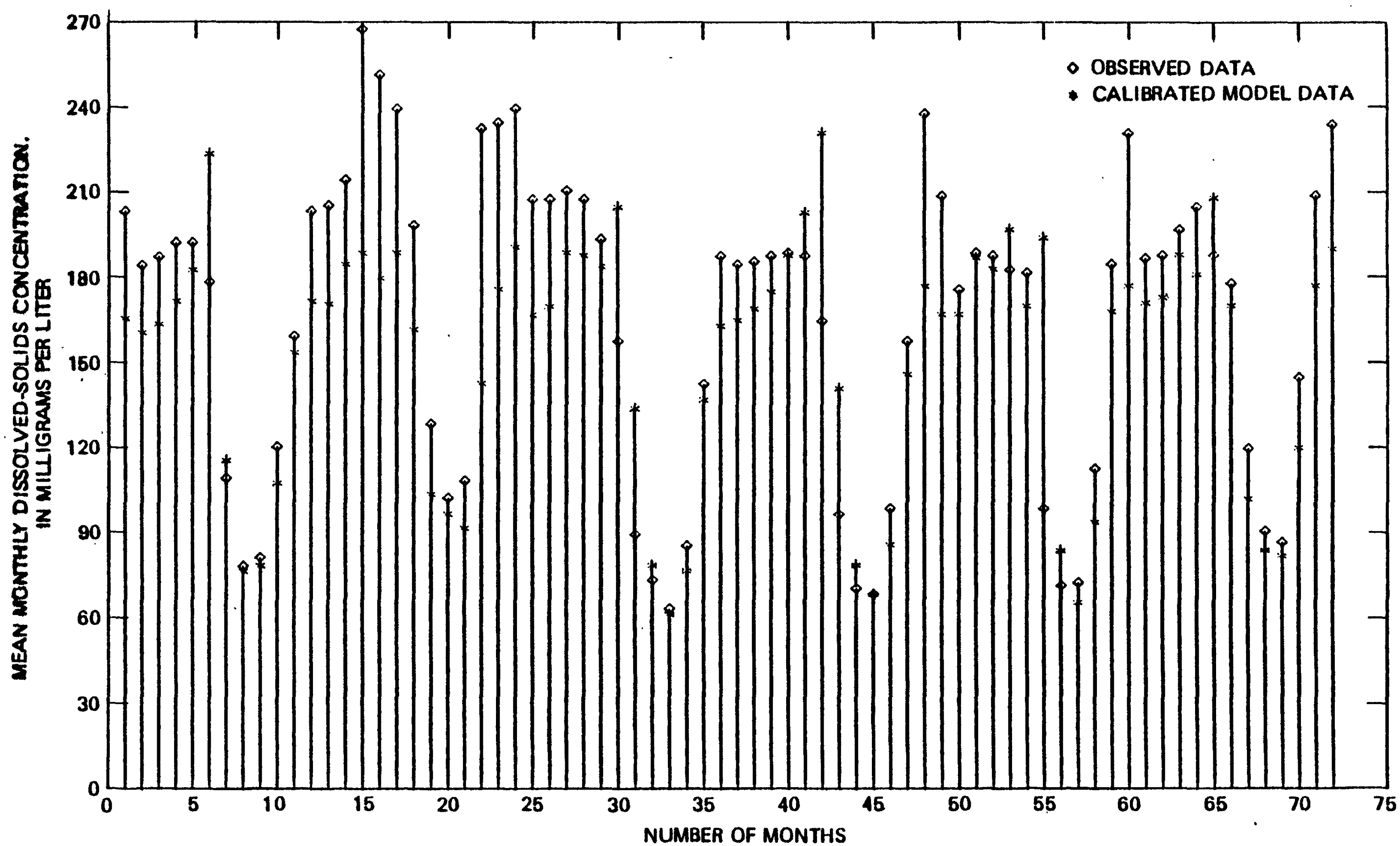

Figure 13.--A comparison of calibrated model output and observed mean monthly dissolved-solids concentration at node 27, Yampa River below diversion, near Hayden.

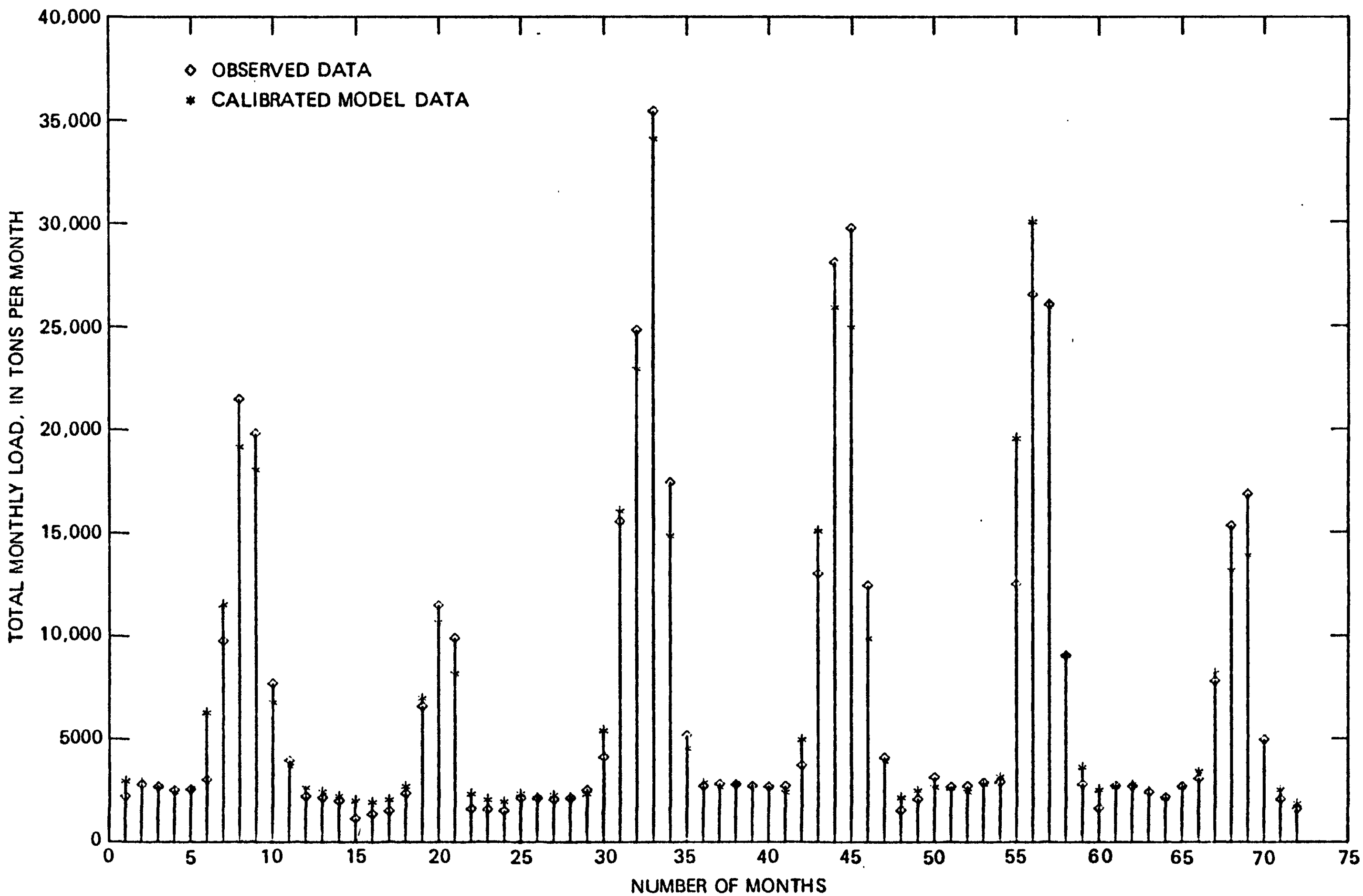

Figure 14.--A comparison of calibrated model output and observed total monthly load at node 27, Yampa River below diversion, near Hayden.

Table 4.--*Error analysis for modeled mean monthly discharge, dissolved-solids concentration, and dissolved-solids load for 72 months*

Node No.	Bias ($\bar{x}$)	Variance (s^2)	Mean square error (*MSE*)	Mean error (percent)
	Logarithm of mean monthly discharge, in cubic feet per second			
15	0	0	0	0
19	0	0	0	0
20	.099	.039	.049	12.6
27	-.135	.069	.087	-9.6
	Logarithm of mean monthly dissolved-solids concentration, in milligram per liter			
15	0	0	0	0
19	.028	.005	.006	3.1
20	-.040	.037	.039	-2.1
27	.072	.033	.038	9.3
	Logarithm of total monthly dissolved-solids load, in tons per month			
15	-0.045	0.007	0.009	-4.1
19	.027	.005	.006	3.0
20	.059	.086	.089	10.7
27	-.063	.035	.039	-4.4

Also shown in table 4 is the percent error for each variable at the four nodes. The error function is the logarithm of observed minus predicted values for the total 72 months. The error is divided into the two components of bias and variance. Because of these two facts, the error, in percent, can be derived from Matalas (1967) as:

$$\text{Error}=(e^{\bar{x}}e^{\frac{1}{2}s^2}-1)100, \qquad (19)$$

where: e=the base of the natural logarithms,

$\bar{x}$=bias, and

s^2=variance.

This form of the equation assumes that the differences being examined are of the form:

$$\frac{V_o-V_p}{V_p}, \qquad (20)$$

where:

V_o=one of the observed variables of discharge, concentrations, or load; and

V_p=one of the predicted variables of discharge, concentrations, or load.

Some of the variables at particular nodes have zero error. This is because the observed values of the variables are used at that output node in the model, or the predicted values are a direct summation from values directly upstream (node 15).

The above analysis assumes that the observed values of discharge, concentration, and load are correct. From previous sections it is apparent that this assumption is not true at all nodes. Data used as observed values have been estimated from other stations and regression equations with few data points to construct dissolved-solids concentration for the entire period of record.

Within the time available, there was no way to combine the errors in observed versus predicted values within the model with the errors in constructing the observed set of data. Therefore, the errors may be larger than those identified within the model itself.

An attempt was made to calibrate the model to reflect the observed data. In the next section the calibrated model will be perturbed by adding increased discharge or different concentrations of dissolved solids resulting from anticipated mining. It is known what changes are made to the model input; it is unknown what the magnitude of these changes will be downstream. Therefore, the results of the model runs with increased mining activity will be compared with the calibrated model output.

ANALYSIS OF ANTICIPATED MINING ACTIVITY

The calibrated model used data on streamflow quantity and quality for the period October 1975 to September 1981 (water years 1976 through 1981). Thus, discharges from mines in operation during that time are reflected in the data collected and in the calibrated model. In order to assess changes in the water quantity and quality resulting from anticipated mining activity, it is necessary to convert the information given in the proposed mining plans into actual discharge values and associated dissolved-solids concentrations. Thus, an expansion of a mine by several hundred acres must be evaluated in terms of the actual discharge of water through the mine to the receiving stream and the associated dissolved-solids concentration. These evaluations were provided by the Mined Land Reclamation Division and were based on the life-of-mine area identified in the permit application on file with the Division. The Mined Land Reclamation Division also provided a series of anticipated mining activities in which various levels of mining could be evaluated. Two examples of this series were selected for discussion in this report.

Mining effects were divided into short-term and long-term effects. These time frames are relative. Short-term effects include surface- and ground-water effects, such as discharge from sediment ponds, discharge from underground mine workings, and the discharge of affected waters from shallow ground-water systems that would occur during the mining operation and for a short time following reclamation. The natural flow patterns of the affected ground-water systems are disrupted by mining, and surface and ground water is mixed. Increased evaporation losses from the sediment ponds are assumed to be offset by increased runoff from disturbed areas.

The first predicted simulation with the model was made to reflect short-term changes in water quantity and quality from a mine plan. Changes were made to nodes at mine inputs (fig. 1), which up to this time had been inactive. Existing mines include Apex No. 2, Edna, Eckman Park, Middle Creek, Seneca II, Grassy Creek, Sun Coal's Meadows, and Colorado Yampa Coal Co. Mines Nos. 1, 2, and 3. It is anticipated that these mines will continue operations according to the life-of-mine areas identified in their permit applications. The Middle Creek Mine is not anticipated to reopen, but there is some discharge associated with this mine. Two proposed mines, Trout Creek and Foidel Creek, are located in the study area. For the short-term activity, the values for the Foidel Creek Mine include discharge of water from the mine workings and depletion of flows in Fish Creek but, at the company's request, do not include discharge from the spoils well to the streamflow system.

The changes in discharge and dissolved-solids concentration for the altered mine nodes shown in table 5 reflect:

1. The existing mine in Eckman Park continues to expand (1,204 acres) after 1981 (node 10).
2. The proposed Foidel Creek underground mine is added (node 11).
3. The Middle Creek Mine remains inactive but continues to discharge additional water not identified in the calibration from its portal (node 14).
4. Colorado Yampa Coal Co.'s No. 2 Mine has additional mining (50 acres) after September 1981 (node 18).
5. Seneca II Mine has additional mining activity tributary to Fish Creek (781 acres) (combined into node 18).
6. Seneca II Mine has additional mining (98 acres) and Grassy Creek Mine has additional mining (192 acres) after September 1981 (combined into node 25).
7. Apex No. 2 Mine continues to operate but has no short-term effect.
8. Edna Mine has additional mining (966 acres) after 1981 (node 6).
9. Colorado Yampa Coal Co.'s No. 1 and No. 2 Mines and Sun Coal's Meadows Mines are reclaimed.

The changes in the mine nodes (table 5) were inserted into the model and compared against the existing conditions of the calibrated model at the output nodes--node 15 at the mouth of Middle Creek and node 19 at the mouth of Fish Creek. Both these drainages had substantial changes in mine inflow and outflow. Node 20 is near the mouth of Trout Creek downstream from Fish and Middle Creeks. Node 27 is the outlet of the model. Hydrographs of the existing conditions and the short-term anticipated mining plan for each output node are shown in figures 15 through 26. The changes in the model output are summarized in table 6.

The long-term effects of mining occur after disturbed areas have been successfully reclaimed, and the surface- and ground-water systems have had sufficient time to equilibrate. Sediment-control structures have been removed, and the quantity and quality of runoff from the reclaimed areas have returned to premining conditions. Spoils aquifers and underground mine workings have resaturated, and ground water passing through the disturbed area discharges in its premining disturbed areas. The quantity of ground-water flows would equal premining quantities, but the quality would be degraded.

Table 5.--*Changes from model calibration input to reflect short-term impacts from existing mine expansion and addition of Foidel Creek underground mine*

[ft^3/s=cubic foot per second, mg/L=milligram per liter]

Node No.	Discharge change (ft^3/s)	Dissolved-solids concentration change
6	0.00	0.23 ft^3/s at 2,860 mg/L
10	.00	.29 ft^3/s at 2,860 mg/L
11	1.45	800 mg/L
14	.10	1,100 mg/L
18	.00	.20 ft^3/s at 2,860 mg/L
25	.00	.07 ft^3/s at 2,860 mg/L

[1]Values do not reflect a change in discharge, but the dissolved-solids concentration is changed for flow quantities given.

Table 6.--*A comparison of mean discharge, dissolved-solids concentration, and total dissolved load between the calibrated model and the short-term anticipated mining for the output nodes*

Node No.	Existing conditions (mean)	Short-term anticipated mining (mean)	Short-term minus existing	Percent change
	Discharge, in cubic feet per second (mean discharge per month)			
15	4.9	6.4	1.5	31.0
19	17.2	17.1	-.1	-1.0
20	43.1	44.5	1.4	3.0
27	875	877	2.0	.2
	Concentration, in milligrams per liter (mean concentration per month)			
15	439	755	316	72.0
19	432	530	98	22.7
20	310	391	81	26.1
27	151	159	8	5.3
	Load, in tons per year (mean total load per year)			
15	1,968	3,480	1,512	76.8
19	7,176	7,512	336	4.7
20	14,148	16,584	2,436	17.2
27	84,120	86,832	2,712	3.2

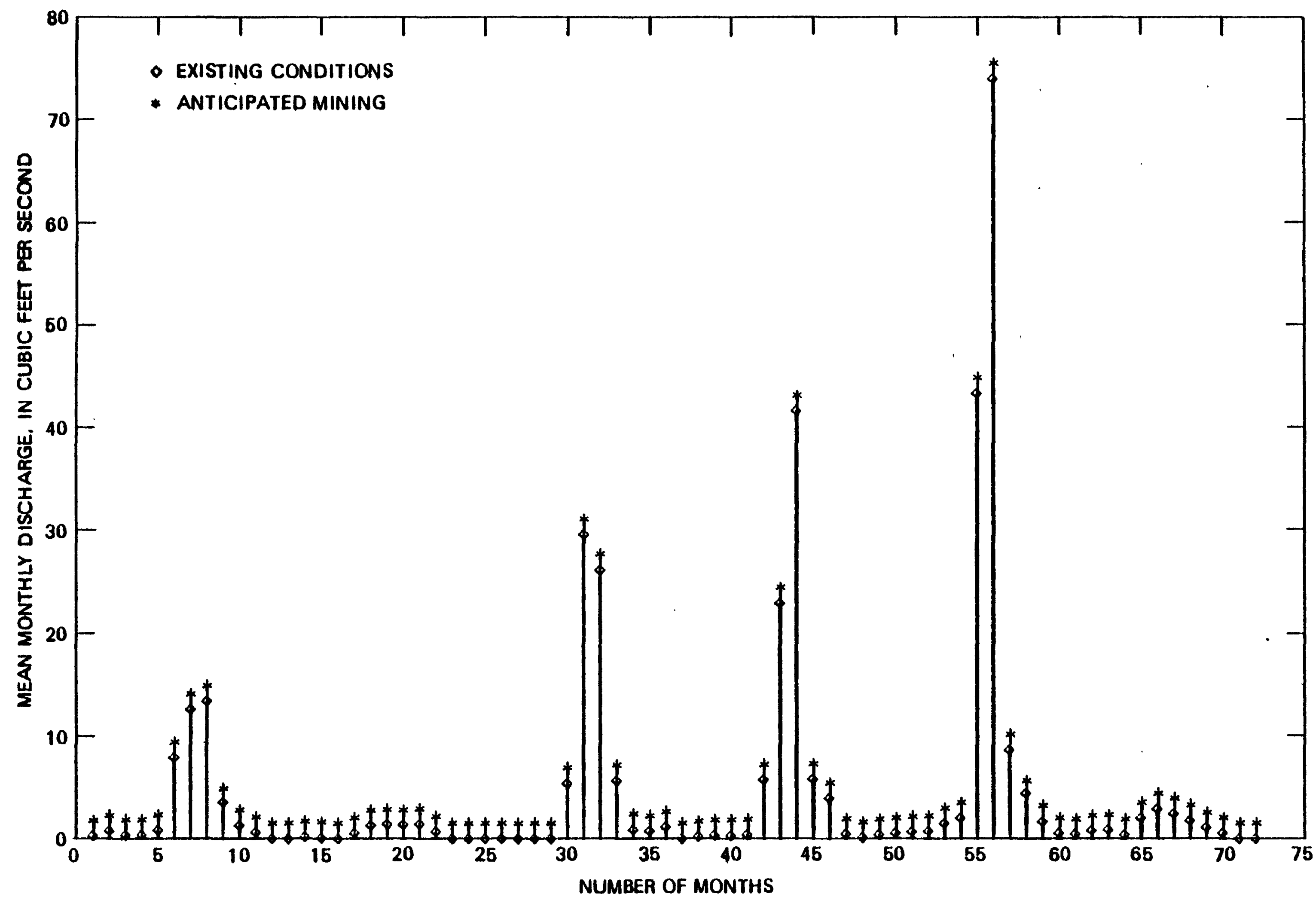

Figure 15.--A comparison of mean monthly discharge for existing conditions and short-term anticipated mining at node 15, Middle Creek at mouth.

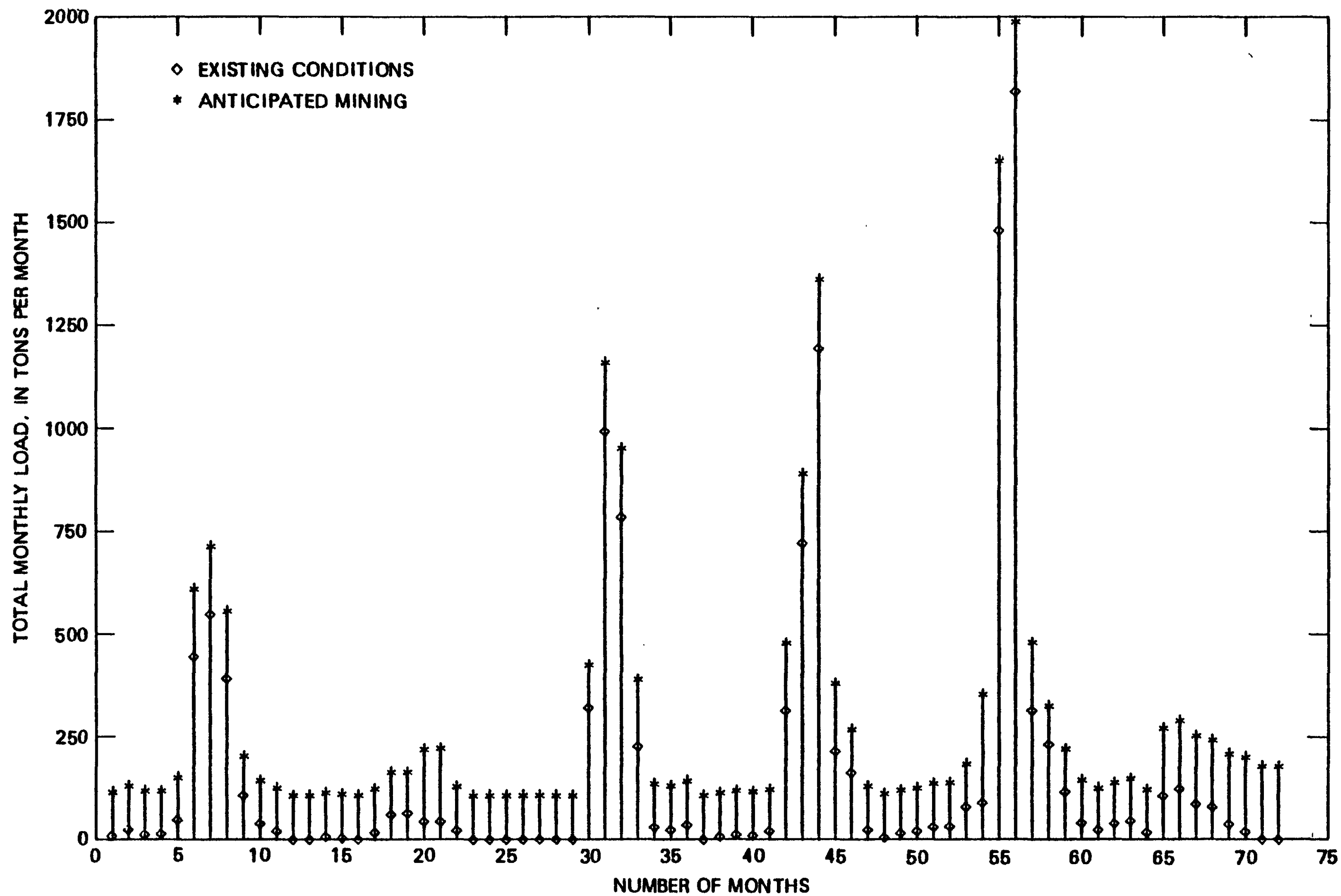

Figure 17.--A comparison of total monthly load for existing conditions and short-term anticipated mining at node 15, Middle Creek at mouth.

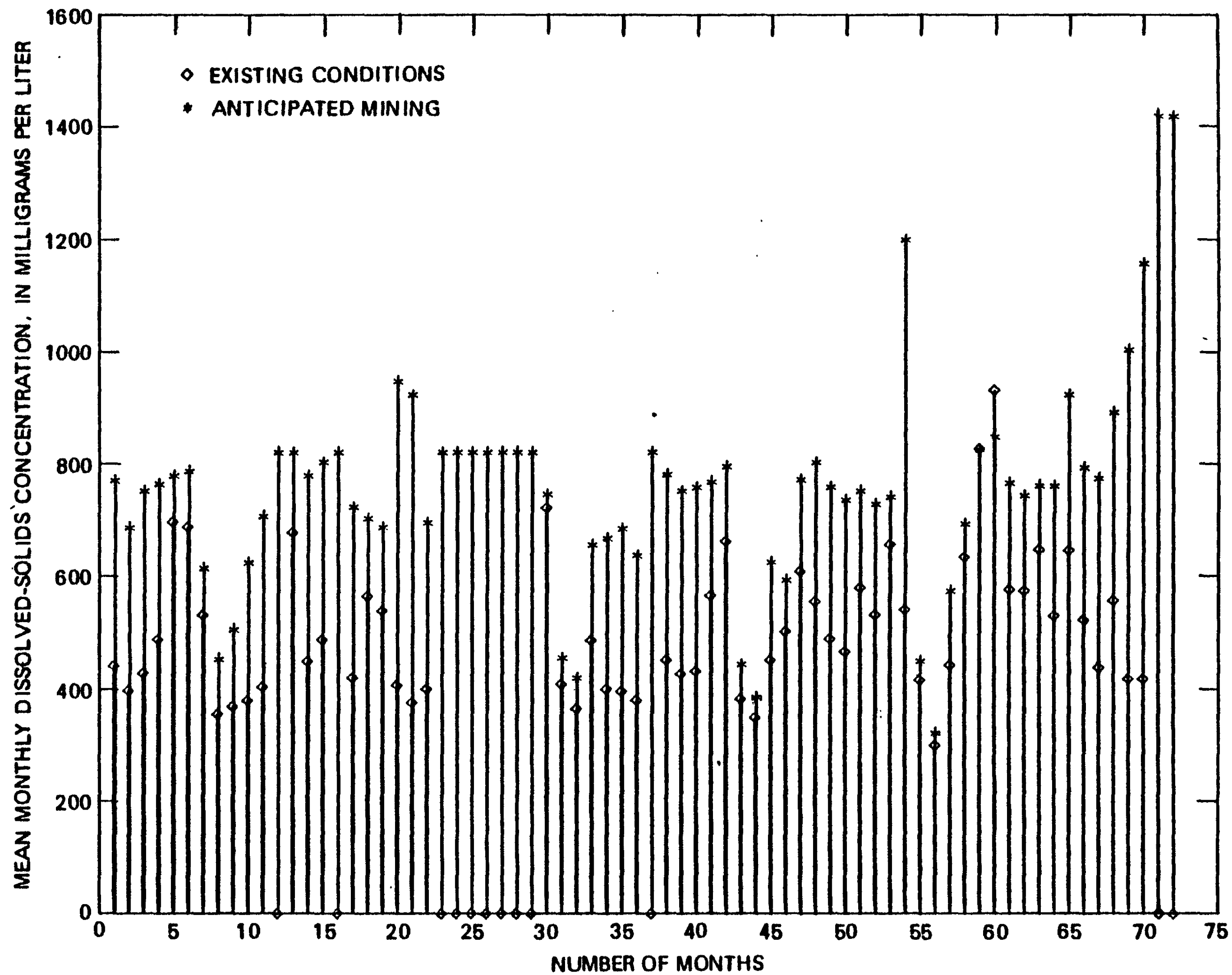

Figure 16.-- A comparison of mean monthly dissolved-solids concentration for existing conditions and short-term anticipated mining at node 15, Middle Creek at mouth.

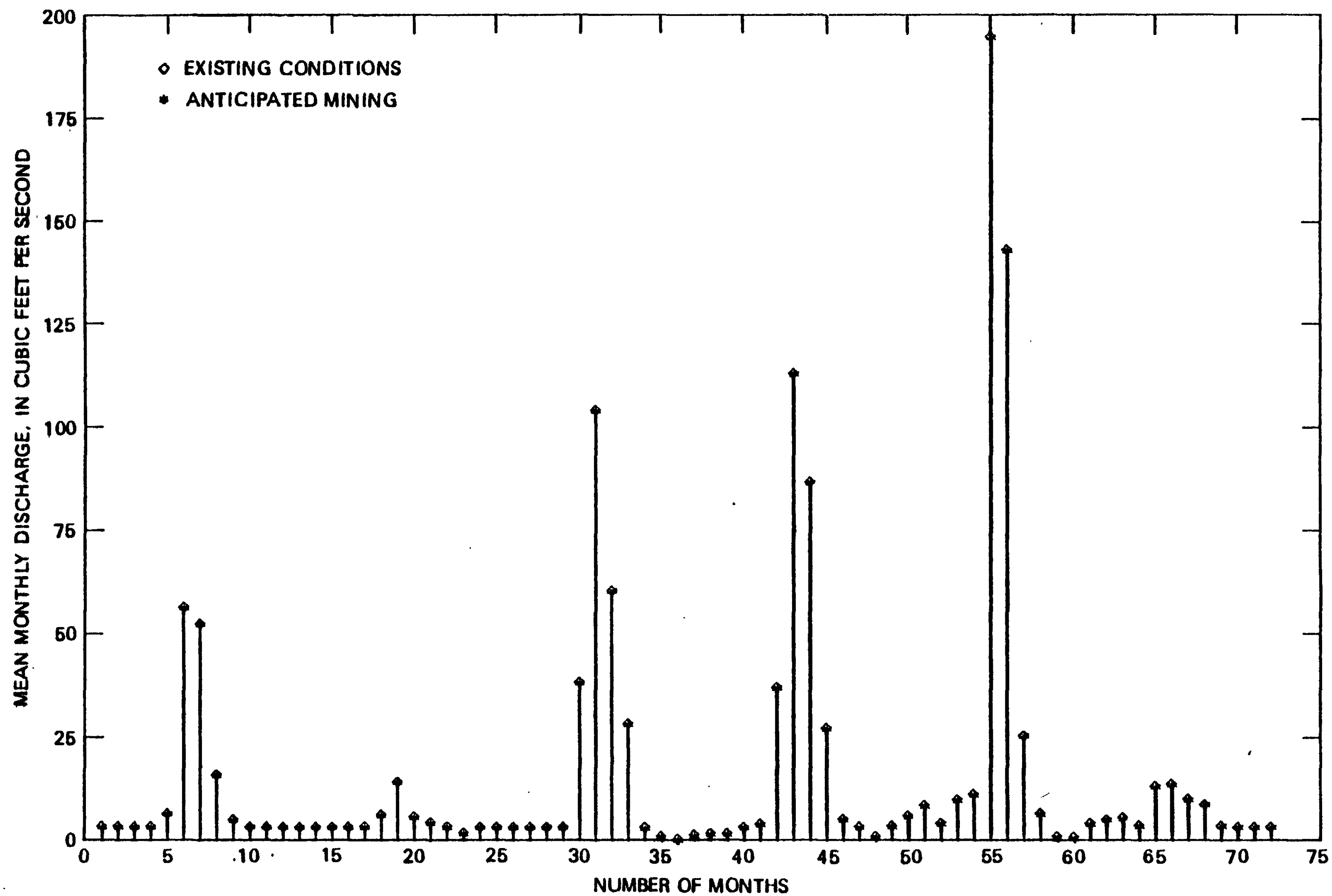

Figure 18.--A comparison of mean monthly discharge for existing conditions and short-term anticipated mining at node 19, Fish Creek at mouth, near Milner.

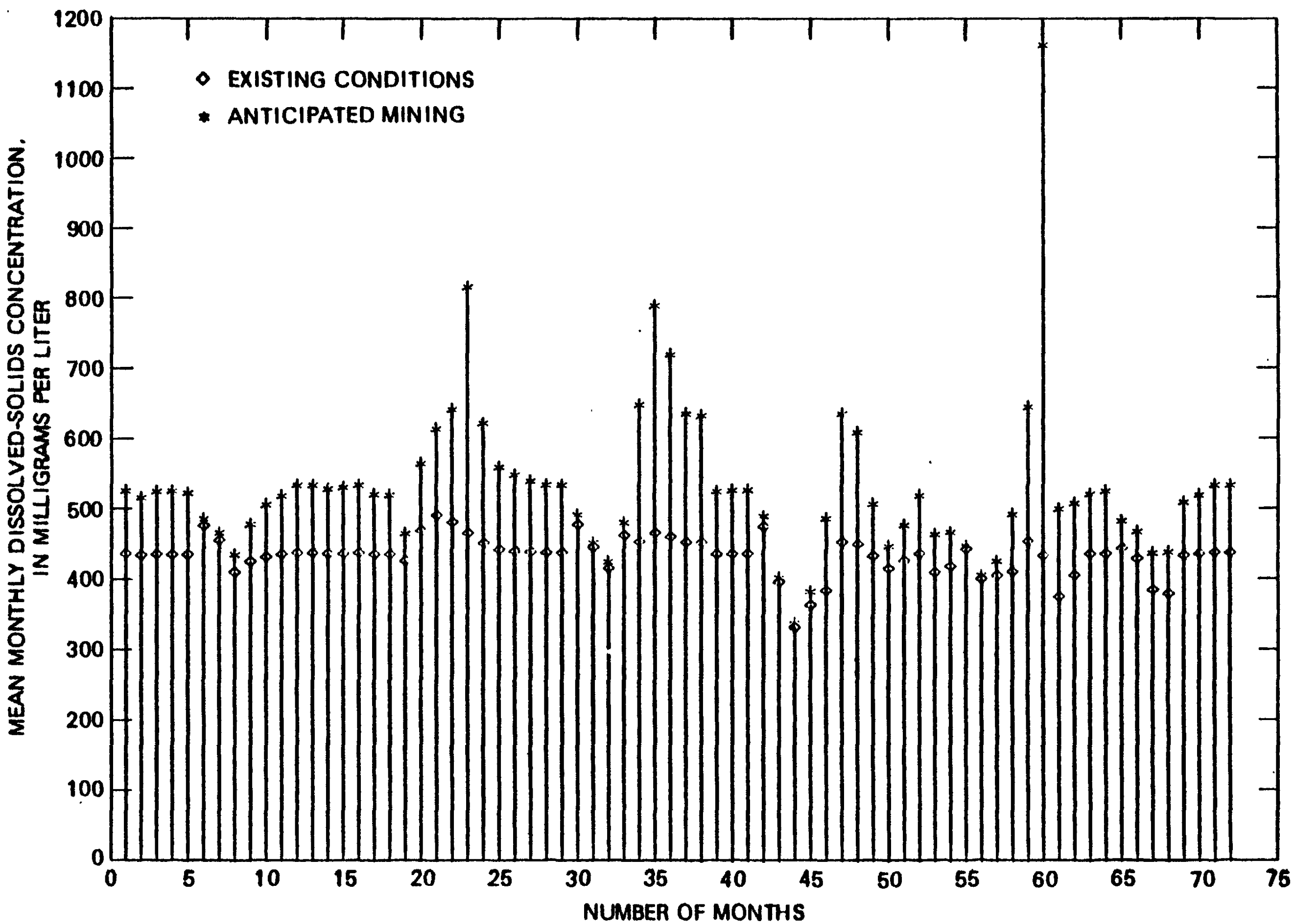

Figure 19.--A comparison of mean monthly dissolved-solids concentration for existing conditions and short-term anticipated mining at node 19, Fish Creek at mouth, near Milner.

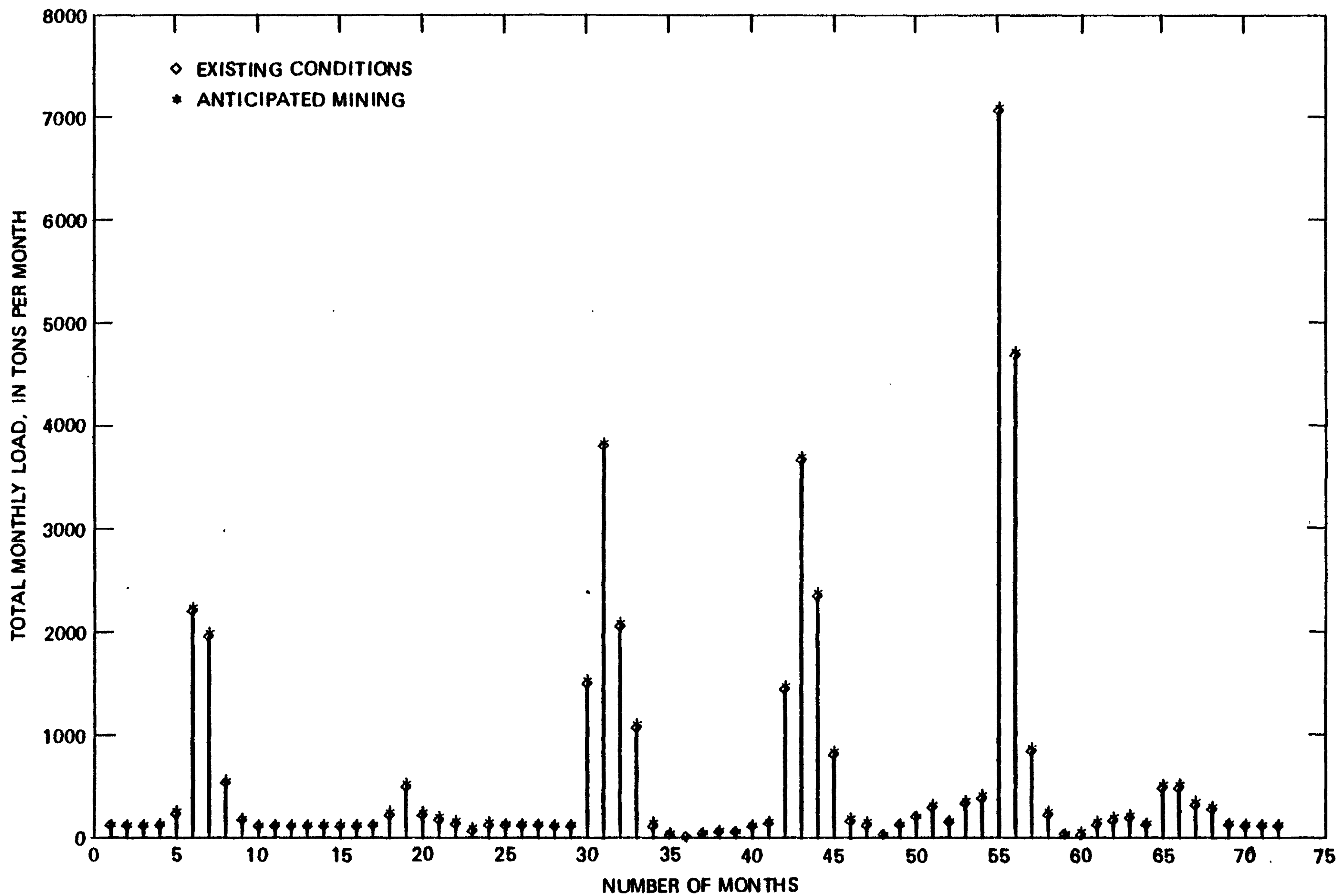

Figure 20.--A comparison of total monthly load for existing conditions and short-term anticipated mining at node 19, Fish Creek at mouth, near Milner.

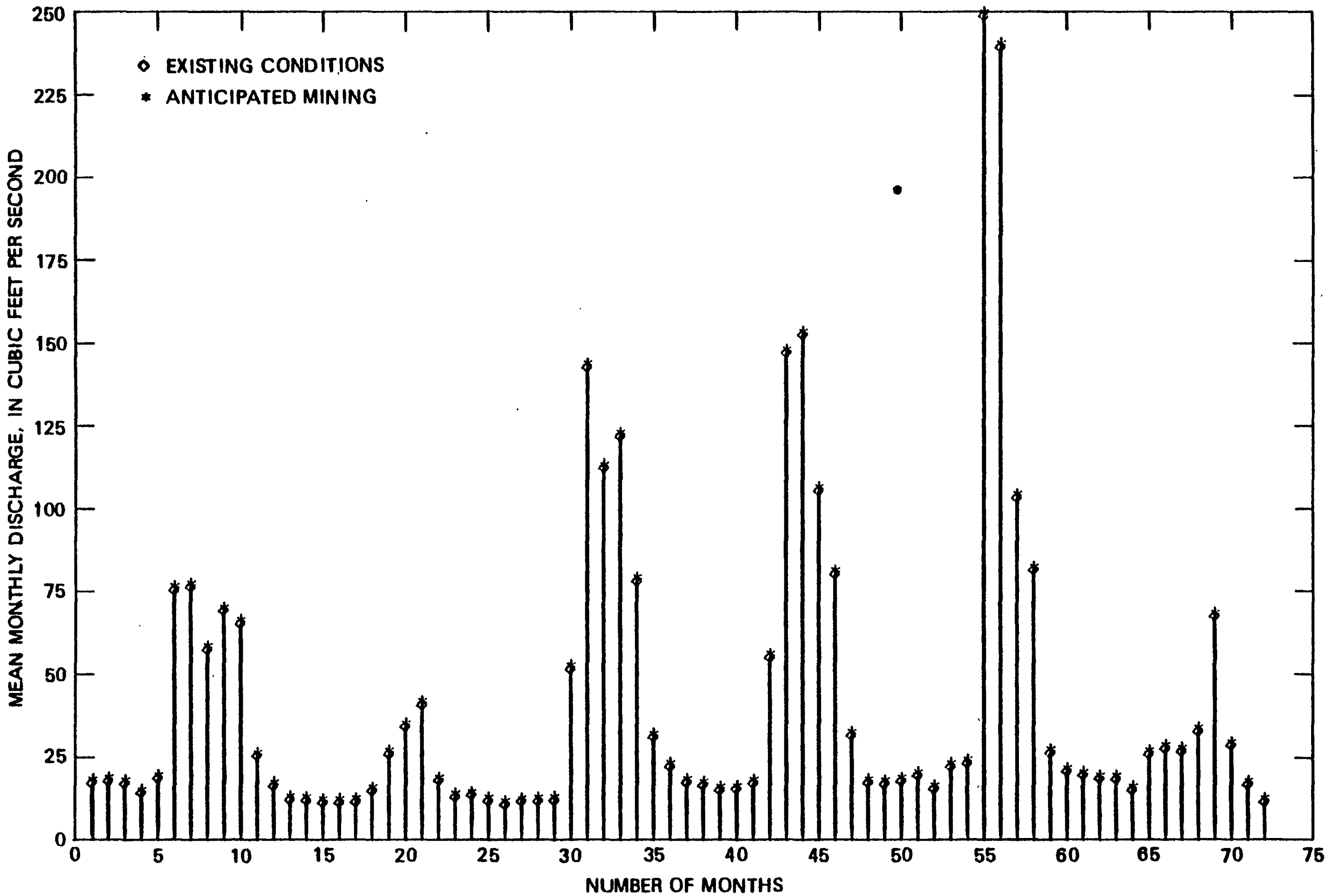

Figure 21.--A comparison of mean monthly discharge for existing conditions and short-term anticipated mining at node 20, Trout Creek above Milner.

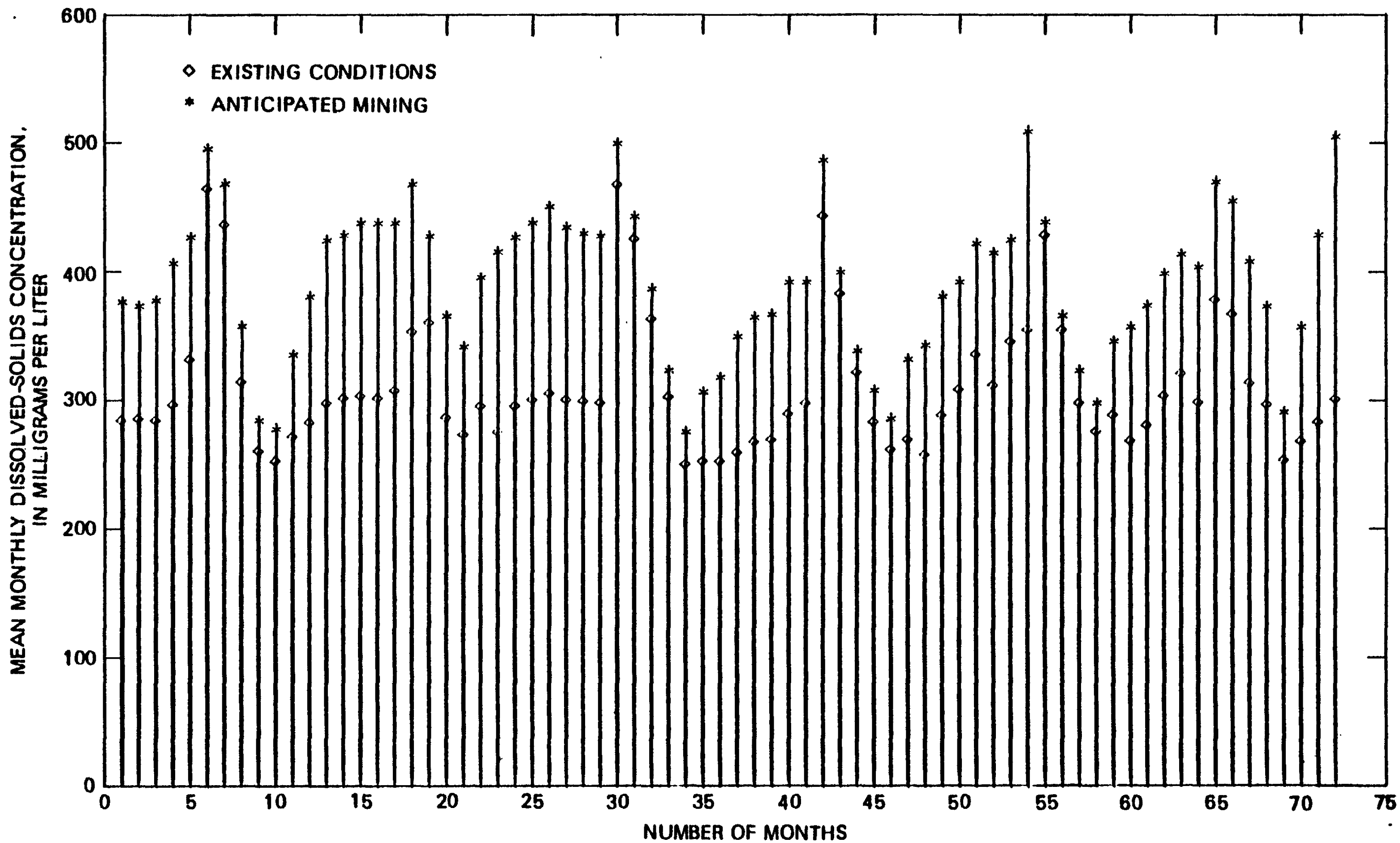

Figure 22.--A comparison of mean monthly dissolved-solids concentration for existing conditions and short-term anticipated mining at node 20, Trout Creek above Milner.

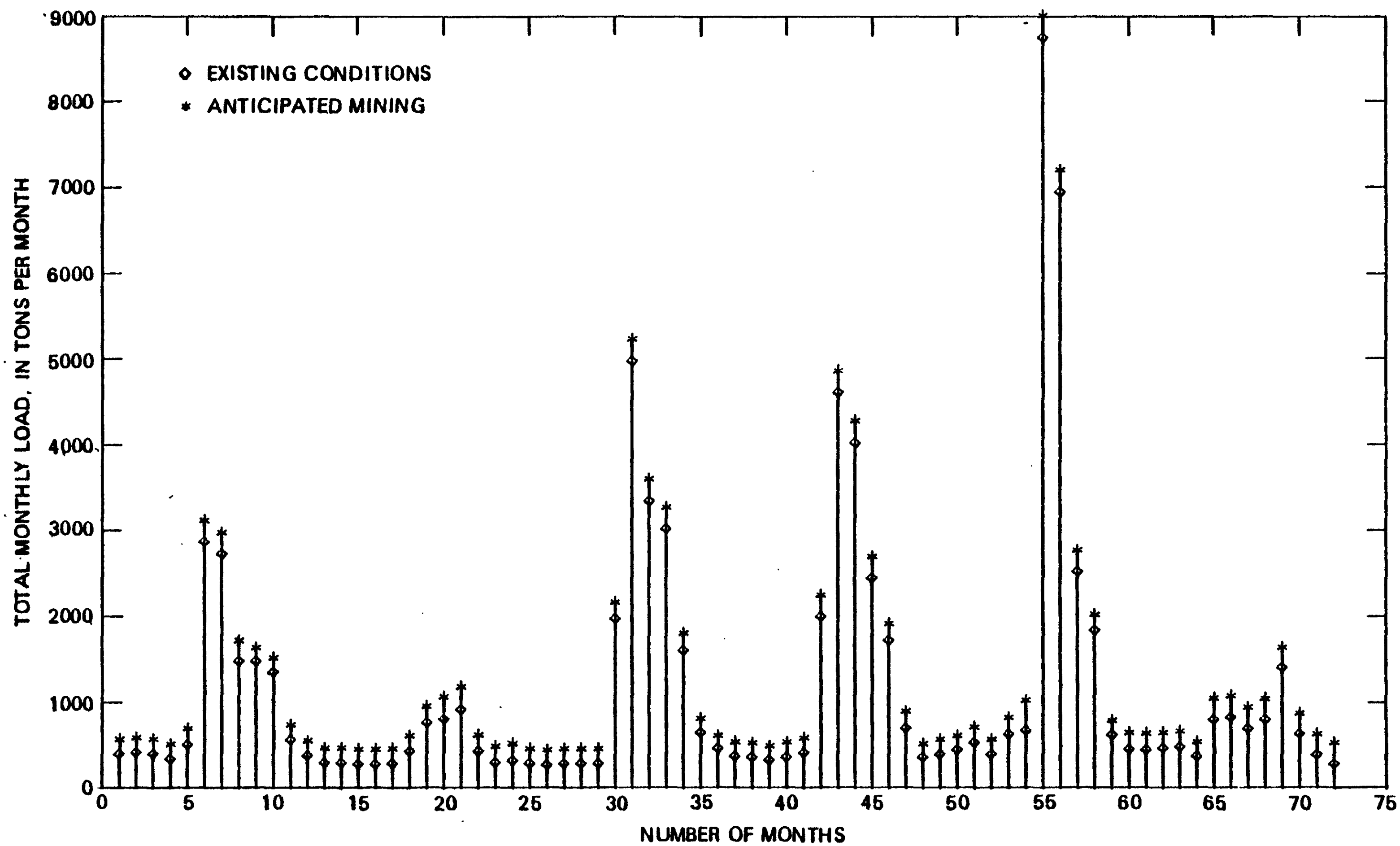

Figure 23.--A comparison of total monthly load for existing conditions and short-term anticipated mining at node 20, Trout Creek above Milner.

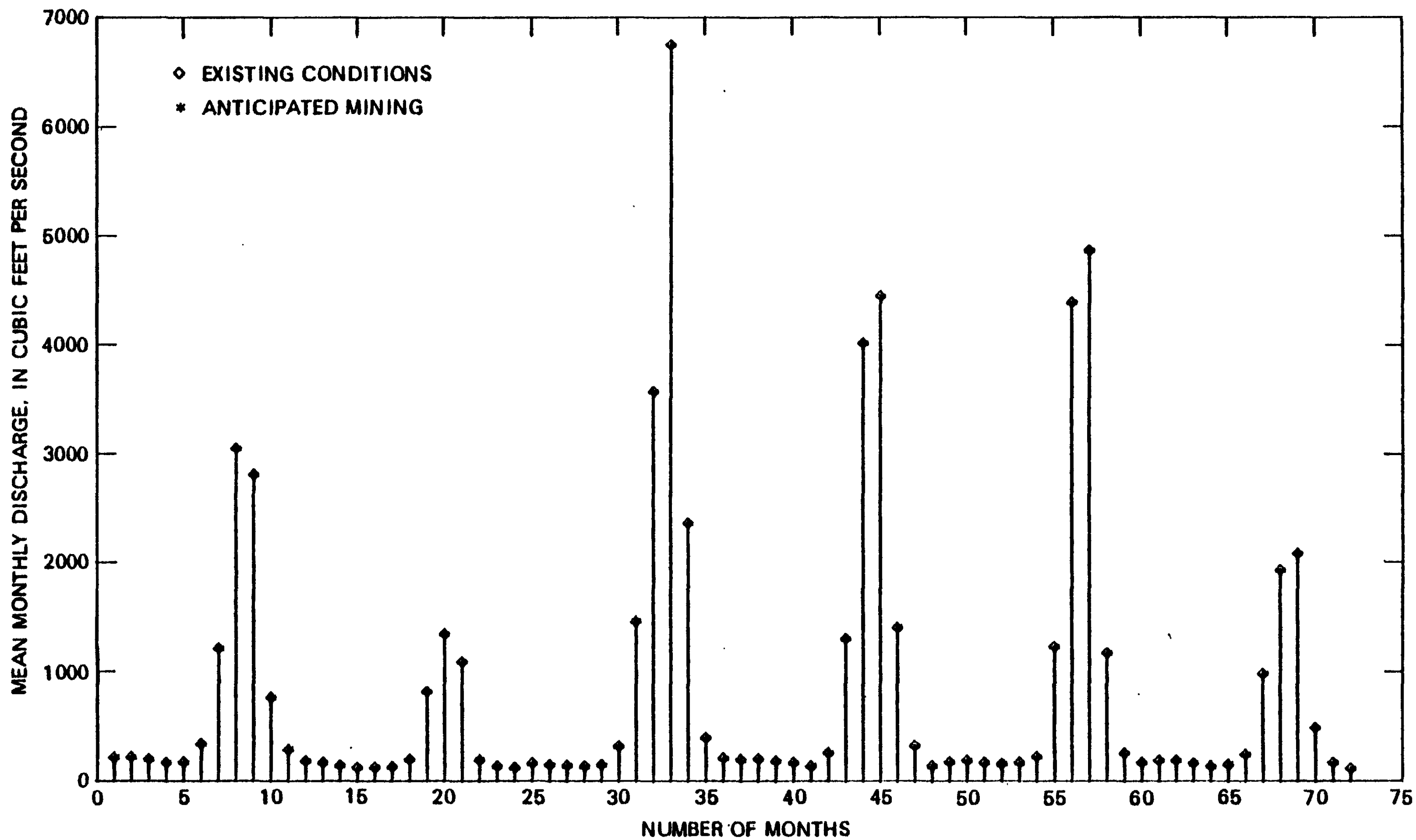

Figure 24.--A comparison of mean monthly discharge for existing conditions and short-term anticipated mining at node 27, Yampa River below diversion, near Hayden.

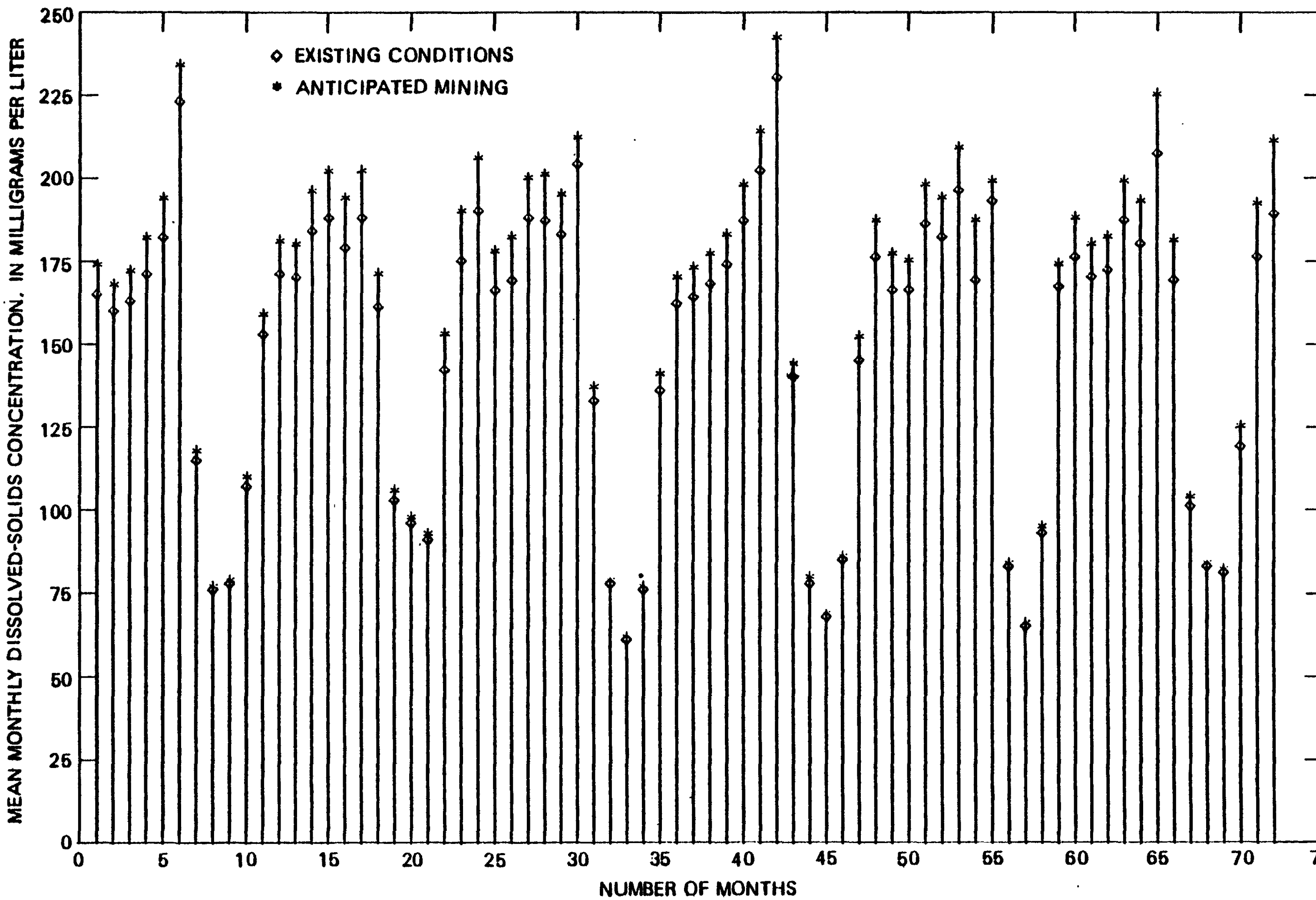

Figure 25.--A comparison of mean monthly dissolved-solids concentration for existing conditions and short-term anticipated mining at node 27, Yampa River below diversion, near Hayden.

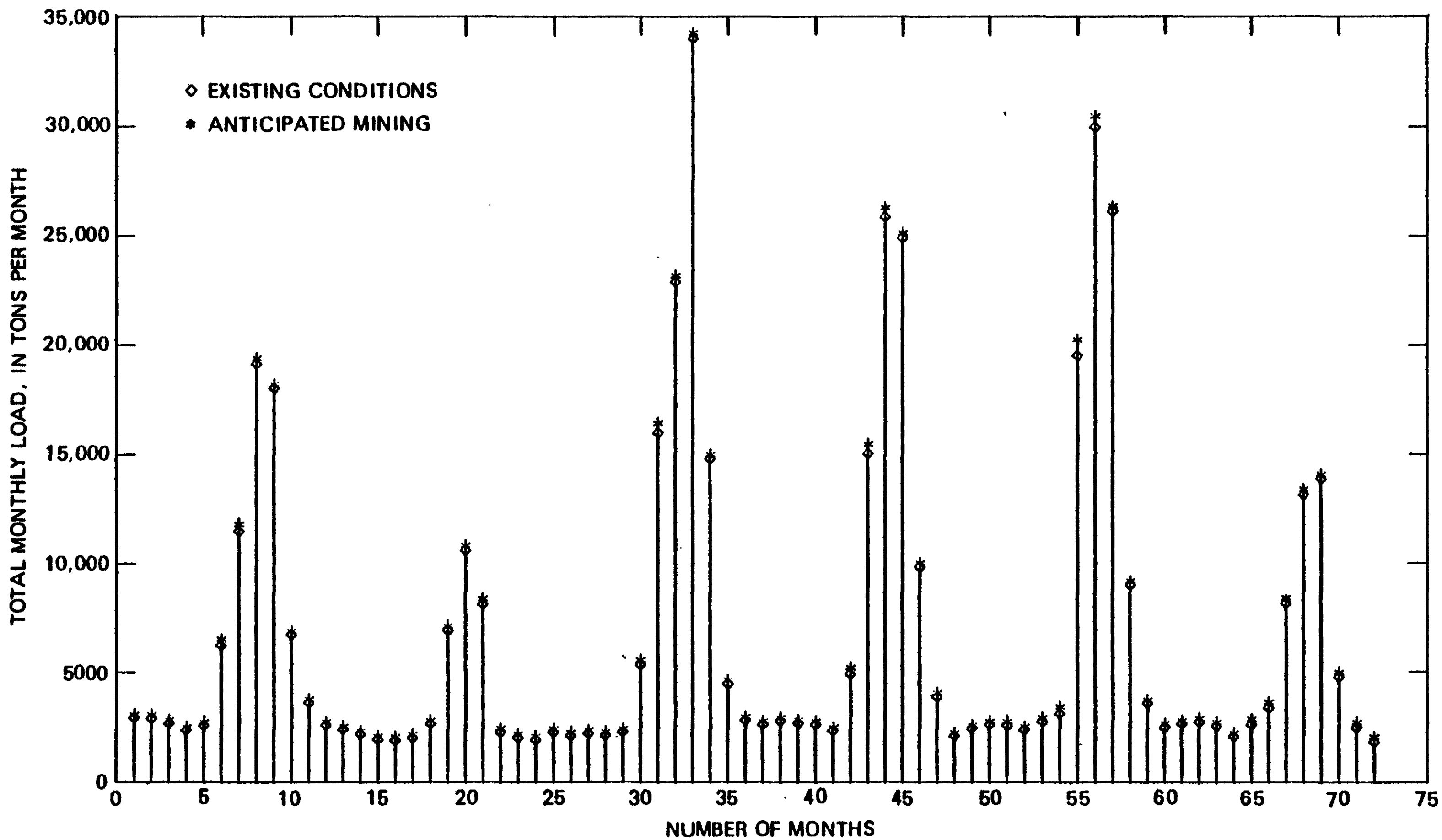

Figure 26.-- A comparison of total monthly load for existing conditions and short-term anticipated mining at node 27, Yampa River below diversion, near Hayden.

The internal nodes at which discharge and dissolved-solids concentration were inserted into the model to reflect these long-term conditions are shown in table 7. Hydrographs of the existing conditions and the long-term plan for each output node for discharge, dissolved-solids concentration, and total dissolved load are shown in figures 27 through 38. The changes between existing conditions and the long-term plan are summarized in table 8.

Calculation for Dry Creek

Changes that may occur in Dry Creek (fig. 1) also were of interest to the Mined Land Reclamation Division. Unfortunately, there were no data available at the mouth of Dry Creek for model calibration. In addition, Dry Creek empties into the Yampa River downstream from the model outlet point--node 27. Data are available for the tributaries of Dry Creek; therefore, the water quantity and quality of the tributaries will be added directly to the mouth of Dry Creek. This assumes no losses in either discharge or dissolved solids through the main stem of Dry Creek. This assumption tends to increase the dissolved-solids concentration in this case.

Following model algorithms, mean monthly discharge, mean monthly dissolved-solids concentration, and total monthly load for the tributaries of Dry Creek (fig. 1) were accumulated to derive the values at the mouth of Dry Creek and added to the Yampa River below diversion, near Hayden. Because Dry Creek is outside the modeled area, an average was used for mean monthly discharge for water years 1977 to 1981.

Discharge

Of the three Dry Creek input nodes used, gaged discharge for the period was available for only the streamflow-gaging station Stokes Gulch near Hayden (09244470, fig. 1). Gaged discharge data were available for only water years 1980 and 1981 for Hubberson Gulch near Hayden (09244464) and Watering Trough Gulch near Hayden (09244460, fig. 1).

Missing discharge record for Hubberson Gulch near Hayden was estimated from data for Grassy Creek near Mount Harris (09244300) from the equation:

$$Q_p=0.26Q_o+0.18, \qquad (21)$$

with a standard error of estimate of 0.79 ft^3/s. Missing discharge data for Watering Trough Gulch near Hayden were then estimated from the data for Hubberson Gulch near Hayden from the equation:

$$Q_p=0.11Q_o+0.023, \qquad (22)$$

with a standard error of estimate of 0.07 ft^3/s.

Table 7.--*Changes from model calibration input to reflect long-term impacts from existing mine expansion and addition of Foidel Creek underground mine*

[ft^3/s=cubic foot per second, mg/L=milligram per liter]

Node No.	Discharge change (ft^3/s)	Dissolved-solids concentration change
6	0.00	0.216 ft^3/s at 3,200 mg/L
14	.11	1,291 mg/L
18	.27	.596 ft^3/s at 3,200 mg/L
25	.00	.065 ft^3/s at 3,200 mg/L

[1]Values do not reflect a change in discharge, but the dissolved-solids concentration is changed for flow quantities given.

Table 8.--*A comparison of mean discharge, dissolved-solids concentration, and total dissolved load between the calibrated model and long-term anticipated mining for the output nodes*

Node No.	Existing conditions (mean)	Long-term anticipated mining (mean)	Long-term minus existing	Percent change
Discharge, in cubic feet per second (mean discharge per month)				
15	4.9	5.0	0.1	2.0
19	17.2	17.5	.3	1.7
20	43.1	43.5	.5	.9
27	875	875	0	0
Concentration, in milligrams per liter (mean concentration per month)				
15	439	722	283	64.5
19	432	718	286	66.2
20	310	401	91	29.4
27	151	159	8	5.3
Load, in tons per year (mean total load per year)				
15	1,968	2,108	140	7.1
19	7,176	8,610	1,434	20.0
20	14,148	16,347	2,199	15.5
27	84,120	86,368	2,248	2.7

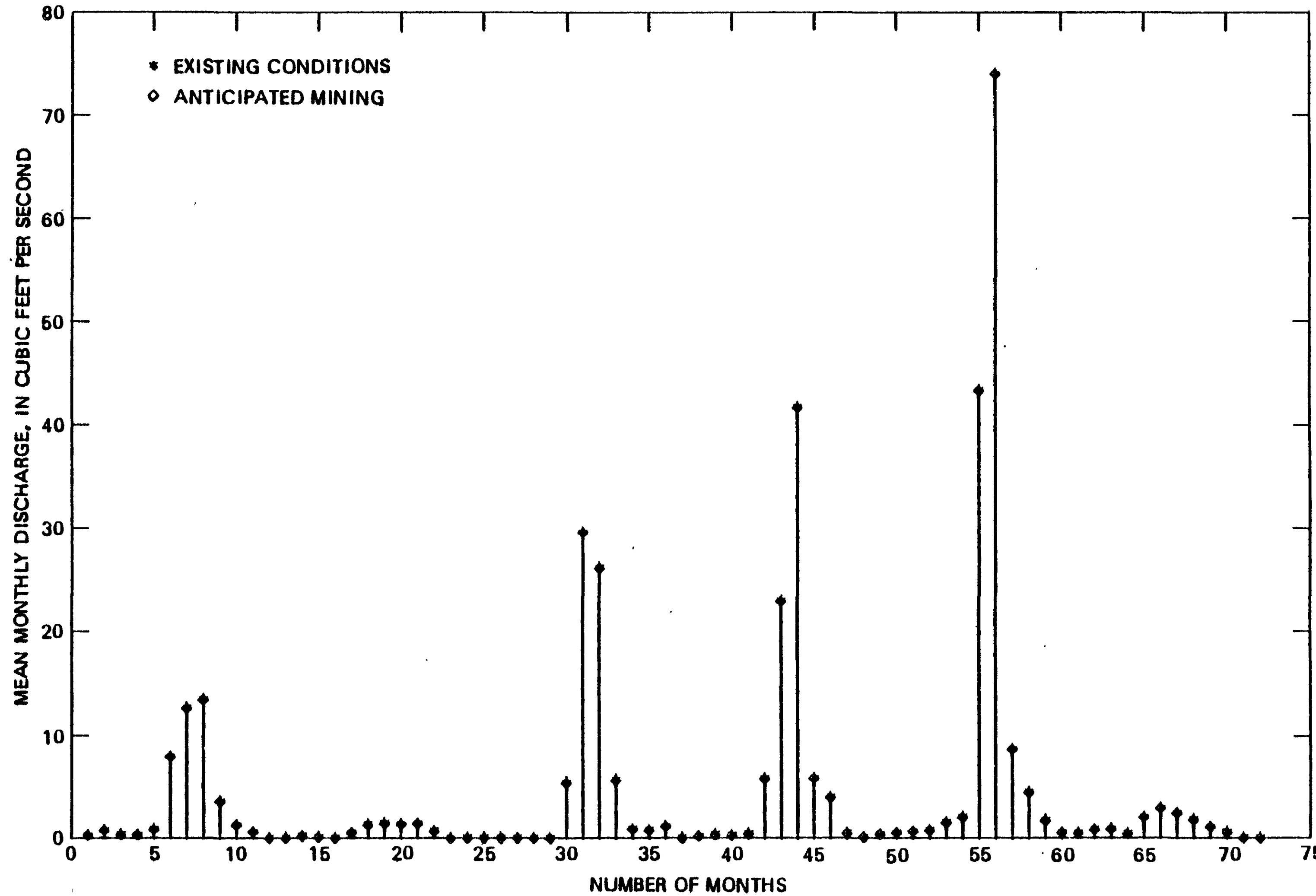

Figure 27.--A comparison of mean monthly discharge for existing conditions and long-term anticipated mining at node 15, Middle Creek at mouth.

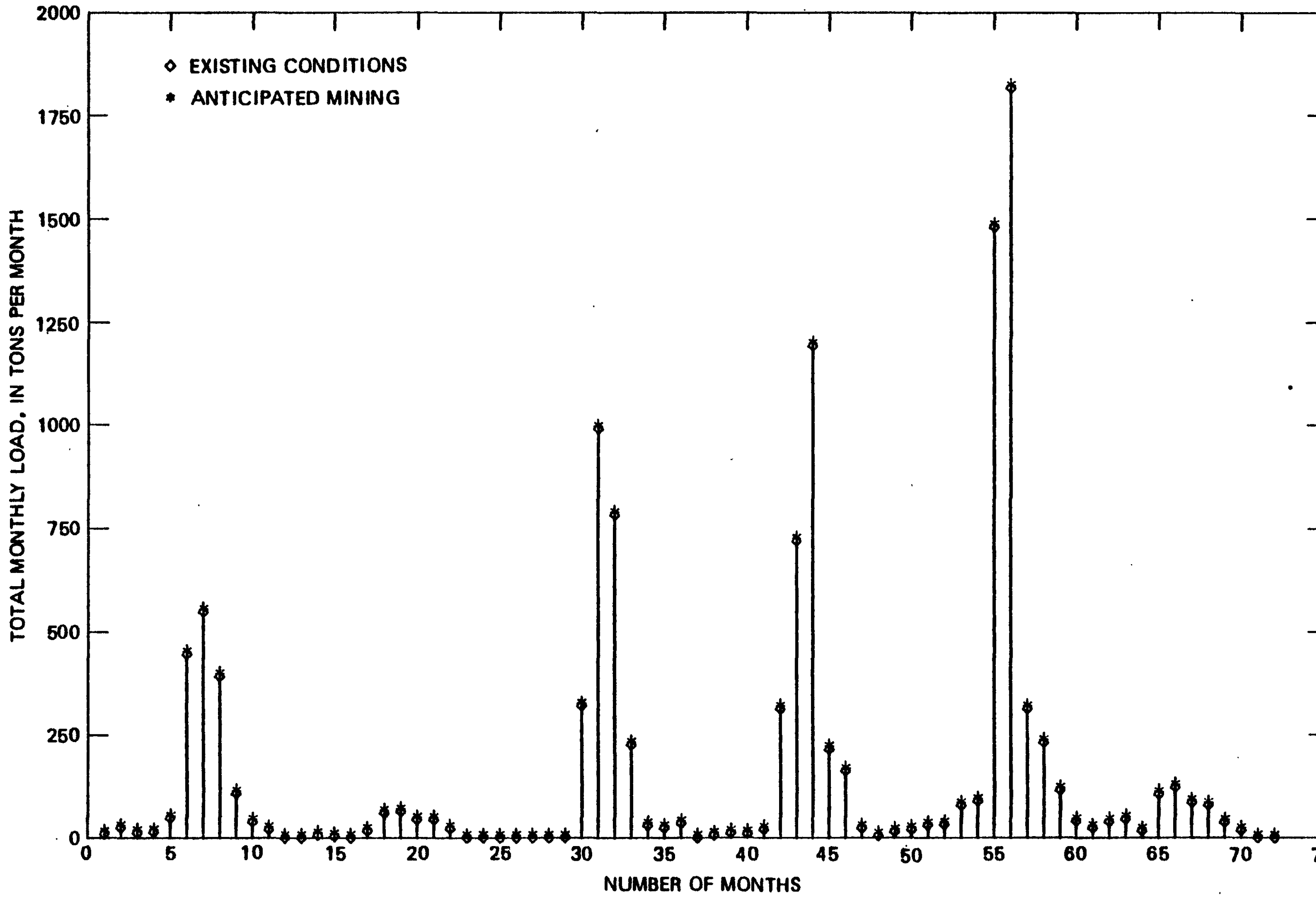

Figure 29.--A comparison of total monthly load for existing conditions and long-term anticipated mining at node 15, Middle Creek at mouth.

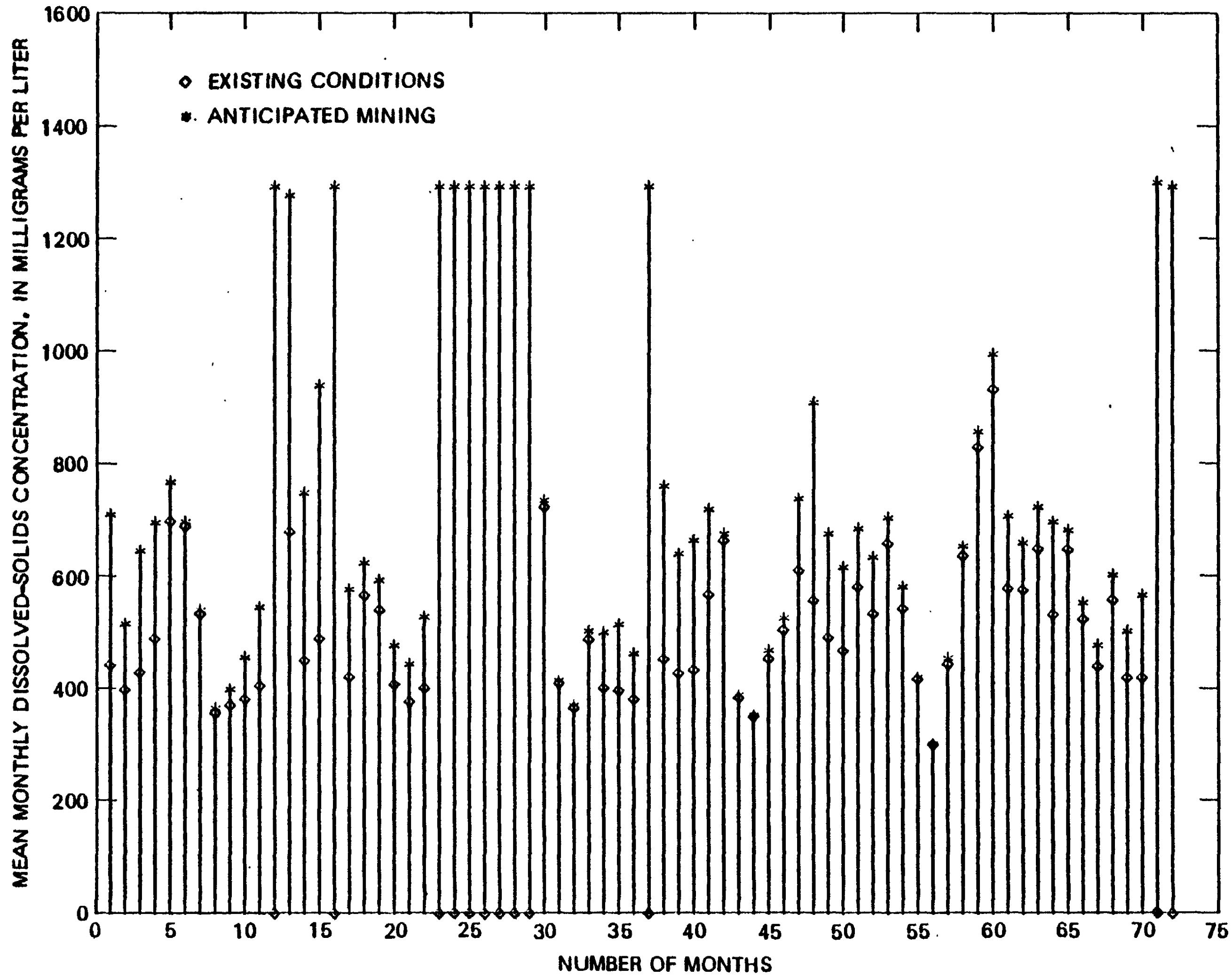

Figure 28.--A comparison of mean monthly dissolved-solids concentration for existing conditions and long-term anticipated mining at node 15, Middle Creek at mouth.

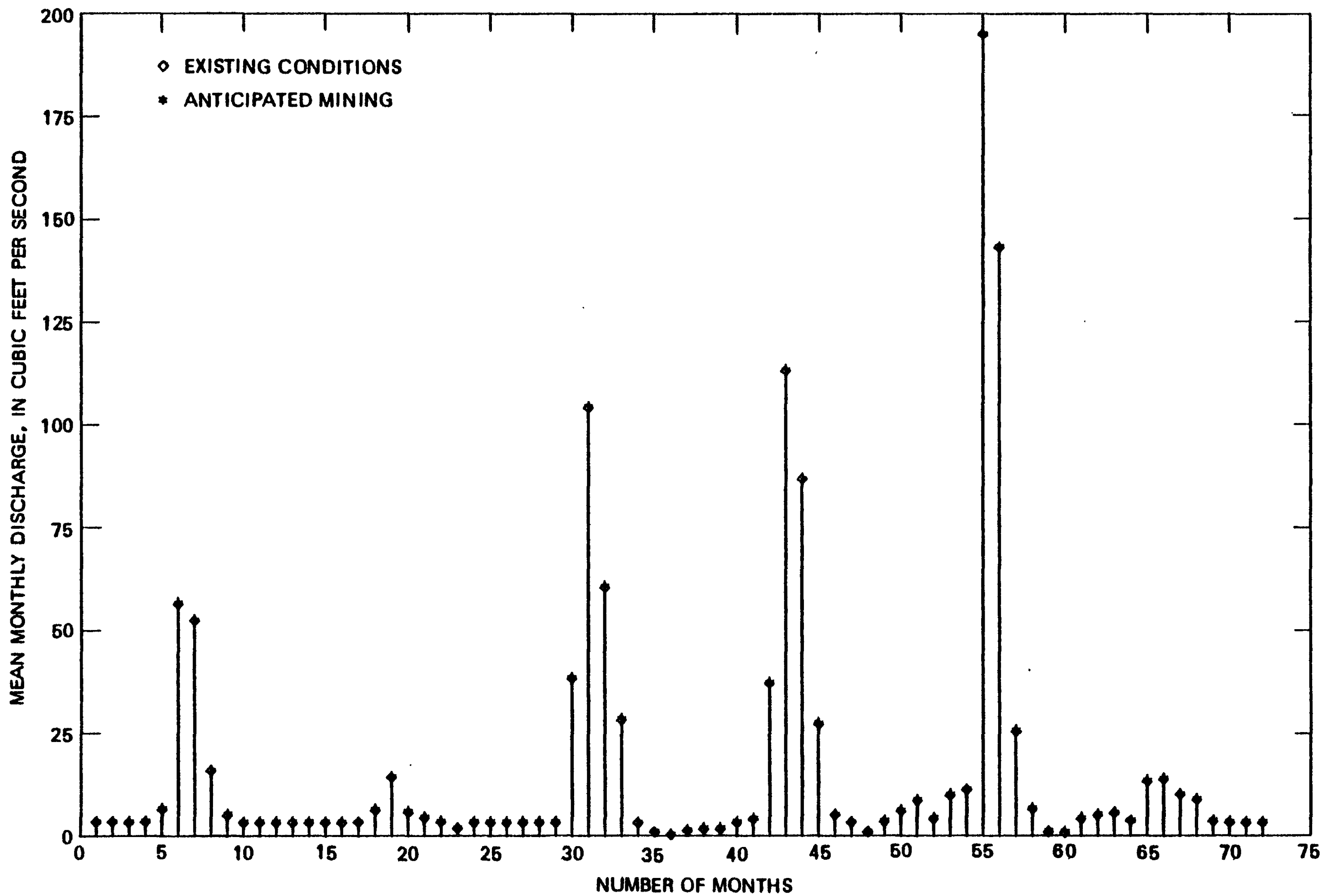

Figure 30.--A comparison of mean monthly discharge for existing conditions and long-term anticipated mining at node 19, Fish Creek at mouth, near Milner.

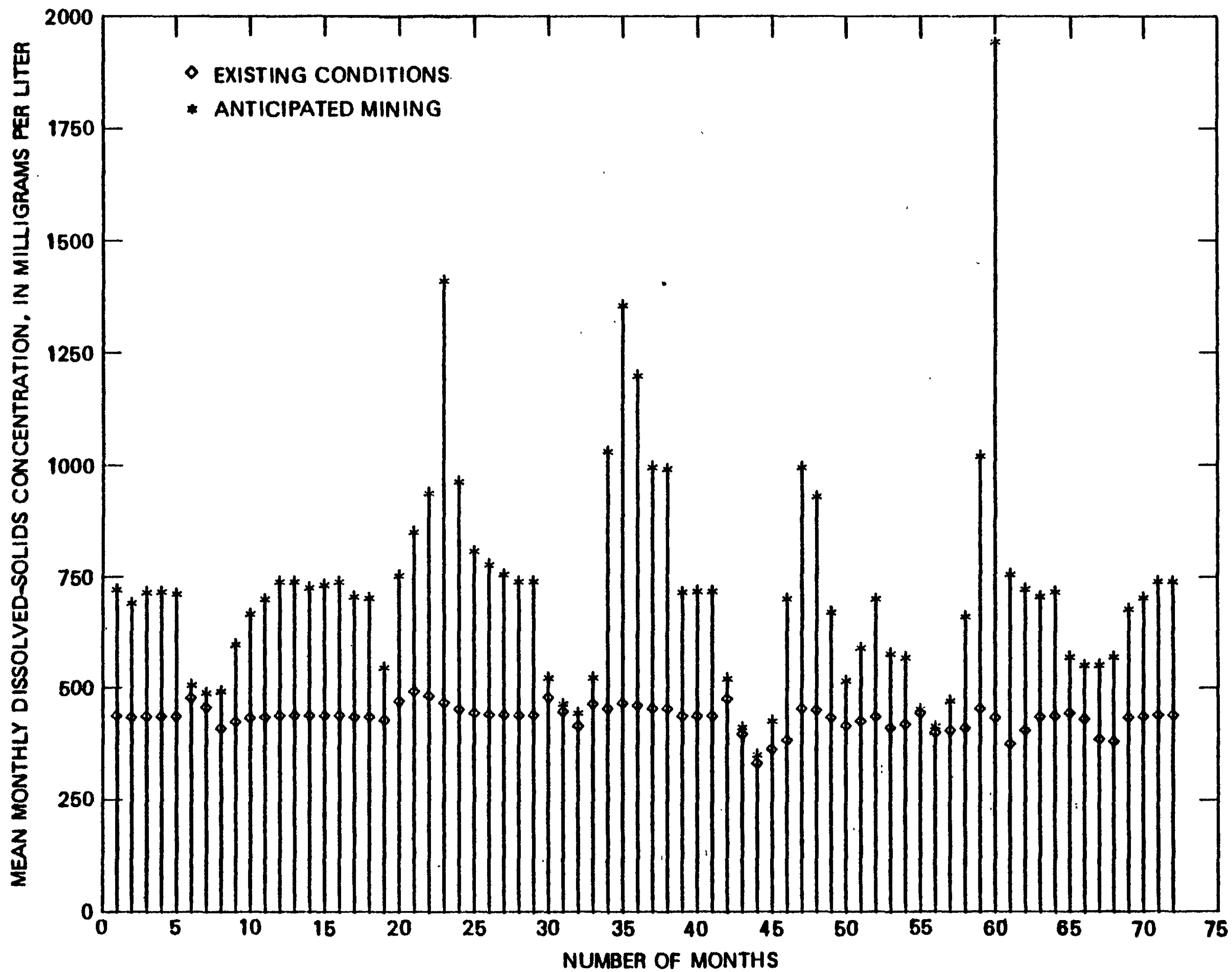

Figure 31.--A comparison of mean monthly dissolved-solids concentration for existing conditions and long-term anticipated mining at node 19, Fish Creek at mouth, near Milner.

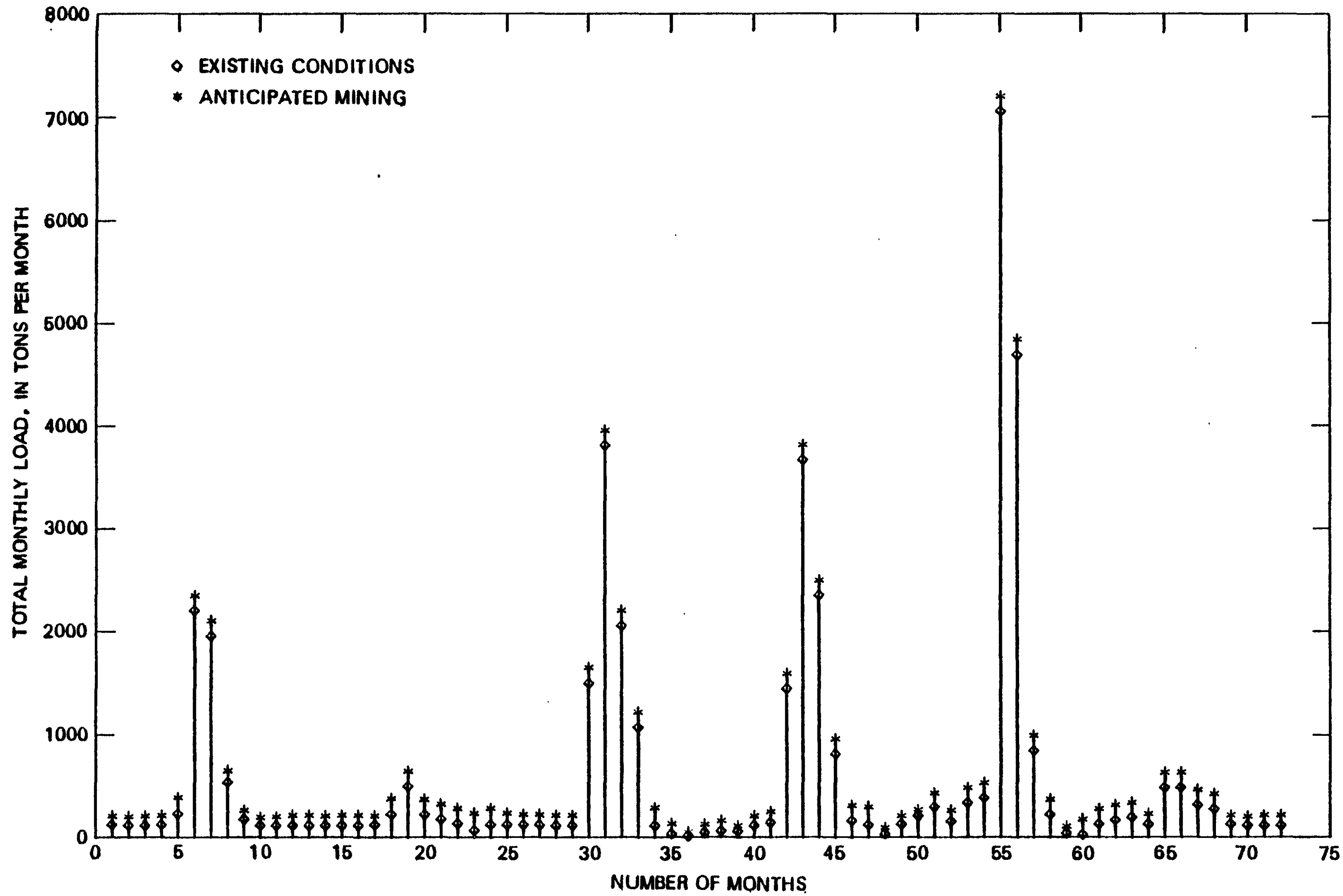

Figure 32.--A comparison of total monthly load for existing conditions and long-term anticipated mining at node 19, Fish Creek at mouth, near Milner.

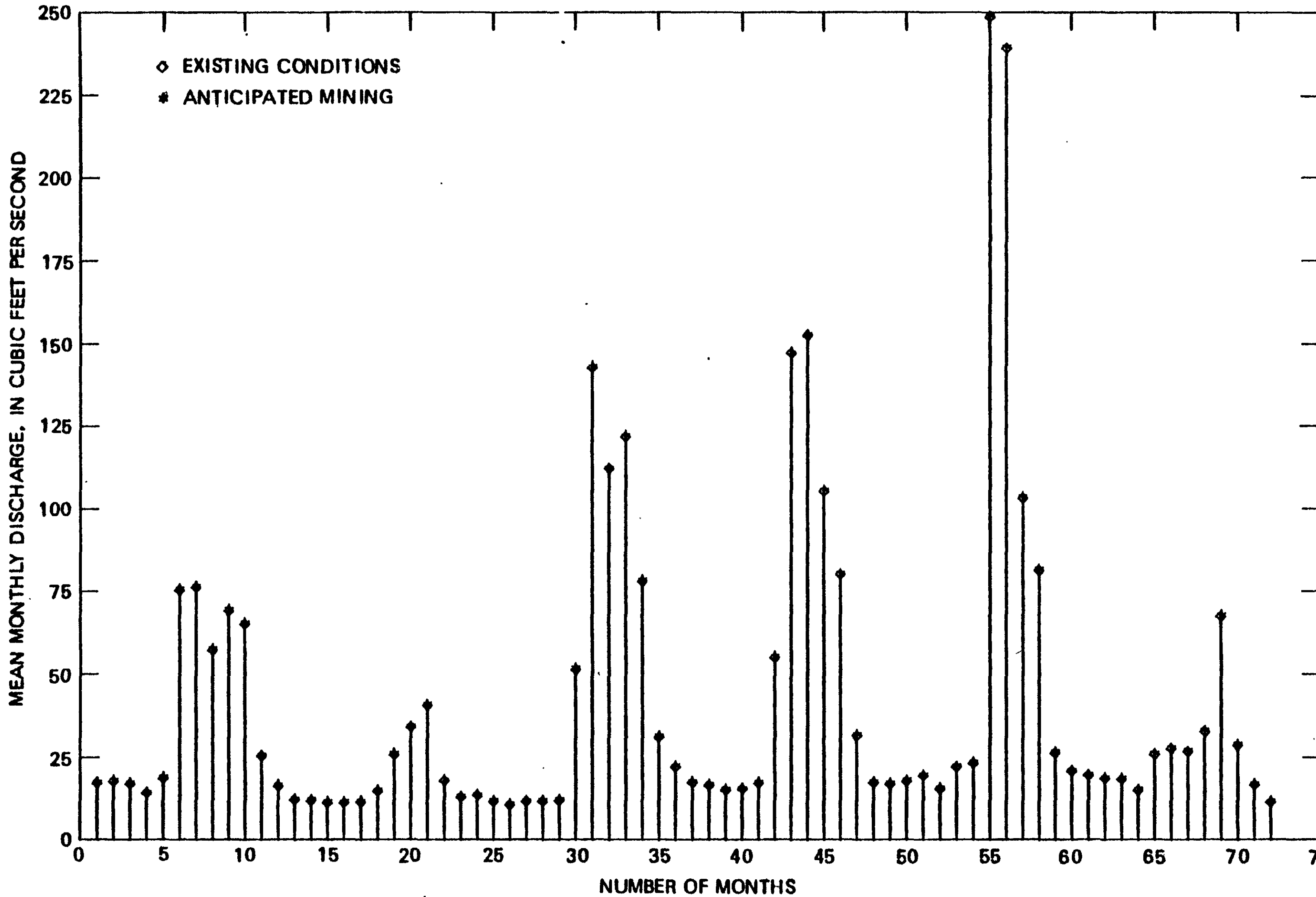

Figure 33.--A comparison of mean monthly discharge for existing conditions and long-term anticipated mining at node 20, Trout Creek above Milner.

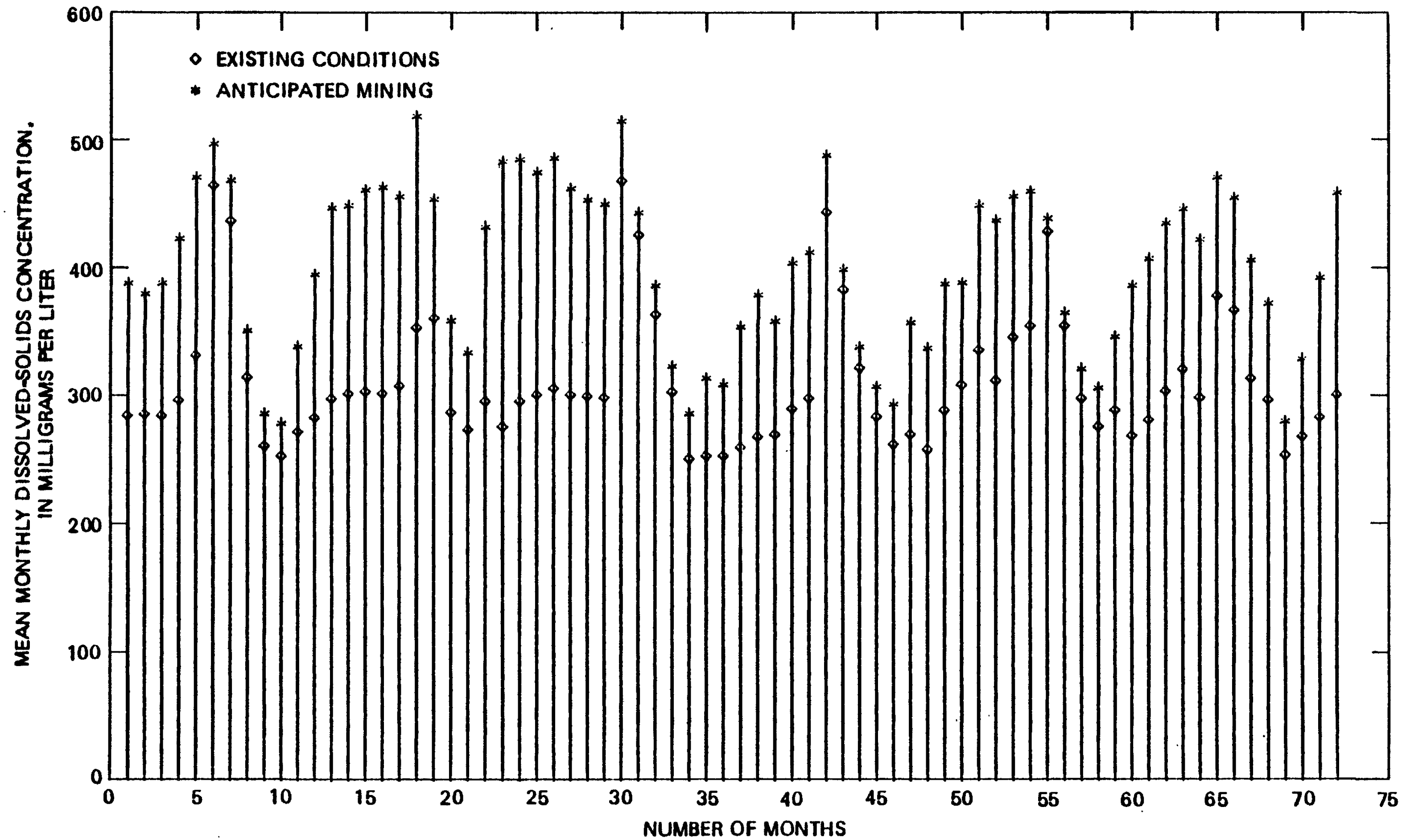

Figure 34.--A comparison of mean monthly dissolved-solids concentration for existing conditions and long-term anticipated mining at node 20, Trout Creek above Milner.

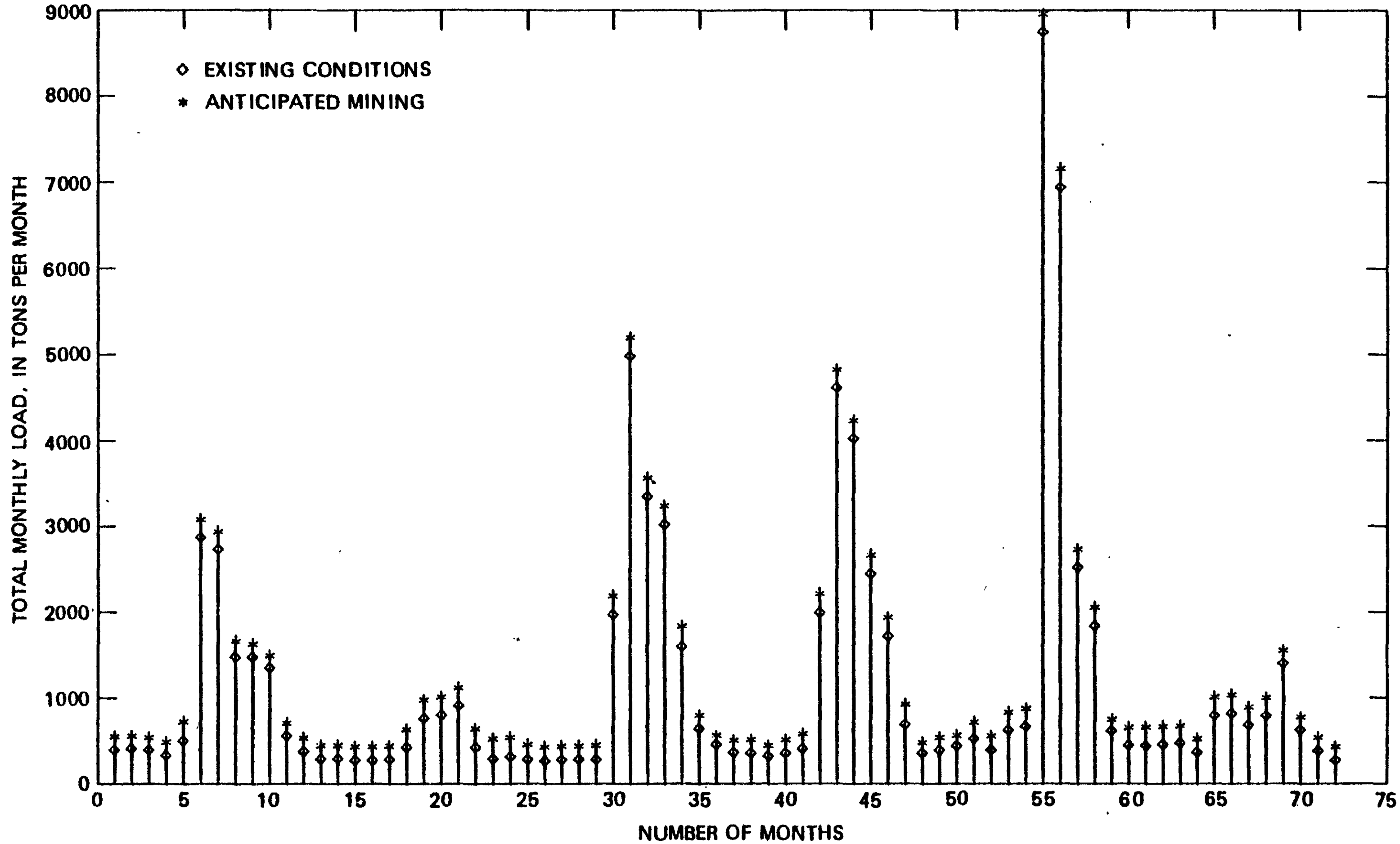

Figure 35.--A comparison of total monthly load for existing conditions and long-term anticipated mining at node 20, Trout Creek above Milner.

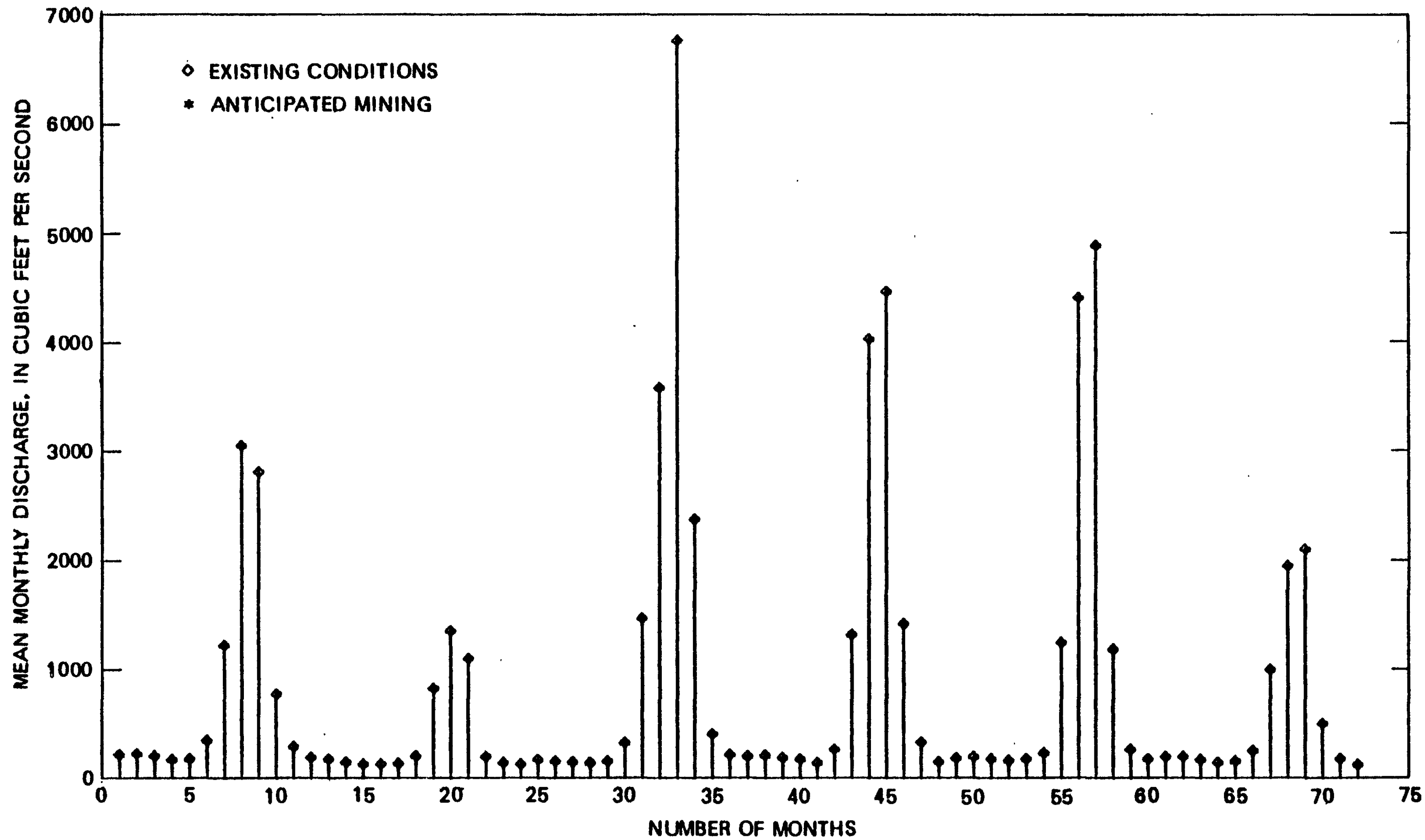

Figure 36.--A comparison of mean monthly discharge for existing conditions and long-term anticipated mining at node 27, Yampa River below diversion, near Hayden.

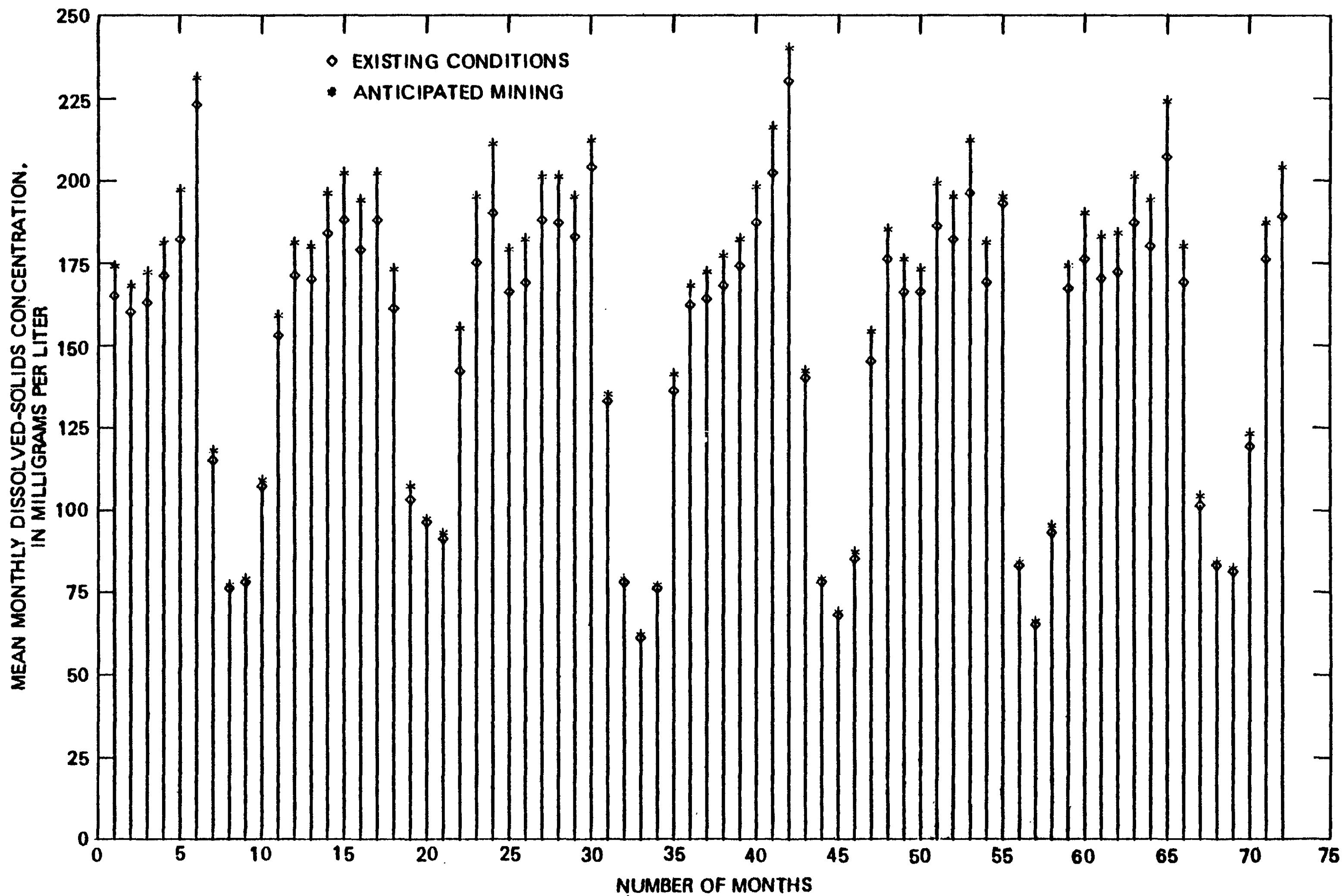

Figure 37.--A comparison of mean monthly dissolved-solids concentration for existing conditions and long-term anticipated mining at node 27, Yampa River below diversion, near Hayden.

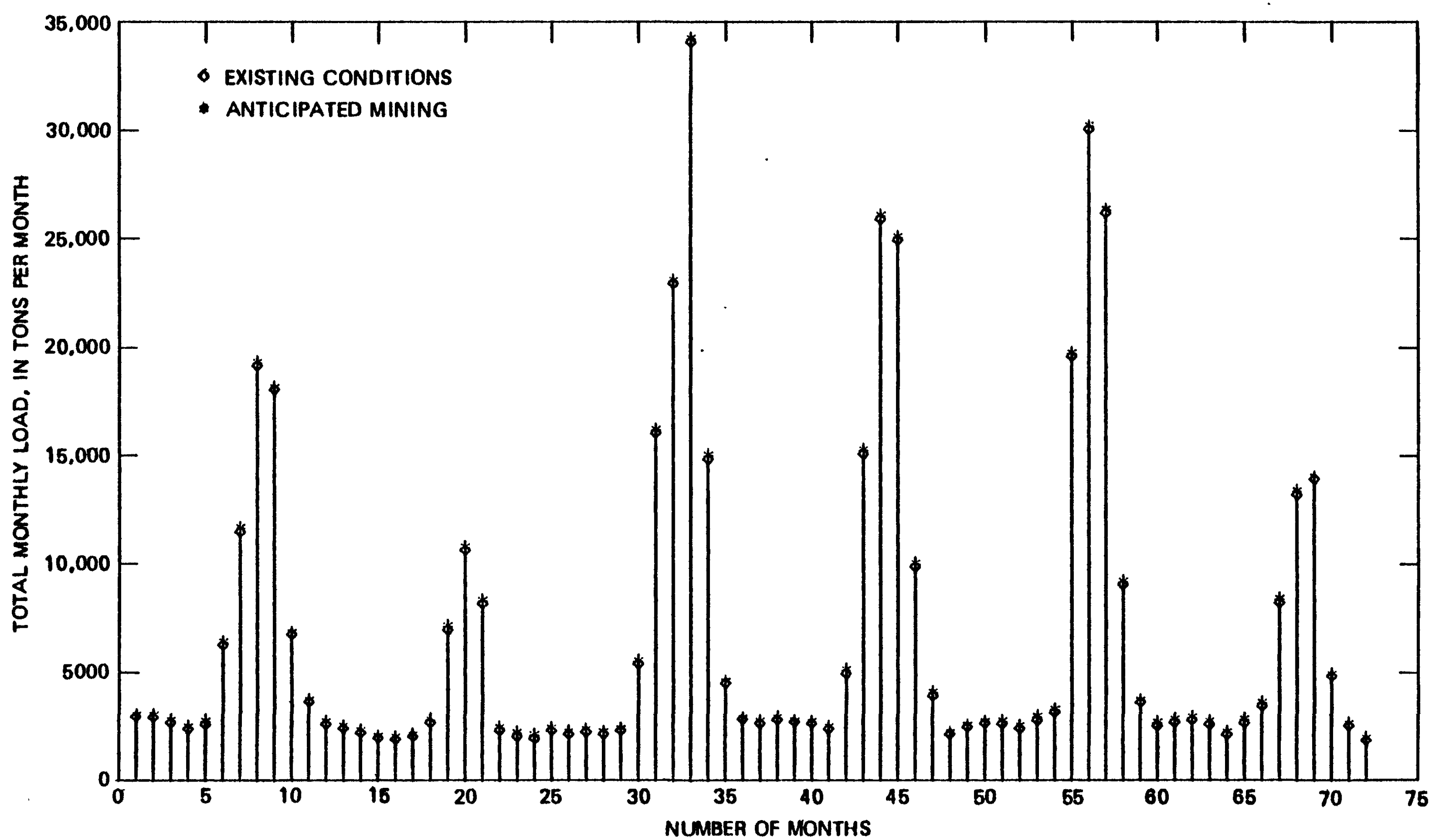

Figure 38.--A comparison of total monthly load for existing conditions and long-term anticipated mining at node 27, Yampa River below diversion, near Hayden.

Dissolved-Solids Concentration

Mean monthly dissolved-solids concentrations were computed from equations derived from data in Maura (1983). Equations to estimate mean monthly dissolved-solids concentrations for the three input nodes are as follows:

1. Stokes Gulch near Hayden,

$$C=4{,}987Q^{-0.24}; \tag{23}$$

2. Hubberson Gulch near Hayden,

$$C=552Q^{-0.18}; \text{ and} \tag{24}$$

3. Watering Trough Gulch near Hayden,

$$C=579Q^{-0.0381}, \tag{25}$$

where: C=mean monthly dissolved-solids concentration (milligrams per liter), and
Q=mean monthly discharge (cubic feet per second).

Existing Conditions

Results of manually routing mean monthly discharge, mean monthly dissolved-solids concentration, and total monthly load from the three input nodes to Dry Creek at mouth are shown in table 9. These results are possibly an overprediction on discharge; hence, the dissolved solids and total monthly loads could have an associated error. The routing assumed that water and associated dissolved solids were routed downstream with no gains and losses.

Table 9.--*Modeled output for Dry Creek at mouth*

Month	Mean monthly discharge (cubic feet per second)	Mean monthly dissolved-solids concentration (milligrams per liter)	Total monthly load (tons per month)
October-----	0.18	763.28	11.10
November----	.18	760.39	11.37
December----	.18	761.26	11.32
January-----	.18	761.85	11.33
February----	.19	912.01	13.87
March-------	.73	3,256.07	195.09
April-------	21.9	2,082.56	3,746.72
May---------	3.00	2,262.70	556.97
June--------	.44	1,316.21	48.03
July--------	.19	758.90	11.54
August------	.13	795.79	8.57
September---	.13	800.76	8.42

Note also the increase in dissolved-solids concentration in the high-flow months of March through June. This is caused by the naturally large dissolved-solids concentration of Stokes Gulch, which usually only flows during these months.

Modeled output of Dry Creek at mouth was added to the modeled output of node 27 (table 10). Because Dry Creek was modeled using average mean monthly values, output at node 27 also was converted to average mean monthly values for 5 years (table 11). Though Dry Creek enters the Yampa River downstream from node 27, modeled output from Dry Creek was combined with output from node 27 to obtain an estimate of the effects of Dry Creek on the Yampa River.

Anticipated Mining

Anticipated mining in the Dry Creek basin includes the Seneca II W Mine. Using Mined Land Reclamation Division values for discharge and dissolved-solids concentration from the anticipated mine, the water in Dry Creek again was routed manually to the mouth of Dry Creek. Mean monthly discharge, mean monthly dissolved-solids concentration, and total monthly load for Dry Creek, with the addition of the new mine into the system, are shown in table 12. This modeled output then was added to the modeled output of node 27, Yampa River below diversion, near Hayden (table 13).

Mined Land Reclamation Division also supplied values on the long-term effects of the anticipated mine. These values were used to model long-term effects on Dry Creek at mouth (table 14) and at node 27, Yampa River below diversion, near Hayden (table 15).

Comparing table 9 to table 12 shows a slight increase of dissolved-solids concentration during the modeled anticipated mining on Dry Creek. However, from tables 10 and 13, there appears to be no effect of the anticipated mining on Dry Creek during mining operations on the Yampa River. The modeled long-term effects of the anticipated mining on Dry Creek increases the dissolved solids more than during the mining operations (tables 12 and 14), and again the modeled effects of mining during the long term on the Yampa River appear negligible (tables 13 and 15).

Table 10.--*Modeled output for Dry Creek at mouth added to output of node 27, Yampa River below diversion, near Hayden, using average mean monthly discharge and dissolved-solids concentration*

[Q=average mean monthly discharge; C=average mean monthly dissolved-solids concentration; L=dissolved-solids load]

Node	Q	C	L	Node	Q	C	L
	October				November		
27---------	187	167	2,568	27---------	186	170	2,591
Dry Creek--	.18	763	11	Dry Creek--	.18	760	11
Total------	188	167	2,580	Total------	186	170	2,599
	December				January		
27---------	166	181	2,472	27---------	152	181	2,254
Dry Creek--	.18	761	11	Dry Creek--	.18	762	11
Total------	166	182	2,483	Total------	152	182	2,274
	February				March		
27---------	154	193	2,447	27---------	265	193	4,200
Dry Creek--	.19	912	14	Dry Creek--	.73	3,256	195
Total------	154	194	2,455	Total------	266	201	4,394
	April				May		
27---------	1,169	131	12,567	27---------	3,053	82	20,657
Dry Creek--	21.9	2,083	3,747	Dry Creek--	3.0	2,263	557
Total------	1,191	167	16,347	Total------	3,056	84	21,098
	June				July		
27---------	3,677	74	22,364	27---------	1,067	104	9,090
Dry Creek--	.44	1,316	48	Dry Creek--	.19	759	12
Total------	3,678	74	22,369	Total------	1,067	104	9,120
	August				September		
27---------	265	159	3,461	27---------	161	177	2,342
Dry Creek--	.13	796	9	Dry Creek--	.13	801	8
Total------	266	159	3,476	Total------	161	178	2,355

Table 11.--*Average mean monthly discharge, mean monthly dissolved-solids concentration, and total load for Yampa River below diversion, near Hayden, output node 27*

Month	Average mean monthly discharge (cubic feet per second)	Average mean monthly dissolved-solids concentration (milligrams per liter)	Average total monthly load (tons per month)
October-------	187	167	2,568
November------	186	170	2,591
December------	166	181	2,472
January-------	152	181	2,254
February------	154	193	2,447
March---------	265	193	4,200
April---------	1,169	131	12,567
May-----------	3,053	82	20,657
June----------	3,677	74	22,364
July----------	1,067	104	9,090
August--------	265	159	3,461
September-----	161	177	2,342

Table 12.--*Modeled output for Dry Creek at mouth with short-term anticipated mining effects*

Month	Mean monthly discharge (cubic feet per second)	Mean monthly dissolved-solids concentration (milligrams per liter)	Total monthly load (tons per month)
October-------	0.18	845.98	12.31
November------	.18	859.36	12.85
December------	.18	860.56	12.80
January-------	.18	861.62	12.82
February------	.19	1,009.80	15.35
March---------	.73	3,283.50	196.73
April---------	21.9	2,084.00	3,749.30
May-----------	3.00	2,271.20	559.07
June----------	.44	1,370.15	49.55
July----------	.19	839.57	12.77
August--------	.13	885.89	9.54
September-----	.13	907.83	9.55

Table 13.--*Modeled output for Dry Creek at mouth added to output at node 27, Yampa River below diversion, near Hayden, with short-term anticipated mining effects on Dry Creek*

Month	Mean monthly discharge[1] (cubic feet per second)	Mean monthly dissolved-solids concentration[1] (milligrams per liter)	Total monthly load (tons per month)
October--------	188	167	2,580
November-------	186	171	2,614
December-------	166	182	2,483
January--------	152	182	2,274
February-------	154	194	2,455
March----------	266	201	4,394
April----------	1,191	167	16,347
May------------	3,056	84	21,098
June-----------	3,678	74	22,369
July-----------	1,067	104	9,120
August---------	266	159	3,476
September------	161	178	2,355

[1]Using average mean monthly discharge and dissolved-solids concentration.

Table 14.--*Modeled output for Dry Creek at mouth with long-term anticipated mining effects*

Month	Mean monthly discharge (cubic feet per second)	Mean monthly dissolved-solids concentration (milligrams per liter)	Total monthly load (tons per month)
October--------	0.18	1,025.6	14.92
November-------	.18	1,016.1	15.20
December-------	.18	1,018.8	15.16
January--------	.18	1,019.9	15.17
February-------	.19	1,165.1	17.71
March----------	.73	3,325.6	199.26
April----------	21.9	2,085.3	3,751.7
May------------	3.0	2,281.6	561.62
June-----------	.44	1,443.3	52.19
July-----------	.19	1,011.4	15.38
August---------	.13	1,142.7	12.30
September------	.13	1,156.0	12.16

Table 15.--*Modeled output for Dry Creek at mouth added to output at node 27, Yampa River below diversion, near Hayden, with long-term anticipated mining effects on Dry Creek*

Month	Mean monthly discharge[1] (cubic feet per second)	Mean monthly dissolved-solids concentration[1] (milligrams per liter)	Total monthly load (tons per month)
October-------	188	167	2,580
November------	186	170	2,599
December------	166	182	2,484
January-------	152	182	2,306
February------	154	194	2,455
March---------	266	201	4,394
April---------	1,191	167	16,347
May-----------	3,056	84	25,704
June----------	3,678	74	22,415
July----------	1,067	104	9,120
August--------	266	159	3,476
September-----	161	178	2,355

[1]Using average mean monthly discharge and dissolved-solids concentration.

SUMMARY

A water-quality model was developed to assess the cumulative effects of anticipated coal mining for a selected reach of the Yampa River between Steamboat Springs and Hayden, Colo. The model is oriented toward an area of concentrated coal-mine development--the drainage of Trout Creek and its tributaries.

This model uses an accounting process which sums upstream surface-water discharge and associated dissolved-solids concentration through the stream network to a downstream point. This is not actually a routing model because the arithmetic operations occur at specific points or nodes and are not continuously modeled through the reach. Changes in discharge or dissolved-solids concentration made at a node are implied for the reach immediately upstream from the node. This model operates in a monthly mode and, therefore, the traveltime through the system is assumed to be 1 month or less.

Three kinds of nodes are identified: Input nodes, internal nodes, and output nodes. To make the model operational, mean monthly discharge and mean monthly dissolved-solids concentration data are needed at each input node. The needed data are available for most of the input nodes for water years 1976 through 1981--the period used in the model.

Monthly discharge data were not available for input node 1, Trout Creek near Oak Creek, nor for input node 24, Grassy Creek at Grassy Gap (402330107082000), which required data extrapolated from other sites. In addition, streamflow data for node 22, Elk River at the mouth, was derived from a station upstream on the Elk River--Elk River at Clark (09241000). The record had to be extended for node 17, Fish Creek near Milner, for water years 1976 and 1981.

Observed discharge and mean dissolved-solids concentration values were required for output nodes 15, 19, 20, and 27 in order to calibrate the model. The data for node 15 is a direct summation of two upstream nodes with observed data and was assumed to have observed data. The record had to be extended for node 19, Fish Creek at mouth, near Milner, for 1976 and 1981. Data for node 20, Trout Creek above Milner, an important node in the model, had to be estimated for the total period. It is unfortunate that gaged record was not available. The final output node is a streamflow-gaging station, node 27, Yampa River below diversion, near Hayden (09244410).

At least some water-quality data were available for all input and output nodes. Sufficient data were available to develop a regression relation between discharge and dissolved-solids concentration. Two notable exceptions are the input nodes for the Elk and the Yampa Rivers--neither node 21 nor node 22 had dissolved-solids concentration data. These data had to be estimated from specific-conductance values at the sites.

Water-quality data used in the model obtained during the water years 1976 through 1981 reflect existing conditions. It is assumed that any effects of mining operations and reclaimed areas during these years are reflected in the observed data and in the calibrated model.

Calibration was performed by changing coefficients in the model in order that the modeled output of discharge, dissolved-solids concentration, and dissolved-solids load closely matched the observed data at the output nodes. Calibration was done qualitatively by overlaying observed and predicted histograms and quantitatively by trying to reduce the mean and variance of the difference between the observed and predicted values.

Mine input nodes are internal nodes that were inactive during the calibration process. These nodes were used to add the short-term and long-term effects of mining to the calibrated model. One node can be used to combine inputs from several mines.

Because of the model structure, inputs at any internal node to reflect mining must have a mean monthly discharge (in cubic feet per second) and an associated dissolved-solids concentration (in milligrams per liter). These data can be either an average value or a specific value for each month within the simulated period. The data may reflect surface-water runoff, ground water that appears as surface water in the stream, or pumping from dewatering activities.

Several anticipated mining activities representing the short-term and long-term effects of mining were provided by the Mined Land Reclamation Division. The effects resulted from the life-of-mine operations of existing mines, post-1981, and from the proposed Foidel Creek underground mine. Two of the anticipated mining activities for the Trout Creek drainage are included in this report. One plan is the short-term effects from a given plan; the second is the long-term effects from the same anticipated mining activity.

In the short-term anticipated mining, the greatest change in model variables is shown at Middle Creek (node 15) and Fish Creek (node 19). The mean discharge is increased by 31 percent at node 15 and decreased by 1 percent at node 19. This primarily is a reflection of anticipated dewatering activities directly upstream.

At node 15, the mean monthly dissolved-solids concentration increases by 316 milligrams per liter from all anticipated mining upstream. At node 19, the mean monthly dissolved-solids concentration increases by 98 milligrams per liter. The combined influence of these two tributaries, plus anticipated mining along the main stem of Trout Creek, increases the mean monthly dissolved-solids concentration near the mouth of Trout Creek (node 20) by 81 milligrams per liter. This increase raises the mean monthly value to 391 milligrams per liter at node 20. The diluting effect of the Yampa River main stem is seen at node 27 where a 5-percent increase occurs in the mean monthly dissolved-solids concentration.

The total monthly load of dissolved solids increases to varying degrees at all output nodes. The increases in these load values primarily are the result of increased values in the dissolved-solids concentrations.

A long-term version of this anticipated mining reveals little change in the increased dissolved-solids concentration values. For example, values at node 15 in the short term increased 72 percent from existing conditions and in the long term increased 64.5 percent from existing conditions. Values at node 20 increased 26.1 percent in the short term and 29.4 percent in the long term.

The use of the model in the Trout Creek drainage helps to identify data-collection needs. The most serious lack of data is near the mouth of Trout Creek, represented in the model by node 20. A streamflow-gaging station is needed in this vicinity to obtain daily stream discharge and associated water-quality data.

Nearly 90 percent of the water at node 27--the outlet of the model--is represented by two important input nodes, 21 and 22. Continuous record of stream discharge, available for these input nodes, lacks water-quality data. Water-quality data should be collected for these nodes.

If the model is extended to include more of the tributaries of the Yampa River with coal development, additional data will need to be collected for input, internal, and output nodes. The lack of both water-quantity and water-quality data is particularly evident for the tributaries north of the Yampa River main stem. If the model is extended, these data are needed to maintain a water balance.

Best estimates of water quantity and its associated water quality were made for individual mine developments by the Mined Land Reclamation Division. Additional research on small watersheds and hillslope segments with and without mining disturbances would provide actual data for mine-water input to the model.

Through an ongoing project, continued refinements will be made to the model. The most serious problem to model improvement is the lack of sufficient data; perhaps this report will stimulate and orient this data collection.

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