AN ASSESSMENT OF CUMULATIVE IMPACTS OF COAL MINING ON THE HYDROLOGY IN PART OF THE POWDER RIVER STRUCTURAL BASIN, WYOMING--A PROGRESS REPORT

By Paul R. Jordan, Richard M. Bloyd, and Pamela B. Daddow

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CONVERSION FACTORS AND VERTICAL DATUM

For those readers who may prefer to use metric units, the conversion factors for inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	hectare
square mile	2.590	square kilometer
inch per hour	25.40	millimeter per hour
inch per year	25.40	millimeter per year
cubic foot per second	0.02832	cubic meter per second
square foot per day	0.09290	square meter per day
acre-foot	0.001233	cubic hectometer

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.

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ABSTRACT

The U.S. Geological Survey and the Wyoming Department of Environmental Quality are involved in a cooperative effort to assess the probable cumulative impacts of coal mining on the hydrology in a part of the Powder River structural basin in Wyoming. The purpose of the progress report is to present initial results. Emphasis is placed upon presentation of results of analysis of surface-water resources in the Caballo Creek drainage.

For the purposes of this study the assumption was made that the principal impacts on the ground-water system due to mining will occur in the relatively shallow aquifers. A further assumption was that the shallow aquifers can be divided into three relatively homogeneous aquifers: the Wyodak-Anderson coal, the overburden, and the underburden.

A surface-water model of the Caballo Creek drainage was developed to help assess the impacts of mining activities on streamflow. The Hydrological Simulation Program-Fortran model was used in the study. The Caballo Creek drainage was divided into 10 land segments and 6 stream reaches in the modeling process.

Three model simulations show little, if any, change in streamflow between pre- and post-mining conditions and very little change between pre-mining and during-mining conditions. The principal reasons for the absence of change are the small fraction of the drainage area that is mined and the rapid rate of infiltration used in the model for all three conditions.

INTRODUCTION

The Surface Mining Control and Reclamation Act of 1977 and the Wyoming Department of Environmental Quality Rules and Regulations require the Department of Enviromental Quality to assess the probable cumulative impacts of all anticipated mining in the area on the hydrology of the appropriate drainage basin each time there is an application for a permit to mine. The Powder River structural basin in Wyoming (fig. 1) is a specific basin where the Department of Environmental Quality is required to assess cumulative impacts of mining because of existing and pending applications for permits to mine coal.

The potential for adverse cumulative impacts on the hydrology of the basin does exist. Strip mining of coal disrupts watersheds and can cause changes in the quantity and quality of surface-water runoff from a mined area. Ground-water flow and quality also can be altered.

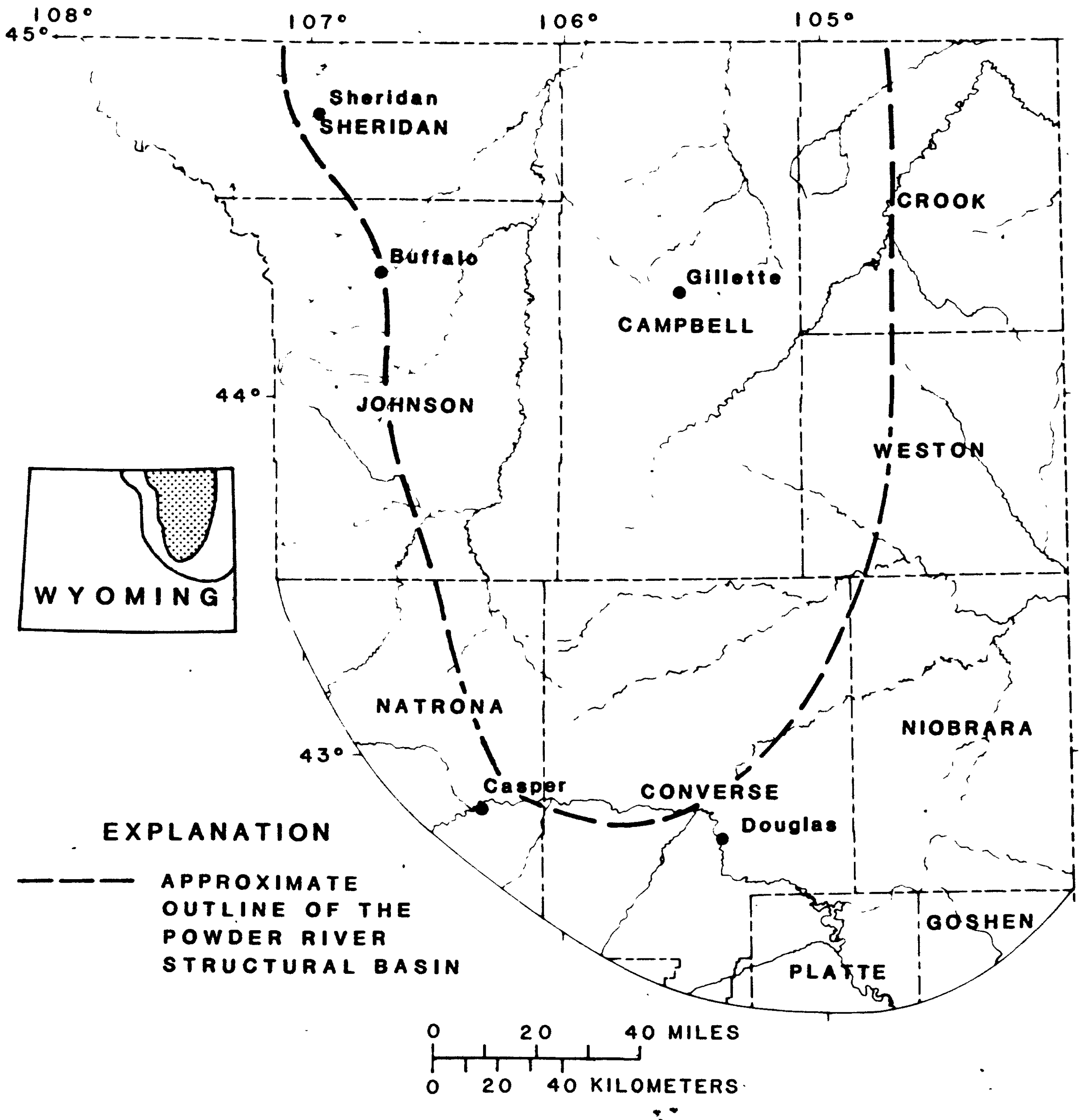

Figure 1.--Extent of Powder River structural basin in Wyoming.

Two factors complicate this cumulative-impacts evaluation:

1. Limited time is available for the evaluation.

2. Large quantites of data of unknown or undetermined reliability exist.

The study is being done in cooperation with the Wyoming Department of Environmental Quality and is designed to provide an evaluation of the probable individual and cumulative impacts of mine operations on the surface- and ground-water hydrology in part of the Powder River structural basin in Wyoming. Because of time constraints imposed by upcoming permit decisions, the evaluation is forced to be somewhat cursory. A more in-depth evaluation will be needed in the future.

The study involves four major tasks leading to evaluation of impacts:

1. The collection and assembling of pertinent data;

2. The identification of probable impacts on the hydrologic system;

3. The definition of the hydrologic system in the potentially impacted part of the Powder River structural basin in Wyoming; and

4. The development of mathematical models of the ground-water system and of selected streams in the potentially impacted part of the basin.

The purpose of this progress report is to present initial results of the study. Emphasis is placed upon presentation of results of analysis of the impacts of mining activities on streamflow in the Caballo Creek drainage.

The study area includes parts of six counties in northeastern Wyoming (fig. 2). Most of the study area is in Campbell County. The study area is that part of the Powder River structural basin in Wyoming that will be most directly affected by coal-mining activities.

As previously stated, large quantities of hydrologic data for the study area are available. Principal sources of the data are the Wyoming Department of Environmental Quality, the Wyoming State Engineer, and the U.S. Geological Survey. Special emphasis was placed upon obtaining and using data from the Department of Environmental Quality in the analysis process. Much of the data in their files resulted from requirements imposed on mining companies in the submission of mine plans and are site specific.

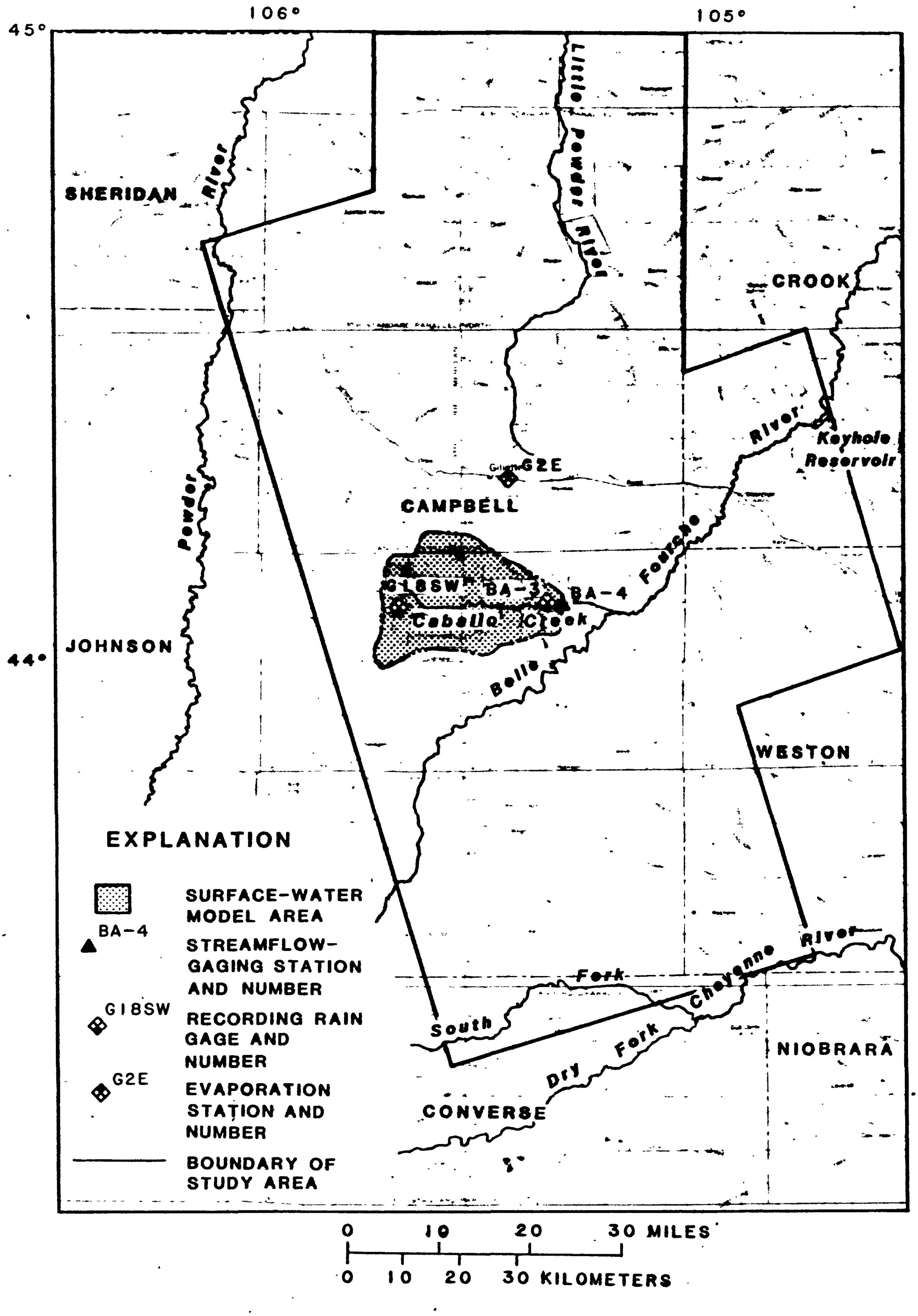

Figure 2.--Location of study area, Caballo Creek drainage area, and data sites used in surface-water model.

COAL MINING IN THE STUDY AREA--THE IMPACTS

In order to assess potential impacts of mining on the hydrologic system, the where, when, and what aspects of the impacts must be identified. Activities of 21 mines (fig. 3 and table 1) are considered in the study. All but one of these mines are in Campbell County. Earliest coal production in the study area began in 1922, from the Wyodak Mine. However, in the 1960's many proposals were made for strip mining coal in the area. Start-up dates for mines are projected through 1985 (table 1). In terms of surface area to be disturbed, the Caballo Mine will be the largest mine in the area.

For the purpose of this study, the assumption was made that the principal potential impacts on the ground-water system due to mining will occur in the relatively shallow aquifers. Such an assumption was made for the following reasons: (1) The depth to which coal will be mined is limited by the overburden-to-coal ratio: the maximum depth of overburden and coal removal presently proposed is 400 feet; (2) there are limited data for the deep aquifers; (3) time allowed for the study is constrained; and (4) pumping from the deep aquifers has not yet affected water levels in the shallow aquifers at the few observation wells presently measured, which indicates there is limited hydraulic connection between the deep and shallow aquifers.

In order to demonstrate the potential for impacts on ground-water levels, an example is presented herein to show that mining operations during 1974-81 at the Belle Ayr Mine already have caused water-level declines in the lease area of the Belle Ayr and Caballo Rojo Mines. The intent is not to single out activities at the Belle Ayr Mine, but to present a typical example.

According to information available in Belle Ayr Mine plans, dewatering of the coal seam in the mine area began in 1974 and dewatering of overburden deposits began in 1977. No dewatering on the Caballo Rojo lease area occurred during 1974-81. The commonly used method of dewatering is to pump directly from the bottom of a mined pit. Actual locations of pumping and the quantity of pumpage were not analyzed for this report.

Ground-water-level declines occurred in wells completed in the coal underlying both the Belle Ayr and Caballo Rojo lease areas (fig. 4) but not in wells completed in the overburden. From November 1977 to August 1981, a water-level decline of about 27 feet occurred in the coal in well C-75-6 (figs. 4 and 5). Comparable water-level declines occurred in wells C-75-13 and M-75-34. A decline of about 5 feet occurred in well M-75-36. The water level in well C-75-32 did not decline. It is not obvious why the water-level decline in well M-75-36 is less than in well M-75-34, but time was not available for further analysis of depth and perforated intervals of wells used in the example. Because there was no obvious impact to water levels in wells perforated in the overburden, the data are not presented here nor in figure 4.

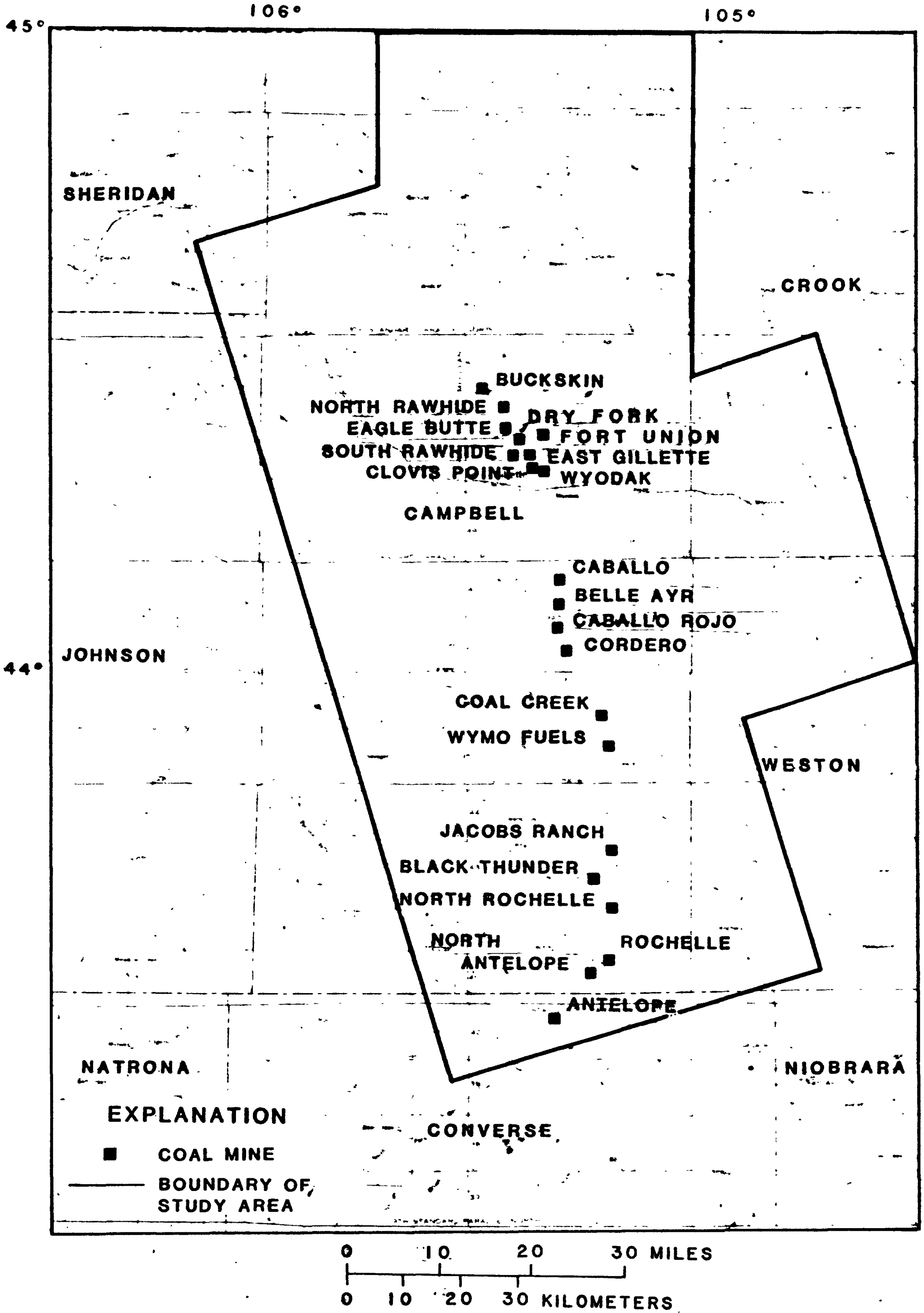

Figure 3.--Location of coal mines.

Table 1.--Coal mines in the study area

Mine	Production: Start-up date	Production: Projected end date	Surface area disturbed thru 1982 (acres)	Total surface area to be disturbed (acres)
1. Antelope	1982	2011	219	5,900
2. Belle Ayr	1972	2001	1,844	4,334
3. Black Thunder	1977	2014	1,488	8,170
4. Buckskin	1981	1996	631	1,315
5. Caballo	1979	2021	855	9,104
6. Caballo Rojo	1983	2007	0	4,818
7. Clovis Point	1979	1998	646	1,047
8. Coal Creek	1982	2012	765	8,310
9. Cordero	1976	2006	1,417	8,232
10. Dry Fork	1984	2005	0	2,905
11. Eagle Butte	1976	2009	805	3,470
12. East Gillette	1983	2012	0	2,702
13. Fort Union	1979	1992	155	419
14. Jacobs Ranch	1975	2006	1,547	4,691
15. North Antelope	1982	2026	443	2,709
16. North Rawhide	1976	2004	1,003	4,735
17. North Rochelle	1983	2012	0	3,271
18. Rochelle	1985	2027	0	5,312
19. South Rawhide	1984	2020	0	2,006
20. Wymo Fuels	1983	1995	0	750
21. Wyodak	1922	2016	463	1,720

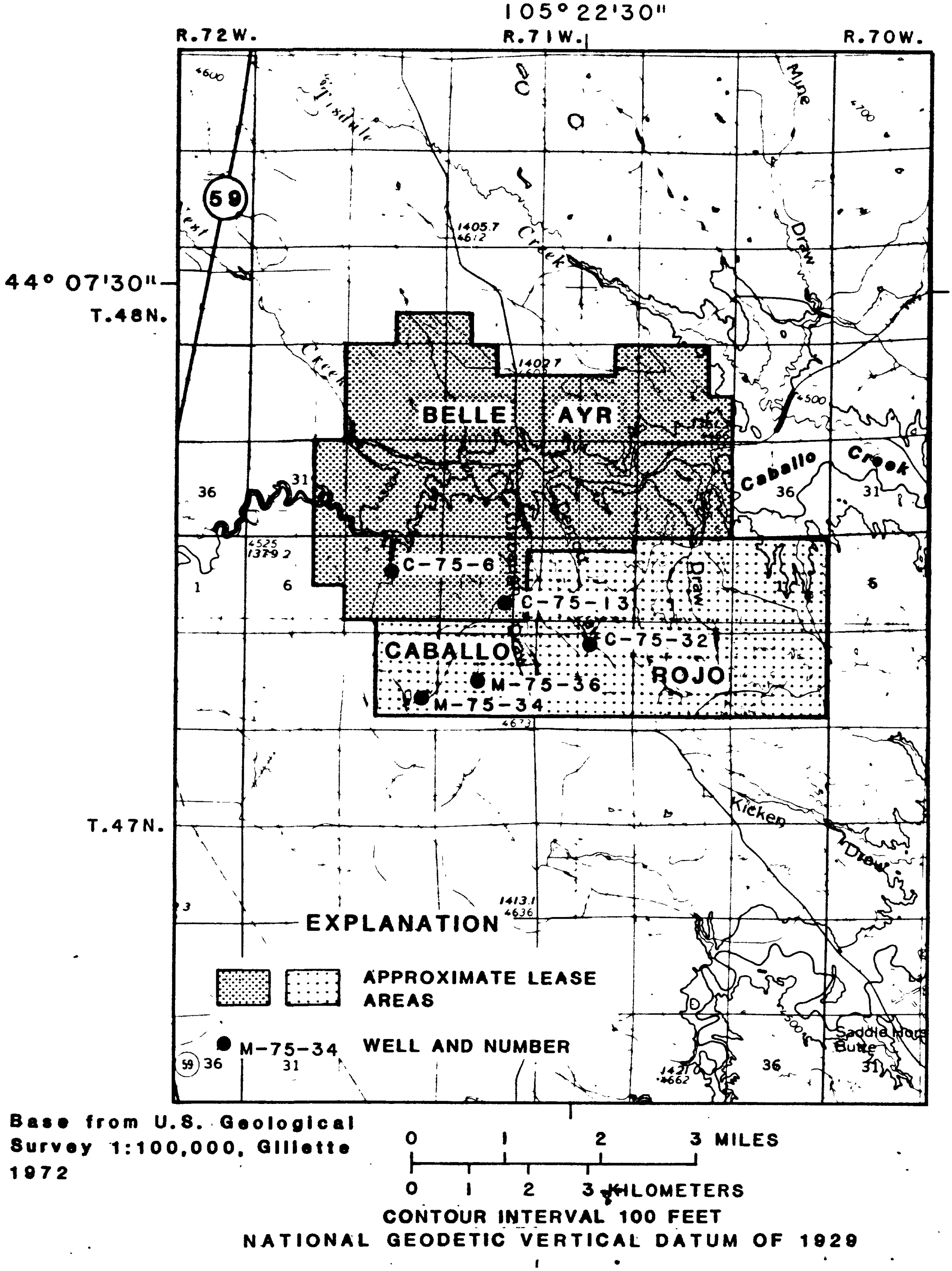

Figure 4.--Location of Belle Ayr and Caballo Rojo lease areas and selected wells.

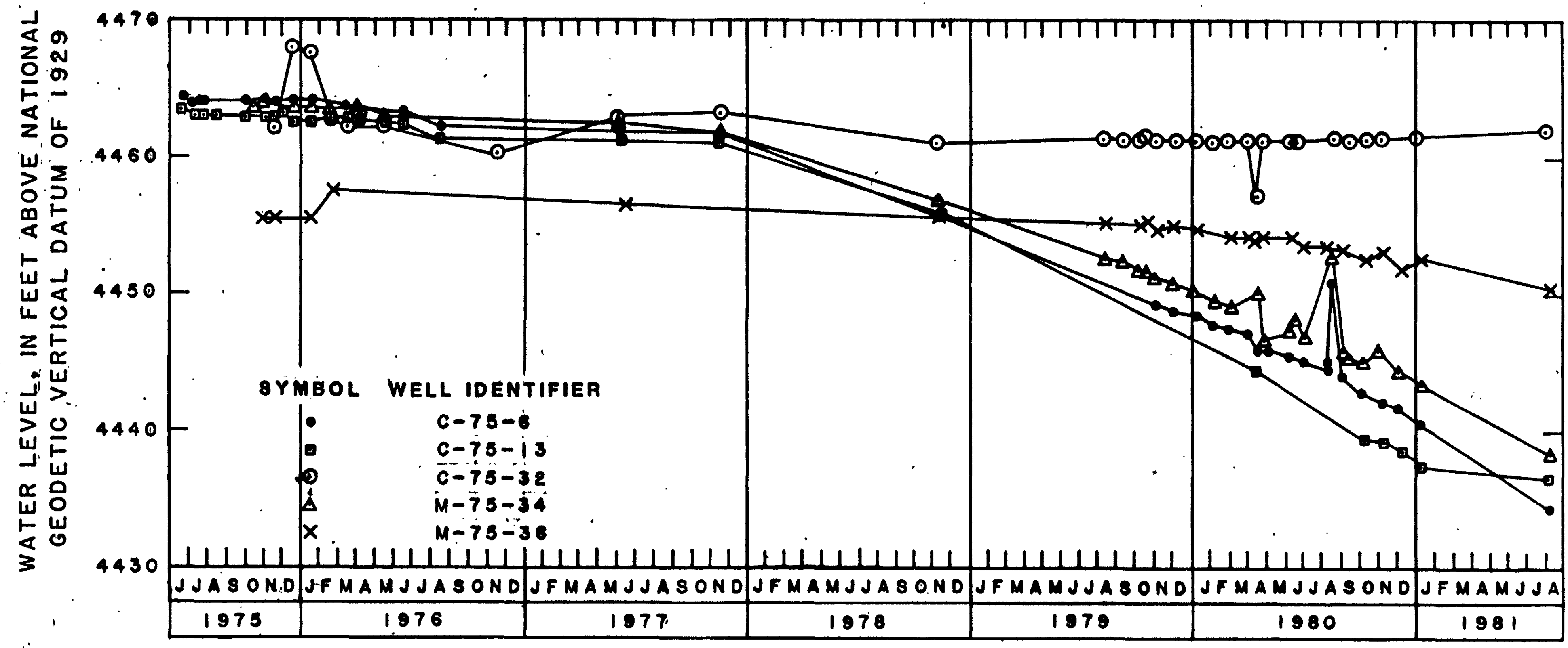

Figure 5.—Water-level hydrographs.

GROUND-WATER HYDROLOGY OF THE STUDY AREA

General Description

The hydrology, as well as the geology, is extremely complex in the study area. The Powder River structural basin is a deep, elongated, and assymmetrical sedimentary basin. Beikman (1962) notes that the deepest part of the basin is on the west side. Consistent with the assumption that mining impacts principally will occur in the relatively shallow aquifers, only the shallow aquifers will be considered in this study. These shallow aquifers are contained in the Fort Union Formation of Paleocene age and the Wasatch Formation of Eocene age (U.S. Department of the Interior, 1979, fig. R2-4).

Ground water flows through a series of discontinuous lenticular sandstones and coal beds in the shallow aquifers. Because of the discontinuous nature of these consolidated aquifers, definition of the aquifers on a regional basis is difficult. However, the assumption was made that the shallow aquifers can be divided into three relatively homogeneous aquifers, namely, the overburden, the coal, and the underburden.

The overburden aquifer, which is assumed to include all aquifers above the coal, ranges in thickness from 0 to 1,000 feet and is in the Fort Union and Wasatch Formations. The aquifer is assumed to be unconfined in its entirety with specific yield ranging from 0.1 to 0.3. Transmissivity ranges from about 0.4 to 770 square feet per day. The aquifer properties were obtained from data presented in the various mine plans.

The coal aquifer referred to here is the Wyodak-Anderson coal in the Fort Union Formation. In places the Wyodak coal divides into the Canyon and the Anderson coals. The coal aquifer ranges in thickness from 5 to 190 feet. Except in the outcrop area, the coal is assumed to be confined with storage coefficients ranging from $1x10^{-4}$ to $1x10^{-6}$. Transmissivity ranges from about 0.7 to 10,000 square feet per day. The aquifer properties were obtained from data presented in the various mine plans.

The underburden aquifer is assumed to be the Lebo Shale Member of the Fort Union Formation. The Fort Union Formation is divided, in order of increasing age, into the Tongue River, Lebo Shale, and Tullock Members. Not all the members are mapped at all locations and some consider the Tongue River Member, which contains the Wyodak-Anderson coal, to be a facies in the Lebo. The Lebo Shale Member directly underlies the coal in the southeastern part of the study area, and is assumed to underlie the coal throughout the remainder of the study area. The Lebo ranges in thickness from 0 to 1,000 feet. Except in the outcrop area, it is confined with a storage coefficient of $5x10^{-4}$ to $1x10^{-5}$. Transmissivity ranges from about 0.3 to 600 square feet per day. The aquifer properties were obtained from W. R. Hotchkiss (U.S. Geological Survey, written commun., 1983) and from data presented in mine plans.

Conceptual Model of the System

The conceptual model of the hydrologic system is a statement of the hydrologist's understanding of the physical and functional nature of the aquifers. The model should include sources of recharge and discharge, directions of flow, variations in aquifer properties and hydraulic potential, and the relation of the aquifer(s) studied to surface water and other aquifers. For the purposes of this report, only a very general conceptual model is presented. As the study is completed, concepts presented here will be tested and re-evaluated with a mathematical model.

Recharge to the overburden aquifer is from infiltration of precipitation and streamflow. Uniform areal recharge is assumed to average 0.2 inch per year. Principal recharge to the coal aquifer is infiltration of precipitation in the aquifer outcrop area. The largest quantity of recharge occurs in the clinker where the coal outcrop has burned. Initial analysis of water levels in wells indicates that the principal recharge to the underburden aquifer is in the southern part of the study area. Further analysis is needed to confirm the source.

The general direction of ground-water flow in the three aquifers defined in this study is from south to north under natural, undisturbed conditions. Although the principal component of flow is assumed to be horizontal, some vertical flow does occur. Initial analysis indicates there is flow into the coal from the overburden and possibly flow from the coal into the underburden. Further analysis is needed to define the interchange between ground and surface water in the area. There are numerous springs that discharge ground water in the study area. In the final phase of the study, the springs will be located and estimates of discharge will be made.

SURFACE-WATER HYDROLOGY OF THE STUDY AREA

The study area is drained to the north by the Little Powder River, to the east by the Belle Fourche River and by the Cheyenne River and its tributaries, and to the west by tributaries to the Powder River (fig. 2). Most streams in the study area are ephemeral.

To date, the Caballo Creek drainage, a tributary of the Belle Fourche River (fig. 2), is the only part of the study area analyzed. Future studies will consist of modeling the entire Belle Fourche River drainage upstream from Keyhole Reservoir. The entire Caballo Creek drainage will be included in the new model and attempts will be made to improve the Caballo Creek modeling. The modeled time periods will be extended so that low-flow conditions will be included in the simulations of changes due to mining. In addition, three water-quality characteristics--concentrations of suspended sediment, sulfate ion, and dissolved solids--will be modeled for sites where sufficient data are available for calibration of the model. Limited sensitivity analyses will be performed for the model parameters most difficult to evaluate and for those most important in evaluating the effects of mining in the study area.

Surface-Water Model of Caballo Creek

The process used to develop and apply the model included the following steps:

1. Identify the problems to be addressed;

2. Select an appropriate model to address the identified problems;

3. Identify data requirements for the model;

4. Collect and assemble the appropriate data;

5. Calibrate the model for a historical period for which appropriate data were available; and

6. Apply the calibrated model for two historical periods for which appropriate data were available in order to simulate and compare results for the three drainage-basin conditions associated with the following phases of mining operations--

    a. Pre-mining,

    b. During-mining and reclamation, and

    c. Post-mining and post-reclamation.

Model Development

Caballo Creek was chosen for study because mining is occurring in the drainage area and because the percentage of the drainage area ultimately to be affected by mining and subsequent reclamation is greater than in other basins having adequate data for calibration and simulation of streamflow.

The impact on streamflow in the Caballo Creek drainage due to changes in the land surface can be predicted by using a deterministic, distributed-parameter type model (rather than statistical). The deterministic model uses mathematical formulations of physical processes. The distributed-parameter type is needed if there are areal variations in model-input parameters or if only part of a basin land surface is to be altered. In the Caballo Creek drainage there is areal variation in model-input parameters and only a part of the basin land surface will be altered by mining activities.

The specific deterministic, distributed-parameter-type model chosen for use in the study was the Hydrological Simulation Program-Fortran model (Johanson and Kittle, 1983). It is the product of a long period of development, testing, and application beginning with the Stanford Watershed Model (Crawford and Linsley, 1966). Its use is documented and guided by a comprehensive manual (Johanson, Imhoff, and Davis, 1981). The model is extremely versatile, and includes numerous options for the display of results. The model also can simulate water-quality changes; however, water-quality simulation was not included in this first phase of the study because of time constraints.

The Caballo Creek drainage was divided into 10 land segments and 6 stream reaches in order to account for areal variations in precipitation, land and channel characteristics, and changes in the land surface due to mining and reclamation (fig. 6). Data on the land surface and channel characteristics were determined from topographic maps, mining and reclamation plans, a report on infiltration for a reclaimed area in the basin (Gifford, 1981), and streamflow-discharge measurements.

Some explanation is necessary to better define a land segment as used in the model (table 2). In the first 8 land segments of the Caballo Creek drainage there will be neither mining nor reclamation activities. Segments 9 and 10 are the segments of the basin that will be mined and reclaimed during the total period of mining. According to information found in the appropriate mine plans, reclamation follows mining by about 5 years. Hence, at any one time no more than 2.2 square miles of the two mines in the basin will be in a disturbed state. So, segment 9 is used to depict 2.2 square miles of mine area that during mining (table 2) is either being mined or awaiting reclamation. Segment 10 depicts 10.8 square miles of mine area that is treated as undisturbed land for the during-mining modeling, but will be mined and reclaimed by the projected end of production.

Time periods for which data were suitable for calibration and simulation were extremely limited. In fact, the only periods suitable for the present study were April 15-May 31, 1978, and May 1-31, 1982. Periods with significant snowfall or snowmelt runoff were not suitable because of model requirements for large quantities of different types of data. Periods consisting entirely of little or no flow were also unsuitable for calibration and evaluation of impacts.

Hourly precipitation data were available for the National Weather Service station Gillette 18SW (G18SW in fig. 2) in the western part of the basin (U.S. Department of Commerce, 1978 and 1982) and Belle Ayr Mine station BA-3 in the eastern part of the basin. Potential evapotranspiration was estimated from the pan evaporation data at the National Weather Service station Gillette 2E (G2E in fig. 2) (U.S. Department of Commerce, 1978 and 1982). Streamflow data for calibration were from Belle Ayr Mine station BA-4 downstream from all of the Belle Ayr Mine and most of the Caballo Rojo Mine areas.

Parameter values used in the calibration and simulation phases of model development are presented in table 2. The effects of the many small stock ponds and natural depressions in the drainage area were not explicitly simulated in the model but were implicitly included in the parameter UZSN.

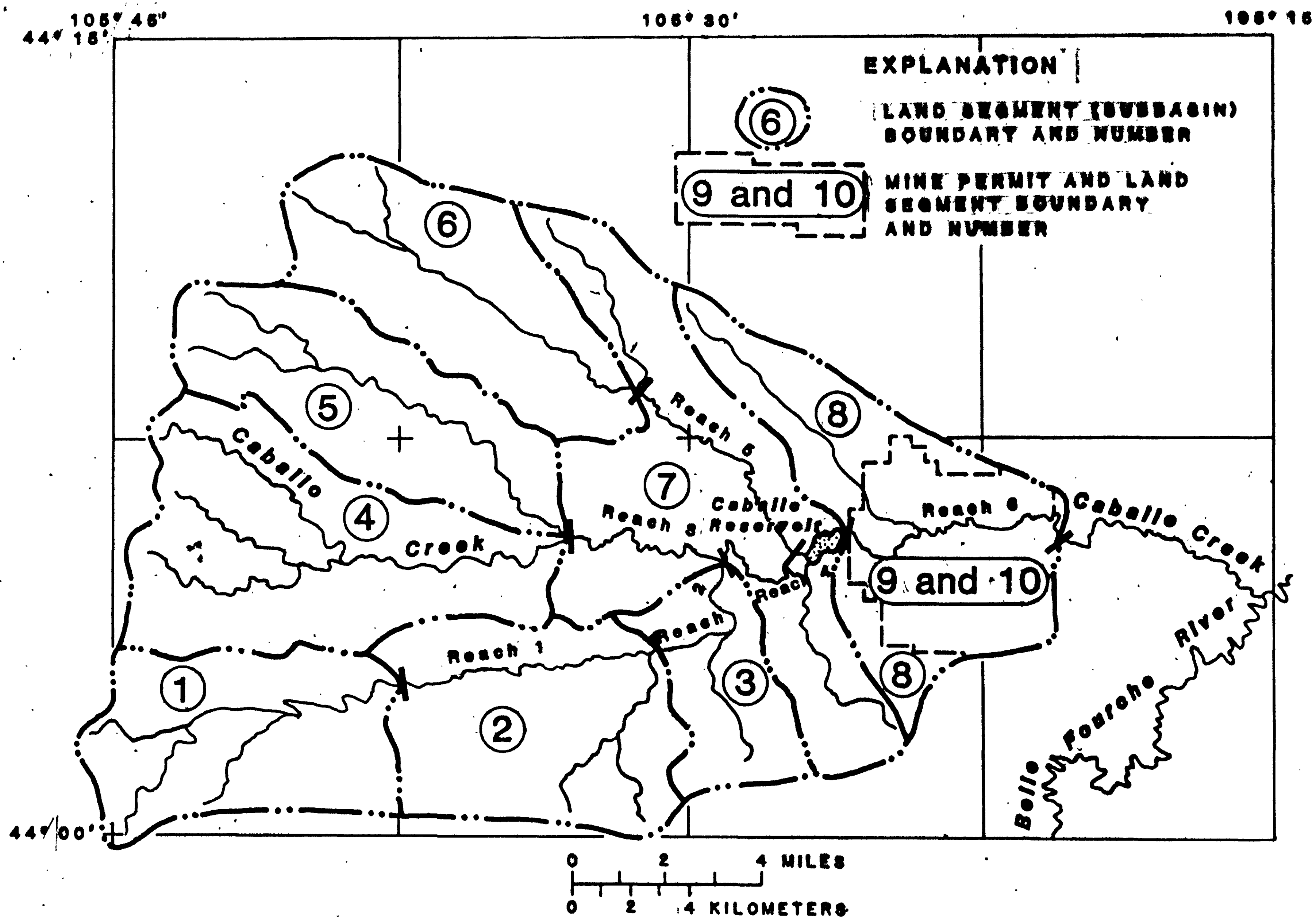

Figure 6.--Land segments and stream reaches used in Caballo Creek model.

Table 2.--Parameter values used in model calibration and simulations

[LSUR, the average length of overland flow path; SLSUR, the average slope of overland flow paths; INFILT, the nominal infiltration capacity; UZSN, the nominal water-storage capacity of the upper soil zone; LZSN, the nominal water-storage capacity of the lower soil zone; LZETP, the index of density of deep-rooted vegetation (roots in the lower soil zone); DEEPFR, the fraction of percolation from the lower soil zone that exits to a deep aquifer]

Land segment	Area (square miles)	Rain gage	LSUR (feet)	SLSUR (dimensionless)	INFILT (inches per hour)	UZSN (inches)	LZSN (inches)	LZETP (dimensionless)	DEEPFR (dimensionless)
1	23.8	G18SW	600	0.06	2.0	2.0	10.0	0.85	0.84
2	24.0	G18SW	700	.05	2.0	2.0	10.0	.85	.84
3	13.5	BA-3	400	.09	2.0	2.0	10.0	.85	.84
4	35.0	G18SW	700	.05	2.0	2.0	10.0	.85	.84
5	22.0	G18SW	600	.06	2.0	2.0	10.0	.85	.84
6	23.0	G18SW	600	.06	2.0	2.0	10.0	.85	.84
7	33.0	BA-3	600	.06	2.0	2.0	10.0	.85	.84
8	17.5	BA-3	600	.06	2.0	2.0	10.0	.85	.84
9 (Maximum area in disturbed condition at any one time):									
A. Pre-mining	2.2	BA-3	600	.06	2.0	2.0	10.0	.85	.84
B. During-mining (sedimentation ponds included in model)	2.2	BA-3	100	.04	2.0	2.0	10.0	.15	.70
C. Post-mining (reclaimed)	2.2	BA-3	2,000	.03	2.0	2.0	10.0	.85	.84
10 (Within mine area but not included in land segment 9):									
A. Pre-mining	10.8	BA-3	600	.06	2.0	2.0	10.0	.85	.84
B. During-mining	10.8	BA-3	600	.06	2.0	2.0	10.0	.85	.84
C. Post-mining (reclaimed)	10.8	BA-3	2,000	.03	2.0	2.0	10.0	.85	.84

Model Calibration

The April-May 1978 period, which had the largest range of flows in the period of data record, was chosen as the calibration period for the model. Although the calibration process was not problem free, reasonably good results were achieved. First, one of the problems will be discussed, and then, results will be presented.

The calibration process was hampered because of the effects of Caballo Reservoir (fig. 6) on the streamflow. The dam, which had a storage volume of about 700 acre-feet, was breached on May 18. Prior to that date, flow in Caballo Creek was affected by storage behind the dam. When the dam breached (beginning at about noon on May 18), the outflow exceeded the inflow during parts of 2 days. This was followed by several days in which the flow was much closer to natural flow, although it probably was affected by drainage from reservoir bank storage. Such events made it impossible to judge the calibration by direct day-by-day comparison or statistical analysis of simulated versus observed flows.

In spite of the effects of Caballo Reservoir on streamflow, the total simulated flow volume closely approximated the actual flow volume for May, and the magnitude and timing of increases and decreases in flow for May 19-31 (after the dam breach) were closely approximated (fig. 7) when the effects of the dam breach and drainage from bank storage were considered. Volume parameters adjusted in the calibration process were INFILT, UZSN, LZSN, LZETP, AND DEEPFR (table 2). No adjustments in timing parameters were necessary.

The close agreement between simulated and observed flow volumes was achieved only when a rapid rate of infiltration (INFILT) was used that resulted in simulation of very little surface runoff from 8 to 10 inches of precipitation during 1 month. In addition, it was necessary to use large values for LZSN and DEEPFR, which resulted in simulation of a large quantity of recharge to a deep aquifer that does not contribute to streamflow at the gaging station used for calibration.

A large value for recharge to a deep aquifer (DEEPFR) is not consistent with the concept presented previously that the coal and underburden are confined aquifers which receive small quantities of recharge. It also is not consistent with the earlier assumption that recharge to the overburden aquifer is only a small quantity (0.2 inch per year), which must percolate through the overburden in order to recharge the deep aquifer. However, the calibration period had much more precipitation and therefore recharge, than normal; whereas in a typical year there is probably very little excess soil moisture available for recharge. Clearly, further study and data collection are needed in order to determine more accurately the relationships among infiltration, soil moisture, recharge, and ground-water flow, although such additional work is beyond the scope of the present project. However, the calibration results obtained with the model are consistent with observed flows within a large range of flow, so the simulation results for pre-, during-, and post-mining conditions should be reasonable estimates of the impacts of mining and reclamation on streamflow.

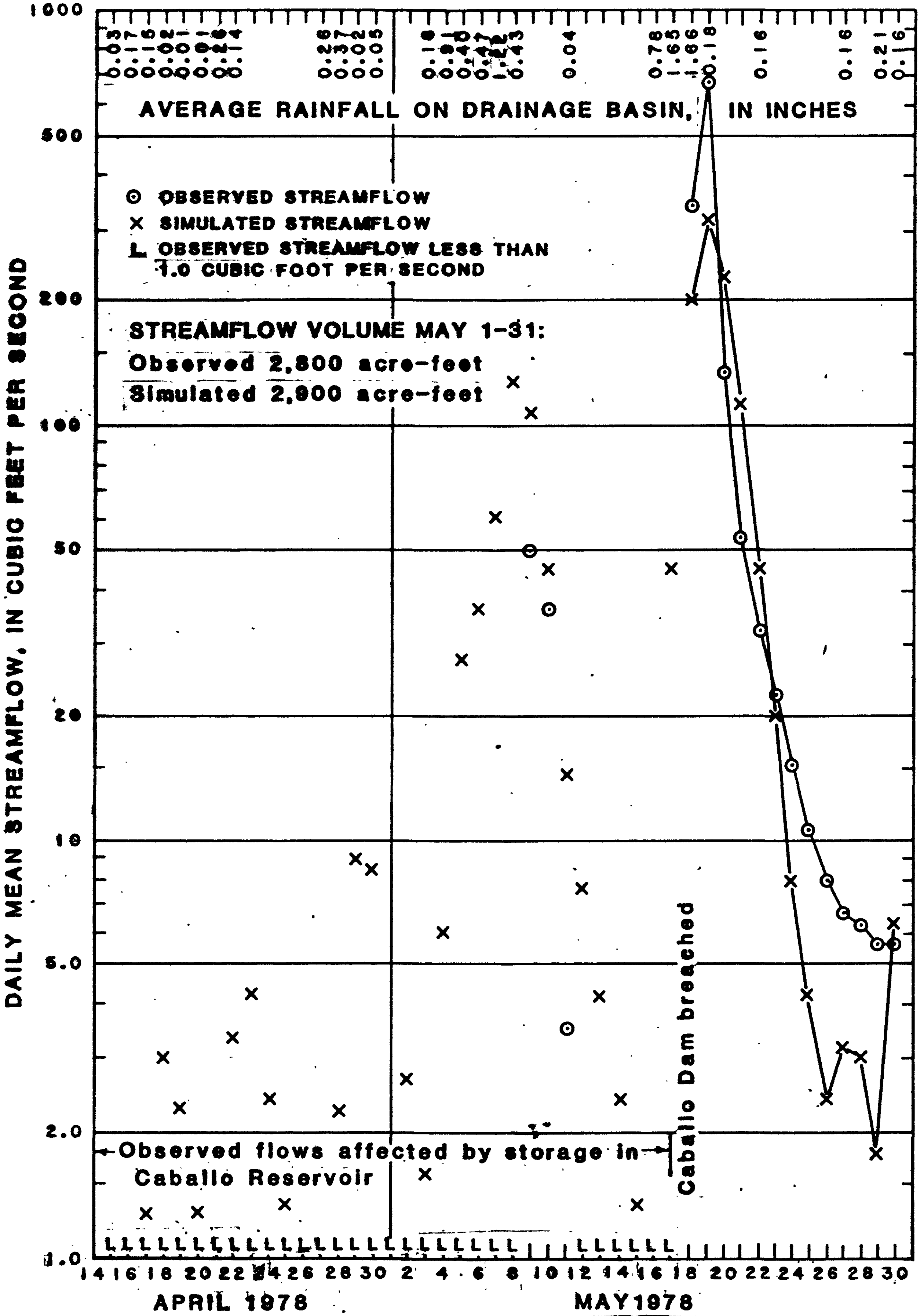

Figure 7.--Hydrographs of observed and simulated streamflows in Caballo Creek at station BA-4 for calibration period in 1978.

Model Simulations

Three model simulations were made for April-May 1978 and May 1982. The first simulation was for natural or pre-mining conditions. The second simulation was for during-mining conditions wherein a total of 2.2 square miles of mine area was in a disturbed state of mining or awaiting reclamation; and the remaining 10.8 square miles of mine area were not yet disturbed. The third simulation was for post-mining conditions wherein reclamation was finished on the total 13 square miles of land segments 9 and 10.

Assumed changes in parameter values for the during-mining simulation (2.2 square-mile area disturbed) are shown in table 2: length of overland flow path was shortened and land slope was flattened as indicated by mining plans; the index of vegetation density was decreased to account for the removal of vegetation; and the recharge to a deep aquifer was decreased. Although the average infiltration rate was not changed, the variation of infiltration rates within the area was increased to account for backfill areas and open pits. Parameters needed for the simulation of storage in ponds and outflow from ponds constructed to control high flow and sediment from the mining area were also used. The pond simulation was done without detailed data on the geometry and hydraulics of the ponds.

Changes in parameter values for the post-mining simulation (a total of 13 square miles reclaimed after completion of mining) also are shown in table 2. The only changes from pre-mining conditions were the increase in the length and the decrease in the slope of overland flow paths as indicated in the reclamation plans.

Discussion of Results

Due to the time constraints of this study, the data assembled were inadequate to verify the model calibration. In addition, streamflow during the limited time periods simulated by the model is not representative of hydrologic conditions throughout the year; this model limitation must be considered in any interpretation of the results.

The results of the simulations (figs. 8-11) show little, if any, change in streamflow between pre- and post-mining conditions in the 205-square-mile drainage area. The post-mining conditions consist of 13 square miles reclaimed to a flatter topography with fewer drainage channels and with sedimentation ponds removed. The principal reasons for the absence of change in simulated streamflow are the small fraction of the drainage area that is mined and the rapid rate of infiltration used in the model for both conditions, which nearly precludes surface runoff, even from a monthly total of 8 to 10 inches of rain as in May of 1978, or from an intense downpour of 1.03 inches in 1 hour as recorded at station BA-3 on May 27, 1982. The change in topography from gently sloping before mining to flatter after reclamation has virtually no effect on the volume of subsurface flow.

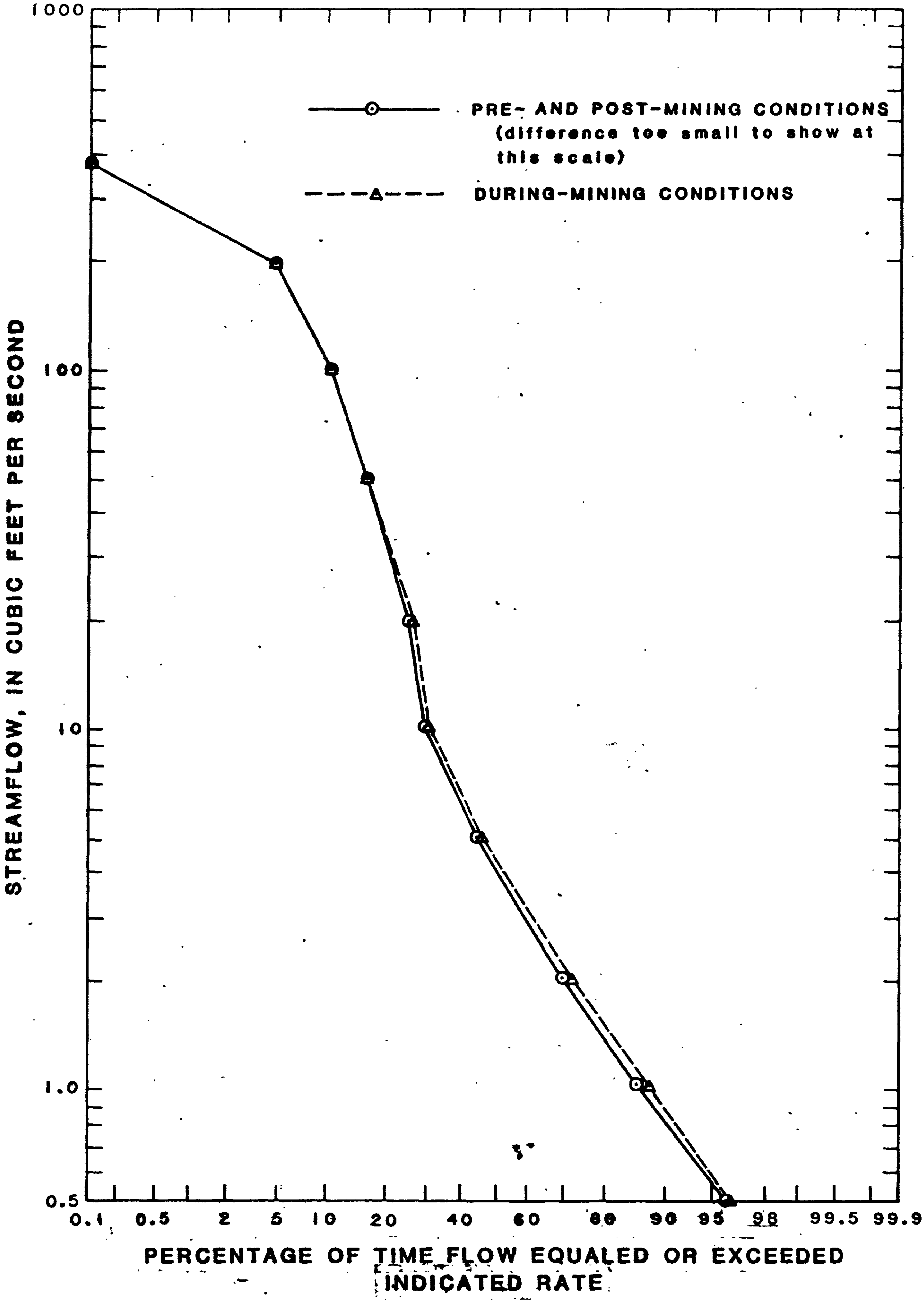

Figure 8.--Duration curves of simulated flows in Caballo Creek at station BA-4 from rain of April 15-May 31, 1978 for pre-, during-, and post-mining conditions.

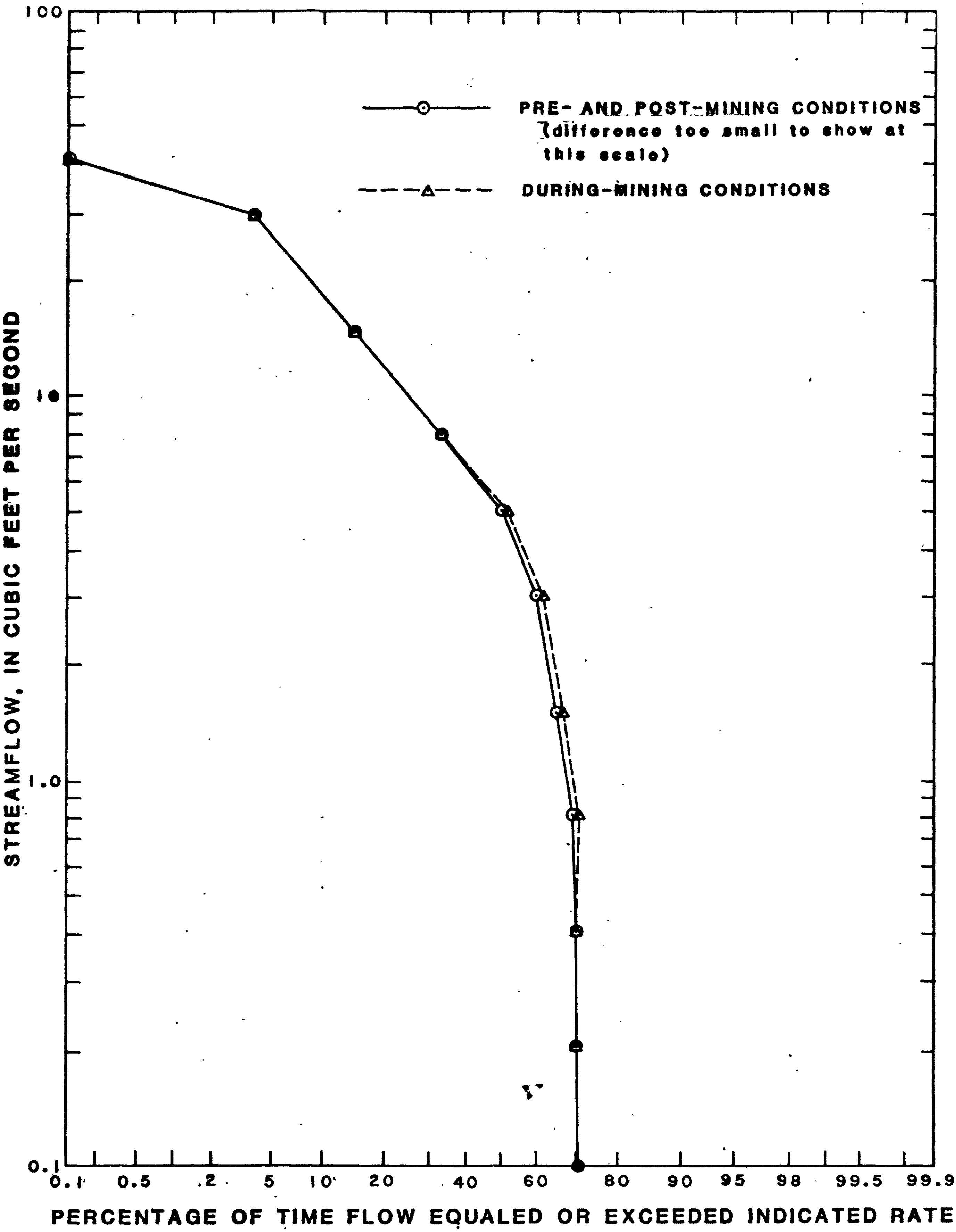

Figure 9.--Duration curves of simulated flows in Caballo Creek at station BA-4 from rain of May 1-31, 1982 for pre-, during-, and post-mining conditions.

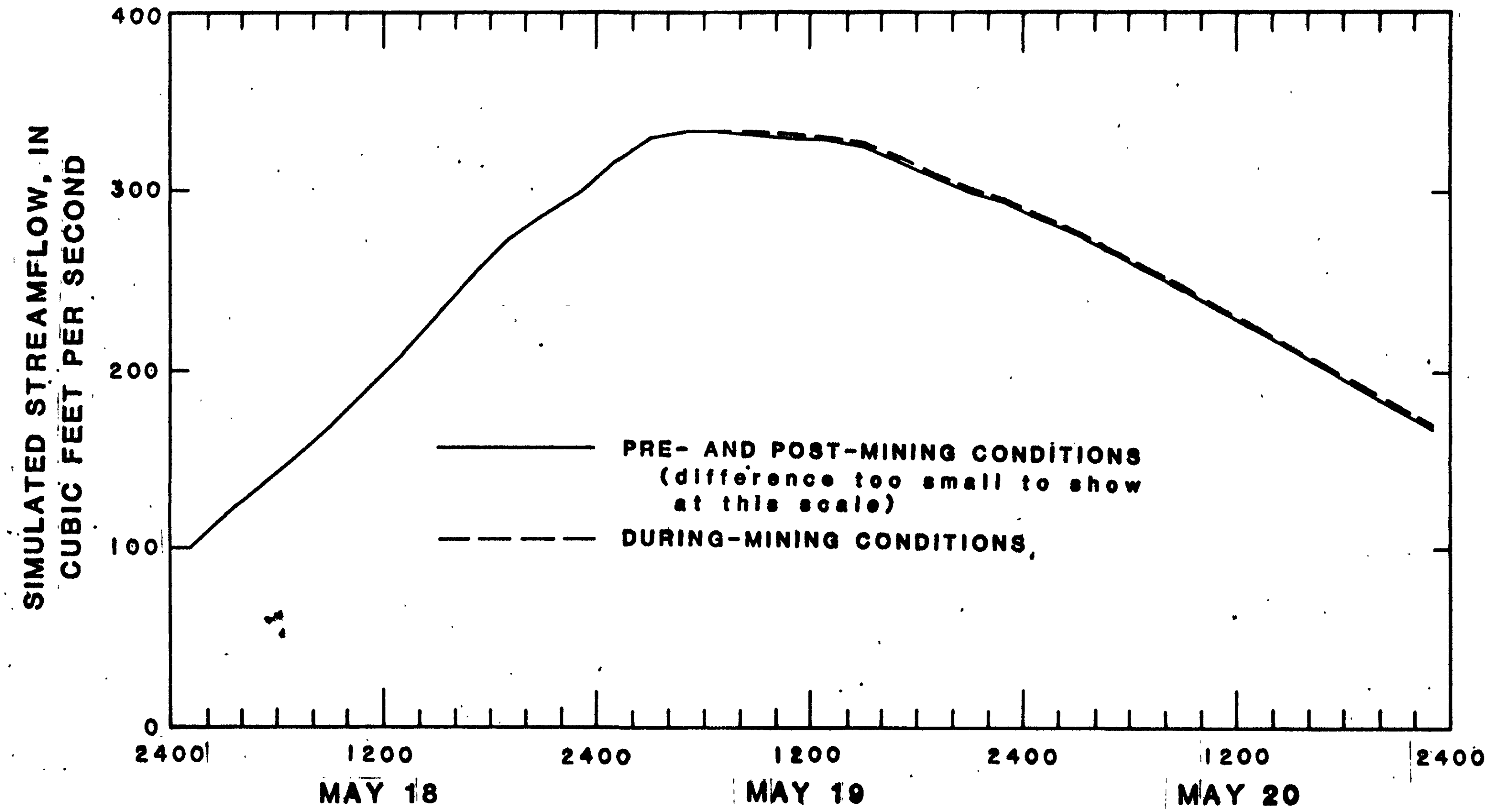

Figure 10.--Hydrographs of simulated streamflows in Caballo Creek at station BA-4 during days of highest flow from rain of May 1978 for pre-, during-, and post-mining conditions.

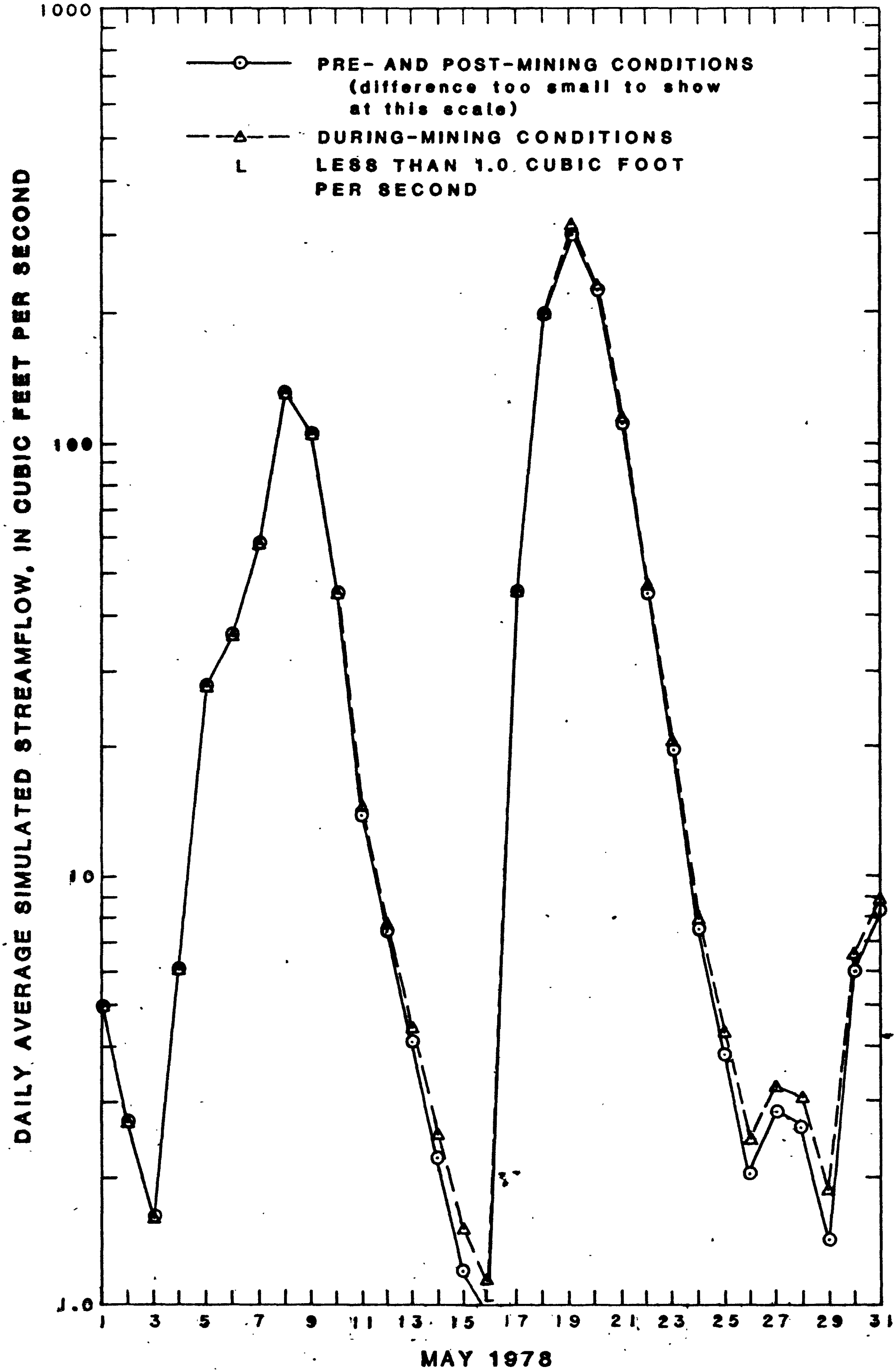

Figure 11.--Hydrographs of simulated streamflows in Caballo Creek at station BA-4 from rain of May 1978 for pre-, during-, and post-mining conditions.

The simulations also show very little change between pre-mining and during-mining conditions with 2.2 square miles mined and not yet reclaimed. There is virtually no change in the high-flow hydrograph (fig. 10), and little change in the daily mean flows (fig. 11). The small change is attributable to the small fraction of the drainage basin in a disturbed condition at any one time (slightly more than 1 percent) and the effect of the sedimentation ponds in detaining runoff. The magnitude, or even the direction of the change, indicated by the model are not meaningful because the characteristics of the sedimentation ponds were not modeled in detail. The slight increase in simulated flow resulted from the decrease in recharge to a deep aquifer (DEEPFR) which, in retrospect, does not appear justified. Future studies will attempt to determine whether any change in DEEPFR should be used in during-mining conditions. The results do indicate that the change in streamflow for the conditions simulated is too small to have any measurable effects.

SUMMARY AND CONCLUSIONS

The Surface Mining Control and Reclamation Act of 1977 and the Wyoming Department of Environmental Quality Rules and Regulations require the Department of Environmental Quality to assess the probable cumulative impacts on the hydrology of the appropriate drainage basin each time there is an application for a permit to mine. The Powder River structural basin in Wyoming is a specific basin where the Department of Environmental Quality is required to assess cumulative impacts of mining because of existing and pending applications for permits to mine coal. The U.S. Geological Survey, in a cooperative effort with the Wyoming Department of Environmental Quality, is making the cumulative-impact assessment. For the purposes of this study the assumption was made that the principal impacts on the ground-water system due to mining will occur in the relatively shallow aquifers. A further assumption was that the shallow aquifers can be divided into three relatively homogeneous aquifers, namely, the coal, the overburden and the underburden. The coal aquifer referred to here is the Wyodak-Anderson coal.

In the development of a conceptual model of the ground-water system of the study area, the principal component of ground-water flow is assumed to be horizontal. The general direction of flow is from south to north.

A surface-water model of the Caballo Creek drainage was developed to help assess the impacts of mining activities on streamflow. The Hydrological Simulation Program-Fortran model was used in the study. The Caballo Creek drainage was divided into 10 land segments and 6 stream reaches in the modeling process.

Due to data limitations, the model was not verified. After model calibration, three simulations were made for April-May 1978, and May 1982. The first simulation was for natural or pre-mining conditions. The second simulation was for during-mining conditions wherein a total of 2.2 square miles of mined area was disturbed and not yet reclaimed. The third simulation was for post-mining conditions wherein a total of 13 square miles of drainage area was reclaimed.

The simulations show little, if any, change in streamflow between pre- and post-mining conditions and very little change between pre-mining and during-mining conditions. The principal reasons for the absence of change are the small fraction of drainage basin that is mined and the rapid rate of infiltration used in this model for all 3 conditions, which nearly precludes surface runoff, even from a monthly total rainfall of 8 to 10 inches, as in May of 1978, or from an intense downpour of 1.03 inches in 1 hour as on May 27, 1982.

Use of the surface-water model for Caballo Creek has revealed some methods by which improvements of the model can be made. With these improvements, evaluation of the hydrologic impacts of surface mining could be made with greater confidence. Improvements can be made by the following methods: (1) Compile available data for more periods of precipitation and runoff so that model verification could be done in addition to calibration. Such compilation may be possible in the next phase of the project. (2) Perform sensitivity analyses with the model in order to evaluate the effect of parameter errors on the determination of impacts. A limited amount of sensitivity analyses of selected parameters is planned for the next phase of this project. (3) Although this study is focused on cumulative hydrologic impacts, calibration of the model for small drainages within mined areas would provide better understanding of the hydrology and the degree of allowable adjustment of model parameters. Completion of existing data and collection of new data for such a calibration cannot be accomplished within the present project.

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