SIMULATION OF STREAMFLOW IN SMALL DRAINAGE BASINS IN THE SOUTHERN YAMPA RIVER BASIN, COLORADO

By R.S. Parker and J.M. Norris

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 88-4071

Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

Denver, Colorado
1989

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Federal Center
Denver, CO 80225-0046

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CONVERSION FACTORS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Sea level: In this report "sea level" refers to the 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 "Sea Level Datum of 1929."

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ABSTRACT

Coal mining operations in northwestern Colorado commonly are located in areas that have minimal available water-resource information. Drainage-basin models can be a method for extending water-resource information to include periods for which there are no records or to transfer the information to areas that have no streamflow-gaging stations. To evaluate the magnitude and variability of the components of the water balance in the small drainage basins monitored, and to provide some method for transfer of hydrologic data, the U.S. Geological Survey's Precipitation-Runoff Modeling System was used for small drainage basins in the southern Yampa River basin to simulate daily mean streamflow using daily precipitation and air-temperature data. For all of the drainage basins except one, period of record used for calibration and verification included water years 1976-81.

The study area was divided into three hydrologic regions, and in each of these regions, three drainage basins were monitored. Two of the drainage basins in each region were used to calibrate the Precipitation-Runoff Modeling System. The model was not calibrated for the third drainage basin in each region; instead, parameter values from the calibrated models were used in the uncalibrated model for the third drainage basin.

Simulated annual volumes of streamflow for drainage basins used in calibration compared well with observed annual values. The difference between observed and simulated annual streamflow volumes ranged from 0.03 to 1.22 inches, although the prediction errors were as large as 100 percent for small streamflow volumes. Individual streamflow hydrographs indicated timing differences between observed and simulated daily mean streamflow. Observed and simulated annual average streamflows compared well for the periods of record; but, values of simulated high and low streamflows differed substantially from observed values. Similar results were obtained when calibrated parameter values were transferred to drainage basins that were uncalibrated. The difference between observed and simulated annual streamflow volumes for the model with transferred parameters ranged from 0.0 to 1.38 inches per year.

INTRODUCTION

The Nation's demand for energy has increased the need for coal. As a result, coal mining has increased in Colorado and particularly in the Yampa River basin of Colorado. Much of the mining is in the southern part of the Yampa River basin at lower elevations.

The major source of water in northwestern Colorado is the high-elevation mountains east and south of the Yampa River valley. Water from these high mountain areas flows through the more arid valley. In the past, streamflow-gaging stations were operated on tributaries that drain the high mountain areas and on the main stem of the Yampa River. Streamflow gaging of tributaries in the more arid valley virtually was ignored.

Coal mining in the southern Yampa River basin generally is concentrated in small drainage basins in the arid valley where there are few streamflow-gaging stations. Mining companies and government agencies have been concerned about the effects of mining on the water resources, and they also have been concerned about the availability of water for mining-related activities and other uses. However, because the tributaries in these small drainage basins generally were ungaged and because streamflow characteristics can be derived only after some years of measuring streamflow at appropriate sites, a streamflow-gaging program for the small drainage basins was needed to identify these characteristics. Measurements made in one drainage basin may be useful in answering questions about the water resource in that specific basin, but it is not known whether these data would be useful or appropriate for other similar drainage basins that are several miles away and for which no streamflow measurements are available. Therefore, a technique was needed to assess the water resources in gaged drainage basins and to provide a mechanism to transfer these data to ungaged drainage basins. These capabilities are available in the Precipitation-Runoff Modeling System (PRMS) (Leavesley and others, 1983). This modeling system enables an evaluation of the magnitude and variability of the components of the water balance in the drainage basins monitored and provides some mechanism for transfer of hydrologic data.

This study was done in cooperation with the U.S. Bureau of Land Management, which manages much of the Federal land and coal reserves in the study area. The water-resource information is needed so that the U.S. Bureau of Land Management can assess the effects of coal mining in the small drainage basins. Therefore, the study was done to: (1) Determine drainage basin characteristics and calibrate PRMS for simulating streamflow in drainage basins monitored in the program, and (2) assess the transferability of model parameters within the southern Yampa River basin.

The purposes of this report are to:

1. Describe the methods used in the study.
2. Describe the drainage basins monitored.
3. Describe the model results for these drainage basins.
4. Describe the applicability of the model to additional monitored basins and to assess transferability of model parameters.

Three drainage basins were monitored in each of three hydrologic regions in the study area. Two drainage basins in each region were used to calibrate and verify PRMS and to assess hydrologic variability. The third drainage basin in each region was not calibrated but was used to test the transferability of model parameters in the particular region. For all of the drainage basins except one, period of record used for calibration and verification included water years 1976-81.

DESCRIPTION OF STUDY AREA AND DRAINAGE BASINS USED IN STREAMFLOW SIMULATION

The study area is in Moffatt, Routt, and Rio Blanco Counties and includes the Yampa River valley south of the Yampa River main stem (fig. 1). The area is bounded on the east by the Oak Creek drainage and its confluence with the Yampa River. Upstream from this confluence, the drainage basin primarily is bounded by high mountains composed of igneous and metamorphic rock; therefore, minimal coal mining occurs in this upland area. The study area is bounded on the southwest by the Danforth Hills, a topographic high on the southwestern side of the Axial basin (fig. 1). Coal has been mined in the Danforth Hills for many years, and speculation of additional coal mining occurring in the area persists.

Between these boundaries, the southern valley of the Yampa River has quite diverse hydrologic environments. Unfortunately, the number of streamflow-gaging stations that could be installed was limited by economic considerations. Therefore, the study area was qualitatively divided into three hydrologic regions (fig. 1). In each region, streamflow-gaging stations were established to monitor streamflow in three small drainage basins.

The three hydrologic regions were differentiated primarily by annual precipitation totals. However, such factors as vegetative type and density indicate the change in precipitation and provide a visual index of the change in the quantity of moisture. A general decrease in precipitation occurs from east to west in the study area. Thus, the three hydrologic regions generally are oriented east to west (fig. 1). The dominant form of precipitation is snow, and the quantity of annual precipitation is affected by elevation.

Few long-term precipitation stations exist in the southern Yampa River basins; available stations generally are located in the valley at lower elevations. The general east-west trend of precipitation change is indicated by long-term precipitation data collected at Steamboat Springs and at Hayden (National Climatic Data Center, 1983, p. 5 and 7). The long-term average precipitation between 1951 and 1980 was 23.30 in. at Steamboat Springs (elevation 6,770 ft) and 15.90 in. at Hayden (elevation 6,375 ft), about 20 mi west of Steamboat Springs. Average precipitation for the same 30-year period was 17.59 in. at Hamilton (elevation 6,230 ft), 15 mi south of Craig. Other precipitation stations in the study area did not have sufficient records to calculate a long-term average; however, a map of normal annual precipitation for Colorado has been developed using all data from 1951 through 1980 (U.S. Weather Bureau, 1985). This map indicates about 12 in. of annual precipitation at Maybell, at the western edge of the study area. From these data, an approximate 11-in. change in precipitation has been calculated along the Yampa River main stem, from the eastern to the western edge of the study area.

Much of the area of the southern valley of the Yampa River basin is not classified in a hydrologic region (fig. 1); this area includes the Williams Fork drainage basin and the upper reaches of Milk Creek. Data collection from small drainage basins in these areas was not part of the scope of this study.

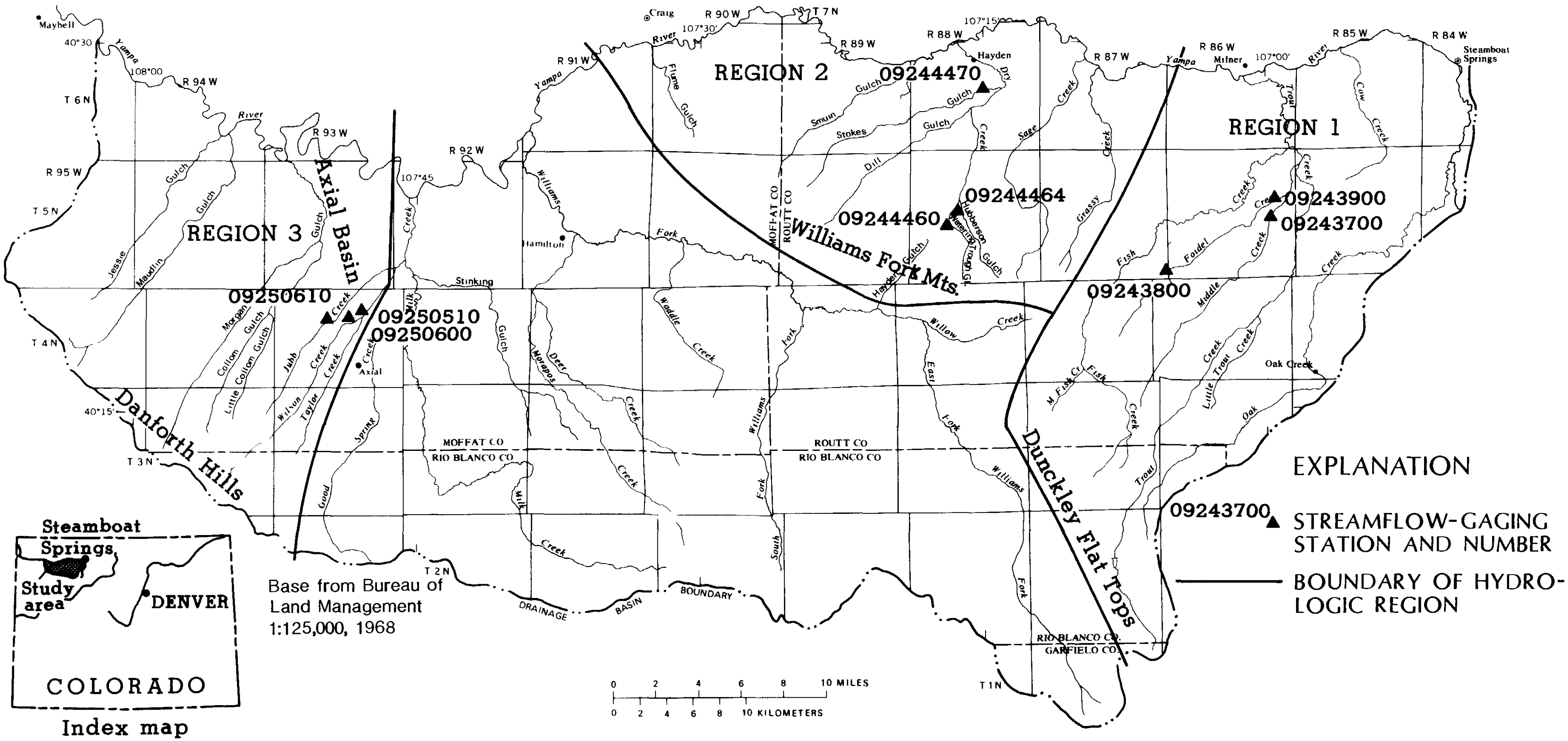

Figure 1.--Southern Yampa River basin, northwestern Colorado, and locations of hydrologic regions and selected streamflow-gaging stations.

The distribution of precipitation is divided almost evenly among the four seasons of the year. At the National Weather Service precipitation station at Hayden, 27 percent of the average annual precipitation for a 30-year period (1951-80) occurs during December, January, and February (National Climatic Data Center, 1983, p. 2). An additional 25 percent of the average annual precipitation occurs during March, April, and May. About 24 percent of the average annual precipitation occurs during each of the periods of June, July, and August; and September, October, and November.

The seasonal distribution of annual precipitation does not change greatly with increasing elevation. The gage at Pyramid is at an elevation of 8,009 ft, and the winter and spring average annual precipitation is 28 percent each of the total. The summer and fall average annual precipitation is 22 percent each of the total.

Although precipitation is somewhat evenly distributed throughout the year, runoff from the small drainage basins in the study area primarily occurs during the spring. At streamflow-gaging station Foidel Creek at mouth near Oak Creek (09243900), 88 percent of the annual total runoff occurred during the spring from 1976 through 1981. An additional 8 percent of the annual total runoff occurred during the summer. Four percent of the annual total runoff occurred during the fall and winter.

Late fall and winter precipitation is stored as snow and released as snowmelt during the spring. Spring snow and rain augment the melting snowpack. Runoff during the summer primarily is a continuation of the spring snowmelt. Precipitation during the summer and fall generally does not occur as runoff downstream because much of this precipitation replenishes deficits in the soil moisture. Thus, the precipitation-runoff system in these small drainage basins begins with storage of moisture by snowpack accumulation during the fall and winter, followed by a release of this water into the soil, into the ground-water reservoirs, and to surface runoff during the spring and summer.

Region 1

Region 1 of the three hydrologic regions (fig. 1) includes the upper reaches of Oak Creek and Trout Creek, the tributaries of Trout Creek, and Cow Creek. In this region, drainage-basin divides generally are 8,000 ft or higher. For example, the headwaters of Fish Creek, a tributary of Trout Creek, are in the Dunckley Flat Tops and have a maximum elevation of 10,000 ft. The precipitation map (U.S. Weather Bureau, 1985) indicates that total annual precipitation in region 1 is about 20 to 35 in. These drainage basins have elevations between 6,500 and 7,000 ft in the low valleys. Annual precipitation in the lower valley areas is about 20 in. Higher elevations develop a fairly deep snowpack, and the effect of the increase in precipitation is indicated by large stands of aspen. Runoff is derived from high- and low-elevation areas. Depending on the particular spring melt sequence, two separate runoff peaks may be identified on a hydrograph. Melt from the lower elevations causes an initial runoff peak, and melt from higher elevations can lag by as much as 1 month. A single- or multiple-peaked snowmelt-runoff hydrograph may result depending on spring weather patterns.

In region 1, the drainage basins were monitored by streamflow-gaging stations (table 1): Middle Creek near Oak Creek (09243700), Foidel Creek near Oak Creek (09243800), and Foidel Creek at mouth near Oak Creek (09243900). Foidel and Middle Creeks are roughly parallel and contiguous (fig. 1). The elevation of headwaters of both drainage basins are at or above 8,000 ft. The predominant vegetative cover in the upper areas of both drainage basins is aspen (table 1). No coal mining occurred in the drainage basin upstream from Foidel Creek near Oak Creek (09243800) during the data-collection period (1976-79), but mining commenced during 1980. Coal mining was ongoing in the downstream part of the Foidel Creek drainage basin during the total data-collection period, and may have affected flow at Foidel Creek at mouth near Oak Creek (09243900). Virtually no coal mining occurred in the Middle Creek drainage basin.

In region 1, the two streamflow-gaging stations used in calibration and verification were Foidel Creek near Oak Creek (09243800) and Foidel Creek at mouth near Oak Creek (09243900). The upstream gaging station monitors about one-half the drainage area of Foidel Creek. The streamflow-gaging station, Middle Creek near Oak Creek, was used to evaluate the transferability of the model parameters within the region. Two precipitation stations were used to provide additional data about the three drainage basins in region 1. One precipitation station near the mouth of Foidel Creek was at 6,730 ft, and the other station on the divide between Middle and Foidel Creeks was at 8,050 ft.

Region 2

Region 2 generally is located south of Hayden and west to Craig (fig. 1) and includes Grassy, Sage, and Dry Creeks; the tributaries of Dry Creek, such as Hubberson, Watering Trough, Stokes, and Dill Gulches; and the other small tributaries that drain north directly to the Yampa River. These drainage basins have headwaters in a series of low-lying hills, called the Williams Fork Mountains, between the Yampa River and the Williams Fork. The elevation of these hills ranges from about 7,000 to 7,600 ft, but some peaks are as high as 8,000 ft. The precipitation map (U.S. Weather Bureau, 1985) indicates that total annual precipitation in the Williams Fork Mountains is about 20 in. Drainage basins in region 2 have limited highlands, and descend rapidly to the valley areas. The valleys have elevations between 6,480 and 6,800 ft. The total annual precipitation in the lower elevations is about 16 in., and is similar to that at Hayden. Because these drainage basins have large areas at lower elevations, total annual precipitation generally is less than in region 1. Region 2 has some dryland farming in the valleys.

In region 2, the drainage basins were monitored by streamflow-gaging stations (table 1): Watering Trough Gulch near Hayden (09244460), Hubberson Gulch near Hayden (09244464), and Stokes Gulch near Hayden (09244470). Hubberson and Watering Trough Gulches are contiguous and they are upstream from Stokes Gulch on Dry Creek (fig. 1). The predominant vegetative cover in these two drainage basins is oak and sage. Almost 60 percent of the land use in Stokes Gulch drainage basin is dryland farming (table 1).

Table 1.--*Physical characteristics of monitored drainage basins*

[mi^2, square miles; ft, feet]

Streamflow-gaging-station name and number	Drainage area (mi^2)	Highest elevation (ft)	Lowest elevation (ft)	Percent vegetative cover				
				Oak	Sage	Aspen	Farm	Mine
DRAINAGE BASINS IN REGION 1								
Middle Creek near Oak Creek (09243700)[1].	23.5	9,000	6,720	28	29	43	0	0
Foidel Creek near Oak Creek (09243800)[2].	8.61	8,285	6,920	9	35	56	0	0
Foidel Creek at mouth near Oak Creek (09243900)[2].	17.5	8,285	6,720	9	39	27	8	17
DRAINAGE BASINS IN REGION 2								
Watering Trough Gulch near Hayden (09244460)[1].	2.65	5,070	6,780	62	38	0	0	0
Hubberson Gulch near Hayden (09244464)[2].	8.08	8,400	6,800	58	42	0	0	0
Stokes Gulch near Hayden (09244470)[2].	13.6	7,903	6,400	28	13	0	59	0
DRAINAGE BASINS IN REGION 3								
Taylor Creek at mouth near Axial (09250510)[1].	7.22	8,380	6,350	45	35	20	0	0
Wilson Creek near Axial (09250600)[2].	27.4	8,680	6,350	43	31	26	0	0
Jubb Creek near Axial (09250610)[2].	7.53	8,421	6,400	27	58	15	0	0

[1]Not calibrated, but used to assess transferability of model parameters.
[2]Calibrated and verified.

In region 2, the two streamflow-gaging stations used in calibration and verification were Hubberson Gulch near Hayden (09244464) and Stokes Gulch near Hayden (09244470). Watering Trough Gulch near Hayden (09244460) was not calibrated but was used to evaluate the transferability of the model parameters within the region. One precipitation station was used in this region and the data were obtained from the National Weather Service station at Hayden.

Region 3

Region 3 is south and west of Craig (fig. 1) and includes a series of roughly parallel streams that drain from the Danforth Hills--Taylor, Wilson, and Jubb Creeks and Collum and Morgan Gulches. Drainage basins in this region typically have drainage divides in the Danforth Hills, where elevations are about 8,000 ft, although some peaks are as high as 8,800 ft. Streams in this region drain from these higher elevations into the Axial basin, where the elevation is about 6,500 ft in the central area. The Axial basin is very dry; the precipitation map (U.S. Weather Bureau, 1985) indicates that total annual precipitation is 12 in. In this region, drainage-basin divides have elevations comparable to drainage-basin divides in region 1; snowpacks also are comparable at similar elevations. Large areas of these drainage basins are in intermediate valleys and have elevations of about 7,000 ft, which accumulate much less snow than areas at higher elevations. Lower elevations in region 3 are drier than those in region 1, and a greater change of precipitation with elevation occurs in region 3. An early runoff peak may occur in February or March from melting snow in the lower elevations, and secondary runoff peaks from melting snow in the higher elevations may occur in May or June. Lower elevations have complexities in water balances caused by increased evapotranspiration and storage of water in alluvial aquifers.

In region 3, the drainage basins were monitored by streamflow-gaging stations (table 1): Taylor Creek at mouth near Axial (09250510), Wilson Creek near Axial (09250600), and Jubb Creek near Axial (09250610). The three streams are roughly parallel, and the drainage basins are contiguous (fig. 1). Considerably more streamflow occurs throughout the year in the Wilson Creek drainage basin than in most of the other drainage basins in the region, partly because of its larger drainage area, much of which is above 8,000 ft. The larger total area with vegetation primarily of aspen in the Wilson Creek drainage basin (table 1), compared to the other drainage basins in this region, indicates a wetter environment.

Wilson Creek near Axial (09250600) and Jubb Creek near Axial (09250610) were the two streamflow-gaging stations used for calibration and verification in region 3. Taylor Creek at mouth near Axial (09250510) was used to evaluate the transferability of the model parameters within the region. Only one precipitation station was used to provide additional data about the three drainage basins in this region. This station was located near the mouth of Wilson Creek at 6,520 ft. Additional precipitation data were available from the divide of Wilson Creek at 8,000 ft, but the data were not used directly in the model.

DESCRIPTION OF MODEL AND SEQUENCE OF STREAMFLOW SIMULATION ANALYSIS

The PRMS model used in this study is a modeling system developed in modules to enable flexibility in a variety of uses (Leavesley and others, 1983). PRMS was used in this study because it is a distributed-parameter model that accounts for the spatial and temporal variation in hydrologic characteristics within the drainage basins. Although the modeled drainage basins are small, elevation differences can be substantial, and changes in precipitation can be dramatic. The variety of vegetation types within the drainage basins indicates the variability in precipitation. PRMS also has snow accumulation and snowmelt algorithms, and for drainage basins in this study area the primary input to the water balance is snow.

Characteristics of a drainage basin are distributed in this modeling system by dividing the drainage basin into hydrologic response units (HRU's). In theory, these HRU's represent homogeneous areas in the drainage basin that have a uniform and characteristic response to hydrologic input. Dividing the drainage basin into HRU's enables variation in such factors as different infiltration rates resulting from changes in soils, different precipitation input resulting from changes in elevation, or different evapotranspiration rates resulting from changes in vegetation. In practice, HRU's can be difficult to describe because sufficient information about the drainage basin is not always available. The designation of HRU's is based on features that can be observed from aerial photographs and from topographic and soils maps and from general observations of vegetation, elevation, slope, and aspect.

PRMS, as used in this study, requires daily precipitation and daily maximum and minimum air temperature as input data. A schematic diagram of the watershed system used in PRMS is shown in figure 2. The model computes a daily water balance using values of net precipitation, adjusted maximum and minimum air temperature based on the elevation of the HRU, interception, solar radiation, potential and actual evapotranspiration, soil-moisture content, subsurface and ground-water reservoir contents, and water equivalent in the snowpack. Daily mean streamflow for the drainage basin is computed from an area-weighted average of these water-balance computations.

Daily solar shortwave radiation that is needed to compute the energy balance of the snowpack is estimated from air-temperature data using the method developed for a part of the Rocky Mountains and described by Leaf and Brink (1973). The daily solar shortwave radiation is adjusted for the particular slope and aspect of each HRU and for the time of year at the specific latitude of each HRU (Frank and Lee, 1966).

Daily potential evapotranspiration is computed for each HRU using the Jensen-Haise technique (Jensen and Haise, 1963). Actual evapotranspiration then is estimated for each HRU from the potential evapotranspiration and the available soil moisture.

Within each HRU, an accounting of soil moisture is maintained in PRMS. Water is added from rainfall and snowmelt and water is lost through evapotranspiration and seepage to subsurface and ground-water reservoirs. The maximum available water-holding capacity of the soil profile is the difference

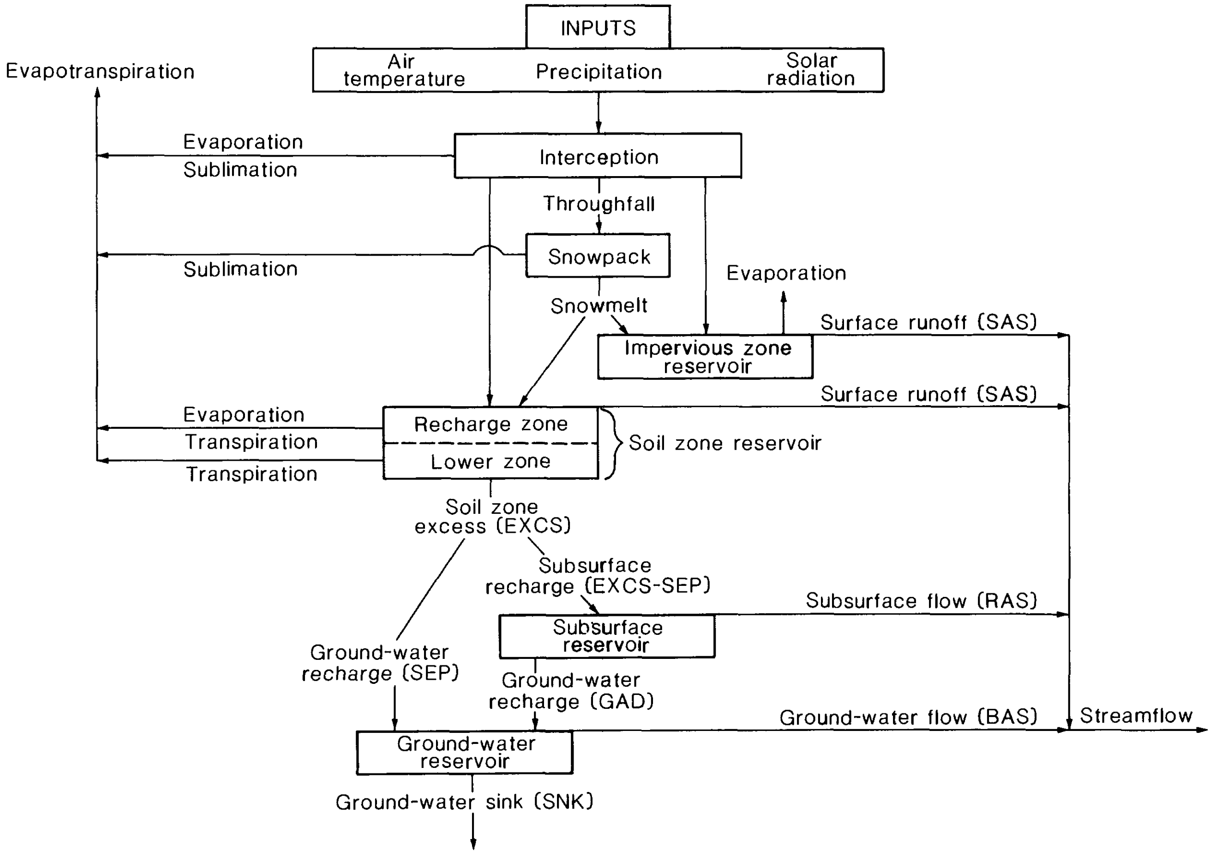

Figure 2.--Conceptual drainage-basin system and its inputs (Leavesley and others, 1983).

between field capacity and the wilting point. Water from snowmelt is assumed to infiltrate into the soil up to a maximum specified quantity per day, and any quantity greater than this maximum becomes surface runoff. When the maximum water content of the soil profile is exceeded, the excess water is routed to surface runoff or to subsurface and ground-water reservoirs.

Snowpack computations are done for each HRU using the energy-balance method developed by Obled and Rosse (1977). Snowpack accumulation, evaporation and sublimation, water content, and melt are calculated for each day.

To transfer parameter values to other drainage basins, model parameters are categorized by the method in which they will be determined (L.G. Saindon and J.J. Vacarro, U.S. Geological Survey, written commun., 1985). Model parameters and their respective definitions for three different categories (1, 2, and 3) are listed in table 2. Category 1 includes nondistributed parameters that are determined from regional climatic characteristics. These parameters may be defined using long-term climatic data. Within the context of this study, category 1 parameters do not change in the hydrologic regions. To transfer values to an ungaged drainage basin, values for the particular hydrologic region are used.

Table 2.--*Model parameters and definitions*

[Based on categories from L.G. Saindon and J.J. Vacarro (U.S. Geological Survey, written commun., 1985)]

Parameter	Definition
	CATEGORY 1--NONDISTRIBUTED PARAMETER VALUES THAT ARE DETERMINED MAINLY FROM REGIONAL CLIMATIC CHARACTERISTICS AND THAT APPLY TO AN ENTIRE DRAINAGE BASIN OR REGION
BST----------	Base air temperature above which precipitation is considered rain and below which precipitation is considered all snow.
CTS----------	Air temperature-evapotranspiration coefficient for use in Jensen-Haise equation.
CTW----------	Proportion of potential evapotranspiration that may be sublimated from a snow surface.
DENI----------	Initial density of new-fallen snow.
DENMX---------	Average maximum-snowpack density.
FWCAP---------	Free water-holding capacity of snowpack.
PAT----------	Maximum air temperature that, when it is exceeded, causes spring and summer precipitation to be rain.
SETCON--------	Snowpack-settlement time constant.
TLX/TLN-------	Lapse rate for maximum/minimum daily air temperature.
TST----------	Temperature index to determine beginning date of transpiration.
	CATEGORY 2--VALUES FOR PARAMETERS DISTRIBUTED BY HYDROLOGIC RESPONSE UNITS (HRU's); DETERMINED FROM PHYSICAL CHARACTERISTICS, SOILS, AND VEGETATION ON EACH UNIT.
COVDNS/COVDNW-	Summer/winter vegetative cover density.
CTX----------	Air temperature-evapotranspiration coefficient used in Jensen-Haise equation.
ICOV----------	Predominant vegetative cover type (bare, grass, shrubs, trees).
ISOIL---------	Soil type (clay, loam, sand).
REMX----------	Maximum available water-holding capacity of soil recharge zone.
RNSTS/RNSTW---	Summer/winter interception storage capacity of major vegetation for rain.
SCX/SCN-------	Maximum/minimum area contributing to surface runoff as a proportion of HRU area.
SMAX----------	Maximum available water-holding capacity of soil profile.
SNST----------	Interception storage capacity of major vegetation for snow.
SRX----------	Maximum daily snowmelt infiltration capacity of soil profile.
TXAJ/TNAJ-----	Adjustment for maximum/minimum air temperature for slope and aspect.
TRNCF---------	Transmission coefficient for solar radiation through the vegetative canopy.
	CATEGORY 3--PARAMETERS DISTRIBUTED BY SUBSURFACE OR GROUND-WATER RESERVOIRS.
RCB----------	Ground-water routing coefficient.
RCF, RCP------	Subsurface-flow routing coefficients.
SEP----------	Coefficient for determining seepage from subsurface reservoirs to ground-water reservoirs.

Category 2 includes parameters distributed by HRU's in a particular drainage basin (table 2). These parameters are determined from the physical characteristics in a particular HRU. To transfer values, data for these parameters can be obtained from aerial photographs, maps, or from direct observation of soils and vegetation in the drainage basin.

Category 3 includes parameters distributed by subsurface or ground-water reservoirs. These parameters affect the timing and quantity of simulated streamflow and indicate the flow paths of the various sources of streamflow (for example, surface water or ground water). In ungaged drainage basins, values of these parameters may be difficult to obtain. In gaged drainage basins, values of these parameters can be derived mathematically from the hydrograph.

In each region, an analysis was done using PRMS for the two basins to be calibrated. Following analysis, the parameters that were indicated as most sensitive were then optimized to obtain the best fit of simulated to observed streamflow. After calibration, these optimized parameters were used for verification.

To enable calibration and verification, the period of record for each drainage basin was divided into two parts. The first part was used for calibration, and the second part was used for verification. In all of the drainage basins except Hubberson Gulch, the total period of record included water years 1976-81. In all basins except Hubberson Gulch, water year 1976 was used as an initialization period, water years 1977-79 were used as the calibration period, and water years 1980-81 were used as the verification period. For streamflow-gaging station Hubberson Gulch near Hayden (09244464), data were available for only 3 water years. Because of the short period of record, no initialization period was used, and water years 1979-80 were used as the calibration period and water year 1981 was used as the verification period.

The third drainage basin in each hydrologic region was not used for calibration and verification. These drainage basins were used to evaluate the error that resulted from transferring the model parameters to a nearby drainage basin. Parameter values for these drainage basins were obtained from the calibrated drainage basins, and the specific methods used in transferring these parameter values will be described in the "Assessing Transferability of Model Parameters" section of this report.

RESULTS OF CALIBRATION

To select parameters for model calibration, sensitivity analyses were done on a number of sets of parameters. The most sensitive parameters then were optimized using methods developed by Norris and Parker (1985) and using the Gauss-Newton technique (Leavesley and others, 1983, p. 49).

Sensitivity Analysis

Results of the sensitivity analysis are listed in table 3. Sensitivity is defined as the change in error variance resulting from a 10-percent change in the value of the parameter. In table 3, the error variance between observed and simulated daily streamflow and the increase in that variance for a 10-percent change in the particular parameter are listed for each station. The most sensitive parameters for all six drainage basins used for calibration and varification were divided almost equally between category 1, parameters from regional climatic characteristics, and from category 2, parameters determined from physical characteristics within individual HRU's.

Two parameters from category 1 (table 2) are sensitive in all six drainage basins. The first parameter is CTS, the air temperature-evapotranspiration coefficient used in the Jensen-Haise equation (Leavesley and others, 1983, p. 20). CTS affects the volume of water lost to evapotranspiration and, because of the resulting soil-moisture deficits, affects the volume of surface runoff.

The second parameter from category 1 that is sensitive in all six drainage basins is BST, the air temperature above which precipitation is considered all rain and below which precipitation is considered all snow (Leavesley and others, 1983, p. 13). BST is particularly important at the onset of spring snowmelt, although it is important for each storm occurrence. Precipitation is identified in the model as rain, snow, or a mixture, depending on the value of BST and the observed air temperature. Depending on the type of precipitation, large volumes of meltwater can leave the drainage basin in a short period of time or can be stored in the snowpack.

Two parameters from category 2 (table 2) that are determined from physical characteristics of the HRU's are sensitive in five of the six drainage basins. The first parameter is SMAX, the maximum available water-holding capacity of the soil profile. SMAX substantially affects the runoff component in the model. The effect of SMAX in the model's water balance was emphasized by Norris and Parker (1985), and a special optimization routine for calibration was developed for this parameter. The second sensitive parameter from category 2 is TRNCF, the transmission coefficient for shortwave radiation through the vegetative canopy (Leavesley and others, 1983, p. 42). TRNCF affects the energy budget in computations and, thus, the rate of snowmelt.

Optimization

Initial optimization was done using the parameter, SMAX, for all six drainage basins following the procedure described by Norris and Parker (1985). The objective function for this optimization was annual volume of streamflow, and parameter adjustment primarily resulted in changes in volume, although the timing of the water at the gage also was affected.

Table 3.--*Results of sensitivity analysis for each calibrated drainage basin*

[Increase in error variance results from a 10-percent change in parameter value]

Streamflow-gaging-station name and number	Parameter (see table 2)	Increase in error variance (cubic feet per second squared)
DRAINAGE BASINS IN REGION 1		
Foidel Creek near Oak Creek (09243800)--error variance is 5.35 cubic feet per second squared.	CTS	1.24
	SMAX	.97
	BST	.39
	TRNCF	.18
	TLX	.09
	SMAX	.97
Foidel Creek at mouth near Oak Creek (09243900)--error variance is 26.53 cubic feet per second squared.	BST	16.16
	SMAX	10.48
	TRNCF	10.08
	CTS	3.08
	PAT	2.57
DRAINAGE BASINS IN REGION 2		
Hubberson Gulch near Hayden (09244464)--error variance is 0.32 cubic foot per second squared.	TNAJ	.05
	COVDNW	.03
	CTS	.00
	RCB	.00
	BST	.00
Stokes Gulch near Hayden (09244470)--error variance is 0.41 cubic foot per second squared.	SMAX	.35
	BST	.18
	TRNCF	.06
	CTS	.02
DRAINAGE BASINS IN REGION 3		
Wilson Creek near Axial (09250600)--error variance is 0.27 cubic foot per second squared.	SMAX	.23
	BST	.23
	TRNCF	.06
	CTS	.04
	TLX	.03
Jubb Creek near Axial (09250610)--error variance is 0.32 cubic foot per second squared.	BST	.04
	SMAX	.02
	CTS	.01
	COVDNW	.01
	TRNCF	.00

After optimizing SMAX, all other sensitive parameters were optimized using the Gauss-Newton technique incorporated in the model (Leavesley and others, 1983, p. 48). The objective function in this part of the optimization was the sum of the squared differences between the observed and simulated daily mean streamflow. As such, streamflow timing had a substantial effect on the fitting of the included parameters. Optimized values for selected parameters are listed in table 11 in the "Supplemental Data" section at the back of the report.

The observed and simulated annual streamflow volumes for each of the six calibrated drainage basins after optimization are listed in table 4 for the calibration period. The volumes of streamflow are not large for any of the drainage basins, and the variability among water years in a specific drainage basin can be substantial. For example, at streamflow-gaging station, Stokes Gulch near Hayden (09244470), values of observed streamflow were 0 in. in 1977 and 2.10 in. in 1979. Small streamflow values and their variability make calibration of the model difficult.

An index of error is listed in table 4 by calculating the percent error between observed and simulated streamflow volumes. Because of the small values recorded, these percent errors can be extremely large and may not indicate the actual differences observed; therefore, the absolute difference between volumes of observed and simulated streamflow, in inches, also is listed in table 4.

RESULTS OF VERIFICATION

Values of observed and simulated annual streamflow volume for each of the six calibrated drainage basins for the verification period are listed in table 5. Values of the absolute differences between observed and simulated annual streamflow volume, in inches, are listed, and values of the percent error between observed and simulated annual streamflow volume also are listed; therefore, the calibration (table 4) and verification periods (table 5) can be compared. The two Foidel Creek streamflow-gaging stations in region 1 had values of absolute difference between observed and simulated annual streamflow volume that ranged from 0.10 to 0.87 in. for the calibration period (table 4). Values of absolute difference between observed and simulated annual streamflow volume ranged from 0.20 to 1.22 in. for the verification period (table 5).

Values of absolute difference between observed and simulated annual streamflow volume for Hubberson and Stokes Gulch streamflow-gaging stations in region 2 ranged from 0 to 1.21 in. for the calibration period (table 4). Values of the absolute difference between observed and simulated annual streamflow volume ranged from 0.08 to 0.32 in. for the verification period (table 5).

Values of absolute difference between observed and simulated annual streamflow volume for Wilson and Jubb Creek streamflow-gaging stations in region 3 ranged from 0 to 0.56 in. for the calibration period (table 4). Values of absolute difference between observed and simulated annual streamflow volume ranged from 0.03 to 0.41 in. for the verification period (table 5).

Table 4.--*Observed and simulated annual streamflow volumes and prediction errors for each calibrated drainage basin for the calibration period*

[in., inches; --, no data; ---, not applicable]

Streamflow-gaging-station name and number	1977				1978				1979				1980			
	Annual streamflow volume		Volume difference[1] (in.)	Percent error[2]	Annual streamflow volume		Volume difference[1] (in.)	Percent error[2]	Annual streamflow volume		Volume difference[1] (in.)	Percent error[2]	Annual streamflow volume		Volume difference[1] (in.)	Percent error[2]
	Observed (in.)	Simulated (in.)			Observed (in.)	Simulated (in.)			Observed (in.)	Simulated (in.)			Observed (in.)	Simulated (in.)		
DRAINAGE BASINS IN REGION 1																
Foidel Creek near Oak Creek (09243800).	0.03	0.13	-0.10	-333	1.26	1.67	-0.41	-33	2.02	1.20	0.82	41	---	---	---	---
Foidel Creek at mouth near Oak Creek (09243900).	.05	.16	-.11	-220	1.76	1.99	-.23	-13	2.09	1.22	.87	42	---	---	---	---
DRAINAGE BASINS IN REGION 2																
Hubberson Gulch near Hayden (09244464).	--	--	--	--	--	--	--	--	.01	.01	.00	0	1.87	1.99	-.12	-6
Stokes Gulch near Hayden (09244470).	.00	.00	.00	0	1.88	2.84	-.96	-51	2.10	.89	1.21	58	---	---	---	---
DRAINAGE BASINS IN REGION 3																
Wilson Creek near Axial (09250600).	.22	.15	.07	32	.54	.11	.43	80	1.93	1.85	.08	4	---	---	---	---
Jubb Creek near Axial (09250610).	.02	.06	-.04	-200	.01	.01	.00	0	.05	.61	-.56	-1,120	---	---	---	---

[1]Calculated as observed volume minus simulated volume.
[2]Calculated as observed volume minus simulated volume divided by observed volume, and rounded to nearest percentage.

Table 5.--*Observed and simulated annual streamflow volumes and prediction errors for each calibrated drainage basin for the verification period*

[in., inches; ---, not applicable]

Streamflow-gaging-station name and number	1980 Annual streamflow volume Ob-served (in.)	1980 Annual streamflow volume Simu-lated (in.)	1980 Volume differ-ence[1] (in.)	1980 Per-cent error[2]	1981 Annual streamflow volume Ob-served (in.)	1981 Annual streamflow volume Simu-lated (in.)	1981 Volume differ-ence[1] (in.)	1981 Per-cent error[2]
DRAINAGE BASINS IN REGION 1								
Foidel Creek near Oak Creek (09243800).	3.17	1.95	1.22	38	0.35	0.03	0.32	91
Foidel Creek at mouth near Oak Creek (09243900).	3.35	2.38	.97	29	.33	.13	.20	61
DRAINAGE BASINS IN REGION 2								
Hubberson Gulch near Hayden (09244470).	---	---	---	---	.16	.00	.16	100
Stokes Gulch near Hayden (09244470).	3.72	4.04	-.32	-9	.08	.00	.08	100
DRAINAGE BASINS IN REGION 3								
Wilson Creek near Axial (09250600).	2.14	1.73	.41	19	.48	.28	.20	42
Jubb Creek nèar Axial (09250610).	.69	.72	-.03	-4	.20	.17	.03	15

[1]Calculated as observed volume minus simulated volume.

[2]Calculated as observed volume minus simulated volume divided by observed volume, and rounded to nearest percentage.

These comparisons indicate minimal difference in the magnitude of errors in annual streamflow volumes between the calibration and verification periods for all six of the drainage basins. Calibration and verification periods have dry and wet years of record. Similar magnitude of errors in streamflow volumes seem to occur during the calibration and verification periods.

To assess further the results of the predictive capability of the model, an examination of some statistical properties was done. The values of observed and simulated annual average streamflow for the period of record for each of the six calibrated drainage basins are listed in table 6. By comparing absolute differences in streamflow, it seems that the model does quite well at predicting these annual average values. Part of this accuracy results because annual streamflow volume is the primary objective function of optimization and because of the smoothing that takes place by averaging volumes for dry and wet years.

Another statistic that is important in these semiarid drainage basins is the percentage of days in the year that the stream has zero flow (table 6). Comparison of the observed and simulated percent days of zero streamflow indicates that as the stream approaches a perennial situation (zero percent), the simulated values closely relate to the observed values. This is to be expected for the statistic loses its meaning in a truly perennial situation. For example, there is virtually no difference between observed and simulated percent days of zero streamflow for the Wilson Creek streamflow-gaging station. In the ephemeral situation, there is zero streamflow 83 percent of the time or more than 300 days a year for the observed record for the Stokes Gulch streamflow-gaging station. The absolute difference between the observed and simulated percentages was 3 percent. For the remainder of the streamflow-gaging stations listed in table 6, the observed percent of days of zero streamflow ranges from 36 to 57 percent, and the simulated values differ from the observed values by 16 to 37 percent. Thus, as the number of days zero streamflow approaches one-third to one-half of the year, the simulated percentages are less reliable.

Several factors affect these percentages. One factor is the small numbers involved. A stream in this study area can have very small streamflow values for many days before reaching zero streamflow. Observed streamflow was less than 0.50 ft^3/s at Foidel Creek at the mouth near Oak Creek (09243900) for much of the period from July through September 1979 before streamflow ceased. Because of these small values, it is difficult to predict the cessation of streamflow. A second factor that affects simulated percentages is that during September, the streamflow fluctuated between flow and zero flow. Because of this fluctuation, some of the lack of fit between observed and simulated streamflow results from the smoothing nature of the combination of algorithms in the model. The mathematics tend to average daily situations, and the random natural fluctuations are ignored. These two factors primarily result from the mathematics of the small numbers and have minimal effect on the calibration of the model. These factors could account for much of the difference between observed and simulated percent of days of zero streamflow.

Table 6.--*Statistical properties of annual average streamflow for each calibrated drainage basin for the period of record*

Streamflow-gaging-station name and number	Average streamflow for period of record[1] (cubic feet per second)			Days of zero streamflow (percent)		
	Observed	Simulated	Absolute difference	Observed	Simulated	Absolute difference
			DRAINAGE BASINS IN REGION 1			
Foidel Creek near Oak Creek (09243800).	0.86	0.63	0.23	57	77	20
Foidel Creek at mouth near Oak Creek (09243900).	1.97	1.53	.44	45	68	23
			DRAINAGE BASINS IN REGION 2			
Hubberson Gulch near Hayden (09244464).	.40	.39	.01	36	73	37
Stokes Gulch near Hayden (09244470).	1.66	1.56	.10	83	86	3
			DRAINAGE BASINS IN REGION 3			
Wilson Creek near Axial (09250600).	2.11	1.64	.47	0	.2	.2
Jubb Creek near Axial (09250610).	.11	.18	.07	45	29	16

[1]Period of record is water years 1976-81 for all streamflow-gaging stations except Hubberson Gulch near Hayden (09244464). For this station the period of record is water years 1979-81.

Additional difficulty in predicting low streamflows may be the result of a lack of appropriate algorithms in PRMS. The model does not include alluvial aquifers or the transfer of water into or out of such an aquifer during low-streamflow conditions. If this inclusion is an important component in causing low streamflow, PRMS cannot duplicate the situation. The importance of alluvial aquifers or the transfer of water is unknown in the drainage basins studied. PRMS assumes a closed system; therefore, it is difficult to simulate ground-water source areas, influencing low streamflow, that are larger than the basins being modeled.

Flow-duration curves provide a logical extension of the singular statistic, percent of days of zero streamflow. The flow-duration curve includes a frequency of all streamflow values and not just the frequency of zero flow days. Flow-duration curves are shown for each of the six streamflow-gaging stations (figs. 3 through 8) for the period of record.

The steep flow-duration curves indicate the ephemeral nature of the streams, with the possible exception of Wilson Creek (fig. 7). Most simulated flow-duration curves generally correspond to the observed curves; the correspondence is greatest for the midrange streamflows. At high flows (less than 1 percent of the time that flow is equaled or exceeded), there is a deviation of the simulated streamflow from the observed streamflow for most of the drainage basins. For flows less than 1.0 ft^3/s, deviations of the simulated streamflow from the observed streamflow also tend to occur. These deviations for the smaller streamflows have been described in the paragraphs above about the zero-flow statistic.

Additional difficulty in predicting streamflow is indicated when the water balance produced by the model is studied (table 7). In the water balance, net precipitation is total precipitation minus losses from interception. Basin storage is the sum of all storage in the soil profile, the subsurface reservoirs, and the ground-water reservoirs. In the overall water balance, much of the net precipitation was lost to evapotranspiration. The average loss for all drainage basins, for all years, was 96 percent. During some years, evapotranspiration exceeded precipitation because water was extracted from basin storage. Actual streamflow was a small component of the water balance and streamflow comprised the remaining 4 percent of net precipitation.

Because streamflow is such a small percentage of the water balance, substantial difficulty occurs when calibrating PRMS or any model for this semiarid environment. The error generated when distributing the point values of precipitation in time and space probably is larger than the annual volume of streamflow. Furthermore, the error generated when predicting evapotranspiration values probably is larger than the annual volume of streamflow. Both of these errors are combined in this analysis. Neither source of error can be defined effectively without intensive data collection. In hydrologic regimes where streamflow is a more substantial part of the water balance, errors in precipitation distribution and evapotranspiration may not result in large difficulties in calibration, but, in a semiarid region, such errors can easily hinder streamflow prediction.

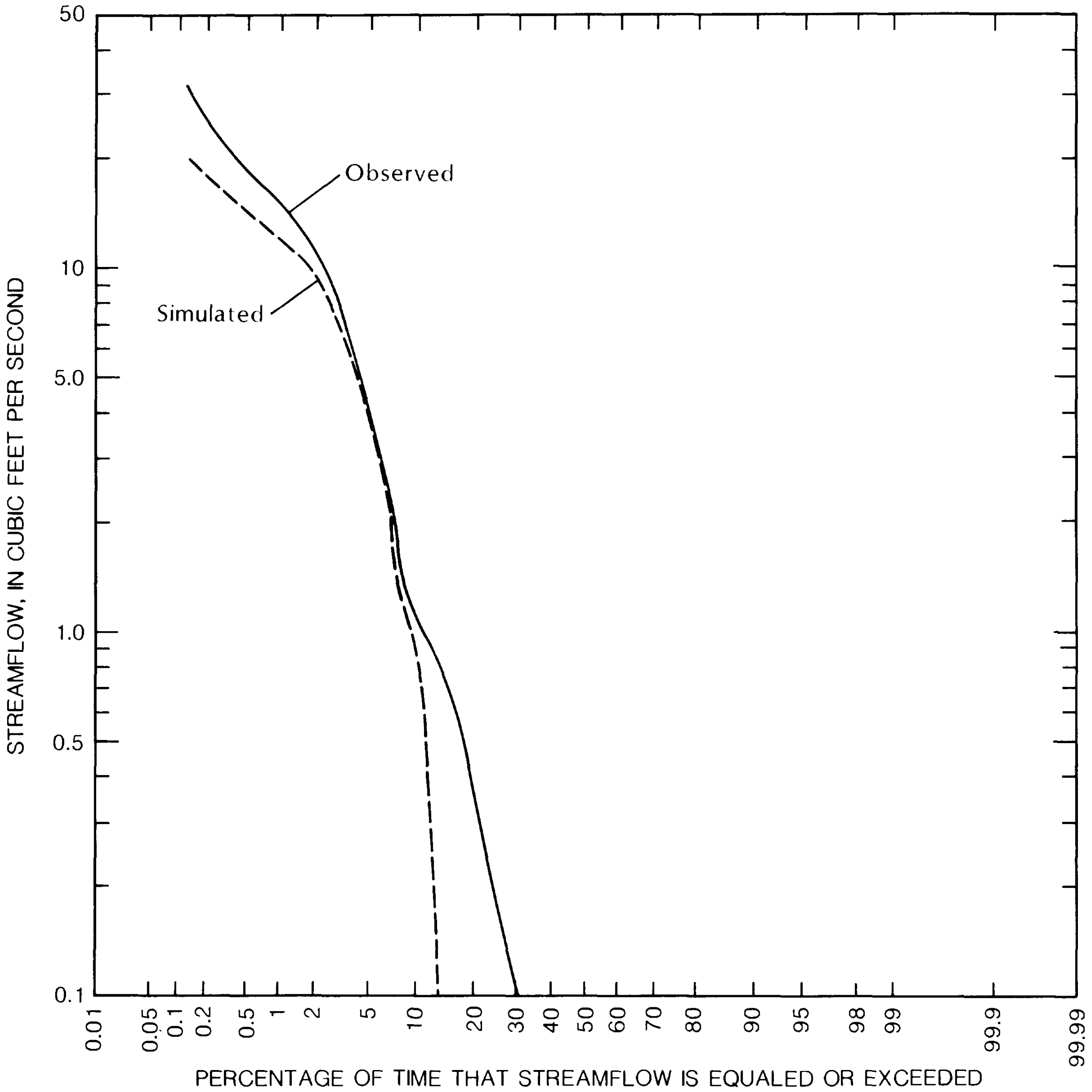

Figure 3.--Observed and simulated streamflow for the period of record (water years 1976-81) for streamflow-gaging station Foidel Creek near Oak Creek (09243800).

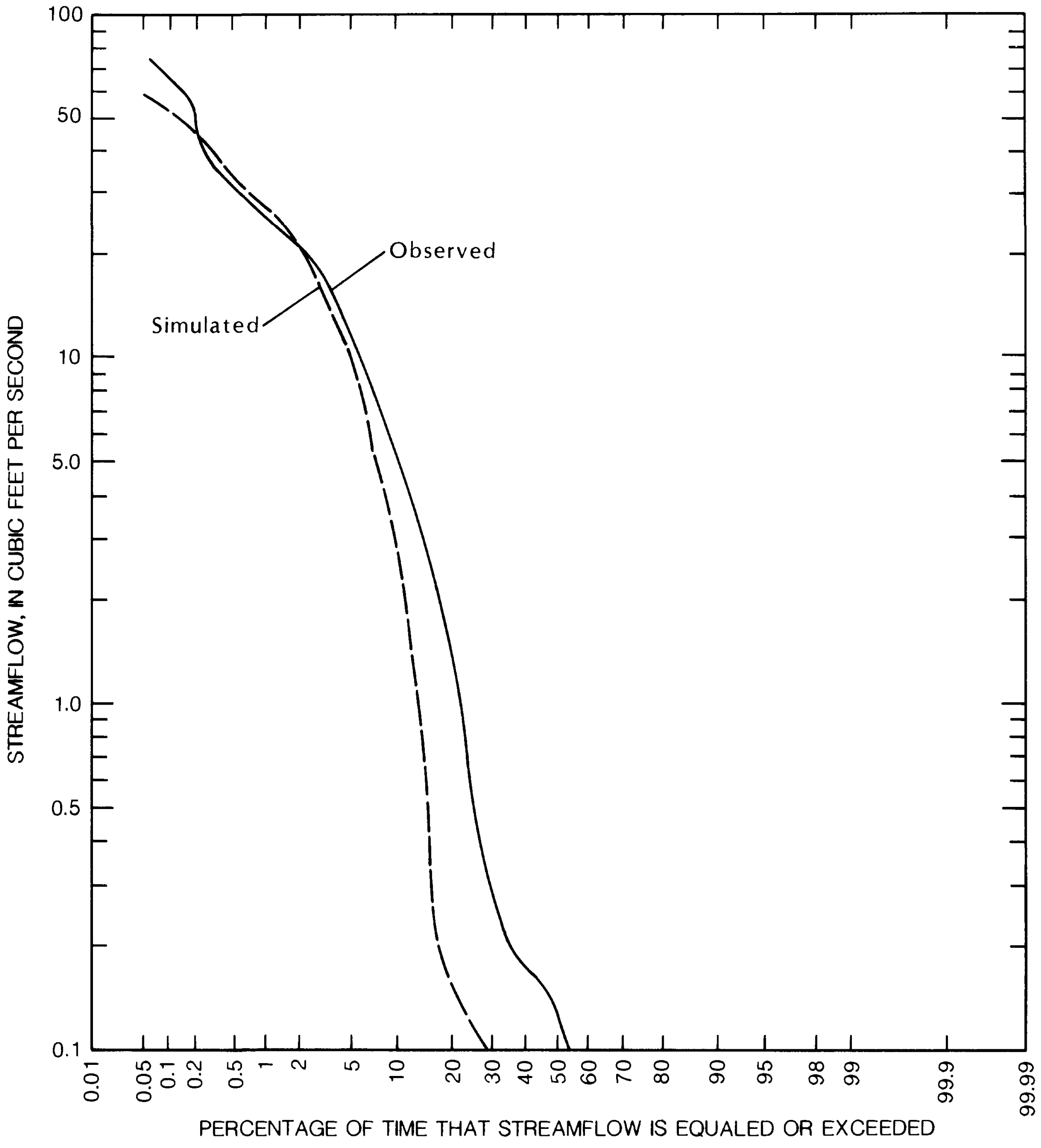

Figure 4.--Observed and simulated streamflow for the period of record (water years 1976-81) for streamflow-gaging station Foidel Creek at mouth near Oak Creek (09243900).

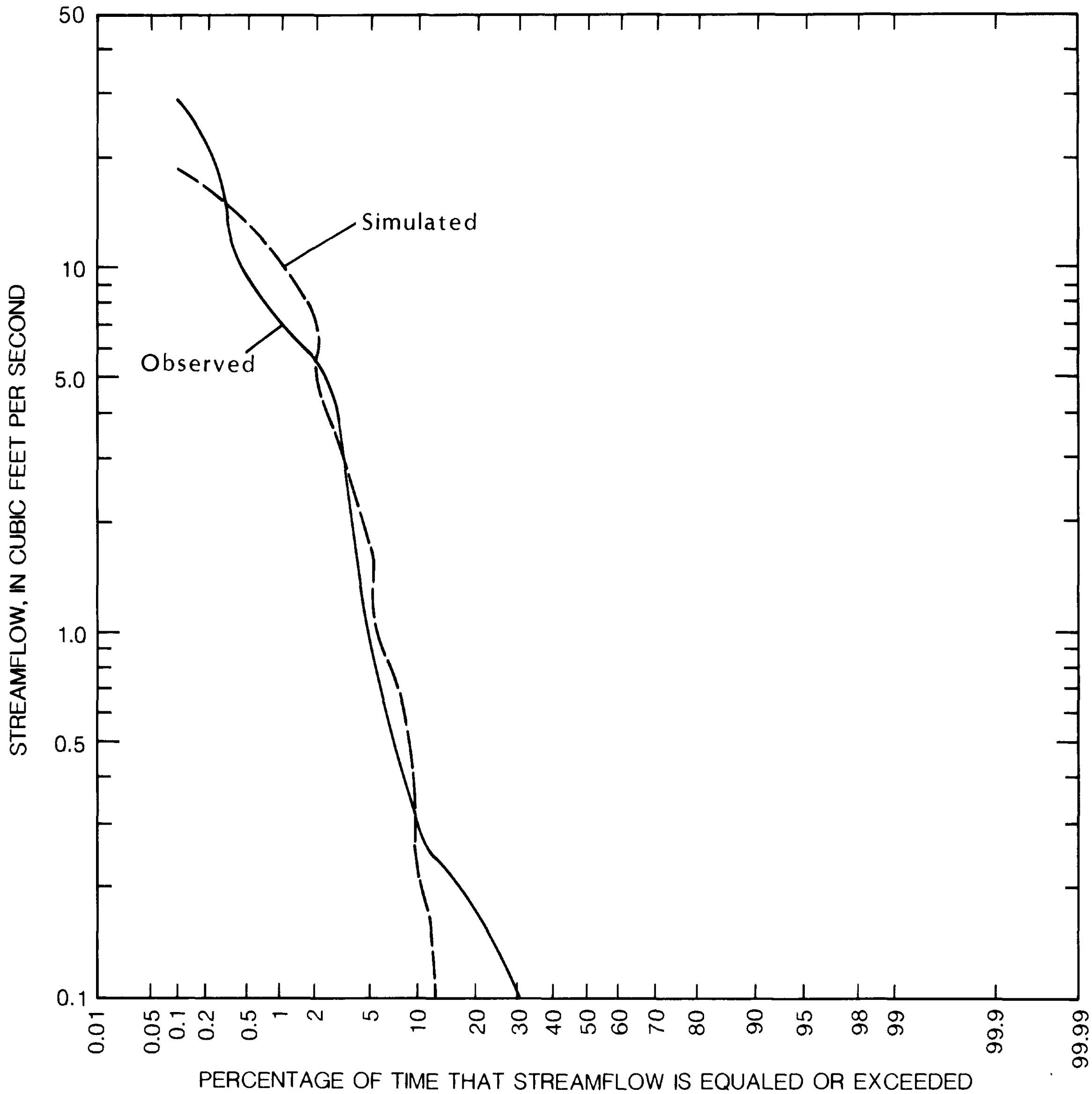

Figure 5.--Observed and simulated streamflow for the period of record (water years 1979-81) for streamflow-gaging station Hubberson Gulch near Hayden (09244464).

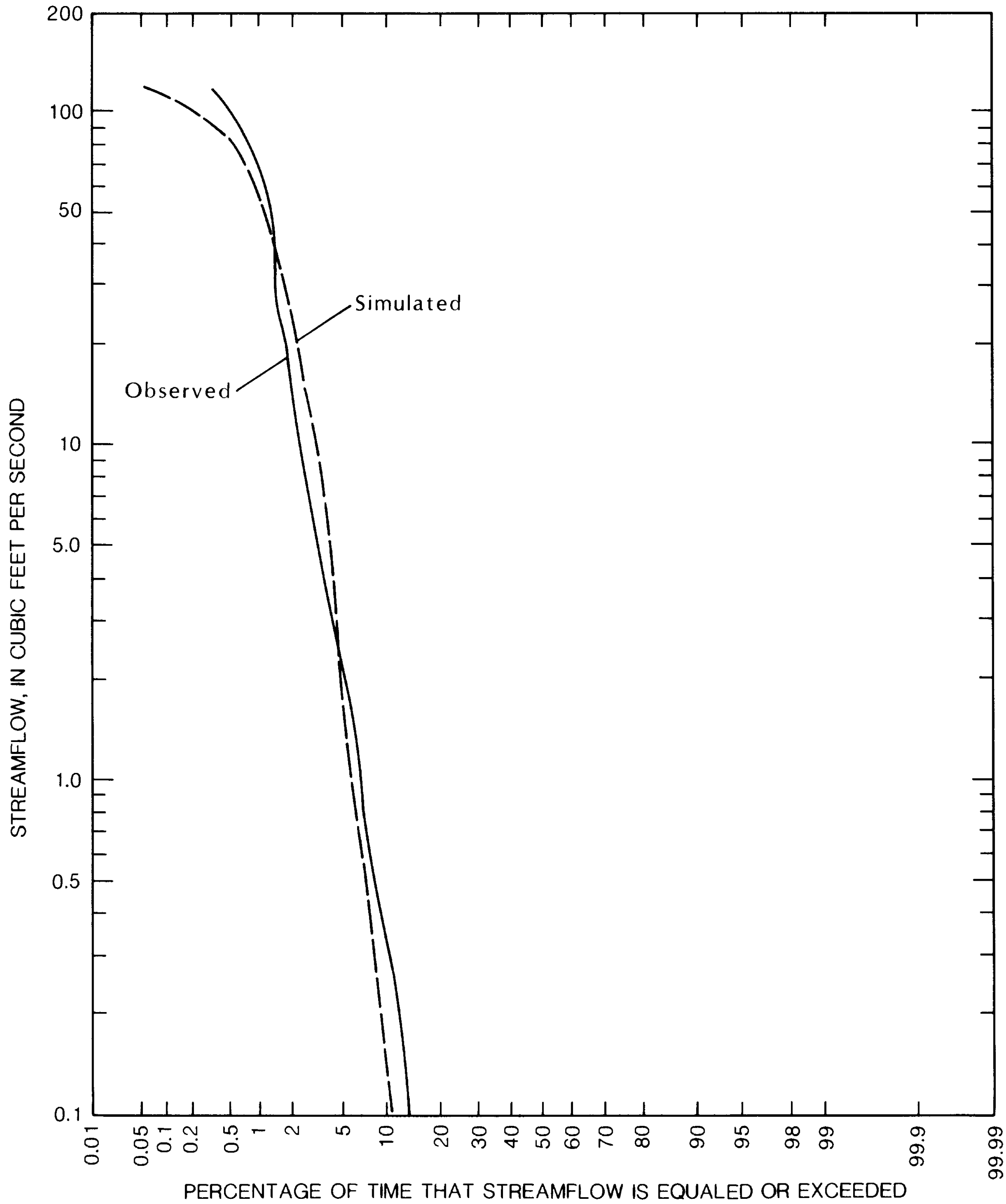

Figure 6.--Observed and simulated streamflow for the period of record (water years 1976-81) for streamflow-gaging station Stokes Gulch near Hayden (09244470).

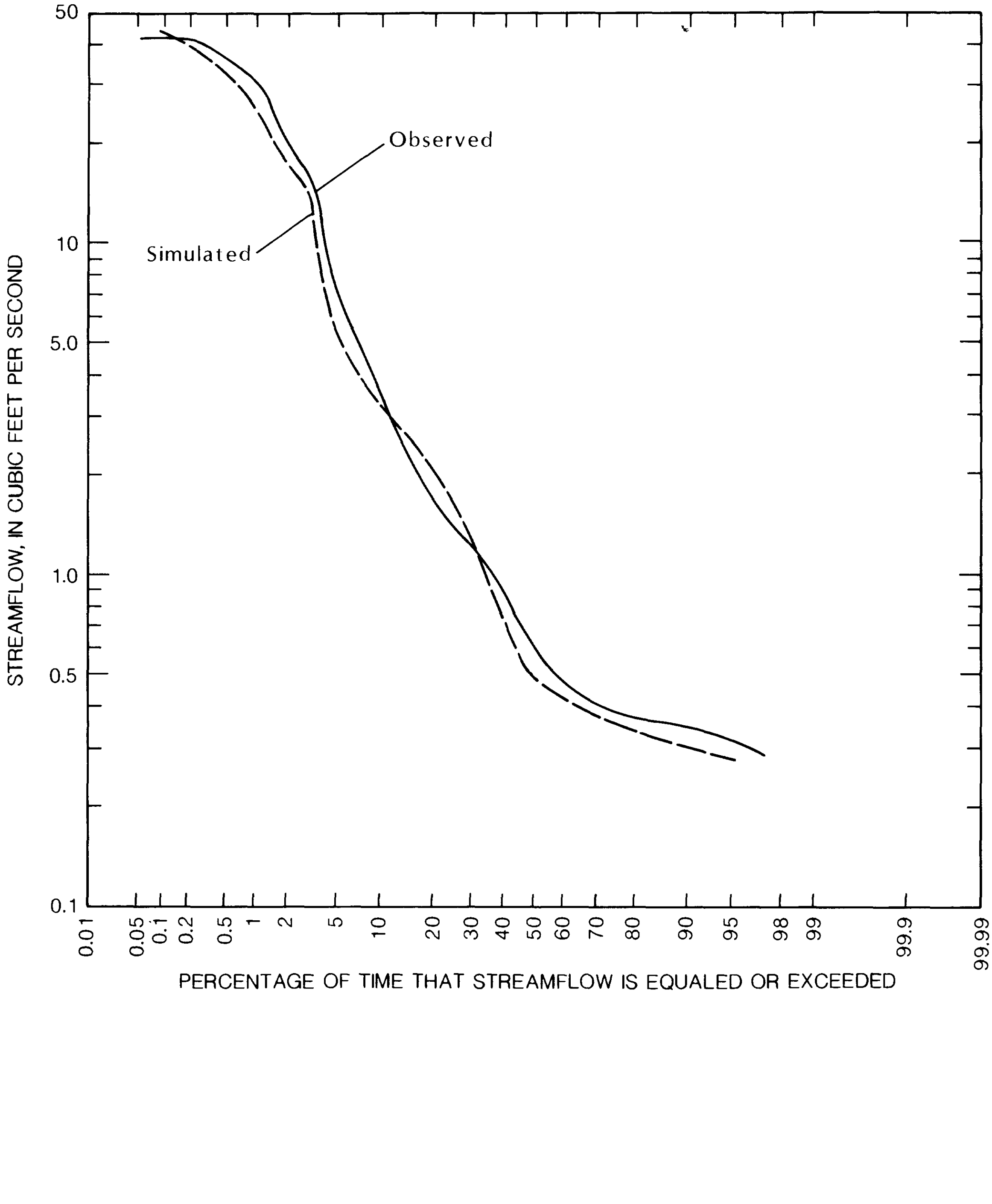

Figure 7.--Observed and simulated streamflow for the period of record (water years 1976-81) for streamflow-gaging station Wilson Creek near Axial (09250600).

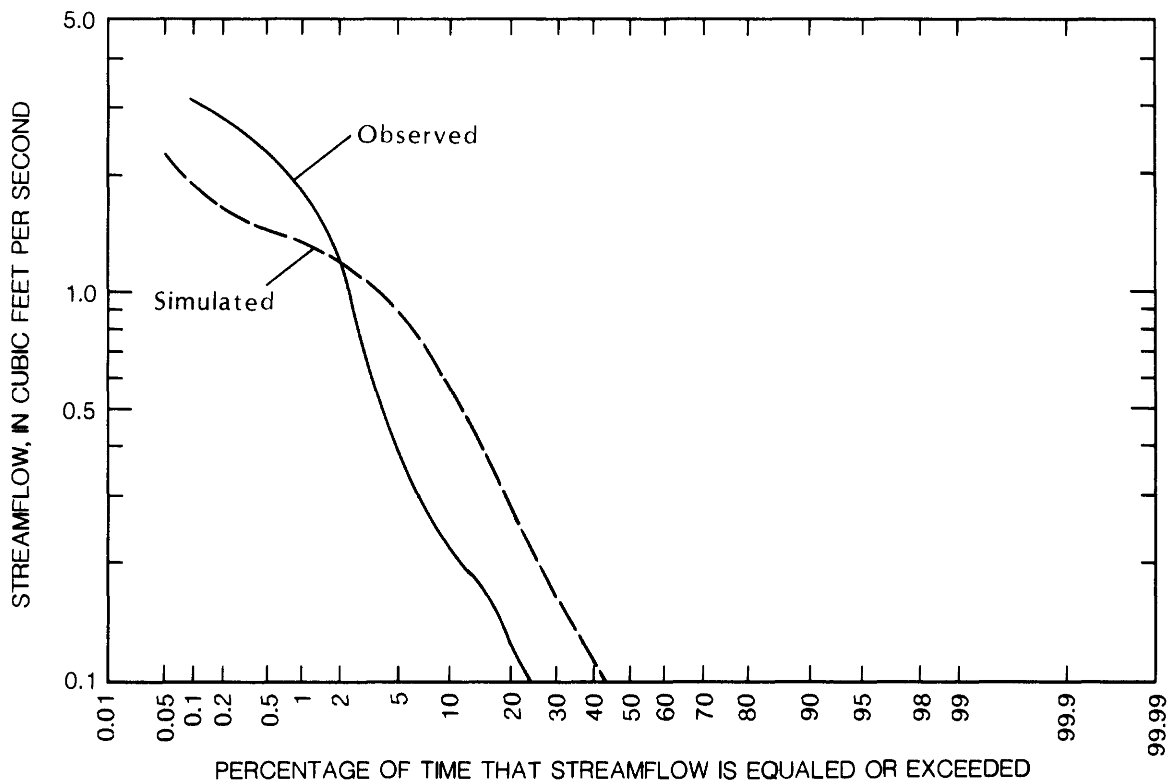

Figure 8.--Observed and simulated streamflow for the period of record (water years 1976-81) for streamflow-gaging station Jubb Creek near Axial (09250610).

Basin storage is an important component of the water balance. In these semiarid drainage basins, the storage of water from a previous wet year is used in subsequent dry years. This is indicated in the model results by the sequence of pluses and minuses through the years as listed in table 7.

Water storage that is used in subsequent years or in a sequence of wet years to augment streamflow is shown in figure 9, which is a plot of the relation of annual net precipitation to observed and simulated annual streamflows, in inches, for one streamflow-gaging station. The plot indicates that the relation between annual net precipitation and annual observed or simulated streamflow is not strictly linear. For example, water years 1978 and 1980 have almost the same net precipitation; however, the observed streamflow ranges from 1.76 in. in 1978 to 3.35 in. in 1980. The annual precipitation for the preceding year was much different in these two instances--1977 was a dry year and 1979 was much wetter. The simulated streamflow for 1978 was about 2.0 in. and for 1980 was about 2.4 in. These simulated values follow the same trend as the observed values, but the simulated values do not have the large difference that occur in the observed values.

Table 7.--*Simulated water balance of the optimized drainage basins*

Streamflow-gaging-station name and number	Water year	Net precipitation (inches)	Evapotranspiration (inches)	Basin storage[1] (inches)	Streamflow (inches)
		DRAINAGE BASINS IN REGION 1			
Foidel Creek near Oak Creek (09243800).	1977	11.47	12.81	-1.47	0.13
	1978	20.14	17.82	+.65	1.67
	1979	16.94	16.74	-1.00	1.20
	1980	20.25	17.67	+.63	1.95
	1981	13.35	13.69	-.37	.03
Foidel Creek at mouth near Oak Creek (09243900).	1977	10.89	11.94	-1.21	.16
	1978	19.53	16.95	+.59	1.99
	1979	15.73	15.38	-.87	1.22
	1980	19.58	16.89	+.31	2.38
	1981	11.98	12.09	-.24	.13
		DRAINAGE BASINS IN REGION 2			
Hubberson Gulch near Hayden (09244464).	1979	15.72	15.15	+.56	.01
	1980	20.89	19.00	-.10	1.99
	1981	10.16	10.33	-.17	.00
Stokes Gulch near Hayden (09244470).	1977	9.19	8.82	+.37	.00
	1978	16.84	13.16	+.84	2.84
	1979	12.90	12.56	-.55	.89
	1980	17.34	13.45	-.15	4.04
	1981	9.34	9.40	-.06	.00
		DRAINAGE BASINS IN REGION 3			
Wilson Creek near Axial (09250600).	1977	8.83	9.77	-1.09	.15
	1978	15.87	15.57	+.19	.11
	1979	21.74	19.42	+.47	1.85
	1980	20.98	19.21	+.04	1.73
	1981	13.90	14.32	-.70	.28
Jubb Creek near Axial (09250610).	1977	8.57	9.33	-.82	.06
	1978	15.27	15.05	+.21	.01
	1979	21.08	20.07	+.40	.61
	1980	20.25	19.66	-.13	.72
	1981	13.46	13.71	-.42	.17

[1]A plus sign indicates the quantity of water contributed to storage during the water year; a minus sign indicates the quantity of water removed from storage during the water year.

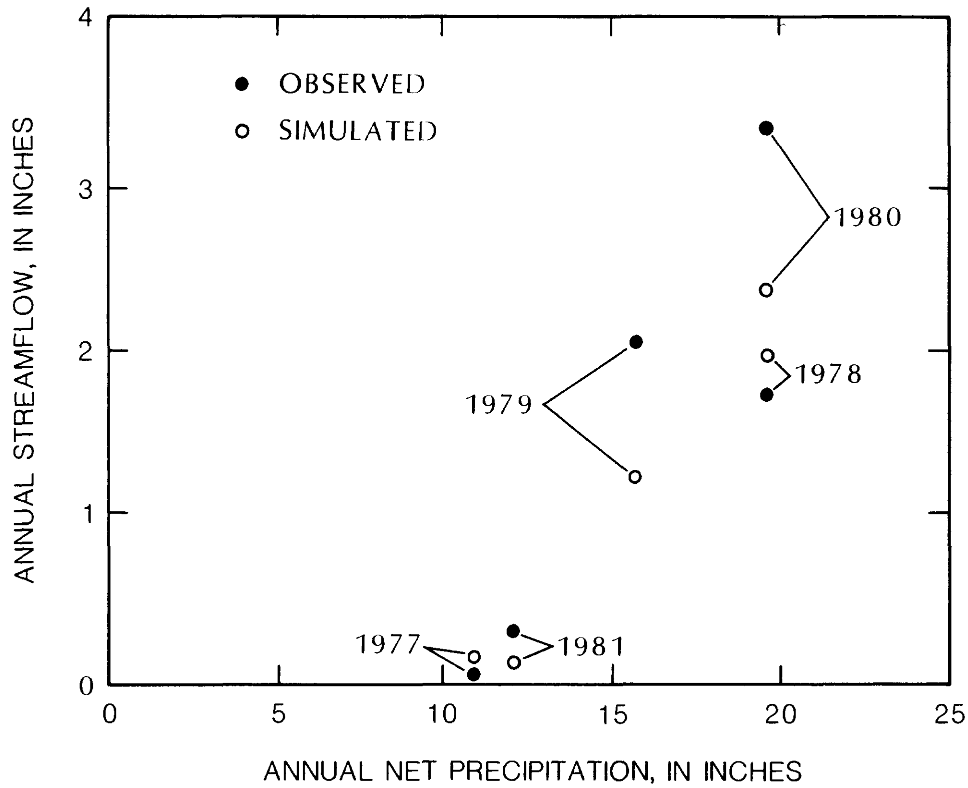

Figure 9.--Relation between annual net precipitation and observed and simulated annual streamflow for streamflow-gaging station Foidel Creek at mouth near Oak Creek (09243900).

The use of PRMS as a closed system for this semiarid environment also may affect the relation between observed and simulated values of annual streamflow. Because of the routing components of the drainage-basin system (fig. 2), minimal opportunity exists for substantial storage of water for longer than 1 year in the drainage basins. However, storage of water, or the lack of storage from the previous year, seems to affect the water balance of the present year. What may be needed in the routing scheme is a reservoir that can hold substantial quantities of water and that has the ability to adjust flow rates for given volumes of water within these reservoirs.

Further difficulties in obtaining accurate simulated values of streamflow are indicated in the hydrograph for the snowmelt season, as typified by streamflow-gaging station Foidel Creek at mouth near Oak Creek (09243900). Hydrographs for the snowmelt season for three consecutive water years at this station are shown in figure 10. A difference in the timing of observed streamflow occurs between 1978 and 1980--2 years of record with nearly the same measured net precipitation (a difference of 0.05 in.). The hydrograph for 1978 shows a rapid rise in observed streamflow in late March to about 25 ft^3/s; the streamflow remained high except for some fluctuations, until late April. In 1980, the rapid rise occurred in mid-April, and the peak of the observed streamflow was about 75 ft^3/s.

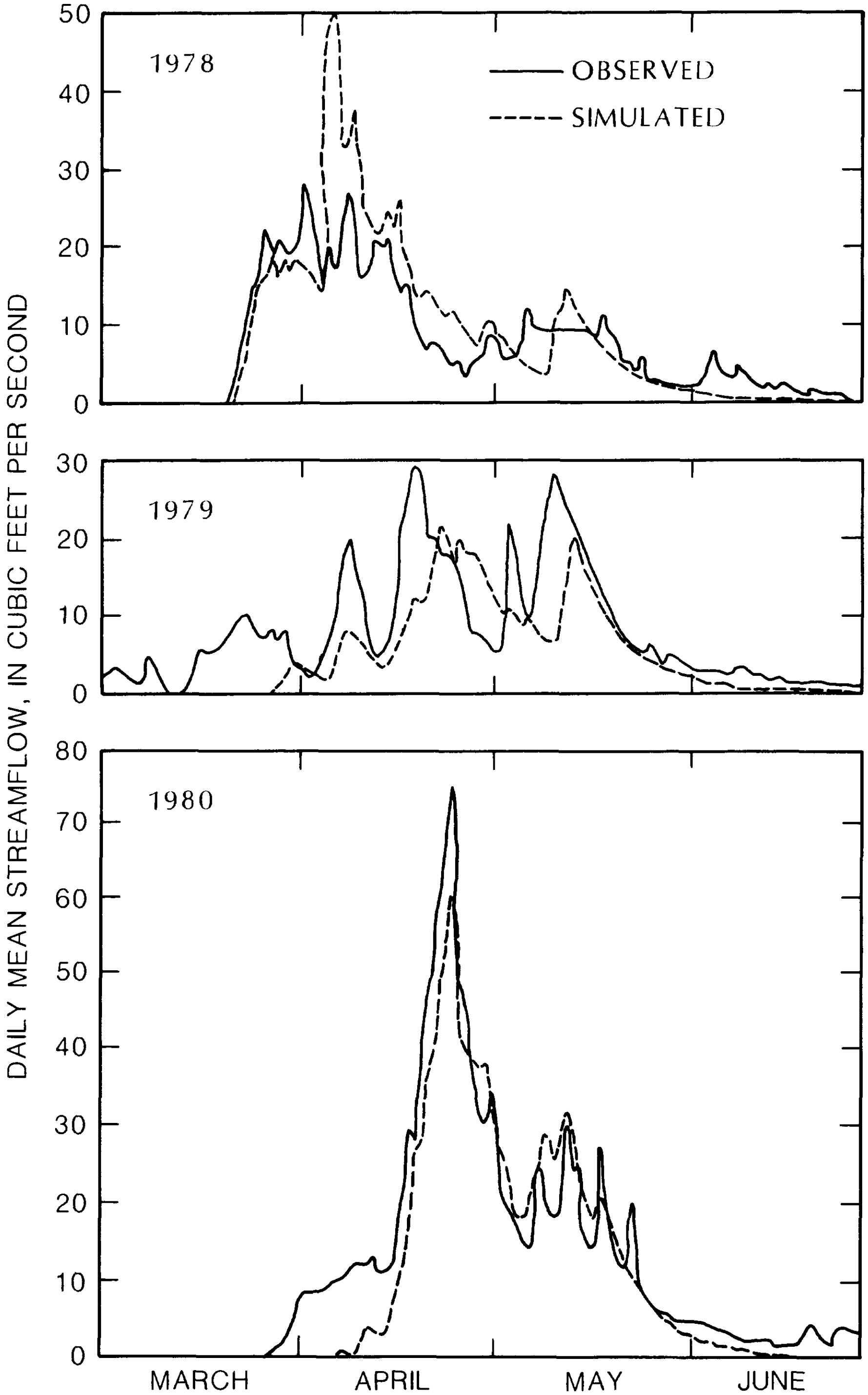

Figure 10.--Comparison of observed and simulated daily mean streamflow for streamflow-gaging station Foidel Creek at mouth near Oak Creek (09243900) for water years 1978 through 1980.

Basically, winter was an accumulation period when precipitation was stored as snow on the ground. Because the drainage basins are in a semiarid environment, the soil moisture storage was minimal during winter. When snowmelt commenced, the first meltwater replenished the soil-moisture storage. Once the soil-moisture storage was recharged, the additional meltwater was available for streamflow. However, the hydrographs in figure 10 indicate that streamflow prediction is much more complicated.

The differences in the observed streamflow between the 1978 and 1980 water years (fig. 10) indicate such physical conditions as differences in solar radiation that affect the snowmelt sequence, interactions of temperature and snow cover that affect frozen ground, and spring rains that fall on the snowpack and contribute to a rapid melt. These physical conditions become difficult to model appropriately because of a lack of suitable algorithms for some of the processes and a lack of good representation of meteorologic inputs.

Values of observed solar radiation may be used in PRMS; however, in this study, observed data were not used because they generally were not available for the study area. Errors associated with this lack of data are included in the calibration process.

An algorithm for frozen soil currently is not available in PRMS. The modeling of frozen soil is complicated, and many researchers now are attempting to solve this modeling difficulty. In shallow snowpack areas of the drainage basins, frozen soil during snowmelt can decrease infiltration to zero, and substantial streamflow may be observed at the streamflow-gaging station. Shallow snowpacks decrease the insulation effect on the soil and, as a result, frozen soil occurs more frequently. A frozen-soil algorithm probably would increase the predictive capabilities of the model in the study area; but, such an algorithm might require additional input data.

Because the form of precipitation affects the energy to the snow pack and thereby changes daily streamflow, a PRMS user can specify the form of precipitation. The precipitation-form option was not used in this study because these data generally are not available. Thus, the calibration process included errors associated with the temperature-based, precipitation-form algorithm.

Probably the major source of error in the daily streamflow predictions for water years 1978 and 1979 is the inadequate identification of the form of precipitation. On some individual days, the observed and simulated streamflow are moving in opposite directions (fig. 10). Such a difference in the observed and simulated values of streamflow indicate that precipitation was improperly identified (rain versus snow), resulting in an inaccurate estimation of energy to snowpack and resulting error in timing of snowmelt runoff. The error in estimation of simulated daily streamflow indicates that using daily maximum and minimum air temperature to identify the form of precipitation is not adequate.

ASSESSING TRANSFERABILITY OF MODEL PARAMETERS

One drainage basin in each of the three hydrologic regions was not calibrated. These drainage basins were used to assess the transferability of the model parameters determined during calibration of the other two drainage basins in each region. To model these uncalibrated drainage basins, values for each needed parameter were obtained based on the categories in table 2.

Parameters in category 1 (table 2) are regional in nature; therefore, the parameter values for the uncalibrated drainage basins could be derived from the parameters used in the calibrated drainage basins. If differences in values occurred between the two calibrated drainage basins after they were optimized, the average of the two values was used for the transfer value. The values or range of values for the parameters in category 1 are listed in table 8 for the three hydrologic regions.

For parameters in category 2, values for the uncalibrated drainage basins were obtained from maps, aerial photographs, and onsite inspection, just as they were for the calibrated drainage basins in each hydrologic region. The parameter, SMAX, was an exception. SMAX was sensitive in all regions, and it was optimized separately. To assess the transferability of SMAX, average values for the uncalibrated drainage basins were determined from the two calibrated drainage basins in each hydrologic region. However, because SMAX is a distributed parameter, independent variables to determine values of SMAX for specific HRU's were needed.

Table 8.--*Values used in model transfer for parameters in category 1, which are determined from regional climatic characteristics*

Parameter (see table 2)	Region 1	Region 2	Region 3
BST	34	34	35.9
CTS	.017	.016-.021	.017-.021
CTW	1.00	1.00	1.60
DENI	.10	.10	.10
DENMX	.45	.45	.45
FWCAP	.04	.04	.04
PAT	40-50	40-60	41-61
SETCON	.10	.10	.10
TST	950	950	950

A comparison of SMAX among the three hydrologic regions for the calibrated drainage basins is shown in figure 11. Using the calibration procedure developed by Norris and Parker (1985), the independent variables used in adjusting SMAX were: (1) The average elevation of the HRU; and (2) the primary vegetation type in the HRU. The relation of SMAX to elevation and the primary vegetation (oak and sage) are shown in figure 11. SMAX values required for sage for each of the three regions are similar and vary by only 3.5 in. SMAX values required for oak for regions 2 and 3 vary by 2.5 in. SMAX values required for oak for region 1 differ from those of the other regions by more than 10 in. Part of the reason for these differences may be the difficulties discussed in the section "Results of Verification" for streamflow-gaging station Foidel Creek at mouth near Oak Creek (09243900). SMAX values for oak also may have been decreased subtantially during calibration to allow early runoff from the low-lying areas, particularly where the soil is frozen.

SMAX values required for aspen were not plotted because no relation of aspen to elevation in the drainage basins was determined. In region 1, the calibrated SMAX value required for aspen was 15.0 in.; and in region 3, the SMAX value required for aspen was 9.5 in. Drainage basins in region 2, which have lower mean elevations and drier conditions, did not have any HRU's in which aspen was the major vegetation type.

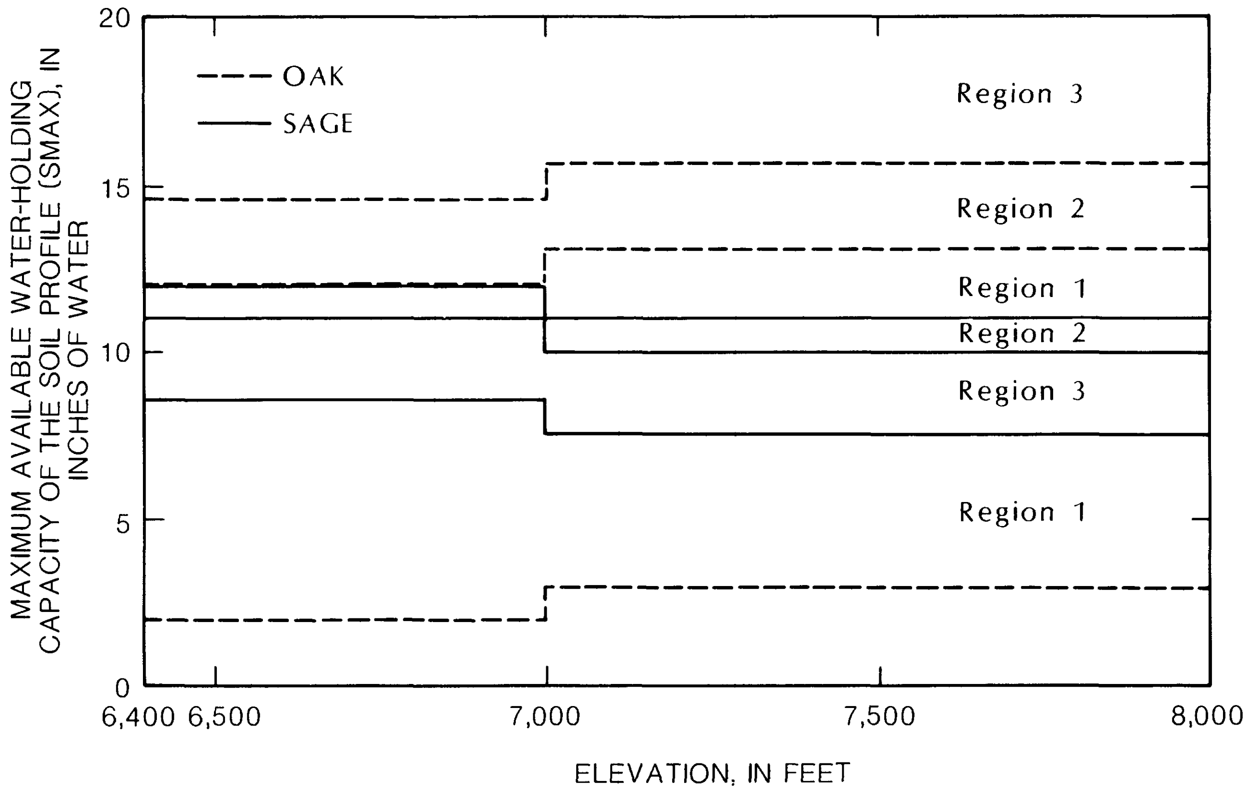

Figure 11.--Relation of the soil-moisture parameter, SMAX, to elevation and principal vegetation type for each of the three hydrologic regions.

In addition, two drainage basins in the study area had dryland farming. These areas of dryland farming generally were at lower elevations and are not plotted in figure 11. In region 1, HRU's that had dryland farming were assigned a SMAX value of 4.5 in., and they did not vary by elevation. In region 2, HRU's that had dryland farming were assigned a SMAX value of 3.0 in. No HRU's that had dryland farming were located in region 3. In region 1, reclamation of mined areas occurred in one HRU, and a SMAX value of 12.0 in. was calibrated for that HRU. Because only one HRU of this type occurred in the study area, the variability of this value was not tested. Values for parameters distributed by HRU are given in table 11 (in the "Supplemental Data" section at the back of this report) for these three drainage basins.

For parameters in category 3 (table 2), values for the uncalibrated drainage basins were obtained from average values from the two calibrated drainage basins in each of the hydrologic regions. Values of these parameters could be improved if some knowledge of the streamflow hydrograph could be obtained. Transferring these parameter values from other drainage basins may not provide good recession characteristics.

After including the parameters for the individual hydrologic regions, model simulations were done for the uncalibrated drainage basins for the available period of record. The observed and simulated annual volumes of streamflow and the associated prediction errors for each of the three uncalculated drainage basins are listed in table 9. For individual years, the values of absolute difference in streamflow volume ranged from 0.0 to 1.38 in/yr. The percent errors are shown and range from 0 to about 1,200 percent. Because of such small streamflow volumes, the absolute differences probably need to be compared. Values of simulated annual streamflow volume compared well with observed values during the drier water years of 1977 and 1981. When a sequence of a dry year (1977) followed by a wet year (1978) occurred at streamflow-gaging station Middle Creek near Oak Creek (09243700), some difficulty in prediction resulted. Part of the difficulty probably is the same as reported for the other drainage basins in region 1.

In region 3, the observed and simulated annual streamflow volumes for streamflow-gaging station Taylor Creek at mouth near Axial (09250510) were overpredicted for all water years except 1977. Land-use transition was occurring in the Taylor Creek drainage basin during these years of observed record. Although coal was not mined in this drainage basin, coal loading and yarding activity for a nearby coal mine were done in the Taylor Creek drainage. During the period of data collection, check dams were built on Taylor Creek, and tributary diversions resulted from road construction and from placement of culverts. Therefore, some of the differences in streamflow volume listed in table 9 for this station may be the result of man-induced changes in the drainage basin.

Statistical properties of the observed and simulated streamflow data for each of the three uncalibrated drainage basins used in transferability assessment are listed in table 10. Differences in observed and simulated annual average streamflow for the uncalibrated drainage basins for the period of record were similar to the differences reported for the calibrated drainage basins (table 6). The absolute difference in the average streamflow values in the calibrated drainage basins ranged from 0.01 to 0.47 ft^3/s (table 6).

Table 9.--*Observed and simulated annual streamflow volumes and prediction*

[in., inches;

Streamflow-gaging-station name and number	1977				1978			
	Annual streamflow volume		Volume differ-ence[1] (in.)	Per-cent error[2]	Annual streamflow volume		Volume differ-ence[1] (in.)	Per-cent error[2]
	Ob-served (in.)	Simu-lated (in.)			Ob-served (in.)	Simu-lated (in.)		
DRAINAGE BASINS								
Middle Creek near Oak Creek (09243700).	0.28	0.22	0.06	21	1.99	3.37	-1.38	-69
DRAINAGE BASINS								
Watering Trough Gulch near Hayden (09244460).	---	---	---	---	---	---	---	---
DRAINAGE BASINS								
Taylor Creek at mouth near Axial (09250510).	0	0	0	0	0	.05	-.05	---

[1]Calculated as observed volume minus simulated volume.
[2]Calculated as observed volume minus simulated volume divided by observed volume, and rounded to nearest percentage.

errors for each uncalibrated drainage basin used in transferability assessment

---, not applicable]

1979				1980				1981			
Annual streamflow volume		Volume differ- ence[1] (in.)	Per- cent error[2]	Annual streamflow volume		Volume differ- ence[1] (in.)	Per- cent error[2]	Annual streamflow volume		Volume differ- ence[1] (in.)	Per- cent error[2]
Ob- served (in.)	Simu- lated (in.)			Ob- served (in.)	Simu- lated (in.)			Ob- served (in.)	Simu- lated (in.)		
IN REGION 1											
2.36	2.40	-0.04	-2	4.10	3.59	0.51	12	0.37	0.20	0.17	46
IN REGION 2											
.03	.03	.0	0	.49	.81	-.32	-65	.10	.04	.06	60
IN REGION 3											
.11	1.38	-1.27	-1,154	.66	1.49	-.83	-126	.06	.10	-.04	-67

Table 10.--*Statistical properties of annual average streamflow for each uncalibrated drainage basin used in transferability assessment, for the period of record*

Streamflow-gaging-station name and number	Average streamflow for period of record[1] (cubic feet per second)			Days of zero streamflow (percent)		
	Observed	Simulated	Absolute difference	Observed	Simulated	Absolute difference
DRAINAGE BASINS IN REGION 1						
Middle Creek near Oak Creek (09243700).	2.84	3.10	0.26	24	58	34
DRAINAGE BASINS IN REGION 2						
Watering Trough Gulch near Hayden (09244460).	.06	.09	.03	32	58	26
DRAINAGE BASINS IN REGION 3						
Taylor Creek at mouth near Axial (09250510).	.13	.46	.33	59	49	10

[1]Period of record is water years 1976-81.

In the three uncalibrated drainage basins, the absolute differences in the average streamflow values ranged from 0.03 to 0.33 ft^3/s (table 10).

The absolute difference between observed and simulated percentage of days of zero streamflow for the uncalibrated drainage basins for the period of record (table 10) ranged from 10 to 34 percent. These absolute differences are similar to those for the calibrated drainage basins, which ranged from near 0 to 37 percent (table 6). Flow-duration curves for each of the three uncalibrated drainage basins are shown in figures 12 through 14. These curves seem to have similar characteristics and difficulties as those for calibrated drainage basins. Additional prediction error may be observed in the low-flow part of the curves because values of parameters that affect the rates of recession were determined from mean values from the calibrated drainage basins.

SUMMARY

Minimal water-resource information for the southern Yampa River basin in northwestern Colorado was available; therefore, when various mining companies and government agencies became concerned about the availability of water and effects of mining on the water resources, a streamflow-gaging program was started to identify streamflow characteristics. However, because of economic considerations, only a few streamflow-gaging stations were established in the basin, and a technique was needed to transfer streamflow data from gaged drainage basins to ungaged drainage basins. To evaluate the magnitude and variability of the components of the water balance in the small drainage basins monitored and to provide some method for transfer of hydrologic data, the U.S. Geological Survey's Precipitation-Runoff Modeling System (PRMS) was used to simulate mean daily streamflow by using daily precipitation and air-temperature data.

The study area was divided into three general hydrologic regions. These regions were differentiated primarily by precipitation totals. In each hydrologic region, streamflow-gaging stations were established on streams in three representative drainage basins. Data from two of these drainage basins were used to calibrate PRMS. The remaining drainage basin in each region was not used in calibration but was used to assess the transferability of model parameters in the particular region. For all of the drainage basins except one, period of record used for calibration and verification included water years 1976-81.

The calibration process consisted of a sensitivity analysis of the parameters in PRMS and an optimization of the most sensitive parameters. The most sensitive parameters include CTS, SMAX, BST, TRNCF, TLX, PAT, TNAJ, COVDNW, and RCB, although the combining of these parameters was different for each drainage basin. Verification of the optimized values of these parameters then was done. The period of record for the drainage basins was divided so that calibration could be done on an initial series of years, and verification could be done on a subsequent series of years.

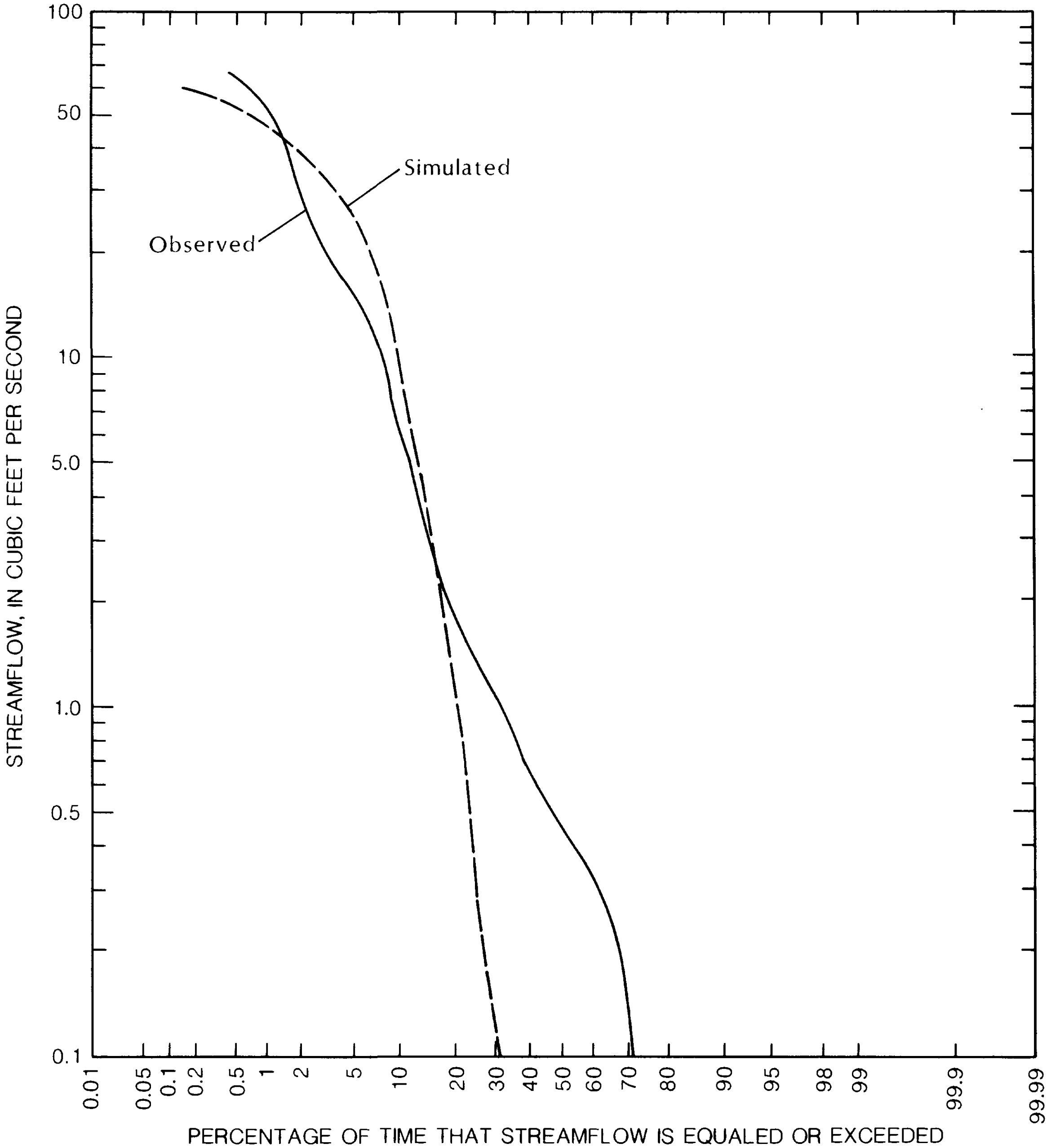

Figure 12.--Observed and simulated streamflow for the period of record (water years 1976-81) for streamflow-gaging station Middle Creek near Oak Creek (09243700).

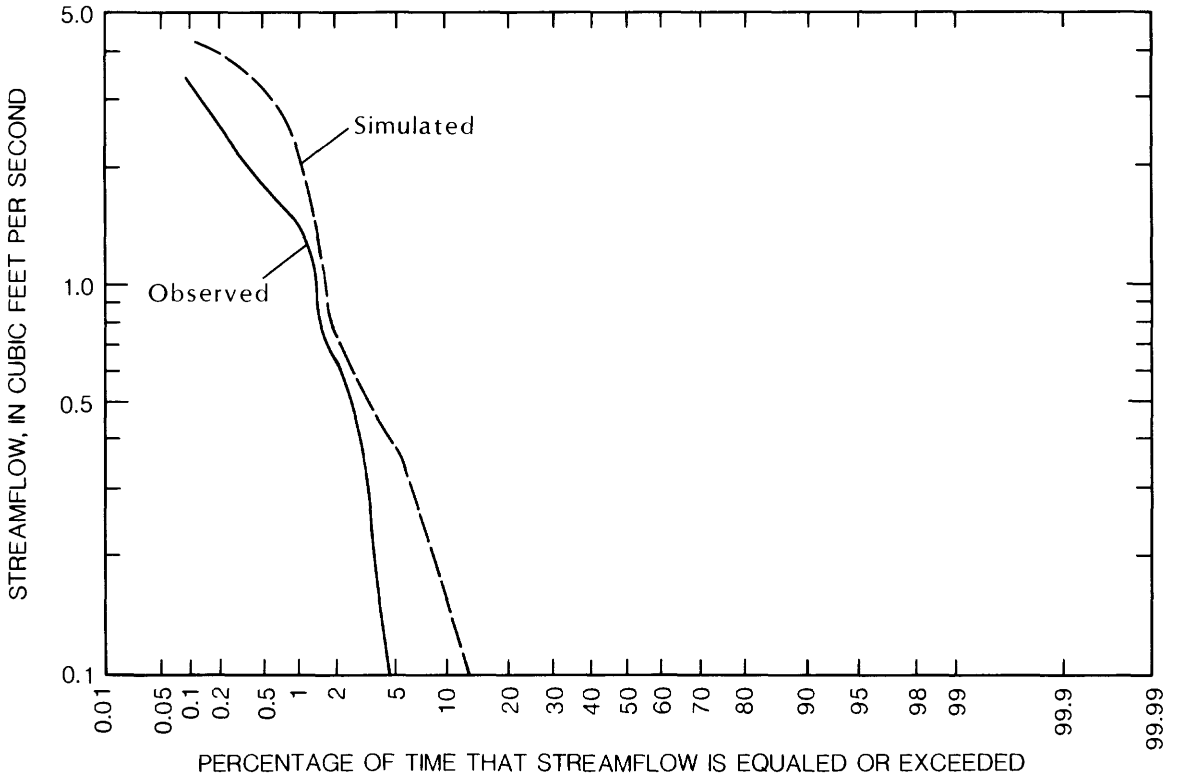

Figure 13.--Observed and simulated streamflow for the period of record (water years 1979-81) for streamflow-gaging station Watering Trough Gulch near Hayden (09244460).

The parameter SMAX, maximum available water-holding capacity of the soil, was optimized separately. After optimizing SMAX, all other sensitive parameters were optimized using the Gauss-Newton method incorporated in PRMS.

For the drainage basins involved in the calibration process, prediction errors between observed and predicted annual volumes of streamflow were similar for the calibration period and the verification period. Simulated values of annual volumes of streamflow in the verification period differed from the observed volumes by 0.03 to 1.22 in. Because of these small volumes of streamflow, the prediction errors were as large as 100 percent.

Simulated average streamflow compared favorably with observed average streamflow. The absolute difference between observed and simulated average streamflow for the period of record ranged from 0.01 to 0.47 ft^3/s for all the monitored drainage basins. Simulated values of percentage of days of zero flow for the period of record deviated by nearly 40 percent from the observed values. Part of the difficulty in predicting days of zero flow is the mathematical smoothing that occurs in the model. The effect of the smoothing is indicated when observed and simulated streamflows, plotted as flow-duration curves, are compared. The midrange of the observed and simulated streamflows are similar, but the low and high simulated streamflows deviate substantially from low and high observed streamflows.

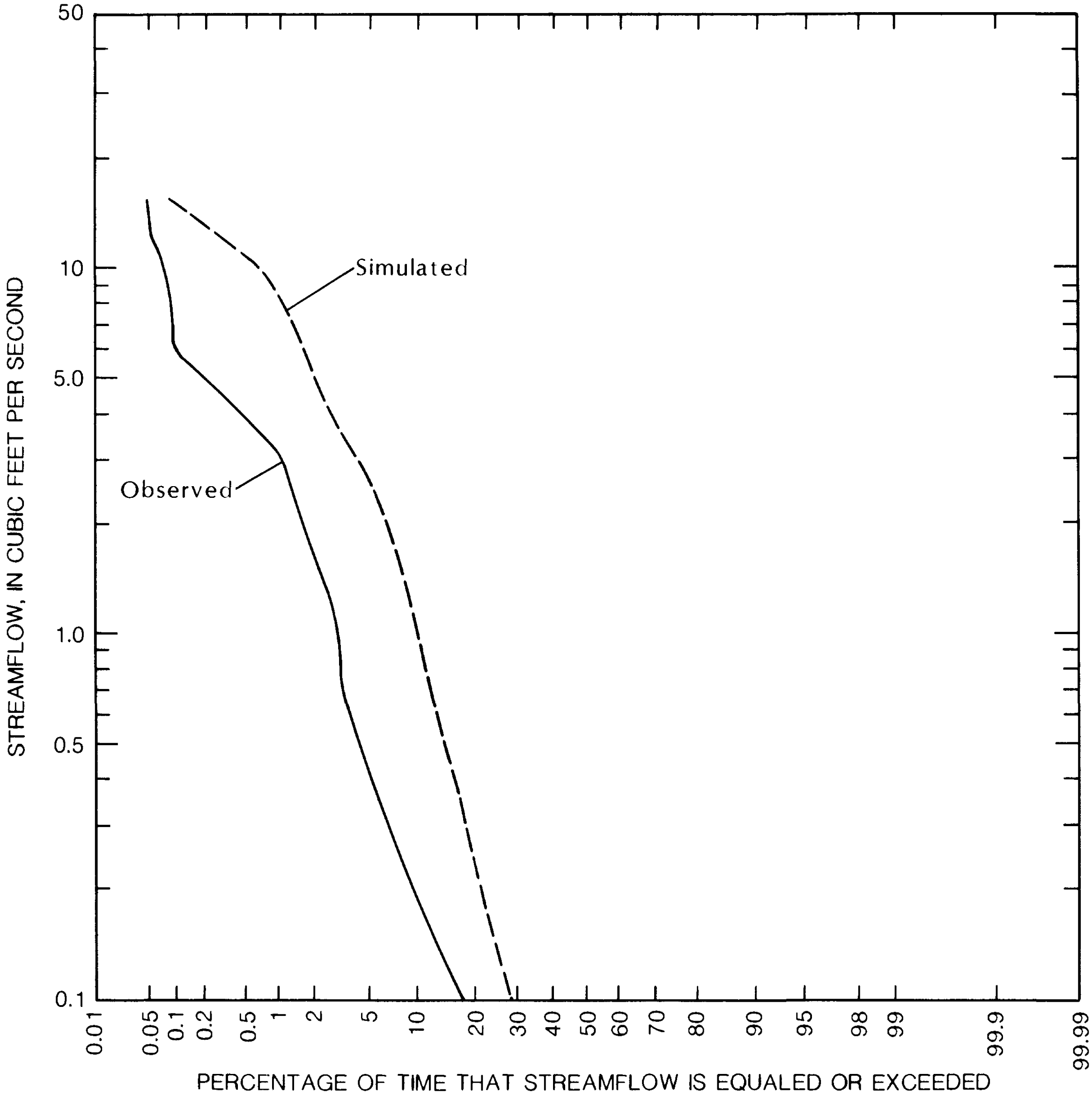

Figure 14.--Observed and simulated streamflow for the period of record (water years 1976-81) for streamflow-gaging station Taylor Creek at mouth near Axial (09250510).

A comparison of observed and simulated hydrographs for the snowmelt season indicates that simulated daily mean streamflow does not compare well with observed daily mean streamflow, although the overall shape of the hydrograph is reproduced. Differences in daily mean streamflow are partly the result of not using observed daily mean solar radiation and the lack of an algorithm for frozen soil in PRMS. The major cause probably is the inadequate identification of rain and snow during the onset of the snowmelt season and inadequate representation of meteorologic input data.

To assess the transferability of the model parameters determined for calibrated drainage basins, one drainage basin in each of the hydrologic regions was used. Parameters were grouped into three categories. Parameters from category 1 are regional climatic characteristics that were obtained from the calibrated model of the other two drainage basins in the region. Parameters from category 2 are physical characteristics that were obtained for the specific drainage basin from maps, aerial photographs, and onsite inspection. Parameters from category 3 are those for subsurface and ground-water reservoirs that were obtained by averaging the values from the two calibrated models of the drainage basins in that region. The timing of the hydrograph would be improved if parameter values from category 3 could be calculated from an observed hydrograph of the drainage basin being analyzed.

The difference between observed and simulated annual streamflow volumes for the models with transferred parameters ranged from 0.0 to 1.38 in/yr. The annual difference for the calibrated model was between 0.03 and 1.22 in/yr. Thus, the annual volumes simulated by the calibrated model compare favorably with those simulated by the model with transferred parameters.

Statistical summaries of streamflow simulated by the calibrated and uncalibrated models were similar. The average streamflow for the period of record, which ranged from 0.03 to 0.33 ft^3/s, compares closely to the calibrated model, which ranged from 0.01 to 0.47 ft^3/s. The percentage of days of zero flow, which ranged from 10 to 34 percent, also compares with the range of 0 to 37 percent simulated by the calibrated model. Differences between flow-duration curves calculated from observed data and from data simulated from the uncalibrated model were similar to differences between the flow-duration curves calculated from observed data and from data simulated from the calibrated model.

REFERENCES CITED

Frank, E.C., and Lee, Richard, 1966, Potential solar beam irradiation on slopes: U.S. Department of Agriculture, Forest Service Research Paper RM-18, 116 p.

Jensen, M.E., and Haise, H.R., 1963, Estimating evapotranspiration from solar radiation: Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage, v. 89, no. IR4, p. 15-41.

Leaf, C.F., and Brink, G.E., 1973, Hydrologic simulation model of Colorado subalpine forest: U.S. Department of Agriculture, Forest Service Research Paper RM-107, 23 p.

Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G., 1983, Precipitation-runoff modeling system; user's manual: U.S. Geological Survey Water-Resources Investigations 83-4238, 207 p.

National Climatic Data Center, 1983, Climatological data annual summary, Colorado: Asheville, N.C., National Oceanic and Atmospheric Administration, 25 p.

Norris, J.M., and Parker, R.S., 1985, Calibration procedure for a daily flow model of small watersheds with snowmelt runoff in the Green River coal region of Colorado: U.S. Geological Survey Water-Resources Investigations 83-4263, 32 p.

Obled, Charles, and Rosse, B.B., 1977, Mathematical models of a melting snowpack at an index plot: Journal of Hydrology, no. 31/32, p. 139-163.

U.S. Weather Bureau, 1985, Normal annual precipitation 1931-1960, Colorado: Washington, D.C., U.S. Weather Bureau map, scale 1:500,000.

SUPPLEMENTAL DATA

Table 11.--*Values for parameters distributed by hydrologic response unit (HRU) after optimization*

[See table 2 for definition of model parameters]

HRU	ELEV	CTX	TRNCF	COVDS	COVDW	ICOV	ISOIL	SMAX	REMX	SRX
				Middle Creek near Oak Creek (09243700)						
1	7,900	20	0.42	0.50	0.30	2	2	3.0	1.5	2.0
2	7,300	20	.42	.50	.30	2	2	3.0	1.5	2.0
3	7,000	20	.42	.37	.30	2	2	12.0	1.5	2.0
4	7,600	20	.42	.58	.30	3	2	15.0	1.5	2.0
5	7,600	20	.32	.37	.40	2	2	11.0	.5	2.0
6	7,900	20	.32	.58	.40	3	2	15.0	1.5	2.0
7	7,700	20	.32	.50	.40	2	2	3.0	1.5	2.0
8	7,800	20	.32	.58	.40	3	2	15.0	1.5	2.0
9	7,700	20	.32	.50	.40	2	2	3.0	1.5	2.0
10	7,700	20	.42	.50	.30	2	2	3.0	1.5	2.0
11	7,300	20	.42	.50	.30	2	2	3.0	1.5	2.0
12	7,000	20	.32	.43	.40	2	2	2.0	1.5	2.0
13	7,000	20	.32	.30	.40	2	2	2.0	.5	2.0
14	6,900	20	.57	.27	.20	2	2	12.0	1.5	2.0
15	6,800	20	.43	.37	.30	2	2	12.0	1.5	2.0
16	8,200	20	.32	.58	.40	3	2	15.0	1.5	2.0
17	7,000	20	.43	.37	.30	2	2	12.0	1.5	2.0
18	7,200	20	.43	.37	.30	2	2	11.0	1.5	2.0
19	7,400	20	.42	.50	.30	2	2	3.0	1.5	2.0
				Foidel Creek near Oak Creek (09243800)						
1	7,000	20	.62	.37	.20	2	2	12.0	1.5	2.0
2	7,200	20	.62	.37	.20	2	2	11.0	1.5	2.0
3	7,000	20	.62	.37	.20	2	2	12.0	1.5	2.0
4	7,400	20	.62	.50	.20	2	2	3.0	1.5	.5
5	7,200	20	.62	.50	.20	2	2	3.0	1.5	.5
6	7,200	20	.62	.50	.20	2	2	3.0	1.5	.5
7	7,400	20	.30	.58	.50	3	2	15.0	1.5	2.0
8	7,650	20	.50	.58	.30	3	2	15.0	1.5	2.0
9	7,400	20	.43	.58	.35	3	2	15.0	1.5	2.0
10	7,000	20	.62	.37	.20	2	2	12.0	1.5	2.0

Table 11.--*Values for parameters distributed by hydrologic response unit (HRU) after optimization*--Continued

HRU	ELEV	CTX	TRNCF	COVDS	COVDW	ICOV	ISOIL	SMAX	REMX	SRX
				Foidel Creek at mouth near Oak Creek (09243900)						
1	7,000	20	0.55	0.37	0.20	2	2	12.0	1.5	2.0
2	7,200	20	.55	.37	.20	2	2	11.0	1.5	2.0
3	7,000	20	.55	.37	.20	2	2	12.0	1.5	2.0
4	7,400	20	.55	.50	.20	2	2	3.0	1.5	.5
5	7,200	20	.55	.50	.20	2	2	3.0	1.5	.5
6	7,200	20	.55	.50	.20	2	2	3.0	1.5	.5
7	7,400	20	.23	.58	.50	3	2	15.0	1.5	2.0
8	7,650	20	.43	.58	.30	3	2	15.0	1.5	2.0
9	7,400	20	.36	.58	.35	3	2	15.0	1.5	2.0
10	7,200	20	.88	.10	.05	1	2	11.0	1.5	.4
11	7,000	20	.55	.37	.20	2	2	12.0	1.5	2.0
12	7,400	20	.46	.50	.25	2	2	3.0	1.5	.5
13	6,850	20	.55	.37	.20	2	2	12.0	1.5	2.0
14	7,400	20	.46	.50	.25	2	2	3.0	1.5	2.0
15	7,400	20	.46	.50	.25	2	2	3.0	1.5	.4
16	7,000	20	.66	.10	.15	1	2	4.5	1.5	1.0
17	6,800	20	.55	.37	.20	2	2	12.0	1.5	2.0
				Watering Trough Gulch near Hayden (09244460)						
1	7,200	20	.60	.44	.20	2	2	10.0	1.3	2.5
2	7,400	20	.60	.44	.20	2	2	10.0	1.3	2.5
3	7,400	20	.60	.44	.20	2	2	10.0	1.3	2.5
4	7,100	20	.57	.37	.20	2	2	10.0	1.3	2.5
5	7,300	20	.57	.37	.20	2	2	10.0	1.3	2.5
6	7,400	20	.57	.37	.20	2	2	10.0	1.3	2.5
7	7,300	20	.57	.37	.20	2	2	10.0	1.3	2.5
8	7,300	20	.50	.51	.25	2	2	13.0	1.3	2.5
9	7,400	20	.50	.51	.25	2	2	13.0	1.3	2.5
10	7,300	20	.50	.51	.25	2	2	13.0	1.3	2.5
11	7,300	20	.50	.51	.25	2	2	13.0	1.3	2.5
12	7,200	20	.50	.51	.25	2	2	13.0	1.3	2.5
13	7,500	20	.50	.51	.25	2	2	13.0	1.3	2.5
14	7,600	20	.50	.51	.25	2	2	13.0	1.3	2.5

Table 11.--*Values for parameters distributed by hydrologic response unit (HRU) after optimization*--Continued

HRU	ELEV	CTX	TRNCF	COVDS	COVDW	ICOV	ISOIL	SMAX	REMX	SRX
				Hubberson Gulch near Hayden (09244464)						
1	7,200	20	0.95	0.37	0.20	2	2	10.0	1.3	2.5
2	7,400	20	.95	.37	.20	2	2	10.0	1.3	2.5
3	7,700	20	.95	.37	.20	2	2	10.0	1.3	2.5
4	7,000	20	.95	.37	.20	2	2	11.0	1.3	2.5
5	7,300	20	.95	.37	.20	2	2	10.0	1.3	2.5
6	7,400	20	.90	.44	.20	2	2	10.0	1.3	2.5
7	8,000	20	.90	.44	.20	2	2	10.0	1.3	2.5
8	8,000	20	.90	.44	.20	2	2	10.0	1.3	2.5
9	7,200	20	.90	.51	.20	2	2	13.0	1.3	2.5
10	7,700	20	.90	.51	.20	2	2	13.0	1.3	2.5
11	8,000	20	.90	.51	.20	2	2	13.0	1.3	2.5
12	7,200	20	.90	.51	.20	2	2	13.0	1.3	2.5
13	7,500	20	.90	.51	.20	2	2	13.0	1.3	2.5
				Stokes Gulch near Hayden (09244470)						
1	6,400	20	.47	.37	.25	2	2	11.0	1.3	2.5
2	6,550	20	.47	.37	.25	2	2	11.0	1.3	2.5
3	6,750	20	.47	.37	.25	2	2	11.0	1.3	2.5
4	6,900	20	.47	.37	.25	2	2	11.0	1.3	2.5
5	6,450	20	.42	.51	.30	2	2	11.0	1.3	2.5
6	7,200	20	.42	.51	.30	2	2	13.0	1.3	2.5
7	7,400	20	.42	.51	.30	2	2	13.0	1.3	2.5
8	7,400	20	.42	.51	.30	2	2	13.0	1.3	2.5
9	7,400	20	.42	.51	.30	2	2	13.0	1.3	2.5
10	7,400	20	.42	.51	.30	2	2	13.0	1.3	2.5
11	6,500	20	.24	.70	.50	1	2	3.0	1.3	1.5
12	6,500	20	.24	.70	.50	1	2	3.0	1.3	1.5
13	6,600	20	.24	.70	.50	1	2	3.0	1.3	1.5
				Jubb Creek near Axial (09250610)						
1	8,000	20	.12	.58	.60	3	2	9.5	1.5	2.0
2	7,400	20	.19	.51	.70	2	2	15.5	1.5	2.0
3	7,400	20	.19	.51	.70	2	2	15.5	1.3	2.0
4	7,200	20	.12	.37	.60	2	2	7.5	1.3	2.0
5	7,300	20	.12	.37	.60	2	2	7.5	1.3	2.0
6	6,900	20	.12	.37	.60	2.	2	8.5	1.3	2.0
7	7,000	20	.12	.37	.60	2	2	8.5	1.3	2.0
8	6,700	20	.12	.37	.60	2	2	8.5	1.3	2.0

Table 11.--*Values for parameters distributed by hydrologic response unit (HRU) after optimization*--Continued

HRU	ELEV	CTX	TRNCF	COVDS	COVDW	ICOV	ISOIL	SMAX	REMX	SRX
				Taylor Creek at mouth near Axial (09250510)						
1	6,800	20	0.28	0.37	0.50	2	2	8.5	1.3	1.0
2	7,000	20	.28	.37	.50	2	2	8.5	1.3	1.0
3	7,500	20	.28	.37	.50	2	2	7.5	1.3	1.0
4	7,000	20	.28	.37	.50	2	2	8.5	1.3	1.0
5	7,000	20	.28	.37	.50	2	2	8.5	1.3	1.0
6	6,400	20	.28	.37	.50	2	2	8.5	1.3	1.0
7	7,200	20	.43	.51	.30	2	2	15.5	1.5	1.0
8	7,800	20	.43	.51	.30	2	2	15.5	1.5	1.0
9	7,000	20	.43	.51	.30	2	2	14.5	1.5	1.0
10	7,800	20	.43	.51	.30	2	2	15.5	1.5	1.0
11	7,600	20	.43	.51	.30	2	2	15.5	1.5	1.0
12	8,000	20	.28	.58	.50	3	2	9.5	5.0	2.0
				Wilson Creek near Axial (09250600)						
1	6,800	20	.23	.37	.56	2	2	8.5	1.3	1.0
2	6,800	20	.23	.37	.56	2	2	8.5	1.3	1.0
3	8,000	20	58	.37	.27	2	2	7.5	1.3	1.7
4	7,000	20	.23	.37	.57	2	2	8.5	1.3	1.0
5	7,800	20	.58	.37	.27	2	2	7.0	1.3	1.7
6	7,200	20	.23	.37	.57	2	2	7.5	1.3	1.0
7	7,000	20	.23	.37	.57	2	2	8.5	1.3	1.0
8	7,000	20	.23	.37	.57	2	2	8.5	1.3	1.0
9	8,200	20	.58	.37	.27	2	2	7.5	1.3	1.7
10	6,400	20	.23	.37	.57	2	2	8.5	1.3	1.0
11	8,200	20	.38	.58	.42	3	2	9.5	5.0	2.0
12	8,000	20	.33	.58	.42	3	2	9.5	3.0	2.0
13	7,200	20	.13	.51	.62	2	2	15.5	1.3	1.0
14	7,800	20	.13	.51	.62	2	2	15.5	1.3	1.0
15	7,300	20	.13	.51	.62	2	2	15.5	1.3	1.0
16	7,100	20	.13	.51	.62	2	2	15.5	1.3	1.0
17	7,800	20	2.13	.51	.62	2	2	15.5	1.3	1.0
18	7,600	20	.13	.51	.62	2	2	15.5	1.3	1.0
19	7,500	20	.13	.51	.62	2	2	15.5	1.3	1.0
20	7,200	20	.13	.51	.62	2	2	15.5	1.3	1.0
21	7,800	20	.13	.51	.62	2	2	15.5	1.3	1.0
22	7,900	20	.13	.51	.62	2	2	15.5	1.3	1.0

*U.S. GOVERNMENT PRINTIG OFFICE: 1989-0-673-196/00025