

APPLICATION OF THE PRECIPITATION-RUNOFF MODELING SYSTEM
TO SMALL BASINS IN THE PARACHUTE CREEK BASIN, COLORADO

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to International System of Units (SI) by using the following conversion factors.

<i>Multiply</i>	<i>By</i>	<i>To obtain</i>
cubic foot per second (ft ³ /s)	0.02932	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi ²)	2.590	square kilometer

Temperature in degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation: °F = 9/5°C + 32; degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation: °C = 5/9(°F-32).

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 "Mean Sea Level of 1929."

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ABSTRACT

The U.S. Geological Survey's Precipitation-Runoff Modeling System was calibrated and verified for two small basins in western Colorado. To determine relative errors that might be expected from using the Precipitation-Runoff Modeling System for record extension, a statistical analysis of observed and model-predicted streamflow is presented. Observed and predicted hydrographs show many similarities. Average monthly mean, average monthly maximum, average annual total, and average daily mean observed and model-predicted streamflow differences were small, on the average less than 10 percent, indicating the Precipitation-Runoff Modeling System can, when adequately calibrated, satisfactorily estimate these streamflow factors. Average monthly minimum streamflow generally was overpredicted, but actual differences between observed and model-predicted average monthly minimum streamflow are small.

To determine relative errors of streamflow prediction in ungaged basins, three different model-parameter sets were used to predict streamflow in a nearby gaged basin. The first model-parameter set was based on little prior information about the test basin; the second model-parameter set was based on only climatic information for the test basin; the third model-parameter set was based on data from nearby model-calibrated basins. As would be expected, the more information available, the better the Precipitation-Runoff Modeling System was able to predict streamflow. Results from this analysis imply this modeling system can be used to estimate streamflow in ungaged basins, if a calibrated basin is nearby from which to transfer model-parameter values.

INTRODUCTION

As in other western States, Colorado has experienced increased energy resources development. Questions regarding impacts to and availability of the water resources are raised as development proceeds, or new areas are proposed for development. However, many of these questions are difficult to answer as development often occurs in small drainage basins or other areas where little hydrologic information is available.

One method of overcoming a lack of hydrologic information for an area is to establish a data-collection network and collect the required information. Although this is the preferred method, it is costly and time-consuming. A second method is to estimate the needed data. A study was begun to estimate streamflow in the Parachute Creek basin using the U.S. Geological Survey's Precipitation-Runoff Modeling System (PRMS) (Leavesly and others, 1983), and to report the calibration and verification results.

One objective of this report is to document the calibration and verification results of the U.S. Geological Survey's PRMS on two basins in western Colorado. Another purpose is to demonstrate relative errors in streamflow prediction in ungaged basins using PRMS. This purpose was accomplished by transferring model parameters from calibrated basins to a gaged basin, and by performing statistical analyses of observed and predicted streamflow.

STUDY AREA DESCRIPTION

The study basins, Northwater Creek, East Middle Fork Parachute Creek, and East Fork Parachute Creek are part of the Naval Oil Shale Reserve located in Garfield County, and are in the Uinta basin section of the Colorado Plateau (fig. 1). Surface water in this area drains to the Colorado River. Altitudes in the basins range from about 7,800 ft to over 9,200 ft above sea level.

The area's climate is semiarid, with annual precipitation ranging from near 12 in. at lower elevations to over 30 in. at higher elevations. Most precipitation occurs as snow, although summer thunderstorms can contribute large amounts of precipitation to local areas. Temperatures in the study area can range from near 100 °F in summer to less than -20 °F in winter. The number of frost-free days is about 75 days at higher elevations.

Geology of the study area is of Tertiary age and generally it is in the Green River and Uinta Formations. Permeability of rocks in these two formations mostly results from fractures and faults. Donnell (1961) and Keighin (1975) provide a more detailed description of the geology in the study area.

The major soil groups in the area are the Trigul, Parachute, Roan, and Northwater series. These four soil series are similar and are characterized as well-drained, moderately deep to deep loam soils. Harman and Murray (1979) describe the plateau soils as "...deep to shallow, well-drained, moderately sloping to steep soils...", and lower soils as "...well-drained to poorly drained, nearly level to gently sloping soils on terraces and flood plains..."

DESCRIPTION OF PRECIPITATION-RUNOFF MODEL

The model used for this study is the U.S. Geological Survey's PRMS, documented in the user's manual (Leavesley and others, 1983). It is a deterministic, distributed, physical-process model that can be used to estimate changes of a hydrologic system in response to changes in system input or changes in the system itself. The model's driving variables are daily air temperature, precipitation, and solar radiation. Model output is daily mean streamflow.

To account for spatial and temporal variations of basin characteristics that influence hydrologic response in the model, basins are subdivided into hydrologic-response units (HRU's) on the basis of climatic, physiographic, vegetative, and soils features. The area within an HRU is considered

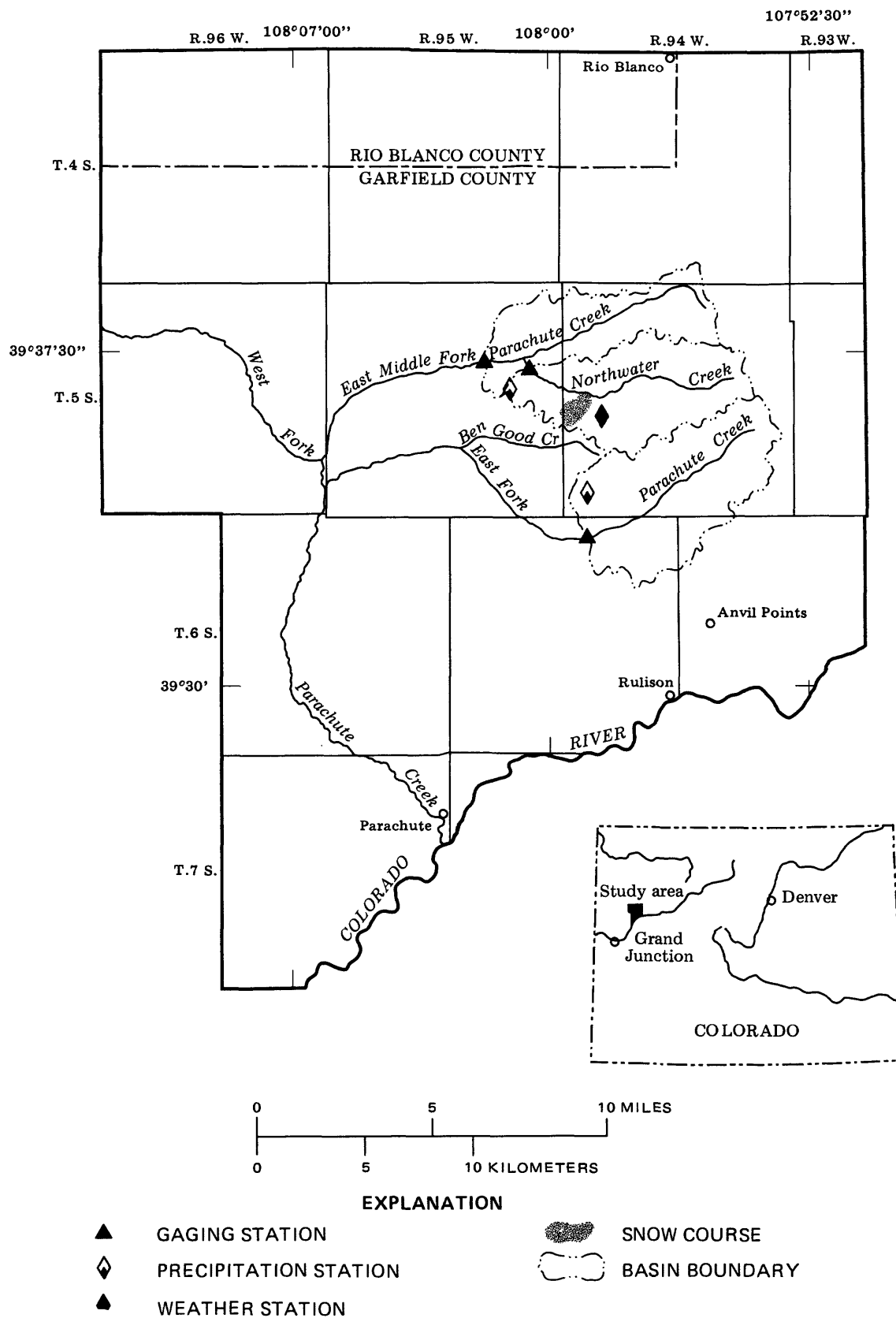


Figure 1.--Location of study area.

homogeneous with respect to hydrologic response. Total basin response is determined daily by calculating a water balance for each HRU, then summing the response of all the basin's HRU's.

Most hydrologic-system components in the model are described by physical laws or empirical relations. The associated model parameters can be adjusted to reproduce the physical processes as nearly as possible. The model uses a series of linear and nonlinear reservoirs to define the watershed system with the output combined to produce total system response. This reservoir system is described in detail in Leavesley and others (1983).

The model's structure and sequence of operations are shown in the flow chart in figure 2. Model initialization occurs at step Input A; for each day of simulation, the model operates from step Input B through the evapotranspiration algorithm for each HRU. Flow through the subsurface and ground-water reservoirs are routed after computing the water balance for all HRU's. The model output, daily mean streamflow, is the sum of these reservoirs' output, plus any surface flow.

Model parameters found to be most sensitive in predicting streamflow from snowmelt in a previous study (Leavesley, 1981) are listed in table 1. Norris and Parker (1985) found that the model parameter defining the soils maximum available water-holding capacity (SMAX) appears most sensitive in predicting snowmelt-runoff volume. SMAX is defined as the amount of water held in the soil between field capacity and wilting point. For further discussion on these and other model parameters, see Leavesley and others (1983).

Table 1.--*Definitions of model parameters influencing streamflow prediction from snowmelt*

Model parameter	Definition
BST	Air temperature above which all precipitation is rain.
COVDNW	Winter vegetation-cover density.
CTS	Air-temperature evapotranspiration coefficient.
RCB	Ground-water routing coefficient.
RSEP	Rate water moves from subsurface to ground-water reservoir.
SMAX	Soil maximum available water-holding capacity.
TLX	Maximum air-temperature lapse rate.
TRNCF	Solar-radiation transmission coefficient.
TST	Air-temperature index to determine start of evapotranspiration.

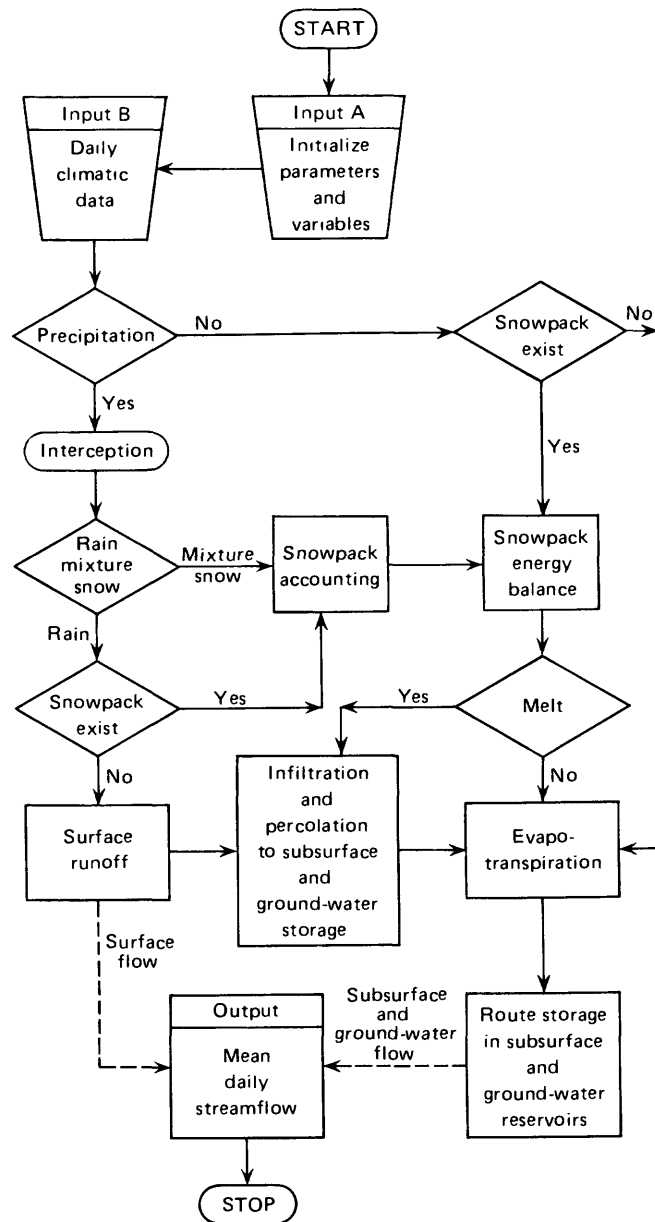


Figure 2.--Generalized flow chart of the U.S. Geological Survey's Precipitation-Runoff Modeling System.

MODEL CALIBRATION

The model was calibrated for the study basins using a modification of the procedure described in Norris and Parker (1985). The procedure in Norris and Parker calibrated this model by an optimizing procedure for SMAX. The procedure was modified as follows: after calibrating SMAX as described, other parameters found sensitive to predicting streamflow also were calibrated using the same procedure. To obtain the best possible estimates for model parameters, sensitive parameters other than SMAX then were optimized using the model's Gauss-Newton optimization procedure. The Gauss-Newton optimization procedure (Leavesly and others, 1983) attempts to minimize the error between daily observed (mean daily streamflow from streamflow-gaging station) and predicted streamflow, and because the procedure in Norris and Parker (1985) uses an objective function of minimizing the error between annual observed and predicted streamflow, it was felt that the Gauss-Newton procedure would aid in more accurate prediction of streamflow timing.

Assumptions

Assumptions made during calibration for each basin were that: (1) The slopes of Wymore's (1974) relations of maximum water-holding capacity and elevation are correct; (2) all HRU's have equal opportunity to contribute water to streamflow; (3) SMAX and other selected model parameters reflect model errors from other sources; and (4) SMAX can be calculated only to the nearest one-half inch.

By assuming that the slopes in Wymore's (1974) relations of maximum water-holding capacity and elevation are correct, the calibration of SMAX was simplified. Wymore's values for maximum water-holding capacity were adjusted for a specific area by allowing the intercept value for each vegetation type to change while keeping Wymore's slopes of the relation.

The second assumption was included because the HRU's that actually contribute water to streamflow were unknown. This assumption allowed the calibration procedure to determine which HRU's contributed to streamflow based on observed streamflow volume and timing. The third assumption, that SMAX and other selected parameters contain all other sources of errors, simplified the calibration process by distributing the errors into a few sensitive parameters. The last assumption, that SMAX can be estimated only to the nearest one-half inch, is included to simplify later efforts of transferability of model parameters to ungaged basins.

One additional restriction was made during the calibration process. It was assumed that not only were the slopes of the maximum water-holding capacity and elevation relations for the two calibration basins the same, but the intercept values for both basins also were the same. This meant that SMAX values for a given vegetation type at the same elevation were the same for both basins. This assumption also was included to simplify later transferability efforts.

Characteristics of Calibration Basins

Basins used for model calibration were Northwater Creek, a subbasin of East Middle Fork Parachute Creek, and East Middle Fork Parachute Creek. The HRU delineation map for Northwater Creek is in figure 3, and the HRU delineation map for East Middle Fork Parachute Creek is in figure 4. Estimated streamflow for each basin was calibrated to observed streamflow data from streamflow-gaging stations at the outlet of each basin for water years 1977 to 1979. The Northwater Creek basin was calibrated to gaging station 09092830 Northwater Creek near Anvil Points; the East Middle Fork Parachute Creek basin was calibrated to gaging station 09092850 East Middle Fork Parachute Creek near Rio Blanco. Physical characteristics of the two basins are listed in table 2.

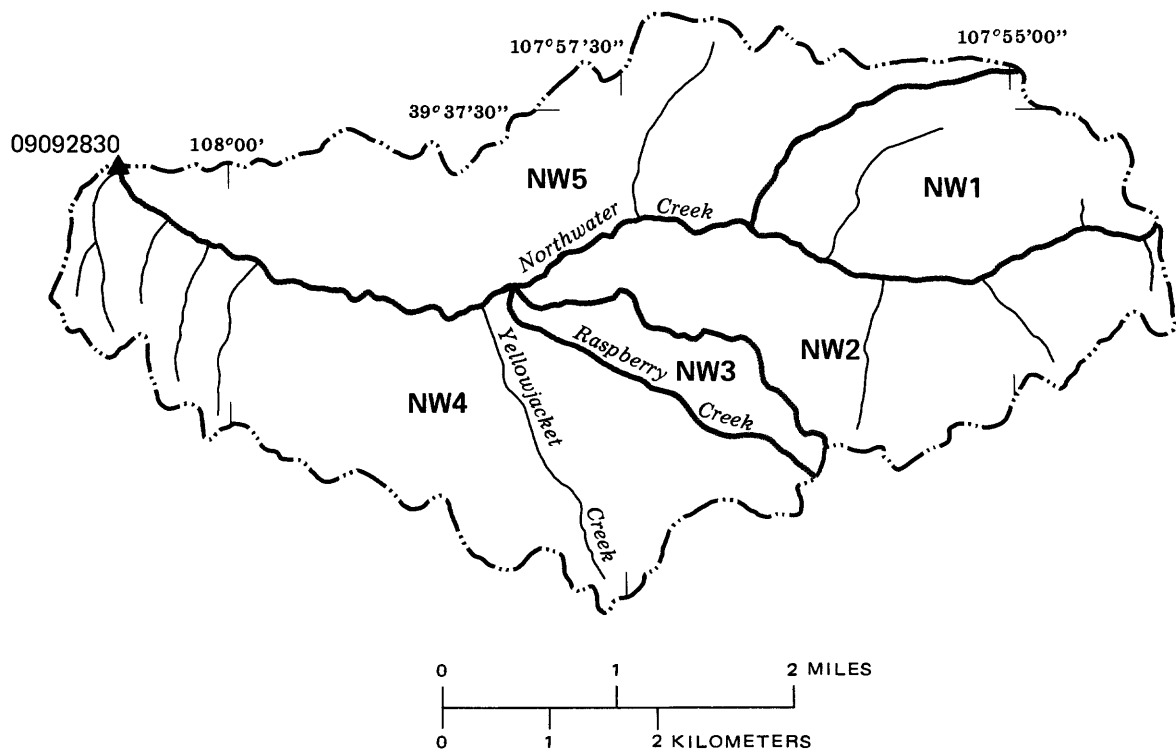
Table 2.--Physical characteristics of calibration basins

Streamflow-gaging-station number and name	Drainage area (square mile)	Relief ¹ (feet)	Vegetation cover (percent)			
			Oak	Sage	Aspen	Other
09092830 Northwater Creek near Anvil Points-----	12.6	1,668	2	46	21	31
09092850 East Middle Fork Parachute Creek near Rio Blanco-----	22.1	1,748	7	40	18	35

¹Difference between maximum and minimum basin elevation.

Sensitivity Analysis

Prior to using the model's optimization procedure, a sensitivity analysis was done for model parameters in table 1. Results from the sensitivity analysis for both the Northwater Creek basin and East Middle Fork Parachute Creek basin are given in table 3; the values presented in table 3 are the mean of the squared differences between daily observed and predicted streamflow for the calibration water years. For both basins, the five most sensitive model parameters were the same. The most sensitive model parameter for predicting daily streamflow was TRNCF, a solar-radiation transmission coefficient. TRNCF is the percentage of shortwave radiation received at the top of the winter vegetative canopy that passes through the canopy; thus, TRNCF is highly related to winter vegetation-cover density. This model parameter was sensitive in the study area because of its influence on the snowpack-energy balance. TRNCF mainly influences streamflow timing, but also can influence volume. The winter vegetation-cover density parameter, COVDNW, is highly correlated to TRNCF, and values for COVDNW were determined after TRNCF was optimized.



EXPLANATION

- 09092830 ▲ GAGING STATION-- Number is gaging station identification
- BASIN BOUNDARY
- NW4 BOUNDARY AND IDENTIFICATION FOR NORTHWATER CREEK HYDROLOGIC RESPONSE UNIT

Figure 3.--Hydrologic response unit delineation for the Northwater Creek basin.

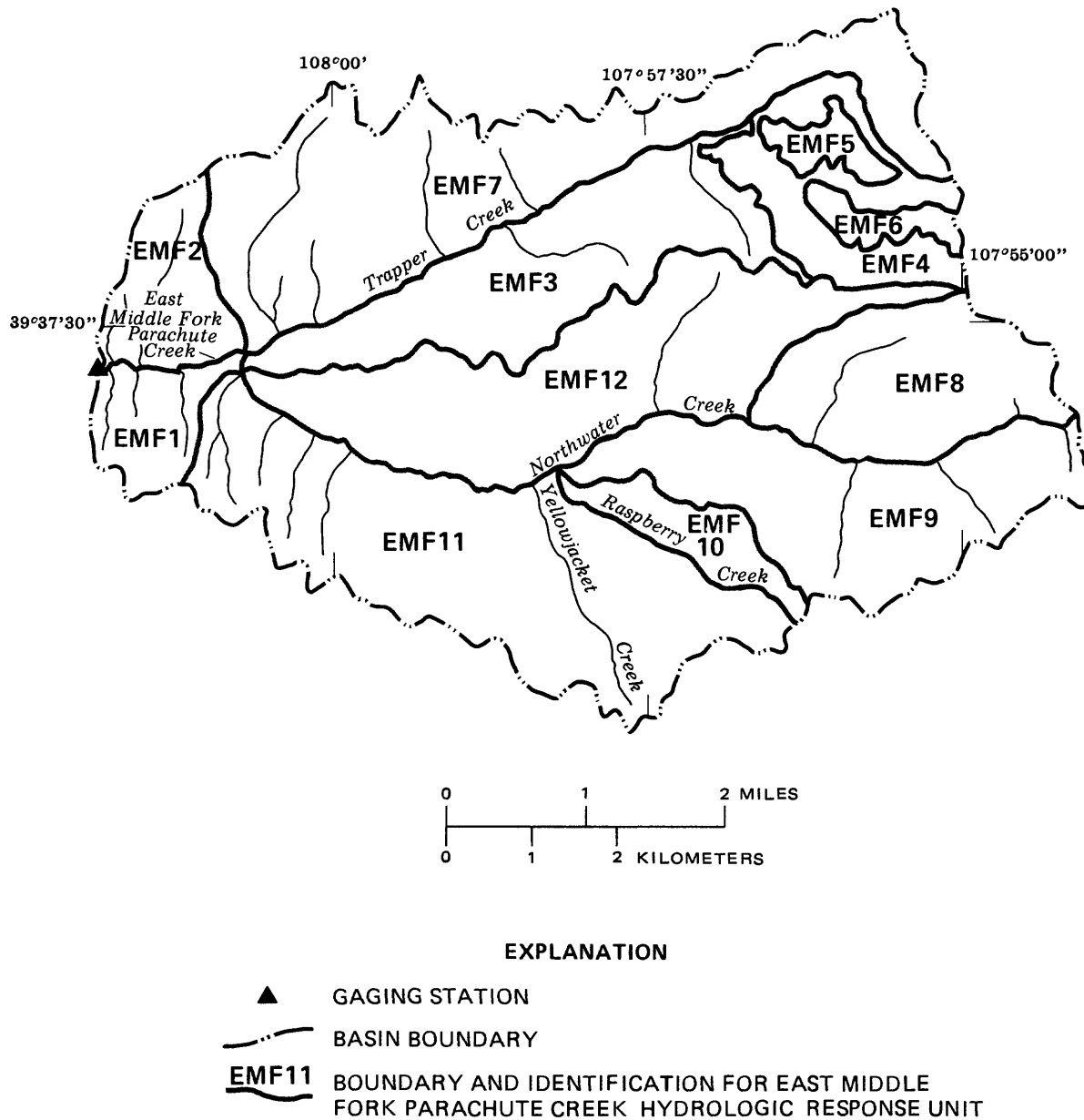


Figure 4.--Hydrologic response unit delineation for the East Middle Fork Parachute Creek basin.

Table 3.--Mean squared runoff prediction error resulting from 10 percent parameter errors for Northwater Creek near Anvil Points and for East Middle Fork Parachute Creek near Rio Blanco

[Variance for Northwater Creek = 64.9197; variance for East Middle Fork Parachute Creek = 81.0386]

Parameter (See table 1 for definition)	Northwater Creek	East Middle Fork Parachute Creek
COVDNW	0.55241	0.92650
TRNCF	17.13649	49.46749
SMAX	7.51610	20.85304
RSEP	.00314	.06474
RCB	.00365	.00161
TLX	7.44804	18.86106
CTS	.73419	4.14584
TST	.30018	.77342
BST	2.99177	12.08417

The second most sensitive model parameter for these basins was SMAX. In areas where snowmelt is the major contributor to streamflow, SMAX is probably the most critical model parameter for predicting streamflow volume. However, model parameters that influence the snowpack accumulation, such as TRNCF, also are sensitive in predicting streamflow volume from snowmelt. The model's soil moisture zone is the only reservoir where water may be stored without eventually becoming streamflow. It also is the only model reservoir where water input to the system can be lost to evapotranspiration. Unless snowmelt on a given day exceeds the infiltration rate, all water from a melting snowpack first moves into the soil-moisture reservoir prior to moving to the other reservoirs, and eventually to the channel as streamflow. SMAX defines the maximum amount of water that can be held in the soil for each HRU. Only after the amount of water in the soil-moisture reservoir is equal to SMAX can water then move to other model reservoirs. Thus, SMAX is important for predicting streamflow volume in areas with snowmelt runoff as the major contributor to streamflow. The larger the SMAX value, the more water required to fill the soil-moisture reservoir (and the more water subject to evapotranspiration losses), before any water can become streamflow. SMAX also influences streamflow timing.

The third most sensitive model parameter was TLX, the maximum air-temperature lapse rate. This model parameter is important in predicting streamflow timing because of its influence on the snowpack energy balance at different elevations.

BST, the air temperature above which all precipitation is rain, and CTS, the air-temperature evapotranspiration coefficient, were the fourth and fifth most sensitive model parameters. BST is sensitive in the snowmelt period

because of the way it influences the snowpack energy balance. If precipitation is defined as snow, the melt rate is slowed or stopped; but if the precipitation is defined as rain, energy is added to the snowpack, increasing the melt. In this manner, BST mainly influences streamflow timing. CTS mostly influences volume but also can influence timing, as it is distributed by month. It has a direct influence on the amount of water lost to evapotranspiration and is not available for streamflow.

CALIBRATION AND VERIFICATION RESULTS

A summary of the differences between observed and predicted annual runoff using calibrated and optimized model-parameter values for both basins is in table 4. For the calibration period in the Northwater Creek basin, the absolute value of the average difference between observed and predicted annual runoff was 0.23 in. and the absolute value of the average annual percent error was 2.93. For East Middle Fork Parachute Creek basin, the absolute value of the average difference between observed and predicted annual total runoff was 0.30 in. and the absolute value of the average annual percent error was 7.0.

Observed and predicted hydrographs for gaging station 09092830 Northwater Creek near Anvil Points are shown in figure 5 and for gaging station 09092850 East Middle Fork Parachute Creek near Rio Blanco are shown in figure 6. Hydrographs for water year 1977 are not shown in figures 5 and 6 because of relatively low streamflows compared to water years 1978 and 1979.

Compared to observed snow-course data from the area, model-predicted snowpack water content for both basins was low by approximately 65 percent on March 24 in water year 1979. The model option to adjust the predicted snowpack to observed data was used for this date to increase the snowpack water content by about 65 percent. This added 6.31 in. of water to the Northwater Creek basin snowpack, and 6.06 in. to the East Middle Fork Parachute Creek basin snowpack. These increases brought the total predicted annual precipitation values nearer to values recorded at other nearby precipitation gages. Predicted snowpack water content for the other years was near measured values from the snow courses.

Table 4.--*Summary of annual observed and predicted runoff and prediction error after calibration and optimization*

Streamflow-gaging-station number and name	Water year	Total observed runoff (inches)	Total predicted runoff (inches)	Prediction error (inches)	Prediction error (percent)
09092830 Northwater Creek near Anvil Points-----	1977	0.62	0.62	0.00	0.00
	1978	4.47	4.45	-.02	-.44
	1979	8.02	7.35	-.67	-8.35
09092850 East Middle Fork Parachute Creek near Rio Blanco-----	1977	.42	.41	-.01	-2.38
	1978	4.41	3.70	-.71	-16.10
	1979	7.13	7.31	.18	2.52

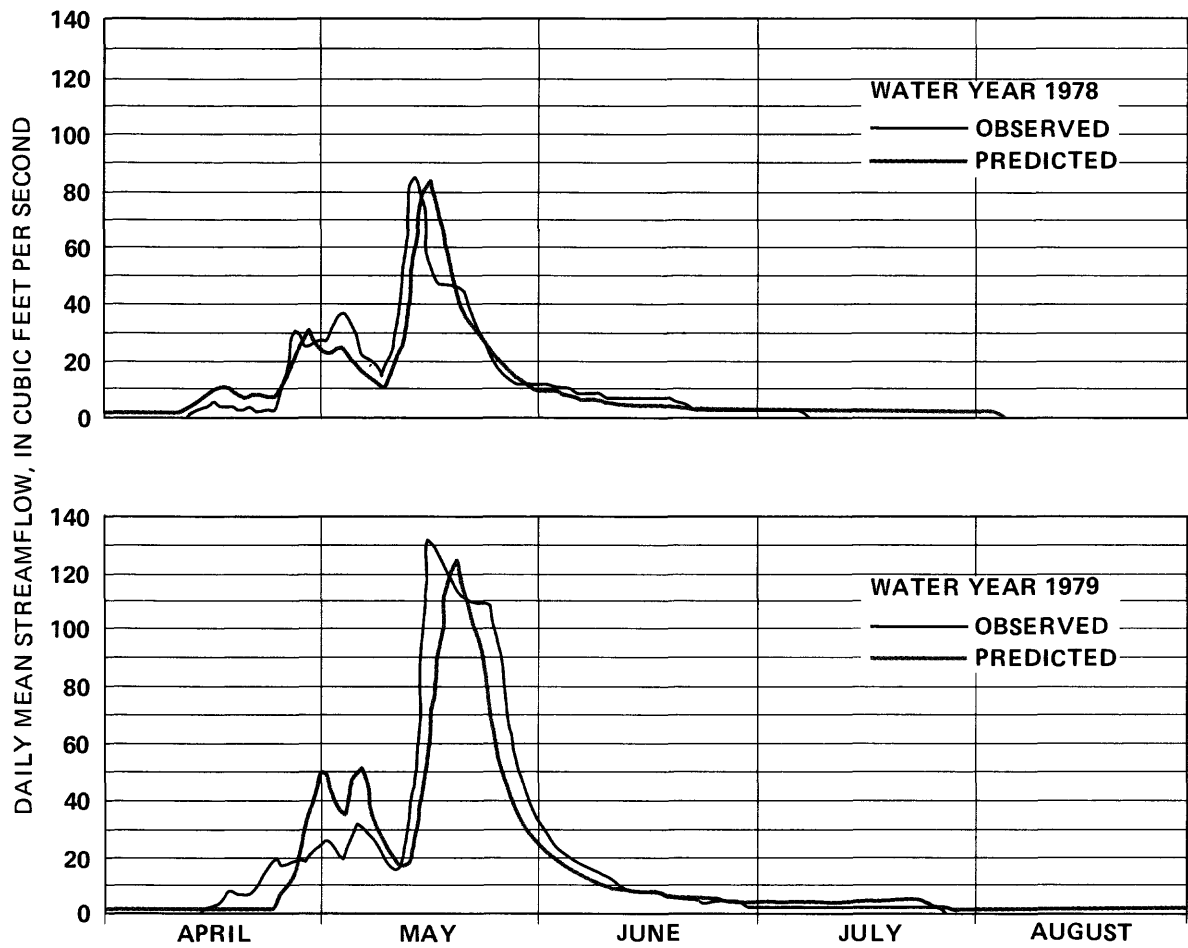


Figure 5.--Observed and predicted daily mean streamflow after calibration for Northwater Creek near Anvil Points.

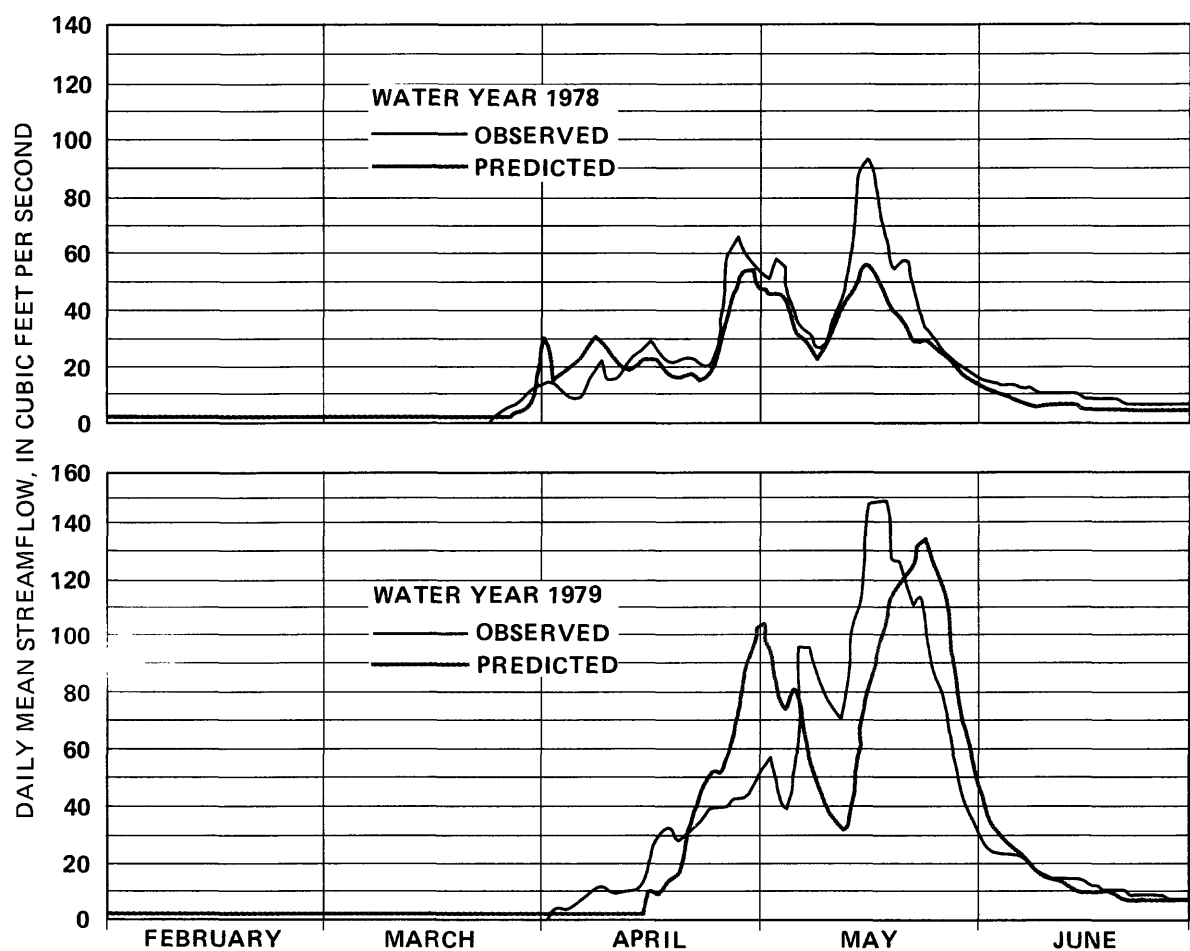


Figure 6.--Observed and predicted daily mean streamflow after calibration for East Middle Fork Parachute Creek near Rio Blanco.

Calibrated model parameter values are shown in table 5 for the Northwater Creek basin and in table 6 for the East Middle Fork Parachute Creek basin. As stated earlier, the Northwater Creek basin is a subbasin of the East Middle Fork Parachute Creek basin, and HRU's 8-12 in table 6 for East Middle Fork Parachute Creek are the same HRU's in table 5 for Northwater Creek. The reason for the differences in TRNCF between the same HRU's in the tables is that TRNCF was defined as sensitive and was optimized in an attempt to improve the predicted streamflow timing. Comparing tables 5 and 6, most calibrated values for the two basins are similar except for TST, an air-temperature index to determine the specific date that evapotranspiration starts. The reason for the difference in TST between the basins cannot be determined, although it may be related to restrictions and introduced errors caused by the assumption (included for later efforts of transferability) that SMAX values for the two basins should follow the same relations.

In tables 5 and 6, TLX and CST are given as ranges, because these parameters are monthly-distributed and some months have higher values than others. After model calibration for the two basins, observed data for water years 1980 and 1981 were added as a means of verifying the calibration. The model was used to predict streamflow for each basin for 1980 and 1981 using calibrated model parameter values for that basin. The error summary for the verification period is listed in table 7.

As in water year 1979, the snowpack water content for water year 1980 was updated. Compared to snow-course data, the April predicted snowpack water content was low by about 60 percent. Increasing the water content on each HRU by approximately 60 percent increased the predicted snowpack water content by 6.17 in. in the Northwater Creek basin and by 4.58 in. in the East Middle Fork Parachute Creek basin.

For the verification period, the absolute value of the average difference between observed and predicted annual streamflow is 0.49 in. and the absolute value of the average annual percent error is 22.6 percent for Northwater Creek near Anvil Points. For East Middle Fork Parachute Creek near Rio Blanco, the absolute value of the average difference between observed and predicted annual streamflow is 0.50 in. and the absolute value of the average annual percent error is 28.2 percent. These errors are larger than the errors from the calibration period (table 4).

Observed and predicted hydrographs for the 1980 verification period for both basins are in figure 7. Timing of the predicted streamflow is not as good for verification as for calibration, although the timing for the verification years may still be acceptable for many uses. Hydrographs for water year 1981 are not shown, because of the small streamflow compared to water year 1980.

Table 5.--Calibrated model parameter values for Northwater Creek near Anvil Points

[See table 1 for definitions of abbreviations]

Hydrologic response unit number	Vege- tation type	Slope (percent)	Average elevation (feet above sea level)	Aspect	SMAx (inches)	COVDNW (percent)	TRNCF (percent)	TST (Fahren- heit- degree- days)	TLX (degrees Fahrenheit per 1,000 feet)	BST (degrees Fahrenheit)	CST (degrees Fahrenheit)
1	Sage	20	8,790	West	13.0	14	62	1,023	1.38-6.87	32.9	0.015-0.019
2	Aspen	20	8,680	North	23.0	10	72	998			
3	Sage	20	8,650	South- west	13.0	34	37	973			
4	Oak-aspen- sage	20	8,380	North							
5	Sage	20	8,350	South	19.5 13.0	17 39	55 32	948 948			

Table 6.--Calibrated model parameter values for East Middle Fork Parachute Creek near Rio Blanco

[See table 1 for definitions of abbreviations]

Hydrologic response unit number	Vege- tation type	Slope (percent)	Average elevation (feet above sea level)	Aspect	SMAx (inches)	COVDNW (percent)	TRNCF (percent)	TST (Fahren- heit- degree- days)	TLX (degrees Fahrenheit per 1,000 feet)	BST (degrees Fahrenheit)	CST (degrees Fahrenheit)
1	Oak	20	8,020	North	5.5	15	72	567	1.31-6.80	35.0	0.014-0.018
2	Oak	20	8,110	South- west	5.5	20	62	567			
3	Sage	10	8,330	South- west	13.0	20	62	567			
4	Aspen	20	8,610	North- east	23.0	20	62	592			
5	Sage	20	8,530	South	13.0	25	52	592			
6	Sage	25	8,690	North	13.0	25	52	642			
7	Sage-Oak	10	8,260	West	12.0	40	37	567			
8	Sage	20	8,790	West	13.0	23	57	642			
9	Aspen	20	8,680	North	23.0	15	72	642			
10	Sage	20	8,650	South- west	13.0	40	37	642			
11	Oak-Sage- Aspen	20	8,380	North	19.5	35	42	592			
12	Sage	20	8,350	South	13.0	20	62	592			

Table 7.--Summary of annual observed and predicted runoff and prediction error for verification period

Streamflow-gaging-station number and name	Water year	Annual total observed runoff (inches)	Annual total predicted runoff (inches)	Difference (inches)	Annual difference (percent)
09092830 North-water Creek near Anvil Points	1980	8.06	8.58	0.52	6.45
	1981	1.19	0.73	-.46	-38.66
09092850 East Middle Fork Parachute Creek near Rio Blanco	1980	6.53	7.13	0.60	9.19
	1981	0.87	1.28	.41	47.13

OBSERVED AND PREDICTED FLOW ANALYSES

The PRMS can be used for extension of streamflow records in basins with some continuous streamflow data but where the length of available data are not sufficient for determination of streamflow characteristics. By using the model to extend the streamflow record in time, statistical analyses of the generated streamflow information then could provide estimated results for such characteristics as flow-duration curves, mean annual flow, maximum flows, and minimum flows. This section provides some insight into the magnitude of errors that could be expected if the calibrated model is used for streamflow-record extension.

For the following observed and predicted streamflow analyses, 6 years of daily streamflow records were used--water years 1977 to 1981 (the calibration and verification years) and 1982. A minimum of 10 years of streamflow records generally are used when doing statistical analyses to summarize streamflow data. However, it was felt that the 6-year period could demonstrate the applicability of PRMS for streamflow-record extension and would provide estimates of anticipated errors from such use.

Flow-Duration Curves

Observed and predicted flow-duration curves for Northwater Creek near Anvil Points, and East Middle Fork Parachute Creek near Rio Blanco are in figures 8 and 9. Predicted curves for both basins closely approximate observed curves at larger streamflows and at the steep section of the curves. This implies that the model adequately predicts the snowmelt-runoff period when most of the flow in these basins occurs.

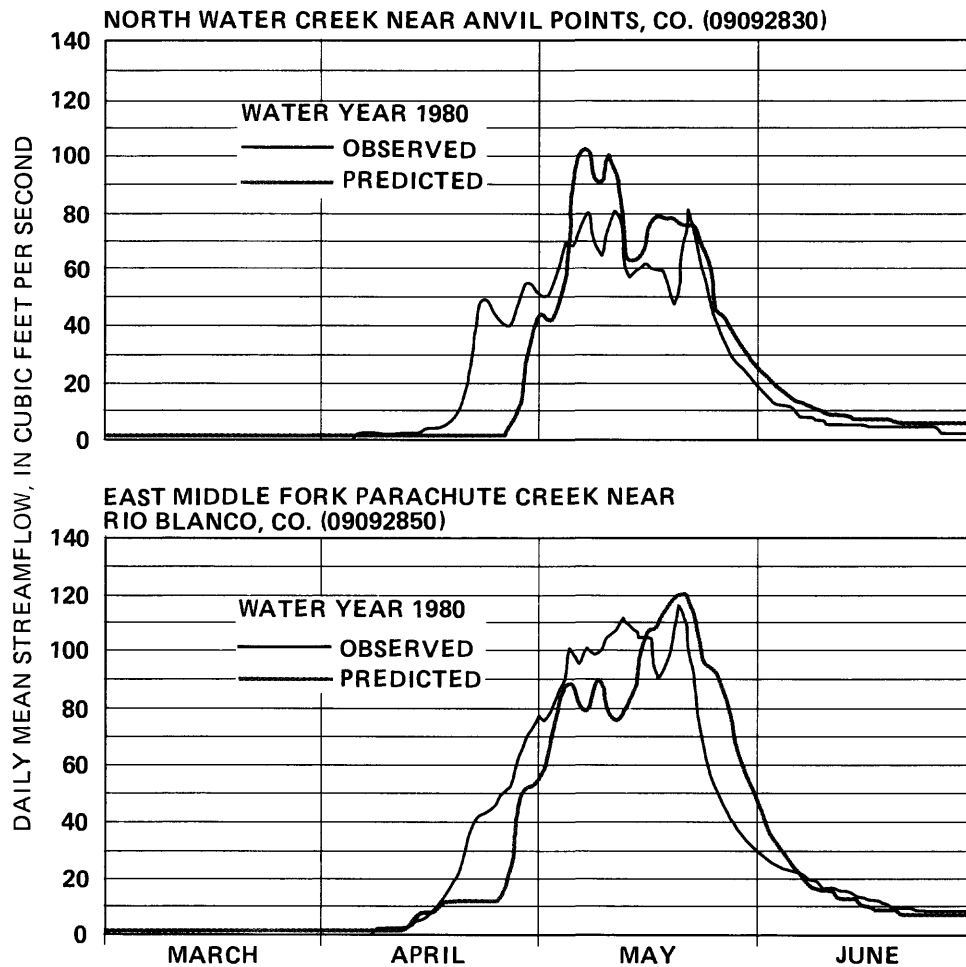


Figure 7.--Observed and predicted daily mean streamflow for verification year 1980 for Northwater Creek near Anvil Points and East Middle Fork Parachute Creek near Rio Blanco.

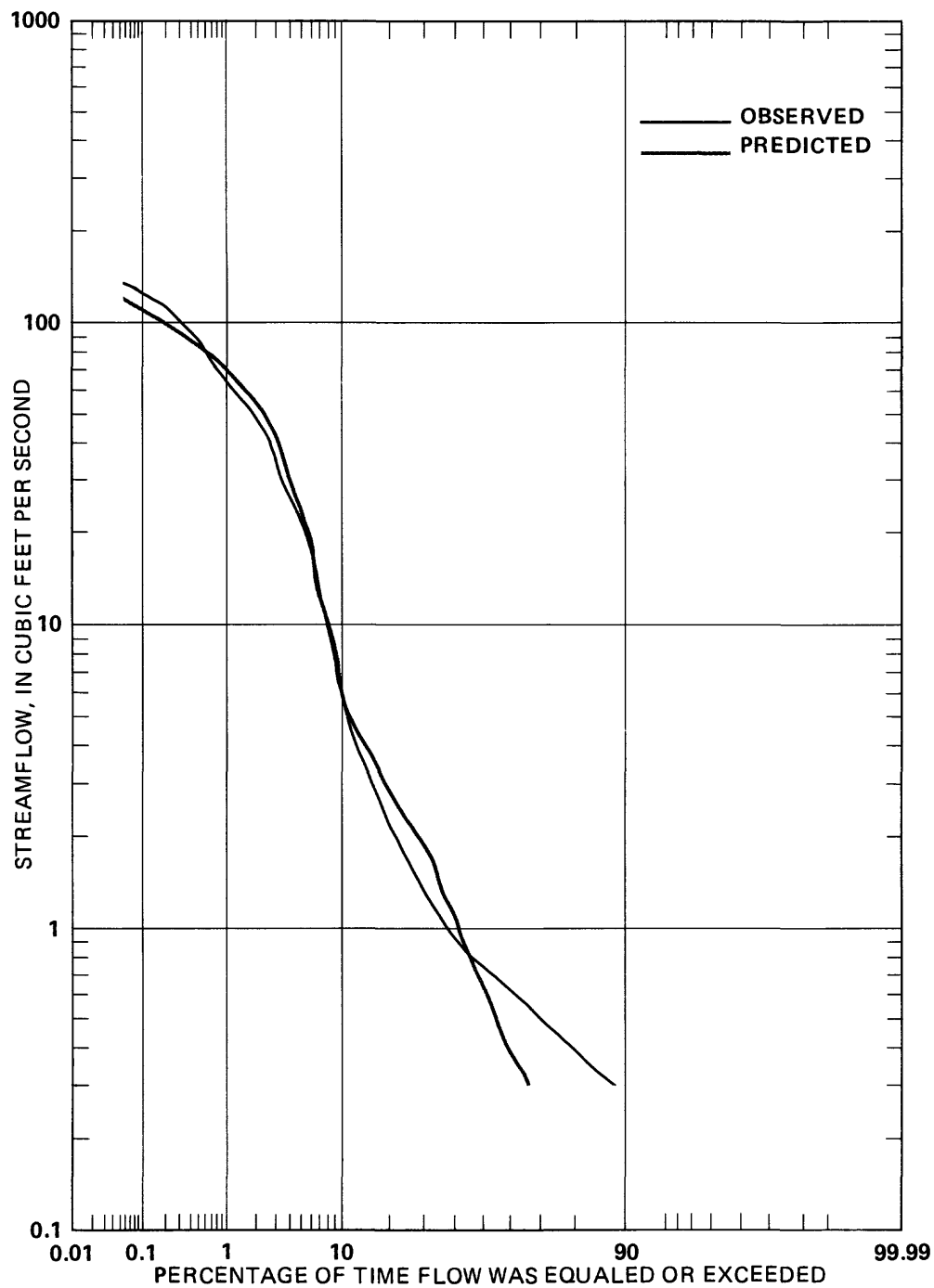


Figure 8.--Observed and predicted flow-duration curves for Northwater Creek near Anvil Points for water years 1977-82.

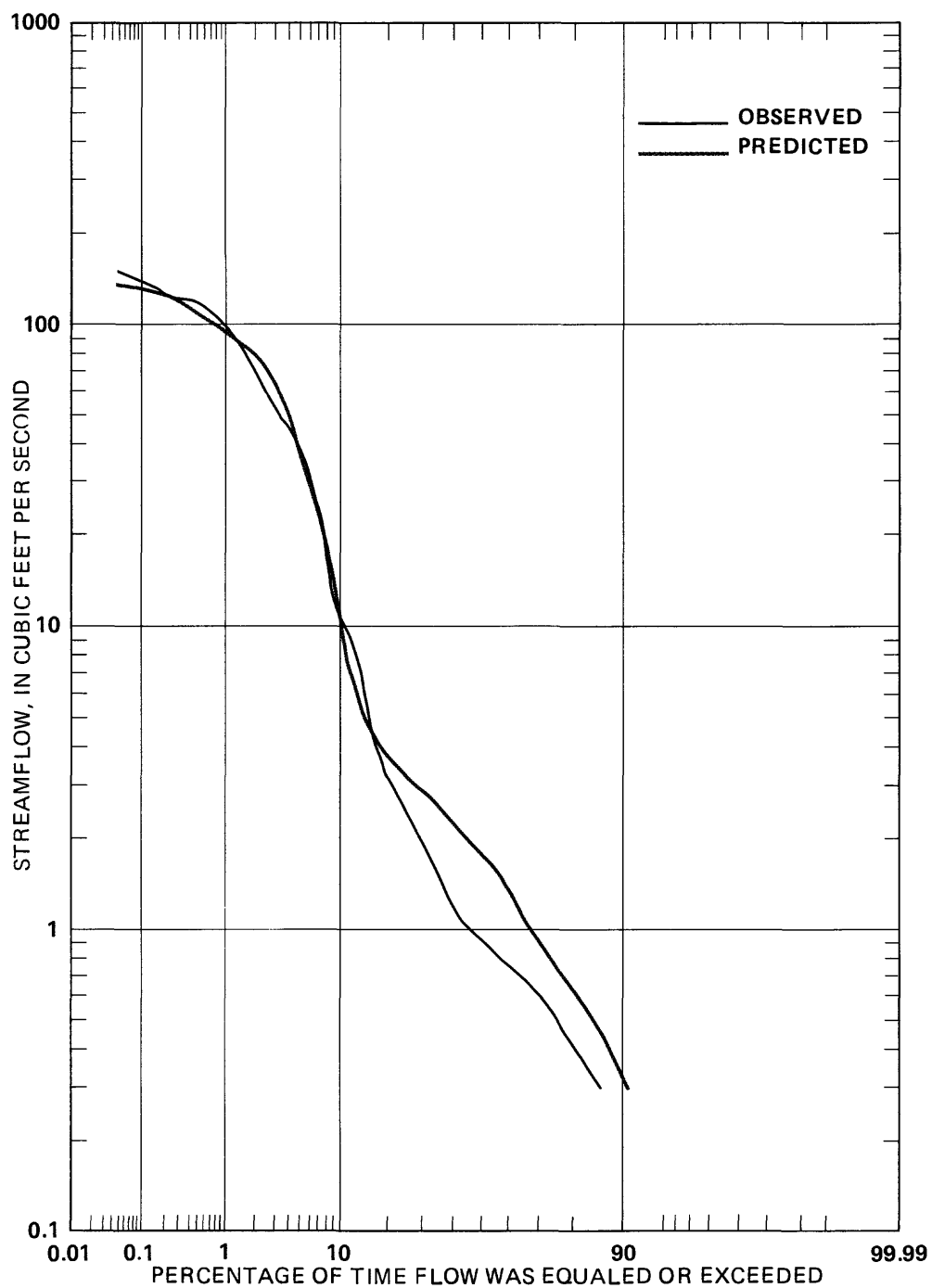


Figure 9.--Observed and predicted flow-duration curves for East Fork Middle Parachute Creek near Rio Blanco for water years 1977-82.

At lower flows, however, the predicted curve for both basins begins to deviate from the observed. For Northwater Creek near Anvil Points (fig. 8), the predicted curve falls below the observed curve, indicating that the model underpredicts at low flows for this basin. However, actual differences in streamflow are small. The observed data show that 60 percent of the time flow is equal to or greater than $0.62 \text{ ft}^3/\text{s}$, and the predicted curve shows that 60 percent of the time flow is equal to or greater than $0.40 \text{ ft}^3/\text{s}$, a difference of $0.22 \text{ ft}^3/\text{s}$. From these curves, the maximum difference in discharge occurs at higher streamflows with the largest streamflow difference being about $15 \text{ ft}^3/\text{s}$ at 0.18 percent of the time that the flow is equaled or exceeded.

At East Middle Fork Parachute Creek near Rio Blanco (fig. 9), the largest deviation between curves again occurs at the lower flows, although these curves appear to have the largest separation at about 47 percent of the time that flow is equaled or exceeded, then the curves start to converge again. For this station, at the point of maximum curve separation, the difference in streamflow is $1 \text{ ft}^3/\text{s}$. The maximum difference in streamflow is about $15 \text{ ft}^3/\text{s}$, which occurs when flow is equaled or exceeded 0.05 percent of the time.

If PRMS is used for record extension, additional errors could be introduced beyond those demonstrated here. For example, errors in estimating air temperature and precipitation input data could be substantial. Also, the flow-duration curves presented here are used only to compare the observed and predicted flow regime for the six years of streamflow information available, not as a means of describing the hydrology of the study area.

Monthly Mean Streamflow

Average monthly mean observed and predicted streamflow for water years 1977 to 1982 for Northwater Creek near Anvil Points are shown in figure 10. During October to February, predicted average monthly mean streamflow was nearly the same as observed average monthly mean streamflow. In March and April, predicted average monthly mean streamflow was smaller than observed, but in May, predicted was larger than observed. This implies that timing of snowmelt is late in the calibrated model, forcing streamflow that was observed in March and April to be predicted in May. Average monthly mean predicted streamflow for June was near the observed value, but values for July, August, and September were slightly overpredicted. The greatest difference was in April, where an underprediction of $4.26 \text{ ft}^3/\text{s}$ occurred, 59-percent error.

Average monthly mean observed and predicted streamflow for East Middle Fork Parachute Creek near Rio Blanco are shown in figure 11. Other than a small overprediction for October through February, the plot is similar to that in figure 10 for Northwater Creek basin. A slight underprediction in April and overprediction in May occurred, suggesting that the snowmelt prediction was somewhat late. August and September also were overpredicted, as in Northwater Creek basin. The largest difference was in May, with an overprediction of $1.8 \text{ ft}^3/\text{s}$, a 4-percent difference. Other than April values for Northwater Creek near Anvil Points, the model appears to give adequate estimates for monthly mean streamflow.

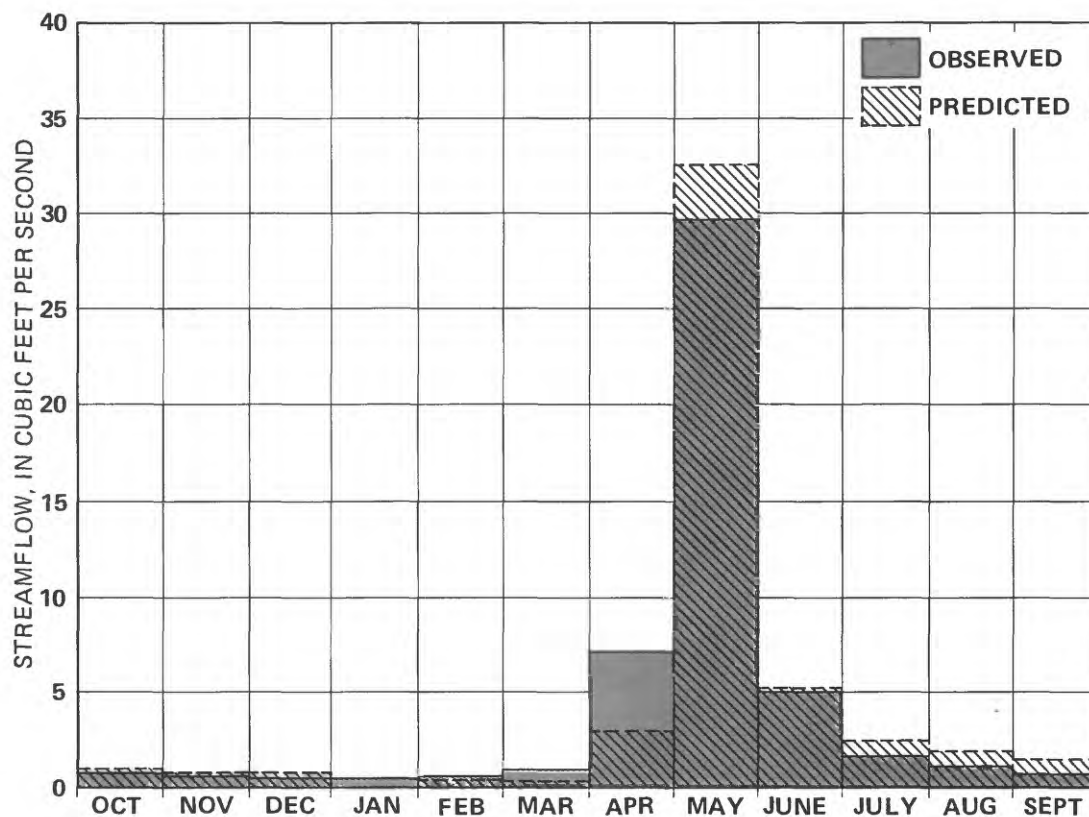


Figure 10.--Observed and predicted average monthly mean streamflow for Northwater Creek near Anvil Points for water years 1977-82.

Monthly Maximum Streamflow

Values of maximum streamflow averaged by month for Northwater Creek near Anvil Points are shown in figure 12. These values are the average of the maximum daily streamflow that occurred in each month over the 6-year period. As with the monthly mean plot in figure 10, the average monthly maximum streamflow was underpredicted in March and April and overpredicted in May. Other months were estimated fairly accurately. The greatest difference occurred in April, with an underprediction of 5.1 ft³/s, a 21-percent difference.

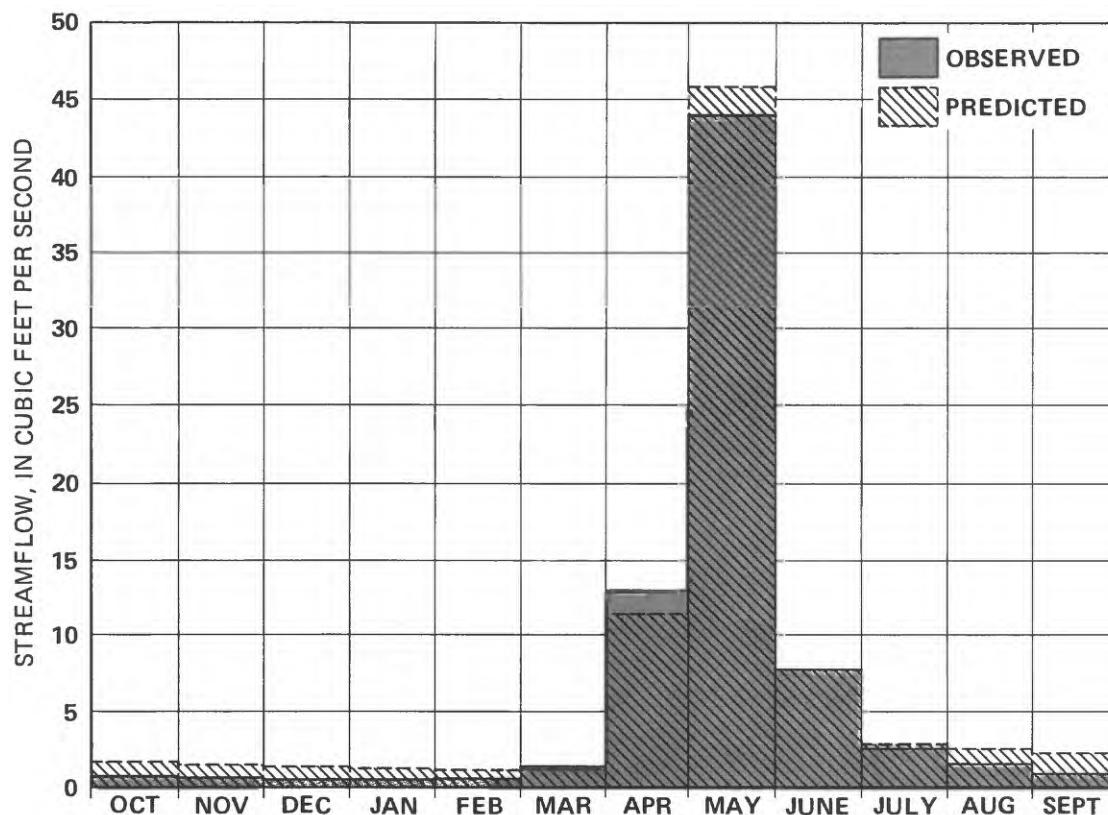


Figure 11.--Observed and predicted average monthly mean streamflow for East Middle Fork Parachute Creek near Rio Blanco for water years 1977-82.

Observed and predicted average monthly maximum streamflows for East Middle Fork Parachute Creek near Rio Blanco are in figure 13. Unlike the monthly mean streamflows in figure 11, the average monthly maximum streamflow was overpredicted in April, underpredicted in May, and overpredicted again in June. The greatest difference between observed and predicted average monthly maximum streamflow for this basin occurred in June, with an overprediction of 7.7 ft³/s, a 32-percent difference.

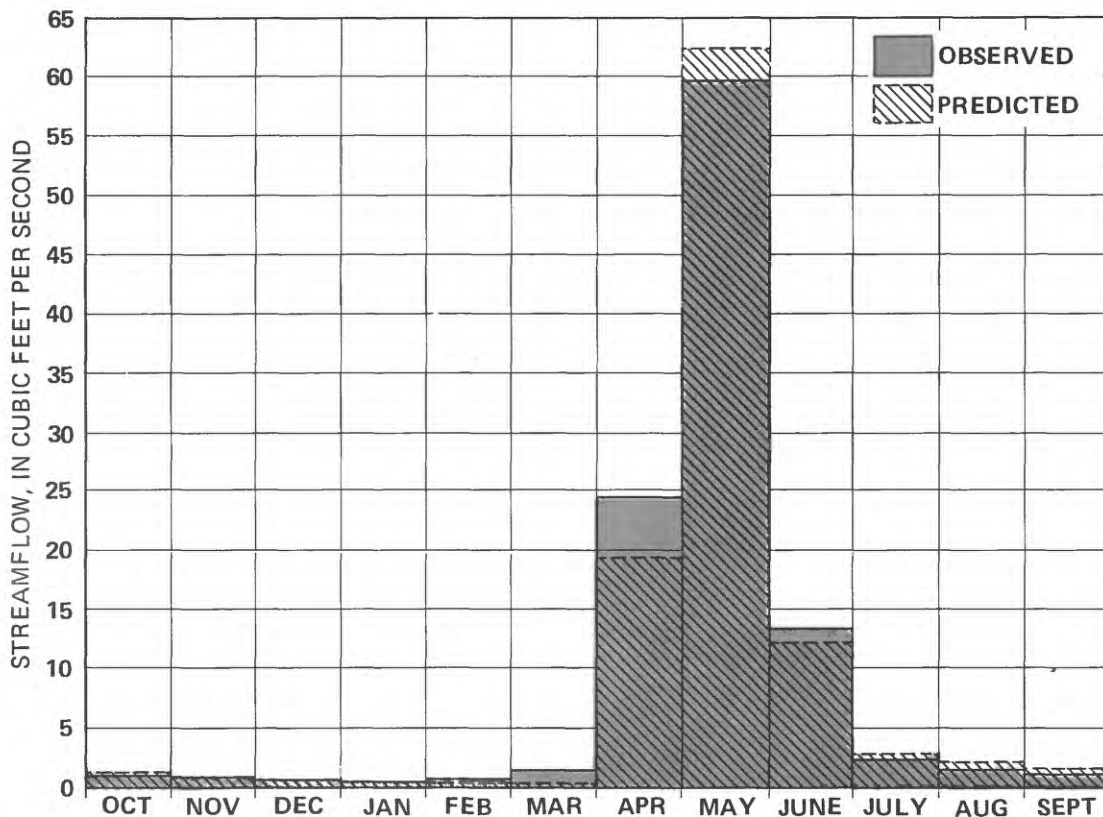


Figure 12.--Observed and predicted average monthly maximum streamflow for Northwater Creek near Anvil Points for water years 1977-82.

Monthly Minimum Streamflow

Observed and predicted average monthly minimum streamflow for Northwater Creek near Anvil Points are shown in figure 14. Except for February, March, and April, the calibrated model overpredicted average monthly minimum streamflow. Months with the greatest difference between observed and predicted average monthly minimum streamflow were May and July, with a 1 ft³/s difference. May had a 9-percent difference and July an 86-percent difference.

Observed and predicted average monthly minimum streamflow for East Middle Fork Parachute Creek near Rio Blanco is shown in figure 15. The calibrated model for this basin overpredicted average monthly minimum streamflow for all months except June. The largest overprediction was in May, with a difference of 3.3 ft³/s, an 18-percent difference.

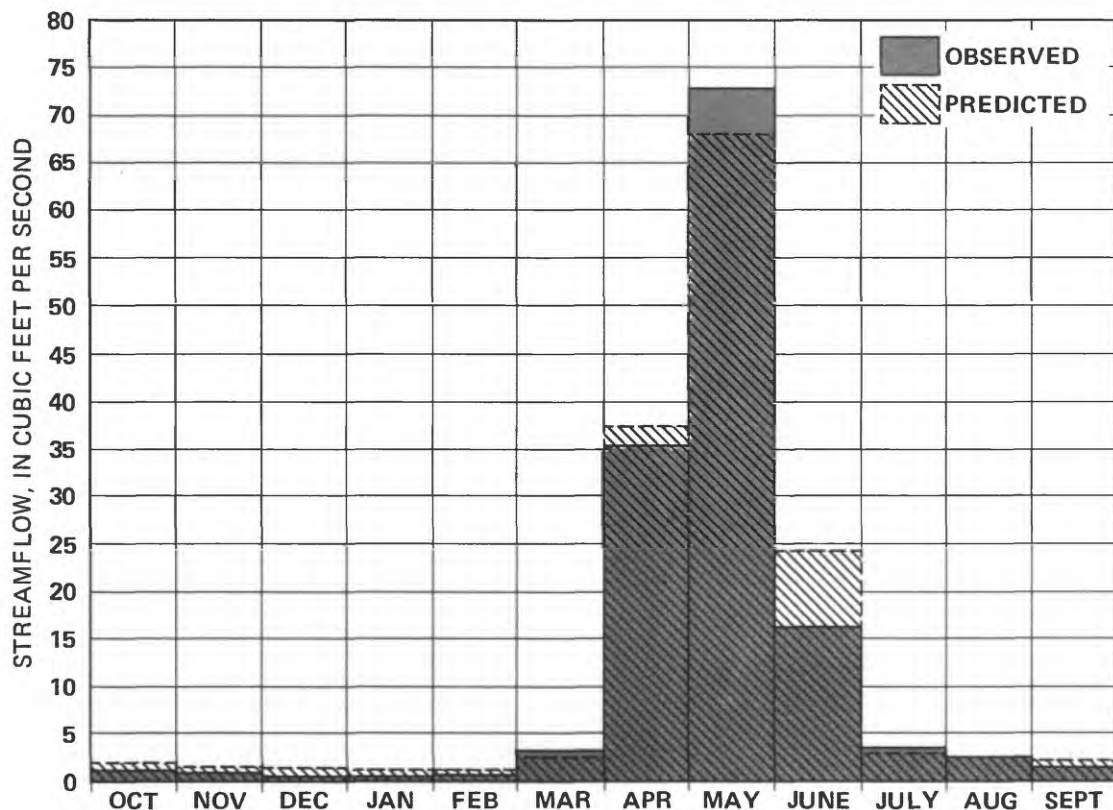


Figure 13.--Observed and predicted average monthly maximum streamflow for East Middle Fork Parachute Creek near Rio Blanco for water years 1977-82.

Mean Streamflow

Observed and predicted average annual total runoff, average daily mean streamflow, average annual maximum streamflow, and average annual minimum streamflow for the calibrated basins are in table 8. Percentage differences between the observed and predicted values for each category also are included in table 8. The percentage differences are small (less than 10 percent) for both stations for all categories except average annual minimum streamflow; although the percentage differences are large, the magnitudes of the differences are small. For both basins, average annual total runoff and average daily mean streamflow are slightly overpredicted. For Northwater Creek near Anvil Points, average annual maximum streamflow was overestimated by 5.1 percent; for East Middle Fork Parachute Creek near Rio Blanco, average annual maximum streamflow was underestimated by 9.07 percent.

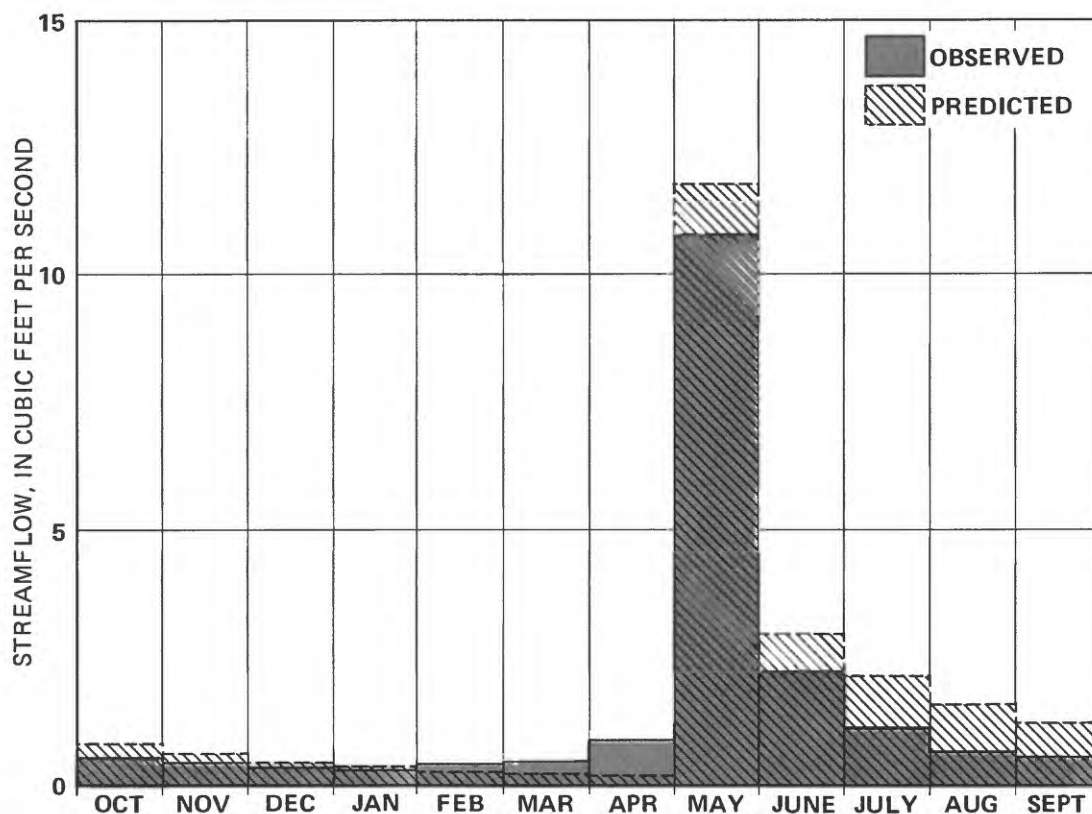


Figure 14.--Observed and predicted average monthly minimum streamflow for Northwater Creek near Anvil Points for water years 1977-82.

Water Balance

Another suggested application of PRMS is to produce estimates of unknown components of the water balance. A yearly water balance computed from model output for the calibrated basins is presented in table 9. Change in basin-storage values in table 9 represent changes of water content in either the soil moisture or ground-water system, or both.

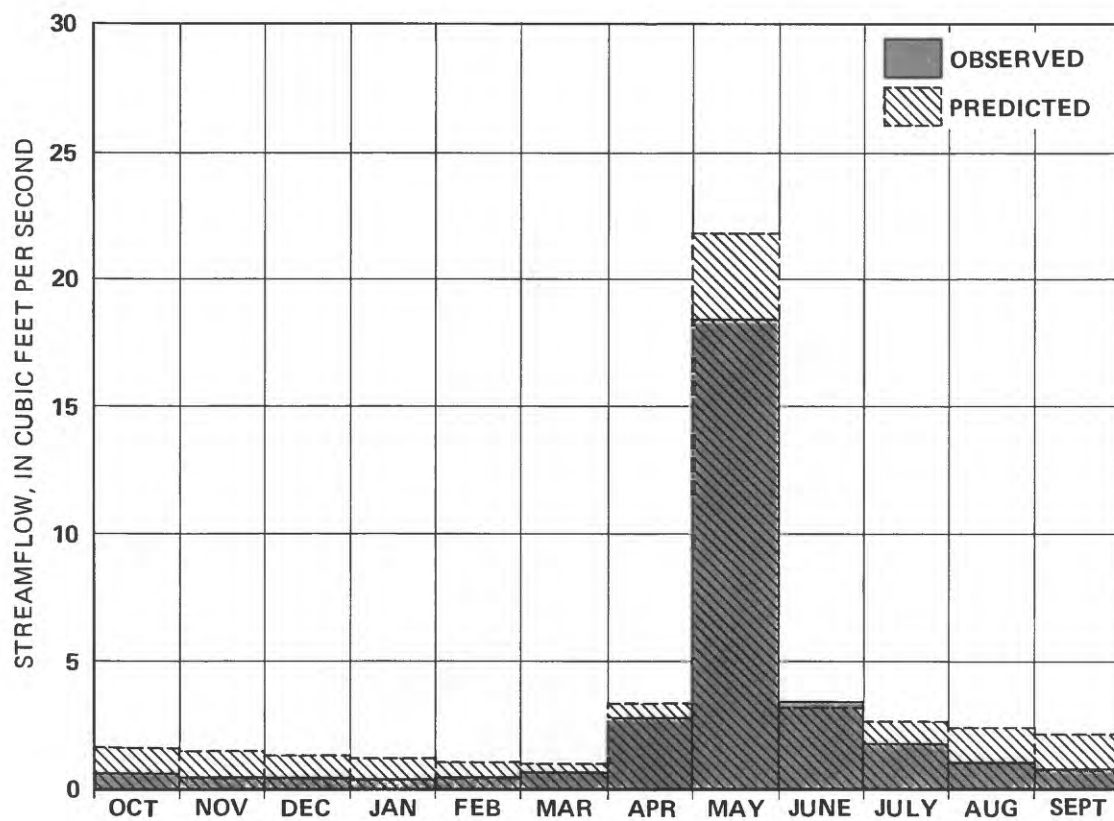


Figure 15.--Observed and predicted average monthly minimum streamflow for East Middle Fork Parachute Creek near Rio Blanco for water years 1977-82.

For Northwater Creek near Anvil Points, predicted average annual net precipitation was 23.87 in. Of this, 19 percent (4.48 in.) became streamflow, and 81 percent (19.3 in.) was lost from the system as evapotranspiration. For the 6 years used, the average predicted net change in storage was small, 0.06 in.

Table 8.--Statistical analysis of observed and predicted runoff for water years 1977 to 1982

Streamflow- gaging-station number and description	Average annual total runoff (inches)		Average daily mean runoff (cubic feet per second)		Average annual maximum runoff (cubic feet per second)		Average annual minimum runoff (cubic feet per second)	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
09092830 North- water Creek near Anvil Points	4.44	4.49	4.12	4.16	60.7	63.8	0.25	0.12
Percent difference	1.13		0.97		5.1		-52.0	
09092850 East Middle Fork Parachute Creek near Rio Blanco	3.81	4.17	6.20	6.78	75.0	68.2	0.27	0.76
Percent difference	9.45		9.35		-9.07		181.0	

Table 9.--Annual water-balance analysis for calibrated basins

Streamflow-gaging-station number and name	Water year	Net precipitation (inches)	Predicted runoff (inches)	Predicted evapotranspiration (inches)	Predicted change in basin storage (inches)
09092830 North-water Creek near Anvil Points	1977	12.40	0.62	17.32	-5.54
	1978	25.70	4.45	20.19	1.06
	1979	26.77	7.33	19.12	0.32
	1980	27.29	8.57	19.00	-0.28
	1981	20.49	0.73	19.97	-0.21
	1982	30.37	5.19	20.18	5.00
09092850 East Middle Fork Parachute Creek near Rio Blanco	1977	11.98	0.41	12.54	-0.97
	1978	24.51	3.70	18.53	2.28
	1979	25.64	7.29	17.56	0.79
	1980	24.70	7.12	17.69	-0.11
	1981	19.83	1.28	19.35	-0.80
	1982	29.06	5.17	18.79	5.10

Average predicted annual net precipitation for East Middle Fork Parachute Creek basin was 22.62 in. Average annual total streamflow was 18 percent (4.16 in. and average annual evapotranspiration losses were 77 percent (17.41 in. of the 22.62 in. of precipitation. In the East Middle Fork Parachute Creek basin, the average change in storage for the 6 years was 5 percent of the average precipitation, with an average predicted net change of 1.05 in. more water in storage. The reasons for this increase in basin storage is unknown, however, as the average annual minimum streamflow was underpredicted for both basins (table 8); one probable reason is an error in the value for the model parameter that defines the rate water moves from the ground-water reservoir to become streamflow.

TRANSFERABILITY OF MODEL

Another use for PRMS is to predict streamflow in ungaged basins where hydrologic information is needed but not available. To test the transferability of model parameters to ungaged basins, three sets of model parameters were used to estimate streamflow for a nearby gaged basin (09092960 East Fork Parachute Creek near Anvil Points). The first set assumed little knowledge of the basin; the second set assumed only knowledge of climatic information for the basin; the third set assumed that PRMS calibrated basins were nearby to define HRU characteristics and other parameters. The three different cases were used to determine how errors between observed and predicted streamflow changed, given increasing amounts of information about the basin. For the three cases, snowpack water content for water years 1979 and 1980 were adjusted by the same percentages as in the calibration and verification sections. Physical characteristics for the East Fork Parachute Creek basin are in table 10.

Table 10.--Physical characteristics of East Fork Parachute Creek basin

Streamflow- gaging- station name	Basin drainage area (square mile)	Basin relief ¹ (feet)	Basin vegetation cover (percent)			
			Oak	Sage	Aspen	Other
East Fork Para- chute Creek near Anvil Points	15.1	1428	0	23	37	40

¹Difference between maximum and minimum basin elevations.

Case 1

The first set of model parameters used to predict streamflow assumed that there was only information available to delineate HRU's based on the physical characteristics of the basin. HRU delineations for the East Fork Parachute Creek basin are shown in figure 16. It was assumed daily precipitation, snow course, and air-temperature data were available from nearby stations, but no other basin information was available to define model climatic or HRU parameters.

Model-parameter values were assigned from a previous study using PRMS in northwestern Colorado (Norris and Parker, 1985). That study was in the Yampa River drainage, approximately 75 mi northeast of the present study area. Many model-parameter values from that study were used directly. Model parameters with a relation to elevation (or other easily obtained physical characteristic of the basin) were adjusted accordingly.

Results from using these model-parameter values to predict streamflow in the East Fork Parachute Creek basin are in table 11. For the 6-year period, streamflow was overpredicted for all years except water years 1977 and 1981, both years of lower precipitation. The model, with this set of parameter values, overpredicted streamflow in years of larger flow, and underpredicted streamflow in years of smaller streamflow. The absolute value of the average annual percent difference for the 6-year period was 44.6 percent.

Observed and predicted hydrographs for transferability case 1 are in figure 17. Water years 1977 and 1981 are not shown in figure 17, because the relatively low streamflow in those years provided no information as to timing errors at the scale used. In water years 1979, 1980, and 1982, timing of predicted streamflow was similar to observed streamflow, although the recession section of the predicted hydrographs are flatter. This is probably due to errors in the subsurface reservoir routing coefficients. In water year 1978, however, the timing of the predicted hydrograph was not similar to the observed, with the peak predicted streamflow being a month earlier than the observed. In all years, the start and end of the predicted snowmelt hydrographs are near the observed.

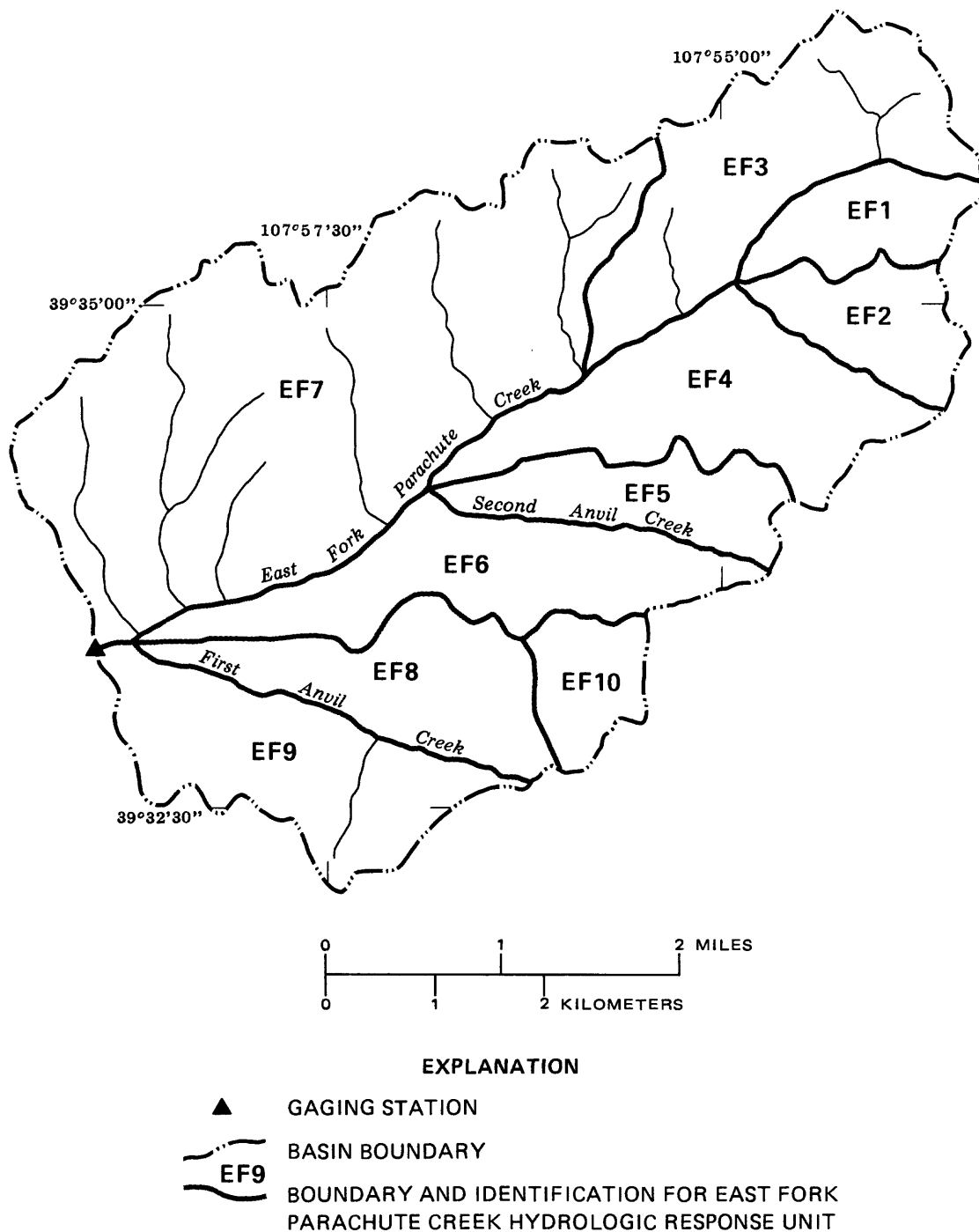


Figure 16.--Hydrologic response unit delineation for East Fork Parachute Creek basin.

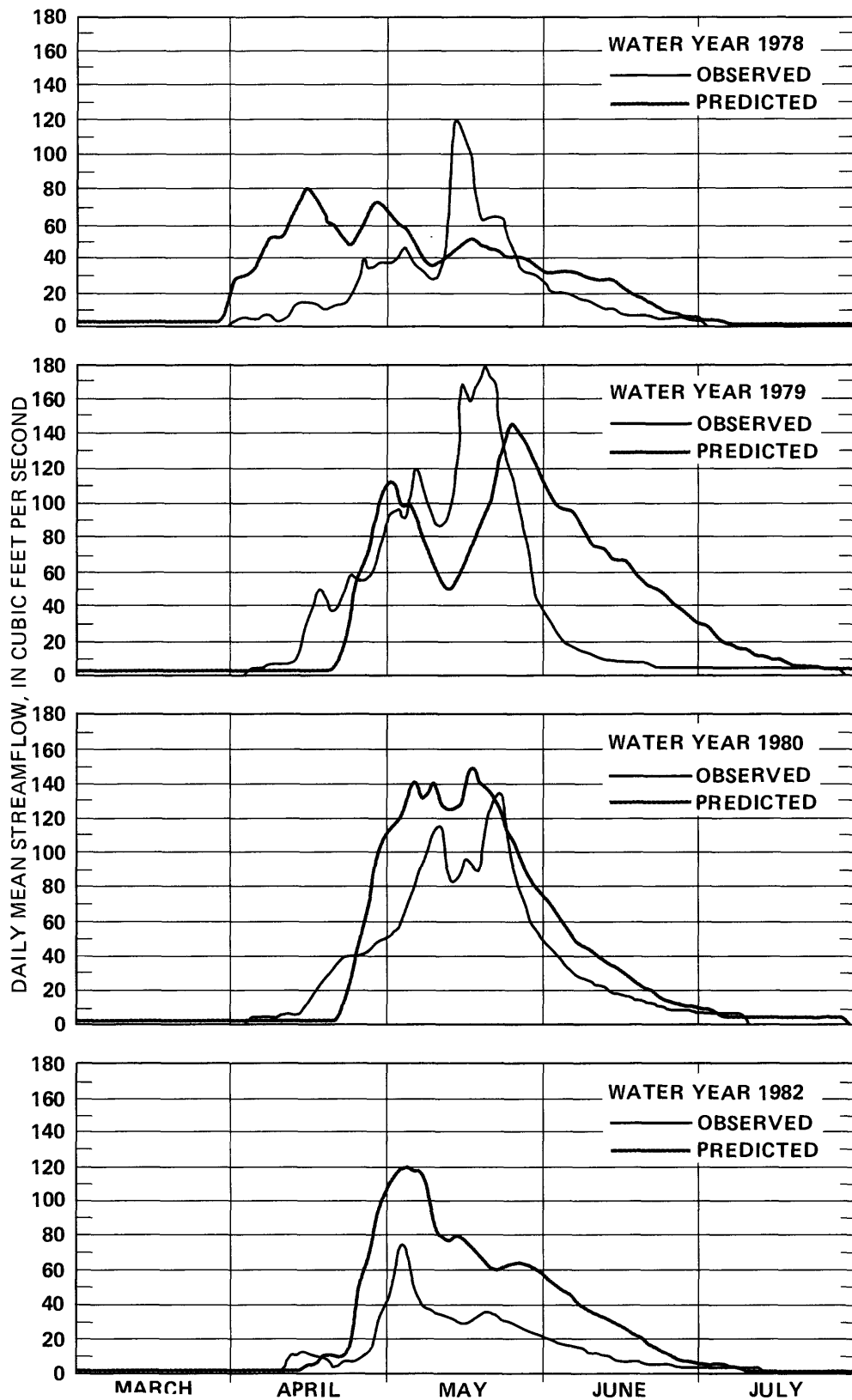


Figure 17.--Observed and predicted daily mean streamflow for transferability case 1, for East Fork Parachute Creek near Anvil Points.

Table 11.--*Summary of annual observed and predicted runoff and prediction error for East Fork Parachute Creek near Anvil Points, using model parameter values from other model-calibrated areas*

Water year	Total observed runoff (inches)	Total predicted runoff (inches)	Prediction error (inches)	Prediction error (percent)
1977	0.60	0.50	-0.10	-16.7
1978	6.15	9.09	2.94	47.8
1979	12.29	14.26	1.97	16.0
1980	10.49	13.24	2.75	26.2
1981	1.45	.61	-.84	-57.9
1982	4.98	10.11	5.13	103.0

Case 2

The second set of model parameters used to predict streamflow in the East Fork Parachute Creek basin was based on the assumption that prior information existed to allow better estimation of the model's climatic parameters. However, it was assumed, as in transferability case 1, that no information existed for defining HRU parameters. HRU parameter values were defined as in case 1. Climatic parameter values were those from the calibration basins. When parameters were different for the two calibrated basins, an average value was used.

Streamflow prediction results for transferability case 2 are summarized in table 12. As in transferability case 1, all water years were overpredicted except water years 1977 and 1981, which were underpredicted. However, comparing table 11 to table 12, the prediction error decreased for every year except water years 1977 and 1981 using the climatic parameter values from the calibrated basin. The error in water year 1977 stayed the same and in 1981 it increased. The absolute value of the average annual percent difference between observed and predicted streamflow for transferability case 2 was 37.6 percent, down 7.0 percent from transferability case 1.

Observed and predicted hydrographs for transferability case 2 are shown in figure 18. Comparing figure 17 to figure 18, the timing of predicted streamflow also is improved with better estimates for the climatic parameters. As for transferability case 1, water years 1977 and 1981 are not shown in figure 18 because of the relatively low streamflow in those years, and provides no information on timing errors.

Table 12.--*Summary of annual observed and predicted runoff and prediction error for East Fork Parachute Creek near Anvil Points, using calibrated-optimized model climatic-parameter values*

Water year	Total observed runoff (inches)	Total observed runoff (inches)	Prediction error (inches)	Prediction error (percent)
1977	0.60	0.50	-0.10	-16.7
1978	6.15	7.81	1.66	27.0
1979	12.29	12.94	.65	5.3
1980	10.49	11.87	1.38	13.2
1981	1.45	.24	-1.21	-83.3
1982	4.98	8.95	3.97	79.7

Case 3

Transferability case 3 assumed at least one nearby model-calibrated basin. HRU and climate model-parameter values used to estimate streamflow for East Fork Parachute Creek near Anvil Points, for transferability case 3 were averaged from the parameter values in the two calibration basins discussed earlier, the Northwater Creek and East Middle Fork Parachute Creek basins. These parameter values are in table 13.

The error summary between observed and predicted streamflow using parameter values in table 13 for East Fork Parachute Creek near Anvil Points are in table 14. Predicted runoff was low for water years 1977 to 1980, and high for water years 1981 and 1982, compared to observed runoff. Comparing table 12 to table 14, percent differences for all years except 1977 and 1979 decreased, using model-parameter values from nearby calibrated basins. The absolute value of the average percent difference for case 3 was 16.3 percent compared to 37.6 percent for case 2, a 21.3 percent improvement using transferred calibrated model parameters. For comparison, the average annual percent difference of observed and predicted streamflow for the calibration basins for the calibration and verification period was 12.9 percent.

Observed and predicted hydrographs for transferability case 3 are in figure 19. Comparing hydrographs in figure 19 to hydrographs for transferability case 2 in figure 18, predicted streamflow timing was improved for all water years except water year 1982. Water year 1982 is also the year with the largest annual percent difference (table 14). The reasons for this are unknown, but it is the year of highest precipitation of the years used. Again, water years 1977 and 1981 are not included, because the low streamflow in these years provides no information about timing errors.

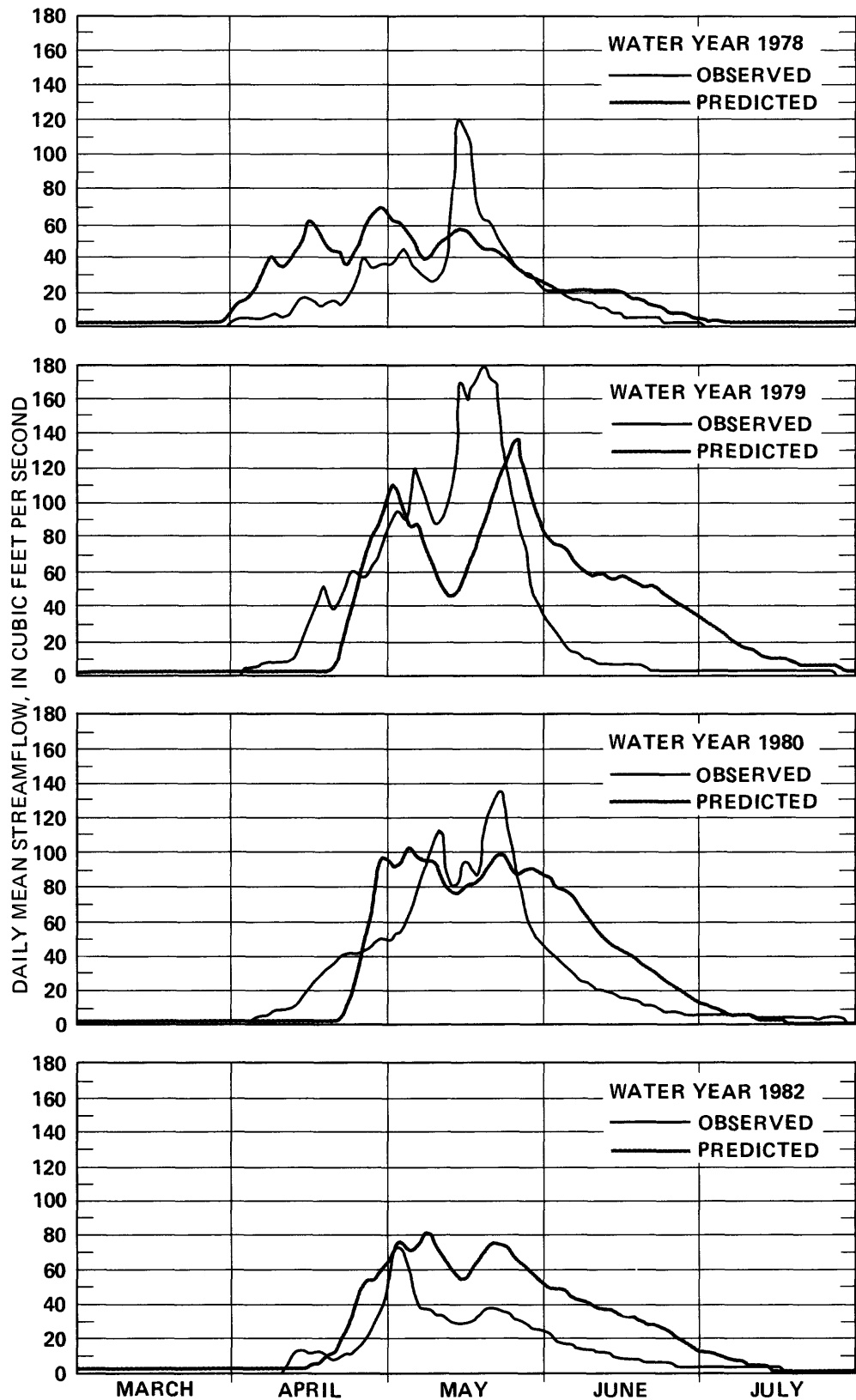


Figure 18.--Observed and predicted daily mean streamflow for transferability case 2, for East Fork Parachute Creek near Anvil Points.

Table 13.--*Calibrated model parameters used to predict runoff for East Fork Parachute Creek near Anvil Points*

[See table 1 for definitions of abbreviations]

Hydrologic- response unit number	Vegetation type	Average elevation (feet above sea level)	SMAX (inches)	COVDNW (percent)	TRNCF (percent)	TST (Fahrenheit- degree- days)
1	Sage	8,880	13.0	27	50	833
2	Sage	8,880	13.0	27	50	833
3	Sage	8,820	13.0	27	50	833
4	Aspen	8,720	23.0	15	69	833
5	Sage-Oak	8,720	12.0	31	45	833
6	Aspen	8,500	23.0	15	69	782
7	Sage-Oak	8,530	12.0	31	45	782
8	Aspen	8,500	23.0	15	69	782
9	Aspen	8,400	23.0	15	69	782
10	Sage	8,850	13.0	27	50	833
		TLX 1.38-6.87	BST 34.0	CST 0.015-0.019		

Table 14.--*Summary of annual observed and predicted runoff and prediction error for East Fork Parachute Creek near Anvil Points, using calibrated-optimized model parameter values*

Water year	Total observed runoff (inches)	Total predicted runoff (inches)	Prediction error (inches)	Prediction error (percent)
1977	0.60	0.45	-0.15	-25.0
1978	6.15	4.78	-1.37	-22.3
1979	12.29	11.05	-1.24	-10.1
1980	10.49	10.46	-.03	-.3
1981	1.45	1.65	.20	13.8
1982	4.98	6.30	1.32	26.5

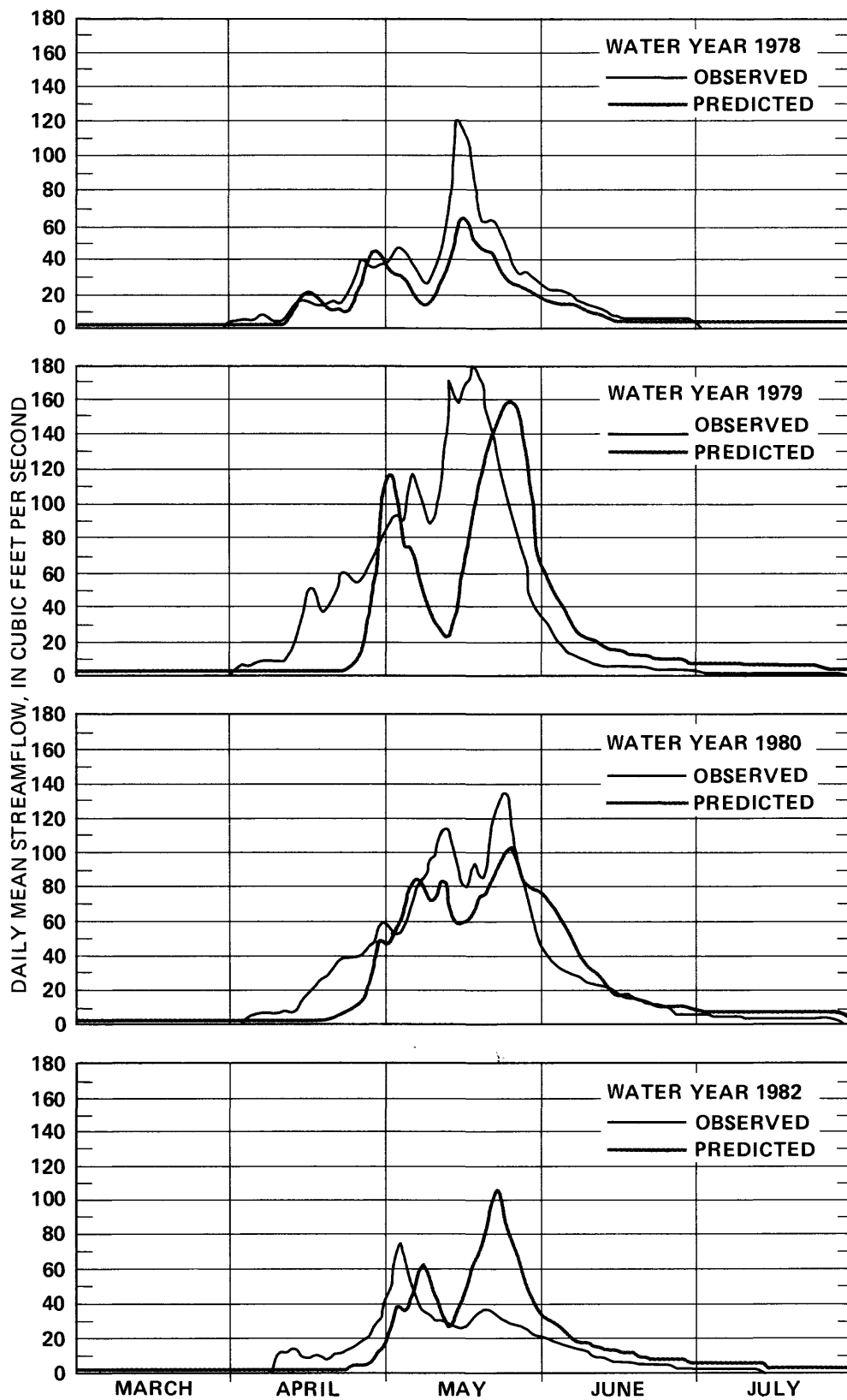


Figure 19.--Observed and predicted daily mean streamflow for transferability case 3, for East Fork Parachute Creek near Anvil Points.

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey's Precipitation-Runoff Modeling System (PRMS) was calibrated and verified for two small basins in western Colorado. A comparison of observed and predicted streamflow data to determine the magnitude of errors that might be expected if PRMS was used for streamflow-record extension was done. Observed and predicted flow-duration curves were derived and indicated few differences in streamflow. Analysis of observed and predicted average annual total streamflow, average daily mean streamflow, monthly mean streamflow, and average monthly maximum streamflow demonstrated that the calibrated model adequately simulated streamflow for this area. The model tended to overpredict average monthly minimum streamflow, but the absolute difference in cubic feet per second was small.

In an effort to determine the model's ability to predict streamflow in an ungaged basin, three different sets of model parameter values were used to predict streamflow in a gaged basin near the calibrated basins. The first set of parameters was based on the assumption that little information about this basin was available. Model parameters used to calibrate basins approximately 75 mi away were adjusted to model this basin on the basis of easily obtainable physical basin characteristics, such as elevation and slope.

The second set of parameters was based on the first set, except it was assumed that local climate information was available to better estimate the model's climatic parameters for the basin. The second set of parameters improved streamflow estimation in this basin by about 7 percent over the first model-parameter set.

The third set of model-parameters assumed that the model had been calibrated to similar, nearby basins. This model-parameter set was derived from the model parameters of the earlier calibrated basins. Using these calibrated model parameter values improved streamflow estimates by approximately 21 percent over the second parameter set. The average difference between observed and predicted average annual total streamflow for the basin using these parameters was 16.3 percent. For comparison, the average difference between observed and predicted average annual total streamflow for the calibration basins was 12.9 percent. This suggests that, with some increase in error, this model can be used to estimate streamflow in ungaged basins, if the model has been calibrated to a nearby gaged basin with similar physical characteristics.

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