USE OF A PRECIPITATION-RUNOFF MODEL FOR SIMULATING EFFECTS OF FOREST MANAGEMENT ON STREAMFLOW IN 11 SMALL DRAINAGE BASINS, OREGON COAST RANGE

By John C. Risley

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U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey, WRD
10615 S.E. Cherry Blossom Drive
Portland, Oregon 97216

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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 in this report, values may be converted by using the following factors:]

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	4,047	square meter
	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer

To convert degrees Fahrenheit (°F) to degrees Celsius (°C), use the following equation:

$$°C = 5/9\ (°F - 32)$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum 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.

Use of a Precipitation-Runoff Model for Simulating Effects of Forest Management on Streamflow in 11 Small Drainage Basins, Oregon Coast Range

By John C. Risley

Abstract

The Precipitation-Runoff Modeling System (PRMS) model of the U.S. Geological Survey was used to simulate the hydrologic effects of timber management in 11 small, upland drainage basins of the Coast Range in Oregon. The coefficients of determination for observed and simulated daily flow during the calibration periods ranged from 0.92 for the Flynn Creek Basin to 0.68 for the Priorli Creek Basin; percent error ranged from -0.25 for the Deer Creek Basin to -4.49 for the Nestucca River Basin. The coefficients of determination during the validation periods ranged from 0.90 for the Flynn Creek Basin to 0.66 for the Wind River Basin; percent error during the validation periods ranged from -0.91 for the Flynn Creek Basin to 22.3 for the Priorli Creek Basin. In addition to daily simulations, 42 storms were selected from the time-series periods in which the 11 basins were studied and used in hourly storm-mode simulations. Sources of simulation error included the quality of the input data, deficiencies in the PRMS model algorithms, and the quality of parameter estimation.

Times-series data from the Flynn Creek and Needle Branch Basins, collected during an earlier U.S. Geological Survey paired-watershed study, were used to evaluate the PRMS as a tool for predicting the hydrologic effects of timber-management practices. The Flynn Creek Basin remained forested and undisturbed during the data-collection period, while the Needle Branch Basin had been clearcut 82 percent at a midpoint during the period of data collection. Using the PRMS, streamflow at the Needle Branch Basin was simulated during the postlogging period using prelogging parameter values. Comparison of postlogging observed streamflow with the simulated data showed an increase in annual discharge volume of approximately 8 percent and a small increase in peak flows of from 1 to 2 percent.

The simulated flows from the basins studied were generally insensitive to the number of hydrologic-response units used to replicate basin surface detail. The average number of hydrologic-response units used in the storm period simulations was one-half the average number of hydrologic-response units used in the daily period simulations. With the exception of one basin, however, the coefficient of determination between observed and simulated daily flow differed by only 3 percent.

Calibration and validation of the PRMS for 11 basins—that encompass a variety of forest, soil, and topographic conditions—provided regionalized parameter values. The parameter values assist the PRMS hydrologic simulations of other gaged and ungaged basins in the Coast Range with landscape conditions similar to those of the basins studied.

INTRODUCTION

Timber harvesting is a predominant activity in many upland, forested drainage basins of the Oregon Coast Range and in other mountainous regions of the Pacific Northwest. In recent decades, public concern has increased regarding the effects of timber harvesting on both water quality and stream conditions. Concern has been expressed over the threat to the domestic water supply, recreation, salmonid fish, and the health of aquatic and riparian ecosystems posed by timber-harvesting activities (MacDonald and others, 1991).

Passage of the Clean Water Act and subsequent amendments (1986) has increased Federal responsibility for controlling nonpoint pollution initiating from timber-harvesting activities. Environmental assessment and the adoption and implementation of Best Management Practices are important components of this responsibility. The complexity of prescription and analysis has called for a more accurate quantification of natural forest-hydrological processes and of forest-hydrological processes altered by human activity. Through development and application of precipitation-runoff computer models, runoff response to land-use alterations in a basin can be better estimated. Precipitation-Runoff Modeling System (PRMS) model algorithms that emulate the movement and storage of water in the surface, subsurface, and ground-water components of the watershed provide insight into the hydrologic processes governing the overall flow regime. The user of the PRMS model can test the effects of various land-management scenarios by varying the physical parameters of the PRMS model.

Background

The U.S. Geological Survey (USGS), in cooperation with the U.S. Bureau of Land Management (BLM), began a study in fiscal year 1989 and used the PRMS to evaluate the hydrologic effects of land-management practices in the East Fork Lobster Creek Basin of the Oregon Coast Range. A deterministic, physical-process-modeling system, the PRMS is designed to analyze the effects of varying climatological and land-use conditions on streamflow, sediment yield, and general basin hydrology (Leavesley and others, 1983). The results of the calibration and application of the PRMS to the East Fork Lobster Creek Basin, obtained during the first phase of this study, were presented in an earlier report (Nakama and Risley, 1993).

During the second phase of this study, the application of PRMS to simulate three additional basins was evaluated. Those three basins – Flynn Creek, Deer Creek, and Needle Branch – are located approximately 25 miles northwest of the East Fork Lobster Creek Basin. All four basins (East Fork Lobster Creek, Flynn Creek, Deer Creek, and Needle Branch) are tributaries of the Alsea River. Hydrologic and climatological data were collected from 1959 to 1973 in the Flynn Creek, Deer Creek, and Needle Branch Basins for a USGS paired-watershed study about the effects of timber harvesting on streamflow, water quality (temperature and sediment concentrations), and fish productivity (Harris, 1977). The three Alsea basins included an uncut control basin (Flynn Creek), a partially clearcut basin (Deer Creek), and a basin that was almost entirely clearcut (Needle Branch). The results of the calibration and application of PRMS to the Alsea basins are presented in Allen and Laenen (1993).

In the third phase of this study, seven additional basins were evaluated using the PRMS to expand the analyses of the Alsea basins, thereby encompassing the entire Coast Range of Oregon. Selection of those seven additional basins was based on the availability of time-series data on streamflow and precipitation. For all 11 basins, the flow record represented unregulated conditions; basins with reservoirs, channel alignments, and flow diversions were not used. Excluding possible recreational activities, the only human activities were related to timber harvesting and reforestation. Geographically, the basins are evenly located over most of the Oregon Coast Range (fig. 1). By calibrating the seven additional basins with the PRMS, and recalibrating the four basins studied earlier, determining sets of regionalized parameter values for the model was made possible. Those sets of regionalized parameter values represent characteristics of the 11 basins studied, and can be used with the PRMS to model ungaged basins in the Coast Range with similar characteristics. None of the seven additional basins were paired basins, where one basin is completely clearcut at a midpoint in the time-series data and the other basin is left undisturbed (similar to Flynn Creek and Needle Branch Basins). In the third phase of this study, timber harvests in the seven basins used were limited to small clearcut, seed tree, and commercial-thinning operations during the

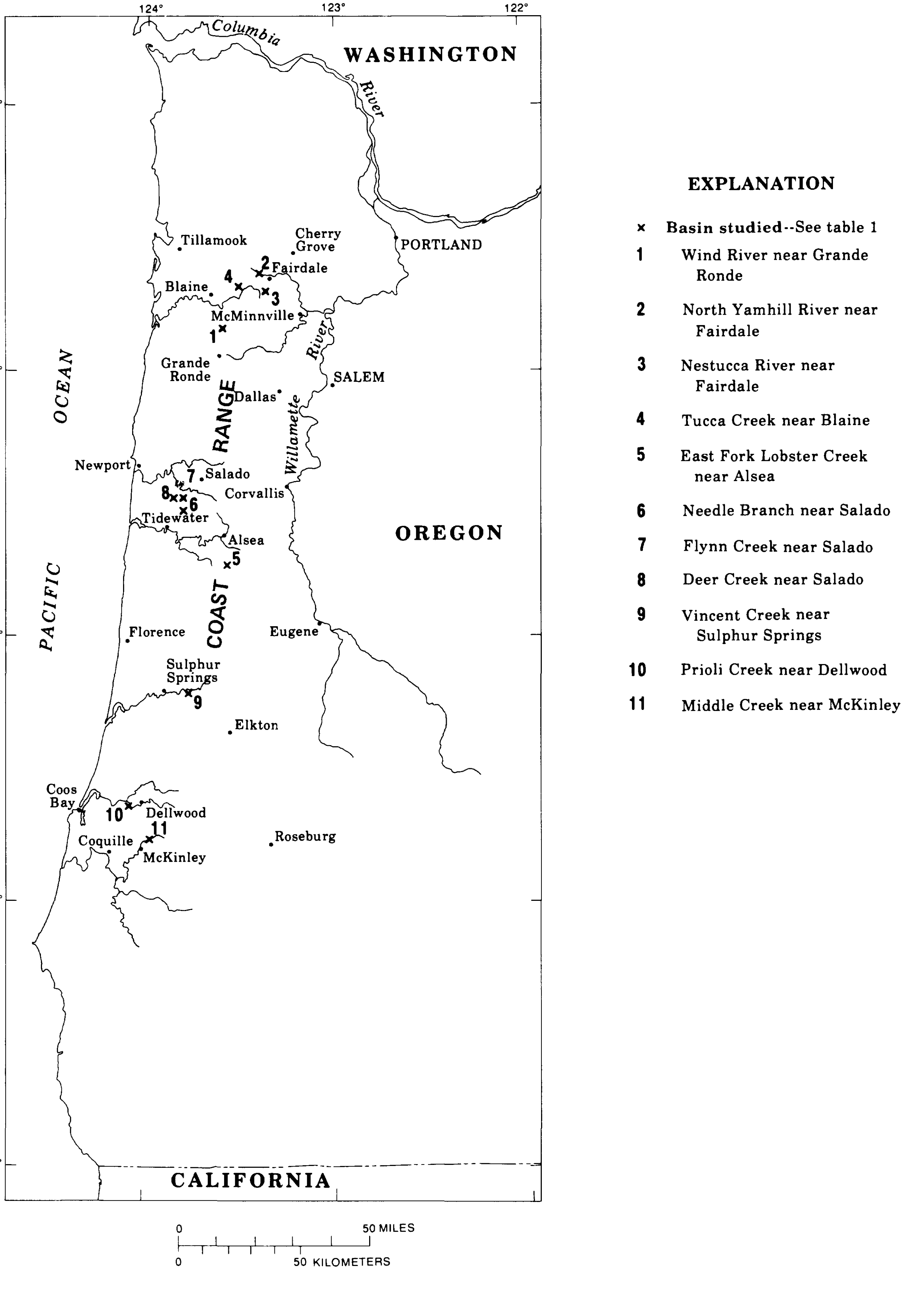

Figure 1. Location of study region and basins used for Precipitation-Runoff Modeling System model calibration and validation.

period of record. The most useful data and analyses for determining parameter values for forested and clearcut areas were obtained from the second phase of this study. The seven additional basins were used to test the transferability of parameter values to other regions of the Coast Range.

Purpose and Scope

This report (1) describes the calibration and validation of the PRMS model for 11 coastal basins, (2) evaluates the PRMS model as a predictive tool for assessing effects of forest-management practices on streamflow, and (3) regionalizes parameter values of the model for use when predicting hydrologic effects of forest-management practices on small basins, gaged and ungaged, in the Coast Range of Oregon.

As the third and final of a three-part study, this report extends the results of the two prior reports (Allen and Laenen, 1993; and Nakama and Risley, 1993) by adding analyses of seven additional basins. To meet the objectives of the study, observed precipitation, streamflow, temperature time-series data, and the physical characteristics of the 11 basins were used to calibrate and validate the PRMS model. The ability of the model to assess the effects of different forest-management practices on streamflow, described in the first and second reports, was reaffirmed by the final phase of this study. Calibration and validation results from all the basins were used to accomplish the third objective — regionalizing the parameter values.

Description of the Study Area

All the basins studied are located in the Coast Range physiographic province of western Oregon and situated between the Willamette Valley to the east and the Pacific Ocean to the west. The geologic formations underlying the Coast Range are composed of Tertiary marine sediment and associated volcanic rock. The study region extends from the Nestucca and Yamhill River Basins in the north to the Coquille River Basin in the south (fig. 1). Locations of the basin outlets are listed in table 1. The sizes of the drainage basins range from 0.27 to 22.3 square miles. Elevations of the discharge-gaging stations for the basins range from 80 to 1,779 feet above sea level. The highest elevation in the basins studied is in the Yamhill Basin, at a point 3,424 feet above sea level. Nine of the 11 basins are tributaries of coastal rivers. The Tucca Creek and Nestucca River Basins are in the Nestucca River drainage. The East Fork Lobster Creek, Needle Branch, Flynn Creek, and Deer Creek Basins are in the Alsea River drainage. Vincent Creek Basin is in the Smith River drainage. Priorli Creek Basin is in the Coos River drainage. Middle Creek Basin is in the Coquille River drainage. The two remaining basins — Wind River and North Yamhill River — are located in the Yamhill River drainage, which drains to the east into the Willamette River.

The climate of the Coast Range in Oregon is characterized as mid-latitude and coastal. Summers are warm and dry in contrast to cool and humid winters. Temperatures generally range from -7°C (degrees Celsius) to 32°C, with a mean of about 10°C. Mean annual precipitation ranges from approximately 50 inches in the Willamette Valley to 100 inches or more at higher elevations in the Coast Range (Loy and others, 1977). Most of the annual precipitation falls between October and April. Winter storms, originating from frontal activity moving inland, may last for several days. Although snowstorms occasionally pass through the Coast Range, accumulated snow that lasts for more than a couple of days is uncommon at the elevations of the basins studied. Potential evapotranspiration (PET) in the Coast Range is approximately 35 inches annually. Actual evapotranspiration is approximately 20 to 30 inches, because available soil moisture during the late summer is limited. The water balances of the Alsea River basins are fairly representative of forest conditions in the Coast Range. From 1959 to 1965, mean recorded precipitation of the Flynn Creek and Needle Branch Basins was 95.35 inches per year; mean runoff was 75.98 inches (Harris, 1977). Most of the approximately 20 inches of difference between precipitation and mean annual runoff was attributed to evapotranspiration losses from the basins.

In all of the basins studied, which are covered primarily with lush second- and third-growth conifer forests, the primary land use is intensive forest management. Some areas of the basins studied, usually in or near riparian zones, contain a mixture of hardwoods and conifers. Douglas fir *(Pseudotsuga mensesii)* and red alder

Table 1. Physical characteristics of the 11 Oregon drainage basins during calibration and validation periods

[LF = loam soils, mature-forest cover [1]; LPG = loam soils, partial-growth cover; LCC = loam soils, clearcut cover; CF = clay soils, mature- forest cover; CPG = clay soils, partial-growth cover; CCC = clay soils, clearcut cover; ^{o} = degree; ' = minutes; " = seconds]

Basin name	Station number	Station location Latitude – Longitude	Soil and vegetation characteristics [2] (in percent of basin area) LF	LPG	LCC	CF	CPG	CCC	Station elevation (feet)	Total area upstream of station (square miles)
Wind River near Grand Ronde	14192450	45°08'00" 123°38'30"	6 3.6 62.8	13.9 34.7	20.7 .7	1.0 .8	0.3 .3	0.5	550	2.35
North Yamhill River near Fairdale	14194300	45°21'55" 123°22'40"	63.2 90.9	34.3 4.7	2.5 4.4	0 0	0 0	0 0	560	9.03
Nestucca River near Fairdale	14302900	45°18'40" 123°25'05"	61.8 54.9	21.8 31.4	11.1 8.4	2.5 2.5	2.6 2.6	.2 .2	1,779	6.18
Tucca Creek near Blaine	14303200	45°19'28" 123°32'43"	70.8 65.3	15.3 28.6	13.9 6.1	0 0	0 0	0 0	1,400	3.09
East Fork Lobster Creek near Alsea	14306340	44°14'53" 123°38'07"	25.8 26.8	65.8 68.7	8.4 4.5	0 0	0 0	0 0	680	5.7
Needle Branch [3] near Salado	14306700	44°30'35" 123°51'20"	82.5	17.5	0	0	0	0	440	0.27
Needle Branch [4] near Salado	14306700	44°30'35" 123°51'20"	0	17.5	82.5	0	0	0	440	0.27
Flynn Creek near Salado	14306800	44°32'20" 123°51'05"	100	0	0	0	0	0	685	0.78
Deer Creek near Salado	14306810	44°32'05" 123°52'35"	94.6	5.4	0	0	0	0	600	1.17
Vincent Creek near Sulphur Springs	14323098	43°47'04" 123°46'11"	49.3	38.3	6.1	3	2.3	1	220	16.0
Priorli Creek near Dellwood	14323997	43°20'24" 124°04'45"	100	0	0	0	0	0	80	0.44
Middle Creek near Mckinley	14326860	43°13'52" 123°59'38"	40.7	48.6	6.9	.8	1.9	1.1	180	22.3

[1] Vegetation characteristics are defined in the text. Mature forests are dominated by trees older than 30 years. Partial-growth forests are areas that were clearcut from 2 to 30 years earlier. A more detailed vegetation classification was used for the model simulations than the one shown in this table.

[2] Values for the calibration period for each basin are shown in the first line; values for the validation period, if different, are shown in the second line. Dates of the calibration and validation periods are shown in table 2.

[3] Prelogging period, 1960–1963.

[4] Postlogging period, 1967–1968.

(*Alnus rubra*) are the dominate species. Except for Flynn Creek, all the basins studied have areas of recent harvest and restocked stands. Within a few years after an area has been clearcut, Douglas fir or a mixture of conifer species are planted.

Most soils in the basins studied are of the loam textural class, which is characteristic of most soils in Douglas-fir forests (U.S. Soil Conservation Service, 1973, 1974, 1989). Loam soils are well-drained, formed over both sedimentary and basaltic bedrock, and range in classification from sandy loam to cobbly clay loam.

Acknowledgments

The author thanks Chester Novak and Kirk Appleman of the U.S. Bureau of Land Management for providing some of the meteorologic and hydrologic data used in the modeling and for delineating the land-use classification of all the basins from aerial photography. The author also acknowledges James Fogg, U.S. Bureau of Land Management, for spearheading interest within the U.S. Bureau of Land Management and the U.S. Geological Survey for this project. The author also thanks George Miller, Oregon State Climatologist, who provided some meteorologic data. General comments and suggestions about the project from Gordon Grant, Research Hydrologist with the Pacific Northwest Research Station of the U.S. Forest Service, and specific soils information from John A. Shipman of the U.S. Soil Conservation Service, also were appreciated.

CHARACTERIZATION OF RUNOFF PROCESSES

The movement of storm waters on or through upland drainage basins in the Coast Range is controlled by mechanisms that are largely a function of the physical characteristics of the basins. These mechanisms and corresponding flow paths are altered when the land-surface conditions of a basin are disturbed by timber-harvesting activities.

Undisturbed Basin Conditions

Dunne (1983) discussed three mechanisms by which storm runoff may be generated: Hortonian overland flow, saturation overland flow, and subsurface flow. Hortonian overland flow occurs when rainfall or snowmelt rates exceed the soil-infiltration capacity (Horton, 1933). This flow mechanism often is evident in arid and semiarid landscapes and in disturbed landscapes in humid regions. Saturation overland flow is generated when the surface soil layer becomes saturated by a rise in the ground-water table. These saturated areas typically expand and contract in response to the intensity and duration of storms (Troendle, 1985). All subsequent additions of water on the saturated soil surface, regardless of the rate of intensity, are directed into overland flow. Saturation overland flow often occurs on landscapes that have thin soils, gentle concave footslopes, and wide valley bottoms. The temporal and spatial variation of areas that generate storm flow led to the use of the term variable source-area concept (Hewlett and Hibbert, 1967). Subsurface flow often occurs in basins that have high soil conductivity because of coarse soil texture or large structural openings in densely vegetated soils; these basins typically have steep hillslopes with narrow valley bottoms, and are located in regions of high humidity. A storm hydrograph of those basins is dominated almost entirely by subsurface flow. The high infiltration rates prohibit the occurrence of overland flow in the upper slope areas. Dunne (1983) describes much of the stormflow generation in undisturbed, humid forests as a combination of the latter two flow mechanisms – subsurface and saturated overland. The change from one storm flow mechanism to another in a basin is dependent on seasonal and climatic conditions, such as precipitation intensities and antecedent-soil moisture.

In addition to dominant flow paths in a drainage basin, residence times are important in characterizing runoff processes. Various hypotheses explaining the controlling mechanisms of rapid subsurface flow have been broadly categorized by Pearce and others (1986) as those relying on rapid throughflow of "new" water (water derived from current precipitation or melt) and those relying on displacement of old water. Hypothesized throughflow processes include piping and macropore flow; hypothesized displacement processes include pressure responses in the saturated and unsaturated zones. Using dye tracers in a highly responsive drainage basin, Mosley (1979) suggested that storm-runoff generation was a rapid transmission of "new" (current storm rain) water to the stream through macropores. However, Sklash and others (1986) studied the same basin and disputed Mosley's study results, suggesting that throughflow was dominated by "old" waters.

Subsurface flow is the dominant, although not exclusive, storm-runoff mechanism of the forested basins in the Coast Range of Oregon (Harr and others, 1975). Overland flow rarely occurs on undisturbed upslope soils because rainfall amounts rarely exceed the infiltration capacity of the soil. However, the streams respond quickly to rainfall. Most basin soils are well-drained and have a percentage of loam and gravel content that is formed mostly in mixed volcanic rocks and sandstones. Channel valleys are narrow, and hillslopes generally are steep and covered with dense vegetation. The rare occurrence of overland flow is limited to small, saturated areas that border stream channels.

Harr (1977) evaluated water flux in soil and subsoil zones of a forested, 10.23-hectare drainage basin in the Cascade Range of western Oregon. Overstory vegetation in that basin was dominated by 450-year-old Douglas fir and younger, western red hemlock. The slightly convex slopes had a mean gradient of 75 percent. Dominant soils in the basin were gravelly clay loams that overlie subsurface material consisting of highly weathered, coarse, volcanic breccias. In conjunction with soil analyses, tensiometer, piezometer, streamflow, and rainfall data were analyzed to evaluate the temporal and spatial water flux in the soil and subsurface layers. Some of the results of that study are excerpted below (Harr, 1977, p. 56):

> Both magnitude and direction of water flux in soil and subsoil varied temporally ***. Water flux below 30 centimeters was directed mostly downslope during storms and more vertically downward between storms. Water flux in surface soils was directed downslope between storms and more vertically downward during storms ***. Unsaturated flow dominated over all but the bottom 12-15 meters of the study slope ***. Saturated flow conditions at the bottom of the slopes in the watershed appeared to be related to the drainage of soil pores which filled with water during a storm. About 10 hours after rainfall had ceased, these pores had essentially drained. Discharge from a seep and streamflow exhibited a marked increase in their rates of decrease at this time ***. Subsurface storm flow dominated storm flow from the study watershed. Overland flow did not occur. Total storm flow averaged 38 percent of storm precipitation. Subsurface storm flow and channel interception, respectively, averaged 97 percent and 3 percent of total storm flow.

Disturbed Basin Conditions

When a forested basin has been clearcut, the hydrologic effects during non-snow conditions typically can include increased annual runoff, decreased evapotranspiration losses, and increased periods of both peak and low streamflow. However, various studies have shown that the hydrologic effects of clearcutting often can vary, depending on the specific characteristics of a basin. Because many of these studies used data collected from paired-watersheds, quantifying the hydrologic effects of clearcutting was possible. Typically, in paired-watershed studies, streamflow and precipitation data are collected from two basins in close proximity that are similar in size and physical characteristics. The "control" basin is left undisturbed and the "experimental" basin is subjected to clearcutting or other timber-management treatment at a midpoint during the data-collection period.

In an earlier paired-watershed study, which included an evaluation of clearcutting a 74-acre watershed in the Fernow Experimental Forest in West Virginia (Reinhart and others, 1963), peak streamflows increased 21 percent during the growing season and decreased 4 percent during the dormant season. After a hardwood forest on a 108-acre watershed in (Coweeta Hydrologic Laboratory) North Carolina was clearcut, storm runoff increased by 11 percent and peak streamflow increased by 7 percent (Hewlett and Helvey, 1970). In a similar study at the Hubbard Brook Experimental Forest in New Hampshire, clearcutting of a 38-acre watershed resulted in a 0.51-inch increase in storm runoff during the growing season, but no change in runoff during the dormant season (Hornbeck, 1973).

Under the auspices of an experimental-watershed study, hydrologic data from the Alsea River basins in western Oregon were collected from 1959–73, (Harris, 1977). For that study, the Needle Branch Basin was clearcut approximately 82 percent, but the Flynn Creek Basin was left undisturbed. Harris (1977) found the effect of clearcutting resulted in a 26-percent increase in annual runoff, a 20-percent increase in peak flows, and a 0-percent increase in low flow. The increase in peak flow was noticeable, but statistically insignificant when a 95-percent prediction limit was used.

Results from a a paired-watershed study at the H.J. Andrews Experimental Forest on the west slope of the Cascade Range – where average annual precipitation ranges from 91 to 140 inches, depending on the elevation – were similar. Harr and others (1982) found that total runoff increased about 17 inches in the first year after clearcutting. After 4 years, increases in annual runoff averaged about 15 inches in the clearcut basin and about 8 inches in the partially cut basin. A fewer number of low streamflow days were recorded in the summer in the clearcut basin. The timing and magnitude of peak streamflows, however, did not change significantly after logging in either basin.

The occurrence of fog drip in western Oregon also could play a role in the hydrologic effects of clearcutting. After patch logging 25 percent of two small basins in the Bull Run Watershed, which is located in northern Oregon in the Cascade Range, Harr (1980) did not find a significant change in annual runoff. After clearcutting, the water gained from decreased evapotranspiration losses could have been offset by the loss of water from fog drip. The decrease in leaf-surface area decreased the volume of water falling on the ground surface from fog-drip condensation.

The effect that clearcutting may have on changing the magnitude of peak streamflows appears to be related to the season and to the nature of the land disturbance during the logging operation (Rothacher, 1973). Land disturbance includes increased surface-soil compaction resulting from tractor yarding and road building. Using data collected at subbasins of the Deer Creek Basin, Harr and others (1975) found a greater increase in peak streamflow for fall storms when compared with winter storms. Greater changes were expected in the fall season. A forested slope will have a drier soil profile due to summer transpiration losses and should absorb much of the rainfall from the first storm of fall. The wetter soil profile of a clearcut slope, however, should respond more quickly to rainfall.

Harr and others (1975) found significant peak streamflow increases when logging roads occupied at least 12 percent of a basin. A compacted surface reduces infiltration, and excess water is carried by a more efficient delivery system consisting of the road surface, ditches, and culverts. The routing effect of roads has been documented in various studies (Burroughs and others, 1972; Fredriksen and Harr, 1979; Harr, 1983).

Clearcut logging also can have the opposite effect on the magnitude of peak streamflows when compared to the studies discussed in the two preceding paragraphs. Cheng and others (1975), in a study of southwestern British Columbia, found that the magnitude of peak streamflows was significantly reduced after clearcut logging. This reduction was attributed to the compaction of subsurface macropores by logging activities. Cheng and others (1975) concluded that after an area had been logged, sealing the channel networks (which previously had transmitted water rapidly during storms) forced water to follow slower routes through the soil matrix.

In the first and second phases of this study, Nakama and Risley (1993) and Allen and Laenen (1993) evaluated the PRMS model as a predictive tool for assessing effects of forest-management practices on streamflow. Data sets from the East Fork Lobster Creek Basin and the three Alsea basins (Flynn Creek, Needle Branch, and Deer Creek), described in the paired-watershed study previously mentioned, were used. All these authors found that parameter values calibrated in one basin could be transferred to the other basins to yield similar precision and accuracy. This was expected due to the geographic proximity and similarity of the three Alsea basins. Parameter values also could be adjusted in the PRMS models to predict the relative effects of logging on streamflow. Simulated postlogging changes in the Needle Branch Basin showed an increase in annual discharge volume (12.8 percent) that was similar to published data, and showed a small increase in peak flows (1 to 2 percent). All four authors, however, also acknowledged that these changes were equal to or smaller than errors in the PRMS-modeled runoff.

PRECIPITATION-RUNOFF MODEL

The first objective of the study was the calibration and validation of a precipitation-runoff model for each of the 11 basins studied. Precipitation-runoff models typically simulate the hydrologic response of a basin at the outlet to the precipitation that falls over the basin surface. The hydrologic signal at a basin outlet represents a composite of numerous physical processes in that basin. The selection of a precipitation-runoff model for a study is based on the specific study objectives and the availability of data representing the climatic, hydrologic, and physical characteristics of a basin.

Parameters are used to tune the structure of a model, so that the physical processes of a specific basin are represented. Mathematically, parameters are defined as numerical constants used as referents for determining variables. A parameter value remains fixed for each time step during the simulation, whereas variables of the model are computed by equations in the model and vary with each time step. For example, the parameters in a simple regression model are slope and intercept. The parameter values, selected by the user, are unique to a specific application or basin.

Although some parameter values of a model are measured in the field, other parameter values must be determined through trial adjustments. During calibration of a model, these parameters are adjusted to minimize the error between observed- and simulated-streamflow data. Typically, half of the available climatological and streamflow data are used for the calibration-simulation period. After the parameter values have been determined, a validation simulation is usually performed using the remaining half of the time-series data.

Description of the Simulation Model

The PRMS was the computer-simulation model selected for this study (Leavesley and others, 1983). Major advantages of using the PRMS include that the model: (1) continuously simulates the moisture balance of each component of the hydrologic cycle, (2) accounts for heterogeneous physical characteristics of a basin, and (3) simulates both naturally and humanly affected flows in a basin.

The PRMS is schematically diagramed in figure 2 to show the components used in this study. A basin is conceptualized as an interconnected series of reservoirs whose collective output produces the total hydrologic response. These reservoirs include interception storage in the vegetation canopy, impervious-area storage on the surface, storage in the soil zone, subsurface storage between the surface of a basin and the water table, and ground-water storage. The movement of water from one reservoir to another is computed throughout the simulation. In the application of the model for this study, the system inputs included precipitation and daily maximum- and minimum-air temperature. Streamflow at a basin outlet is the sum of surface, subsurface, and ground-water flows. An example of simulated surface, subsurface, and ground-water flows for water year 1985 at USGS station 14303200 in Tucca Creek Basin is shown in figure 3.

The PRMS operates in two time-step modes—daily and storm. In the daily mode, variables are simulated as daily mean or volumetric depth. In the storm mode, variables are simulated using a smaller, user-defined time step which can vary from 1 minute to 1 hour. Streamflows are routed across overland flow segments and channels.

Heterogeneity in a basin is accounted for by partitioning the basin into a number of units based on user-defined criteria, such as slope, aspect, land use, soil type, geology, and precipitation distribution. Each unit is assumed to have a homogeneous, hydrologic response and is called a hydrologic-response unit (HRU). A water balance is computed during each time step for each HRU and for the entire basin. Because processes such as surface runoff, interception storage, and soil rooting depth vary among HRUs, distributed parameters are used to assign specific parameter values to each HRU. The ability to model various timber-cutting scenarios, in which land use in parts of a basin can be changed, is provided by partitioning.

Channel- and overland-flow-routing simulation is performed only in the storm mode. The basin is partitioned into a series of interconnected flow planes and channel segments that overlie the HRUs. Surface runoff is routed through overland flow planes to channel segments. Channel flow is routed through the channel network.

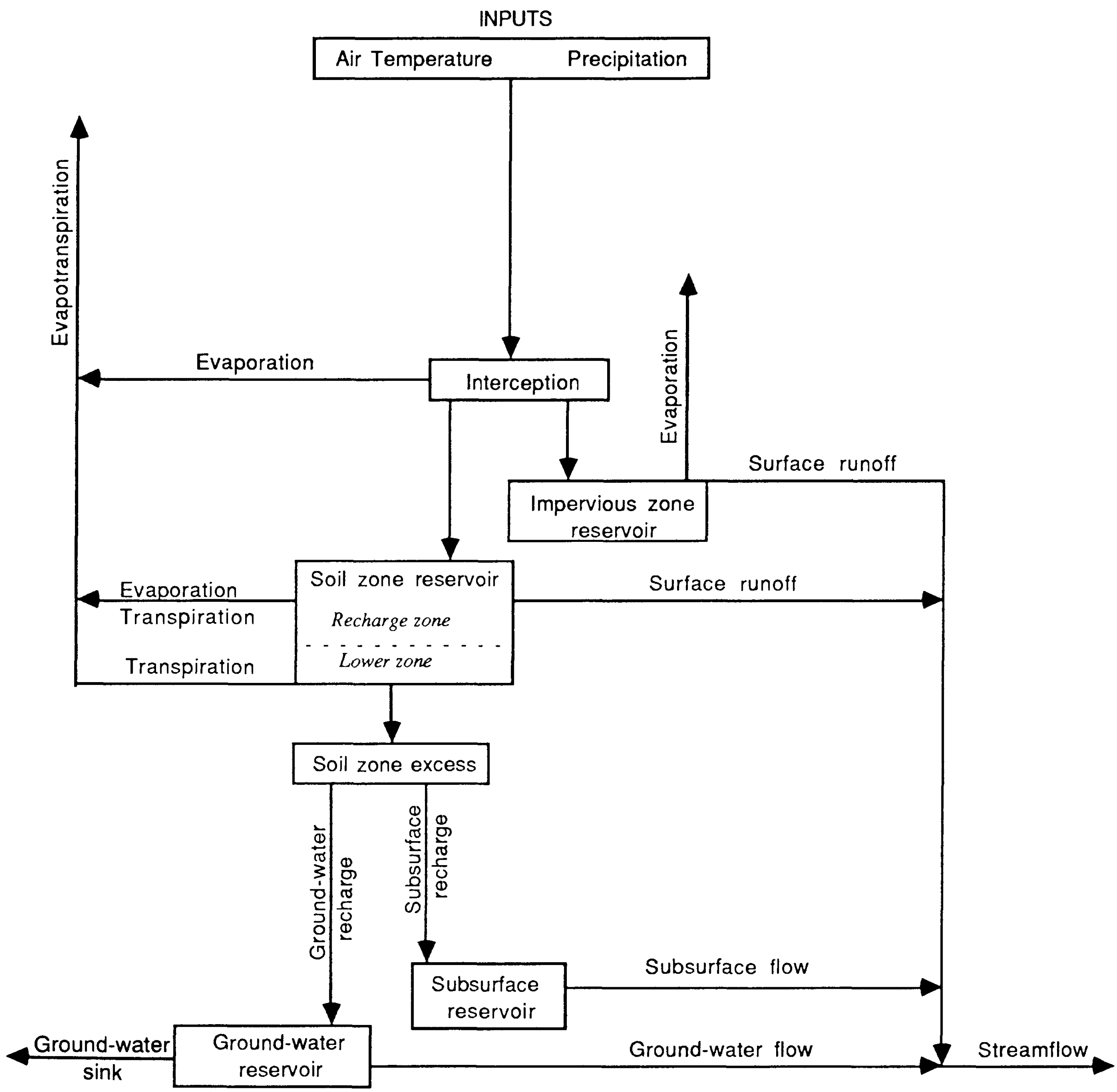

Figure 2. Schematic diagram of the Precipitation-Runoff Modeling System (PRMS) model.

Channel-and overland-flow-plane routing is based on a finite-difference approximation of the continuity equation and the kinematic-wave approximation, relating flow and the cross-sectional area of flow.

The PRMS uses separate algorithms to compute surface runoff and infiltration in the daily and storm modes. In the daily mode, surface runoff is computed using the variable source-area approach. Surface runoff is related to a dynamic source area that expands and contracts according to rainfall characteristics, and to the capability of the soil mantle to store and transmit water (Troendle, 1985). As conditions become wetter, the proportion of precip-itation diverted to surface runoff increases, while the proportion of precipitation that infiltrates to the soil zone and the subsurface reservoir decreases. Daily infiltration (net precipitation minus surface runoff) is computed as either a linear or nonlinear function of antecedent-soil moisture and the amount of rainfall. The nonlinear method was used in this study, because it used parameter values that could be estimated from observed streamflow records.

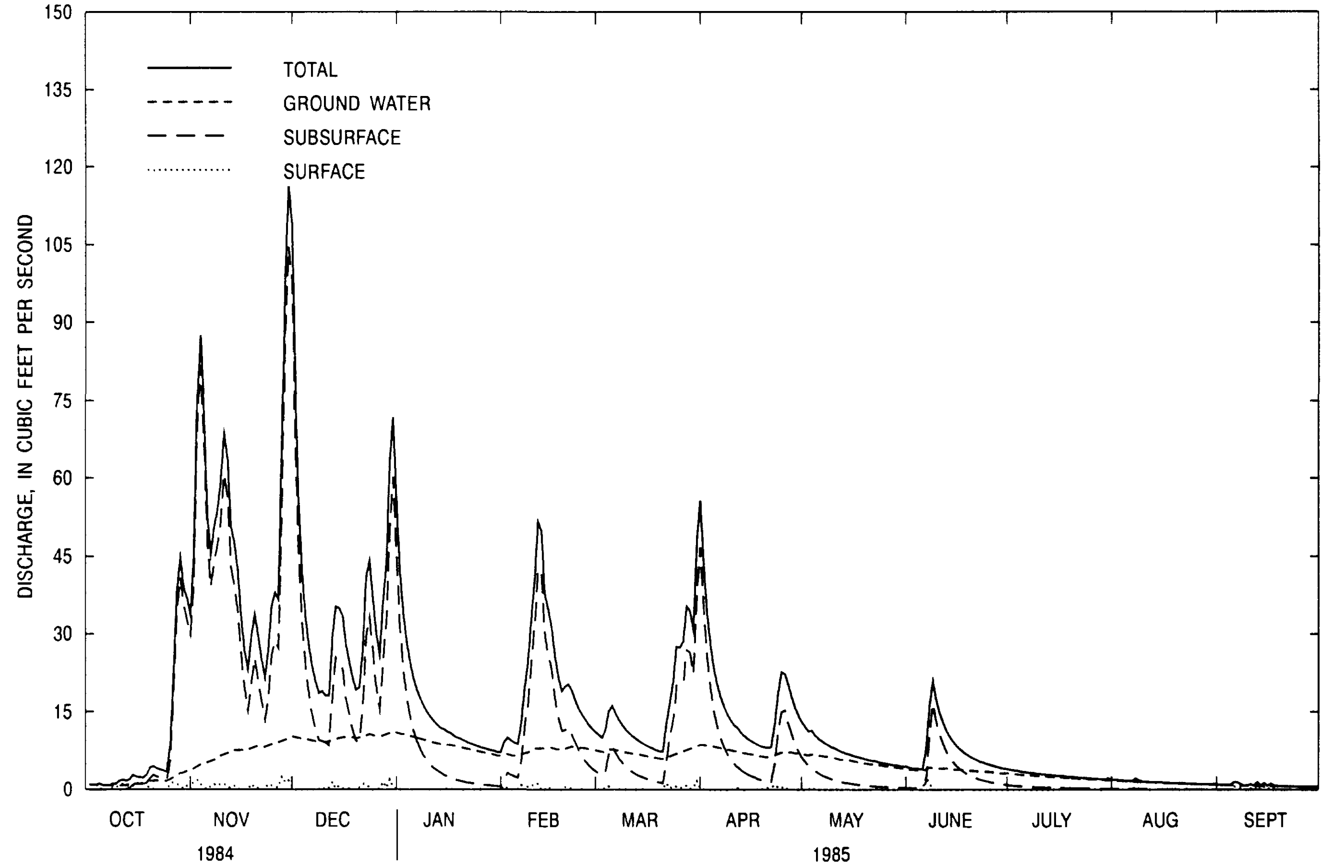

Figure 3. Simulated ground water, subsurface, surface, and total discharge for station 14303200 in Tucca Creek Basin, October 1984–September 1985.

In the storm mode, surface runoff and infiltration for storms are computed using a variation of the Green and Ampt equation (Green and Ampt, 1911). The Green and Ampt equation (Green and Ampt, 1911) allocates the net rainfall reaching the soil surface to rainfall excess and infiltration, using either a user-specified time step or a 5-minute time step, whichever is less. Surface runoff is then computed using the rainfall excess as input to the kinematic-wave approximation to overland flow.

To simulate the effects of soil compaction resulting from logging operations and from roads, a percentage of a basin surface was defined as impervious. Precipitation retained on the land surface is modeled as surface-retention storage. A maximum retention-storage capacity for this land surface must be satisfied before surface runoff can occur. When free of snow, the retention storage is depleted by evaporation.

In the pervious surface areas of a basin, precipitation that falls through the crown canopy infiltrates the soil zone. The soil zone is viewed as a two-layered system. Moisture in the upper soil (or recharge) zone and in the lower soil zone is depleted through root uptake and seepage to lower zones. In the upper soil zone, moisture also can be depleted through evaporation. The depths of both the upper and the lower soil zones are defined by the user on the basis of water-storage characteristics. The depth of the lower soil zone also is based on the rooting depth of the dominant vegetation.

In the application of the PRMS to this study, PET losses were computed as a function of daily mean air temperature and maximum possible hours of sunshine (Hamon, 1961). When soil moisture is nonlimiting, actual evapotranspiration (AET) is equal to PET. When soil moisture is limiting, AET is computed from PET-AET relations for sand, clay, or loam soil types as a function of the ratio of current available water in the soil profile to the maximum available water holding capacity of the soil profile (Zahner, 1967). An example of simulated potential and actual evapotranspiration at USGS station 14303200 in the Tucca Creek Basin for water year 1985 is shown in figure 4.

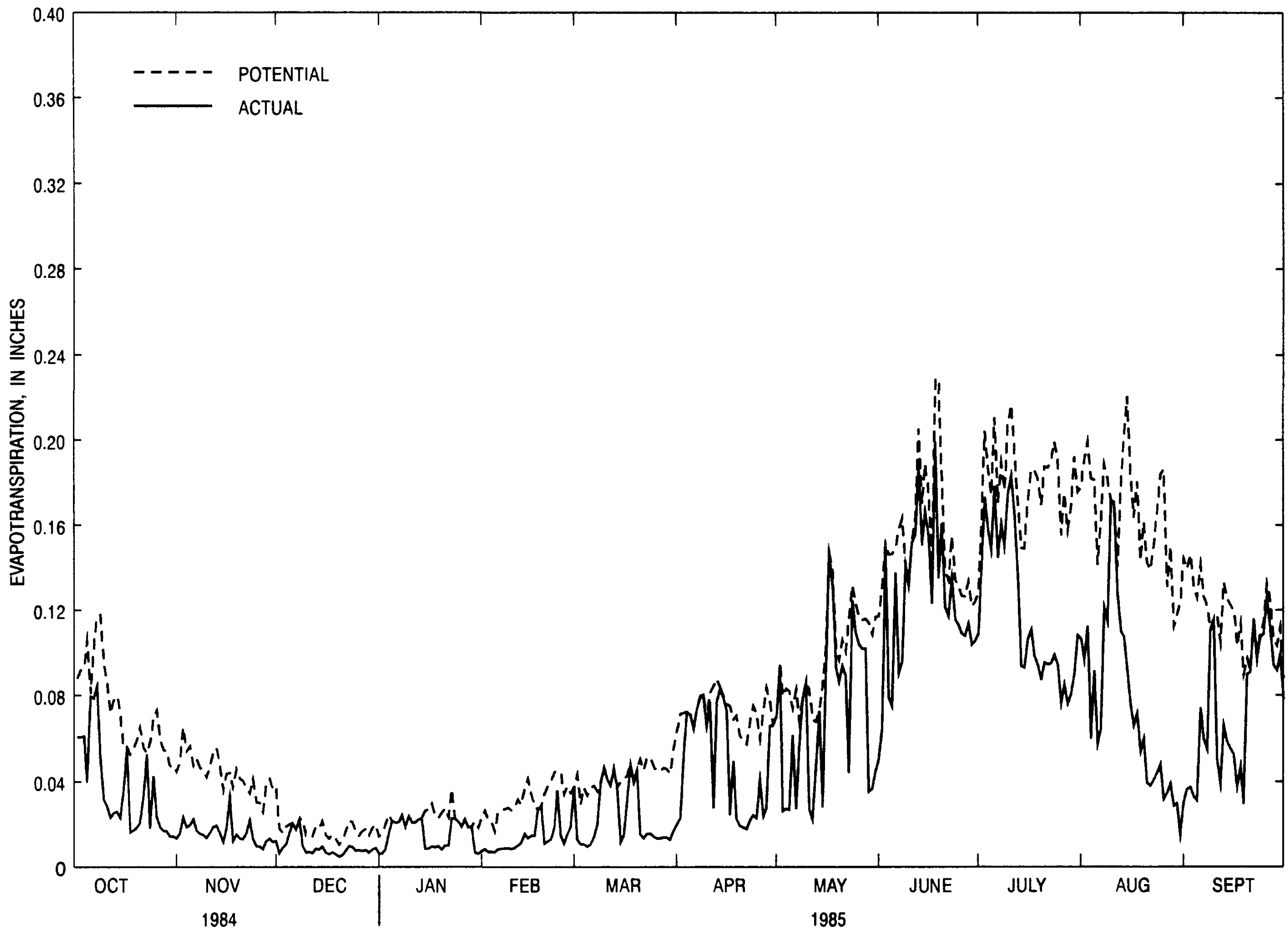

Figure 4. Simulated daily potential and actual evapotranspiration for station 14303200 in Tucca Creek Basin, October 1984–September 1985.

The PRMS contains a snow routine to simulate the initiation, accumulation, and depletion of a snowpack in each HRU. In this study, PRMS model parameters that control snow occurrence were set to default values. Although snow occasionally occurs in the Coast Range of Oregon, the volume of snowpack accumulation in the basins studied is not a significant component of the hydrographs of those basins. The snow routine requires either observed or computed, daily shortwave radiation. In this study, daily shortwave radiation was computed using a relation between solar radiation and sky cover and a relation between sky cover and a daily range in air temperature. This procedure is applicable to the Northwest, because periods of cloud cover with or without precipitation often occur.

Soil water in excess of field capacity drains to subsurface and ground-water reservoirs. Excess moisture in the subsurface reservoir either percolates to a ground-water reservoir or flows downslope to some point of discharge above the water table. Seepage to the ground-water reservoir is computed as a function of a recharge-rate coefficient and the volume of water in the subsurface reservoir. The ground-water reservoir, defined as a linear system, is the source of base flow to a basin outlet. The downward movement of ground water out of a basin to a regional aquifer is accomplished by routing a portion of the ground water to a ground-water sink. Definitions of the PRMS model parameters used in this study are shown in table 16 (at back of report). A list of PRMS parameters and variable names and their equivalent Modular Hydrologic Modeling Systems (MHMS) names is contained in Appendix B. The MHMS will be a future version of the PRMS (Leavesley and others, 1992).

Time-Series Data

Eleven models, created with the PRMS to simulate each of the basins studied, were calibrated and validated using observed precipitation, discharge, and air-temperature time-series data. The beginning and ending dates of the calibration and validation periods for each of the model simulations are listed in table 2. Selection of those periods was based on the availability of time-series data. Entire water years were selected whenever possible. Because data were missing from almost all of the precipitation records and one of the temperature records, using regression relations to estimate data was required. The storms used in the storm-mode simulations were selected based on the availability of hourly precipitation and discharge data.

Table 2. Model calibration and validation periods for each basin

Basin name	Calibration period	Validation period
Wind River	Oct. 1, 1984 - Sept. 30, 1986	Oct. 1, 1986 - Sept. 30, 1988
North Yamhill River	Oct. 1, 1982 - Sept. 30, 1985	Oct. 1, 1985 - Sept. 30, 1988
Nestucca River	Oct. 1, 1960 - Sept. 30, 1963	Oct. 1, 1966 - Sept. 30, 1968
Tucca Creek	Oct. 1, 1983 - Sept. 30, 1986	Oct. 1, 1986 - Sept. 30, 1989
East Fork Lobster Creek	Oct. 1, 1983 - Sept. 30, 1985	Oct. 1, 1985 - Sept. 30, 1988
Needle Branch [1]	Oct. 1, 1959 - Sept. 30, 1961	Oct. 1, 1961 - Sept. 30, 1963
Needle Branch [2]	Oct. 1, 1966 - Sept. 30, 1968	
Flynn Creek	Oct. 1, 1959 - Sept. 30, 1961	Oct. 1, 1961 - Sept. 30, 1963
Deer Creek	Oct. 1, 1959 - Sept. 30, 1961	Oct. 1, 1961 - Sept. 30, 1963
Vincent Creek	Oct. 1, 1983 - Sept. 30, 1986	Oct. 1, 1986 - Sept. 30, 1989
Priorli Creek	Oct. 1, 1988 - Sept. 30, 1989	Oct. 1, 1989 - Sept. 30, 1990
Middle Creek	Oct. 1, 1985 - Sept. 30, 1988	Dec. 1, 1988 - Sept. 30, 1990

1 Prelogging calibration and verification periods.

2 Postlogging simulation period.

Precipitation

Hourly precipitation data used in the PRMS model simulations were collected from weighing-bucket gages located in or near the basins studied (figs. 5–8). If the record from a gage located in a basin was inadequate, precipitation records of neighboring gages were used in some PRMS model simulations. The PRMS model simulations of the Deer Creek, Flynn Creek, and Needle Branch Basins used precipitation data from the Deer Creek precipitation gage. The PRMS model simulations of the North Yamhill River and Nestucca River Basins used precipitation data collected from a Haskins Reservoir gage, located approximately 3 miles east of the Nestucca River discharge gaging station (14302900). The Deer Creek precipitation gage was installed and operated by Oregon State University. Precipitation gages used for other basins in the study were installed and operated by the BLM. Regression relations, based on precipitation records from neighboring stations, were used to estimate missing periods of record. These regression relations are shown in table 3. Precipitation records with a higher coefficient of determination were used in order of preference over precipitation records with a lower coefficient of determination. Daily precipitation data from the Wind River and Tucca Creek Basins for the 1984 to 1988 water years are shown in figure 9.

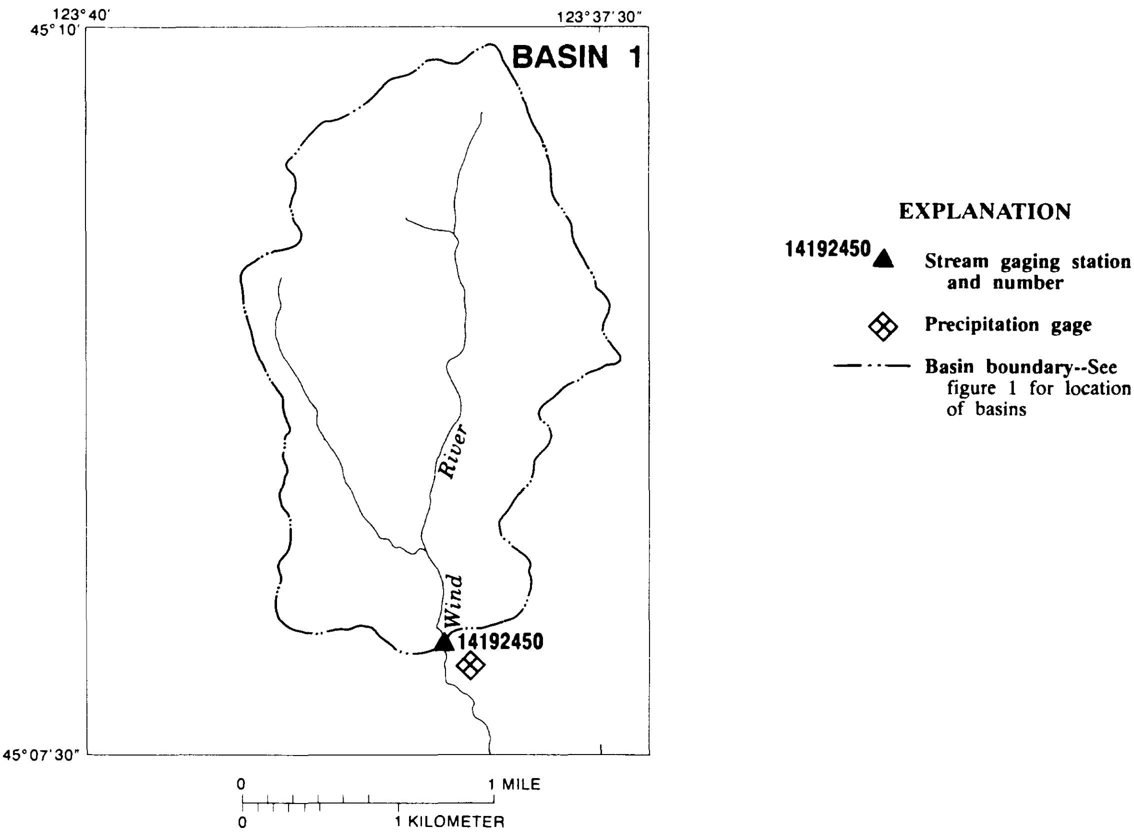

Figure 5. Wind River Basin.

Discharge

Daily mean and hourly streamflow data were collected, at gaging stations in all 11 basins studied, according to standardized techniques of the USGS (Rantz, 1982). Discharge data for 7 of the 11 basins were collected by the USGS. Complete records of daily streamflow are available in USGS annual water summary publications for the following gaging stations: North Yamhill River (14194300), Nestucca River (14302900), Tucca Creek (14303200), East Fork Lobster Creek (14306340), Needle Branch (14306700), Flynn Creek (14306800), and Deer Creek (14306810). Discharge data for Wind River (14192450) were collected by the BLM. Streamflow data for Vincent Creek (14323098), Priorli Creek (14323997), and Middle Creek (14326860) were collected by the Oregon Department of Water Resources in cooperation with the BLM.

Air Temperature

Observed, daily, minimum- and maximum-air-temperature data collected by the U.S. National Weather Service were used in this report. The location names and elevations of the air-temperature stations used for each basin are shown in table 4. To account for differences in elevation between the stations and the basins, the PRMS model adjusts the temperature data using a lapse rate of 2.8°C for every 1-thousand-foot increase in elevation. The Wind River Basin simulation used temperature data collected in Dallas; missing values were estimated using a regression relation with temperature data collected nearby in McMinnville. The coefficient of determination for the maximum- and minimum-air-temperature regressions was 0.98 and 0.91, respectively.

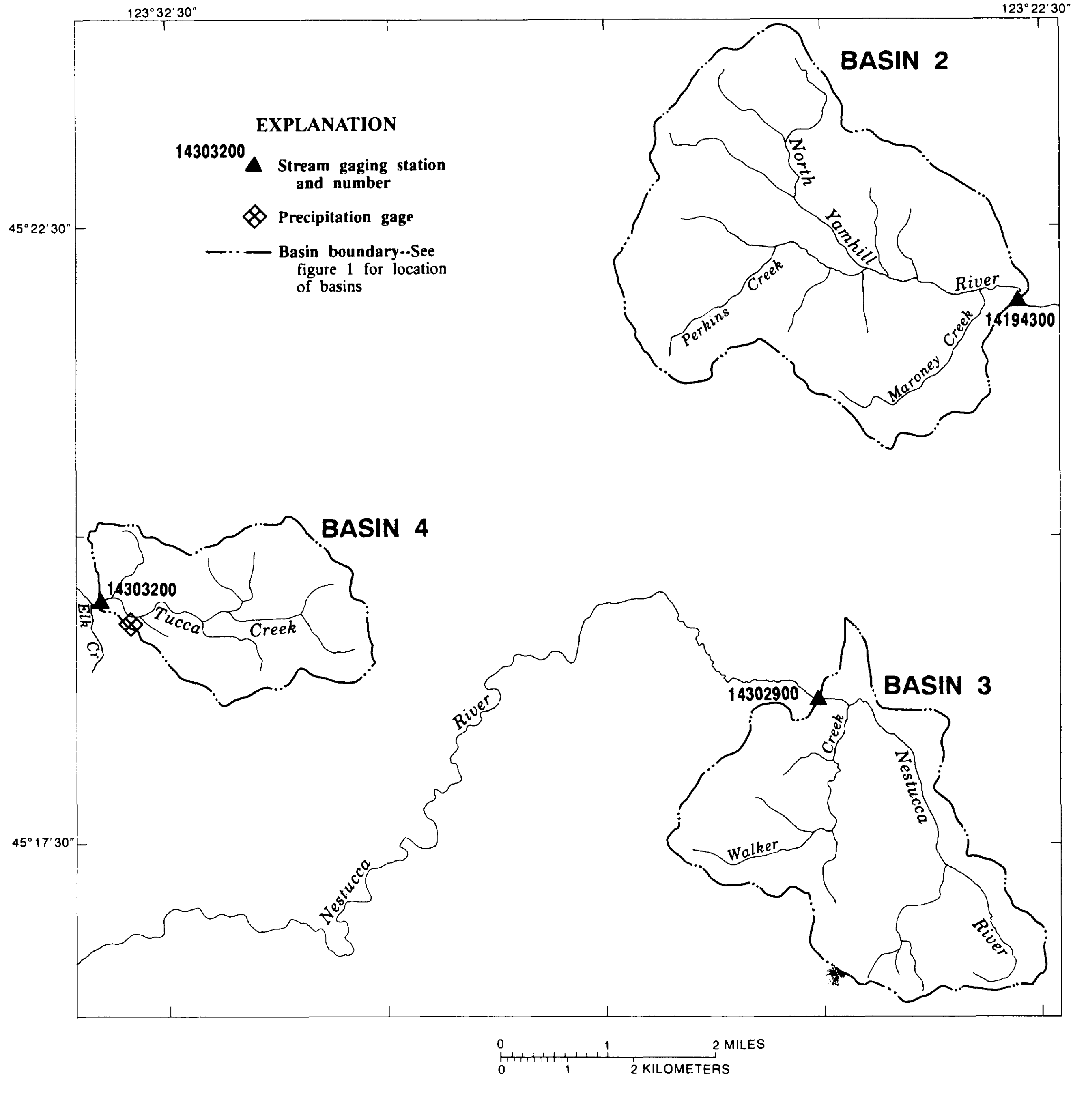

Figure 6. North Yamhill River, Nestucca River, and Tucca Creek Basins.

Delineation of Basin Physical Characteristics

The HRUs of the 11 basins have similar combinations of soil texture and depth, slope, and vegetation. Soils data for the Alsea and Yamhill areas and for Coos County were acquired from county soil surveys that had been compiled by the U.S. Soil Conservation Service (1973, 1974, and 1989). Soils data for Tillamook and Douglas Counties were provided from local offices of the U.S. Soil Conservation Service (J.A. Shipman, U.S. Soil Conservation Service, written commun., 1993). The most prominent soil series for each of the 11 basins studied are listed in table 5. Although the soil-texture classification of each soil series is detailed, for application to the PRMS the soil textures were simplified into three classes: sand, loam, or clay. Those three classes were subdivided by soil depth as shallow (1 to 20 inches), moderately deep (21 to 40 inches), or deep (41 inches or greater).

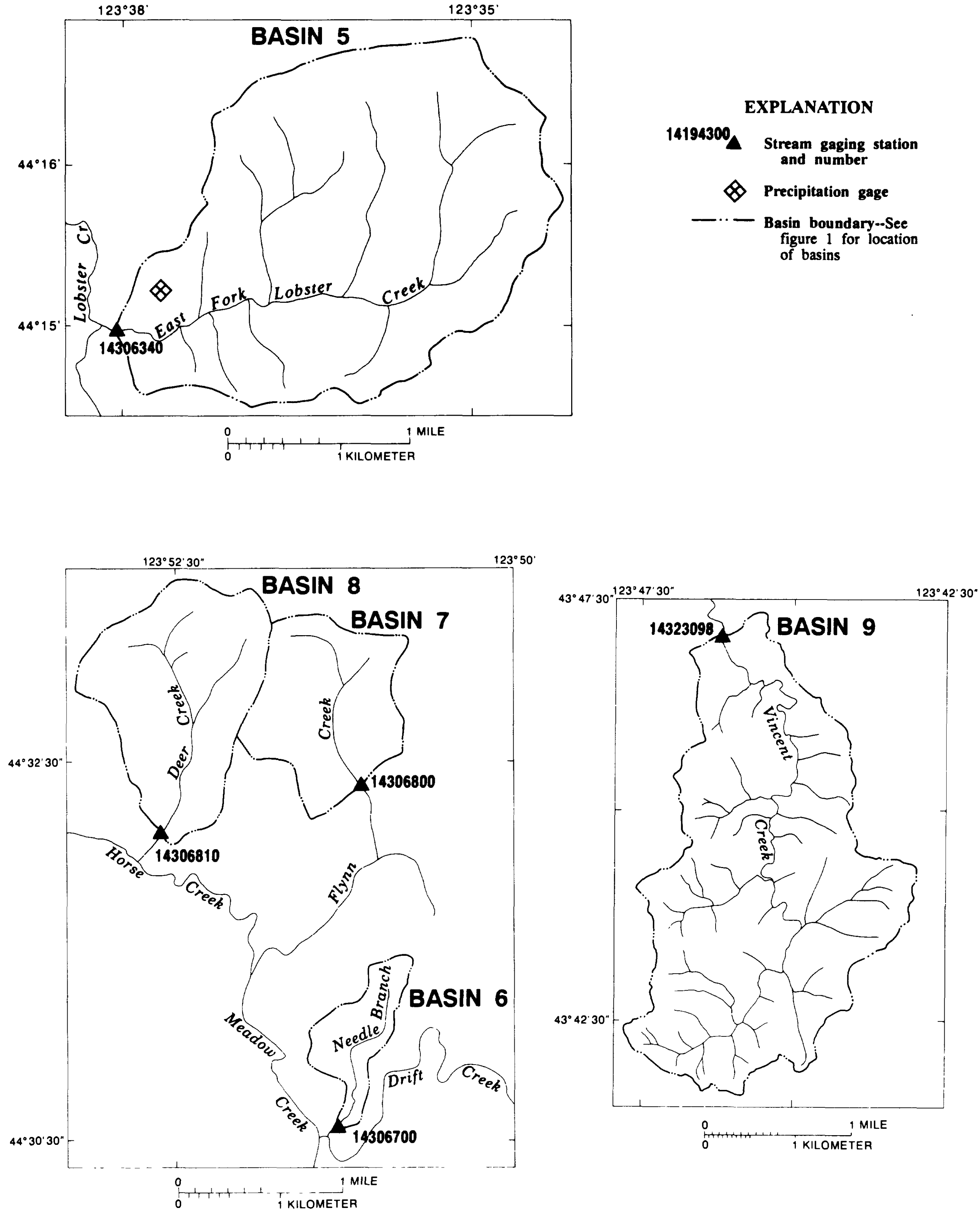

Figure 7. East Fork Lobster Creek, Needle Branch, Flynn Creek, Deer Creek, and Vincent Creek Basins.

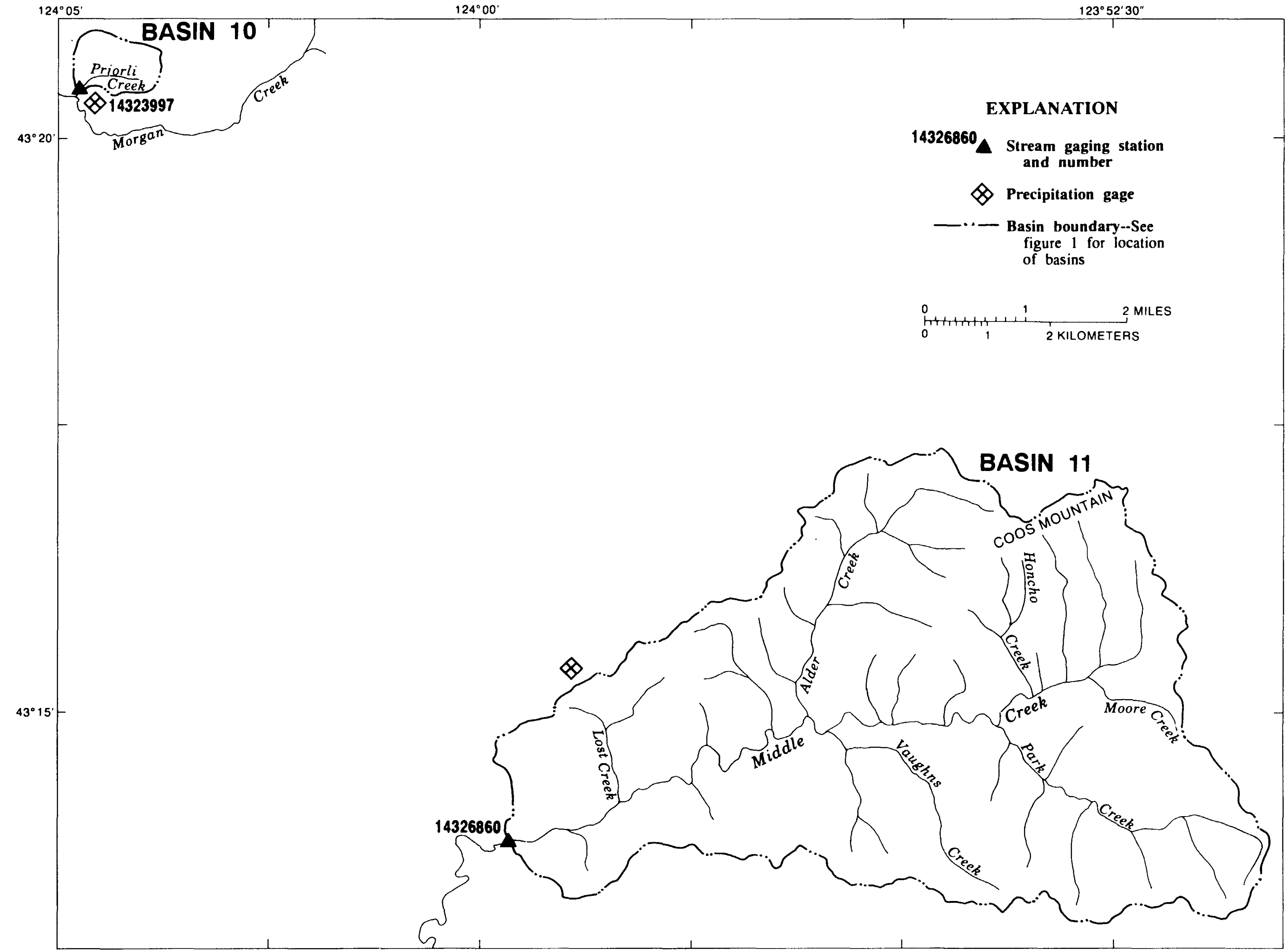

Figure 8. Priorli Creek and Middle Creek Basins.

Table 3. Regression relations used to estimate missing daily precipitation data

Dependent record	Independent record	Correlation coefficient [1]	Period of record
Wind River	Tucca Creek	0.84	1984-1988
	Haskins Reservoir [2]	.76	1984-1988
Haskins Reservoir	Nestucca River	.81	1960-1968
	Wind River	.76	1984-1988
	Tucca Creek	.71	1982-1989
Deer Creek	Flynn Creek	.92	1959-1968
	Needle Branch	.87	1959-1968
	Newport	.76	1959-1968
Tucca Creek	Wind River	.84	1984-1988
	Haskins Reservoir	.71	1982-1989
Vincent Creek	East Fork Lobster Creek	.75	1983-1989

[1] Correlation coefficient, r =

$$r = \frac{\sum_{i=1}^{n} X_i Y_i - n\bar{X}\bar{Y}}{\sqrt{\left(\sum_{i=1}^{n} X_i^2 - n\bar{X}^2\right)\left(\sum_{i=1}^{n} Y_i^2 - n\bar{Y}^2\right)}}$$

where

X is the independent data,
Y is the dependent data,
$\bar{X}$ is the mean of the independent data, and
$\bar{Y}$ is the mean of the dependent data.

[2] Precipitation record used for Nestucca River and North Yamhill River Basins.

Topographic information for the basins was acquired from 1:24,000 Digital Elevation Models. Using a "geographic information system" (GIS), elevation-matrix points in each basin were classified into regions of slope of either less than or greater than 35 percent. Vegetation data for all the basins studied were acquired from interpretation of 1:12,000-scale aerial photography provided by the BLM and the U.S. Forest Service. Vegetation patterns were divided into seven classes, which included "clearcut," "partial-growth young forest," "partial-growth old forest," "mature conifer forest," "mature hardwood-conifer forest," "mature conifer-hardwood forest," and "grasslands."

The clearcut classification pertains to areas that have been completely timber harvested within 2 years of the start of the calibration or validation periods. Exposed soil and lack of vegetation is still evident. Typically, these clearcut areas have only a small percentage of impervious surface resulting from soil compaction caused by logging operations and roads. Areas that were clearcut 2 to 15 years ago are classified as partial-growth young forest; planted or natural vegetation regrowth are established and are visually apparent. The age class of partial-growth forests was determined through existing records or photographic interpretation of crown development. Partial-growth old forest are areas that were clearcut 15 to 30 years ago. The class of mature conifer forest are areas that have nearly 100-percent conifer trees; typically, Douglas fir is the dominant species. The mature hardwood-conifer class are forests where most of the trees are hardwoods, whereas the mature conifer-hardwood class are forests where most of the trees are conifers. A final class pertains to the grasslands that exist in a small area of the East Fork Lobster Creek Basin.

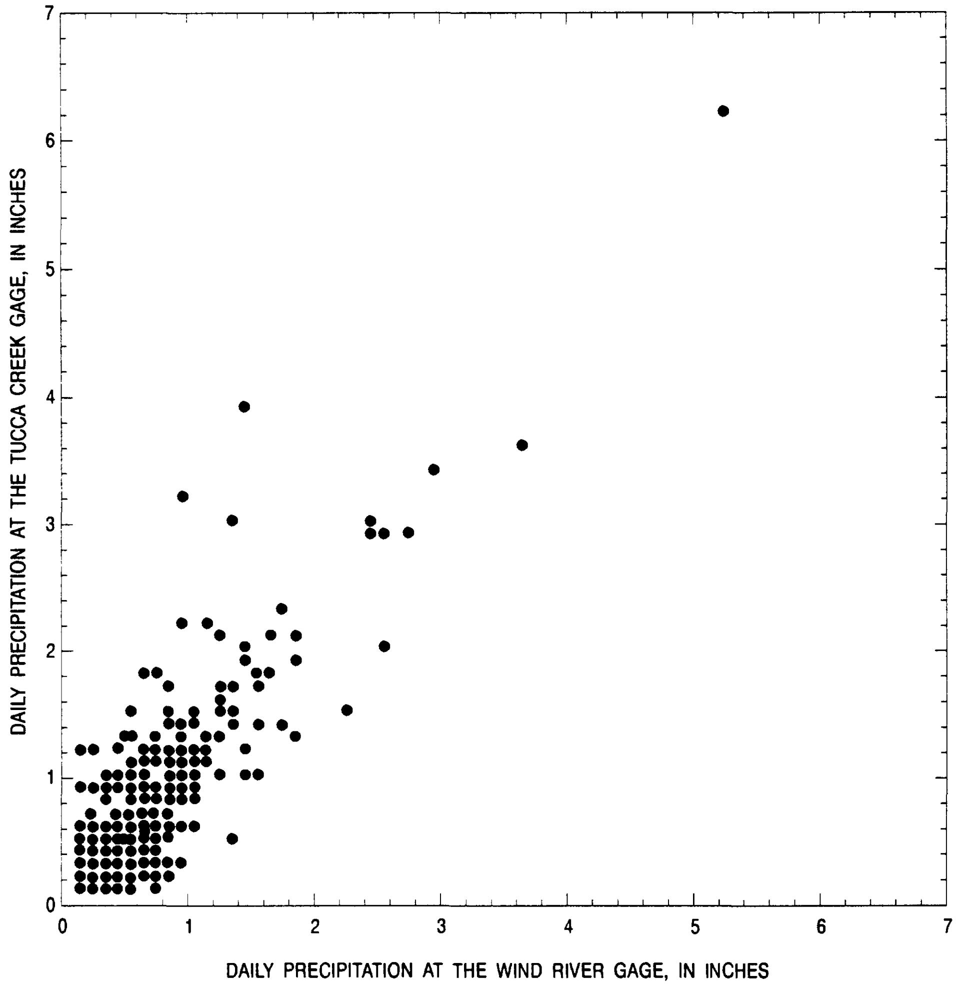

Figure 9. Daily precipitation data from Wind River and Tucca Creek Basins for water years 1984 to 1988.

Table 4. Air temperature stations used in model simulations for each basin

Basin name	Temperature station	Temperature station elevation (feet)[1]
Wind River	Dallas	290
North Yamhill River	McMinnville	150
Nestucca River	Cherry Grove	780
Tucca Creek	Tillamook	10
East Fork Lobster Creek	Tidewater	50
Needle Branch	Tidewater	50
Flynn Creek	Tidewater	50
Deer Creek	Tidewater	50
Vincent Creek	Elkton	120
Priorli Creek	Coquille	20
Middle Creek	Coquille	20

[1] Above mean sea level.

Table 5. Dominant soil series of each basin

Basin name	Soil series	Dominant soil texture
Wind River	Astoria	Silt loam
North Yamhill River	Hembre	Silt loam
	Olyic	Silt loam
	Klickitat	Stony loam
Nestucca River	Hembre	Silt loam
	Astoria	Silt loam
	Fresh water marsh	Gravelly loam
Tucca Creek	Murtip	Loam
	Caterl	Gravelly loam
	Laderly	Gravelly loam
East Fork Lobster Creek	Bohannon	Gravelly loam
	Bohannon-Slickrock	Gravelly loam
	Klickitat	Gravelly clay loam
Needle Branch	Bohannon	Gravelly loam
	Slickrock	Gravelly loam
Flynn Creek	Bohannon	Gravelly loam
	Slickrock	Gravelly loam
Deer Creek	Bohannon	Gravelly loam
	Slickrock	Gravelly loam
Vincent Creek	Bohannon	Gravelly loam
	Preacher	Loam
	Digger	Gravelly loam
	Umpcoos	Gravelly sandy loam
Priorli Creek	Bohannon	Gravelly loam
	Preacher	Loam
	Milbury	Gravelly sandy loam
	Digger	Gravelly loam
	Blachly	Silty clay loam
Middle Creek	Bohannon	Gravelly loam
	Preacher	Loam
	Umpcoos	Gravelly sandy loam
	Milbury	Gravelly sandy loam

Daily Mode

Using GIS software, digital files of vegetation, slope, and soil classification were made for each of the 11 basins. These digital files were merged together to create a new file containing the distribution of homogenous combinations of the three other digital files. As an example, a clearcut forest unit with deep loam soils on slopes greater than 35 percent would be one class. Another class would be a mature conifer forest unit with shallow clay soils on slopes less than 35 percent. Each combination class was defined as a single HRU. The 11 basins had from 8 to 19 classes. Spatially, the HRUs were noncontiguous. When using the PRMS daily mode, spatial grouping of the HRUs is not necessary; all travel times in a basin were assumed to be less than 24 hours. An example of the spatial distribution of HRUs for the Tucca Creek Basin is shown in figure 10. Information from GIS that was inserted into PRMS-parameter files included the cumulative area, mean elevation, and mean aspect of each HRU. The distributed parameters related to HRUs are used in the evapotranspiration, interception, soil-zone, and surface-runoff subroutines of the PRMS.

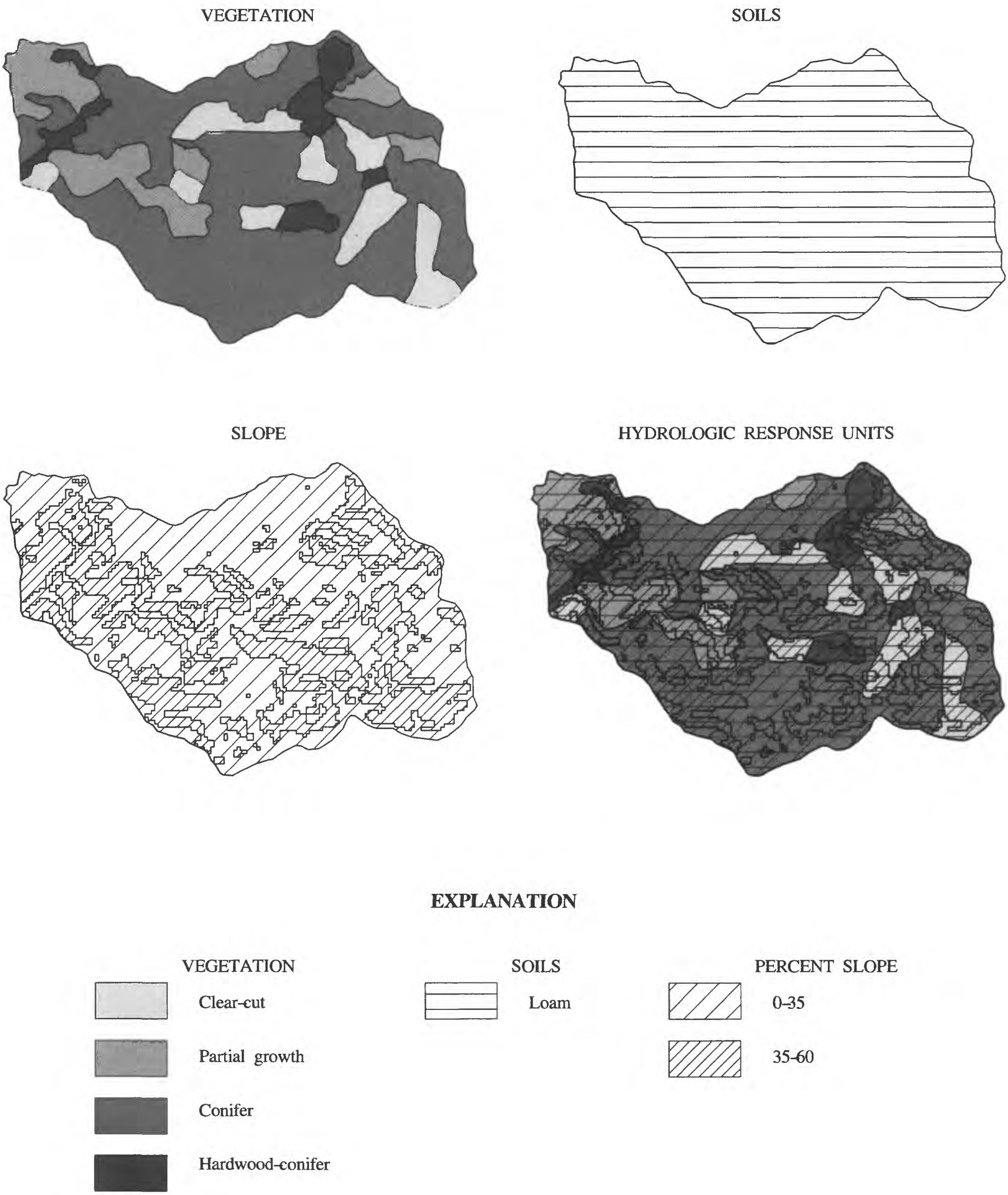

Figure 10. Soil, vegetation, and topographic characteristics of the Tucca Creek Basin.

If basin geology is fairly homogenous, only one subsurface and one ground-water reservoir for a basin usually is used in the PRMS model. If necessary, however, the user is allowed to dimension the model to have more than one subsurface or ground-water reservoir. In the PRMS application to this study, only one subsurface reservoir and one ground-water reservoir were used for each of the 11 models.

Storm Mode

To use the PRMS storm-simulation mode, defining a network of overland flow planes and channel segments in each of the 11 basins was necessary. Manually redelineating the HRUs as spatially contiguous units of each basin also was necessary, because each overland flow plane is unique and must be superimposed only over a single HRU. However, several unique overland flow planes may be superimposed over a single HRU. The HRU delineation, overland flow planes, and channel network of the East Fork Lobster Creek Basin are shown as an example (fig. 11).

Parameters related to overland flow planes define the physical characteristics that affect kinematic-overland flow on basin slopes. These characteristics include the slope, length, roughness, and infiltration properties of the flow plane. The flow planes are linked together by channel segments. Channel-segment parameters are used to define channel characteristics such as slope, length, geometry, and roughness.

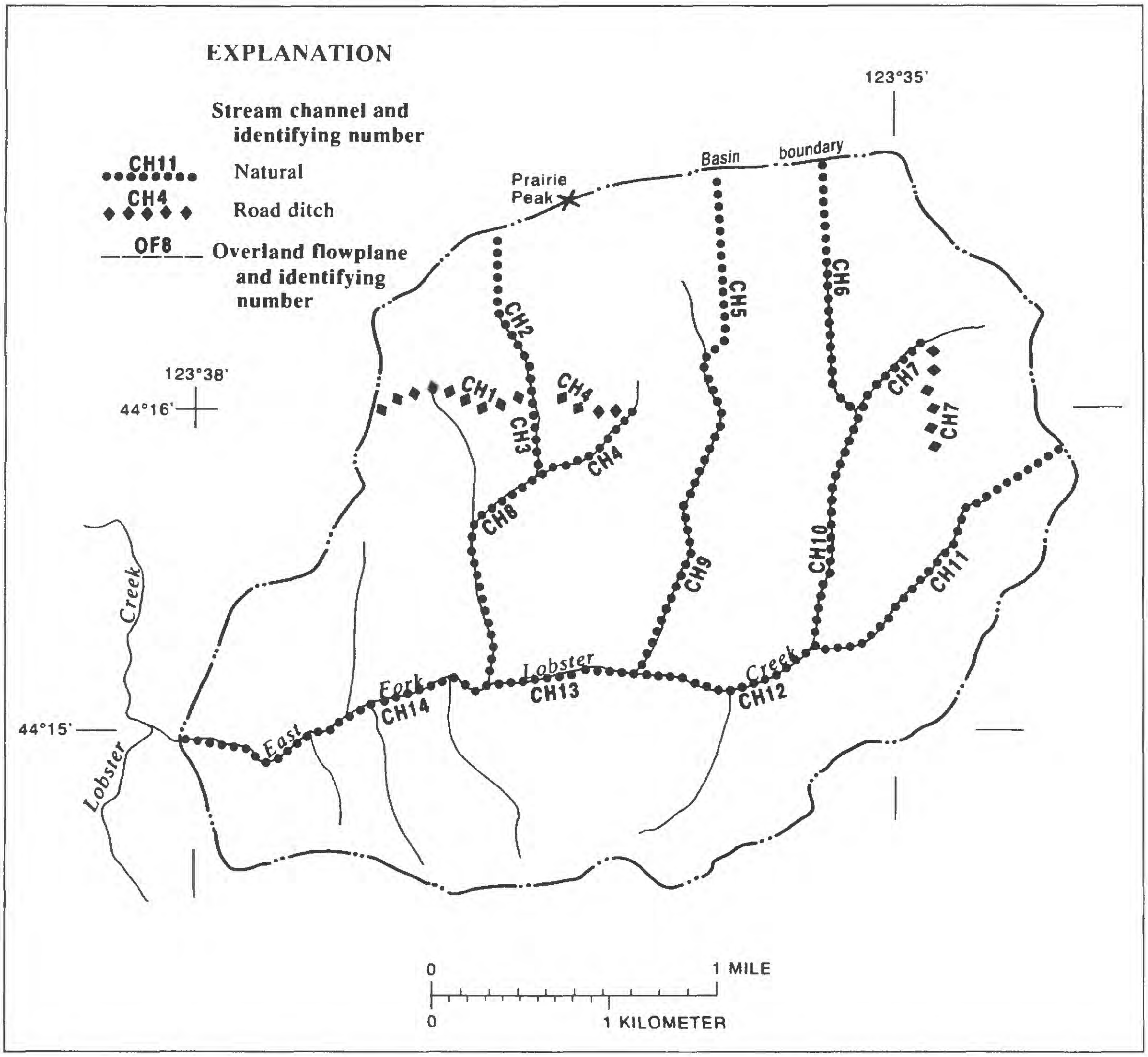

Figure 11. Overland-flow planes and channel segmentation of the East Fork Lobster Creek Basin.

Overland flow on basin slopes was assumed to be negligible, because of naturally high infiltration rates and generally slow rainfall intensities. Parameters for the Green and Ampt infiltration algorithms (Green and Ampt, 1911) were set to allow nearly all precipitation to enter the soil zone. The hydraulic conductivity of the transmission zone was set to 20 inches per hour. This water was routed to the channel segment as either subsurface or ground-water flow. The minor quantity of existing surface runoff flowed directly to the channel segment without kinematic routing.

The configuration of channel segments in the basins was based on the natural stream-drainage network, some of the forest access roads, and the prominent stream channels. Subsurface flow from hills that are intercepted by roads can be transformed to overland flow and transported more quickly through road culverts to stream channels.

Calibration and Validation of the Simulation Model

In phase three of this study, the approach used to regionalize PRMS model parameters was similar to a USGS study in which the Hydrologic Simulation Program-FORTRAN simulation model was used to characterize precipitation-runoff relations for 21 headwater basins in western King and Snohomish Counties, Washington (Dinicola, 1990). In the Hydrologic Simulation Program FORTRAN study, parameter values were kept constant for similar land-segment types that existed throughout those 21 basins; the objective was to determine the optimal parameter values for specific land-segment types rather than for individual basins. Similarly, during the third phase of the PRMS study for this report, trial and error adjustments of parameter values for similar HRU categories were made simultaneously at all of the 11 basins during the calibration process. Confidence in using this approach was strengthened by the knowledge that the soils and surficial geology of the 11 basins in the PRMS study were more homogeneous than the 21 basins in the Washington study. The optimization of parameter values, accomplished by minimizing the errors between simulated- and observed-streamflow data, is discussed in the proceeding section. An example of output from the PRMS calibration simulation of the Tucca Creek Basin is provided in Appendix A.

Daily Mode

Observed- and simulated-annual data for the daily mode calibration and validation periods for each basin are shown in table 6. PRMS statistical output was used to measure the strength of the daily mode calibration of the 11 basins. The calibration process maximized the coefficient-of-determination statistic, which is comparable to R^2 for a regression, and minimized the volume bias. The statistical results for the calibration and validation periods for the basins are shown in table 7.

Final parameter values, estimated from the Alsea basins (Allen and Laenen, 1993), were used as the initial parameter estimates for all 11 basins. Results from the two earlier phases of this study provided estimates for distributed parameters for clearcut and forested HRUs, as well as nondistributed parameters that could be applied to an entire basin.

In all of the 11 basins, surface runoff from pervious areas was assumed to be negligible, because of dense vegetation and well-drained, loamy soils. The parameter SCX is the maximum possible contributing area for surface runoff as a proportion of each HRU; parameter SCX was set to 1 percent for the forested HRUs.

The first part of the calibration procedure required a trial and error adjustment of those parameters related to the water balance of the basins. Monthly CTS parameters, which are coefficients of the Hamon evapotranspiration formula (Hamon, 1961), were manually adjusted for each of the basins to make simulated, monthly evapotranspiration losses consistent with published, monthly pan-evaporation losses for the region (Farnsworth and Thompson, 1982). A single, regionalized set of monthly CTS parameter values eventually was selected for all of the basins. In addition to adjusting evapotranspiration losses, using the DRCOR parameter for adjusting the volume of rain that falls on the basins also was necessary. Typically, in precipitation-runoff modeling studies, errors are introduced to the simulation because of errors in the rainfall data. Rainfall volume is a point measurement that must be extrapolated as an estimate of basin-wide precipitation. Because the average basin elevation usually is higher than the gage elevation at which rainfall is measured, average basin rainfall is often underestimated.

Table 6. Observed and simulated annual runoff data

[Sim. = simulated value, in inches; Obs. = observed value, in inches; difference in inches = Sim - Obs.; difference in percent = 100 x ([Sim. - Obs.]/Obs.)]

	Annual runoff				
	Water			Difference	
Basin name	year	Obs.	Sim.	Inches	Percent
Wind River	1985	46.81	43.99	-2.82	-6.02
	1986	40.30	41.08	0.78	1.94
	1987	32.67	40.02	7.35	22.5
	1988	36.96	45.06	8.10	21.9
North Yamhill River	1983	83.36	91.65	8.29	9.94
	1984	71.34	66.39	-4.95	-6.94
	1985	56.73	61.73	5.00	8.81
	1986	49.48	49.10	-0.38	-0.77
	1987	55.13	60.40	5.27	9.56
	1988	48.05	43.80	-4.26	-8.86
Nestucca River	1961	92.38	99.32	6.94	7.51
	1962	66.30	53.04	-13.26	-20.0
	1963	70.33	66.37	-3.96	-5.63
	1967	72.14	77.35	5.21	7.22
	1968	70.08	74.15	4.07	5.81
Tucca Creek	1984	78.49	86.53	8.04	10.24
	1985	65.06	66.65	1.59	2.44
	1986	61.54	60.26	-1.28	-2.08
	1987	63.11	56.44	-6.67	-10.57
	1988	58.76	57.23	-1.53	-2.60
	1989	66.16	67.36	1.20	1.81
East Fork Lobster Creek	1984	70.06	72.05	1.99	2.84
	1985	59.12	61.65	2.53	4.28
	1986	51.79	58.74	6.95	13.42
	1987	51.47	60.87	9.40	18.26
	1988	47.43	48.08	0.65	1.37
Needle Branch	1960	64.79	69.29	4.50	6.95
	1961	79.84	81.62	1.78	2.23
	1962	57.53	66.29	8.76	15.23
	1963	58.50	60.56	2.06	3.52
	1967	81.27	87.68	6.41	7.89
	1968	79.94	78.89	-1.05	-1.31
Flynn Creek	1960	67.92	68.69	0.77	1.13
	1961	87.79	83.10	-4.69	-5.34
	1962	62.52	65.44	2.92	4.67
	1963	65.07	60.99	-4.08	-6.27
Deer Creek	1960	68.44	73.42	4.98	7.28
	1961	90.48	85.11	-5.37	-5.94
	1962	64.88	69.90	5.02	7.74
	1963	65.30	63.57	-1.73	-2.65
Vincent Creek	1984	59.45	49.41	-10.04	-16.89
	1985	48.13	52.91	4.78	9.93
	1986	46.90	50.96	4.06	8.66
	1987	40.91	45.81	4.90	11.98
	1988	40.07	47.00	6.93	17.29
	1989	44.80	47.03	2.23	4.98
Priorli Creek	1989	43.81	42.54	-1.27	-2.9
	1990	29.07	34.97	5.90	20.3
Middle Creek	1986	61.47	58.66	-2.81	-4.57
	1987	46.78	51.87	5.09	10.88
	1988	49.58	54.55	4.97	10.02
	1990	40.50	45.52	5.02	12.4

Table 7. Statistical results for daily mean discharge simulations
[- - = Period not simulated]

Basin name	Coefficient of determination[1]		Error (in percent)[2]	
	Calibration	Validation	Calibration	Validation
Wind River	0.89	0.66	- 2.44	20.8
North Yamhill River	.76	.85	3.94	2.05
Nestucca River	.82	.75	- 4.49	6.52
Tucca Creek	.86	.88	3.86	- 3.72
East Fork Lobster Creek	.86	.87	3.49	11.5
Needle Branch[3]	.90	.87	4.35	9.33
Needle Branch[4]	.90	- -	.03	- -
Flynn Creek	.92	.90	- 2.52	- .91
Deer Creek	.91	.88	- .25	2.53
Vincent Creek	.73	.71	- .78	11.2
Priorli Creek	.68	.78	- 2.91	22.3
Middle Creek	.75	.81	2.57	12.4

[1] $e = S - O$,
where S is simulated runoff; and
O is observed runoff.
$e_M = O - \overline{O}$,
where $\overline{O}$ is mean observed runoff for full period of simulation.
coefficient of determination $= 1 - \Sigma e^2 / \Sigma e_M^2$.

[2] Bias, as a percent of mean observed runoff, $= 100 \times \Sigma (S - O) / \Sigma O$.

[3] Prelogging calibration and validation periods.

[4] Postlogging simulation period.

Actual rainfall also may be underestimated if the gage used to measure rainfall is unprotected from the wind. With the exception of the Tucca Creek and Wind River Basins, rain gages used in this study were not protected by wind shields. Residual error, which is the difference between observed and simulated discharges, was used as a guide to adjust the rainfall volume. Assuming simulated evapotranspiration losses are realistic and there is no significant ground-water loss to a basin, the most appropriate DRCOR estimate is the value that results in simulation of a mean-residual error closest to zero. The final DRCOR values for all 11 basins in this study were greater than 1 for 5 of the of the basins, and were kept equal to 1 for the other 6 basins.

After the water balances of all the basins had been adjusted within 5 percent, the ground-water parameters SEP, RSEP, and RCB (defined in table 16, at back of report) were adjusted to graphically fit the base-flow recessions of the hydrographs. Adjusting those same ground-water parameters (SEP, RSEP, and RCB) changes the base-flow slope and the low-flow portion of the hydrograph.

The RCF and RCP parameters determine the rate of subsurface flow as a function of subsurface-reservoir storage. Because defining those parameters (RCF and RCP) from any measured, physical, basin data is difficult, an automatic-optimization procedure using the Rosenbrock search algorithm (Rosenbrock, 1960) was used in each basin calibration. All other parameters were held constant, while incremental adjustments were made to RCF and RCP parameters until the residual error was minimized. A linear-objective function (sum of absolute values of the differences between predicted and observed flows) was used to compute the residual errors. Because of the geologic similarities, the variations in RCF and RCP values between the basins were not significant. Allen and Laenen (1993) found that these two parameters (RCF and RCP) and the ground-water-flow parameter (RCB) showed the most sensitivity in the Alsea basins; optimized all three parameters for both separate general- and peak-fit calibrations; and found peak flows could be improved by decreasing the RCF parameter and increasing the RCP and RCB parameters. This sensitivity, however, was at the expense of increased error during periods of low flow. Optimization of these parameters for separate general- and peak-fit calibrations, using data from the seven additional basins, did not show improvement or a consistent pattern.

Validation of the models was accomplished through PRMS simulations of the validation periods (dates of these periods are shown in table 2), using the final parameter values determined from the calibration-period simulations. The statistical results of the validation-period simulations also are shown in tables 6 and 7. With the exception of the Nestucca River and Middle Creek Basins, the validation period began immediately after the end of the calibration period. For all the basins, the change in vegetation characteristics that occurred during the two periods was taken into account in the simulation. Some mature, forested areas were reclassified for the validation-period simulation as "clearcut;" and some areas that were classified as "clearcut" became "partial-growth young forest." However, with the exception of the Needle Branch Basin, changes in vegetation characteristics were not hydrologically significant. As shown in table 1, the total area of clearcut land was less than 21 percent for all the basins during the period of calibration. During the period of validation for each basin, the total area of clearcut lands was less than 10 percent.

Final PRMS model-parameter values, determined through calibration of each basin, are shown in tables 8-12. The rain-gage adjustment (DRCOR) and the ground-water-sink coefficients (GSNK) were used to set the initial water balance in each basin (see table 8). The remaining parameters in table 8 determined subsurface and ground-water-flow rates. Future PRMS simulations for ungaged basins in upland drainage basins of the Coast Range could use averages of these subsurface- and ground-water-parameter values or use parameter values from a basin that is the most physically similar to the ungaged basin. Parameter values for the dominant vegetation classes in the Coast Range are shown in table 9. The classes were determined from aerial photography of the 11 basins. Some adjustments to selected parameter values, such as IMPERV, were made to more accurately reflect the land-surface and vegetation conditions of the basin being simulated. Parameter values for various soil classes are based on the available water capacity of the soils (table 10). Those parameter values, obtained from county soil surveys, were not adjusted during the calibration. Additional parameter values (many of which are default) used in the calibration of the basins are shown in tables 11-12.

Table 8. Calibration parameter values specific to the 11 basins
[in./day = inches per day; parameters defined in table 16, at back of report]

Basin name	DRCOR	GSNK	SEP(in./day)	RSEP(in./day)	RCF	RCP	RCB
Wind River	1.0	0.005	0.15	0.01	0.0001	0.05	0.02
North Yamhill River	1.11	0	.15	.03	.0001	.027	.017
Nestucca River	1.30	0	.2	.04	.0001	.087	.02
Tucca Creek	1.0	.002	.2	.02	.0001	.05	.02
East Fork Lobster Creek	1.0	.001	.2	.04	.0001	.13	.02
Needle Branch [1]	1.0	.003	.15	.02	.0001	.12	.02
Flynn Creek	1.01	0	.15	.02	.0001	.044	.02
Deer Creek	1.0	0	.15	.02	.0001	.084	.02
Vincent Creek	1.3	0	.15	.02	.0001	.187	.02
Priorli Creek	1.45	0	.2	.02	.0001	.06	.02
Middle Creek	1.25	0	.15	.02	.0001	.174	.02

[1] The same parameter values were used in the prelogging and postlogging periods.

Hydrographs of daily mean-simulated and observed streamflow, and of daily precipitation for the Tucca Creek Basin calibration period, are shown in figure 12. The simulated streamflow for this calibration period had a coefficient of determination of 0.86 and an error of 3.86 percent. Discerning the relation of streamflow response to varying magnitudes of precipitation events becomes possible when streamflow and precipitation are displayed simultaneously. Similar to the calibration hydrographs of the other 10 basins, the simulated hydrograph of the Tucca Creek Basin showed a fit for medium and low streamflows that generally is reliable. When predicted by the PRMS model, peak streamflow tended to be underestimated.

Table 9. Calibration parameter values for vegetation classes

[CC = clearcut; PGY = partial-growth young forest; PGO = partial-growth old forest; C = mature conifer forest; HC = mature hardwood-conifer forest; CH = mature conifer-hardwood forest; G = grasslands; df = decimal form; in. = inches; -- = values shown on table 10; parameters defined in table 16, at back of report]

Parameter	CC	PGY	PGO	C	HC	CH	G
IMPERV (df)	0.05	0	0	0	0	0	0
RETIP (in.)	.1	0	0	0	0	0	0
ICOV	0	2	2	3	3	3	0
COVDNS (df)	0	.5	.5	.9	.9	.9	0
COVDNW (df)	0	.5	.5	.7	.4	.6	0
SNST (in.)	0	.1	.1	.1	.1	.1	.1
RNSTS (in.)	0	.03	.05	.1	.1	.1	0
RNSTW (in.)	0	.03	.05	.1	.04	.1	0
ITST	0	1	1	1	3	1	0
ITND	0	12	12	12	11	12	0
SMAX[1] (in.)	1	--	--	--	--	--	1
SMAV[1] (in.)	1	--	--	--	--	--	1
REMX[1] (in.)	1	--	--	--	--	--	1
RECHR[1] (in.)	1	--	--	--	--	--	1

[1] Soil-zone parameter values for forested vegetation classes listed in table 10.

Table 10. Calibration parameter values for soil classes

[SC = shallow clay; MC = moderately deep clay; DC = deep clay; SS = shallow sand; MS = moderately deep sand; DS = deep sand; SL = shallow loam; ML = moderately deep loam; DL = deep loam; in. = inches; approximate profile depth: shallow soils = 1 to 20 inches; moderately deep soils = 21 to 40 inches, and deep soils = 41 inches or greater; parameters defined in table 16, at back of report]

Parameter[1]	SC	MC	DC	SS	MS	DS	SL	ML	DL
ISOIL	3	3	3	1	1	1	2	2	2
SMAX (in.)	1.6	6.4	10.0	1	4	7	2	8	12
SMAV (in.)	1.3	3.2	5	0.8	2	3.5	1.6	4	6
REMX (in.)	1.3	1.3	1.3	.8	.8	.8	1.6	1.6	1.6
RECHR (in.)	1.3	1.3	1.3	.8	.8	.8	1.6	1.6	1.6

[1] Listed parameter values apply only to forested, hydrologic-response units that have an ICOV equal to 2 or 3. ICOV refers to the Precipitation-Runoff Modeling System parameter, as defined in table 16, of the vegetation cover type for each hydrologic-response unit (0 = bare, 1 = grasses, 2 = shrubs, 3 = trees).

Table 11. Monthly calibration parameter values

[f = degrees Fahrenheit; cal./deg. = calories per degree Celsius; parameters defined in table 16, at back of report]

	Parameters								
Months	RDM	RDC	TSOLX (f)	CTS	PAT (f)	AJMX	TLX (f)	TLN (f)	CECN (cal./deg.)
January	-0.13	1.83	50	0.007	32.0	1.0	3.0	3.0	5.0
February	- .13	1.83	50	.008	32.0	1.0	3.0	3.0	5.0
March	- .10	1.60	50	.008	32.0	1.0	3.0	3.0	5.0
April	- .08	1.46	50	.009	32.0	1.0	3.0	3.0	5.0
May	- .08	1.46	50	.009	32.0	1.0	3.0	3.0	5.0
June	- .07	1.42	50	.012	32.0	1.0	3.0	3.0	5.0
July	- .07	1.42	50	.013	32.0	1.0	3.0	3.0	5.0
August	- .07	1.42	50	.013	32.0	1.0	3.0	3.0	5.0
September	- .08	1.46	50	.012	32.0	1.0	3.0	3.0	5.0
October	- .08	1.46	50	.011	32.0	1.0	3.0	3.0	5.0
November	- .13	1.83	50	.01	32.0	1.0	3.0	3.0	5.0
December	- .13	1.83	50	.006	32.0	1.0	3.0	3.0	5.0

Table 12. Additional calibration parameter values

[f = degrees Fahrenheit; df = decimal form; in. = inches; hr. = hour; in./hr = inches per hour; parameters defined in table 16, at back of report]

Parameter	Value	Parameter	Value
ARSA	0.05	RDP	.61
ARSM	.2	RES (in.)	.5
BST (f)	32	RESMX	1.0
CTW	.5	REXP	1.0
DENI (df)	.1	RGF[1]	50.0
DENMX	.6	RMXA	.8
DRN[1]	2.0	RMXM	.6
EAIR	.85	RTB	1.0
FWCAP (df)	.05	RTC	1.0
GW (in.)	1.13	SCN	.001
KSAT (in./hr.)[1]	20	SCX	.01
PARS (df)	.44	SC1	.2
PARW df)	.50	SETCON	.1
PSP (in.)[1]	.01	SRX (in.)	2.0
RDB	.40	TRNCF (df)	.5
RDMX (df)	.80		

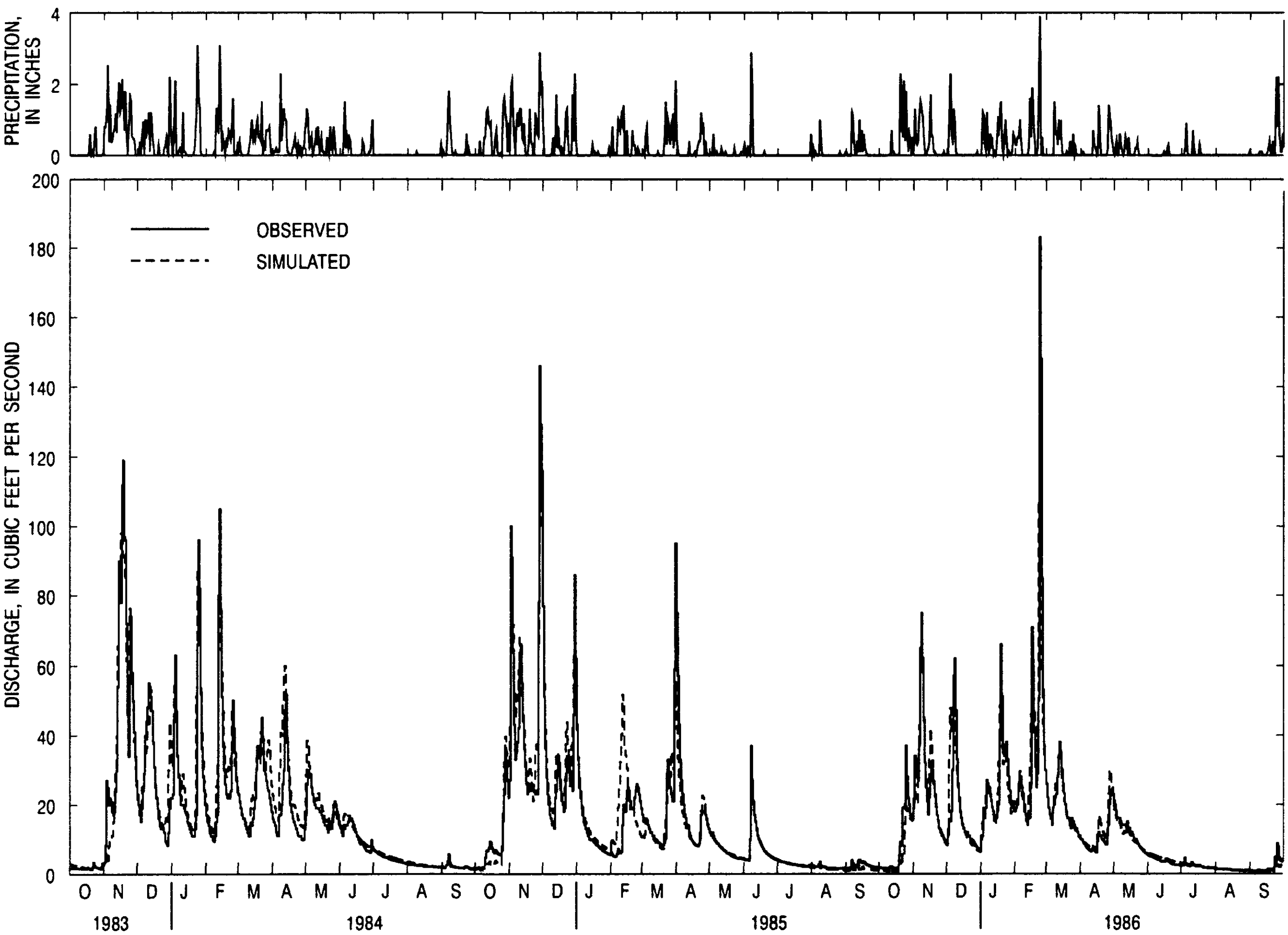

Figure 12. Observed precipitation and observed and simulated daily mean discharge for station 14303200 in Tucca Creek Basin, October 1983–September 1986.

Simulated and observed daily streamflow hydrographs from the postlogging simulation period at the Needle Branch Basin are shown in figure 13. The Needle Branch Basin had been clearcut 82 percent at the midpoint of the data-collection period. The prelogging phase for the Needle Branch Basin contained a calibration and a validation period. Streamflow at the Needle Branch Basin was simulated during the postlogging period, using prelogging parameter values. The simulated flow represents an approximation of flow from a basin that would have occurred during the period of postlogging, if that basin had not been disturbed by logging. Comparing that simulated flow with the observed flow made assessment of some of the hydrologic effects of timber harvesting possible. The annual-discharge volume increased by approximately 8 percent for the water years 1967 and 1968. Discussion about preliminary simulations – made using data from the Needle Branch, Deer Creek, and Flynn Creek Basins – is provided by Allen and Laenen (1993).

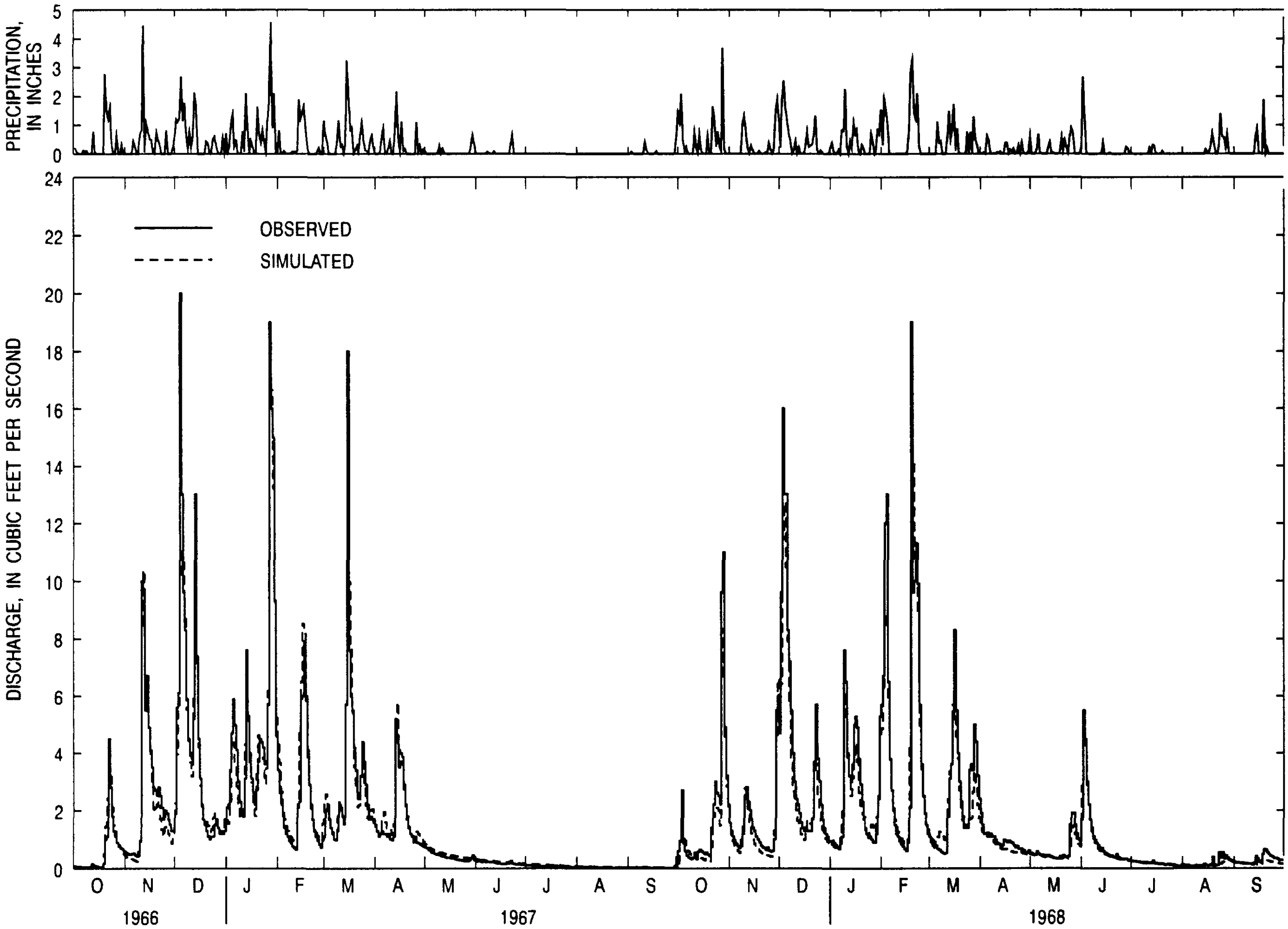

Figure 13. Observed and simulated daily mean discharge using prelogging parameters and daily precipitation for the Needle Branch Basin, October 1966–September 1968

Storm Mode

Forty-two storms, selected from the time periods during which the 11 basins were simulated, were used in the storm-mode calibration. Observed storm-runoff volume, simulated storm-runoff volume, and peak-streamflow data for those storms are listed in table 13. Statistical errors for storm peaks and storm volumes for each basin are shown in table 14. As an example, a graph of observed and simulated hourly streamflow for the Tucca Creek Basin during the storm period of February 8–16, 1984, is shown in figure 14.

Table 13. Observed and simulated storm-runoff and peak-discharge data

[Obs. = observed value, in inches for storm runoff and in cubic feet per second for peak discharge; Sim. = simulated value, in inches for storm runoff and in cubic feet per second for peak discharge]

Basin name	Date of storm	Date of peak	Storm runoff Obs.	Storm runoff Sim.	Peak discharge Obs.	Peak discharge Sim.
Wind River	12/7-12/87	12/9/87	3.91	6.38	136	132.4
	1/13-19/88	1/14/88	5.42	3.47	103	37.93
	3/23-29/88	3/24/88	1.86	2.86	39	35.52
North Yamhill River	11/20-25/61	11/22/61	2.78	2.19	473	181.74
	11/30-12/3/61	12/1/61	1.37	1.81	98.8	134.34
	12/15-25/61	12/20/61	8.42	6.56	468	240.03
	1/2-6/62	1/3/62	2.13	1.39	147.6	77.54
Nestucca River	2/16-23/68	2/19/68	6.7	8.44	273	338.6
	3/10-20/68	3/16/68	4.6	5.82	182	256.83
Tucca Creek	12/8-15/83	12/12/83	4.54	4.61	59.74	59.7
	1/22-28/84	1/25/84	4.16	5.35	104.45	109.39
	2/8-16/84	2/13/84	4.75	5.67	120.53	110.1
East Fork Lobster Creek	11/12-16/83	11/13/83	2.77	2.99	185	196.99
	12/14-18/83	12/14/83	2.82	2.06	164	115.67
	12/29/83-1/2/84	12/29/83	3.22	2.64	348	144.49
	1/23-27/84	1/24/84	2.18	1.94	120	88.46
	2/12-16/84	2/13/84	5.28	5.73	435	384.60
	2/24-28/84	2/24/84	2.69	2.24	174	131.29
	11/1-5/84	11/2/84	6.37	7.52	652	503.88
	11/9-13/84	11/10/84	5.4	5.35	318	246.25
	11/27-12/1/84	11/28/84	5.27	4.60	264	207.37
	12/29/84-1/2/85	12/30/84	2.7	2.83	232	174.86
	6/6-10/85	6/7/85	2.8	2.26	149.9	163.31
Needle Branch	11/23-26/60	11/24/60	6.83	5.25	32.4	22.19
	2/9-16/61	2/10/61	12.98	11.85	28.1	23.78
	3/5-7/61	3/5/61	2.78	2.68	9.12	9.99
	3/12-15/61	3/13/61	4.05	3.40	12.5	8.7
Flynn Creek	11/23-26/60	11/24/60	6.78	5.04	74.8	49.76
	2/9-16/61	2/10/61	13.05	11.24	62.6	48.94
	3/5-7/61	3/5/61	2.96	2.64	25.8	25.23
	3/12-15/61	3/13/61	4.44	3.56	33	24.15
Deer Creek	11/23-26/60	11/24/60	6.56	5.10	114	78.74
	2/9-16/61	2/10/61	13.04	11.50	106	80.27
	3/5-7/61	3/5/61	2.97	2.63	43.9	36.73
	3/12-15/61	3/13/61	4.78	3.42	62.6	33.28
Vincent Creek	1/7-14/88	1/10/88	5.54	5.74	967.0	936.51
Priorli Creek	1/5-15/89	1/10/89	5.4	5.10	26	14.63
	3/8-20/89	3/13/89	5.43	5.76	8.8	9.04
	2/5-15/90	2/8/90	6.23	6.11	19.37	15.73
Middle Creek	10/19-23/85	10/23/85	1.99	4.27	411.46	628.74
	5/1-9/86	5/6/86	2.23	2.73	441	567.71
	1/7-13/88	1/10/88	8.09	6.94	3,366	2,231.57

Table 14. Measures of error in simulated storm volume and peak discharge

Basin name	Mean absolute storm volume error (in percent)[1]	Mean absolute peak discharge error (in percent)[2]
Wind River	48.4	25.97
North Yamhill River	24.70	52.62
Nestucca River	26.14	30.87
Tucca Creek	16.21	5.41
East Fork Lobster Creek	12.64	26.65
Needle Branch	13.02	23.39
Flynn Creek	17.43	24.53
Deer Creek	17.14	29.86
Vincent Creek	3.64	3.15
Priorli Creek	4.41	28.15
Middle Creek	31.98	35.04

[1] Mean absolute error, percent = $100 \times \Sigma |S - O| / \Sigma O$,
where S = Simulated runoff volume of the storm, in inches; and
O = Observed runoff volume of the storm, in inches.

[2] Mean absolute error, percent = $100 \times \Sigma |S - O| / \Sigma O$,
where S = Simulated peak discharge of the storm, in cubic feet per second; and
O = Observed peak discharge of the storm, in cubic feet per second.

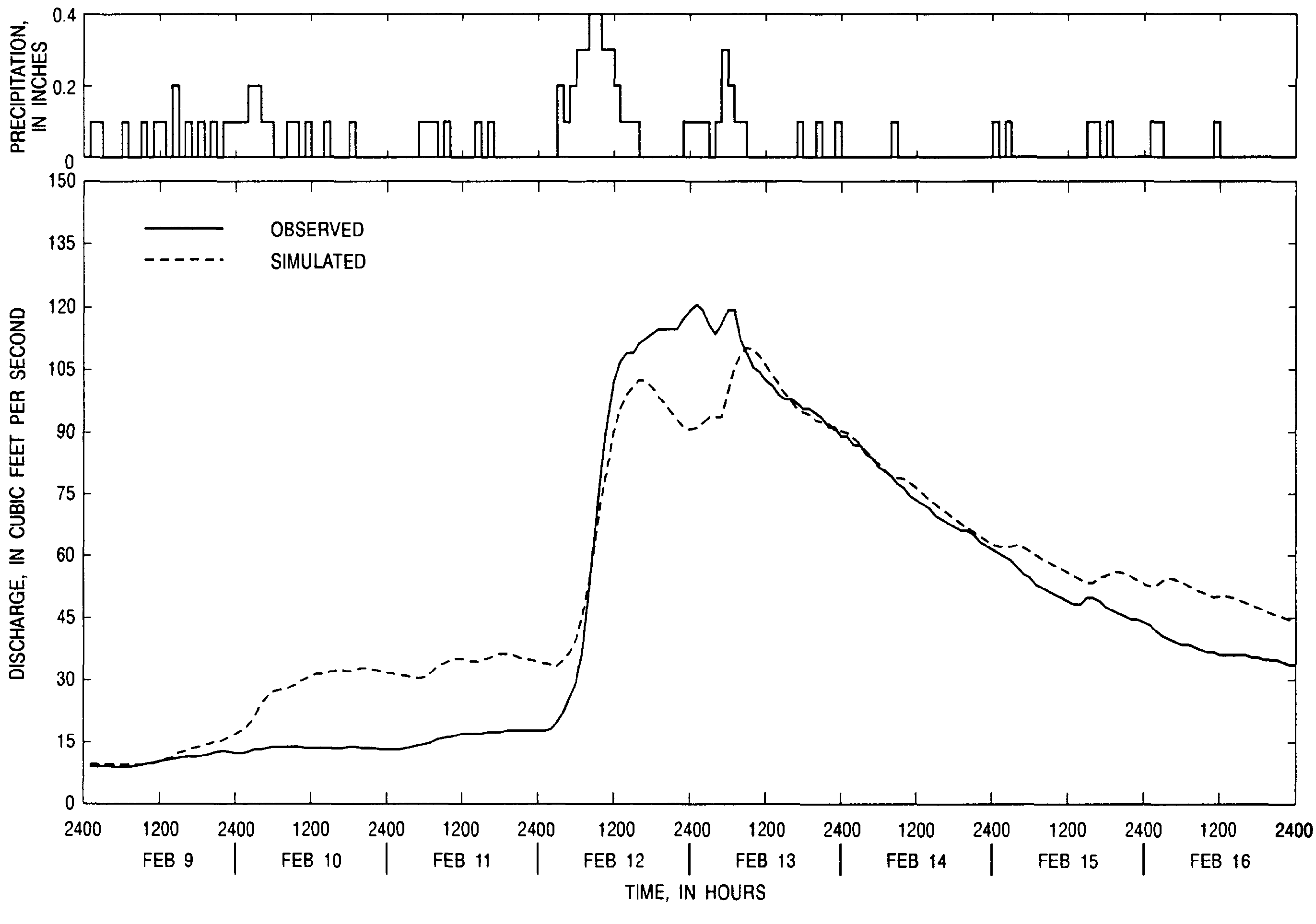

Figure 14. Observed and simulated hourly mean discharge and hourly precipitation for the Tucca Creek Basin, storm period February 8–16, 1984.

Infiltration for the storm mode is computed by PRMS, using a variation of the Green and Ampt (1911) equation. Soil parameters required in the storm mode include KSAT (which is the parameter for hydraulic conductivity of the transmission zone) and RGF and PSP (which represent the product of capillary drive and moisture deficit). Because of negligible overland flow in the Coast Range forests, the KSAT parameter was given a high value so that nearly all rainfall infiltrated. Most of the other storm-mode parameters used to define the overland flow plane and the channel segments were estimated from measured data.

The subsurface parameters RCF and RCP, which had been optimized using the daily data, were reoptimized using the storm data. The optimization routine for the storm mode used a linear-objective function and the data from each hourly time step of the storms. Results of the second optimization did not show a significant improvement in calibration of the model when compared with the earlier optimization made for the daily calibration periods. Final parameter estimates for RCF and RCP are shown in table 8.

ANALYSIS OF ERRORS IN THE SIMULATION

All precipitation-runoff modeling studies contain errors. Precipitation-runoff modeling errors typically are caused by a combination of inadequate input data, inadequate representation of the physical processes by the algorithms of a model, and inadequate parameter estimation during the calibration procedure (Troutman, 1985). Inadequate input data often account for most of the errors. Those errors and the consequent effects on the intended use of the PRMS model need to be acknowledged and addressed by the user. This report has described how the PRMS operates, and what procedures were used to calibrate and validate the PRMS model when simulating 11 small, upland drainage basins in the Coast Range of Oregon. How the PRMS model is used to simulate the relative effects of timber harvesting on the hydrologic regime is discussed in this report and the two prior reports (Allen and Laenen, 1993; Nakama and Risley, 1993) for this study. The procedure presented, which simulates timber-harvesting effects by adjusting the parameters of the PRMS model, is not statistically valid. Parameter adjustments were based on what appeared to be physically appropriate. Those parameter adjustments produced the expected simulation output; that output was similar to the findings in the literature used for this report. However, in all the basin simulations, measured rainfall and streamflow errors were in the same range or greater than the change in runoff caused by timber harvesting. Nonetheless, the modeling procedure can be used to estimate relative changes in runoff when simulating various timber-harvesting scenarios.

Data Error

Using the PRMS model to simulate each of the basins studied required the following input: observed rainfall data, streamflow data, temperature time-series data, and data on physical characteristics of the basin. An adequate representation of basin rainfall coverage is often the most difficult input data to acquire. The rainfall volume is a point measurement that must be extrapolated as an estimate of basin-wide precipitation. Most of the rainfall in the Coast Range of Oregon comes from large, frontal-system storms and is assumed to have a relatively homogeneous spatial distribution. However, the rainfall data often indicated variations in rainfall volumes between relatively short distances. As previously mentioned, when the average elevation of a basin is greater than the elevation of the rain gage, measured rainfall can be an underestimate of average basin rainfall. If the rain gage is unprotected from wind, measured rainfall also can be an underestimate of actual rainfall. Most of the rainfall collectors used in this study were located near the basin outlets and were not protected with wind shields. Rainfall measurement errors at an unprotected rain gage can range from several percent to 20 percent, depending on gage exposure to rainfall and wind (Larson and Peck, 1974). Missing time periods from five of the precipitation records were estimated using regression relations of nearby gaging stations. Estimating rainfall from regression equations undoubtedly introduced additional error to the records. Future PRMS simulations of ungaged (having no streamflow records) basins in the Coast Range will not have an accurate water balance, unless measured rainfall data are collected in the confines of a basin and one or more properly protected rain collectors are used.

From 7 of the 11 basins, streamflow data were collected and published by the USGS. Standard practices and techniques of the USGS were used in the data collection to ensure quality control. Streamflow data from those 7 basins were ranked as being from good to fair, meaning that the accuracy of the streamflow data was from 8 to 10 percent. Streamflow data from the four other basins were collected by the BLM and the Oregon Department of Water Resources.

Temperature records used by the PRMS model for the simulations also were a source of potential error. None of the temperature stations were located in or near the basins. All temperature stations were located at elevations lower than the basins and in towns either on the Oregon coast or in the Willamette Valley. Temperature records are nearly nonexistent for stations at higher elevations on the ridge of the Coast Range. In recent years, the U.S. Forest Service began collecting temperature data at some ridge locations in the Coast Range; however, most of that data collection has been restricted to the summer period.

Some error also is introduced into the simulation by the criteria used to delineate the HRUs. For most of the 11 basins, the storm-mode simulations used fewer HRUs than the daily mode simulations. The storm-mode set of HRUs were spatially contiguous, whereas the daily mode set of HRUs were spatially noncontiguous. Although the storm-mode set of HRUs did not use any parameter values that were not already included in the daily mode HRU set, the resolution of basin surface detail in the storm-mode set was not as fine as the resolution in the daily mode HRU set. With the exception of the Vincent Creek Basin, the change in the HRU configuration did not cause a significant increase in error. The coefficient of determination and the percentage of volume errors for daily simulations, using both sets of HRUs for both the calibration and the validation periods, are shown in table 15.

Table 15. Error statistics for simulations using separate hydrologic-response-unit (HRU) configurations

Basin name	Daily-mode HRU configuration			Storm-mode HRU configuration		
	Number of HRUs	Coefficient of Determination[1]	Bias (in percent)[2]	Number of HRUs	Coefficient of Determination[1]	Bias (in percent)[2]
Wind River	10	0.66	22.2	3	0.63	-0.97
North Yamhill River[3]	---	---	---	---	---	---
Nestucca River	12	.75	6.52	5	.76	- .46
Tucca Creek	16	.86	3.86	5	.85	4.90
East Fork Lobster Creek	19	.86	3.49	5	.89	-4.20
Needle Branch[4]	8	.90	4.35	7	.92	4.36
Flynn Creek	8	.92	-2.52	11	.94	.38
Deer Creek	13	.91	- .25	13	.93	1.41
Vincent Creek	19	.71	11.2	4	.50	37.0
Priorli Creek[5]	7	.76	-4.11	2	.78	-5.07
Middle Creek	19	.75	2.57	5	.76	8.63

[1] $e = S - O$,
where S is simulated runoff; and
O is observed runoff.
$e_M = O - \bar{O}$,
where $\bar{O}$ is mean observed runoff for full period of simulation.
coefficient of determination $= 1 - \Sigma e^2 / \Sigma e_M^2$.

[2] Bias, as a percent of mean observed runoff, $= 100 \times \Sigma (S - O) / \Sigma O$.

[3] Storm period did not overlap with the daily calibration and validation periods.

[4] Prelogging calibration period.

[5] Simulation period of water years 1989 and 1990.

Model Error

PRMS model error can occur when the model does not adequately represent the physical processes of a basin. Although some precipitation-runoff models perform better than others, all hydrologic models contain structural weaknesses in replicating the physical processes of any given basin. Accurately ascertaining what part of simulation error can be attributed to model weakness rather than to input data or parameter estimation is difficult, if not impossible. Although a variety of elaborate techniques for error analysis exist (Troutman, 1985; Aitken, 1973), the use of those techniques was not within the scope of this study. There are reasons to suggest that some PRMS algorithms, such as subsurface flow and evapotranspiration, might require improvement in future applications for forests of the Pacific Northwest.

Subsurface flow is a more dominant component of the storm hydrograph for the Coast Range of Oregon than in most other forests of the United States (Dunne and Leopold, 1978). The gravelly, loam soils drain well and contain numerous macropores that permit pipe flow. In some storm simulations done for this study, although not most, the timing of the simulated storms were earlier than the timing of the observed storms. The simulations could not show, conclusively, that the subsurface-algorithm performance was weak. However, a better mathematical representation of the subsurface-flow processes could benefit the overall simulation. The current subsurface-flow equation, which routes flow through a reservoir, contains only two parameters that are used to compute the rate of flow based on the volume of reservoir storage. A more appropriate algorithm might contain a roughness coefficient or a kinematic-wave approximation, similar to the overland-flow algorithm. Adequately defining subsurface processes would require field-measurement experiments that were not within the scope of this study.

To estimate evapotranspiration, the PRMS provides the user with the choice of using either observed pan-evaporation data, or one of the procedures developed by Jensen and Haise (1963) or Hamon (1961) that use observed temperature data. In this PRMS study, the Hamon method (Hamon, 1961) was used because temperature data were available at more locations than were observed pan-evaporation data and because the Hamon method is more applicable to humid regions. By contrast, the Jensen and Haise method (Jensen and Haise, 1963) is more commonly applied and used to estimate evapotranspiration of arid regions. The Hamon method (Hamon, 1961) was empirically developed using data of the eastern United States, where summer is the most humid period of the year. Evapotranspiration for the Pacific Northwest, where summer is the driest season, tends to be underestimated when the Hamon method (Hamon, 1961) is used. Increasing the monthly Hamon coefficients to values that were outside the usual range recommended was necessary to increase the volume of evapotranspiration.

Parameter Error

Parameter error arises when improper parameter values are selected during the calibration process. Often, the various combinations of parameter values that have been selected seem to be appropriate, because the residual error in the calibration-period data has been reduced. Some of these parameter values, however, could be unrealistic representations of a process. The error introduced by one parameter could cancel out the error introduced by another parameter. In this study, parameter estimation was based on manual- and automatic-calibration procedures. Most optimization techniques must be used conservatively and usually are employed only after extensive manual calibration. The degree of error reduction from automatic optimization is not expected to be dramatic. Depending on the objectives of a study, parameters are usually optimized for annual volumes, peak streamflows, or low streamflows by using different types of objective functions. A linear-objective function typically is used in a general calibration of annual streamflow volumes and low streamflows, whereas a nonlinear- (sum of squares) objective function might be used for a peak-streamflow calibration. Linear-objective functions were used for parameter estimation in this study because timber-resource managers are interested in simulating the overall hydrologic regime (annual volumes, peak and low flows).

SUMMARY AND CONCLUSIONS

In recent decades, public concern has increased regarding the effects of timber harvesting in many upland, forested drainage basins of the Pacific Northwest. Assessing how management activities will affect federal lands and identifying the Best Management Practices are required, by law, under the Clean Water Act and the National Environmental Policy Act. Those legal requirements are based on the need to accurately quantify the effects of forest management on the hydrologic regimes of a basin. Precipitation-runoff computer models provide one method of estimating runoff response to land-use alterations. Precipitation-Runoff Modeling System model parameters emulate the flux and storage of water in the surface, subsurface, and ground-water components of the watershed and provide insight into the hydrologic processes governing the overall flow characteristic. By adjusting those parameters of the model that pertain to land-surface conditions, the user can test the effects of various timber-harvesting scenarios.

The Precipitation-Runoff Modeling System was used for this study to simulate the hydrologic effects of timber management in 11 small, upland drainage basins of the Coast Range in Oregon. Study objectives included the calibration and validation of a Precipitation-Runoff Modeling System model for each of those 11 basins; the evaluation of the Precipitation-Runoff Modeling System model as a tool for predicting the hydrologic effects of timber-management practices; and the determination of regionalized, Precipitation-Runoff Modeling System model-parameter values.

Situated between the Pacific Ocean and the Willamette River valley, the Coast Range of Oregon typically receives more than 80 inches of precipitation each year, primarily as rain. The basins studied only receive snow occasionally, and that snow does not result in the formation of significant snowpack. Summers are warm and dry, and contrast with cool and humid winters. The mean temperature is approximately 10°C. Headwater basins in the region are covered mostly with lush, dense, conifer forests. Some hardwoods are found in riparian zones. Soils in those headwater basins are almost exclusively well-drained, gravelly loams. Geologic formations underlying the Coast Range are composed of Tertiary-marine sediment and underlying volcanic rock. Elevations of the streamflow-monitoring stations for the basins studied range from 80 to 1,779 feet above sea level. Surface area of the basins studied ranged from 0.27 to 22.3 square miles. Runoff processes in the basins studied are dominated by subsurface flows; generally, surface runoff is negligible.

Observed time-series climatological and streamflow data, as well as measured surface characteristics of each of the 11 basins studied, were incorporated into the Precipitation-Runoff Modeling System simulations during the calibration and validation phase. A minimum of 2 years of daily time-series data from each basin was used. Hourly time-series data from select storms in each basin also were used. The hydrologic-response units were delineated for each basin by soil, topography, and vegetation criteria. Although many parameter values were estimated from measured surface characteristics, other parameter values were estimated by graph fitting (ground-water parameters) or by using optimization routines that minimized the error between observed and simulated discharge (subsurface parameters). Coefficients of determination used during the daily mode calibration periods ranged from 0.92 for the Flynn Creek Basin to 0.68 for the Priorli Creek Basin. The percentage of error ranged from -0.25 for the Deer Creek Basin to -4.49 for the Nestucca River Basin. Coefficients of determination used during the validation periods ranged from 0.90 for the Flynn Creek Basin to 0.66 for the Wind River Basin. The percentage of error during the validation periods ranged from -0.91 for the Flynn Creek Basin to 22.3 for the Priorli Creek Basin. In addition to daily simulations, 42 storms selected from the time-series periods of the 11 basins studied were used in hourly storm-mode simulations. Sources of simulation error included: precipitation, streamflow, and temperature data that were used as input to the model; deficiencies of the Precipitation-Runoff Modeling System model algorithms; and parameter estimations. Precipitation-Runoff Modeling System model calibration and validation error is extremely dependent on precipitation data input. Correlation coefficients for basin precipitation gages and nearby precipitation gages ranged from 0.92 to 0.71, indicating a major source of error in simulations.

Times-series data from the Flynn Creek and Needle Branch Basins were used to evaluate the Precipitation-Runoff Modeling System as a tool for predicting the hydrologic effects of timber-management practices. The Flynn Creek Basin remained forested and undisturbed during the data-collection period, while the Needle Branch Basin had been clearcut 82 percent by the midpoint of the data-collection period. Using the Precipitation-Runoff Modeling System, streamflow at the Needle Branch Basin was simulated during the postlogging period using prelogging parameter values. When compared with observed postlogging streamflows, simulated output showed an increase in annual discharge volume of approximately 8 percent, but an increase in peak flows of only 1 to 2 percent. These results were similar to the results of an earlier study (Harris, 1977).

The basins studied were fairly insensitive to variations in the number and in the resolution of basin-surface detail used to delineate hydrologic-response units. The average number of hydrologic-response units used in the storm-mode simulations was one-half the average number of hydrologic-response units used in the daily mode simulations. With the exception of the Vincent Creek Basin, however, the change in the coefficient of determination was within 3 percent.

By calibrating and validating the Precipitation-Runoff Modeling System for each of the 11 basins—which encompass a variety of forest, soil, and topographic conditions—ranges of Precipitation-Runoff Modeling System model-parameter values that were indicative of the land-surface conditions in the Coast Range region were determined. Those regionalized-parameter values can assist users to apply the Precipitation-Runoff Modeling System when modeling other small basins—gaged or ungaged—of the Coast Range and land managers to assess the affect of timber harvesting and road building when applying the model. For application to a gaged basin, parameter values should be used for the initial simulation run, thereby shortening the calibration procedure. For application to an ungaged basin, appropriate parameter values reflecting land-surface conditions would first be selected for each hydrologic-response unit. Simulated, streamflow time-series data could then be produced by the Precipitation-Runoff Modeling System model, using historical or synthetic precipitation-time-series data. Unless the precipitation data are collected from within the confines of the basins at one or more properly protected rainfall gages, the assumption that the water balance in the simulated streamflow is accurate cannot be made. The procedure presented, which simulates timber-harvesting effects by adjusting the parameters of the Precipitation-Runoff Modeling System model, is not statistically valid. Parameter adjustments were based on what appeared to be physically appropriate. Those parameter adjustments produced expected simulation output that was similar to findings in the literature referred to for this study. However, measured rainfall and streamflow errors in all the basin simulations were in the same range, or greater than, the change in runoff that resulted from harvesting timber. Nonetheless, the Precipitation-Runoff Modeling System model can be used to estimate relative changes in runoff by simulating various timber-harvesting scenarios. A modeler of the Precipitation-Runoff Modeling System, who needs to determine a more accurate estimate of the runoff changes that would occur due to timber harvesting in a basin, would find that installing precipitation and streamflow gages for at least one season to be advisable. The accuracy of the rainfall adjustment and of the ground-water-sink coefficients could then be confirmed, using measured data.

SUGGESTIONS FOR FUTURE STUDIES

Suggestions for future studies that could improve future analysis of the effects of timber-harvesting in western Oregon include: (1) additional field-data-collection studies, (2) improved subsurface-flow models, and (3) hillslope-hydrology research.

Field-Data Collection

The first objective of this study—to calibrate and validate a precipitation-runoff model for each of the 11 basins—was hindered by the quality and availability of observed precipitation, streamflow, and temperature data used in each basin simulation. The second objective—to evaluate the model as a predictive tool for assessing effects of forest-management practices on streamflow—was hindered by the limited time-series data available for basins with homogenous forest conditions. With the exception of the Needle Branch and Flynn Creek Basins, the surface characteristics of the other basins included heterogenous mosaics of mature conifer forests and mature hardwood forests, clearcut areas, and partial-growth forest areas that changed throughout the calibration and validation time periods. The third objective—to regionalize the Precipitation-Runoff Modeling System model-parameter values throughout the Coast Range of Oregon—was hindered by the limited availability and quality of observed precipitation, streamflow, and temperature data from the southern part of the area studied.

To be most effective and useful for future analyses, data collected from watersheds in the Coast and Cascade Ranges needs to include the following components:

(1) Installation of new streamflow and precipitation gages: Most streamflow gages in western Oregon are located in large, low, bottom-land drainage basins that have significant flow regulation. Adequate streamflow time-series data for small watersheds (less than 15-square miles in surface area) in Oregon are not available, especially in the southern region of the Coast Range and in sections of the Cascade Range. To improve the data distribution, new streamflow gaging stations need to be installed in small, upland drainage basins of western Oregon.

To be most effective and readily useful in precipitation-runoff simulations, streamflow data needs to be collected using U.S. Geological Survey procedures and guidelines that are accepted by the U.S. Bureau of Standards. Published U.S. Geological Survey streamflow data contain quality-control rankings that provide a watershed-modeling specialist with information regarding the adequacy of that data for use in basin calibrations.

For watershed-modeling simulations, precipitation and streamflow data need to be collected simultaneously. Precipitation gages need to have wind shields and need to be located in, or in proximity of, the basin being studied. (Specific suggestions for collection of precipitation data are discussed in component number 3.)

It is difficult to discern from outlet flow data the hydrologic signals that reflect specific forest conditions in a basin. Most of the time-series streamflow data from small basins in the Coast Range were collected from basins with extremely heterogenous forest conditions. Those extremely heterogenous forest conditions represent a mixture of mature forests of both conifer and hardwood, partial-growth forests, and clearcut sections. For precipitation-runoff modeling, streamflow data collected from basins with homogenous forest coverages would be critical for defining the appropriate parameter values for that type of forest coverage. Streamflow data sets from small basins that are classified as completely partial-growth forest would be of interest for future studies of Precipitation-Runoff Modeling System modeling.

(2) Additional paired-watershed studies: Collecting data from paired-watershed studies is the preferred method for calibrating and validating a watershed model. The model can then be more confidently used as a tool for quantifying the effects of timber-cutting practices on the hydrologic regime of small watersheds. Data from the "control" and "experimental" basins are used as a means of validating the appropriate changes in the Precipitation-Runoff Modeling System model-parameter values that are needed when different land-surface conditions are simulated.

A paired-watershed study is expensive and usually is accomplished over a period of 5 to 10 years. The number of paired-watershed studies that have been done in the Pacific Northwest is limited. Much of the research about the Pacific Northwest and the effects of timber-cutting practices on hydrology is based on data collected only from three paired-watershed sites in the Pacific Northwest: Alsea River basins, H. J. Andrews Experimental Forest, and the Bull Run Watersheds.

A long period of data-collection would not be required, necessarily, in new studies of paired-watersheds. Even a 2-year period of data collection, 1 year before and 1 year after logging, could provide valuable data regarding the hydrologic response to timber-cutting practices. One suggested site for a paired-watershed study is the southern region of the Coast Range mountains in Oregon, where current streamflow data for small watersheds is insufficient for watershed-modeling simulations.

Because the hydrologic response to timber-cutting practices is extremely dependent on the method of cutting and removal, complete documentation of all details concerning timber-harvesting operations is essential. For example, the layout of the logging-road network can have the effect of either accelerating or delaying storm runoff. And, log removal that requires using heavy tractor equipment will cause significantly greater soil compaction than cable yarding.

In addition, knowing whether "slash burns" have been used in the clearcut areas to prepare the surface areas for planting would be necessary; parameter values that are related to surface imperviousness would need to be adjusted accordingly to reflect those conditions.

(3) Precipitation-gage network studies: Precipitation-runoff modeling is hindered by the availability of observed-precipitation data as only a point measurement. Quite often, precipitation data do not provide an adequate representation of the spatial variability over relatively short distances that occurs when actual precipitation is falling on small basins. This spatial variability in precipitation is directly related to the variability of runoff that occurs in different sectors of a basin. Precipitation gages often are located near a basin outlet. Precipitation catch near a basin outlet typically is less than mean basin catch, because the volume of precipitation usually increases with elevation. Because coastal storms typically are accompanied by high, gusty winds during the early part of a storm, the end result is under catchment of precipitation.

Additional collection of precipitation data from the Coast Range region is needed to better describe the spatial variability of storm events. A small basin, with physical characteristics typical of upland drainage basins in the Coast Range of Oregon, could be selected for such a study. Throughout that basin, a dense network of precipitation gages could be installed. The appropriate density of the gage placement could be determined if, in between storms, the gages were moved. Two to three years of data collection would probably be sufficient. Such a study also would define how the spatial variability of precipitation may change with the seasons.

Subsurface-Flow Algorithm

The development of a more sophisticated subsurface-flow algorithm is justifiable, because subsurface flow is the principal component of storm runoff from basin slopes typically found in the Coast Range (Dunne and Leopold, 1978). The dominant soils are well-drained, gravelly loams that contain numerous macropores. The rate of precipitation rarely exceeds the rate of soil infiltration. With the exception of flat riparian areas, overland flow in most upland drainage basins is not significant. Although the Precipitation-Runoff Modeling System has elaborate algorithms for routing overland flow in the storm mode, subsurface flow is routed to the channel through a simple linear- or nonlinear-reservoir algorithm. A more sophisticated algorithm could be constructed to define a subsurface flow "roughness coefficient" or a kinematic-wave approximation similar to the overland-flow algorithm. Another alternative would be to use the TOPMODEL watershed model, which could show some improvement in routing subsurface flow if compared to the Precipitation-Runoff Modeling System. However, using TOPMODEL requires Digital Elevation Model digital files of basin topography. A significant amount of data processing of the Digital Elevation Models is required before TOPMODEL can be used in a basin simulation run.

Hillslope-Hydrology Research

Accurate, physically based models of subsurface-flow processes are still needed. According to Beven (1989, p. 159): "There remains much that is only poorly understood about the way that catchments [drainage basins] respond to rainfall." A limited amount of research on hillslope hydrology has been done in forests of the Pacific Northwest. Field observations and descriptions of subsurface flow are needed in either the Coast Range or Cascade Range forests to determine stormflow processes, subsurface flow paths, residence times of infiltrated water, and biogeochemical budgets.

Some of the research ideas proposed by R.L. Allen and Antonius Laenen (written commun., 1990) for a study in the H.J. Andrews Experimental Forest need to be considered in future research programs and are discussed in the proceeding paragraphs.

Additional field-data collection and experiments are needed for future programs. To observe water flow paths under reasonably undisturbed conditions, conservative tracers (artificial and natural) could be applied upslope from existing road cuts and stream-channel embankments. This observation of water flow paths could be a relatively small-scale experiment, less than a hectare in surface area, and use a network of neutron moisture-probe access tubes to locate flow paths. Collection troughs could be installed at road cuts or stream-channel embankments to measure the volume of macropore seepage.

In addition to studies of macropores, instrumentation over an entire slope is needed to estimate hydraulic flux and water budget. A network of nested tensiometers and piezometers would be placed at locations from the subbasin divide to the channel. The tensiometers, installed at various depths in the root zone, would be used to monitor unsaturated-zone-potential gradients and to detect saturated layers in the root zone as soil texture changes. Deep piezometers would be used for monitoring water-table responses to deep percolation.

Research studies of hillslope hydrology need to be done to improve the methodologies of timber-cumulative-effects analysis. The type of data collected and the results from field experiments need to be directly coordinated with efforts to improve the subsurface-flow algorithms for the watershed models. The type of instrumentation discussed above could be installed in a variety of forested and clearcut hillslopes.

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SUPPLEMENTAL DATA TABLE

Table 16. Definitions of Precipitation-Runoff Modeling System parameters

Parameter	Description
AJMX	Adjustment proportion of rain in a rain-snow mix event, for months I = 1, 12
ARSA	Minimum snowfall, in water equivalent, needed to reset snow albedo during the snowpack accumulation stage
ARSM	Minimum snowfall, in water equivalent, needed to reset snow albedo during the snowpack melt stage
BST	Temperature below which precipitation is snow and above which it is rain (degrees F or C)
CECN	Convection-condensation energy coefficient for months I = 1, 12 (cal/°C above zero)
COVDNS	Summer cover density for major vegetation for each hydrologic-response unit (decimal percent)
COVDNW	Winter cover density for major vegetation for each hydrologic-response unit (decimal percent)
CTS	Monthly evapotranspiration coefficients
CTW	Coefficient for computing snowpack sublimation from potential evapotranspiration (PET)
DENI	Initial density of new-fallen snow (decimal fraction)
DENMX	Average maximum density of snowpack (decimal fraction)
DRCOR	Daily precipitation correction factor for rain for each hydrologic-response unit
DRN	Drainage factor for redistribution of saturated moisture storage as a fraction of KSAT—storm mode
DTM	Routing interval for overland flow or channel segment—storm mode (minutes)
EAIR	Emissivity of air on days without precipitation
ELV	Elevation of hydrologic-response unit (feet above MSL)
EVC	Evaporation pan coefficient for months 1—12
FLGTH	Length of overland flow plane or channel segment feet—storm mode
FRN	Roughness parameter for overland flow plane or channel segment—storm mode
FWCAP	Free water holding capacity of snowpack (decimal fraction of snowpack water equivalent)
GSNK	Coefficient to compute seepage from each ground-water reservoir to a ground-water sink
GW	Storage in each ground-water reservoir (acre-inches)
HRU	Hydrologic-response unit
ICOV	Vegetation cover type for each hydrologic-response unit (0=bare, 1=grasses, 2=shrubs, 3=trees)
IMPERV	Percent impervious area for each hydrologic-response unit (decimal percent)
IPET	Potential evapotranspiration method switch (0=Jensen-Haise, 1= Hamon, 2=use pan data)
IRU	Index for specific hydrologic-response unit
ISOIL	Soil type for each hydrologic-response unit (1=sand, 2=loam, 3=clay)
ISSR1	Surface runoff method switch (0=linear, 1=nonlinear)
ISUN	Storm subsurface and ground-water routing switch (0=not done, 1=subsurface and ground-water included in storm mode computation)
ITND	Month that transpiration ends for each hydrologic-response unit
ITST	Month to begin checking for start of transpiration for each hydrologic-response unit
ITSW	Transpiration switch for each hydrologic-response unit (0=vegetation dormant, 1= vegetation transpiring)

Table 16. Definitions of Precipitation-Runoff Modeling System parameters—Continued

Parameter	Description
KDS	Index of rain gage associated with each hydrologic-response unit
KGW	Index of ground-water reservoir receiving seepage from each hydrologic-response unit
KRES	Index of subsurface reservoir receiving seepage from each hydrologic-response unit
KRSP	Index of ground-water reservoir receiving seepage from each subsurface reservoir
KSAT	Hydraulic conductivity of transmission zone—storm mode
LBC	I.D. of overland flow plane providing lateral inflow to channel segment—storm mode
MRDC	Switch to determine method used to compute solar radiation for missing days (0 = radiation not used; 1 = degree - day; 2 = sky cover)
NCRSEG	Number of channel routing segments—storm mode
NDS	Number of rain gage data sets
NDX	Number of intervals to subdivide overland flow planes or channel segments for finite-difference calculations—storm mode
NGW	Number of ground-water storage reservoirs
NIRU	Hydrologic-response unit associated with overland flow plane—storm mode
NOFSEG	Number of overland flow planes—storm mode
NRES	Number of subsurface storage reservoirs
NRU	Number of hydrologic-response units
NS	Number of hydrograph segments in storm period—storm mode
NSP	Number of storm periods—storm mode
PARM1	Kinematic parameter alpha for plane or channel type = 4; or width of channel for channel type = 1 or 3—storm mode
PARS	Correction factor for computed solar radiation on summer day with precipitation (decimal fraction)
PARW	Correction factor for computed solar radiation on winter day with precipitation (decimal fraction)
PAT	Maximum air temperature, which when exceeded forces precipitation to be rain regardless of minimum air temperature, for months I = 1, 12
PCRID	Identification characters for overland flow planes, channel and reservoir segments and junctions—storm mode
PERV	Percent of pervious area on each hydrologic-response unit (decimal)
PSP	Combined effect of moisture deficit and capillary potential (inches)—storm mode
RBA	Index of overland flow segment to be used as input to channel segment—storm mode
RBC	Identification of overland flowplane providing lateral inflow to channel segment—storm mode
RCB	Routing coefficient for each ground-water reservoir
RCF	Linear routing coefficient for each subsurface reservoir
RCP	Nonlinear routing coefficient for each subsurface reservoir
RDB	Coefficient used in sky cover—solar radiation relation
RDC	Y–intercept for relation between temperature (X) and 1) degree day (Y) or 2) sky cover (Y) when MRDC = 1 or 2
RDM	Slope for relation between temperature (X) and 1) degree day (Y) or 2) sky cover (Y) when MRDC = 1 or 2
RDMX	Maximum percent of potential solar radiation (decimal fraction)
RDP	Coefficient used in sky cover - solar radiation relation
RECHR	Storage in upper part of soil profile where losses occur as evaporation and transpiration (inches)
REMX	Maximum value of RECHR for each hydrologic-response unit (inches)
RES	Storage in each subsurface reservoir (acre - inches)

Table 16. Definitions of Precipitation-Runoff Modeling System parameters—Continued

Parameter	Description
RESMX	Coefficient for routing water from each subsurface reservoir to ground-water reservoir
RETIP	Maximum retention storage on impervious area for each hydrologic-response unit (inches)
REXP	Coefficient for routing water from each subsurface reservoir to ground-water reservoir
RGF	Ratio of combined effects of moisture deficit and capillary potential at wetting front from wilting point to field capacity – storm mode
RMXA	Proportion of rain in rain/snow event above which snow albedo is not reset for snowpack accumulation stage
RMXM	Proportion of rain in rain/snow event above which snow albedo is not reset for snowpack melt stage
RNSTS	Interception storage capacity of unit area of vegetation for rain during summer period, for each hydrologic-response unit (inches)
RNSTW	Interception storage capacity of unit area of vegetation for rain (inches) during winter period, for each hydrologic-response unit
RSEP	Seepage rate from each subsurface reservoir to ground-water reservoir (inches per day)
RSTOR	Retention storage on impervious area for each hydrologic-response unit
RTB	Y-intercept of temperature range and estimated solar radiation adjusted factor relation
RTC	Slope of temperature range and estimated solar radiation adjusted factor relation
SCN	Minimum contributing area for surface runoff when ISSR1=0; coefficient in contributing area – soil moisture index relation when ISSR1=1
SCX	Maximum possible contributing area for surface runoff as proportion of each hydrologic-response unit
SC1	Coefficient in surface runoff contributing area – soil moisture index relation
SETCON	Snowpack settlement time constant
SEP	Seepage rate from soil moisture excess to each ground-water reservoir (inches per day)
SMAV	Daily available water in soil profile for each hydrologic-response unit (inches)
SMAX	Maximum available water holding capacity of soil profile for each hydrologic-response unit (inches)
SNST	Interception storage capacity of unit area of vegetation for snow, for each HRU (inches, water equivalent)
SRX	Maximum daily snowmelt infiltration capacity of soil profile at field capacity for each HRU (inches)
THRES	Minimum depth of flow for continuation of routing (feet) – storm mode
TLN	Lapse rate for minimum daily air temperature for months I = 1, 12
TLX	Lapse rate for maximum daily air temperature for months I = 1, 12
TRNCF	Transmission coefficient for shortwave radiation through vegetation canopy for each HRU
TSOLX	Maximum daily air temperature below which solar radiation adjustment factor equals RTB, for months I = 1, 12
TYPE	Type of overland flow plane or channel routing segment – storm mode
UPCOR	Storm precipitation correction factor for each hydrologic-response unit
UP1	Upstream inflow segment for channel routing segment – storm mode
UP2	Upstream inflow segment for channel routing segment – storm mode
UP3	Upstream inflow segment for channel routing segment – storm mode

APPENDIX A

Precipitation-Runoff Modeling System (PRMS)
Daily and Storm Mode Output
for the Tucca Creek Basin from the Calibration Period

APPENDIX A

```
1     PRMS -- VERSION 0888

 T

   IOPT=    0     ISIM=    2     IOBS=    1     ISEN=    0     PROB=    0
   IDOUT=   3     IUOUT=   2     SCODE=OR       IPSW=    0

   IPET=    1     ISSR1=   1     MRDC=    2     ISUN=    1     ILPS=    0
   NYR=     3     NDS=     1     NRU=     5     NRD=     6     NRES=   1    NGW=    1    NSTOR=   0    DAT=        1977.20
   NTS=     1     NPLW=    ONDC=    0
   BYR/BMO/BDY= 1983/10/ 1     EYR/EMO/EDY= 1986/ 9/30

   MFS= 10      MFN=  9

    DATA TYPE      PARAMETER STATISTIC           STATION ID
                      CODE      CODE     DSN
 DAILY DISCHARGE       60         3        1
 DAILY EVAP             0         0        0
 DAILY MAX TEMP     99998         1        4     D000000000000040

 DAILY MIN TEMP     99998         2        3     D000000000000040

 DAILY SOLAR RAD        0         0        0
 SNOW PILLOW            0         0
 USER VARIABLE 2        0         0        0
 UNIT DISCHARGE        60        11        5
 DAILY PRECIP          45         6        2     D000000000000020
 UNIT PRECIP           45         6        6     U000000000000021


   POT SOLAR RADIATION
       1       HOR         252.3   276.9   319.9   382.3   461.5   551.7   647.4   741.8   827.8   902.1   960.3  1000.6  1023.8
       2       SE40        477.1   501.5   542.3   598.2   664.4   733.7   800.8   860.8   909.1   946.2   971.7   987.4   995.7
       3        W40        266.8   290.9   332.9   393.4   469.6   555.5   646.0   734.4   814.2   882.5   935.6   972.0   992.9
       4        N20         93.6   114.9   154.1   214.8   296.7   395.9   507.4   622.9   732.7   831.2   911.2   967.9  1001.3
       5        W20        257.2   281.6   324.2   386.1   464.3   553.2   647.3   739.9   824.1   896.5   953.2   992.3  1014.9
       6       SW20        375.6   400.4   442.8   502.6   575.7   655.7   736.9   813.7   880.1   934.8   975.7  1003.0  1018.3


   RDM(1-12)= -0.13 -0.13 -0.10 -0.08 -0.08 -0.07 -0.07 -0.07 -0.08 -0.08 -0.13 -0.13
   RDC(1-12)=  1.83  1.83  1.60  1.46  1.46  1.42  1.42  1.42  1.46  1.46  1.83  1.83

   MRDC=  2    PARS=  0.44    PARW=  0.50    RDB=  0.40    RDP=  0.61    RDMX=  0.80    RTB=  1.00    RTC=  1.00    ITSOL=  1

   TSOLX(1-12) -     50.0     50.0     50.0     50.0     50.0     50.0     50.0     50.0     50.0     50.0     50.0     50.0


   SUNLIGHT HOURS/12
       1       HOR           0.7     0.7     0.8     0.8     0.9     0.9     1.0     1.1     1.1     1.2     1.2     1.3     1.3
       2       SE40          0.7     0.7     0.7     0.8     0.8     0.9     0.9     1.0     1.0     1.0     1.1     1.1     1.1
       3        W40          0.6     0.6     0.6     0.7     0.7     0.8     0.8     0.9     1.0     1.0     1.0     1.1     1.1
       4        N20          0.5     0.6     0.6     0.7     0.8     0.9     1.0     1.1     1.1     1.2     1.2     1.3     1.3
       5        W20          0.6     0.7     0.7     0.7     0.8     0.9     0.9     1.0     1.0     1.1     1.1     1.2     1.2
       6       SW20          0.7     0.7     0.8     0.8     0.8     0.9     1.0     1.0     1.1     1.1     1.1     1.2     1.2
1T

             RMXA= 0.80     RMXM= 0.60     MTSS=    0     MTSE=    0     ARSA= 0.05     ARSM= 0.20

   CSEL(1-5)=        290.

   MPCS=   0          MPCN=   0      MPC1=   0      PCONR=  1.00     PCONS=  1.00

   PCR(1-NRU) -        1.00   1.00   1.00   1.00   1.00

   PCS(1-NRU) -        1.00   1.00   1.00   1.00   1.00

   CTS(1-12)= 0.007000 0.008000 0.008000 0.009000 0.009000 0.012000 0.013000 0.013000 0.012000 0.011000 0.010000 0.006000
   CTW=    0.50

   PAT(1-12)=    32.00    32.00    32.00    32.00    32.00    32.00    32.00    32.00    32.00    32.00    32.00    32.00
   AJMX(1-12)=     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00

   TLX(1-12)=     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00
   TLN(1-12)=     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00     3.00

   EVC(1-12)=   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000

   ISP1= 90     ISP2=120     EAIR= 0.850     FWCAP= 0.05     DENI= 0.10     DENMX= 0.60     SETCON= 0.10     BST= 32.00


   CECN(1-12)=     5.00     5.00     5.00     5.00     5.00     5.00     5.00     5.00     5.00     5.00     5.00     5.00

      #       RES       RSEP       RESMX       REXP     KRSP     RCF          RCP                 #       GW       GSNK       RCB
     --      ----       ----      ------       ----     ----  ---------    ---------            --      -----     -----     ------
      1     0.500      0.020      1.0000      1.0000     1   0.0001000    0.0500000              1      1.130     0.002     0.0200
```

APPENDIX A

1T

IRU	IRD	ITST	ITSW	TXAJ	RNSTS	SNST	COVDS	ICOV	SMAX	REMX	SCN	SRX	RETIP	SEP	KRES
	ELEV	ITND	CTX	TNAJ	RNSTW	TRNCF	COVDW	ISOIL	SMAV	RECHR	SC1	SCX	IMPRV	KSTOR	KGW
1	2	1	1	0.00	0.04	0.10	0.50	3	12.00	1.60	0.00100	2.00	0.00	0.20	1
	1850.	12	0.00	0.00	0.04	0.50	0.50	2	6.00	1.60	0.20000	0.01	0.00	0	1
2	3	1	1	0.00	0.04	0.10	0.50	3	7.00	0.80	0.00100	2.00	0.00	0.20	1
	2400.	12	0.00	0.00	0.04	0.50	0.50	1	3.50	0.80	0.20000	0.01	0.00	0	1
3	4	1	1	0.00	0.10	0.10	0.90	3	12.00	1.60	0.00100	2.00	0.00	0.20	1
	2000.	12	0.00	0.00	0.10	0.50	0.70	2	6.00	1.60	0.20000	0.01	0.00	0	1
4	5	1	1	0.00	0.04	0.10	0.50	3	12.00	1.60	0.00100	2.00	0.00	0.20	1
	1800.	12	0.00	0.00	0.04	0.50	0.50	2	6.00	1.60	0.20000	0.01	0.00	0	1
5	6	1	1	0.00	0.10	0.10	0.90	3	7.00	0.80	0.00100	2.00	0.00	0.20	1
	2200.	12	0.00	0.00	0.10	0.50	0.70	1	3.50	0.80	0.20000	0.01	0.00	0	1

IRU	IDS	SLOPE	AREA	PERV AREA	IMPERV AREA	UPCOR	DRCOR	DSCOR	TST	KTS	KSP	KDC	AIMX	PKFAC
1	1	0.40	142.5	142.5	0.0	1.00	1.00	1.00	0.0	1	0	0	50.00	1.00
2	1	0.40	236.2	236.2	0.0	1.00	1.00	1.00	0.0	1	0	0	50.00	1.00
3	1	0.20	564.4	564.4	0.0	1.00	1.00	1.00	0.0	1	0	0	50.00	1.00
4	1	0.20	474.8	474.8	0.0	1.00	1.00	1.00	0.0	1	0	0	50.00	1.00
5	1	0.20	559.3	559.3	0.0	1.00	1.00	1.00	0.0	1	0	0	50.00	1.00
TOTAL			1977.2	1977.2	0.0									

```
1BYR= 1983 BMO=   10 BDY=    1
 NSP=    3
   1  1198312 819831215  NE= 16
   2  11984 1221984 128  NE= 16
   3  11984 2 81984 216  NE= 16
 INV=1984
 INV=1985
 INV=1986
```

STORMFLOW HYDROGRAPH PARAMETERS FOR EACH HYDROLOGIC-RESPONSE UNIT(IRU)

IRU	KSAT	PSP	RGF	DRN
1	20.000	0.010	50.000	2.000
2	20.000	0.010	50.000	2.000
3	20.000	0.010	50.000	2.000
4	20.000	0.010	50.000	2.000
5	20.000	0.010	50.000	2.000

WY	WYD	#HS	ST#	RFL	SFL	BEGIN AND END TIMES FOR #HS
1984	69	1	1	0	1	0.1440.
1984	70	1	1	1	1	0.1440.
1984	71	1	1	1	1	0.1440.
1984	72	1	1	1	1	0.1440.
1984	73	1	1	1	1	0.1440.
1984	74	1	1	1	1	0.1440.
1984	75	1	1	1	1	0.1440.
1984	76	1	1	1	0	0.1440.
1984	114	1	2	0	1	0.1440.
1984	115	1	2	1	1	0.1440.
1984	116	1	2	1	1	0.1440.
1984	117	1	2	1	1	0.1440.
1984	118	1	2	1	1	0.1440.
1984	119	1	2	1	1	0.1440.
1984	120	1	2	1	0	0.1440.
1984	131	1	3	0	1	0.1440.
1984	132	1	3	1	1	0.1440.
1984	133	1	3	1	1	0.1440.
1984	134	1	3	1	1	0.1440.
1984	135	1	3	1	1	0.1440.
1984	136	1	3	1	1	0.1440.
1984	137	1	3	1	1	0.1440.
1984	138	1	3	1	1	0.1440.
1984	139	1	3	1	0	0.1440.

APPENDIX A

NUMBER OF OVERLAND FLOW PLANE SEGMENTS IS 30. THEIR CHARACTERISTICS ARE AS FOLLOWS:

SEGMENT #	NAME	IDS	IRU	THRES DEPTH	TYPE	PRINT IN	PRINT OUT	NDX	LENGTH	SLOPE	ROUGH-NESS	PARM1	PARM2	ALPHA	EXPM	ROUTE INT.	PRINT INT.
1	OF1	1	4	0.0000	99	0	0	1	461.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
2	OF2	1	4	0.0000	99	0	0	1	474.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
3	OF3	1	1	0.0000	99	0	0	1	1397.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
4	OF4	1	3	0.0000	99	0	0	1	832.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
5	OF5	1	4	0.0000	99	0	0	1	435.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
6	OF6	1	4	0.0000	99	0	0	1	422.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
7	OF7	1	4	0.0000	99	0	0	1	1732.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
8	OF8	1	4	0.0000	99	0	0	1	319.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
9	OF9	1	3	0.0000	99	0	0	1	955.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
10	OF10	1	3	0.0000	99	0	0	1	461.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
11	OF11	1	3	0.0000	99	0	0	1	1848.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
12	OF12	1	3	0.0000	99	0	0	1	990.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
13	OF13	1	3	0.0000	99	0	0	1	344.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
14	OF14	1	4	0.0000	99	0	0	1	471.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
15	OF15	1	4	0.0000	99	0	0	1	880.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
16	OF16	1	4	0.0000	99	0	0	1	815.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
17	OF17	1	4	0.0000	99	0	0	1	753.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
18	OF18	1	4	0.0000	99	0	0	1	327.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
19	OF19	1	5	0.0000	99	0	0	1	161.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
20	OF20	1	5	0.0000	99	0	0	1	1923.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
21	OF21	1	5	0.0000	99	0	0	1	2305.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
22	OF22	1	5	0.0000	99	0	0	1	1014.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
23	OF23	1	2	0.0000	99	0	0	1	597.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
24	OF24	1	2	0.0000	99	0	0	1	1564.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
25	OF25	1	2	0.0000	99	0	0	1	758.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
26	OF26	1	5	0.0000	99	0	0	1	1544.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
27	OF27	1	5	0.0000	99	0	0	1	1306.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
28	OF28	1	2	0.0000	99	0	0	1	1603.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
29	OF29	1	2	0.0000	99	0	0	1	1538.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0
30	OF30	1	5	0.0000	99	0	0	1	373.0	.0000	.000	0.00	0.00	1.23	1.33	5.0	5.0

NUMBER OF CHANNEL AND RESERVOIR SEGMENTS IS 15

SEGMENT #	NAME	UPSTREAM SEGMENTS		ADJACENT SEGMENTS		INC. AREA	CUM. AREA	THRES DISC.	TYPE	PRINT IN	PRINT OUT	NDX	LENGTH	SLOPE	ROUGH-NESS	PARM1	PARM2	ALPHA	EXPM	ROUTE INT.	PRINT INT.
1	CH15			OF29	OF28	109.2	109.2	0.10	3	0	0	3	1514.0	.2200	.050	10.00	10.00	4.06	1.33	60.0	60.0
2	CH14	CH15		OF27	OF26	92.4	201.6	0.10	3	0	0	3	1413.0	.1600	.050	10.00	10.00	3.47	1.33	60.0	60.0
3	CH11	CH14		OF25	OF24	82.7	284.3	0.10	3	0	0	3	1552.0	.2000	.050	10.00	10.00	3.88	1.33	60.0	60.0
4	CH10			OF21	OF22	256.0	256.0	0.10	3	0	0	3	3360.0	.1500	.050	10.00	10.00	3.36	1.33	60.0	60.0
5	CH9	CH10	CH11	OF30	OF23	82.6	623.0	0.10	3	0	0	3	3711.0	.0500	.050	10.00	10.00	1.94	1.33	60.0	60.0
6	CH12			OF17	OF20	251.6	251.6	0.10	3	0	0	3	4095.0	.0500	.050	10.00	10.00	1.94	1.33	60.0	60.0
7	CH13			OF15	OF16	136.6	136.6	0.10	3	0	0	3	3510.0	.0800	.050	10.00	10.00	2.45	1.33	60.0	60.0
8	CH8	CH12	CH13	OF18	CH19	7.8	395.9	0.10	3	0	0	3	1037.0	.0400	.050	10.00	10.00	1.73	1.33	60.0	60.0
9	CH7	CH8	CH9	OF14	OF13	29.8	1048.7	0.10	3	0	0	3	1591.0	.1000	.050	10.00	10.00	2.74	1.33	60.0	60.0
10	CH6			OF12	OF11	355.2	355.2	0.10	3	0	0	3	5452.0	.1300	.050	10.00	10.00	3.12	1.33	60.0	60.0
11	CH5	CH6	CH7	OF7	OF8	182.5	1586.4	0.10	3	0	0	3	3876.0	.0500	.050	10.00	10.00	1.94	1.33	60.0	60.0
12	CH4			OF9	OF10	112.0	112.0	0.10	3	0	0	3	3446.0	.2000	.050	10.00	10.00	3.88	1.33	60.0	60.0
13	CH3	CH4	CH5	OF5	OF6	40.4	1738.8	0.10	3	0	0	3	2052.0	.0400	.050	10.00	10.00	1.73	1.33	60.0	60.0
14	CH2			OF3	OF4	227.5	227.5	0.10	3	0	0	3	4446.0	.1700	.050	10.00	10.00	3.57	1.33	60.0	60.0
15	CH1	CH2	CH3	OF1	OF2	19.5	1985.8	0.10	3	0	3	3	909.0	.0900	.050	10.00	10.00	2.60	1.33	60.0	60.0

APPENDIX A

1 OBSERVED AND PREDICTED RUNOFF FOR WY 1984

0 DAY	OCTOBER		NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH	
	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED
1	1.60	2.92	3.30	1.87	23.00	22.07	22.00	30.87	17.00	20.00	23.00	21.43
2	1.70	2.80	8.30	2.20	20.00	20.25	23.00	32.26	15.00	17.65	21.00	19.90
3	1.80	2.70	27.00	4.52	17.00	18.08	44.00	53.31	14.00	15.83	19.00	17.82
4	1.80	2.60	25.00	4.41	15.00	19.41	63.00	57.88	12.00	14.39	17.00	16.23
5	1.70	2.52	20.00	10.00	19.00	25.33	47.00	43.18	11.00	13.22	16.00	14.95
6	1.70	2.43	22.00	14.30	24.00	26.07	34.00	34.09	11.00	12.26	16.00	13.89
7	1.70	2.36	21.00	13.97	29.00	29.46	28.00	28.38	9.70	11.49	15.00	13.00
8	1.70	2.28	18.00	15.63	40.00	33.30	23.00	24.15	9.40	9.95	13.00	12.25
9	1.60	2.22	17.00	20.00	44.00	34.63	20.00	20.95	11.00	11.77	12.00	11.63
10	1.60	2.15	18.00	29.01	48.00	45.80	20.00	26.67	15.00	28.98	11.00	11.30
11	1.60	2.09	24.00	34.04	55.00	45.25	20.00	28.91	17.00	33.80	11.00	12.66
12	1.60	2.03	30.00	43.84	54.00	46.33	19.00	24.59	80.00	74.39	14.00	17.83
13	1.50	1.98	54.00	69.43	51.00	57.43	18.00	21.29	105.00	98.18	14.00	21.03
14	1.60	1.93	90.00	82.46	47.00	53.23	17.00	18.86	75.00	75.50	16.00	22.30
15	1.60	1.88	78.00	83.28	38.00	41.76	15.00	16.97	51.00	57.31	19.00	22.96
16	1.50	1.83	78.00	99.53	31.00	61.00	14.00	15.48	37.00	49.84	22.00	25.64
17	1.70	1.81	112.00	109.57	25.00	28.80	13.00	14.27	30.00	73.53	30.00	32.63
18	1.70	2.09	119.00	93.15	22.00	24.23	12.00	13.27	26.00	34.43	37.00	35.22
19	1.60	1.70	97.00	91.89	19.00	21.73	11.00	12.42	23.00	29.82	37.00	33.53
20	1.40	1.69	96.00	85.89	16.00	19.19	11.00	11.75	22.00	29.59	34.00	31.32
21	1.40	1.62	72.00	62.34	14.00	17.16	11.00	12.36	23.00	31.43	39.00	40.00
22	3.40	1.87	46.00	48.91	13.00	15.57	13.00	18.56	22.00	30.39	45.00	42.02
23	2.20	2.07	34.00	58.93	13.00	14.29	17.00	38.89	24.00	33.15	39.00	34.17
24	2.00	1.51	55.00	76.85	13.00	13.24	66.00	91.13	35.00	47.72	32.00	28.71
25	2.00	1.48	74.00	72.12	12.00	13.03	96.00	99.43	50.00	49.04	29.00	28.84
26	1.90	1.45	58.00	57.57	9.50	14.86	82.00	75.46	42.00	37.73	27.00	32.02
27	1.90	1.42	50.00	48.05	8.90	15.92	52.00	52.68	35.00	30.45	25.00	34.66
28	1.90	1.39	41.00	38.91	8.20	14.54	36.00	39.27	28.00	25.95	24.00	37.85
29	1.90	1.36	34.00	31.13	12.00	29.19	28.00	63.63	25.00	22.57	22.00	35.23
30	3.10	1.36	27.00	25.84	19.00	43.91	24.00	27.40	0.00	0.00	20.00	29.35
31	2.80	1.86	0.00	0.00	22.00	38.51	20.00	23.12	0.00	0.00	18.00	25.23

1 OBSERVED AND PREDICTED RUNOFF FOR WY 1984

0 DAY	APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER	
	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED
1	16.00	22.23	17.00	27.88	14.00	13.09	7.00	6.76	2.80	3.34	2.10	1.74
2	15.00	19.94	26.00	37.82	12.00	12.43	6.70	6.59	2.80	3.27	1.90	1.69
3	14.00	18.40	30.00	36.55	11.00	12.14	6.40	6.43	2.70	3.20	1.90	1.65
4	12.00	16.92	29.00	30.82	14.00	15.44	6.20	6.28	2.70	3.13	1.80	1.62
5	11.00	15.81	28.00	28.74	13.00	16.29	5.90	6.13	2.70	3.07	2.50	1.94
6	11.00	14.87	25.00	26.10	14.00	16.36	5.70	5.98	2.70	3.00	3.70	2.62
7	17.00	29.32	23.00	22.90	14.00	15.70	5.50	5.84	2.60	2.94	5.70	2.13
8	17.00	40.34	21.00	20.87	15.00	15.86	5.30	5.70	2.50	2.90	3.10	1.84
9	20.00	39.51	20.00	21.21	16.00	15.93	5.10	5.57	2.50	2.81	2.50	1.49
10	26.00	48.22	19.00	20.94	16.00	14.80	4.90	5.44	2.40	2.75	2.20	1.42
11	30.00	56.25	19.00	22.92	16.00	13.86	4.80	5.32	2.40	2.70	2.10	1.39
12	47.00	59.38	19.00	23.02	15.00	13.06	4.80	5.20	2.40	2.64	2.10	1.41
13	51.00	51.79	18.00	20.74	14.00	12.37	4.70	5.08	2.40	2.58	1.90	1.34
14	38.00	40.26	18.00	20.45	13.00	11.76	4.50	4.97	2.30	2.53	1.80	1.31
15	30.00	32.73	17.00	19.32	12.00	11.23	4.30	4.86	2.30	2.47	1.80	1.28
16	24.00	27.59	16.00	17.76	11.00	10.76	4.20	4.75	2.20	2.42	1.80	1.25
17	20.00	23.91	15.00	16.43	10.00	10.33	4.00	4.64	2.20	2.37	1.70	1.23
18	18.00	21.28	14.00	15.36	9.00	9.95	3.90	4.54	2.20	2.32	1.70	1.20
19	16.00	19.45	14.00	15.15	8.60	9.59	3.90	4.44	2.20	2.27	1.70	1.18
20	15.00	19.49	13.00	14.29	9.10	9.55	3.90	4.34	2.10	2.22	1.60	1.15
21	14.00	18.95	12.00	13.48	9.30	9.16	3.80	4.25	2.10	2.18	1.70	1.16
22	13.00	17.28	13.00	15.38	8.00	8.68	3.70	4.16	2.10	2.13	2.20	1.49
23	12.00	16.49	14.00	15.83	7.30	8.42	3.60	4.07	2.10	2.09	2.00	1.11
24	11.00	15.31	13.00	14.78	6.90	8.17	3.50	3.98	2.10	2.04	1.90	1.17
25	11.00	14.73	15.00	17.16	6.60	7.94	3.50	3.89	2.00	2.00	1.80	1.04
26	11.00	13.83	20.00	19.54	6.70	7.75	3.40	3.81	1.90	1.96	1.60	1.02
27	10.00	13.40	21.00	18.58	6.30	7.54	3.20	3.73	2.00	1.92	1.60	0.99
28	9.80	13.02	20.00	17.03	6.20	7.76	3.20	3.64	2.00	1.88	1.60	0.97
29	10.00	14.31	18.00	15.77	9.80	7.90	3.10	3.57	1.90	1.84	1.60	0.95
30	13.00	18.41	17.00	14.72	7.80	6.94	3.00	3.49	1.90	1.89	1.60	0.93
31	0.00	0.00	15.00	13.84	0.00	0.00	3.00	3.42	2.00	1.76	0.00	0.00

O-PPT N-PPT XINT POTET ACTET SMELT IRLOS P-ROFF TO-ROFF O-ROFF

ANNUAL SUMMARY 1984 OBSERVED PRECIP=115.55 POTENTIAL ET= 30.68 PREDICTED RUNOFF(IN) = 87.49 OBSERVED RUNOFF(IN) = 78.65
NET PRECIP=108.47 ACTUAL ET= 18.86 (CFS)= 7280.69 (CFS)= 6545.00
INTERCEPTION LOSS= 7.08 SNOWMELT= 1.68 MEAN DAILY(CFS)= 19.89 MEAN DAILY(CFS)= 17.88

GW IN= 21.15 SSR IN= 67.19 SSR TO GW= 9.80 SURFACE RO= 0.93 SSR FLOW= 57.85 GW FLOW= 28.71 GW SINK= 2.82

APPENDIX A

1 OBSERVED AND PREDICTED RUNOFF FOR WY 1985

0 DAY	OCTOBER		NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH	
	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED
1	1.60	0.91	27.00	45.21	77.00	78.09	43.00	42.04	6.50	9.16	17.00	10.57
2	1.60	0.89	100.00	75.84	51.00	55.23	33.00	33.88	5.50	9.96	15.00	10.03
3	1.60	0.88	91.00	87.47	36.00	41.93	25.00	28.35	5.10	9.40	15.00	11.44
4	1.80	1.09	64.00	72.95	28.00	33.50	22.00	24.41	5.00	8.96	16.00	15.08
5	1.70	0.84	43.00	52.86	23.00	27.82	19.00	21.50	5.00	8.71	15.00	16.12
6	1.60	0.82	33.00	45.23	20.00	23.80	17.00	19.28	5.80	12.37	14.00	14.58
7	1.60	0.81	35.00	50.58	17.00	20.84	15.00	17.54	7.20	19.16	13.00	13.38
8	1.90	1.09	38.00	53.87	16.00	18.63	14.00	16.14	6.10	24.63	12.00	12.40
9	2.00	1.10	42.00	59.08	14.00	18.98	13.00	14.99	6.00	32.41	12.00	11.58
10	4.70	1.66	61.00	68.51	15.00	18.15	12.00	14.03	6.40	40.42	11.00	10.88
11	6.80	1.83	66.00	63.50	13.00	18.10	11.00	13.22	14.00	51.67	11.00	10.28
12	6.70	1.61	55.00	50.58	22.00	29.45	10.00	12.52	20.00	49.71	10.00	9.76
13	7.50	1.87	44.00	47.53	24.00	35.25	9.80	11.91	18.00	37.79	10.00	9.29
14	9.40	2.73	36.00	42.07	30.00	35.03	10.00	11.65	18.00	34.80	9.70	8.92
15	9.00	2.42	31.00	32.83	34.00	33.48	9.80	11.15	24.00	31.15	9.20	8.52
16	7.50	2.29	26.00	26.73	32.00	28.03	9.20	10.84	25.00	25.70	8.90	8.18
17	6.40	2.22	23.00	23.01	27.00	24.49	8.90	10.38	24.00	21.84	8.60	7.88
18	6.10	2.83	25.00	29.43	23.00	21.42	8.50	10.01	21.00	19.00	8.40	7.60
19	7.00	4.22	24.00	33.80	20.00	19.20	8.30	9.79	19.00	19.95	8.10	7.34
20	6.50	4.47	26.00	29.70	18.00	19.71	8.10	9.42	19.00	20.27	8.30	7.40
21	6.00	4.09	25.00	25.11	19.00	27.13	7.70	9.13	19.00	19.07	9.10	12.68
22	5.70	3.81	24.00	21.52	27.00	40.96	7.40	8.86	22.00	17.21	10.00	16.71
23	5.60	3.60	24.00	26.73	34.00	44.10	7.10	8.60	24.00	15.57	29.00	20.95
24	5.50	3.35	23.00	35.38	34.00	36.51	6.80	8.36	26.00	14.52	33.00	27.55
25	8.10	8.55	24.00	37.99	31.00	30.10	6.60	8.13	25.00	13.48	28.00	27.40
26	15.00	22.70	23.00	36.63	27.00	25.78	6.30	7.91	23.00	12.52	25.00	28.55
27	23.00	37.97	78.00	65.29	26.00	36.52	6.20	7.70	21.00	11.76	23.00	35.34
28	35.00	44.71	146.00	99.34	24.00	43.70	6.00	7.50	19.00	11.10	21.00	34.46
29	32.00	38.78	129.00	116.20	46.00	62.37	5.80	7.45	0.00	0.00	21.00	30.73
30	27.00	36.86	116.00	108.59	86.00	71.69	5.60	7.15	0.00	0.00	59.00	47.83
31	22.00	33.55	0.00	0.00	62.00	54.84	5.50	7.13	0.00	0.00	95.00	55.66

1 OBSERVED AND PREDICTED RUNOFF FOR WY 1985

0 DAY	APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER	
	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED
1	75.00	43.03	12.00	12.07	4.20	4.26	4.00	3.82	2.40	1.87	1.60	0.95
2	57.00	33.77	12.00	11.25	4.00	4.13	3.90	3.70	2.30	1.76	1.60	0.93
3	43.00	27.64	12.00	11.38	4.00	4.15	3.70	3.59	2.20	1.75	1.50	0.91
4	33.00	23.35	11.00	10.46	4.20	3.98	3.60	3.49	2.10	1.69	1.50	0.89
5	27.00	20.22	10.00	9.84	3.90	3.85	3.50	3.39	2.00	1.65	1.90	1.39
6	23.00	17.87	9.50	9.38	10.00	7.68	3.40	3.30	2.00	1.62	3.90	1.49
7	20.00	16.05	9.00	8.90	37.00	15.80	3.40	3.21	2.30	2.09	3.10	1.07
8	17.00	14.60	8.70	8.51	27.00	20.84	3.30	3.12	3.50	1.75	2.30	0.82
9	16.00	13.43	8.20	8.16	21.00	17.39	3.20	3.04	2.30	1.52	2.00	0.81
10	14.00	12.46	8.10	7.95	17.00	14.85	3.10	2.96	2.10	1.49	2.50	1.02
11	14.00	11.93	7.60	7.58	15.00	12.92	3.10	2.89	2.00	1.46	2.30	0.80
12	12.00	10.95	7.30	7.28	13.00	11.41	3.00	2.82	2.00	1.43	3.80	1.46
13	11.00	10.36	7.00	7.03	11.00	10.22	2.90	2.75	1.90	1.40	4.00	0.78
14	10.00	9.84	6.80	6.84	10.00	9.26	2.90	2.68	1.80	1.37	3.30	1.25
15	9.50	9.38	6.50	6.59	9.40	8.47	2.80	2.62	1.80	1.34	3.60	0.75
16	9.00	9.00	6.10	6.39	8.50	7.81	2.70	2.56	1.80	1.31	3.10	1.15
17	8.50	8.60	5.90	6.20	7.80	7.25	2.70	2.50	1.70	1.29	3.50	0.80
18	8.20	8.30	5.70	6.02	7.20	6.81	2.60	2.44	1.70	1.26	3.10	0.71
19	8.30	8.18	5.50	5.85	6.70	6.36	2.50	2.39	1.70	1.23	2.80	0.66
20	8.20	8.03	5.30	5.70	6.40	6.01	2.50	2.33	1.70	1.21	2.60	0.65
21	8.60	8.19	5.10	5.54	6.00	5.69	2.50	2.28	1.70	1.19	2.50	0.63
22	10.00	12.49	4.90	5.52	5.70	5.41	2.40	2.23	1.60	1.16	2.30	0.62
23	17.00	18.18	4.80	5.26	5.40	5.16	2.40	2.18	1.60	1.14	2.20	0.61
24	18.00	22.65	4.70	5.13	5.30	4.94	2.40	2.13	1.60	1.11	2.10	0.60
25	18.00	22.35	4.60	5.00	5.00	4.73	2.30	2.09	1.60	1.11	2.00	0.58
26	18.00	20.25	4.50	4.88	4.80	4.55	2.20	2.04	1.60	1.07	1.90	0.57
27	17.00	17.96	4.40	4.76	4.60	4.38	2.20	2.00	1.60	1.05	1.90	0.56
28	16.00	15.92	4.40	4.68	4.40	4.22	2.10	1.96	1.60	1.03	1.80	0.55
29	14.00	14.35	4.50	4.57	4.40	4.08	2.10	1.91	1.50	1.01	1.80	0.54
30	13.00	13.10	4.30	4.46	4.20	3.94	2.60	2.14	1.70	1.00	1.80	0.53
31	0.00	0.00	4.40	4.52	0.00	0.00	2.50	1.83	1.60	0.99	0.00	0.00

O-PPT N-PPT XINT POTET ACTET SMELT IRLOS P-ROFF TO-ROFF O-ROFF

ANNUAL SUMMARY 1985 OBSERVED PRECIP= 94.90 POTENTIAL ET= 30.72 PREDICTED RUNOFF(IN) = 67.00 OBSERVED RUNOFF(IN) = 65.20
NET PRECIP= 88.91 ACTUAL ET= 19.04 (CFS)= 5575.74 (CFS)= 5425.39
INTERCEPTION LOSS= 5.99 SNOWMELT= 0.00 MEAN DAILY(CFS)= 15.28 MEAN DAILY(CFS)= 14.86

GW IN= 16.68 SSR IN= 51.46 SSR TO GW= 8.17 SURFACE RO= 0.87 SSR FLOW= 43.28 GW FLOW= 22.85 GW SINK= 2.24

APPENDIX A

1 OBSERVED AND PREDICTED RUNOFF FOR WY 1986

0 DAY	OCTOBER		NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH	
	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED
1	1.70	0.52	19.00	22.90	8.20	8.79	11.00	9.81	18.00	19.81	26.00	24.63
2	1.80	0.51	34.00	27.45	11.00	13.22	11.00	17.28	19.00	20.30	22.00	21.56
3	1.70	0.50	33.00	23.84	15.00	34.30	17.00	20.64	20.00	21.76	19.00	19.23
4	1.60	0.49	28.00	21.46	15.00	48.73	16.00	18.26	24.00	27.21	17.00	17.41
5	1.60	0.48	27.00	27.70	18.00	41.52	19.00	24.18	27.00	30.05	16.00	15.96
6	1.60	0.47	37.00	43.61	30.00	45.55	27.00	27.66	28.00	26.47	14.00	14.78
7	1.60	0.46	65.00	58.32	57.00	53.27	26.00	23.33	25.00	22.91	19.00	19.15
8	1.60	0.45	75.00	64.72	62.00	46.33	25.00	23.22	23.00	20.26	20.00	24.13
9	1.60	0.44	62.00	58.63	47.00	35.63	23.00	22.89	20.00	18.21	22.00	26.86
10	1.60	0.43	45.00	45.03	33.00	28.70	21.00	21.79	17.00	16.60	23.00	26.06
11	2.00	0.90	32.00	34.29	26.00	23.93	19.00	19.72	16.00	15.30	28.00	29.62
12	2.00	0.46	25.00	27.39	22.00	20.50	18.00	17.46	14.00	14.39	34.00	33.77
13	1.80	0.45	21.00	23.00	18.00	17.94	16.00	15.54	16.00	23.01	38.00	36.36
14	1.70	0.40	17.00	21.27	16.00	15.98	15.00	14.46	16.00	30.81	35.00	34.02
15	1.60	0.39	22.00	33.14	14.00	14.44	16.00	17.95	25.00	45.70	30.00	28.31
16	1.70	0.38	27.00	42.33	13.00	13.20	18.00	23.42	71.00	64.70	26.00	24.31
17	1.60	0.37	32.00	39.20	12.00	12.18	20.00	32.29	60.00	62.02	23.00	21.35
18	1.60	0.37	30.00	33.16	12.00	11.34	41.00	48.46	41.00	48.46	20.00	19.14
19	5.40	2.27	26.00	27.09	12.00	10.62	66.00	48.86	31.00	37.73	18.00	17.34
20	9.20	1.73	23.00	22.70	11.00	10.01	51.00	37.37	25.00	31.06	16.00	15.93
21	8.20	1.49	20.00	19.56	11.00	9.48	36.00	31.96	29.00	43.60	16.00	15.34
22	19.00	5.88	17.00	17.20	10.00	9.01	34.00	35.41	50.00	105.54	14.00	14.10
23	19.00	8.48	15.00	15.38	10.00	8.60	37.00	36.86	183.00	115.28	14.00	13.27
24	20.00	19.64	13.00	13.93	9.70	8.23	38.00	31.10	148.00	78.43	16.00	14.34
25	37.00	28.46	12.00	12.77	9.10	7.90	33.00	26.09	85.00	57.81	15.00	14.05
26	28.00	23.83	11.00	11.81	8.60	7.60	28.00	22.35	53.00	43.67	14.00	13.47
27	22.00	22.53	11.00	11.04	8.10	7.36	24.00	19.61	37.00	34.78	13.00	12.63
28	20.00	22.04	10.00	10.33	7.60	7.07	20.00	17.60	30.00	28.83	13.00	12.00
29	17.00	18.65	9.10	9.74	7.20	6.83	19.00	18.88	0.00	0.00	12.00	11.45
30	17.00	17.70	8.60	9.23	6.90	6.61	20.00	21.07	0.00	0.00	11.00	10.95
31	16.00	16.31	0.00	0.00	6.60	6.41	18.00	20.94	0.00	0.00	11.00	10.51

1 OBSERVED AND PREDICTED RUNOFF FOR WY 1986

0 DAY	APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER	
	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED	OBS	PRED
1	10.00	10.14	21.00	18.64	5.40	6.13	2.30	3.07	1.40	1.59	0.93	0.83
2	9.80	9.79	20.00	17.61	5.10	5.97	2.30	3.01	1.40	1.55	0.92	0.81
3	9.10	9.41	18.00	16.06	5.00	5.82	2.30	3.02	1.30	1.52	0.87	0.79
4	8.60	9.10	16.00	14.50	4.90	5.68	4.60	3.38	1.30	1.49	0.82	0.78
5	8.00	8.81	16.00	14.74	4.70	5.54	2.80	2.84	1.30	1.46	0.79	0.76
6	7.60	8.54	16.00	14.38	4.70	5.40	2.50	2.76	1.30	1.43	0.76	0.75
7	7.30	8.29	15.00	13.21	4.50	5.27	2.30	2.70	1.30	1.40	0.77	0.73
8	6.90	8.05	14.00	12.24	4.30	5.15	2.20	2.64	1.20	1.37	0.88	0.73
9	6.70	7.82	14.00	11.48	4.10	5.02	2.20	2.59	1.20	1.34	1.10	0.71
10	6.40	7.61	14.00	11.97	4.00	4.91	2.80	2.91	1.20	1.31	0.90	0.70
11	7.00	7.97	14.00	11.98	3.90	4.79	2.90	2.56	1.20	1.29	0.88	0.67
12	7.40	7.75	13.00	11.24	3.70	4.68	2.50	2.43	1.20	1.26	0.82	0.66
13	6.80	7.72	15.00	12.15	3.50	4.58	2.30	2.37	1.20	1.23	0.85	0.64
14	6.30	7.39	13.00	11.92	3.70	4.50	2.20	2.32	1.20	1.21	0.87	0.63
15	6.10	7.24	13.00	11.22	3.60	4.37	2.20	2.28	1.10	1.18	0.89	0.63
16	9.40	11.66	12.00	10.62	3.50	4.27	2.40	2.37	1.00	1.16	1.00	0.64
17	12.00	16.70	12.00	10.10	3.70	4.27	2.40	2.21	1.00	1.13	1.30	0.69
18	11.00	16.30	11.00	9.64	3.80	4.25	2.20	2.14	1.00	1.11	1.30	0.58
19	11.00	14.63	10.00	9.34	3.40	3.99	2.10	2.09	1.10	1.09	0.99	0.57
20	10.00	13.29	10.00	8.97	3.80	3.91	2.00	2.05	1.00	1.06	1.30	0.66
21	9.70	12.21	9.90	8.87	3.00	3.82	1.70	2.00	0.98	1.04	0.98	0.54
22	9.10	11.31	9.30	8.33	2.90	3.74	1.70	1.96	0.97	1.02	0.89	0.53
23	8.50	10.56	8.60	8.00	2.70	3.66	1.70	1.92	0.90	1.00	4.80	1.57
24	8.40	10.04	8.00	7.74	2.60	3.58	1.70	1.88	0.94	0.98	4.20	1.03
25	11.00	14.40	7.50	7.49	2.60	3.50	1.60	1.84	0.92	0.96	8.70	2.29
26	14.00	22.86	7.10	7.26	2.50	3.42	1.60	1.80	0.89	0.94	7.80	0.90
27	20.00	29.76	6.80	7.05	2.50	3.35	1.60	1.76	0.86	0.92	4.60	0.56
28	24.00	29.59	6.40	6.85	2.50	3.28	1.60	1.73	0.91	0.90	3.70	0.56
29	24.00	25.16	6.10	6.65	2.50	3.21	1.50	1.69	0.99	0.88	4.10	1.03
30	23.00	21.27	5.90	6.47	2.40	3.14	1.50	1.66	1.10	0.88	3.50	0.91
31	0.00	0.00	5.60	6.30	0.00	0.00	1.50	1.62	0.98	0.85	0.00	0.00

```
                         O-PPT  N-PPT  XINT POTET ACTET                  SMELT              IRLOS P-ROFF  TO-ROFF  O-ROFF

ANNUAL SUMMARY 1986 OBSERVED PRECIP= 88.90  POTENTIAL ET= 30.93  PREDICTED RUNOFF(IN) =    61.09   OBSERVED RUNOFF(IN) =      61.66
                         NET PRECIP= 83.05     ACTUAL ET= 17.15                 (CFS)=   5083.75                  (CFS)=   5131.45
                   INTERCEPTION LOSS=  5.85     SNOWMELT=  0.00        MEAN DAILY(CFS)=    13.93         MEAN DAILY(CFS)=      14.06

GW IN= 17.77  SSR IN= 44.89  SSR TO GW=  7.52  SURFACE RO=  0.81  SSR FLOW= 37.34  GW FLOW= 22.94  GW SINK=  2.25
```

APPENDIX A

1

T
SUMMARY STATISTICS FOR WATER YEAR 1984

		MEAN RUNOFF (CFS)		TOTAL RUNOFF (CFS DAYS)		# OF RESIDUALS		# OF RUNS
		OBSV.	PRED.	OBSV.	PRED.	+	-	
0	OCT	1.85	1.98	57.20	61.37	10	21	2
0	NOV	48.29	47.65	1448.60	1429.62	20	10	7
0	DEC	25.21	29.15	781.60	903.58	6	25	4
0	JAN	29.65	34.56	919.00	1071.46	3	28	5
0	FEB	30.18	35.18	875.10	1020.34	7	22	4
0	MAR	23.13	25.02	717.00	775.60	16	15	6
0	APR	18.76	25.78	562.80	773.38	0	30	1
0	MAY	18.68	20.50	579.00	635.37	8	23	4
0	JUN	11.05	11.36	331.60	340.77	12	18	7
0	JUL	4.47	4.87	138.70	150.87	2	29	2
0	AUG	2.30	2.47	71.20	76.63	7	24	4
0	SEP	2.11	1.39	63.20	41.71	30	0	1
0								
	YEAR	17.88	19.89	6545.00	7280.69	121	245	36
0	MFS-MFN SEASON	17.88	19.89	6545.00	7280.69	121	245	36

0 RESIDUAL = OBSERVED - PREDICTED
MFS-MFN SEASON IS OCT TO SEP

1

T
SUMMARY STATISTICS FOR WATER YEAR 1985

		MEAN RUNOFF (CFS)		TOTAL RUNOFF (CFS DAYS)		# OF RESIDUALS		# OF RUNS
		OBSV.	PRED.	OBSV.	PRED.	+	-	
0	OCT	8.96	8.86	277.90	274.56	24	7	2
0	NOV	50.07	52.12	1502.00	1563.56	9	21	8
0	DEC	30.84	34.67	956.00	1074.82	9	22	6
0	JAN	12.18	13.90	377.60	430.97	1	30	2
0	FEB	15.70	21.51	439.60	602.32	9	19	4
0	MAR	18.88	17.71	585.30	549.09	21	10	7
0	APR	19.11	16.08	573.30	482.42	19	11	6
0	MAY	6.93	7.02	214.80	217.68	11	20	3
0	JUN	9.24	7.68	277.10	230.53	27	3	2
0	JUL	2.85	2.66	88.50	82.41	31	0	1
0	AUG	1.90	1.37	59.00	42.32	31	0	1
0	SEP	2.48	0.84	74.30	25.06	30	0	1
0								
	YEAR	14.86	15.28	5425.39	5575.74	222	143	33
0	MFS-MFN SEASON	14.86	15.28	5425.39	5575.74	222	143	33

0 RESIDUAL = OBSERVED - PREDICTED
MFS-MFN SEASON IS OCT TO SEP

APPENDIX A

1

T
SUMMARY STATISTICS FOR WATER YEAR 1986

		MEAN RUNOFF (CFS)		TOTAL RUNOFF (CFS DAYS)		# OF RESIDUALS		# OF RUNS
		OBSV.	PRED.	OBSV.	PRED.	+	-	
0	OCT	8.65	6.37	268.20	197.45	26	5	2
0	NOV	26.89	27.61	806.70	828.22	8	22	7
0	DEC	17.65	19.07	547.00	591.29	22	9	4
0	JAN	25.26	24.72	783.00	766.44	17	14	10
0	FEB	41.11	39.45	1151.00	1104.71	13	15	6
0	MAR	19.84	19.74	615.00	612.03	22	9	7
0	APR	10.64	12.85	319.10	385.38	2	28	4
0	MAY	11.88	10.74	368.20	333.02	25	6	2
0	JUN	3.65	4.44	109.50	133.19	0	30	1
0	JUL	2.17	2.31	67.20	71.60	7	24	7
0	AUG	1.11	1.18	34.34	36.55	5	26	4
0	SEP	2.07	0.80	62.21	23.88	30	0	1
0								
	YEAR	14.06	13.93	5131.45	5083.75	177	188	45
0	MFS-MFN SEASON	14.06	13.93	5131.45	5083.75	177	188	45

0 RESIDUAL = OBSERVED - PREDICTED
MFS-MFN SEASON IS OCT TO SEP

1

T
SUMMARY STATISTICS FOR OPTIMIZATION PERIOD 1984 TO 1986

		MEAN RUNOFF (CFS)		TOTAL RUNOFF (CFS DAYS)		# OF RESIDUALS		# OF RUNS
		OBSV.	PRED.	OBSV.	PRED.	+	-	
0	TOTAL	15.60	16.37	17101.83	17940.19	520	576	112
0	MFS-MFN SEASON	15.60	16.37	17101.83	17940.19	520	576	112

0 RESIDUAL = OBSERVED - PREDICTED
MFS-MFN SEASON IS OCT TO SEP

VERIFICATION CRITERIA

	DAILY		MONTHLY	
	TOTAL	MFS-MFN	TOTAL	MFS-MFN
COEFFICIENT OF DETERMINATION	0.854	0.854	0.965	0.965
(LOGS)	0.901	0.901		
0COEFFICIENT OF PERSISTENCE	-26.395	-26.395		
0COEFFICIENT OF GAIN FROM DAILY AVERAGES	0.709	0.709		
0RESIDUAL-PREDICTED CORRELATION	-0.453	-0.453		

ERROR SUMMARY (MFS-MFN PERIOD)

	ERRORS		ABSOLUTE ERRORS		SQUARED ERRORS	
	NO LOG	LOG	NO LOG	LOG	NO LOG	LOG
SUM	-838.43	12.58	3724.33	222.58	57263.16	107.71
MEAN	-0.76	0.01	3.40	0.20	52.25	0.10
PERCENT	-4.90		21.78		46.32	

APPENDIX A

```
                         ERROR SUMMARY (TOTAL PERIOD)
                      ERRORS                  ABSOLUTE ERRORS                SQUARED ERRORS
               NO LOG       LOG               NO LOG       LOG               NO LOG       LOG
     SUM      -838.43     12.58              3724.33    222.58             57263.16    107.71
    MEAN        -0.76      0.01                 3.40      0.20                52.25      0.10
 PERCENT        -4.90                          21.78                          46.32
1STORM PREDICTED  ROUTED   OBSERVED   PREDICTED OBSERVED
        VOLUME    OUTFLOW   OUTFLOW     PEAK     PEAK
       (INCHES)  (INCHES)  (INCHES)    (CFS)    (CFS)
----- -----------------------------  ------------------
     1     4.61      4.31      4.54    59.70     59.74
     2     5.35      5.00      4.16   109.39    104.45
     3     5.67      5.29      4.75   110.11    120.53

  MEAN     5.21      4.87      4.48    93.07     94.91
  LOGS     1.65      1.58      1.50     4.50      4.51


                            STORM VOLUME ERROR SUMMARY
                     ABS VALUE OBF FNC                   SUM OF SQUARES OBF FNC
                 NO LOG                   LOG            NO LOG                  LOG
     SUM          2.18                   0.44             2.27                  0.09
    MEAN          0.73                   0.15             0.76                  0.03
 PERCENT         16.21                                   19.41


                            STORM PEAK ERROR SUMMARY
                     ABS VALUE OBF FNC                   SUM OF SQUARES OBF FNC
                 NO LOG                   LOG            NO LOG                  LOG
     SUM         15.40                   0.14           133.08                  0.01
    MEAN          5.13                   0.05            44.36                  0.00
 PERCENT          5.41                                    7.02
1
              1 - NUMBER OF PRECIPITATION GAGES
              1 - NUMBER OF SEGMENTS SAVED FOR PLTGEN
              1 - NUMBER OF SEGMENTS SAVED FOR PRINT, PLOT, AND PLTGEN
              3 - NUMBER OF CURVES OUTPUT TO PLTGEN FILE(S)
              0 - NUMBER OF PLTGEN SEGMENTS SKIPPED
              3     0 NC1, NC2


          TIME0 1983   12    8    0    0
          TIMEN 1983   12   15   24    0
          LAPSED TIME    11521

           CH1   5   2

          INCDT  480
          MAXRD   24
          KOUNT    3
          KSKIP    0

          INC   24   24   24
          INC    1    1    1
```

APPENDIX B
Equivalent Modular Hydrologic Modeling System Parameter and Variable Labels

The daily simulations for all the basins were initially made using the Modular Hydrologic Modeling System (MHMS) computer software (Leavesley and others, 1992). Using Unix work station technology, MHMS incorporates the same algorithms of the original Precipitation-Runoff Modeling System (PRMS) program within a set of linked program modules. The major components of MHMS include a graphical user interface and a modular model library. The graphical user interface provides an interactive environment for users to access system features, apply selected options, and graphically display results on screen. The modular model library provides a collection of compatible simulation algorithms representing the hydrologic cycle. The library and its support functions permit the application of algorithms from more than one watershed model, in addition to PRMS. The user is allowed to use a predetermined module configuration or develop their own.

All final simulations for this study were made using the earlier version of PRMS described in Leavesley and others (1983). At the time of writing this report, MHMS had not been released for public use. Although MHMS uses many of the same PRMS algorithms, all parameter and variable labels were changed. The list below provides the equivalent PRMS label for many of the MHMS labels.

APPENDIX B

Parameters

MHMS Label	PRMS Label
adjmix_rain	AJMX
albset_rna	RMXA
albset_rnm	RMXM
albset_sna	ARSA
albset_snm	ARSM
basin_area	DAT
basin_tsta	ITSOL
carea_max	SCX
carea_min	SCN
ccov_intcp	RDC (in cc option)
ccov_slope	TDM (in cc option)
cecn_coef	CECN
cov_type	ICOV
covden_sum	COVDNS
covden_win	COVDNW
crad_coef	RDB
crad_exp	RDP
dday_intcp	RDM (in dd option)
dday_slope	RDC (in dd option)
den_init	DENI
den_max	DENMX
emis_noppt	EAIR
epan_coef	EVC
final_node	
freeh2o_cap	FWCAP

MHMS Label	PRMS Label
gw_node	
gwflow_coef	RCB
gwsink_coef	GSNK
gwstor_init	GW
hamon_coef	CTS
hi_index	
hru_area	DARU
hru_deplcrv	KDC
hru_elev	ELV
hru_gwres	KGW
hru_imperv	IMPERV
hru_node	
hru_psta	IDS
hru_radpl	IRD
hru_slope	SLP
hru_ssres	KRES
hru_tsta	KTS
imperv_stor_max	RETIP
jh_coef	CTS
jh_coef_hru	CTX
lo_index	
melt_force	ISP2
melt_look	ISP1
moyrsum	

APPENDIX B

Parameters

MHMS Label	PRMS Label
node_type	
pmo	
potet_sublim	CTW
rad_trncf	TRNCF
radadj_intcp	RTB
radadj_slope	RTC
radj_sppt	PARS
radj_wppt	PARW
radmax	RDMX
radpl_aspect	ASP
radpl_lat	ALAT
radpl_slope	SL
rain_adj	DRCOR
route_time	
settle_const	SETCON
smidx_coef	SCN
smidx_exp	SC1
snarea_curve	
snarea_thresh	AIMX
snow_adj	DSCOR
snow_intcp	SNST
snowinfil_max	SRX
soil2gw_max	SEP
soil_moist_init	SMAV
soil_moist_max	SMAX

MHMS Label	PRMS Label
soil_rechr_init	RECHR
soil_rechr_max	REMX
soil_type	ISOIL
srain_intcp	RNSTS
ssr2gw_exp	REXP
ssr2gw_rate	RSEP
ssr_gwres	KRSP
ssr_node	
ssrcoef_lin	RCF
ssrcoef_sq	RCP
ssrmax_coef	RESMX
ssstor_init	RES
tmax_adj	TXAJ
tmax_lapse	TLX
tmaxf_allrain	PAT
tmaxf_allsnow	BST
tmaxf_index	TSOLX
tmin_adj	TNAJ
tmin_lapse	TLN
tonode	
transp_beg	ITST
transp_end	'ITND
transp_tmaxf	TST
tsta_elev	CSEL
tstorm_mo	MTSS-MTSE
wrain_intcp	RNSTW

APPENDIX B

Variables

MHMS Label	PRMS Label
albedo	
basin_actet	ETA
basin_actet_mo	
basin_cfs	
basin_et	
basin_et_mo	
basin_gwflow	BAS
basin_gwflow_mo	
basin_gwin	
basin_gwsink	
basin_gwstor	SGW
basin_infil	
basin_intcp_evap	
basin_intcp_stor	
basin_max_temp_mo	
basin_min_temp_mo	
basin_net_ppt	
basin_net_ppt_mo	
basin_potet	
basin_potet_mo	
basin_ppt	PP
basin_ppt_mo	
basin_pweqv	
basin_snowcov	
basin_snowevap	
basin_snowmelt	
basin_snowmelt_mo	
basin_soil_moist	
basin_soil_rechr	

MHMS Label	PRMS Label
basin_sroff	SAS
basin_sroff_mo	
basin_ssflow	RAS
basin_ssflow_mo	
basin_ssin	
basin_ssstor	RS
basin_stflow	
basin_stflow_mo	
basin_storage	
basin_tmaxf	
drad	
form_data	
gw_in_soil	UGS
gw_in_ssr	SSGW
gwres_area	
gwres_flow	BASQ
gwres_in	
gwres_sink	GWSNK
gwres_stor	GW
hru_actet	AET
hru_actet_mo	
hru_net_ppt_mo	
hru_perv	PERV
hru_potet_mo	
hru_ppt	PPT
hru_ppt_mo	

APPENDIX B

Variables

MHMS Label	PRMS Label
hru_rain	PRN
hru_snow	PSN
hru_snowmelt_mo	
hru_sroff_mo	
imperv_evap	EVIMP
imperv_stor	RSTOR
infil	ENFIL
intcp_evap	
intcp_form	
intcp_on	
intcp_stor	
net_ppt	
net_rain	
net_snow	
newsnow	
node_cfs	
obs_inches	
obs_inches_mo	
order	
pan_evap	
perv_actet	
pk_den	
pk_temp	
pkwater_equiv	
potet	PET
pptmix	IMIX
pptmix_nopack	
precip	
prmx	
pvnode_cfs	

MHMS Label	PRMS Label
radpl_cossl	COSSL
radpl_potsw	RAD
radpl_sunhrs	DYL
runoff	
snow_evap	
snowcov_area	
snowmelt	
soil_moist	SMAV
soil_rechr	RECHR
soil_to_gw	UGS
soil_to_ssr	USS
solrad	
sroff	SRO
ssr_to_gw	SSGW
ssres_area	
ssres_flow	RASQ
ssres_in	EXSS
ssres_stor	RES
swrad	SWRD
tavgc	TAVC
tavgf	TAVF
tcal	
tmaxf	TMXF
tminf	TMNF
tonode_cfs	
transp_check	IT
transp_on	ITSW

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