

# Conceptualization and Simulation of Runoff Generation from Rainfall for Three Basins in Thurston County, Washington

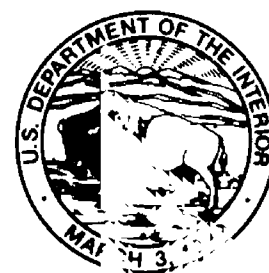
By S. N. Berris

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U.S. GEOLOGICAL SURVEY

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## CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047.	square meter
square mile (mi <sup>2</sup> )	2.590	square kilometer
cubic foot per second (ft <sup>3</sup> /s)	0.028317	cubic meter per second
degree Fahrenheit (°F)	°C=5/9 x (°F-32)	degree Celsius

# Conceptualization and Simulation of Runoff Generation from Rainfall for Three Basins in Thurston County, Washington

By S. N. Berris

## ABSTRACT

A study was conducted to conceptualize and simulate the generation of runoff from rainfall in three drainage basins in north-central Thurston County, located at the southern end of the Puget Sound Lowland of western Washington. The drainage basins in the area are complex because the basin properties (such as geology, soils, topography, land covers, and climate) that influence the characteristics of runoff vary from one part of the area to another. The study basins--Percival Creek, Woodard Creek, and Woodland Creek--face urban development that will also affect the characteristics of runoff. A conceptual model was derived to link the physical properties of the three basins to the drainage mechanisms and hydrologic processes that govern runoff generation. The conceptual model provided a qualitative framework for quantifying the generation of runoff in numerical simulation models, called basin models, constructed for each of the study basins. Hydrological Simulation Program-FORTRAN (HSPF) was the hydrologic-simulation program used to construct the basin models. Streamflow data collected at five streamflow-gaging stations over a 2-year period from March 1988 to March 1990 were used for model calibration.

The study, conducted in cooperation between the U.S. Geological Survey and the Thurston County Department of Public Works, found that the conceptual model of runoff generation adequately described runoff generation in the three study basins. The seven features included in the conceptual model differentiated the drainage mechanisms of runoff in undisturbed and disturbed areas of the study basins. The main runoff mechanisms of undisturbed

areas were identified as shallow subsurface flow from hillslopes mantled with glacial till, bedrock, and, to a lesser degree, lacustrine deposits; as ground-water flow from glacial-outwash deposits; and as saturation overland flow from depressions, stream bottoms, and flat upland areas underlain by glacial till or, less so, lacustrine deposits. Hortonian overland flow was not an important mechanism in undisturbed areas. In disturbed impervious areas, however, Hortonian overland flow was the dominant mechanism. In disturbed pervious areas, Hortonian overland flow also was an important mechanism in combination with some of the other mechanisms. Surface detention and retention storage, interception, and plant transpiration were less characteristic of disturbed areas than of undisturbed areas.

The conceptual model was tested by incorporating its features into basin models built with Hydrological Simulation Program-FORTRAN (HSPF). The simulation results from the basin models generally confirmed the study's conceptual model. Absolute differences between simulated and observed total runoff volumes for the entire calibration period were less than 6 percent; differences for each single water year were less than 8 percent. Seasonal runoff differences also were generally modest. Absolute differences for winter and spring runoff were less than 8 percent for the entire calibration period. Although absolute differences for summer runoffs were as much as 100 percent, the large percentages represented only a small actual difference in the total volume of runoff. The simulations produced mean absolute differences of daily mean discharges equal to or less than 32 percent. However, these differences exceeded an average 25 percent at only one of five stations. Large daily mean discharges were

generally the most accurately simulated; mean absolute differences were less than 15 percent. Absolute differences for storm runoff volumes and peak discharges were less than 32 percent and 33 percent, respectively.

In addition to confirming the conceptual model of runoff generation, the simulations for this study showed that the values of most HSPF land-segment parameters obtained from a previous study of other Puget Sound basins also applied to the Thurston County study basins. The exception was the value for the parameter KVAR, which governs ground-water discharge rates in the simulation models. Parts of the study area are underlain by aquifers that responded differently to rainfall than did the aquifers underlying the areas in the earlier study that first determined the parameter value. The value for this parameter will likely vary elsewhere in the Puget Sound Lowland.

It was also found that the conceptual model of runoff generation did not adequately describe the flow paths from land segments to streams. The study showed that both the flow paths between land segments and streams and the hydraulic characteristics of streams varied throughout the study basins.

## INTRODUCTION

Rural, undeveloped land in north-central Thurston County, Wash., faces development into urban and suburban communities that will change the hydrology of the County's drainage basins. Development will cover pervious areas with such impervious surfaces as pavement and buildings, and the added impervious area will decrease the infiltration of rainfall into the soil and ground-water system and increase the flow of water over the ground directly to streams. Additionally, the added impervious surfaces allow more rapid drainage because of reduced depression storage and surface roughness. Runoff will increase, and the increase will not be limited to the immediate area of the development but will extend downslope and downstream. The increased runoff may result in increased soil erosion, increased flood magnitudes and frequencies, and increased degradation of fish habitat.

Adverse changes in runoff can be mitigated by limiting the rate and volume of runoff after development to those existing before development. Such planning requires the determination of what runoff rates and volumes are before development and what they will be afterwards. Streamflow records can help determine predevelopment runoff, although they often are not sufficiently

long enough for that task. Post-development runoff, however, can be determined only by use of some type of predictive method. Runoff rates and volumes before and after development can be estimated by a hydrologic-simulation program.

A hydrologic-simulation program can represent how basin properties affect the hydrologic processes involved in generating runoff from rainfall. Such basin properties that affect runoff include basin area, geology, soils, topography, vegetation, land cover, and climate. The hydrologic processes involved in runoff generation include evapotranspiration, interception, infiltration, percolation, and flow of water over the land and laterally through the earth. Once calibrated, hydrologic-simulation programs can simulate runoff characteristics resulting from future development in a basin by adjusting parameter values that represent land cover and vegetation properties in that basin. Thus, these programs are helpful to assess how alternative urban-development plans may change runoff characteristics.

A sensible strategy for constructing a hydrologic-simulation program is (1) to qualitatively describe the hydrologic processes that generate runoff from rainfall in a conceptual model and (2) to quantitatively describe the hydrologic processes conceptualized to generate runoff in a numerical model. The conceptual and numerical models can be evaluated by comparing model-simulated runoff values with observed runoff data. If the numerical model adequately simulates runoff, then it can serve as a useful tool for predicting changes in runoff resulting from changes in basin properties, such as from urban development.

The drainage basins in north-central Thurston County are complex because basin properties vary dramatically from one part of the area to another. Therefore, alternative urban-development plans cannot be examined using simple, empirical runoff relations. To conceptualize and simulate runoff generation in three complex Thurston County drainage basins--Percival Creek, Woodard Creek, and Woodland Creek--the U.S. Geological Survey entered into a cooperative agreement with the Thurston County Department of Public Works, the agency responsible for mitigating adverse changes in runoff that may come from development.

The program chosen for this study was the Hydrological Simulation Program-FORTRAN (HSPF; U.S. Environmental Protection Agency, 1984), on which basin models would be constructed. HSPF can represent the pertinent basin properties, such as soils, surface cover, and



topography, that affect the movement and storage of water in the basins. HSPF also simulates hydrologic processes (evapotranspiration, interception, infiltration, percolation, and flow of water over the land and laterally through the earth) by allocating and distributing water to drainage pathways and storage reservoirs according to values of specified parameters. When HSPF-based basin models accurately simulate hydrologic processes, the streamflows simulated by those models match actual streamflows. This study compared simulated streamflow values with streamflow data collected at gaging stations in order to assess how accurately the basin models simulated runoff generation processes.

A previous study conceptualized and simulated the influence of soils, surface cover, and topography on runoff generation in headwater basins in King and Snohomish Counties, about 60 miles northeast of Thurston County (Dinicola, 1990). Because the King and Snohomish County basins and the Thurston County basins have similar soils, surface cover, and topography, the conceptual model formulated for the Thurston County basins incorporated the conceptual model formulated for the King and Snohomish County basins. Thurston County, however, does have large areas covered by soils that are not common in the King and Snohomish County basins. Therefore, parts of the previous study's conceptual model have been modified in this study to accommodate the differences in soils, and these modifications have been incorporated into the simulation of runoff generation in the Thurston County basins.

## **Purpose and Scope**

This report (1) describes a qualitative conceptual model of how runoff is generated in three Thurston County basins, (2) explains the construction of numerical models that were based on the conceptual model and parameter values formulated for other Puget Sound basins and that were designed to simulate runoff generation in the Thurston County basins, (3) presents both the calibration strategy used in model development and the statistical measures of the final model accuracy, and (4) discusses the significant results regarding the adequacy of the models in describing runoff generation and the inadequacy of the models in describing flow paths from land segments to streams.

The conceptual model of the study basins provides a qualitative framework for quantifying how basin properties govern the movement and storage of water and thereby influence runoff generation. This report explains

how the conceptual model was transformed into numerical models (simulation models) constructed with HSPF; how the conceptual model guided assignment of numerical values to HSPF parameters; and how the simulation models were calibrated to simulate runoff in the Percival Creek, Woodard Creek, and Woodland Creek Basins.

Data to operate and calibrate the simulation models were collected between March 1988 and March 1990. Rainfall data (15-minute time step) and potential evapotranspiration (PET) values (daily time step) were used as input time series for operating the models. Stream discharge data (15-minute time step) were compared with simulated streamflow values during model calibration.

## **Acknowledgments**

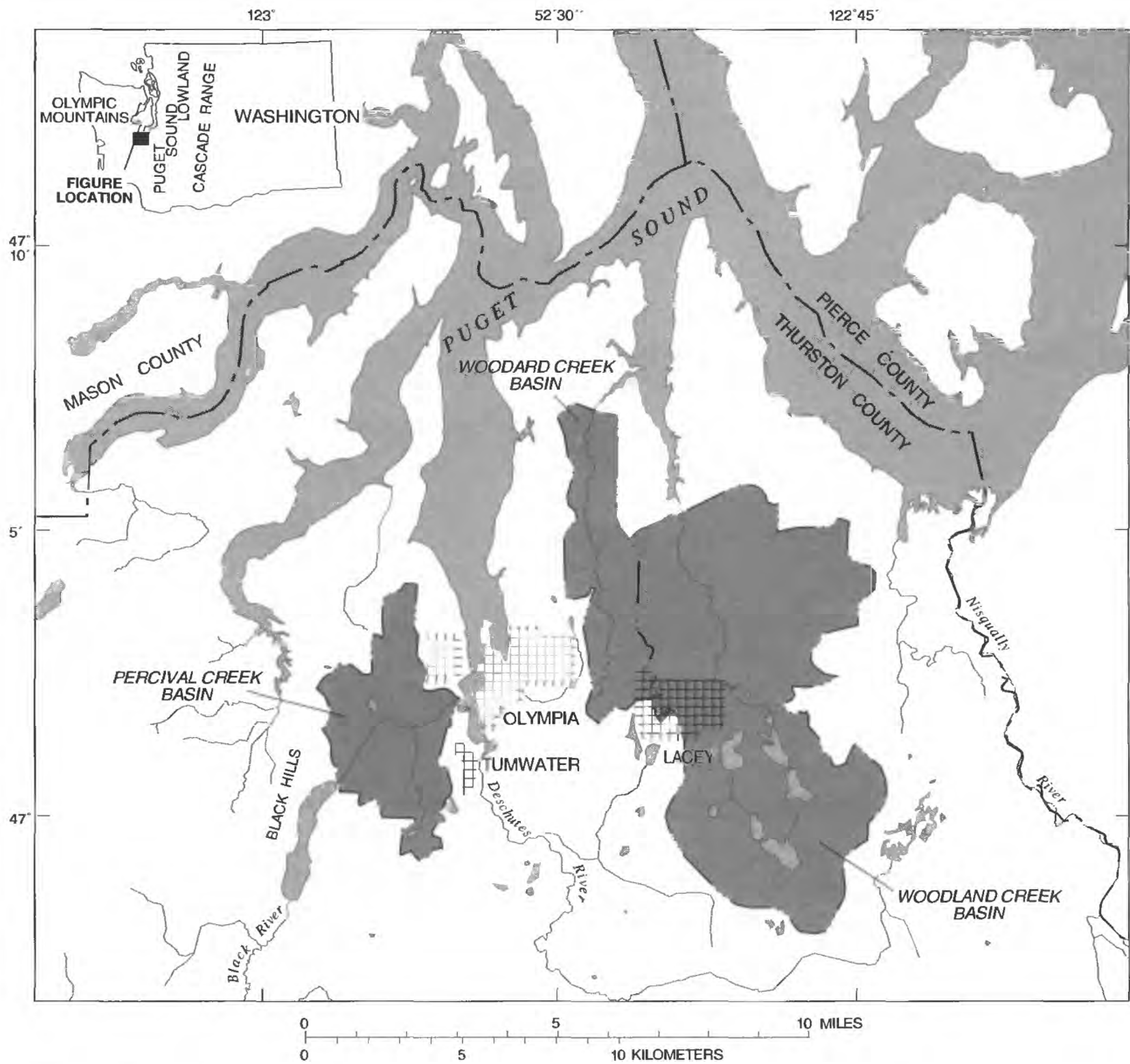
Personnel from the Storm and Surface Water Utility and the Thurston Geographical Information Facility of the Thurston County Department of Public Works and from the Environmental Health Division of the Thurston County Health Department have assisted with the design, data collection, and mapping involved in this study. Several Thurston County citizens have allowed gage installations on their property and have recorded data for the study. Their cooperation and assistance is appreciated.

## **DESCRIPTION OF THE STUDY AREA**

The three study basins lie in north-central Thurston County, in western Washington at the southern end of the Puget Sound Lowland (fig. 1). The Lowland trends north and south between the Cascade Range to the east and the Olympic Mountains to the west, and it is partly occupied by the waters of Puget Sound. This broad, rolling glacial-drift plain has undergone several episodes of glacial deposition. Its surface layers were formed by erosion and deposition during the last glaciation period about 15,000 years ago (Noble and Wallace, 1966) and by the large prehistoric meltwater Lake Russell. The southern limit of glaciation extends slightly south of the study area. Along the southwestern edge of the study area, bedrock ridges of basalt and sandstone known as the Black Hills protrude above the drift plain.

The three study basins cover a total of 40 square miles: Percival Creek, 8 square miles; Woodland Creek, 26 square miles; and Woodard Creek, 6 square miles. All are situated on the drift plain, except for the southwestern edge of the Percival Creek Basin, which extends into the bedrock of the Black Hills.





**Figure 1.--Location of the study area and basins used for model calibration and evaluation.**

The mid-latitude, west-coast marine climate of the study area produces warm, dry summers and cool, wet winters. The mean annual temperature at Olympia is about 50°F, and the mean monthly temperatures in January and July are about 37°F and 63°F, respectively. Mean annual precipitation at Olympia is about 51 inches, most of which falls as rain. About 79 percent of this precipitation falls between October and March as long-duration storms of light to moderate intensity (National Oceanic and Atmospheric Administration, 1982).

The landscape of the study basins is complex. It exhibits varied (rather than uniform) topography, land cover, and soils, all of which interact with water from rainfall and influence the generation of runoff.

Two landform types dominate parts of the study basins within the drift plain: (1) rolling, hilly areas of glacial till and stratified, glacial lake-laid sediments and (2) level to mildly undulating areas of glacial outwash. Many depressions in the glacial outwash areas have no outward surface drainage and are referred to as "closed". The southwestern edge of the study area, known as the Black Hills, is not within the drift plain. It consists of moderately to steeply (up to 65 percent) sloping ridges.

Land cover in the drainage basins predominantly consists of forest, grass, water, and impervious areas. Ample rainfall in the wet season supports evergreen forests, and they are widespread throughout the study basins. However, grassy areas, or prairies, lie on soils derived from glacial outwash that drain too quickly to support dense forests. Water commonly covers areas of the study basins: swamps and peat bogs occupy depressions in areas of glacial till and lake-laid sediments, and three large lakes fill depressions in Woodland Creek Basin's southern areas of glacial outwash. Grass and impervious surfaces overlie land converted to urban and residential uses. Impervious cover is found throughout the study area but is most common along an east-west axis midway between the northern and southern parts. The impervious cover, commonly pavement and buildings, prevents nearly all downward drainage, causing water to drain laterally over the surface.

Most soils in the drainage basins derived from deposits of glacial till, glacial outwash, and lake-laid sediments on the drift plain. Soils near the southwestern boundary of Percival Creek Basin derived from the weathered basalt and sandstone of the Black Hills (U.S. Department of Agriculture, 1990).

Soils derived from glacial till, common in the northern peninsular regions, are made up of a loose 2- to 4-foot layer of ablation till on top of a dense 3- to 45-foot layer of basal till. The loose ablation till consists of a highly permeable gravelly silt loam derived from sediments that settled from the surface of melting ice. Basal till consists of a strongly compacted material of low permeability, commonly known as hardpan. Derived from sediments compacted by the pressure of ice, basal till retards the downward movement of water and causes winter and spring periods of saturated soils and summer periods of only moderate moisture retention.

Soils derived from glacial outwash are common in the southern and east-central parts of Woodland and Woodard Creek Basins and in the south-central part of Percival Creek Basin. Outwash soils, formed from sediments deposited by heavily laden glacial-meltwater streams, consist of poorly sorted, unconsolidated deposits of coarse sand and gravel at least 10 to 20 feet thick. These loose, gravelly loam soils are highly permeable and tend to drain quickly.

Soils derived from stratified, glacial lake-laid (lacustrine) sediments are found in the northern peninsular regions of the Woodland and Woodard Creek Basins. These soils consist of silty loams, averaging 2 feet in thickness, that overlie fine-textured clays and silty clays 2 to 10 feet thick. The fine-textured substratum slows downward drainage, causing periods of saturated soil conditions during winter. The moderately fine-textured upper layer of silty loam helps these soils retain moisture during the summer.

Soils derived from Black Hills rock consist mainly of a 4-foot-thick mantle of gravelly, moderately permeable silt loams overlying basalt or sandstone bedrock. Poorly drained soils derived from a variety of sources are found locally in depressions and low areas along drainageways throughout the study area. The soils in these places are often saturated because the water table is at or near the surface for most of the year.

## CONCEPTUAL MODEL

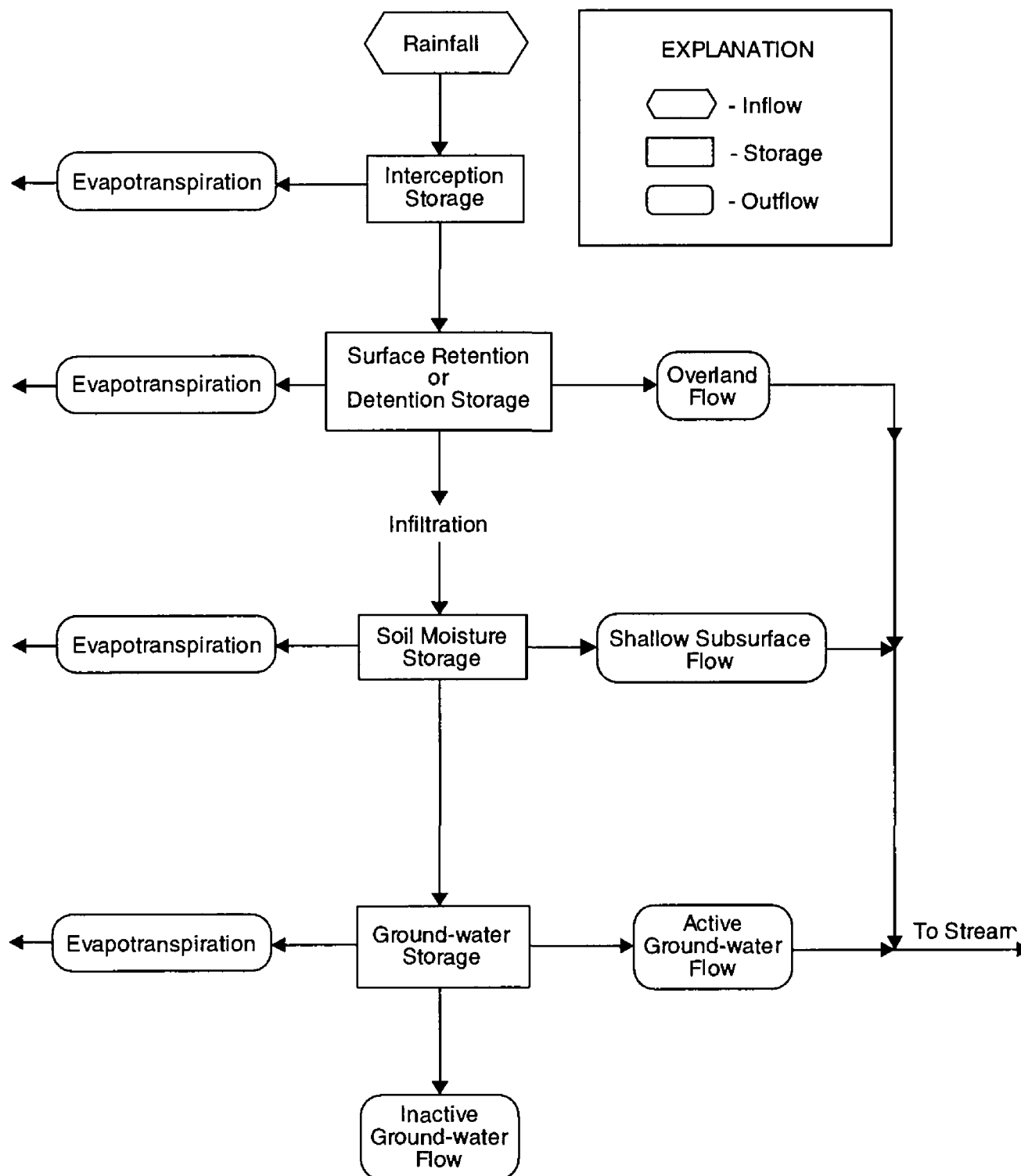
A conceptual model can provide a qualitative description of how the underlying hydrologic system works. The conceptual model derived for the Thurston County study area was drawn partly from the description of the study area, and partly from past research and observations of rainfall-runoff processes. The conceptual

model provided a framework for understanding runoff generation and for constructing numerical simulation models for the study basins.

The following review of rainfall-runoff processes in the study basins is included to provide background information on the specific conceptual model determined for this study. Fluxes and storages related to the rainfall-runoff processes are shown in schematic form in figure 2.

## Rainfall-Runoff Processes

Rainfall over the basins reaches the canopy of trees and shrubs or falls directly onto the surface of the ground. Water intercepted by the canopy remains stored on leaves and branches for later evaporation. When the canopy can hold no more (when its interception capacity is met), additional rainfall will drip off the branches and leaves or flow down the stems to the ground surface, where it joins rainfall that has fallen directly there.



**Figure 2.**--Fluxes and storages related to the rainfall-runoff process.

On the ground surface, water may collect in small surface depressions or infiltrate into the soil. Water is stored in small surface depressions as either retention storage or detention storage. Only evaporation can remove water in retention storage. If the depressions that retain water are filled with water (if, in other words, the retention storage capacity of the surface is met), then additional water falling on the surface will flow over the tops of these depressions as overland flow. Water in detention storage is only temporarily stored before it will move downgradient either by overland flow or by infiltration into the ground.

Water can flow downgradient on the surface of the ground as overland flow. Overland flow occurs in two distinct situations: (1) when the rainfall intensity exceeds the soil's infiltration capacity and moves over the surface as Hortonian overland flow or (2) when the water table rises to the surface of the ground, thereby saturating the soil and causing the overland flow called saturation overland flow. Runoff rates of overland flow, which depend on slope, are generally quick, peaking quickly after rainfall intensity peaks and declining quickly after rainfall intensity slackens.

Water that infiltrates into the soil moves into what is called soil moisture storage. This stored water can later undergo evaporation or transpiration, or it can move laterally or downward through the soil. If it accumulates in the soil above a drainage-impeding horizon, it may flow laterally just above the horizon as shallow subsurface flow, often referred to as interflow. Such horizons occur in the study basins at the top of compacted basal till, compacted glacial-lake sediments, and bedrock. Rates of subsurface flow depend on slope, but they are usually fairly quick, though slower and more attenuated than overland flow (Viessman and others, 1977; and Dunne and Black, 1970).

Water in the soil that recharges the ground-water system may be available for transpiration, or it may flow downgradient as ground-water flow. Ground-water flow that seeps out of the ground to a surface-water channel is called active ground-water flow; ground-water flow that does not reach a surface-water channel is called inactive ground-water flow. Ground-water flow is generally much slower and more attenuated than shallow subsurface flow or overland flow (Viessman and others, 1977).

Overland flow, shallow subsurface flow, and ground-water flow, the three runoff pathways, often interact, and all may occur simultaneously in a basin. Overland flow, for example, may infiltrate and become shallow subsurface or ground-water flow when land cover, such as forest litter, limits the velocity of overland flow and provides

storage for later infiltration. As another example, when rain falls on a soil that slowly drains by shallow subsurface or ground-water flow, prolonged infiltration may fill the soil's storage capacity. If the soil profile is saturated to the surface, then the infiltration rate is reduced to zero, and saturation overland flow will occur.

Rainfall allocated to the three drainage pathways may contribute to streamflow either by seeping or by flowing into channels in the drainage network. In the drainage network, it moves downgradient toward a basin mouth. The water is now measurable as streamflow, or runoff. Determining streamflow rates, also called discharge, involves considering the volume of water in a channel and such hydraulic properties of a channel as the slope, the channel shape, and the channel roughness.

There are, thus, three drainage pathways for the four generally accepted drainage mechanisms: an overland flow pathway for either the Hortonian overland flow or the saturation overland flow mechanism; a shallow subsurface flow pathway for the shallow subsurface flow mechanism; and a ground-water flow pathway for the ground-water flow mechanism (Pearce and others, 1986; Dunne and Leopold, 1978). (It is inconvenient, but the same name can designate both the pathway and the mechanism.) These four mechanisms are the intermediaries between basin properties and runoff responses. That is, by means of the four drainage mechanisms, certain basin properties are consistently related to certain runoff responses. The conceptual model associates basin properties with runoff responses by these four drainage mechanisms. More detailed descriptions of the four mechanisms with specific regard to the study basins are presented below.

### **Hortonian Overland Flow**

Hortonian overland flow occurs when the rainfall rate exceeds the infiltration rate of a soil. The upper soil becomes saturated before lower parts do, surface depressions fill with water, and runoff begins. The rate of runoff peaks soon after the rainfall rate peaks and then declines quickly after the rainfall rate subsides below the infiltration rate of the soil. This mechanism rarely occurs in undisturbed, forested areas with ample forest litter and natural soil structure. The litter detains even heavy rainfall so that it has time to percolate into the soil profile.

Hortonian overland flow is an unlikely drainage mechanism in the undisturbed, forested parts of the Thurston County study basins, where the rainfall rate seldom exceeds the soil's infiltration capacity. The 2-year,

1-hour rainfall rate in the study basins is about 0.5 inch per hour. (The 2-year, 1-hour rainfall rate is the average rate of rainfall over a 1-hour interval that is exceeded only once every 2 years.) The 100-year, 1-hour rainfall rate is about 1.1 inches per hour (U.S. Department of Commerce, 1973). These rates are lower than the saturated hydraulic conductivities of soils in most of the study area, which vary between 2 and 6 inches per hour (U.S. Department of Agriculture, 1990). The saturated hydraulic conductivity of a soil is its minimum infiltration rate (Skaggs and Khaleel, 1982; Steinbrenner and Gessel, 1955). In some places, study area soils have lower saturated hydraulic conductivities of 0.6 to 2 inches per hour, but rainfall rates reach or exceed 0.6 inch per hour only once in about 15 years. Thus, Hortonian overland flow seldom occurs because most undisturbed forest soils in the study area can detain rainwater from storms in the forest litter and store it in depressions for later percolation into the soil (Burgess, 1989).

When urban development transforms natural land surfaces, it can change the types and relative effects of the mechanisms that generate runoff. The largest changes occur when an impervious surface, a pavement or a building, for instance, covers a formerly pervious surface and reduces the amount of area over which infiltration can take place. Hortonian overland flow then becomes a dominant mechanism, producing larger volumes of runoff at faster rates than would take place on pervious areas. Impervious areas directly connected to drainage networks cover about a tenth of the study basins.

Urban development activities can also affect runoff processes on pervious parcels within a developed area. Compacting the soil and clearing away vegetation and forest litter can increase runoff rates and volumes. Clearing and grading land eliminates surface depressions that provide retention storage. Adding imported, fine-textured topsoils to lawns and gardens, parks, and golf courses reduces soil porosity in the upper soil. Replacing deep-rooted trees with shallow-rooted vegetation disturbs soil structure. Because all of these activities diminish the soil's capacity to infiltrate water, they promote Hortonian overland flow.

Disturbing pervious areas also makes more water available for runoff. More water drains from adjacent rooftops and similar surfaces, and less water is intercepted as rainfall by plant surfaces. Less water is removed by transpiration of soil moisture.

### **Saturation Overland Flow**

When rain falls on saturated soil and cannot infiltrate, saturation overland flow is generated. This condition develops in areas like stream bottoms, depressions, and many other flat or low-lying areas where soils are poorly drained and easily saturated during wet periods. Rainfall infiltration or shallow subsurface flow and ground-water flow from adjacent hillslopes raise the water tables and saturate the low-lying soils. Once these soils are saturated, further rainfall will generate flow over the soil surface. These poorly drained areas, essentially acting like impervious areas, produce quick, sharp runoff responses. Although both saturation overland flow and Hortonian overland flow take place over the soil surface, the conditions that initiate them are different. In contrast to saturation overland flow, Hortonian overland flow occurs when the texture and structure of the upper soil layers inhibit infiltration.

Saturation overland flow can be an important mechanism in two distinct settings in the study area. The first setting comprises areas of flat to mildly undulating soils, usually in uplands, derived from glacial till or lacustrine sediments. In these areas, which make up about 8 percent of the study area, direct precipitation is the main contributor of water to saturation overland flow, though incoming shallow subsurface and ground-water flow from surrounding hillslopes may also contribute. Because these soils usually can hold at least 12 inches of water before they are saturated, they may need priming from a prolonged wet period before saturation overland flow begins after the summer dry season. During a wet period such as late winter or early spring, the soils, already primed, may need only a single storm to initiate saturation overland flow.

The second setting for saturation overland flow consists of topographic depressions and areas adjacent to streams or other drainage courses. In these areas, which make up about 7 percent of the study area, the water table may be near or above land surface throughout the year. Shallow subsurface flow, ground-water flow, and direct precipitation may all contribute substantial quantities of water to saturation overland flow when these areas are saturated. Because the soils are commonly saturated throughout the year and the water tables are high, these areas generate runoff more frequently and more copiously than the upland areas with till and lacustrine-sediment deposits.

## **Shallow Subsurface Flow**

Shallow subsurface flow is common where moderately to highly permeable soil layers lie over a substratum of low permeability, such as compact glacial till or bedrock. Shallow subsurface flow is generated when rainfall rapidly infiltrates the upper layers of the soil and accumulates above a substratum of low permeability that impedes vertical drainage. The accumulated water will flow laterally downhill through the permeable soil until a break in slope, a topographic convergence, or an incised channel allows the water to seep, or exfiltrate, to the surface.

The rate of shallow subsurface flow is directly related to the slope. If the slope is mild or flat, shallow subsurface flow will only slowly move through the soil matrix. In these flat or mildly sloping soils, water can accumulate above the drainage-impeding substratum and saturate the soil matrix to the surface to generate saturation overland flow. Runoff rates from shallow subsurface flow are usually fairly quick, but these rates are slower and more attenuated than runoff rates from overland flow (Viessman and others, 1977; and Dunne and Black, 1970).

Shallow subsurface flow is a predominant drainage mechanism on hillslopes in both undisturbed and developed areas of the study basins where soils derived from glacial till or lacustrine deposits or where shallow soils lie over bedrock. The upper horizon of these soils, typically 2 to 4 feet thick, has a saturated hydraulic conductivity greater than 0.6 inch per hour; the substratum has a hydraulic conductivity of less than 0.06 inch per hour (U.S. Department of Agriculture, 1990). These soils cover about 22 percent of the study area.

## **Ground-Water Flow**

Runoff from ground-water flow is generated when water percolates through the soil matrix until it reaches the ground-water system and then flows toward surface channels or, in the study area, toward Puget Sound. Ground-water flow is a large component of total runoff in areas where soils are derived from glacial-outwash deposits. These soils, which cover about half the study area, are extremely permeable, having saturated hydraulic conductivities greater than 2 inches per hour, so rainfall infiltrates rapidly to recharge ground-water reservoirs. Because these soils are rarely saturated, water typically is not diverted from ground-water recharge by overland flow under any slope condition. Runoff rates from a storm by ground-water flow generally are much slower and more

attenuated than by shallow subsurface or overland flow--usually on the scale of days rather than hours in small basins (Viessman and others, 1977). The slope of the water table, which usually follows topography, influences the rate of ground-water flow (Heath, 1983): the steeper the slope, the faster the flow rate. In the glacial-outwash deposits of the study area, however, both topography and water table slopes are fairly mild.

## **Conceptual Features of Runoff Generation in the Study Basins**

The drainage mechanisms and hydrologic processes discussed above are the basis for the conceptual model of runoff generation in the Thurston County study area. The following seven features of the model are the same as those applied by Dinicola (1990) to headwater basins in King and Snohomish Counties, except that in this study the second and third features have been modified to include runoff generation from shallow soils underlain by bedrock or fine-grained lacustrine deposits. The first four features apply to undisturbed forested areas.

- (1) Classic Hortonian overland flow is not an important mechanism in most, if not all, of these undisturbed areas.
- (2) Saturation overland flow is the predominant mechanism in depressions, stream bottoms, and flat upland areas mantled by glacial till. It is a secondary mechanism in flat upland areas underlain by fine-grained lacustrine deposits. Runoff is generated more rapidly and more often from the depressions and stream bottoms than from the flat uplands. In the flat uplands, runoff is generated only during prolonged wet periods.
- (3) Shallow subsurface flow, sometimes combined with seepage, is the predominant drainage mechanism on hillslopes mantled with glacial till, bedrock, or, to a lesser degree, fine-grained lacustrine deposits. Within the soil profile, water does not move readily, but once it seeps to the surface, it may become a large part of storm runoff. The rate of runoff from subsurface flow is proportional to the angle of the hillslope.
- (4) Ground-water flow is the predominant mechanism on glacial-outwash deposits. Runoff rates from this mechanism are slow and attenuated.

The final three features apply to disturbed nonforested areas. The fifth and sixth features pertain to mechanisms that generate runoff, and the seventh feature pertains to additional hydrologic processes affected by disturbances of natural, pervious areas.

- (5) Rapid Hortonian overland flow is the sole drainage mechanism on impervious areas.
- (6) Hortonian overland flow, in combination with other runoff mechanisms, is a viable drainage mechanism in disturbed pervious areas where development changes the soil structure and texture and increases the moisture supply from nearby impervious surfaces.
- (7) Pervious parcels within disturbed areas have decreased surface detention, decreased detention storage, decreased rainfall interception, and decreased plant transpiration.

## **SIMULATION OF RUNOFF GENERATION**

Three basin models using Hydrological Simulation Program-FORTRAN, one for each study basin, were constructed to approximate the conceptual model numerically and to simulate the runoff generation. The following sections describe (1) how the HSPF program simulates runoff generation, (2) how the basin models were constructed, and (3) how the basin models were calibrated to observed streamflow.

### **Description of the Computer Program**

HSPF was used for the basin simulation models because this program had been effective in simulating runoff generation for headwater basins with similar properties elsewhere in the Puget Sound Lowland (Dinicola, 1990). The following features of HSPF make it suitable to simulate rainfall-runoff processes in the Thurston County study basins.

- (1) HSPF can represent the hydrologic processes, including the four drainage mechanisms, described by the conceptual model.
- (2) HSPF can simulate the generation of runoff continuously over time, including periods of storm runoff and low flows, and account for antecedent soil moisture conditions.

- (3) HSPF can simulate the hydraulics of natural and man-made drainage networks.

HSPF approximates the conceptual model in a numerical representation of the hydrologic system that can distribute and track water that falls as rain. This numerical representation of the system includes numerous water-drainage pathways and water-storage reservoirs of a basin. In this system, overland flow, shallow surface flow, and ground-water flow are considered the pathways that drain to channels, whereas ground-water recharge to deep aquifers and evapotranspiration (ET) are considered pathways that do not drain to local channels. Water-storage reservoirs in this system include interception storage, retention storage, detention storage, soil-moisture storage, and ground-water storage. After distributing rainfall to initial starting points in the system, HSPF combines the parts of it that contribute to runoff and simulates inflow to each channel of a drainage network. Simulated channel inflow is then routed as streamflow through the drainage network by a modified kinematic wave mathematical routine that is a component of HSPF. The drainage network may include any man-made or natural flow-conveyance system, but hydraulic properties of individual channels must be held constant. HSPF cannot accommodate such hydraulic conditions as backwater and pressurized flow.

HSPF uses numerical values of model parameters to represent land and hydraulic properties of specific land parcels and channel reaches in a drainage basin during runoff simulations. The following discussion (1) introduces the concepts of "process-related" and "fixed" parameters; (2) describes the division of drainage basins into land segments, subbasins, and channel reaches; and (3) describes how HSPF simulates runoff generation and delivery.

HSPF represents the land and hydraulic properties of drainage basins by "process-related" parameters and by "fixed" parameters. Process-related parameters represent properties that govern the movement or storage of water once it reaches the land or vegetation surface, but before it reaches a channel in the drainage network. Process-related parameters include the quantity of rainfall intercepted by vegetation; the quantity of water perched on the land surface or absorbed in the forest litter; the quantity of water stored in the soil matrix; the soil infiltration rate; the evapotranspiration rate; and the rates at which overland flow, shallow subsurface flow, and ground-water flow drain to channels in the drainage network. Measuring the physical properties to be represented by process-related parameters is rarely easy. Numerical values for the parameters of the Thurston County study basins initially were



selected from a previous modeling study (Dinicola, 1990) or estimated from available physiographic information. The parameter values then were evaluated and, when necessary, refined during model calibration.

Fixed parameters represent the hydraulic properties of the drainage network and other measurable drainage basin properties, such as the amount of area covered by the respective soil types, land covers, and slopes. These are the parameters commonly modified during engineering and planning applications of the calibrated model to predict runoff responses to alternate urban development scenarios for a drainage basin. The hydraulic properties, which include channel shape, channel roughness, channel slope, and channel length, determine the relation of discharge to the volume of water stored in a channel. Water volume in storage and corresponding discharge are the fixed parameters that define how water is routed through a channel. For this study, field reconnaissance and maps provided the information about hydraulic properties that determined parameter values used for channel routing. The parameter values for the areas of different classifications of such basin properties as soil, land cover, and slope also came from information provided on maps.

A drainage basin can be divided into three components for runoff simulation by HSPF: land segments, subbasins, and channel reaches. This division allows both (1) the assignment of parameter values to discrete land parcels and channel reaches and (2) the assignment of runoff to specific destinations.

HSPF requires that the surface of each drainage basin be divided into land segments. A land segment is a parcel of land with distinctive but fairly uniform meteorologic, physical (soil, land cover, and slope), and hydrologic traits. On the basis of its traits, each individual land segment is classified as one of the land-segment types. The classification of basin properties and the division of the land surface into land-segment types is called the segmentation scheme. Individual land segments with the same package of traits belong to the same land-segment type. Each land-segment type is assigned its own set of process-related parameters. The distinctive set of parameters for each land-segment type belongs to all land segments classified to that type. This arrangement enables the program to simulate distinct hydrologic responses to rainfall and potential evapotranspiration for distinctive basin areas.

While providing enough land-segment types to account for all physical properties that exert notable influence on runoff in the study basins, this study has restricted the number of land-segment types to reduce the number of

parameters requiring calibration. The HSPF program does not require that all land segments of the same type be contiguous. It only requires (1) that the parameters represent the hydrologic properties of all land segments within each land-segment type and (2) that the total area of each land segment within a given type be known. Thus, relatively few land-segment types represent the complex areal mosaic of soils, land covers, and slopes in each modeled basin.

HSPF allows division of drainage basins into subbasins so that a simulation model can more closely control the delivery of runoff to specific destinations. A simulation model typically delivers runoff generated in a subbasin to the channel draining that subbasin. This typical delivery scheme, however, is not mandatory. Sometimes, for example, a subbasin may be closed; that is, it may lack connection to a surface-drainage network. In such cases, HSPF allows a simulation model to deliver water elsewhere, for instance, to inactive ground water. Another example occurs when different outflows from land segments in a given subbasin are delivered to channels in different subbasins. Overland flow and shallow subsurface flow from a land segment in a subbasin may be delivered to the channel draining that subbasin, but ground-water flow may be delivered to a channel farther downstream in a different subbasin.

HSPF can route streamflow along channels of a drainage network to the outlet of a drainage basin. Using the routing capability requires that the linked network of stream channels, drainage pipes, and perennial lakes, ponds, and wetlands be divided into segments called reaches. A reach must have relatively uniform hydraulic properties and must drain or connect subbasins. A reach sometimes may lose water when it seeps from a channel or lake bottom or when it discharges from one or more outlets outside the reach's subbasin. Reach segmentation was somewhat generalized in the study basins to simulate only the essential hydraulic properties that affect streamflow rates in a drainage network. It was not necessary to simulate flow through every pipe, ditch, pond, and channel in the study basins.

The previous discussion introduced the concept of process-related and fixed parameters and described the division of drainage basins. The following discussion describes how HSPF simulates runoff by using process-related and fixed parameter values to represent land and hydraulic properties of land segments, subbasins, and reaches. For a detailed description of runoff simulation by HSPF, refer to the HSPF user's manual, pages 158-176 for

pervious land segments, pages 209-212 for impervious land segments, and pages 221-240 for reaches (U.S. Environmental Protection Agency, 1984).

HSPF bases the allocation, travel rates, and destinations of water from incident precipitation on the process-related parameters assigned to land segments where the precipitation falls. Table 1 defines the HSPF process-related parameters of the three basin models used in this study. In basing allocation, travel rates, and destinations on land-segment type parameters, HSPF distinguishes between impervious and pervious land segments.

HSPF allocates precipitation falling on impervious land segments either to surface retention or detention storage, or to overland flow (fig. 3a). The process-related parameter RETSC defines retention storage capacity and removes this retained water from the quantity available for overland flow. Only evaporation removes water from this reservoir. When the retention storage is full, further rainfall moves to surface detention storage, where it is detained temporarily until it moves to a channel as overland flow. The process-related parameters LSUR, NSUR, and SLSUR all influence the rate of overland flow.

Precipitation falling on pervious land segments is intercepted by the vegetal canopy, or it reaches the surface of the ground (fig. 3b). The process-related parameter CEPSC defines the quantity of water intercepted by the canopy, and this water in interception storage is later removed by evapotranspiration. When the interception storage capacity is met, further precipitation is allocated to the surface of the ground.

Water that reaches the surface of the ground is directed by HSPF either to direct infiltration or to potential runoff. This initial allocation is affected by multiple influences: the supply rate of water, the current soil moisture storage, and the physical properties of the soil as represented by the process-related parameters INFILT, INFILD, INFEXP, and LZSN. In general, low supply rates, low soil moisture storage volumes, and high INFILT values will result in large quantities of direct infiltration. Conversely, high supply rates, high soil moisture storage volumes, and low INFILT values will favor potential runoff. A portion of the potential runoff may still infiltrate as delayed infiltration, as will be discussed later in this section.

Water that infiltrates (directly or delayed) is stored in the unsaturated lower zone of the soil as lower zone storage, or it enters the ground-water system. The capacity of lower zone storage is defined by the process-related parameter LZSN. Water stored in the lower zone can only

be removed by evapotranspiration, and the rate of evapotranspiration is determined by the process-related parameter LZETP. As water stored in the lower zone increases, more infiltrated water enters either active ground-water storage or inactive ground-water storage. The parameter DEEPFR defines the proportion of water entering inactive ground-water storage, where stored water is not available for runoff. Water allotted to active ground-water storage, on the other hand, is available either for evapotranspiration or for ground-water flow toward channels. Evapotranspiration is determined by the parameter AGWETP, and the rate of ground-water flow toward a channel is influenced by the parameters AGWRC and KVAR. Additionally, ground-water flow toward a channel is subject to evapotranspiration as determined by the parameter BASETP.

Rainfall reaching the ground but not routed by HSPF to direct infiltration becomes potential runoff. HSPF makes this potential runoff available to three storages: upper zone storage, surface detention storage, and interflow storage. The parameter UZSN allocates a share of the potential runoff to be stored in surface depressions and the upper, organic soil layers as upper zone storage. HSPF may, in turn, assign water in upper zone storage either to evapotranspiration or to delayed infiltration toward either lower zone storage or ground-water storage. Delayed infiltration depends on the relative volumes of water in upper zone storage and lower zone storage, and on the influence of the parameter INFILT. In general, if the upper zone storage is wetter than the lower zone storage, HSPF will assign water to delayed infiltration. If, conversely, the lower zone storage is wetter than the upper zone storage, then HSPF will send more water to surface detention storage and, subsequently, to overland flow toward channels. The rate of overland flow from pervious land segments, as from impervious segments, is influenced by the parameters LSUR, NSUR, and SLSUR. Finally, the parameters INTFW and LZSN determine the share of potential runoff for interflow storage, which may provide outflow as shallow subsurface flow toward channels. The parameter IRC influences the rate of subsurface flow.

HSPF does not distinguish between Hortonian and saturation overland flows. The user, however, can assign parameter values that will appropriately simulate these two flow mechanisms. To simulate saturation overland flow, for example, the user can adjust the parameter value for INFEXP, the exponent in the infiltration equation. A high INFEXP value will dramatically decrease infiltration capacity when there is a relatively small increase in soil moisture storage (represented in HSPF by lower zone storage). This adjustment, which makes lower zone storage

**Table 1.--Definitions of process-related parameters used in the study basins in Thurston County, Washington**

Parameter	Definition
AGWETP	Active ground-water evapotranspiration (ET); accounts for the fraction of available PET that can be met from active ground-water storage. It simulates ET from deep-rooted plants. Active ground water is that portion of ground-water storage that can discharge to a surface channel. No units.
AGWRC	Active-ground-water recession coefficient; governs the changing rate at which active ground water drains from the land over time. Units: 1/day.
BASETP	Baseflow ET; accounts for the fraction of available potential evapotranspiration (PET) that can be met as baseflow from ground water to the surface channel. It simulates ET from riparian vegetation. No units.
CEPSC	Interception-storage capacity of plants. Units: inches.
DEEPFR	Fraction of deep ground water; governs the fraction of ground water that becomes inactive ground water and does not discharge at the surface inside the modeled basin. No units.
INFEXP	Infiltration equation exponent; governs the decrease of infiltration rate with increasing soil moisture in the unsaturated lower zone. No units.
INFILD	Ratio of maximum to mean infiltration rate; accounts for differences in the infiltration rate caused by variations within a given land-segment type. No units.
INFILT	Soil infiltration capacity index; governs the ability of water to directly infiltrate soil and become soil moisture in the unsaturated lower zone. Water stored in the lower zone is available for evapotranspiration or recharge to ground-water storage. For HSPF, the water that does not directly infiltrate to the unsaturated lower zone is available for overland flow, shallow subsurface flow, or later direct infiltration. Units: inches/hour.
INTFW	Interflow index; governs the quantity of water that becomes shallow subsurface flow to a surface channel. No units.
IRC	Interflow recession coefficient; governs the changing rate at which subsurface flow drains from the land over time. Units: 1/day.
KVARY	Active-ground-water outflow modifier; governs the amount of influence that ground-water inflow has on ground-water outflow. Units: 1/inch.
LSUR	Surface length of the average overland flow plane. Units: feet.
LZETP	Lower-zone evapotranspiration (ET); represents the density of deep-rooted vegetation that conveys water from the unsaturated lower zone upward to the atmosphere. No units.
LZSN	Lower-zone nominal storage; accounts for the capacity of soil-moisture storage in the unsaturated lower zone. Units: inches.
NSUR	Surface roughness (Manning's "n" value); the average overland flow plane. No units.
RETSC	Retention-storage capacity of impervious surfaces. Units: inches.
SLSUR	Surface slope of the average overland flow plane. No units.
UZSN	Upper-zone nominal storage; accounts for storage capacity in depressions and surface layers of a pervious area. Units: inches.

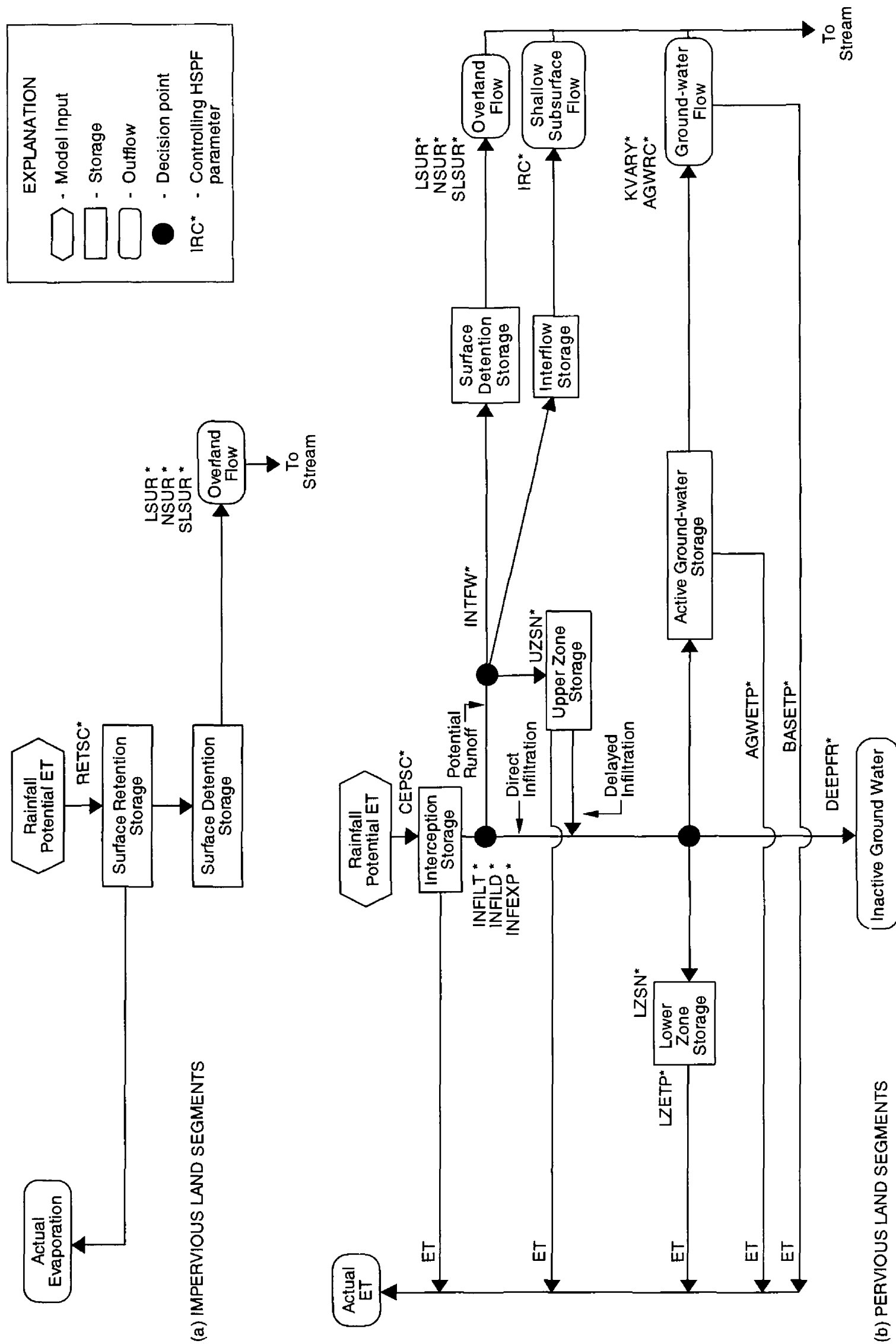


Figure 3.--Hydrological Simulation Program-FORTRAN flowchart for (a) impervious and (b) pervious land segments.

act as a surrogate for the depth of the water table, simulates saturation overland flow. Infiltration will be larger when soils are dry and negligible when soils are wet.

The HSPF-based simulation models determine for each subbasin the volume of water draining in a given time to a surface channel reach or to inactive ground water. A subbasin may contain some or all of the land-segment types in a drainage basin. The quantity of incident precipitation that is time-allocated along each drainage path is multiplied by the surface area of the associated land-segment type (a fixed parameter) to determine the volume of water draining from a land-segment type per unit of time either to a surface reach or to inactive ground water. The total volume of water entering from a subbasin into a reach or into inactive ground water over a given time interval is the sum of the volumes produced from all of the land-segment types in the subbasin during the interval. In turn, the total volume of water stored in a reach in a given time is the sum of all the volumes draining into the reach from all connected subbasins and the initial volume stored in the reach, minus the volume discharged from the reach during this time. The total volume of water in the reach determines the outlet discharge as specified by fixed parameters.

## **Construction of the Simulation Models**

Numerical simulation models for the three study basins were constructed by incorporating the previously described conceptual model into the HSPF program. Constructing the HSPF-based simulation models required division of the study area into land-segment types, subbasins, and stream reaches.

Division of each basin into land-segment types enabled each basin model to simulate the runoff generation conceptualized for the distinct physical properties of the basin. Each land-segment type had distinct, uniform physical properties that, in the conceptual model, were associated with certain hydrologic processes and runoff responses. Process-related parameters were assigned to each land-segment type to simulate these processes and responses.

Division of each basin into subbasins enabled each model to provide the necessary hydraulic linkage from specifically located land-segment types to specific channel segments or to inactive ground water. The surface area of each land-segment type within a subbasin was used to

determine the volume of runoff from each type, and these runoff volumes were assigned to specific destinations, usually to stream reaches draining the subbasin.

Division of each study basin's drainage network into channel segments, called reaches, enabled each basin model to route streamflow along the reaches of the drainage network to the drainage basin outlet. Each reach received runoff volumes from the land-segment types in its own associated subbasin and also from all connected upstream reaches. A more detailed description of how the study area was divided into land-segment types, subbasins, and reaches is presented below.

### **Land-Segment Types**

The HSPF program separates operations of rainfall-runoff simulation into modules called blocks. The PERLND block computes water budgets for pervious land-segment types, and the IMPLND block computes water budgets for impervious land-segment types. These blocks contain the process-related parameters for their respective pervious and impervious types.

Simulating runoff generation from each land-segment type in the study basins involved two tasks during model construction: (1) defining the land-segment types in the study area and (2) assigning values to the process-related parameters for each type. The land-segment type definitions were based on three basin properties: soil type, land cover, and slope. The parameter values numerically represented physical properties that govern the movement or storage of water between the vegetal canopy or ground and the channels in the drainage network.

### **Definition of Land-Segment Types**

The first phase of model construction divided each study basin into 17 land-segment types, 16 that represent pervious areas (called PERLNDS in HSPF) and 1 that denotes impervious areas (IMPLNDS). The PERLNDS were differentiated on the basis of soil type (outwash, till, Kitsap, saturated), land cover (forest, nonforest, crop), and slope (flat, moderate, steep).

Soil types in the pervious parts of the study area came from combining the soil series shown on Soil Conservation Service Soil Survey maps (U.S. Department of Agriculture, 1990) into four general categories--outwash, till, Kitsap (contains two soil series derived from lacustrine deposits), and saturated soils--on the basis of

physical and hydrologic response characteristics (table 2). The distribution of soil types in the study basins appears on figure 4.

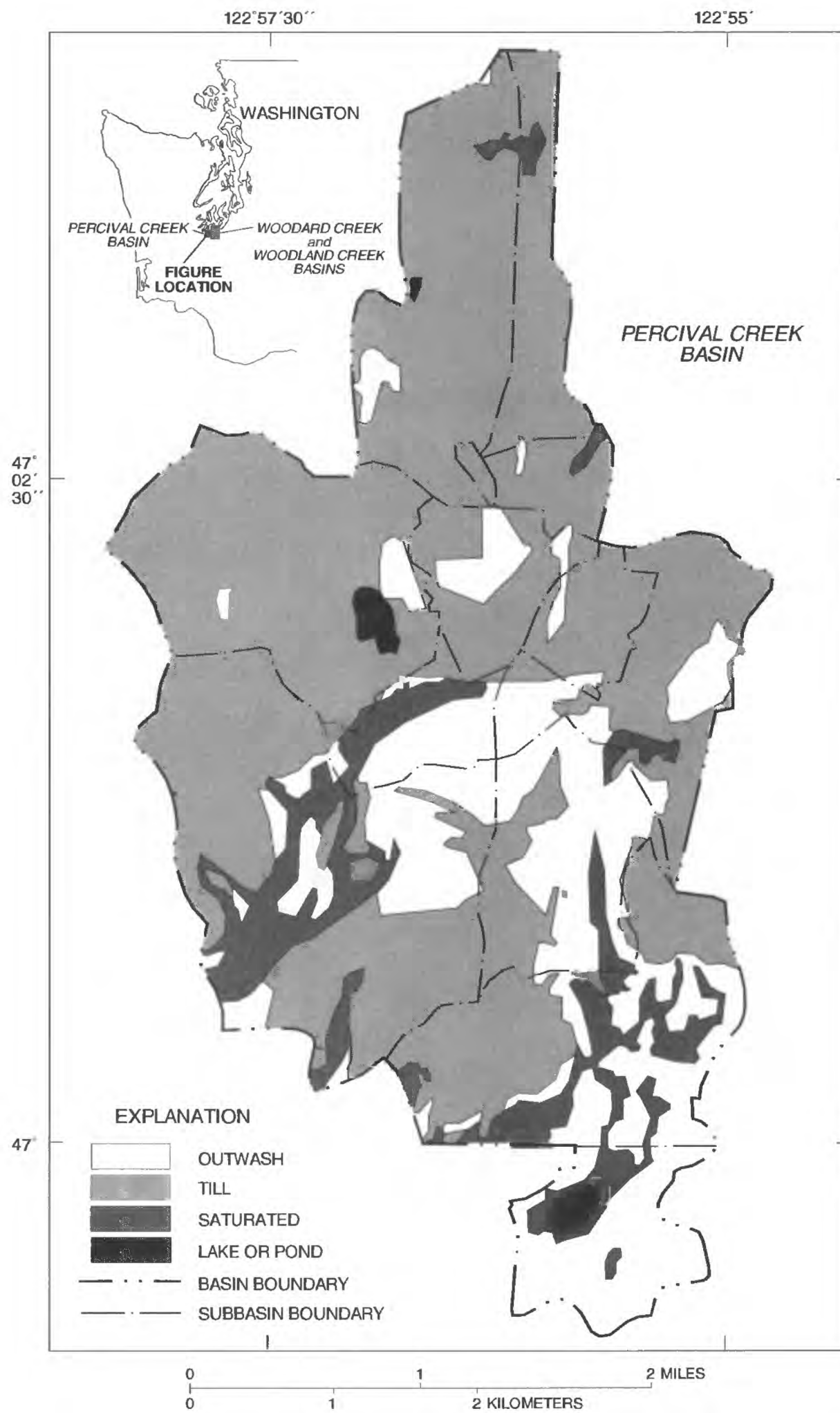
**Table 2.**--*Soil series, and the land-segment soil type that represents each soil series in the calibrated rainfall-runoff models (U.S. Department of Agriculture, 1990)*

Land-segment soil type	Thurston County soil series
Outwash	Cagey
	Chehalis
	Everett
	Giles
	Indianola
	Nisqually
	Spana
	Spanaway
	Yelm
Kitsap	Hoogdal
	Skipopa
Till	Alderwood
	Delphi
	Dystric
	Xerochrypts
	Kapowsin
	McKenna
	Melbourne
	Olympia
	Rainier-Rock Complex
	Schneider
Saturated	Bellingham
	Everson
	Hydraquents
	Mukilteo
	Norma
	Semiahoo
	Shalcar
	Tisch

Land-segment types based on outwash soil types (hereafter called outwash segment types) represent areas covered by soils formed in glacial outwash deposits and by other well-drained soils. This study divided outwash segment types into three land-cover classes: forest, nonforest, and crops. As described in the conceptual model, runoff comes mostly from ground water in forested and disturbed areas of outwash, but disturbed areas, with nonforested or crop land covers, also may generate some Hortonian overland flow during intense rainstorms. Disturbed, pervious areas were divided into nonforested and crop land covers to represent greater evapotranspiration (ET) for crop land cover than for nonforested land cover. The crop land cover occurs only in areas of outwash soils. Outwash segment types were not divided into slope classes because slopes in areas of glacial-outwash deposits are flat to moderate and do not vary widely through the basins. Dinicola (1990) found that slope has little affect on the runoff characteristics of outwash and other well-drained soils.

Till segment types represent areas where soils cover a layer of compacted glacial till or bedrock. Till areas mostly produce runoff from shallow subsurface flow in both forested and nonforested locations. However, till segment types covered by disturbed, nonforested areas commonly produce Hortonian overland flow during storms. This study subdivided till segment types according to two land cover classes: forested or nonforested. Slope also affects the subsurface and overland flow characteristics of till segment types. For example, till soil types with flat slopes often generate runoff from saturation overland flow when soils become saturated during extended wet periods. Thus, both forested and nonforested till segment types were further subdivided according to their slope: flat, moderate, or steep.

Kitsap segment types, not designated for basins previously investigated by Dinicola (1990), represent areas with soils derived from fine-grained lacustrine deposits. Kitsap segment types, like the till segment types, represent soils underlain by a substratum of low permeability. Kitsap soils, however, have greater soil-moisture storage capacities and, because of more interstitial pore space than till soils, they have slightly greater rates of vertical drainage through the substratum. Thus, subsurface flow is slightly less important, and ground-water flow is slightly more important in Kitsap segment types than in till segment types. In nonforested Kitsap segment types, as in till segment types, intense storms may produce Hortonian overland flow. In Kitsap segment types with flat slopes, saturation overland flow is an important mechanism. Accordingly, Kitsap segment types also were subdivided according to their land cover and slope.



**Figure 4.**--Distribution of soil-type land segments for Percival Creek, Woodard Creek, and Woodland Creek Basins.



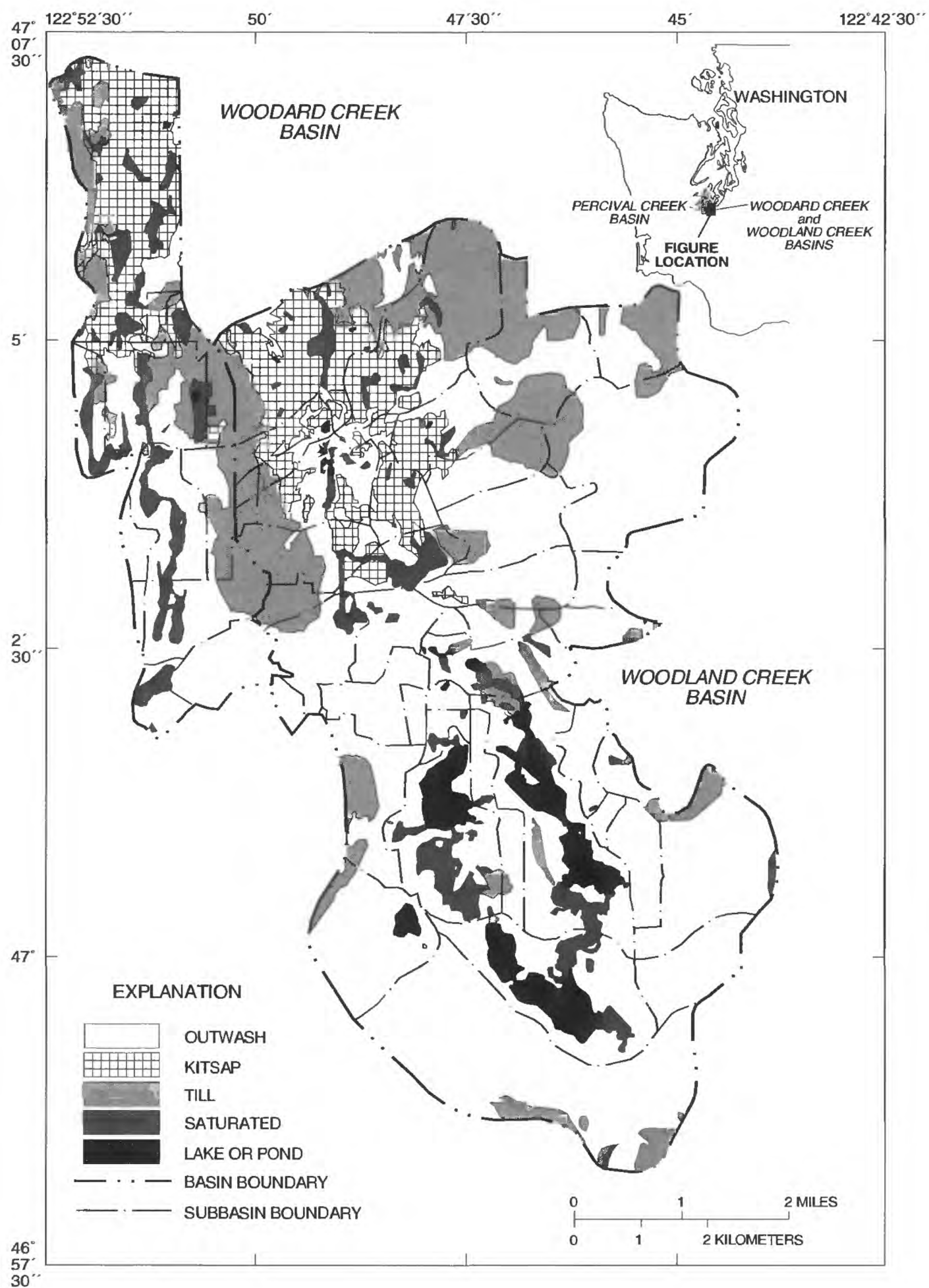


Figure 4.--Continued.

The saturated segment type represents topographic depressions and stream bottoms that are poorly drained and seasonally inundated. This segment type mainly generates runoff from saturation overland flow. Because this segment type represents undeveloped, flat-sloped areas, it was not subdivided according to land cover and slope. The undeveloped land cover of this flat-sloped segment type is generally a mixture of wetland forests, shrubs, and meadow grasses.

The classes of land cover in pervious parts of the study area--forest, nonforest, or crops--were determined and mapped from interpretation of aerial photographs. Forest land cover denotes undisturbed and forested areas. Nonforested land cover refers to land segments that are disturbed and nonforested, such as grass lawns, pastures, and gravel pits. Crop land cover, not designated for basins previously investigated by Dinicola (1990), refers to agricultural areas that undergo tillage and intensive crop production. Crop land cover shows up only in areas of outwash soil types. For each class of land cover, distinct values for the process-related parameters represent the interception storage, infiltration rate, depression storage, and evapotranspiration.

This study assigned till and Kitsap land segments to one of three slope classes--flat (0 to 3 percent), moderate (3 to 15 percent), and steep (greater than 15 percent)--on the basis of Soil Survey maps from the Soil Conservation Service (U.S. Department of Agriculture, 1990). Topographic maps were used to verify the classifications.

Determining the areal extent of effective impervious areas in the basins was more difficult than determining the extent of pervious areas. Effective impervious areas generate runoff that drains directly from impervious surfaces to channels. However, most impervious areas are not completely effective because a portion of the runoff drains to adjacent pervious land segments rather than directly to channels (rooftops that drain to lawns are a common example). The extent of effective impervious areas in the study basins was estimated by first measuring from aerial photographs the area of six classes of land use that contained impervious land cover: sparse, moderate, suburban, and high-density residential, and medium and heavy commercial-industrial. The total area for each of the six classes was then adjusted, using previously defined percentages, to estimate the area within each class covered solely by impervious surfaces (Alley and Veenhuis, 1983; Dinicola, 1990). Finally, the estimate of impervious area was further adjusted by applying another set of previously defined percentages to estimate the effective impervious area of each land cover class (Alley and Veenhuis, 1983;

Dinicola, 1990; U.S. Department of Agriculture, 1986). Definitions of the impervious land-cover classes and the estimated percentages of impervious and effective impervious areas for each class appear in table 3.

Because all noneffective impervious areas (those impervious areas that do not drain directly to channels) were assumed to drain to adjacent pervious land, the study assigned noneffective impervious areas to the same soil type and slope class as those of the adjacent pervious segments. The land cover of noneffective impervious areas within sparse residential areas was classified into the same forest or nonforest land cover type as the adjacent land segment. Noneffective impervious areas in the other five impervious classes were always classified as nonforest land cover.

Table 4 lists the designations and characteristics of land-segment types for pervious areas. Table 5 shows the area of each land-segment type contributing to each of the five stream-gaging stations. Contributing areas are those areas that supply runoff to stream reaches and are distinguished from noncontributing areas, which are closed subbasins that do not drain to stream reaches. Table 5 expresses contributing areas as percentages of total contributing areas upstream of stations.

### Process-Related Parameters

Each land-segment type was characterized as having a rainfall-runoff response distinct from those of other land-segment types. During model construction, distinctive numerical values were assigned to the process-related parameters of each land-segment type to represent these responses.

For 10 of the 17 land-segment types in this study, the initial values of process-related parameters were the values used earlier by Dinicola (1990) for basins elsewhere in the Puget Sound Lowland. These 10 land-segment types were outwash segment types OF and OG; till segment types TFF, TFM, TFS, TGF, TGM, and TGS; saturated segment type SAT; and effective impervious area segment type EIA. One outwash land-segment type with crop land cover (OC) and six land-segment types with Kitsap soils (KFF, KFM, KFS, KGS, KGM, and KGS) were not present in the basins of the earlier study. For the outwash-crop land-segment type (OC), the initial process-related parameter values were those previously determined for outwash-nonforest land-segment types (OG), except that one parameter value was adjusted to increase evapotranspiration. For the Kitsap land-segment types, the

**Table 3.--Estimated impervious area and effective impervious area for impervious land cover classes represented in the Woodland Creek, Woodard Creek, and Percival Creek models**

Impervious land-cover class	Definition/ examples	Estimated percentage of impervious area	Estimated percentage of effective impervious area	Reduced estimated percentage of effective impervious area <sup>1</sup>
Sparse residential	1 unit per 2-5 acres	10	4	0
Moderate residential	1-3 units per acre	20	10	0
Suburban residential	4-8 units per acre	35	23	0
High density residential	Apartments, and mobile home parks	60	48	24
Medium commercial/ light industrial	Office parks and low density industrial	60	48	24
Heavy commercial/ industrial	Shopping centers, dense strip development, urban cores, and heavily industrialized areas	90	86	58

<sup>1</sup> This column applies to the final calibrated models for Woodland Creek subbasins WL2, WL9, WL13, and WL14; and Woodard Creek subbasins WD1, WD2, and WD3.

**Table 4.--Designations and characteristics of land-segment types for pervious areas**  
[--, no data]

Designations		Characteristics		
Land-segment type <sup>1</sup>	Soil type	Land-cover type	Slope type	
OF	Outwash	Forest	--	
OG	Outwash	Nonforest (mostly "grass")	--	
OC	Outwash	Crop	--	
TFF	Till	Forest	Flat	
TFM	Till	Forest	Moderate	
TFS	Till	Forest	Steep	
TGF	Till	Nonforest	Flat	
TGM	Till	Nonforest	Moderate	
TGS	Till	Nonforest	Steep	
KFF	Kitsap	Forest	Flat	
KFM	Kitsap	Forest	Moderate	
KFS	Kitsap	Forest	Steep	
KGF	Kitsap	Nonforest	Flat	
KGM	Kitsap	Nonforest	Moderate	
KGS	Kitsap	Nonforest	Steep	
SAT	Saturated	--	--	

<sup>1</sup> Land-segment type definitions: OF, outwash soils, forest cover, all slopes; OG, outwash soils, nonforest cover, all slopes; OC, outwash soils, crops, all slopes; TFF, till soils, forest cover, flat slopes; TFM, till soils, forest cover, moderate slopes; TFS, till soils, forest cover, steep slopes; TGF, till soils, nonforest cover, flat slopes; TGM, till soils, nonforest cover, moderate slopes; TGS, till soils, nonforest cover, steep slopes; KFF, Kitsap soils, forest cover, flat slopes; KFM, Kitsap soils, forest cover, moderate slopes; KFS, Kitsap soils, forest cover, steep slopes; KGF, Kitsap soils, nonforest cover, flat slopes; KGM, Kitsap soils, nonforest cover, moderate slopes; KGS, Kitsap soils, nonforest cover, steep slopes; SAT, saturated soils, all covers, all slopes.

**Table 5.--Areal extent of the land-segment types found in the three study basins and used for model calibration**

BASIN Station name		Station number	Total area of land-segment types of the indicated type (in percent of total drainage area of the entire basin or upstream of station) <sup>1,2</sup>																Total area of basin or upstream of station (square miles)	
			OF	OG	OC	KFF	KFM	KFS	KGF	KGM	KGS	TFF	TFM	TFS	TGF	TGM	TGS	SAT		EIA <sup>3</sup>
Woodland Creek Basin			26.6	26.5	5.0	0.2	4.0	1.3	0.3	3.1	0.3	2.4	7.5	0.7	1.1	3.0	0.3	4.6	8.3	26.2
Woodland Creek near Olympia	12081000		28.6	28.3	5.5	.1	2.5	.7	.3	1.5	.2	1.4	7.5	.6	1.1	2.8	.3	4.5	8.9	23.9
Woodland Creek at Martin Way at Lacey	12080670		24.6	36.4	9.8	0	0	0	0	0	0	1.1	1.5	.6	.6	1.5	.4	5.2	9.1	13.3
Woodard Creek Basin			15.0	20.0	0	11.0	4.4	4.4	4.3	1.7	.5	1.8	6.4	.1	1.2	4.9	0	13.8	10.4	5.91
Woodard Creek near Olympia	12080500		22.9	31.0	0	.4	.6	.4	.6	0	.1	1.5	4.6	0	1.2	5.1	0	14.2	17.3	3.43
Percival Creek Basin			12.7	9.1	0	0	0	0	0	0	0	9.9	17.2	17.8	3.7	6.7	1.6	9.5	10.9	8.28
Black Lake Ditch near Olympia	12078720		7.9	4.0	0	0	0	0	0	0	0	11.2	24.8	15.7	5.2	9.4	1.2	8.4	11.4	5.10
Percival Creek near Olympia	12078730		24.5	21.1	0	0	0	0	0	0	0	4.2	.2	23.0	.5	.3	2.7	14.8	7.3	2.28

<sup>1</sup> Land-segment type definitions: OF, outwash soils, forest cover, all slopes; OG, outwash soils, nonforest cover, all slopes; OC, outwash soils, crops, all slopes; KFF, Kitsap soils, forest cover, flat slopes; KFM, Kitsap soils, forest cover, moderate slopes; KFS, Kitsap soils, forest cover, steep slopes; KGF, Kitsap soils, nonforest cover, flat slopes; KGM, Kitsap soils, nonforest cover, moderate slopes; KGS, Kitsap soils, nonforest cover, steep slopes; TFF, till soils, forest cover, flat slopes; TFM, till soils, forest cover, moderate slopes; TFS, till soils, forest cover, steep slopes; TGF, till soils, nonforest cover, flat slopes; TGM, till soils, nonforest cover, moderate slopes; TGS, till soils, nonforest cover, steep slopes; SAT, saturated soils, all covers, all slopes; EIA, effective impervious areas, all slopes.

<sup>2</sup> When the sum of the percentages is less than 100, the remaining area is covered by open water. Drainage areas do not include closed subbasins that do not drain to the channel system.

<sup>3</sup> Effective impervious areas were computed by the methods shown in table 3.

initial parameter values were those previously determined for till land-segment types, except that two parameter values were adjusted to increase soil moisture capacities and vertical drainage rates.

Only a few of the 18 process-related HSPF parameters described in table 1 strongly controlled the simulation of runoff generation for each land-segment type. Numerical values for these parameters followed the principles discussed below, which come from the conceptual model of runoff generation in the study basins. It was through the assigned parameter values that the features of the conceptual model were incorporated into the numerical simulation models.

In areas of outwash soil types, ground-water flow was the principal drainage mechanism. Therefore, high values were assigned to the soil-infiltration capacity index, INFILT, and low values to the interflow index, INTFW, to simulate rapid infiltration of precipitation and subsequent recharge to ground water. Because Hortonian overland flow was a viable mechanism for disturbed areas, the soil-infiltration capacity index, INFILT, was reduced for outwash-nonforest and outwash-crop segment types. This allowed Hortonian overland flow during extreme storms. Simulated interception storage and evapotranspiration were also reduced for the outwash-nonforest and outwash-crop segment types by lowering the interception storage-capacity index, CEPSC, and the lower-zone ET index, LZETP. A higher lower-zone ET index, LZETP, was assigned to the crop segment to make simulated ET greater than that for the nonforested segment types.

In areas of till soil types, including soils underlain by bedrock, shallow subsurface flow was a chief drainage mechanism. In undisturbed till segment types with moderate to steep slopes, low values were assigned to the soil-infiltration capacity index, INFILT, and high values to the interflow index, INTFW, to simulate shallow subsurface flow. The low INFILT value simulated impeded vertical drainage through the compacted till to the unsaturated lower zone and ground-water storage; and the high INTFW value simulated large amounts of shallow subsurface flow over the compacted till. Simulated shallow subsurface response was accelerated for undisturbed till segment types with steep slopes by lowering the interflow recession coefficient, IRC. To increase the amount of simulated shallow subsurface flow from undisturbed till segment types with steep slopes, the INTFW values were made higher than for moderate-sloped till segment types. To increase subsurface drainage even further for steep-sloped, undisturbed till segment types, the values of INFEXP, the infiltration equation exponent, were lowered.

Simulated runoff generated from till segment types with flat slopes was similar to but slower than that from those segment types on hillslopes during small storms. Because the rate of shallow subsurface flow was proportional to the angle of hillslopes, flat areas of till segment types can produce saturation overland flow, especially during large storms. In these segment types, restricted vertical and lateral drainage caused high water tables perched above the compacted till to saturate the soil profiles fully during large storms. These flat till segment types were assigned relatively higher INFEXP values (to simulate slow vertical drainage), lower INTFW values (to simulate reduced shallow subsurface flow), and higher IRC values (to simulate slow subsurface flow response) than the respective values assigned to till segment types with moderate to steep slopes.

Segment types representing disturbed till hillslopes (defined by moderate to steep slope and nonforest land cover) generated more Hortonian overland flow than segment types for undisturbed till hillslopes. Thus, parameter values for the soil infiltration-capacity index, INFILT, were lowered to simulate reduced vertical drainage, and values for the upper-zone nominal storage index, UZSN, were lowered to simulate decreased retention and detention of surface runoff. The interception storage-capacity index, CEPSC, and the lower-zone ET index, LZETP, were also lowered to simulate reduced interception storage and evapotranspiration, two changes that follow the conversion of forest land cover to grass or pasture.

In areas of fine-grained lacustrine deposits designated as Kitsap segment types, as in areas of till segment types, shallow subsurface flow was an important drainage mechanism on moderate or steep hillslopes, and saturation overland flow was a viable mechanism in flat areas. However, both vertical drainage through the substratum and soil moisture storage capacities were slightly greater in areas of Kitsap segment types than in areas of till segment types. Accordingly, for Kitsap segment types, the study used values for process-related parameters that were similar to those for till segment types, except that INFILT values were increased slightly to allow for more simulated infiltration and LZSN values were raised to simulate greater soil-moisture storage capacities. Other process-related parameter values remained the same as those for till segment types.

Saturated soil types--poorly draining soils in topographical depressions and stream bottoms--produce saturation overland flow when these soils are saturated during wet periods of the year. Therefore, parameter values were assigned to generate substantial overland flow in saturated



segment types during wet periods, but to inhibit runoff during the dry season. Large INFILT values were assigned so that simulated infiltration would be large when these soils had a soil-moisture deficit in the dry season. Large values were also used for UZSN, the upper-zone nominal storage index, to simulate a large quantity of water stored in the deep upper organic horizon as retention and detention storage before overland flow was generated. Furthermore, large values for INFEXP, the infiltration equation exponent, simulated rapid saturation of these soils because of rising water tables and poor drainage during wet periods; and large values for AGWETP, the active ground-water ET index, and for LZETP, the lower-zone ET index, represented substantial evapotranspiration from these soils.

### **Subbasins**

Construction of simulation models also involved dividing each study basin into subbasins in order to route runoff from specifically located land-segment types to specific reaches. The hydraulic linkages from any of the 17 land-segment types possible in a subbasin to a specific stream reach or to inactive ground water are assigned in the NETWORK block of HSPF. Additionally, runoff in the form of streamflow from upstream reaches to downstream reaches was designated in the NETWORK block.

In the simulation models constructed for this study, subbasins were delineated along the topographic divides that separate surface runoff into respective basins or subbasins and along the divisions of the surface-drainage network into reaches. Most subbasins were assigned to drain through their reaches, but to account for the areas that do not drain to surface reaches, some closed subbasins were delineated where rainfall moves only to evapotranspiration or to recharge ground water.

In the final simulation models, Woodland Creek Basin was divided into 44 subbasins, Woodard Creek Basin into 12 subbasins, and Percival Creek Basin into 13 subbasins, for a total of 69 subbasins (figs. 5 and 6). There were 16 closed subbasins in Woodland Creek Basin, 6 in Woodard Creek Basin, and none in Percival Creek Basin.

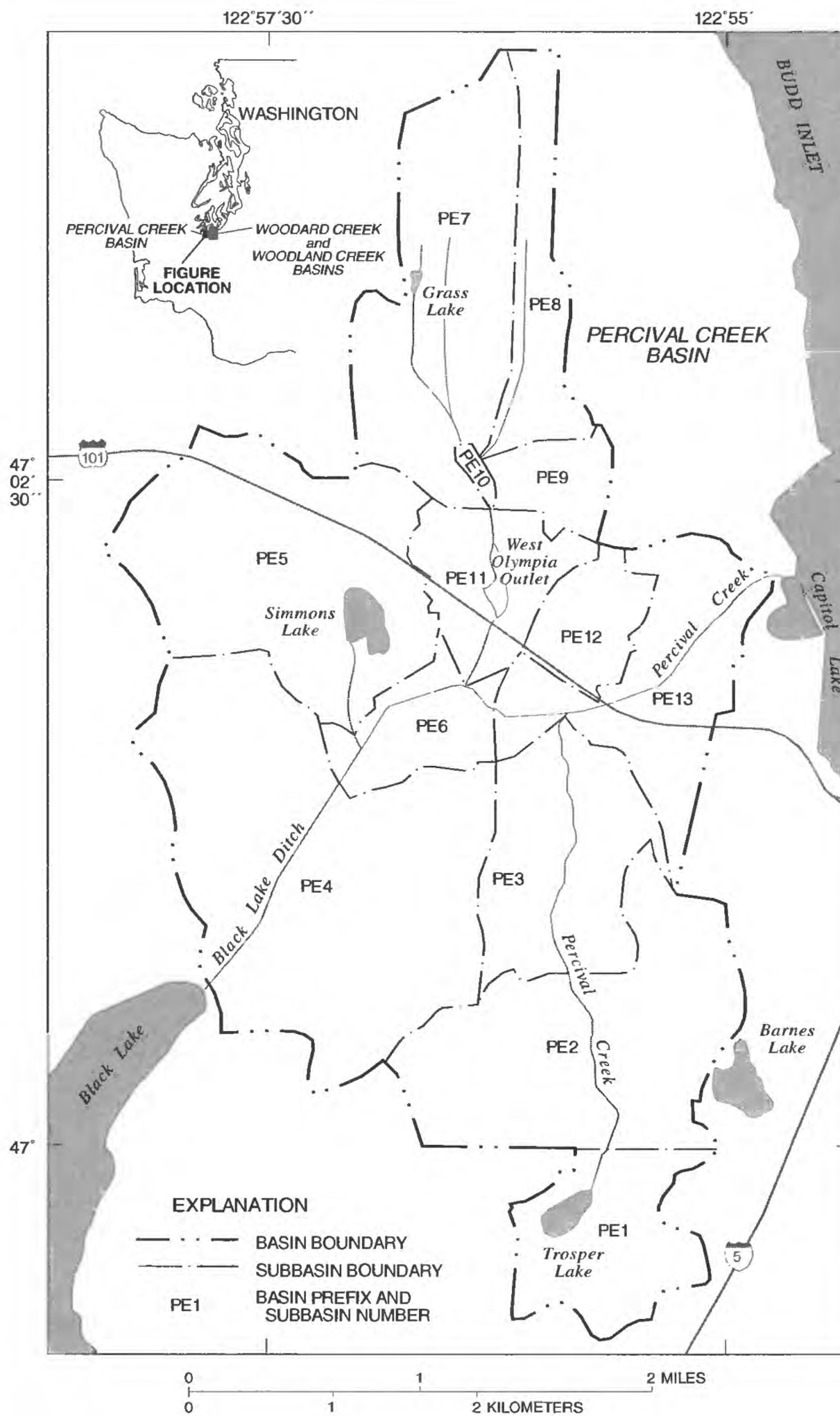
For the pre-calibration models, all overland flow, shallow subsurface flow, and ground-water flow generated in most model subbasins discharged to the reach and through the mouth of the subbasins in which they

originated. For closed subbasins, ground water discharged in the nearest stream reach draining an adjacent lower-elevation subbasin.

Not all runoff, however, necessarily discharges out of the surface-water outlets of the subbasins in which it originates. Some subbasins may have, for example, a reach that consists of a man-made drainage ditch or storm-sewer system. If these drainage systems run above the water table or shallow subsurface flow pathway or if they consist of impervious pipe or concrete, ground-water flow or shallow subsurface flow may bypass subbasin reaches as it flows downgradient. During model construction, it was specified in the NETWORK block that all runoff generated in these subbasins would discharge to the reaches and through the mouths of these originating subbasins. Later, though, during model calibration, these specifications were changed for some subbasins, and, additionally, new subbasins were defined. These types of modifications allowed more accurate definitions of runoff contributions from land segments to stream reaches. These types of modifications will be further discussed in the subsections, "Modifications to Subbasins" in the sections, "First Calibration and Evaluation" and "Final Calibration."

During model calibration, ground-water flow, shallow subsurface flow, or overland flow generated in a given subbasin was sometimes specified to drain to a reach located at a lower elevation in another subbasin. This specification was intended to simulate such situations as ground water flowing from a closed subbasin or ground-water flow or shallow subsurface flow bypassing man-made ditches or storm sewer systems. If several short, small tributary channels only sporadically drain an actual subbasin from several outlets, the NETWORK block was constructed to represent the situation by specifying that overland flow discharged to a lower-elevation reach in an adjacent subbasin.

In the natural hydrologic system of a basin, runoff drains by way of actual flow paths through or over all land intervening on the way to the surface drainage network. HSPF, however, does not simulate the actual pathway of water through all the land segments to the stream reach. Instead, it assumes that runoff from a land segment drains directly to a reach. The reach may be the most nearby reach, or it may be a reach in another subbasin. HSPF does not explicitly simulate water moving through the many individual flow paths in land segments, and this simplification helps keep basin models relatively efficient and simple.



**Figure 5.**--Subbasins in the Percival Creek Basin used in the final simulation model.





Because HSPF simplifies the delivery of runoff from land-segment types to subbasin reaches, simulated travel times may be shorter than actual travel times. Nevertheless, these differences in time-of-travel were not found to be significant for overland flows and ground-water flows in the small subbasins of the study and were minimized for shallow subsurface flow.

The difference in travel times between simulated and actual overland flow was negligible because actual overland flow moves relatively quickly to reaches. The travel time difference also was not significant for ground-water flow. Although the study defined subbasin boundaries on surface-water divides, these divides probably do not always coincide with ground-water divides for mildly sloping areas. For mildly sloping areas where hydraulic conductivities of the underlying ground-water system were high, some ground-water flow was assigned, during calibration, to lower elevation, downgradient reaches outside originating subbasins. It is likely that rainfall causes ground water in these areas to respond uniformly as a large system underlying several subbasins. The effect of rainfall on these subbasins, including closed subbasins and other subbasins where ground water may not discharge to nearby channels, is to raise the water table, to increase its gradient, and to increase ground-water flow throughout the ground-water system. As the gradient of the water table increases, ground-water flow moves downgradient and displaces lower elevation ground water located near a downgradient channel at increasing rates, and the displacement in turn increases ground-water discharge to that channel. Thus, recharge to an aquifer lying under an upgradient closed subbasin can displace downgradient ground water to a lower-elevation channel. The HSPF simulation of direct drainage to a channel reach that bypasses intervening land segments is a reasonable approximation of ground-water displacement, and the time-of-travel differences should not be significant.

Travel-time differences may noticeably affect the simulation of shallow subsurface flow because actual shallow subsurface flow is much slower than overland flow, and, unlike ground-water flow, it does not respond to precipitation uniformly under several subbasins. To minimize travel-time differences, the study generally did not assign shallow subsurface flow to drain to reaches in adjacent subbasins but instead confined the flow to reaches within its own originating subbasin. When the simulation had to assign shallow subsurface flow to an adjacent subbasin, the study required that the originating subbasin be small (less than 150 acres) so that the drainage path would be short and the actual travel time brief.

## Reaches

The last phase of model construction involved dividing the drainage network into segments, or reaches, each with relatively uniform hydraulic characteristics. The reaches were used either to drain or to connect subbasins. Each reach had its own contributing subbasin area, and each received runoff discharge from the land segments within the subbasin and from all connected upstream reaches. Each reach consisted of stream channels, storm-drainage pipes, lakes, ponds, or wetlands. In the final basin models, Percival Creek was divided into 13 reaches, Woodard Creek into 6 reaches, and Woodland Creek into 22 reaches, for a total of 41 reaches.

The RCHRES (reach-reservoir) block of HSPF routes streamflow along connected reaches of a drainage network to the outlet of a drainage basin. Streamflow routing is based on the hydraulic characteristics of the stream reaches, and those characteristics are defined by fixed parameters in the flow tables, or F-tables, of the RCHRES block. F-tables represent the relation of surface-water discharge at the downstream end of a reach to surface-water volume temporarily stored in the reach. HSPF uses this stored volume of water to simulate the discharge from a reach during a given time interval. F-tables also can specify losses from channel or lake seepage.

The initial volume-discharge relations for reaches were determined from measurements or estimates of hydraulic properties during field reconnaissance and from measurements of some channel properties directly from maps. Reconnaissance data collected in a previous investigation (Bortleson and others, 1976) provided information on lake properties in Woodland Creek Basin. This information was used to determine the volume-discharge relations for Hicks Lake in subbasin WL4, Pattison Lake in subbasin WL5, and Long Lake in subbasin WL6. Field reconnaissance yielded measurements or estimates of channel cross sections, channel roughness, culvert lengths, culvert slopes, culvert roughness, culvert cross sections, and culvert entrance shapes. Map data provided information on channel lengths and slopes, and on storm-drainage pipe cross sections, slopes, and lengths. Because HSPF simulates stream discharges at the downstream end of reaches, field reconnaissance usually took place at or near these downstream ends. However, hydraulic properties sometimes were observed at several locations within a reach because cross sections measured during field reconnaissance had to represent the reach as a whole. The hydraulic information was collected so that depth-discharge relations could be estimated from Manning's equation for open channels or from the energy equation for



culverts. For a given depth and discharge, cross-sectional areas were multiplied by channel length to determine the volume of water stored in the reach. Each F-table represented a general average for the entire reach rather than a specific relation for every single channel, pipe, lake, pond, or wetland within the reach.

The relative sensitivity of a reach, or the degree to which a change in the stored volume of a reach changes its discharge, is represented in the F-tables. For example, an F-table for a reach consisting of a lake would have a large range of storage volumes corresponding to a small range of discharge at the outlet. Thus, for a large storm, a large change in storage volume will correspond to only a small change in discharge at the lake outlet. Discharge from this reach would be relatively insensitive to changes in storage volume. Pattison Lake (subbasin WL5) and Long Lake (subbasin WL6) in the Woodland Creek Basin are examples of insensitive reaches.

## **Calibration and Evaluation of the Simulation Models**

After the study area was divided into land-segment types, subbasins, and reaches and after initial values were assigned to HSPF parameters, the simulation models were calibrated and evaluated. The underlying goal of model calibration and evaluation was to appraise the conceptual model of runoff generation in the Woodland, Woodard, and Percival Creek Basins. If the initial simulation models constructed using the same general approach and parameter values determined by Dinicola (1990) (along with using the first approximation of parameter values for the land-segment types not found in that previous study) had resulted in adequate simulations of streamflow, then model calibration would not have been needed. Favorable results would have implied that the conceptual model and the quantitative expression of the conceptual model (the numerical models) were adequate for the Thurston County study basins. Thus, the conceptualizations and parameters for land-segment types in basins in King and Snohomish Counties in the central Puget Sound Lowland also would have applied to those land-segment types in basins in Thurston County in the southern Puget Sound Lowland. However, because the initial simulation models did not adequately simulate observed streamflow, the simulation models required calibration and further evaluation.

The immediate goal of calibrating the basin models was to minimize differences between observed and simulated streamflows at stream-gage sites. This procedure

involved testing and, when necessary, adjusting the values of process-related and fixed parameters. The need for adjustments was signalled by significant differences between simulated and observed hydrographs and volumes. The nature and extent of adjustments was guided by supplemental information on drainage networks, soils, geology, and ground water.

The goal of evaluating the basin models was to test how well the calibrated models could simulate streamflows for periods other than those used during the calibration process. If the calibrated models were truly representative of the runoff generation process, then the differences between observed and simulated streamflows for both the calibration and the evaluation periods should have been similar in magnitude. If the differences were significantly larger for the evaluation period, then it could have been concluded that the calibrated models were not adequately representing the runoff generation processes.

The original study plan for this investigation was designed so that the first year of observed data would be used for model calibration and the second year would be used for evaluation. The results of this "split-sample" approach are presented in the section of this report entitled "First Calibration and Evaluation." As described in that section, some measures of simulation differences for the evaluation period were much larger in magnitude than those differences reported for the calibration period. It was decided that improvements could be made to the first calibration if observed data from the evaluation period were used to refine the calibration.

The section of this report entitled "Final Calibration" presents the results of calibrating the basin models with 2 years of observed data. These final basin models were not evaluated with additional streamflow data as part of this investigation because the entire observed record was used for calibration, but some important features were added to the basin models as a result of the 2-year calibration effort.

Calibration and evaluation were based on streamflow (stream discharge and volume) because it is an easily measured basinwide response to precipitation. However, identifying the individual hydrologic processes that generate this response is difficult, and the process-related parameters that govern the simulation of these processes are difficult to measure independently. Nevertheless, calibrating basin models to observed streamflow data is a practical method of comparing runoff theory and observations.

The following sections describe (1) the observed data used for model calibration and evaluation; (2) the sources of difference between observed and simulated streamflows; (3) the adjustments and refinements to model parameters for both the first calibration and evaluation effort, and the final calibration effort; and (4) the calibration and evaluation results. The sections discussing calibration and evaluation results include an evaluation of differences between observed and simulated streamflows for (1) the first-year calibrated models calibrated to a little more than 1 year of observed streamflow and evaluated with a second year of observed streamflows and for (2) the final calibrated models calibrated to a little more than 2 years of observed streamflows.

### **Data Collection**

The streamflow data for model calibration and evaluation were collected during the period March 1, 1988, through March 15, 1990, at 15-minute intervals from six continuous-record streamflow gages--two gages in Woodland Creek Basin, one in Woodard Creek Basin, and three in Percival Creek Basin (figs. 7 and 8). Because the upstream boundary of Percival Creek Basin was defined as the northern outlet of Black Lake, lake outflow data obtained at gage 12078705 (Black Lake Ditch at Lake Outlet near Tumwater) were not used for model calibration but were used to define the upstream inflows for streamflow simulation with the Percival Creek model. Calibration for this part of the Percival Creek model was carried out at the downstream gaging station 12078720 (Black Lake Ditch near Olympia). The contributing areas to the five other gages used for calibration ranged from 2.3 to 23.9 square miles. For the same period, instantaneous peak flows were estimated a few times each year at two crest-stage gage sites in the basins; stage was measured periodically at five lake and stream sites; and occasional measurements of discharge were obtained at a number of sites scattered throughout the basins.

The basin models simulated runoff generation and streamflows for each entire basin even though each basin contained substantial area between the farthest downstream gaging station and the basin mouths. These areas are called "ungaged areas." Gaging stations were not installed farther downstream toward the basin mouths because either (1) access was not available or (2) locations with hydraulic conditions suitable for collection of streamflow data were not available. Ungaged areas cover 11 percent of the Percival Creek Basin (579 acres), 42 percent of the Woodard Creek Basin (1,584 acres), and 9 percent of the Woodland Creek Basin (1,480 acres). The basin

models were not calibrated to observed streamflows in the ungaged areas, and model results for these areas are not presented in this report. It is likely that streamflow simulations will be less accurate in the ungaged areas than in the gaged areas.

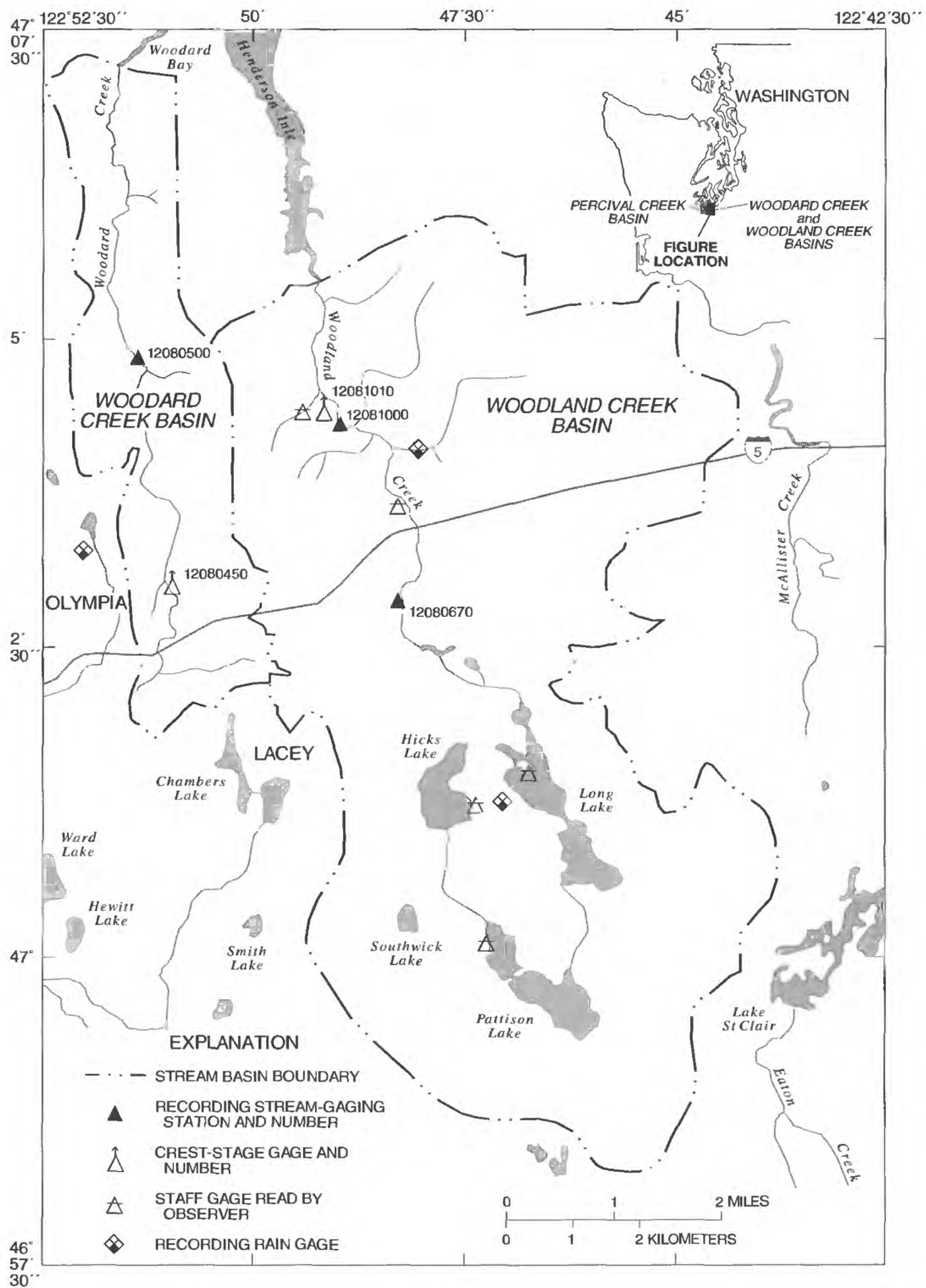
Simulation of stream discharge and runoff volumes required input time series for observed rainfall and estimated potential evapotranspiration. Rainfall accumulation data were collected continuously at 15-minute intervals from March 1, 1988, through March 15, 1990, at four sites in the three basins (figs. 7 and 8). Pan-evaporation data were obtained from the National Weather Service Class A evaporation pan near Puyallup, Wash., about 30 miles northeast of the study area, for the periods March through October 1988 and May through September 1989. A coefficient of 0.75 applied to pan data yielded potential evapotranspiration (PET) (Farnsworth and Thompson, 1982). PET data for the periods November 1988 through April 1989 and October 1989 through March 1990 were estimated from a version of the Jensen-Haise equations (Bauer and Vaccaro, 1986), which required temperature data from the National Weather Service station at Olympia Airport.

The data-collection period represented a variety of hydrologic conditions. Although there were variations of rainfall throughout the study area, rainfall was generally slightly below average (mean annual precipitation is about 51 inches in the Olympia area) from March 1, 1988, through February 28, 1989, and slightly above average from March 1, 1989, through February 28, 1990. A large range of streamflows was present during the data-collection period--from the low streamflows in the summer of 1988 to the high streamflows in the winter of 1990. An extremely large series of storms between January 4 and 9, 1990, dropped 8 to 10 inches of rain in 6 days, more intense rain than at any other time in the study period. These storms provided the opportunity to calibrate the models to extremely high streamflows.

### **Sources of Differences Between Observed and Simulated Streamflow**

There is commonly a difference between model-simulated streamflow and observed streamflow. Two reasons usually account for the difference: (1) the basic data to drive or calibrate the model are inadequate or inaccurate; or (2) the models inadequately represent runoff processes.





**Figure 7.--Data-collection network for Woodard and Woodland Creek Basins.**



Rainfall data may not always be adequate or accurate. Although precipitation from the frontal storms that commonly generate runoff in the Puget Sound region was assumed to be homogeneous throughout the area, the data from this study's rain gages, spaced about one per 10 square miles, show that rainfall varied significantly from one gage to another. Thus, precipitation may not have been adequately represented for each subbasin. Another problem was that the rain gages were not constructed to measure snowfall or snowmelt accurately. Although snow is not common in the study area, Olympia Airport recorded about 7 inches of snow in January 1988, 14 inches in February 1989, 9 inches in March 1989, 2 inches in January 1990, and 27 inches in February 1990. Finally, rain-gage malfunctions, although not significant, resulted in periods of missing record that contributed some inaccuracy. Rainfall for periods of missing record had to be estimated from nearby gages because model runs required continuous rainfall records with no gaps. The precipitation measurement and distribution problems described above may subsequently result in inaccurate streamflow simulations in the study basins.

Daily PET rates also may contribute inaccuracy to simulated streamflow. PET rates were not directly measured in the study area. Therefore, daily PET rates in the study area were derived from pan-evaporation records for Puyallup, Wash., and from temperature data at Olympia Airport. Although the data used to derive the daily PET rates were collected near the study basins, these derived rates may vary from the actual PET rates in the study's drainage basins. Thus, PET rates may not be adequately represented in the drainage basins.

Differences between simulated and observed streamflows may also result from inaccuracy in the observed streamflow data. The most common source of inaccuracy in observed streamflow data was the inconsistent quality of records from some stations. Although locations for stream-gaging stations were chosen specifically for model calibration and evaluation, unstable channels at some locations caused variable stage-discharge relations. Discharge was measured at these locations frequently to improve the accuracy of these relations, but even so, the accuracy of stage-discharge records at certain gaging stations was rated "fair". A fair rating means that 95 percent of the observed daily streamflows are accurate only to within 15 percent of true values. Moreover, missing periods of stream-flow records resulted from malfunctioning stream-gage stations, usually because of freezing. Streamflow records for these missing periods were estimated from the hydrographs of nearby unaffected gages.

Differences between simulated and observed streamflows also arise from uncertain representations of hydrologic processes by HSPF and by uncertain parameter values in the basin models. The HSPF program can represent most of the many complex physical processes that affect runoff generation, but like all current rainfall-runoff models, it simplifies the natural system, and this simplification sometimes produces differences between simulated and observed streamflows. Because values for the model parameters that are used in the representation of processes could not be directly and precisely measured, they were determined or adjusted by calibration to observed streamflows. Parameter values were in accord with reliable information on soils, geology, ground water, and channel networks, but there is some uncertainty about how accurately and fully parameter values represent all the features controlling the hydrologic processes at work throughout the study basins. Later sections of this report will discuss evaluations of these discrepancies.

### **First Calibration and Evaluation**

As mentioned previously, the simulation models initially constructed using the general approach and parameter values determined by Dinicola (1990) did not adequately simulate streamflow without further calibration. These initial models were thus calibrated to observed streamflow data in the surface drainages of Woodard Creek, Woodland Creek, and Percival Creek downstream from Black Lake between March 1, 1988, and March 29, 1989. The calibration process involved modifying (1) a process-related parameter in the PERLND block, (2) surface- and ground-water contributions to subbasin drainage networks in the NETWORK block, and (3) volume-discharge relations of reaches in the F-tables of the RCHRES block. An attempt was made to evaluate these calibrated models, also referred to as the first-year calibrated models, by comparing simulated streamflows with observed streamflows for the period March 30, 1989, through March 15, 1990.

### **Modifications to Process-Related Parameter Values**

Process-related parameter values are commonly modified during calibration to minimize differences between observed and simulated streamflows at streamflow-gaging stations. The following discussion describes, in a general manner, the poor simulation results from the initially constructed models, the explanation why the



values of process-related parameters were sometimes not modified to improve the poor simulations, and the modification of one process-related parameter value, KVARV.

Initial simulation results (after model construction) were considered to be poor from the Woodland and Woodard Creek models and from the Percival Creek model representing the part of Percival Creek Basin upstream from Black Lake Ditch near Olympia, Wash. (station 12078720). The simulation results were considered to be poor for two reasons listed below.

- (1) Simulated runoff volumes, daily mean discharges, peak discharges, and high runoff volumes from storms generally exceeded observed data. Such results are called "over-simulation," and converse results are called "under-simulation" in this report.
- (2) Timing and magnitude of simulated ground-water discharge did not coincide with observed seasonal baseflows.

There are two possible reasons for over-simulating runoff volume at the gaging stations: the under-simulation of actual evapotranspiration (AET) and the over-simulation of runoff contributions to a reach from land segments in a subbasin. The potential evapotranspiration data input to the three basin models averaged about 24 inches per year for the 2-year calibration period. The simulated AET averaged about 17 inches per year for the three basins during that same period. It is likely that AET did not satisfy the PET demand during the dry summer months when soil-moisture levels were low. Additionally, simulated AET values are consistent with AET values simulated for basins in King and Snohomish Counties (R.S. Dinicola, U.S. Geological Survey, written commun., 1992). Therefore, the simulated values of AET are reasonable, leaving the over-simulation of runoff contributions from land segments to reaches as a likely source of errors.

Adjusting process-related parameter values is a common calibration technique to reduce runoff contributions to stream reaches. However, except for KVARV, adjustment of process-related parameter values did not consistently improve the over-simulation of runoff at four of the five gaging stations used for calibration. Most adjustments produced variable results, depending on the season and location of the gaging stations.

Results from runoff simulations, using the original parameter values chosen during model construction, at the fifth gaging station were generally satisfactory, except that simulated ground-water baseflows were lower than

measured baseflows. The fifth gaging station, Percival Creek station 12078730, collected streamflow data from a relatively simple basin. This part of the Percival Creek Basin is relatively simple because, except in the headwater subbasin (PE1), Percival Creek lies in a valley between moderately to steeply sloped hills that clearly define the subbasin boundaries. All ground-water flow, shallow subsurface flow, and overland flow generated in this part of Percival Creek Basin was simulated to contribute to streamflows without over-simulating observed streamflow. Thus, for this relatively simple part of Percival Creek Basin, the process-related parameter values adequately represented the hydrologic responses of land segments to rainfall. It is also probable that the parameter values also adequately represented the hydrologic responses of land segments to rainfall for the other basins because most of the same land-segment types were present throughout all of the basins. However, the process-related parameters do not direct outflow from land segments (ground-water flow, shallow subsurface flow, and overland flow) to reaches. The NETWORK block is used to direct these outflows. In the initially constructed models, outflows from land segments were directed to reaches in the same subbasins or, in the case of closed subbasins, to reaches in adjacent downstream subbasins. Thus, in the initially constructed models, oversimulation of runoff contributions from land segments to reaches occurred where outflows contribute to inactive ground water or to reaches in other subbasins.

The deep fraction (DEEPFR) parameter can be used to assign outflows from land-segment types to inactive ground water. However, this parameter governs outflows from all land segments in a given type regardless of the location of that land segment. This parameter was not adjusted in the basin models because contributions from land segments to inactive ground water varied with location. Thus, the only practical method of adjusting contributions of outflows to reaches or inactive ground water was to adjust the routing of outflows in the NETWORK block of the HSPF program. This is discussed in the following section, "Modifications to Subbasins."

The value of only one process-related parameter was modified in the PERLND block during first calibration. The parameter KVARV (the active ground-water outflow modifier) was reduced for all land-segment types in the initial Woodland and Woodard Creek Basin models to improve the timing and magnitude of simulated ground-water discharge. This value was changed because during winter and spring wet periods, simulated streamflows decreased more gradually than observed streamflows after storm-driven hydrograph peaks, with the recession limb of the simulated hydrograph having a flatter slope than the

recession limb of the observed hydrograph. Simulated baseflows during these winter and spring wet periods were higher than observed baseflows, but simulated baseflows during summer low-flow periods were lower than observed streamflows. Reducing the value for KVAR<sub>Y</sub> improved streamflow simulations by decreasing simulated ground-water flow contributions to reaches during winter and spring wet periods and by increasing these contributions during the summer dry period. The other process-related parameter values did not need adjustment in first calibration.

### Modifications to Subbasins

Several modifications related to the delineation of subbasins and the drainage from subbasins were made during first calibration. Additional subbasins were delineated; contributions of ground-water flow, shallow subsurface flow, and overland flow to stream reaches in some subbasins were changed; and the percentage estimates of effective impervious area for each partially impervious land cover class in some subbasins were revised.

Additional subbasins were delineated using two methods: (1) subdividing existing subbasins into two or more subbasins and (2) adding new subbasins from outside the previously defined basin boundaries. The need to subdivide subbasins into two or more subbasins was recognized when simulated streamflows exceeded streamflows observed in several Woodland and Woodard Creek subbasins. Subsequent field reconnaissance indicated that surface-water runoff from large parts of these subbasins did not drain to the reaches within the subbasins and that it was questionable whether all shallow subsurface flow and ground-water flow drained to the reaches. Therefore, some existing subbasins were subdivided to allow more accurate definition of the hydraulic linkages between the land segments and reaches (table 6). The refinement of these linkages in the NETWORK blocks of the basin models resulted in more accurate simulations.

The need to add new subbasin area from outside the previously determined basin boundaries was recognized when simulated ground-water baseflows were lower than measured baseflows at the Percival Creek stream gage at Mottman Road near Olympia. A new subbasin (PE1A) of 180 acres was added to the initial Percival Creek model. This new subbasin functioned to add ground-water flow contributions to Percival Creek from outside the basin.

**Table 6.--Initial subbasins (delineated prior to calibration) that were subdivided into new subbasins during first and final calibrations**

Basin	Initial sub-basins	New subbasins for the first-year calibrated models	New subbasins for the final calibrated models
Woodland Creek	WL5	WL5A	WL5A
		WL5B	WL5B
	WL6	WL6A	WL6A
		WL6B	WL6B
		WL6C	WL6C
		WL6D	WL6D
		WL46	WL6E
		WL46A	
	WL8	WL1A	WL1A
		WL8A	WL8A
		WL8B	WL8B
	WL9	WL9A	WL9A
	WL13	WL13A	WL13A
	WL16	WL16A	WL16A
Woodard Creek	WL20	WL20A	WL20A
	WL22	WL22B	WL22A
	WL25	WL22A	WL25A
		WL25A	WL25B
	WD2 and WD3 <sup>1</sup>	WD3A	WD2
			WD3
	WD4	WD4A	WD3A
		WD4B	
		WD4C	WD4A
	WD5	WD4B	WD4B
		WD5A	WD5A
		WD5B	WD5B
	WD6	WD6A	WD6A

<sup>1</sup> WD2 and WD3 were considered one subbasin in the initial Woodard Creek model and the first-year calibrated Woodard Creek model.

The boundary of headwater subbasin PE1 was poorly defined because of the flat topography of the outwash plain in that area, and the apparent surface-water divide in the area did not seem to coincide with the ground-water divide. Thus, ground water under PE1 is likely part of a larger ground-water system that can respond to precipitation falling outside the basin. Although the precise location of the boundaries of PE1A was unknown, total size of the new subbasin was determined by calibration to observed baseflows.

Simulated streamflows commonly exceeded observed streamflows, and the frequent disparity indicated some ground-water flow, shallow subsurface flow, or overland flow from some subbasins did not drain into the reaches that discharge at the mouths of the originating subbasins (subbasin reaches). The flow mechanisms presumably bypassed subbasin mouths for the following reasons:

- (1) Ground-water recharge in extensive outwash areas drained to regional rather than local aquifers;
- (2) Ground-water and shallow subsurface flows never surfaced in a basin because the reach draining a subbasin, or sections of the reach, was higher than the ground-water table;
- (3) Contributions of runoff to the drainage networks were modified by complex ground-water/surface-water interactions at lakes; and
- (4) Contributions of subsurface flow and overland flow were decreased in areas with man-made conveyance systems, infiltration facilities, dry wells, or hummocky areas with many closed depressions.

Specifications in the NETWORK block of the calibrated models were revised so that estimated parts of ground-water, shallow subsurface, and overland flow would not discharge at the mouth of certain subbasins. Some simulated runoff was specified to discharge into the subbasin reach, and the remainder of runoff was specified to either discharge at a downgradient reach in a nearby subbasin or recharge to inactive ground water. For example, a part of the ground-water flow from a series of Woodland Creek subbasins (WL1A, 8A, 8B, 9, 9A, 10, 12, 13, 13A, 14, 16, and 16A) was assigned to contribute to a complex system of springs in subbasin WL17 of the Woodland Creek Basin. The quantity of ground-water contributions to the springs was estimated from stream

discharge measurements of Woodland Creek immediately upstream and downstream of the springs, and at the springs.

Another subbasin-related modification made during first calibration was for subbasins where outwash land segments lay immediately downhill from till segments. Observed runoff responses from such areas were dampened and attenuated--more typical of outwash rather than till segments. The NETWORK block in the basin models was revised to treat such uphill till segments as though they were outwash segments, a modification designed to represent the drainage of runoff from a till segment to the first downhill outwash segment. This adjustment assumed that the overland flow and shallow subsurface flow generated on an uphill till segment would become recharge once they reached a downhill outwash segment. On the basis of streamflow information, the proportion of land segments having till and outwash soil types was refined for Woodard Creek subbasin WD3 and for Woodland Creek subbasins WL13, 14, 15, 16, 16A, 17, 19, 20, and 21.

Errors in the initial estimates of effective impervious area were suspected when, in some highly urbanized subbasins in outwash areas of Woodland and Woodard Creek Basins, simulated discharge peaks resulting from storms were higher and quicker than the observed peaks and simulated runoff volumes after storms were greater than observed volumes. Hence, contributions of runoff from impervious areas in these urbanized subbasins were adjusted in the NETWORK block. The drainage systems in these areas are mostly grass-lined swales rather than curb-and-gutter systems, and grass-lined swales can store and infiltrate large quantities of runoff generated from impervious areas. On the basis of calibration to observed streamflow, the estimated percent effectiveness was decreased for the six classes of impervious land cover (table 3) in Woodland Creek subbasins WL9, 13, and 14 and Woodard Creek subbasin WD1. These were the decreases:

- Sparse residential--from 4 percent to 0 percent;
- Moderate residential--from 10 percent to 0 percent;
- Suburban residential--from 23 percent to 0 percent;
- High-density residential--from 48 percent to 24 percent;
- Medium commercial/low-density industrial--from 48 to 24 percent;
- Heavy commercial/heavy industrial--from 86 to 58 percent.

## Modifications to Reaches

The F-tables in the RCHRES block of the initial models were modified to refine volume-discharge relations and to account for documented reach losses. The volume-discharge relations were refined when the simulated magnitude and timing of storm hydrographs did not closely match those of observed hydrographs. These refinements, based on information from field surveys and reconnaissance and from maps, usually involved small-scale adjustments of the volume or corresponding discharge for a given depth of water in a stream reach. However, defining the volume-discharge relations at the outlets of large lakes in the Woodland Creek Basin was difficult, and the calibration of volume-discharge relations in these cases involved larger adjustments.

Losses of water due to infiltration into bed materials was simulated by adding a second discharge column in the volume-discharge relation of certain F-tables. Visual observations of streamflows often detected reach losses, which were verified by streamflow measurements where possible. Seepage runs, which are serial, nearly concurrent discharge measurements along the length of a stream to determine losses and gains, were performed on Woodland Creek, the only creek where such channel-bed losses were thought to be significant. Reach losses were especially common in subbasins with lakes or with large areas of outwash soil where ground-water levels have a significant influence on surface-water processes.

## Calibration and Evaluation Results

After all of the discussed modifications were completed, the calibrated models simulated the first year of observed streamflow data, from March 1, 1988, through March 29, 1989, reasonably well at most of the streamflow-gaging stations. These first-year calibrated models then were evaluated by simulating a second year of streamflow data collected between March 30, 1989, and March 15, 1990. Most of the models simulated this second year of observed streamflow data less accurately than the first year of data. A statistical analysis of differences in simulating total runoff volumes, daily mean discharges, and storm runoff and peak discharges is outlined in the following sections.

**Total runoff volume.**--Observed and simulated runoff volumes from five of the six gaging stations were compared for both the calibration and the evaluation periods. Data from a sixth gaging station not used for calibration, 12078705, were used to define streamflows entering Percival Creek Basin from Black Lake. Observed and simulated values of total runoff volume for the first-year calibrated models are compared in table 7 for both the calibration and evaluation periods.

For the calibration period, the absolute values of differences between observed and simulated total runoff ranged from 1.7 to 12.8 percent, the largest difference being for Woodland Creek station 12081000. For the

**Table 7.**--Observed and simulated runoff data for the first-year calibrated models during the calibration and evaluation periods

[Observed, observed value; Simulated, simulated value; Difference, simulated-observed; Percent difference, 100 x (simulated-observed/observed)]

Station name/ station number	Simulation period <sup>1</sup>	Observed (inches)	Simulated (inches)	Difference (inches)	Percent difference
Black Lake Ditch near Olympia/12078720	C	93.41	97.26	3.85	4.1
	E	96.21	103.25	7.04	7.3
Percival Creek near Olympia/12078730	C	46.15	47.38	1.23	2.7
	E	45.89	47.07	1.18	2.6
Woodard Creek near Olympia/12080500	C	25.92	25.49	-.43	-1.7
	E	28.93	28.47	-.46	-1.6
Woodland Creek at Martin Way at Lacey/ 12080670	C	2.32	2.26	-.06	-2.6
	E	5.42	4.06	-1.36	-25.1
Woodland Creek near Olympia/12081000	C	10.82	12.21	1.39	12.8
	E	12.79	14.41	1.62	12.7

<sup>1</sup> Simulation period C, calibration period from March 1, 1988, through March 29, 1989.

Simulation period E, evaluation period from March 30, 1989, through March 15, 1990.

evaluation period, percent differences for four of the five stations were similar to those for the calibration period. For the fifth station, Woodland Creek station 12080670, the percent difference increased from 2.6 percent to 25.1 percent in absolute value. Differences greater than 10 percent for both the calibration and evaluation periods for the Woodland Creek model suggest that this first-year model was not adequately simulating some important processes.

**Daily mean discharge.**--The accuracy of the models in simulating daily mean discharges was assessed by comparing observed and simulated hydrographs from the five streamflow-gaging stations for the calibration and the evaluation periods (figs. 9-13) and by computing statistical measures of difference between observed and simulated values of daily mean discharges for the total flow record and for low, medium, and high flows. Tables 8 and 9 show these statistical measures of difference for the calibration period and the evaluation period respectively. The differences, usually largest at the upstream Woodland Creek station (12080670), were generally larger for the evaluation period. Differences were particularly large for the period after a large January 1990 storm.

Three statistical measures of difference were useful in evaluating the success of the simulations: the mean absolute difference, the bias, and the root-mean-square difference. The mean absolute difference is the average of differences between observed and simulated daily mean discharges without regard to whether the differences were positive or negative. The bias is the arithmetic average of the actual differences. A large positive bias usually means that a model is overestimating streamflow, and a large negative bias means that it is underestimating streamflow. The root-mean-square is the standard deviation of the differences. Assuming a normal distribution of differences, two-thirds of all the difference are less than or equal to this value. The statistical measures of difference also are expressed in terms of percent relative to the observed values. A mean absolute difference of 25 percent, for instance, means that the simulated daily mean discharges differ, on average, 25 percent from their corresponding observed values. (See footnote 3 of table 9 for a formal definition.)

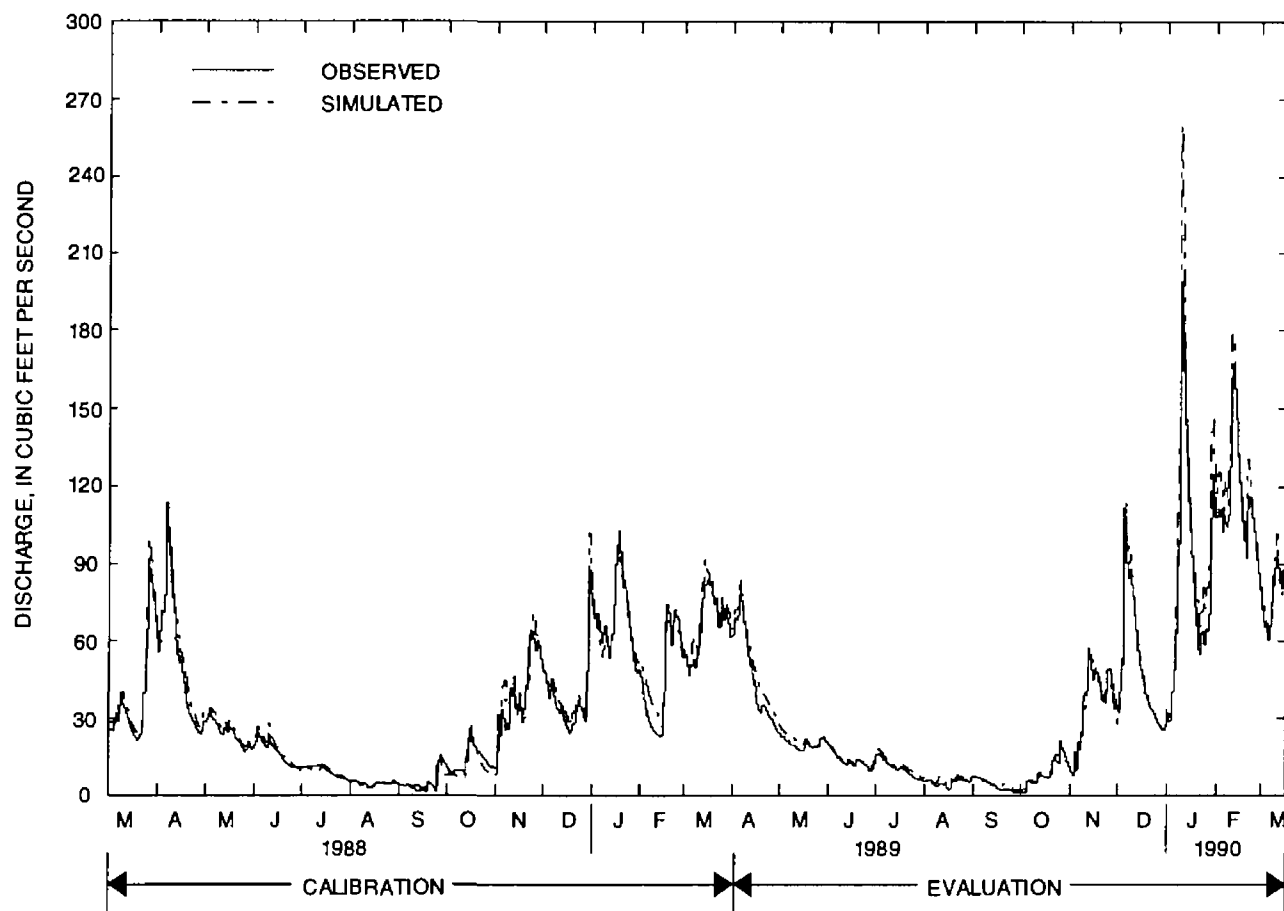
Mean absolute differences for the daily mean discharge record for all flow regimes ranged from 13.2 to 36.5 percent during the first calibration period and from 13.7 to 79.1 percent during the evaluation period. For the calibration period, mean absolute differences for the total flow record were less than 17 percent for four of the five stations, but the difference was 36.5 percent for the fifth station, Woodland Creek station 12080670. The large

difference at this station was primarily due to the 60.7 percent difference for low flows. Note that a small difference in cubic feet per second--only a little more than 0.5 cubic foot per second here--can translate into large percent difference. For the evaluation period, the largest absolute differences between observed and simulated daily mean discharges--79.1 percent for total flows--were from the same Woodland Creek station (12080670). Differences for the other stations were less than 30 percent.

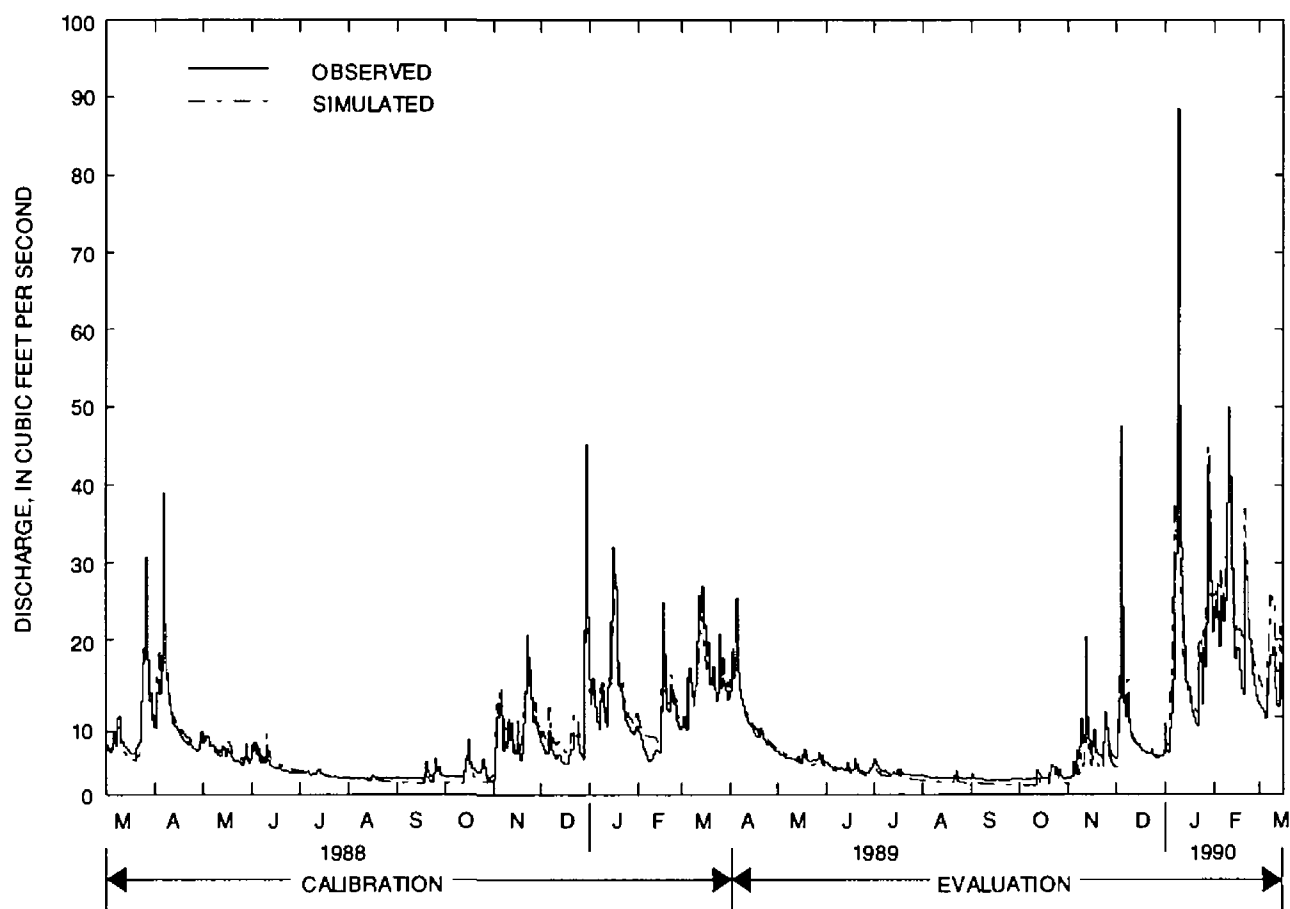
Most of the measures of differences increased for the evaluation period. Mean absolute differences for all flow regimes, for example, increased from 16.5 to 27.7 percent for Woodard Creek station 12080500 and increased from 36.5 to 79.1 percent for Woodland Creek station 12080670. Mean absolute differences for low flows increased from 26.2 to 42.6 percent for Woodard Creek station 12080500, from 60.7 to 161 percent for Woodland Creek station 12080670, and from 8.1 to 19.3 percent for Woodland Creek station 12081000. Mean absolute differences for medium flows increased from 28.6 to 53.1 percent for Woodland Creek station 12080670; and for high flows, the differences increased from 11.5 to 21.8 percent for Woodard Creek station 12080500.

Despite the increased statistical measures of difference, most hydrographs of observed and simulated daily mean discharges usually matched fairly well for the evaluation period (figs. 9-13). An exception was the hydrographs from Woodland Creek station 12080670, which show that the model underestimated flows in the spring of 1989 and the winter of 1990 (fig. 12). Other exceptions were the hydrographs in figures 9, 11, 12, and 13, which show that the models overestimated daily mean discharge at four of the five stream-gaging stations for the large storm of January 8-9, 1990.

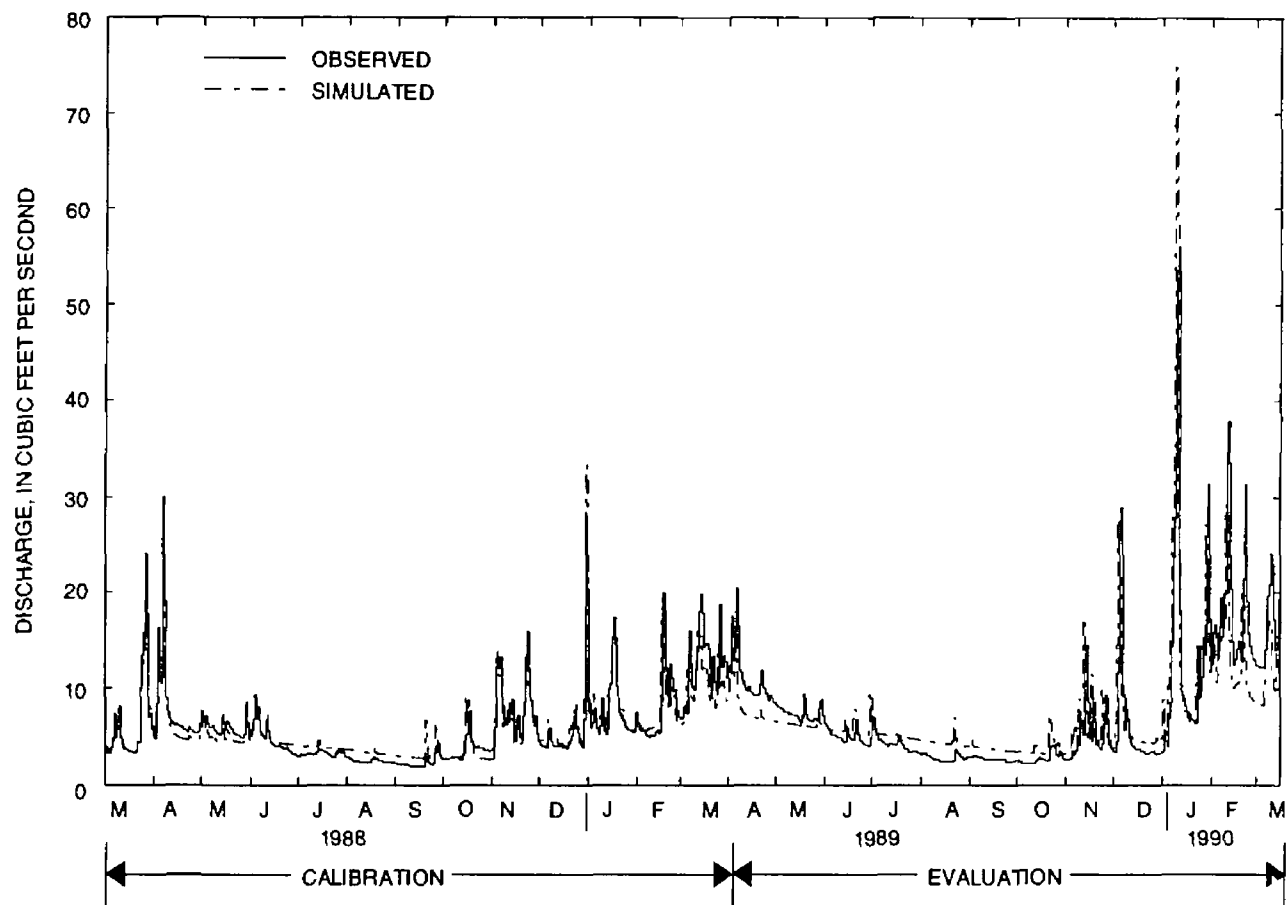
**Storm runoff and peak discharge.**--Periods of storm-runoff when hydrographs displayed large, distinct peaks provided additional opportunities to judge the performance of the basin models. Figures 14 through 23 show hydrographs for observed and simulated discharges during selected storm periods, and table 10 compares observed and simulated storm-runoff volumes and peak discharges. Only one storm period was assessed for Woodland Creek station 12080670 in the calibration period because the annual hydrograph plainly indicates the influence of a dominant ground-water component rather than responses from individual storms (fig. 12). Differences between simulated and observed storm runoff volumes (for the duration of high water resulting from storms) during the first calibration period ranged from 1.6 to 50.0 percent in absolute value, though only 1 of 16



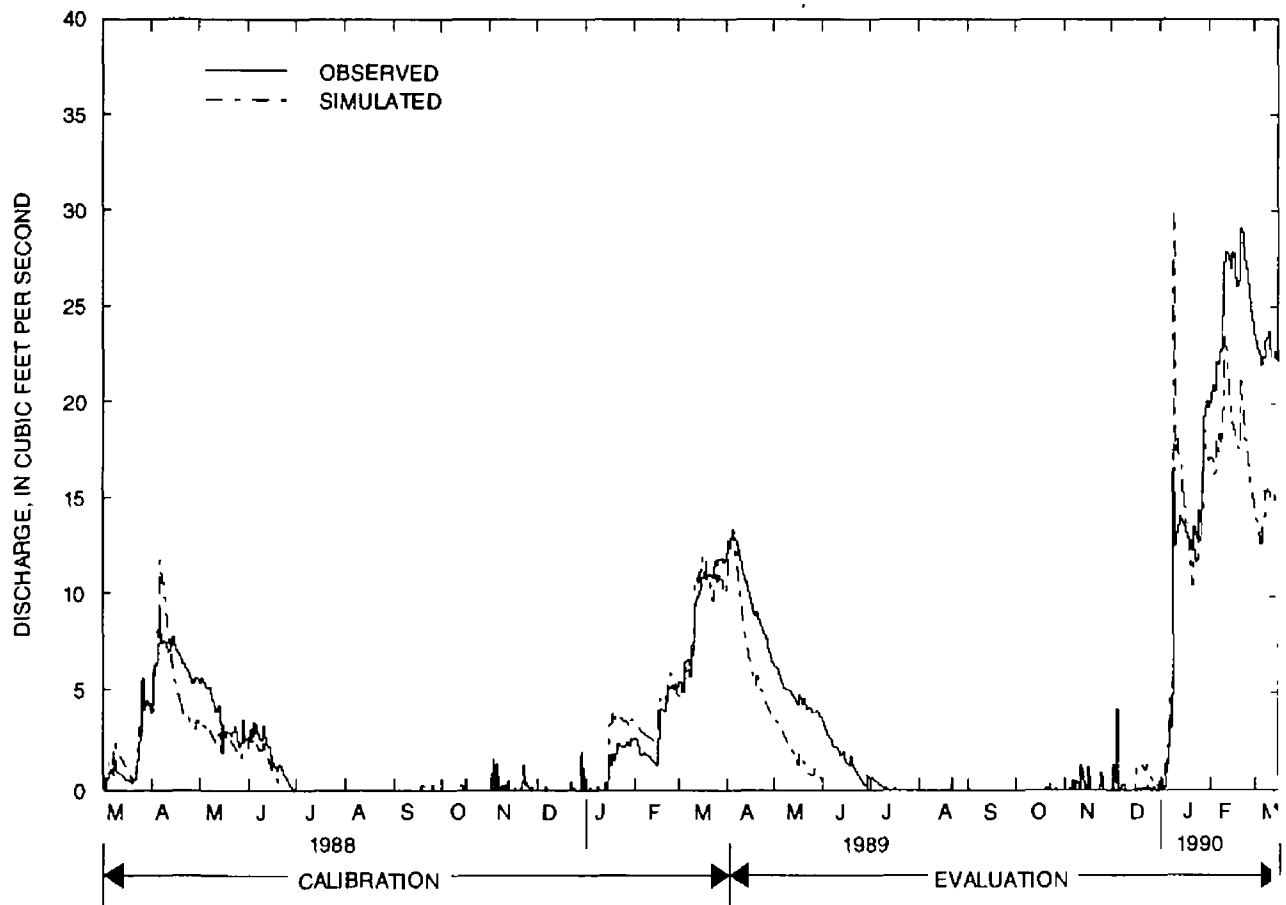
**Figure 9.--**Observed and simulated daily mean discharges for Black Lake Ditch near Olympia, Washington (station 12078720), in the Percival Creek Basin. Simulated discharges are from the first-year calibrated model applied to the period March 1, 1988, through March 15, 1990.



**Figure 10.--**Observed and simulated daily mean discharges for Percival Creek near Olympia, Washington (station 12078730), in the Percival Creek Basin. Simulated discharges are from the first-year calibrated model applied to the period March 1, 1988, through March 15, 1990.

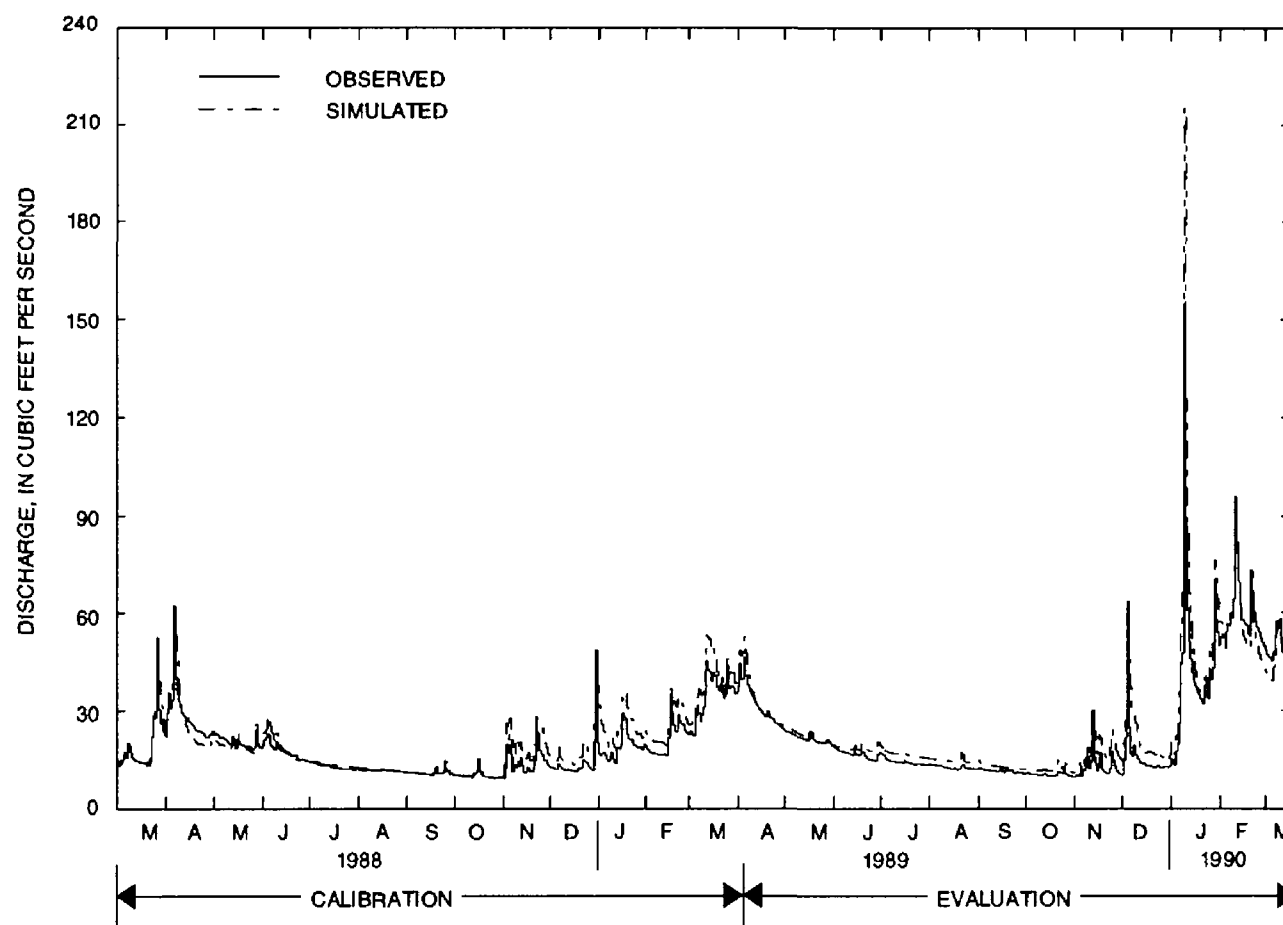


**Figure 11.--**Observed and simulated daily mean discharges for Woodard Creek near Olympia, Washington (station 12080500), in the Woodard Creek Basin. Simulated discharges are from the first-year calibrated model applied to the period March 1, 1988, through March 15, 1990.



**Figure 12.--**Observed and simulated daily mean discharges for Woodland Creek at Martin Way at Lacey, Washington (station 12080670), in the Woodland Creek Basin. Simulated discharges are from the first-year calibrated model applied to the period March 1, 1988, through March 15, 1990.





**Figure 13.--**Observed and simulated daily mean discharges for Woodland Creek near Olympia, Washington (station 12081000), in the Woodland Creek Basin. Simulated discharges are from the first-year calibrated model applied to the period March 1, 1988, through March 15, 1990.

**Table 8.--Measures of difference between simulated and observed daily mean discharges of Woodland Creek, Woodard Creek, and Percival Creek for the first-year calibrated models during the calibration period March 1, 1988, through March 29, 1989**

Station number <sup>1</sup>	Flow regime <sup>2</sup>	Mean absolute difference <sup>3</sup>		Root mean square difference <sup>4</sup>		Bias <sup>5</sup>	
		Average	Percent	Average	Percent	Average	Percent
12078720	Low	1.278	19.1	1.708	32.3	-0.431	3.2
	Medium	3.705	14.1	4.573	17.2	3.392	12.8
	High	3.783	6.3	4.636	7.7	1.059	2.1
	Total	2.912	13.2	3.877	21.7	1.332	6.0
12078730	Low	.434	17.7	.531	21.4	-.272	-12.2
	Medium	1.029	20.0	1.248	25.0	.685	13.4
	High	1.337	10.0	1.750	12.5	.156	4.1
	Total	.934	15.9	1.278	20.4	.195	1.9
12080500	Low	.696	26.2	.855	32.2	.571	22.6
	Medium	.599	12.2	.798	16.3	-.092	-1.4
	High	1.215	11.5	1.594	13.9	-.723	-5.9
	Total	.838	16.5	1.145	22.2	-.089	4.9
12080670	Low	.526	60.7	.712	71.6	.214	8.5
	Medium	.760	28.6	.916	36.7	.057	6.9
	High	1.285	19.1	1.564	24.3	-.560	-9.7
	Total	.856	36.5	1.124	49.0	-.096	1.8
12081000	Low	.938	8.1	1.578	13.5	.782	6.6
	Medium	2.657	17.0	3.683	23.5	2.286	14.7
	High	4.205	16.1	5.049	19.7	2.693	9.9
	Total	2.583	13.7	3.706	19.3	1.909	10.3

<sup>1</sup> Station names for the displayed station numbers are shown in table 7.

<sup>2</sup> Low, medium, and high flow regimes are the lower, middle, and upper thirds of the daily mean discharge values from each station. Total refers to the complete daily mean discharge record specified for the stations.

<sup>3</sup> AVERAGE =  $\sum (|S-M|/n)$  for all  $M > 0.1$

PERCENT =  $100.0 * [\sum (|S-M|/M)]/n$  for all  $M > 0.1$  (where S= simulated daily mean discharge in cubic feet per second; M= observed daily mean discharge in cubic feet per second; sum = summation over days for which  $M > 0.1$  in the calibration period; n= number of pairs of daily values for which  $M > 0.1$  in the calibration period; and  $| |$  = absolute value. NOTE: Because of the method of computing percentages, measured daily mean discharges below 0.1 cubic foot per second are considered as "dry" and are not considered in this analysis).

<sup>4</sup> AVERAGE =  $\text{square root}\{\sum [(S-M)**2]/n\}$  for all  $M > 0.1$

PERCENT =  $100.0 * \text{square root}(\sum \{[(S-M)/M]**2\}/n)$  for all  $M > 0.1$

<sup>5</sup> AVERAGE =  $\sum (S-M)/n$  for all  $M > 0.1$

PERCENT =  $100.0 * \{\sum [(S-M)/M]/n\}$  for all  $M > 0.1$

**Table 9.--Measures of difference between simulated and observed daily mean discharges of Woodland Creek, Woodard Creek, and Percival Creek for the first-year calibrated models during the evaluation period March 30, 1989, through March 15, 1990**

Station number <sup>1</sup>	Flow regime <sup>2</sup>	Mean <u>absolute difference</u> <sup>3</sup>		Root mean <u>square difference</u> <sup>4</sup>		<u>Bias</u> <sup>5</sup>	
		Average	Percent	Average	Percent	Average	Percent
12078720	Low	1.053	24.3	1.306	36.1	0.942	22.8
	Medium	2.051	8.8	2.755	10.7	.886	4.4
	High	7.359	8.4	11.840	11.5	6.482	7.0
	Total	3.448	13.7	6.981	22.6	2.722	11.2
12078730	Low	.578	26.6	.601	27.8	-.565	-26.0
	Medium	.542	11.8	.715	14.9	-.355	-8.4
	High	2.631	16.7	3.606	22.2	1.553	12.4
	Total	1.244	18.3	2.143	22.2	.206	-7.3
12080500	Low	1.186	42.6	1.244	45.2	1.186	42.6
	Medium	.908	18.4	1.109	23.3	.578	13.6
	High	3.196	21.8	4.161	24.1	-2.081	-15.5
	Total	1.771	27.7	2.597	32.6	-.110	13.6
12080670	Low	.673	161.4	.919	288.5	-.278	61.4
	Medium	2.827	53.1	2.894	58.6	-2.758	-51.1
	High	5.196	23.3	6.240	27.3	-4.222	-16.6
	Total	2.922	79.1	4.047	171.0	-2.432	-1.6
12081000	Low	2.226	19.3	2.611	22.5	2.223	19.3
	Medium	2.883	18.9	4.075	26.0	2.871	18.8
	High	4.645	9.6	8.747	14.9	2.248	5.2
	Total	3.260	15.9	5.799	21.6	2.442	14.3

<sup>1</sup> Station names for the displayed station numbers are shown in table 7.

<sup>2</sup> Low, medium, and high flow regimes are the lower, middle, and upper thirds of the daily mean discharge values from each station. Total refers to the complete daily mean discharge record specified for the stations.

<sup>3</sup> AVERAGE =  $\sum (|S-M|/n)$  for all  $M > 0.1$

PERCENT =  $100.0 * [\sum (|S-M|/M)]/n$  for all  $M > 0.1$  (where S= simulated daily mean discharge in cubic feet per second; M= observed daily mean discharge in cubic feet per second; sum = summation over days for which  $M > 0.1$  in the calibration period; n= number of pairs of daily values for which  $M > 0.1$  in the calibration period; and || = absolute value. NOTE: Because of the method of computing percentages, measured daily mean discharges below 0.1 cubic foot per second are considered as "dry" and are not considered in this analysis).

<sup>4</sup> AVERAGE =  $\sqrt{\sum [(S-M)^2]/n}$  for all  $M > 0.1$

PERCENT =  $100.0 * \sqrt{\sum [(S-M)/M]^2}/n$  for all  $M > 0.1$

<sup>5</sup> AVERAGE =  $\sum (S-M)/n$  for all  $M > 0.1$

PERCENT =  $100.0 * \{ \sum [(S-M)/M]/n \}$  for all  $M > 0.1$

storm-runoff volumes exceeded 20 percent. Differences for instantaneous peak discharges during that period ranged from 4.1 to 25.5 percent in absolute value, but only 2 of 16 peak discharges exceeded 20 percent.

For the evaluation period, differences in storm runoff volumes ranged from 0.0 to 50.0 percent in absolute value, the largest differences associated with high runoff after the January 8-9, 1990 storm. As table 10 shows, the dates of high runoff sometimes lagged behind the dates of storms because flood waves took time to travel downstream. Differences in peak discharges ranged from 0.3 to 107.0 percent in absolute value, and the largest differences were again associated with the January 8-9 storm. The small differences between observed and simulated storm-runoff volumes and peak discharges resulting from most storms indicated that the models usually produced adequate simulations. Nevertheless, the large differences associated with the January 8-9 storm suggested that further refinements may be required.

#### **Discussion of calibration and evaluation**

**results.**--The preceding results showed that the first-year calibrated models simulated the first year of observed streamflows reasonably well, but differences between simulated and observed streamflows usually increased when the models were evaluated with the second year of observed streamflows. Simulation results indicated that the models needed improvement in the simulation of the amount and timing of ground-water discharge, of low streamflows, and of high streamflows such as those recorded in January 1990. The Percival Creek Basin model, however, adequately simulated streamflows at Percival Creek gaging station 12078730.

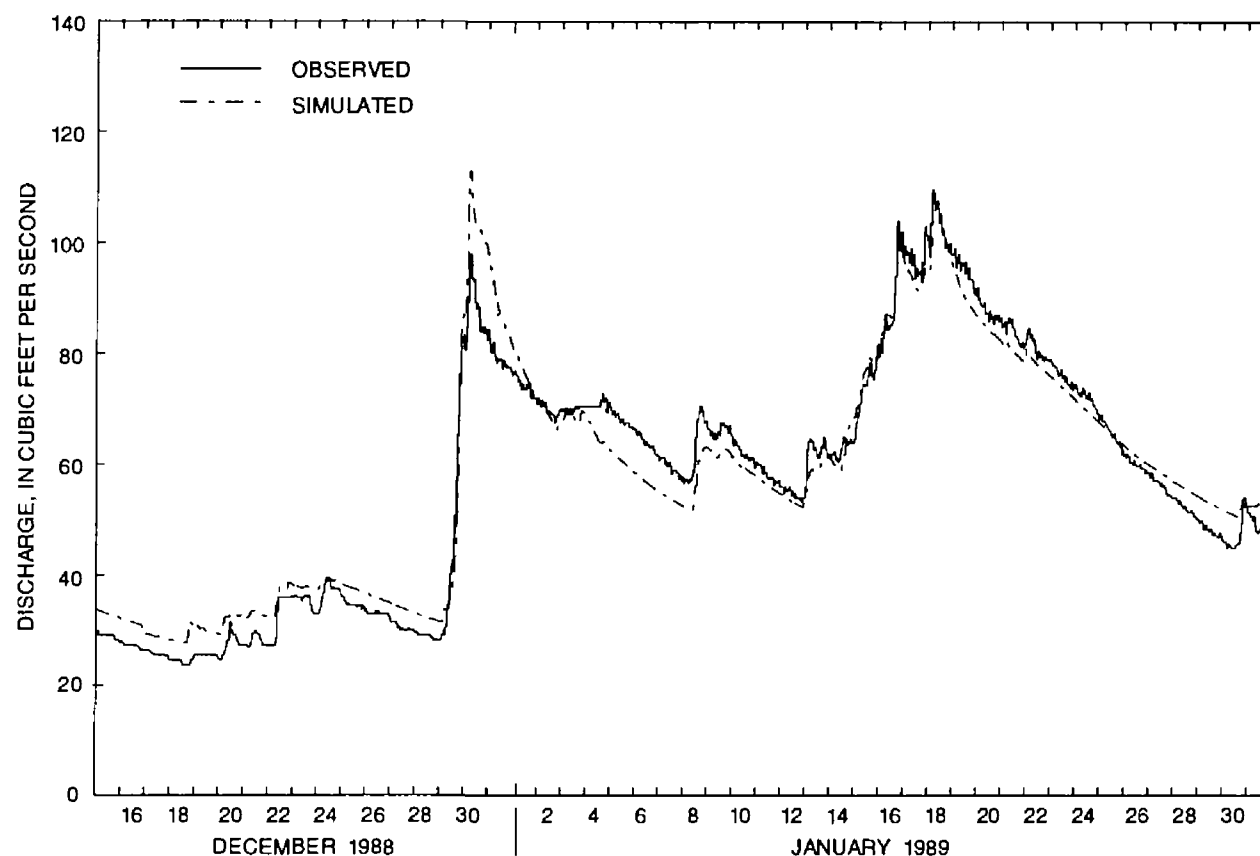
The simulation of the quantity and timing of ground-water contributions by the Woodland Creek model needed improvement. Streamflows upstream of Woodland Creek station 12080670 are primarily sustained by ground-water contributions. More than 70 percent of the Woodland Creek Basin area upstream of this station is represented by outwash segment types (table 5), wherein ground-water flow, according to the conceptual model, is the predominant runoff mechanism. Hydrographs from wells in this area indicate that water-table elevations were highest during late winter or spring, the same time that the model underestimated streamflows (N.P. Dion, U.S. Geological Survey, written commun., 1991). The high water-table elevations during these periods suggest that ground-water contributions may have been greater than those simulated by the Woodland Creek model. Like headwater subbasin PE1 in Percival Creek Basin, the upstream portion of the Woodland Creek Basin consists of

a flat outwash plain, and the drainage divides for ground water and surface water do not necessarily coincide. Instead, the ground water underlying this area is likely part of a larger ground-water system that is influenced by precipitation falling outside the study basin. Additionally, it is likely that the large lakes and wetlands here are affected by ground water-surface water interactions. Thus, the first-year Woodland Creek model did not adequately represent ground-water contributions influenced by regional ground-water characteristics and stratigraphy.

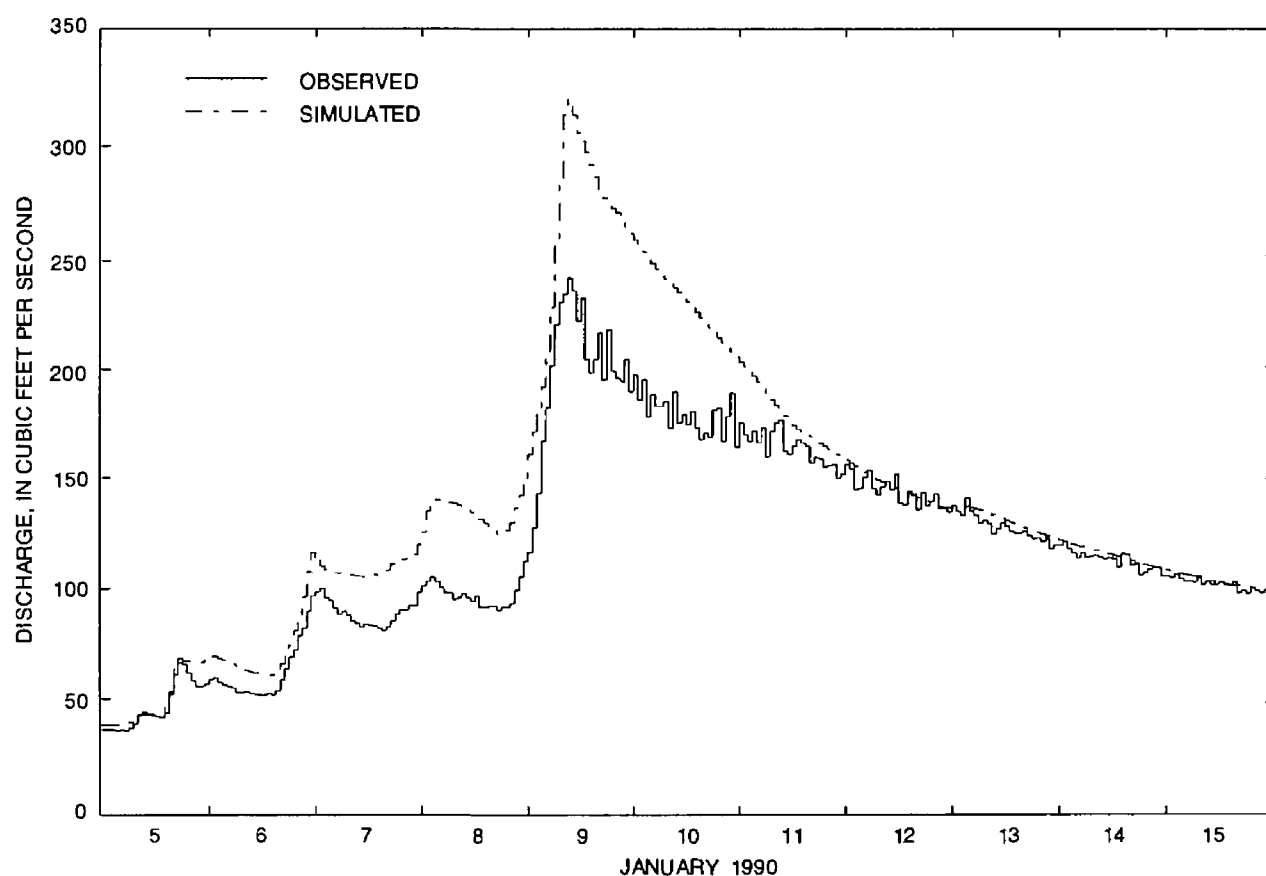
The simulation of low flows by the Woodland and Woodard Creek models needed improvement. For the first year of streamflow data, these models showed noticeable discrepancies between observed and simulated low flows (table 8). Subsequently, all the gaging stations, notably in the Woodard Creek Basin, showed increased differences between observed and simulated low flows after simulating the second year of streamflow data (table 9). Simulated low flows usually exceeded observed low flows during the evaluation period.

The simulation of high flows resulting from storms by all models except for a part of the Percival Creek model needed improvement. Differences between observed and simulated runoff volumes and peak discharges were large during high flows, especially for those resulting from the extremely large January 8-9, 1990, storm in the second year of data collection (table 10). At four of the five gaging stations, simulated peak discharges and runoff volumes exceeded observed amounts. This storm, one of five in early January 1990, dropped 3 to 4 inches of rain in 24 hours, more intense rain than at any other time during the study period. The previous four storms between January 4 and 8 had dropped a total of 4 to 6 inches of rain on the study area. The storms provided an opportunity to calibrate the models to some of the highest streamflows recorded in the region.

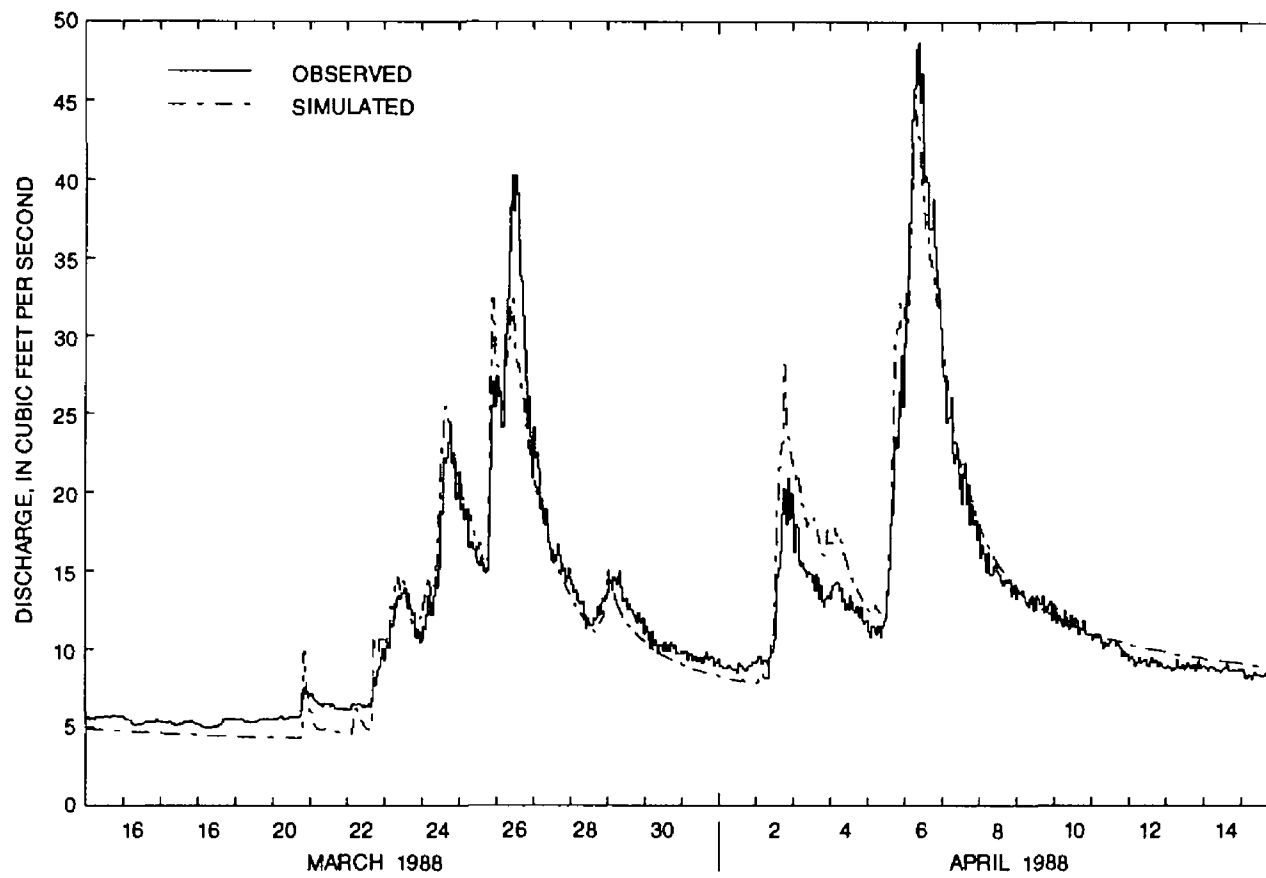
Simulation results from the first-year calibrated models indicated that, despite the model shortcomings previously described, the conceptual model--represented in the numerical models by the segmentation scheme and the values of the process-related parameters--adequately described the generation of runoff from the land-segment types in the basins. The process-related parameter values, except for KVAR, obtained from the King and Snohomish County basins (Dinicola, 1990) applied to the basins in Thurston County. The values of KVAR were refined to improve the timing of ground-water discharge to reaches. These refinements were necessary because some areas in Thurston County are underlain by aquifers that respond differently to rainfall than the areas in King and



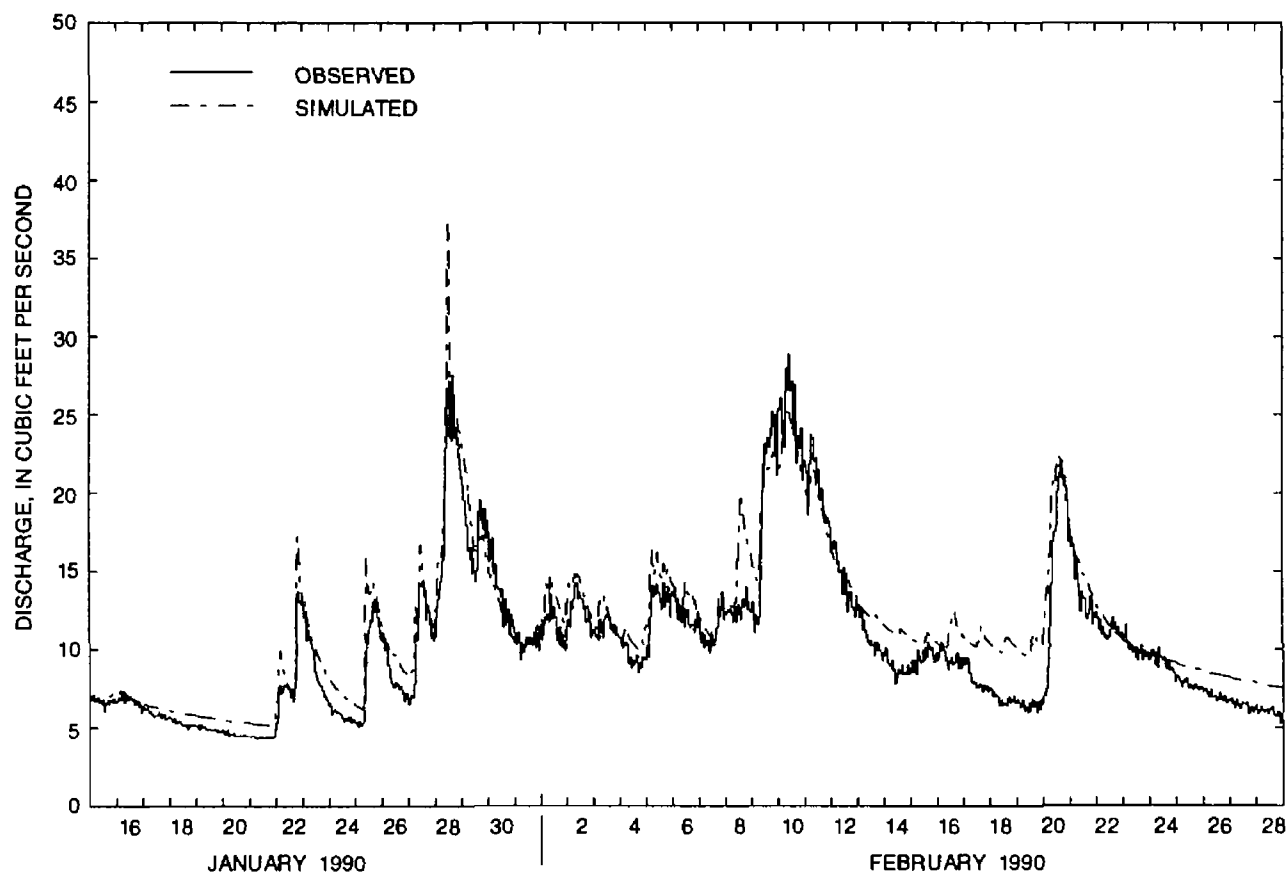
**Figure 14.**--Observed and simulated hourly mean discharges for Black Lake Ditch near Olympia, Washington (station 12078720), in the Percival Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period December 15, 1988, through January 31, 1989.



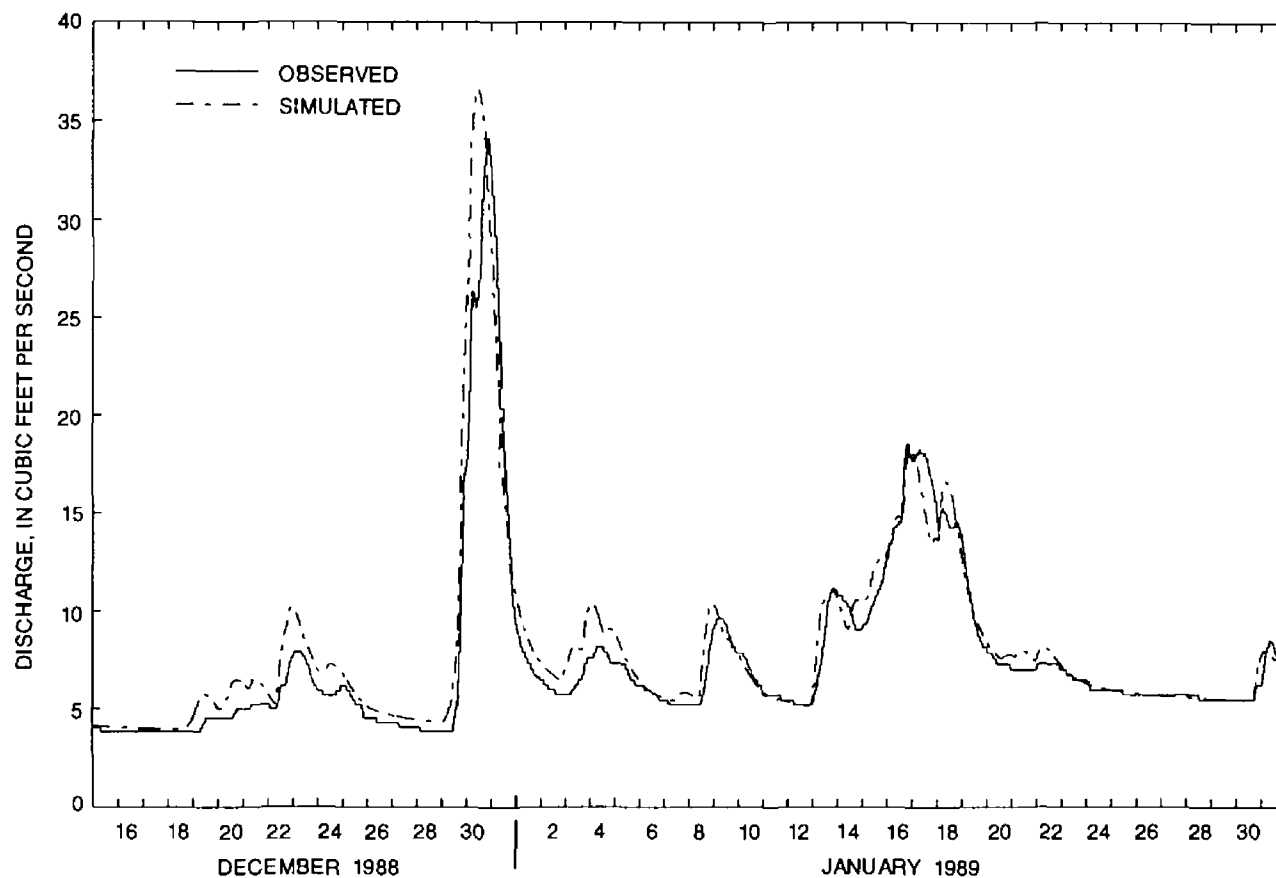
**Figure 15.**--Observed and simulated hourly mean discharges for Black Lake Ditch near Olympia, Washington (station 12078720), in the Percival Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period January 5 through 15, 1990.



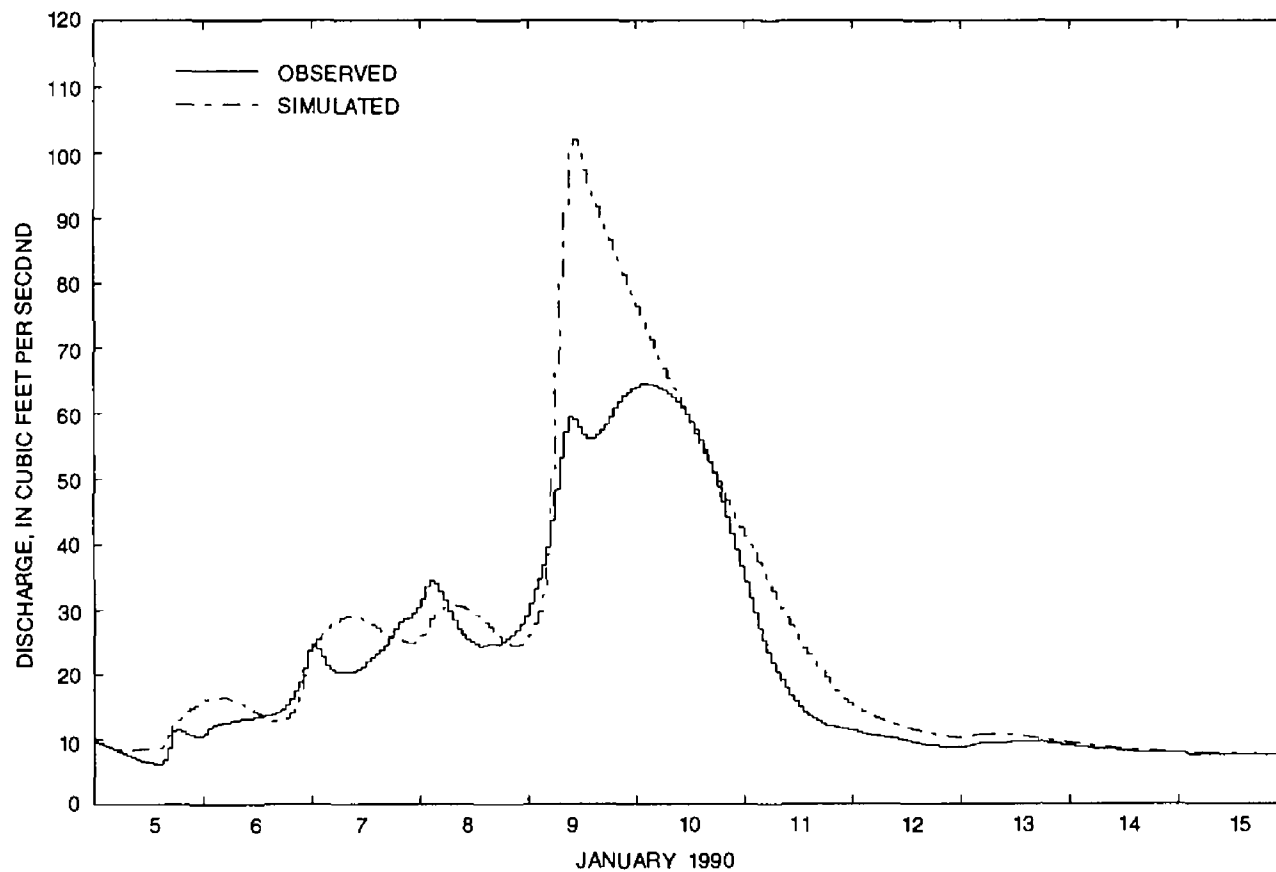
**Figure 16.--**Observed and simulated hourly mean discharges for Percival Creek near Olympia, Washington (station 12078730), in the Percival Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period March 15, 1988, through April 15, 1988.



**Figure 17.--**Observed and simulated hourly mean discharges for Percival Creek near Olympia, Washington (station 12078730), in the Percival Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period January 15, 1990, through February 28, 1990.

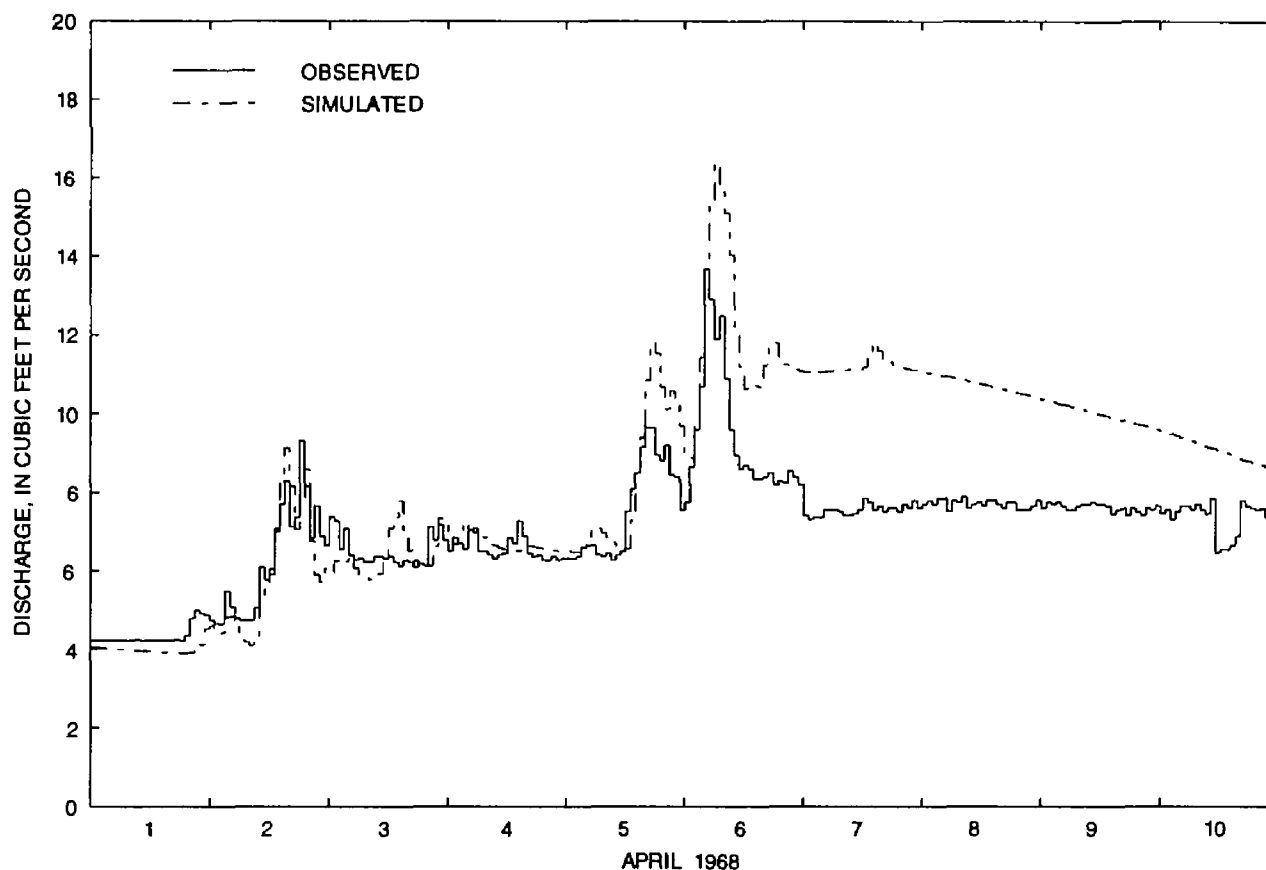


**Figure 18.**--Observed and simulated hourly mean discharges for Woodard Creek near Olympia, Washington (station 12080500), in the Woodard Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period December 15, 1988, through January 31, 1989.

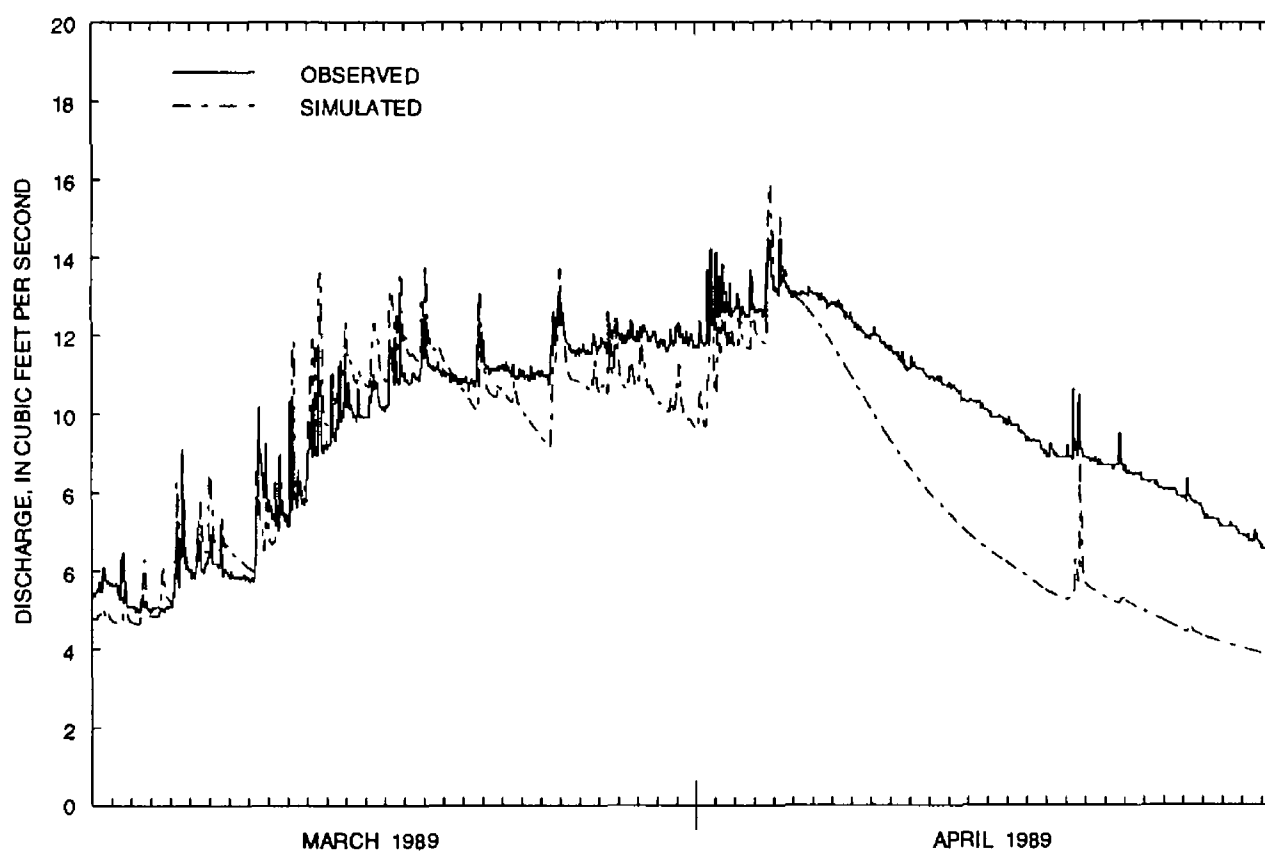


**Figure 19.**--Observed and simulated hourly mean discharges for Woodard Creek near Olympia, Washington (station 12080500), in the Woodard Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period January 5 through 15, 1990.

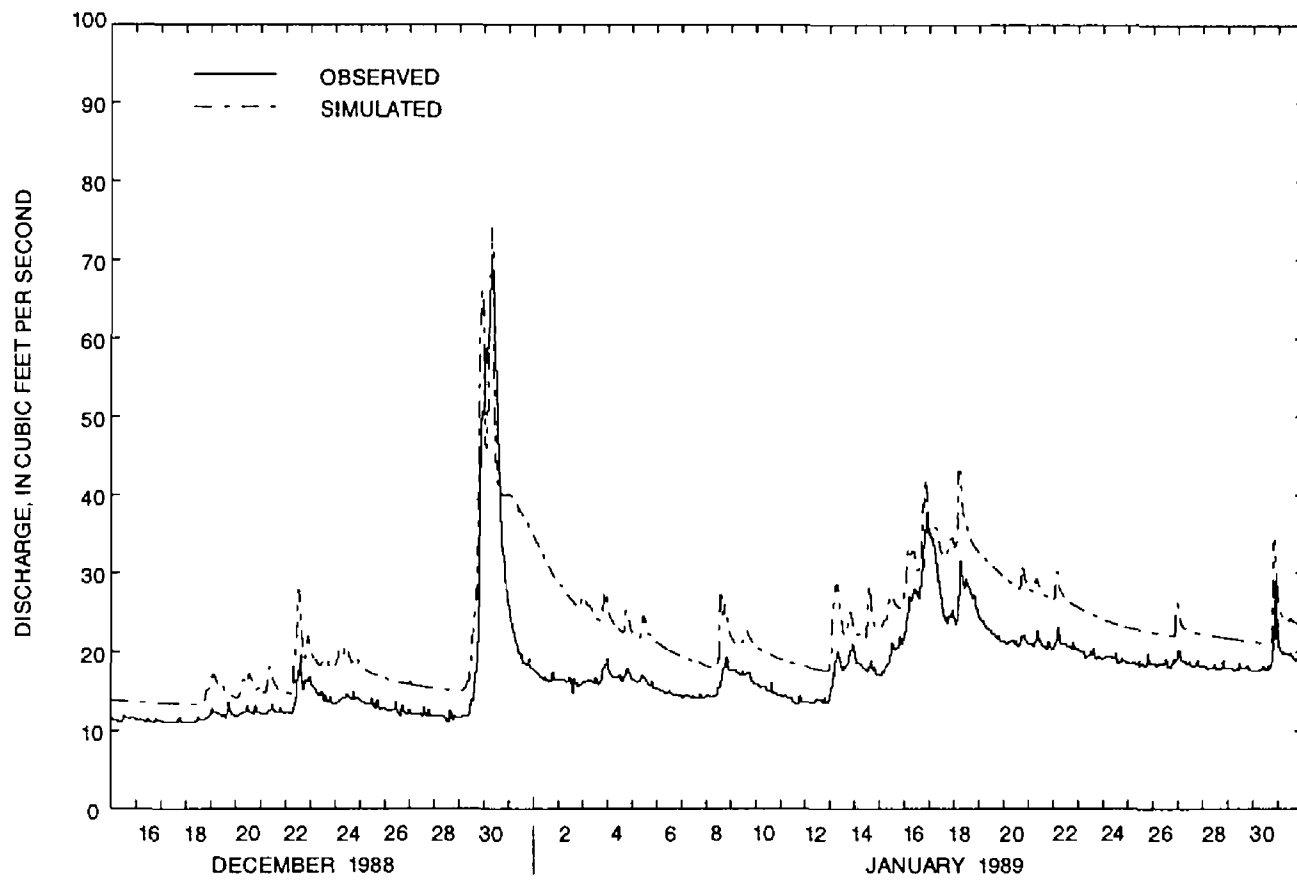




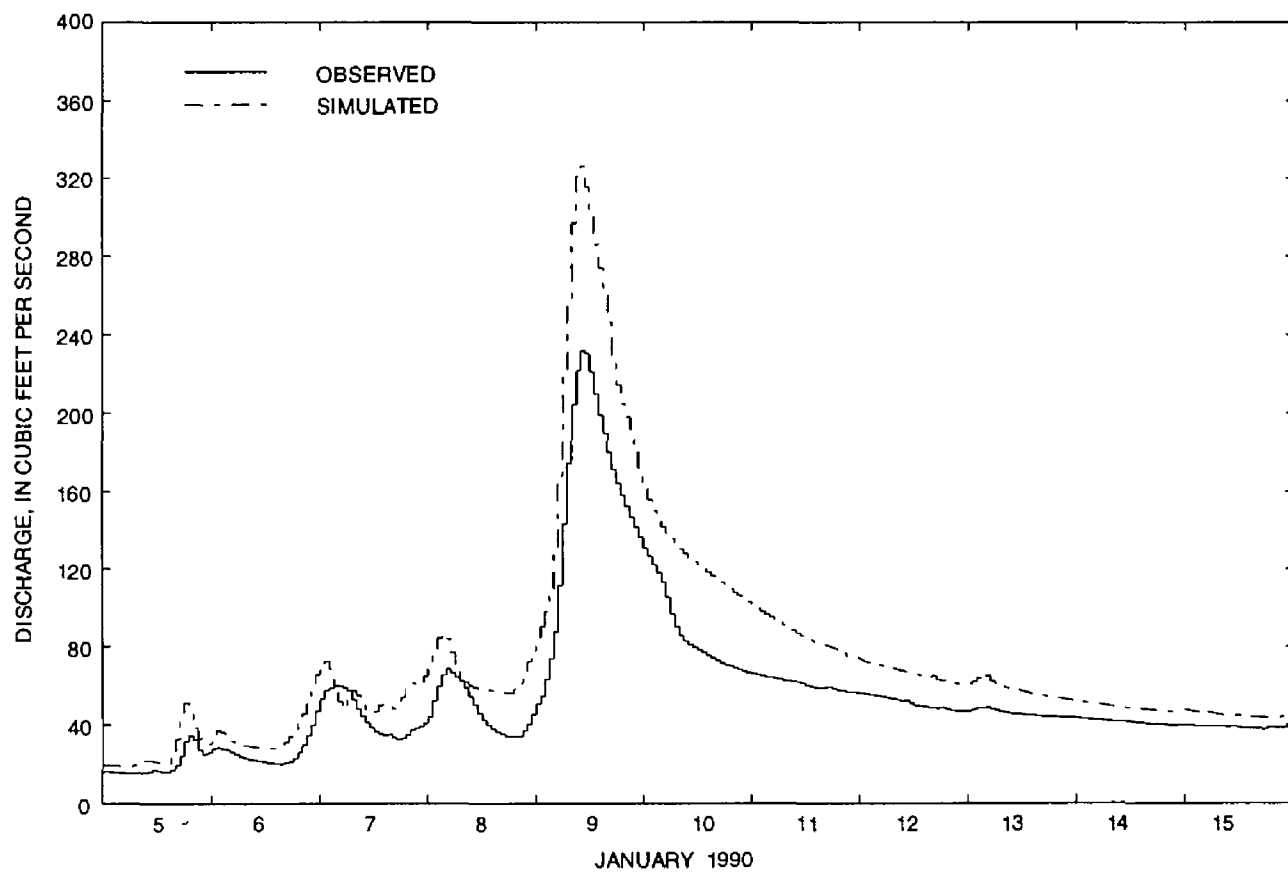
**Figure 20.**--Observed and simulated hourly mean discharges for Woodland Creek at Martin Way at Lacey, Washington (station 12080670), in the Woodland Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period April 1 through 10, 1988.



**Figure 21.**--Observed and simulated hourly mean discharges for Woodland Creek at Martin Way at Lacey, Washington (station 12080670), in the Woodland Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period March 1, 1989, through April 30, 1989.



**Figure 22.**--Observed and simulated hourly mean discharges for Woodland Creek near Olympia, Washington (station 12081000), in the Woodland Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period December 15, 1988, through January 31, 1989.



**Figure 23.**--Observed and simulated hourly mean discharges for Woodland Creek near Olympia, Washington (station 12081000), in the Woodland Creek Basin. Simulated discharges are from the first-year calibrated model applied to the storm period January 5 through 15, 1990.

**Table 10.--Observed and simulated storm runoff and peak discharge data of Woodland Creek, Woodard Creek, and Percival Creek for the first-year calibrated models**

[Obs., observed value; Sim., simulated value; Diff., difference: simulated-observed; Percent diff., percent difference: 100 x [(simulate-1-observed)/observed], in percent]

Station number <sup>1</sup>	Date of storm	Date of peak	Storm runoff, in inches <sup>2</sup>				Peak discharge, in cubic feet per second <sup>3</sup>			
			Obs.	Sim.	Diff.	Percent diff.	Obs.	Sim.	Diff.	Percent diff.
12078720	3/25-28/88	3/26/88	2.28	2.53	0.25	11.0	97.3	106.4	9.1	9.4
	4/5-8/88	4/6/88	2.86	2.74	-.12	-4.2	123.1	118.0	-5.1	-4.1
	12/29/88-1/1/89	12/30/88	2.11	2.29	.18	8.5	102.0	114.1	12.1	11.9
	1/16-20/89	1/18/89	3.44	3.36	-.08	-2.3	115.0	107.6	-7.4	-6.4
	3/12-19/89	3/16/89	4.68	4.93	.25	5.3	91.0	95.0	4.0	4.4
	12/3-7/89	12/4/89	3.24	3.35	.11	3.4	130.0	119.1	-10.9	-8.4
	1/9-10/90	1/9/90	2.76	3.58	.82	29.7	<sup>4</sup> 239.9	319.9	80.0	33.3
	1/28-30/90	1/29/90	2.55	3.06	.51	20.0	142.5	186.1	43.6	30.6
	2/9-14/90	2/11/90	6.51	6.86	.35	5.4	<sup>4</sup> 175.8	187.9	12.1	6.9
	2/20-23/90	2/20/90	3.28	3.50	.22	6.7	135.0	150.1	15.1	11.2
12078730	3/23-27/88	3/26/88	1.57	1.54	-.03	-1.9	44.0	32.8	-11.2	-25.5
	4/5-7/88	4/6/88	1.25	1.27	.02	1.6	<sup>4</sup> 48.7	45.7	-3.0	-6.2
	12/29-31/88	12/30/88	1.43	1.39	-.04	-2.8	<sup>4</sup> 55.9	62.9	7.0	12.5
	1/14-19/89	1/16/89	2.30	2.00	-.30	-13.0	41.0	31.7	-9.3	-22.7
	12/4-5/89	12/4/89	1.16	1.09	-.07	-6.0	<sup>4</sup> 62.2	48.3	-13.9	-22.3
	1/9-10/90	1/9/90	2.26	2.00	-.26	-11.5	<sup>4</sup> 141.6	103.7	-37.9	-26.8
	1/27-30/90	1/28/90	2.04	2.14	.10	4.9	59.3	78.5	19.2	32.4
	2/9-12/90	2/10/90	2.56	2.51	-.05	-2.0	<sup>4</sup> 57.7	50.5	-7.2	-12.5
	2/20-22/90	2/20/90	1.34	1.47	.13	9.7	47.4	44.9	-2.5	-5.3
12080500	3/23-27/88	3/26/88	.88	.78	-.10	-11.4	28.1	25.1	-3.0	-10.7
	4/5-7/88	4/6/88	.65	.59	-.06	-9.2	33.5	30.3	-3.2	-9.6
	12/29/88-1/1/89	12/30/88	.67	.75	.08	11.9	34.5	36.6	2.1	6.1
	12/2-6/89	12/5/89	.88	.86	-.02	-2.3	34.0	33.8	-.2	-.6
	1/9-11/90	1/10/90	1.38	1.74	.36	26.1	64.4	102.6	38.2	59.3
	1/27-30/90	1/29/90	.96	.92	-.04	-4.2	36.3	36.2	-.1	-.3
	2/9-12/90	2/10/90	1.21	.91	-.30	-24.8	43.0	32.5	-10.5	-24.4
	2/20-22/90	2/21/90	.78	.58	-.20	-25.6	35.7	26.1	-9.6	-26.9
12080670	4/5-7/88	4/6/88	.07	.08	.01	14.3	15.5	16.5	1.0	6.5
	4/1-8/89	4/2/89	.31	.27	-.04	-12.9	16.4	16.0	-.4	-2.4
	1/8-10/90	1/9/90	.10	.15	.05	50.0	25.6	53.0	27.4	107.0
	2/9-12/90	2/11/90	.31	.25	-.06	-19.4	33.6	31.8	-1.8	-5.4
	2/20-21/90	2/20/90	.16	.12	-.04	-25.0	31.1	23.6	-7.5	-24.1
12081000	3/23-28/88	3/26/88	.28	.30	.02	7.1	72.6	64.0	-8.6	-11.8
	4/5-8/88	4/6/88	.26	.31	.05	19.2	84.8	80.2	-4.6	-5.4
	12/29/88-1/1/89	12/30/88	.16	.24	.08	50.0	71.2	74.5	3.3	4.6
	12/4-6/89	12/4/89	.17	.22	.05	29.4	99.3	75.9	-23.4	-23.6
	1/9-10/90	1/9/90	.37	.54	.17	45.9	233.6	327.7	94.1	40.3
	1/28-30/90	1/28/90	.28	.33	.05	17.9	100.5	110.8	10.3	10.2
	2/9-12/90	2/10/90	.48	.48	.00	.0	118.0	107.3	-10.7	-9.1
	2/20-22/90	2/20/90	.30	.28	-.02	-6.7	85.3	73.8	-11.5	-13.5

<sup>1</sup> Station names for the displayed station numbers are in table 7.

<sup>2</sup> Storm runoff data are the total streamflow volumes for the period of each storm.

<sup>3</sup> Peak discharge data are the maximum 15-minute mean discharges for each storm.

<sup>4</sup> Observed peak discharge data are hourly mean discharges during periods of extreme surge at a stream-gaging station.

Snohomish Counties that were used to determine this parameter value. The adequacy of the conceptual model describing runoff generation is not affected because this parameter represents the timing rather than the volume of ground-water flow.

Calibration indicated that the conceptual model, however, did not adequately describe the routing of outflows along flow paths from land segments to the subbasin reaches. Thus, an initial guideline used for model construction had to be modified during calibration. This initial guideline had designated all rain falling on a subbasin either to evapotranspiration or to runoff that discharges to the reach and through the surface-water outlet of that same subbasin. Modifications reduced the initial contributions of runoff to reaches during calibration. These modifications represented outflows from land segments that sometimes recharged inactive ground water and at other times discharged to reaches in other subbasins. Despite the modifications of runoff contributions to subbasin reaches, the model shortcomings previously discussed were apparent during evaluation of the basin models.

The model shortcomings apparent during model evaluation indicated that calibration to only 1 year of streamflow data was not adequate to describe the complex variations of runoff contributions to reaches. Further calibration of the basin models to both years of streamflow data led to improved simulation results, particularly for the Woodland Creek model. However, no further modifications were made to the part of the Percival Creek Basin model that represented subbasins PE1, PE2, and PE3 because the model adequately simulated streamflows at station 12078730, located in subbasin PE3. The following sections of this report describe further adjustments and refinements to model parameters, and results from calibration of the basin models with 2 years of observed data.

### **Final Calibration**

As the evaluation of the first-year calibrated models revealed, most of the models needed improvement in the simulation of the amount and timing of ground-water discharge, of low flows, and of high streamflows such as those recorded in January 1990. Only a part of the Percival Creek model, representing the Percival Creek Basin upstream of gaging station 12078730 (subbasins PE1, PE2, and PE3), did not require further calibration. In final calibration, simulation results were improved by further modification of (1) the value of the process-related parameter KVARV in the PERLND block, (2) the surface-

and ground-water contributions from subbasins to drainage networks in the NETWORK block, and (3) the hydraulic parameters of stream reaches in the F-tables of the RCHRES block. Also, a "ground-water controller" was added that entailed modifications to the PERLND, NETWORK, and RCHRES blocks. The controller improved simulation of ground-water contributions to Woodland Creek upstream of station 12080670. Final calibration was performed using the entire data set collected from March 1, 1988, through March 15, 1990.

The input sequences for the final calibrated HSPF-based models of the Woodland, Woodard, and Percival Creek Basins appear in tables 17-19 at the end of the report. The format and parameters of HSPF input sequences are explained fully in the Hydrological Simulation Program-FORTRAN Users Manual (U.S. Environmental Protection Agency, 1984).

### **Modifications to Process-Related Parameter Values**

Modifications to the process-related parameter values during final calibration again included adjusting the values of KVARV, the active ground-water flow modifier in the PERLND block, for all land-segment types in the Woodard Creek model. In addition, parameter values were determined for new land-segment types that were defined solely to recharge a ground-water controller in the final Woodland Creek model. A later section on the ground-water controller will discuss these new land-segment types and their associated parameter values.

The value for KVARV was increased for all land-segment types in the Woodard Creek model. First calibration results revealed that the decreased KVARV values used in the first-year models did not result in accurate simulations of the timing of ground-water discharge. Raising the KVARV values increased ground-water flow contributions to reaches during winter and spring wet periods and decreased these contributions during the summer dry spells. As a result, simulated streamflows after runoff peaks receded more gradually, and simulated baseflow increased in winter and spring and decreased in summer. Simulated streamflows thus more closely matched observed flows.

The final values for the process-related parameters for all land-segment types, except those associated with the ground-water controller, appear in table 11.

**Table 11.--Process-related parameters used for pervious and impervious land-segment types in the final calibrated models**

[\*, Percival Creek Basin; \*\*, Woodland Creek Basin; and \*\*\*, Woodard Creek Basin; in., inches; in/hr, inches per hour; ft, feet; 1/in., 1/inch; n/a, not applicable; where units are not listed, the parameter has no units]

Land-segment type <sup>1</sup>	Process-Related Parameter <sup>2</sup>																		
	LZSN	INFILT	LSUR	SLSUR	KVARY		AGWRC	INFEXP	INFILD	DEEPPFR	BASETP	AGWETP	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP	RETSC
	(in.)	(in/hr)	(ft)		(1/in.)		(l/day)						(in.)	(in.)			(l/day)		(in.)
					*	**	***												
OF	5.0	2.0	400	0.05	0.3	0	0.0125	0.996	2.0	2.0	0.0	0.0	0.2	0.5	0.35	0.0	0.7	0.7	n/a
OG	5.0	.80	400	.05	.3	0	.0125	.996	2.0	2.0	.0	.0	.1	.5	.25	.0	.7	.25	n/a
OC	5.0	.80	400	.05	n/a	0	n/a	.996	2.0	2.0	.0	.0	.1	.5	.25	.0	.7	.5	n/a
KFF	9.0	.16	400	.05	.5	0	.5	.996	3.5	2.0	.0	.0	.2	1.0	.35	3.0	.7	.7	n/a
KFM	9.0	.16	400	.10	.5	0	.5	.996	2.0	2.0	.0	.0	.2	.5	.35	6.0	.5	.7	n/a
KFS	9.0	.16	200	.20	.5	0	.5	.996	1.5	2.0	.0	.0	.2	.3	.35	7.0	.3	.7	n/a
KGF	9.0	.06	400	.05	.5	0	.5	.996	3.5	2.0	.0	.0	.1	.5	.25	3.0	.7	.25	n/a
KGM	9.0	.06	400	.10	.5	0	.5	.996	2.0	2.0	.0	.0	.1	.25	.25	6.0	.5	.25	n/a
KGS	9.0	.06	200	.20	.5	0	.5	.996	1.5	2.0	.0	.0	.1	.15	.25	7.0	.3	.25	n/a
TFP	4.5	.08	400	.05	.5	0	.5	.996	3.5	2.0	.0	.0	.2	1.0	.35	3.0	.7	.7	n/a
TFM	4.5	.08	400	.10	.5	0	.5	.996	2.0	2.0	.0	.0	.2	.5	.35	6.0	.5	.7	n/a
TFS	4.5	.08	200	.20	.5	0	.5	.996	1.5	2.0	.0	.0	.2	.3	.35	7.0	.3	.7	n/a
TGF	4.5	.03	400	.05	.5	0	.5	.996	3.5	2.0	.0	.0	.1	.5	.25	3.0	.7	.25	n/a
TGM	4.5	.03	400	.10	.5	0	.5	.996	2.0	2.0	.0	.0	.1	.25	.25	6.0	.5	.25	n/a
TGS	4.5	.03	200	.20	.5	0	.5	.996	1.5	2.0	.0	.0	.1	.15	.25	7.0	.3	.25	n/a
SAT	4.0	2.0	100	.001	.5	0	.5	.996	10.0	2.0	.0	.0	.1	3.0	.50	1.0	.7	.8	n/a
EIA	n/a	n/a	500	.01	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	.10	n/a	n/a	n/a	0.10

<sup>1</sup> Land-segment type definitions: OF, outwash soils, forest cover, all slopes; OG, outwash soils, nonforest cover, all slopes; OC, outwash soils, crops, all slopes; KFF, Kitsap soils, forest cover, flat slopes; KFM, Kitsap soils, forest cover, moderate slopes; KFS, Kitsap soils, forest cover, steep slopes; KGF, Kitsap soils, nonforest cover, flat slopes; KGM, Kitsap soils, nonforest cover, moderate slopes; KGS, Kitsap soils, nonforest cover, steep slopes; TFF, till soils, forest cover, flat slopes; TFM, till soils, forest cover, moderate slopes; TFS, till soils, forest cover, steep slopes; TGF, till soils, nonforest cover, flat slopes; TGM, till soils, nonforest cover, moderate slopes; TGS, till soils, nonforest cover, steep slopes; SAT, saturated soils, all covers, all slopes; EIA, effective impervious areas, all slopes.

<sup>2</sup> Process-related parameter definitions: LZSN, lower-zone nominal storage; INFILT, soil infiltration capacity index; LSUR, surface length of the average overland flow plane; SLSUR, surface slope of the average overland flow plane; KVARY, active-ground-water outflow modifier; AGWRC, active-ground-water recession rate-of-change; INFEXP, infiltration equation exponent; INFILD, ratio of maximum to mean infiltration rate; DEEPPFR, fraction of deep ground water; BASETP, baseflow evapotranspiration; AGWETP, active-ground-water evapotranspiration; CEPSC, interception-storage capacity of plants; UZSN, upper-zone nominal storage; NSUR, surface roughness of the average overland flow plane; INTFW, interflow index; IRC, interflow recession rate of change; LZETP, lower zone evapotranspiration; RETSC, retention-storage capacity of impervious surfaces.

## Modifications to Subbasins

In the NETWORK block of the final models, subbasins were added and aggregated, and contributions to stream reaches from ground-water, subsurface, and overland flow were further adjusted. The subbasin addition involved separating one Woodard Creek subbasin into two new subbasins, WD2 and WD3, to allow more refined simulation of peak flows. Results from the first calibration had shown that simulated peak flows in the original subbasin exceeded observed peak flows after the large storm on January 8-9, 1990, and reconnaissance indicated the reach draining the upstream part of that subbasin controlled those peak flows. The upstream part of the original subbasin was divided from the lower part. In turn, the two new subbasins divided the original reach into a new upstream reach and a new downstream reach. Each reach had a new, separate volume-discharge relation in an F-table. These changes resulted in more accurate simulations of peak flows after large storms.

Other Woodard and Woodland Creek subbasins that had been subdivided during first calibration were recombined. These previously separated subbasins had identical hydraulic connections to the same reach, and their aggregation simplified the Woodard and Woodland Creek models. The configuration of subbasins in the three final calibration models appears in figures 5 and 6.

In subbasins where contributions from ground-water, subsurface, or overland flow had been adjusted during first calibration, differences between simulated and observed streamflows were either positive or negative; that is, simulated streamflows sometimes exceeded and sometimes fell short of observed streamflows. In subbasins where contributions had not been adjusted during first calibration, differences between simulated and observed streamflows were usually positive; simulated streamflows exceeded observed streamflows. As in the first calibration, these differences, along with specific characteristics of simulated hydrographs, indicated which flow contributions to stream reaches needed adjustment.

If observed and simulated hydrographs showed large differences during baseflow periods or periods when streamflow responses to rainfall were slow and attenuated, then simulated ground-water contributions were adjusted. This was done most often for subbasins with large areas of outwash segment types. If large differences appeared when streamflow responses to rainfall were neither slow and attenuated nor extremely quick and peaked, then shallow subsurface flow contributions were adjusted. This was done most commonly for subbasins with large areas

of till or Kitsap segment types. If differences were large for high flows and streamflow peaks when streamflow responses to rainfall were quick and peaked, then overland flow contributions were adjusted. This was done most often for subbasins with large areas of effective impervious cover and saturated segment types.

Final calibration, like first calibration, also involved representing till segments with outwash segments for Woodland Creek subbasin WL23. Till segments that were not directly connected to a reach usually lay uphill from outwash segments in this subbasin, and the simulated runoff peaks were higher and more peaked than the observed runoff peaks. The concept behind this modification was that overland or shallow subsurface flow generated from up-slope till segments could drain directly into recharge ground water once the flow reached downslope outwash deposits. The modification reduced the differences between observed and simulated hydrograph peaks, especially the peak following the storm of January 8-9, 1990. All of the subbasins affected by this modification appear at the end of this section in a list that presents conditions that warranted restricting flow contributions to reaches and the affected subbasins.

The first-year calibrated models for the Woodland and Woodard Creek Basins sometimes produced simulated hydrograph peaks higher and flashier than observed hydrograph peaks for some highly urbanized subbasins with large areas of outwash segment types. For the final calibration, the adjustments to percent effective impervious area for the partially impervious land cover classes were extended to three new subbasins. (See the discussion of effective impervious area adjustments in the "Modifications to Subbasins" subsection of the section "First Calibration and Evaluation.") Like those subbasins adjusted in first calibration, these subbasins contained drainage systems of grassy swales that could store and infiltrate runoff from impervious areas and decrease overland flow contributions to streams. The adjustments were made in Woodard Creek subbasin WD2 and parts of WD3 and in parts of Woodland Creek subbasin WL2. All of the subbasins affected by this modification appear at the end of this section in a list that presents conditions that warrant restricting flow contributions to reaches and the affected subbasins.

Although it was initially assumed that all precipitation falling on a subbasin was either evapotranspired or was discharged out the surface-water outlet of that same subbasin, this assumption was not adequate for many Woodland, Woodard, and Percival Creek subbasins. The first-year calibrated models produced, during the



evaluation period, simulated low flows and after-storm peak flows that often exceeded observed streamflows. Consequently, during the final calibration, simulated ground-water, shallow subsurface, and overland flow contributions from certain subbasins were decreased. Information collected from the field suggested seven specific subbasin conditions that warranted restricting flow contributions to reaches. The first four had been recognized during first calibration, and the latter three were added during final calibration. The subbasin conditions that warranted restricting flow contributions to reaches and the subbasins affected are as follows (more than one of the following conditions may apply to any given subbasin).

- (1) A subbasin contained large areas of outwash that drained to regional rather than local aquifers. This condition was found in Woodland Creek subbasins WL2, WL4, WL6, WL6B, WL6C, WL6D, WL6E, WL9, WL10, WL12, WL13, WL14, and WL20; and Woodard Creek subbasin WD1.
- (2) The mouth of a subbasin or parts of a subbasin's surface-water drainage network were above the ground-water table, so ground-water flow contributions to the drainage network decreased. This condition was found in Woodland Creek subbasins WL2, WL6B, WL6C, WL6D, WL6E, WL9, WL10, WL12, WL13, WL14, WL20, WL21, WL22, WL23; Woodard Creek subbasin WD1; and Percival Creek subbasins PE5, PE7, PE8, PE9, PE10, PE11, and PE12.
- (3) Complex ground water-surface water interactions in lakes modified ground-water flow contribution to drainage networks. This condition was found in Woodland Creek subbasins WL4 and WL6 and Percival Creek subbasin PE5.
- (4) The subbasin contained man-made conveyance systems, infiltration facilities, grassy swales, dry wells, or hummocky areas with many closed depressions that modified contributions of subsurface flow or overland flow to drainage networks. This condition was found in Woodland Creek subbasins WL2, WL6, WL6B, WL6C, WL8, WL9, WL10, WL12, WL13, WL14, and WL19; Woodard Creek subbasins WD1, WD2, and WD3; and Percival Creek subbasin PE11.
- (5) A subbasin was closed, with no hydraulic connection between land segments and the surface drainage system. This condition was found in Woodland Creek

subbasins WL1, WL5B, WL6A, WL7, WL11, WL20A, and WL22A; and Woodard Creek subbasins WD4A, WD5A, and WD5B.

- (6) A subbasin was closed, but ground-water flow drained to a lower elevation reach in another, usually adjacent, subbasin. This condition was found in Woodland Creek subbasins WL1A, WL3, WL5A, WL8A, WL8B, WL9A, WL13A, WL16, WL16A, and WL25B; and Woodard Creek subbasins WD3A, WD4B, and WD6A.
- (7) A subbasin contained areas of outwash soils adjacent to drainage networks and downgradient from glacial till areas. Overland and subsurface flow generated from the till recharged ground water in the outwash deposits. This condition was found in Woodland Creek subbasins WL13, WL14, WL15, WL16, WL16A, WL17, WL19, WL20, WL21, and WL23; and Woodard Creek subbasin WD3.

Schematic diagrams of the hydraulic connections from subbasins to drainage networks are shown in figures 39-41 on pages 73-76.

### **Modifications to Reaches**

Final revisions to the RCHRES blocks of the basin models consisted of constructing three new stream reaches and their associated F-tables and of making final adjustments to reach losses and to volume-discharge relations. One of the new reaches was the major component of the ground-water controller discussed in the following section. The other two new reaches, both in the Woodard Creek Basin, were constructed for subbasins WD2 and WD3 when the subdivision of an existing subbasin created these new subbasins.

In final calibration, the volume-discharge relations in the F-tables were adjusted to account for higher storage volumes in the drainage network and for greater channel losses during high flows. Hydrographs simulated by the first-year calibrated models had exceeded observed hydrographs during peak flows, and field information indicated that the volume and the loss components of the F-tables could be higher. For example, field observations indicated that during high-flow periods, once-dry depressions and swales often filled with water and flowed toward major channels. The drainage networks expanded, and the number of channels flowing toward major reaches increased during these periods. Field observations also indicated that low-lying areas near some major channels

stored large amounts of channel backwater and channel overflow and then released the stored water back to the channel as streamflows receded. In both of these instances, larger volumes of water were stored in the actual reaches than were accounted for in the F-table volumes of the first-year calibrated models. Thus, in the part of the F-tables pertaining to high volumes and discharges, volumes often were increased in relation to corresponding discharges, and, by doing so, greater volumes were required to increase discharges during high flows. The adjustments reduced the simulated peak flows and, consequently, their differences from observed volumes.

Another reach-related adjustment to reduce simulated peak flows was prompted by the observation that in flat, low-lying areas adjacent to channels, storage areas received overflow water that was diverted away from the drainage network. This water would eventually infiltrate or evaporate. To represent these losses in the basin models, a second outflow was added to the F-tables of certain reaches. Streamflow directed to this second outflow was considered to be lost from the basin model either to inactive ground water (ground water not available for runoff) or to evaporation.

To improve simulations during periods of moderate or low flows, many minor adjustments of the same kinds discussed above were made. These adjustments dealt with reach losses stemming from interactions of ground water and surface water in subbasins containing lakes and large areas of outwash soils or containing channels that flowed through outwash soils. Tables 17-19 (at the end of the report) show the F-tables within the input sequences for the three basin models.

### **Ground-Water Controller**

After the first-year calibrated model underestimated daily mean flows in late winter and spring at Woodland Creek station 12080670 (see fig. 12), it was concluded that the simplified representation of the behavior of a ground-water system in the HSPF PERLND block could not adequately simulate ground-water recharge, storage, flow, and discharge of the large aquifer system that underlies several subbasins in the Woodland Creek Basin. To compensate for this shortcoming, a "ground-water controller" was developed to better simulate the many complex aquifer features that underlie the flat outwash plains upstream of Woodland Creek station 12080670. The controller was not designed to explicitly simulate the actual movement

and storage of water in an aquifer, but it could accurately simulate the magnitude and timing of ground-water discharge to Woodland Creek.

The major component of the controller was an F-table that governed the outflow of the ground-water system as a function of simulated ground-water storage. The simulated ground-water system could store large volumes of water supplied by outflows from the PERLND and NETWORK blocks of the model, and it could delay the discharge of this water by using a threshold F-table volume. Below the threshold, discharge would be zero, and above it discharge to Woodland Creek took place. A second discharge outflow defined in the F-tables allowed for drainage of stored water to inactive ground water. If simulated ground-water storage fell below the threshold storage, drainage was directed to inactive ground water, which did not discharge to the creek. During summer and fall dry periods, the storage in the simulated ground-water system was too small to maintain ground-water discharge to Woodland Creek, and during the late winter or spring, the storage rose above the threshold, and ground water was discharged to the creek.

To simulate recharge to the controller reach, the PERLND component of the ground-water controller used simulated ground-water recharge from certain land segments within some designated subbasins in the flat outwash plains of the Woodland Creek Basin upstream of Woodland Creek station 12080670. These land segments did not contribute runoff to reaches in the first-year calibrated Woodland Creek model. Outwash land segments contributed a large portion of the recharge to the ground-water controller, but till and saturated land segments also contributed some recharge. The outwash land segments that recharged to the controller reach were assigned to newly defined controller land-segment types. These controller land-segment types were designated outwash-forest ground water, outwash-nonforest ground water, and outwash-crops ground water, and they retained the same process-related parameter values, except for KVAR values, as their counterparts in the regular land-segment types. The active ground-water modifier, KVAR, though, received a value of 0.2 for all controller segment types. Determined by calibration the KVAR value fine-tuned both large and small levels of ground-water discharge from the land segments to the reach. The till and saturated land segments that contributed recharge to the ground-water controller were classified into the same land-segment types and assigned the same process-related parameter values as their counterparts that drained to reaches.

The NETWORK component of the ground-water controller served (1) to designate specific areas in some Woodland Creek subbasins to land-segment types that recharged the controller reach; (2) to supply the recharge water to the controller reach for storage and delayed discharge; and (3) to discharge the ground water from the controller reach to Woodland Creek. Large parts of Woodland Creek subbasins WL2, WL3, WL5A, WL6, and WL6E, consisting mostly of outwash segments but also some till and saturated segments, were designated to recharge the controller reach. These parts had not previously contributed runoff to the creek. The areas assigned to the controller land-segment types were determined by trial-and-error model runs repeated until enough recharge was directed to the controller to yield satisfactory simulations. These areas, selected by calibration and available ground-water information, did not necessarily represent the actual areas that recharged to the actual ground-water system under this part of the Woodland Creek Basin. Nevertheless, the segments of these areas in fact did lie in subbasins uphill from the controller discharge point, Long Lake, located in subbasin WL6.

### Calibration Results

First calibration had identified three general features requiring additional calibration to improve runoff simulation: ground-water contributions to Woodland Creek, low streamflows in both Woodland and Woodard Creeks, and high streamflows, especially after the large January storm, in Woodland, Woodard, and Percival Creeks. Simulations of those three features were improved during final calibration. The ground-water controller in the final Woodland Creek model noticeably improved runoff simulations for late winter and spring at Woodland Creek station 12080670. Refinements in the contributions of ground-water, shallow subsurface, and overland flows and in the volume-discharge relations improved runoff simulations of both high and low flows in all three basin models.

**Yearly and seasonal runoff.**--The relatively small simulation differences for yearly, winter, and spring runoff (total volumes) suggest that the final models simulated runoff generation adequately for most of the year. Table 12 shows the observed and simulated yearly and seasonal runoff volumes for the entire study period from the final calibrated models for the five gaging stations, and table 13 shows similar results from the first-year calibrated models for comparison. For the whole study period, the absolute differences produced by the final models between observed and simulated yearly runoff ranged from 1.4 to 5.2 percent, and for individual water years, from 0.4 to

7.5 percent. For winter and spring runoff during the entire study period, the absolute differences ranged from 1.8 to 7.9 percent and from 0.2 to 6.9 percent, respectively. For summer runoff, the differences ranged between 0.3 and 100 percent, but the large percent differences reflect small differences between observed and simulated runoff volumes. Indeed, simulation results from the final Woodland Creek model showed the greatest improvement over results from the first-year model: the absolute difference for all years decreased from 18.3 to 1.4 percent at station 12080670 and from 12.7 to 3.9 percent at station 12081000.

**Daily mean discharge.**--The final calibrated models adequately simulated daily mean discharges and performed best with medium and high flows. Tables 14 and 15 list the statistical measures of difference for daily mean discharges simulated by the final calibrated and first-year calibrated models. Mean absolute differences for all flows were between 7.5 to 32.0 percent, compared with 13.4 to 57.3 percent differences produced by the first-year calibrated models. Once again, the largest percent differences occurred during low-flow periods, when absolute differences were relatively small. Figures 24 through 28 show the observed and simulated hydrographs of daily mean discharges from the final calibrated models.

The final calibration of the Woodland Creek model showed the greatest improvement over the first calibration. The addition of the ground-water controller and the refinements to flow contributions and to the F-tables greatly improved the simulation results. At station 12080670, mean absolute differences in daily discharges were reduced from 109.4 to 66.2 percent for the low flow regime and from 57.3 to 32.0 percent for all flows. Large percent differences were reported for the low-flow regime, but again the actual differences were small (less than 0.5 cubic foot per second). Streamflow records indicated that during low-flow periods Woodland Creek became ephemeral (fig. 27), and percent differences were especially high for these periods because percentages were computed using extremely low observed flows.

**Storm runoff and peak discharge.**--Hourly mean discharge hydrographs and statistical measures confirm that the final calibrated models improved storm runoff and peak discharge simulations (figs. 29-38 and table 16). Absolute differences between simulated and observed storm runoff volumes ranged from 0.0 to 31.2 percent, though only 1 of 40 runoff volumes exceeded 20 percent difference. By comparison, absolute differences from first-year calibrated models had ranged from 0.0 to 50.0 percent, with 10 of 40 runoff volumes exceeding

**Table 12.** --Observed and simulated yearly and seasonal runoff data of Woodland Creek, Woodward Creek, and Percival Creek for the final calibrated models during the calibration period March 1, 1988, through March 15, 1990

[Obs., observed value; Sim., simulated value; Difference, sim. - obs., in inches; Difference, 100 x [(sim. - obs.)/obs.], in percent; --, no data]

Station <sup>1</sup> number	Water year	Yearly runoff <sup>2</sup>				Winter runoff <sup>3</sup>				Spring runoff <sup>4</sup>				Summer runoff <sup>5</sup>			
		Obs. (in.)	Sim. (in.)	Difference		Obs. (in.)	Sim. (in.)	Difference		Obs. (in.)	Sim. (in.)	Difference		Obs. (in.)	Sim. (in.)	Difference	
				Inches	Percent			Inches	Percent			Inches	Percent			Inches	Percent
12078720	1988	33.82	35.65	1.83	5.4	--	--	--	--	29.50	31.43	1.93	6.5	4.32	4.21	-0.11	-2.5
	1989	82.70	86.76	4.06	4.9	42.43	44.12	1.69	4.0	32.72	34.89	2.17	6.6	4.49	5.16	.67	14.9
	1990	73.10	77.06	3.96	5.4	62.56	66.46	3.90	6.2	8.44	8.64	.20	2.4	--	--	--	--
	1988-1990	189.62	199.47	9.85	5.2	104.99	110.58	5.59	5.3	70.66	74.96	4.30	6.1	8.81	9.37	.56	6.4
12078730	1988	17.91	18.12	.21	1.2	--	--	--	--	14.35	14.92	.57	4.0	3.56	3.19	-.37	-10.4
	1989	41.20	41.39	.19	.5	19.20	21.06	1.86	9.7	16.96	16.58	-.38	-2.2	3.53	2.72	-.81	-23.0
	1990	32.93	34.94	2.01	6.1	28.39	29.61	1.22	4.3	3.34	4.44	1.10	32.9	--	--	--	--
	1988-1990	92.04	94.45	2.41	2.6	47.59	50.67	3.08	6.5	34.65	35.94	1.29	3.6	7.09	5.91	-1.18	-16.6
12080500	1988	11.03	11.86	.83	7.5	--	--	--	--	8.35	8.47	.12	1.4	2.69	3.39	.70	26.0
	1989	26.09	26.32	.23	.9	9.66	10.42	.76	7.9	11.95	10.74	-1.21	-10.1	3.22	4.08	.86	26.7
	1990	17.73	18.00	.27	1.5	14.15	14.65	.50	3.5	2.66	2.16	-.50	-18.8	--	--	--	--
	1988-1990	54.85	56.18	1.33	2.4	23.81	25.07	1.26	5.3	22.96	21.37	-1.59	-6.9	5.91	7.47	1.56	26.4
12080670	1988	1.18	1.19	.01	.8	--	--	--	--	1.17	1.19	.02	1.7	0	0	0	0
	1989	2.61	2.62	.01	.4	.38	.44	.06	15.8	2.21	2.18	-.03	-1.4	.01	0	-.01	-100
	1990	3.95	3.82	-.13	-3.3	3.00	2.88	-.12	-4.0	.95	.95	0	0	--	--	--	--
	1988-1990	7.74	7.63	-.11	-1.4	3.38	3.32	-.06	-1.8	4.33	4.32	-.01	-.2	.01	0	-.01	-100
12081000	1988	5.66	5.47	-.19	-3.4	--	--	--	--	3.99	3.86	-.13	-3.3	1.66	1.61	-.05	-3.0
	1989	10.33	11.04	.71	6.9	3.14	3.54	.40	12.7	4.89	5.20	.31	6.3	1.81	1.85	.04	2.2
	1990	7.62	8.01	.39	5.1	5.97	6.29	.32	5.4	1.15	1.23	.08	7.0	--	--	--	--
	1988-1990	23.61	24.52	.91	3.9	9.11	9.83	.72	7.9	10.03	10.29	.26	2.6	3.47	3.46	-.01	-.3

<sup>1</sup> Station names for the displayed station numbers are shown in table 7.

<sup>2</sup> Yearly runoff data are the total streamflow volumes for each water year (October-September) during the data collection period March 1, 1988, through March 15, 1990. Streamflow volumes for the 1988 water year are for the period March 1, 1988, through September 30, 1988; for the 1990 water year are for the period October 1, 1989, through March 15, 1990; and for the 1988-1990 water years are for the period March 1, 1988, through March 15, 1990.

<sup>3</sup> Winter runoff data are the total streamflow volumes for each winter season (November-February).

<sup>4</sup> Spring runoff data are the total streamflow volumes for each spring season (March-June). Streamflow volumes for the 1990 water year are for the period March 1-15, 1990.

<sup>5</sup> Summer runoff data are the total streamflow volumes for each summer season (July-September).

**Table 13.--Observed and simulated yearly and seasonal runoff data of Woodland Creek, Woodard Creek, and Percival Creek for the first-year calibrated models during the period March 1, 1988, through March 15, 1990**

[Obs., observed value; Sim., simulated value; Difference, sim. - obs., in inches; Difference, 100 x [(sim. - obs.)/obs.], in percent; --, no data]

Station number	Water year	Yearly runoff <sup>2</sup>				Winter runoff <sup>3</sup>				Spring runoff <sup>4</sup>				Summer runoff <sup>5</sup>			
		Obs.		Sim.		Difference		Obs.		Sim.		Difference		Obs.		Sim.	
		(in.)	(in.)	(in.)	(in.)	Inches	Percent	(in.)	(in.)	(in.)	(in.)	Inches	Percent	(in.)	(in.)	(in.)	Inches
12078720	1988	33.82	35.86	2.04	6.0	--	--	--	--	29.50	31.61	2.11	7.2	4.32	4.24	-0.08	-1.9
	1989	82.70	86.80	4.10	5.0	42.43	51.3	44.01	53.2	32.72	35.03	2.31	7.1	4.49	5.16	.67	14.9
	1990	73.10	77.85	4.75	6.5	62.56	85.6	67.18	91.9	8.44	8.68	.24	2.8	--	--	--	--
	1988 - 1990	189.62	200.51	10.89	5.7	104.99	55.3	111.19	58.6	70.66	75.32	4.66	6.6	8.81	9.40	.59	6.7
12078730	1988	17.91	18.12	.21	1.2	--	--	--	--	14.35	14.92	.57	4.0	3.56	3.19	-.37	-10.4
	1989	41.20	41.39	.19	.5	19.20	4.6	21.06	5.1	16.96	16.58	-.38	-2.2	3.53	2.72	-.81	-23.0
	1990	32.93	34.94	2.01	6.1	28.39	86.2	29.61	90.0	3.34	4.44	1.10	32.9	--	--	--	--
	1988 - 1990	92.04	94.45	2.41	2.6	47.59	51.7	50.67	55.0	34.65	35.94	1.29	3.6	7.09	5.91	-1.18	-16.6
12080500	1988	11.03	11.28	.25	2.3	--	--	--	--	8.35	7.78	-.57	-6.8	2.69	3.50	.81	30.1
	1989	26.09	25.54	-.55	-2.1	9.66	-35.5	9.76	36.3	11.95	10.23	-1.72	-14.4	3.22	4.42	1.20	37.3
	1990	17.73	17.14	-.59	-3.3	14.15	-78.1	13.97	-18.3	2.66	1.89	-.77	-28.9	--	--	--	--
	1988 - 1990	54.85	53.96	-.89	-1.6	23.81	-43.4	23.73	-43.4	22.96	19.90	-3.06	-13.3	5.91	7.92	2.01	34.0
12080670	1988	1.18	1.01	-.17	-14.4	--	--	--	--	1.17	1.00	-.17	-14.5	0	0	0	0
	1989	2.61	2.13	-.48	-18.4	.38	14.6	.50	19.5	2.21	1.61	-.60	-27.1	.01	0	-.01	-100
	1990	3.95	3.18	-.77	-19.5	3.00	-76.3	2.57	-43.3	.95	.61	-.34	-35.8	--	--	--	--
	1988 - 1990	7.74	6.32	-1.42	-18.3	3.38	-69.3	3.07	-9.2	4.33	3.22	-1.11	-25.6	.01	0	-.01	-100
12081000	1988	5.66	5.82	.16	2.8	--	--	--	--	3.99	4.07	.08	2.0	1.66	1.74	.08	4.8
	1989	10.33	12.16	1.83	17.7	3.14	30.4	4.10	30.6	4.89	5.43	.54	11.0	1.81	2.12	.31	17.1
	1990	7.62	8.64	1.02	13.4	5.97	77.3	6.94	91.2	1.15	1.11	-.04	-3.5	--	--	--	--
	1988 - 1990	23.61	26.62	3.01	12.7	9.11	38.6	11.04	21.2	10.03	10.61	.58	5.8	3.47	3.86	.39	11.2

<sup>1</sup> Station names for the displayed station numbers are shown in table 7.

<sup>2</sup> Yearly runoff data are the total streamflow volumes for each water year (October-September) during the data-collection period March 1, 1988, through March 15, 1990. Streamflow volumes for the 1988 water year are for the period March 1, 1988, through September 30, 1988, for the 1989 water year are for the period October 1, 1988, through March 15, 1989, and for the 1990 water year are for the period March 1, 1989, through March 15, 1990.

<sup>3</sup> Winter runoff data are the total streamflow volumes for each winter season (November-February).

<sup>4</sup> Spring runoff data are the total streamflow volumes for each spring season (March-June). Streamflow volumes for the 1990 water year are for the period March 1-15, 1990.

<sup>5</sup> Summer runoff data are the total streamflow volumes for each summer season (July-September).

**Table 14.** --Measures of difference between simulated and observed daily mean discharges of Woodland Creek, Woodard Creek, and Percival Creek for the final calibrated models during the calibration period March 1, 1988, through March 15, 1990

Station number <sup>1</sup>	Flow regime <sup>2</sup>	Mean absolute difference <sup>3</sup>		Root mean square difference <sup>4</sup>		Bias <sup>5</sup>	
		Average	Percent	Average	Percent	Average	Percent
12078720	Low	1.057	20.6	1.350	33.4	0.327	13.0
	Medium	2.873	11.8	3.657	14.7	1.951	7.3
	High	5.084	7.1	6.960	9.2	3.121	3.9
	Total	3.002	13.2	4.606	21.8	1.796	8.1
12078730	Low	.489	21.5	.549	24.3	-.416	-18.9
	Medium	.822	16.6	1.055	21.4	.209	3.5
	High	1.944	13.1	2.782	17.6	.827	8.1
	Total	1.083	17.1	1.742	21.3	.207	-2.4
12080500	Low	.847	30.5	.981	35.0	.777	28.4
	Medium	.778	16.0	.988	20.4	.454	9.8
	High	1.828	14.8	2.542	18.2	-.695	-4.0
	Total	1.152	20.4	1.675	25.6	.177	11.3
12080670	Low	.446	66.2	.604	75.5	-.032	-22.6
	Medium	.741	21.6	.906	26.9	-.187	-1.1
	High	.989	8.3	1.200	10.7	-.159	-.6
	Total	.726	32.0	.936	46.6	-.126	-8.1
12081000	Low	.725	6.6	.908	8.2	-.236	-2.4
	Medium	1.177	7.4	1.770	10.9	.527	3.2
	High	2.728	8.5	3.866	11.5	.526	1.5
	Total	1.539	7.5	2.505	10.3	.271	.7

<sup>1</sup> Station names for the displayed station numbers are shown in table 7.

<sup>2</sup> Low, medium, and high flow regimes are the lower, middle, and upper thirds of the daily mean discharge values from each station. Total refers to the complete daily mean discharge record specified for the stations.

<sup>3</sup> AVERAGE =  $\sum (|S-M|/n)$  for all  $M > 0.1$

PERCENT =  $100.0 * [\sum (|S-M|/M)]/n$  for all  $M > 0.1$  (where S = simulated daily mean discharge in cubic feet per second; M = observed daily mean discharge in cubic feet per second; sum = summation over days for which  $M > 0.1$  in the calibration period; n = number of pairs of daily values for which  $M > 0.1$  in the calibration period; and || = absolute value. NOTE: Because of the method of computing percentages, measured daily mean discharges below 0.1 cubic feet per second are considered as "dry" and are not considered in this analysis).

<sup>4</sup> AVERAGE =  $\text{square root}\{\sum [(S-M)^2/n]\}$  for all  $M > 0.1$

PERCENT =  $100.0 * \text{square root}(\sum \{[(S-M)/M]^2\}/n)$  for all  $M > 0.1$

<sup>5</sup> AVERAGE =  $\sum (S-M)/n$  for all  $M > 0.1$

PERCENT =  $100.0 * \{\sum [(S-M)/M]/n\}$  for all  $M > 0.1$

**Table 15.**--Measures of difference between simulated and observed daily mean discharges of Woodland Creek, Woodard Creek, and Percival Creek for the first-year calibrated models during the period March 1, 1988, through March 15, 1990

Station number <sup>1</sup>	Flow regime <sup>2</sup>	Mean absolute difference <sup>3</sup>		Root mean square difference <sup>4</sup>		Bias <sup>5</sup>	
		Average	Percent	Average	Percent	Average	Percent
12078720	Low	1.062	20.7	1.362	33.7	0.336	13.2
	Medium	3.034	12.3	3.882	15.3	2.252	8.4
	High	5.404	7.3	8.718	9.7	3.382	3.9
	Total	3.164	13.4	5.568	22.1	1.987	8.5
12078730	Low	.489	21.5	.549	24.3	-.416	-18.9
	Medium	.822	16.6	1.055	21.4	.209	3.5
	High	1.944	13.1	2.782	17.6	.827	8.1
	Total	1.083	17.1	1.742	21.3	.207	-2.4
12080500	Low	.945	34.5	1.082	39.5	.881	32.6
	Medium	.712	14.6	.898	18.8	.171	4.6
	High	2.175	16.5	3.101	19.6	-1.338	-10.0
	Total	1.278	21.8	1.967	27.6	-.099	9.0
12080670	Low	.564	109.4	.765	208.1	.079	39.6
	Medium	1.461	39.5	1.805	48.8	-1.025	-23.3
	High	3.548	22.9	4.681	27.2	-2.744	-15.8
	Total	1.862	57.3	2.938	124.4	-1.234	.2
12081000	Low	1.527	13.3	2.117	18.3	1.443	12.4
	Medium	2.937	18.8	3.993	25.2	2.714	17.4
	High	4.258	12.1	7.010	16.8	2.329	6.8
	Total	2.902	14.7	4.807	20.4	2.160	12.2

<sup>1</sup> Station names for the displayed station numbers are shown in table 7.

<sup>2</sup> Low, medium, and high flow regimes are the lower, middle, and upper thirds of the daily mean discharge values from each station. Total refers to the complete daily mean discharge record specified for the stations.

<sup>3</sup> AVERAGE =  $\sum (|S-M|/n)$  for all  $M > 0.1$

PERCENT =  $100.0 * [\sum (|S-M|/M)]/n$  for all  $M > 0.1$  (where S = simulated daily mean discharge in cubic feet per second; M = observed daily mean discharge in cubic feet per second; sum = summation over days for which  $M > 0.1$  in the calibration period; n = number of pairs of daily values for which  $M > 0.1$  in the calibration period; and || = absolute value. NOTE: Because of the method of computing percentages, measured daily mean discharges below 0.1 cubic feet per second are considered as "dry" and are not considered in this analysis).

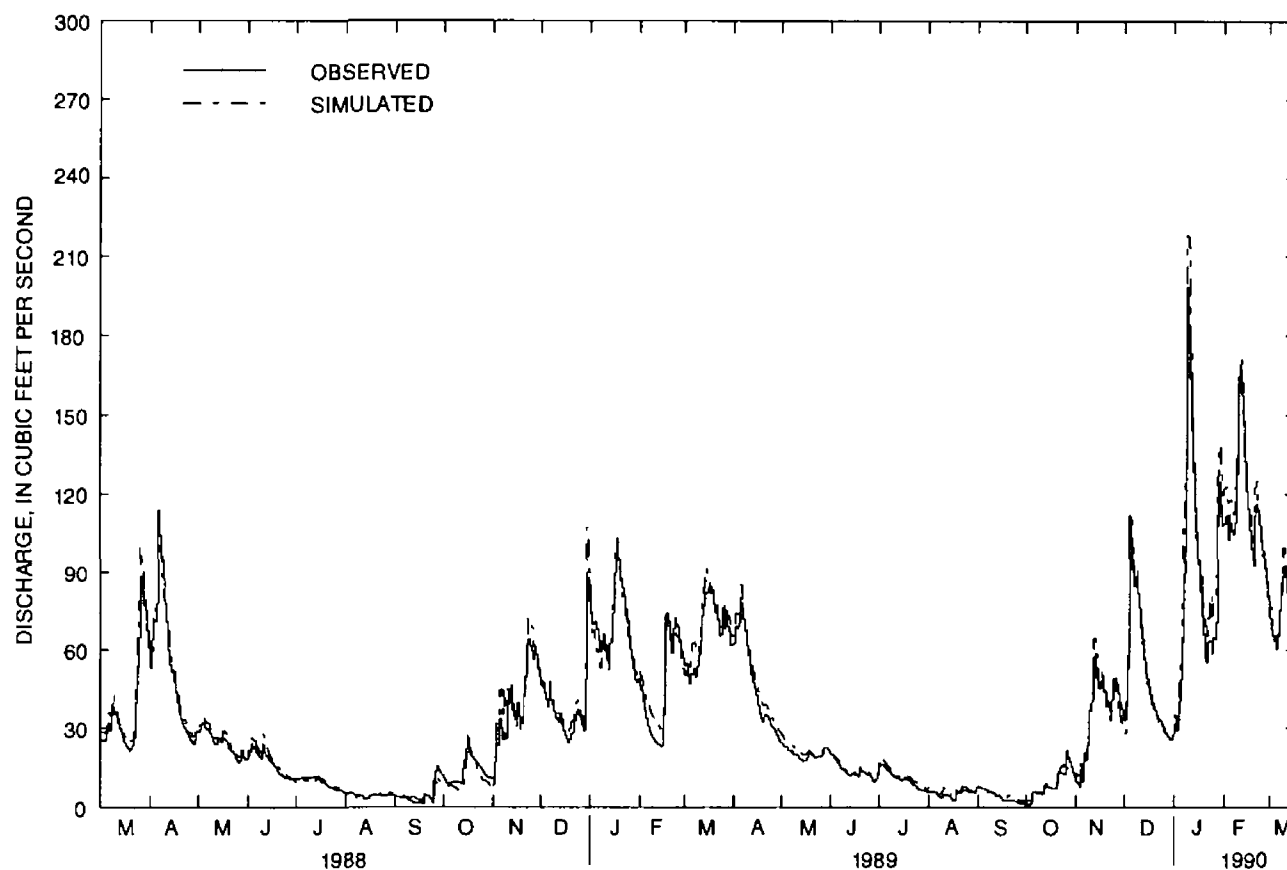
<sup>4</sup> AVERAGE =  $\text{square root} \{ \sum [(S-M)^2/n] \}$  for all  $M > 0.1$

PERCENT =  $100.0 * \text{square root} \{ [\sum ((S-M)/M)^2/n] \}$  for all  $M > 0.1$

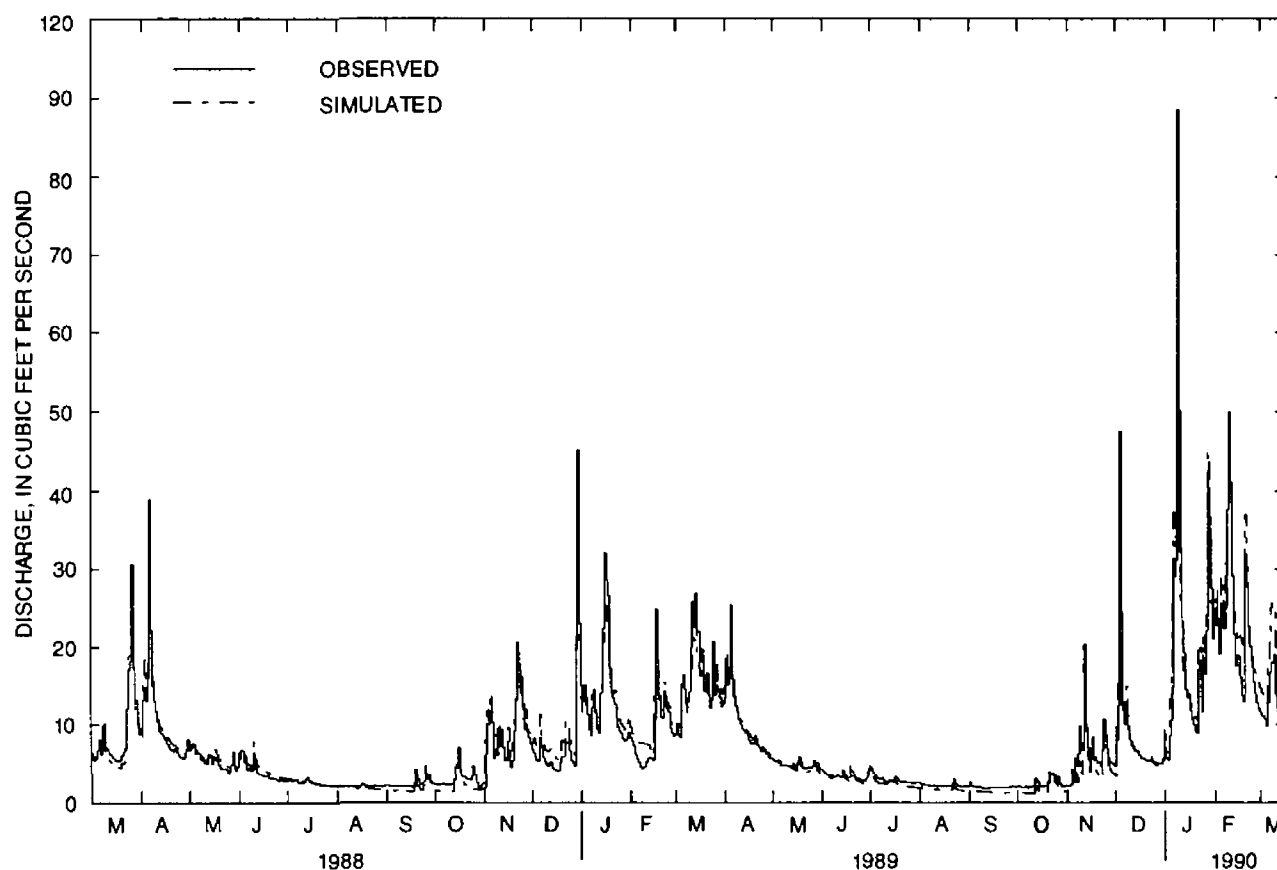
<sup>5</sup> AVERAGE =  $\sum (S-M)/n$  for all  $M > 0.1$

PERCENT =  $100.0 * \{ \sum [(S-M)/M]/n \}$  for all  $M > 0.1$

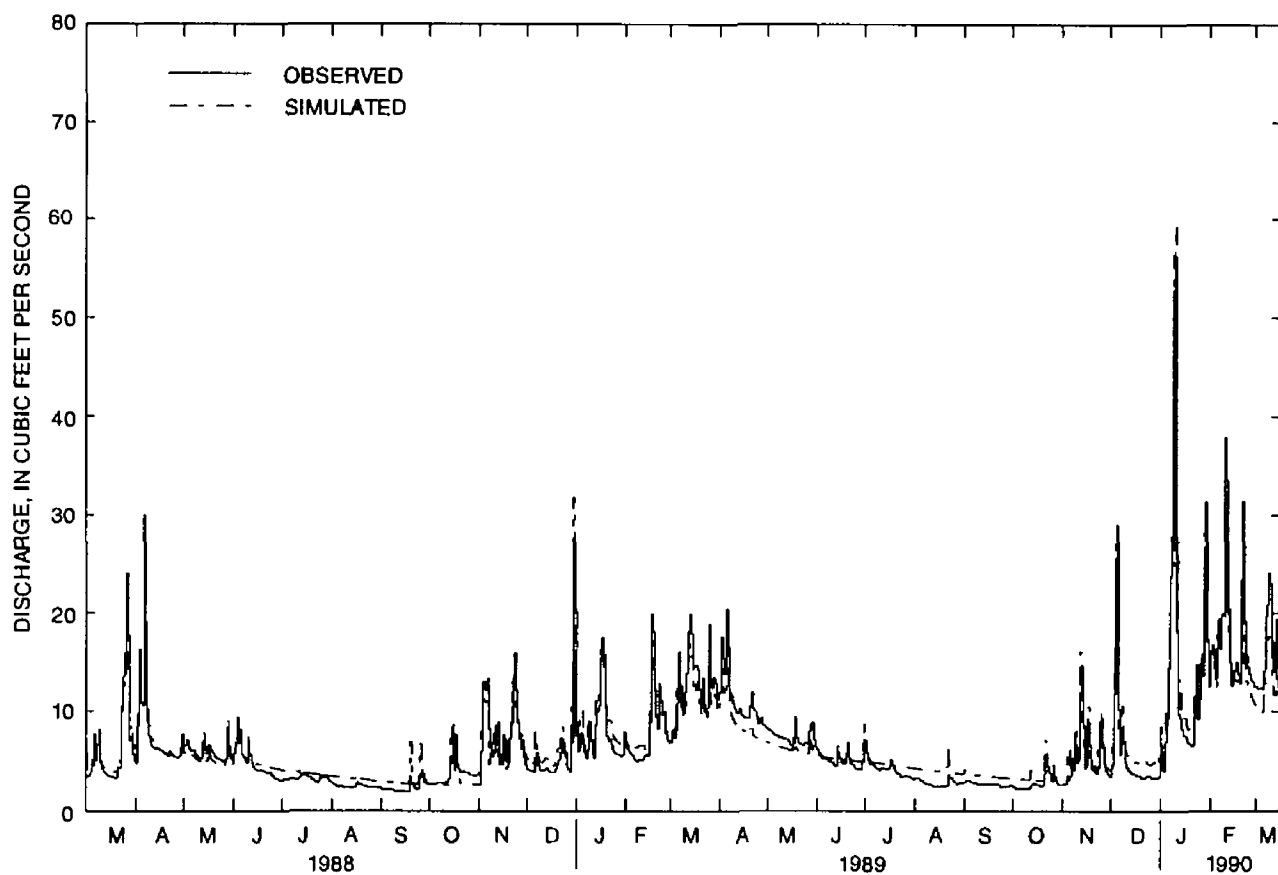




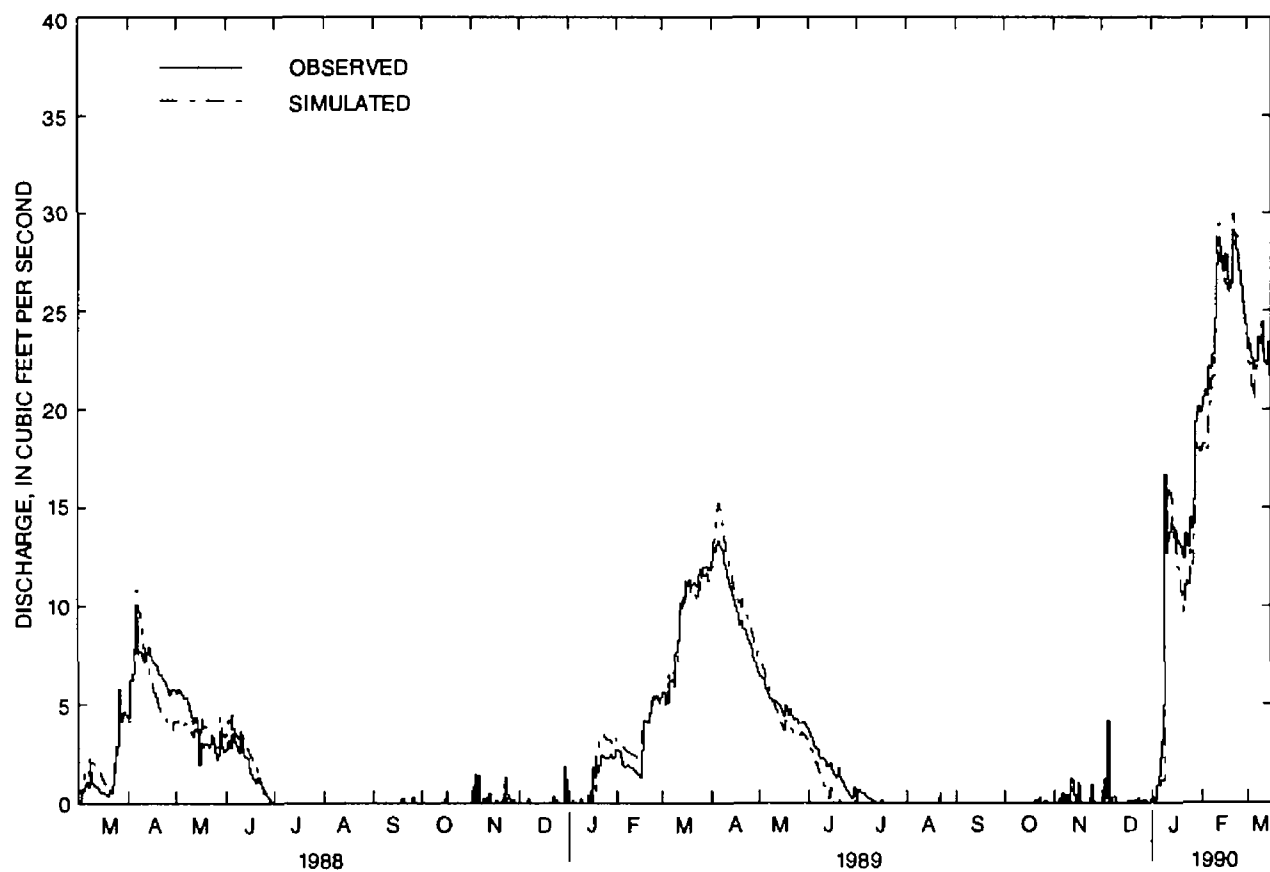
**Figure 24.**--Observed and simulated daily mean discharges for Black Lake Ditch near Olympia, Washington (station 12078720), in the Percival Creek Basin. Simulated discharges are from the final calibrated model applied to the period March 1, 1988, through March 15, 1990.



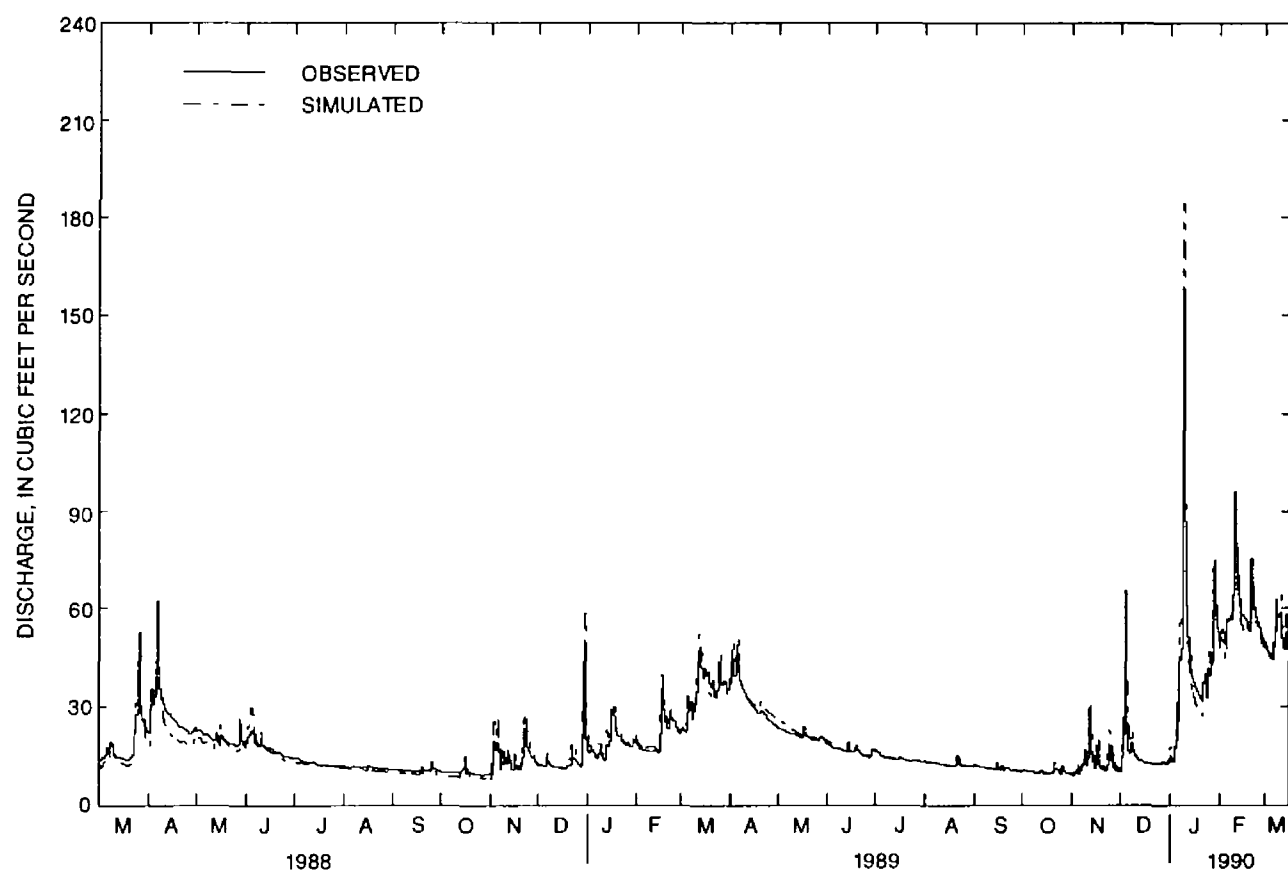
**Figure 25.**--Observed and simulated daily mean discharges for Percival Creek near Olympia, Washington (station 12078730), in the Percival Creek Basin. Simulated discharges are from the final calibrated model applied to the period March 1, 1988, through March 15, 1990.



**Figure 26.**--Observed and simulated daily mean discharges for Woodard Creek near Olympia, Washington (station 12080500), in the Woodard Creek Basin. Simulated discharges are from the final calibrated model applied to the period March 1, 1988, through March 15, 1990.



**Figure 27.**--Observed and simulated daily mean discharges for Woodland Creek at Martin Way at Lacey, Washington (station 12080670), in the Woodland Creek Basin. Simulated discharges are from the final calibrated model applied to the period March 1, 1988, through March 15, 1990.



**Figure 28.**--Observed and simulated daily mean discharges for Woodland Creek near Olympia, Washington (station 12081000), in the Woodland Creek Basin. Simulated discharges are from the final calibrated model applied to the period March 1, 1988, through March 15, 1990.

20 percent difference (table 10). Furthermore, absolute differences between simulated and observed peak discharges from the final models were between 0.0 and 32.4 percent, but only 4 of 40 peak discharges exceeded 25 percent difference. Again by comparison, absolute differences from the first-year calibrated models were between 0.3 and 107 percent, with 9 of 40 peak discharges exceeding 25 percent difference.

The final models produced much improved simulations of the high streamflows resulting from the large January 1990 storm. At station 12078720, absolute differences in runoff volume from this storm decreased from 29.7 percent for the first-year calibration to 14.1 percent for the final calibration. Absolute differences in peak discharges for the same station decreased from 33.3 to 0.7 percent. At station 12080500, absolute differences in runoff volume decreased from 26.1 to 16.7 percent, and in peak discharge, from 59.3 to 5.9 percent.

**Discussion of calibration results.**--The preceding results displayed the successful streamflow simulations by the basin models calibrated to 2 years of observed streamflow data. Additionally, the results of final calibration indicate that the simulation of ground-water discharge, low streamflows, and high streamflows improved from the results of model calibration to only 1 year of streamflow data.

During final calibration, like first calibration, the only process-related parameter value adjusted was KVAR. Other final values of process-related parameters assigned to land-segment types were the same as those determined for the same land-segment types in King and Snohomish County basins by Dinicola (1990). All process-related parameter values, other than KVAR, were those originally assigned to represent the features of runoff generation in the conceptual model. Thus, the conceptual model is adequate to represent runoff generation in the three Thurston County basins. However, the conceptual model--represented in the basin models by process-related parameters and land-segment types--does not adequately represent the hydraulic connectivity, or flow paths, from land segments to reaches when all outflows from land segments in sub-basins do not contribute to reaches in the same subbasins.

Final calibration demonstrated that contributions of runoff to streamflow are strongly influenced by flow paths of land segment outflows to channel reaches. Outflows from land segments in a subbasin commonly recharge inactive ground water or contribute to streamflow in other subbasins. Additionally, ground-water contributions to

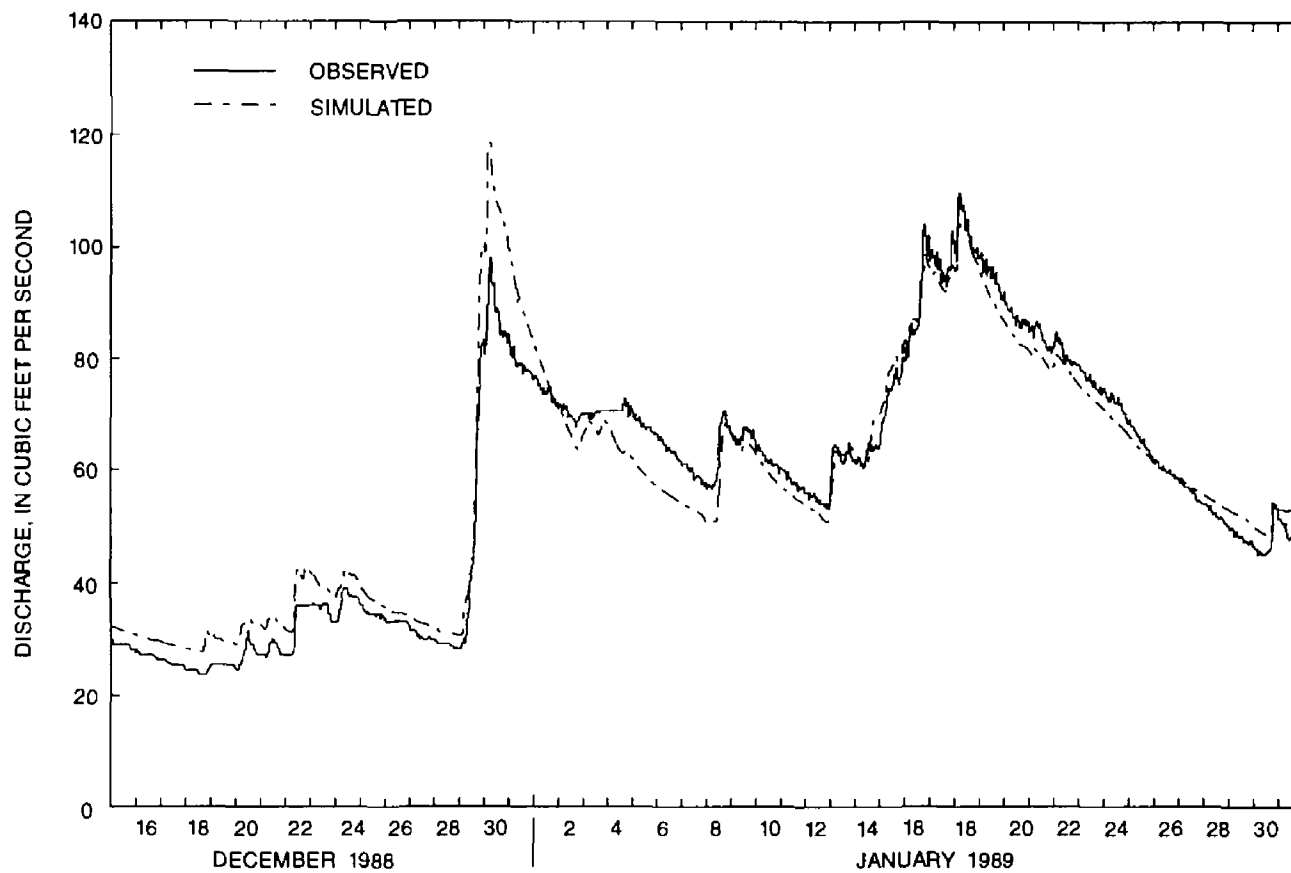
streamflow are variable, not only depending on the quantity and timing of rainfall, but also depending on both period (season) and geographic location and elevation of a given reach relative to the local water table.

The inadequacy of the conceptual model in describing flow paths prompted more data collection than was originally thought to be necessary. However, basin properties related to flow paths (such as geologic stratigraphy, aquifer characteristics, and subbasin topography) were difficult to measure directly and to incorporate directly in the basin models, which are based primarily on the relation of surficial physiography and storm runoff generation. Thus, additional streamflow data, lake-stage data, and field observations of subbasin conditions (see the discussion of "Modifications to Subbasins" in this section) had to be used as the most practical method to estimate runoff contributions and generalized flow paths to reaches.

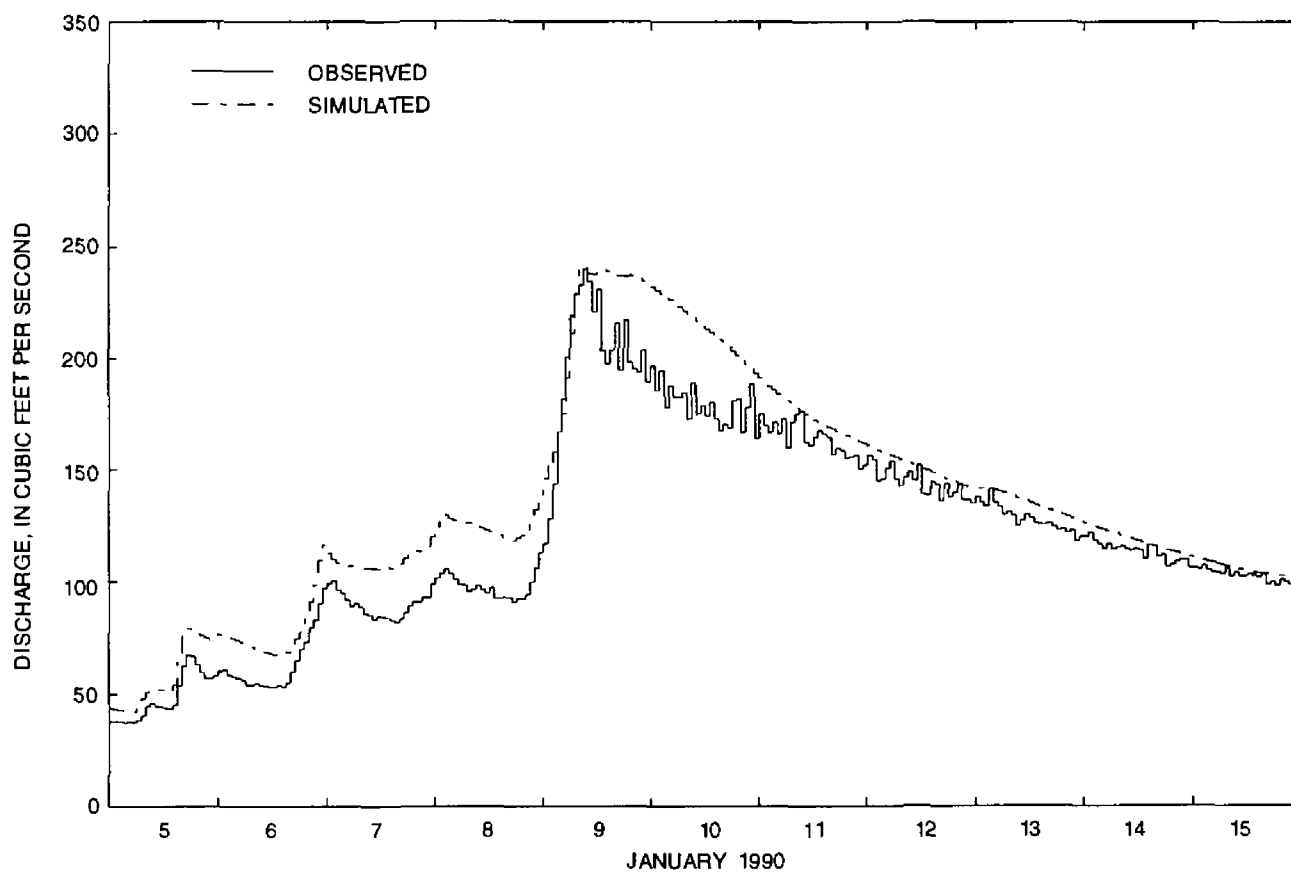
Although final calibration results were satisfactory, obtaining adequate streamflow simulations at most gaging stations required extensive streamflow data and field information. Additionally, in most cases, calibration to only 1 year of streamflow data simply was not adequate to describe the complex variation of runoff contributions to reaches. Only the model representing the part of Percival Creek Basin upstream of gaging station 12078730 did not require calibration to both years of streamflow data. This part of Percival Creek, except for the headwater subbasin PE1, is the only gaged study basin with clearly defined subbasin boundaries along high ridges. Additionally, it is the only study basin where all ground-water flow, shallow subsurface flow, and overland flow generated in a subbasin contributed to streamflow in that same subbasin.

Although results from final calibration show successful streamflow simulations to 2 years of observed data, streamflow simulations may not be as accurate either (1) outside of the gaged areas in the basins or (2) outside of the calibration period. The basin models simulated runoff generation and streamflows for each entire basin, including the ungaged parts between the farthest downstream gaging stations and the basin mouths. Field information guided modifications to the models for the ungaged parts of the basins in the same manner as the gaged parts of the basins. However, because observed streamflow information about the ungaged parts of the basins was not available for model calibration and evaluation, the accuracy of streamflow simulations there is uncertain.

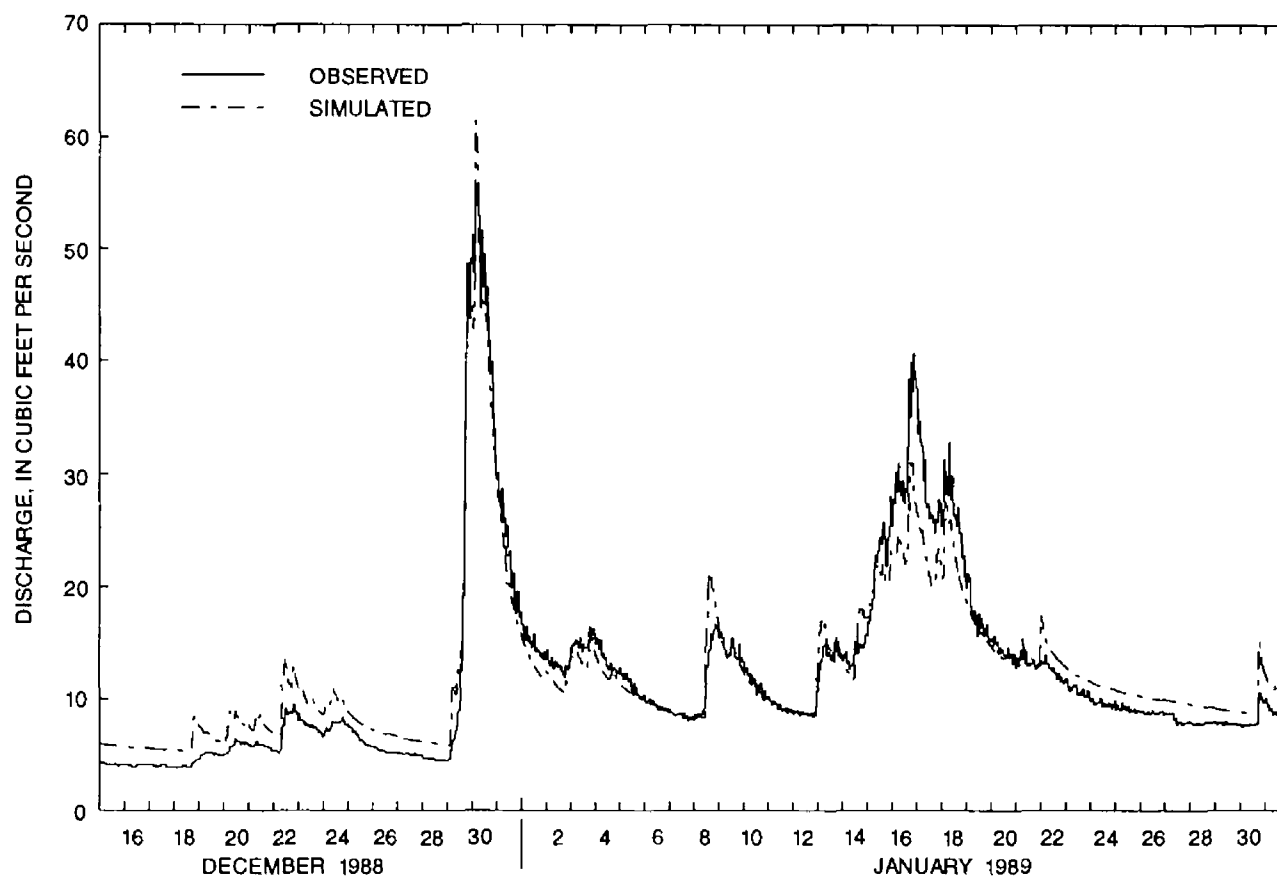
Evaluation of the first-year calibrated models demonstrated that, in most cases, differences between observed and simulated streamflows could increase when the basin



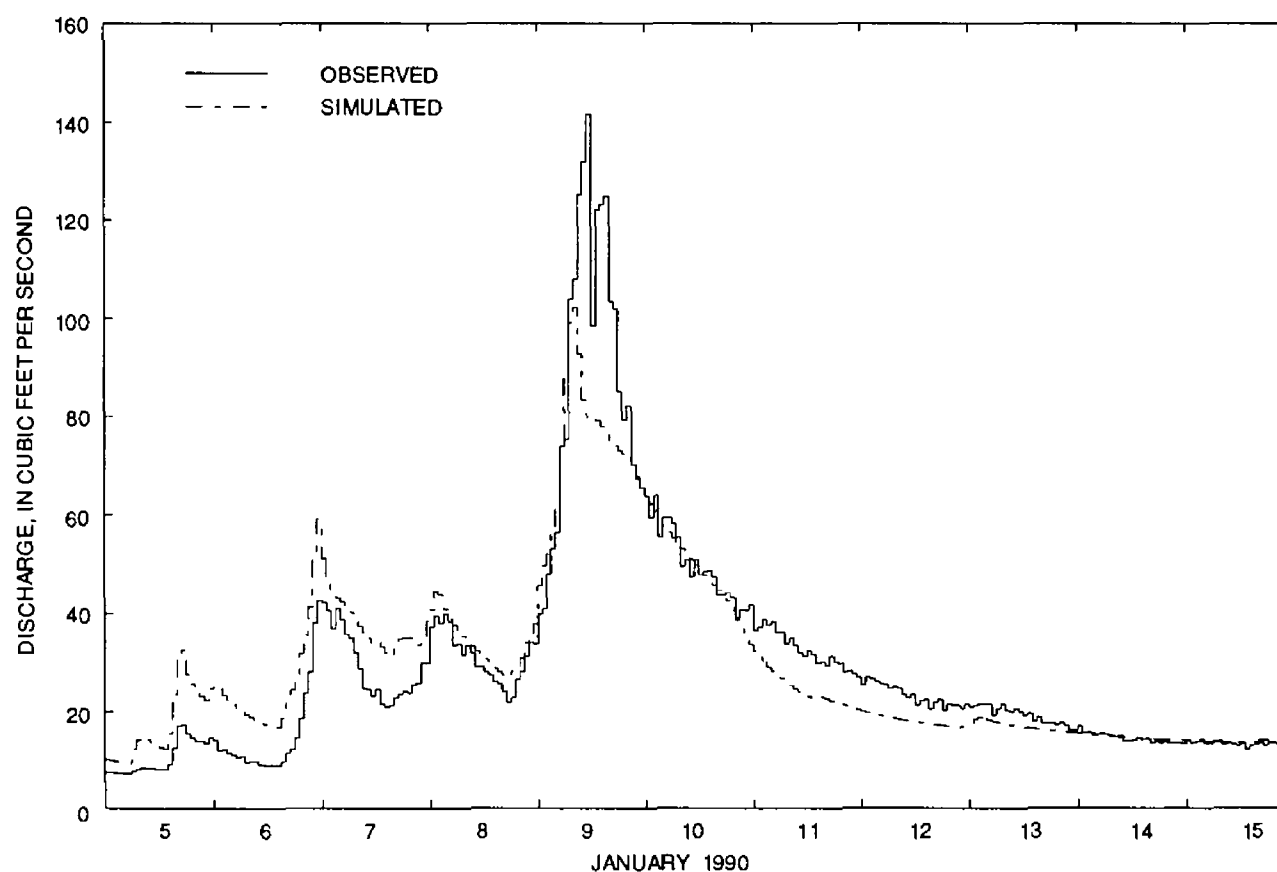
**Figure 29.**--Observed and simulated hourly mean discharges for Black Lake Ditch near Olympia, Washington (station 12078720), in the Percival Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period December 15, 1988, through January 31, 1989.



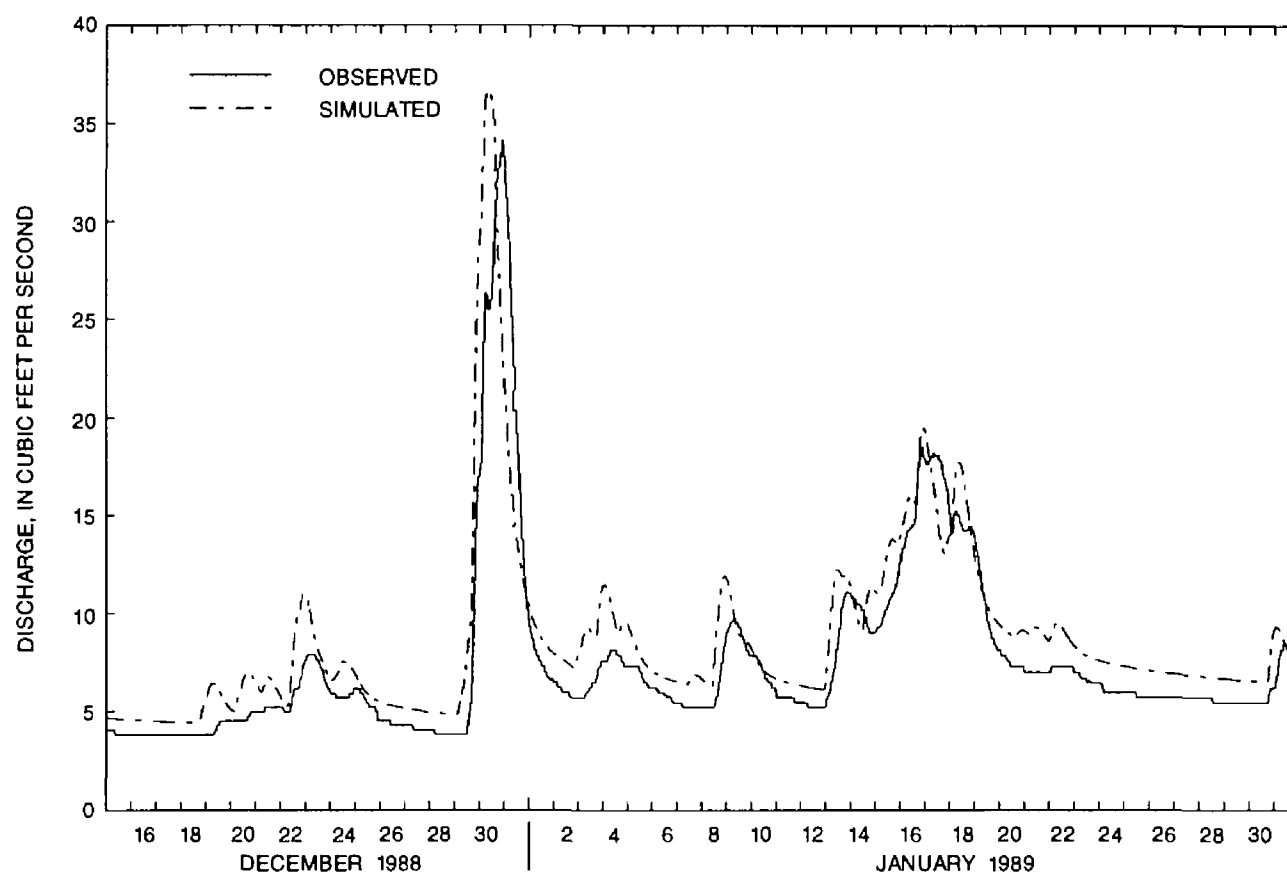
**Figure 30.**--Observed and simulated hourly mean discharges for Black Lake Ditch near Olympia, Washington (station 12078720), in the Percival Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period January 5 through 15, 1990.



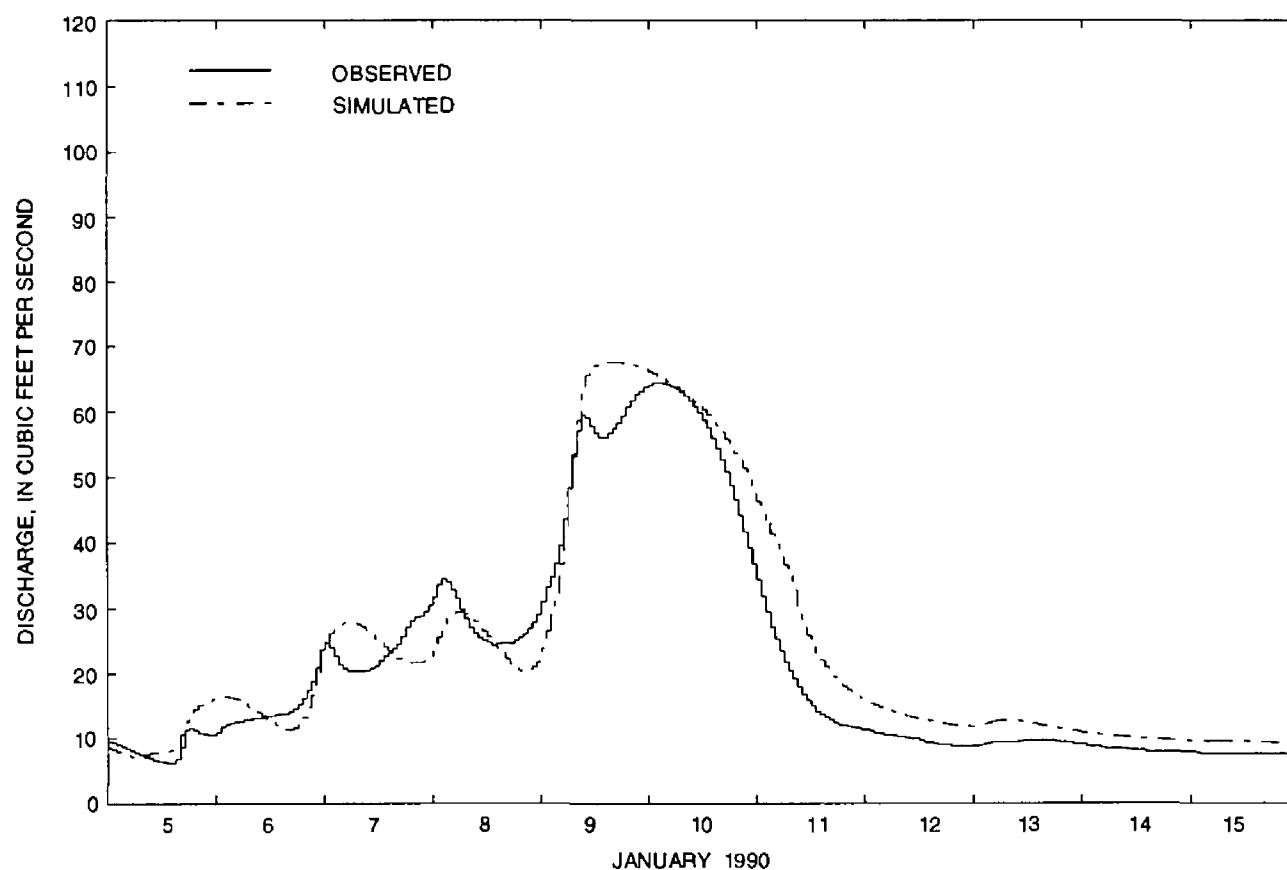
**Figure 31.**--Observed and simulated hourly mean discharges for Percival Creek near Olympia, Washington (station 12078730), in the Percival Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period December 15, 1988, through January 31, 1989.



**Figure 32.**--Observed and simulated hourly mean discharges for Percival Creek near Olympia, Washington (station 12078730), in the Percival Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period January 5 through 15, 1990.

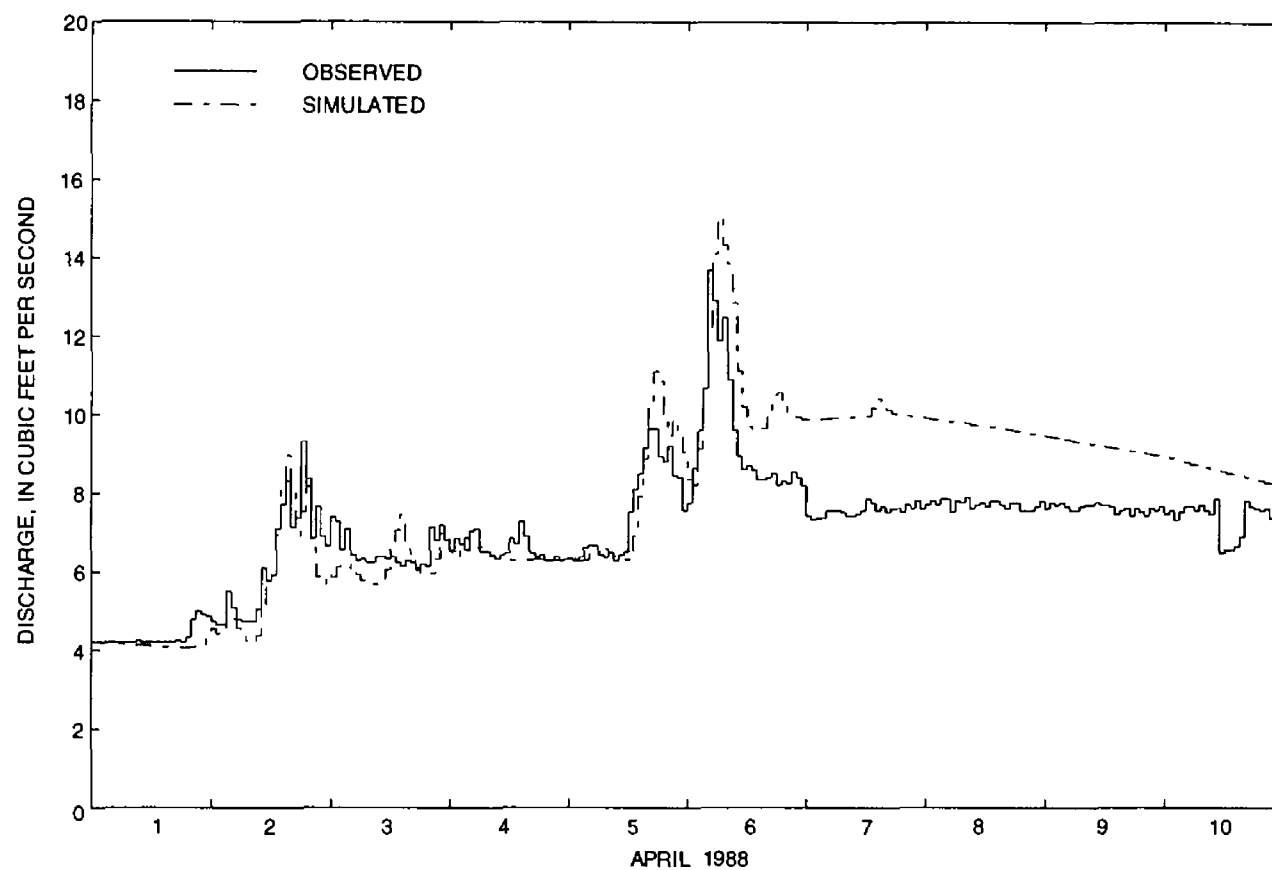


**Figure 33.**--Observed and simulated hourly mean discharges for Woodard Creek near Olympia, Washington (station 12080500), in the Woodard Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period December 15, 1988, through January 31, 1989.

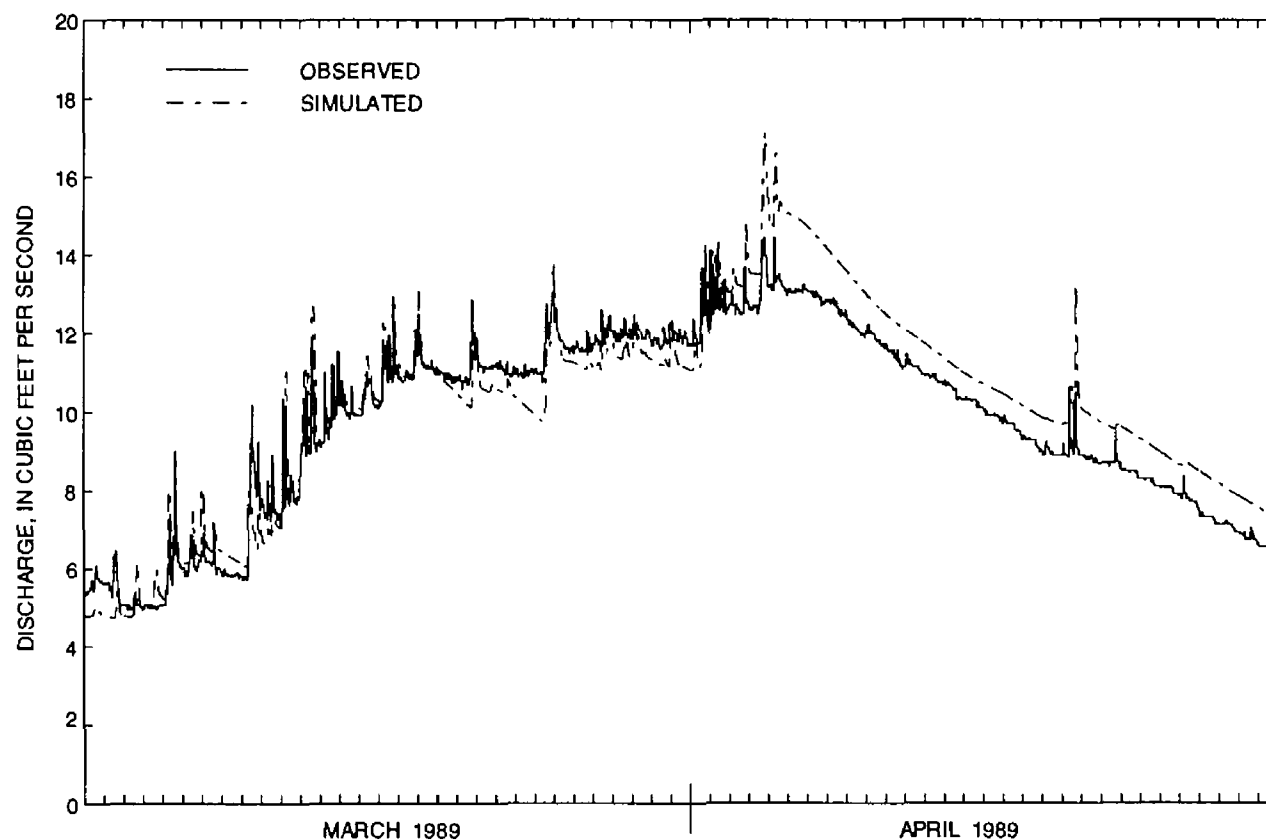


**Figure 34.**--Observed and simulated hourly mean discharges for Woodard Creek near Olympia, Washington (station 12080500), in the Woodard Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period January 5 through 15, 1990.

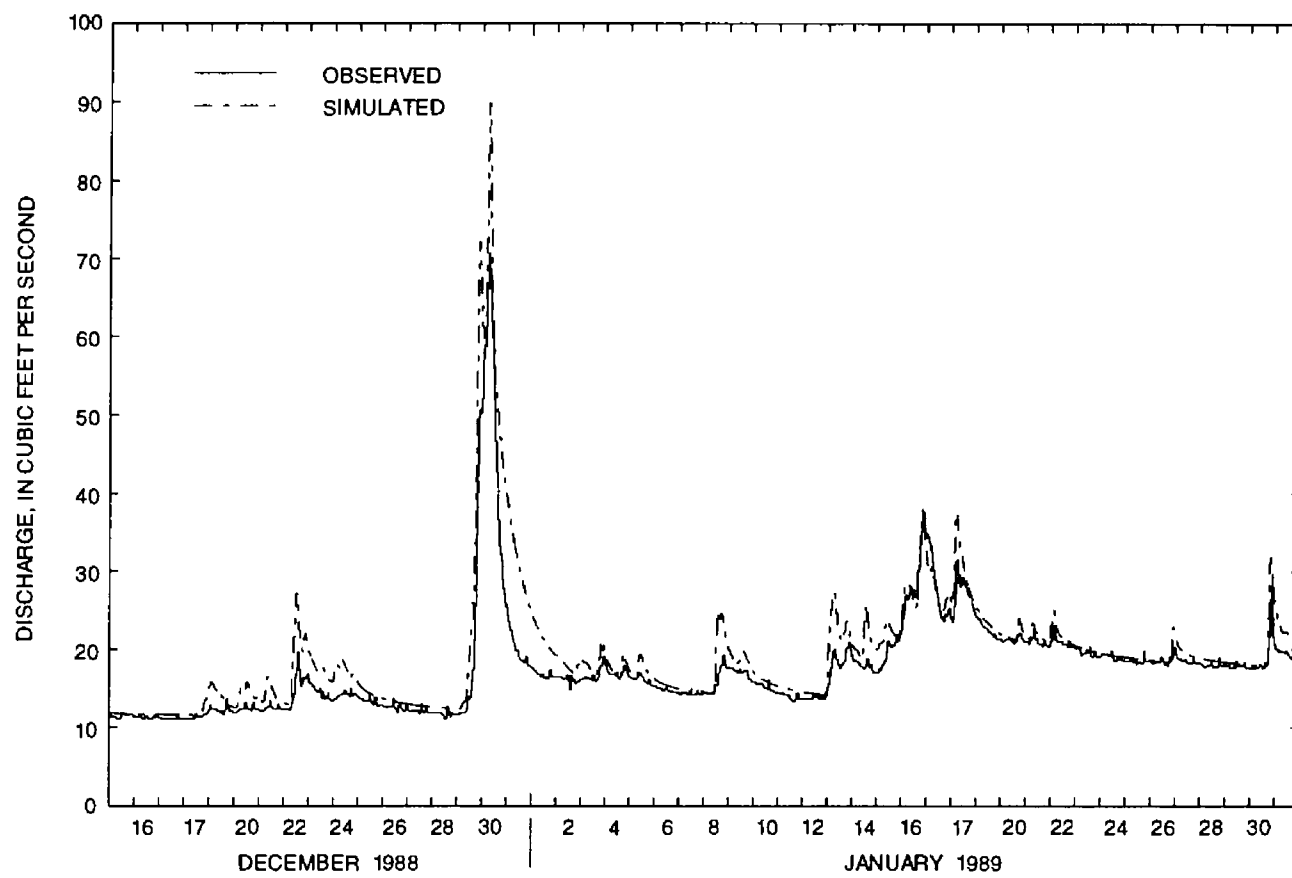




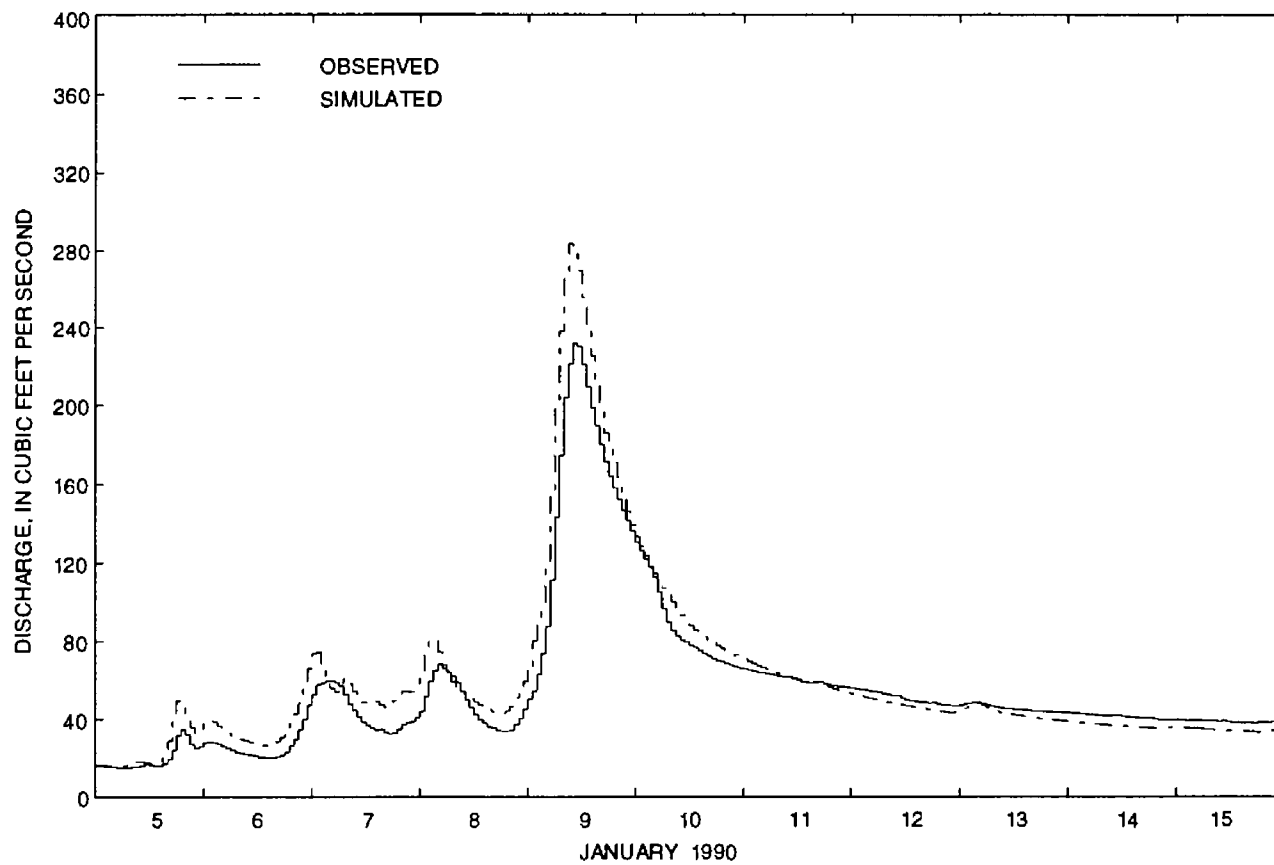
**Figure 35.**--Observed and simulated hourly mean discharges for Woodland Creek at Martin Way at Lacey, Washington (station 12080670), in the Woodland Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period April 1 through 10, 1988.



**Figure 36.**--Observed and simulated hourly mean discharges for Woodland Creek at Martin Way at Lacey, Washington (station 12080670), in the Woodland Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period March 1, 1989, through April 30, 1989.



**Figure 37.**--Observed and simulated hourly mean discharges for Woodland Creek near Olympia, Washington (station 12081000), in the Woodland Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period December 15, 1988, through January 31, 1989.



**Figure 38.**--Observed and simulated hourly mean discharges for Woodland Creek near Olympia, Washington (station 12081000), in the Woodland Creek Basin. Simulated discharges are from the final calibrated model applied to the storm period January 5 through 15, 1990.

**Table 16.--Observed and simulated storm runoff and peak discharge data of Woodland Creek, Woodard Creek, and Percival Creek for the final calibrated models**

[Obs., observed value; Sim., simulated value; Diff., difference: simulated-observed; Percent diff., percent difference: 100 x [(simulated-observed)/observed], in percent]

Station number <sup>1</sup>	Date of storm	Date of peak	Storm runoff, in inches <sup>2</sup>				Peak discharge, in cubic feet per second <sup>3</sup>			
			Obs. (in.)	Sim. (in.)	Diff. (in.)	Percent diff.	Obs. (in.)	Sim. (in.)	Diff. (in.)	Percent diff.
12078720	3/25-28/88	3/26/88	2.28	2.59	-0.31	-13.6	97.3	105.7	8.4	8.6
	4/5-8/88	4/6/88	2.86	2.70	-.16	-5.6	123.1	113.7	-9.4	-7.6
	12/29/88-1/1/89	12/30/88	2.11	2.41	.30	14.2	102.0	119.9	17.9	17.5
	1/16-20/89	1/18/89	3.44	3.35	-.09	-2.6	115.0	104.2	-10.8	-9.4
	3/12-19/89	3/16/89	4.68	4.94	.26	5.6	91.0	94.1	3.1	3.4
	12/3-7/89	12/4/89	3.24	3.42	.18	5.6	130.0	117.9	-12.1	-9.3
	1/9-10/90	1/9/90	2.76	3.15	.39	14.1	<sup>4</sup> 239.9	241.6	1.7	.7
	1/28-30/90	1/29/90	2.55	2.90	.35	13.7	142.5	157.6	15.1	10.6
	2/9-14/90	2/11/90	6.51	6.70	.19	2.9	<sup>4</sup> 175.8	177.0	1.2	.7
	2/20-23/90	2/20/90	3.28	3.45	.17	5.2	135.0	135.0	.0	.0
12078730	3/23-27/88	3/26/88	1.57	1.54	-.03	-1.9	44.0	32.8	-11.2	-25.5
	4/5-7/88	4/6/88	1.25	1.27	.02	1.6	<sup>4</sup> 48.7	45.7	-3.0	-6.2
	12/29-31/88	12/30/88	1.43	1.39	-.04	-2.8	<sup>4</sup> 55.9	62.9	7.0	12.5
	1/14-19/89	1/16/89	2.30	2.00	-.30	-13.0	41.0	31.7	-9.3	-22.7
	12/4-5/89	12/4/89	1.16	1.09	-.07	-6.0	<sup>4</sup> 62.2	48.3	-13.9	-22.3
	1/9-10/90	1/9/90	2.26	2.00	-.26	-11.5	<sup>4</sup> 141.6	103.7	-37.9	-26.8
	1/27-30/90	1/28/90	2.04	2.14	.10	4.9	59.3	78.5	19.2	32.4
	2/9-12/90	2/10/90	2.56	2.51	-.05	-2.0	<sup>4</sup> 57.7	50.5	-7.2	-12.5
	2/20-22/90	2/20/90	1.34	1.47	.13	9.7	47.4	44.9	-2.5	-5.3
12080500	3/23-27/88	3/26/88	.88	.78	-.10	-11.4	28.1	26.4	-1.7	-6.0
	4/5-7/88	4/6/88	.65	.60	-.05	-7.7	33.5	33.1	-.4	-1.2
	12/29/88-1/1/89	12/30/88	.67	.73	.06	9.0	34.5	37.0	2.5	7.2
	12/2-6/89	12/5/89	.88	.78	-.10	-11.4	34.0	32.9	-1.1	-3.2
	1/9-11/90	1/10/90	1.38	1.61	.23	16.7	64.4	68.2	3.8	5.9
	1/27-30/90	1/29/90	.96	.94	-.02	-2.1	36.3	37.0	.7	1.9
	2/9-12/90	2/10/90	1.21	.99	-.22	-18.2	43.0	34.7	-8.3	-19.3
	2/20-22/90	2/21/90	.78	.64	-.14	-17.9	35.7	28.9	-6.8	-19.0
12080670	4/5-7/88	4/6/88	.07	.08	.01	14.3	15.5	15.1	-.4	-2.6
	4/1-8/89	4/2/89	.31	.31	.00	.0	16.4	17.3	.9	5.5
	1/8-10/90	1/9/90	.10	.09	-.01	-10.0	25.6	26.5	.9	3.5
	2/9-12/90	2/11/90	.31	.31	.00	.0	33.6	36.3	2.7	8.0
	2/20-21/90	2/20/90	.16	.16	.00	.0	31.1	31.9	.8	2.6
12081000	3/23-28/88	3/26/88	.28	.31	.03	10.7	72.6	67.4	-5.2	-7.2
	4/5-8/88	4/6/88	.26	.27	.01	3.8	84.8	84.2	-.6	-.7
	12/29/88-1/1/89	12/30/88	.16	.21	.05	31.2	71.2	90.6	19.4	27.2
	12/4-6/89	12/4/89	.17	.20	.03	17.6	99.3	85.5	-13.8	-13.9
	1/9-10/90	1/9/90	.37	.44	.07	18.9	233.6	288.2	54.6	23.4
	1/28-30/90	1/28/90	.28	.31	.03	10.7	100.5	110.4	9.9	9.8
	2/9-12/90	2/10/90	.48	.47	-.01	-2.1	118.0	111.5	-6.5	-5.5
	2/20-22/90	2/20/90	.30	.31	.01	3.3	85.3	85.3	.0	.0

<sup>1</sup> Station names for the displayed station numbers are in table 7.

<sup>2</sup> Storm runoff data are the total streamflow volumes for the time period of each storm.

<sup>3</sup> Peak discharge data are the maximum instantaneous discharges for each storm.

<sup>4</sup> Observed peak discharge data are mean hourly discharges during periods of extreme surge at a stream-gaging station.

models were applied outside of a calibration period. Refinements to the basin models during final calibration were based on observed information during the 2-year calibration period. However, most of these refinements were not designed to explicitly simulate many hydrologic processes, such as the routing of runoff along actual flow paths to reaches or the actual movement and storage of water in aquifers. These refinements were designed only to simulate the amount of runoff contributions to streamflow. Although the 2-year calibration period included a variety of hydrologic conditions, ranging from the low streamflows present in the summer of 1988 to the high streamflows present in the winter of 1990, all possible sequences and magnitudes of flow conditions cannot be present in a calibration period of only 2 years. Because many hydrologic processes could not be explicitly simulated, streamflow simulations for hydrologic conditions not represented in the calibration period may indicate that further model refinements will be necessary.

## SUMMARY

The U.S. Geological Survey and the Thurston County Department of Public Works conducted a cooperative study to conceptualize and simulate the generation of runoff from rainfall in three complex drainage basins in north-central Thurston County, located at the southern end of the Puget Sound Lowland of western Washington. These drainage basins--Percival Creek, Woodard Creek, and Woodland Creek--face urban development that will modify hydrologic processes and affect runoff characteristics. These basins are complex because the basin properties (such as geology, soils, topography, land cover, and climate) that influence runoff characteristics vary from one part of each basin to another. A hydrologic-simulation program can represent how basin properties affect the hydrologic processes involved in runoff generation from rainfall. Once calibrated to existing conditions, a hydrologic-simulation program can be a helpful tool to assess how urban development may affect runoff characteristics. Hydrological Simulation Program-FORTRAN (HSPF) was the program used to construct basin models for the simulation of runoff generation in these basins. Streamflow data collected at five streamflow-gaging stations over a 2-year period from March 1988 to March 1990 were used for model calibration.

From a description of the physical properties of the study area, a conceptual model was derived that linked the physical properties to associated drainage mechanisms and hydrologic processes. These links were formalized in seven conceptual features about runoff generation. The

features, obtained from a previous study of rainfall-runoff relations in headwater basins of King and Snohomish Counties, about 60 miles northeast of Thurston County, were modified to account for shallow soils underlain by bedrock or fine-grained lacustrine deposits in the study area that were not found in the King and Snohomish County basins.

The conceptual features differentiated the drainage mechanisms of runoff in undisturbed and disturbed areas of the study basins. The main runoff mechanisms of undisturbed areas were identified as shallow subsurface flow from hillslopes mantled with glacial till, bedrock, and, to a lesser degree, lacustrine deposits; as groundwater flow from glacial-outwash deposits; and as saturation overland flow from depressions, stream bottoms, and flat upland areas underlain by glacial till or, less so, lacustrine deposits. Although Hortonian overland flow was not an important mechanism in undisturbed areas, it was the dominant mechanism in disturbed impervious areas, primarily urban areas. In pervious disturbed areas, Hortonian overland flow also was a viable mechanism in combination with some of the other mechanisms. The study also noted that surface detention and retention storage, interception, and plant transpiration were less characteristic of disturbed areas than of undisturbed areas.

From the conceptual model of the Thurston County basins, a simulation model for each of the three basins, called a basin model, was constructed. The basin models, based on Hydrological Simulation Program-FORTRAN (HSPF), were numerical approximations capable of confirming the features of the conceptual model if they produced accurate simulations. Construction of the basin models involved three phases: division of each study basin into land-segment types, subbasins, and stream reaches.

In the first phase, each study basin was divided into as many as 17 land-segment types (16 types that describe pervious areas on the basis of soil types, land cover, and slope; and 1 type that describes impervious areas). Numerical values were assigned to process-related parameters of each of the 17 land-segment types. Initial parameter values were the same as those from a previous study (Dinicola, 1990) for 10 land-segment types that also had appeared in King and Snohomish County headwater basins, but parameter values were estimated for the other 7 land-segment types not present in the basins of the earlier study. In the second phase of model construction, each basin was divided into subbasins. Initially, all subbasins, except closed basins, were designed so that all overland flow, shallow subsurface flow, and ground-water flow

generated in those basins discharged to the reaches and through the mouths of the originating subbasins. Similarly, all closed subbasins discharged their ground-water flow to the nearest reach draining a downhill subbasin. Finally, in the last phase of model construction, the drainage network was divided into reaches with uniform hydraulic characteristics that drained and connected subbasins. To represent the hydraulic characteristics of each reach, volume-discharge relations were defined in F-tables of each model and used for routing streamflow through the basins.

The basin models, initially constructed using the same general approach and parameter values as those determined by Dinicola (1990), did not adequately simulate observed streamflows. Therefore, the simulation models required calibration and further evaluation.

The basin models were calibrated to observed streamflows at five gaging stations for two purposes: to minimize the differences between the simulated and the observed streamflows and more generally to evaluate the adequacy of the conceptual model of runoff generation. When the models were calibrated to a little over 1 year (March 1988 through March 1989) and evaluated to a second year (March 1989 through March 1990) of observed streamflows, refinements were needed (1) to the process-related parameter, KVAR (active ground-water outflow modifier), (2) to the number of subbasins, (3) to the surface- and ground-water contributions to stream reaches, and (4) to the volume-discharge relations of stream reaches.

Differences between observed and simulated streamflows commonly increased when the models were evaluated with a second year of observed streamflow data. Absolute differences between observed and simulated runoff volumes for the first calibration ranged from 1.7 to 12.8 percent and, for evaluation, from 1.6 to 25.1 percent at five gaging stations. The mean absolute differences between observed and simulated daily mean discharges ranged between 13.2 and 36.5 percent for the first calibration and between 13.7 and 79.1 percent for evaluation. Absolute differences between storm runoff volumes ranged from 1.6 to 50.0 percent and from 0.0 to 50.0 percent for the first calibration and evaluation respectively. Finally, absolute differences between peak discharges ranged between 4.1 and 25.5 percent for the first calibration and between 0.3 and 107.0 percent for evaluation.

The evaluation results indicated that the models needed to improve simulations of (1) ground-water contributions in one drainage basin, (2) low flows in two basins,

and (3) high flows after large storms in all three basins. Simulation results from both calibration and evaluation indicated that the conceptual model--represented in the basin models by parameter values assigned to land-segment types--adequately described the generation of runoff from the land-segment types in the three basins. The conceptual model, however, did not adequately describe the routing of ground-water flow, shallow subsurface flow, and overland flow along flow paths from land segments to stream reaches. Model shortcomings indicated that calibration to only 1 year of streamflow data was not adequate for satisfactory streamflow simulations. Thus, the basin models were calibrated to both years of observed streamflow data during final calibration.

In final calibration of the models, which used both years of observed streamflows (March 1988 through March 1990), further refinements were made to the process-related parameter KVAR for one basin, the number of subbasins, the surface- and ground-water contributions to reaches, and the volume-discharge relations of certain reaches. In addition, a ground-water controller was constructed for the Woodland Creek Basin model to improve the timing and magnitude of ground-water contributions to streamflow. Final calibration did improve simulations. For the entire 2-year period, absolute differences between observed and simulated streamflow values were less than 6 percent for total runoff volumes, equal to or less than an average of 32 percent for daily mean discharges, less than 32 percent for storm runoff volumes, and less than 33 percent for peak discharges.

The successful streamflow simulations from the final calibrated models confirmed that the conceptual model of runoff generation in the study area was applicable to the basins in Thurston County. The results also demonstrated that, except for KVAR, the process-related parameters obtained from an earlier rainfall-runoff investigation in another part of the Puget Sound Lowland (Dinicola, 1990) applied as well to Thurston County basins. The values of KVAR, though, needed to be refined because areas in Thurston County underlain by aquifers responded differently to rainfall than did areas in the King and Snohomish County that originally determined this parameter value. This parameter, thus, is likely to vary elsewhere in the Puget Sound Lowland.

The conceptual model represented runoff generation from land segments in the three Thurston County basins fairly well. The conceptual model, however, did not adequately represent the flow paths from land segments to stream reaches when all ground-water flow, shallow subsurface flow, and overland flow generated in a subbasin

did not contribute to streamflow in that same subbasin. During calibration, it was necessary to adjust the initial ground-water, shallow subsurface, and overland flow contributions to reaches. Calibration indicated that the initial guideline that all rain falling on a subbasin either evapotranspires or discharges out the surface-water outlet of that same subbasin was an inadequate assumption for many subbasins. Sometimes rainfall recharged to inactive ground water, and at other times it discharged to reaches in other subbasins. Finally, during calibration, the volume--discharge relations in the F-tables needed adjustment to adequately simulate channel-bottom seepage and the magnitude and timing of peak flows.

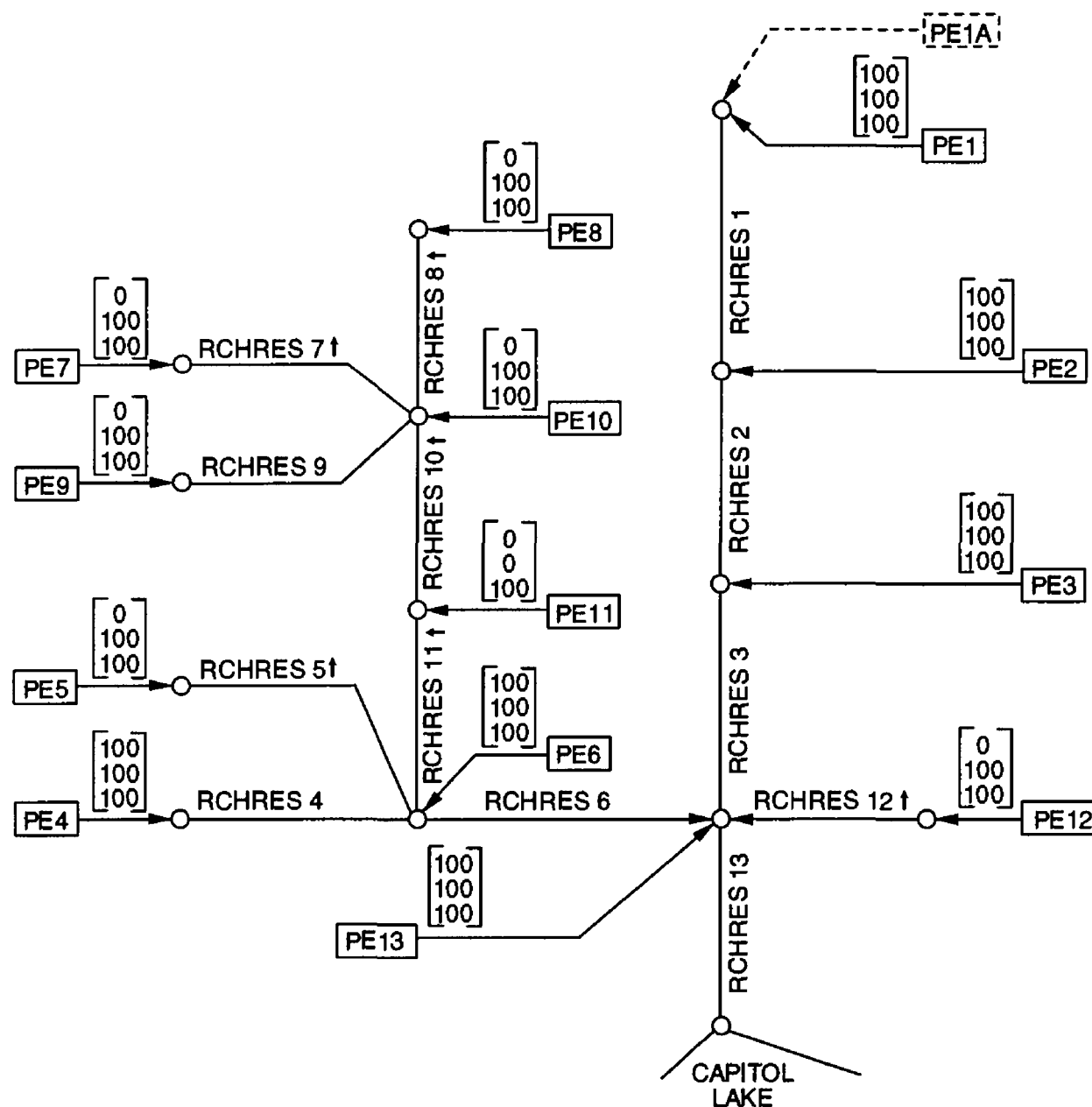
Because the conceptual model did not adequately describe flow paths from land segments to stream reaches, it was necessary to obtain extensive streamflow data and field information to obtain satisfactory streamflow simulations. Additionally, it was necessary to calibrate the basin models to 2 years of streamflow data to obtain satisfactory streamflow simulation. It is uncertain if streamflow simulations will be as accurate as those presented in this report for hydrologic conditions not represented in the calibration period because many hydrologic processes could not be explicitly simulated by the basin models.

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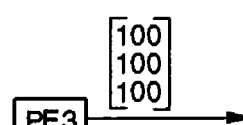
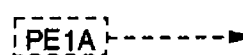

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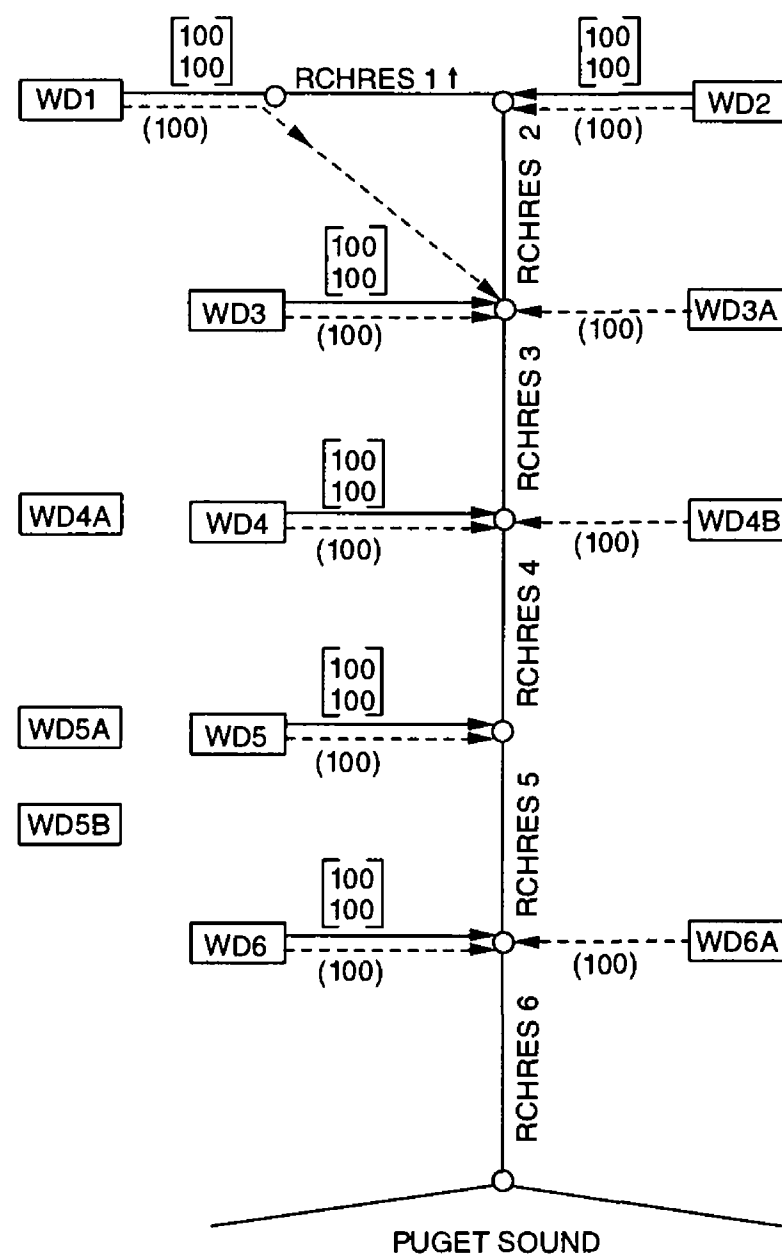
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#### EXPLANATION

-  Percival Creek subbasin prefix and number. Solid arrow indicates ground-water, shallow subsurface, and overland flow contributions to a stream reach from pervious and impervious areas within the specified subbasin. Ground-water flow (top number in brackets), shallow subsurface flow (middle number), and overland flow (bottom number) are expressed as percentages of the total flow generated that contribute to a stream reach.
-  Dummy subbasin prefix and number. Dashed arrow indicates ground-water flow contributions to a stream reach.
-  Stream reach and number. Presence of arrow indicates losing reach.

**Figure 39.--**A diagram of the hydraulic linkages between subbasins and stream reaches for the final calibrated model for Percival Creek Basin.



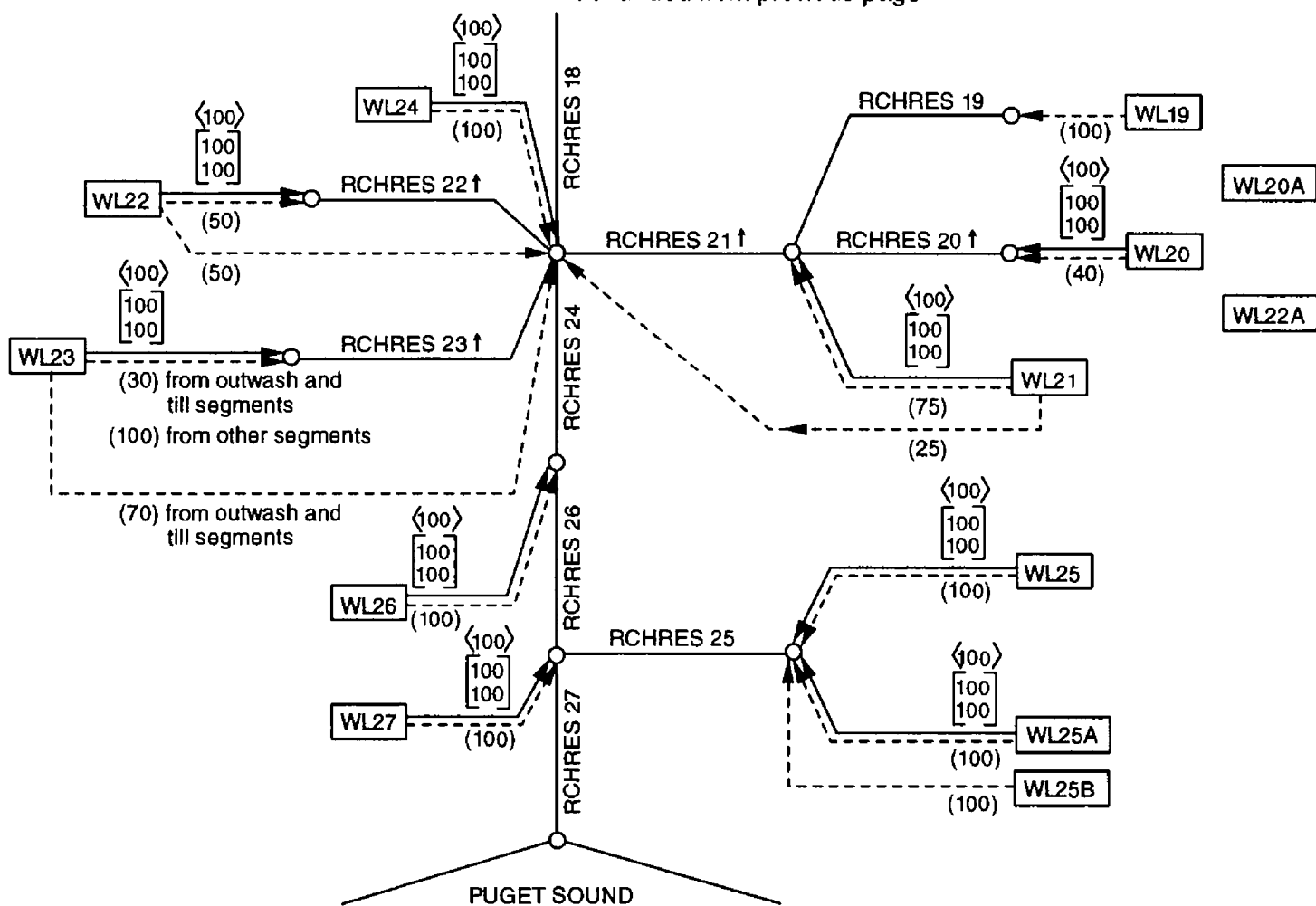
#### EXPLANATION

<span style="border: 1px solid black; padding: 2px;">WD4A</span>	Woodard Creek subbasin prefix and number; closed subbasin that does not contribute any flow to stream reaches in Woodard Creek Basin.
<span style="border: 1px solid black; padding: 2px;">WD3A</span> <span style="display: inline-block; width: 20px; border-bottom: 1px dashed black; position: relative; top: -5px;"> <span style="position: absolute; right: -5px; top: -5px;">▶</span> </span>	Ground-water flow (dashed arrow) from the specified subbasin that contributes to a stream reach. Number in parentheses is the contribution of ground-water flow, expressed as a percentage of the total ground-water flow generated in a subbasin.
<span style="border: 1px solid black; padding: 2px;">WD3</span> <span style="display: inline-block; width: 20px; border-bottom: 1px dashed black; position: relative; top: -5px;"> <span style="position: absolute; right: -5px; top: -5px;">▶</span> </span>	Solid arrow indicates shallow subsurface and overland flow that contributes to a stream reach from pervious and impervious areas within the specified subbasin. Top brackets indicate contributions of shallow subsurface flow (top number) and overland flow (bottom number), expressed as percentages of the total flow of that type generated in a subbasin. Dashed arrow and number in bottom parentheses indicate ground-water flow, as indicated above.
<span style="display: inline-block; width: 20px; border-bottom: 1px solid black; position: relative; top: -5px;"> <span style="position: absolute; right: -5px; top: -5px;">▶</span> </span> RCHRES 1 ↑	Stream reach and number. Presence of arrow indicates losing reach.

**Figure 40.**--A diagram of the hydraulic linkages between subbasins and stream reaches for the final calibrated model for Woodard Creek Basin.



Continued from previous page



**EXPLANATION**

- |  |       |  |
|--|-------|--|
| <div style="border: 1px solid black; padding: 2px; display: inline-block;">WL7</div>   |       | Woodland Creek subbasin prefix and number; closed subbasin that does not contribute any flow to stream reaches in Woodland Creek Basin.  |
| <div style="border: 1px solid black; padding: 2px; display: inline-block;">WL13A</div> <span style="font-size: 2em; vertical-align: middle;">---</span> <span style="font-size: 1.5em; vertical-align: middle;">→</span> | (100) | Ground-water flow (dashed arrow) from the specified subbasin that contributes to a stream reach. Number in parentheses is the contribution of ground-water flow, expressed as a percentage of the total ground-water flow generated in a subbasin. |
| <div style="border: 1px solid black; padding: 2px; display: inline-block;">WL24</div> <span style="font-size: 2em; vertical-align: middle;">—</span> <span style="font-size: 1.5em; vertical-align: middle;">→</span>    |       | Shallow subsurface and overland flow (solid arrow) that contribute to a stream from pervious and impervious areas within the specified subbasin.   |
| <div style="border: 1px solid black; padding: 2px; display: inline-block; text-align: center;">100<br/>100</div>   |       | Contribution of shallow subsurface flow (top number) and overland flow (bottom number), each expressed as a percentage of the total flow of that type generated in a subbasin.   |
| <span style="font-size: 1.5em;">{</span> 100 <span style="font-size: 1.5em;">}</span>  |       | Percentage of effective impervious area in a subbasin that generates overland flow that contributes to a stream reach.   |
| <div style="display: inline-block; text-align: center;">○ — RCHRES 12↑ — ○</div>   |       | Stream reach and number. Presence of arrow indicates losing reach.   |
| <div style="display: inline-block; text-align: center;">○ - - - - - ○</div>  |       | Ground-water controller.   |

**Figure 41.--Continued.**

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)

---

```

RUN
GLOBAL
    ***                                     ***
    *** Contains information which applies to every operation in the ***
    ***   model run.                                     ***
    ***                                     ***

    PERCIVAL CREEK BASIN 2ND YR CALIBRATION: 3/1/88 - 3/15/90
    START      1988/03/01 00:00   END      1990/03/15 24:00
    RUN INTERP OUTPUT LEVEL      0
    RESUME     0 RUN      1 TSSFL      0 WDMSFL      16
END GLOBAL
OPN SEQUENCE
    ***                                     ***
    *** Specifies the operations to be performed in the model run. ***
    ***                                     ***

    INGRP              INDELT  0:15
    PERLND      21
    PERLND      23
    PERLND      45
    PERLND      47
    PERLND      49
    PERLND      51
    PERLND      53
    PERLND      55
    PERLND      93
    IMPLND      95
    RCHRES       1
    RCHRES       2
    RCHRES       3
    RCHRES       4
    RCHRES       5
    RCHRES       7
    RCHRES       8
    RCHRES       9
    RCHRES      10
    RCHRES      11
    RCHRES       6
    RCHRES      12
    RCHRES      13
    DISPLY       1
    DISPLY       2
    DISPLY       3
    DISPLY       4
    DISPLY       5
    DISPLY       6
    DISPLY       7
    DISPLY       8
    DISPLY       9
    DISPLY      10
    DISPLY      11
    DISPLY      12
    DISPLY      13
    DISPLY      14
    DISPLY      15

```



**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

END INGRP
END OPN SEQUENCE
PERLND
***
*** Simulates the hydrology of the pervious land segments.
***
GEN-INFO
***
*** Assigns a land segment name to each PERLND number.
***
<PLS >      Name      NBLKS  Unit-systems  Printer      ***
# - #              User  t-series  Engl Metr      ***
                        in  out      ***
21      OF              1      1      1      1      6      0
23      OG              1      1      1      1      6      0
45      TF MILD         1      1      1      1      6      0
47      TF MODERATE     1      1      1      1      6      0
49      TF STEEP        1      1      1      1      6      0
51      TG MILD         1      1      1      1      6      0
53      TG MODERATE     1      1      1      1      6      0
55      TG STEEP        1      1      1      1      6      0
93      SATURATED       1      1      1      1      6      0
END GEN-INFO
ACTIVITY
<PLS > ***** Active Sections *****
# - # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC      ***
21  93   0   0   1   0   0   0   0   0   0   0   0   0   0
END ACTIVITY
PRINT-INFO
<PLS > ***** Print-flags ***** PIVL  PYR
# - # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC *****
21  93   0   0   6   0   0   0   0   0   0   0   0   0   1   9
END PRINT-INFO
PWAT-PARM1
<PLS > ***** Flags *****
# - # CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE      ***
21  93   0   0   0   0   0   0   0   0   0   0
END PWAT-PARM1
PWAT-PARM2
***
*** Assigns values to the following process-related parameters.
***
<PLS > ***
# - # ***FOREST      LZSN      INFILT      LSUR      SLSUR      KVARV      AGWRC
21      5.0000      2.0000      400.00      0.0500      0.3000      0.9960
23      5.0000      0.8000      400.00      0.0500      0.3000      0.9960
45      4.5000      0.0800      400.00      0.0500      0.5000      0.9960
47      4.5000      0.0800      400.00      0.1000      0.5000      0.9960
49      4.5000      0.0800      200.00      0.2000      0.5000      0.9960
51      4.5000      0.0300      400.00      0.0500      0.5000      0.9960
53      4.5000      0.0300      400.00      0.1000      0.5000      0.9960
55      4.5000      0.0300      200.00      0.2000      0.5000      0.9960
93      4.0000      2.0000      100.00      0.0010      0.5000      0.9960
END PWAT-PARM2

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

PWAT-PARM3

```

***                                     ***
*** Assigns values to the following process-related parameters. ***
***                                     ***

```

<PLS >\*\*\*

# -	****	PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
21				2.0000	2.0000	.00	0.	0.
23				2.0000	2.0000	.00	0.	0.
45				3.5000	2.0000	.00	0.	0.
47				2.0000	2.0000	.00	0.	0.
49				1.5000	2.0000	.00	0.	0.
51				3.5000	2.0000	.00	0.	0.
53				2.0000	2.0000	.00	0.	0.
55				1.5000	2.0000	.00	0.	0.
93				10.000	2.0000	.00	0.	0.7

END PWAT-PARM3

PWAT-PARM4

```

***                                     ***
*** Assigns values to the following process-related parameters. ***
***                                     ***

```

<PLS >

# -	#	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP***
21		0.2000	0.5000	0.3500	0.0000	0.7000	0.7000
23		0.1000	0.5000	0.2500	0.0000	0.7000	0.2500
45		0.2000	1.0000	0.3500	3.0000	0.7000	0.7000
47		0.2000	0.5000	0.3500	6.0000	0.5000	0.7000
49		0.2000	0.3000	0.3500	7.0000	0.3000	0.7000
51		0.1000	0.5000	0.2500	3.0000	0.7000	0.2500
53		0.1000	0.2500	0.2500	6.0000	0.5000	0.2500
55		0.1000	0.1500	0.2500	7.0000	0.3000	0.2500
93		0.1000	3.0000	0.5000	1.0000	0.7000	0.8000

END PWAT-PARM4

PWAT-STATE1

```

***                                     ***
*** Assigns initial values to various storages. Values were ***
*** determined from an initial model run for the period ***
*** October 1, 1987 through February 28, 1988. AGWS (active ***
*** ground-water storage) was adjusted during calibration. ***
***                                     ***

```

<PLS > PWATER state variables\*\*\*

# -	****	CEPS	SURS	UZS	IFWS	LZS	AGWS	GWVS
21		0.03	0.	0.1210	0.	8.064	12.508	2.480
23		0.03	0.	0.3010	0.	8.235	12.895	2.535
45		0.03	0.	1.7540	0.	7.141	8.235	2.019
47		0.03	0.	0.8210	0.	7.238	8.437	2.155
49		0.03	0.	0.4440	0.	7.255	8.223	2.185
51		0.03	0.	0.7890	0.	6.766	7.270	1.431
53		0.03	0.	0.3100	0.	6.871	7.560	1.649
55		0.03	0.	0.1340	0.	6.892	7.355	1.703
93		0.03	0.	3.7030	0.	6.616	7.290	1.848

END PWAT-STATE1

END PERLND

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

IMPLND
  ***
  *** Simulates the hydrology of the impervious land segment.
  ***
GEN-INFO
  ***
  *** Assigns a land segment name to the IMPLND number.
  ***
  <ILS >      Name              Unit-systems  Printer
  # - #              User  t-series Engl Metr
                        in  out
95      IMPERVIOUS          1    1    1    6    0
END GEN-INFO
ACTIVITY
  <ILS > ***** Active Sections *****
  # - # ATMP SNOW IWAT  SLD  IWG IQAL  ***
95      0    0    1    0    0    0
END ACTIVITY
PRINT-INFO
  <ILS > ***** Print-flags ***** PIVL  PYR
  # - # ATMP SNOW IWAT  SLD  IWG IQAL *****
95      0    0    6    0    0    0    1    9
END PRINT-INFO
IWAT-PARM1
  <ILS >      Flags
  # - # CSNO RTOP  VRS  VNN RTLI
95      0    0    0    0    0
END IWAT-PARM1
IWAT-PARM2
  ***
  *** Assigns values to the following process-related parameters.
  ***
  <ILS >
  # - #      LSUR      SLSUR      NSUR      RETSC
95      500.00      0.0500      0.1000      0.1000
END IWAT-PARM2
IWAT-PARM3
  <ILS >
  # - #      PETMAX      PETMIN
95
END IWAT-PARM3
IWAT-STATE1
  <ILS >  IWATER state variables
  # - #      RETS      SURS
95      1.0000E-3 1.0000E-3
END IWAT-STATE1
END IMPLND

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

EXT SOURCES

```

***
*** Specifies the time series which are input to the operations ***
*** from external WDM files. ***
***
*** NOTE: The only RCHRES that precip and PET are applied to are ***
*** lakes. ***
***

```

<-Volume->	<Member>	SsysSgap<--Mult-->	Tran	<-Target vols>	<-Grp>	<-Member->	***
<Name>	#	<Name>	#	tem strg<-factor->	strg	<Name>	# #
WDM	4	PRCP	ENGL	PERLND	21	EXTNL	PREC
WDM	4	PRCP	ENGL	PERLND	23	EXTNL	PREC
WDM	4	PRCP	ENGL	PERLND	45	EXTNL	PREC
WDM	4	PRCP	ENGL	PERLND	47	EXTNL	PREC
WDM	4	PRCP	ENGL	PERLND	49	EXTNL	PREC
WDM	4	PRCP	ENGL	PERLND	51	EXTNL	PREC
WDM	4	PRCP	ENGL	PERLND	53	EXTNL	PREC
WDM	4	PRCP	ENGL	PERLND	55	EXTNL	PREC
WDM	4	PRCP	ENGL	PERLND	93	EXTNL	PREC
WDM	4	PRCP	ENGL	IMPLND	95	EXTNL	PREC
WDM	6	EVAP	ENGL	PERLND	21 93	EXTNL	PETINP
WDM	6	EVAP	ENGL	IMPLND	95	EXTNL	PETINP
WDM	4	PRCP	ENGL	RCHRES	1	EXTNL	PREC
WDM	4	PRCP	ENGL	RCHRES	5	EXTNL	PREC
WDM	4	PRCP	ENGL	RCHRES	7	EXTNL	PREC
WDM	6	EVAP	ENGL	RCHRES	1	EXTNL	POTEV
WDM	6	EVAP	ENGL	RCHRES	5	EXTNL	POTEV
WDM	6	EVAP	ENGL	RCHRES	7	EXTNL	POTEV
WDM	4	PRCP	ENGL	DISPLY	1	INPUT	TIMSER
WDM	6	EVAP	ENGL	DISPLY	2	INPUT	TIMSER
WDM	1	FLOW	ENGL	.020661SAME	RCHRES	4	EXTNL

```

***
*** Note: The above MULTFACTOR converts cubic feet per second ***
*** to acre-feet per 15 minutes. The MULTFACTORS below ***
*** convert cubic feet per second to inches of runoff per ***
*** 15 minutes. ***
***

```

WDM	1	FLOW	ENGL	DISPLY	3	INPUT	TIMSER
WDM	2	FLOW	ENGL	DISPLY	4	INPUT	TIMSER
WDM	2	FLOW	ENGL	DISPLY	5	INPUT	TIMSER
WDM	2	FLOW	ENGL	.000076	DISPLY	6	INPUT
WDM	3	FLOW	ENGL	DISPLY	7	INPUT	TIMSER
WDM	3	FLOW	ENGL	DISPLY	8	INPUT	TIMSER
WDM	3	FLOW	ENGL	.000170	DISPLY	9	INPUT

END EXT SOURCES

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

EXT TARGETS

```

***
*** Specifies the time series which are output from operations
*** to external WDM files.
*** Note: MULTFACTOR 48.4 converts acre-feet of runoff per
*** 15-minute interval to cubic feet per second.
***
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Tgap Amd ***
<Name> # <Name> # #<-factor->strg <Name> # <Name> tem strg strg***
RCHRES 3 HYDR ROVOL 48.4SAME WDM 8 SFLO ENGL REPL
RCHRES 6 HYDR ROVOL 48.4SAME WDM 7 SFLO ENGL REPL
END EXT TARGETS

```

NETWORK

```

***
*** Specifies the time series which are passed between
*** operations.
***
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name> # <Name> # #<-factor->strg <Name> # # <Name> # # ***
***
*** The following linkages pass total outflow (PERO),
*** ground-water flow (AGWO), subsurface flow (IFWO), or
*** overland flow (SURO) to assigned stream reaches (RCHRES).
***
*** Note: MULTFACTORS for converting inches to acre/feet =
*** area (in acres)/12
***
*** SUB-BASIN PE1A ***
*** DUMMY BASIN: GROUND-WATER FLOW (AGWO) ORIGINATING FROM ***
*** OUTSIDE BASIN BOUNDARY DISCHARGES TO REACH 1 ***
PERLND 21 PWATER AGWO 15.000 RCHRES 1 EXTNL IVOL
***
*** SUB-BASIN PE1 ***
PERLND 21 PWATER PERO 6.653 RCHRES 1 EXTNL IVOL
PERLND 23 PWATER PERO 11.284 RCHRES 1 EXTNL IVOL
PERLND 93 PWATER PERO 3.560 RCHRES 1 EXTNL IVOL
IMPLND 95 IWATER SURO 3.090 RCHRES 1 EXTNL IVOL
***
*** SUB-BASIN PE2 ***
PERLND 21 PWATER PERO 11.733 RCHRES 2 EXTNL IVOL
PERLND 23 PWATER PERO 6.559 RCHRES 2 EXTNL IVOL
PERLND 45 PWATER PERO 0.692 RCHRES 2 EXTNL IVOL
PERLND 47 PWATER PERO 0.102 RCHRES 2 EXTNL IVOL
PERLND 49 PWATER PERO 23.214 RCHRES 2 EXTNL IVOL
PERLND 51 PWATER PERO 0.035 RCHRES 2 EXTNL IVOL
PERLND 53 PWATER PERO 0.323 RCHRES 2 EXTNL IVOL
PERLND 55 PWATER PERO 2.496 RCHRES 2 EXTNL IVOL
PERLND 93 PWATER PERO 12.466 RCHRES 2 EXTNL IVOL
IMPLND 95 IWATER SURO 3.168 RCHRES 2 EXTNL IVOL

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN PE3 ***
PERLND  21  PWATER  PERO          11.432    RCHRES    3    EXTNL  IVOL
PERLND  23  PWATER  PERO           7.832    RCHRES    3    EXTNL  IVOL
PERLND  45  PWATER  PERO           4.368    RCHRES    3    EXTNL  IVOL
PERLND  47  PWATER  PERO           0.121    RCHRES    3    EXTNL  IVOL
PERLND  49  PWATER  PERO           4.791    RCHRES    3    EXTNL  IVOL
PERLND  51  PWATER  PERO           0.548    RCHRES    3    EXTNL  IVOL
PERLND  53  PWATER  PERO           0.077    RCHRES    3    EXTNL  IVOL
PERLND  55  PWATER  PERO           0.769    RCHRES    3    EXTNL  IVOL
PERLND  93  PWATER  PERO           2.064    RCHRES    3    EXTNL  IVOL
IMPLND  95  IWATER  SURO           2.648    RCHRES    3    EXTNL  IVOL
***
*** SUB-BASIN PE4 ***
PERLND  21  PWATER  PERO          11.248    RCHRES    4    EXTNL  IVOL
PERLND  23  PWATER  PERO           6.622    RCHRES    4    EXTNL  IVOL
PERLND  45  PWATER  PERO           3.032    RCHRES    4    EXTNL  IVOL
PERLND  47  PWATER  PERO          18.052    RCHRES    4    EXTNL  IVOL
PERLND  49  PWATER  PERO          30.712    RCHRES    4    EXTNL  IVOL
PERLND  51  PWATER  PERO           1.234    RCHRES    4    EXTNL  IVOL
PERLND  53  PWATER  PERO           1.184    RCHRES    4    EXTNL  IVOL
PERLND  55  PWATER  PERO           1.794    RCHRES    4    EXTNL  IVOL
PERLND  93  PWATER  PERO          16.682    RCHRES    4    EXTNL  IVOL
IMPLND  95  IWATER  SURO           3.724    RCHRES    4    EXTNL  IVOL
***
*** SUB-BASIN PE5 ***
*** NO GROUND-WATER FLOW (AGWO) DISCHARGES TO REACH 5 ***
PERLND  21  PWATER  SURO           1.148    RCHRES    5    EXTNL  IVOL
PERLND  23  PWATER  SURO           0.916    RCHRES    5    EXTNL  IVOL
PERLND  45  PWATER  SURO           9.592    RCHRES    5    EXTNL  IVOL
PERLND  47  PWATER  SURO          16.788    RCHRES    5    EXTNL  IVOL
PERLND  49  PWATER  SURO          11.790    RCHRES    5    EXTNL  IVOL
PERLND  51  PWATER  SURO           5.868    RCHRES    5    EXTNL  IVOL
PERLND  53  PWATER  SURO           8.060    RCHRES    5    EXTNL  IVOL
PERLND  55  PWATER  SURO           0.601    RCHRES    5    EXTNL  IVOL
PERLND  93  PWATER  SURO           0.028    RCHRES    5    EXTNL  IVOL
PERLND  21  PWATER  IFWO           1.148    RCHRES    5    EXTNL  IVOL
PERLND  23  PWATER  IFWO           0.916    RCHRES    5    EXTNL  IVOL
PERLND  45  PWATER  IFWO           9.592    RCHRES    5    EXTNL  IVOL
PERLND  47  PWATER  IFWO          16.788    RCHRES    5    EXTNL  IVOL
PERLND  49  PWATER  IFWO          11.790    RCHRES    5    EXTNL  IVOL
PERLND  51  PWATER  IFWO           5.868    RCHRES    5    EXTNL  IVOL
PERLND  53  PWATER  IFWO           8.060    RCHRES    5    EXTNL  IVOL
PERLND  55  PWATER  IFWO           0.602    RCHRES    5    EXTNL  IVOL
PERLND  93  PWATER  IFWO           0.028    RCHRES    5    EXTNL  IVOL
PERLND  21  PWATER  AGWO           1.148    INACTIVE  GROUND WATER ***
PERLND  23  PWATER  AGWO           0.916    INACTIVE  GROUND WATER ***
PERLND  45  PWATER  AGWO           9.592    INACTIVE  GROUND WATER ***
PERLND  47  PWATER  AGWO          16.788    INACTIVE  GROUND WATER ***
PERLND  49  PWATER  AGWO          11.790    INACTIVE  GROUND WATER ***
PERLND  51  PWATER  AGWO           5.868    INACTIVE  GROUND WATER ***
PERLND  53  PWATER  AGWO           8.060    INACTIVE  GROUND WATER ***
PERLND  55  PWATER  AGWO           0.602    INACTIVE  GROUND WATER ***
PERLND  93  PWATER  AGWO           0.028    INACTIVE  GROUND WATER ***
IMPLND  95  IWATER  SURO           4.696    RCHRES    5    EXTNL  IVOL

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN PE7 ***
*** NO GROUND-WATER FLOW (AGWO) DISCHARGES TO REACH 7 ***
PERLND 21 PWATER SURO      1.571    RCHRES  7    EXTNL  IVOL
PERLND 23 PWATER SURO      0.308    RCHRES  7    EXTNL  IVOL
PERLND 45 PWATER SURO     13.943    RCHRES  7    EXTNL  IVOL
PERLND 47 PWATER SURO     18.388    RCHRES  7    EXTNL  IVOL
PERLND 49 PWATER SURO      0.054    RCHRES  7    EXTNL  IVOL
PERLND 51 PWATER SURO      2.386    RCHRES  7    EXTNL  IVOL
PERLND 53 PWATER SURO      7.939    RCHRES  7    EXTNL  IVOL
PERLND 55 PWATER SURO      0.774    RCHRES  7    EXTNL  IVOL
PERLND 93 PWATER SURO      0.539    RCHRES  7    EXTNL  IVOL
PERLND 21 PWATER IFWO      1.571    RCHRES  7    EXTNL  IVOL
PERLND 23 PWATER IFWO      0.308    RCHRES  7    EXTNL  IVOL
PERLND 45 PWATER IFWO     13.943    RCHRES  7    EXTNL  IVOL
PERLND 47 PWATER IFWO     18.388    RCHRES  7    EXTNL  IVOL
PERLND 49 PWATER IFWO      0.054    RCHRES  7    EXTNL  IVOL
PERLND 51 PWATER IFWO      2.386    RCHRES  7    EXTNL  IVOL
PERLND 53 PWATER IFWO      7.939    RCHRES  7    EXTNL  IVOL
PERLND 55 PWATER IFWO      0.774    RCHRES  7    EXTNL  IVOL
PERLND 93 PWATER IFWO      0.539    RCHRES  7    EXTNL  IVOL
PERLND 21 PWATER AGWO      1.571    INACTIVE GROUND WATER ***
PERLND 23 PWATER AGWO      0.308    INACTIVE GROUND WATER ***
PERLND 45 PWATER AGWO     13.943    INACTIVE GROUND WATER ***
PERLND 47 PWATER AGWO     18.388    INACTIVE GROUND WATER ***
PERLND 49 PWATER AGWO      0.054    INACTIVE GROUND WATER ***
PERLND 51 PWATER AGWO      2.386    INACTIVE GROUND WATER ***
PERLND 53 PWATER AGWO      7.939    INACTIVE GROUND WATER ***
PERLND 55 PWATER AGWO      0.774    INACTIVE GROUND WATER ***
PERLND 93 PWATER AGWO      0.539    INACTIVE GROUND WATER ***
IMPLND 95 IWATER SURO      3.769    RCHRES  7    EXTNL  IVOL
***
*** SUB-BASIN PE8 ***
*** NO GROUND-WATER FLOW (AGWO) DISCHARGES TO REACH 8 ***
PERLND 21 PWATER SURO      0.026    RCHRES  8    EXTNL  IVOL
PERLND 45 PWATER SURO      1.960    RCHRES  8    EXTNL  IVOL
PERLND 47 PWATER SURO      7.310    RCHRES  8    EXTNL  IVOL
PERLND 51 PWATER SURO      1.525    RCHRES  8    EXTNL  IVOL
PERLND 53 PWATER SURO      4.588    RCHRES  8    EXTNL  IVOL
PERLND 93 PWATER SURO      0.868    RCHRES  8    EXTNL  IVOL
PERLND 21 PWATER IFWO      0.026    RCHRES  8    EXTNL  IVOL
PERLND 45 PWATER IFWO      1.960    RCHRES  8    EXTNL  IVOL
PERLND 47 PWATER IFWO      7.310    RCHRES  8    EXTNL  IVOL
PERLND 51 PWATER IFWO      1.525    RCHRES  8    EXTNL  IVOL
PERLND 53 PWATER IFWO      4.588    RCHRES  8    EXTNL  IVOL
PERLND 93 PWATER IFWO      0.868    RCHRES  8    EXTNL  IVOL
PERLND 21 PWATER AGWO      0.026    INACTIVE GROUND WATER ***
PERLND 45 PWATER AGWO      1.960    INACTIVE GROUND WATER ***
PERLND 47 PWATER AGWO      7.310    INACTIVE GROUND WATER ***
PERLND 51 PWATER AGWO      1.525    INACTIVE GROUND WATER ***
PERLND 53 PWATER AGWO      4.588    INACTIVE GROUND WATER ***
PERLND 93 PWATER AGWO      0.868    INACTIVE GROUND WATER ***
IMPLND 95 IWATER SURO      4.028    RCHRES  8    EXTNL  IVOL
***

```



**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN PE9 ***
*** NO GROUND-WATER FLOW DISCHARGES TO REACH 9 ***
PERLND  21  PWATER  SURO           0.092    RCHRES   9      EXTNL  IVOL
PERLND  23  PWATER  SURO           0.041    RCHRES   9      EXTNL  IVOL
PERLND  45  PWATER  SURO           0.447    RCHRES   9      EXTNL  IVOL
PERLND  47  PWATER  SURO           1.537    RCHRES   9      EXTNL  IVOL
PERLND  51  PWATER  SURO           0.409    RCHRES   9      EXTNL  IVOL
PERLND  53  PWATER  SURO           1.031    RCHRES   9      EXTNL  IVOL
PERLND  93  PWATER  SURO           0.302    RCHRES   9      EXTNL  IVOL
PERLND  21  PWATER  IFWO           0.092    RCHRES   9      EXTNL  IVOL
PERLND  23  PWATER  IFWO           0.041    RCHRES   9      EXTNL  IVOL
PERLND  45  PWATER  IFWO           0.447    RCHRES   9      EXTNL  IVOL
PERLND  47  PWATER  IFWO           1.537    RCHRES   9      EXTNL  IVOL
PERLND  51  PWATER  IFWO           0.409    RCHRES   9      EXTNL  IVOL
PERLND  53  PWATER  IFWO           1.031    RCHRES   9      EXTNL  IVOL
PERLND  93  PWATER  IFWO           0.302    RCHRES   9      EXTNL  IVOL
PERLND  21  PWATER  AGWO           0.092    INACTIVE  GROUND WATER ***
PERLND  23  PWATER  AGWO           0.041    INACTIVE  GROUND WATER ***
PERLND  45  PWATER  AGWO           0.447    INACTIVE  GROUND WATER ***
PERLND  47  PWATER  AGWO           1.537    INACTIVE  GROUND WATER ***
PERLND  51  PWATER  AGWO           0.409    INACTIVE  GROUND WATER ***
PERLND  53  PWATER  AGWO           1.031    INACTIVE  GROUND WATER ***
PERLND  93  PWATER  AGWO           0.302    INACTIVE  GROUND WATER ***
IMPLND  95  IWATER  SURO           5.893    RCHRES   9      EXTNL  IVOL
***
*** SUB-BASIN PE10 ***
*** NO GROUND-WATER FLOW (AGWO) DISCHARGES TO REACH 10 ***
PERLND  45  PWATER  SURO           0.017    RCHRES  10      EXTNL  IVOL
PERLND  51  PWATER  SURO           1.208    RCHRES  10      EXTNL  IVOL
PERLND  45  PWATER  IFWO           0.017    RCHRES  10      EXTNL  IVOL
PERLND  51  PWATER  IFWO           1.208    RCHRES  10      EXTNL  IVOL
PERLND  45  PWATER  AGWO           0.017    INACTIVE  GROUND WATER ***
PERLND  51  PWATER  AGWO           1.208    INACTIVE  GROUND WATER ***

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN PE11 ***
*** NO GROUND-WATER FLOW (AGWO) DISCHARGES TO REACH 11 ***
*** NO SHALLOW SUBSURFACE FLOW (IFWO) DISCHARGES TO REACH 11 ***
*** MAN-MADE DITCH SYSTEM ***
PERLND  21  PWATER  SURO          2.556    RCHRES  11    EXTNL  IVOL
PERLND  23  PWATER  SURO          0.701    RCHRES  11    EXTNL  IVOL
PERLND  45  PWATER  SURO          1.230    RCHRES  11    EXTNL  IVOL
PERLND  47  PWATER  SURO          4.428    RCHRES  11    EXTNL  IVOL
PERLND  49  PWATER  SURO          0.151    RCHRES  11    EXTNL  IVOL
PERLND  51  PWATER  SURO          1.485    RCHRES  11    EXTNL  IVOL
PERLND  53  PWATER  SURO          1.884    RCHRES  11    EXTNL  IVOL
PERLND  55  PWATER  SURO          0.059    RCHRES  11    EXTNL  IVOL
PERLND  21  PWATER  IFWO          2.556    RECHARGES INACTIVE GROUND WATER ***
PERLND  23  PWATER  IFWO          0.701    RECHARGES INACTIVE GROUND WATER ***
PERLND  45  PWATER  IFWO          1.230    RECHARGES INACTIVE GROUND WATER ***
PERLND  47  PWATER  IFWO          4.428    RECHARGES INACTIVE GROUND WATER ***
PERLND  49  PWATER  IFWO          0.151    RECHARGES INACTIVE GROUND WATER ***
PERLND  51  PWATER  IFWO          1.485    RECHARGES INACTIVE GROUND WATER ***
PERLND  53  PWATER  IFWO          1.884    RECHARGES INACTIVE GROUND WATER ***
PERLND  55  PWATER  IFWO          0.059    RECHARGES INACTIVE GROUND WATER ***
PERLND  21  PWATER  AGWO          2.556    INACTIVE GROUND WATER ***
PERLND  23  PWATER  AGWO          0.701    INACTIVE GROUND WATER ***
PERLND  45  PWATER  AGWO          1.230    INACTIVE GROUND WATER ***
PERLND  47  PWATER  AGWO          4.428    INACTIVE GROUND WATER ***
PERLND  49  PWATER  AGWO          0.151    INACTIVE GROUND WATER ***
PERLND  51  PWATER  AGWO          1.485    INACTIVE GROUND WATER ***
PERLND  53  PWATER  AGWO          1.884    INACTIVE GROUND WATER ***
PERLND  55  PWATER  AGWO          0.059    INACTIVE GROUND WATER ***
IMPLND  95  IWATER  SURO          7.218    RCHRES  11    EXTNL  IVOL
***
*** SUB-BASIN PE6 ***
PERLND  21  PWATER  PERO          4.730    RCHRES   6    EXTNL  IVOL
PERLND  23  PWATER  PERO          2.283    RCHRES   6    EXTNL  IVOL
PERLND  45  PWATER  PERO          0.108    RCHRES   6    EXTNL  IVOL
PERLND  47  PWATER  PERO          0.824    RCHRES   6    EXTNL  IVOL
PERLND  49  PWATER  PERO          0.090    RCHRES   6    EXTNL  IVOL
PERLND  51  PWATER  PERO          0.005    RCHRES   6    EXTNL  IVOL
PERLND  53  PWATER  PERO          0.768    RCHRES   6    EXTNL  IVOL
PERLND  93  PWATER  PERO          4.535    RCHRES   6    EXTNL  IVOL
IMPLND  95  IWATER  SURO          1.662    RCHRES   6    EXTNL  IVOL

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN PE12 ***
*** NO GROUND-WATER FLOW (AGWO) DISCHARGES TO REACH 12 ***
PERLND  21  PWATER  SURO           0.288    RCHRES  12    EXTNL  IVOL
PERLND  23  PWATER  SURO           0.472    RCHRES  12    EXTNL  IVOL
PERLND  45  PWATER  SURO           2.853    RCHRES  12    EXTNL  IVOL
PERLND  47  PWATER  SURO           1.937    RCHRES  12    EXTNL  IVOL
PERLND  49  PWATER  SURO           0.143    RCHRES  12    EXTNL  IVOL
PERLND  51  PWATER  SURO           0.656    RCHRES  12    EXTNL  IVOL
PERLND  53  PWATER  SURO           2.502    RCHRES  12    EXTNL  IVOL
PERLND  21  PWATER  IFWO           0.288    RCHRES  12    EXTNL  IVOL
PERLND  23  PWATER  IFWO           0.472    RCHRES  12    EXTNL  IVOL
PERLND  45  PWATER  IFWO           2.853    RCHRES  12    EXTNL  IVOL
PERLND  47  PWATER  IFWO           1.937    RCHRES  12    EXTNL  IVOL
PERLND  49  PWATER  IFWO           0.143    RCHRES  12    EXTNL  IVOL
PERLND  51  PWATER  IFWO           0.656    RCHRES  12    EXTNL  IVOL
PERLND  53  PWATER  IFWO           2.502    RCHRES  12    EXTNL  IVOL
PERLND  21  PWATER  AGWO           0.288    INACTIVE GROUND WATER ***
PERLND  23  PWATER  AGWO           0.472    INACTIVE GROUND WATER ***
PERLND  45  PWATER  AGWO           2.853    INACTIVE GROUND WATER ***
PERLND  47  PWATER  AGWO           1.937    INACTIVE GROUND WATER ***
PERLND  49  PWATER  AGWO           0.143    INACTIVE GROUND WATER ***
PERLND  51  PWATER  AGWO           0.656    INACTIVE GROUND WATER ***
PERLND  53  PWATER  AGWO           2.502    INACTIVE GROUND WATER ***
IMPLND  95  IWATER  SURO           3.218    RCHRES  12    EXTNL  IVOL
***
*** SUB-BASIN PE13 ***
PERLND  21  PWATER  PERO           4.611    RCHRES  13    EXTNL  IVOL
PERLND  23  PWATER  PERO           3.007    RCHRES  13    EXTNL  IVOL
PERLND  45  PWATER  PERO           5.312    RCHRES  13    EXTNL  IVOL
PERLND  47  PWATER  PERO           6.512    RCHRES  13    EXTNL  IVOL
PERLND  49  PWATER  PERO           7.519    RCHRES  13    EXTNL  IVOL
PERLND  51  PWATER  PERO           1.112    RCHRES  13    EXTNL  IVOL
PERLND  53  PWATER  PERO           1.402    RCHRES  13    EXTNL  IVOL
PERLND  55  PWATER  PERO           0.332    RCHRES  13    EXTNL  IVOL
PERLND  93  PWATER  PERO           1.165    RCHRES  13    EXTNL  IVOL
IMPLND  95  IWATER  SURO           5.195    RCHRES  13    EXTNL  IVOL

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** CHANNEL NETWORK LINKAGES ***
***
*** The following linkages pass streamflow from one stream reach ***
*** (RCHRES) to another stream reach. ***
***
RCHRES  1 HYDR  ROVOL  1          RCHRES  2      EXTNL  IVOL
RCHRES  2 HYDR  ROVOL  1          RCHRES  3      EXTNL  IVOL
RCHRES  4 HYDR  ROVOL  1          RCHRES  6      EXTNL  IVOL
RCHRES  5 HYDR  OVOL   1 1        RCHRES  6      EXTNL  IVOL
RCHRES  7 HYDR  OVOL   1 1        RCHRES 10      EXTNL  IVOL
RCHRES  8 HYDR  OVOL   1 1        RCHRES 10      EXTNL  IVOL
RCHRES  9 HYDR  ROVOL  1          RCHRES 10      EXTNL  IVOL
RCHRES 10 HYDR  OVOL   1 1        RCHRES 11      EXTNL  IVOL
RCHRES 11 HYDR  OVOL   1 1        RCHRES  6      EXTNL  IVOL
RCHRES  6 HYDR  ROVOL  1          RCHRES 13      EXTNL  IVOL
RCHRES 12 HYDR  OVOL   1 1        RCHRES 13      EXTNL  IVOL
RCHRES  3 HYDR  ROVOL  1          RCHRES 13      EXTNL  IVOL
***
*** The following linkages pass streamflow time series to tables ***
*** for display. ***
***
*** Note: MULTFACTOR 48.4 converts acre-feet of runoff to ***
*** average cubic feet per second per 15 minute interval. ***
*** It is timestep dependent. The other MFACTORS convert ***
*** acre-feet of runoff to inches of runoff per 15 minutes. ***
***
RCHRES  6 HYDR  ROVOL  1          48.4  DISPLY 10      INPUT  TIMSER 1
RCHRES  6 HYDR  ROVOL  1          48.4  DISPLY 11      INPUT  TIMSER 1
RCHRES  6 HYDR  ROVOL  1          0.00368 DISPLY 12      INPUT  TIMSER 1
RCHRES  3 HYDR  ROVOL  1          48.4  DISPLY 13      INPUT  TIMSER 1
RCHRES  3 HYDR  ROVOL  1          48.4  DISPLY 14      INPUT  TIMSER 1
RCHRES  3 HYDR  ROVOL  1          0.00822 DISPLY 15      INPUT  TIMSER 1
****
END NETWORK

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

RCHRES
***
*** Simulates streamflows in stream reaches (RCHRES)
***

GEN-INFO
RCHRES      Name      Nexits   Unit Systems   Printer      ***
# - #<-----><----> User T-series  Engr Metr LKFG  ***
                        in out
1    TROSPER LAKE    PE1     1     1     1     1     6     0     0
2    MID-PERCIVAL    PE2     1     1     1     1     6     0     0
3    PERCY (12078730) PE3     1     1     1     1     6     0     0
4    BK LK DT BLW OUT PE4     1     1     1     1     6     0     0
5    SIMMONS LK      PE5     2     1     1     1     6     0     0
7    GRASS LAKE      PE7     2     1     1     1     6     0     0
8    W OLY DT-CUL    PE8     2     1     1     1     6     0     0
9    CAPITOL MALL    PE9     1     1     1     1     6     0     0
10   YAUGER PARK     PE10    2     1     1     1     6     0     0
11   W OLY OUTLET    PE11    2     1     1     1     6     0     0
6    BLD (12078720)  PE6     1     1     1     1     6     0     0
12   AUTO MALL      PE12    2     1     1     1     6     0     0
13   LOW PERCIVAL    PE13    1     1     1     1     6     0     0
END GEN-INFO

ACTIVITY
RCHRES ***** Active Sections *****
# - # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG      ***
1  13  1  0  0  0  0  0  0  0  0  0  0
END ACTIVITY

PRINT-INFO
RCHRES ***** Printout Flags ***** PIVL  PYR
# - # HYDR ADCA CONS HEAT  SED  GOL OXRX NUTR PLNK PHCB *****
1  13  6  0  0  0  0  0  0  0  0  0  1  9
END PRINT-INFO

HYDR-PARM1
RCHRES  Flags for each HYDR Section      ***
# - # VC A1 A2 A3  ODFVFG for each *** ODGTFG for each  FUNCT for each
      FG FG FG FG  possible exit *** possible exit  possible exit
      * * * * * * * * * * * * * * * * *
1      0 1 0 0    4 0 0 0 0    0 0 0 0 0    2 2 2 2 2
2      0 0 0 0    4 0 0 0 0    0 0 0 0 0    2 2 2 2 2
4      0 0 0 0    4 0 0 0 0    0 0 0 0 0    2 2 2 2 2
5      0 1 0 0    4 5 0 0 0    0 0 0 0 0    2 2 2 2 2
7      0 1 0 0    4 5 0 0 0    0 0 0 0 0    2 2 2 2 2
8      0 0 0 0    4 5 0 0 0    0 0 0 0 0    2 2 2 2 2
9      0 0 0 0    4 0 0 0 0    0 0 0 0 0    2 2 2 2 2
10     0 0 0 0    4 5 0 0 0    0 0 0 0 0    2 2 2 2 2
6      0 0 0 0    4 0 0 0 0    0 0 0 0 0    2 2 2 2 2
12     0 0 0 0    4 5 0 0 0    0 0 0 0 0    2 2 2 2 2
13     0 0 0 0    4 0 0 0 0    0 0 0 0 0    2 2 2 2 2
END HYDR-PARM1

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

HYDR-PARM2

```

***
*** Assigns an F-table number to each reach.  Supplies the length ***
*** of the reach and a weighting factor for hydraulic routing. ***
***

```

RCHRES		FTABNO	LEN	DELTH	STCOR	KS	DB50	***
#	-	#						***
1		1	0.184			0.5		***
2		2	0.883			0.5		
3		3	1.184			0.5		
4		4	1.033			0.5		
5		5	0.410			0.5		
7		7	1.311			0.5		
8		8	1.484			0.5		
9		9	1.588			0.5		
10		10	0.316			0.5		
11		11	0.889			0.5		
6		6	0.872			0.5		
12		12	0.096			0.5		
13		13	1.436			0.5		

END HYDR-PARM2

HYDR-INIT

```

***
*** Initial conditions for each HYDR section.
***

```

RCHRES		VOL	Initial value of COLIND	Initial value of OUTDGT
#	-	*** ac-ft	for each possible exit	for each possible exit
1		200.000	4.0	
2		0.280	4.0	
3		0.560	4.0	
4		2.680	4.0	
5		200.900	4.0	5.0
7		25.000	4.0	5.0
8		0.000	4.0	5.0
9		0.000	4.0	
10		0.000	4.0	5.0
11		2.000	4.0	5.0
6		1.690	4.0	
12		0.300	4.0	5.0
13		1.840	4.0	

END HYDR-INIT

END RCHRES

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

FTABLES

```

***
*** The following function tables (F-tables) portray
*** relationships between volume and outflow and in some
*** cases area (for lakes) for the defined channel reaches.
*** The columns for volume and outflow are used for routing
*** streamflow from reach to reach. For reaches that
*** represent streams, only the volume-outflow
*** relationship is considered for routing streamflow. The
*** area column is used for the application of precipitation
*** and PET to lakes. Outflow1 is the streamflow routed
*** from one reach to another reach, and other outflows
*** represent either channel losses from seepage or flow that
** leaves the reach through another outlet.
***

```

FTABLE 1

```

*** Drains subbasin PE1. This reach consists of Trosper Lake.
***

```

Rows Cols

6 4

Depth (ft)	Area (acres)	Volume (acre-ft)	Outflow1 (cfs)
0.0	0.0	0.0	0.0
14.0	19.0	170.0	0.0
15.0	19.0	189.0	0.0
16.0	19.0	210.0	7.0
18.0	19.0	250.0	30.0
20.0	19.0	325.0	50.0

END FTABLE 1

FTABLE 2

```

*** Drains subbasin PE2

```

Rows Cols (PE2)

8 4

Depth (ft)	Area (acres)	Volume (acre-ft)	Outflow1 (cfs)
0.0	0.0	0.0	0.0
0.5	0.0	0.32	5.0
1.0	0.0	4.0	20.0
1.6	0.0	10.0	35.0
2.0	0.0	24.55	47.0
3.0	0.0	62.0	90.0
5.0	0.0	172.0	200.0
6.0	0.0	272.0	300.0

END FTABLE 2



**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      3
*** Drains subbasin PE3.  Gaging station 12078730 (Percival ***
*** Creek near Olympia) is located in the lower portion of the ***
*** reach. ***
Rows Cols
7      4
Depth      Area      Volume  Outflow1
(ft)      (acres)  (acre-ft)  (cfs)
0.0      0.0      0.0      0.0
0.5      0.0      0.65     7.0
0.7      0.0      1.00     16.0
0.8      0.0      1.50     30.0
1.0      0.0      3.32     66.0
1.50     0.0      11.00    180.0
3.20     0.0      40.00    960.0
END FTABLE  3
FTABLE      4
*** Drains subbasin PE4.  Streamflow entering the reach is from ***
*** one of the two outlets of Black Lake and is measured at ***
*** gaging station 12078705 (Black Lake Ditch at lake outlet ***
*** near Tumwater, WA). ***
Rows Cols      (PE4)
9      4
Depth      Area      Volume  Outflow1
(ft)      (acres)  (acre-ft)  (cfs)
0.0      0.0      0.0      0.0
1.0      0.0      1.63     10.0
1.8      0.0      3.13     30.0
2.5      0.0      7.32     50.0
3.0      0.0      24.8     65.0
3.5      0.0      52.3     80.0
5.0      0.0      157.3    170.0
6.8      0.0      285.7    350.0
10.0     0.0      350.0    665.0
END FTABLE  4
FTABLE      5
*** Drains subbasin PE5.  The reach consists of Simmons Lake and ***
*** the channel system in PE5.  Outflow2 represents channel and ***
*** lake losses by seepage. ***
Rows Cols
11     5
Depth      Area      Volume  Outflow1  Outflow2
(ft)      (acres)  (acre-ft)  (cfs)    (cfs)
0.0      0.0      0.0      0.0      0.0
10.0     26.0     175.0    0.0      0.0
10.5     26.0     187.0    0.0      0.0
11.0     26.0     200.0    0.4      0.0
11.2     26.0     208.0    2.0      1.0
11.5     26.0     215.0    4.0      4.0
11.7     26.0     235.0    8.0      6.0
12.0     26.0     275.0    12.0     8.0
12.5     26.0     300.0    25.0     12.0
13.0     26.0     325.0    39.0     16.0
13.5     26.0     350.0    55.0     16.0
END FTABLE  5

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      7
*** Drains subbasin PE7.  The reach consists of a small wetland ***
*** lake (Grass Lake) that has two outlets.  Flows from the ***
*** outlet to the downstream modeled reach are restricted by a ***
*** blocked culvert.  Backwater conditions and a poorly ***
*** defined channel result in seasonal wetland conditions. ***
*** Outflow2 represents reach losses through the second outlet ***
*** and channel seepage. ***

Rows Cols
8      5
Depth      Area      Volume  Outflow1  Outflow2
(ft)      (acres)  (acre-ft)  (cfs)    (cfs)
0.0      0.0      0.0      0.0      0.0
1.0      2.21     7.5      0.0      1.0
2.0      2.21     30.0     0.0      1.5
3.0      2.21     65.0     0.5      2.0
4.0      2.21     107.5    0.75     4.0
5.0      2.21     155.0    1.0      8.0
6.0      2.21     207.5    1.0     14.0
7.0      2.21     265.0    1.0     24.0

END FTABLE  7
FTABLE      8
*** Drains subbasin PE8.  Outflow2 represents reach losses by ***
*** channel seepage. ***

Rows Cols
7      5
Depth      Area      Volume  Outflow1  Outflow2
(ft)      (acres)  (acre-ft)  (cfs)    (cfs)
0.0      0.0      0.0      0.0      0.0
0.5      0.0      0.2      0.0      0.5
1.0      0.0      0.65     5.0      1.0
1.7      0.0      2.50     10.0     3.0
2.3      0.0      5.50     15.0     6.0
3.0      0.0      9.75     20.0     9.0
3.5      0.0     16.7     25.0    12.0

END FTABLE  8
FTABLE      9
*** Drains subbasin PE9.  The reach consists of storm sewers. ***

Rows Cols
12      4
Depth      Area      Volume  Outflow1
(ft)      (acres)  (acre-ft)  (cfs)
0.0      0.0      0.0      0.0
0.2      0.0      0.10     0.0
0.46     0.0      0.14     2.48
0.98     0.0      0.22     10.5
1.47     0.0      0.31     19.0
1.96     0.0      0.42     25.5
2.42     0.0      0.50     29.5
2.80     0.0      0.65     33.0
2.90     0.0      0.70     33.5
2.98     0.0      0.80     34.0
3.12     0.0      1.30     35.5
3.30     0.0      1.70     36.0

END FTABLE  9

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      10
*** Drains subbasin PE10.  The reach consists of a park that ***
***   detains and infiltrates stormwater.  Regulation at the ***
***   outlet (culvert) occurs intermittently.  Outflow2 ***
***   represents reach losses by seepage ***
Rows Cols
7      5
Depth      Area      Volume  Outflow1  Outflow2
(ft)      (acres)  (acre-ft)  (cfs)    (cfs)
0.0        0.0        0.0        0.0      0.0
1.7        0.0        14.0        0.0      1.0
4.5        0.0        17.9        15.0     2.0
6.5        0.0        35.7        25.0     4.0
7.4        0.0        53.6        30.0     4.0
8.2        0.0        71.5        35.0     4.0
8.7        0.0        82.5        50.0     4.0
END FTABLE 10
FTABLE      11
*** Drains subbasin PE11.  The reach is a man-made ditch system ***
***   with stormwater facilities that detain and infiltrate ***
***   water.  Outflow2 represents reach losses by seepage. ***
Rows Cols
5      5
Depth      Area      Volume  Outflow1  Outflow2
(ft)      (acres)  (acre-ft)  (cfs)    (cfs)
0.0        0.0        0.0        0.0      0.0
2.0        0.0        2.28        0.0      0.5
3.0        0.0        5.18        5.0      1.0
4.0        0.0       13.18       24.0     7.0
5.0        0.0       29.18       50.0    15.0
END FTABLE 11
FTABLE      6
*** Drains subbasin PE6.  Gaging station 12078720 (Black Lake ***
***   Ditch near Olympia, WA) located at lower end. ***
Rows Cols
6      4
Depth      Area      Volume  Outflow1
(ft)      (acres)  (acre-ft)  (cfs)
0.0        0.0        0.0        0.0
0.5        0.0        0.55        5.0
1.0        0.0        1.37       20.0
1.5        0.0        2.96       45.0
3.0        0.0        8.19      225.0
9.0        0.0       70.29     1900.0
END FTABLE 6

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      12
  *** Drains subbasin PE12.  The reach is a large detention pond  ***
  *** that can detain and infiltrate water and the channel system ***
  *** that drains PE12.  Outflow2 represents reach losses by      ***
  *** by seepage.                                                ***

Rows Cols
14      5
  Depth      Area      Volume  Outflow1  Outflow2
  (ft)      (acres)  (acre-ft)  (cfs)    (cfs)
  0.0      0.0      0.0      0.0      0.0
  2.0      0.0      0.03     0.0      0.1
  6.0      0.0      0.61     0.0      0.3
  6.5      0.0      0.74     1.0      0.5
  6.7      0.0      0.80     2.0      0.7
  6.9      0.0      0.85     3.0      1.0
  7.2      0.0      0.94     5.0      1.0
  7.5      0.0      1.02     7.0      1.0
  7.9      0.0      1.15    10.0      1.0
  8.4      0.0      1.34    14.0      1.0
  8.7      0.0      1.43    16.0      1.0
  9.0      0.0      1.54    17.7      1.0
 12.0      0.0      2.75    29.7      1.0
 17.0      0.0      5.79    40.2      1.0
END FTABLE 12
FTABLE      13
  *** Drains subbasin PE13.                                     ***

Rows Cols
5        4
  Depth      Area      Volume  Outflow1
  (ft)      (acres)  (acre-ft)  (cfs)
  0.0      0.0      0.0      0.0
  0.5      0.0      0.61     5.0
  1.5      0.0      2.09    35.0
  3.0      0.0      7.31   130.0
 10.0      0.0     50.0  2500.0
END FTABLE 13
END FTABLES

```

**Table 17.**--Input sequence of the Percival Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

DISPLY

\*\*\*

\*\*\*

\*\*\* Displays time series on output.

\*\*\*

\*\*\*

\*\*\*

DISPLY-INFO1

#thru#\*\*\*<-----Title----->

<-short-span->

\*\*\*

<---disply--->

<annual summary ->

\*\*\*

		TRAN	PIVL	DIG1	FIL1	PYR	DIG2	FIL2	YRND
1	DOT PRECIP (IN)	SUM	0	2	6	1	2	6	9
2	PET (IN)	SUM	0	2	6	1	2	6	9
3	BLK LK DT OTLT: OBS (CFS)	AVER	0	2	6	1	2	6	9
4	BK LK DT MTMN: OBS (CFS)	AVER	0	2	6	1	2	6	9
5	BK LK D MTMN:OBS MX (CFS)	MAX	0	2	6	1	2	6	9
6	BK LK DT MTMN: OBS (IN)	SUM	0	2	6	1	2	6	9
7	PERCY MTMN: OBS (CFS)	AVER	0	2	6	1	2	6	9
8	PERCY MTMN: OBS MAX (CFS)	MAX	0	2	6	1	2	6	9
9	PERCY MTMN: OBS (IN)	SUM	0	2	6	1	2	6	9
10	BLK LK DT MTMN-SIM (CFS)	AVER	0	2	6	1	2	6	9
11	BK LK D MTMN:SIM MX (CFS)	MAX	0	2	6	1	2	6	9
12	BK LK DT @ MTMN SIM (IN)	SUM	0	2	6	1	2	6	9
13	PERCY @ MTMN - SIM (CFS)	AVER	0	2	6	1	2	6	9
14	PERCY @ MTMN MAX SM (CFS)	MAX	0	2	6	1	2	6	9
15	PERCY @ MOTTMAN SIM (IN)	SUM	0	2	6	1	2	6	9

END DISPLY-INFO1

END DISPLY

\*\*\*

END RUN

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)

---

```

RUN
GLOBAL
  ***
  *** Contains information which applies to every operation in the ***
  *** model run. ***
  ***
  WOODARD CREEK BASIN 2ND YEAR CALIBRATION: 3/1/88 - 3/15/90
  START      1988/03/01 00:00  END      1990/03/15 24:00
  RUN INTERP OUTPUT LEVEL      5
  RESUME      0 RUN      1 TSSFL      0 WDMSFL      16
END GLOBAL
OPN SEQUENCE
  ***
  *** Specifies the operations to be performed in the model run. ***
  ***
  INGRP              INDELT 00:15
    PERLND           21
    PERLND           23
    PERLND           34
    PERLND           36
    PERLND           38
    PERLND           40
    PERLND           42
    PERLND           44
    PERLND           45
    PERLND           47
    PERLND           49
    PERLND           51
    PERLND           53
    PERLND           55
    PERLND           93
    IMPLND           95
    RCHRES            1
    RCHRES            2
    RCHRES            3
    RCHRES            4
    RCHRES            5
    RCHRES            6
    DISPLY            1
    DISPLY            2
    DISPLY            3
    DISPLY            4
    DISPLY            5
    DISPLY            6
    DISPLY            7
  END INGRP
END OPN SEQUENCE

```

\*\*\*

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

PERLND
***
*** Simulates the hydrology of the pervious land segments.
***

GEN-INFO
***
*** Assigns a land segment name to each PERLND number.
***

<PLS >      Name      NBLKS   Unit-systems   Printer      ***
# -  #              User   t-series Engl Metr      ***
                        in   out
21      OF              1      1      1      1      6      0
23      OG              1      1      1      1      6      0
34      KF MILD         1      1      1      1      6      0
36      KF MODERATE     1      1      1      1      6      0
38      KF STEEP        1      1      1      1      6      0
40      KG MILD         1      1      1      1      6      0
42      KG MODERATE     1      1      1      1      6      0
44      KG STEEP        1      1      1      1      6      0
45      TF MILD         1      1      1      1      6      0
47      TF MODERATE     1      1      1      1      6      0
49      TF STEEP        1      1      1      1      6      0
51      TG MILD         1      1      1      1      6      0
53      TG MODERATE     1      1      1      1      6      0
55      TG STEEP        1      1      1      1      6      0
93      SATURATED       1      1      1      1      6      0

END GEN-INFO

ACTIVITY
<PLS > ***** Active Sections *****
# -  # ATMP SNOW PWAT  SED  PST  PWG  PQAL MSTL PEST NITR PHOS TRAC      ***
21  93   0   0   1   0   0   0   0   0   0   0   0   0   0
END ACTIVITY

PRINT-INFO
<PLS > ***** Print-flags ***** PIVL  PYR
# -  # ATMP SNOW PWAT  SED  PST  PWG  PQAL MSTL PEST NITR PHOS TRAC *****
21  93   0   0   6   0   0   0   0   0   0   0   0   0   1   9
END PRINT-INFO

PWAT-PARM1
<PLS > ***** Flags *****
# -  # CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE      ***
21  93   0   0   0   0   0   0   0   0   0   0   0
END PWAT-PARM1

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

PWAT-PARM2

```

***
*** Assigns values to the following process-related parameters.
***

```

<PLS > \*\*\*

#	-	#	***FOREST	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
21				5.0000	2.0000	400.00	0.0500	0.0125	0.9960
23				5.0000	0.8000	400.00	0.0500	0.0125	0.9960
34				9.0000	0.1600	400.00	0.0500	0.5000	0.9960
36				9.0000	0.1600	400.00	0.1000	0.5000	0.9960
38				9.0000	0.1600	200.00	0.2000	0.5000	0.9960
40				9.0000	0.0600	400.00	0.0500	0.5000	0.9960
42				9.0000	0.0600	400.00	0.1000	0.5000	0.9960
44				9.0000	0.0600	200.00	0.2000	0.5000	0.9960
45				4.5000	0.0800	400.00	0.0500	0.5000	0.9960
47				4.5000	0.0800	400.00	0.1000	0.5000	0.9960
49				4.5000	0.0800	200.00	0.2000	0.5000	0.9960
51				4.5000	0.0300	400.00	0.0500	0.5000	0.9960
53				4.5000	0.0300	400.00	0.1000	0.5000	0.9960
55				4.5000	0.0300	200.00	0.2000	0.5000	0.9960
93				4.0000	2.0000	100.00	0.0010	0.5000	0.9960

END PWAT-PARM2

PWAT-PARM3

```

***
*** Assigns values to the following process-related parameters.
***

```

<PLS >\*\*\*

#	-	#	*** PETMAX	PETMIN	INFEXP	INFILD	DEEPPFR	BASETP	AGWETP
21					2.0000	2.0000	.00	0.	0.
23					2.0000	2.0000	.00	0.	0.
34					3.5000	2.0000	.00	0.	0.
36					2.0000	2.0000	.00	0.	0.
38					1.5000	2.0000	.00	0.	0.
40					3.5000	2.0000	.00	0.	0.
42					2.0000	2.0000	.00	0.	0.
44					1.5000	2.0000	.00	0.	0.
45					3.5000	2.0000	.00	0.	0.
47					2.0000	2.0000	.00	0.	0.
49					1.5000	2.0000	.00	0.	0.
51					3.5000	2.0000	.00	0.	0.
53					2.0000	2.0000	.00	0.	0.
55					1.5000	2.0000	.00	0.	0.
93					10.000	2.0000	.00	0.	0.7

END PWAT-PARM3



**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

PWAT-PARM4

```

***
*** Assigns values to the following process-related parameters. ***
***
<PLS >
# - #      CEPSC      UZSN      NSUR      INTFW      IRC      LZETP***
21      0.2000      0.5000      0.3500      0.0000      0.7000      0.7000
23      0.1000      0.5000      0.2500      0.0000      0.7000      0.2500
34      0.2000      1.0000      0.3500      3.0000      0.7000      0.7000
36      0.2000      0.5000      0.3500      6.0000      0.5000      0.7000
38      0.2000      0.3000      0.3500      7.0000      0.3000      0.7000
40      0.1000      0.5000      0.2500      3.0000      0.7000      0.2500
42      0.1000      0.2500      0.2500      6.0000      0.5000      0.2500
44      0.1000      0.1500      0.2500      7.0000      0.3000      0.2500
45      0.2000      1.0000      0.3500      3.0000      0.7000      0.7000
47      0.2000      0.5000      0.3500      6.0000      0.5000      0.7000
49      0.2000      0.3000      0.3500      7.0000      0.3000      0.7000
51      0.1000      0.5000      0.2500      3.0000      0.7000      0.2500
53      0.1000      0.2500      0.2500      6.0000      0.5000      0.2500
55      0.1000      0.1500      0.2500      7.0000      0.3000      0.2500
93      0.1000      3.0000      0.5000      1.0000      0.7000      0.8000

```

END PWAT-PARM4

PWAT-STATE1

```

***
*** Assigns initial values to various storages. Values were ***
*** determined from an initial model run for the period ***
*** October 1, 1987 through February 28, 1988. AGWS (active ***
*** ground-water storage) was adjusted during calibration. ***
***
<PLS > PWATER state variables***
# - #*** CEPSC SURS UZS IFWS LZS AGWS GWVS
21      0.03      0.      0.1210      0.      8.064      10.857      2.480
23      0.03      0.      0.3010      0.      8.235      11.609      2.535
34      0.00      0.      1.0340      0.      11.922      7.390      1.773
36      0.00      0.      0.6530      0.      12.014      7.514      1.860
38      0.00      0.      0.3590      0.      12.026      7.125      1.878
40      0.00      0.      0.6710      0.      11.928      7.286      1.729
42      0.00      0.      0.2640      0.      11.922      7.249      1.750
44      0.00      0.      0.1150      0.      11.907      6.806      1.750
45      0.03      0.      1.7540      0.      7.141      8.399      2.019
47      0.03      0.      0.8210      0.      7.238      8.858      2.155
49      0.03      0.      0.4440      0.      7.255      8.551      2.185
51      0.03      0.      0.7890      0.      6.766      6.701      1.431
53      0.03      0.      0.3100      0.      6.871      7.150      1.649
55      0.03      0.      0.1340      0.      6.892      6.864      1.703
93      0.03      0.      3.7020      0.      6.616      7.328      1.848

```

END PWAT-STATE1

END PERLND

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

IMPLND
  ***
  *** Simulates the hydrology of the impervious land segment.
  ***
GEN-INFO
  ***
  *** Assigns a land segment name to the IMPLND number.
  ***
  <ILS >      Name      Unit-systems  Printer      ***
  # - #              User  t-series  Engl Metr      ***
                        in  out      ***
  95      IMPERVIOUS      1    1    1    6    0
END GEN-INFO
ACTIVITY
  <ILS > ***** Active Sections *****
  # - # ATMP SNOW IWAT  SLD  IWG IQAL  ***
  95      0    0    1    0    0    0
END ACTIVITY
PRINT-INFO
  <ILS > ***** Print-flags ***** PIVL  PYR
  # - # ATMP SNOW IWAT  SLD  IWG IQAL *****
  95      0    0    6    0    0    0    1    9
END PRINT-INFO
IWAT-PARM1
  <ILS >      Flags      ***
  # - # CSNO RTOP  VRS  VNN RTLI  ***
  95      0    0    0    0    0
END IWAT-PARM1
IWAT-PARM2
  ***
  *** Assigns values to the following process-related parameters.
  ***
  <ILS >
  # - #      LSUR      SLSUR      NSUR      RETSC      ***
  95      500.00      0.0500      0.1000      0.1000
END IWAT-PARM2
IWAT-PARM3
  <ILS >
  # - #      PETMAX      PETMIN      ***
  95
END IWAT-PARM3
IWAT-STATE1
  <ILS >  IWATER state variables      ***
  # - #      RETS      SURS      ***
  95      0.0300      0.0000
END IWAT-STATE1
END IMPLND
  ***

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

EXT SOURCES

```

***                                     ***
*** Specifies the time series which are input to the operations ***
*** from external WDM files. ***
***                                     ***
*** NOTE: The only RCHRES that precip and PET are applied to are ***
*** lakes. ***
***                                     ***

<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name> # <Name> # tem strg<-factor->strg <Name> # # <Name> # # ***
WDM 2 PRCP ENGL PERLND 21 93 EXTNL PREC
WDM 2 PRCP ENGL IMPLND 95 EXTNL PREC
WDM 4 PET ENGL PERLND 21 93 EXTNL PETINP
WDM 4 PET ENGL IMPLND 95 EXTNL PETINP
WDM 2 PRCP ENGL DISPLY 1 INPUT TIMSER
WDM 1 FLOW ENGL DISPLY 2 INPUT TIMSER
WDM 1 FLOW ENGL DISPLY 3 INPUT TIMSER
WDM 1 FLOW ENGL 0.000113 DISPLY 4 INPUT TIMSER
***                                     ***
*** Note: The above MULTFACTOR converts cubic feet per second ***
*** to inches of runoff per 15 minutes. ***
***                                     ***

```

END EXT SOURCES

\*\*\*

EXT TARGETS

```

***                                     ***
*** Specifies the time series which are output from operations ***
*** to external WDM files. ***
*** Note: MULTFACTOR 48.4 converts acre-feet of runoff per ***
*** 15-minute interval to cubic feet per second. ***
***                                     ***

```

```

<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Tgap Amd ***
<Name> # <Name> # #<-factor->strg <Name> # <Name> tem strg strg***
RCHRES 5 HYDR ROVOL 48.4SAME WDM 5 SFLO ENGL REPL
END EXT TARGETS

```

\*\*\*

NETWORK

```

***                                     ***
*** Specifies the time series which are passed between ***
*** operations. ***
***                                     ***

<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name> # <Name> # #<-factor->strg <Name> # # <Name> # # ***
***                                     ***
*** The following linkages pass total outflow (PERO), ***
*** ground-water flow (AGWO), subsurface flow (IFWO), or ***
*** overland flow (SURO) to assigned stream reaches (RCHRES). ***
***                                     ***
*** Note: MULTFACTORS for converting inches to acre/feet = ***
*** area (in acres)/12 ***
***                                     ***

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WD1 ***
*** ALL GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 2 ***
*** EFFECTIVE IMPERVIOUS AREA (EIA) RULES MODIFIED - SEE REPORT ***
***     SPARSE RESIDENTIAL           - 0% EIA ***
***     MODERATE RESIDENTIAL          - 0% EIA ***
***     SUBURBAN RESIDENTIAL          - 0% EIA ***
***     HIGH DENSITY RESIDENTIAL      - 24% EIA ***
***     MEDIUM COMMERCIAL / LIGHT INDUSTRIAL - 24% EIA ***
***     HEAVY COMMERCIAL / INDUSTRIAL - 58% EIA ***
PERLND  21 PWATER SURO           4.371    RCHRES  1    EXTNL  IVOL
PERLND  23 PWATER SURO          14.358    RCHRES  1    EXTNL  IVOL
PERLND  51 PWATER SURO           0.002    RCHRES  1    EXTNL  IVOL
PERLND  93 PWATER SURO           0.493    RCHRES  1    EXTNL  IVOL
PERLND  21 PWATER IFWO           4.371    RCHRES  1    EXTNL  IVOL
PERLND  23 PWATER IFWO          14.358    RCHRES  1    EXTNL  IVOL
PERLND  51 PWATER IFWO           0.002    RCHRES  1    EXTNL  IVOL
PERLND  93 PWATER IFWO           0.493    RCHRES  1    EXTNL  IVOL
PERLND  21 PWATER AGWO           4.371    RCHRES  2    EXTNL  IVOL
PERLND  23 PWATER AGWO          14.358    RCHRES  2    EXTNL  IVOL
PERLND  51 PWATER AGWO           0.002    RCHRES  2    EXTNL  IVOL
PERLND  93 PWATER AGWO           0.493    RCHRES  2    EXTNL  IVOL
IMPLND  95 IWATER SURO           9.058    RCHRES  1    EXTNL  IVOL
***
*** SUB-BASIN WD2 ***
*** EIA RULES MODIFIED - SEE NOTES FOR SUBBASIN WD1 IN THE ***
***     NETWORK BLOCK ***
PERLND  21 PWATER PERO           4.030    RCHRES  2    EXTNL  IVOL
PERLND  23 PWATER PERO           5.933    RCHRES  2    EXTNL  IVOL
PERLND  93 PWATER PERO           3.269    RCHRES  2    EXTNL  IVOL
IMPLND  95 IWATER SURO           0.297    RCHRES  2    EXTNL  IVOL
***
*** SUB-BASIN WD3 ***
*** ALL TILLS DRAIN TO OUTWASHES (ACCOUNTED FOR IN OUTWASH AREAS) ***
*** EIA RULES MODIFIED FOR ONLY OUTWASH AREAS - SEE NOTES FOR ***
***     SUBBASIN WD1 IN THE NETWORK BLOCK ***
PERLND  21 PWATER PERO           9.848    RCHRES  3    EXTNL  IVOL
PERLND  23 PWATER PERO          15.438    RCHRES  3    EXTNL  IVOL
PERLND  45 PWATER PERO           0.943    DRAINS TO OUTWASH PERLND 21 ***
PERLND  47 PWATER PERO           1.936    DRAINS TO OUTWASH PERLND 21 ***
PERLND  51 PWATER PERO           0.339    DRAINS TO OUTWASH PERLND 23 ***
PERLND  53 PWATER PERO           4.118    DRAINS TO OUTWASH PERLND 23 ***
PERLND  93 PWATER PERO           4.767    RCHRES  3    EXTNL  IVOL
IMPLND  95 IWATER SURO           7.940    RCHRES  3    EXTNL  IVOL
***
*** SUB-BASIN WD3A ***
*** CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT ***
***     RCHRES 3 ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND  23 PWATER AGWO           4.456    RCHRES  3    EXTNL  IVOL
IMPLND  95 IWATER SURO           1.516    DRAINS TO ADJACENT PERLND ***

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WD4 ***
PERLND  21  PWATER  PERO          10.858    RCHRES    4    EXTNL  IVOL
PERLND  23  PWATER  PERO          16.347    RCHRES    4    EXTNL  IVOL
PERLND  45  PWATER  PERO           0.098    RCHRES    4    EXTNL  IVOL
PERLND  49  PWATER  PERO           0.017    RCHRES    4    EXTNL  IVOL
PERLND  51  PWATER  PERO           0.551    RCHRES    4    EXTNL  IVOL
PERLND  53  PWATER  PERO           0.074    RCHRES    4    EXTNL  IVOL
PERLND  93  PWATER  PERO           8.358    RCHRES    4    EXTNL  IVOL
IMPLND  95  IWATER  SURO           1.934    RCHRES    4    EXTNL  IVOL
***
*** SUB-BASIN WD4A ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND  21  PWATER  AGWO           3.402    RECHARGES  INACTIVE GROUND WATER ***
PERLND  23  PWATER  AGWO           5.518    RECHARGES  INACTIVE GROUND WATER ***
PERLND  45  PWATER  AGWO           6.270    RECHARGES  INACTIVE GROUND WATER ***
PERLND  47  PWATER  AGWO           0.224    RECHARGES  INACTIVE GROUND WATER ***
PERLND  51  PWATER  AGWO           2.606    RECHARGES  INACTIVE GROUND WATER ***
PERLND  53  PWATER  AGWO           1.576    RECHARGES  INACTIVE GROUND WATER ***
IMPLND  95  IWATER  SURO           2.089    DRAINS TO ADJACENT PERLND AND THEN ***
                                         RECHARGES INACTIVE GROUND WATER ***
***
*** SUB-BASIN WD4B ***
*** CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES ***
*** AT RCHRES 4. ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND  21  PWATER  AGWO           0.586    RCHRES    4    EXTNL  IVOL
PERLND  23  PWATER  AGWO           8.727    RCHRES    4    EXTNL  IVOL
IMPLND  95  IWATER  SURO           0.340    DRAINS TO ADJACENT PERLND ***
**
*** SUB-BASIN WD5 ***
PERLND  21  PWATER  PERO          15.214    RCHRES    5    EXTNL  IVOL
PERLND  23  PWATER  PERO           7.639    RCHRES    5    EXTNL  IVOL
PERLND  34  PWATER  PERO           0.668    RCHRES    5    EXTNL  IVOL
PERLND  36  PWATER  PERO           1.020    RCHRES    5    EXTNL  IVOL
PERLND  38  PWATER  PERO           0.692    RCHRES    5    EXTNL  IVOL
PERLND  40  PWATER  PERO           1.114    RCHRES    5    EXTNL  IVOL
PERLND  42  PWATER  PERO           0.043    RCHRES    5    EXTNL  IVOL
PERLND  44  PWATER  PERO           0.113    RCHRES    5    EXTNL  IVOL
PERLND  45  PWATER  PERO           1.712    RCHRES    5    EXTNL  IVOL
PERLND  47  PWATER  PERO           6.561    RCHRES    5    EXTNL  IVOL
PERLND  49  PWATER  PERO           0.002    RCHRES    5    EXTNL  IVOL
PERLND  51  PWATER  PERO           1.229    RCHRES    5    EXTNL  IVOL
PERLND  53  PWATER  PERO           5.212    RCHRES    5    EXTNL  IVOL
PERLND  93  PWATER  PERO           9.303    RCHRES    5    EXTNL  IVOL
IMPLND  95  IWATER  SURO           0.694    RCHRES    5    EXTNL  IVOL

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WD5A ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND  21  PWATER  AGWO           0.417  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  23  PWATER  AGWO           0.270  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  34  PWATER  AGWO           0.831  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  36  PWATER  AGWO           0.224  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  40  PWATER  AGWO           0.452  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  42  PWATER  AGWO           0.395  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  45  PWATER  AGWO           3.572  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  47  PWATER  AGWO           3.986  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  51  PWATER  AGWO           1.853  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  53  PWATER  AGWO           2.449  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  93  PWATER  AGWO           2.529  RECHARGES  INACTIVE  GROUND  WATER ***
IMPLND  95  IWATER  SURO           0.062  DRAINS TO  ADJACENT  PERLND  AND THEN ***
                                         RECHARGES  INACTIVE  GROUND  WATER ***

***

*** SUB-BASIN WD5B ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND  21  PWATER  AGWO           3.384  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  23  PWATER  AGWO           8.698  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  34  PWATER  AGWO           0.766  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  40  PWATER  AGWO           0.255  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  45  PWATER  AGWO           1.380  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  51  PWATER  AGWO           0.822  RECHARGES  INACTIVE  GROUND  WATER ***
PERLND  93  PWATER  AGWO           5.576  RECHARGES  INACTIVE  GROUND  WATER ***
IMPLND  95  IWATER  SURO           0.342  DRAINS TO  ADJACENT  PERLND  AND THEN ***
                                         RECHARGES  INACTIVE  GROUND  WATER

***

*** SUB-BASIN WD6 ***
PERLND  21  PWATER  PERO           4.228    RCHRES    6    EXTNL    IVOL
PERLND  23  PWATER  PERO           5.912    RCHRES    6    EXTNL    IVOL
PERLND  34  PWATER  PERO          33.695    RCHRES    6    EXTNL    IVOL
PERLND  36  PWATER  PERO          12.582    RCHRES    6    EXTNL    IVOL
PERLND  38  PWATER  PERO          13.246    RCHRES    6    EXTNL    IVOL
PERLND  40  PWATER  PERO          12.029    RCHRES    6    EXTNL    IVOL
PERLND  42  PWATER  PERO           5.201    RCHRES    6    EXTNL    IVOL
PERLND  44  PWATER  PERO           1.396    RCHRES    6    EXTNL    IVOL
PERLND  45  PWATER  PERO           2.795    RCHRES    6    EXTNL    IVOL
PERLND  47  PWATER  PERO          10.761    RCHRES    6    EXTNL    IVOL
PERLND  49  PWATER  PERO           0.208    RCHRES    6    EXTNL    IVOL
PERLND  51  PWATER  PERO           1.560    RCHRES    6    EXTNL    IVOL
PERLND  53  PWATER  PERO           4.887    RCHRES    6    EXTNL    IVOL
PERLND  55  PWATER  PERO           0.136    RCHRES    6    EXTNL    IVOL
PERLND  93  PWATER  PERO          17.526    RCHRES    6    EXTNL    IVOL
IMPLND  95  IWATER  SURO           1.123    RCHRES    6    EXTNL    IVOL

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WD6A ***
*** CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES ***
*** AT RCHRES 6 ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 21 PWATER AGWO          0.903      RCHRES 6      EXTNL IVOL
PERLND 23 PWATER AGWO          0.349      RCHRES 6      EXTNL IVOL
PERLND 34 PWATER AGWO          0.433      RCHRES 6      EXTNL IVOL
PERLND 36 PWATER AGWO          0.132      RCHRES 6      EXTNL IVOL
PERLND 40 PWATER AGWO          0.388      RCHRES 6      EXTNL IVOL
PERLND 42 PWATER AGWO          0.214      RCHRES 6      EXTNL IVOL
PERLND 47 PWATER AGWO          1.010      RCHRES 6      EXTNL IVOL
PERLND 51 PWATER AGWO          0.037      RCHRES 6      EXTNL IVOL
PERLND 53 PWATER AGWO          1.362      RCHRES 6      EXTNL IVOL
IMPLND 95 IWATER SURO          0.148      DRAINS TO ADJACENT PERLND ***
***

** CHANNEL NETWORK LINKAGES **
***
*** The following linkages pass streamflow from one stream reach ***
*** (RCHRES) to another stream reach. ***
***
RCHRES 1 HYDR  OVOL  1 1      RCHRES 2      EXTNL IVOL
RCHRES 2 HYDR  ROVOL 1      RCHRES 3      EXTNL IVOL
RCHRES 3 HYDR  ROVOL 1      RCHRES 4      EXTNL IVOL
RCHRES 4 HYDR  ROVOL 1      RCHRES 5      EXTNL IVOL
RCHRES 5 HYDR  ROVOL 1      RCHRES 6      EXTNL IVOL
***
*** The following linkages pass streamflow time series to tables ***
*** for display. ***
***
*** Note: MULTFACTOR 48.4 converts acre-feet of runoff to ***
*** average cubic feet per second per 15 minute interval. ***
*** It is timestep dependent. The other MFACTOR converts ***
*** acre-feet of runoff to inches of runoff per 15 minutes. ***
***
RCHRES 5 HYDR  ROVOL 1      48.4      DISPLY 5      INPUT TIMSER 1
RCHRES 5 HYDR  ROVOL 1      48.4      DISPLY 6      INPUT TIMSER 1
RCHRES 5 HYDR  ROVOL 1      0.00546    DISPLY 7      INPUT TIMSER 1
****
END NETWORK
***

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

RCHRES
***
*** Simulates streamflows in stream reaches (RCHRES)
***

GEN-INFO
RCHRES      Name      Nexits  Unit Systems  Printer
# - #<-----><----> User T-series  Engl Metr LKFG
                        in  out
1      SS CNTR DTCH - WD1      2      1      1      1      6      0      0
2      WDRD CK HEAD - WD2      1      1      1      1      6      0      0
3      WDRD CK-ENS RD WD3      1      1      1      1      6      0      0
4      WOODWARD CR. - WD4      1      1      1      1      6      0      0
5      WDWRD (120805)-WD5      1      1      1      1      6      0      0
6      WOODWARD CR. - WD6      1      1      1      1      6      0      0

END GEN-INFO

ACTIVITY
RCHRES ***** Active Sections *****
# - # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
1   6   1   0   0   0   0   0   0   0   0   0   0

END ACTIVITY

PRINT-INFO
RCHRES ***** Printout Flags ***** PIVL  PYR
# - # HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB *****
1      6      0      0      0      0      0      0      0      0      0      1      9
2      6      0      0      0      0      0      0      0      0      0      1      9
3      6      0      0      0      0      0      0      0      0      0      1      9
4      6      0      0      0      0      0      0      0      0      0      1      9
5      6      0      0      0      0      0      0      0      0      0      1      9
6      6      0      0      0      0      0      0      0      0      0      1      9

END PRINT-INFO

HYDR-PARM1
RCHRES  Flags for each HYDR Section
# - #  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each  FUNCT for each
      FG FG FG FG  possible  exit *** possible  exit  possible  exit
      * * * * * * * * * * * * * * * * * * * * * *
1      0 0 0 0      4 5 0 0 0      0 0 0 0 0      2 2 2 2 2
2      6 0 0 0 0      4 0 0 0 0      0 0 0 0 0      2 2 2 2 2

END HYDR-PARM1

HYDR-PARM2
***
*** Assigns an F-table number to each reach. Supplies the length
*** of the reach and a weighting factor for hydraulic routing.
***
RCHRES
# - #  FTABNO      LEN      DELTH      STCOR      KS      DB50
<-----><-----><-----><-----><-----><----->
1      1      0.900
2      2      0.580
3      3      0.870
4      4      1.550
5      5      1.200
6      6      3.100

END HYDR-PARM2

```



**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

HYDR-INIT
***                                     ***
*** Initial conditions for each HYDR section. ***
***                                     ***
    RCHRES                                     ***
    # - # *** VOL      Initial value of COLIND      Initial value of OUTDGT
          *** ac-ft      for each possible exit      for each possible exit
    <-----><----->      <---><---><---><---><---> *** <---><---><---><---><--->
    1      0.1900      4.0  5.0
    2      0.5000      4.0
    3      0.5000      4.0
    4      1.0700      4.0
    5      3.0900      4.0
    6      1.9800      4.0
END HYDR-INIT
END RCHRES
FTABLES
***                                     ***
*** The following function tables (F-tables) portray ***
*** relationships between volume and outflow and in some ***
*** cases area (for lakes) for the defined channel reaches. ***
*** The columns for volume and outflow are used for routing ***
*** streamflow from reach to reach. For reaches that ***
*** represent streams, only the volume-outflow ***
*** relationship is considered for routing streamflow. The ***
*** area column is used for the application of precipitation ***
*** and PET to lakes. Outflow1 is the streamflow routed ***
*** from one reach to another reach, and other outflows ***
*** represent either channel losses from seepage or flow that ***
*** leaves the reach through another outlet. ***
***                                     ***
FTABLE      1
*** Drains subbasin WD1. The reach consists of a storm sewer ***
*** and man-made ditch system that can detain and infiltrate ***
*** water. Outflow2 represents reach losses by seepage. ***
Rows Cols                                     ***
9      5
Depth      Area      Volume      Outflow1      Outflow2
(ft)      (acres)      (acre-ft)      (cfs)      (cfs)
0.0      0.0      0.0      0.0      0.0
0.3      0.0      0.15      0.0      1.0
0.5      0.0      0.30      0.0      1.0
0.8      0.0      0.70      1.2      2.0
2.0      0.0      2.05      10.8      6.0
2.8      0.0      3.40      25.0      8.0
3.3      0.0      4.25      36.2      12.0
4.8      0.0      5.40      42.0      12.0
5.5      0.0      9.25      60.0      12.0
END FTABLE      1

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      2
  *** Drains subbasin WD2 and receives drainage from WD1.  Outflow ***
  *** controlled by a partially collapsed, submerged culvert.      ***
Rows Cols
  6      4
  Depth      Area      Volume  Outflow1
  (ft)      (acres) (acre-ft)  (cfs)
  0.0      0.0      0.0      0.0
  0.5      0.0      0.75     2.80
  1.0      0.0      2.50     5.00
  2.0      0.0      9.50    10.0
  3.0      0.0     23.00    19.00
  5.0      0.0     65.00    24.00
END FTABLE  2
FTABLE      3
  *** Drains subbasins WD3 and receives drainage from WD3A.      ***
  *** Crest-stage gage 12080450 (Woodard Creek at Ensign Road at ***
  *** Olympia, WA) located at lower end of reach.                ***
Rows Cols
  6      4
  Depth      Area      Volume  Outflow1
  (ft)      (acres) (acre-ft)  (cfs)
  0.0      0.0      0.0      0.0
  0.5      0.0      0.50     1.50
  1.0      0.0      2.00     4.50
  2.0      0.0      9.00    24.0
  3.0      0.0     39.0    48.00
  5.0      0.0    116.0    55.00
END FTABLE  3
FTABLE      4
  *** Drains subbasins WD4 and receives drainage from WD4B.      ***
Rows Cols
  6      4
  Depth      Area      Volume  Outflow1
  (ft)      (acres) (acre-ft)  (cfs)
  0.0      0.0      0.0      0.0
  1.0      0.0      0.75     5.0
  2.0      0.0      6.25    25.0
  2.5      0.0     17.4    40.0
  3.0      0.0     44.7    53.5
  5.0      0.0    225.7   100.0
END FTABLE  4

```

**Table 18.**--Input sequence of the Woodard Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      5
*** Drains subbasin WD5.  Gaging station 12080500 (Woodard Creek ***
*** near Olympia, WA) located at lower end of reach.          ***

Rows Cols
7      4
Depth      Area      Volume  Outflow1
(ft)      (acres)  (acre-ft)  (cfs)
0.0      0.0      0.0      0.0
1.0      0.0      0.75     5.0
2.0      0.0      5.00     20.0
2.5      0.0      10.5     35.0
3.0      0.0      24.0     50.0
3.5      0.0      54.0     75.0
4.5      0.0      144.0    125.0
END FTABLE  5
FTABLE      6
*** Drains subbasins WD6 and receives drainage from WD6A.      ***

Rows Cols
7      4
Depth      Area      Volume  Outflow1
(ft)      (acres)  (acre-ft)  (cfs)
0.0      0.0      0.0      0.0
0.5      0.0      0.93     3.0
1.5      0.0      4.09     20.0
2.5      0.0      25.0     69.7
4.0      0.0      137.5    200.0
4.5      0.0      193.8    225.0
7.0      0.0      588.8    700.0
END FTABLE  6
END FTABLES

DISPLY
***
*** Displays time series on output.
***

DISPLY-INFO1
#thru#***<-----Title----->
***
***
1      BROWN'S POND PRECIP (IN)
2      WDRD 36TH - OBS      (CFS)
3      WDRD 36TH - OBS MAX(CFS)
4      WDRD 36TH - OBS VOL (IN)
5      WDRD CK 36 SIM      (CFS)
6      WDRD CK 36 SIM MAX (CFS)
7      WDRD CK 36 SIM VOL  (IN)

END DISPLY-INFO1
END DISPLY

END RUN

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)

```

RUN
GLOBAL
    ***                                     ***
    *** Contains information which applies to every operation in the ***
    ***   model run.                                     ***
    ***                                     ***
WOODLAND CREEK BASIN 2ND YR CALIBRATION: 3/1/88 - 3/15/90
START      1988/03/01 00:00  END      1990/03/15 24:00
RUN INTERP OUTPUT LEVEL      0
RESUME      0 RUN      1 TSSFL      0 WDMSFL      16
END GLOBAL
OPN SEQUENCE
    ***                                     ***
    *** Specifies the operations to be performed in the model run. ***
    ***                                     ***
INGRP                                INDELT  0:15
    PERLND      21
    PERLND      22
    PERLND      23
    PERLND      24
    PERLND      25
    PERLND      34
    PERLND      36
    PERLND      38
    PERLND      40
    PERLND      42
    PERLND      44
    PERLND      45
    PERLND      46
    PERLND      47
    PERLND      48
    PERLND      49
    PERLND      50
    PERLND      51
    PERLND      52
    PERLND      53
    PERLND      54
    PERLND      55
    PERLND      56
    PERLND      93
    PERLND      94
    PERLND      97
    PERLND      98
    PERLND      99
    IMPLND      95
    IMPLND      96

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

RCHRES	2
RCHRES	4
RCHRES	5
RCHRES	50
RCHRES	6
RCHRES	8
RCHRES	9
RCHRES	10
RCHRES	12
RCHRES	13
RCHRES	14
RCHRES	15
RCHRES	17
RCHRES	18
RCHRES	19
RCHRES	20
RCHRES	21
RCHRES	22
RCHRES	23
RCHRES	24
RCHRES	25
RCHRES	26
RCHRES	27
DISPLY	1
DISPLY	2
DISPLY	3
DISPLY	4
DISPLY	5
DISPLY	6
DISPLY	7
DISPLY	8
DISPLY	9
DISPLY	10
DISPLY	11
DISPLY	12
DISPLY	13
END INGRP	
END OPN SEQUENCE	

\*\*\*

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

PERLND
***                                     ***
*** Simulates the hydrology of the pervious land segments. ***
***                                     ***

GEN-INFO
***                                     ***
*** Assigns a land segment name to each PERLND number. ***
***                                     ***

<PLS >      Name      NBLKS   Unit-systems   Printer      ***
# - #              User  t-series  Engl Metr      ***
                        in  out      ***

21  22 OF          1      1      1      1      6      0
23  24 OG          1      1      1      1      6      0
25      OCROPS      1      1      1      1      6      0
34      KF MILD      1      1      1      1      6      0
36      KF MODERATE  1      1      1      1      6      0
38      KF STEEP     1      1      1      1      6      0
40      KG MILD      1      1      1      1      6      0
42      KG MODERATE  1      1      1      1      6      0
44      KG STEEP     1      1      1      1      6      0
45  46 TF MILD      1      1      1      1      6      0
47  48 TF MODERATE  1      1      1      1      6      0
49  50 TF STEEP     1      1      1      1      6      0
51  52 TG MILD      1      1      1      1      6      0
53  54 TG MODERATE  1      1      1      1      6      0
55  56 TG STEEP     1      1      1      1      6      0
93  94 SATURATED    1      1      1      1      6      0
97      OF GRDWTR    1      1      1      1      6      0
98      OG GRDWTR    1      1      1      1      6      0
99      OCROPSGW     1      1      1      1      6      0

END GEN-INFO

ACTIVITY
<PLS > ***** Active Sections *****
# - # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC      ***
21  99  0    0    1    0    0    0    0    0    0    0    0    0
END ACTIVITY

PRINT-INFO
<PLS > ***** Print-flags ***** PIVL  PYR
# - # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC *****
21  99  0    0    6    0    0    0    0    0    0    0    0    1    9
END PRINT-INFO

PWAT-PARM1
<PLS > ***** Flags *****
# - # CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE      ***
21  99  0    0    0    0    0    0    0    0    0
END PWAT-PARM1

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

PWAT-PARM2

```

***
*** Assigns values to the following process-related parameters.
***
<PLS > ***
# - # ***FOREST      LZSN      INFILT      LSUR      SLSUR      KVARV      AGWRC
21  22                5.0000      2.0000      400.00      0.0500      0.0000      0.9960
23  24                5.0000      0.8000      400.00      0.0500      0.0000      0.9960
25                5.0000      0.8000      400.00      0.0500      0.0000      0.9960
34                9.0000      0.1600      400.00      0.0500      0.0000      0.9960
36                9.0000      0.1600      400.00      0.1000      0.0000      0.9960
38                9.0000      0.1600      200.00      0.2000      0.0000      0.9960
40                9.0000      0.0600      400.00      0.0500      0.0000      0.9960
42                9.0000      0.0600      400.00      0.1000      0.0000      0.9960
44                9.0000      0.0600      200.00      0.2000      0.0000      0.9960
45  46                4.5000      0.0800      400.00      0.0500      0.0000      0.9960
47  48                4.5000      0.0800      400.00      0.1000      0.0000      0.9960
49  50                4.5000      0.0800      200.00      0.2000      0.0000      0.9960
51  52                4.5000      0.0300      400.00      0.0500      0.0000      0.9960
53  54                4.5000      0.0300      400.00      0.1000      0.0000      0.9960
55  56                4.5000      0.0300      200.00      0.2000      0.0000      0.9960
93  94                4.0000      2.0000      100.00      0.0010      0.0000      0.9960
97                5.0000      2.0000      400.00      0.0500      0.2000      0.9960
98                5.0000      0.8000      400.00      0.0500      0.2000      0.9960
99                5.0000      0.8000      400.00      0.0500      0.2000      0.9960

```

END PWAT-PARM2

PWAT-PARM3

```

***
*** Assigns values to the following process-related parameters.
***
<PLS >***
# - #*** PETMAX      PETMIN      INFEXP      INFILD      DEEPFR      BASETP      AGWETP
21  22                2.0000      2.0000      .00          0.          0.
23  24                2.0000      2.0000      .00          0.          0.
25                2.0000      2.0000      .00          0.          0.
34                3.5000      2.0000      .00          0.          0.
36                2.0000      2.0000      .00          0.          0.
38                1.5000      2.0000      .00          0.          0.
40                3.5000      2.0000      .00          0.          0.
42                2.0000      2.0000      .00          0.          0.
44                1.5000      2.0000      .00          0.          0.
45  46                3.5000      2.0000      .00          0.          0.
47  48                2.0000      2.0000      .00          0.          0.
49  50                1.5000      2.0000      .00          0.          0.
51  52                3.5000      2.0000      .00          0.          0.
53  54                2.0000      2.0000      .00          0.          0.
55  56                1.5000      2.0000      .00          0.          0.
93  94                10.000      2.0000      .00          0.          0.7
97                2.0000      2.0000      .00          0.          0.
98                2.0000      2.0000      .00          0.          0.
99                2.0000      2.0000      .00          0.          0.

```

END PWAT-PARM3

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

PWAT-PARM4

```

***                                     ***
*** Assigns values to the following process-related parameters. ***
***                                     ***
<PLS >                                     ***
# - #      CEPSC      UZSN      NSUR      INTFW      IRC      LZETP***
21  22      0.2000     0.5000     0.3500     0.0000     0.7000     0.7000
23  24      0.1000     0.5000     0.2500     0.0000     0.7000     0.2500
25      0.1000     0.5000     0.2500     0.0000     0.7000     0.5000
34      0.2000     1.0000     0.3500     3.0000     0.7000     0.7000
36      0.2000     0.5000     0.3500     6.0000     0.5000     0.7000
38      0.2000     0.3000     0.3500     7.0000     0.3000     0.7000
40      0.1000     0.5000     0.2500     3.0000     0.7000     0.2500
42      0.1000     0.2500     0.2500     6.0000     0.5000     0.2500
44      0.1000     0.1500     0.2500     7.0000     0.3000     0.2500
45  46      0.2000     1.0000     0.3500     3.0000     0.7000     0.7000
47  48      0.2000     0.5000     0.3500     6.0000     0.5000     0.7000
49  50      0.2000     0.3000     0.3500     7.0000     0.3000     0.7000
51  52      0.1000     0.5000     0.2500     3.0000     0.7000     0.2500
53  54      0.1000     0.2500     0.2500     6.0000     0.5000     0.2500
55  56      0.1000     0.1500     0.2500     7.0000     0.3000     0.2500
93  94      0.1000     3.0000     0.5000     1.0000     0.7000     0.8000
97      0.2000     0.5000     0.3500     0.0000     0.7000     0.7000
98      0.1000     0.5000     0.2500     0.0000     0.7000     0.2500
99      0.1000     0.5000     0.2500     0.0000     0.7000     0.5000

```

END PWAT-PARM4

PWAT-STATE1

```

***                                     ***
*** Assigns initial values to various storages. Values were ***
*** determined from an initial model run for the period ***
*** October 1, 1987 through February 28, 1988. AGWS (active ***
*** ground-water storage) was adjusted during calibration. ***
***                                     ***
<PLS > PWATER state variables***
# - #***      CEPS      SURS      UZS      IFWS      LZS      AGWS      GWVS
21      0.03      0.      0.1210      0.      8.064      12.857      0.140
22      0.03      0.      0.1210      0.      8.064      15.857      0.140
23      0.03      0.      0.3010      0.      8.235      13.609      0.190
24      0.03      0.      0.3010      0.      8.235      16.609      0.190
25      0.03      0.      0.3010      0.      8.235      13.609      0.190
34      0.00      0.      1.0340      0.      11.922      9.390      0.170
36      0.00      0.      0.6530      0.      12.014      9.514      0.150
38      0.00      0.      0.3590      0.      12.026      9.125      0.110
40      0.00      0.      0.6710      0.      11.928      9.286      0.200
42      0.00      0.      0.2640      0.      11.922      9.249      0.190
44      0.00      0.      0.1150      0.      11.907      8.806      0.150
45  46      0.03      0.      1.7540      0.      7.141      10.399      0.180
47  48      0.03      0.      0.8210      0.      7.238      10.858      0.160
49  50      0.03      0.      0.4440      0.      7.255      10.551      0.120
51  52      0.03      0.      0.7890      0.      6.766      8.701      0.210
53  54      0.03      0.      0.3100      0.      6.871      9.150      0.200
55  56      0.03      0.      0.1340      0.      6.892      8.864      0.160
93  94      0.03      0.      3.7030      0.      6.616      9.328      0.000

```



**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

97          0.03          0.    0.1210          0.    8.064    11.217    2.480
98          0.03          0.    0.3010          0.    8.235    11.706    2.540
99          0.03          0.    0.3010          0.    8.235    11.432    2.480
END PWAT-STATE1
END PERLND
IMPLND
***
*** Simulates the hydrology of the impervious land segment.
***
GEN-INFO
***
*** Assigns a land segment name to the IMPLND number.
***
<ILS >      Name          Unit-systems  Printer
# - #        User  t-series Engl Metr
              in  out
95  96 IMPERVIOUS          1    1    1    6    0
END GEN-INFO
ACTIVITY
<ILS > ***** Active Sections *****
# - # ATMP SNOW IWAT  SLD  IWG IQAL ***
95  96    0    0    1    0    0    0
END ACTIVITY
PRINT-INFO
<ILS > ***** Print-flags ***** PIVL  PYR
# - # ATMP SNOW IWAT  SLD  IWG IQAL *****
95  96    0    0    6    0    0    0    1    9
END PRINT-INFO
IWAT-PARM1
<ILS >          Flags          ***
# - # CSNO RTOP  VRS  VNN RTLI  ***
95  96    0    0    0    0    0
END IWAT-PARM1
IWAT-PARM2
***
*** Assigns values to the following process-related parameters.
***
<ILS >
# - #      LSUR      SLSUR      NSUR      RETSC
95  96    500.00    0.0500    0.1000    0.1000
END IWAT-PARM2
IWAT-PARM3
<ILS >
# - #      PETMAX    PETMIN
95  96
END IWAT-PARM3
IWAT-STATE1
<ILS >  IWATER state variables
# - #      RETS      SURS
95  96 1.0000E-3 1.0000E-3
END IWAT-STATE1
END IMPLND
***

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

EXT SOURCES

```

***
*** Specifies the time series which are input to the operations ***
*** from external WDM files. ***
***
*** NOTE: The only RCHRES that precip and PET are applied to are ***
*** lakes. ***
***

```

```

***
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name> # <Name> # tem strg<-factor->strg <Name> # # <Name> # # ***
WDM 3 PRCP ENGL PERLND 21 EXTNL PREC
WDM 3 PRCP ENGL PERLND 23 EXTNL PREC
WDM 3 PRCP ENGL PERLND 25 EXTNL PREC
WDM 3 PRCP ENGL PERLND 45 EXTNL PREC
WDM 3 PRCP ENGL PERLND 47 EXTNL PREC
WDM 3 PRCP ENGL PERLND 49 EXTNL PREC
WDM 3 PRCP ENGL PERLND 51 EXTNL PREC
WDM 3 PRCP ENGL PERLND 53 EXTNL PREC
WDM 3 PRCP ENGL PERLND 55 EXTNL PREC
WDM 3 PRCP ENGL PERLND 93 EXTNL PREC
WDM 3 PRCP ENGL PERLND 97 EXTNL PREC
WDM 3 PRCP ENGL PERLND 98 EXTNL PREC
WDM 3 PRCP ENGL PERLND 99 EXTNL PREC
WDM 3 PRCP ENGL IMPLND 95 EXTNL PREC
WDM 4 PRCP ENGL PERLND 22 EXTNL PREC
WDM 4 PRCP ENGL PERLND 24 EXTNL PREC
WDM 4 PRCP ENGL PERLND 34 EXTNL PREC
WDM 4 PRCP ENGL PERLND 36 EXTNL PREC
WDM 4 PRCP ENGL PERLND 38 EXTNL PREC
WDM 4 PRCP ENGL PERLND 40 EXTNL PREC
WDM 4 PRCP ENGL PERLND 42 EXTNL PREC
WDM 4 PRCP ENGL PERLND 44 EXTNL PREC
WDM 4 PRCP ENGL PERLND 46 EXTNL PREC
WDM 4 PRCP ENGL PERLND 48 EXTNL PREC
WDM 4 PRCP ENGL PERLND 50 EXTNL PREC
WDM 4 PRCP ENGL PERLND 52 EXTNL PREC
WDM 4 PRCP ENGL PERLND 54 EXTNL PREC
WDM 4 PRCP ENGL PERLND 56 EXTNL PREC
WDM 4 PRCP ENGL PERLND 94 EXTNL PREC
WDM 4 PRCP ENGL IMPLND 96 EXTNL PREC
WDM 6 EVAP ENGL PERLND 21 99 EXTNL PETINP
WDM 6 EVAP ENGL IMPLND 95 96 EXTNL PETINP
WDM 3 PRCP ENGL RCHRES 4 EXTNL PREC
WDM 3 PRCP ENGL RCHRES 5 EXTNL PREC
WDM 3 PRCP ENGL RCHRES 6 EXTNL PREC
WDM 4 PRCP ENGL RCHRES 8 EXTNL PREC
WDM 6 EVAP ENGL RCHRES 4 EXTNL POTEV
WDM 6 EVAP ENGL RCHRES 5 EXTNL POTEV
WDM 6 EVAP ENGL RCHRES 6 EXTNL POTEV
WDM 6 EVAP ENGL RCHRES 8 EXTNL POTEV
WDM 3 PRCP ENGL DISPLY 1 INPUT TIMSER
WDM 1 FLOW ENGL DISPLY 2 INPUT TIMSER

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

WDM      1 FLOW      ENGL                      DISPLY  3      INPUT TIMSER
WDM      1 FLOW      ENGL                      .000029  DISPLY  4      INPUT TIMSER
WDM      2 FLOW      ENGL                      DISPLY  5      INPUT TIMSER
WDM      2 FLOW      ENGL                      DISPLY  6      INPUT TIMSER
WDM      2 FLOW      ENGL                      .000016  DISPLY  7      INPUT TIMSER
***
*** Note: The above MULTFACTORS converts cubic feet per second ***
*** to inches of runoff per 15 minutes. ***
***
END EXT SOURCES
***

EXT TARGETS
***
*** Specifies the time series which are output from operations ***
*** to external WDM files. ***
*** Note: MULTFACTOR 48.4 converts acre-feet of runoff per ***
*** 15-minute interval to cubic feet per second. ***
***
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Tgap Amd ***
<Name> # <Name> # #<-factor->strg <Name> # <Name> tem strg strg***
RCHRES 10 HYDR OVOL 1 1 48.4SAME WDM 7 SFLO ENGL REPL***
RCHRES 24 HYDR ROVOL 1 48.4SAME WDM 8 SFLO ENGL REPL***
END EXT TARGETS
***

NETWORK
***
*** Specifies the time series which are passed between ***
*** operations. ***
***
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name> # <Name> # #<-factor->strg <Name> # # <Name> # # ***
***
*** The following linkages pass total outflow (PERO), ***
*** ground-water flow (AGWO), subsurface flow (IFWO), or ***
*** overland flow (SURO) to assigned stream reaches (RCHRES). ***
***
*** Note: MULTFACTORS for converting inches to acre/feet = ***
*** area (in acres)/12 ***
***
*** SUB-BASIN WL1 ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EFFECTIVE IMPERVIOUS AREA (EIA) DRAINS TO ADJACENT PERLND ***
*** (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 23 PWATER AGWO 6.531 RECHARGES INACTIVE GROUND WATER ***
PERLND 93 PWATER AGWO 1.077 RECHARGES INACTIVE GROUND WATER ***
IMPLND 95 IWATER SURO 1.571 DRAINS TO ADJACENT PERLND AND THEN ***
RECHARGES INACTIVE GROUND WATER ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WL2 ***
*** ALL GROUND-WATER FLOW (AGWO) DRAINS TO GROUND-WATER CONTROLLER ***
*** (RCHRES 50) ***
*** EIA RULES MODIFIED FOR 50% OF OUTWASH AREAS - SEE REPORT ***
*** SPARSE RESIDENTIAL - 0% EIA ***
*** MODERATE RESIDENTIAL - 0% EIA ***
*** SUBURBAN RESIDENTIAL - 0% EIA ***
*** HIGH DENSITY RESIDENTIAL - 24% EIA ***
*** MEDIUM COMMERCIAL / LIGHT INDUSTRIAL - 24% EIA ***
*** HEAVY COMMERCIAL / INDUSTRIAL - 58% EIA ***
PERLND 21 PWATER SURO 4.950 RCHRES 2 EXTNL IVOL
PERLND 23 PWATER SURO 24.218 RCHRES 2 EXTNL IVOL
PERLND 45 PWATER SURO 0.500 RCHRES 2 EXTNL IVOL
PERLND 47 PWATER SURO 1.701 RCHRES 2 EXTNL IVOL
PERLND 51 PWATER SURO 1.289 RCHRES 2 EXTNL IVOL
PERLND 53 PWATER SURO 5.798 RCHRES 2 EXTNL IVOL
PERLND 21 PWATER IFWO 4.950 RCHRES 2 EXTNL IVOL
PERLND 23 PWATER IFWO 24.218 RCHRES 2 EXTNL IVOL
PERLND 45 PWATER IFWO 0.500 RCHRES 2 EXTNL IVOL
PERLND 47 PWATER IFWO 1.701 RCHRES 2 EXTNL IVOL
PERLND 51 PWATER IFWO 1.289 RCHRES 2 EXTNL IVOL
PERLND 53 PWATER IFWO 5.798 RCHRES 2 EXTNL IVOL
PERLND 97 PWATER AGWO 4.950 RCHRES 50 EXTNL IVOL
PERLND 98 PWATER AGWO 24.218 RCHRES 50 EXTNL IVOL
PERLND 45 PWATER AGWO 0.500 RCHRES 50 EXTNL IVOL
PERLND 47 PWATER AGWO 1.701 RCHRES 50 EXTNL IVOL
PERLND 51 PWATER AGWO 1.289 RCHRES 50 EXTNL IVOL
PERLND 53 PWATER AGWO 5.798 RCHRES 50 EXTNL IVOL
IMPLND 95 IWATER SURO 4.520 RCHRES 2 EXTNL IVOL
***
*** SUB-BASIN WL3 ***
*** CLOSED SUBBASIN - ALL GROUND-WATER FLOW (AGWO) RECHARGES ***
*** GROUND-WATER CONTROLLER (RCHRES 50) ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 97 PWATER AGWO 14.986 RCHRES 50 EXTNL IVOL
PERLND 98 PWATER AGWO 40.384 RCHRES 50 EXTNL IVOL
PERLND 45 PWATER AGWO 3.271 RCHRES 50 EXTNL IVOL
PERLND 47 PWATER AGWO 0.107 RCHRES 50 EXTNL IVOL
PERLND 51 PWATER AGWO 0.715 RCHRES 50 EXTNL IVOL
PERLND 53 PWATER AGWO 0.217 RCHRES 50 EXTNL IVOL
PERLND 93 PWATER AGWO 0.046 RCHRES 50 EXTNL IVOL
IMPLND 95 IWATER SURO 5.579 DRAINS TO ADJACENT PERLND ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WL4 ***
*** ALL GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 5 ***
PERLND  21  PWATER  SURO           20.003    RCHRES   4    EXTNL  IVOL
PERLND  23  PWATER  SURO           14.672    RCHRES   4    EXTNL  IVOL
PERLND  47  PWATER  SURO            0.546    RCHRES   4    EXTNL  IVOL
PERLND  53  PWATER  SURO            1.354    RCHRES   4    EXTNL  IVOL
PERLND  93  PWATER  SURO           14.835    RCHRES   4    EXTNL  IVOL
PERLND  21  PWATER  IFWO           20.003    RCHRES   4    EXTNL  IVOL
PERLND  23  PWATER  IFWO           14.672    RCHRES   4    EXTNL  IVOL
PERLND  47  PWATER  IFWO            0.546    RCHRES   4    EXTNL  IVOL
PERLND  53  PWATER  IFWO            1.354    RCHRES   4    EXTNL  IVOL
PERLND  93  PWATER  IFWO           14.835    RCHRES   4    EXTNL  IVOL
PERLND  21  PWATER  AGWO           20.003    RCHRES   5    EXTNL  IVOL
PERLND  23  PWATER  AGWO           14.672    RCHRES   5    EXTNL  IVOL
PERLND  47  PWATER  AGWO            0.546    RCHRES   5    EXTNL  IVOL
PERLND  53  PWATER  AGWO            1.354    RCHRES   5    EXTNL  IVOL
PERLND  93  PWATER  AGWO           14.835    RCHRES   5    EXTNL  IVOL
IMPLND  95  IWATER  SURO            4.531    RCHRES   4    EXTNL  IVOL
***
*** SUB-BASIN WL5 ***
PERLND  21  PWATER  SURO           23.923    RCHRES   5    EXTNL  IVOL
PERLND  23  PWATER  SURO           25.544    RCHRES   5    EXTNL  IVOL
PERLND  53  PWATER  SURO            0.204    RCHRES   5    EXTNL  IVOL
PERLND  93  PWATER  SURO            8.590    RCHRES   5    EXTNL  IVOL
PERLND  21  PWATER  IFWO           23.923    RCHRES   5    EXTNL  IVOL
PERLND  23  PWATER  IFWO           25.544    RCHRES   5    EXTNL  IVOL
PERLND  53  PWATER  IFWO            0.204    RCHRES   5    EXTNL  IVOL
PERLND  93  PWATER  IFWO            8.590    RCHRES   5    EXTNL  IVOL
PERLND  21  PWATER  AGWO           23.923    RCHRES   5    EXTNL  IVOL
PERLND  23  PWATER  AGWO           25.544    RCHRES   5    EXTNL  IVOL
PERLND  53  PWATER  AGWO            0.204    RCHRES   5    EXTNL  IVOL
PERLND  93  PWATER  AGWO            8.590    RCHRES   5    EXTNL  IVOL
IMPLND  95  IWATER  SURO            6.131    RCHRES   5    EXTNL  IVOL

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WL5A ***
*** CLOSED SUBBASIN - 35% GROUND-WATER FLOW (AGWO) DISCHARGES ***
      AT RCHRES 5 ***
*** 65% GROUND-WATER FLOW (AGWO) RECHARGES GROUND-WATER CONTROLLER ***
*** (RCHRES 50)
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 21 PWATER AGWO          16.933      RCHRES 5      EXTNL IVOL
PERLND 23 PWATER AGWO          14.457      RCHRES 5      EXTNL IVOL
PERLND 45 PWATER AGWO           0.304      RCHRES 5      EXTNL IVOL
PERLND 47 PWATER AGWO           2.675      RCHRES 5      EXTNL IVOL
PERLND 49 PWATER AGWO           1.292      RCHRES 5      EXTNL IVOL
PERLND 51 PWATER AGWO           0.044      RCHRES 5      EXTNL IVOL
PERLND 53 PWATER AGWO           0.066      RCHRES 5      EXTNL IVOL
PERLND 55 PWATER AGWO           0.032      RCHRES 5      EXTNL IVOL
PERLND 93 PWATER AGWO           0.180      RCHRES 5      EXTNL IVOL
PERLND 25 PWATER AGWO          24.305      RCHRES 5      EXTNL IVOL
PERLND 97 PWATER AGWO          31.477      RCHRES 50     EXTNL IVOL
PERLND 98 PWATER AGWO          26.848      RCHRES 50     EXTNL IVOL
PERLND 45 PWATER AGWO           0.564      RCHRES 50     EXTNL IVOL
PERLND 47 PWATER AGWO           4.967      RCHRES 50     EXTNL IVOL
PERLND 49 PWATER AGWO           2.400      RCHRES 50     EXTNL IVOL
PERLND 51 PWATER AGWO           0.082      RCHRES 50     EXTNL IVOL
PERLND 53 PWATER AGWO           0.122      RCHRES 50     EXTNL IVOL
PERLND 55 PWATER AGWO           0.059      RCHRES 50     EXTNL IVOL
PERLND 93 PWATER AGWO           0.333      RCHRES 50     EXTNL IVOL
PERLND 99 PWATER AGWO          45.138      RCHRES 50     EXTNL IVOL
IMPLND 95 IWATER SURO           2.723      DRAINS TO ADJACENT PERLND ***
***
*** SUB-BASIN WL5B ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 21 PWATER AGWO           9.650      RECHARGES INACTIVE GROUND WATER ***
PERLND 23 PWATER AGWO          21.290      RECHARGES INACTIVE GROUND WATER ***
IMPLND 95 IWATER SURO           1.340      DRAINS TO ADJACENT PERLND AND THEN ***
                                         RECHARGES INACTIVE GROUND WATER ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WL6 ***
*** 50% GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 6 ***
*** 50% GROUND-WATER FLOW (AGWO) RECHARGES GROUND-WATER CONTROLLER ***
*** (RCHRES 50) ***
*** 15% EIA DRAINS TO OGMILD (ACCOUNTED FOR IN AREA FOR OGMILD), ***
*** 85% DRAINS TO RCHRES 6 ***

PERLND 21 PWATER SURO      24.582    RCHRES 6    EXTNL  IVOL
PERLND 23 PWATER SURO      29.588    RCHRES 6    EXTNL  IVOL
PERLND 45 PWATER SURO       1.910    RCHRES 6    EXTNL  IVOL
PERLND 47 PWATER SURO       0.500    RCHRES 6    EXTNL  IVOL
PERLND 49 PWATER SURO       0.180    RCHRES 6    EXTNL  IVOL
PERLND 51 PWATER SURO       0.610    RCHRES 6    EXTNL  IVOL
PERLND 53 PWATER SURO       0.230    RCHRES 6    EXTNL  IVOL
PERLND 55 PWATER SURO       0.470    RCHRES 6    EXTNL  IVOL
PERLND 93 PWATER SURO       7.890    RCHRES 6    EXTNL  IVOL
PERLND 21 PWATER IFWO      24.582    RCHRES 6    EXTNL  IVOL
PERLND 23 PWATER IFWO      29.588    RCHRES 6    EXTNL  IVOL
PERLND 45 PWATER IFWO       1.910    RCHRES 6    EXTNL  IVOL
PERLND 47 PWATER IFWO       0.500    RCHRES 6    EXTNL  IVOL
PERLND 49 PWATER IFWO       0.180    RCHRES 6    EXTNL  IVOL
PERLND 51 PWATER IFWO       0.610    RCHRES 6    EXTNL  IVOL
PERLND 53 PWATER IFWO       0.230    RCHRES 6    EXTNL  IVOL
PERLND 55 PWATER IFWO       0.470    RCHRES 6    EXTNL  IVOL
PERLND 93 PWATER IFWO       7.890    RCHRES 6    EXTNL  IVOL
PERLND 21 PWATER AGWO      12.291    RCHRES 6    EXTNL  IVOL
PERLND 23 PWATER AGWO      14.794    RCHRES 6    EXTNL  IVOL
PERLND 45 PWATER AGWO       0.955    RCHRES 6    EXTNL  IVOL
PERLND 47 PWATER AGWO       0.250    RCHRES 6    EXTNL  IVOL
PERLND 49 PWATER AGWO       0.090    RCHRES 6    EXTNL  IVOL
PERLND 51 PWATER AGWO       0.305    RCHRES 6    EXTNL  IVOL
PERLND 53 PWATER AGWO       0.115    RCHRES 6    EXTNL  IVOL
PERLND 55 PWATER AGWO       0.235    RCHRES 6    EXTNL  IVOL
PERLND 93 PWATER AGWO       3.945    RCHRES 6    EXTNL  IVOL
PERLND 97 PWATER AGWO      12.291    RCHRES 50   EXTNL  IVOL
PERLND 98 PWATER AGWO      14.794    RCHRES 50   EXTNL  IVOL
PERLND 45 PWATER AGWO       0.955    RCHRES 50   EXTNL  IVOL
PERLND 47 PWATER AGWO       0.250    RCHRES 50   EXTNL  IVOL
PERLND 49 PWATER AGWO       0.090    RCHRES 50   EXTNL  IVOL
PERLND 51 PWATER AGWO       0.305    RCHRES 50   EXTNL  IVOL
PERLND 53 PWATER AGWO       0.115    RCHRES 50   EXTNL  IVOL
PERLND 55 PWATER AGWO       0.235    RCHRES 50   EXTNL  IVOL
PERLND 93 PWATER AGWO       3.945    RCHRES 50   EXTNL  IVOL
IMPLND 95 IWATER SURO       7.520    RCHRES 6    EXTNL  IVOL

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WL6A ***
*** CLOSED SUBBASIN - NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 21 PWATER AGWO      35.136 RECHARGES INACTIVE GROUND WATER ***
PERLND 23 PWATER AGWO      36.342 RECHARGES INACTIVE GROUND WATER ***
PERLND 45 PWATER AGWO       0.440 RECHARGES INACTIVE GROUND WATER ***
PERLND 47 PWATER AGWO       4.387 RECHARGES INACTIVE GROUND WATER ***
PERLND 49 PWATER AGWO       1.599 RECHARGES INACTIVE GROUND WATER ***
PERLND 53 PWATER AGWO       0.168 RECHARGES INACTIVE GROUND WATER ***
PERLND 55 PWATER AGWO       0.022 RECHARGES INACTIVE GROUND WATER ***
PERLND 93 PWATER AGWO       1.558 RECHARGES INACTIVE GROUND WATER ***
IMPLND 95 IWATER SURO       2.030 DRAINS TO ADJACENT PERLND AND THEN ***
                                RECHARGES INACTIVE GROUND WATER ***
***
*** SUB-BASIN WL6B ***
*** ALL GROUND-WATER FLOW (AGWO) DRAINS OUT OF THIS BASIN - ***
*** INACTIVE GROUND WATER ***
*** 85% EIA DRAINS TO RCHRES 6, 15% DRAINS TO ADJACENT PERLND ***
*** (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 21 PWATER AGWO       5.404 INACTIVE GROUND WATER ***
PERLND 23 PWATER AGWO      13.808 INACTIVE GROUND WATER ***
PERLND 45 PWATER AGWO       0.006 INACTIVE GROUND WATER ***
PERLND 47 PWATER AGWO       0.113 INACTIVE GROUND WATER ***
PERLND 49 PWATER AGWO       0.046 INACTIVE GROUND WATER ***
PERLND 21 PWATER IFWO       5.404 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER IFWO      13.808 RCHRES 6 EXTNL IVOL
PERLND 45 PWATER IFWO       0.006 RCHRES 6 EXTNL IVOL
PERLND 47 PWATER IFWO       0.113 RCHRES 6 EXTNL IVOL
PERLND 49 PWATER IFWO       0.046 RCHRES 6 EXTNL IVOL
PERLND 21 PWATER SURO       5.404 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER SURO      13.808 RCHRES 6 EXTNL IVOL
PERLND 45 PWATER SURO       0.006 RCHRES 6 EXTNL IVOL
PERLND 47 PWATER SURO       0.113 RCHRES 6 EXTNL IVOL
PERLND 49 PWATER SURO       0.046 RCHRES 6 EXTNL IVOL
IMPLND 95 IWATER SURO       2.916 RCHRES 6 EXTNL IVOL
***
*** SUB-BASIN WL6C ***
*** ALL GROUND-WATER FLOW (AGWO) DRAINS OUT OF THIS BASIN - ***
*** INACTIVE GROUND WATER ***
*** 85% EIA DRAINS TO RCHRES 6, 15% DRAINS TO ADJACENT PERLND ***
*** (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 21 PWATER AGWO       6.730 INACTIVE GROUND WATER ***
PERLND 23 PWATER AGWO       8.840 INACTIVE GROUND WATER ***
PERLND 93 PWATER AGWO       0.080 INACTIVE GROUND WATER ***
PERLND 21 PWATER IFWO       6.730 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER IFWO       8.840 RCHRES 6 EXTNL IVOL
PERLND 93 PWATER IFWO       0.080 RCHRES 6 EXTNL IVOL
PERLND 21 PWATER SURO       6.730 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER SURO       8.840 RCHRES 6 EXTNL IVOL
PERLND 93 PWATER SURO       0.080 RCHRES 6 EXTNL IVOL
IMPLND 95 IWATER SURO       0.340 RCHRES 6 EXTNL IVOL

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WL6D ***
*** ALL GROUND-WATER FLOW (AGWO) DRAINS OUT OF THIS BASIN - ***
*** INACTIVE GROUND WATER ***
PERLND 21 PWATER AGWO 0.250 INACTIVE GROUND WATER ***
PERLND 23 PWATER AGWO 3.300 INACTIVE GROUND WATER ***
PERLND 21 PWATER IFWO 0.250 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER IFWO 3.300 RCHRES 6 EXTNL IVOL
PERLND 21 PWATER SURO 0.250 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER SURO 3.300 RCHRES 6 EXTNL IVOL
IMPLND 95 IWATER SURO 0.990 RCHRES 6 EXTNL IVOL
***
*** SUB-BASIN WL6E ***
*** 50% GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 6 ***
*** 50% GROUND-WATER FLOW (AGWO) DRAINS TO GROUND-WATER CONTROLLER ***
*** (RCHRES 50) ***
PERLND 97 PWATER AGWO 2.140 RCHRES 50 EXTNL IVOL
PERLND 98 PWATER AGWO 6.580 RCHRES 50 EXTNL IVOL
PERLND 53 PWATER AGWO 0.170 RCHRES 50 EXTNL IVOL
PERLND 93 PWATER AGWO 0.265 RCHRES 50 EXTNL IVOL
PERLND 21 PWATER AGWO 2.140 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER AGWO 6.580 RCHRES 6 EXTNL IVOL
PERLND 53 PWATER AGWO 0.170 RCHRES 6 EXTNL IVOL
PERLND 93 PWATER AGWO 0.265 RCHRES 6 EXTNL IVOL
PERLND 21 PWATER IFWO 4.280 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER IFWO 13.160 RCHRES 6 EXTNL IVOL
PERLND 53 PWATER IFWO 0.340 RCHRES 6 EXTNL IVOL
PERLND 93 PWATER IFWO 0.530 RCHRES 6 EXTNL IVOL
PERLND 21 PWATER SURO 4.280 RCHRES 6 EXTNL IVOL
PERLND 23 PWATER SURO 13.160 RCHRES 6 EXTNL IVOL
PERLND 53 PWATER SURO 0.340 RCHRES 6 EXTNL IVOL
PERLND 93 PWATER SURO 0.530 RCHRES 6 EXTNL IVOL
IMPLND 95 IWATER SURO 3.960 RCHRES 6 EXTNL IVOL
***
*** SUB-BASIN WL7 ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 21 PWATER AGWO 1.305 RECHARGES INACTIVE GROUND WATER ***
PERLND 23 PWATER AGWO 12.847 RECHARGES INACTIVE GROUND WATER ***
PERLND 47 PWATER AGWO 0.878 RECHARGES INACTIVE GROUND WATER ***
PERLND 53 PWATER AGWO 1.329 RECHARGES INACTIVE GROUND WATER ***
IMPLND 95 IWATER SURO 1.962 DRAINS TO ADJACENT PERLND AND THEN ***
RECHARGES INACTIVE GROUND WATER ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

*** SUB-BASIN WL8 ***
*** ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 8 ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 22 PWATER AGWO          5.540      RCHRES 8      EXTNL IVOL
PERLND 24 PWATER AGWO         11.048      RCHRES 8      EXTNL IVOL
PERLND 46 PWATER AGWO          0.750      RCHRES 8      EXTNL IVOL
PERLND 48 PWATER AGWO          0.870      RCHRES 8      EXTNL IVOL
PERLND 52 PWATER AGWO          0.180      RCHRES 8      EXTNL IVOL
PERLND 54 PWATER AGWO          1.956      RCHRES 8      EXTNL IVOL
PERLND 56 PWATER AGWO          1.570      RCHRES 8      EXTNL IVOL
PERLND 94 PWATER AGWO          3.228      RCHRES 8      EXTNL IVOL
IMPLND 96 IWATER SURO          2.910      DRAINS TO ADJACENT PERLND ***
***

*** SUB-BASIN WL1A ***
*** CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT ***
*** RCHRES 17 ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 22 PWATER AGWO          0.710      RCHRES 17     EXTNL IVOL
PERLND 24 PWATER AGWO          3.972      RCHRES 17     EXTNL IVOL
IMPLND 96 IWATER SURO          1.620      DRAINS TO ADJACENT PERLND ***
***

*** SUB-BASIN WL8A ***
*** CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT ***
*** RCHRES 17 ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 22 PWATER AGWO          0.499      RCHRES 17     EXTNL IVOL
PERLND 24 PWATER AGWO         15.452      RCHRES 17     EXTNL IVOL
PERLND 52 PWATER AGWO          1.605      RCHRES 17     EXTNL IVOL
PERLND 54 PWATER AGWO          1.241      RCHRES 17     EXTNL IVOL
PERLND 56 PWATER AGWO          1.112      RCHRES 17     EXTNL IVOL
PERLND 94 PWATER AGWO          0.762      RCHRES 17     EXTNL IVOL
IMPLND 96 IWATER SURO          4.447      DRAINS TO ADJACENT PERLND ***
***

*** SUB-BASIN WL8B ***
*** CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT ***
*** RCHRES 17 ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 22 PWATER AGWO          0.110      RCHRES 17     EXTNL IVOL
PERLND 24 PWATER AGWO          3.612      RCHRES 17     EXTNL IVOL
IMPLND 96 IWATER SURO          0.830      DRAINS TO ADJACENT PERLND ***
***

*** SUB-BASIN WL9 ***
*** ALL GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 17 ***
*** ALL SHALLOW SUBSURFACE FLOW (IFWO) DRAINS TO RCHRES 10 ***
*** EIA RULES MODIFIED - SEE NOTES FOR SUBBASIN WL2 IN THIS ***
*** NETWORK BLOCK ***
PERLND 22 PWATER SURO          1.680      RCHRES 9      EXTNL IVOL
PERLND 24 PWATER SURO         21.486      RCHRES 9      EXTNL IVOL
PERLND 22 PWATER IFWO          1.680      RCHRES 10     EXTNL IVOL
PERLND 24 PWATER IFWO         21.486      RCHRES 10     EXTNL IVOL
PERLND 22 PWATER AGWO          1.680      RCHRES 17     EXTNL IVOL
PERLND 24 PWATER AGWO         21.486      RCHRES 17     EXTNL IVOL
IMPLND 96 IWATER SURO          3.262      RCHRES 9      EXTNL IVOL

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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*** SUB-BASIN WL9A ***
*** CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT ***
*** RCHRES 17
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 22 PWATER AGWO          0.700      RCHRES 17      EXTNL IVOL
PERLND 24 PWATER AGWO          5.009      RCHRES 17      EXTNL IVOL
IMPLND 96 IWATER SURO          1.610      DRAINS TO ADJACENT PERLND ***
***

*** SUB-BASIN WL10 ***
*** ALL GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 17 ***
*** NO OVERLAND FLOW (SURO) OR SHALLOW SUBSURFACE FLOW (IFWO) ***
*** DRAINS FROM SATURATED SEGMENTS TO RCHRES 10 ***
*** 50% SURO AND IFWO FROM OUTWASH SEGMENTS DRAINS TO RCHRES 10 - ***
*** 50% SURO AND IFWO FROM OUTWASH SEGMENTS RECHARGE ***
*** GROUND WATER ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 22 PWATER SURO          6.228      RCHRES 10      EXTNL IVOL
PERLND 24 PWATER SURO          5.122      RCHRES 10      EXTNL IVOL
PERLND 22 PWATER IFWO          6.228      RCHRES 10      EXTNL IVOL
PERLND 24 PWATER IFWO          5.122      RCHRES 10      EXTNL IVOL
PERLND 22 PWATER AGWO          12.456     RCHRES 17      EXTNL IVOL
PERLND 24 PWATER AGWO          11.858     RCHRES 17      EXTNL IVOL
PERLND 94 PWATER AGWO          0.849      RCHRES 17      EXTNL IVOL
IMPLND 96 IWATER SURO          1.628      DRAINS TO ADJACENT PERLND ***
***

*** SUB-BASIN WL11 ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 22 PWATER AGWO          1.089      RECHARGES INACTIVE GROUND WATER ***
PERLND 24 PWATER AGWO          7.951      RECHARGES INACTIVE GROUND WATER ***
IMPLND 96 IWATER SURO          1.929      DRAINS TO ADJACENT PERLND AND THEN ***
                                         RECHARGES INACTIVE GROUND WATER ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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*** SUB-BASIN WL12 ***
*** 25% GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 17, ***
*** 25% DISCHARGES AT RCHRES 12, 50% RECHARGES INACTIVE ***
*** GROUND WATER ***
*** 25% EIA DRAINS TO RCHRES 12, 75% EIA DRAINS TO ADJACENT PERLND ***
*** (ACCOUNTED FOR IN PERLND AREAS) ***
*** NO SHALLOW SUBSURFACE FLOW (IFWO) DRAINS TO RCHRES 12 - ***
*** RECHARGES GROUND WATER ***

PERLND 22 PWATER SURO      1.454      RCHRES 12      EXTNL  IVOL
PERLND 24 PWATER SURO     24.235      RCHRES 12      EXTNL  IVOL
PERLND 40 PWATER SURO      0.929      RCHRES 12      EXTNL  IVOL
PERLND 42 PWATER SURO      0.037      RCHRES 12      EXTNL  IVOL
PERLND 52 PWATER SURO      0.411      RCHRES 12      EXTNL  IVOL
PERLND 54 PWATER SURO      1.012      RCHRES 12      EXTNL  IVOL
PERLND 56 PWATER SURO      0.784      RCHRES 12      EXTNL  IVOL
PERLND 94 PWATER SURO      0.046      RCHRES 12      EXTNL  IVOL
PERLND 22 PWATER AGWO      0.364      RCHRES 12      EXTNL  IVOL
PERLND 24 PWATER AGWO      6.059      RCHRES 12      EXTNL  IVOL
PERLND 40 PWATER AGWO      0.232      RCHRES 12      EXTNL  IVOL
PERLND 42 PWATER AGWO      0.009      RCHRES 12      EXTNL  IVOL
PERLND 52 PWATER AGWO      0.103      RCHRES 12      EXTNL  IVOL
PERLND 54 PWATER AGWO      0.253      RCHRES 12      EXTNL  IVOL
PERLND 56 PWATER AGWO      0.196      RCHRES 12      EXTNL  IVOL
PERLND 94 PWATER AGWO      0.012      RCHRES 12      EXTNL  IVOL
PERLND 22 PWATER AGWO      0.364      RCHRES 17      EXTNL  IVOL
PERLND 24 PWATER AGWO      6.059      RCHRES 17      EXTNL  IVOL
PERLND 40 PWATER AGWO      0.232      RCHRES 17      EXTNL  IVOL
PERLND 42 PWATER AGWO      0.009      RCHRES 17      EXTNL  IVOL
PERLND 52 PWATER AGWO      0.103      RCHRES 17      EXTNL  IVOL
PERLND 54 PWATER AGWO      0.253      RCHRES 17      EXTNL  IVOL
PERLND 56 PWATER AGWO      0.196      RCHRES 17      EXTNL  IVOL
PERLND 94 PWATER AGWO      0.012      RCHRES 17      EXTNL  IVOL
PERLND 22 PWATER AGWO      0.727      INACTIVE GROUND WATER ***
PERLND 24 PWATER AGWO     12.117      INACTIVE GROUND WATER ***
PERLND 40 PWATER AGWO      0.464      INACTIVE GROUND WATER ***
PERLND 42 PWATER AGWO      0.018      INACTIVE GROUND WATER ***
PERLND 52 PWATER AGWO      0.205      INACTIVE GROUND WATER ***
PERLND 54 PWATER AGWO      0.506      INACTIVE GROUND WATER ***
PERLND 56 PWATER AGWO      0.392      INACTIVE GROUND WATER ***
PERLND 94 PWATER AGWO      0.023      INACTIVE GROUND WATER ***
IMPLND 96 IWATER SURO      2.050      RCHRES 12      EXTNL  IVOL

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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*** SUB-BASIN WL13 ***
*** ALL GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 17 ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***
*** EIA RULES MODIFIED - SEE NOTES FOR SUBBASIN WL2 IN THIS ***
*** NETWORK BLOCK ***
PERLND 22 PWATER SURO          12.960      RCHRES 13      EXTNL  IVOL
PERLND 24 PWATER SURO          12.938      RCHRES 13      EXTNL  IVOL
PERLND 94 PWATER SURO          3.035      RCHRES 13      EXTNL  IVOL
PERLND 22 PWATER IFWO          12.960      RCHRES 13      EXTNL  IVOL
PERLND 24 PWATER IFWO          12.938      RCHRES 13      EXTNL  IVOL
PERLND 94 PWATER IFWO          3.035      RCHRES 13      EXTNL  IVOL
PERLND 22 PWATER AGWO          12.960      RCHRES 17      EXTNL  IVOL
PERLND 24 PWATER AGWO          12.938      RCHRES 17      EXTNL  IVOL
PERLND 94 PWATER AGWO          3.035      RCHRES 17      EXTNL  IVOL
IMPLND 96 IWATER SURO          3.962      RCHRES 13      EXTNL  IVOL
PERLND 48 PWATER PERO          0.960      DRAINS TO PERLND 22      ***
PERLND 54 PWATER PERO          0.810      DRAINS TO PERLND 24      ***
***

*** SUB-BASIN WL13A ***
*** CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT ***
*** RCHRES 17 ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 24 PWATER AGWO          6.372      RCHRES 17      EXTNL  IVOL
IMPLND 96 IWATER SURO          1.470      DRAINS TO ADJACENT PERLND      ***
***

*** SUB-BASIN WL14 ***
*** ALL GROUND-WATER FLOW (AGWO) AND SHALLOW SUBSURFACE FLOW (IFWO) ***
*** DISCHARGES AT RCHRES 17 ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***
*** EIA RULES MODIFIED - SEE NOTES FOR SUBBASIN WL2 IN THIS ***
*** NETWORK BLOCK ***
PERLND 22 PWATER SURO          1.668      RCHRES 14      EXTNL  IVOL
PERLND 24 PWATER SURO          5.102      RCHRES 14      EXTNL  IVOL
PERLND 22 PWATER IFWO          1.668      RCHRES 17      EXTNL  IVOL
PERLND 24 PWATER IFWO          5.102      RCHRES 17      EXTNL  IVOL
PERLND 22 PWATER AGWO          1.668      RCHRES 17      EXTNL  IVOL
PERLND 24 PWATER AGWO          5.102      RCHRES 17      EXTNL  IVOL
IMPLND 96 IWATER SURO          3.561      RCHRES 14      EXTNL  IVOL
PERLND 48 PWATER PERO          1.477      DRAINS TO PERLND 22      ***
PERLND 54 PWATER PERO          2.595      DRAINS TO PERLND 24      ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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***SUB-BASIN WL15 ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***
PERLND 22 PWATER SURO      12.139      RCHRES 15      EXTNL  IVOL
PERLND 24 PWATER SURO      12.337      RCHRES 15      EXTNL  IVOL
PERLND 34 PWATER SURO       0.033      RCHRES 15      EXTNL  IVOL
PERLND 36 PWATER SURO       2.402      RCHRES 15      EXTNL  IVOL
PERLND 40 PWATER SURO       0.065      RCHRES 15      EXTNL  IVOL
PERLND 42 PWATER SURO       2.536      RCHRES 15      EXTNL  IVOL
PERLND 94 PWATER SURO       1.498      RCHRES 15      EXTNL  IVOL
PERLND 22 PWATER IFWO      12.139      RCHRES 15      EXTNL  IVOL
PERLND 24 PWATER IFWO      12.337      RCHRES 15      EXTNL  IVOL
PERLND 34 PWATER IFWO       0.033      RCHRES 15      EXTNL  IVOL
PERLND 36 PWATER IFWO       2.402      RCHRES 15      EXTNL  IVOL
PERLND 40 PWATER IFWO       0.065      RCHRES 15      EXTNL  IVOL
PERLND 42 PWATER IFWO       2.536      RCHRES 15      EXTNL  IVOL
PERLND 94 PWATER IFWO       1.498      RCHRES 15      EXTNL  IVOL
PERLND 22 PWATER AGWO      12.139      RCHRES 15      EXTNL  IVOL
PERLND 24 PWATER AGWO      12.337      RCHRES 15      EXTNL  IVOL
PERLND 34 PWATER AGWO       0.033      RCHRES 15      EXTNL  IVOL
PERLND 36 PWATER AGWO       2.402      RCHRES 15      EXTNL  IVOL
PERLND 40 PWATER AGWO       0.065      RCHRES 15      EXTNL  IVOL
PERLND 42 PWATER AGWO       2.536      RCHRES 15      EXTNL  IVOL
PERLND 94 PWATER AGWO       1.498      RCHRES 15      EXTNL  IVOL
IMPLND 96 IWATER SURO       2.782      RCHRES 15      EXTNL  IVOL
PERLND 46 PWATER PERO       4.926      DRAINS TO PERLND 22      ***
PERLND 48 PWATER PERO       2.604      DRAINS TO PERLND 22      ***
PERLND 52 PWATER PERO       7.492      DRAINS TO PERLND 24      ***
PERLND 54 PWATER PERO       0.559      DRAINS TO PERLND 24      ***
***
*** SUB-BASIN WL16 ***
*** CLOSED BASIN: 50% GROUND-WATER FLOW (AGWO) DISCHARGES AT ***
*** RCHRES 17, 50% DRAINS OUT OF BASIN - INACTIVE GROUND WATER ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***
PERLND 22 PWATER AGWO       10.368      RCHRES 17      EXTNL  IVOL
PERLND 24 PWATER AGWO       11.526      RCHRES 17      EXTNL  IVOL
PERLND 22 PWATER AGWO       10.368      INACTIVE GROUND WATER      ***
PERLND 24 PWATER AGWO       11.526      INACTIVE GROUND WATER      ***
PERLND 46 PWATER PERO       0.205      DRAINS TO PERLND 22      ***
PERLND 48 PWATER PERO       2.432      DRAINS TO PERLND 22      ***
PERLND 50 PWATER PERO       0.498      DRAINS TO PERLND 22      ***
PERLND 54 PWATER PERO       0.497      DRAINS TO PERLND 24      ***
PERLND 56 PWATER PERO       0.050      DRAINS TO PERLND 24      ***
IMPLND 96 IWATER SURO       6.072      DRAINS TO ADJACENT PERLND      ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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*** SUB-BASIN WL16A ***
*** CLOSED BASIN: 50% GROUND-WATER FLOW (AGWO) DISHCARGES AT ***
*** RCHRES 17, 50% DRAINS OUT OF BASIN - INACTIVE GROUND WATER ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***
PERLND 22 PWATER AGWO 35.721 RCHRES 17 EXTNL IVOL
PERLND 24 PWATER AGWO 21.082 RCHRES 17 EXTNL IVOL
PERLND 22 PWATER AGWO 35.721 INACTIVE GROUND WATER ***
PERLND 24 PWATER AGWO 21.082 INACTIVE GROUND WATER ***
PERLND 46 PWATER PERO 0.051 DRAINS TO PERLND 22 ***
PERLND 48 PWATER PERO 6.305 DRAINS TO PERLND 22 ***
PERLND 52 PWATER PERO 0.029 DRAINS TO PERLND 24 ***
PERLND 54 PWATER PERO 2.988 DRAINS TO PERLND 24 ***
IMPLND 96 IWATER SURO 9.596 DRAINS TO ADJACENT PERLND ***
***
*** SUB-BASIN WL17 ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***
PERLND 22 PWATER PERO 10.538 RCHRES 17 EXTNL IVOL
PERLND 24 PWATER PERO 0.709 RCHRES 17 EXTNL IVOL
PERLND 34 PWATER PERO 0.126 RCHRES 17 EXTNL IVOL
PERLND 36 PWATER PERO 3.396 RCHRES 17 EXTNL IVOL
PERLND 38 PWATER PERO 0.172 RCHRES 17 EXTNL IVOL
PERLND 42 PWATER PERO 0.090 RCHRES 17 EXTNL IVOL
PERLND 44 PWATER PERO 0.006 RCHRES 17 EXTNL IVOL
PERLND 94 PWATER PERO 7.992 RCHRES 17 EXTNL IVOL
IMPLND 96 IWATER SURO 1.324 RCHRES 17 EXTNL IVOL
PERLND 48 PWATER PERO 3.004 DRAINS TO PERLND 22 ***
PERLND 50 PWATER PERO 0.008 DRAINS TO PERLND 22 ***
PERLND 54 PWATER PERO 0.611 DRAINS TO PERLND 24 ***
***
***SUB-BASIN WL18 ***
PERLND 22 PWATER PERO 1.975 RCHRES 18 EXTNL IVOL
PERLND 24 PWATER PERO 4.668 RCHRES 18 EXTNL IVOL
PERLND 34 PWATER PERO 1.171 RCHRES 18 EXTNL IVOL
PERLND 36 PWATER PERO 3.138 RCHRES 18 EXTNL IVOL
PERLND 38 PWATER PERO 2.023 RCHRES 18 EXTNL IVOL
PERLND 40 PWATER PERO 2.204 RCHRES 18 EXTNL IVOL
PERLND 42 PWATER PERO 2.459 RCHRES 18 EXTNL IVOL
PERLND 44 PWATER PERO 0.744 RCHRES 18 EXTNL IVOL
PERLND 94 PWATER PERO 0.665 RCHRES 18 EXTNL IVOL
IMPLND 96 IWATER SURO 0.695 RCHRES 18 EXTNL IVOL

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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*** SUB-BASIN WL19 ***
*** ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 19 ***
*** (SPRING FED CREEK) ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***
PERLND 22 PWATER AGWO      21.594      RCHRES 19      EXTNL  IVOL
PERLND 24 PWATER AGWO      4.621      RCHRES 19      EXTNL  IVOL
PERLND 36 PWATER AGWO      0.082      RCHRES 19      EXTNL  IVOL
PERLND 38 PWATER AGWO      0.620      RCHRES 19      EXTNL  IVOL
PERLND 42 PWATER AGWO      0.522      RCHRES 19      EXTNL  IVOL
PERLND 44 PWATER AGWO      0.018      RCHRES 19      EXTNL  IVOL
PERLND 94 PWATER AGWO      0.013      RCHRES 19      EXTNL  IVOL
PERLND 46 PWATER PERO      8.422      DRAINS TO PERLND 22      ***
PERLND 54 PWATER PERO      1.882      DRAINS TO PERLND 24      ***
IMPLND 96 IWATER SURO      0.016      DRAINS TO ADJACENT PERLND ***
***

*** SUB-BASIN WL20 ***
*** 40% GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 20, ***
*** 60% DRAINS OUT OF BASIN - INACTIVE GROUND WATER ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***
PERLND 22 PWATER SURO      45.595      RCHRES 20      EXTNL  IVOL
PERLND 24 PWATER SURO      8.953      RCHRES 20      EXTNL  IVOL
PERLND 22 PWATER IFWO      45.595      RCHRES 20      EXTNL  IVOL
PERLND 24 PWATER IFWO      8.953      RCHRES 20      EXTNL  IVOL
PERLND 22 PWATER AGWO      18.238      RCHRES 20      EXTNL  IVOL
PERLND 24 PWATER AGWO      3.581      RCHRES 20      EXTNL  IVOL
IMPLND 96 IWATER SURO      1.749      RCHRES 20      EXTNL  IVOL
PERLND 22 PWATER AGWO      27.357      INACTIVE GROUND WATER      ***
PERLND 24 PWATER AGWO      5.371      INACTIVE GROUND WATER      ***
PERLND 46 PWATER PERO      1.600      DRAINS TO PERLND 22      ***
PERLND 48 PWATER PERO      23.519      DRAINS TO PERLND 22      ***
PERLND 52 PWATER PERO      0.286      DRAINS TO PERLND 24      ***
PERLND 54 PWATER PERO      4.988      DRAINS TO PERLND 24      ***
***

*** SUB-BASIN WL20A ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND 22 PWATER AGWO      15.000      RECHARGES INACTIVE GROUND WATER ***
PERLND 24 PWATER AGWO      0.068      RECHARGES INACTIVE GROUND WATER ***
PERLND 46 PWATER AGWO      0.277      RECHARGES INACTIVE GROUND WATER ***
PERLND 48 PWATER AGWO      16.068      RECHARGES INACTIVE GROUND WATER ***
IMPLND 96 IWATER SURO      0.032      DRAINS TO ADJACENT PERLND AND THEN ***
                                   RECHARGES INACTIVE GROUND WATER ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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*** SUB-BASIN WL21 ***
*** 75% GROUND-WATER FLOW (AGWO) FROM OUTWASH SEGMENTS DISCHARGES AT ***
*** RCHRES 21, 25% DISCHARGES AT RCHRES 24 ***
*** ALL TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED FOR ***
*** IN AREAS FOR OUTWASHES) ***

PERLND 22 PWATER SURO      19.201      RCHRES 21      EXTNL  IVOL
PERLND 24 PWATER SURO       0.865      RCHRES 21      EXTNL  IVOL
PERLND 22 PWATER IFWO      19.201      RCHRES 21      EXTNL  IVOL
PERLND 24 PWATER IFWO       0.865      RCHRES 21      EXTNL  IVOL
PERLND 22 PWATER AGWO      14.401      RCHRES 21      EXTNL  IVOL
PERLND 24 PWATER AGWO       0.649      RCHRES 21      EXTNL  IVOL
PERLND 22 PWATER AGWO       4.800      RCHRES 24      EXTNL  IVOL
PERLND 24 PWATER AGWO       0.216      RCHRES 24      EXTNL  IVOL
PERLND 34 PWATER PERO       0.007      RCHRES 21      EXTNL  IVOL
PERLND 36 PWATER PERO       1.215      RCHRES 21      EXTNL  IVOL
PERLND 38 PWATER PERO       0.574      RCHRES 21      EXTNL  IVOL
PERLND 40 PWATER PERO       0.517      RCHRES 21      EXTNL  IVOL
PERLND 42 PWATER PERO       7.024      RCHRES 21      EXTNL  IVOL
PERLND 44 PWATER PERO       1.255      RCHRES 21      EXTNL  IVOL
PERLND 94 PWATER PERO       1.257      RCHRES 21      EXTNL  IVOL
IMPLND 96 IWATER SURO       0.025      RCHRES 21      EXTNL  IVOL
PERLND 46 PWATER PERO       0.080      DRAINS TO PERLND 22      ***
PERLND 48 PWATER PERO       4.654      DRAINS TO PERLND 22      ***
PERLND 52 PWATER PERO       0.032      DRAINS TO PERLND 24      ***
PERLND 54 PWATER PERO       0.483      DRAINS TO PERLND 24      ***
***

*** SUB-BASIN WL22 ***
*** 50% GROUND-WATER FLOW (AGWO) DISCHARGES AT RCHRES 22, ***
*** 50% DISCHARGES AT RCHRES 24 ***

PERLND 22 PWATER SURO      16.005      RCHRES 22      EXTNL  IVOL
PERLND 24 PWATER SURO       4.762      RCHRES 22      EXTNL  IVOL
PERLND 34 PWATER SURO       0.051      RCHRES 22      EXTNL  IVOL
PERLND 36 PWATER SURO       5.562      RCHRES 22      EXTNL  IVOL
PERLND 38 PWATER SURO       0.422      RCHRES 22      EXTNL  IVOL
PERLND 40 PWATER SURO       0.422      RCHRES 22      EXTNL  IVOL
PERLND 42 PWATER SURO       1.971      RCHRES 22      EXTNL  IVOL
PERLND 44 PWATER SURO       0.098      RCHRES 22      EXTNL  IVOL
PERLND 46 PWATER SURO       1.809      RCHRES 22      EXTNL  IVOL
PERLND 48 PWATER SURO       0.066      RCHRES 22      EXTNL  IVOL
PERLND 52 PWATER SURO       1.652      RCHRES 22      EXTNL  IVOL
PERLND 54 PWATER SURO       0.052      RCHRES 22      EXTNL  IVOL
PERLND 94 PWATER SURO       2.869      RCHRES 22      EXTNL  IVOL
PERLND 22 PWATER IFWO      16.005      RCHRES 22      EXTNL  IVOL
PERLND 24 PWATER IFWO       4.762      RCHRES 22      EXTNL  IVOL
PERLND 34 PWATER IFWO       0.051      RCHRES 22      EXTNL  IVOL
PERLND 36 PWATER IFWO       5.562      RCHRES 22      EXTNL  IVOL
PERLND 38 PWATER IFWO       0.422      RCHRES 22      EXTNL  IVOL
PERLND 40 PWATER IFWO       0.422      RCHRES 22      EXTNL  IVOL
PERLND 42 PWATER IFWO       1.971      RCHRES 22      EXTNL  IVOL
PERLND 44 PWATER IFWO       0.098      RCHRES 22      EXTNL  IVOL

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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*** SUB-BASIN WL22 --Continued ***
PERLND  46 PWATER IFWO          1.809    RCHRES  22    EXTNL  IVOL
PERLND  48 PWATER IFWO          0.066    RCHRES  22    EXTNL  IVOL
PERLND  52 PWATER IFWO          1.652    RCHRES  22    EXTNL  IVOL
PERLND  54 PWATER IFWO          0.052    RCHRES  22    EXTNL  IVOL
PERLND  94 PWATER IFWO          2.869    RCHRES  22    EXTNL  IVOL
PERLND  22 PWATER AGWO          8.003    RCHRES  22    EXTNL  IVOL
PERLND  24 PWATER AGWO          2.381    RCHRES  22    EXTNL  IVOL
PERLND  34 PWATER AGWO          0.026    RCHRES  22    EXTNL  IVOL
PERLND  36 PWATER AGWO          2.781    RCHRES  22    EXTNL  IVOL
PERLND  38 PWATER AGWO          0.211    RCHRES  22    EXTNL  IVOL
PERLND  40 PWATER AGWO          0.211    RCHRES  22    EXTNL  IVOL
PERLND  42 PWATER AGWO          0.986    RCHRES  22    EXTNL  IVOL
PERLND  44 PWATER AGWO          0.049    RCHRES  22    EXTNL  IVOL
PERLND  46 PWATER AGWO          0.905    RCHRES  22    EXTNL  IVOL
PERLND  48 PWATER AGWO          0.033    RCHRES  22    EXTNL  IVOL
PERLND  52 PWATER AGWO          0.826    RCHRES  22    EXTNL  IVOL
PERLND  54 PWATER AGWO          0.026    RCHRES  22    EXTNL  IVOL
PERLND  94 PWATER AGWO          1.434    RCHRES  22    EXTNL  IVOL
PERLND  22 PWATER AGWO          8.003    RCHRES  24    EXTNL  IVOL
PERLND  24 PWATER AGWO          2.381    RCHRES  24    EXTNL  IVOL
PERLND  34 PWATER AGWO          0.026    RCHRES  24    EXTNL  IVOL
PERLND  36 PWATER AGWO          2.781    RCHRES  24    EXTNL  IVOL
PERLND  38 PWATER AGWO          0.211    RCHRES  24    EXTNL  IVOL
PERLND  40 PWATER AGWO          0.211    RCHRES  24    EXTNL  IVOL
PERLND  42 PWATER AGWO          0.986    RCHRES  24    EXTNL  IVOL
PERLND  44 PWATER AGWO          0.049    RCHRES  24    EXTNL  IVOL
PERLND  46 PWATER AGWO          0.905    RCHRES  24    EXTNL  IVOL
PERLND  48 PWATER AGWO          0.033    RCHRES  24    EXTNL  IVOL
PERLND  52 PWATER AGWO          0.826    RCHRES  24    EXTNL  IVOL
PERLND  54 PWATER AGWO          0.026    RCHRES  24    EXTNL  IVOL
PERLND  94 PWATER AGWO          1.435    RCHRES  24    EXTNL  IVOL
IMPLND  96 IWATER SURO          1.930    RCHRES  22    EXTNL  IVOL
***
*** SUB-BASIN WL22A ***
*** CLOSED SUBBASIN: NO HYDROLOGIC CONNECTION TO BASIN ***
*** EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) ***
PERLND  46 PWATER AGWO          2.140    RECHARGES INACTIVE GROUND WATER ***
PERLND  52 PWATER AGWO          1.108    RECHARGES INACTIVE GROUND WATER ***
IMPLND  96 IWATER SURO          0.260    DRAINS TO ADJACENT PERLND AND THEN ***
                                         RECHARGES INACTIVE GROUND WATER ***

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**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

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*** SUB-BASIN WL23 ***
*** 30% GROUND-WATER FLOW (AGWO) FROM OUTWASH AND TILL SEGMENTS ***
*** DISCHARGES AT RCHRES 23, 70% AGWO FROM OUTWASH AND TILL ***
*** SEGMENTS DISCHARGES AT RCHRES 24 ***
*** 50% OF FOREST TILL SEGMENTS DRAIN TO OUTWASH SEGMENTS (ACCOUNTED ***
*** FOR IN AREAS FOR OUTWASHES) ***

PERLND 22 PWATER SURO      30.254    RCHRES 23    EXTNL  IVOL
PERLND 24 PWATER SURO      0.817    RCHRES 23    EXTNL  IVOL
PERLND 22 PWATER IFWO      30.254    RCHRES 23    EXTNL  IVOL
PERLND 24 PWATER IFWO      0.817    RCHRES 23    EXTNL  IVOL
PERLND 22 PWATER AGWO      9.076    RCHRES 23    EXTNL  IVOL
PERLND 24 PWATER AGWO      0.245    RCHRES 23    EXTNL  IVOL
PERLND 22 PWATER AGWO     21.178    RCHRES 24    EXTNL  IVOL
PERLND 24 PWATER AGWO      0.572    RCHRES 24    EXTNL  IVOL
PERLND 34 PWATER PERO      0.256    RCHRES 23    EXTNL  IVOL
PERLND 36 PWATER PERO     13.689    RCHRES 23    EXTNL  IVOL
PERLND 38 PWATER PERO      4.893    RCHRES 23    EXTNL  IVOL
PERLND 42 PWATER PERO      2.678    RCHRES 23    EXTNL  IVOL
PERLND 44 PWATER PERO      0.489    RCHRES 23    EXTNL  IVOL
PERLND 46 PWATER PERO      0.312    DRAINS TO PERLND 22    ***
PERLND 48 PWATER PERO     15.584    DRAINS TO PERLND 22    ***
PERLND 50 PWATER PERO      1.861    DRAINS TO PERLND 22    ***
PERLND 46 PWATER SURO      0.312    RCHRES 23    EXTNL  IVOL
PERLND 48 PWATER SURO     15.584    RCHRES 23    EXTNL  IVOL
PERLND 50 PWATER SURO      1.861    RCHRES 23    EXTNL  IVOL
PERLND 52 PWATER SURO      0.463    RCHRES 23    EXTNL  IVOL
PERLND 54 PWATER SURO      8.371    RCHRES 23    EXTNL  IVOL
PERLND 56 PWATER SURO      0.398    RCHRES 23    EXTNL  IVOL
PERLND 46 PWATER IFWO      0.312    RCHRES 23    EXTNL  IVOL
PERLND 48 PWATER IFWO     15.584    RCHRES 23    EXTNL  IVOL
PERLND 50 PWATER IFWO      1.861    RCHRES 23    EXTNL  IVOL
PERLND 52 PWATER IFWO      0.463    RCHRES 23    EXTNL  IVOL
PERLND 54 PWATER IFWO      8.371    RCHRES 23    EXTNL  IVOL
PERLND 56 PWATER IFWO      0.398    RCHRES 23    EXTNL  IVOL
PERLND 46 PWATER AGWO      0.094    RCHRES 23    EXTNL  IVOL
PERLND 48 PWATER AGWO      4.675    RCHRES 23    EXTNL  IVOL
PERLND 50 PWATER AGWO      0.558    RCHRES 23    EXTNL  IVOL
PERLND 52 PWATER AGWO      0.139    RCHRES 23    EXTNL  IVOL
PERLND 54 PWATER AGWO      2.511    RCHRES 23    EXTNL  IVOL
PERLND 56 PWATER AGWO      0.119    RCHRES 23    EXTNL  IVOL
PERLND 46 PWATER AGWO      0.218    RCHRES 24    EXTNL  IVOL
PERLND 48 PWATER AGWO     10.909    RCHRES 24    EXTNL  IVOL
PERLND 50 PWATER AGWO      1.303    RCHRES 24    EXTNL  IVOL
PERLND 52 PWATER AGWO      0.324    RCHRES 24    EXTNL  IVOL
PERLND 54 PWATER AGWO      5.860    RCHRES 24    EXTNL  IVOL
PERLND 56 PWATER AGWO      0.279    RCHRES 24    EXTNL  IVOL
PERLND 94 PWATER PERO      4.135    RCHRES 23    EXTNL  IVOL
IMPLND 96 IWATER SURO      1.220    RCHRES 23    EXTNL  IVOL

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

\*\*\*SUB-BASIN WL24 \*\*\*

PERLND	22	PWATER	PERO	2.188	RCHRES	24	EXTNL	IVOL
PERLND	24	PWATER	PERO	1.310	RCHRES	24	EXTNL	IVOL
PERLND	36	PWATER	PERO	1.823	RCHRES	24	EXTNL	IVOL
PERLND	38	PWATER	PERO	0.292	RCHRES	24	EXTNL	IVOL
PERLND	42	PWATER	PERO	1.128	RCHRES	24	EXTNL	IVOL
PERLND	44	PWATER	PERO	0.122	RCHRES	24	EXTNL	IVOL
IMPLND	96	IWATER	SURO	0.052	RCHRES	24	EXTNL	IVOL

\*\*\*

\*\*\*SUB-BASIN WL25 \*\*\*

PERLND	22	PWATER	PERO	2.082	RCHRES	25	EXTNL	IVOL
PERLND	24	PWATER	PERO	1.917	RCHRES	25	EXTNL	IVOL
PERLND	36	PWATER	PERO	2.888	RCHRES	25	EXTNL	IVOL
PERLND	38	PWATER	PERO	1.726	RCHRES	25	EXTNL	IVOL
PERLND	42	PWATER	PERO	2.718	RCHRES	25	EXTNL	IVOL
PERLND	44	PWATER	PERO	0.248	RCHRES	25	EXTNL	IVOL
PERLND	46	PWATER	PERO	3.994	RCHRES	25	EXTNL	IVOL
PERLND	48	PWATER	PERO	0.027	RCHRES	25	EXTNL	IVOL
PERLND	52	PWATER	PERO	0.048	RCHRES	25	EXTNL	IVOL
PERLND	54	PWATER	PERO	0.052	RCHRES	25	EXTNL	IVOL
PERLND	94	PWATER	PERO	0.335	RCHRES	25	EXTNL	IVOL
IMPLND	96	IWATER	SURO	0.128	RCHRES	25	EXTNL	IVOL

\*\*\*

\*\*\* SUB-BASIN WL25A \*\*\*

PERLND	22	PWATER	PERO	1.586	RCHRES	25	EXTNL	IVOL
PERLND	24	PWATER	PERO	1.426	RCHRES	25	EXTNL	IVOL
PERLND	36	PWATER	PERO	1.748	RCHRES	25	EXTNL	IVOL
PERLND	38	PWATER	PERO	0.140	RCHRES	25	EXTNL	IVOL
PERLND	42	PWATER	PERO	0.470	RCHRES	25	EXTNL	IVOL
PERLND	46	PWATER	PERO	0.042	RCHRES	25	EXTNL	IVOL
PERLND	52	PWATER	PERO	0.144	RCHRES	25	EXTNL	IVOL
IMPLND	96	IWATER	SURO	0.047	RCHRES	25	EXTNL	IVOL

\*\*\*

\*\*\* SUB-BASIN WL25B \*\*\*

\*\*\* CLOSED SUBBASIN: ONLY GROUND-WATER FLOW (AGWO) DISCHARGES AT \*\*\*

\*\*\* RCHRES 25 \*\*\*

\*\*\* EIA DRAINS TO ADJACENT PERLND (ACCOUNTED FOR IN PERLND AREAS) \*\*\*

PERLND	22	PWATER	AGWO	0.120	RCHRES	25	EXTNL	IVOL
PERLND	46	PWATER	AGWO	3.010	RCHRES	25	EXTNL	IVOL
PERLND	52	PWATER	AGWO	0.018	RCHRES	25	EXTNL	IVOL
IMPLND	96	IWATER	SURO	0.004	DRAINS TO ADJACENT PERLND			***

\*\*\*

\*\*\*SUB-BASIN WL26 \*\*\*

PERLND	22	PWATER	PERO	0.772	RCHRES	26	EXTNL	IVOL
PERLND	24	PWATER	PERO	0.421	RCHRES	26	EXTNL	IVOL
PERLND	36	PWATER	PERO	1.947	RCHRES	26	EXTNL	IVOL
PERLND	38	PWATER	PERO	0.107	RCHRES	26	EXTNL	IVOL
PERLND	42	PWATER	PERO	0.332	RCHRES	26	EXTNL	IVOL
PERLND	44	PWATER	PERO	0.047	RCHRES	26	EXTNL	IVOL
IMPLND	96	IWATER	SURO	0.061	RCHRES	26	EXTNL	IVOL

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

***SUB-BASIN WL27 ***
PERLND  22  PWATER  PERO          3.158    RCHRES  27    EXTNL  IVOL
PERLND  24  PWATER  PERO          6.994    RCHRES  27    EXTNL  IVOL
PERLND  34  PWATER  PERO          0.453    RCHRES  27    EXTNL  IVOL
PERLND  36  PWATER  PERO         17.274    RCHRES  27    EXTNL  IVOL
PERLND  38  PWATER  PERO          7.886    RCHRES  27    EXTNL  IVOL
PERLND  40  PWATER  PERO          0.451    RCHRES  27    EXTNL  IVOL
PERLND  42  PWATER  PERO         21.480    RCHRES  27    EXTNL  IVOL
PERLND  44  PWATER  PERO          1.040    RCHRES  27    EXTNL  IVOL
PERLND  46  PWATER  PERO          9.001    RCHRES  27    EXTNL  IVOL
PERLND  48  PWATER  PERO          8.805    RCHRES  27    EXTNL  IVOL
PERLND  50  PWATER  PERO          1.408    RCHRES  27    EXTNL  IVOL
PERLND  52  PWATER  PERO          1.008    RCHRES  27    EXTNL  IVOL
PERLND  54  PWATER  PERO          6.205    RCHRES  27    EXTNL  IVOL
PERLND  56  PWATER  PERO          0.922    RCHRES  27    EXTNL  IVOL
PERLND  94  PWATER  PERO          6.515    RCHRES  27    EXTNL  IVOL
IMPLND  96  IWATER  SURO          1.874    RCHRES  27    EXTNL  IVOL
***
*** CHANNEL NETWORK LINKAGES ***
***
*** The following linkages pass streamflow from one stream reach ***
*** (RCHRES) to another stream reach. ***
***
RCHRES  2  HYDR  ROVOL  1          RCHRES  4    EXTNL  IVOL
RCHRES  4  HYDR  OVOL   1 1        RCHRES  5    EXTNL  IVOL
RCHRES 50  HYDR  OVOL   1 1        RCHRES  6    EXTNL  IVOL
RCHRES  5  HYDR  OVOL   1 1        RCHRES  6    EXTNL  IVOL
RCHRES  6  HYDR  OVOL   1 1        RCHRES  8    EXTNL  IVOL
RCHRES  8  HYDR  OVOL   1 1        RCHRES 10    EXTNL  IVOL
RCHRES  9  HYDR  OVOL   1 1        RCHRES 10    EXTNL  IVOL
RCHRES 10  HYDR  OVOL   1 1        RCHRES 17    EXTNL  IVOL
RCHRES 12  HYDR  OVOL   1 1        RCHRES 17    EXTNL  IVOL
RCHRES 13  HYDR  OVOL   1 1        RCHRES 15    EXTNL  IVOL
RCHRES 14  HYDR  OVOL   1 1        RCHRES 15    EXTNL  IVOL
RCHRES 15  HYDR  OVOL   1 1        RCHRES 17    EXTNL  IVOL
RCHRES 17  HYDR  ROVOL  1          RCHRES 18    EXTNL  IVOL
RCHRES 18  HYDR  ROVOL  1          RCHRES 24    EXTNL  IVOL
RCHRES 19  HYDR  ROVOL  1          RCHRES 21    EXTNL  IVOL
RCHRES 20  HYDR  OVOL   1 1        RCHRES 21    EXTNL  IVOL
RCHRES 21  HYDR  OVOL   1 1        RCHRES 24    EXTNL  IVOL
RCHRES 22  HYDR  OVOL   1 1        RCHRES 24    EXTNL  IVOL
RCHRES 23  HYDR  OVOL   1 1        RCHRES 24    EXTNL  IVOL
RCHRES 24  HYDR  ROVOL  1          RCHRES 26    EXTNL  IVOL
RCHRES 26  HYDR  ROVOL  1          RCHRES 27    EXTNL  IVOL
RCHRES 25  HYDR  ROVOL  1          RCHRES 27    EXTNL  IVOL

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

***                                     ***
*** The following linkages pass streamflow time series to tables ***
***   for display.                                     ***
***                                     ***
*** Note: MULTFACTOR 48.4 converts acre-feet of runoff to ***
***   average cubic feet per second per 15 minute interval. ***
***   It is timestep dependent. The other MFACTOR converts ***
***   acre-feet of runoff to inches of runoff per 15 minutes. ***
***                                     ***
RCHRES 10 HYDR  OVOL  1 1      48.4    DISPLY  8      INPUT  TIMSER 1
RCHRES 10 HYDR  OVOL  1 1      48.4    DISPLY  9      INPUT  TIMSER 1
RCHRES 10 HYDR  OVOL  1 1    0.00141  DISPLY 10      INPUT  TIMSER 1
RCHRES 24 HYDR  ROVOL 1      48.4    DISPLY 11      INPUT  TIMSER 1
RCHRES 24 HYDR  ROVOL 1      48.4    DISPLY 12      INPUT  TIMSER 1
RCHRES 24 HYDR  ROVOL 1    0.00079  DISPLY 13      INPUT  TIMSER 1
****
END NETWORK

***

RCHRES
***                                     ***
*** Simulates streamflows in stream reaches (RCHRES) ***
***                                     ***

GEN-INFO
RCHRES      Name      Nexits  Unit Systems  Printer                                     ***
# - #<-----><----> User T-series  Engr Metr LKFG ***
      in out                                     ***
2     HKS LK ST SEW    WL2     1    1    1    1    6    0    0
4     HICKS LAKE      WL4     2    1    1    1    6    0    0
5     PATTERSON LAKE  WL5     1    1    1    1    6    0    0
6     LONG LAKE      WL6     2    1    1    1    6    0    0
8     LAKE LOIS      WL8     3    1    1    1    6    0    0
9     LK LOIS ST SEW  WL9     2    1    1    1    6    0    0
10    WDLD - MTN WAY  WL10    2    1    1    1    6    0    0
50    GROUND -WATER   WL50    2    1    1    1    6    0    0
12    TNGWLWD ST SEW WL12    2    1    1    1    6    0    0
13    CLG ST ST SEW  WL13    2    1    1    1    6    0    0
14    MTN WAY ST SEW WL14    2    1    1    1    6    0    0
15    ST PLCD DT-WTL WL15    2    1    1    1    6    0    0
17    WDLD MT WAY-I5 WL17    1    1    1    1    6    0    0
18    WDLD DRAHAM RD WL18    1    1    1    1    6    0    0
19    SPRG - CARP RD WL19    1    1    1    1    6    0    0
20    UP CK AB CARP  WL20    2    1    1    1    6    0    0
21    LOW CK AB CARP WL21    2    1    1    1    6    0    0
22    W TRB US PL GL WL22    2    1    1    1    6    0    0
23    E TRB US PL GL WL23    2    1    1    1    6    0    0
24    WDLD @ PLS GLD WL24    1    1    1    1    6    0    0
25    JRGNSN RD TRIB WL25    1    1    1    1    6    0    0
26    WDLD AB JRGNSN WL26    1    1    1    1    6    0    0
27    WDLD BL JRGNSN WL27    1    1    1    1    6    0    0
END GEN-INFO

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

ACTIVITY

RCHRES \*\*\*\*\* Active Sections \*\*\*\*\*

#	-	#	HYFG	ADFG	CNFG	HTFG	SDFG	GQFG	OXFG	NUFG	PKFG	PHFG	***
2		50	1	0	0	0	0	0	0	0	0	0	

END ACTIVITY

PRINT-INFO

RCHRES \*\*\*\*\* Printout Flags \*\*\*\*\* PIVL PYR

#	-	#	HYDR	ADCA	CONS	HEAT	SED	GQL	OXRX	NUTR	PLNK	PHCB	*****
2		50	6	0	0	0	0	0	0	0	0	0	1 9

END PRINT-INFO

HYDR-PARM1

RCHRES Flags for each HYDR Section

#	-	#	VC	A1	A2	A3	ODFVFG for each	***	ODGTFG for each	FUNCT for each	
			FG	FG	FG	FG	possible	exit	***	possible	exit
			*	*	*	*	*	*	*	*	*
2			0	0	0	0	4	0	0	0	0
4			0	1	0	0	4	5	0	0	0
5			0	1	0	0	4	0	0	0	0
6			0	1	0	0	4	5	0	0	0
8			0	1	0	0	4	5	6	0	0
9			0	0	0	0	4	5	0	0	0
10			0	0	0	0	4	5	0	0	0
50			0	0	0	0	4	5	0	0	0
12			0	0	0	0	4	5	0	0	0
13			0	0	0	0	4	5	0	0	0
14			0	0	0	0	4	5	0	0	0
15			0	0	0	0	4	5	0	0	0
17			0	0	0	0	4	0	0	0	0
18	19		0	0	0	0	4	0	0	0	0
20	21		0	0	0	0	4	5	0	0	0
22			0	0	0	0	4	5	0	0	0
23			0	0	0	0	4	5	0	0	0
24	26		0	0	0	0	4	0	0	0	0
27			0	1	0	0	4	0	0	0	0

END HYDR-PARM1

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

HYDR-PARM2

```

***
*** Assigns an F-table number to each reach.  Supplies the length ***
*** of the reach and a weighting factor for hydraulic routing. ***
***

```

RCHRES							***
# - #	FTABNO	LEN	DELTH	STCOR	KS	DB50	***
<-----><-----><-----><-----><-----><-----><----->							***
2	2	1.053			0.5		
4	4	1.921		-29.55	0.5		
5	5	1.864		-17.60	0.5		
6	6	2.362		-19.88	0.5		
8	8	0.979		135.0	0.5		
9	9	1.066			0.5		
10	10	0.709			0.5		
50	50	1.000			0.5		
12	12	1.737			0.5		
13	13	1.212			0.5		
14	14	0.568			0.5		
15	15	0.442			0.5		
17	17	0.589			0.5		
18	18	0.965			0.5		
19	19	0.099			0.5		
20	20	0.602			0.5		
21	21	1.354			0.5		
22	22	0.889			0.5		
23	23	1.452			0.5		
24	24	0.633			0.5		
25	25	0.828			0.5		
26	26	0.433			0.5		
27	27	1.175			0.5		

END HYDR-PARM2

HYDR-INIT

```

***
*** Initial conditions for each HYDR section.
***

```

RCHRES		VOL	Initial value of COLIND		Initial value of OUTDGT	
# - #	*** ac-ft		for each possible exit		for each possible exit	
<-----><----->		<---><---><---><---><--->	*** <---><---><---><---><--->			
2	0.006	4.0				
4	2532.000	4.0	5.0			
5	4050.000	4.0				
6	4241.000	4.0	5.0			
8	57.300	4.0	5.0	6.0		
9	0.000	4.0	5.0			
10	0.320	4.0	5.0			
50	804.000	4.0	5.0			
12	0.005	4.0	5.0			
13	0.380	4.0	5.0			
14	0.000	4.0	5.0			
15	0.722	4.0	5.0			
17	0.680	4.0				



**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

18          0.890          4.0
19          0.010          4.0
20          0.100          4.0  5.0
21          0.150          4.0  5.0
22          1.000          4.0  5.0
23          1.500          4.0  5.0
24          0.920          4.0
25          0.070          4.0
26          0.584          4.0
27          1.810          4.0
END HYDR-INIT
END RCHRES
FTABLES
***
*** The following function tables (F-tables) portray
*** relationships between volume and outflow, and in some
*** cases area (for lakes) for the defined channel reaches.
*** The columns for volume and outflow are used for routing
*** streamflow from reach to reach. For reaches that
*** represent streams, only the volume-outflow
*** relationship is considered for routing streamflow. The
*** area column is used for the application of precipitation
*** and PET to lakes. Outflow1 is the streamflow routed
*** from one reach to another reach, and other outflows
*** represent either channel losses from seepage or flow that
** leaves the reach through another outlet.
***
FTABLE      2
*** Drains subbasin WL2. Reach consists of storm sewer and
*** a small channel system within WL2.
Rows Cols
9      4
Depth      Area      Volume      Outflow1
(ft)      (acres) (acre-ft)      (cfs)
0.0      0.0      0.0      0.0
0.2      0.0      0.05     0.88
0.6      0.0      0.20     7.59
1.0      0.0      0.37    16.56
1.4      0.0      0.57    30.48
2.0      0.0      0.77    42.58
2.5      0.0      2.12    55.56
3.0      0.0      5.12    56.0
4.0      0.0     12.0    56.1
END FTABLE  2

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      4
*** Drains subbasin WL4.  Reach consists of Hicks Lake and ***
*** system within subbasin WL4.  Outflow2 represents reach ***
*** losses by seepage. ***

Rows Cols
9      5
Depth      Area      Volume      Outflow1      Outflow2
(ft)      (acres) (acre-ft)      (cfs)      (cfs)
0.0        0.0        0.0        0.0        0.0
32.0       140        2139       0.0        0.0
33.1       143        2300       0.10       1.0
33.8       146        2415       0.45       1.0
34.5       150        2546       1.30       0.2
35.0       150        2750       2.35       0.0
35.5       150        3007       3.50       0.0
36.0       150        3292       6.00       0.0
36.3       150        3463       17.0       0.0
END FTABLE  4
FTABLE      5
*** Drains subbasin WL5 and receives drainage from WL4 and WL5A. ***
*** Reach consists of Pattison Lake and channel system within ***
*** subbasin WL5. ***

Rows Cols
7      5
Depth      Area      Volume      Outflow1
(ft)      (acres) (acre-ft)      (cfs)
0.0        0.0        0.0        0.0
21.5       265        3400       0.0
22.0       271        3635       0.0
22.5       275        3870       5.0
23.0       280        4095       9.6
23.5       280        4320       15.9
23.8       280        4545       21.0
END FTABLE  5
FTABLE      6
*** Drains subbasin WL6 and receives drainage from WL6B, 6C, 6D, ***
*** and 6E.  Reach consists of Long Lake and channel system ***
*** within subbasin WL6.  Outflow2 represents reach losses by ***
*** seepage. ***

Rows Cols
9      5
Depth      Area      Volume      Outflow1      Outflow2
(ft)      (acres) (acre-ft)      (cfs)      (cfs)
0.0        0.0        0.0        0.0        0.0
20.0       320        3500       0.0        0.0
20.5       325        3724       0.0        4.9
21.0       330        3949       1.3        4.8
21.3       330        4079       3.5        4.5
21.6       332        4209       7.28       3.5
21.9       335        4339       11.0       0.7
22.3       345        4495       20.0       0.0
22.9       345        4700       35.0       0.0
END FTABLE  6

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      8
*** Drains subbasin WL8.  Reach consists of a small lake and a ***
*** channel system within subbasin WL8.  Outflow2 represents ***
*** reach losses by seepage from Lake Lois and Outflow3 ***
*** represents additional reach losses by seepage. ***

Rows Cols
12      6
  Depth      Area      Volume  Outflow1  Outflow2  Outflow3
  (ft)      (acres)  (acre-ft)   (cfs)    (cfs)    (cfs)
    0.0      0.0      0.0      0.0      0.0      0.0
    2.0      6.0      6.0      0.0      0.0      0.0
    3.0      8.0     13.0      0.0      5.5      1.0
    4.0     15.0     23.0      0.0      5.5      1.0
    5.3     16.1     50.2      0.0      5.5      3.0
    5.4     16.9     51.9      0.00     5.5      3.0
    5.6     19.2     60.6      0.25     5.5      1.0
    6.2     21.3     73.3      6.34     5.5      1.0
    6.9     26.6     90.6     19.0      5.5      1.0
    8.2     35.8    127.6     70.5      0.0      0.0
    9.0     42.6    159.2    114.0      0.0      0.0
   10.0     51.3    206.6    187.0      0.0      0.0
END FTABLE  8
FTABLE      9
*** Drains subbasin WL9.  Reach consists of storm-sewer system ***
*** and those drainage systems that drain to the storm-sewer ***
*** ststem.  Outflow2 represents reach losses by seepage and ***
*** infiltration from swales and ponds.  Last entry stores ***
*** water for ponding conditions when drainage system conveys ***
*** at near-maximum capacity. ***

Rows Cols
13      5
  Depth      Area      Volume  Outflow1  Outflow2
  (ft)      (acres)  (acre-ft)   (cfs)    (cfs)
    0.0      0.0      0.0      0.0      0.0
    0.06      0.0      0.02      0.0      0.1
    0.15      0.0      0.03      0.27     0.2
    0.30      0.0      0.05      1.13     0.3
    0.45      0.0      0.07      2.53     0.3
    0.60      0.0      0.11      4.35     0.3
    0.75      0.0      0.14      6.45     0.4
    0.90      0.0      0.17      8.66     0.5
    1.05      0.0      0.20     10.8      1.0
    1.20      0.0      0.22     12.6      3.0
    1.35      0.0      2.24     13.7      4.0
    2.00      0.0      6.00     18.0      5.0
    3.00      0.0     20.0     19.0      7.0
END FTABLE  9

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      10
*** Drains subbasin WL10 and receives drainage from WL9.  Gaging ***
*** station 12080670 (Woodland Creek at Martin Way at Lacey, ***
*** WA) located at downstream end of reach.  Outflow2 ***
*** represents reach losses by channel seepage. ***

Rows Cols
6      5
Depth      Area      Volume  Outflow1  Outflow2
(ft)      (acres)  (acre-ft)  (cfs)    (cfs)
0.0        0.0        0.0        0.0      0.0
0.2        0.0        0.10       0.0      1.0
0.5        0.0        0.50       1.9      1.0
1.0        0.0        1.00       8.0      2.0
2.0        0.0        3.50      40.0      2.0
5.0        0.0       15.00     350.0     0.0
END FTABLE 10

FTABLE      50
*** This reach consists of ground-water controller.  Some ***
*** ground-water flow from WL2, 3, 5A, 6, and 6E recharges ***
*** this reach.  Outflow2 represents reach losses by ground- ***
*** water flow out of the basin. ***

Rows Cols
10     5
Depth      Area      Volume  Outflow1  Outflow2
(ft)      (acres)  (acre-ft)  (cfs)    (cfs)
0.0        0.0        0.0        0.0      0.0
0.5        0.0       720.0       0.0      0.0
1.0        0.0       820.0       0.0      8.5
1.5        0.0       900.0       0.0      9.0
2.0        0.0      1000.0       0.5      9.0
2.5        0.0      1100.0       1.0      9.0
3.0        0.0      1200.0       2.0      9.5
3.5        0.0      1300.0       5.0     10.0
3.8        0.0      1380.0      10.0     15.0
4.1        0.0      1460.0      15.0     20.0
END FTABLE 50

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

FTABLE 12

```
*** Drains subbasin WL12. Reach consists of storm sewer system ***
*** with perforated pipes and those drainage systems that ***
*** drain to it. Ground water can drain into or out of the ***
*** pipe system. Storage is added for ponded water, ***
*** backwater, and sewer "bank storage" during periods when ***
*** the system conveys water under surcharge or near-maximum ***
*** capacity conditions. Outflow2 represents reach losses ***
*** from pipes, ponds, or other structures. ***
```

Rows Cols

13 5

Depth	Area	Volume	Outflow1	Outflow2
(ft)	(acres)	(acre-ft)	(cfs)	(cfs)
0.0	0.0	0.0	0.0	0.0
0.01	0.0	0.005	0.00	0.3
0.12	0.0	0.02	0.22	0.3
0.24	0.0	0.05	0.97	0.4
0.36	0.0	0.08	2.28	0.4
0.48	0.0	0.11	4.13	0.4
0.60	0.0	0.15	6.52	0.5
0.72	0.0	0.25	9.40	1.0
0.84	0.0	0.40	12.7	2.0
0.96	0.0	0.60	16.5	4.0
1.08	0.0	0.85	20.6	8.0
1.20	0.0	2.33	25.0	11.0
1.30	0.0	8.00	30.0	15.0

END FTABLE 12

FTABLE 13

```
*** Drains subbasin WL13. Reach consists of storm sewer system ***
*** and a surface-drainage reach with wetland storage areas. ***
*** Outflow2 represents reach losses by seepage. ***
```

Rows Cols

12 5

Depth	Area	Volume	Outflow1	Outflow2
(ft)	(acres)	(acre-ft)	(cfs)	(cfs)
0.0	0.0	0.0	0.0	0.0
0.3	0.0	0.38	0.00	0.75
0.6	0.0	1.54	0.62	0.75
0.9	0.0	3.26	2.62	0.5
1.2	0.0	7.30	5.86	0.0
1.5	0.0	10.64	10.1	0.0
1.8	0.0	13.57	15.0	0.0
2.1	0.0	16.43	20.1	0.0
2.4	0.0	19.32	25.0	0.0
2.7	0.0	22.30	29.2	0.0
3.0	0.0	25.30	31.9	0.0
3.1	0.0	26.50	32.2	0.0

END FTABLE 13

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

FTABLE 14

```

*** Drains subbasin WL14. Reach consists of storm sewer network ***
*** and some surface drainage. Storage is added to store ***
*** backwater, surcharged water, and ponded water during ***
*** periods when the system nears maximum-conveyance capacity. ***
*** Outflow2 represents reach losses by seepage when water ***
*** is not contained within drainage system.
*** LAST ENTRY TO STORE SURCHARGED AND BACKWATER. ***

```

Rows Cols

11 5

Depth	Area	Volume	Outflow1	Outflow2
(ft)	(acres)	(acre-ft)	(cfs)	(cfs)
0.0	0.0	0.0	0.0	0.0
0.1	0.0	0.014	0.103	0.0
0.2	0.0	0.019	0.381	0.0
0.4	0.0	0.035	1.56	0.0
0.6	0.0	0.056	3.55	0.0
0.8	0.0	0.086	5.81	0.5
1.0	0.0	0.150	8.30	1.0
1.2	0.0	0.250	10.3	1.0
1.4	0.0	0.500	13.3	2.0
2.0	0.0	1.000	18.0	3.0
2.2	0.0	7.000	23.0	4.0

END FTABLE 14

FTABLE 15

```

*** Drains subbasin WL15. Reach consists of drainage-ditch ***
*** systems with drainage facilities and a channel system with ***
*** areas of wetland storage. Outflow is controlled by a ***
*** culvert and backwater can occur. Outflow2 represents ***
*** reach losses by infiltration in drainage facilities and ***
*** seepage.

```

Rows Cols

8 5

Depth	Area	Volume	Outflow1	Outflow2
(ft)	(acres)	(acre-ft)	(cfs)	(cfs)
0.0	0.0	0.0	0.0	0.0
0.2	0.0	0.2	0.0	0.5
1.0	0.0	2.68	5.0	1.0
2.0	0.0	5.35	12.6	2.0
3.0	0.0	8.02	20.0	3.0
6.6	0.0	22.49	40.0	3.0
9.3	0.0	49.40	50.0	5.0
13.0	0.0	68.80	60.0	8.0

END FTABLE 15

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      17
*** Drains subbasin WL17 and receives drainage from WL1A, 8A, ***
*** 8B, 9, 9A, 10, 12, 13, 13A, 14, 16, and 16A. Reach ***
*** consists of springs and the channel system within ***
*** subbasin WL17. ***

Rows Cols
7      4
Depth      Area      Volume      Outflow1
(ft)      (acres)    (acre-ft)    (cfs)
0.0        0.0         0.0          0.0
0.5        0.0         0.43         5.0
1.0        0.0         1.43        25.0
1.25       0.0         2.07        40.5
1.50       0.0         5.02        60.0
2.00       0.0        10.92       115
3.00       0.0        25.53       225
END FTABLE 17

FTABLE      18
*** Drains subbasin WL18. ***

Rows Cols
5      4
Depth      Area      Volume      Outflow1
(ft)      (acres)    (acre-ft)    (cfs)
0.0        0.0         0.0          0.0
0.5        0.0         0.47         5.0
1.5        0.0         2.57        40.0
2.5        0.0         6.09        125
4.5        0.0        15.56       525
END FTABLE 18

FTABLE      19
*** Drains subbasin WL19. Reach consists of springs and the ***
*** channel system that receives the spring outflow. ***

Rows Cols
5      4
Depth      Area      Volume      Outflow1
(ft)      (acres)    (acre-ft)    (cfs)
0.0        0.0         0.0          0.0
1.0        0.0         0.03         5.0
2.0        0.0         0.09        20.0
2.5        0.0         0.15        25.0
4.0        0.0         0.40        120
END FTABLE 19

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      20
*** Drains subbasin WL20.  Reach consists of the channel system ***
***   within subbasin WL20.  Outflow2 represents channel losses ***
***   by seepage. ***

Rows Cols
6      5
  Depth      Area      Volume  Outflow1  Outflow2
  (ft)      (acres) (acre-ft)  (cfs)    (cfs)
    0.0      0.0      0.0      0.0      0.0
    0.05      0.0      0.04      0.0      0.8
    0.1      0.0      0.05      0.1      0.8
    0.5      0.0      0.12      2.0      0.8
    1.5      0.0      1.82     20.0      4.0
    3.0      0.0      5.35     75.0     10.0
END FTABLE 20

FTABLE      21
*** Drains subbasin WL21.  Reach consists of the channel system ***
***   and some wetland storage areas within subbasin WL21. ***
***   Outflow2 represents channel losses by seepage. ***

Rows Cols
5      5
  Depth      Area      Volume  Outflow1  Outflow2
  (ft)      (acres) (acre-ft)  (cfs)    (cfs)
    0.0      0.0      0.0      0.0      0.0
    0.25      0.0      0.13      1.25     2.0
    1.0      0.0      1.04      5.0      2.0
    2.0      0.0      7.04     15.0      5.0
    4.0      0.0     36.04    100.0     10.0
END FTABLE 21

FTABLE      22
*** Drains subbasin WL22.  Reach consists of the channel system ***
***   and some wetland storage areas within subbasin WL22. ***
***   Outflow2 represents channel losses by seepage. ***

Rows Cols
4      5
  Depth      Area      Volume  Outflow1  Outflow2
  (ft)      (acres) (acre-ft)  (cfs)    (cfs)
    0.0      0.0      0.0      0.0      0.0
    0.25      0.0      0.50      1.25     0.2
    1.0      0.0      5.38      5.0      1.5
    3.0      0.0     44.4     85.0      4.0
END FTABLE 22

```



**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      23
*** Drains subbasin WL23.  Reach consists of the channel system ***
*** and some wetland storage areas within subbasins WL23.      ***
*** Outflow2 represents channel losses by seepage.             ***

Rows Cols
  9      5
  Depth      Area      Volume  Outflow1  Outflow2
  (ft)      (acres) (acre-ft)  (cfs)    (cfs)
    0.0      0.0      0.0      0.0      0.0
    1.0      0.0      0.25     0.0      0.0
    1.25     0.0      0.41     0.25     0.5
    1.5      0.0      0.63     0.60     0.7
    2.0      0.0      1.38     2.00     1.0
    3.0      0.0      5.38     15.0     2.0
    3.5      0.0      8.88     38.0     4.0
    4.0      0.0     14.1     60.0     8.0
    5.0      0.0     39.1     90.0    16.0
END FTABLE 23

FTABLE      24
*** Drains subbasin WL24 and receives drainage from WL21, 22, ***
*** and 23.  Gaging station 12081000 (Woodland Creek near ***
*** Olympia, WA) located at downstream end of the reach.      ***

Rows Cols
  5      4
  Depth      Area      Volume  Outflow1
  (ft)      (acres) (acre-ft)  (cfs)
    0.0      0.0      0.0      0.0
    1.0      0.0      1.23     20.0
    3.0      0.0      4.99     120
    3.1      0.0      5.30     125
    6.0      0.0     15.1     350
END FTABLE 24

FTABLE      25
*** Drains subbasins WL25 and 25A, and receives drainage from ***
*** subbasin WL25B.  Crest-stage gage 12081010 (Woodland Creek ***
*** Tributary at Jorgenson Road near Olympia, WA) is located ***
*** at the lower end of the reach.

Rows Cols
  4      4
  Depth      Area      Volume  Outflow1
  (ft)      (acres) (acre-ft)  (cfs)
    0.0      0.0      0.0      0.0
    0.5      0.0      0.20     2.0
    1.5      0.0      0.80     10.0
    4.5      0.0      5.12     80.0
END FTABLE 25

```

**Table 19.**--Input sequence of the Woodland Creek model used to run Hydrological Simulation Program-FORTRAN (HSPF)--Continued

```

FTABLE      26
*** Drains subbasin WL26.                                     ***
Rows Cols                                     ***
  4      4
  Depth      Area      Volume  Outflow1                                     ***
  (ft)      (acres) (acre-ft)  (cfs)                                     ***
    0.0      0.0      0.0      0.0
    1.0      0.0      0.73     25.0
    3.0      0.0      3.04     175
    6.0      0.0      9.02     500
END FTABLE 26
FTABLE      27
*** Drains subbasin WL27.                                     ***
Rows Cols                                     ***
  5      4
  Depth      Area      Volume  Outflow1                                     ***
  (ft)      (acres) (acre-ft)  (cfs)                                     ***
    0.0      0.0      0.0      0.0
    1.0      1.14     0.93     10.0
    4.0      3.42     7.69     125
    6.5      4.84     56.2     450
    9.0      6.69     185      1000
END FTABLE 27
END FTABLES

DISPLY
***
*** Displays time series on output.
***

DISPLY-INFO1
#thru#***<-----Title----->          <-short-span->
***          <----disply---->  <annual summary ->
***          PYR DIG2 FIL2 YRND
1      FAIRGROUND PRECIP  (IN)  SUM      0      2      6      1      2      6      9
2      WDLD MTN WAY OBS   (CFS)  AVER      0      2      6      1      2      6      9
3      WDLD MTN WY OBS MAX(CFS)  MAX      0      2      6      1      2      6      9
4      WDLD MTN WY OBS VOL (IN)  SUM      0      2      6      1      2      6      9
5      WDLD PL GLD OBS   (CFS)  AVER      0      2      6      1      2      6      9
6      WDLD PL GLD OBS MAX(CFS)  MAX      0      2      6      1      2      6      9
7      WDLD PL GLD OBS VOL (IN)  SUM      0      2      6      1      2      6      9
8      WDLD MTN WY SIM FLW(CFS)  AVER      0      2      6      1      2      6      9
9      WDLD MTN WY SIM MAX(CFS)  MAX      0      2      6      1      2      6      9
10     WDLD MTN WY SIM VOL (IN)  SUM      0      2      6      1      2      6      9
11     WDLD PL GLD SIM   (CFS)  AVER      0      2      6      1      2      6      9
12     WDLD PL GLD SIM MAX(CFS)  MAX      0      2      6      1      2      6      9
13     WDLD PL GLD SIM VOL (IN)  SUM      0      2      6      1      2      6      9
END DISPLY-INFO1
END DISPLY

END RUN

```