Rainfall-Runoff Relations for the Puget Sound Area

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Abstract

The characteristics of rainfall-runoff relations were hypothesized for the study area using existing information. These hypotheses were incorporated into the Hydrologic Simulation Program-FORTRAN, and the model was calibrated concurrently at 21 stream-gage sites in the study area. The simulation errors after model calibration were not large enough to reject the hypothesized characteristics. A proxy-basin validation effort was performed.

Introduction

A quantitative understanding of how a drainage basin responds to precipitation has proved elusive because of the complexity of the runoff processes involved and the spatial and temporal variability of precipitation and basin characteristics. A usual approach has been to incorporate available knowledge about the processes into a conceptual model of the system, and then to compare model-simulated results with observed data, such as streamflow. With regard to standard scientific method, wherein hypotheses are tested with measurements taken from carefully formulated, controlled situations, this approach is difficult.

Hydrologic fluxes measured in the field, such as streamflow, are usually basin-integrated responses that commonly do not lead to clear understanding of all the individual processes involved in generating the flux. Additionally, many parameters in hydrologic simulation models cannot be measured independently in the field, but need to be calibrated with observed data. Regardless of these difficulties, simulation models of basin response remain the only practical approach to comparing runoff theory with observations.

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The purpose of this study was to characterize and simulate rainfall-runoff relations for headwater drainage basins in western King and Snohomish Counties, Washington. The purpose of this report is to present the hypothesized characteristics of the relations, and to describe the construction and calibration of a computer model designed to simulate the relations. The approach used to meet these objectives included formulation of hypotheses concerning rainfall-runoff relations in the study area, construction and calibration of the simulation model, and validation of the simulation model and the hypothesized rainfall-runoff relations (Dinicola, 1989).

Description of the Study Area

The study area is in the southeastern part of the Puget Sound lowland in Washington. The area is a broad, rolling glacial-drift plain that merges eastward with foothills of the Cascade Range. The drift plain is characterized by hilly glacial-till plains and generally level glacial-outwash bench lands. Numerous lakes, swamps, and peat bogs occupy depressions on the till plains, whereas the outwash plains are generally well drained. Twenty-one drainage basins ranging from 1.3 to 65.8 square miles were gaged for model calibration, and eleven additional basins ranging from 0.8 to 6.3 square miles were gaged for model validation. The land use in the basins is primarily suburban to rural, with isolated parcels of urban development.

Results

The characteristics of rainfall-runoff relations that follow were hypothesized for the study area as a whole by using existing information presented in published soils-surveys, climate atlases, and rainfall-runoff investigations in similar physiographic regions. In undisturbed areas, shallow-subsurface flow from hillslopes mantled with glacial till, ground-water flow from glacial outwash deposits, and saturation overland flow from depressions, stream bottoms, and till-capped hilltops are the important runoff mechanisms. In distrubed, primarily urban areas, Horton overland flow, which is runoff generated from rain falling at a greater rate than the infiltration rate of the soil, is a significant mechanism, along with overland flow from impervious surfaces.

The hypothesized rainfall-runoff characteristics were incorporated into the Hydrologic Simulation Program: FORTRAN (HSPF; U.S. Environmental Protection Agency, 1984) using a distributed-parameter approach. This approach required division of a drainage basin into land segments, each with relatively uniform physical and hydrologic characteristics. Twelve land-segment types were defined for this investigation. All the area of a particular land segment need not be contiguous, so it was possible to represent complex mosaics of soil types, vegetative cover, topography, and land use by using a relatively small number of segments. The goal of the segmentation scheme was to construct a conceptual model with the minimum number of land segments needed to simulate the physical and hydrologic processes of any upland drainage basin in the study area. This, in turn, reduced the number of parameters that required calibration, and led to a more realistic portrayal of the hypothesized processes that could be adequately tested with observed streamflow data.

The HSPF model was calibrated concurrently for 21 stream-gage sites in the study area with precipitation, potential evapotranspiration, and streamflow data from the 1985-86 water years. A given set of parameters characterizing a given type of land segment were held constant for each trial calibration in all basins where that segment existed, and subsequent adjustments of the parameters were likewise made consistently in all basins. The calibration resulted in 12 sets of generalized HSPF parameters, one set for each land-segment type with a unique hydrologic response.

The composite simulation errors for all of the calibration streamflow gages in the region, as evaluated by several methods, are summarized in table 1. The runoff volumes and peak discharges shown represent the four highest streamflow periods for which complete records of observed rainfall and streamflow data were available for each gaged basin.

The calibration errors from runoff simulation with the regional model come from two distinct sources: inadequate or inaccurate rainfall, streamflow, and PET data; and inadequate representation of the region's rainfall-runoff processes by the model. Although it is not possible to assign accurate magnitudes to all the errors in the basic data, errors do exist in the precipitation, streamflow, and evapotranspiration data, and they do have an effect on the simulation accuracy of the model. With this in perspective, the overall validity of the simulation model and the hypothesized rainfall-runoff relations on a basin-wide scale is interpreted as follows.

The simulation of annual runoff was generally unbiased for the region as a whole, and errors in annual runoff ranged from 0 to 23 percent at individual gaging stations, with a regional standard error of estimate of 8 percent. The relatively small errors in the simulation of annual, winter, and spring runoff are well within the limitations of the observed data, and do not suggest any significant model inadequacies in representing regional water balances during most of the year. The much larger simulation errors for summer runoff suggest that stream baseflow characteristics are not properly represented.

The simulation of large storms was unbiased for the region as a whole. Errors for individual events ranged from 0 to 106 percent for runoff volumes, but only 2 of 84 runoff volumes were in error more than 40 percent. Errors for peak discharges ranged from less than 1 to 64 percent, but only 3 of 84 peak discharges were in error more than 40 percent. The standard errors of estimate for storm runoff volumes and peaks were 21 and 22 percent, respectively.

The magnitude of these errors does not suggest any significant model inadequacies for the study area as a whole, but rather that some specific storm events in some basins were poorly simulated.

Table 1.--Measures of composite errors in model-simulated annual runoff, seasonal runoff, storm runoff, peak discharges simulated for all stream gages and basins with the regionally calibrated model

Data set name	Mean absolute[1] error		Bias		Standard error of estimate	
	Average	percent	Average	percent	Average	percent
Annual runoff	1.03	5.6	0.01	-0.5	1.53	7.9
Winter runoff	.81	8.4	-.29	-4.3	1.08	11.2
Spring runoff	.53	9.9	-.27	5.5	.75	13.1
Summer runoff	.36	31.0	-.02	-9.1	.42	40.1
Storm runoff	.13	15.0	.01	-2.9	.19	21.4
Peak discharge	29.24	16.4	3.03	1.4	50.19	21.7
Daily mean discharge						
Low flow[2]	1.71	35.0	-.28	7.5	2.59	47.9
Medium flow	3.62	27.1	-1.13	-3.7	6.12	42.8
High flow	8.25	24.2	.98	4.2	17.33	34.3
Total	4.54	28.8	-.13	2.8	10.80	42.3

[1]To convert inches to millimeters, multiply by 25.4; To convert cubic feet per second to cubic meters per second, multiply by 0.0283.

[2]Low medium, and high flow regimes are the lower, middle, and upper thirds of the flow duration curve of daily mean discharge values from each station. Total refers to the complete 2-year record of daily mean flow at the station.

The simulation of daily mean low-flow discharge had an 8-percent positive bias, but the simulation of medium, high, and combined total daily mean discharges had a much smaller bias. The standard error of estimate for the totals of all daily mean flows at individual stations ranged from 20 to 65 percent, and was 42 percent for the region as a whole. The magnitude of the daily flow simulation errors does not suggest any inadequacies in the model. The regional standard errors of estimate for low, medium, and high daily flows were 48, 43, and 34 percent respectively, again reflecting that the model performs best while simulating high flows and is least accurate when simulating low flows.

In summary, the simulation errors that remained after model calibration were not large enough to reject the hypotheses concerning rainfall-runoff relations in the study area. The postulated mechanisms of storm-runoff generation appeared to be well supported by the simulation model results, although interstorm and dry-period streamflow generation were not as well represented.

A proxy-basin test of the simulation model, and hence the rainfall-runoff relations incorporated therein, was designed to validate the model parameters. The proxy-basin test involved collecting streamflow and rainfall data from eleven additional drainage basins physiographically similar to those used for model calibration, applying the previously calibrated simulation model to these basins, and then comparing the simulated and observed streamflow data for the new basins. The validation part of this study is currently (1992) under way.

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