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RAINFALL-RUNOFF RELATION FOR REDWOOD CREEK ABOVE ORICK, CALIFORNIA

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Abstract

A digital computer was used to calibrate a model for synthesizing daily runoff for two periods, one in the late 1950's before intensive logging began and another in the late 1960's and early 1970's after intensive logging had been started, in the Redwood Creek basin on the northern California coast. The calibrated models were used with the daily rainfall records for these two periods to provide estimates of synthetic daily runoff records. The synthetic and observed runoff data were compared for each period. These comparisons indicate the runoff increased about 20 percent as a result of changes in hydrology and not as a result of climatic changes.

Introduction

Redwood Creek is a coastal basin in northern California which lies between the Mad and Klamath River basins. It contains the Redwood National Park in its lower portions. There has been considerable activity by man in this basin in recent years, particularly lumbering of stands of virgin redwoods. The question was raised as to whether there has been a change in the hydrology of the Redwood Creek basin, particularly of storm season runoff and how much of the change in storm runoff, if any, is caused by climatic factors.

The model chosen to study this problem is based on work done by Betson and others (1969). Their model is an adaptation of the former

U. S. Weather Bureau co-axial graphically solved rainfall-runoff relation method (Kohler and Linsley, 1951). The model is used to compute an antecedent precipitation index (API) as a measure of soil moisture. Using the API and storm rainfall the model is then used to compute surface runoff. For purposes of this study the model was modified to compute daily rather than storm runoff.

Rainfall-Runoff Model

The initial model was defined by six parameters (a, b, c, d, k, n):

$$RI = c + (a + d^{*}\ SI)\ e^{-b^{*}\ API} \quad (1)$$

$$SRO = (RF^{n} + RI^{n})^{\frac{1}{n}} - RI \quad (2)$$

where, RI = runoff index, an indicator of that portion of basin precipitation that contributes to runoff, in inches.

SI = season index, a factor used to indicate seasonal variations in the runoff index (RI); dimensionless, and varying between -1.0 and 1.0.

RF = daily rainfall, in inches

SRO = surface runoff, in inches

a = parameter associated with soil type

b = parameter associated with the soil moisture retention effect on runoff

c = parameter associated with minimum infiltration

d = scaling factor for the season index (SI)

n = parameter associated with the degree of curvature of the rainfall-runoff relation

The API (antecedent precipitation index), an indicator of basin soil moisture conditions, is computed at day t by the equation $API_t = k * API_{t-1} + RF_t$

where k is a depletion factor.

In order to eliminate the need for hydrograph separation to determine surface runoff, the total runoff was estimated by estimating the daily base-flow component during the storm, computing the daily surface-runoff component using the model, and adding the two components to obtain total daily runoff. A storm period was defined arbitrarily to begin with a day with measured rainfall and to end with two consecutive days without rainfall.

The initial magnitude of baseflow was assumed equal to the runoff occurring on the day before the storm. The rate of baseflow recession during the storm was assumed to decrease exponentially with a recession coefficient of 0.98.

The surface runoff generated by the model was initially divided into two equal parts, and distributed over a two-day period (half the storm runoff initially assumed to occur on the day of rainfall; the other half on the day following). A surface runoff recession coefficient of 0.65 was then applied to these initial magnitudes to generate a distribution hydrograph for the storm.

Calibration

An optimization procedure (Dawdy and others, 1972) was used to determine the parameters in the model. The calibration was restricted to winter, or "storm season" events (October 1 - April 30). The first 30 to 45 days were used as a "warm-up period" and were not included in the optimization, nor were any storm events with less than one inch of total rainfall. Two calibrations were made, one for the 1954, 1956, and 1958 Water Years (before intensive logging began) and one for the 1968, 1970, and 1972 Water Years (after intensive logging had been started) (Janda and others, 1975, p. 121). Use of only the "storm season" events minimizes seasonal variations so that the season index (SI) can be eliminated. Equation 1 then becomes

$$RI = c + (a + d)e^{-b * API}$$

The optimization used an objective function of the sum of the squares of the differences of the logarithms of daily streamflows. This gives equal weight to relative errors rather than absolute errors. However, it introduces a small bias, because it tries to preserve the mean of the logarithm of daily flows rather than the mean flow. Thus, the fitted parameters slightly underestimate total yield each year by up to 7 percent, with an average bias of about 4 percent. No attempt was made to remove the bias because it applied to both periods of study. Because relative changes are the item of interest, a similar bias in all periods should not affect estimates of change.

The parameter k is the API parameter for measuring the residence time of precipitation in the soil moisture. It stabilized at a value of about 0.95 for all years early in the optimization process. This value is rather high for an API index based on experience elsewhere. Its size probably results from the fact that in northern California the major portion of rainfall occurs during the winter months, a period of low evapotranspiration.

Parameters a and d act as one parameter in the model as used in this study. This results because seasonal effect was not considered. Because d measures the relative seasonal effect of soil moisture, it could be set constant without affecting the modeling results. Thus, four parameters (a, b, c, n) remained to be optimized.

During subsequent optimization runs, a and n stabilized at approximately common values for all six years. The two remaining parameters were c, which determines the rainfall-runoff relation for saturated conditions, and b, which determines the relative effect of soil moisture conditions on the rainfall-runoff relation. A pair of parameter values for b and c were then determined for the 1954, 1956 and 1958 data and another pair for the 1968, 1970 and 1972 data. The data for each year were optimized separately to obtain values for b and c. The average values for b and c for the three years in each group were then computed. Use of the average values in an optimization run did not result in further significant improvement of the goodness of fit for any of the years used. The derived average values of the parameters were as follows:

	Parameter set B (Before)	Parameter set A (After)
a	45	45
b	.70	.45
c	3.0	3.5
d	5	5
k	.95	.95
n	1.85	1.85

In figure 1, the relation of rainfall to SRO with variation in API is shown for both sets of optimized parameters. The most pronounced variations in the rainfall-runoff relation occur in the mid-range of soil moisture conditions (values of API 4 to 8) where predicted runoff differs considerably for the parameter sets "before" and "after." The distribution of API values during each year is summarized in table 1. The data shown in this table provide a significant contrast in API for the "before" and "after" periods. However, the range of API from 6 to 10 is well represented in every year. Therefore the relation in that range is relatively well defined.

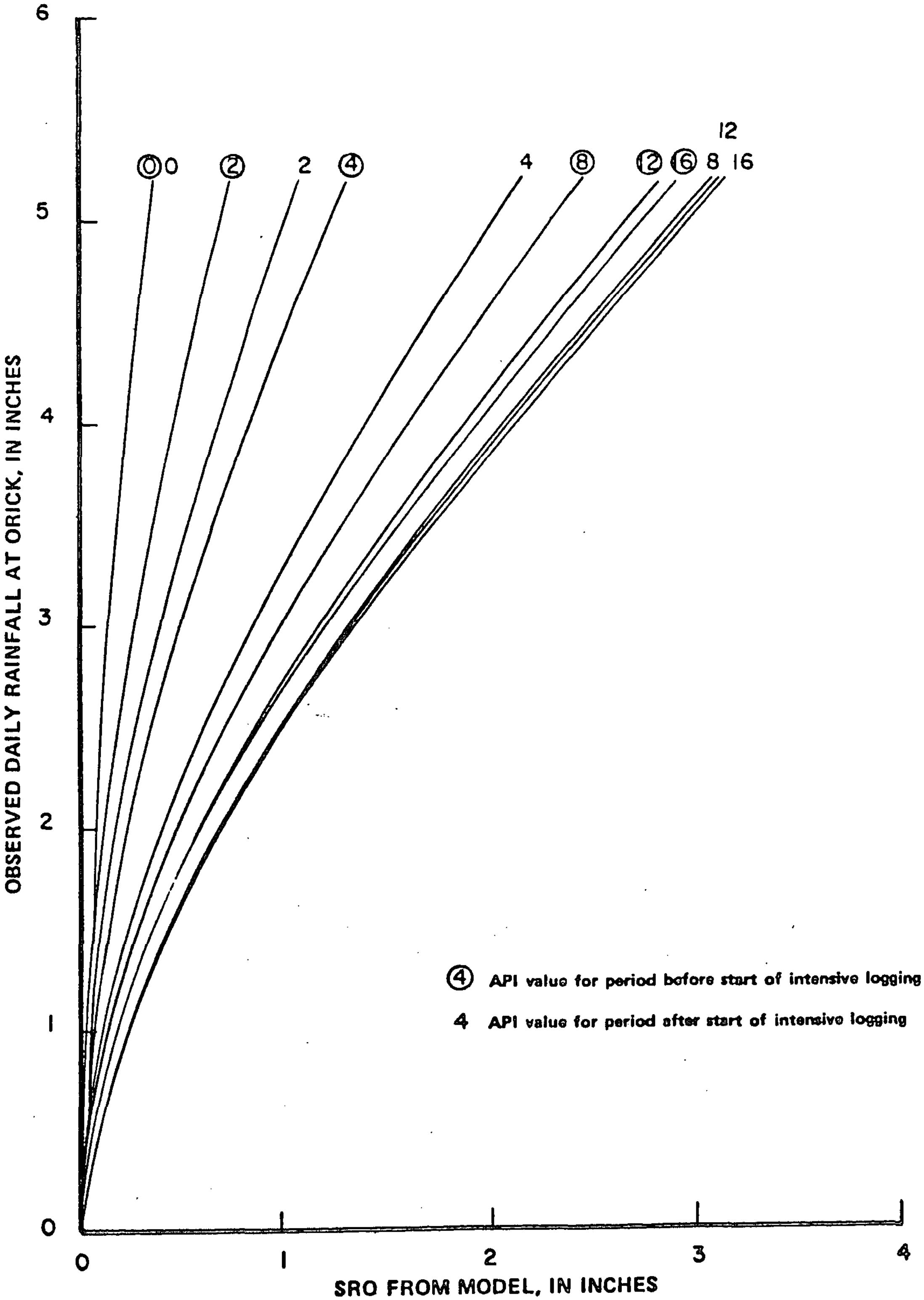

Figure 1. -- Graph showing relation of rainfall to SRO
as a function of API

Table 1. — Number of days the API was in indicated range.

Water year	Range, in inches								
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16+
1954	0	9	1	16	8	8	7	0	0
1956	0	13	0	11	13	8	6	20	12
1958	1	7	1	21	20	9	11	11	1
1968	0	23	1	12	2	0	0	0	0
1970	3	16	1	17	9	3	2	6	2
1972	1	4	1	25	10	2	2	3	0

The magnitudes for the b and c parameters were used with the previously determined common magnitudes of the other parameters (a, d, k, and n) in equations 1 and 2 to predict runoff for various "storm-seasons" utilizing observed rainfall for those years. Observed rainfall and runoff for both the water year and the "storm-season" period within the water year are shown with the predicted runoff for each storm season in table 2. About 75 percent of the daily rainfall and runoff (in the storm season) for each modeled year was used in the analysis.

Comparison of Observed and Synthetic Runoff Values

Optimized model parameters b and c for the earlier period (1954, 1956, and 1958) (parameter set B) were used with the rainfall and API data for the later period (1968, 1970, and 1972) and equations 1 and 2 to predict surface runoff for the later period. Parameters b and c for the later period (parameter set A) were then used with rainfall and API data for the earlier period and equations 1 and 2 to predict surface runoff for the earlier period.

Table 2.--Comparisons of rainfall and observed and synthetic runoff, in inches, in water year and storm season, with parameter set used for synthesis indicated.

	WATER YEAR		MODELED STORM PERIOD		
Year	Measured Rainfall (Inches)	Measured Runoff (Inches)	Measured Rainfall (Inches)	Measured Runoff (Inches	Computed Runoff (Inches)
1954	80.2	60.9	60.3	41.6	39.9
1956	90.0	79.2	76.6	64.8	60.7
1958	87.5	66.3	73.1	52.7	51.8
1968	54.5	32.5	35.9	18.7	17.3
1970	60.6	49.0	44.6	34.7	35.1
1972	72.5	71.8	63.5	58.3	54.3

Model predicted runoff and observed runoff for the storm season in each modeled year are listed in table 3.

A test of the validity of the results of the model study was made by the use of data not used in the fitting of the parameters. In table 4, seven additional years of runoff data for each set of parameters, are compared. The results in the years 1955, 1959, and 1961 using parameter set B generally agree with the results found for 1954, 1956, and 1958 (table 3). Similarly, results in 1969 and 1971 agree fairly well with those found for 1968, 1970, and 1972 (table 3). In the years 1963 and 1965, however, synthetic runoff values are underestimated by both sets of parameters.

Conclusions

Data presented in table 3 indicate that for the later period after the beginning of intensive logging, the storm season runoff is about 20 percent greater than would be expected under conditions found for the earlier period before the beginning of intensive logging. With no hydrologic changes in the basin, the differences between models for the two calibration periods should produce different but unbiased results. Thus, using the rainfall record for the earlier period, before the start of intensive logging, with the model calibrated with data collected for the later period, after the start of intensive logging, should produce virtually the same synthetic runoff values as were computed with the model calibrated with data from the earlier period, i.e., no over-prediction would be expected as a result of climatic changes. Such was

Table 3. - - Comparison of observed and synthetic runoff, in inches, for periods using inter-changed parameter sets

Water year	Measured Runoff (inches)	Predicted Runoff Using Parameters Optimized for Respective Years		Difference From Measured Runoff		Predicted Runoff Using "Before" Optimized Parameters with "After" Data and "After" parameters with "Before" Data		Differences Between Predicted Runoss Using the Two Sets of Parameters	
		Parameter Set	Runoff (inches)	Inches	%	Parameter Set	Runoff (inches)	Inches	%
1954	41.6	B	39.9	-1.7	-4	A	49.9	+10.0	+25
1956	64.8	B	60.7	-4.1	-6	A	71.2	+10.5	+17
1958	52.7	B	51.8	-0.9	-2	A	63.8	+12.0	+23
1968	18.7	A	17.3	-1.4	-7	B	12.6	-4.7	-27
1970	34.7	A	35.1	+0.4	+1	B	27.6	-7.5	-21
1972	58.3	A	54.3	-4.0	-7	B	43.9	-10.4	-19

Table 4. -- Comparison of observed and predicted runoff, in inches, for years not used in calibrations in normal and interchanged order.

Water year	Rainfall	Observed runoff	Parameter set	Synthetic runoff	Difference in runoff in inches	Difference in runoff in percent	Parameter set	Synthetic runoff	Difference in runoff in inches	Difference in runoff in percent
1955	51.1	24.2	B	22.4	-1.8	-7	A	29.8	5.6	19
1957	51.7	32.2	B	27.3	-4.9	-15	A	35.4	3.2	10
1961	58.3	35.5	B	31.3	-4.2	-12	A	40.3	4.8	14
1963	43.2	35.2	B	18.2	-17.0	-48	A	24.8	-10.4	-30
1965	60.0	59.4	B	38.6	-20.8	-35	A	45.9	-13.5	-23
1969	42.7	39.9	B	27.7	-12.2	-31	A	33.2	-6.7	-17
1971	70.8	53.8	B	47.2	-6.6	-12	A	58.2	4.4	8

not the case, however, and it can be assumed that physical basin changes contributed significantly to the increased surface runoff in the storm season during the later period.

Apparently a major change took place in the hydrology of the basin during the middle 1960's, with some readjustment during the late 1960's and early 1970's. Further study and refinement would be required to trace the adjustments of the hydrology with greater precision.

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