USE OF REGRESSION EQUATIONS AND HYDROLOGIC MODELS FOR FLOOD FORECASTING - A CASE STUDY

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SYNOPSIS

This paper summarizes the experience gained and the results of a forecasting study on the Grand Lake Basin in Newfoundland. Conventional regression equations and two different runoff simulation models were used. The basin has only three precipitation stations to cover a drainage area of 1940 square miles, which influences the use of the models. In addition, the computed inflows to Grand Lake were affected by variations in the lake levels due to wind.

INTRODUCTION

The objective of the study that is being reported upon herein is to establish a technique for forecasting seven-day inflow volumes to a reservoir using the available meteorologic and hydrologic data during the snowmelt-runoff period. The study has been undertaken by The Shawinigan Engineering Company Limited for the Bowater Power Company Limited. These forecasts are required in order to improve the means of regulating the Grand Lake Reservoir in Newfoundland which provides storage for a 125-MW hydro-electric plant. Their purpose is to provide information for efficient and safe control of the reservoir when water levels are close to full supply level toward the end of the spring-runoff period that are useful to anticipate when spillage is required. Furthermore, when available sufficiently in advance, they allow spillage to take place over a longer duration. This results in lower rates of spill with lower probability of downstream flood damages.

Both regression techniques and deterministic hydrologic models were used. The former gave adequate results; however, the latter proved to be unsatisfactory with the available input data. Nevertheless, the hydrologic models did provide information on the water equivalent of the snowpack through the winter and at the beginning of the snowmelt-runoff period.

THE WATERSHED

The Grand Lake Watershed is situated in the north-west portion of Newfoundland. The basin is approximately 100 miles long, 20 miles wide and has a drainage area of 1942 square miles. (figure 1)

Note:

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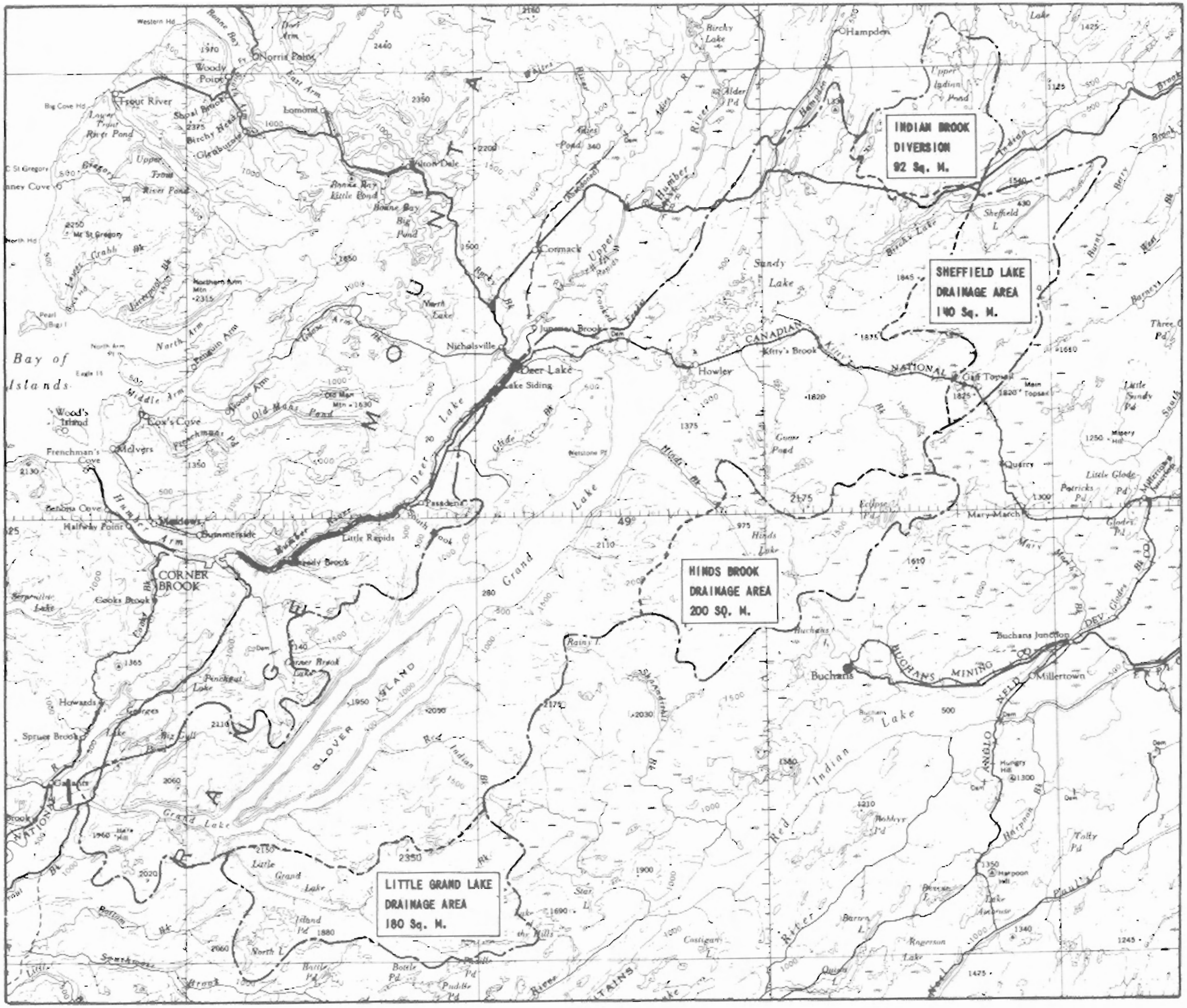
FIGURE 1



THE BOWATER POWER COMPANY LTD.

FLOOD VOLUME ESTIMATES AND FLOW FORECAST
GRAND LAKE SYSTEM
MAP SHOWING GRAND LAKE DRAINAGE AREA
AND METEOROLOGICAL STATIONS USED ●
SCALE 1" = 8 MILES

The long axis of the basin is orientated in a north-east/south-west direction. The topography may be described as rugged with the elevation range extending from 300 to 2100 feet above mean sea level with 75% of the basin being lower than 1300 feet. The main valley is occupied by the Grand Lake storage reservoir which has a surface area of 186 square miles.

HYDROMETEOROLOGIC INPUT DATA

In carrying out the regression analysis and hydrologic modelling both meteorologic data, precipitation and temperature readings, and hydrologic parameters, such as inflows to the reservoir and water equivalent of the snowpack, are required. There are four meteorologic stations in and around the watershed - Deer Lake, Buchans, Corner Brook Lake and Howley. The latter two were excluded from consideration. The information applied by the Howley gauge is redundant because of its proximity to the Deer Lake gauge, i.e. 14 miles. The Corner Brook Lake gauge was excluded because of the large gaps in its record and poor quality of data. The Deer Lake gauges have been read for temperature and precipitation since 1926 and are situated adjacent to the hydro-electric plant. The Buchan station has been reading since 1940. It is situated at an elevation of 900 feet six miles from the south central boundary of the watershed and twenty six miles from its geometric center. There are no meteorologic gauges at the higher elevation of the watershed; hence no statements can be made about the elevation variation of precipitation. There are hydrometric stations in four tributaries, which are distributed along the length of the watershed. An analysis of runoff per square mile for two years of record of these stations shows that the runoff increased by at least 40% from the north-east to the south-west part of the watershed, which reflects a wide areal variation of precipitation amounts.

Snow surveys at nineteen locations on the watershed have been made by Bowater Power Company in March of each year since 1926. Inflows to the reservoir have been computed using the continuity equation,outflows from the reservoir and changes in water surface elevation.

REGRESSION ANALYSIS

Regression equations were developed for seven-day intervals using values of hydrometeorologic parameters recorded from 1940 to 1972. The reasons for the use of seven-day volumes were two-fold. First, there are only two water level recording gauges available to determine changes in water levels. Both are situated at one end of the lake and thus limited in their ability to portray the average lake elevation. The water level is subject to variations due to wind; consequently, there are significant random errors in the computed daily inflows. By using a longer forecast period, the relative errors become smaller. Secondly, seven-day forecasts are useful in formulating operational procedures and has hydrologic justification since a one-day unit hydrograph for the watershed has a time base of eight days.

A stepwise regression analysis was carried out. Starting with 13 independent hydrometeorological parameters, the analysis was continued until five parameters were found that explained between 69 and 79 percent of the variance. Different equations were developed for five periods, normally of three-week duration, which together constitute the snowmelt-runoff season. These equations along with the coefficients of correlation and standard errors of estimate are given in Table 1. The correlation coefficients vary between .83 and .89. The standard errors of estimate range from 0.8 to 2.5 B.C.F., which represents 0.2 to 0.6 inches of water over the drainage area. The independent terms of equations in Table 1 are arranged in their order of selection in the stepwise regression and thus in their order of influence on runoff volumes.

Most of the independent variables reflect the condition on the watershed at the beginning of an interval; examples are the previous seven flows, VP, and rainfall total for the three days immediately previous of the interval, RP. There are two variables that represent meteorologic conditions during the forecast interval: rainfall recorded on the first three days and the sum of degree-days greater than 32°F for the first five days. These parameters were selected because they can be currently forecasted for these durations.

The regression equations were used during the 1975 snowmelt-runoff period to forecast inflow to the reservoir. The results compared with recorded flows are shown in Table II. Also in this table are regression results when the recorded meteorological inputs were used. The difference between the simulated and recorded inflows range from plus 3.0 to minus 1.7 B.C.F. with average absolute difference of 1.6 B.C.F. Using forecasted temperature and rainfall in the interval the range of difference is from minus 5.0 to plus 5.4 B.C.F. and has an average absolute value of 2.7 B.C.F.

HYDROLOGIC MODELLING

In parallel with the development of the regression equations, the usefullness of a parametric, deterministic model to simulate the hydrologic response of the watershed during the snowmelt-runoff period was explored. If such a model could give accurate inflows to the reservoir, then it would be useful means of forecasting reservoir levels and outflows during a snowmelt-runoff season.

The model used was one developed by S.I. Solomon (1). It is based on water budget principles using precipitation and temperature as inputs with evaporation, snowpack water equivalent and runoff as outputs.

The model was operated on a daily basis from October 1st to June 30th of each year, and the outflows were converted into seven-day volumes in order that comparisons could be made with those obtained by the regression equations. The model was calibrated for the 1964 and 1965 years and validated for the 1967 snowmelt-runoff year. Moreover, in order to verify the model ability to simulate the snowpack water equivalent, the computed values of this quantity were compared with those obtained from the snow surveys for the years 1952 to 1961. These are given in Table III. The two sets of water equivalents for the ten years compare fairly well except for 1960. The seasonal temperatures were recorded to be unusually high during the winter of 1959-60. Hence the difference of 6.5 in. may be attributed to poor temperatures representation.

TABLE I

PERIOD OF APPLICABLE	GRAND LAKE WATERSHED REGRESSION FOR SEVEN DAY REGRESSION EQUATION	FLOW VOLUMES COEFFICIENT OF CORRELATION	STANDARD ERROR B CF
APRIL 1 TO APRIL 28	VF = 0.086 D + 5.48 R + 0.46 VP + 0.088 DP - 0.032 SD + 0.04	0.89	1.6
APRIL 21 TO MAY 5	VF = 0.48 VP + 0.11 D + 2.78 R - 0.032 SD + 0.081 DP + 0.58	0.86	1.9
MAY 6 TO MAY 26	VF = 0.019 SD + 3.61 R + 0.23 VP + 0.063 SB + 0.023 D + 5.1	0.83	2.5
MAY 27 TO JUNE 9	VF = -0.019 SD + 3.61 R + 0.23 VP + 0.063 SB + 0.033 D + 5.1	0.85	1.9
JUNE 10 TO JUNE 30	VF = 0.35 VP + 1.90 R - 0.133 T + 0.89 RP + 7.11	0.86	0.8

DEFINITIONS: THE FOLLOWING DEFINITIONS WILL BE ILLUSTRATED ASSUMING THAT AN ESTIMATE IS BEING MADE FOR DAYS 8 TO 14 OF A GIVEN MONTH.

VF = 7 DAY FORECAST NATURAL INFLOW TO GRAND LAKE SYSTEM B.C.F. = SUM OF DAYS 8 TO 14

VP = 7 DAY PREVIOUS NATURAL INFLOW TO GRAND LAKE SYSTEM B.C.F. = SUM OF DAYS 1 TO 7

D = SUM OF DEGREE DAYS GREATER THAN 32 FOR FIRST 5 DAYS OF FORECAST PERIOD = SUM OF (T-32) FOR DAYS 8 TO 12 WHERE T = MEAN DAILY TEMPERATURE

DP = SUM OF DEGREE DAYS GREATER THAN 32 FOR PREVIOUS 3 DAYS = SUM OF (T-32) FOR DAYS 5 TO 7

SD = SUM OF DEGREE DAYS GREATER THAN 35 FROM MARCH 20 TO THE DAY PREVIOUS TO START OF FORECAST = SUM (T-35) FOR DAYS FROM MARCH 20 TO DAY 7 OF THE GIVEN MONTH

R = RAINFALL IN THE FIRST 3 DAYS OF THE FORECAST PERIOD = SUM OF RAIN FOR DAYS 8 TO 10 (THIS IS RAINFALL AND NOT PRECIPITATION)

RP = RAINFALL IN THE 3 DAYS PREVIOUS = SUM OF RAIN FOR DAYS 5 TO 7

SB = SNOWBLANKET AS MEASURED IN MARCH (B.C.F.)

T = AVERAGE TEMPERATURE IN THE 30 DAY PERIOD ENDING ON DAY 7

TABLE II

SEVEN-DAY VOLUMES OF RUNOFF WITH REGRESSION EQUATIONS USING RECORDED AND FORECASTED METEOROLOGICAL DATA

DATE 1975		RECORDED RUNOFF (B.C.F.) X	ESTIMATE OF RUNOFF USING RECORDED MET. DATA (B.C.F.) Y	DIFFERENCE Y-X (B.C.F.)	ESTIMATE OF RUNOFF USING FORECASTED MET. DATA (B.C.F.) Z	DIFFERENCE Z-X (B.C.F.)
APRIL	21-27	4.0	2.7	-1.3	2.3	-1.7
	28-4	7.6	5.9	-1.7	6.8	- .8
MAY	5-11	15.0	13.6	-1.4	10.0	-5.0
	12-18	16.4	16.8	+ .4	12.7	-3.7
	19-25	7.7	10.7	+3.0	13.1	+5.4
	26-1	4.2	5.8	+1.6	7.0	+2.8
JUNE	2-8	3.4	5.8	+2.4	4.6	+1.2
	9-15	2.7	2.0	- .7	2.0	- .7
AVERAGE OF ABSOLUTE VALUES				1.6		2.7

TABLE III

YEAR *	MEASURED SNOW PACK WATER EQUIVALENT (IN)	COMPACTED SNOW PACK WATER EQUIVALENT BY ONE ZONE MODEL (IN)	DIFFERENCE (IN)
1952	8.3	5.2	-3.1
53	3.8	3.7	-0.1
54	5.8	5.6	-0.2
55	3.0	2.9	-0.1
56	4.9	4.9	0.0
1957	8.2	9.4	+1.2
58	0.0	0.0	0.0
59	7.0	8.4	+1.4
60	7.4	1.1	-6.3
61	10.8	8.3	-2.5
AVERAGE	6.6	5.5	
AVERAGE OF ABSOLUTE DIFFERENCES			1.7

* SNOW SURVEYS WERE TAKEN ABOUT MARCH 21st OF EACH YEAR

The results for the 1974 and 1975 snowmelt-runoff season are given in Table IV. When compared with recorded flows, the average difference is 2.2 B.C.F. for 1974 and 4.4 B.C.F. for 1975. These statistics represent differences between simulated and recorded total spring runoff volumes of 33 and 42 percent, respectively. These differences are too high for realistic hydrological forecasting, and there is a tendency for simulated flows to recede too quickly; consequently, the model was modified so that precipitation and temperature were assumed to vary with elevation throughout the watershed. This was executed by dividing the watershed into three zones by elevation bands and assuming that the hydrologic inputs are constant within each zone.

The relations used to do this are:

Zone 1	$M = (M_B + M_{DL})/2$
Zone 2	$M = M_B$
Zone 3	$M = M_B + (M_B - M_{DL})/2$

where M is a meteorological input parameter, either temperature or precipitation, and the subscripts B and DL represent Buchans and Deer Lake readings, respectively.

The results of these simulations are given in Table V. The ranges of differences are a little higher than those obtained using the one-zone model, although the average differences between recorded and simulated seven-day volume are less.

A widely used model in reservoir inflow forecasting is one developed by the U.S. Army Corps of Engineers called the SSARR Model (2). It was applied to the Grand Lake 1974 and 1975 spring-runoff seasons. The results obtained by this model and the two versions of the parametric model as well as recorded inflow volumes are shown in Figures 2 and 3. The absolute values of the difference between each set of simulated flow volumes and recorded volumes are given for Table VI and VII. The relative errors vary from 7 to 80 percent and there is no consistency in the two years of simulations as to which model gives the best results.

Moreover, a comparison of the results of the two models indicated that higher sophistication of the SSARR model does not lead to better results than a simple model of this watershed. This indicates again the basic requirements for the application of any snowmelt runoff model is the availability of reliable meteorologic data.

CONCLUDING REMARKS

The objectives of the study have not yet been obtained, since a forecasting technique accurate enough to objectively operate the reservoir has not been developed. The regression equations give at present the best means of hydrologic forecasting. The inadequate results obtained by the hydrologic models are believed due to the poor areal and elevation representation provided by two meteorologic stations. Until more stations are established on the watershed, hydrologic forecasting will have to rely on the regressional equations. At present, the number and location of additional meteorologic stations are being considered.

TABLE IV

COMPARISON OF SEVEN-DAY SIMULATED VOLUMES USING THE ONE-ZONE MODEL WITH RECORDED SEVEN-DAY VOLUMES

PERIOD	SIMULATED VOLUME (B.C.F.) Y	RECORDED VOLUME (B.C.F.) X	DIFFERENCE (B.C.F.) Y-X	$\frac{Y-X}{X}$ %
1974 APRIL 1-7	1.9	2.1	+ .8	+38
8-14	3.6	3.9	- .3	- 8
15-21	2.8	2.0	+ .8	+40
22-28	3.4	2.5	+ .9	+36
29-5	6.5	4.4	+2.1	+48
MAY 6-12	6.7	6.0	+ .7	+12
13-19	8.7	10.9	-2.2	-20
20-26	8.1	11.1	-3.0	-27
27-2	3.4	12.3	-8.9	-72
AVERAGE OF ABSOLUTE VALUES			2.2	33
1975 APRIL 7-13	5.6	4.1	+1.5	+37
14-20	3.0	2.7	+ .3	+11
21-27	5.1	4.0	+1.1	+28
28-4	6.9	7.6	- .7	- 9
MAY 5-11	7.2	15.0	-7.8	-52
12-18	3.2	16.4	-13.2	-80
19-25	1.8	7.7	-5.9	-77
26-1		4.2		
JUNE 2-8		3.4		
AVERAGE OF ABSOLUTE VALUES			4.4	42

NOTE: SIMULATION MADE USING RECORDED METEOROLOGICAL DATA

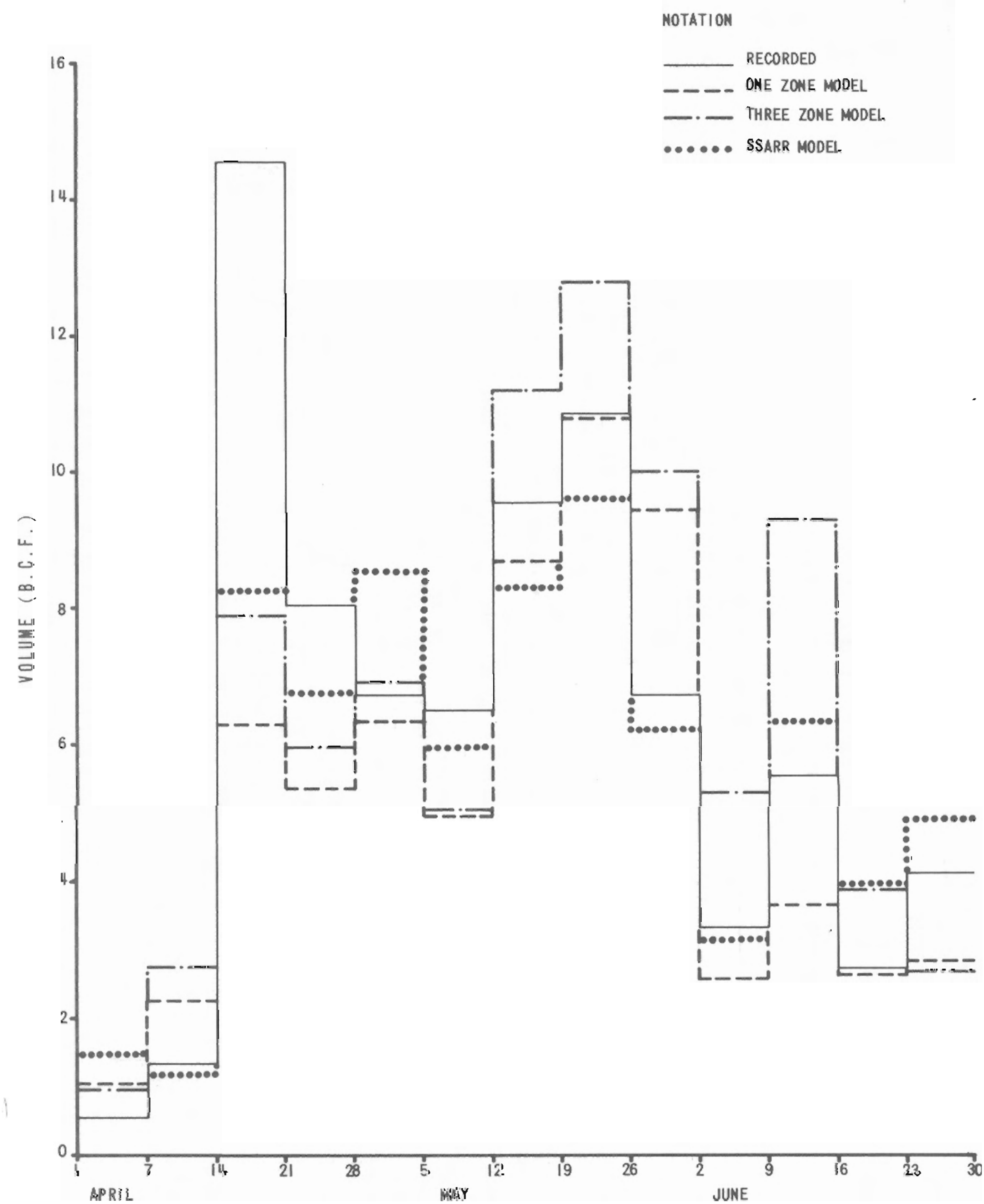
TABLE V

COMPARISON OF SEVEN-DAY RUNOFF VOLUMES SIMULATED USING THE THREE ZONE MODEL WITH RECORDED SEVEN-DAY RUNOFF VOLUMES

PERIOD	THREE-ZONE MODEL SIMULATED VOLUMES (B.C.F.) Y	RECORDED VOLUMES (B.C.F.) X	DIFFERENCE (B.C.F.)	$\frac{Y-X}{X}$ %
1974 APRIL 1-7	3.4	2.1	+1.3	+62
8-14	4.3	3.9	+ .4	+10
15-21	3.4	2.0	+1.4	+70
22-28	3.9	2.5	+1.4	+56
29-5	7.9	4.4	+3.5	+80
MAY 6-12	7.8	6.0	+1.8	+30
13-19	11.7	10.9	+ .8	+ 7
20-26	9.0	11.1	-2.1	-19
27-2	7.1	12.3	-5.2	-42
JUNE 3-9	6.9	10.5	-3.6	-34
10-16	7.0	5.9	+1.1	+19
AVERAGE OF ABSOLUTE VALUES			2.1	39
1975 APRIL 7-13	6.9	4.1	+2.8	+68
14-20	2.9	2.7	+ .2	+ 7
21-27	7.1	4.0	+3.1	+78
28-4	6.1	7.6	-1.5	-20
MAY 5-11	9.8	15.0	-5.2	-35
12-18	8.4	16.4	-8.0	-49
19-25	4.6	7.7	-3.1	-40
26-1	1.5	4.2	-2.7	-64
JUNE 2-8	2.2	3.4	-1.2	-35
AVERAGE OF ABSOLUTE VALUES			3.1	44

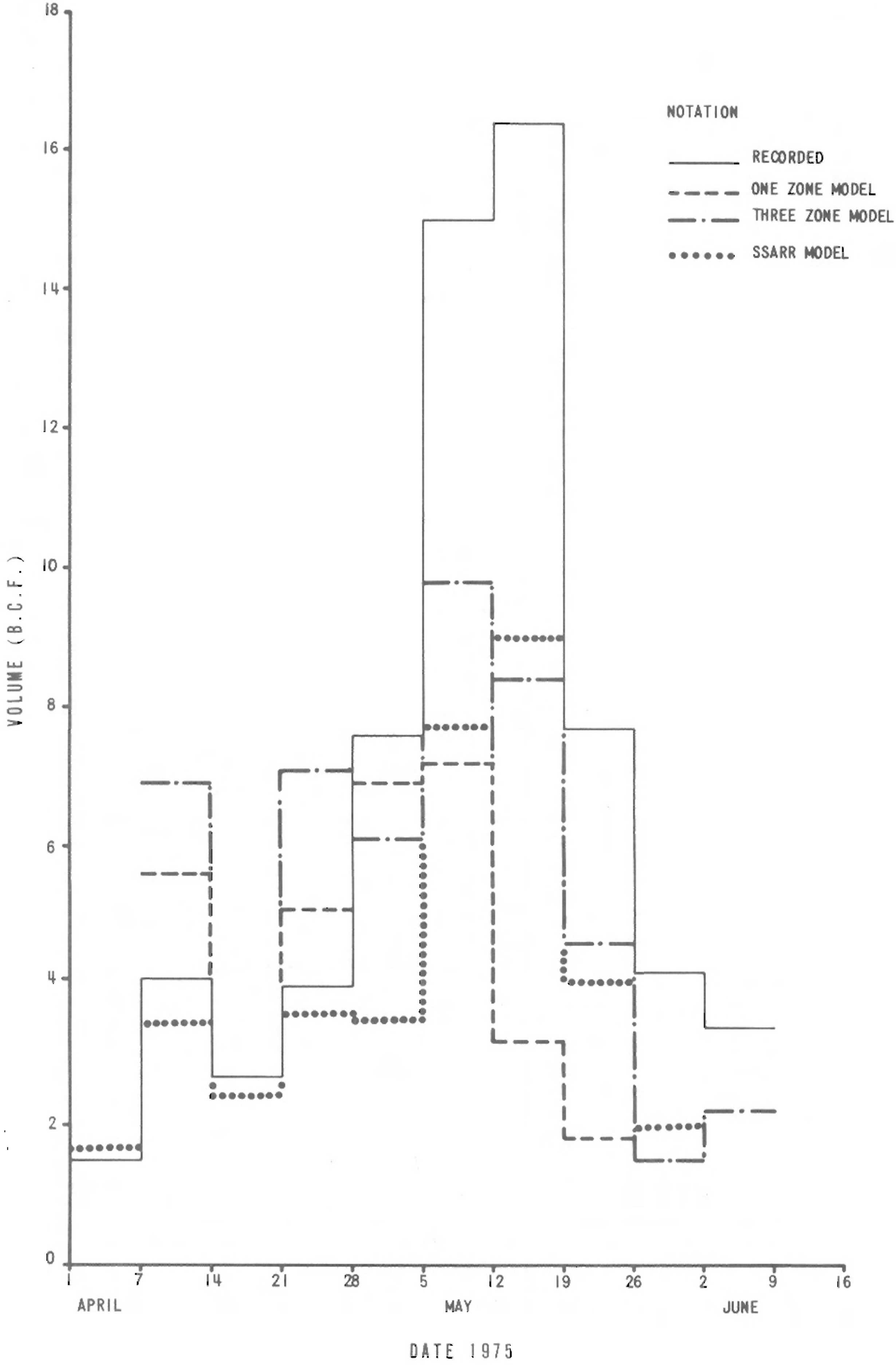
NOTE: MODEL APPLIED USING RECORDED METEOROLOGICAL DATA

FIGURE 2



DATE 1964

FIGURE 3



NOTATION
RECORDED
ONE ZONE MODEL
THREE ZONE MODEL
SSARR MODEL
VOLUME (B.C.F.)
0
2
4
6
8
10
12
14
16
18
1
7
14
21
28
5
12
19
26
2
9
16
APRIL
MAY
JUNE
DATE 1975

TABLE VI

COMPARISON OF SEVEN-DAY SIMULATED VOLUMES USING THE ONE-ZONE, THREE ZONE AND SSARR MODELS WITH RECORDED SEVEN-DAY VOLUMES

PERIOD 1964		RECORDED VOL. (BCF) Y	ONE-ZONE (BCF) X_1	DIFFERENCE (BCF) X_1-Y	THREE-ZONE (BCF) X_2	DIFFERENCE (BCF) X_2-Y	SSARR (BCF) X_3	DIFFERENCE (BCF) X_3-Y
APRIL	1-7	.6	1.0	.4	.9	0.3	1.5	0.9
	8-14	1.3	2.3	1.0	2.8	1.5	1.2	-0.1
	15-21	14.5	6.3	-8.2	7.9	-6.6	8.3	-6.2
	22-28	8.0	5.4	-2.6	6.0	-2.0	6.8	-1.2
	29-5	6.7	6.3	-0.4	6.9	0.2	8.5	1.8
MAY	6-12	6.5	4.9	-1.6	5.1	-1.4	5.9	-0.6
	13-19	9.6	8.7	-0.9	11.2	1.6	8.3	-1.3
	20-26	10.9	10.8	-0.1	12.8	1.9	9.6	-1.3
	27-2	6.8	9.4	2.6	10.0	3.2	6.2	-0.6
JUNE	3-9	3.3	2.5	-0.8	5.3	2.0	3.2	-0.1
	10-16	5.5	3.6	-1.9	9.3	3.8	6.3	0.8
	17-23	2.8	2.5	-0.3	3.9	1.1	4.0	1.2
	24-30	4.2	2.9	-1.3	2.7	-1.5	4.9	0.7
AVERAGE OF ABSOLUTE VALUES				1.7		2.1		1.3

TABLE VII

COMPARISON OF SEVEN-DAY SIMULATED VOLUMES USING THE ONE-ZONE, THREE-ZONE AND SSARR MODELS WITH RECORDED SEVEN-DAY VOLUMES

PERIOD 1975	RECORDED VOL. (BCF) Y	ONE-ZONE (BCF) X_1	DIFFERENCE (BCF) X_1-Y	THREE-ZONE (BCF) X_2	DIFFERENCE (BCF) X_2-Y	SSARR (BCF) X_3	DIFFERENCE (BCF) X_3-Y
APRIL 7-13	4.1	5.6	1.5	6.9	2.8	1.6	-2.5
14-20	2.7	3.0	0.3	2.9	0.2	3.5	0.8
21-27	4.0	5.1	1.1	7.1	3.1	2.4	-1.6
28-4	7.6	6.9	-0.7	6.1	-1.5	3.6	-4.0
MAY 5-11	15.0	7.2	-7.8	9.8	-5.2	3.6	-11.4
12-18	16.4	3.2	-13.2	8.4	-8.0	7.7	-8.7
19-25	7.7	1.8	-5.9	4.6	-3.1	9.0	1.3
26-1	4.2			1.5	-2.7	4.0	-0.2
JUNE 2-8	3.4			2.2	-1.2	1.9	-1.5
AVERAGE OF ABSOLUTE VALUES			4.4		3.1		3.4

Furthermore, the possibility of utilizing interrogated hydrometric and meteorologic readings via LANDSAT satellite is being explored. Moreover, the use of the four gauged basins as index basins for obtaining better hydrologic forecasts is also being investigated.

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