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LAKE ONTARIO BASIN RUNOFF MODELING

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NOTICE

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LAKE ONTARIO BASIN RUNOFF MODELING*

Thomas E. Croley II and Holly C. Hartmann

An interdependent tank-cascade model of basin runoff, employing analytical solutions of climatological considerations relevant for large watersheds, has been developed. The mass balance is coupled with physically-based concepts of linear reservoir storages, partial-area infiltration, complementary evapotranspiration and evapotranspiration opportunity based on available supply, and heat balance determinations of snowmelt and net supply. Daily air temperature, precipitation, and runoff data are required for calibration of the nine parameters; data are grouped for 15 watersheds about Lake Ontario, as well as for the entire basin above Elevator, N.Y., and Kingston, Ont. The model has been applied to the Lake Ontario Basin in both lumped- and distributed-parameter approaches; 11 subbasins and 2 basins have been modeled for 7-d and 30-d mass balance computation intervals. Parameter values have been interpreted for physical meaning and relation to data errors and computation intervals. Temporal and spatial integration effects have been analyzed with respect to error reduction, modeling information and resolution, and cost trade-offs. The model is an accurate, fast representation of weekly or monthly runoff volumes from large watersheds with simple calibration and data requirements. Parameter values have physical significance and appear reasonable and consistent.

1. INTRODUCTION

Physically-based rainfall-runoff watershed models are required to simulate basin outflows to the Great Lakes for use in routing models for lake levels simulation and forecast. The models must be specific for weekly or monthly outflow volumes from large areas with severely limited data availability. Only daily precipitation and air temperatures are available over the Great Lakes Basin in an often sparse meteorological network. The Great Lakes Environmental Research Laboratory (GLERL) recently completed development and testing of its Large Basin Runoff Model; the model and its operation are described in detail by Croley (1982c). An earlier paper compared the model on the Genesee River Basin above Portageville, N.Y., with two other models that were adapted by others for use on a large scale (Potok, 1980). The GLERL model was tested on 30-d flow volumes and found to be superior for simulation on both a monthly and an annual basis. It is an accurate, fast model with relatively simple calibration and data requirements for large watersheds. Subsequent to the comparisons of the preceding paper, the model is being used to simulate basin runoff contributions to each of the Great Lakes for use in routing models.

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*GLERL Contribution No. 360.

This paper describes the application of the model to the subbasins of Lake Ontario (identified in fig. 1) for both 7-d and 30-d flow volumes. The model and its use are briefly outlined to establish parameter definitions. Calibrated parameter values are interpreted with regard to physical meaning and time scale of the models. Several spatial and temporal resolution tradeoffs with model accuracy and cost are investigated and model results for the Lake Ontario drainage basin are presented. Observations on the model and recommendations for future use are made and subsequent applications are outlined.

2. RUNOFF MODEL

An abbreviated model presentation is given here for convenience of reference. For details, see Croley (1982a, b, c). The model uses the tank-cascade concept pictured schematically in figure 2. Inputs of daily precipitation, daily minimum and maximum air temperature, and seasonal insolation

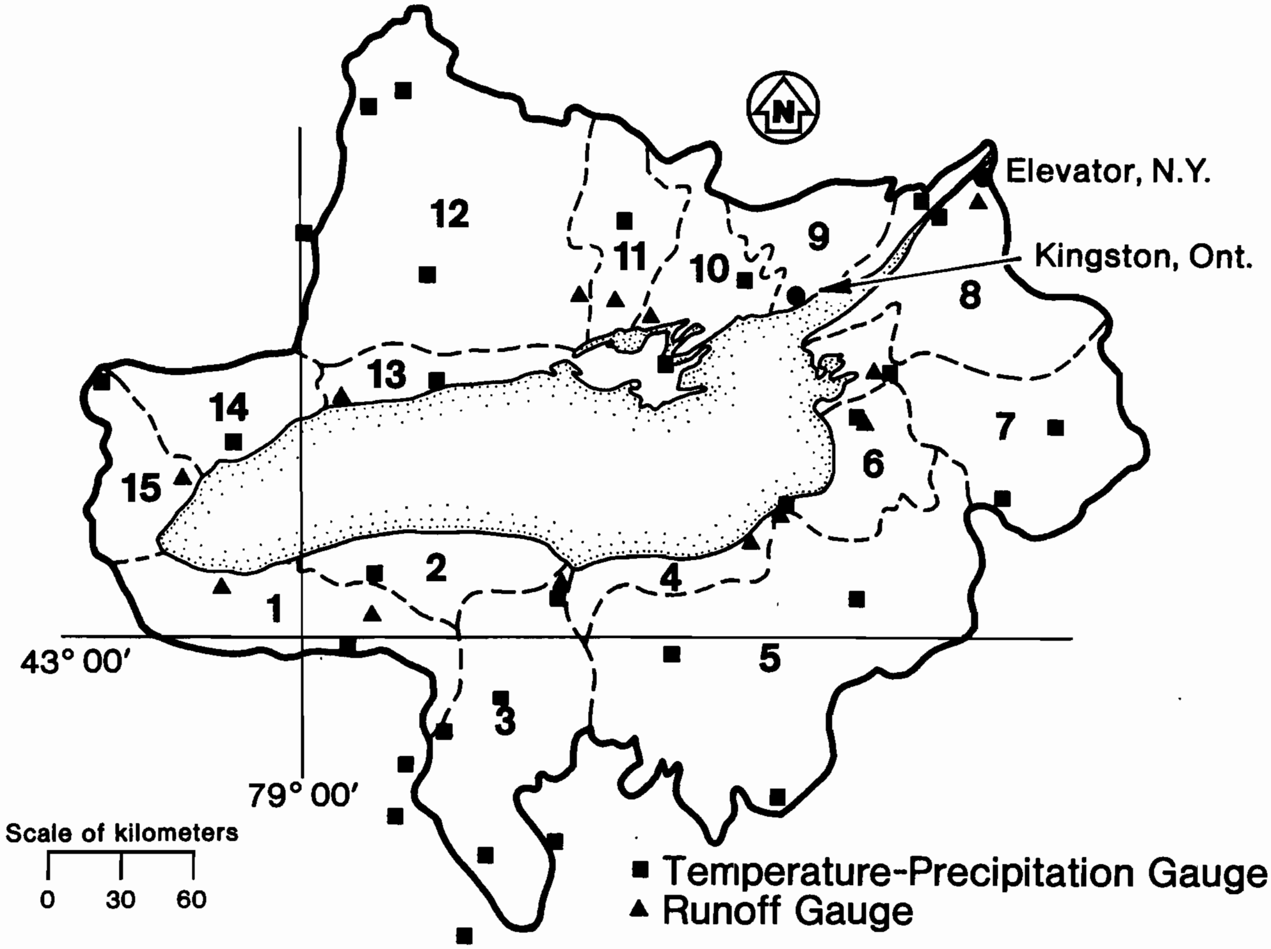

FIGURE 1.--*Lake Ontario basins location map.*

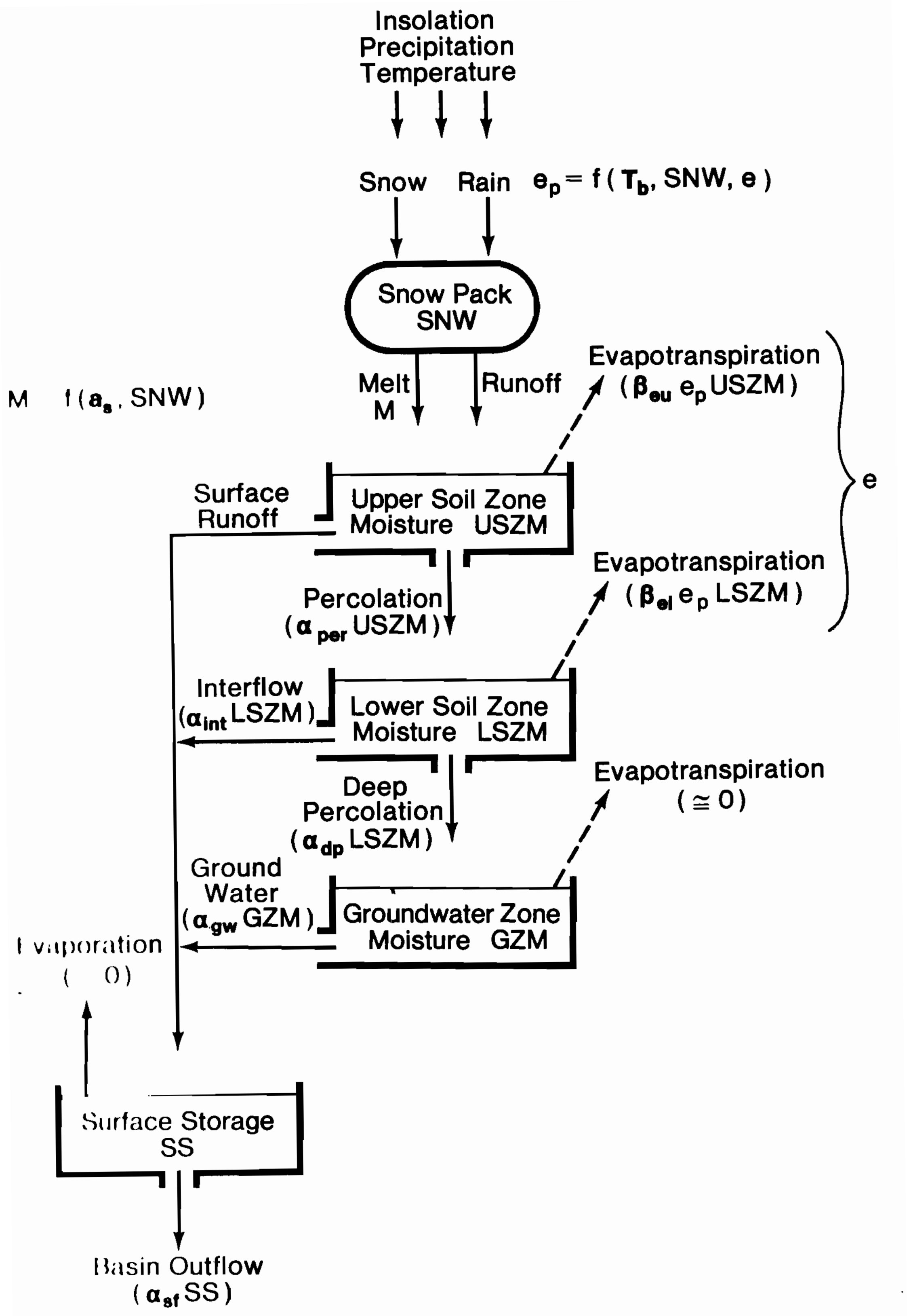

FIGURE 2.--*GLERL Large Basin Runoff Model schematic.*

determine the snowpack accumulation and the resulting net supply rate to the watershed. Net supply is divided into surface runoff and infiltration into the upper soil zone. Percolation from the upper soil zone recharges the lower soil zone. Deep percolation from the lower soil zone recharges the groundwater zone. Flows from these three storages of surface runoff, interflow, and groundwater recharge the surface storage. Evapotranspiration losses may occur from any of the storages. The following equations represent the basis for the runoff model and identify both data and parameter requirements. They are presented in their approximate order of use within the model.

Cloud cover is estimated from daily air temperatures (Crawford and Linsley, 1966):

$$X = \min \left[\frac{T_{max} - T_{min}}{15}\right] 1.0 \; , \qquad (1)$$

where X = daily ratio of hours of bright sunshine to maximum possible hours of bright sunshine, T_{max} = maximum daily air temperature (°C), and T_{min} = minimum daily air temperature (°C). Daily insolation is:

$$rr = 10000 \, A_w \, \tau \, (b_1 + b_2 X), \qquad (2)$$

where rr = daily solar insolation at the watershed surface (cal/d), A_w = area of the watershed (m^2), τ = daily extra-terrestrial solar radiation (langleys/d), and b_1 and b_2 = constants. Potential snowmelt is what occurs if the snowpack is not limiting:

$$\begin{aligned} m_p &= 0 && , \quad T < 0 \\ &= [rr\,(1 - a_s) + \rho \, p \, T]/(\rho \, \gamma_m) && , \quad T > 0, \end{aligned} \qquad (3)$$

where m_p = daily potential snowmelt rate (m^3/d), a_s = albedo of the snow surface, ρ = density of water (= 10^6 g/m^3), p = precipitation rate (m^3/d), T = air temperature estimated as the average of the daily maximum and minimum temperatures (°C), and γ_m = latent heat of fusion (= 79.7 cal/g). Data availability limitations do not allow consideration of changing conditions of snowpack depth, age, etc. Hence, a_s is treated as a parameter and is optimized as a constant. Actual snowmelt depends upon the snowpack

$$\begin{aligned} m &= m_p && , \quad m_p \, d < SNW_0 \\ &= SNW_0/d && , \quad m_p \, d > SNW_0, \end{aligned} \qquad (4)$$

where m = daily snowmelt rate (m^3/d), d = 1 day (since snowmelt is determined on a daily basis), and SNW_0 = water content of snowpack at the beginning of the day (m^3). Snowpack mass balance and water supply to the watershed surface can now be determined:

$$\frac{\partial}{\partial t} SNW = p \quad , \quad T < 0$$
$$= -m \quad , \quad T > 0 \tag{5}$$

$$ns = 0 \quad , \quad T < 0$$
$$= p + m \quad , \quad T > 0, \tag{6}$$

where t = time and ns = daily net supply rate to the watershed surface (m^3/d).

Over large areas, climatic observations suggest that actual evapotranspiration affects temperatures, wind speeds, humidities, etc., and hence potential evapotranspiration (evapotranspiration opportunity or capacity). This concept is modified here by considering that, for short time periods, the total amount of energy available for evapotranspiration during the time period, W, is split into that used for evapotranspiration and that used for atmospheric heating. For the daily time period

$$W = H + \rho\gamma_v(E_u + E_\ell + E_g + E_s), \tag{7}$$

where W = total energy available for evapotranspiration during the day (cal), H = nonlatent heat released to the atmosphere during the day (cal), γ_v = latent heat of vaporization (= 596 cal/g), and E = evaporation or evapotranspiration from the upper soil zone, lower soil zone, groundwater, and surface storage, respectively. The evaporation from stream channels and other water surfaces (surface zone) in a large basin is very small compared to the basin evapotranspiration; groundwater evapotranspiration is also taken here as being relatively small.

The heat available for evapotranspiration is

$$W = K(T - T_b) \quad , \quad T > T_b \quad , \quad SNW_0 = 0$$
$$= 0 \quad , \quad T > T_b \quad , \quad SNW_0 > 0$$
$$= 0 \quad , \quad T < T_b, \tag{8}$$

where K = units and proportionality constant (cal/°C), and T_b = "base" temperature (°C). The constant, K, is determinable from the following boundary constraint on the long-term heat balance:

$$\sum_{i\varepsilon\Omega} W_i = \sum_{i\varepsilon\Omega} rr_i \; d, \qquad \Omega = \{i \mid SNW_i = 0\}, \tag{9}$$

where the subscript, i, refers to daily values. Equation (9) conserves energy in that all absorbed insolation not used for snowmelt appears sooner or later as other components of the heat balance that determine W. While calculations for ns and W are performed on a daily basis, the mass balance computations (following) are performed on an n-day basis (n = 7 and n = 30 are used herein). The net supply and energy available for evapotranspiration are summed over the n-day periods prior to the mass balance

$$\overline{ns} = \frac{1}{n} \sum_{i=1}^{n} ns_i \tag{10}$$

$$\overline{W} = \sum_{i=1}^{n} W_i, \tag{11}$$

where $\overline{ns}$ = average net supply rate over n days (m^3/d), $\overline{W}$ = accumulated energy available for evapotranspiration over n days (cal), and n = number of days in the mass balance computation periods. The subscripts refer to daily values within the computation period.

At any instant, the rate of evaporation or evapotranspiration, e, is proportional to the amount of water available, S (reflecting both areal coverage and extent of supply), and to the rate of nonlatent heat released to the atmosphere, dH/dt (atmospheric heating)

$$e = \beta S e_p \, , \qquad e_p = \frac{dH}{dt} \Big/ (\rho \gamma_v), \tag{12}$$

where e = evaporation or evapotranspiration rate (m^3/d), β = partial linear reservoir constant (m^{-3}), S = volume of water in storage (m^3), and e_p = rate of evaporation or evapotranspiration, respectively, still possible (m^3/d). This agrees with existing climatological and hydrological concepts for evapotranspiration opportunity. For all storage zones then, the mass balance is

$$\overline{ns} - \frac{\overline{ns}}{USZC} USZM - \alpha_{per} USZM - \beta_{eu} e_p USZM = \frac{\partial}{\partial t} USZM \tag{13}$$

$$\alpha_{per} USZM - \alpha_{int} LSZM - \alpha_{dp} LSZM - \beta_{el} e_p LSZM = \frac{\partial}{\partial t} LSZM \tag{14}$$

$$\alpha_{dp} LSZM - \alpha_{gw} GZM - \beta_{eg} e_p GZM = \frac{\partial}{\partial t} GZM \tag{15}$$

$$\frac{\overline{ns}}{USZC} USZM + \alpha_{int} LSZM + \alpha_{gw} GZM - \alpha_{sf} SS - \beta_{es} e_p SS = \frac{\partial}{\partial t} SS \tag{16}$$

$$Q = \alpha_{sf} \int_0^{\Delta} SS \, \partial t, \tag{17}$$

where USZC = capacity of the upper soil zone (m^3), USZM = content of upper soil zone (m^3), α_{per} = percolation coefficient (d^{-1}), β_{eu} = upper zone evapotranspiration coefficient (m^{-3}), α_{int} = interflow coefficient (d^{-1}), LSZM = content of lower soil zone (m^3), α_{dp} = deep percolation coefficient (d^{-1}), β_{el} = lower zone evapotranspiration coefficient (m^{-3}), α_{gw} = groundwater coefficient (d^{-1}), GZM = content of groundwater zone (m^3), β_{eg} = groundwater zone evapotranspiration coefficient (m^{-3}), α_{sf} = surface outflow coefficent (d^{-1}), SS = content of surface storage zone (m^3), β_{es} = surface zone evapotranspiration coefficient (m^{-3}), Q = basin outflow volume for n days (m^3), and Δ = n times d. The value of e_p is determined by simultaneous solution of eqs. (13)-(17) and the following complementary relationship between actual evapotranspiration and that still possible from atmospheric heat:

$$\int_0^{\Delta} [e_p + (\beta_{eu} USZM + \beta_{el} LSZM + \beta_{eg} GZM + \beta_{es} SS) e_p] \, \partial t = \frac{\overline{W}}{\rho \gamma_v}. \tag{18}$$

Similar complementary relationships have been observed by others; see Morton (1978, 1979, 1982).

Data requirements include daily minimum and maximum air temperatures, daily precipitation, and for comparison purposes, daily basin outflow. Other data requirements are easily met. The mid-monthly extra-terrestrial solar radiation (from which daily values are interpolated) and the empirical constants, b_1 and b_2, are available in standard climatological summaries. (See, for example, Gray, 1973.) The area of the watershed is also required.

Values must be estimated for nine parameters: T_b, a_s, α_{per}, β_{eu}, α_{int}, α_{dp}, β_{el}, α_{gw}, and α_{sf}. Other parameters are unused herein. The upper soil zone capacity, USZC, is arbitrarily set to correspond to 2 cm of water over the watershed area. Since a change in USZC can be exactly compensated for (in terms of intrabasin flows and evapotranspiration) by changes in the other parameters, USZC is set arbitrarily. However, the magnitude of USZC affects the magnitudes of all tank storage volumes and should be determined if boundary conditions on soil moisture (or other storage volumes) are available. Since evaporation from the surface and evapotranspiration from the groundwater zone are small relative to evapotranspiration from the upper and lower soil zones, β_{eg} and β_{es} are set to zero. For convenience, the nine parameters are summarized in figure 2.

Equations (1)-(7) are implemented on a daily basis to compute the daily net supply, the daily heat used for and remaining from actual evapotranspiration, and the daily snowpack accumulation. These computations are independent of any mass balance computations and may be made for the entire data set as functions of only two parameters: T_b and a_s. The n-day net supply and heat equivalent series are computed from equations (10) and (11) and are input to the mass balance of equations (13)-(18) on an n-day basis. The simultaneous solution of equations (10) and (13)-(18) to determine the n-day basin outflow volumes is exact, requiring 30 different sets of 4 equations, depending upon the values of $\overline{ns}$, $\overline{W}$, and the model parameters (Croley, 1982b). Solution of equation (18) proceeds in concert with equations (13)-(17) through the use of an implicit technique based upon Newton's method of approximation; convergence is very fast, requiring two to four iterations for each n-day period to achieve a relative difference in successive values of e_p less than 10^{-6}.

3. DATA PREPARATION AND CALIBRATION

The Lake Ontario Basin above Elevator, N.Y., drains over 70,000 km^2 of New York and Ontario. There are 30 meteorological stations and 13 subbasin outflow stations used in this study as identified in figure 1. The basin above Elevator includes part of the St. Lawrence River and, since there is interest also in just the lake itself, the basin above Kingston, Ont., is also delineated. This one drains over 63,000 km^2 and there are 28 meteorological stations and 12 subbasin outflow stations used herein. The basin is divided into 15 subbasins for use with the model as pictured in figure 1. Subbasin boundaries are based on the New York and Pennsylvania state hydrological unit maps from the U.S. Geological Survey (USGS) and drainage basin maps with associated overlays from the Water Resources Branch of the Inland Waters Directorate of Environment Canada, for the United States and Canada, respectively. Subbasins not draining directly into Lake Ontario were combined with those into which they drained, so that all resulting subbasins have a direct outlet to the lake.

The meteorological stations whose Thiessen polygons intersect each subbasin are used to determine the Thiessen-weighted average minimum temperature, maximum temperature, and precipitation on a daily basis. Meteorological data for stations in the United States are from the National Climatic Center, National Environmental Satellite, Data, and Information Service, NOAA. Data for Canadian meteorological stations is from the Canadian Climate Centre, Atmospheric Environment Service, Environment Canada. Mid-monthly cloudless-day insolation at Ithaca, N.Y., was used for basins 1-5; that at Toronto, Ont., was used for basins 6-15 (Gray, 1973).

Relevant subbasin daily outflow is added to each data set after dividing by the relative areal extent of the drainage area at the gage to total area to extrapolate for the ungaged area in each subbasin. Flow data are from the Water Resources Division of the USGS and the Water Resources Branch of the Inland Waters Directorate for those gages in the United States and Canada, respectively. The drainage area of each gage is given by the USGS (1980a,b) or Inland Waters Directorate (1979), while the total area in each subbasin is based on planimetered measurement.

Thiessen weights for all meteorological stations over all subbasins used in this study are identified in table 1; relative areal drainage coverage for all flow stations used herein are identified in table 2. The subbasin information is summarized in table 3. Of the 17 data sets identified in table 3 (one for each subbasin, one for the entire basin above Elevator, L1, and one for the entire basin above Kingston, L2), 4 have incomplete or missing outflow data. Outflow data for the lumped data sets, L1 and L2, were extrapolated for these ungaged areas in a manner analagous to that used for individual subbasins. Some discontinuous outflow data were available for subbasin 1; it was not sufficient for use in a model application for this subbasin, but was included in the lumped data sets, L1 and L2.

There are five variables in the model: SNW, USZM, LSZM, GZM, and SS, to be initialized prior to modeling as SNW_0, $USZM_0$, $LSZM_0$, GZM_0, and SS_0, respectively. While SNW_0 is easy to determine as zero during major portions of the year, the other variables are generally difficult to estimate. The effect of the initial values diminishes with the length of the simulation, and after about 1 year of simulation, the effects are nil from a practical point of view. In all the calibrations described herein, the first 1,260 days of data are used for initializing the model and the remainder of the data sets are used for measuring the goodness-of-fit of the models to the data sets.

The runoff model was applied to the 13 data sets with outflow data for both a 30-d and a 7-d mass balance computation interval. A 28-d computation interval would allow direct comparison with the 7-d model, but a 30-d interval was chosen to approximate months better, as required for current operational decision-making. Each application required determination of the nine parameter values used in the model. Parameter determination was accomplished via a systematic search of the parameter space to minimize the sum-of-squared errors between actual outflow volumes and model outflow volumes. The search consisted of minimizing this error for each parameter, selected in rotation, until convergence to two significant digits in all parameters was achieved. This search technique was as efficient as the calibration procedure described previously (Croley, 1982c), while being easier to learn by operations personnel. The procedure requires between one-half to one man-days of interactive computing in FORTRAN IV on the CDC Cyber 170/750 computer by an experienced operator to determine the parameter values for one of the data sets.

TABLE 1.--*Selected meteorological station Thiessen weights on Lake Ontario subbasins*

Met. station number*	Basin number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	L1	L2
6153300	0.31														0.50	0.035	0.039
301012	0.40															0.025	0.028
304844	0.19	0.65														0.036	0.041
305597	0.10		0.30		0.13											0.058	0.065
307167		0.35	0.20	0.42	0.01											0.045	0.050
300085			0.13													0.012	0.013
300183			0.15													0.014	0.015
300220			0.04													0.004	0.004
303025			0.02													0.002	0.002
308962			0.13													0.012	0.013
361806			0.03													0.003	0.003
303184				0.22	0.33											0.068	0.075
306314				0.36	0.01	0.33										0.023	0.026
308383					0.25	0.06										0.049	0.054
304174					0.27											0.050	0.056
309000						0.50	0.33	0.24								0.062	0.051
300785						0.11	0.22									0.022	0.025
6101265							0.01		0.67	0.47						0.042	0.022
306184							0.44	0.11								0.045	0.042
6100969								0.13	0.33							0.019	-
301185								0.52								0.035	-
6156533										0.18	0.06	0.01	0.41			0.029	0.032
6159010										0.35	0.94	0.14				0.078	0.087
6163156												0.24				0.044	0.048
6156670												0.06	0.53			0.032	0.036
6165195												0.09				0.017	0.019
6166428												0.33				0.059	0.065
6164615												0.13				0.023	0.025
6158350													0.06	0.78	0.15	0.038	0.042
6155788														0.22	0.35	0.019	0.022

*Seven-digit numbers are Canadian stations, available from Canadian Climate Center, Environment Canada. Six-digit numbers are United States stations, available from the National Environmental Satellite, Data, and Information Service, NOAA, U.S. Department of Commerce.

TABLE 2.—*Selected discharge station areal drainage extent on Lake Ontario subbasins*

Flow station number*	Basin number																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	L1	L2
Q02HA006	0.07															0.004	0.005
4218000	0.21															0.013	0.015
4232000			0.98													0.090	0.100
4232100				0.06												0.002	0.002
4249000					1.00											0.187	0.208
4250750						0.13										0.005	0.005
4260500							0.81									0.069	0.076
4263000								0.53								0.036	-
Q02HM003										0.31						0.013	0.014
Q02HL001											0.90					0.037	0.041
Q02HK004												0.94				0.171	0.190
Q02HD008													0.04			0.002	0.002
Q02HB002															0.38	0.012	0.013
All Stations																0.641	0.671

*Eight-digit numbers are Canadian stations, available from Inland Waters Directorate, Environment Canada. Seven-digit numbers are United States stations, available from U.S. Geological Survey, U.S. Department of Interior.

Simulation speed is good; the model requires about 39K words of storage (with use of 17.5 yr of data) and uses 0.009 s/yr of simulation for 30-d values (0.036 s/yr for 7-d values). These figures include auxiliary computations related to the evaluation of the calibration.

4. APPLICATION

Optimum parameter sets for the 30-d model and for the 7-d model are presented in tables 4 and 5, respectively. There are 13 calibrations each for both the 30-d and 7-d runoff models. Eleven correspond to the 11 subbasins and two correspond to the entire basin above Elevator (L1) and Kingston Ont. (L2). All calibrations used data sets for the common period of 17.5 yr beginning April 19, 1960, and ending October 31, 1977.

The 30-d and 7-d applications to subbasin 13 yielded an infinite surface storage coefficient, α_{sf}; the 30-d applications for subbasins 11 and 15 also gave infinite surface storage coefficients. This is equivalent to no

TABLE 3.--*Lake Ontario subbasin information*

Subbasin no.	Basin area (km^2)	Last date (d-m-y)	Data set length (yr)	No. of met. sta.	Areal extent	Normal annual precip. (cm)*	Normal annual flow (cm)*
1	4431	31-12-79	28.7	4	0.**	89	
2	2650	31-10-77	17.5	2	0.	89	
3	6475	31-12-78	30.4	8	0.98	82	40
4	1899	31-12-78	24.7	3	0.06	89	52
5	13201	31-12-78	42.4	6	1.00	90	47
6	2533	31-12-78	24.7	4	0.13	108	72
7	5991	31-12-79	30.2	4	0.81	120	75
8	4794	31-12-79	43.4	4	0.53	97	61
9	2264	31-12-79	18.7	2	0.	93	
10	2885	31-12-79	24.9	3	0.31	91	35
11	2906	31-12-79	29.0	2	0.90	90	33
12	12745	31-12-79	19.7	7	0.94	91	35
13	2823	20-12-79	23.2	3	0.04	82	29
14	2771	31-12-79	18.7	2	0.	82	
15	2204	31-12-79	30.5	3	0.38	82	30
L1	70572	31-10-77	17.5	30	0.64	93	46
L2	63514	31-10-77	17.5	28	0.67	93	45

*Equivalent depth over basin.

**Unused poor-quality flow data.

surface storage "tank" in figure 2. Subbasins 13 and 15 are narrow strips along the lake with short times of concentration; surface response is much faster than a 7-d or 30-d time interval and is not detectable at these time scales. Furthermore, other narrow subbasins are also represented by large surface storage coefficients: subbasin 4 has the largest finite 30-d coefficient and subbasin 6 has the largest finite 7-d coefficient. In general, the surface storage is not significant for small basins and large computation intervals. For large basins or small computation intervals, surface storage may be significant.

Other interesting parameter values obtained during the calibrations for the 30-d model (see table 4) include: $\alpha_{per} = 0$ for basin 6, indicating that no percolation is modeled and the basin response is "flashy"; $\beta_{eu} = 0$ for basin 12, indicating that model evapotranspiration is controlled by the lower soil zone; $\alpha_{int} = 0$ for basins 3, 5, and 8, indicating that no interflow is modeled for these basins; and $\alpha_{dp} = 0$ for basin 4, indicating that nothing

TABLE 4.--*Lake Ontario subbasin 30-d model parameters*[*]

			Linear reservoir and evapotranspiration coefficients						
Sub-basin no.	T_b (°C)	Albedo	Percolation (d^{-1})	Upper zone evap. (m^{-3})	Interflow (d^{-1})	Deep percolation (d^{-1})	Lower zone evap. (m^{-3})	Groundwater (m^{-3})	Surface storage outflow (d^{-1})
3	6.5	0.74	84E-03	82E-10	0	28E-03	50E-10	38E-03	98E-03
4	7.2	0.83	78E-03	60E-09	28E-03	0	87E-11	-	29E-02
5	8.1	0.80	60E-03	42E-10	0	45E-03	19E-10	16E-02	48E-03
6	10.6	0.83	0	50E-09	-	-	-	-	15E-02
7	11.0	0.57	16E-02	64E-10	33E-03	62E-04	48E-03	44E-05	45E-03
8[†]	9.9	0.82	19E-02	23E-09	0	49E-02	18E-09	36E-03	15E-02
10	7.3	0.80	39E-02	12E-02	14E-03	30E-04	26E-10	14E-03	13E-02
11	5.7	0.87	71E-02	18E-06	12E-03	48E-04	47E-10	18E-03	∞
12	4.2	0.73	32E-01	0	14E-03	64E-04	20E-10	24E-05	15E-02
13	0.5	0.74	10E-01	13E-08	54E-04	13E-03	19E-09	62E-04	∞
15	5.4	0.83	41E-02	93E-09	43E-04	88E-04	18E-09	15E-03	∞
L1	5.7	0.80	10E-01	16E-10	19E-03	26E-04	12E-11	37E-05	19E-02
L2	5.5	0.79	84E-02	19E-10	18E-03	35E-04	12E-11	31E-05	15E-02

[*] Applications used data sets of 6405d, beginning April 19, 1960, and ending October 31, 1977.

[†] This data set is known to contain much missing temperature data that were reported as zeroes. This causes a breakdown of the $W = K(T - T_b)$ relation for determining K from the boundary condition on absorbed insolation.

passes on to the groundwater zone in the model. Interesting parameter values for the 7-d model (see table 5) include $\beta_{eu} = 0$ for basin 12, indicating that model evapotranspiration is controlled by the lower soil zone; $\alpha_{int} = 0$ for basin 3, indicating that no interflow is modeled for this basin; $\alpha_{dp} = 0$ for basins 5 and 8, indicating that nothing passes on to the groundwater zone in the model; and $\beta_{el} = 0$ for basin 6, indicating that model evapotranspiration is controlled by the upper soil zone. Individual parameter values, while interesting, may reflect only local optimums. The physical relevance of these parameters allows for verification as empirical techniques develop. Admittedly, errors in individual parameters may compensate in the calibrations owing to the synergistic relationships among all parameters.

The agreement between all parameter values for each subbasin for both the 30-d and 7-d model applications is very good, and is an improvement over previous applications using different constraints on surface storage and

TABLE 5.--*Lake Ontario subbasin 7-d model parameters*[*]

			Linear reservoir and evapotranspiration coefficients						
Sub-basin no.	T_b (°C)	Albedo	Percolation (d^{-1})	Upper zone evap. (m^{-3})	Interflow (d^{-1})	Deep percolation (d^{-1})	Lower zone evap. (m^{-3})	Groundwater (m^{-3})	Surface storage outflow (d^{-1})
3	6.0	0.73	54E-03	13E-09	0	26E-03	13E-09	38E-03	70E-03
4	5.8	0.80	10E-02	10E-08	29E-03	11E-08	60E-11	11E-05	47E-02
5	7.4	0.80	25E-03	59E-10	42E-03	0	53E-10	-	41E-03
6	8.1	0.83	19E-02	14E-08	62E-03	11E-08	0	15E-05	10E-01
7	7.6	0.53	78E-03	11E-09	20E-03	71E-04	46E-03	30E-05	40E-03
8[†]	11.0	0.69	10E-08	29E-09	10E-09	0	20E-07	-	50E-03
10	6.4	0.72	90E-02	86E-03	13E-03	41E-04	69E-10	17E-03	14E-02
11	5.6	0.78	82E-02	34E-07	10E-03	42E-04	17E-09	17E-03	16E-02
12	5.1	0.68	38E-01	0	11E-03	60E-04	19E-10	20E-05	12E-02
13	1.1	0.81	16E-01	11E-07	47E-04	12E-03	11E-09	38E-04	∞
15	4.3	0.86	51E-02	57E-08	57E-04	12E-03	31E-09	87E-04	39E-02
L1	5.5	0.80	16E-01	21E-10	18E-03	29E-04	13E-11	41E-05	33E-02
L2	4.6	0.81	16E-01	27E-10	17E-03	32E-04	13E-11	39E-05	34E-02

[*] Applications used data sets of 6405d, beginning April 19, 1960, and ending October 31, 1977.

[†] Parameter values are radically different from other sets; this data set is known to contain much missing temperature data that were reported as zeroes. This causes a breakdown of the $W = K(T - T_b)$ relation for determining K from the boundary condition on absorbed insolation.

evapotransporation coefficients. (See appendix B.) With the exception of 6 values out of 117 possible matches, all parameters are within an order of magnitude of each other between tables 4 and 5. Since parameter error compensation is probably present in the calibrations, an order-of-magnitude agreement between the 30-d and 7-d models is considered to be very good. Better agreement is probably obtainable if more than 2-digit convergence is used in the parameter optimizations. With only two digits, the optimum is approached crudely, yielding multiple near-optimums dependent on the starting parameter set.

To focus the discussion on parameter similarities between the 30-d and 7-d models, the entire basin applications, L1 and L2, are considered further for the two models. The spatial integration of the data sets eliminates the effects of data errors for individual subbasins on parameter differences between the 30-d and 7-d model applications. Table 6 contains storage lives obtained from the solution of the continuity equation for lumped outflows only

$$-\alpha\ S = \frac{\partial S}{\partial t}, \tag{19}$$

which is

$$t_2 - t_1 = \frac{1}{\alpha} \ln\ \frac{S_1}{S_2}\ , \tag{20}$$

where t = time, α = lumped outflow coefficient, S = storage, and the subscripts refer to the beginning (1) and the end (2) of a time interval. If t_1 = 0 and $S_2 = \frac{1}{2}S_1$, then the half-life, t_2, becomes

$$t_2 = \frac{\ln 2}{\alpha}. \tag{21}$$

Table 6 reveals that the upper soil zone, groundwater zone, and surface zone storages generally detain flows longer in the 30-d applications than in the 7-d applications. This undoubtedly results from the "filter" effect of the 30-d computation period and 30-d summation of net supply, ns; heat available for evapotranspiration, W; and actual basin outflow, as compared to the 7-d calculations. The filtering eliminates high-frequency fluctuations in the 30-d model that are still present in the 7-d model. Parameter calibrations reflect this filter effect somewhat to give slightly "flashier" behavior in the 7-d model.

5. RESULTS

Model results for the 30-d model and 7-d model applications are presented in tables 7 and 8, respectively. The mean precipitation, mean actual outflow, mean model outflow, relative difference between the mean outflows, standard deviation of the actual outflows, root mean square error (rmse) between actual and model outflows, and the correlation coefficient (root explained variance) between actual and mean outflows are presented. All dimensional units are expressed as depths over the basin for convenience. The 11 subbasins for which flow data are available are presented by basin number in these tables. The two rows of tables 7 and 8 labeled L1 and L2 represent a lumped-parameter application of the runoff model to the entire Lake Ontario drainage basin. The results from the 11 subbasin applications

TABLE 6.--*Lake Ontario Basin model half-lives*

Model and basin	Upper soil zone storage half-life*	Lower soil zone storage half-life*	Groundwater zone storage half-life	Surface zone storage half-life
7-d Model				
L1	10 h	4.7 w	4.6 y	2.1 d
L2	10 h	4.9 w	4.9 y	2.0 d
30-d Model				
L1	17 h	4.6 w	5.1 y	3.6 d
L2	20 h	4.6 w	6.1 y	4.6 d

*Uncorrected for evapotranspiration.

TABLE 7.--*Lake Ontario subbasin 30-d model results*

Sub-basin no.	Mean 30-d precip. (cm)*	Mean 30-d flow (cm)*	Mean 30-d model flow (cm)*	Rel. diff. in mean flows	Stand. dev. of flows (cm)*	Root mean square error (cm)*	Corr. coeff.
3	6.86	3.43	3.44	0.003	2.68	1.44	0.85
4	7.50	4.39	4.11	-0.063	4.26	2.30	0.85
5	7.49	4.08	4.05	-0.009	2.63	1.26	0.88
6	9.14	6.07	5.54	-0.086	5.66	2.78	0.88
7	10.30	6.49	6.37	-0.017	4.28	2.11	0.87
8	8.10	5.20	4.80	-0.076	3.87	1.89	0.88
10	7.57	3.04	3.03	-0.002	3.31	1.40	0.91
11	7.63	2.89	2.82	-0.025	3.36	1.41	0.91
12	7.42	2.84	2.86	0.007	2.17	1.09	0.86
13	6.83	2.40	2.37	-0.012	1.71	0.95	0.83
15	6.85	2.63	2.60	-0.013	2.20	1.06	0.88
L1	7.68	3.81	3.82	0.001	2.62	1.08	0.91
L2	7.65	3.70	3.72	0.007	2.54	1.02	0.92
S1	7.58	3.93	3.84	- 0.022	2.65	1.01	0.93
S2	7.55	3.81	3.75	- 0.015	2.56	0.97	0.93

*Equivalent depth over basin.

TABLE 8.--*Lake Ontario subbasin 7-d model results*

Sub-basin no.	Mean 7-d precip. (cm)*	Mean 7-d flow (cm)*	Mean 7-d model flow (cm)*	Rel. diff. in mean flows	Stand. dev. of flows (cm)*	Root mean square error (cm)*	Corr. coeff.
3	1.60	0.80	0.80	-0.001	0.72	0.38	0.85
4	1.75	1.03	0.95	-0.071	1.34	0.86	0.77
5	1.75	0.96	0.95	-0.009	0.68	0.31	0.90
6	2.13	1.42	1.31	-0.077	1.79	1.02	0.83
7	2.40	1.52	1.51	-0.004	1.21	0.73	0.80
8	1.89	1.22	1.14	-0.065	1.10	0.61	0.83
10	1.77	0.71	0.72	0.012	0.87	0.38	0.90
11	1.78	0.67	0.68	0.009	0.91	0.44	0.87
12	1.73	0.66	0.66	0.003	0.57	0.29	0.86
13	1.59	0.56	0.55	-0.021	0.57	0.40	0.71
15	1.60	0.61	0.60	-0.018	0.71	0.47	0.75
L1	1.79	0.89	0.89	-0.002	0.70	0.32	0.89
L2	1.78	0.86	0.86	-0.000	0.68	0.30	0.89
S1	1.77	0.92	0.90	-0.018	0.70	0.28	0.92
S2	1.76	0.89	0.88	-0.012	0.68	0.26	0.93

*Equivalent depth over basin.

are combined as represented by S1 (entire basin above Elevator) and S2 (entire basin above Kingston) in these tables. These combined results represent a distributed-parameter application of the runoff model to the entire Lake Ontario drainage basin. The statistics in tables 7 and 8 for S1 were computed by summing precipitation and actual flow from the individual data sets of subbasins number 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, and 15 and the model flow from the model applications for these data sets. The summed results were extrapolated to account for ungaged areas. Data sets for subbasins 1, 2, 9, and 14 were not used since they contain no usable flow data and model applications were not made to them. The statistics for S2 excluded basin 8, as well as basins 1, 2, 9, and 14, to eliminate the portion of the basin between Elevator and Kingston. Example results representing the range of applications are given in appendix C.

The rmse and the correlations for these model applications allow several comparisons to be made. While all model applications appear to be very good for the limited data used, the entire-basin models perform notably better than the subbasin models for both the 30-d and the 7-d applications.

There is an apparent spatial filtering effect in operation where model errors for small areas tend to cancel as the areas are added together. The spatial integration effect was expected and was part of the design philosophy for the runoff model. While the 30-d rmse for individual subbasins range from 1 to 3 cm, the entire-basin models have a 30-d rmse of about 1 cm. Likewise, the 7-d rmse for subbasins range from 0.3 to 1 cm, while the entire-basin models have a 7-d rmse of about 0.3 cm. Improvements in correlation follow similar trends.

The distributed-parameter models (S1 and S2) show better rmse and correlations than do the lumped-parameter models (L1 and L2) for both the 30-d and the 7-d model applications. This improvement undoubtedly results from the use of more information for the distributed-parameter applications, which is lost in the spatial integration of data by the lumped-parameter model. Even so, the improvement of the distributed-parameter models over the lumped-parameter models is not striking; the 30-d correlation improves from 0.92 to 0.93 and the 7-d correlation improves from 0.89 to 0.93. Improvements in rmse are also slight. Thus, the lumped-parameter models may be adequate for many purposes, while costing about one-tenth as much to use.

It is interesting to note that, while the distributed-parameter models, S1 and S2, perform better than the lumped-parameter models, L1 and L2, in terms of rmse and correlation in tables 7 and 8, they are slightly more biased as measured by the relative difference in mean flows. While the biases are small, the differences appear significant. They probably reflect the arbitrary initial tank storages used in the model. Since the same initial volumes were used in all applications, they were relatively closer to zero for large basins than for small basins. The S1 and S2 applications thus reflect 11 times the initial storages used for the L1 and L2 applications. Better starting values or a longer initialization period would reduce the small bias even further.

In addition to considering the spatial integration effects on data and model results, tables 7 and 8 can be used to investigate temporal effects as the computation interval changes from 30-d to 7-d. Since it is difficult to compare 30-d and 7-d correlations or rmse directly, the output series were analyzed to compute 360-d correlations and rmse for the 30-d model and to compute 28-d and 364-d correlations and rmse for the 7-d model. (See table 9.) The 30-d model's 30-d correlation and rmse are comparable to the 7-d model's 28-d correlation and rmse; both the 30-d and 28-d correlations and rmse are referred to as monthly herein. Likewise, the 30-d model's 360-d values are comparable to the 7-d model's 364-d values, and both the 360-d and 364-d values are referred to as annual herein. In general, the annual (360-d or 364-d) correlations and rmse vary more widely than do the monthly (30-d or 28-d) values for the subbasin applications of both the 30-d and the 7-d models. Likewise, annual correlations are lower than monthly correlations for some of the subbasin model applications; e.g., results for subbasins 3, 4, 10, 11, and 13 are poorer on an annual basis than on a monthly basis for both the 30-d and 7-d models. This probably indicates the presence of bias or consistent error for these subbasin model applications. Since annual

TABLE 9.--*Lake Ontario subbasin model comparisons*

	30-d model				7-d model			
	30-d		360-d		28-d		364-d	
Sub-basin no.	Corr. coeff.	Root mean square error (cm)*	Corr. coeff.	Root mean square error (cm)*	Corr. coeff.	Root mean square error (cm)*	Corr. coeff.	Root mean square error (cm)*
3	0.85	1.44	0.54	8.06	0.89	1.16	0.59	7.74
4	0.85	2.30	0.59	13.69	0.84	2.29	0.58	14.13
5	0.88	1.26	0.94	6.54	0.92	0.98	0.94	6.39
6	0.88	2.78	0.89	12.45	0.89	2.61	0.87	12.68
7	0.87	2.11	0.96	7.68	0.88	1.97	0.96	7.32
8	0.88	1.89	0.95	7.98	0.90	1.67	0.94	7.20
10	0.91	1.40	0.61	6.42	0.92	1.22	0.64	6.09
11	0.91	1.41	0.61	6.06	0.91	1.31	0.50	6.55
12	0.86	1.09	0.92	4.26	0.89	0.93	0.88	4.65
13	0.83	0.95	0.71	3.89	0.79	0.98	0.65	4.21
15	0.88	1.06	0.84	3.44	0.86	1.08	0.86	3.22
L1	0.91	1.08	0.95	4.81	0.93	0.95	0.94	5.16
L2	0.92	1.02	0.96	4.54	0.93	0.90	0.95	5.01
S1	0.93	1.01	0.96	4.71	0.95	0.81	0.97	4.52
S2	0.93	0.97	0.96	4.62	0.95	0.78	0.97	4.46

*Equivalent depth over basin.

variations in actual outflows are much smaller than monthly variations, consistent errors form a relatively large part of the annual variation. These errors may be present in the data sets (reflecting low gage density, flow gage error, areal measurement errors, Thiessen weighting errors, etc.) or in the model (reflecting improper modeling concepts such as snowmelt). Two of the subbasins in the above group (4 and 13) have the smallest areal flow coverages of all subbasins. (See table 3.) Subbasin 11 has the second sparsest meteorological gage density (two gages for 2,906 km^2). Subbasin 3 has diversions (New York State Barge Canal) and regulated reservoirs, unaccounted for in the runoff model.

However, the entire-basin applications show better agreement uniformly. As expected, the distributed-parameter applications are better than the lumped-parameter applications on both a monthly and an annual basis for the 7-d and 30-d models. The 7-d distributed-parameter applications are better on both a monthly and annual basis than the respective 30-d entire-basin applications. For the entire basin above Kingston, the 7-d model yields monthly correlation and rmse of about 0.95 and 0.78 cm, respectively, and annual correlation and rmse of 0.97 and 4.46 cm, respectively, for the distributed-parameter model (S2). The lumped-parameter applications for the 30-d model are better than the 7-d model on an annual basis, but the 7-d model lumped-parameter applications are better than the 30-d model on a monthly basis. Overall, the entire-basin models are judged to be excellent; the 7-d distributed-parameter model application for the entire basin above Kingston (S2) has an rmse of about 9.6 percent of the mean annual outflow; example results for this application are plotted in figure 3. The agreement in this figure is typical for all the entire-basin applications.

The explained seasonal variance was examined to give some idea of model weaknesses. Figure 4 presents the correlation between 7-d actual and model outflows on a weekly basis for the distributed-parameter model for the Lake Ontario Basin above Kingston. This plot was constructed by grouping all like weeks within each 364-d cycle and computing the correlation within each group between actual and model outflows. Similar plots representing a range of subbasin types are presented in appendix D. A clear seasonal trend is apparent in the weekly correlations. The worst periods of model performance

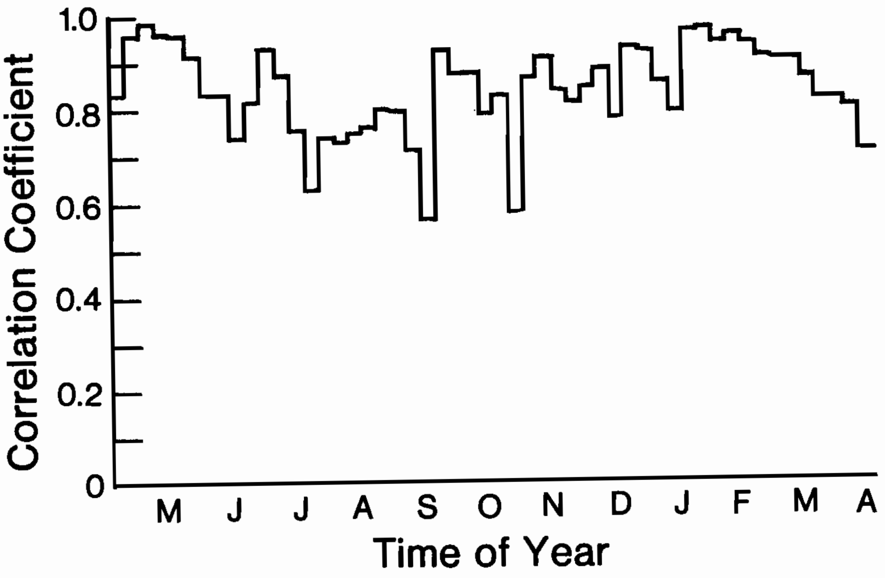

FIGURE 3.--*GLERL 7-d distributed-parameter model fit to the Lake Ontario Basin above Kingston, Ont.*

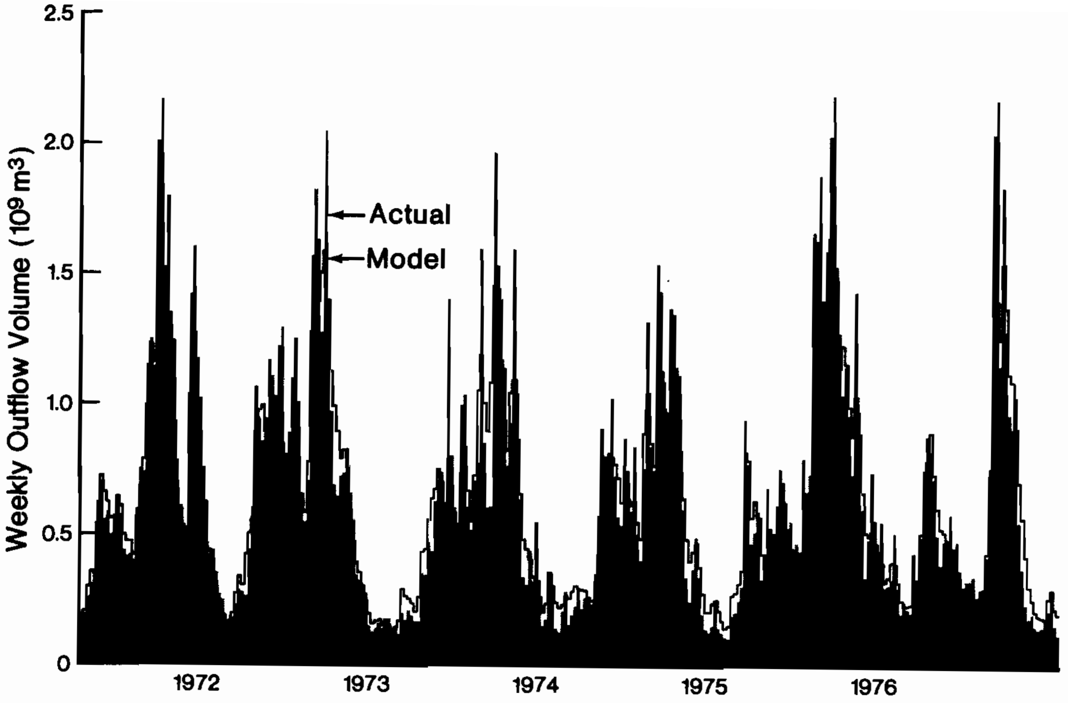

FIGURE 4.--*Weekly correlation between distributed-parameter model and actual flows for Lake Ontario above Kingston, Ont.*

appear to be in the late summer/early fall and in the early spring. The first period corresponds to the lowest flows of the season and hence model errors appear relatively large when they are in fact quite acceptable. (See fig. 3.) The latter period corresponds to the large flows resulting from major snowmelt events and points out the weakness of the relatively simple snowmelt computations of this model. However, the snowmelt over the entire Lake Ontario Basin, while represented as the weakest part of the model, is surprisingly good. The lowest weekly correlation during the snowmelt period is about 0.72. Of course, the correlations for snowmelt are lower for the smaller subbasins.

The reasonableness of the complementary evapotranspiration concept was investigated by modifying e_p to represent what is classically considered potential evapotranspiration

$$e_p = W/d/\rho\gamma_v \tag{22}$$

for the lumped-parameter model for the Lake Ontario Basin above Kingston. The recalibrated optimum parameter set resulted in an rmse 1.8-percent higher than was obtained using the complementary relationship between actual evapotranspiration and potential evapotranspiration. Thus, although only one model application was examined, the complementary evapotranspiration concept appears marginally better and allows a more realistic description of the process.

6. SUMMARY

The Large Basin Runoff Model developed at GLERL is an accurate, fast model of weekly or monthly runoff volumes from large watersheds, with relatively simple calibration and data requirements. Parameters have physical significance and calibrated values obtained from parameter optimizations appear reasonable and consistent between weekly and monthly applications. Seven-day and 30-d distributed-parameter and lumped-parameter applications to Lake Ontario illustrate temporal and spatial integration effects on model resolution and filtering of both information and data errors consequent with these applications. The 7-d applications make significantly better use of available data on a monthly basis than do the 30-d applications, at about four times the cost to use. The distributed-parameter applications are marginally better than the lumped-parameter applications, at about 11 times the cost to use. The 7-d distributed-parameter application to Lake Ontario above Kingston yielded a weekly correlation of 0.93 (monthly--0.95 and annual--0.97). All applications to the entire Lake Ontario Basin show exceptional agreement with available flow data on both a monthly and an annual basis.

The model has potential for use in predictive studies since basin storages are represented directly. Predictions are limited by available meteorological information, but forecasting is practical if near real-time data requirements are met. Since requisite data are limited to precipitation and air temperature, these requirements may soon be met for many areas of the Great Lakes Basin. Furthermore, flow data unavailability may be tolerated to some extent in calibration since small ungaged areas can be grouped with large gaged areas, thereby using parameter transference potential. This will be tested later when the runoff models are used in concert with lake-level routing models.

While snowmelt is the weakest part of the model, as evidenced by observed reductions of explained variance of basin runoff during the early spring, it may not be debilitating for the 7-d or 30-d runoff volume determinations. The use of snow surveys to more accurately reflect actual snowpack conditions may improve model performance. Investigation is underway to explore the use of aerial gamma surveys of snowpack and soil moisture equivalents in the model for the Lake Superior Basin. Since these water storages are explicitly modeled, the incorporation of such data appears realistic. Other model improvements relate to the use of air temperature as an index of the heat available for evapotranspiration. The linear first approximation used here may be improved upon. With an allowance of more data, the daily heat balance could be included to improve the estimation of energy available for evapotranspiration.

The model is now to be applied to large basins around the remaining Great Lakes to simulate basin runoff for use in routing models. Data acquisition and reduction are underway for the remaining portions of the Great Lakes Basin. More data for each basin, as available, will be used than was used for Lake Ontario since calibration and model use requirements have proved to be modest.

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Appendix A.--SYMBOLS

a_s	albedo of the snow surface
A_w	area of the watershed (m^2)
b_1	empirical constant for determining effects of cloud cover
b_2	empirical constant for determining effects of cloud cover
d	one day (d)
e	evaporation or evapotranspiration rate (m^3/d)
e_p	rate of evaporation or evapotranspiration still possible (m^3/d)
E_g	n-day groundwater zone evapotranspiration volume (m^3)
E_ℓ	n-day lower soil zone evapotranspiration volume (m^3)
E_s	n-day surface storage evaporation volume (m^3)
E_u	n-day upper soil zone evapotranspiration volume (m^3)
GZM	volume of water in groundwater zone (m^3); may be subscripted with time
H	nonlatent heat released to the atmosphere during the day (cal)
i	one time within period of record
K	proportionality constant for evapotranspiration energy (cal/°C)
LSZM	volume of water in lower soil zone (m^3); may be subscripted with time
m	snowmelt rate (m^3/d)
n	number of days in mass balance computation period
ns	net supply rate (m^3/d)
p	precipitation rate (m^3/d)
Q	n-day basin outflow volume (m^3)
rr	solar insolation at the watershed surface (cal/d)
S	volume of water remaining in storage (m^3); may be subscripted with time
SNW	water volume equivalent in snowpack (m^3); may be subscripted with time
SS	volume of water in surface storage (m^3); may be subscripted with time
t	time (d)

T	mean daily air temperature (°C)
T_b	base temperature for evapotranspiration energy (°C)
T_{max}	maximum daily air temperature (°C)
T_{min}	minimum daily air temperature (°C)
USZC	capacity of the upper soil zone (m^3)
USZM	volume of water in upper soil zone (m^3); may be subscripted with time
W	total energy available for evapotranspiration (cal)
X	ratio of hours of bright sunshine to maximum possible hours of bright sunshine
α	lumped outflow coefficient (d^{-1})
α_{dp}	linear reservoir constant on LSZM for deep percolation (d^{-1})
α_{gw}	linear reservoir constant on GZM for groundwater flow (d^{-1})
α_{int}	linear reservoir constant on LSZM for interflow (d^{-1})
α_{per}	linear reservoir constant on USZM for percolation (d^{-1})
α_{sf}	linear reservoir constant on SS for basin outflow (d^{-1})
β	partial linear reservoir constant (m^{-3})
β_{eg}	partial linear reservoir constant on GZM for evapotranspiration (m^{-3})
β_{el}	partial linear reservoir constant on LSZM for evapotranspiration (m^{-3})
β_{es}	partial linear reservoir constant on SS for evaporation (m^{-3})
β_{eu}	partial linear reservoir constant on USZM for evapotranspiration (m^{-3})
γ_m	latent heat of fusion (cal/g)
γ_v	latent heat of vaporization (cal/g)
ρ	density of water (g/m^3)
τ	extraterrestrial solar radiation (langleys/d)
Ω	set of all times within period of record

Appendix B.--PREVIOUS CALIBRATIONS USING DIFFERENT SURFACE STORAGE AND EVAPOTRANSPIRATION COEFFICIENTS

This appendix presents a previous calibration of the GLERL Large Basin Runoff Model for Lake Ontario and its subbasins, and analyzes the effect of subsequent model modifications on parameter determination and model behavior. A summary of the differing calibration conditions is presented in table 10. Initial calibration for both the 7-d and the 30-d models determined K using parameter optimization. The 30-d model surface storage coefficient, a_{sf}, was initially constrained to infinity for the 11 subbasins to simplify parameter optimization; the constraint was based on preliminary testing of the model on the Genesee River Basin above Portageville, N.Y., (Croley, 1982c), which showed no modeled storage effects on the surface. The 7-d calibration was not subjected to any restriction on surface storage coefficients. Initial calibrations for the 30-d model used data sets ranging from 17.5 yr to 40 yr in length. The 7-d model calibrations used only 17.5-yr data sets to save on calibration costs.

Introducing the boundary constraint on the long-term heat balance allowed K to be directly determined. Concurrent modifications in the parameter optimization program, increasing its efficiency, effectively eliminated the computational advantage of removing the surface storage tank from the 30-d model. In subsequent calibrations, then, the surface storage coefficient was determined via parameter optimization for all applications. In addition, the 30-d model was recalibrated using only 17.5 yr of data to facilitate comparison with the 7-d model.

Ideally for the purposes of this analysis, the modifications would have been incorporated sequentially, allowing each change to be analyzed individually. However, the modifications were simultaneous, and analysis of resultant effects is clouded by the synergistic nature of the parameters. Therefore, only the 7-d model can be used to specifically assess the effects of reducing degrees of freedom on model performance.

TABLE 10.--*Calibration conditions for GLERL runoff model applied to Lake Ontario*

	Initial calibration	Modified calibration
7-d Model	- No long-term heat balance - Surface storage allowed - 17.5-yr data set	- Long-term heat balance - Surface storage allowed - 17.5-yr data set
30-d Model	- No long-term heat balance - No surface storage allowed - Variable length data set (17.5-40 yr)	- Long-term heat balance - Surface storage allowed - 17.5-yr data set

Optimum parameter sets for the 7-d and 30-d models using individual calibration conditions are given in tables 11 and 12, respectively. Parameter values for subbasin 8 are not presented or included in any comparisons because the data set for this subbasin contains many missing temperature data that were reported as zeroes, causing a breakdown in the $W = K(T - T_b)$ relation for determining K.

Intuitively, one would expect that parameter values for both the 7-d and 30-d model applications would agree closely. However, using initial calibration conditions, 27 percent of the linear reservoir and evapotranspiration coefficients differed by more than an order of magnitude. Such a difference is considered significant. As parameter constraints changed, parameter values changed for both the 7-d and the 30-d model applications. Subsequent recalibration produced 7-d parameter values with much better agreement; only 7 percent of the linear reservoir and evapotranspiration coefficients differed by more than an order of magnitude.

The 30-d model experienced comparatively more changes from recalibration than the 7-d model. Twenty-seven percent of the linear reservoir and evapotranspiration coefficients changed significantly for the 30-d application. In contrast, only 12 percent of the 7-d models' linear reservoir and evapotranspiration coefficients changed significantly.

TABLE 11.--*Lake Ontario subbasin 30-d model parameters--initial calibration**

				Linear reservoir and evapotranspiration coefficients						
Subbasin No.	K (cal/°C)	T (°C)	Albedo	Percolation (d^{-1})	Upper zone evap. (m^{-3})	Interflow (d^{-1})	Deep percolation (d^{-1})	Lower zone evap. (m^{-3})	Groundwater (m^{-3})	Surface storage outflow (d^{-1})
3	85E+13	0.4	0.82	99E-02	80E-08	17E-03	32E-03	0	71E-03	∞
4	29E+13	4.8	0.81	15E-02	24E-07	28E-03	11E-08	47E-10	16E-05	∞
5	14E+14	1.6	0.60	∞	-	14E-03	12E-03	15E-09	10E-02	∞
6	38E+13	4.7	0.82	33E-02	42E-07	67E-03	11E-08	49E-10	22E-05	∞
7	11E+14	2.4	0.62	39E-01	0	19E-03	71E-04	10E-09	∞	∞
10	14E+14	7.0	0.81	69E-02	60E-05	54E-04	14E-03	30E-09	48E-03	∞
11	78E+13	3.4	0.85	80E-02	36E-07	10E-03	10E-03	11E-08	29E-03	∞
12	11E+15	3.2	0.79	44E-01	0	10E-03	39E-05	34E-11	∞	∞
13	16E+14	1.8	0.86	83E-02	11E-08	42E-04	65E-04	11E-10	35E-04	∞
15	59E+13	2.9	0.86	48E-02	64E-08	76E-04	14E-03	36E-09	94E-04	∞
L1	74E+14	1.0	0.80	78E-01	17E-06	31E-03	18E-03	27E-08	10E-03	16E-01
L2	72E+14	1.4	0.79	55E-01	79E-08	29E-03	15E-03	35E-09	82E-04	69E-02

*Applications used data sets of 6405d beginning April 19, 1960, and ending October 31, 1977.

TABLE 12.--*Lake Ontario subbasin 7-d model parameters--initial calibration**

				Linear reservoir and evapotranspiration coefficients						
Sub-basin no.	K (cal/°C)	T (°C)	Albedo	Percolation (d^{-1})	Upper zone evap. (m^{-3})	Interflow (d^{-1})	Deep percolation (d^{-1})	Lower zone evap. (m^{-3})	Groundwater (m^{-3})	Surface storage outflow (d^{-1})
3	10E+14	1.7	0.72	19E-03	15E-08	0	12E-03	41E-07	36E-03	59E-03
4	67E+13	5.6	0.80	11E-02	23E-08	29E-03	11E-08	90E-11	11E-05	49E-02
5	16E+14	3.0	0.80	13E-03	74E-05	13E-02	0	44E-05	-	38E-03
6	73E+13	6.8	0.83	23E-02	17E-07	63E-03	11E-08	0	16E-05	11E-01
7	10E+14	2.2	0.52	27E-03	17E-08	20E-03	94E-04	44E-03	∞	36E-03
10	18E+14	6.6	0.72	94E-02	14E-02	64E-04	70E-04	25E-10	∞	15E-02
11	11E+14	4.4	0.78	84E-02	17E-06	11E-03	37E-04	34E-09	15E-03	16E-02
12	35E+15	7.9	0.68	31E-01	0	10E-03	45E-04	44E-11	22E-05	10E-02
13	18E+14	1.9	0.81	15E-01	23E-08	45E-04	11E-03	31E-10	44E-04	52E-01
15	10E+14	4.2	0.86	50E-02	44E-08	56E-04	12E-03	25E-09	90E-04	39E-02
L1	12E+15	5.4	0.80	19E-01	63E-05	20E-03	10E-03	98E-07	70E-05	41E-02
L2	76E+14	2.3	0.81	22E-01	54E-04	21E-03	10E-03	72E-07	67E-05	50E-02

*Applications used data sets of 6405d beginning April 19, 1960, and ending October 31, 1977.

While the modified calibration released the parameter constraint on the subbasin surface storage coefficients for the 30-d model, it did not prevent the coefficients from optimizing at infinity. Three of the subbasins (11, 13, and 15) continued to have infinite surface storage coefficients. For subbasin 11, only one parameter (lower zone evapotranspiration) changed significantly between the two calibration series, while for subbasins 13 and 15, no parameters changed significantly. In contrast, the seven remaining subbasins, where recalibration produced noninfinite surface storage coefficients, had significant changes in a total of 17 parameter values, not counting surface storage. It is interesting to note that subbasin 13 has an infinite surface storage coefficient for both the 7-d and 30-d applications, equivalent to no surface storage "tank" in the model. This subbasin is a very narrow strip along the lake with a faster modeled time of concentration than 7-d or 30-d; this was not detectable at these time intervals.

For those cases where the 7-d and 30-d parameter values became more consistent using the modified calibration, two trends are apparent. In six cases, the parameter values for both applications changed toward similar values. Five of these cases occurred in the cases of upper and lower zone evapotranspiration coefficients. More often, during the second calibration, parameters from the 30-d application became more consistent with stationary 7-d values; such changes occurred in 22 instances. In only four instances did parameters from the 7-d application change to become more similar to stationary 30-d values. A summary of the differences between optimum parameter sets for the two calibration series is given in table 13.

Review of the changes in the 7-d and 30-d model applications as the parameter constraints were modified reveals a comparatively large number of changes in the 30-d parameter values, except for those subbasins where the surface storage coefficient remained infinite. Also, a greater percentage of 30-d values changed in the recalibration to become more similar to stationary 7-d values than vice-versa. These trends suggest that removing the constraint on the 30-d subbasins' surface storage coefficient allowed the model to be more realistic, resulting in more consistent parameter values between the two time intervals. The initial assumption that all subbasin surface storage response times are faster than the 30-d time interval, and are therefore not detectable, was computationally convenient, but had a limited physical basis.

TABLE 13.--*Summary of differences between optimum parameter sets resulting from initial and modified calibrations**

INITIAL CALIBRATION	MODIFIED CALIBRATION
30-d model vs. 7-d model	30-d model vs. 7-d model
27 percent of the parameters differed significantly.	7 percent of the parameters differed significantly.
30-D MODEL	7-D MODEL
Initial vs. modified calibration	Initial vs. modified calibration
27 percent of the parameters changed significantly.	12 percent of the parameters changed significantly.
26 percent of the parameters changed to become more consistent with stationary 7-d values.	5 percent of the parameters changed to become more consistent with stationary 30-d values.
Subbasins with surface storage from the modified calibration	Subbasins with no surface storage from the modified calibration
40 percent of the other parameters changed significantly.	6 percent of the other parameters changed significantly.

*Comparisons concern linear reservoir and evapotranspiration coeffients only.

Focusing on the 7-d applications, the majority of changes resulting from modifying the method of determining K are concerned with the evapotranspiration coefficients. Seventy percent of the parameter values that changed significantly between the two calibration series were evapotranspiration coefficients. This is understandable because K is instrumental in determining the total heat available for evapotranspiration.

The simultaneous change of evapotranspiration coefficients for the 7-d and 30-d models toward more consistent values suggests that the heat balance boundary constraint is not unreasonable. However, it is difficult to assess the roles of the surface storage coefficient changes and modified data set lengths in the 30-d applications attaining those more consistent values.

Because there are fewer degrees of freedom in the modified 7-d calibration, one would expect the model fit to be poorer. The correlation coefficients decreased by 0.01 for 2 of 11 subbasins, while the rmse increased by 0.01 for the 2 others. (Rmse decreased by 0.01 for one subbasin.) For three of the four entire-basin applications, the correlation coefficient decreased by 0.01, while the rmse for those applications increased by 0.01. Comparison of typical outflows produced by the model for both calibration series (figs. 1 and 2) shows that the recalibrated model produces only slightly greater annual minimum basin outflows, indicating that direct determination of K according to the boundary constraint on the long-term heat balance does not seriously compromise the model's evapotranspiration capability.

In summary, modifications of the GLERL Large Basin Runoff Model, resulting in the model described in the main text, have resulted in its overall improvement. The increased consistency of the model parameters following removal of the subbasins' surface storage constraint for 30-d applications illustrates the desirability of using only those parameters that have a sound physical basis. Simplifying assumptions may be convenient, but there are trade-offs. Reducing degrees of freedom in parameter optimization can be desirable if the associated boundary constraint is reasonable. In the case of K, the slightly poorer model fit is acceptable because realistic boundary conditions are used to remove a "fudging factor" with no physical significance from the optimization. Of the remaining parameters, it would be most desirable to limit the value of "base" temperature, T_b, by some acceptable boundary condition. Other boundary constraints could be established with knowledge of soil moisture conditions or snowpack. However, given present data availability limitations and lack of sound physical relationships, elimination of T_b or any other parameters from the optimization cannot be currently justified. Further reducing degrees of freedom at present could prematurely exclude possible alternatives in the future.

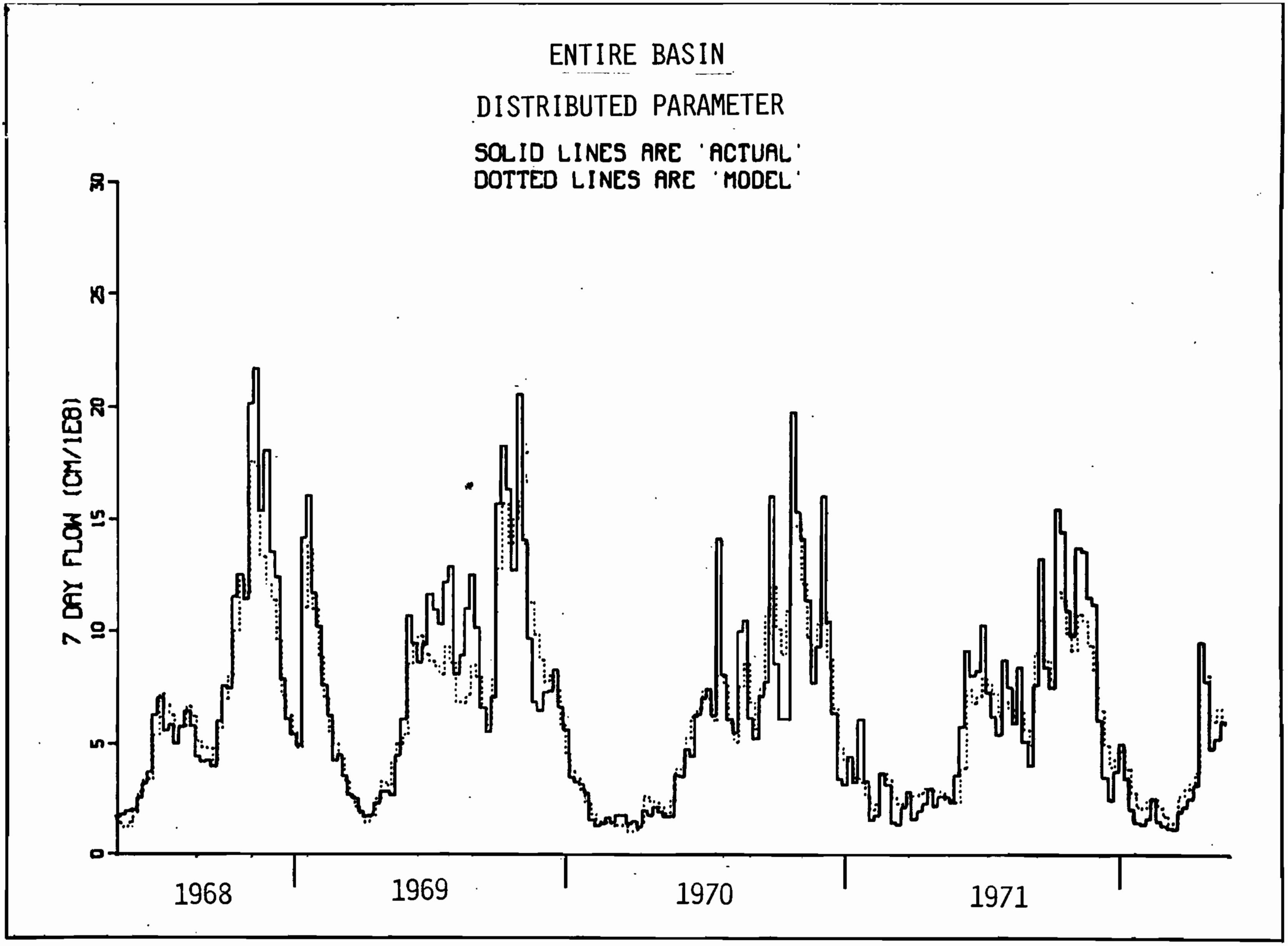

FIGURE 5.--*7-d distributed-parameter model fit to Lake Ontario Basin above Kingston, Ont., using initial calibration.*

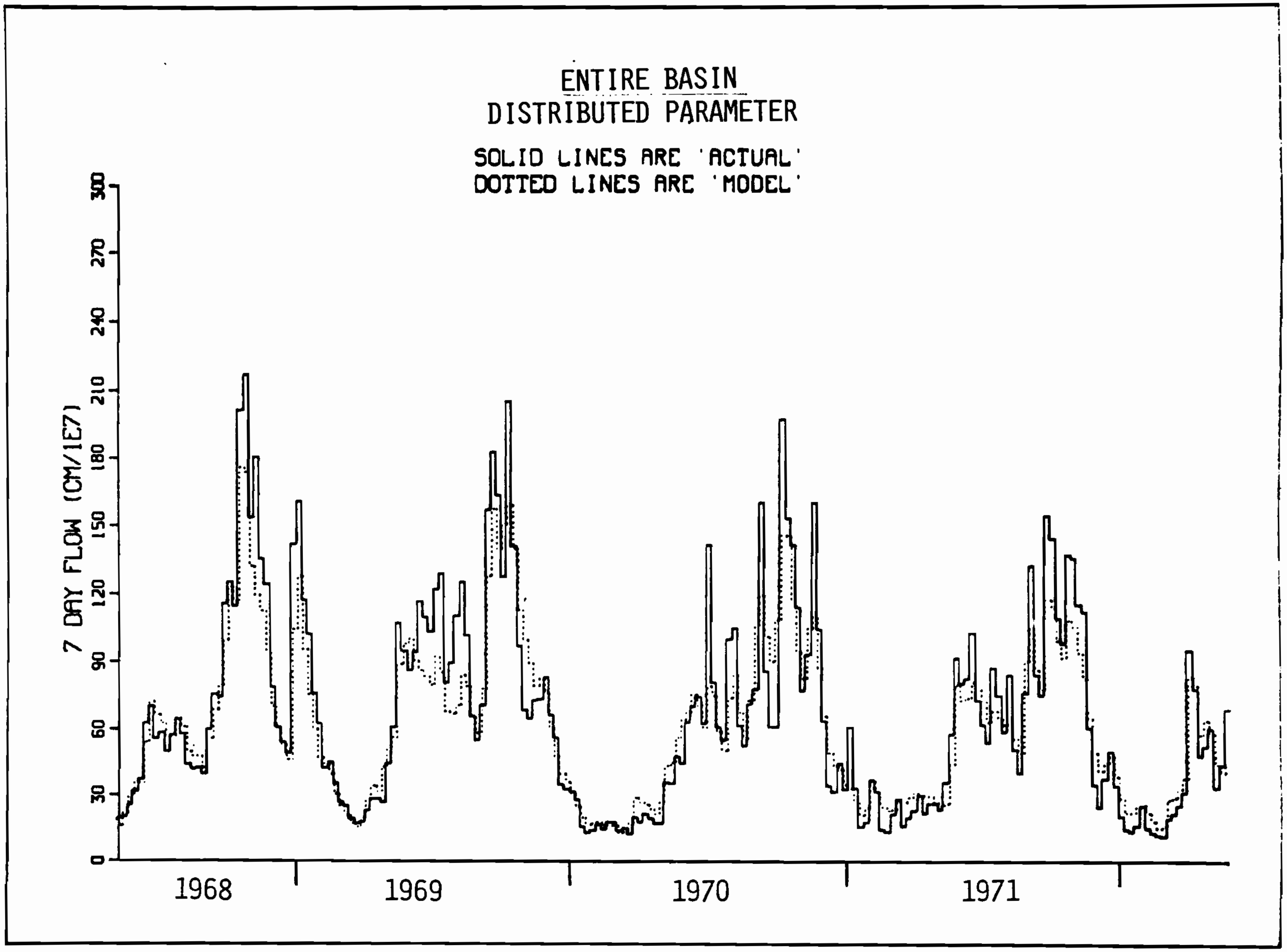

FIGURE 6.--*7-d distributed parameter model fit to Lake Ontario Basin above Kingston, Ont., using modified calibration.*

Appendix C.--MODEL FITS FOR 7-D, 28-D, AND 30-D OUTFLOW VOLUMES

Figures 7-24, presented in this appendix, are typical model fits for the indicated applications to Lake Ontario and its subbasins. To conserve space, only 4-6 yr of actual and model flows are presented. A complete set of figures is on file at the Great Lakes Environmental Research Laboratory, Ann Arbor, Mich. 48104.

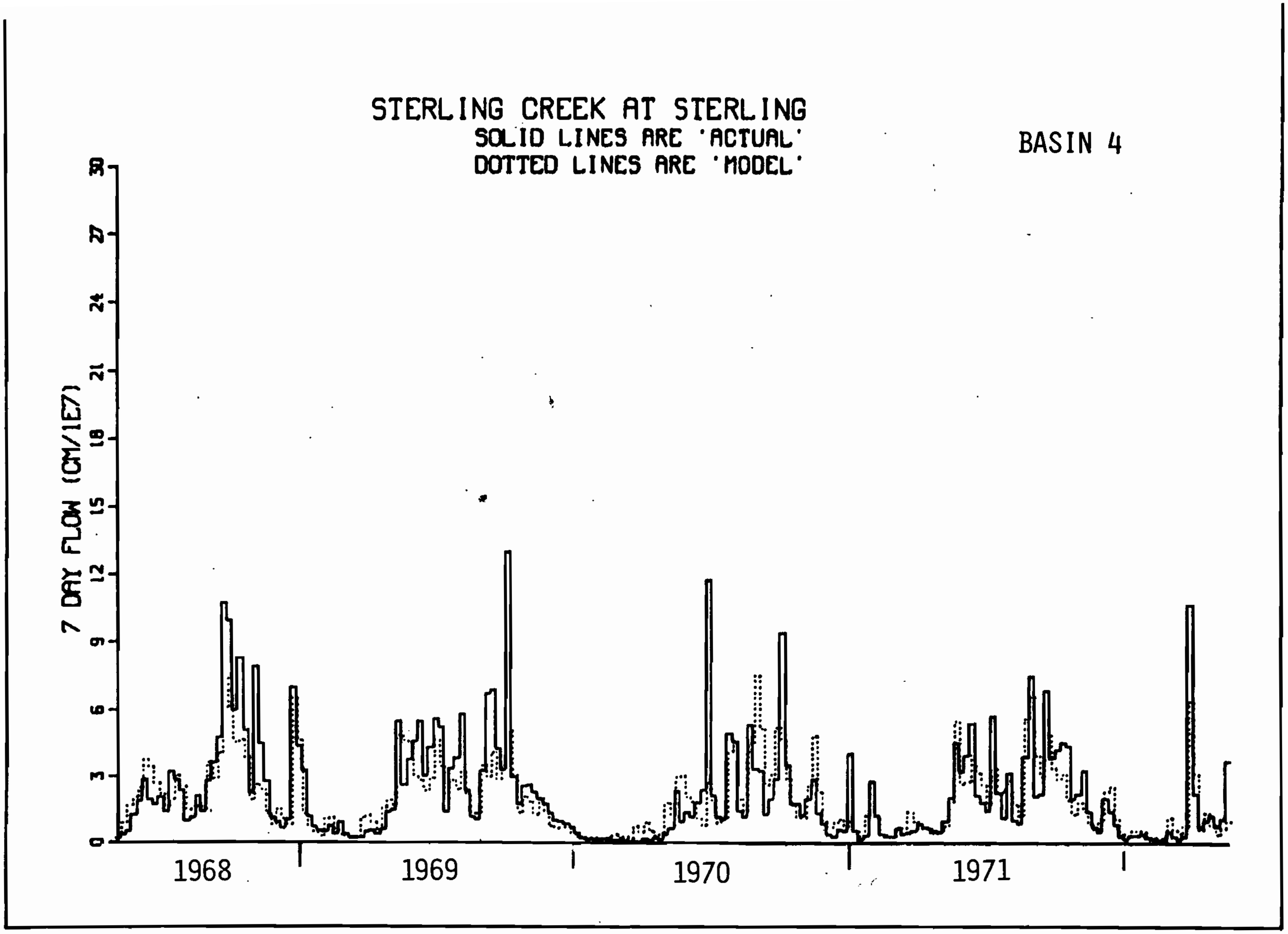

FIGURE 7.--*7-d model fit to Sterling Creek at Sterling, Mich.*

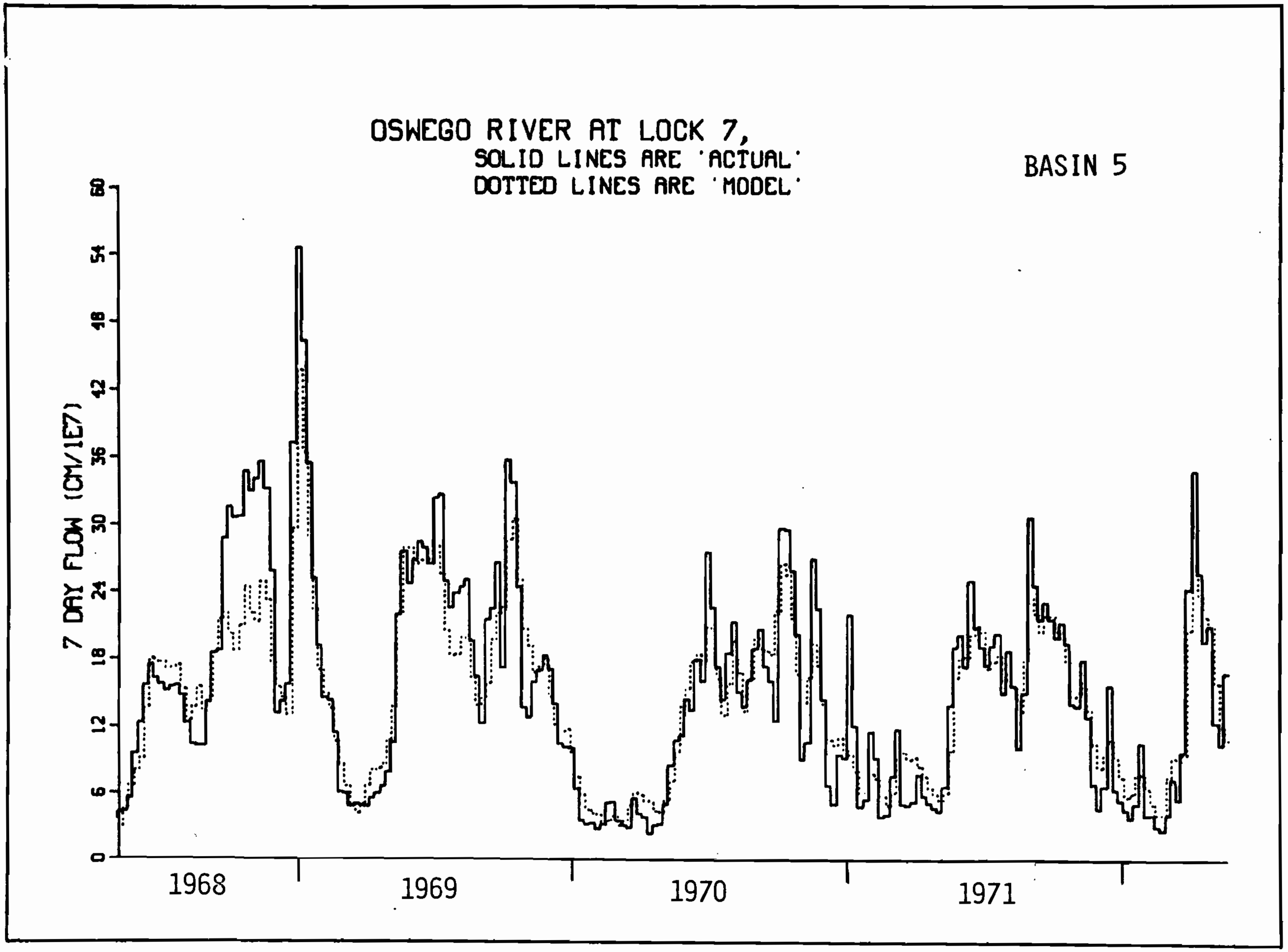

FIGURE 8.--*7-d model fit to the Oswego River at lock 7.*

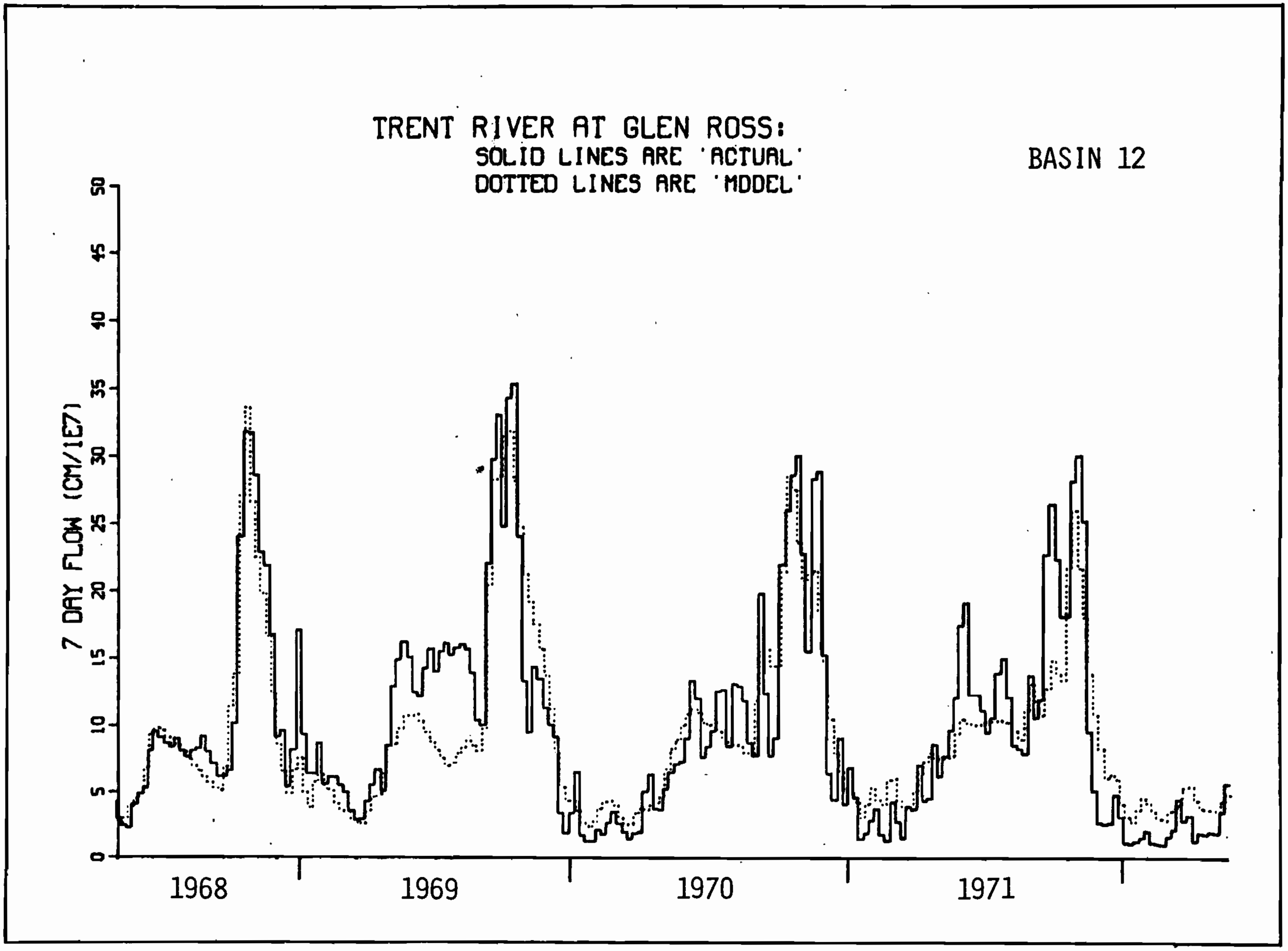

FIGURE 9.--*7-d model fit to the Trent River at Glen Ross, Ont.*

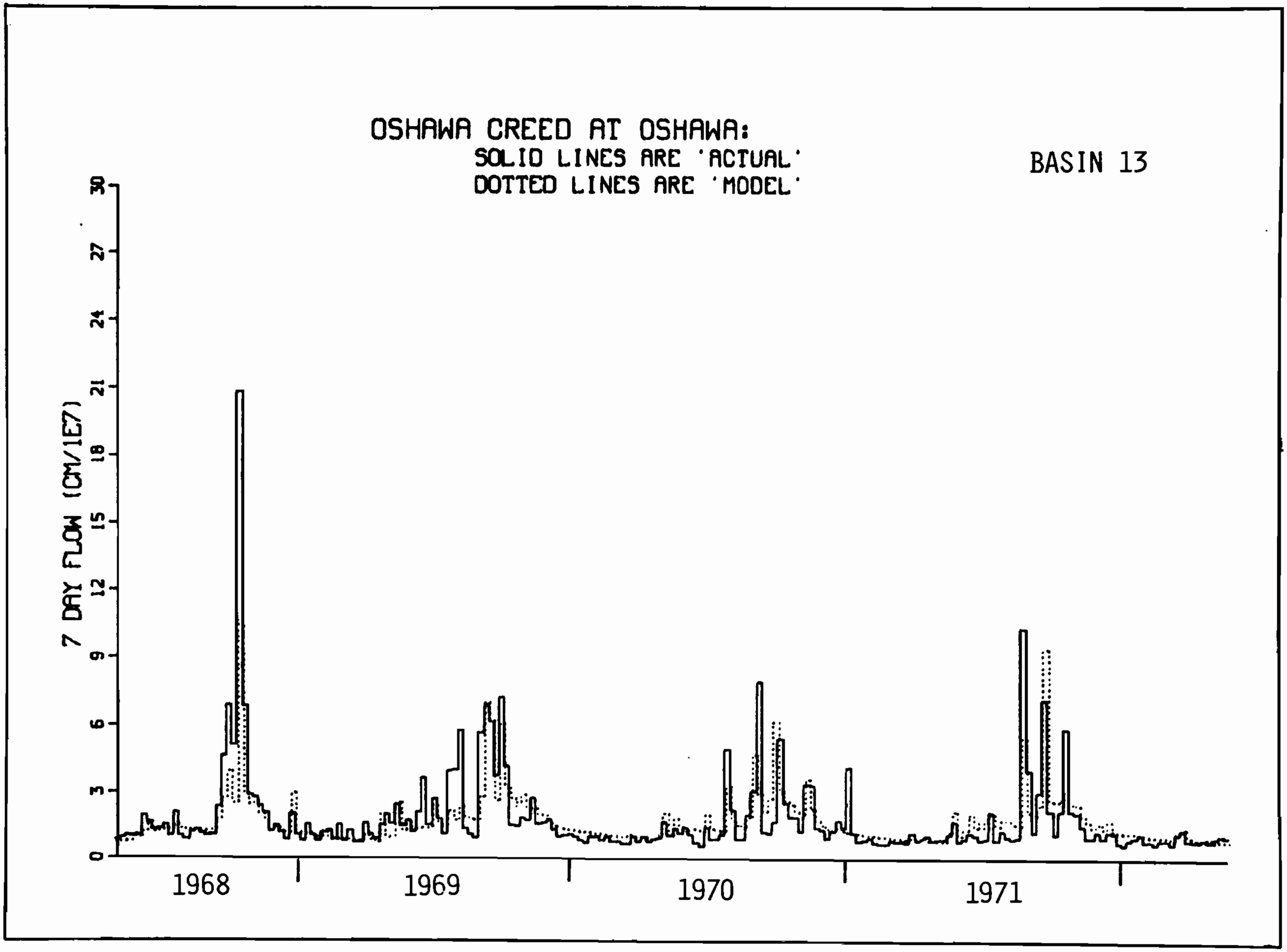

FIGURE 10.--*7-d model fit to Oshawa Creek at Oshawa, Ont.*

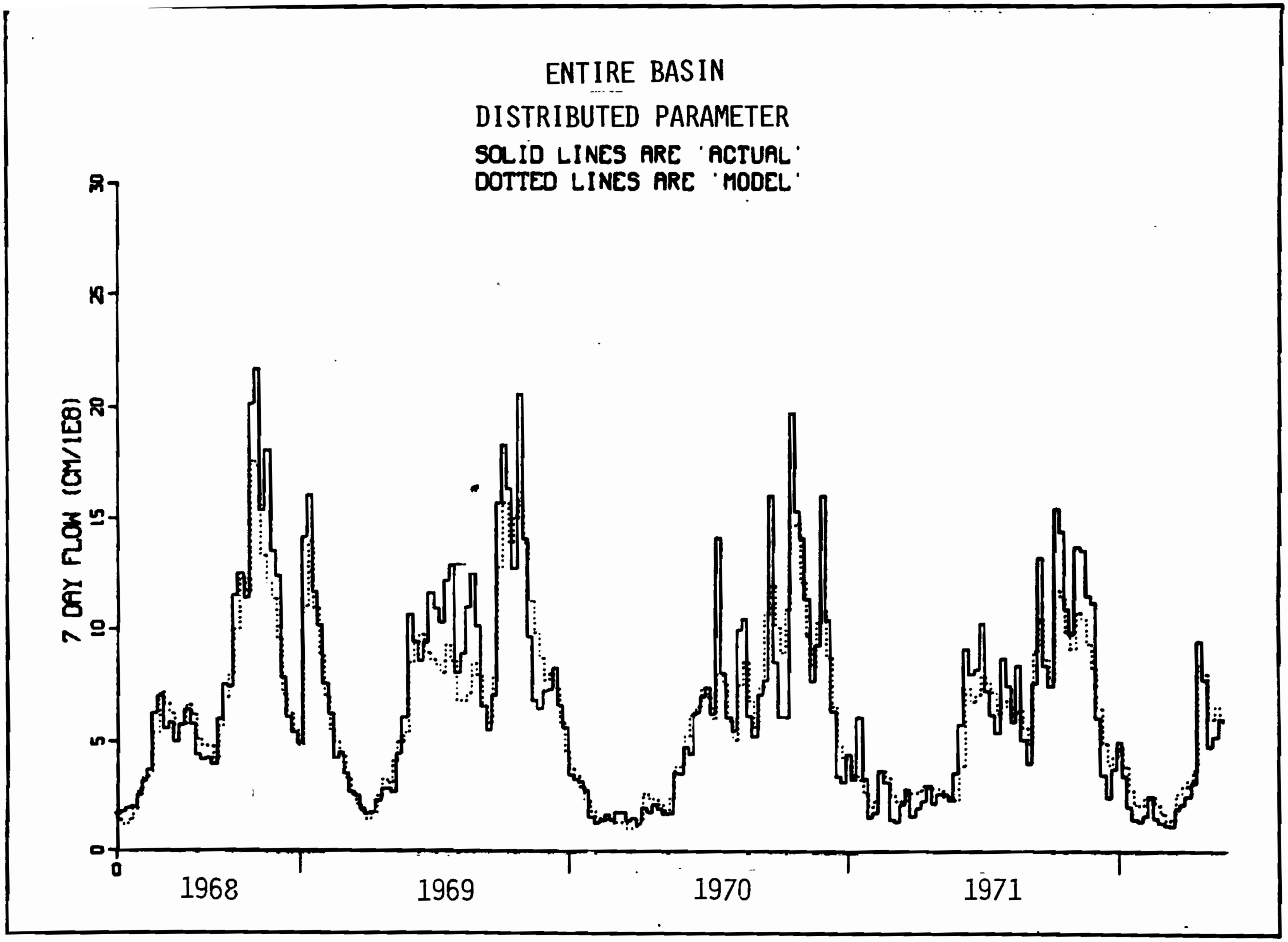

FIGURE 11.--*7-d distributed parameter model fit to the Lake Ontario Basin above Kingston, Ont.*

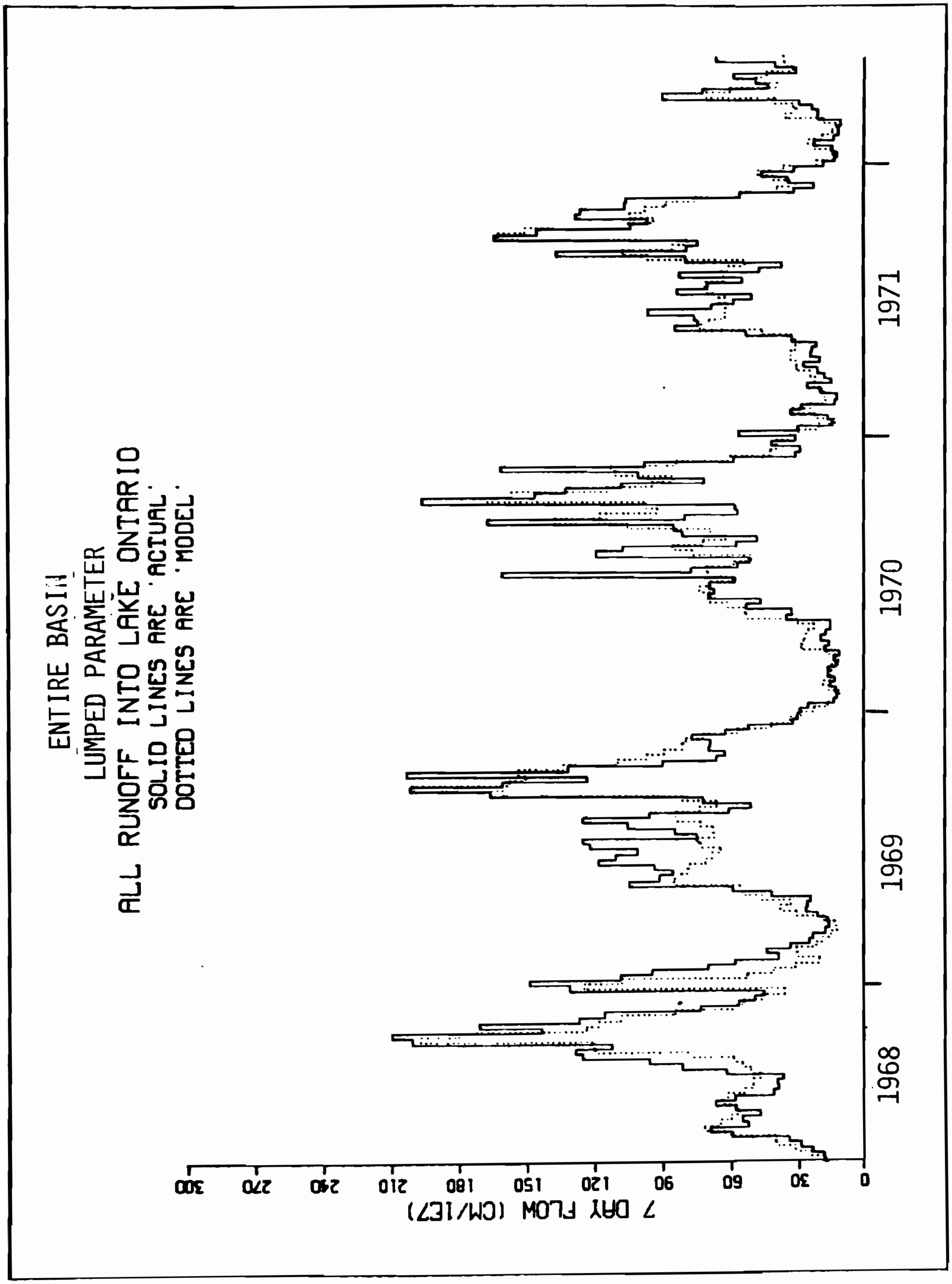

FIGURE 12.--*7-d lumped parameter model fit to the Lake Ontario Basin above Kingston, Ont.*

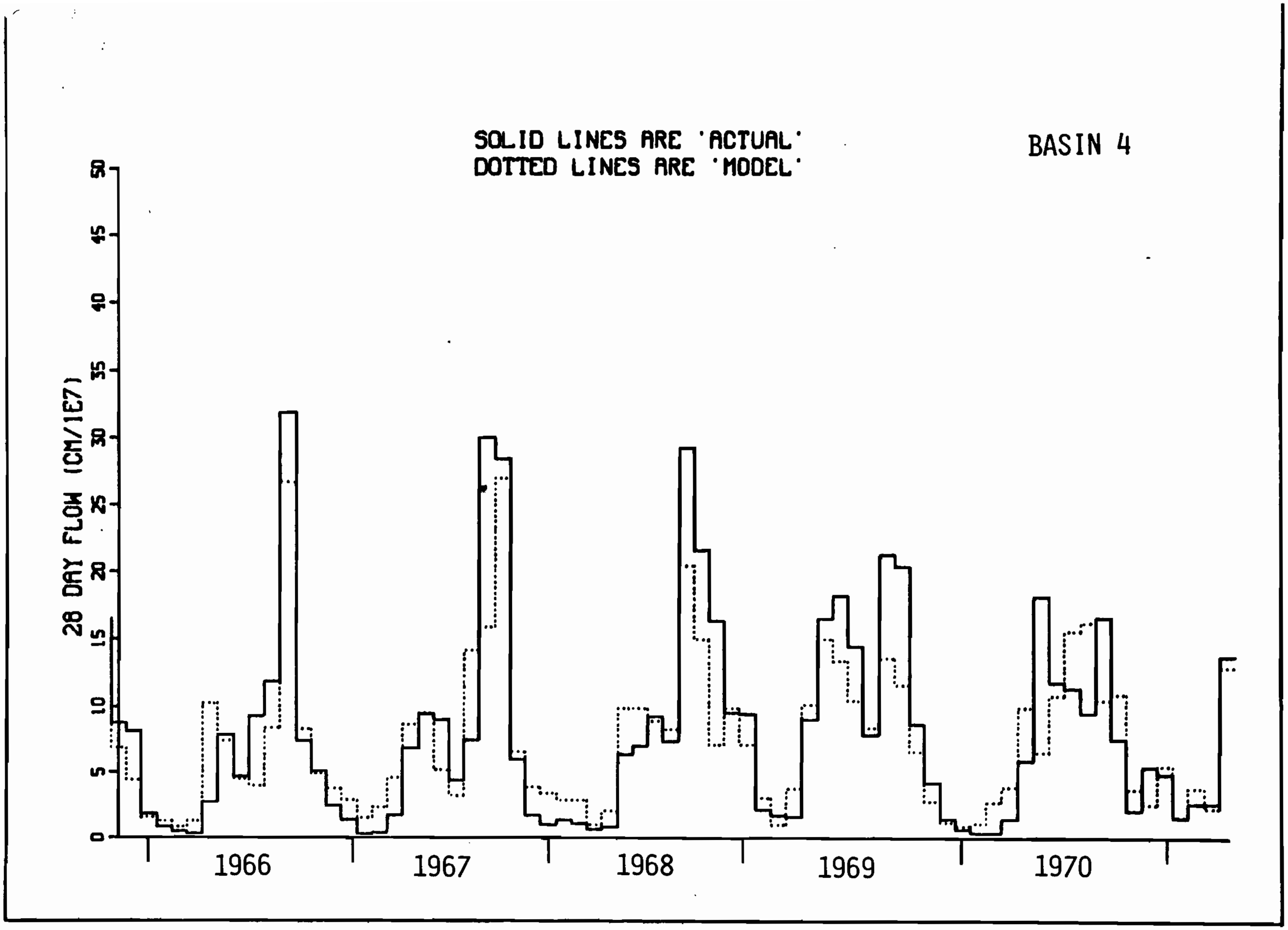

FIGURE 13.--*28-d model fit to Sterling Creek at Sterling, Mich.*

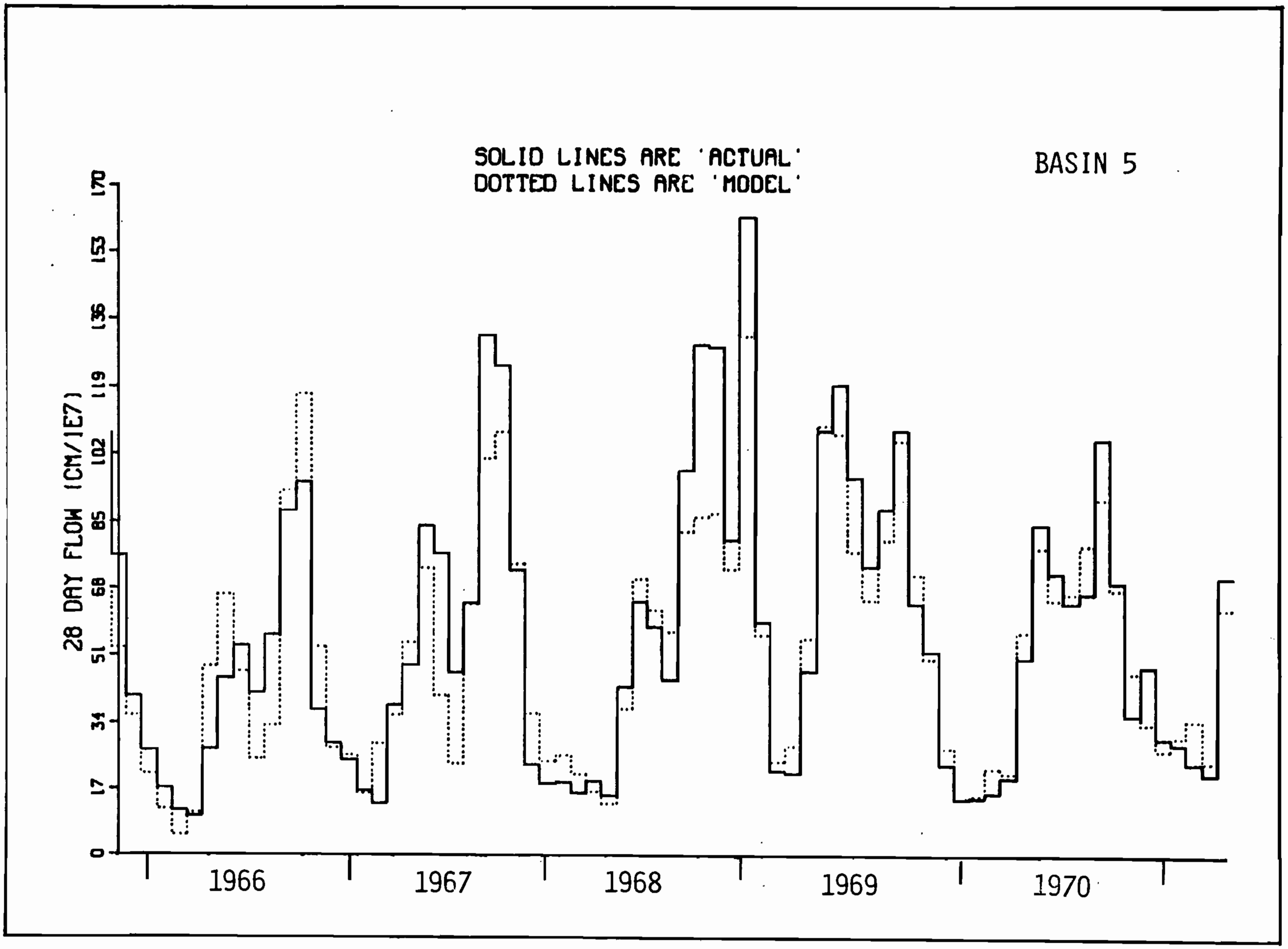

FIGURE 14.--*28-d model fit to the Oswego River at lock 7.*

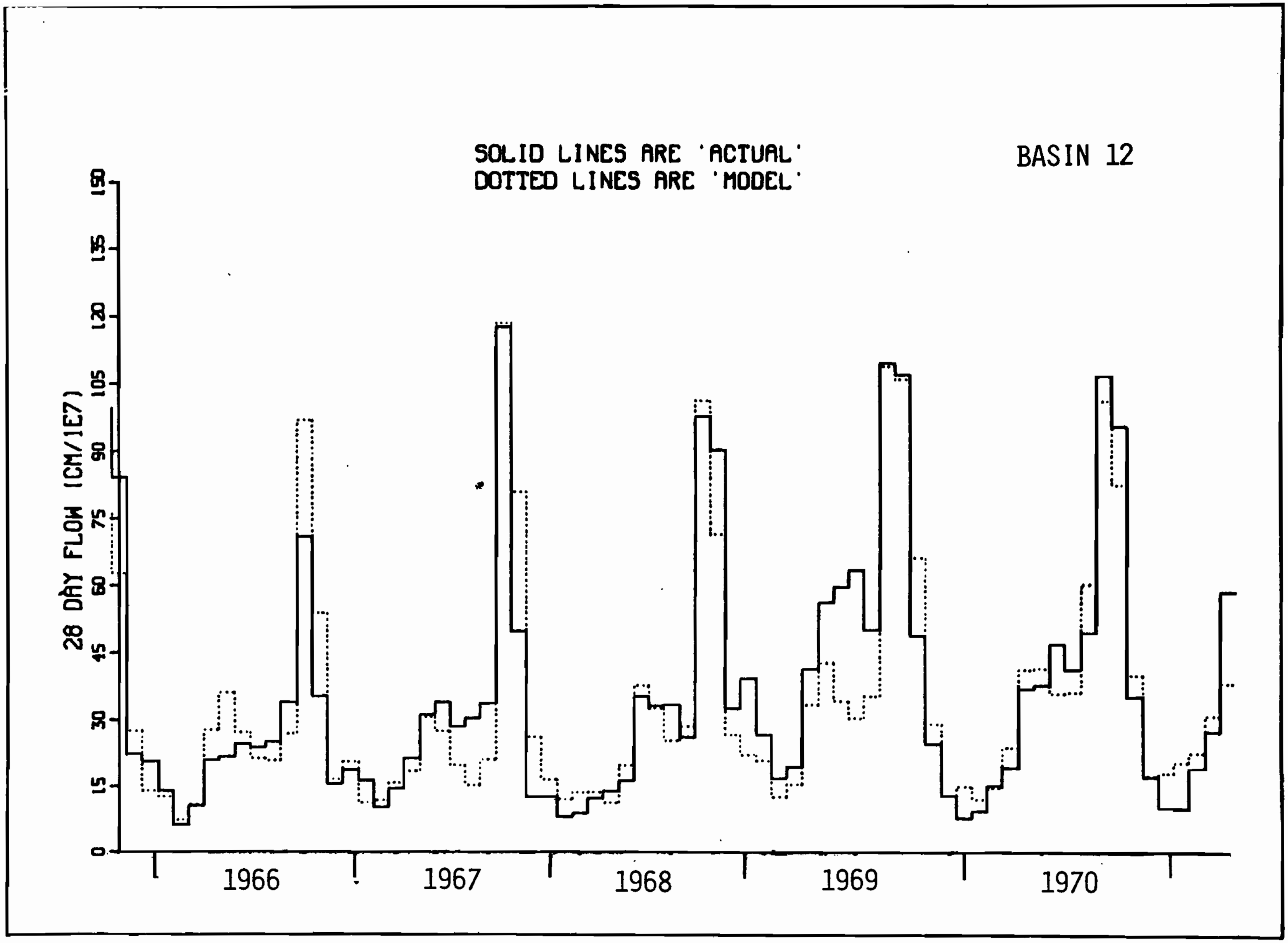

FIGURE 15.--*28-d model fit to the Trent River at Glen Ross, Ont.*

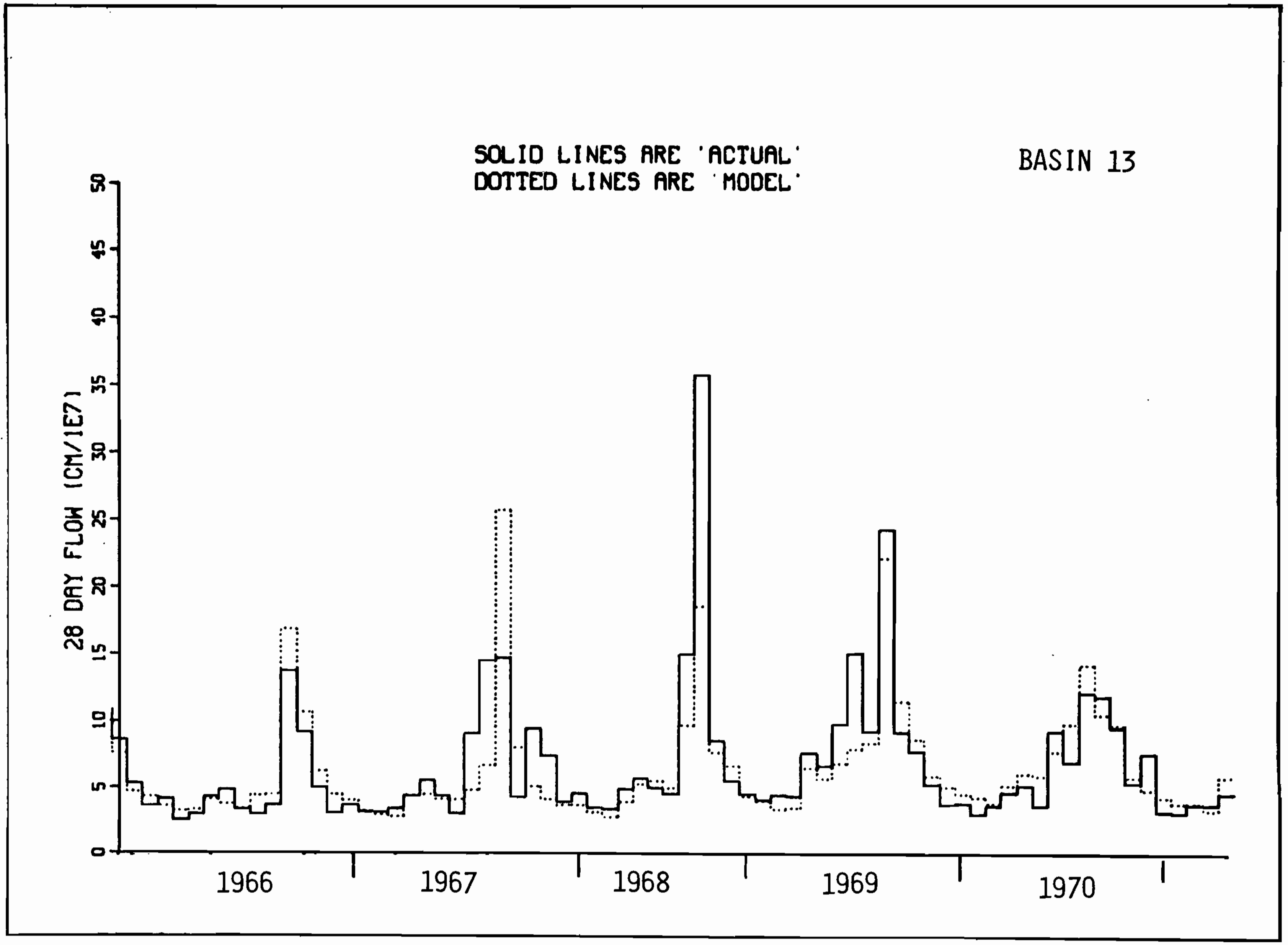

FIGURE 16.--*28-d model fit to Oshawa Creek at Oshawa, Ont.*

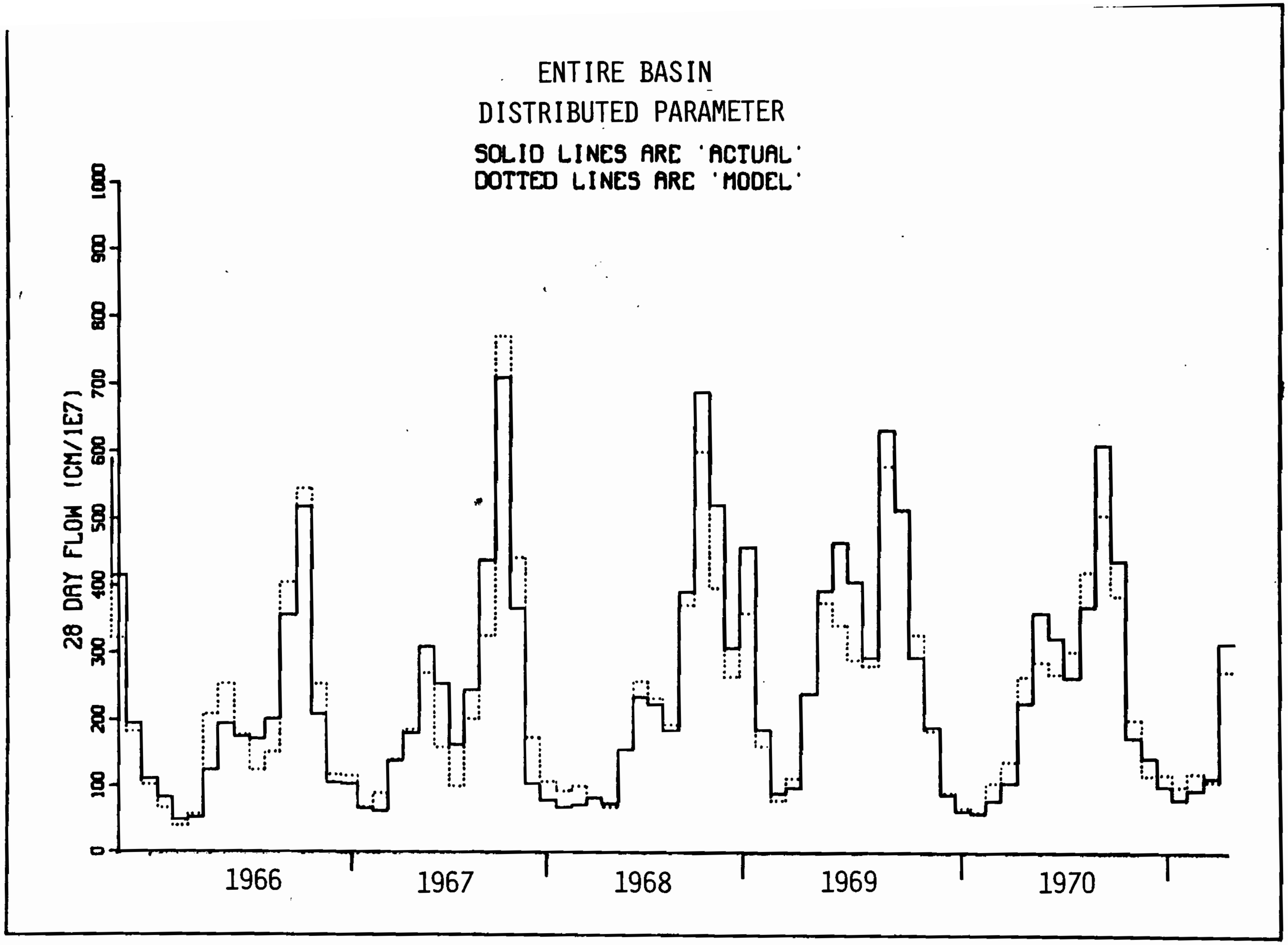

FIGURE 17.--*28-d distributed parameter model fit to the Lake Ontario Basin above Kingston, Ont.*

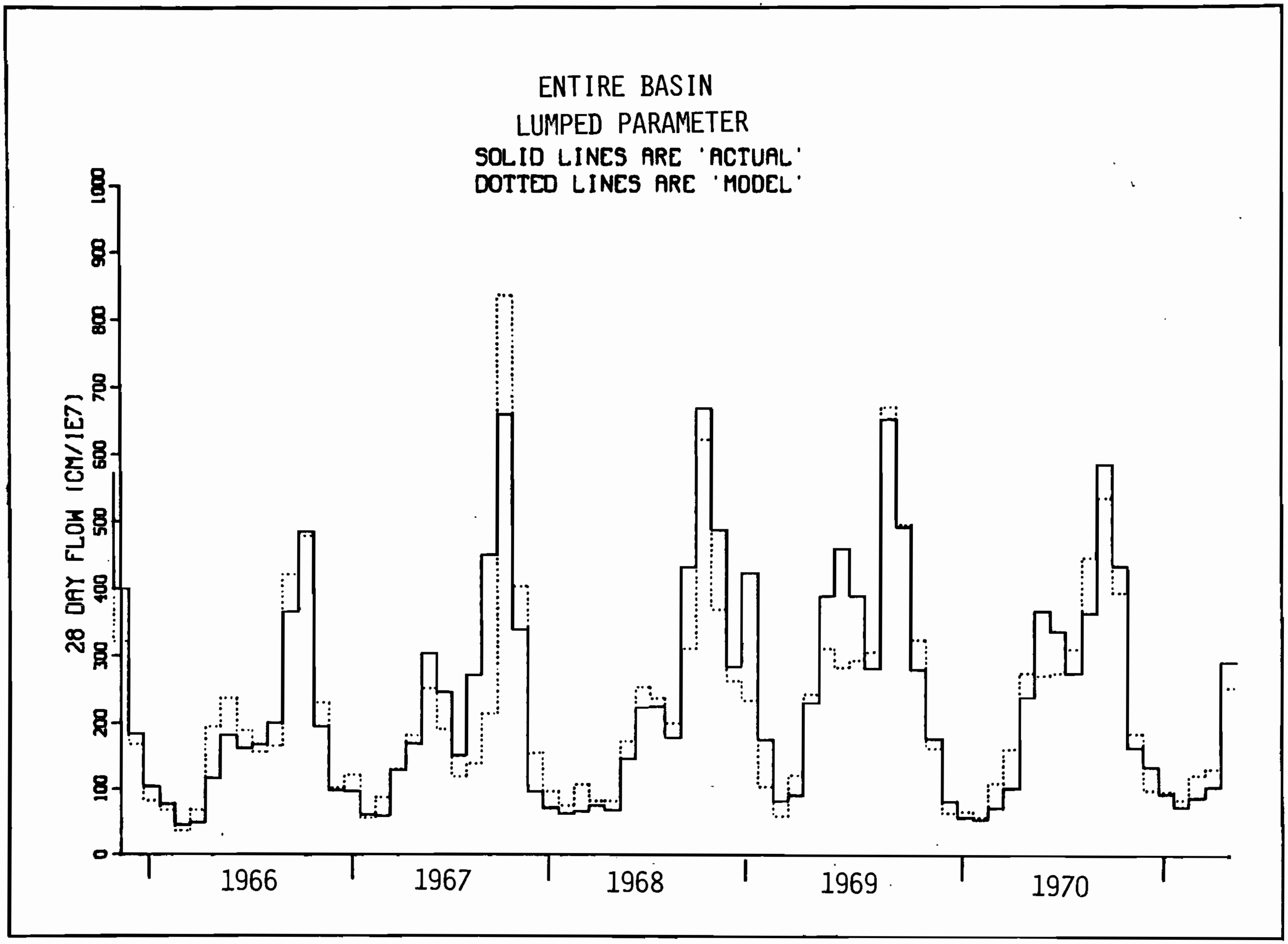

FIGURE 18.--*28-d lumped parameter model fit to the Lake Ontario Basin above Kingston, Ont.*

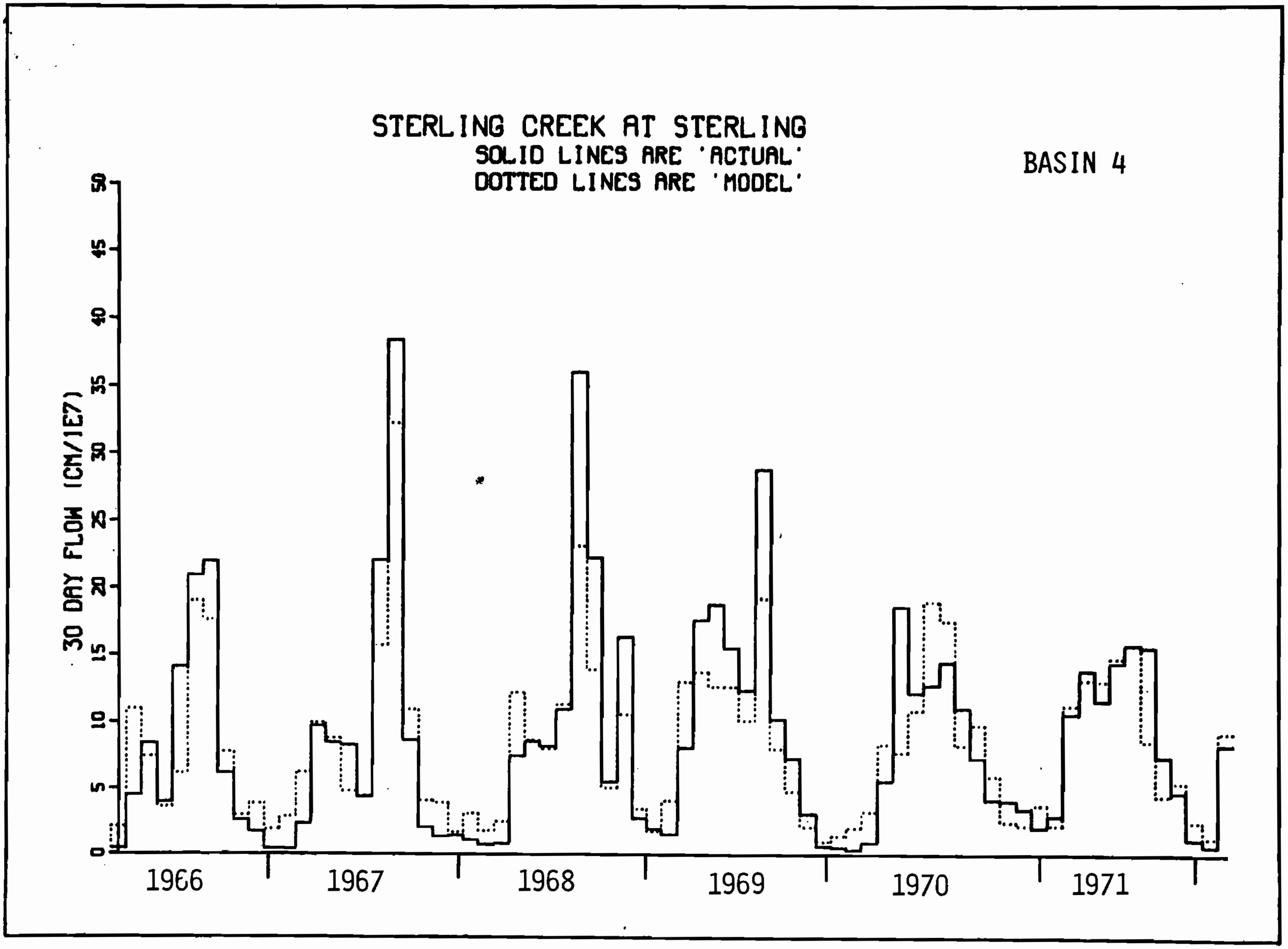

FIGURE 19.--*30-d model fit to Sterling Creek at Sterling, Mich.*

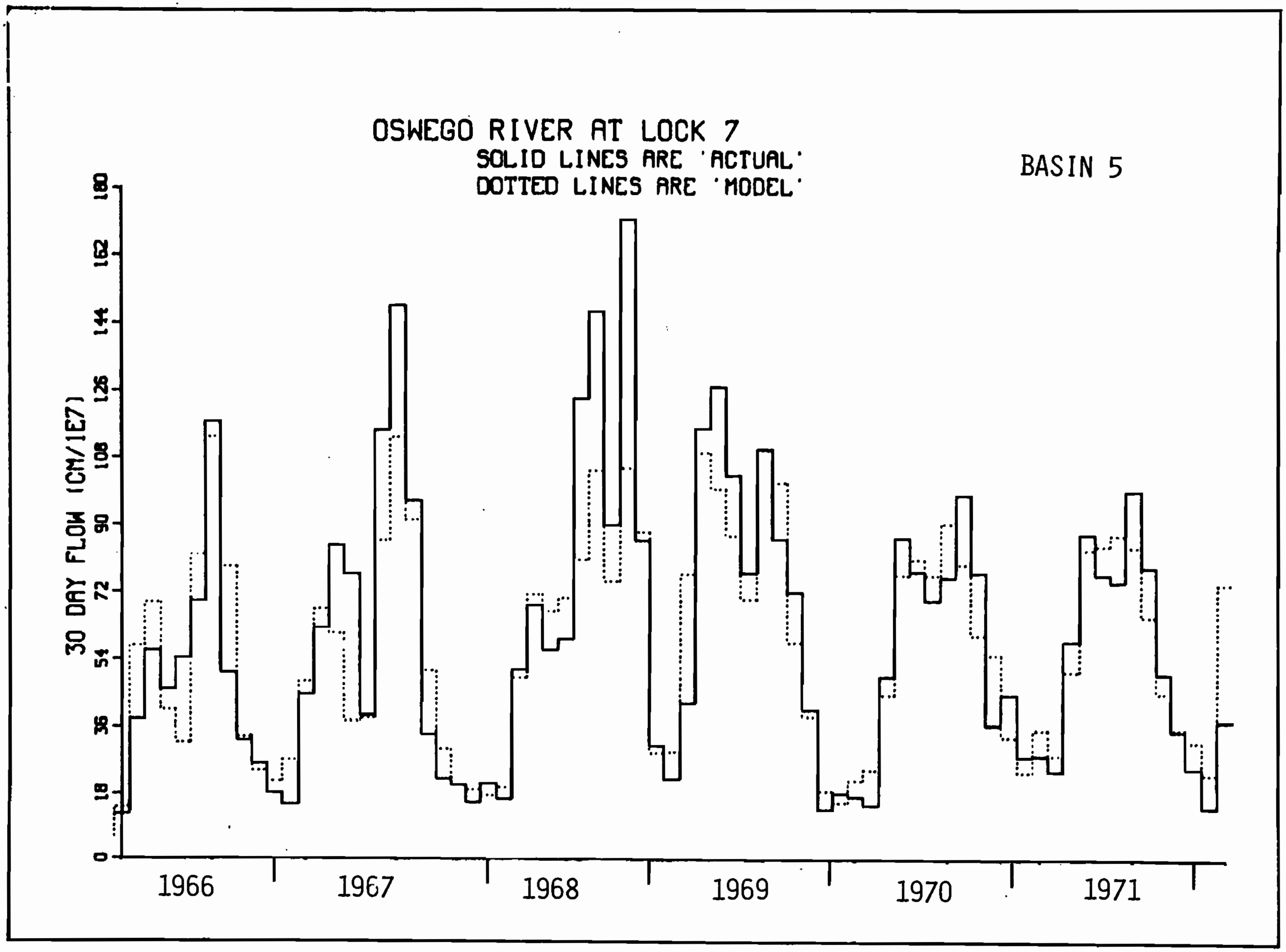

FIGURE 20.--*30-d model fit to the Oswego River at lock 7.*

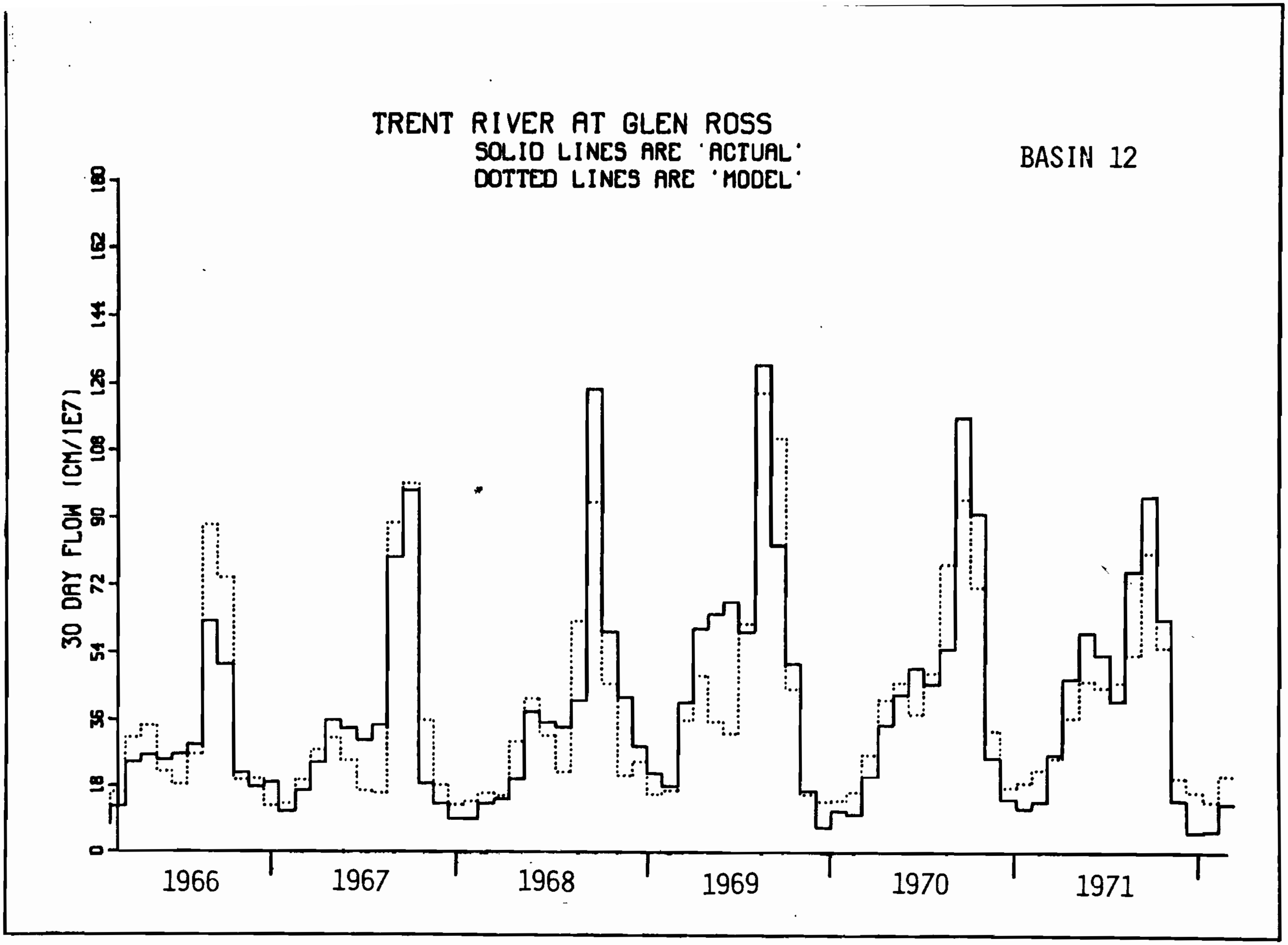

FIGURE 21.--*30-d model fit to the Trent River at Glen Ross, Ont.*

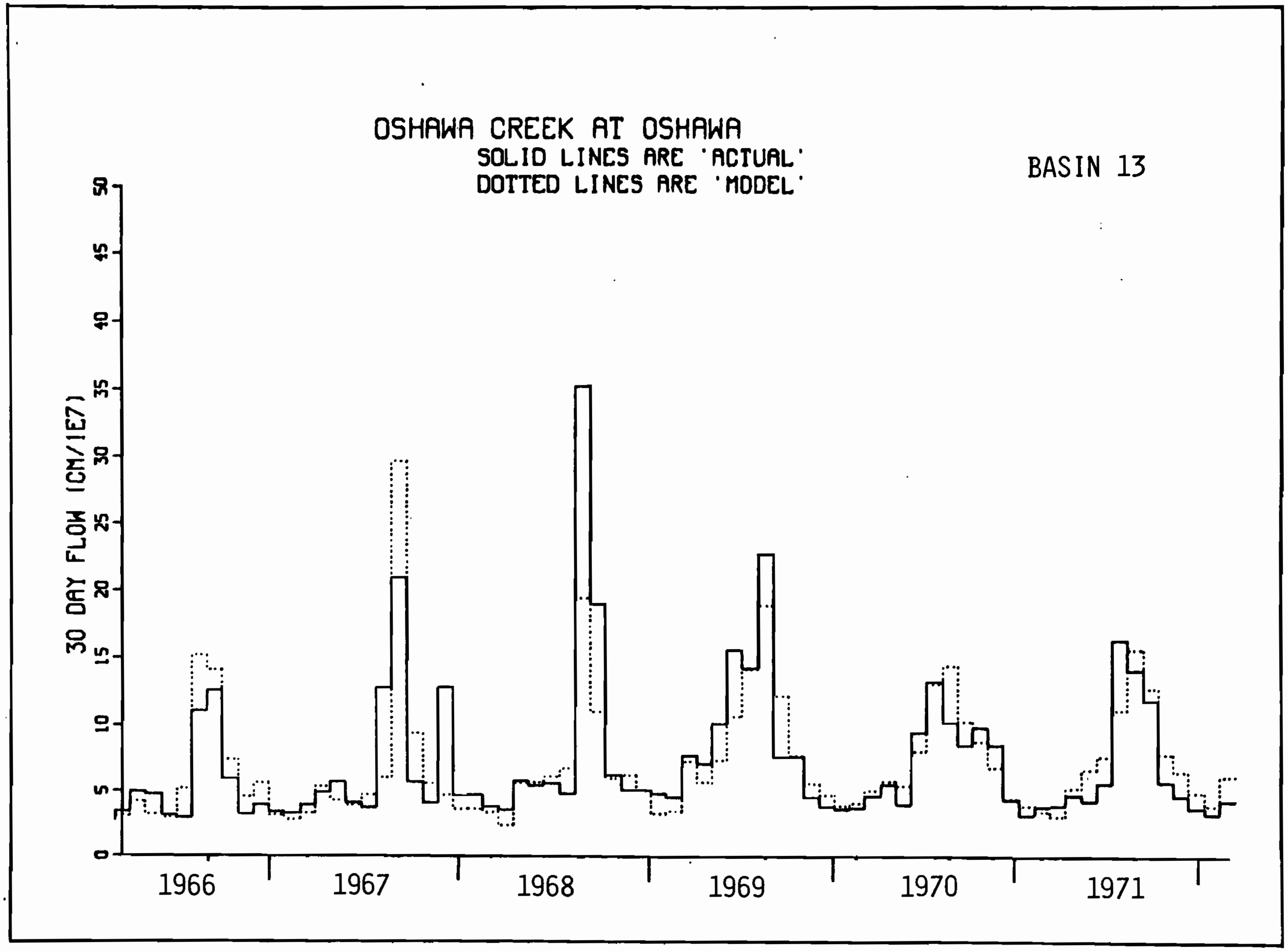

FIGURE 22.--*30-d model fit to Oshawa Creek at Oshawa, Ont.*

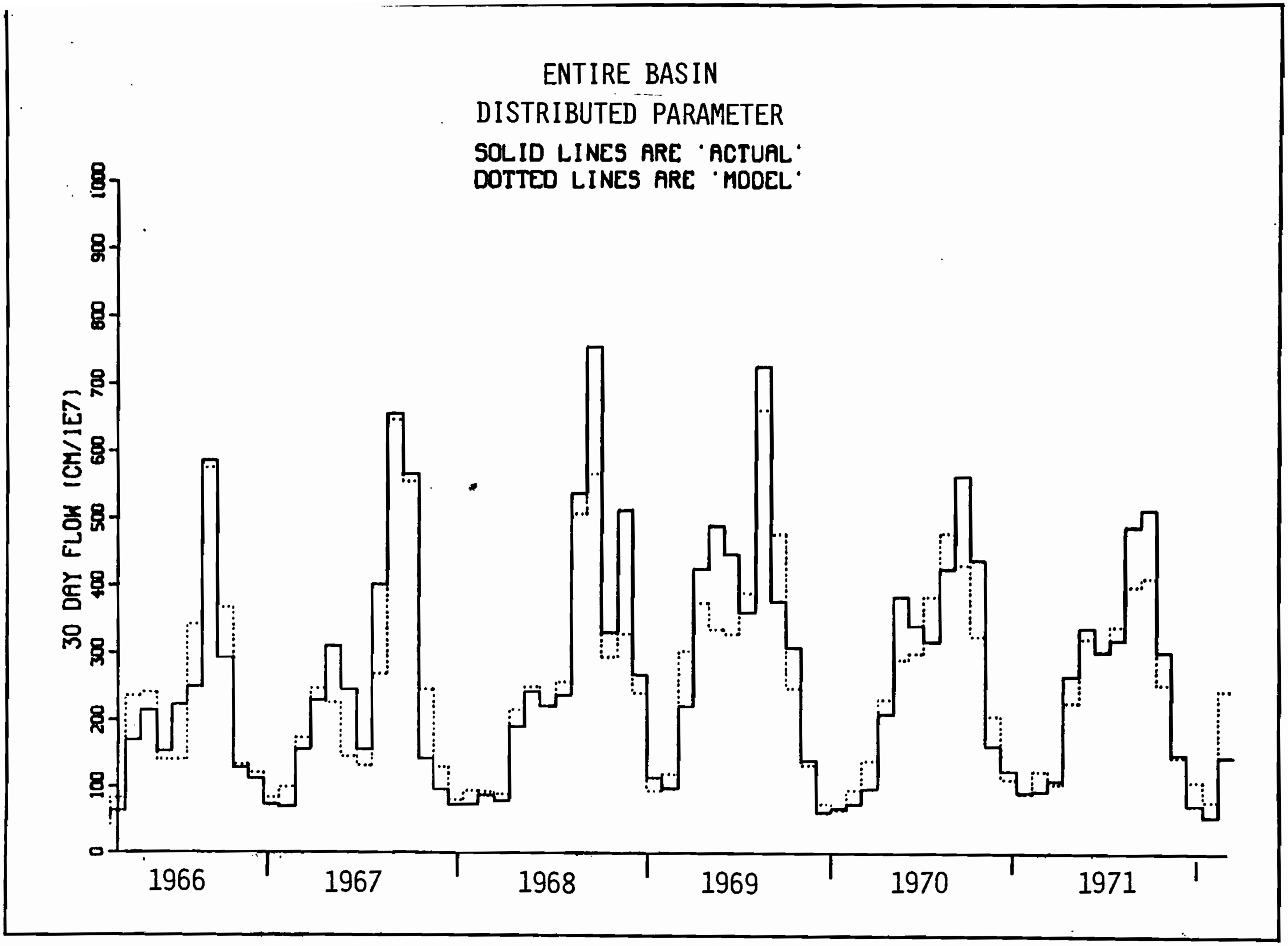

FIGURE 23.--*30-d distributed parameter model fit to the Lake Ontario Basin above Kingston, Ont.*

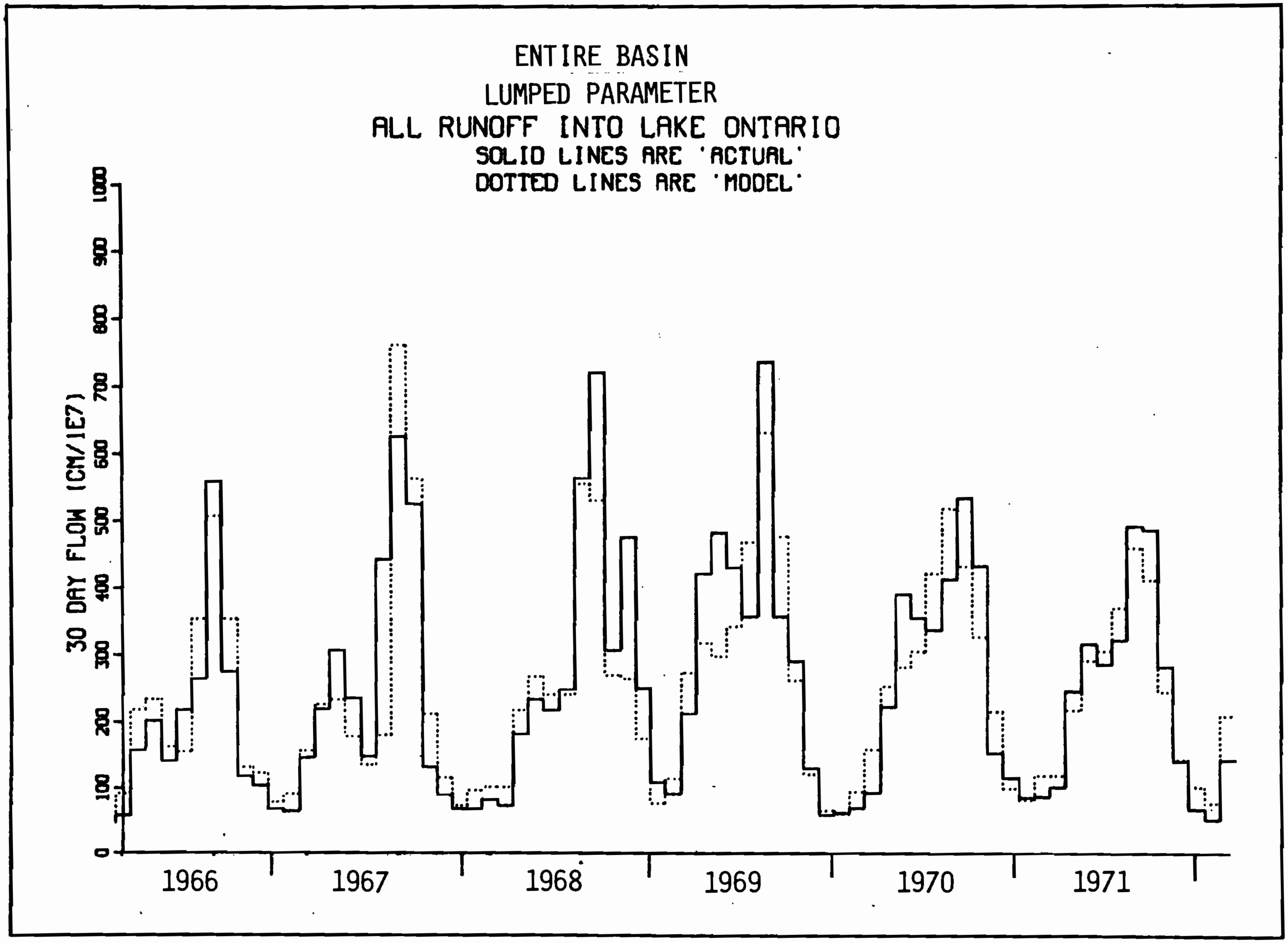

FIGURE 24.--*30-d lumped parameter model fit to the Lake Ontario Basin above Kingston, Ont.*

Appendix D.--SEASONAL CORRELATION

Figures 25-30, presented in this appendix, are correlations between 7-d actual and model outflows on a weekly basis for selected subbasins and entire-basin applications to Lake Ontario. A complete file of seasonal correlations is on file at the Great Lakes Environmental Research Laboratory, Ann Arbor, Mich. 48104.

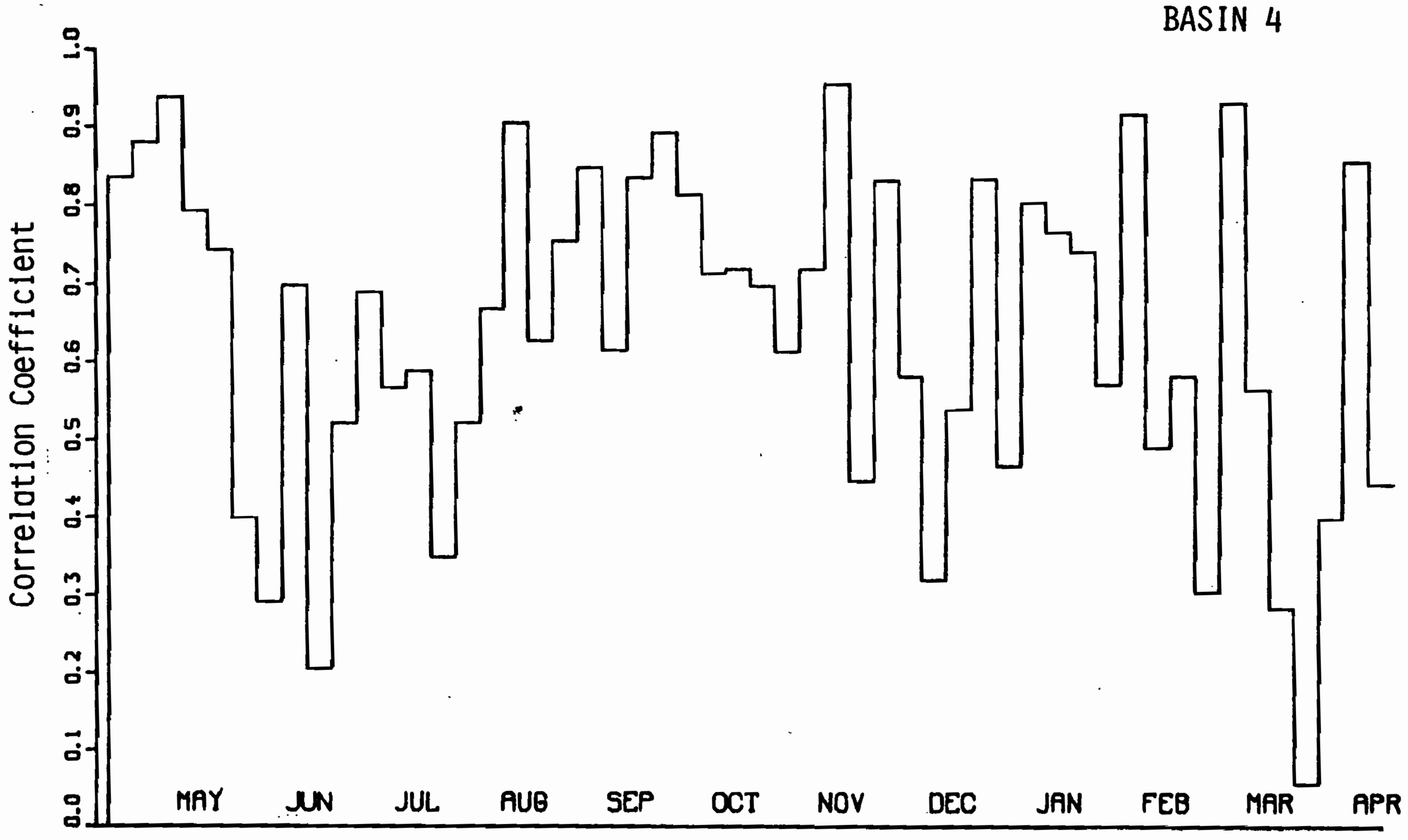

FIGURE 25.--*Weekly correlations between 7-d actual and model outflows for Sterling Creek at Sterling, Mich.*

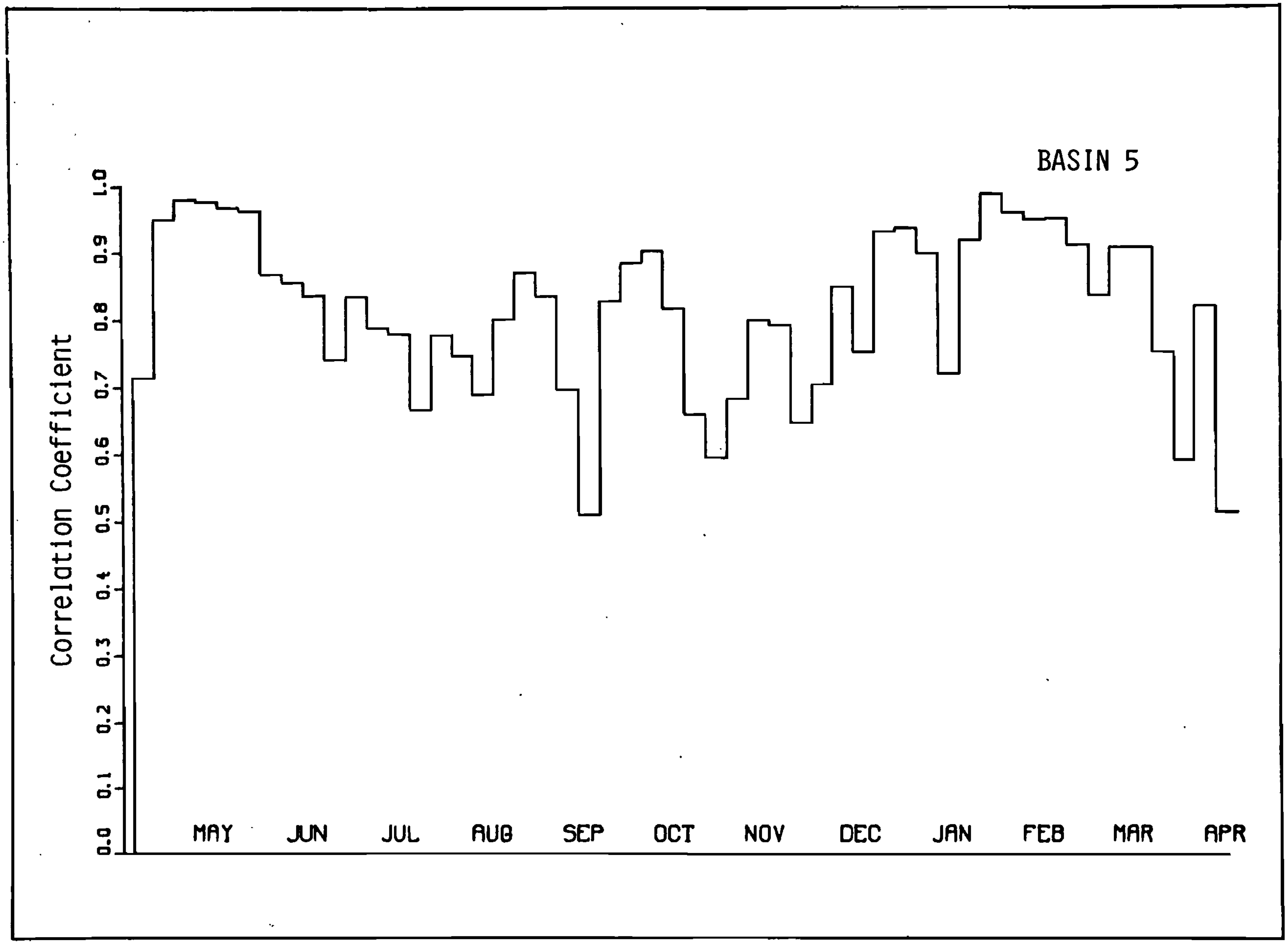

FIGURE 26.--*Weekly correlations between 7-d actual and model outflows for the Oswego River at lock 7.*

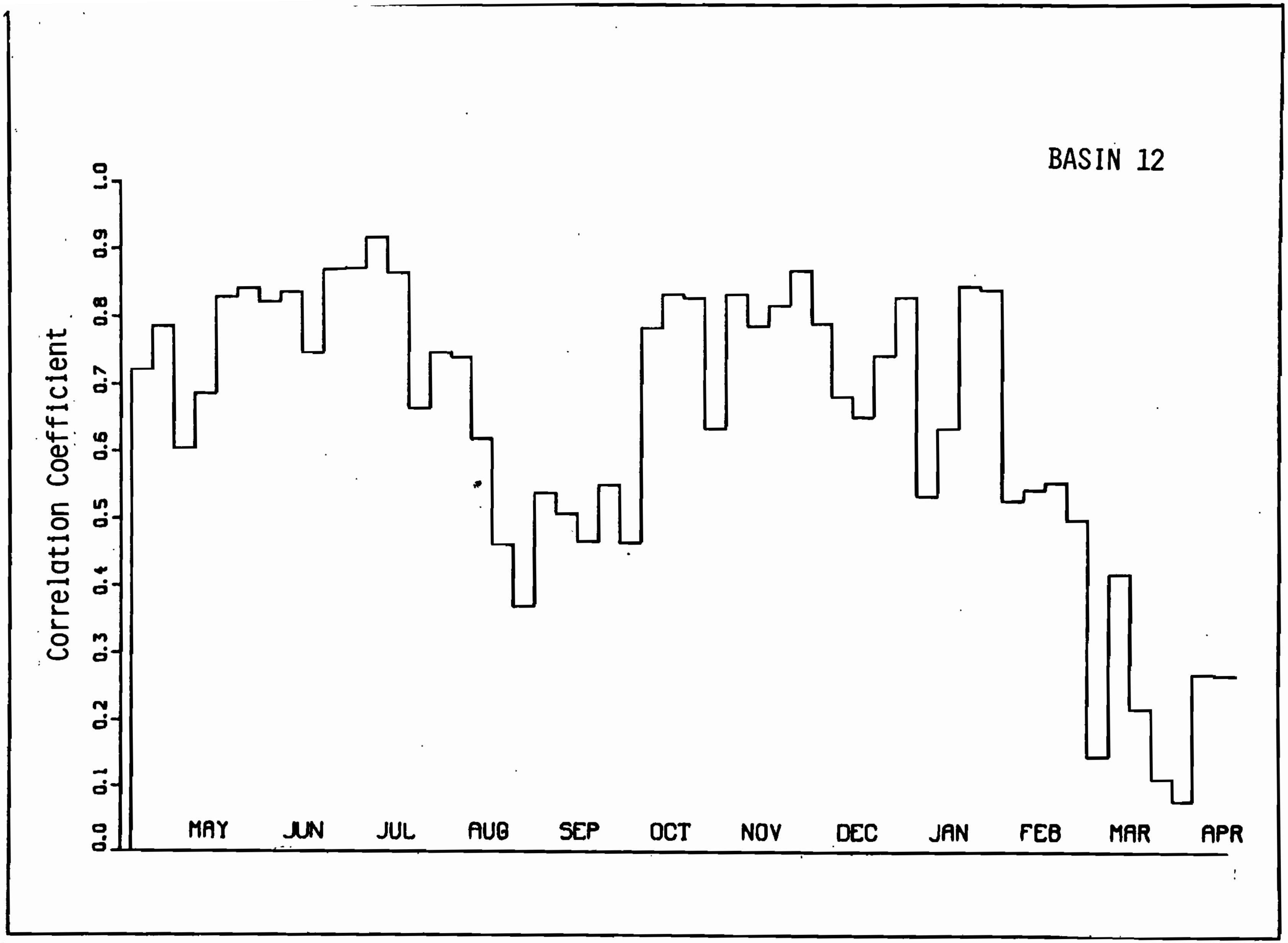

FIGURE 27.--*Weekly correlations between 7-d actual and model outflows at the Trent River at Glen Ross, Ont.*

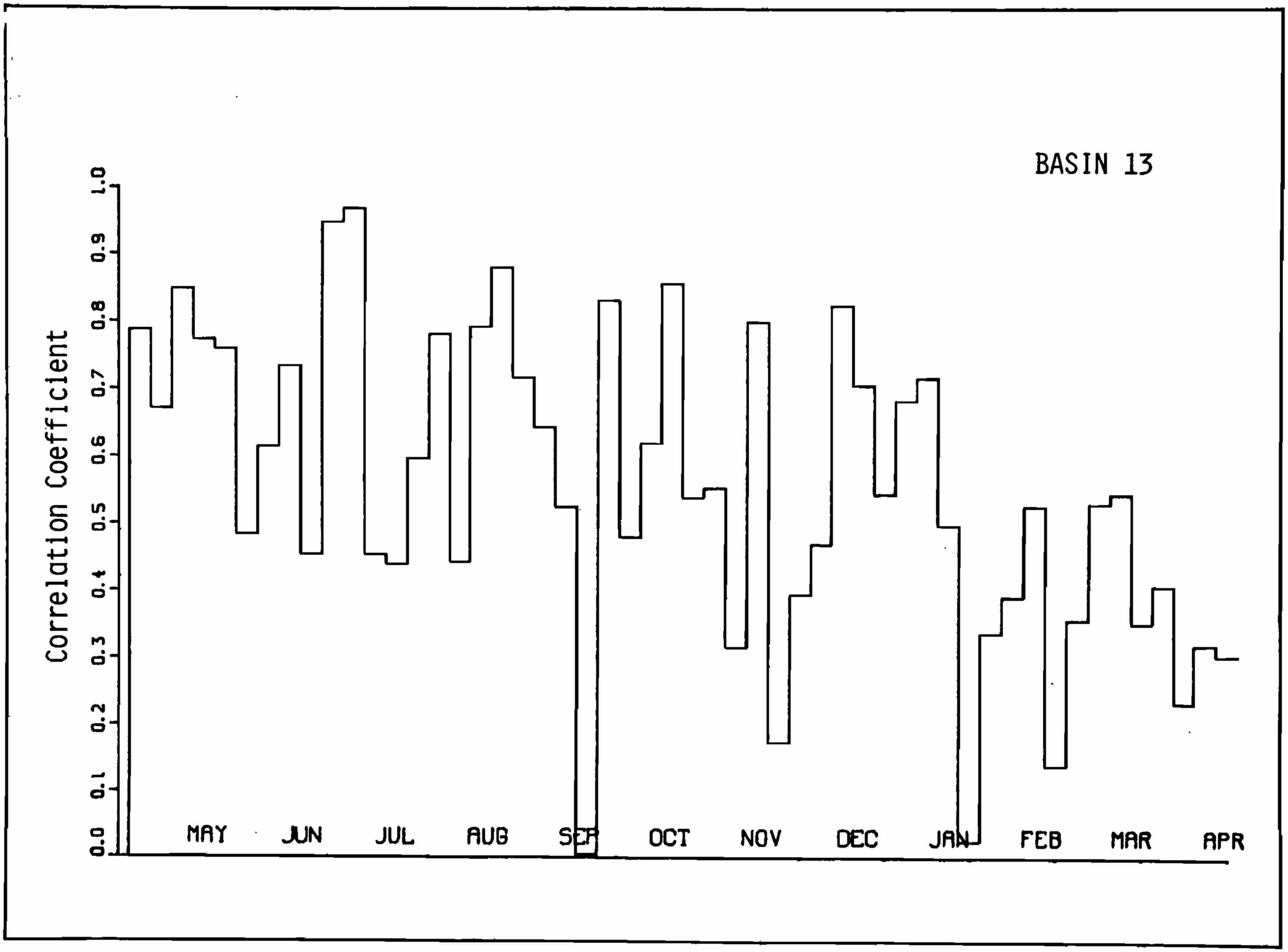

FIGURE 28.--*Weekly correlations between 7-d actual and model outflows for Oshawa Creek at Oshawa, Ont.*

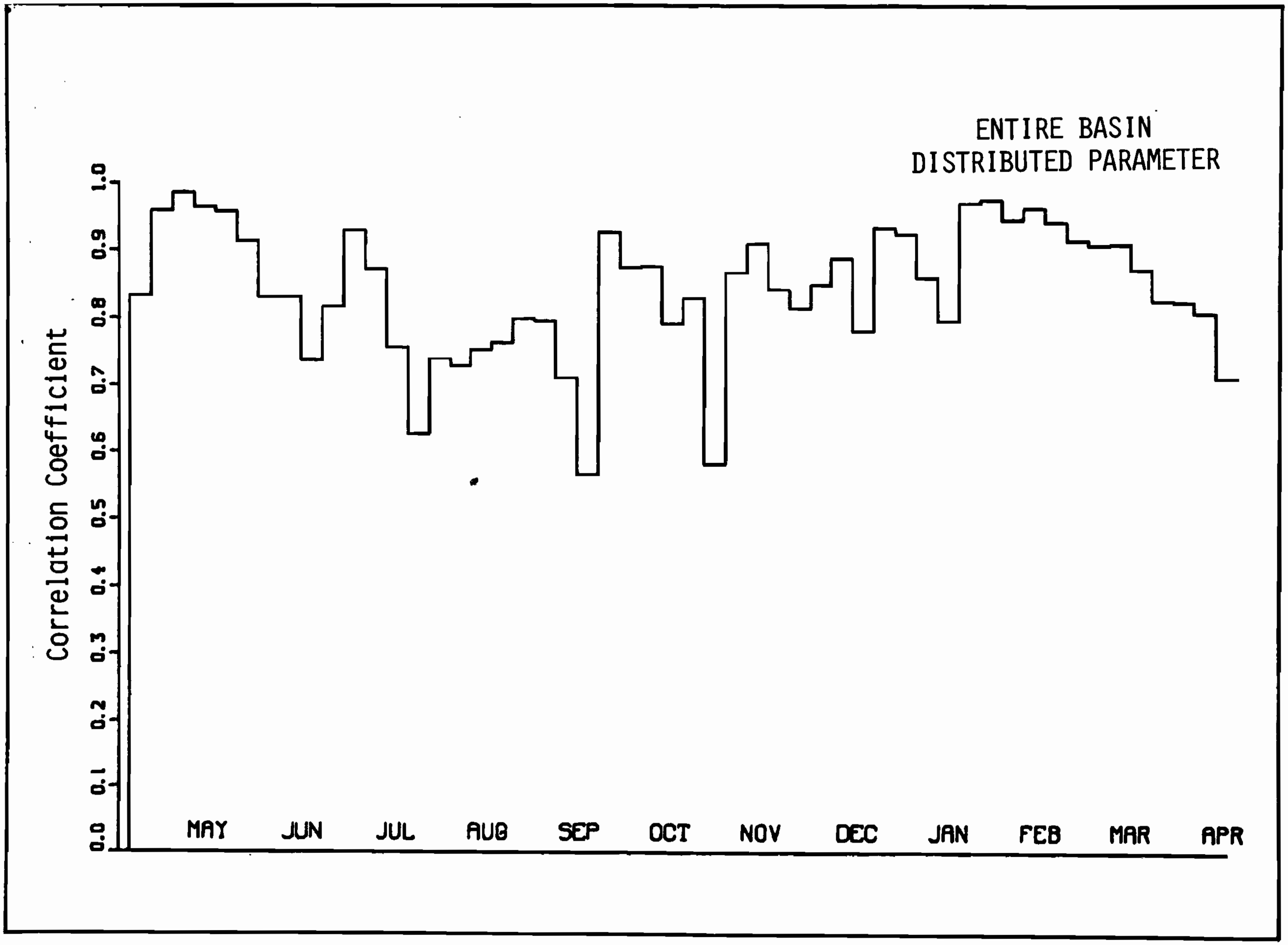

FIGURE 29.--*Weekly distributed parameter correlations between 7-d actual and model outflows for the Lake Ontario Basin above Kingston, Ont.*

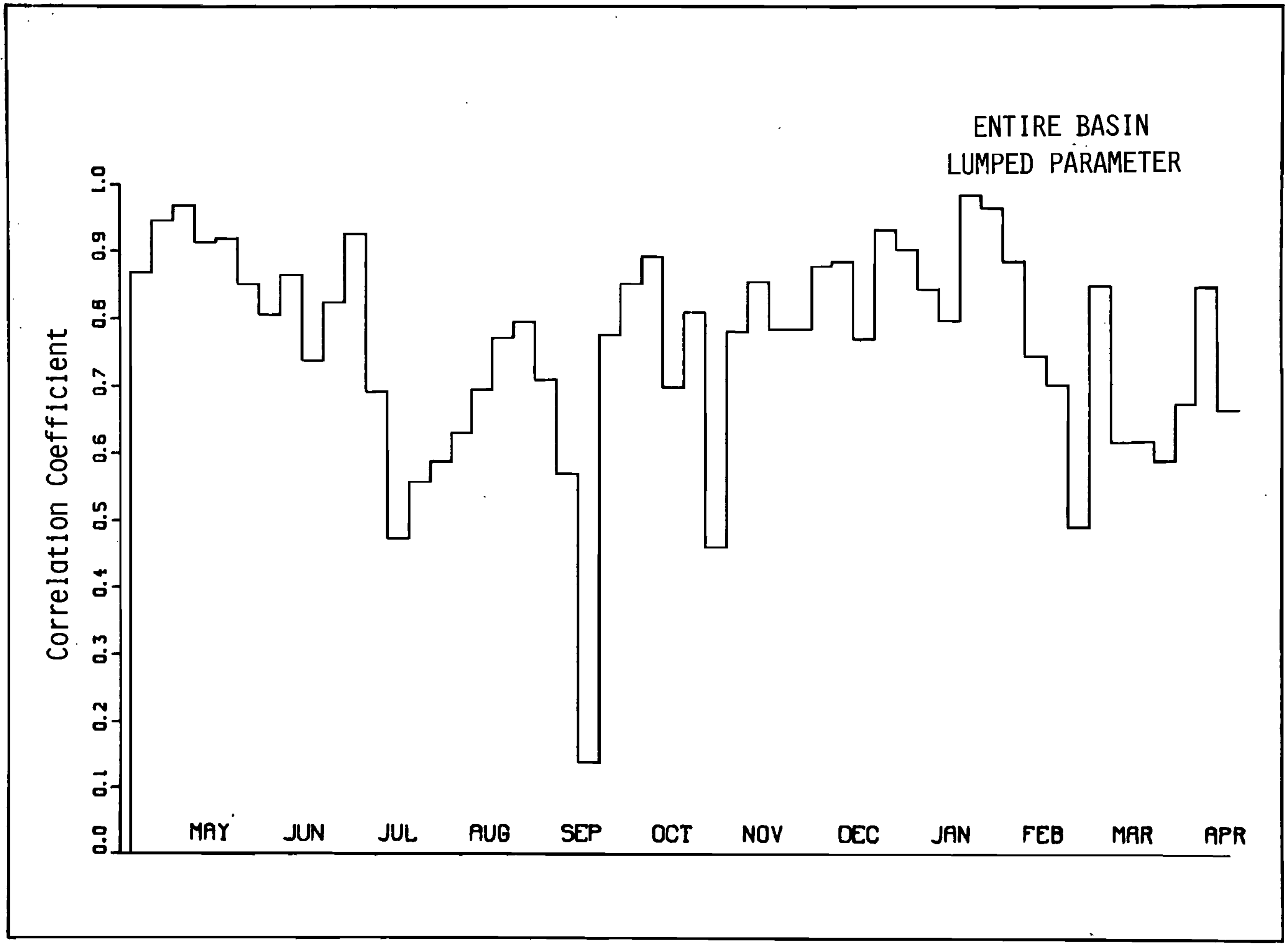

FIGURE 30.--*Weekly lumped parameter correlations between 7-d actual and model outflows for the Lake Ontario Basin above Kingston, Ont.*

Appendix E.--CALIBRATION PROGRAM (CALIB)

The FORTRAN program in this appendix is for model calibration; its use is illustrated in appendices F, G, and H. Lines 38, 49, 50, 51, and 52 are modified by the user for the intended application. Line 38 defines the average mid-month cloudless-day insolation (10 langleys/d) for January through December, respectively. Line 49 gives the watershed area (square meters); lines 50 and 51 define the beginning and end of the data set portion to be used in calibration (Q, to be contained within the input file). Line 51 gives the number of days to be used in the mass balance computation period. If evapotranspiration from the groundwater zone or evaporation from the surface is considered important, lines 43 and 44, respectively, may be changed.

```
      PROGRAM WASSERS(DATA,TAPE5=DATA,OUTPUT,TAPE6=OUTPUT,
     +SVRSLT,TAPE7=SVRSLT)
      IMPLICIT REAL (A-H,J-Z)
      COMMON/VAROF/USZM,LSZM,GZM,SS,EVAP,HPLSE,USZMAVG,LSZMAVG
      COMMON/PAROF/USZC,ALPPER,ALPUEV,ALPINT,ALPDPR,ALPLEV
      COMMON/PAROF2/ALPGW,ALPGEV,ALPSF,ALPSEV
      COMMON/INDICAT/FFF,NSS,SSS,EVAPS,DAY,EPSILON,DPSILON,GPSILON
      COMMON/VAROF2/VRUN,VINT,VPER,VGW,VUEV,VLEV
      DIMENSION R(14),INDPM(13)
      DIMENSION PARM(10),XRC(10)
      DIMENSION DATA(8,6405)
      DIMENSION IERR(6)
      DATA IERR/6*0/
      DATA INDPM/0,31,59,90,120,151,181,212,243,273,304,334,366/
C*****
C*****  PROGRAM FOR INTERACTIVE INVESTIGATION OF MODEL - MONTHLY
C*****
C*****
C  AREA    = WATERSHED AREA, SQ. M.
C  FLOW    = ACTUAL BASIN OUTFLOW VOLUME, CUB. M.
C  ID      = CALENDAR DAY OF THE YEAR
C  IM      = CALENDAR MONTH OF THE YEAR
C  INDPGOD= NUMBER OF DAYS PER GROUP OF DAYS, DAYS
C  INODAYS= NUMBER OF DAYS TO BE CONSIDERED IN DATA SET, DAYS
C  IY      = CALENDAR YEAR
C  PRECIP = DAILY PRECIPITATION VOLUME (LIQUID EQUIVALENT), CUB. M.
C  R       = AVERAGE MID-MONTH CLOUDLESS-DAY INSOLATION, LANGLEYS/DAY
C            (INPUT IN UNITS OF 10*LANGLEYS/DAY)
C  RR      = DAILY SURFACE INSOLATION, CAL.
C  SNW     = SNOWPACK VOLUME (LIQUID EQUIVALENT), CUB. M.
C  TA      = AVERAGE DAILY AIR TEMPERATURE, DEG. C.
C  TMAX    = MAXIMUM DAILY AIR TEMPERATURE, DEG. C.
C  TMIN    = MINIMUM DAILY AIR TEMPERATURE, DEG. C.
C*****
C*****
C*****  INPUT CONSTANTS
C*****
      DATA R/20.,31.,46.,60.,70.,74.,71.,61.,48.,34.,22.,18./
      CALL SYSTEMC(115,IERR)
      EPSILON=1.E-7
      DPSILON=1.E-200
      GPSILON=1.E-3
      ALPGEV=0.
      ALPSEV=0.
      R(14)=R(1)*10.
      DO 33 IXY=1,12
   33 R(14-IXY)=R(13-IXY)*10.
      R(1)=R(13)
      AREA    = 2906000000.
      ISTART = 1260
      INODAYS= 6405
      INDPGOD= 30
      DAY=FLOAT(INDPGOD)
      IIST=ISTART/INDPGOD
C*****
```

```
C*****  SYSTEMATIC PARAMETER SEARCH
C*****
      IFTFG=1
      IRTN=0
      IRPTFG=1
      IUPDN=1
      IRELCNG=1
      S=0.1E+99
      IOPTFG=-1
      USZC=AREA*0.02
      REWIND 7
      READ(7,558)IPARM
      DO 36 I=1,9
   36 READ(7,557) PARM(I),XRC(I)
      READ(7,560) IRELCNG
C*****
C*****        INPUT AND FILL IN DAILY DATA
C*****
      READ(5,1000)
      READ(5,1000)
      READ(5,1000)
      READ(5,1000)
      READ(5,1010) ID,IM,IY,TMIN,TMAX,PRECIP,FLOW
      BACKSPACE 5
      DO 600 I=1,INODAYS
      READ(5,1010) ID,IM,IY,NTMIN,NTMAX,NPRECIP,NFLOW
 1010 FORMAT(1X,I3,I3,I5,5X,2F10.2,2F20.0)
      IF(NTMIN.GT.NTMAX.OR.NTMIN.LT.-900..OR.NTMAX.LT.-900.) GOTO 920
      GOTO 921
  920 NTMIN=TMIN
      NTMAX=TMAX
  921 TMIN=NTMIN
      TMAX=NTMAX
      IF(NPRECIP.LT.-900.) NPRECIP=PRECIP
      IF(NFLOW.LT.-900.) NFLOW=FLOW
      PRECIP=NPRECIP
      FLOW=NFLOW
C*****
C*****        COMPUTE DAILY INSOLATION
C*****
      X=(TMAX-TMIN)/15.
      X=AMIN1(X,1.0)
      IF(ID.GT.15) GOTO 203
      IF(IM.EQ.1) GOTO 200
      II=INDPM(IM)-INDPM(IM-1)
      IF(II.NE.28) GOTO 201
      IF(INT((FLOAT(IY)+.5)/4.)*4.NE.IY) GOTO 201
      II=29
      GOTO 201
  200 II=31
  201 NDYS=FLOAT(II)
      NDY=NDYS-15.+FLOAT(ID)
      RR=(R(IM+1)-R(IM))/NDYS*NDY+R(IM)
      GOTO 204
  203 II=INDPM(IM+1)-INDPM(IM)
```

```
      IF(II.NE.28) GOTO 202
      IF(INT((FLOAT(IY)+.5)/4.)*4.NE.IY) GOTO 202
      II=29
  202 NDYS=FLOAT(II)
      NDY=FLOAT(ID)-15.
      RR=(R(IM+2)-R(IM+1))/NDYS*NDY+R(IM+1)
  204 RR=RR*(0.355+0.68*X)*10000.*AREA
      TA=(TMIN+TMAX)/2.
      DATA(2,I)=TA
      DATA(3,I)=FLOW
      DATA(5,I)=PRECIP
      DATA(6,I)=RR
  600 CONTINUE
      REWIND 5
C*****
C*****   GROUP FLOW BY THE NUMBER OF DAYS PER GROUP OF DAYS (INDPGOD)
C*****
      IKNTR=0
      AVGF=0.
      VAR=0.
      MEAN=0.
      FLOW=0.
      II=0
      III=0
      DO 610 I=1,INODAYS
      IF(I.LE.ISTART) GOTO 620
      AVGF = AVGF + DATA(3,I)
      IKNTR = IKNTR + 1
  620 CONTINUE
      FLOW = FLOW + DATA(3,I)
      II = II + 1
      IF(II.NE.INDPGOD) GOTO 610
        III = III + 1
        DATA(3,III) = FLOW
        IF(III.LE.IIST) GOTO 630
          VAR = VAR + FLOW**2
          MEAN = MEAN + FLOW
  630   FLOW = 0.
        II = 0
  610 CONTINUE
      FI = FLOAT(III-IIST)
      VAR = VAR/FI
      MEAN = MEAN/FI
      VAR = VAR - MEAN**2
      AVGF = AVGF/FLOAT(IKNTR)
C*****
C*****
C*****
      GOTO 21
   20 DO 40 I=1,9
      IF(PARM(I).GT.DPSILON) GOTO 41
      XRC(I)=XRC(I)/10.
      GOTO 40
   41 XRC(I)=10.**(1-IRELCNG+INT(ALOG10(PARM(I))))
      IF(PARM(I).LT.1) XRC(I)=XRC(I)/10.
```

```
   40 CONTINUE
   21 PARM(IPARM)=PARM(IPARM)+XRC(IPARM)*FLOAT(IUPDN)
      IF(IPARM.EQ.1)GOTO 800
      IF(PARM(IPARM).LT.-XRC(IPARM)/2.) GOTO 22
      IF(PARM(IPARM).LT. XRC(IPARM)/2.) PARM(IPARM)=0.
  800 CONTINUE
      TBASE  = PARM(1)
      ALBEDS = PARM(2)
      ALPPER = PARM(3)
      ALPUEV = PARM(4)
      ALPINT = PARM(5)
      ALPDPR = PARM(6)
      ALPLEV = PARM(7)
      ALPGW  = PARM(8)
      ALPSF  = PARM(9)
      IF(IRPTFG.EQ.0) GOTO 554
      IRPTFG=0
      IF(IPARM.LE.2) IRPTFG=1
C*****
C*****  FIND SUM OF SQUARED ERRORS
C*****
      IF(IPARM.NE.2.AND.IPARM.NE.3.AND.IFTFG.EQ.0)GOTO 310
      SNW=0.
      AVGRR=0.
      IFTFG = 0
C*****
C*****  DAILY LOOP - DATA PREPERATION (BEGINNING)
C*****
      DO 300 I=1,INODAYS
C*****
C*****       HEAT BALANCE
C*****
      TA = DATA(2,I)
      RR = DATA(6,I)
      PRECIP = DATA(5,I)
      X=1.
      IF(TA.LE.0.)GOTO 900
      MELT=0.
      IF(SNW.LT.1.)GOTO 901
      MELT=(RR*(1.-ALBEDS)+PRECIP*1000000.*TA)/79.7/1000000.
      IF(MELT.GT.SNW)MELT=SNW
      GOTO 904
  901 X=0.
  904 SNW=SNW-MELT
      NS=PRECIP+MELT
      GOTO 905
  900 IF(SNW.GT.1..OR.PRECIP.GT.1.)GOTO 903
      X=0.
  903 SNW=SNW+PRECIP
      NS=0.
  905 DATA(1,I)=NS
      DATA(7,I)=X
      IF(I.LE.ISTART)GOTO 300
      AVGRR=AVGRR+RR*(1.-X)
  300 CONTINUE
```

```
C*****
C*****  DAILY LOOP - DATA PREPARATION (END)
C*****
C*****
C*****  SUMMARY INFORMATION
C*****
  310 AVGHPLE=0.
      DO 910 I=1,INODAYS
      HPLSE=DATA(2,I)-TBASE
      IF(HPLSE.LT.0..OR.DATA(7,I).GT..5) HPLSE=0.
      DATA(4,I)=HPLSE
      IF(I.LE.ISTART)GOTO 910
      AVGHPLE=AVGHPLE+HPLSE
  910 CONTINUE
      CONS=AVGRR/AVGHPLE
      DO 911 I=1,INODAYS
      HPLSE=DATA(4,I)/(596.-.52*DATA(2,I))/1000000.*CONS
  911 DATA(4,I)=HPLSE
C*****
C*****  CONVERT TO GROUPS OF DAYS INPUTS
C*****
      NS=0.
      HPLSE=0.
      II=0
      III=0
      DO 400 I=1,INODAYS
      NS=NS+DATA(1,I)
      HPLSE=HPLSE+DATA(4,I)
      II=II+1
      IF(II.NE.INDPGOD)GOTO 400
      III=III+1
      DATA(8,III)=NS
      DATA(4,III)=HPLSE
      IF(III.LE.IIST)GOTO 710
  710 NS=0.
      HPLSE=0.
      II=0.
  400 CONTINUE
C*****
C*****  INPUT INITIAL VARIABLE VALUES
C*****
  554 USZM=.09E8
      LSZM=.43E8
      GZM=.27E9
      SS=.12E8
      SSS=.12E8
C*****
C*****  INITIALIZE
C*****
      AVGFM  = 0.
      VARM=0.
      PROD=0.
      VARM2=0.
      PROD2=0.
      AVGFM2 = 0.
```

```
      SSQERR = 0.
      SSQER2 = 0.
C*****
C*****  DAILY LOOP (BEGINNING)
C*****
      DO 100 I=1,III
C*****
C*****        INPUT DAILY PREPARED DATA
C*****
      NS     = DATA(8,I)
      HPLSE=DATA(4,I)
      FLOW   = DATA(3,I)
C*****
C*****        MASS BALANCE
C*****
      CALL OUTFLOW(NS)
C*****
      IF(I.LE.IIST)GOTO 100
      AVGFM=AVGFM+NS
      VARM=VARM+NS**2
      PROD=PROD+FLOW*NS
      VARM2=VARM2+NSS**2
      PROD2=PROD2+FLOW*NSS
      AVGFM2=AVGFM2+NSS
      SSQERR=SSQERR+(FLOW-NS)**2
      SSQER2=SSQER2+(FLOW-NSS)**2
  100 CONTINUE
C*****
C*****  DAILY LOOP (END)
C*****
C*****
C*****  SUMMARY INFORMATION
C*****
      FI = FLOAT(III - IIST)
      AVGFM=AVGFM/FI
      VARM=VARM/FI
      VARM=VARM-AVGFM**2
      PROD=PROD/FI
      EXVA=(PROD-MEAN*AVGFM)**2/VAR/VARM
      AVGFM2=AVGFM2/FI
      VARM2=VARM2/FI
      VARM2=VARM2-AVGFM2**2
      PROD2=PROD2/FI
      EXVA2=(PROD2-MEAN*AVGFM2)**2/VAR/VARM2
      SSQERR=SSQERR/FI
      SSQER2=SSQER2/FI
      EXVA=SQRT(EXVA)
      WRITE(6,556) TBASE,ALBEDS,ALPPER,ALPUEV,ALPINT,ALPDPR,
     +             ALPLEV,ALPGW,ALPSF,EXVA,SSQERR
  556 FORMAT(E6.2E1,8E7.2E1,2X,F3.2,E12.6E2)
  557 FORMAT(5E10.3E2,2E13.6E2)
      REWIND 7
      WRITE(7,558) IPARM
      DO 34 I=1,9
   34 WRITE(7,557) PARM(I),XRC(I)
```

```
      WRITE(7,560) IRELCNG
  560 FORMAT(I5)
      WRITE(7,559) S,EXVAS
      IF(SSQERR.GE.S) GOTO 22
      S=SSQERR
      EXVAS=EXVA
      IRTN=IRTN+1
      IOPTFG=IOPTFG+1
      GOTO 21
   22 PARM(IPARM)=PARM(IPARM)-XRC(IPARM)*FLOAT(IUPDN)
      REWIND 7
      WRITE(7,558) IPARM
      DO 35 I=1,9
   35 WRITE(7,557) PARM(I),XRC(I)
      WRITE(7,560) IRELCNG
      WRITE(7,559) S,EXVAS
      IF(IOPTFG.GT.0) GOTO 23
      IOPTFG=1
      IUPDN=-1
      GOTO 21
   23 IOPTFG=0
      IUPDN=1
      ICRC=0
      IF(IPARM.NE.1) GOTO 24
      IF(IRTN.NE.0) GOTO 25
      ICRC=1
      IRELCNG=IRELCNG+1
   25 IRTN=0
   24 IPARM=IPARM+1
      REWIND 7
      IPARMM=IPARM
      IF(IPARMM.GE.10) IPARMM=1
      WRITE(7,558) IPARMM
      DO 37 I=1,9
   37 WRITE(7,557) PARM(I),XRC(I)
      WRITE(7,560) IRELCNG
      WRITE(7,559) S,EXVAS
   28 IF(IPARM.LT.10)GOTO 26
      IPARM=1
      IRPTFG=1
   26 IF(PARM(IPARM).LT.1.E+98.AND.XRC(IPARM).GT.0) GOTO 27
      IPARM=IPARM+1
      GOTO 28
   27 IF(ICRC.EQ.1.AND.IRELCNG.LT.3) GOTO 20
      IF(IRELCNG.LT.3) GOTO 21
  559 FORMAT(6E13.6E2)
      REWIND 5
      REWIND 7
      WRITE(7,558)IPARM
      DO 42 I=1,9
   42 WRITE(7,557) PARM(I),XRC(I)
      WRITE(7,560) IRELCNG
      WRITE(7,559) S,EXVAS
      REWIND 7
      STOP
```

```
  558 FORMAT(I2)
 1000 FORMAT(3A10)
      END
      SUBROUTINE OUTFLOW (NS)
      IMPLICIT REAL (A-Z)
      COMMON/VAROF/USZM,LSZM,GZM,SS,EVAP,HPLSE,USZMAVG,LSZMAVG
      COMMON/PAROF/USZC,ALPPER,ALPUEV,ALPINT,ALPDPR,ALPLEV
      COMMON/PAROF2/ALPGW,ALPGEV,ALPSF,ALPSEV
      COMMON/INDICAT/III,NSS,SSS,EVAPS,DAY,EPSILON,DPSILON,GPSILON
      COMMON/VAROF2/VRUN,VINT,VPER,VGW,VUEV,VLEV
C*****
C  ALPDPR = LINEAR RESERVOIR CONSTANT FOR DEEP PERCOLATION, INV. DAYS
C  ALPGEV = PARTIAL CONSTANT OF GROUNDWATER EVAPORATION, INV. CUB. M.
C  ALPGW  = LINEAR RESERVOIR CONSTANT FOR GROUNDWATER FLOW, INV. DAYS
C  ALPINT = LINEAR RESERVOIR CONSTANT FOR INTERFLOW, INV. DAYS
C  ALPLEV = PARTIAL CONSTANT OF LOWER ZONE EVAPORATION, INV. CUB. M.
C  ALPPER = LINEAR RESERVOIR CONSTANT FOR PERCOLATION, INV. DAYS
C  ALPSEV = PARTIAL CONSTANT OF SURFACE EVAPORATION, INV. CUB. M.
C  ALPSF  = LINEAR RESERVOIR CONSTANT FOR SURFACE FLOW, INV. DAYS
C  ALPUEV = PARTIAL CONSTANT OF UPPER ZONE EVAP., INV. CUB. M.
C  DAY    = TIME IN ONE GROUP OF DAYS (WEEK, MONTH, ETC.), DAYS
C  EVAP   = TOTAL EVAPOTRANSPIRATION VOLUME, CUB. M.
C  EVPRP  = POTENTIAL EVAPOTRANSPIRATION RATE, CUB. M./DAY
C  GZM    = GROUNDWATER ZONE MOISTURE, CUB. M.
C  HPLSE  = TOTAL ENERGY OUT (EVAP. + POT. EVAP.) WATER EQU., CUB. M.
C  LSZM   = LOWER SOIL ZONE MOISTURE, CUB. M.
C  NS     = NET SUPPLY VOLUME, CUB. M.
C  NS     = BASIN OUTFLOW VOLUME, CUB. M.
C  NSR    = NET SUPPLY RATE, CUB. M./DAY
C  R      = DUMMY VARIABLE FOR STORAGE OF INTERMEDIATE RESULTS
C  SS     = SURFACE WATER STORAGE, CUB. M.
C  T      = DUMMY VARIABLE FOR STORAGE OF INTERMEDIATE RESULTS
C  USZC   = UPPER SOIL ZONE MOISTURE CAPACITY, CUB. M.
C  USZM   = UPPER SOIL ZONE MOISTURE, CUB. M.
C  VDPR   = DEEP PERCOLATION VOLUME, CUB. M.
C  VGEV   = GROUNDWATER ZONE EVAPOTRANSPIRATION VOLUME, CUB. M.
C  VGW    = GROUNDWATER ZONE OUTFLOW VOLUME, CUB. M.
C  VINF   = INFILTRATION VOLUME, CUB. M.
C  VINT   = INTERFLOW VOLUME, CUB. M.
C  VLEV   = LOWER ZONE EVAPOTRANSPIRATION VOLUME, CUB. M.
C  VPER   = PERCOLATION VOLUME, CUB. M.
C  VRUN   = SURFACE RUNOFF VOLUME, CUB. M.
C  VUEV   = UPPER ZONE EVAPOTRANSPIRATION VOLUME, CUB. M.
C*****
      NSR=NS/DAY
      EVPRP=HPLSE/2./DAY
      IF(EVPRP.LE.DPSILON)GOTO 903
  904 B=NSR/USZC+ALPPER+ALPUEV*EVPRP
      C=NSR/B
      A=USZM-C
      USZMAVG=A/B*(1.-EXP(-B*DAY))/DAY+C
      D=ALPINT+ALPDPR+ALPLEV*EVPRP
      IF(ABS((D-B)/D).LE.EPSILON.OR.ABS(D-B).LE.DPSILON)GOTO 905
      F=ALPPER*A/(D-B)
      G=ALPPER*C/D
```

```fortran
      E=LSZM-F-G
      LSZMAVG=(E/D*(1.-EXP(-D*DAY))+F/B*(1.-EXP(-B*DAY)))/DAY+G
      GOTO 906
  905 F=ALPPER*A
      G=ALPPER*C/D
      E=LSZM-G
      LSZMAVG=(E/D*(1.-EXP(-D*DAY))+F/D**2*(1.-(D*DAY+1.)
     +        *EXP(-D*DAY)))/DAY+G
  906 EVPRPO=EVPRP
      EVPRP=HPLSE/DAY/(1.+ALPUEV*USZMAVG+ALPLEV*LSZMAVG)
      IF(ABS((EVPRP-EVPRPO)/EVPRP).GT.GPSILON)GOTO 904
  903 B=NSR/USZC+ALPPER+ALPUEV*EVPRP
      C=ALPPER*NSR/B
      A=ALPPER*USZM-C
      T=EXP(-B*DAY)*A/ALPPER+NSR/B
      USZMAVG=(A/B*(1.-EXP(-B*DAY))/DAY+C)/ALPPER
      R=NS+USZM-T
      USZM=T
      VINF=NS-R*NSR/USZC/B
      VPER=R*ALPPER/B
      VRUN=NS-VINF
      VUEV=R-VRUN-VPER
      D=ALPINT+ALPDPR+ALPLEV*EVPRP
      IF(ABS((D-B)/D).LE.EPSILON.OR.ABS(D-B).LE.DPSILON)GOTO 100
      F=A/(D-B)
      G=C/D
      E=LSZM-F-G
      T=E*EXP(-D*DAY)+F*EXP(-B*DAY)+G
      LSZMAVG=(E/D*(1.-EXP(-D*DAY))+F/B*(1.-EXP(-B*DAY)))/DAY+G
      R=VPER+LSZM-T
      IF(ALPDPR.LT.DPSILON)GOTO 910
      E=ALPDPR*E
      F=ALPDPR*F
      G=ALPDPR*G
  910 LSZM=T
      VINT=R*ALPINT/D
      VDPR=R*ALPDPR/D
      VLEV=R-VINT-VDPR
      H=ALPGW+ALPGEV*EVPRP
      IF(ABS((H-D)/H).LE.EPSILON.OR.ABS(H-D).LE.DPSILON)GOTO 200
      IF(ABS((H-B)/H).LE.EPSILON.OR.ABS(H-B).LE.DPSILON)GOTO 250
      T=(GZM-E/(H-D)-F/(H-B)-G/H)*EXP(-H*DAY)
     + +E/(H-D)*EXP(-D*DAY)+F/(H-B)*EXP(-B*DAY)+G/H
      IF(ALPDPR.LT.DPSILON) T=GZM*EXP(-H*DAY)
      R=VDPR+GZM-T
      IF(ALPDPR.LT.DPSILON)GOTO 911
      L=ALPGW*(GZM-E/(H-D)-F/(H-B)-G/H)
      M=E*(ALPINT/ALPDPR+ALPGW/(H-D))
      N=A*NSR/USZC/ALPPER+F*(ALPINT/ALPDPR+ALPGW/(H-B))
      O=C*NSR/USZC/ALPPER+G*(ALPINT/ALPDPR+ALPGW/H)
      GOTO 912
  911 L=0.
      M=ALPINT*E
      N=ALPINT*F+A*NSR/USZC/ALPPER
      O=ALPINT*G+C*NSR/USZC/ALPPER
```

```
912 GZM=T
    VGW=R*ALPGW/H
    VGEV=R-VGW
    P=ALPSF+ALPSEV*EVPRP
    IF(ABS((P-H)/P).LE.EPSILON.OR.ABS(P-H).LE.DPSILON)GOTO 300
    IF(ABS((P-D)/P).LE.EPSILON.OR.ABS(P-D).LE.DPSILON)GOTO 400
    IF(ABS((P-B)/P).LE.EPSILON.OR.ABS(P-B).LE.DPSILON)GOTO 500
    T=(SS-L/(P-H)-M/(P-D)-N/(P-B)-O/P)*EXP(-P*DAY)
   + +L/(P-H)*EXP(-H*DAY)+M/(P-D)*EXP(-D*DAY)+N/(P-B)*EXP(-B*DAY)+O/P
    III=0.
600 R=VRUN+VINT+VGW+SS-T
    NS=R*ALPSF/P
    SS=T
    EVAP=VUEV+VLEV+VGEV+R-NS
    GOTO 1000
500 T=(SS-L/(P-H)-M/(P-D)+N*DAY-O/P)*EXP(-P*DAY)
   + +L/(P-H)*EXP(-H*DAY)+M/(P-D)*EXP(-D*DAY)+O/P
    III=1.
    GOTO 600
400 T=(SS-L/(P-H)+M*DAY-N/(P-B)-O/P)*EXP(-P*DAY)
   + +L/(P-H)*EXP(-H*DAY)+N/(P-B)*EXP(-B*DAY)+O/P
    III=2.
    GOTO 600
300 T=(SS+L*DAY-M/(P-D)-N/(P-B)-O/P)*EXP(-P*DAY)
   + +M/(P-D)*EXP(-D*DAY)+N/(P-B)*EXP(-B*DAY)+O/P
    III=4.
    GOTO 600
200 T=(GZM+E*DAY-F/(H-B)-G/H)*EXP(-H*DAY)
   + +F/(H-B)*EXP(-B*DAY)+G/H
    IF(ALPDPR.LT.DPSILON) T=GZM*EXP(-H*DAY)
    R=VDPR+GZM-T
    IF(ALPDPR.LT.DPSILON)GOTO 913
    L=ALPGW*(GZM-F/(H-B)-G/H)+ALPINT/ALPDPR*E
    M=ALPGW*E
    N=A*NSR/USZC/ALPPER+F*(ALPINT/ALPDPR+ALPGW/(H-B))
    O=C*NSR/USZC/ALPPER+G*(ALPINT/ALPDPR+ALPGW/H)
    GOTO 914
913 L=ALPINT*E
    M=0.
    N=ALPINT*F+A*NSR/USZC/ALPPER
    O=ALPINT*G+C*NSR/USZC/ALPPER
914 GZM=T
    VGW=R*ALPGW/H
    VGEV=R-VGW
    P=ALPSF+ALPSEV*EVPRP
    IF(ABS((P-H)/P).LE.EPSILON.OR.ABS(P-H).LE.DPSILON)GOTO 203
    IF(ABS((P-B)/P).LE.EPSILON.OR.ABS(P-B).LE.DPSILON)GOTO 204
    T=(SS-L/(P-H)+M/(P-H)**2-N/(P-B)-O/P)*EXP(-P*DAY)
   + +(L/(P-H)+M/(P-H)**2*((P-H)*DAY-1))*EXP(-H*DAY)
   + +N/(P-B)*EXP(-B*DAY)+O/P
    III=8.
    GOTO 600
204 T=(SS-L/(P-H)+M/(P-H)**2+N*DAY-O/P)*EXP(-P*DAY)
   + +(L/(P-H)+M/(P-H)**2*((P-H)*DAY-1))*EXP(-H*DAY)+O/P
    III=9.
```

```
      GOTO 600
  203 T=(SS+L*DAY+M/2*DAY**2-N/(P-B)-O/P)*EXP(-P*DAY)
     + +N/(P-B)*EXP(-B*DAY)+O/P
      III=14.
      GOTO 600
  100 T=(LSZM+A*DAY-C/D)*EXP(-D*DAY)+C/D
      F=A
      G=C/D
      E=LSZM-G
      LSZMAVG=(E/D*(1.-EXP(-D*DAY))+F/D**2*(1.-(D*DAY+1.)
     +        *EXP(-D*DAY)))/DAY+G
      R=VPER+LSZM-T
      IF(ALPDPR.LT.DPSILON)GOTO 920
      E=ALPDPR*E
      F=ALPDPR*F
      G=ALPDPR*G
  920 LSZM=T
      VINT=R*ALPINT/D
      VDPR=R*ALPDPR/D
      VLEV=R-VINT-VDPR
      H=ALPGW+ALPGEV*EVPRP
      IF(ABS((H-D)/H).LE.EPSILON.OR.ABS(H-D).LE.DPSILON)GOTO 120
      T=(GZM-E/(H-D)+F/(H-D)**2-G/H)*EXP(-H*DAY)
     + +(E/(H-D)+F/(H-D)**2*((H-D)*DAY-1))*EXP(-D*DAY)+G/H
      IF(ALPDPR.LT.DPSILON) T=GZM*EXP(-H*DAY)
      R=VDPR+GZM-T
      IF(ALPDPR.LT.DPSILON)GOTO 921
      L=ALPGW*(GZM+F/(H-D)**2-E/(H-D)-G/H)
      M=ALPGW*(E/(H-D)-F/(H-D)**2)+ALPINT/ALPDPR*E
      M=M+(NSR/USZC/ALPPER)*A
      N=F*(ALPGW/(H-D)+ALPINT/ALPDPR)
      O=C*NSR/USZC/ALPPER+G*(ALPINT/ALPDPR+ALPGW/H)
      GOTO 922
  921 L=0.
      M=ALPINT*E+A*NSR/USZC/ALPPER
      N=ALPINT*F
      O=ALPINT*G+C*NSR/USZC/ALPPER
  922 GZM=T
      VGW=R*ALPGW/H
      VGEV=R-VGW
      P=ALPSF+ALPSEV*EVPRP
      IF(ABS((P-H)/P).LE.EPSILON.OR.ABS(P-H).LE.DPSILON)GOTO 130
      IF(ABS((P-D)/P).LE.EPSILON.OR.ABS(P-D).LE.DPSILON)GOTO 140
      T=(SS-L/(P-H)-M/(P-D)+N/(P-D)**2-O/P)*EXP(-P*DAY)
     + +L/(P-H)*EXP(-H*DAY)+O/P
     + +(M/(P-D)+N/(P-D)**2*((P-D)*DAY-1))*EXP(-D*DAY)
      III=16.
      GOTO 600
  140 T=(SS-L/(P-H)+M*DAY+N/2*DAY**2-O/P)*EXP(-P*DAY)
     + +L/(P-H)*EXP(-H*DAY)+O/P
      III=19.
      GOTO 600
  130 T=(SS+L*DAY-M/(P-D)+N/(P-D)**2-O/P)*EXP(-P*DAY)
     + +(M/(P-D)+N/(P-D)**2*((P-D)*DAY-1))*EXP(-D*DAY)+O/P
      III=20.
```

```
      GOTO 600
  120 T=(GZM+E*DAY+F/2*DAY**2-G/H)*EXP(-H*DAY)+G/H
      IF(ALPDPR.LT.DPSILON) T=GZM*EXP(-H*DAY)
      R=VDPR+GZM-T
      IF(ALPDPR.LT.DPSILON)GOTO 923
      L=ALPGW*(GZM-G/H)+ALPINT/ALPDPR*E
      L=L+NSR/USZC/ALPPER*A
      M=ALPGW*E+ALPINT/ALPDPR*F
      N=ALPGW*F/2
      O=C*NSR/USZC/ALPPER+G*(ALPINT/ALPDPR+ALPGW/H)
      GOTO 924
  923 L=ALPINT*E+A*NSR/USZC/ALPPER
      M=ALPINT*F
      N=0.
      O=ALPINT*G+C*NSR/USZC/ALPPER
  924 GZM=T
      VGW=R*ALPGW/H
      VGEV=R-VGW
      P=ALPSF+ALPSEV*EVPRP
      IF(ABS((P-H)/P).LE.EPSILON.OR.ABS(P-H).LE.DPSILON)GOTO 123
      T=(SS-L/(P-H)+M/(P-H)**2-2*N/(P-H)**3-O/P)*EXP(-P*DAY)
     + +(L/(P-H)+M/(P-H)**2*((P-H)*DAY-1)+N/(P-H)*DAY**2
     + -2*N/(P-H)**3*((P-H)*DAY-1))*EXP(-H*DAY)+O/P
      III=56.
      GOTO 600
  123 T=(SS+L*DAY+M/2*DAY**2+N/3*DAY**3-O/P)*EXP(-P*DAY)+O/P
      III=63.
      GOTO 600
  250 T=(GZM-E/(H-D)+F*DAY-G/H)*EXP(-H*DAY)
     + +E/(H-D)*EXP(-D*DAY)+G/H
      IF(ALPDPR.LT.DPSILON) T=GZM*EXP(-H*DAY)
      R=VDPR+GZM-T
      IF(ALPDPR.LT.DPSILON)GOTO 915
      L=ALPGW*(GZM-E/(H-D)-G/H)+ALPINT/ALPDPR*F
      L=L+A*NSR/USZC/ALPPER
      M=E*(ALPINT/ALPDPR+ALPGW/(H-D))
      N=ALPGW*F
      O=C*NSR/USZC/ALPPER+G*(ALPINT/ALPDPR+ALPGW/H)
      GOTO 916
  915 L=ALPINT*F+A*NSR/USZC/ALPPER
      M=ALPINT*E
      N=0.
      O=ALPINT*G+C*NSR/USZC/ALPPER
  916 GZM=T
      VGW=R*ALPGW/H
      VGEV=R-VGW
      P=ALPSF+ALPSEV*EVPRP
      IF(ABS((P-H)/P).LE.EPSILON.OR.ABS(P-H).LE.DPSILON)GOTO 255
      IF(ABS((P-D)/P).LE.EPSILON.OR.ABS(P-D).LE.DPSILON)GOTO 254
      T=(SS-L/(P-H)-M/(P-D)+N/(P-H)**2-O/P)*EXP(-P*DAY)
     + +(L/(P-H)+N/(P-H)**2*((P-H)*DAY-1))*EXP(-H*DAY)
     + +M/(P-D)*EXP(-D*DAY)+O/P
      III=32.
      GOTO 600
  254 T=(SS-L/(P-H)+M*DAY+N/(P-H)**2-O/P)*EXP(-P*DAY)
```

```
     + +(L/(P-H)+N/(P-H)**2*((P-H)*DAY-1))*EXP(-H*DAY)+O/P
      III=34.
      GOTO 600
  255 T=(SS+L*DAY-M/(P-D)+N/2*DAY**2-O/P)*EXP(-P*DAY)
     + +M/(P-D)*EXP(-D*DAY)+O/P
      III=37.
      GOTO 600
 1000 IF(ABS((P-B)/P).GT.EPSILON.AND.ABS(P-B).GT.DPSILON)GOTO 1050
      R=(NSR/USZC/ALPPER)
      T=(SSS+R*A*DAY-R*C/P)*EXP(-P*DAY)+R*C/P
 1600 R=VRUN+SSS-T
      NSS=R*ALPSF/P+VINT+VGW
      SSS=T
      EVAPS=VUEV+VLEV+VGEV+R-R*ALPSF/P
      RETURN
 1050 R=(NSR/USZC/ALPPER)
      T=(SSS-R*A/(P-B)-R*C/P)*EXP(-P*DAY)
     + +R*A/(P-B)*EXP(-B*DAY)+R*C/P
      GO TO 1600
      END
```

Appendix F.--EXAMPLE INPUT FILES (SVRSLT AND DATA)

The program requires two input files, "SVRSLT" and "DATA." "SVRSLT" is given in appendix F. The first line indicates on which parameter the calibration is to begin. The following nine lines provide initial parameter values, each with an associated increment by which that parameter is increased or decreased during calibration. The parameters are listed in this order: T_b, a_s, α_{per}, β_{eu}, α_{int}, α_{dp}, β_{el}, α_{gw}, α_{sf}.

A partial listing of "DATA" is also given in appendix F; it contains the date, minimum daily temperature, maximum daily temperature, daily precipitation volume over the watershed, and daily basin outflow volume from the watershed, each in the units indicated in the file. The first four lines are header information skipped over by the program. Missing data are denoted by "-9999."

```
1
 .670E+01  .100E+00
 .870E+00  .100E-01
 .480E+00  .100E-01
 .240E-03  .100E-04
 .100E-01  .100E-02
 .570E-02  .100E-03
 .230E-07  .100E-08
 .160E-01  .100E-02
 .280E+00  .100E-01
   2
```

```
1 MIORA RIVER NEAR FOXBORO:  BASIN 12
 26-01-01  TO  79-12-31     :    19723 RECORDS
 (1X,I3,I3,I5,5X,2F10.2,2F20.0)
 DAY MONTH YEAR           TMIN(C)   TMAX(C)        PRECIP(M3/D)          FLOW(M3/D)
 19  4 1960          -3.90     10.00                  0.           24768000.
 20  4 1960           -.60     15.60                  0.           23904000.
 21  4 1960           2.20     21.10           20051170.           22848000.
 22  4 1960           3.30     17.20                  0.           21792000.
 23  4 1960           8.90     17.20           43589500.           20544000.
 24  4 1960           8.30     17.20           23538330.           20256000.
 25  4 1960           7.80     10.00            8136707.           20544000.
 26  4 1960           -.60     10.00            5811933.           19776000.
 27  4 1960           3.90     14.40                  0.           18528000.
 28  4 1960           -.60     12.80                  0.           17472000.
 29  4 1960            .60     16.70                  0.           16128000.
 30  4 1960           9.40     13.90           22957137.           14592000.
  1  5 1960           4.40      7.20                  0.           13248000.
  2  5 1960          -1.70     14.40                  0.           12000000.
  3  5 1960           3.30     21.10                  0.           10752000.
  4  5 1960           6.10     23.30                  0.            9571200.
  5  5 1960           8.30     22.80                  0.            8592000.
  6  5 1960           9.40     22.20                  0.            7718400.
  7  5 1960          12.80     21.10           11042673.            6902400.
  8  5 1960          12.20     21.10           39230550.            6336000.
  9  5 1960          10.60     18.90           16273413.            5980800.
 10  5 1960           2.20     12.20            5811933.            5980800.
 11  5 1960           7.20     11.10           44170693.            6086400.
 12  5 1960           2.80     15.00           28187877.            6662400.
 13  5 1960           8.30     13.30                  0.            7286400.
 14  5 1960           3.30     16.70            8136707.            7747200.
 15  5 1960           7.80     19.40                  0.            8044800.
 16  5 1960           8.30     24.40                  0.            8160000.
 17  5 1960           8.90     22.20            7264917.            7776000.
 18  5 1960          13.30     25.60                  0.            7344000.
 19  5 1960          11.70     24.40                  0.            6739200.
 20  5 1960          10.00     21.10                  0.            6172800.
 21  5 1960          10.00     23.90                  0.            5596800.
 22  5 1960          14.40     18.90           30222053.            5193600.
 23  5 1960          10.00     13.30                  0.            4972800.
 24  5 1960          10.00     15.60            2324773.            4809600.
 25  5 1960          11.70     16.70            2905967.            4617600.
 26  5 1960           8.30     23.90                  0.            4406400.
 27  5 1960          10.00     26.10                  0.            4185600.
 28  5 1960          12.20     23.90                  0.            3916800.
 29  5 1960          13.30     19.40            3777757.            3638400.
 30  5 1960           8.90     20.60            4358950.            3427200.
 31  5 1960          11.70     18.30                  0.            3264000.
  1  6 1960          13.90     23.90                  0.            3264000.
  2  6 1960           8.90     24.40            9589690.            3264000.
  3  6 1960          12.80     23.90                  0.            3206400.
  4  6 1960          10.00     25.60                  0.            3072000.
  5  6 1960          15.00     23.30            6683723.            2851200.
  6  6 1960           7.20     19.40                  0.            2668800.
  7  6 1960           5.60     21.10                  0.            2448000.
  8  6 1960           4.40     21.10                  0.            2236800.
```

9	6	1960	6.10	21.10	0.	2054400.
10	6	1960	5.00	22.80	0.	1891200.
11	6	1960	6.70	23.90	6683723.	1756800.
12	6	1960	12.80	25.00	0.	1641600.
13	6	1960	8.90	26.10	0.	1507200.
14	6	1960	13.30	19.40	50854417.	1440000.
15	6	1960	12.80	20.00	8136707.	1507200.
16	6	1960	11.70	25.60	1452983.	1526400.
17	6	1960	16.10	23.30	56085157.	1545600.
18	6	1960	9.40	20.60	0.	1641600.
19	6	1960	8.90	26.10	1452983.	1660800.
20	6	1960	9.40	23.30	0.	1660800.
21	6	1960	9.40	25.60	0.	1603200.
22	6	1960	8.30	23.30	0.	1507200.
23	6	1960	10.60	24.40	8717900.	1420800.
24	6	1960	16.10	23.90	51726207.	1468800.
25	6	1960	12.80	26.10	0.	1488000.
26	6	1960	13.30	27.20	0.	1459200.
27	6	1960	12.20	26.70	0.	1382400.
28	6	1960	12.80	28.30	0.	1334400.
29	6	1960	17.20	25.00	55503963.	1286400.
30	6	1960	11.70	24.40	0.	1238400.
1	7	1960	9.40	22.80	0.	1209600.
2	7	1960	9.40	23.90	0.	1113600.
3	7	1960	15.00	23.30	0.	1056000.
4	7	1960	8.90	21.10	0.	1008000.
5	7	1960	11.10	18.90	0.	960000.
6	7	1960	7.20	21.70	0.	902400.
7	7	1960	12.80	23.90	0.	842880.
8	7	1960	10.00	24.40	0.	774720.
9	7	1960	15.00	28.90	0.	734400.
10	7	1960	12.80	29.40	0.	693120.
11	7	1960	14.40	30.00	0.	693120.
12	7	1960	15.60	29.40	0.	633600.
13	7	1960	15.60	26.70	11042673.	595200.
14	7	1960	8.30	22.20	0.	595200.
15	7	1960	8.30	25.00	0.	541440.
16	7	1960	5.00	26.70	13367447.	508800.
17	7	1960	15.60	23.90	871790.	508800.
18	7	1960	15.00	26.10	24991313.	486720.
19	7	1960	15.60	25.00	0.	476160.
20	7	1960	11.70	22.80	0.	456960.
21	7	1960	10.00	23.90	2905967.	418560.
22	7	1960	15.00	28.90	22085347.	408000.
23	7	1960	17.20	27.80	0.	408000.
24	7	1960	11.10	25.60	0.	391680.
25	7	1960	10.60	27.20	0.	363840.
26	7	1960	12.80	28.90	17726397.	334080.
27	7	1960	17.80	27.20	0.	326400.
28	7	1960	13.30	28.30	0.	334080.
29	7	1960	14.40	30.00	0.	334080.
30	7	1960	16.10	26.70	95896900.	326400.
31	7	1960	12.20	23.30	0.	334080.
1	8	1960	8.90	25.00	0.	347520.
2	8	1960	15.00	23.30	1452983.	347520.

3	8	1960	17.80	26.70	0.	342720.
4	8	1960	16.10	23.90	0.	310080.
5	8	1960	13.30	26.10	0.	288000.
6	8	1960	13.30	27.20	0.	266880.
7	8	1960	13.30	27.20	18598187.	239040.
8	8	1960	15.60	22.80	4358950.	258240.
9	8	1960	7.80	22.20	7264917.	280320.
10	8	1960	13.30	24.40	0.	301440.
11	8	1960	8.90	26.70	0.	288000.
12	8	1960	12.20	27.20	0.	293760.
13	8	1960	13.30	27.20	0.	310080.
14	8	1960	16.10	28.30	40683533.	326400.
15	8	1960	11.70	21.70	0.	391680.
16	8	1960	7.80	25.60	0.	399360.
17	8	1960	11.70	27.20	0.	391680.
18	8	1960	10.60	30.00	0.	372480.
19	8	1960	12.80	29.40	12495657.	347520.
20	8	1960	17.80	20.00	16854607.	356160.
21	8	1960	16.10	27.20	1452983.	342720.
22	8	1960	17.20	25.00	8136707.	334080.
23	8	1960	16.70	22.20	0.	317760.
24	8	1960	6.70	21.70	0.	274560.
25	8	1960	6.10	22.80	0.	244800.
26	8	1960	6.70	26.70	0.	212160.
27	8	1960	17.20	28.30	0.	182400.
28	8	1960	11.10	27.80	0.	154560.
29	8	1960	14.40	30.60	54632173.	166080.
30	8	1960	11.70	26.70	0.	219840.
31	8	1960	10.00	27.20	0.	212160.
1	9	1960	17.20	28.90	0.	182400.
2	9	1960	10.00	19.40	0.	160320.
3	9	1960	5.00	21.10	21504153.	134400.
4	9	1960	13.30	21.10	0.	129600.
5	9	1960	8.30	22.20	0.	120960.
6	9	1960	6.10	23.90	0.	125760.
7	9	1960	12.20	30.60	0.	129600.
8	9	1960	16.10	31.10	0.	111360.
9	9	1960	18.30	27.20	10461480.	111360.
10	9	1960	10.00	20.00	0.	98880.
11	9	1960	7.80	19.40	0.	91200.
12	9	1960	8.30	17.20	0.	91200.
13	9	1960	7.80	18.30	2324773.	78720.
14	9	1960	2.80	18.90	0.	51840.
15	9	1960	10.60	12.20	0.	51840.
16	9	1960	.60	18.90	0.	57600.
17	9	1960	5.00	22.80	3777757.	60480.
18	9	1960	12.80	19.40	0.	57600.
19	9	1960	6.70	17.20	0.	48960.
20	9	1960	12.20	21.70	0.	54720.
21	9	1960	13.90	21.70	0.	51840.
22	9	1960	7.80	23.30	0.	54720.
23	9	1960	15.00	24.40	0.	51840.
24	9	1960	15.00	24.40	0.	54720.
25	9	1960	15.00	23.30	0.	51840.
26	9	1960	13.90	19.40	8136707.	46080.

27	9	1960	15.60	21.10	0.	51840.
28	9	1960	11.10	22.80	0.	54720.
29	9	1960	6.70	22.80	1452983.	54720.
30	9	1960	11.10	20.00	2905967.	54720.
1	10	1960	-.60	12.20	0.	48960.
2	10	1960	.60	11.70	35452793.	54720.
3	10	1960	5.60	15.60	0.	48960.
4	10	1960	1.70	14.40	0.	48960.
5	10	1960	.60	17.80	13948640.	48960.
6	10	1960	10.00	16.70	0.	54720.
7	10	1960	2.20	15.60	0.	60480.
8	10	1960	3.90	19.40	0.	64320.
9	10	1960	2.80	21.70	0.	54720.
10	10	1960	3.90	18.90	0.	48960.
11	10	1960	8.90	18.30	0.	64320.
12	10	1960	2.20	17.20	0.	82560.
13	10	1960	2.20	15.00	0.	78720.
14	10	1960	7.20	22.20	0.	74880.
15	10	1960	11.70	22.20	2324773.	86400.
16	10	1960	12.20	18.30	0.	82560.
17	10	1960	6.10	18.90	0.	86400.
18	10	1960	2.20	13.30	0.	111360.
19	10	1960	.60	11.10	13948640.	91200.
20	10	1960	2.20	5.60	0.	91200.
21	10	1960	-2.80	8.30	0.	91200.
22	10	1960	2.80	12.20	39811743.	71040.
23	10	1960	6.70	12.20	20632363.	74880.
24	10	1960	.60	4.40	4358950.	78720.
25	10	1960	1.70	10.60	0.	98880.
26	10	1960	-2.80	10.60	0.	98880.
27	10	1960	-1.70	16.10	0.	111360.
28	10	1960	2.20	15.00	0.	98880.
29	10	1960	3.30	16.10	0.	95040.
30	10	1960	2.80	16.70	0.	82560.
31	10	1960	3.90	11.10	42717710.	82560.
1	11	1960	9.40	12.80	9589690.	120960.
2	11	1960	5.60	9.40	0.	116160.
3	11	1960	4.40	8.30	5230740.	129600.
4	11	1960	1.10	10.00	0.	129600.
5	11	1960	0.00	5.60	0.	116160.
6	11	1960	-2.20	1.10	0.	102720.
7	11	1960	-6.70	2.20	0.	98880.
8	11	1960	-5.00	7.20	20632363.	102720.
9	11	1960	4.40	7.20	36033987.	120960.
10	11	1960	5.00	5.60	1452983.	138240.
11	11	1960	-3.90	2.20	0.	149760.
12	11	1960	-2.80	8.90	0.	160320.
13	11	1960	1.70	9.40	0.	144000.
14	11	1960	-3.90	12.20	8717900.	134400.
15	11	1960	6.10	13.30	76717520.	144000.
16	11	1960	10.00	15.00	7264917.	182400.
17	11	1960	3.90	7.20	0.	206400.
18	11	1960	-1.70	7.20	0.	212160.
19	11	1960	-2.80	8.90	0.	190080.
20	11	1960	.60	10.60	0.	170880.

21 11 1960	-.60	10.00	0.	176640.
22 11 1960	-1.10	12.20	6683723.	166080.
23 11 1960	1.70	7.20	0.	176640.
24 11 1960	-2.80	7.80	0.	170880.
25 11 1960	.60	10.00	0.	160320.
26 11 1960	-1.10	12.80	0.	154560.
27 11 1960	6.10	10.60	1452983.	154560.
28 11 1960	-.60	11.10	31093843.	166080.
29 11 1960	-2.80	10.00	8717900.	166080.
30 11 1960	-3.90	1.10	5230740.	190080.
1 12 1960	-7.80	-2.20	0.	195840.
2 12 1960	-8.30	2.20	0.	190080.
3 12 1960	-6.10	5.00	0.	195840.
4 12 1960	-1.70	5.60	0.	190080.
5 12 1960	.60	11.10	0.	201600.
6 12 1960	5.60	10.00	5811933.	206400.
7 12 1960	-.60	1.70	871790.	225600.
8 12 1960	-8.30	-7.80	7264917.	225600.
9 12 1960	-17.80	-1.70	5230740.	206400.
10 12 1960	-7.20	-7.20	0.	212160.
11 12 1960	-22.20	-11.70	0.	190080.
12 12 1960	-17.80	-14.40	0.	176640.
13 12 1960	-20.60	-6.70	871790.	166080.
14 12 1960	-12.80	-1.10	3777757.	176640.
15 12 1960	-4.40	2.80	11914463.	182400.
16 12 1960	-.60	2.20	3777757.	195840.
17 12 1960	-8.90	-2.20	2324773.	201600.
18 12 1960	-9.40	-.60	29640860.	201600.
19 12 1960	-7.20	-1.70	0.	206400.
20 12 1960	-17.80	-3.90	22085347.	195840.
21 12 1960	-7.80	-6.10	14820430.	206400.
22 12 1960	-24.40	-7.20	7264917.	195840.
23 12 1960	-15.60	-10.00	0.	212160.
24 12 1960	-23.30	-6.10	2324773.	201600.
25 12 1960	-12.80	1.70	0.	201600.
26 12 1960	-6.10	1.70	18598187.	212160.
27 12 1960	-23.30	-13.30	0.	206400.
28 12 1960	-26.70	-5.00	0.	190080.
29 12 1960	-12.80	-1.70	2324773.	190080.
30 12 1960	-5.00	0.00	3777757.	195840.
31 12 1960	-2.20	-.60	11042673.	201600.

Appendix G.--EXAMPLE CALIBRATION SESSION

The program requires operator intervention to control the behavior of parameter values and to update increment factors; a condensed example of a typical calibration session is given in this appendix. Terminal output documents the systematic search of the parameter space for each parameter selected in rotation. Each line contains the nine parameter values used for a single iteration, followed by the calculated correlation coefficient and sum-of-squared errors between actual outflow volumes and model outflow volumes. For the sake of brevity, only landmark iterations are included in the example: the first iteration of each program run, the first iteration for parameter one (T_b) following one round of iterations for all the other parameters, and the iteration on which a program run is terminated (by the operator or the program itself).

```
 82/09/14. 12.33.23.
PROGRAM   WASSERS

.68E+1 .87E+0 .48E+0 .24E-3 .10E-1 .57E-2 .23E-7 .16E-1 .28E+0  .91 .170366E+16
                 .                           .                              .
                 .                           .                              .

.67E+1 .87E+0 .49E+0 .40E-3 .10E-1 .65E-2 .16E-7 .17E-1 .35E+0  .91 .169087E+16
                 .                           .                              .
                 .                           .                              .

.62E+1 .87E+0 .51E+0 .40E-3 .11E-1 .68E-2 .11E-7 .16E-1 .40E+0  .91 .168182E+16
                 .                           .                              .
                 .                           .                              .

.59E+1 .87E+0 .54E+0 .47E-3 .11E-1 .65E-2 .90E-8 .17E-1 .50E+0  .91 .167171E+16
                 .                           .                              .
                 .                           .                              .

.59E+1 .87E+0 .58E+0 .47E-3 .11E-1 .65E-2 .90E-8 .17E-1 .50E+0  .91 .166980E+16

PROGRAM STOPPED. INCREMENT FACTOR FOR PARAMETER 7 DECREASED BY ORDER OF MAGNITUDE
IN  SVRSLT. PROGRAM RESTARTED.

.59E+1 .87E+0 .57E+0 .54E-3 .11E-1 .62E-2 .90E-8 .18E-1 .55E+0  .91 .166768E+16
                 .                           .                              .
                 .                           .                              .

.60E+1 .87E+0 .59E+0 .55E-3 .11E-1 .64E-2 .84E-8 .19E-1 .76E+0  .91 .166450E+16
                 .                           .                              .
                 .                           .                              .

.60E+1 .87E+0 .61E+0 .56E-3 .11E-1 .64E-2 .81E-8 .19E-1 .94E+0  .91 .166231E+16
                 .                           .                              .
                 .                           .                              .

.59E+1 .87E+0 .63E+0 .57E-3 .11E-1 .64E-2 .81E-8 .20E-1 .10E+1  .91 .166105E+16

PROGRAM STOPPED. INCREMENT FACTOR FOR PARAMETER 9 INCREASED BY ORDER OF MAGNITUDE
IN  SVRSLT. PROGRAM RESTARTED.

.59E+1 .87E+0 .63E+0 .57E-3 .11E-1 .64E-2 .81E-8 .20E-1 .11E+1  .91 .166073E+16
                 .                           .                              .
                 .                           .                              .

.60E+1 .87E+0 .65E+0 .57E-3 .11E-1 .64E-2 .79E-8 .20E-1 .17E+1  .91 .165922E+16
                 .                           .                              .
                 .                           .                              .

.61E+1 .87E+0 .66E+0 .63E-3 .11E-1 .64E-2 .77E-8 .20E-1 .22E+1  .91 .165877E+16
                 .                           .                              .
                 .                           .                              .

.61E+1 .87E+0 .67E+0 .63E-3 .11E-1 .64E-2 .76E-8 .21E-1 .31E+1  .91 .165820E+16
                 .                           .                              .
```

```
                 .                           .                           .

.61E+1 .87E+0 .68E+0 .63E-3 .11E-1 .64E-2 .74E-8 .21E-1 .52E+1   .91 .165761E+16
                 .                           .                           .
                 .                           .                           .

.60E+1 .87E+0 .69E+0 .63E-3 .11E-1 .64E-2 .73E-8 .21E-1 .10E+2   .91 .165695E+16

PROGRAM STOPPED. INCREMENT FACTOR FOR PARAMETER 9 INCREASED BY TWO ORDERS OF MAGNITUDE
IN  SVRSLT. PROGRAM RESTARTED.

.60E+1 .87E+0 .70E+0 .63E-3 .11E-1 .65E-2 .73E-8 .21E-1 .10E+2   .91 .165688E+16
                 .                           .                           .
                 .                           .                           .

.60E+1 .87E+0 .70E+0 .63E-3 .11E-1 .64E-2 .72E-8 .21E-1 .10E+3   .91 .165663E+16

PROGRAM STOPPED. INCREMENT FACTOR FOR PARAMETER 9 INCREASED BY ORDER OF MAGNITUDE
IN  SVRSLT. PROGRAM RESTARTED.

.60E+1 .87E+0 .70E+0 .63E-3 .11E-1 .64E-2 .72E-8 .21E-1 .20E+3   .91 .165662E+16
                 .                           .                           .
                 .                           .                           .

.60E+1 .87E+0 .70E+0 .63E-3 .11E-1 .64E-2 .72E-8 .21E-1 .10E+4   .91 .165662E+16

PROGRAM STOPPED. PARAMETER 9 AND INCREMENT FACTOR SET TO COMPUTER EQUIVALENT OF
INFINITY. PROGRAM RESTARTED.

.60E+1 .87E+0 .70E+0 .63E-3 .11E-1 .64E-2 .72E-8 .21E-1*******   .91 .165662E+16
                 .                           .                           .
                 .                           .                           .

.61E+1 .87E+0 .70E+0 .63E-3 .11E-1 .65E-2 .72E-8 .22E-1*******   .91 .165692E+16
                 .                           .                           .
                 .                           .                           .

.61E+1 .87E+0 .71E+0 .63E-3 .11E-1 .64E-2 .71E-8 .22E-1*******   .91 .165678E+16
                 .                           .                           .
                 .                           .                           .

.60E+1 .87E+0 .71E+0 .63E-3 .11E-1 .64E-2 .71E-8 .21E-1*******   .91 .165661E+16
.61E+1 .87E+0 .71E+0 .63E-3 .11E-1 .64E-2 .71E-8 .22E-1*******   .91 .165678E+16
.59E+1 .87E+0 .71E+0 .63E-3 .11E-1 .64E-2 .71E-8 .22E-1*******   .91 .165672E+16
PROGRAM TERMINATES.
```

Appendix H.--EXAMPLE CALIBRATION OUTPUT

The final "SVRSLT" file resulting from the described application is given in this appendix. The first line indicates on which parameter any further calibration will begin. The nine subsequent lines contain optimum parameter values, each with its current increment size. Line 11 indicates the present limit on the number of digits used in convergence. The last line contains the minimum sum-of-squared errors and the associated correlation coefficient.

Output from Calibration Program: WASSERS

```
 2
  .600E+01  .100E+00
  .870E+00  .100E-01
  .710E+00  .100E-01
  .630E-03  .100E-04
  .110E-01  .100E-02
  .640E-02  .100E-03
  .710E-08  .100E-09
  .220E-01  .100E-02
  .100E+99  .100E+98
    3
  .165654E+16  .909473E+00
```

Corresponding Input to Simulation Program: WATER

```
  .600E+01
  .870E+00
  .710E+00
  .630E-03
  .110E-01
  .640E-02
  .710E-08
  .220E-01
  .100E+99
```

Appendix I.--MODEL APPLICATION PROGRAM (WATER)

The FORTRAN program in this appendix is for basin outflow simulation; its use is illustrated here and in appendices H and J. Lines 38, 49, 50, 51, and 52 are modified by the user for the intended application. Line 38 defines the average mid-month cloudless-day insolation (10 langleys/day) for January through December, respectively. Line 49 gives the watershed area (square meters); lines 50 and 51 define the beginning and end of the data set portion to be used in calibration (Ω, to be contained within the input file). Line 51 gives the number of days to be used in the mass balance computation period. If evapotranspiration from the groundwater zone or evaporation from the surface is considered important, lines 43 and 44, respectively, may be changed. Subroutine OUTFLOW is identical to that in the calibration program (appendix E), and is omitted here for brevity.

The program requires two input files, "PARAM" and "DATA." "PARAM" is simply a nine-line file containing the optimum parameter set produced by calibration, and is shown in appendix H. A partial listing of "DATA" is given in appendix F; it contains the data, minimum daily temperature, maximum daily temperature, daily precipitation volume over the watershed, and daily basin outflow volume from the watershed, each in the units indicated in the file. The first four lines are header information skipped over by the program. Missing data are denoted by "-9999."

```
      PROGRAM WATER(DATA,TAPE5=DATA,OUTPUT,TAPE6=OUTPUT,
                      PARAM,TAPE4=PARAM,RESULT,TAPE7=RESULT)
      IMPLICIT REAL (A-H,J-Z)
      COMMON/VAROF/USZM,LSZM,GZM,SS,EVAP,HPLSE,USZMAVG,LSZMAVG
      COMMON/PAROF/USZC,ALPPER,ALPUEV,ALPINT,ALPDPR,ALPLEV
      COMMON/PAROF2/ALPGW,ALPGEV,ALPSF,ALPSEV
      COMMON/INDICAT/FFF,NSS,SSS,EVAPS,DAY,EPSILON,DPSILON,GPSILON
      COMMON/VAROF2/VRUN,VINT,VPER,VGW,VUEV,VLEV
      DIMENSION R(14),INDPM(13)
      DIMENSION PARM(10),DATA(4,6405)
      DIMENSION IERR(6)
      DATA IERR/6*0/
      DATA INDPM/0,31,59,90,120,151,181,212,243,273,304,334,366/
C*****
C*****  PROGRAM FOR INTERACTIVE INVESTIGATION OF MODEL - MONTHLY
C*****
C*****
C  AREA   = WATERSHED AREA, SQ. M.
C  FLOW   = ACTUAL BASIN OUTFLOW VOLUME, CUB. M.
C  ID     = CALENDAR DAY OF THE YEAR
C  IM     = CALENDAR MONTH OF THE YEAR
C  INDPGOD= NUMBER OF DAYS PER GROUP OF DAYS, DAYS
C  INODAYS= NUMBER OF DAYS TO BE CONSIDERED IN DATA SET, DAYS
C  IY     = CALENDAR YEAR
C  PRECIP = DAILY PRECIPITATION VOLUME (LIQUID EQUIVALENT), CUB. M.
C  R      = AVERAGE MID-MONTH CLOUDLESS-DAY INSOLATION, LANGLEYS/DAY
C            (INPUT IN UNITS OF 10*LANGLEYS/DAY)
C  RR     = DAILY SURFACE INSOLATION, CAL.
C  SNW    = SNOWPACK VOLUME (LIQUID EQUIVALENT), CUB. M.
C  TA     = AVERAGE DAILY AIR TEMPERATURE, DEG. C.
C  TMAX   = MAXIMUM DAILY AIR TEMPERATURE, DEG. C.
C  TMIN   = MINIMUM DAILY AIR TEMPERATURE, DEG. C.
C*****
C*****
C*****  INPUT CONSTANTS
C*****
      DATA R/20.,31.,46.,60.,70.,74.,71.,61.,48.,34.,22.,18./
      CALL SYSTEMC(115,IERR)
      EPSILON=1.E-7
      DPSILON=1.E-200
      GPSILON=1.E-3
      ALPGEV=0.
      ALPSEV=0.
      R(14)=R(1)*10.
      DO 33 IXY=1,12
   33 R(14-IXY)=R(13-IXY)*10.
      R(1)=R(13)
      AREA    = 2906000000.
      ISTART  = 1260
      INODAYS= 6405
      INDPGOD= 30
      DAY=FLOAT(INDPGOD)
      IIST=ISTART/INDPGOD
      USZC    = AREA*0.02
      REWIND 4
```

```
      DO 36 I=1,9
   36 READ(4,559) PARM(I)
      REWIND 4
      TBASE  = PARM(1)
      ALBEDS = PARM(2)
      ALPPER = PARM(3)
      ALPUEV = PARM(4)
      ALPINT = PARM(5)
      ALPDPR = PARM(6)
      ALPLEV = PARM(7)
      ALPGW  = PARM(8)
      ALPSF  = PARM(9)
      REWIND 5
      SNW=0.
      IKNTR=0
      TIME   = 0.
      AVGTA  = 0.
      AVGPR  = 0.
      AVGF   = 0.
      AVGHPLE= 0.
      AVGNS  = 0.
      AVGRR  = 0.
      READ(5,1000)
      READ(5,1000)
      READ(5,1000)
      READ(5,1000)
 1000 FORMAT(3A10)
      READ(5,1010) ID,IM,IY,TMIN,TMAX,PRECIP,FLOW
      BACKSPACE 5
C*****
C*****  DAILY LOOP - DATA PREPERATION (BEGINNING)
C*****
      DO 300 I=1,INODAYS
C*****
C*****        INPUT AND FILL IN DAILY DATA
C*****
      READ(5,1010) ID,IM,IY,NTMIN,NTMAX,NPRECIP,NFLOW
 1010 FORMAT(1X,I3,I3,I5,5X,2F10.2,2F20.0)
      IF(NTMIN.GT.NTMAX.OR.NTMIN.LT.-900..OR.NTMAX.LT.-900.) GOTO 920
      GOTO 921
  920 NTMIN=TMIN
      NTMAX=TMAX
  921 TMIN=NTMIN
      TMAX=NTMAX
      IF(NPRECIP.LT.-900.) NPRECIP=PRECIP
      IF(NFLOW.LT.-900.) NFLOW=FLOW
      PRECIP=NPRECIP
      FLOW=NFLOW
C*****
C*****        COMPUTE DAILY INSOLATION
C*****
      X=(TMAX-TMIN)/15.
      X=AMIN1(X,1.0)
      IF(ID.GT.15) GOTO 203
      IF(IM.EQ.1) GOTO 200
```

```
      II=INDPM(IM)-INDPM(IM-1)
      IF(II.NE.28) GOTO 201
      IF(INT((FLOAT(IY)+.5)/4.)*4.NE.IY) GOTO 201
      II=29
      GOTO 201
  200 II=31
  201 NDYS=FLOAT(II)
      NDY=NDYS-15.+FLOAT(ID)
      RR=(R(IM+1)-R(IM))/NDYS*NDY+R(IM)
      GOTO 204
  203 II=INDPM(IM+1)-INDPM(IM)
      IF(II.NE.28) GOTO 202
      IF(INT((FLOAT(IY)+.5)/4.)*4.NE.IY) GOTO 202
      II=29
  202 NDYS=FLOAT(II)
      NDY=FLOAT(ID)-15.
      RR=(R(IM+2)-R(IM+1))/NDYS*NDY+R(IM+1)
  204 RR=RR*(0.355+0.68*X)*10000.*AREA
C*****
C*****       HEAT BALANCE
C*****
      TA=(TMIN+TMAX)/2.
      X=1.
      IF(TA.LE.0.)GOTO 900
      MELT=0.
      IF(SNW.LT.1.)GOTO 901
      MELT=(RR*(1.-ALBEDS)+PRECIP*1000000.*TA)/79.7/1000000.
      IF(MELT.GT.SNW)MELT=SNW
      GOTO 904
  901 X=0.
  904 SNW=SNW-MELT
      NS=PRECIP+MELT
      GOTO 905
  900 IF(SNW.GT.1..OR.PRECIP.GT.1.)GOTO 903
      X=0.
  903 SNW=SNW+PRECIP
      NS=0.
  905 DATA(1,I)=NS
      DATA(2,I)=TA
      DATA(3,I)=FLOW
      DATA(4,I)=X
      IF(I.LE.ISTART)GOTO 300
      AVGTA=AVGTA+TA
      AVGPR=AVGPR+PRECIP
      AVGF=AVGF+FLOW
      AVGNS=AVGNS+NS
      AVGRR=AVGRR+RR*(1.-X)
      IKNTR=IKNTR+1
  300 CONTINUE
C*****
C*****  DAILY LOOP - DATA PREPARATION (END)
C*****
C*****
C*****  SUMMARY INFORMATION
C*****
```

```
      FI=IKNTR
      AVGTA=AVGTA/FI
      AVGPR=AVGPR/FI
      AVGF=AVGF/FI
      AVGNS=AVGNS/FI
      AVGEVP=AVGNS-AVGF
      AVGHPLE=0.
      DO 910 I=1,INODAYS
      HPLSE=DATA(2,I)-TBASE
      IF(HPLSE.LT.0..OR.DATA(4,I).GT..5)HPLSE=0.
      DATA(4,I)=HPLSE
      IF(I.LE.ISTART)GOTO 910
      AVGHPLE=AVGHPLE+HPLSE
  910 CONTINUE
      CONS=AVGRR/AVGHPLE
      AVGHPLE=0.
      DO 911 I=1,INODAYS
      HPLSE=DATA(4,I)/(596.-.52*DATA(2,I))/1000000.*CONS
      IF(I.LE.ISTART)GOTO 911
      AVGHPLE=AVGHPLE+HPLSE
  911 DATA(4,I)=HPLSE
      AVGHPLE=AVGHPLE/FI
      AVGEVPP=AVGHPLE-AVGEVP
C*****
C*****  CONVERT TO GROUPS OF DAYS INPUTS
C*****
      VAR=0.
      MEAN=0.
      NS=0.
      HPLSE=0.
      FLOW=0.
      II=0
      III=0
      DO 400 I=1,INODAYS
      NS=NS+DATA(1,I)
      HPLSE=HPLSE+DATA(4,I)
      FLOW=FLOW+DATA(3,I)
      II=II+1
      IF(II.NE.INDPGOD)GOTO 400
      III=III+1
      DATA(1,III)=NS
      DATA(4,III)=HPLSE
      DATA(3,III)=FLOW
      IF(III.LE.IIST)GOTO 710
      VAR=VAR+FLOW**2
      MEAN=MEAN+FLOW
  710 NS=0.
      HPLSE=0.
      FLOW=0.
      II=0.
  400 CONTINUE
      FI=FLOAT(III-IIST)
      VAR=VAR/FI
      MEAN=MEAN/FI
      VAR=VAR-MEAN**2
```

```
C*****
C*****  INPUT INITIAL VARIABLE VALUES
C*****
  703 USZM=.09E8
      LSZM=.43E8
      GZM=.27E9
      SS=.12E8
      SSS=.12E8
C*****
C*****  INITIALIZE
C*****
      AVGFM  = 0.
      VARM=0.
      PROD=0.
      VARM2=0.
      PROD2=0.
      AVGSSZ = 0.
      AVGFM2 = 0.
      AVGSSS = 0.
      AVGUSZ = 0.
      AVGLSZ = 0.
      AVGGZ  = 0.
      AVGEVM = 0.
      AVGEV2 = 0.
      SSQERR = 0.
      SSQER2 = 0.
C*****
C*****  DAILY LOOP (BEGINNING)
C*****
      DO 100 I=1,III
C*****
C*****       INPUT PREPARED DATA
C*****
      NS     = DATA(1,I)
      HPLSE=DATA(4,I)
      FLOW   = DATA(3,I)
C*****
C*****       MASS BALANCE
C*****
      CALL OUTFLOW(NS)
C*****
      DATA(2,I)=NS
      IF(I.LE.IIST)GOTO 100
      AVGFM=AVGFM+NS
      VARM=VARM+NS**2
      PROD=PROD+FLOW*NS
      VARM2=VARM2+NSS**2
      PROD2=PROD2+FLOW*NSS
      AVGSSZ=AVGSSZ+SS
      AVGFM2=AVGFM2+NSS
      AVGSSS=AVGSSS+SSS
      AVGUSZ=AVGUSZ+USZMAVG
      AVGLSZ=AVGLSZ+LSZMAVG
      AVGGZ=AVGGZ+GZM
      AVGEVM=AVGEVM+EVAP
```

```
      AVGEV2=AVGEV2+EVAPS
      SSQERR=SSQERR+(FLOW-NS)**2
      SSQER2=SSQER2+(FLOW-NSS)**2
  100 CONTINUE
C*****
C*****  DAILY LOOP (END)
C*****
C*****
C*****
C*****  SUMMARY INFORMATION
C*****
  762 AVGFM=AVGFM/FI
      VARM=VARM/FI
      VARM=VARM-AVGFM**2
      PROD=PROD/FI
      EXVA=(PROD-MEAN*AVGFM)**2/VAR/VARM
      AVGFM2=AVGFM2/FI
      VARM2=VARM2/FI
      VARM2=VARM2-AVGFM2**2
      PROD2=PROD2/FI
      EXVA2=(PROD2-MEAN*AVGFM2)**2/VAR/VARM2
      AVGSSS=AVGSSS/FI
      AVGSSZ=AVGSSZ/FI
      AVGUSZ=AVGUSZ/FI
      AVGLSZ=AVGLSZ/FI
      AVGGZ=AVGGZ/FI
      AVGEVM=AVGEVM/FI
      AVGEV2=AVGEV2/FI
      SSQERR=SSQERR/FI
      SSQER2=SSQER2/FI
      AVGPR=AVGPR/AREA*100.
      AVGF=AVGF/AREA*100.
      AVGHPLE=AVGHPLE/AREA*100.
      AVGNS=AVGNS/AREA*100.
      AVGEVP=AVGEVP/AREA*100.
      AVGEVPP=AVGEVPP/AREA*100.
  559 FORMAT(6E13.6E2)
      MEAN=MEAN/AREA*100.
      VAR=SQRT(VAR)/AREA*100.
      AVGFM=AVGFM/AREA*100.
      AVGEVM=AVGEVM/AREA*100.
      AVGSSZ=AVGSSZ/AREA*100.
      AVGUSZ=AVGUSZ/AREA*100.
      AVGLSZ=AVGLSZ/AREA*100.
      AVGGZ=AVGGZ/AREA*100.
      SSQERR=SQRT(SSQERR)/AREA*100.
      EXVA=SQRT(EXVA)
      AVGFM2=AVGFM2/AREA*100.
      AVGEV2=AVGEV2/AREA*100.
      AVGSSS=AVGSSS/AREA*100.
      SSQER2=SQRT(SSQER2)/AREA*100.
      EXVA2=SQRT(EXVA2)
      REWIND 7
      REWIND 5
      READ(5,1000) I1,I2,I3
```

```
     WRITE(7,1000) I1,I2,I3
     WRITE(7,1020) ISTART,INODAYS,INDPGOD
1020 FORMAT(/,8HFROM DAY,I6,7H TO DAY,I6,3H IN,I3,11H-DAY GROUPS,/)
     WRITE(7,1030)
1030 FORMAT(52H     CONSTANT       ALBEDS     TBASE(C)     AREA(M2))
     WRITE(7,559) CONS,ALBEDS,TBASE,AREA
     WRITE(7,1040) AVGTA,AVGPR,AVGF,AVGHPLE,AVGNS,AVGEVP,AVGEVPP
1040 FORMAT(/,14HDAILY AVERAGES,
    +       /,37H                      TEMPERATURE (C):,E13.6E2,
    +       /,37H                  PRECIPITATION (CM.):,E13.6E2,
    +       /,37H                           FLOW (CM.):,E13.6E2,
    +       /,37H          HEAT LOSS, WATER EQU. (CM.):,E13.6E2,
    +       /,37H                     NET SUPPLY (CM.):,E13.6E2,
    +       /,37H             EVAPOTRANSPIRATION (CM.):,E13.6E2,
    +       /,37H        POT. EVAPOTRANSPIRATION (CM.):,E13.6E2)
     WRITE(7,1050)
1050 FORMAT(/,39H     USZC(M3)  ALPPER(D-1)  ALPUEV(M-3),
    +         26H  ALPDPR(D-1)  ALPINT(D-1))
     WRITE(7,559) USZC,ALPPER,ALPUEV,ALPDPR,ALPINT
     WRITE(7,1060)
1060 FORMAT(/,39H  ALPLEV(M-3)   ALPGW(D-1)  ALPGEV(M-3),
    +         26H   ALPSF(D-1)  ALPSEV(M-3))
     WRITE(7,559) ALPLEV,ALPGW,ALPGEV,ALPSF,ALPSEV
     WRITE(7,1070) INDPGOD
1070 FORMAT(/,I3,15H-DAY STATISTICS)
     WRITE(7,1080) MEAN,VAR,
    +              AVGFM,AVGEVM,AVGSSZ,AVGUSZ,AVGLSZ,AVGGZ,SSQERR,EXVA,
    +              AVGFM2,AVGEV2,AVGSSS,AVGUSZ,AVGLSZ,AVGGZ,SSQER2,EXVA2
1080 FORMAT(  37H                      FLOW MEAN (CM.):,E13.6E2,
    +       /,37H                 FLOW STD. DEV. (CM.):,E13.6E2,
    +      //,37H         MODEL 1           MEAN (CM.):,E13.6E2,
    +       /,37H             EVAPOTRANSPIRATION (CM.):,E13.6E2,
    +       /,37H                        MEAN SS (CM.):,E13.6E2,
    +       /,37H                      MEAN USZM (CM.):,E13.6E2,
    +       /,37H                      MEAN LSZM (CM.):,E13.6E2,
    +       /,37H                       MEAN GZM (CM.):,E13.6E2,
    +       /,37H                           RMSE (CM.):,E13.6E2,
    +       /,37H           COEFFICIENT OF CORRELATION:,E13.6E2,
    +      //,37H         MODEL 2           MEAN (CM.):,E13.6E2,
    +       /,37H             EVAPOTRANSPIRATION (CM.):,E13.6E2,
    +       /,37H                        MEAN SS (CM.):,E13.6E2,
    +       /,37H                      MEAN USZM (CM.):,E13.6E2,
    +       /,37H                      MEAN LSZM (CM.):,E13.6E2,
    +       /,37H                       MEAN GZM (CM.):,E13.6E2,
    +       /,37H                           RMSE (CM.):,E13.6E2,
    +       /,37H           COEFFICIENT OF CORRELATION:,E13.6E2,/)
     WRITE(7,1090) INDPGOD
1090 FORMAT(30HFLOW RATES IN CUBIC METERS PER,I3,5H DAYS,
    +       /,40H              ACTUAL               MODEL)
     IIST=IIST+1
     DO 750 I=IIST,III
 750 WRITE(7,1100) DATA(3,I),DATA(2,I)
1100 FORMAT(2F20.0)
     REWIND 7
     REWIND 5
```

```
STOP
END
SUBROUTINE OUTFLOW (NS)
         .
         .
         .
```

Appendix J.--EXAMPLE MODEL OUTPUT

Appendix J contains the partial print file resulting from the application described by the preceding appendices and should be self-explanatory.

```
1 MIORA RIVER NEAR FOXBORO:  B

FROM DAY  1260 TO DAY  6405 IN 30-DAY GROUPS

     CONSTANT        ALBEDS      TBASE(C)      AREA(M2)
  .152784E+16  .870000E+00  .600000E+01  .290600E+10

DAILY AVERAGES
                          TEMPERATURE (C):  .679999E+01
                      PRECIPITATION (CM.):  .254452E+00
                               FLOW (CM.):  .962466E-01
         HEAT LOSS, WATER EQU. (CM.):  .453181E+00
                         NET SUPPLY (CM.):  .254452E+00
                 EVAPOTRANSPIRATION (CM.):  .158205E+00
            POT. EVAPOTRANSPIRATION (CM.):  .294975E+00

     USZC(M3)  ALPPER(D-1)  ALPUEV(M-3)  ALPDPR(D-1)  ALPINT(D-1)
  .581200E+08  .710000E+00  .630000E-03  .640000E-02  .110000E-01

  ALPLEV(M-3)   ALPGW(D-1)  ALPGEV(M-3)   ALPSF(D-1)  ALPSEV(M-3)
  .710000E-08  .220000E-01 0.            .100000E+99 0.

 30-DAY STATISTICS
                          FLOW MEAN (CM.):  .289333E+01
                     FLOW STD. DEV. (CM.):  .335958E+01

         MODEL 1               MEAN (CM.):  .280829E+01
            EVAPOTRANSPIRATION (CM.):  .484336E+01
                            MEAN SS (CM.):  .958203E-99
                          MEAN USZM (CM.):  .129234E+00
                          MEAN LSZM (CM.):  .380264E+01
                           MEAN GZM (CM.):  .110835E+01
                               RMSE (CM.):  .140057E+01
          COEFFICIENT OF CORRELATION:  .909473E+00

         MODEL 2               MEAN (CM.):  .280829E+01
            EVAPOTRANSPIRATION (CM.):  .484336E+01
                            MEAN SS (CM.):  .278533E-99
                          MEAN USZM (CM.):  .129234E+00
                          MEAN LSZM (CM.):  .380264E+01
                           MEAN GZM (CM.):  .110835E+01
                               RMSE (CM.):  .140057E+01
          COEFFICIENT OF CORRELATION:  .909473E+00

FLOW RATES IN CUBIC METERS PER 30 DAYS
                ACTUAL                MODEL
               4724160.             1859166.
              20301120.            90542722.
              53769600.            67636601.
              47635200.            93052931.
              61891200.            79422264.
             121228800.           110454203.
             187334400.           259914348.
             137433600.           100588563.
              41381760.            32666581.
```

9260160.	14877266.
3794880.	7679698.
5172480.	3968120.
4786560.	2066596.
5120640.	1100748.
13759680.	20531472.
47419200.	57957423.
70391040.	76544232.
106156800.	80838825.
267936000.	253837370.
208992000.	203112086.
32031360.	71944919.
11288640.	24972119.
5121600.	12595398.
9559680.	6513935.
26852160.	3391574.
108028800.	100351660.
197932800.	110552078.
151526400.	111092271.
56851200.	99530211.
140054400.	116848045.
212438400.	302793037.
90432000.	155435870.
72662400.	68617489.
20504640.	25053862.
2916480.	12717333.
4033920.	6574179.
4344000.	3406510.
12355200.	93462634.
170832000.	192025692.
165340800.	122399098.
96835200.	105993918.
59155200.	91756141.
221289600.	239460652.
193468800.	182385163.
86265600.	88298506.
50995200.	30413258.
32504640.	14525705.
8769600.	7500324.
19685760.	3892530.
118352640.	68283404.
173702400.	98482533.
125788800.	103973525.
74928000.	101484958.
73824000.	80677747.
258556800.	287123192.
131788800.	145408013.
63177600.	93562129.
75993600.	36923159.
30143040.	15647272.
9988800.	8055488.
10647360.	4165877.
13902720.	2162516.
42913920.	36304274.
74659200.	56436194.

62572800.	62046780.
91411200.	61410487.
171216000.	126592990.
321648000.	300337996.
283113600.	137252106.
83904000.	53827933.
28311360.	20943415.
21594240.	10683450.
8559360.	5521859.
9756480.	2867198.
31392960.	48750181.
62611200.	42510340.
33844800.	34390800.
39299520.	27265500.
52684800.	63616919.
275923200.	405407971.
172473600.	122025447.
54544320.	39418369.
22299840.	16649011.
14085120.	8564758.
6989760.	4427257.
10840320.	2301612.
31781760.	40450467.
83942400.	45282574.
61075200.	41385513.
50102400.	39230237.
84009600.	49821660.
335808000.	232494815.
280944000.	308330303.
37870080.	100811703.
11399040.	31542575.
5846400.	15291423.
7783680.	7906443.
13108800.	4110277.
15502080.	2121234.
42432000.	75277439.
80016000.	63235625.
64560000.	56840646.
46454400.	44581305.
169785600.	172645066.
448377600.	391686022.
137366400.	118054120.
61248000.	37371407.
55104000.	17055825.
38542080.	8794960.
21380160.	4551468.
69181440.	89340422.
127564800.	108371797.
152640000.	120422274.
163017600.	136359783.
144105600.	166733926.
480777600.	422978596.
162816000.	186248907.
85795200.	85346665.
20791680.	31513717.

```
  7742400.     15793708.
  5625600.      8162808.
  4363200.      4224482.
  9264000.      2197155.
 29894400.     37931835.
 65472000.     47845731.
102134400.     71687961.
 87292800.    110564737.
237744000.    177714982.
347865600.    249130041.
231542400.    132209297.
 49094400.     47503714.
 15310080.     20053416.
  7362240.     10340212.
  7394880.      5346853.
 13952640.      2776104.
 35576640.     59148586.
 57369600.     98741908.
 69321600.     96924499.
 59136000.    124139045.
223737600.    194698077.
338476800.    253451748.
151516800.    103400485.
 33398400.     34510600.
  5053440.     16531597.
  4435200.      8535421.
  4462080.      4447625.
  5069760.      2289898.
  7630080.      8160532.
 36335040.     40092853.
 41308800.     40063767.
 72403200.     50901127.
213753600.    123708165.
540931200.    404679922.
107731200.    228571243.
 44877120.     83985045.
 15092160.     29572140.
  7950720.     14990494.
  5426880.      7751013.
  8703360.      4146608.
 19053120.     17816927.
 21845760.     34847179.
 21772800.     33307679.
 24010560.     32035963.
164498880.    141220143.
267897600.    347131327.
 79180800.    266378453.
 18372480.     90753105.
  6570240.     30864981.
  5313600.     15699438.
  7573440.      8116835.
 18705600.      5196476.
```