A SIMPLIFIED APPROACH TO PREDICT SURFACE RUNOFF AND WATER LOSS HYDROGRAPHS

By

Lalit K. Sinha Systems Engineer, Central and Southern Florida Flood Control District, West Palm Beach, Florida

For presentation at the American Water Resources Association National Symposium on Watershed in Transition to be held at Colorado State University, Fort Collins, Colorado, June 19 -22, 1972. Abstract. A generalized mathematical model with three parameters, P, α and β , has been developed to predict surface runoff and water loss hydrographs from gaged and ungaged watersheds. The parameter P, found to be the most important by sensitivity analysis, was correlated to rainfall and watershed characteristics and time of the year in a Fourier series expression with four terms. The parameter α , second in order of importance, was correlated to rainfall hyetograph characteristics and watershed area. The parameter β is expressed as a function of α in a fifth order polynomial based upon Legendre approximation. The surface runoff hydrographs obtained by using the model approximated very well the observed surface runoff hydrographs consisting of one, two, and more than two peaks.

KEY WORDS: mathematical model; watershed; surface runoff; water loss.

INTRODUCTION

An ability to predict the reactions of a watershed to the complicated input, rainfall, is one of the key factors in watershed management. Availability of high speed computers and advancements in science have encouraged the development of complex models which, in general, involve a large number of parameters. Difficulties in estimating large numbers of parameters arise quite frequently, due not only to unavailability of long term hydrologic records, but also to the complexity of numerous soil, climatic and human factors affecting them spatially and temporally. Therefore, approximations that eliminate some of the elements but which are based upon a minimum number of factors that incorporate the excluded ones are desired.

A considerable amount of work has been done to predict watershed reactions from the application of real or hypothetical storms. Some of them, for example, are as reported by Crawford and Linsley (1966), Huggins and Monke (1966), Holtan and Lopez (1971), Dooge (1959), Nash (1958), Overton (1967), Laurenson (1964), Dawdy <u>et al.(1970)</u> and Prasad (1967). This paper presents an overall model to predict the reactions of gaged or ungaged watersheds in terms of surface runoff and water loss hydrographs. The development of the model and associated simplifying assumptions are discussed hereafter.

MODEL DEVELOPMENT

A good qualitative understanding of the runoff process is necessary to delineate or lump the parts of the process for which explicit mathematical relationships are to be derived. For this purpose, a conceptual model used to show the disposition of rainfall as it reaches the earth surface is presented in Figure 1. When rainfall begins, a portion of the water is intercepted by plant surfaces and never reaches the ground. Water that reaches the ground surface may infiltrate immediately or it may flow into such temporary storages as soil fissures and surface depressions to evaporate or infiltrate later. The water moves off the surface as overland flow after the composite demands for interception, infiltration, depression storage, and surface detention become less than the rate of supply. The portion of surface detention which does not infiltrate and evaporate becomes overland flow after the rainfall ceases. The water that infiltrates either percolates through the soil profile to the groundwater, is stored as soil moisture in the zone of aeration, is lost by evapotranspiration, or moves as interflow to later reappear on the surface at other points within or outside the watershed boundaries.

The rainfall reaching the watershed surface can, therefore, be grouped into two major categories. One category includes the portion of rainfall that is not observed at the watershed outlet and is here referred to as water loss from watersheds. Another category includes the difference between rainfall and water loss and is here referred to as rainfall excess. With this as a background it is hypothesized that

"there exists a parameter, P, which transforms the rainfall over a watershed surface into rainfall excess and water loss. This parameter may be a function of rainfall and watershed characteristics, and time of the year which may act as an index to the watershed conditions."

The transformation of rainfall over a watershed into rainfall excess and water loss is undoubtedly very complex. However, using the work of

(Fig. 1

-2-

Crawford and Linsley (1966) and Dawdy, et al. (1970) as insight, and recognizing watershed heterogeneity, the rate of water loss from a given supply rate of rainfall over a watershed is assumed to be linear from 0 to P and takes the form (for rainfall < P) that is presented in Figure 2.

L/T in Figure 2 is a dimension of rate where L is distance and T is time. Mathematical relationships for determining water loss and rainfall excess can easily be derived from Figure 2 in terms of supply rate of rainfall, R, and parameter, P. These relationships are as follows:

For R < P,

$$WL = R - \frac{R^2}{2P}$$
(1)
$$RE = \frac{R^2}{2P}$$
(2)

$$RE = \frac{R^2}{2P}$$
(2)

For R > P,

 $WL = \frac{P}{2}$ RE

$$= R - \frac{P}{2}$$

where WL is water loss and RE is rainfall excess.

Physically, the parameter P may be viewed with a restriction as an indicator of the rate of water loss occurring from a rainfall event on a watershed. The restriction is that it must distribute rainfall in any selected time interval into rainfall excess and water loss such that at the end of the rainfall storm the total rainfall excess is matched with total observed surface runoff within a specified tolerance. Also, the parameter P sets a maximum limit as one-half of its value for the rate

-3-

Fig.2

(3)

at which water loss can occur in any time interval of the rainfall storm under consideration.

Having determined the rainfall excess that would result from an input rainfall, the remaining problem is to distribute the rainfall excess over time; that is, watershed storage routing. For this purpose it is assumed that storage, S, in the watershed is a function of discharge, Q, alone and the two are related as

$$S = K(Q) \cdot Q \tag{5}$$

where K is a time parameter and from now onwards, K will be used to represent K(Q).

Using Laurenson's (1964) analogy of K to the lag, work of Crawford and Linsley (1966), and the assumption that K is a function of discharge, it may be inferred that the relationship between K and Q is of the form

$$K = \alpha Q^{\beta} \tag{6}$$

where α and β are shape factors.

Substituting rainfall excess, RE, for average inflow in the finite difference form of the continuity equation and rearranging, gives

(RE)
$$\Delta t - (Q_2 + Q_1) \frac{\Delta t}{2} = \Delta S = S_2 - S_1$$
 (7)

where subscripts $_1$ and $_2$ refer respectively to the beginning and end of the routing period, Δ means a change, and t is time.

Substituting equation 6 into equation 7 and solving for Q_2 yield $Q_2 = CO(RE) + C2(Q_1)$ (8)

where
$$CO = \frac{2\Delta t}{2K_2 + \Delta t}$$
 and $C2 = \frac{2K_1 - \Delta t}{2K_2 + \Delta t}$

Equation 8 is the storage routing function. However, an alternate storage routing equation can be obtained in a differential equation form by combining the storage function with the continuity equation. The continuity equation in the differential equation form can be written as

$$RE(t) - Q(t) = \frac{ds(t)}{dt}$$
(9)

where $\frac{d}{dt}$ is the change with respect to time.

Combining equations 5 and 6 with equation 9 and rearranging, gives

$$RE(t) = Q(t) + \alpha (Q[t])^{\beta} \frac{dQ(t)}{dt}$$
(10)

Equation 10 is a first order nonlinear differential equation describing the response of a time invariant, lumped, first order nonlinear system. Equation 10, hereafter referred to as an alternate routing function, can be used to describe the relationship between the input RE and output Q from a basin at time, t. Equation 10 may be written in terms of a differential operator, D, as

$$Q(t) = \frac{RE(t)}{\alpha(Q[t])^{\beta}D + 1}$$
(11)

in which $\frac{1}{\alpha(Q[t])^\beta D + 1}$ is the nonlinear operator which transforms the

input RE into the output Q.

A solution to equation 10 by a numerical integration technique would result in

$$Q_{i+1} = Q_i + (\dot{Q}_i + \dot{Q}_{i+1}) \frac{\Delta t}{2}$$
 (12)

where $\dot{Q} = \frac{dQ(t)}{dt}$ and i and i+1 are the beginning and end of the time step. A detailed derivation of equation 12 is given by Sinha (1970).

Dropping t for convenience of writing, equation 10 can be rewritten as

If the rainfall excess hyetograph and surface runoff hydrograph are known, then two unknowns, \dot{Q}_{i+1} and Q_{i+1} , in equation 12 can be found for a given value of α and β by using equations 12 and 13 in an iterative procedure.

The purpose of developing an alternate routing equation is to illustrate that, starting with a basic continuity equation and storage function, a worker may develop a simple algebraic equation like equation 8 as well as a somewhat complicated nonlinear differential equation like equation 10. Regardless of the form of the equation, it is necessary that the mathematical model developed for the purpose be tested.

MODEL TESTING

Thirty surface runoff producing rainfalls on fourteen small watersheds varying in area between 0.0025 and 7.1563 square miles were selected from the United States Department of Agriculture (1956-1959, 1960-1961). Twelve of the fourteen watersheds were located at Cochocton, Ohio; one was located at Watkinsville, Georgia; and one was located at LaCrosse, Wisconsin. Rainfall and runoff values were tabulated at two minute intervals. The base flow involved in any of the selected hydrographs was negligible. The three parameters, P, α and β were estimated in the following manner.

Estimation of P. The most important parameter in the model is P because it not only defines water loss and thus controls the total volume of surface runoff that is expected to occur from a particular storm event on a watershed, but also, it produces an inflow hydrograph of rainfall

-6-

excess for storage routing. The value of P which would produce the total volume of surface runoff that can be observed from a given pattern of rainfall has been proven analytically by Sinha (1970) to be unique. Thus, a simple iteration technique is used to estimate P for the gaged watershed where rainfall distribution and total volume of surface runoff, ROTO, resulting from this rainfall storm are known. The iteration procedure, which converges fast, involves initializing P as 1 or any other value and then modifying the current value of P by multiplying it with a ratio of ROTC to ROTO until the absolute difference of ROTO and ROTC falls within a specified tolerance. ROTC is the total volume of rainfall excess computed by using equations 2 and 4.

The value of P estimated for each of the thirty storms by the iterative procedure is presented in Table 1. Then, efforts were made to determine P for ungaged watersheds from such input information as rainfall and watershed characteristics and time of the year.

The rainfall and runoff data used in this study were for seven different months of the year and most of them were for the month of June. Hoping that there may be some sort of an annual cycle made perhaps of frequencies that are fractions of a year, week number was used to represent the time of year in the Fourier series expression which will cycle in a (52-week) year. Use of week number in an analysis of this nature has been made by Betson <u>et al</u>. (1969). It was expected in this study that some combination of three to four terms, which can be justified by the data, in Fourier series would do the job. And it so happened in this study that n = 1, 2, 3, 4 did the job. Physically n = 1, 2, 3, 4 represents annual, half-yearly, one-third period of the year, and quarterly terms, respectively. Thus, an equation to estimate

-7-

Table

the value of P as a function of time of the year, and rainfall and watershed characteristics, was written as

 $P_{j} = \int_{n=1}^{4} a_{n} \sin \left(\frac{2\pi n [Y-x_{n}]}{52}\right) + bi x_{i} + e_{j}$ (14) where P = value of parameter P obtained by iterative procedure, j = 1, 2, ..., 29, 30, = serial number for storms, $\sum = summation sign$, n = 1, 2, 3, 4 = number of terms to be used in the series, a = constant, Sin = sine, $\pi = 3.1416$ or 180 degrees, Y = week number, 1, 2, ..., 51, 52, $\ell = lag$, 52 = total number of weeks in a year on which the series would<math>cycle, b = constant,

- i = 1, 2, ... ,
- x = variable representing rainfall and watershed characteristics, and

e = error of fit, or random element associated with each value of P.

The constants in equation 14 can be determined by multiple regression and correlation technique. However, before this technique is used the series expression has to be rearranged as follows:

$$\sum_{n=1}^{4} a_n \sin \left(\frac{2\pi n [Y-\ell_n]}{52} \right) = \sum_{n=1}^{4} (r_{2n-1} \sin W_n - r_{2n} \cos W_n)$$

-8-

where $r_{2n-1} = a_n \cos M_n$, $r_{2n} = a_n \sin M_n$

$$M_n = \frac{2\pi n \ell_n}{52}$$
, $W_n = \frac{2\pi n Y}{52}$

Thus, use of multiple regression and correlation techniques would give the constants r_1 , r_2 , ..., r_7 , r_8 associated with the series terms in equation 14. The values of constants a and ℓ can be determined from the values of r as:

$$\frac{r_{2n}}{r_{2n-1}} = \frac{a_n SinM_n}{a_n CosM_n}, M_n = Tan^{-1} \left(\frac{r_{2n}}{r_{2n-1}}\right) \text{ for } n = 1, 2, 3, \text{ and } 4.$$

After knowing the values of M, the values of L and a can easily be determined as:

$$l_n = \frac{52 \times M_n}{2\pi n}$$
 and $a_n = \frac{r_{2n}}{SinM_n} = \frac{r_{2n-1}}{CosM_n}$ for $n = 1, 2, 3, and 4.$

The coefficients of equation 14 were then determined by using multiple regression and correlation analysis. The statistical results are presented in Table 2 and the resulting equation is as follows:

Table 2

$$P = 0.5758 \text{ SinW}_1 - 0.0863 \text{CosW}_1 + 0.3014 \text{SinW}_2 - 0.3889 \text{CosW}_2 + 0.2065 \text{SinW}_3 - 0.6937 \text{CosW}_3 - 0.3678 \text{SinW}_4 - 0.5362 \text{CosW}_4 - 0.00001 \text{ DIST} - 0.0311 (RT)^2$$
(15)

where \hat{P} = predicted valued of the parameter P,

RT = total rainfall (inch).

Equation 15 seems to indicate that the value of parameter P accociated with a rainfall storm on a given watershed in any week of the year

-9-

would decrease approximately by three-hundredths of the square of total rainfall occurring from that storm. The values of t statistic in Table 2 seem to indicate that the Fourier series terms (cyclic terms) are prominent in explaining variations in P values and dominant among the cyclic terms are the quarterly terms. The dominance of quarterly terms would seem to indicate that there could be four discernible seasons under the watersheds studied, especially in Coshocton, Ohio; and these seasons may have a large effect on the values of parameter P. The values of P predicted by equation 15 for each of the selected thirty storms are presented in Table 1.

Estimation of α and β . The parameters α and β affect the shape of the hydrograph and evidences (1964, 1964-65, 1965-67) indicate that their simultaneous determination is somewhat difficult. Therefore, the values of α and β for each of the selected storms were determined by trial. The trial procedure involved varying one parameter while holding the other two constant. The final estimates of α and β as obtained by trial were those which produced an acceptable fit with the observed hydrograph. The fit was considered acceptable when the model matched the largest value of the observed surface runoff hydrograph within a specified tolerance, routed total volume of surface runoff over a fixed length of time base without any gain or less, and produced the surface runoff values at the end of each time interval fairly close to that of observed values.

The values of α and β obtained by trial for each of the thirty selected storms are presented in Table 1. The final trial values of α were correlated with the rainfall excess characteristics, watershed area, and

-10-

the values of P. The statistical results thus obtained are presented in Table 3 and the resulting equation is as follows:

Table 3

 $\hat{\alpha}$ = -38.7406 + 20.2252 (PKRE) + 28.3973 (RET) + 100.5709(P) + 2935.4238(AREA) - 16.1999 (RET)² + 72.5669(AVRE)² + 0.7710 (AREA)² - 6.9585(PKRE X RET) - 18.9834(PKRE X AVRE) + 23.4920(PKRE X P) - 1074.7770(PKRE X AREA) + 5077.5530(RET X AREA) - 251.3478(AVRE X P) - 5277.4894(AVRE X AREA) -5988.4912(P X AREA). (16)

where $\hat{\alpha}$ = predicted value of α ,

PKRE = peak rate of rainfall excess (in/hr),

- RET = total volume of rainfall excess as computed by the value of P
 for that storm (in),
- AVRE = average rainfall excess rate obtained by dividing RET with DRAIN
 (in/hr). DRAIN is the duration of rainfall (hour) and includes
 the number of intervals only in which it rained, and
 AREA = watershed area (square miles).

Using equation 16, the values of α for each of the thirty storms were regenerated and these values are also presented in Table 1.

The values of t statistic presented in Table 3 seem to indicate that dominant among the selected variables affecting the values of α are the linear term of watershed area, and linear x linear interaction terms of watershed area with PKRE, RET, AVRE and P.

While finding the values of α and β by trial it was observed that the value of β was influenced by the chosen value of α . Therefore, a curve fitting was done between values of β and α obtained by trial. A

-11-

fifth order polynomial based upon Legendre approximation was found satisfactory and the resulting equation is

$$\beta = -0.3449 + 0.0354(\alpha) - 0.00149(\alpha)^2 + 0.000029(\alpha)^3 - 0.00000026(\alpha)^4 + 0.00000009(\alpha)^5$$
(17)

Using equation 17, the values of β for each of the thirty storms were regenerated and these values are presented in Table 1.

<u>Simulation</u>. The value of P as computed by equation 15 was negative for the storm of 6-28-57 on watershed number 115; it was therefore eliminated from simulation. A negative value of P means that R cannot be \leq P and for R \geq P, RE = R - $\frac{P}{2}$ is positive, but RE will be greater than R. Such happenings are physically impossible. Out of twenty-nine storms simulated, nine storms have one peak, nine storms have two peaks, and eleven storms have more than two peaks. Simulation was done by using both the routing equations 8 and 10. The results of simulation for all of the twenty-nine storms in terms of total volume of surface runoff, peak rate (highest discharge rate in case of hydrographs with more than one peak), and time to the peak rate are summarized in Table 4. The entire hydrograph for only three of the storms is presented in Figures 3 through 5. No water loss hydrographs are presented here but they are those obtained by using equations 1 and 3.

Tab

Fig

The ability of equation 10 to simulate total volume of observed surface runoff, peak rate, time to peak and time distribution of surface runoff; that is, the entire surface runoff hydrograph, appeared superior as compared to that of equation 8. This may be due to the use of observed surface runoff values in equation 10. A distinct disadvantage with

-12-

equation 10 is, therefore, that the observed surface runoff hydrograph resulting from every storm must be known. The advantage with equation 8 is that if reliable equations based upon rainfall and watershed characteristics and time of year are developed to produce the values of P, α , and β , then hydrographs for similar ungaged watersheds may be developed. The possibility of developing such reliable equations is very well exemplified with equations 15, 16 and 17. Apparent from the results is that the model, in general, is well suited to watersheds of areas up to 0.2 square mile, with flat to moderate slopes. A sensitivity analysis indicated that the parameter P is most important and next in order is the parameter α , while β seems to be the least important.

SUMMARY AND CONCLUSIONS

A generalized mathematical model with three parameters has been developed to predict surface runoff and water loss hydrographs from gaged and ungaged watersheds. The values of parameter P, which determine the total volume of surface runoff and water loss resulting from given rainfall storms, were estimated by an iterative procedure and then were correlated to rainfall and watershed characteristics and week of the year so that the model could be applied to ungaged watersheds. The 't' statistic indicated that cyclic terms were prominent in explaining the variations in the values of P, and dominant among the cyclic terms was the quarterly term.

The shape parameters α and β were determined by trial. The values of α so determined were correlated to the characteristics of rainfall excess hyetograph and the watershed area and the values of P. The 't'

-13-

statistic seemed to indicate that dominant among the selected factors affecting the values of α were the linear term of watershed area, and linear x linear interaction terms of watershed area with PKRE, RET, AVRE and P. A fifth order polynomial based upon Legendre approximation was developed to determine the values of β from the values of α .

Very high R^2 values of 0.92 and 0.99 associated with equations 15 and 16, respectively, indicate that equations to predict the values of parameters P and α can be developed from such input information as rainfall, watershed characteristics and time of the year. The surface runoff hydrographs obtained by using the model approximated very well the observed surface runoff hydrographs consisting of one peak, two peaks, and more than two peaks. Apparent from the results is that the model is well suited to watersheds with areas up to 0.2 square mile with flat to moderate slopes. Water loss hydrograph resulting from a rainfall storm will be that obtained by using equations 1 and 3 and an appropriate value of parameter P. A sensitivity analysis indicated that P was the most important parameter, and next in order of importance was the parameter α while the parameter β seemed to be the least important.

ACKNOWLEDGEMENTS

The author would like to express his appreciation to the Biological and Agricultural Engineering Department of North Carolina State University at Raleigh, North Carolina, for financing his graduate study, and thanks the Director of the Department of Engineering and the Planning Engineer of the Central and Southern Florida Flood Control District at West Palm Beach, Florida, for reviewing the rough draft of the paper.

-14-

Betson, R. P., R. L. Tucker, and F. M. Haller. 1969. Using analytical methods to develop a surface-runoff model. Water Resources Res., 5(1): 103-111.

- Crawford, N. H. and R. K. Linsley. 1966. Digital simulation in hydrology: Stanford watershed model IV. Dept. of Civil Engr., Stanford Univ. Tech. Report No. 39.
- Dawdy, D. R., R. W. Lichty, and J. M. Bergmann. 1970. A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins. . . a progress report. U.S.G.S. open file report.
- Dooge, J. C. I. 1959. A general theory of the unit hydrograph. J. Geophys. Res. 64:241-256.
- Holtan, H. N. and N. C. Lopez. 1971. USDAHL-70 model of watershed hydrology. USDA, ARS, Tech. Bull. No. 1435.
- Huggins, L. F. and E. J. Monke. 1966. The mathematical simulation of the hydrology of small watersheds. Purdue Univ. Water Resources Res. Center Tech. Report No. 1.
- Laurenson, E. M. 1964. A catchment storage model of runoff routing. J. of Hydrology, 2:141-163.
- Ligon, J. T., A. G. Law, and D. H. Higgins. 1969. Evaluation and application of a digital hydrologic simulation model. Water Resources Res. Inst., Clemson, Univ., Clemson, South Carolina.

Nash, J. E. 1958. Determining runoff from rainfall. Inst. of Civil Engrs., London. 10:163-184.

Overton, D. E. 1967. Analytical simulation of watershed hydrographs from rainfall. Proc. Int'l. Hydrol. Symposium, Fort Collins, Colorado, U.S.A. 1:9-17. Prasad, R. 1967. A nonlinear hydrologic system response model. Am. Soc. Civil Engrs., J. Hydr. Div. 93(HY4):201-221.

- Sinha, L. K. 1971. A mathematical model to simulate surface runoff from small watersheds. Ph.D. Thesis, Biol. and Agri. Engr. Dept., North Carolina State Univ., Raleigh, North Carolina.
- TVA, Office of tributary and area development. 1964. A pilot study in area-storm factor correlation. Res. Paper No. 4, Knoxville, Tenn.
- TVA, in cooperation with U. S. Forest Service. 1964-1965. The Upper Bear Creek experimental project. Knoxville, Tennessee.
- TVA, in cooperation with U. S. Forest Service. 1965-1967. The Upper Bear Creek experimental project. Knoxville, Tennessee.

USDA, ARS. 1960-61. Hydrologic data for experimental agricultural watersheds in the United States. Miscellaneous publication No. 994.
USDA, ARS, 1956-59. Hydrologic data for experimental agricultural watersheds in the United States. Miscellaneous publication No. 945.

5

LIST OF FIGURES

- 1. Disposition of rainfall on earth
- 2. Assumed form of water loss curve for R \leq P
- 3. Simulated and observed surface runoff hydrographs of June 12, 1957 on watershed number 115
- 4. Simulated and observed surface runoff hydrographs of September 23, 1945 on watershed number 129
- Simulated and observed surface runoff hydrographs of June 28, 1940 on watershed number 115





R = RainfallSG = Groundwater storageET = EvapotranspirationDS = Depression storageI = InfiltrationXXXX = Earth surfaceK = PercolationSC = Channel storage Q_0 = Overland flowCEPT = Interception Q_b = Base flowSD = Surface detention Q_I = InterflowM = Groundwater table Q_S = StreamflowDPG = Deep percolated groundwaterSA = Storage in the zone of aeration









Value of ^g by Equation 17 (8)	0.0087 -0.0809 -0.0335 -0.0335 -0.0324 -0.0324 -0.0324 -0.0324 -0.0324 -0.0325 -0.1742 -0.1742 -0.1772 -0.1772 -0.1774 -0.1774 -0.1774	-0.2134
Value of B by Trial (7)		-0.1924
Value of ^α by Equation 16 (6)	6.3289 6.3289 13.2336 9.8861 13.2336 13.2336 13.2336 13.2336 13.2336 13.2336 13.2326 13.255 13.2326 10.3067 10.3067 10.3067 10.3067 10.3067 10.3067 10.3067 11.7110 21.4586 21.2586 21.2586 21.2586 22.0555 23.075555 23.07555 23.07555 23.07555 23.075555 23.075555 23.0	3.9923
P, α and β. Value of α by Trial (5)	6.15 6.15 6.15 6.15 6.15 7.1254 6.31 7.1254 6.31 7.1254 6.31 7.1254 6.35 6.35 7.1254 6.35 7.1254 6.35 7.1254 6.35 7.1254 7.12554 7.12547 7.125577 7.12557777777777777777777777777777777777	4.0
of parameters Value of P by Equation 15 (4)	0.18520 0.10514 0.10514 0.16936 0.17069 0.17069 0.17069 0.17069 0.17069 0.17069 0.17087 0.17643 0.17643 0.17643 0.17643 0.17643 0.17643 0.04197 0.29189 0.29189 0.29189 0.26296 0.26296 0.26296 0.261115 0.17087 0.	0.08079
rning values o Value of P by It- erative Procedure (3)	0.15723 0.02871 0.04586 0.04586 0.025921 0.025921 0.16662 0.16662 0.1879 0.18662 0.1879 0.1879 0.1879 0.1879 0.18655 0.04519 0.15093 0.15093 0.15093 0.16706 0.15093 0.16706	0.08079
storm Date (2)	rgia 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 6-12-57 60 10-12-57 60	7-19-52
Informa Water- Shed Number (1)	viscons vis	CWA
Table 1. Serial Number of Storm Coshoctor	22 23 24 24 25 25 25 25 25 25 25 25 25 25	30

•

Table 2. Stai	tistical results from mul	tiple regression analys	is of
Coefficie Standard Total deg Regressic Error deg	ent of multiple correlati error of dependent varia grees of freedom = 30 on degrees of freedom = 1 grees of freedom = 20	on, R ² = 0.92 ble, σ = 0.0558 0	
Variance	ratio of regression to e	rror, F value = 23.04	·····
Variable	Coefficient	Standard error of coefficient	Student's t
Sin <u>2¤y</u> 52	0.5758 a _l = 0.5822	0.1076	5.3528***
	$l_{1} = 5]$		
Cos <u>211y</u> 52	-0.0863	0.0933	-0.9242
$\sin \frac{2\pi(2)y}{52}$	0.3014 a ₂ = 0.4919	0.0553	3.4524***
$\cos \frac{2\pi(2)y}{52}$	ℓ ₂ = 22 -0.3889	0.1557	-2.4983**
$\sin \frac{2\pi(3)y}{52}$	0.2065 $a_3 = 0.7235$	0.0520	3.9683***
$\cos \frac{2\pi(3)y}{52}$	گ ₃ = 14 ⊷0.6937	0.1958	-3.5426***
$\sin \frac{2\pi(4)y}{52}$	-0.3678 $a_4 = 0.6502$	0.0641	-5.7336***
$cos \frac{2\pi(4)y}{52}$	-0.5362	0.1505	-3.5628***
DIST	-0,000010 [°]	0.000005	-1.9767*
(RT) ²	-0.0311	0.0096	-3.2341***

+ Hereafter single asterisk means significant at a probability level less than or equal to 0.10. **Hereafter double asterisk means significant at a probability level less

**Hereafter double asterisk means significant at a probability level less than or equal to 0.05.

***Hereafter triple asterisk means significant at a probability level less than or equal to 0.01.

Table 3. Stat	istical results fro meter a.	m multiple regression	analysis of				
Coeffici Standard Regressi Total de Regressi Error de Variance	ent of multiple cor l error of dependent on constant or inte grees of freedom = on degrees of freed grees of freedom = ratio of regressio	relation, $R^2 = 0.99$ variable, $\sigma = 3.7212$ rcept = -38.7406 29 om = 15 14 n to error. E value =	00 77				
	Tudio of Tegressio	Standard					
Variable	Coefficient	error of	Student's				
		coefficient	t				
PKRE	20.2252	3.5353	5.7210***				
RET	28.3973	12.3404	2.3012**				
Р	100.5709	26.5896	3.7823***				
AREA	2935.4238	302.2130	9.7131***				
(RET) ²	-16.1999	6.0384	-2.6828**				
(AVRÉ) ²	72.5669	14.5513	4.9870***				
(AREA)2	0.7710	0.3941	1.9565*				
PKRE x RET	-6.9585	4.0983	-1.6979				
PKRE x AVRE	-18,9834	5,9065	-3.2140***				
PKRE x P	23,4920	9.8845	2.3766**				
PKRE x AREA	-1074.7770	109,5971	-9.8066***				
RET X AREA	5077.5530	586.0933	8.6634***				
AVRE x P	-251.3478	66.3353	-3.7890				
AVRE x AREA	-5277,4894	738.3198	-7.1480***				
P x AREA	-5988.4912	621.4242	-9.6367				

	rom begin- off (min.)	lation Equation 10 (10)	38 40	36	285	40 40	34	140 44	38	011	0 4 0	8	28	22	64 50	96 96	64	34	126	140	224 224
	eak rate f irface run	Simu Equation 8 (9)	38 40	44	385	110 44	34	140 40	38	110	÷ ∞	10	24 96	24	78 36	802	18	202	25	52	332 °
	Time to pu ning of su	Observed (8)	40 40	36 58	2 œ ;	40	36	140 44	40	011	င္ ထ	∞ ,	74 86	24	64 50	96 20	64	34	126	140	224
ak rate	hr.)	lated Equation 10 (7)	3.98 1.59	3.17 1 35	2.67	0.76	4.08	1.38 0.78	2.49	1.12	3.29	1.82	ددد. ۲ 09. ۲	0.37	2.75	0.317	0.40	0.2/	0.32	0.261	0.0193
time to pe	rate (in./	Simu Equation 8 (6)	2.84 0.62	3.88 1 32	2.99	0.91	4.19	1.22 0.75	2.8]	1.23	3.40	1.30	0.44 1.30	0.29	1.13 3.45	0.337	0.58	0.30	0.17	0.22	0.0109
rate, and	Peak 1	Observed (5)	4.12	3.11 1 36	2.36	0.527	4.06	1.43 0.852	2.38	1.01 0.678	2.57	1.93	0.550 1.23	0.32	1,32 3,14	0.329	0.432	0.28	0.33	0.265	0.0197
off, peak	ff (in.)	ted Equation 10 (4)	1.16 0.77		1.12	0.28 0.28	1.50	0.92 0.47	1.03	0.67	1.15	0.98	0.82	0.12	0.66	0.43	0.35	0.30	0.72	0.65	0.05
urface run	rface runo	Rou Equation 8 (3)	1.05 0.41	1.47 0.93	1.25	0.70	1.51	0.72 0.49	1.18	0.70	1.11	0.71	0.84	0.13	0.63	0.43	0.42	0.44	0.52	0.67	0.05
volume of s	Jume of su	Predicted Equation 15 (2)	1.05 0.42	1.48 0.93	1.25	0.70 0.35	1.51	0.72	1.18	0.70	1.11	0.71	0.84	0.14	0.64	0.44	0.42	0.44	0.52	0.67	0.05
. Total v	Total vo	Observed (1)	1.21 0.83	1.03	1.02	0.80	1.48	1.02 0.47	0.96	0.66	1.16	1.04	0.81 0.81	0.11	0.67	0.43	0.35	0.36	0.73	0.66	0.05
Table 4		Serial Number of Storm	- ო	4 v	זטנ	~ 8	6,	27	12	е Г	15+	16	18	61	20	22	23	24 24	26 26	27	<u>୧</u> ୧