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INCLUDING UNCERTAINTY IN FLOOD CONTROL DESIGN

T.V. Hromadka II[1], M.ASCE

Abstract

The classic single area unit hydrograph (UH) approach to modeling runoff response from a free draining catchment is shown to represent several modeling considerations including, (i) subarea runoff response (in a discretized model), (ii) the subarea effective rainfall distribution including variations in magnitude, timing, and storm pattern shape, (iii) channel flow routing translation and storage effects, (iv) subarea runoff hydrograph addition, among other factors. Because the UH method correlates the effective rainfall distribution to the runoff hydrograph distribution, the resulting catchment UH may be considered as an expected response from a stochastic distribution of realizations. Should the uncertainty in effective rainfall over the catchment be a major concern in modeling reliability, then the UH model output in the predictive setting may be considered to be a random process.

Introduction

A review of the literature which raises questions as to the development, applications, and calibration, of hydrologic models is contained in Hromadka and Whitley. In that literature review, it appears that the unknown distribution of effective rainfall (i.e., rainfall less losses) over the catchment, R, may be an important barrier to the success in the use of hydrologic models for predicting hydrologic responses.

Hydrologic Model Development

The catchment, R, is assumed free-flowing, without backwater effects. The catchment is subdivided into m homogeneous subareas, R_j. Channel routing along links is assumed to be translation, with a characteristic travel time for each link, for each storm event, i. (Channel

[1]Principal Engineer, Boyle Engineering Corporation, 1501 Quail Street, Newport Beach, California 92658

flow routing storage effects can be modeled by a linear routing technique (Hromadka)). Runoff hydrographs are summed at confluence points. A single stream gauge is located at the downstream end of R. In each R_j, a unit hydrograph (UH) exists for each storm event i such that the subarea runoff hydrograph, $q_j^i(t)$ is given by

$$q_j^i(t) = \int_{s=0}^{t} e_j^i(t-s)\,\phi_j^i(s)\,ds \tag{1}$$

where $e_j^i(t)$ is the effective rainfall. The global model $Q_m^i(t)$ for R and storm event i is given by, for a m-subarea model by

$$Q_m^i(t) = \sum_{j=1}^{m} q_j^i(t-\tau_j^i) \tag{2}$$

where τ_j^i is the sum of link travel times from R_j to the stream gauge.

The rain gauge is associated with a runoff measuring system such that the effective rainfall is also measured, noted as $e_g^i(t)$ for storm i. The $e_j^i(t)$ are assumed to be linear with respect to $e_g^i(t)$,

$$e_j^i(t) = \sum_{k=1}^{n_j^i} \lambda_{jk}^i\, e_g^i\,(t-\theta_{jk}^i) \tag{3}$$

where λ_{jk}^i are coefficients and the θ_{jk}^i are timing offsets.

Combining Eqs. (1), (2), and (3),

$$Q_m^i(t) = \sum_{j=1}^{m} \int_{s=0}^{n_j^i} e_g^i(t-s) \sum_{k=1}^{n_j^i} \lambda_{jk}^i\, \phi_j^i(s-\theta_{jk}^i-\tau_j^i)\,ds \tag{4}$$

Equation (4) is reduced to the single area UH model

$$Q_m^i(t) = Q_1^i(t) = \int_{s=0}^{t} W^i e_g^i(t-s)\;\psi^i(s)\,ds \tag{5}$$

where W^i is the ratio of stream gauge runoff to the measured effective rainfall; and $\psi^i(s)$ is the unit hydrograph for storm event i,

$$\psi^i(s) = \sum_{j=1}^{m} \int_{k=1}^{n_j^i} \lambda_{jk}^i\, \phi_j^i(s-\theta_{jk}^i-\tau_j^i)/W^i \tag{6}$$

A more convenient representation of Eq. (5) is the single area UH model,

$$Q_1^i(t) = \int_{s=0}^{t} e_g^i\,(t-s)\,\eta^i(s)\,ds \tag{7}$$

where

$$\eta^i(s) = W^i\,\psi^i(s) \tag{8}$$

In practice, use of the m-subarea link-node model results in using the estimator, $\hat{Q}_m^i(t)$, given by (using hat notation for estimates)

$$\hat{Q}_m^i(t) = \sum_{j=1}^{m} \int_{s=0}^{t} \hat{e}_j^i\,(t-s)\,\hat{\phi}_j^i(s-\hat{\tau}_j^i)\,ds \tag{9}$$

where the hats are notation for estimates.

<u>Hydrologic Modeling Uncertainty Analysis: Data Representation</u>

It is assumed that there are "sufficient" data to develop equivalence classes of measured effective rainfall distributions at the rain gauge site. These storm classes are noted as $<\xi_q>$. Any two events in $<\xi_q>$ would be nearly identical (storm duration, antecedent moisture conditions, and other effects) such that the catchment response would be anticipated to be alos nearly identical. Let $e_o^i(t)$ be an element of a storm class $<\xi_o>$. To each $e_o^i(t)$ there is an associated $Q_o^i(t)$ measured at the stream gauge. Correlating each pair $\{e_o^i(t), Q_o^i(t)\}$ by the single area UH model results in n_o distributions, $\{\eta_o^i(s)\}$, $i = 1,2,\ldots,n_o$, where n_o is the number of elements in $<\xi_o>$.

The $\eta_o^i(s)$ can be represented by a summation graph, $\bar{S}_o^i(s)$, where

$$\bar{S}_o^i(t) = \int_{t=0}^{s} \eta_o^i(t)\,dt \tag{10}$$

Figure 1 shows a plot of $S_o^i(s)$ developed from storms of similar severity from a basin in Los Angeles County, California. In Fig. 1, plotting each $\bar{S}_o^i(s)$ divided by its ultimate discharge, U_o^i, (i.e., $U_o^i = \bar{S}_o^i(s = \infty)$), normalizes the vertical axis from 0- to 100-percent. Defining lag^i to be the time that $\bar{S}_o^i(s)$ reaches 50-percent of ultimate discharge (U_o^i) normalizes the horizontal axis to be time in percent of lag. Figure 2 shows the resulting S-graphs, noted as $S_o^i(s)$ for storm class $<\xi_o>$. The several S-graphs can now be identified by a characteristic parameter such as a linear scaling X between the enveloping curves of the S-graph data set (see Fig. 3). By identifying an X to each S-graph,

$$S_o^i(X,s) = X\,S_o^A(s) + (1-X)\,S_o^B(s) \tag{11}$$

where S_o^A and S_o^B are the enveloping S-graphs, and X is the scaling parameter with $0 \le X \le 1$. Based on the above normalizations and parameterizations, each distribution graph, $\bar{S}_o^i(s)$, is identified by the three point vector $\underset{\sim}{\eta}\,{}_o^i$, for $i = 1,2,\ldots,n_o$.

Marginal distributions are developed by plotting frequency-distributions of each point in the vector, η_o^i (see Fig. 4). The frequency estimate associated to vector, η_o^i, is given by $P(\eta_o^i)$ where

$$P(\eta_o^i) = P(lag^i, U_o^i, \dot{X}^i) \tag{12}$$

Hydrologic Modeling Uncertainty Analysis: Predictive Relationships

Given a design storm effective rainfall distribution to be applied at the rain gauge site, $e_g^D(t)$, the hydrologic model is to be used to predict a runoff response from R. Let $e_g^D(t) \in <\xi_o>$. Then the runoff response is the random process $[Q_1^D(t)]$ where

$$[Q_1^D(t)] = \int_{s=0}^{t} e_g^D(t-s)\,[\eta_o(s)]\,ds \tag{13}$$

$[Q_1^D(t)]$ is the collection of runoff hydrographs which are possible outcomes associated to the design storm effective rainfall, $e_g^D(t)$. $[\eta_o(s)]$ is the collection of correlation distributions associated to storm class $<\xi_o>$ wherein $e_g^D(t)$ is considered to be similar. Because Eq. (13) is a prediction, any of the elements in $[\eta_o(s)]$, and hence $[Q_1^D(t)]$, are candidates as a realization of the stochastic process.

The variation in flow rate estimates at storm time t_o is given by

$$[Q_1^D(t_o)] = \int_{s=0}^{t_o} e_g^D(t_o-s)\,[\eta_o(s)]\,ds \tag{14}$$

Letting t_p be the time of the peak flow rate (where t_p is a function of the random process, $[\eta_o(s)]$), the uncertainty in peak flow rate estimates, q_p, is

$$[q_p] = Q_1^D(t_p) = \int_{s=0}^{t_p} e_g^D(t_p-s)\,[\eta_o(s)]\,ds \tag{15}$$

Figure 5 shows the distribution of q_p for a catchment in Los Angeles, California.

Conclusions

In a single area UH model, the unit hydrograph serves as the link which correlates effective rainfall data to runoff data. The single area UH model represents a complex link-node model, had subarea hydrologic data been available to evaluate subarea runoff, and had stream gauge data been available to evaluate all link-node hydraulic parameters. Without subarea data, however, the link-node model representation becomes an

estimator which is in error due to the approximation of hydraulic parameters and the misrepresentation of the effective rainfall.

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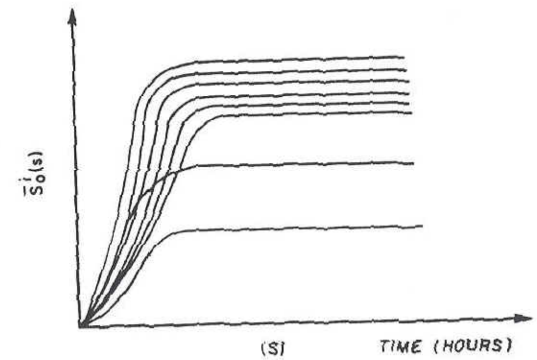

Fig. 1. Example Summation Graphs, $\bar{S}_o^i(s)$, for Storm Class $<\xi_o>$.

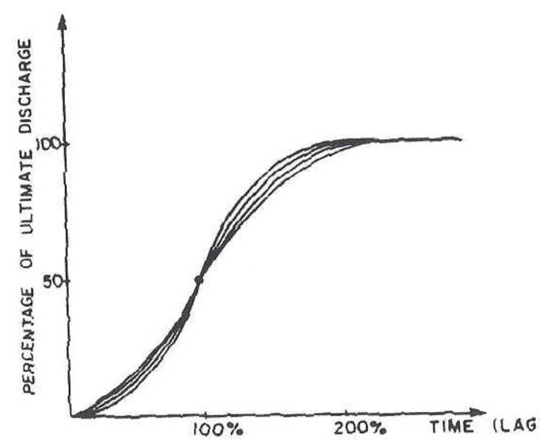

Fig. 2. S-Graphs, $\bar{S}_o^i(s)$, for Storm Class $<\xi_o>$.

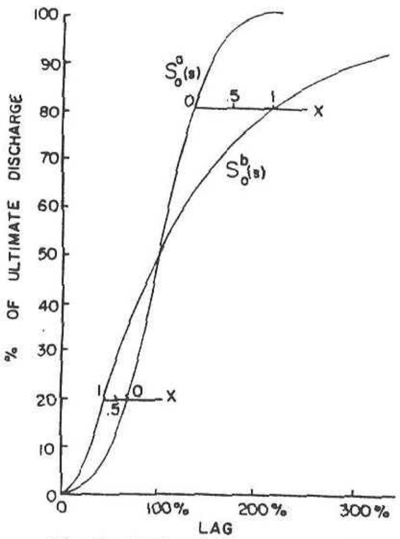

Fig. 3. S-Graph Parameter X using $\bar{S}_o^A(s)$ and $\bar{S}_o^B(s)$.

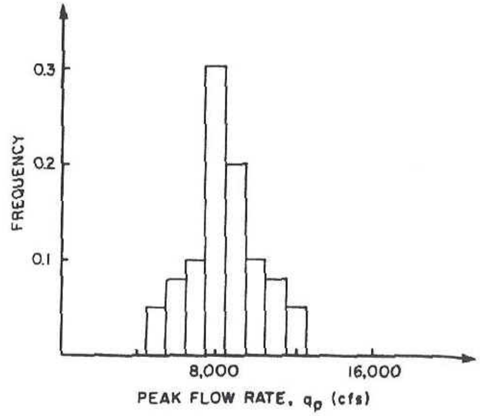

Fig. 4. Marginal Distributions for Vector Components of $\tilde{\eta}_o{}^i$.

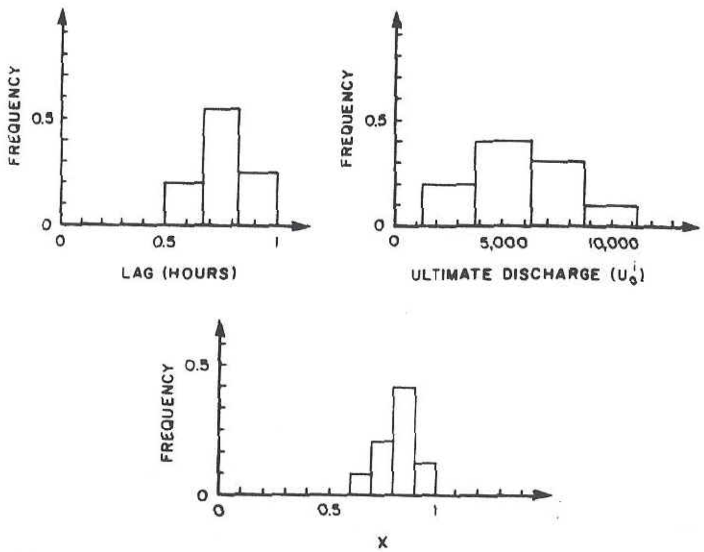

Fig. 5. Distribution for the Estimate of Peak Flow Rate, q_p.

Flash-Flood Forecasting by Using the HEC1F Model

M.A. Mimikou[1], E.A. Baltas[2], & M. Borga[3]

Abstract

The application of a lumped conceptual model, the well known HEC1F, for flash-flood forecasting and warning to the Venetikos river basin in Northwestern Greece, is presented. The combination of on-site and remotely sensed distributed radar rainfall input information will further improve the performance of the model.

Introduction

Real time flash-flood forecasting is a very important issue in Engineering Hydrology. The traditional approach to flood forecasting is to use rainfall input estimated from a number of raingages driving a lumped parameter hydrological model. A commonly used model is the HEC1F model, a special version of the HEC-1 model (HEC-1, 1985), developed for use in real-time flood forecasting and flood-control operations (U.S. Army Corps of Engineers, 1985). In this paper, an attempt is made to apply the well known HEC1F to the Venetikos basin in Northwestern Greece, a region suffering from frequent and hazardous flash-floods, for flash-flood forecasting.

[1]Associate Professor, [2]Research Assistant, Division of Water Resources, Hydraulic and Maritime Engineering, Civil Engineering Department, National Technical University of Athens, 5, Iroon Polytechniou, 15773-Athens, Greece.

[3]Research Associate, University of Padova, Department of Land and Agroforest Environments, Padova, Italy.