CORRELATION ANALYSIS
OF UNIT HYDROGRAPH, STORM
AND WATERSHED PARAMETERS

A Status Report

by

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A Status Report

The purpose of this report is to summarize the activities on the research project:

"Urban Watershed Response Time"
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INTRODUCTION

The activities during this quarterly period were directed to developing correlations between the rainfall and runoff characteristics of the recorded flood events from the Denver Watersheds and selected physical watershed variables. The rainfall and runoff characteristics are standardized by converting all of the recorded floods to a unit hydrograph.

UNIT HYDROGRAPHS

Unit hydrographs were derived by two methods employing the digital computer. The first method used was the HEC Method found in the HEC 1 computer program package. Under some conditions it was found that the HEC Program did not always produce a unit hydrograph. Difficulties were traced to that part of the program where an adjustment is made for an impervious watershed or in those cases where the flood was caused by a moving storm. In the case of the moving storm the rainfall and runoff records may not be in perfect synchronism.

Unit hydrographs were also derived by a matrix inversion method developed by Kavvas (1972). This method experiences some difficulty with resolution of time during the rapidly changing parts of the hydrograph; i.e. rising limb and peak.

The significant parameters of the unit hydrograph are the peak discharge Qp , or the unit peak discharge, $q_p = \frac{Qp}{A}$ and the time to peak, tp . These parameters were correlated with various storm and physiographic watershed parameters.

RESPONSE TIME

The philosophy of this investigation was that the changes inflicted on the unit hydrograph as a result of urbanization are the consequences of a reduced response time. If the urbanization can be defined in terms of the physical watershed changes and then these physical watershed changes in turn related to the watershed response time, a method can be developed for predicting the unit hydrograph shift because of urbanization.

The response time is defined as the significant measure of the length of time required for the watershed to fully respond to a unit of rainfall excess. This response time is related to the various definitions of watershed lag time, time of concentration, etc. which appear in the literature, see Wilson (1972). Several definitions of the Response Time were used in this investigation:

1) Dealing with the Direct Runoff Hydrograph:

   a) Time between centroid of Rainfall Excess and Peak of Direct Runoff Hydrograph,

   b) Time between beginning of Rainfall Excess and Peak of Direct Runoff Hydrograph,

   c) Time between centroid of Rainfall Excess and centroid of Direct Runoff,

   d) Time between beginning of Rainfall Excess and centroid of Direct Runoff,

   e) Time between centroid of Rainfall Excess and mid-volume of the Direct Runoff.

2) Dealing with the Derived Unit Hydrograph:

   f) Time between centroid of unit Rainfall Excess and Peak of the Unit Hydrograph,

   g) Time between the beginning of Rainfall Excess and the Peak of the Unit Hydrographs (Unit Hydrograph Rise Time).

3) Dealing with the Hydraulics of Overland Flow:

   h) Time of Concentration as defined in the HEC program (HEC, 1966).

PHYSIOGRAPHIC PARAMETERS

The physiographic parameters of the watersheds are divided into two groups:

1. General Physical Properties of the watershed,
2. Those properties which define intensity of urbanization.

General Physical Variables - The general physical variables are those variables which are known to affect the unit hydrograph parameters which are not necessarily unique to the urban watersheds. The general physical variables used in this investigation are:

1. Drainage Area, A, in square miles,
2. Watershed Perimeter, P, in miles,
3. Length of Watershed, L_L, in miles,
4. Channel Distance to Watershed Centroid, L_C, in miles.

These variables were combined to form dimensionless parameters.

Urbanization Variables - The urbanization variables are those which are unique to or characteristic of an urban region. In many cases these variables change rapidly during the evolution of the urban region.

1. Area of Impervious Watershed, Ai, in square miles,
2. Length of Paved Streets, L_{PSR}, in miles,
3. Length of Curbed and Guttered Streets, L_{CG}, in miles,
4. Average width of Curbed and Guttered Streets, W_{CGS}, in feet,

5. Length of Unpaved Streets, L_{USR} , in miles,

6. Length of Storm Drains, L_{SS} , in miles,

These variables were used to develop dimensionless parameters or other parameters which were known to be important from analytical considerations:

7. Slope of Curbed and Guttered Streets, S_{CGS} , in feet per foot,

8. Percent of Impervious Area, I_A ,

9. Percent of Area in Paved Streets, A_{PSR} .

Several parameters were developed which were not dimensionless, but were analogous to similar parameters which had been cited by other investigators or which had to do with defining the hydraulic capacity of the watershed:

10. Drainage Density of Paved Streets, D_{PSR} , in miles per square mile,

11. Drainage Density of Curbed Streets, D_{CGS} , in miles per square mile,

12. Drainage Density of Unpaved Streets, D_{USR} , in miles per square mile,

13. Total Drainage Density of Streets, D_{SR} , in miles per square mile,

14. Average Hydraulic Capacity of Curbed Streets, Q_{CGS} , inches per hour,

15. Average Diameter of Storm Drains, D_{SS} , in inches,

16. Average Slope of Storm Drains, S_{SS} , in feet per foot,

17. Average Capacity of Storm Drains, Q_{SSS} , in inches per hour,

18. Hydrologic Radius, $H_R = \frac{A}{P}$, in square miles per mile.

CORRELATION ANALYSIS

A computer-based step-wise multiple regression analysis was employed to select those variables and/or parameters which had the most significant effect on prediction of the unit hydrograph parameters, q_p and tp . In addition correlation analysis was carried out to try to select the most effective definition of the watershed response time.

Preliminary results are summarized:

1. Response Time - The response time defined as the time interval between the centroid of rainfall excess and the centroid of the direct runoff most effectively interacts with the other parameters. From a design point of view, the unit hydrograph rise time is the best definition.

2. Unit Hydrograph Peak - A large number of satisfactory regression equations could be assembled. The best and simplest regression equation was:

$$q_{p(in/hr)} = 10.485\, T_{CC}^{-0.548}\, RF^{-0.145} ,$$

$$R^2 = 0.84$$

where

T_{CC} is the time interval between centroid of rainfall excess and centroid of the direct runoff hydrograph,

RF is the total storm volume.

A complete discussion of the regression analysis will be included in the thesis, Lopez (1973), and will appear in the final report.

Predicting Response Time - Lopez' (1973) results give this regression equation for the response time:

$$T_{CC(minutes)} = 453.346\, T_R^{0.237}\, C_Q^{0.288}\, RE^{0.360}\, H_R^{1.645} ,$$

$$R^2 = 0.78$$

where

T_R is the duration of the total rainfall event,

C_Q is the combined hydraulic capacity of the watershed,

RE is the volume of rainfall excess,

H_R is the Hydrologic Radius.

The thesis by Lopez (1973) develops a large number of cross correlations between the variables. In addition he has carried out an investigation of the effect of using the different definitions of the response time on regression equation using the watershed and storm parameters.

Mr. Lopez is nearing the completion of his thesis. His thesis is barely adequate for the Master of Science degree. His contribution lies in the application of an existing (and now standard) step-wise multiple correlation technique in the selection of significant parameters or variables. He has failed to reconcile his findings with the realities of the physics of the problem. Unless there is a sound physical explanation for the variables selected, the multiple regression analysis is of limited value.

A copy of the thesis by Mr. Lopez will be supplied under the contract; however, the final report will contain a more complete analysis of the problem.

PLANS FOR THE REMAINDER OF CONTRACT

Mr. Lopez' thesis will be duplicated and submitted under the contract. A final report has been started. A review draft will be submitted in accordance with the contract. The basic data tape together with documentation to use the tape will be submitted.

REFERENCES CITED

HEC (1966), *"Generalized Computer Program - Unit Hydrograph and Loss Rate Optimization,"* Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California, August 1966.

Kavvas, M. L. (1972), *"Derivation of Stable Non-Oscillating Unit Hydrographs,"* M.S. Thesis, Dept. of Civil Engineering, Colo. State Univ., July 1972, 106 p.

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