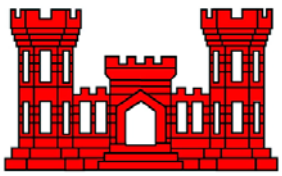
Appendix C
Part 2

Historical Rainfall-Runoff Analysis Using the Antecedent Precipitation Index



U.S. Army Corps of Engineers
Memphis District

HISTORICAL RAINFALL-RUNOFF ANALYSIS USING THE ANTECEDENT PRECIPITATION INDEX

By B. J. Doeing[1], M. ASCE, R. A. Gaines[2], and T. M. James[2]

Abstract

A long term simulation of rainfall-runoff can be used when analyzing the potential for economic benefits or flood damages to result from changes in the watershed, for developing discharge-frequency curves and establishing flow durations, and for applications in unsteady flow hydraulic models. This paper presents a method for computing historical synthetic discharge hydrographs. The procedure uses rainfall gage data, synthetic unit hydrographs, and the antecedent precipitation index (API) to account for regional rainfall losses. A computer program named "HUXRAIN" was developed by the Memphis District U.S. Army Corps of Engineers to simplify the procedure and to perform the analysis.

Introduction

The original HUXRAIN program was written by Robert Brittain of the Memphis District in 1972 as an offshoot to a rainfall runoff model written by Clinton Sumrall of the Lower Mississippi Valley Division. The HUXRAIN program was developed in order to produce period-of-record flow hydrographs in gaged or ungaged basins. Using hydraulic and hydrologic models for a basin, and calibrating these models to gages or historically derived data, period-of-record flow hydrographs can be developed with the program at any designated control point. The duration of the hydrograph simulation depends only on the length of rainfall records available or the study requirements.

---

[1]Vice President, WEST Consultants, Inc., 2111 Palomar Airport Road, Suite 180, Carlsbad, CA 92009-1419, (619) 431-8113

[2]Hydraulic Engineer, U.S. Army Corps of Engineers, Memphis District, 167 North Main Street, Room B202, Memphis, TN 38103-1894, (901) 544-3391

The program has been modified over the years during the transition from mainframe computers to the personal computers of today; however, the structure of the program has remained the same: read in period-of-record rainfall gage data, use a unique unit hydrograph at points where a synthetic flow hydrograph is desired, and use the antecedent precipitation index to account for total rainfall losses.

API - Surface Runoff Relation

The amount of surface runoff from a storm depends on the amount, intensity, and duration of rainfall and the soil moisture deficiency in the catchment at the beginning of the storm. Using rainfall and surface runoff data from gage records and an equation that relates API, precipitation, and time of year, a regional relationship between API and surface runoff was developed. The antecedent precipitation index is one of the more common methods used to account for rainfall loss rates. The rate at which moisture is depleted from a basin is roughly proportional to the soil saturation conditions. The soil moisture should decrease logarithmically with time during periods of no precipitation:

$$API_t = API_0 \; k^t \tag{1}$$

where $\mathbf{API_o}$ is the initial value of antecedent-precipitation index, $\mathbf{API_t}$ is the reduced value **t** days later, and **k** is a recession factor ranging normally between 0.85 and 0.98 (Linsley et al 1975). To compute the API using rainfall data, the equation is rewritten to solve for API as a function of precipitation and time:

$$API = [(0.88^{t_1} PP_1) + (0.88^{t_2} PP_2) + \cdots + (0.88^{t_{30}} PP_{30})] \tag{2}$$

where **t** is the number of days between the date of the API and the date of prior rains (denoted by subscript number), **PP** is the daily precipitation, and **0.88** is the value used for the coefficient **k** in the Memphis District. The correlation developed between API, time of year, rainfall depth, and surface runoff is shown graphically with coaxial curves in Figure 1. On the left side of the figure, a family of curves relate basin recharge and API for particular months of the year in the form of:

$$Y = A(2.0 - API)^2 + B \tag{3}$$

where **Y** represents basin recharge in inches, **API** is determined with equation (2), and **A** and **B** are numerical coefficients used to fit the curves. Basin recharge is the difference between measured rainfall and surface runoff and actually represents all rainfall losses, including evapotranspiration, infiltration, interception, and depression storage. The right side of the figure shows the relationship between rainfall, surface runoff, and recharge that follows from the curves developed on the left side of the figure. Since recharge is the common axis, runoff from a storm event can be

determined when the API is known, as illustrated by the path of the arrows shown in Figure 1.

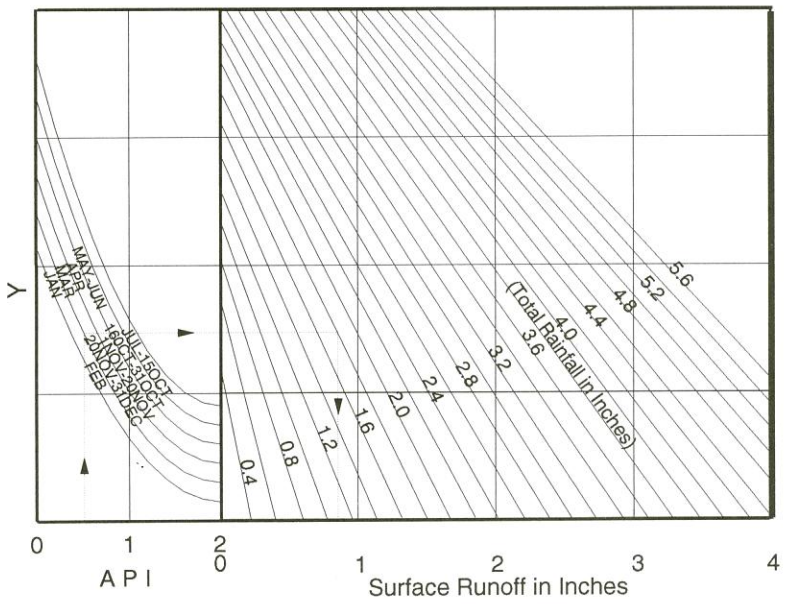


Figure 1. Correlation between API and Surface Runoff

Program Description and Application to Unsteady Flow Modeling.

Analysis of a stream network using an unsteady flow model, such as UNET, requires input of continuous discharge hydrographs throughout the watershed to describe flow at each tributary junction and runoff from intervening sub-basins (UNET 1992). The API methodology and the HUXRAIN program were used successfully to produce continuous hydrographs for an irrigation study in eastern Arkansas. The study area is a humid region where the average annual rainfall ranges from 48 to 52 inches. The procedure used to develop the hydrographs is described below.

In the first step, an HEC-1 model of the watershed was prepared. Although computer program HEC-1 will not yield a long-term hydrograph, runoff from a series of single rainfall events can be analyzed (HEC-1 1990). Partial duration rainfall depths for various return frequency storms were obtained from the National Oceanographic and Atmospheric Administration (NOAA) maps and used with the hypothetical storm option in HEC-1. Input values were estimated for initial and

uniform loss rates and single event discharge hydrographs were produced using Snyder's synthetic unit hydrograph method. The peak flow output for the return frequency flows in HEC-1 was compared to flow rates obtained using the USGS regional regression equations for the basin at selected node points. The loss rates were then adjusted in HEC-1 to produce peak flow output in closer agreement with the regression equation results.

Next, a rainfall data base spanning 24 years was compiled from National Climatic Data Center rain gage data obtained on CD-ROM (Hourly 1993). Gage station weights were based on Thiessen Polygons or similar techniques (Linsley et al 1975). The hourly rainfall data was converted to a 6-hour time base using computer program HEC-DSS (1990). Unit hydrographs with a time base of 6 hours were developed from the HEC-1 output at each point where continuous hydrographs were required. HUXRAIN utilizes a 6 or 24 hour rainfall database to determine the API, then applies the excess rain to unit hydrographs of the same duration to produce the simulated continuous hydrographs.

Having produced a synthetic flow gage of sufficient length of record to establish discharge-frequency relationships, the maximum yearly peak flows obtained from the HUXRAIN program were then evaluated in the flood frequency program HEC-FFA. Adjustments were made to the "A" and "B" coefficients in the API formula for basin recharge until discharge-frequency results agreed more closely with the previous HEC-1 results. After this step, HUXRAIN was executed for each node point, generating a continuous hydrograph and writing it to an HEC-DSS file (HEC 1990) for import to the UNET model. The UNET boundary conditions file was then created by specifying the appropriate DSS input file and path names for the lateral (tributary) and uniform lateral (intervening area) inflow hydrograph records throughout the watershed. The resulting UNET model simulates the combination and routing of all hydrographs along the study reach.

Application to Economic Analysis

Studies involving the analysis of proposed changes to a watershed can be facilitated with long term discharge hydrographs. Proposed changes include channel modifications, such as channel widening or realignment, construction of a dam or reservoir, or simply the removal of debris or bank vegetation from a channel. The changes in the watershed can be evaluated by comparing the impact of the proposed modifications to a baseline condition. In urban areas, economic impacts or benefits can be evaluated using standard discharge exceedence-frequency curves. Damages in urban areas generally occur when a structure is flooded, either partially or completely. However, impacts or benefits in agricultural areas are influenced more by flow duration and timing because damages depend on the time of year and the duration and extent of crop inundation.

Changes in flow duration between the base-line condition and the proposed condition can only be evaluated by comparing long-term discharge hydrographs

under both conditions. Baseline period-of-record discharge hydrographs can be obtained from stream gage records if available; however, ungaged basins or locations without a gage require developing a period-of-record hydrograph synthetically (Grigg 1985). As explained above, HUXRAIN can be used to produce the necessary hydrograph, or synthetic gage, from unit hydrographs obtained from HEC-1.

Economic evaluation of the proposed alternatives begins with the development of discharge exceedence-frequency values and flow and stage durations at the synthetic gages for both baseline and improved conditions. The stage-duration data is derived from flow-duration data and a stage-discharge curve at the gage. Agricultural benefits are accrued if the stage duration above bankfull stage is decreased for the improvement; damages are assessed if the duration increases. The question of whether an alternative is economically feasible (i.e. has a positive Benefit/Cost ratio) would be difficult to answer without stage-duration data and the time of year that bankfull stage is exceeded. These items cannot be accurately estimated without the synthetic gage period-of-record hydrographs.

Conclusions

Regional relationships have been determined by the Memphis District U.S. Army Corps of Engineers for the antecedent precipitation index (API), time of year, rainfall depth, and surface runoff. The District's computer program HUXRAIN uses these relationships with long-term rain gage data and unit hydrographs to develop continuous period-of-record discharge hydrographs. This type of long-term simulation has proven useful in analyzing economic benefits for proposed watershed changes in agricultural areas and for input into unsteady flow models.

References

Grigg, N.S. (1985). *Water Resources Planning*. McGraw-Hill Inc., New York, NY.

HEC-1, Flood Hydrograph Package User's Manual. (1990). U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA.

HEC-DSS User's Guide & Utility Program Manuals. (1990). U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA.

Linsley, R.K., Kohler, M.A. & Paulhus, J.L. (1975). *Hydrology for Engineers*. McGraw-Hill Inc., New York, NY.

UNET, One-Dimensional Unsteady Flow Through a Full Network of Open Channels User's Manual. (1992). U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA.

Hourly Precipitation Data. (1993). U.S. National Climatic Data Center, National Climactic Data Center, Asheville, NC.