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STATISTICAL ANALYSIS OF RAINFALL AND RUNOFF

Proceedings of the International Symposium on Rainfall-Runoff Modeling held May 18-21, 1981 at Mississippi State University, Mississippi State, Mississippi, U.S.A.

Edited by
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PREFACE

In the last three decades there has been a proliferation of research on rainfall-runoff modeling. As a result there exists an abundance of literature in this area. As we enter into a new decade with new possibilities and challenges, it appears appropriate to pause and determine where we are, where we are going, where we ought to be going, and what the most outstanding problems are that ought to be addressed on a priority basis for rapid progress of hydrology. To address these issues in a scientific forum is what constituted essentially the rationale for organizing the International Symposium on Rainfall-Runoff Modeling which was held May 18-21, 1981 at Mississippi State University, Mississippi State, Mississippi.

The objectives of this Symposium were therefore (1) to assess the state of the art of rainfall-runoff modeling, (2) to demonstrate the applicability of current models, (3) to determine directions for future research, (4) to assemble unreported research, (5) to establish complementary elements of seemingly different approaches, and (6) to augment interdisciplinary interaction.

We received an overwhelming response to our call for papers. It was indeed a difficult task to select among the many excellent papers that were contributed, and we regret that we could not include all of them in the Symposium program. The sole criterion for selection of a paper was its merit in relation to the Symposium objectives. The subject matter of the Symposium was divided into 26 major topics encompassing virtually the entire spectrum of rainfall-runoff cycle. Each topic entailed an invited state-of-the-art paper and a number of contributed papers. These contributions blended naturally to evolve a synthesized body of knowledge on that topic. Extended abstracts of all the invited and contributed papers were assembled in a pre-Symposium proceedings volume. Each registered Symposium participant was given this volume. This helped stimulate discussion and exchange of ideas during the Symposium.

The papers presented at the Symposium were refereed in a manner similar to that employed for publishing a journal article. As a result, nearly 40 percent of the papers did not pass the review and were therefore eliminated from inclusion in the final procedings. The accepted papers were divided in four parts. The papers contained in this book, STATISTICAL ANALYSIS OF RAINFALL AND RUNOFF, represent one part of the Symposium contributions. The other parts are embodied in three separate books, MODELING COMPONENTS OF HYDROLOGIC CYCLE, RAINFALL-RUNOFF RELATIONSHIP and APPLIED MODELING IN CATCHMENT HYDROLOGY, which are being published simultaneously. Arrangement of papers in these books under four different titles was a natural consequence of the diversity of technical material discussed in these papers. These books can be treated almost independently, although some overlap does exist between them.

This book contains six sections. Each section starts normally with an invited state-of-the-art paper followed by contributed papers. Beginning with modeling of space-time rainfall the papers go on to discuss application of rainfall models, rainfall-runoff relationship, streamflow, parameter uncertainty and hydrologic extremes.

The book will be of interest to researchers as well as those engaged in practice of Civil Engineering, Agricultural Engineering, Hydrology, Water Resources, Earth Resources, Forestry, and Environmental

Sciences. The graduate students as well as those wishing to conduct research in rainfall-runoff modeling will find this book to be of particular significance.

I wish to take this opportunity to express my sincere appreciation to all the members of the Organizing Committee and the Mississippi State University administration for their generous and timely help in the organization of the symposium. A lack of space does not allow me to list all of them here, but I would like to single out Dr. Victor L. Zitta who chaired the local arrangements pertaining to the Symposium. Numerous other people contributed to the Symposium in one way or another. The authors, including the invited speakers, contributed to the Symposium technically and made it what it was. The session chairmen and co-chairmen administered the sessions in a positive and professional manner. The referees took time out from their busy schedules and reviewed the papers. I owe my sincere gratitude to all these individuals.

If the success of a Symposium is measured in terms of the quality of participants and presentations then most people would agree that this Symposium was a resounding success. A very large number of internationally well-known people, who have long been recognized for their contributions and have long been at the forefront of hydrologic research, came to participate in the Symposium. More than 25 countries, covering the five continents and most of the countries of the world active in hydrologic research, were represented. It is hoped that many long and productive friendships will develop as a result of this Symposium.

Vijay P. Singh
Symposium Director

ACKNOWLEDGEMENTS

The International Symposium on Rainfall-Runoff Modeling was sponsored and co-sponsored by a number of organizations. The sponsors supported the Symposium financially without which it might not have come to fruition. Their financial support is gratefully acknowledged. The co-sponsors extended their help in announcing the Symposium through their journals, transactions, newletters or magazines. This publicity helped increased participation in the Symposium, and is sincerely appreciated. The following is the list of Symposium sponsors and co-sponsors.

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Section 1
SPACE-TIME RAINFALL

STOCHASTIC MODELING OF PRECIPITATION IN SPACE AND TIME

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ABSTRACT

The representation of spacial and temporal changes of precipitation intensity patterns has been recognized for some years by a relatively small group of hydrologists as an important requisite for the successful formulation of distributed models of catchment behavior. Quantitative work in this area, however, probably dates back to the last two decades only.

Since the early 1960's, a number of models were proposed for the simulation of storm precipitation sequences at a point. These models were based on the assumption that precipitation is the result of a stochastic generating process which has specific operating laws and parameters that can be inferred from recorded time series of observed events.

The description and simulation of precipitation fields at ground level for hydrologic modeling dates from the late 1960's or early 1970's. In some of the work published in the last decade, the basic approach consisted of postulating a mathematical stochastic process, the nature of which was assumed on the basis of very general verbal descriptions of the natural processes of precipitation, and to deduce the implications of such a mathematical process in terms of the properties of a simulation model. Other workers have attempted to observe more closely the natural precipitation processes, and to tailor mathematical formulations to their specific description, while recognizing their stochastic nature. In the latter approach, the main support for the formulation of the models has been the consideration of the genetic background of various storm types. A second important point has been the use of a set of field observations obtained from raingage networks, weather radar and other recent remote sensing methods.

Specialized models to describe and simulate the precipitation patterns at ground level due to cyclonic storm bands formed by linear arrays of short-lived cells are reviewed, as well as models of single and multiple cell convective storm patterns. Finally, some of the work accomplished on orographic precipitation is discussed.

The history and theory of these developments is summarized and some of the results obtained are examined.

RAINFALL FIELDS AND CATCHMENT RESPONSE

The effects of spacial distributions of rainfall on the streamflow hydrographs have been recognized intuitively for many years in hydrology. However, attempts to express those effects in general mathematical terms have been hampered by the lack of objective descriptions of precipitation fields at ground level, as well as by the practical difficulties associated with the postulation of general distributed models of catchments. Present-day technology permits the measurement of rainfall rates at points on the ground with some precision, and the installation of dense arrays of telemetering raingages is possible to define temporal and areal patterns in special projects. High resolution doppler radar, with proper ancillary equipment permits the estimation and digital display of precipitation pattens in grids of various coarsenesses, when local topographical conditions do not create excessive "ground clutter" (fixed echoes). These installations and their operation are costly and cannot be expected to be available wherever data are needed for hydrologic modeling. Furthermore, long-term measurements are not available in general, except in selected research catchments. Access to the original information obtained in these catchments is often restricted, and therefore few investigators have had the opportunity to study these problems objectively. There are, however, many instances in common occurrence, which illustrate qualitatively the effects of nonuniformity of spacial and temporal rainfall distributions upon the streamflow rates.

In broad terms, these effects depend on the following factors:

I. Storm Patterns:
  a) Scale of spacial and temporal variability of rainfall.
  b) Coverage of the storms relative to the catchment area.
  c) Storm displacements relative to the ground.
II. Degree of attenuation produced by the catchment on spacial and temporal variability of rainfall.

Storm patterns are associated with reasonably distinct genetic processes. Thus one may state without fear of gross inaccuracy that single-celled convective storms of the so-called "air mass" type are generally characterized by strong transversal precipitation intensity patterns, cover relatively modest areas and have short durations. Likewise, extra-tropical cyclonic storms tend to have banded structures parallel to the fronts. These bands sweep over large areas, and are composed of rapidly moving and evolving clusters of high-intensity precipitation cells.

It can be intuitively expected that a localized convective storm may give rise to quite different streamflow hydrographs at the outlet of a specifically delineated catchment, depending on its area coverage and on the positions it takes over the catchment during its lifetime. The picture is not as clear in the case of an extratropical cyclonic system because although rainbands may sweep large territories, their small scale structure may involve very strong temporal and spacial contrasts.

To illustrate these points, three examples are presented here. The first pertains to thunderstorm activity in Arizona. In a study conducted by the author and his staff at the University of California, Davis (Amorocho, 1973), based on data furnished by the U.S. Department of Agriculture, a detailed, distributed parameter mathematical model was developed for a portion of the Walnut Gulch Experimental Watershed. This semiarid catchment, located near the southeastern corner of the state is instrumented with a very dense network of recording raingages, which permits mapping precipitation events in considerable detail. Runoff-producing storms are almost exclusively of the convective type, and occur during the summer. Figure 1 is a map showing a typical isohyetal pattern of rainfall intensities at a particular moment during one of such storms. This event produced localized runoff in the small subcatchment shown in Figure 2.

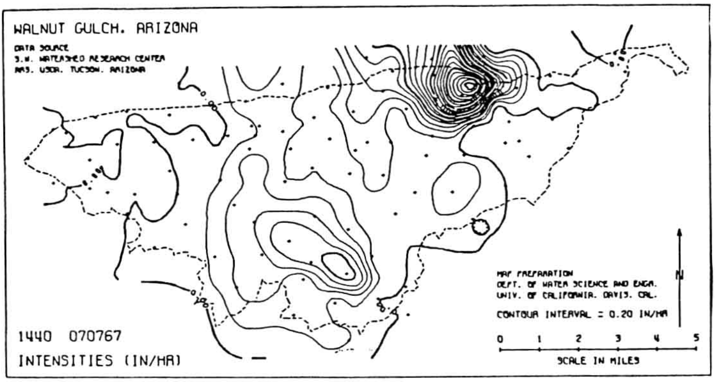

Fig. 1 Instantaneous isohyetal map of a Convective Storm over Walnut Gulch Watershed, Arizona on July 7, 1967, drawn at 14:40 hours local time. (Data furnished by the Department of Agriculture)

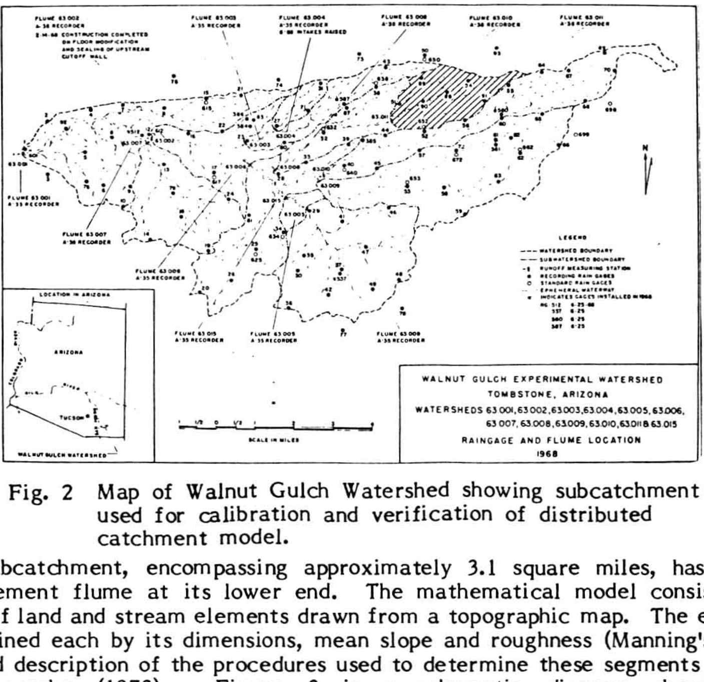

Fig. 2 Map of Walnut Gulch Watershed showing subcatchment used for calibration and verification of distributed catchment model.

This subcatchment, encompassing approximately 3.1 square miles, has a flow measurement flume at its lower end. The mathematical model consists of a series of land and stream elements drawn from a topographic map. The elements are defined each by its dimensions, mean slope and roughness (Manning's n). A detailed description of the procedures used to determine these segments is given by Amorocho (1973). Figure 3 is a schematic diagram showing the interconnections between land and stream segments. To operate the model, rainfall intensities obtained from sets of maps such as that shown in Figure 1 for each time interval, are applied to the center of each underlying land element. Thus, individual hyetographs are found for all the elements. The model then computes the infiltration, and overland flow for each time interval and each land element, keeps account of the lateral inflows to the channel segments and routes the flows in succession. Figure 4 shows a set of hydrographs computed at various positions in the channel network by means of the model, for the storm of July 7, 1967 (Figure 1 is the instantaneous isohyetal map of this storm at the hour 14:40).

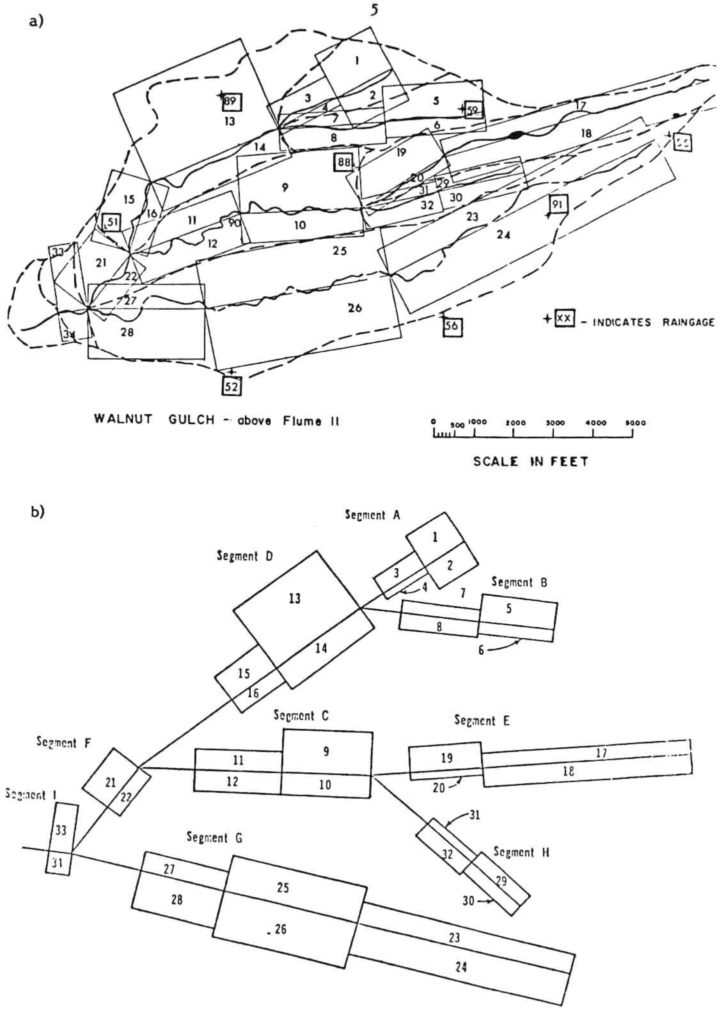

Fig. 3 a) Division of Walnut Gulch subcatchment into equivalent land and stream segments.
b) Schematic diagram of segment linkages. (Amorocho, 1973)

It can be appreciated that a detailed temporal and spacial description of the precipitation field at ground level was crucial. This is particularly evident when one considers that in the Walnut Gulch Watershed the channel infiltration rates are so high that all flows vanish in a short distance. An illustration of the localized nature of the surface flow is given in Figure 5, which shows two hydrographs recorded in August 1968 at measuring flumes installed on the ephemeral stream draining the subcatchment mentioned above, at a distance of approximately 3½ miles from each other. It is seen that the peak flow dropped from about 1500 cfs to slightly above 400 cfs in this distance, and the flow volume was reduced by about one-half.

The second example is the hilly, 5 square mile Castro Valley catchment, located in Northern California, overlooking San Francisco Bay. Here, the

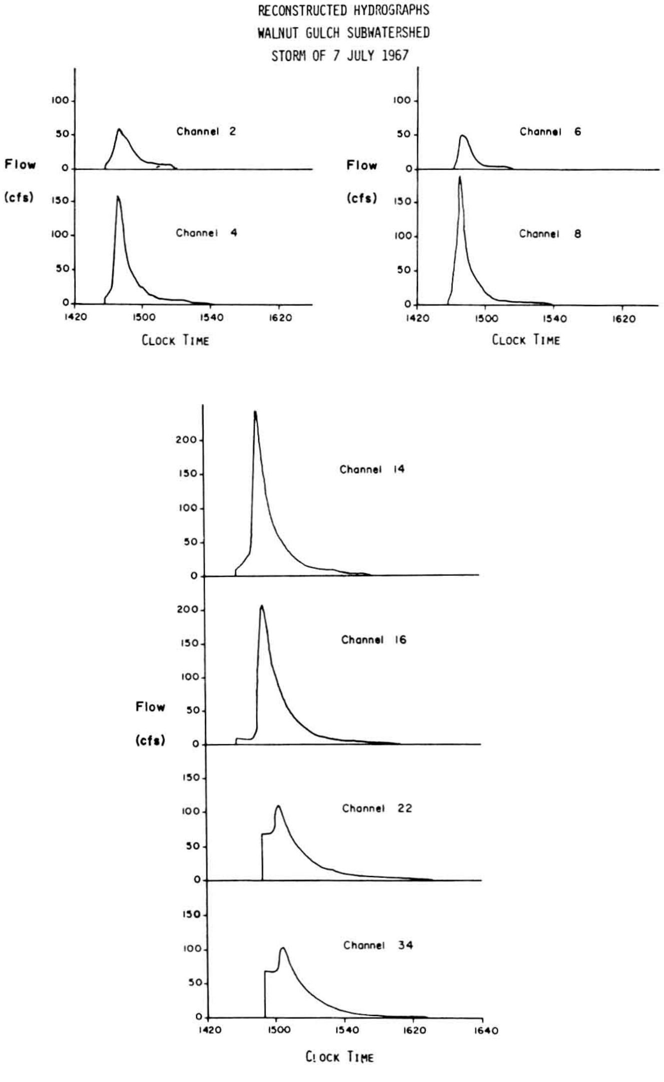

Fig. 4 Reconstructed Hydrographs at various positions within Walnut Gulch Subcatchment, computed with the hydrologic model. (Amorocho, 1973)

runoff-producing events are extratropical cyclonic systems advancing inland from the Pacific Ocean. As remarked earlier, these storms have typically banded configurations consisting of rapidly moving clusters of rain cells. The rainfield is not uniform; although basinwide precipitation may be observed, large contrasts exist between instantaneous rainfall intensities at neighboring points, as illustrated

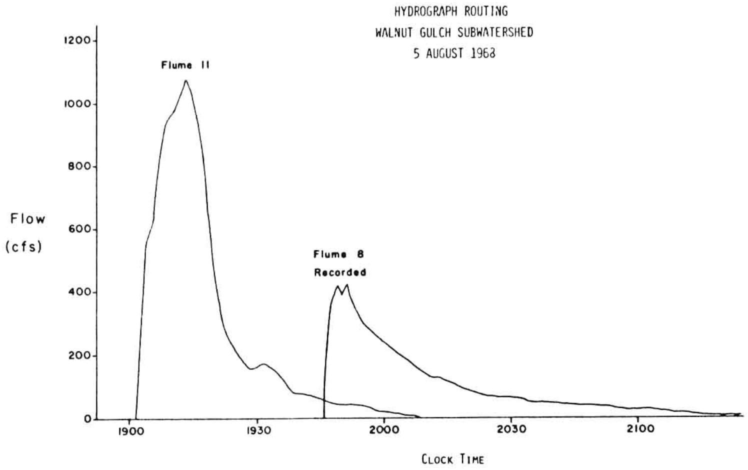

Fig. 5 Hydrographs of the main stream of Walnut Gulch subwatershed showing effect of channel infiltration. No rainfall occurred in the tributary area between streamgaging flumes 11 and 8. (USA data)

by the isohyetal map shown in Figure 6, constructed from data on one such storm, recorded at a dense raingage network near Davis, CA, operated by the University of California, in 1969-70. Unfortunately, the records of only one raingage were available in Castro Valley, together with data from a streamgaging station located at the catchment outlet. A lumped parameter nonlinear functional rainfall-runoff model was tried here. Figure 7 portrays the typical results of a model calibration, in which the flows were computed at 5-minute time intervals from five-minute precipitation data. In general, for this period, the recorded and the computed flows are in reasonably good coincidence. By contrast, some verification calculations performed for other periods, such as the one shown in Figure 8, did not indicate as good an agreement between recorded and computed values. This behavior could have been attributed entirely to model error if it were not for the fact that the model performance tended to improve in this example when the simulation continued, as can be seen in Figure 9.

Furthermore, in some cases not shown here, no rain was recorded when there was a rise in the hydrograph. Given the nonuniformity of the rain in cyclonic storms, it is plausible therefore to conclude that a single raingage may be insufficient for the simulation of runoff in small catchments, when the latter are incapable of attenuating the effects of fairly high frequency and wave number variations of the rain fields.

The third example is the catchment of Petaluma Creek, also in Northern California. A nonlinear functional model of the same type employed for Castro Valley was used. Hourly data from one raingage and one streamgaging station were available here. The basin has an area of approximately 30 square miles and drains into San Francisco Bay. Its runoff is also due primarily to cyclonic storm systems. In Figure 10 is shown a comparison between recorded and computed hydrographs for a calibration period, and Figure 11 depicts the results of a verification run. It is noted that in the verification run the recorded streamflows were reproduced with fair accuracy, although the precipitation data were originated at a single raingage. This example shows that if the catchment