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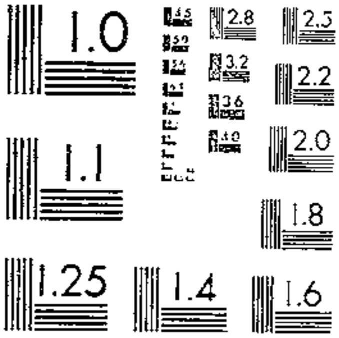

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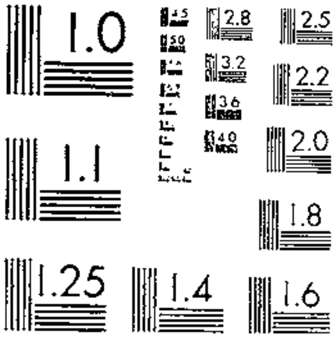

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

The Hydrology and Hydrogeology of Ahoskie Creek Watershed, North Carolina: Data and Analysis

Prepared by
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North Carolina State University Agricultural Experiment Station

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PREFACE

The research upon which this bulletin is based was a cooperative effort of the USDA Agricultural Research Service, the USDA Soil Conservation Service, the U.S. Geological Survey, the North Carolina Department of Natural and Economic Resources, and the North Carolina Agricultural Experiment Station. The purpose of the research was to collect, analyze, and interpret hydrologic data in order to determine the hydrologic characteristics of Ahoskie Creek watershed in the Coastal Plain of North Carolina.

Although the Agricultural Research Service had the primary responsibility for analyzing, summarizing, and publishing the data, the cooperative agencies made important suggestions during all phases of the study and reviewed the findings of the project. The program, as complex as it was, could not have been accomplished by any single agency. ARS was not actively engaged in the collection of field data.

The research team jointly developed a philosophy to make the presentation of data, analyses, and interpretations orderly and meaningful. The general philosophy is to provide users with a complete package including all phases and interrelations of the project. For the sake of brevity, details of methodology are not presented. However, all methodologies are referenced to direct interested readers to sources containing necessary details.

The bulletin is divided into six main sections. The "Introduction" describes the formulation of the project and outlines the study. "Watershed Physical Characteristics" contains the information provided by one-time or survey-type data. "Channel Characteristics" treats stability and conveyance. "Basic Data and Representativeness" describes the data available, data summaries in the appendix, and considerations of precipitation normalcy of record periods. "Data Summarization" gives the first level of information from the time-dependent data. "Analyses and Interpretations" includes information on hydrologic component interrelations and hydrologic and geohydrologic inferences.

Because of the comprehensive nature of the report, a brief summation of the most significant findings is presented, rather than a full summary. Users are cautioned to exercise care in taking excerpts out of context, lest misuse and misinterpretations result. Developments and findings are appropriately referenced.

The research team wants to provide the most practical information possible. Since any publication may be inadequate for specific needs, users needing supplemental information should contact the authors.

SIGNIFICANT DEVELOPMENTS AND FINDINGS

During the study, methods, techniques, and mathematical models were developed to get as much information and as many inferences as possible from the data. These methods and models are significant in themselves because they were established as a means of factoring and expressing information in orderly steps. These technologies are important for application in other analyses in the future and are not limited to the Ahoskie Creek watershed study.

The models are (1) the multiple-event model: the simultaneous analysis of up to seven storm hydrographs to optimize parameters of characteristic, retention, and routing functions that make up the storm model (sec. 6.2.2); (2) the 5-day water-yield model: the development of a seasonally cyclic storage function to express capacity of a watershed to retain rainfall or to partition precipitation into streamflow and not-streamflow (sec. 6.1.2); (3) the recession model: the development of a parametric model to analyze recessions of streamflow volume and ground-water elevation and to predict recessions (secs. 6.3.1 and 6.3.2); and (4) the stochastic rainfall model: the application of frequency-distribution fitting techniques to express stochastically the distribution of storm rainfall in time (sec. 5.1.3).

Several significant findings resulted from the Ahoskie Creek watershed study. The quantitative results are of course unique to the Ahoskie Creek watershed, but inferences can be made concerning the possible hydrologic characteristics of other watersheds with similar treatment and climatic conditions. The study was not adequate to establish conclusively the effects of channelization on the hydrologic response of the Ahoskie Creek watershed. Rainfall data before treatment were limited to daily amounts at one nearby gage; there were no ground-water observations prior to treatment; and only one stream gaging station was operative before channelization.

Ground water in the Yorktown aquifer was recharged to near capacity each year with the channel system that now exists in the Ahoskie Creek watershed. Although some water drained from the aquifer during the growing season and maintained a beneficially low flow, the aquifer was recharged annually to near capacity during the dormant season (secs. 5.3 and 5.4.3.2).

The drainage characteristics of Ahoskie Creek have been changed by the constructed channel system. Prior to channelization, the largest contribution to streamflow occurred in the 5-day period following a 5-day period of precipitation. After channelization, the largest contribution occurred in the same 5-day period as precipitation (sec. 6.1.2).

Streamflow-duration analyses show that the low flow from the full study area during the growing season was greater after channelization than before channelization. Successive months of record low precipitation after treatment did not result in any days without some streamflow at the gaging station for the 57-square-mile watershed (W–A1). Before channelization, periods in excess of a month sometimes had no streamflow (sec. 5.4.2.1).

Construction of channels may have altered the flow regime in the Yorktown aquifer. Watershed W–A1 showed a seasonal reallocation of flows, most likely because of an increased available storage capacity during the recharging season and an increased supply to streamflow during the season of normally low flow (secs. 5.4.2.1 and 5.4.2.2).

During the study, the water table in the Yorktown aquifer was not permanently lowered at an observation point approximately 2 miles from the nearest channel. Since this observation well is within the Ahoskie Creek drainage system, the channel system can have little effect on the Yorktown aquifer outside of the Ahoskie Creek Basin (sec. 5.3).

Channel conveyance capacity at W–A1 increased for low stages and decreased at intermediate and high stages. Capacities at W–A2 and W–A3 decreased at all stages, and the channel capacity at W–A4 remained relatively constant (sec. 3.2).

Published streamflow data show that the average annual streamflow was greater after channelization than before channelization. Average annual point rainfall at the Elliott Station was 48.31 inches before treatment, and average annual measured streamflow was 13.56 inches. After channelization, the average annual point rainfall was 45.58 inches, and streamflow was 15.38 inches. However, some conditions should be pointed out in regard to this finding. Point rainfall does not necessarily represent accurately the watershed rainfall. For example, watershed average annual rainfall for the rain-gage network was 42.47 inches after channelization, about 3 inches less than at the Elliott Station. Most of the increased streamflow occurred during 2 months of extreme rainfall that caused large volumes of runoff (sec. 6.1.1 and tables A–13 and A–15).

The largest storm peak-discharge rate and storm volume in the 23-year record on watershed W–A1 occurred during the first year after channelization. The capacity of the channel was adequate to contain the discharge within banks. Frequency analysis indicates possible return periods of 25 to 50 years, depending upon the method of analysis (secs. 5.2.1 and 5.2.2).

Channels constructed in the Ahoskie Creek watershed are relatively stable. Cross-sectional surveys and resurveys showed little absolute change in time. Some degradation and shifting occurred in curved sections, and aggradation occurred in straight sections. Sections of instability could not be correlated with soil types existing in adjacent banks of the monumented reaches (sec. 3.1).

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SECTION 1.—INTRODUCTION

In 1960, a watershed work plan was developed for the Ahoskie Creek, N.C., watershed by the Soil Conservation Service.[1] Improvements were carried out under the authority of the Watershed Protection and Flood Prevention Act (Public Law 566, 83d Cong., 68 Stat. 666) as amended. This watershed, consisting of 48,150 acres (75.23 square miles), is located in Hertford, Bertie, and Northampton Counties in northeastern North Carolina. Work on the Ahoskie Creek watershed was necessitated by (1) erosion damage, (2) sediment damage, (3) floodwater damage, and (4) other water-management problems.

Older residents of the area recalled that the stream channels in the watershed were well defined in the early 1900's and that flooding of cropland seldom occurred from even extremely heavy rainfall. However, extensive timbering in the broad, swampy flood plain left a great amount of debris, much of which fell, or was later moved by floods, into stream channels. The debris impeded the natural flow of water, resulting in the accumulation of sediment deposits in the channels. Consequently, the stream channels all but completely disappeared. The progressive decrease in stream-channel capacity resulted in more frequent flooding, with higher stages and of longer durations. By the late 1950's, approximately 1,500 acres of cropland and pasture adjacent to the wooded flood plain were inundated as often as five times a year. Over 4,300 additional acres suffered damage directly associated with the flooding of adjacent land. Prolonged flood stages extended into field drainage ditches, preventing the normal movement of surface runoff and causing extremely wet soil conditions for long periods. Moderate to moderately severe sheet-erosion damage occurred on approximately 3,700 acres, and another 4,200 acres suffered from less serious erosion problems. Nearly 1,000 acres of cropland along edges of the flood plain were abandoned.

Under Public Law 566, the following improvements were recommended to alleviate these watershed problems: (1) land-treatment measures, including complete individual farm conservation plans, tile drains, surface field ditches, cover cropping, strip cropping, grass waterways, terraces, legume and grass rotations, and the planting of trees, and (2) structural measures, including the construction of 22.1 miles of stream channels and 43.6 miles of lateral drainage ditches.

These projects were designed to provide drainage, within 24 hours, of storms of a 2- to 5-year frequency of occurrence and to provide every farmer a drainage outlet within a reasonable distance of his farm. Land-treatment practices and channel improvements were completed between 1960 and 1965.

1.1.—STUDY PLAN

In October 1963, a memorandum of understanding was entered into by the Soil Conservation Service (SCS), the Agricultural Research Service (ARS), and the North Carolina Agricultural Experiment Station (NCAES) for a cooperative program for watershed-engineering investigations in the Southern Coastal Plain. The Ahoskie Creek watershed was designated as the study area for these investigations.

An overview of the investigations, as proposed, is given in the following paragraph from the memorandum of understanding:

> The primary purpose of the work contemplated is to determine the relation between watershed characteristics and conditions on runoff rates and water yields in the Coastal Plain. Evaluation, over a 10-year period, of the effects of structural works and land treatments applied under the Watershed Protection and Flood Pre-

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[1] Watershed work plan, Soil Conservation Service, Ahoskie Creek watershed, December 1960.

> vention Program of the Soil Conservation Service is a prime aim. Channel behavior in relation to the program will be considered. The approved watershed program includes land treatment measures such as on-farm drainage, conservation cropping system, strip cropping, terracing, contour farming, etc.; and structural measures consisting of channel improvement. In the course of the investigation it may be necessary to develop procedures for evaluating the effect of certain program measures. The primary aim of the investigation will be to (1) develop hydrologic procedures which will enable better construction of synthetic hydrographs suitable for Coastal Plain watersheds; and (2) develop procedures for predicting water yield from basic climatic data.

The Southeast Watershed Research Center (SEWRC) of ARS was assigned to fulfill ARS obligations to the project. Procedures, objectives, techniques, and so forth were to be developed by the SEWRC in consultation with the other agencies involved. The SEWRC is now designated as the Southeast Watershed Laboratory (SEWL).

1.1.1.—General Purpose

The general objectives of the Ahoskie Creek watershed study as agreed upon by ARS, SCS, and NCAES were (1) to determine the precipitation characteristics, runoff characteristics, and water-yield potential of agricultural watersheds in the Coastal Plain of the Southeastern United States; (2) to measure the effects of channel improvement on surface runoff and ground-water replenishment; and (3) to identify and measure the geological components associated with ground- and surface-water yields from agricultural watersheds in this area. In achieving these objectives, information has been developed for establishing criteria for the planning, construction, and operation of small watershed projects in the coastal area, thereby reducing the costs of these projects.

1.1.2.—Procedures

The following basic steps were listed in the memorandum of understanding: (1) the assemblage and preparation of available pertinent data, (2) analyses of such information to devise procedures for evaluating the effects of watershed treatment and associated factors on runoff rate and yield of streams, (3) a comparison of derived methods with the results obtained from other investigational watersheds to develop regional techniques, and (4) the development of analytical procedures and methods during the project.

1.1.3.—Cooperators' Responsibilities

1.1.3.1.—SOIL CONSERVATION SERVICE

Responsibilities of SCS were (1) to assist local organizations in developing and installing a program of watershed protection and flood prevention, (2) to install, operate, and maintain instrumentation, (3) to collect, assemble, and process basic data, and (4) to determine watershed physical characteristics by surveys and watershed conditions from land use and cover inventories at 5-year intervals.

1.1.3.2.—NORTH CAROLINA AGRICULTURAL EXPERIMENT STATION

Responsibilities of NCAES were (1) to assist in planning instrumentation, (2) to assist in processing basic data, (3) to install, operate, and maintain additional instrumentation as required to meet the objectives of the NCAES, (4) to collect, assemble, and process data obtained from this additional instrumentation, (5) to maintain a file of those data obtained by station personnel and to make copies available to the central file at the SCS State office in Raleigh, (6) to make required analysis, evaluation, and interpretation of data, and (7) to provide biometric services and make computation facilities available to other agencies.

1.1.3.3.—AGRICULTURAL RESEARCH SERVICE

Responsibilities of ARS were (1) to assist in planning the instrumentation, (2) to assist in processing basic data, (3) to prepare, analyze, and publish monthly precipitation and runoff data, annual maximum discharge and maximum volumes for selected time intervals, and selected storm-runoff events, including antecedent rainfall and runoff before the event, runoff rates and accumulated amounts for the event, and watershed characteristics and conditions at time of the event, (4) to analyze, evaluate, and interpret data and results, and (5) to prepare and publish a comprehensive report of the entire project.

1.1.4.—Data-Collection Responsibilities

1.1.4.1.—PRECIPITATION

SCS collected precipitation data from seven analog precipitation gages. The U.S. Geological Survey (USGS), under contract with SCS, collected precipitation data from three tipping-bucket gages.

1.1.4.2.—STREAMFLOW

The U.S. Geological Survey collected streamflow data at one site beginning in 1950. Under contract with SCS, USGS collected streamflow data from one additional site beginning in 1963 and two additional sites beginning in 1964.

1.1.4.3.—GROUND WATER

SCS collected ground-water elevations from eight observation wells equipped with analog stage recorders.

1.1.4.4.—OTHER DATA

SCS prepared land-use maps and soils maps and made channel cross-sectional surveys at selected points. SCS and ARS collected fragmented-washed and flight-auger samples during drilling of the ground-water observation wells, and resistivity logs were obtained at the same time. SCS and ARS made specific capacity tests; SCS collected soil samples and made soil analyses for a channel stability evaluation (table A–6); and USGS made crest-gage observations at selected points along the main channel. (Crest-gage data are not included in this publication, but they are available upon request to the cooperating agencies.)

1.2.—WATERSHED

1.2.1.—Location

The Ahoskie Creek watershed is located in the lower Coastal Plain of northeastern North Carolina. Of the 48,150 acres covered by the Public Law 566 work plan, only about 38,150 acres (59.6 square miles) were included in the study area. Ahoskie Creek originates in the eastern part of Northampton County just east of the town of Rich Square and flows in an easterly direction, joining other tributaries before draining into the Chowan River, which in turn drains into Albermarle Sound.

Gaging stations were located at three points on the main stem and at one point on a tributary stream (*fig.* 1.1). Drainage areas above

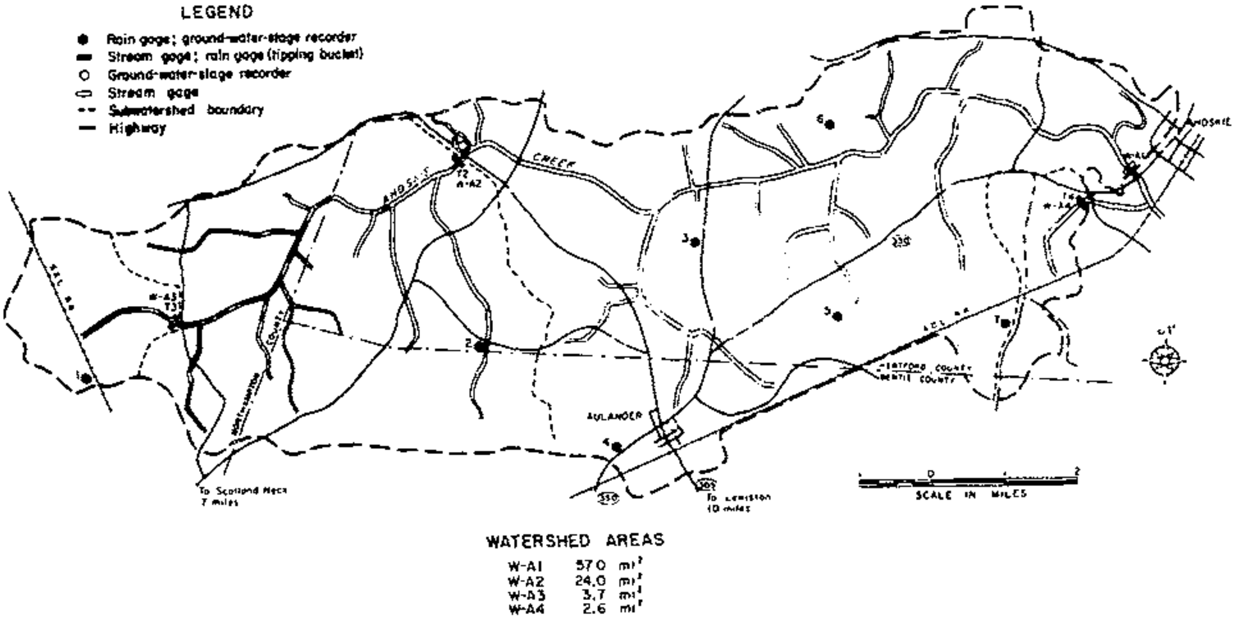

FIGURE 1.1.—Ahoskie Creek, N.C., watershed map.

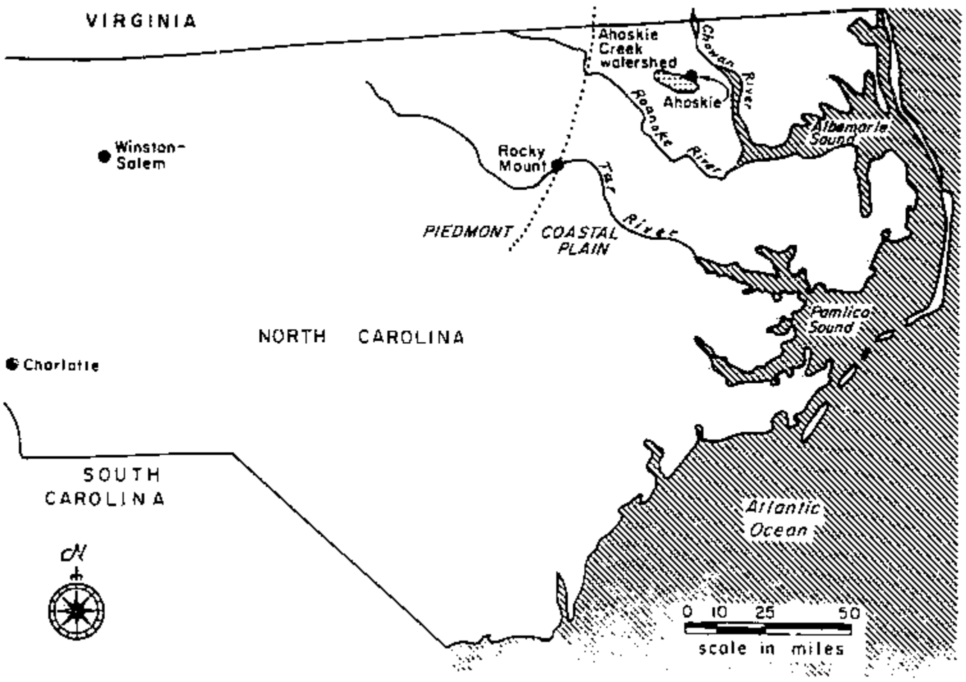

FIGURE 1.2.—Ahoskie Creek, N.C., watershed location map.

the main-stem gaging stations are 57.0, 24.0, and 3.7 square miles, respectively, and the drainage area above the tributary gaging station is 2.6 square miles. The terminal stream-gaging station of the study watershed was at State Highway 350 at Ahoskie. The town of Aulander and a portion of Ahoskie lie within the watershed. The town of Ahoskie is approximately 65 miles from the Atlantic Ocean (fig. 1.2).

1.2.2.—Geology and Soils

The Atlantic Coastal Plain and the Southern Coastal Plain are characterized by broad, flat surfaces that dip gently seaward. These provinces are underlain by several artesian and semiartesian Tertiary and Cretaceous aquifers lying unconformably on crystalline Paleozoic and Precambrian basement rocks. The basement rock is uneven and slopes to the southeast (*21*).[2] This slope steepens at the present coastline, and the basement rock in general controls the surface slope and the slope of the Cretaceous and Tertiary sediments.

The soils of the watershed are representative of those found in the northern part of the Coastal Plain in North Carolina. Derived from moderately fine-textured sediments, they are chiefly members of the Craven, Levin, and Coxville series, having fine sandy loam or silt loam surface soils and firm, slowly permeable clay subsoils. In the lower portion of the watershed, smaller areas of Norfolk, Goldsboro, Lynchburg, and Rains soils series are also found, consisting of fine sandy loam surface soils and moderately permeable sandy clay loam subsoils. Flood plains are covered with recently deposited mixed alluvial materials and also Bibb series sometimes. Data for topsoil, subsoil, and substratum in the four drainage areas, as well as surface slope, soil-erosion class, and land-capability distributions, are presented in tables A–2 through A–5.

1.2.3.—Topography and Surface Drainage

Although Ahoskie Creek is included in the Atlantic Coastal Plain physiographic province, it lies on the boundary of the Atlantic Coast Flatwoods. The nearly flat watershed surface has a number of marine terraces that are erosional remnants from Pleistocene sea transgressions. Since Pleistocene times, rivers and streams have altered the area to form the

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[2] Italic numbers in parentheses refer to items in "Literature Cited," p. 137.

present-day drainage pattern, which in turn has been changed by dredging.

The Coastal Plain of North Carolina is characterized by broad, flat surfaces, which represent an emerged ocean floor, and a lack of topographic variations. Broad, flat interstream areas are dominant and vary from gently rolling to broken slopes toward the drainage ways. There are well-defined flood plains that are subjected to inundation for long periods after rainfall. The Chowan, Roanoke, Tar, and other rivers draining the area originate in or flow through the Piedmont Plateau to the west and flow southeast in a somewhat parallel direction (fig. 1.2).

Ahoskie Creek drainage was well defined some 50 years ago, but large timber operations left debris on the flood plains and in the channel, causing sediment accumulation and reducing channel capacity and drainage rates from farmland. This drainage system was altered by the channel improvement measures taken under the Public Law 566 program and is now one of dredged channels and drainage ditches. In addition, on-farm tile and open-ditch systems have been increased. The principal channel system provides greater efficiency of subsurface drainage by the on-farm systems.

1.2.4.—Land Use

The Ahoskie Creek watershed is predominantly an agricultural and woodland area. Nearly two-thirds of the area is woodland, about one-fourth is cropland, and the remainder is pasture, roads, railroads, or urban areas, or it is idle. The main crops are peanuts, cotton, soybeans, corn, and tobacco. Woodland consists primarily of pine, cypress, cedar, gum, yellow poplar, and oak.[3]

1.2.5.—Climate

The Ahoskie Creek watershed is in a humid, temperate region. Summers are moderately short and cool with high humidity. At the National Weather Service station at nearby Lewiston, N.C. (fig. 1.1), the 18-year mean annual temperature is 59.8° F (*26*). Mean monthly maximum and minimum temperatures are shown in figure 1.3. The mean monthly maximum occurs in July, but the maximum daily temperature generally occurs in late June. An 18-year record high of 103° F was recorded on June 30, 1959, and the record low was a −1° F on January 13, 1962. Maximum temperatures are normally in the upper 90's during June through August, and minimum

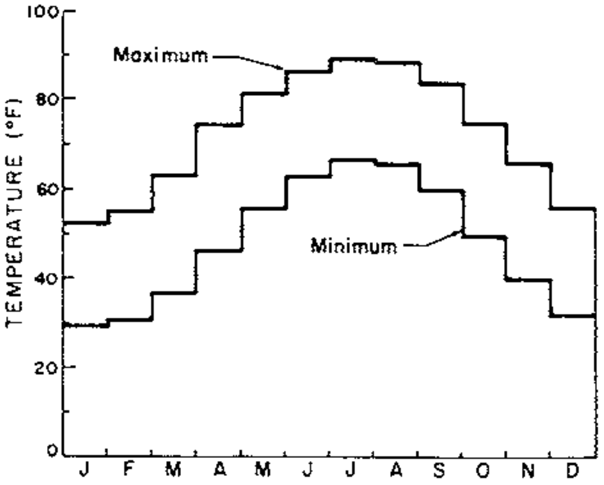

FIGURE 1.3.—Mean monthly maximum and minimum temperatures, Lewiston, N.C. (1954–71).

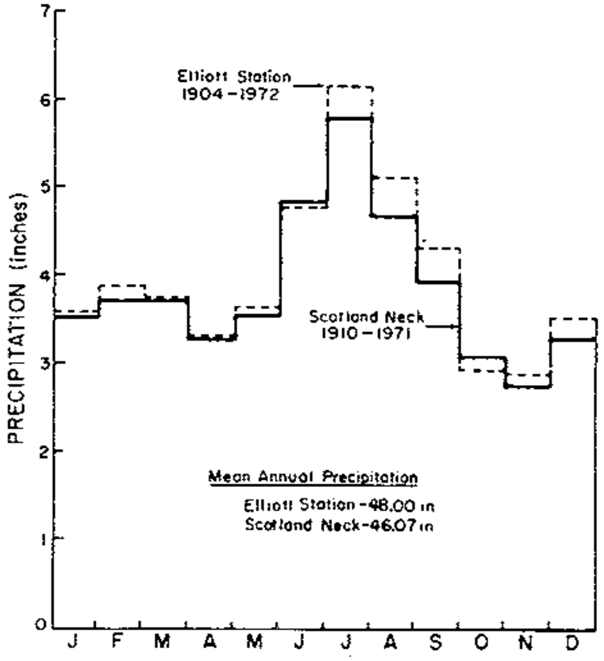

FIGURE 1.4.—Mean monthly precipitation, Scotland Neck, N.C. (1910–71), and Elliott Station, Eagleton, N.C. (1904–72).

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[3] Watershed work plan, Soil Conservation Service, Ahoskie Creek watershed, December 1960.

temperatures are rarely below 10° F. The frost-free season at Lewiston ranged from 157 days in 1963 to 213 days in 1954, the average being 190 days, from April 14 to October 21.

The long-term average annual precipitation at Scotland Neck, N.C. (fig. 1.1), is 46.07 inches (*26*), and at Elliott Station near Eagletown, N.C., 48.00 inches.[1] Mean monthly precipitation values are shown in figure 1.4. Precipitation is reasonably well distributed throughout the year, the mean monthly maximum occurring in July, followed closely by June and August. Winter precipitation is widespread and associated with frontal movement, and the little snowfall that occurs in the watershed is not hydrologically significant. Rainfall during the growing season (April through September) averages approximately 26 inches. Summer rainfall is characterized by convective thunderstorms, and in some years tropical storms have produced heavy rainfall in late summer and early fall. Rainfall observed in the watershed during the study period was not generally excessive in amount or intensity. The heaviest downpour occurred on August 20 and 21, 1967, when a total of 18.6 inches fell. The storm lasted 42 hours, with 14 inches of rain falling in one 8-hour period. A maximum of 6 inches was recorded in 1 hour at a tipping-bucket gage within the watershed. This was a small localized storm of limited areal extent which resulted in a small amount of runoff.

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[1] Unpublished precipitation data furnished by Miss Alice Elliott, Woodland, N.C. Location originally shown as "near Eagletown."

SECTION 2.—WATERSHED PHYSICAL CHARACTERISTICS

Basic physical characteristics were initially examined and evaluated to determine how each might affect or be affected by hydrologic factors or by other physical factors. However, information available was insufficient to properly describe watershed physical characteristics, especially subsurface conditions. Because the limited number of observation wells drilled (eight) did not provide enough information to prepare a satisfactory picture of subsurface conditions, any data analysis involving subsurface factors is necessarily limited. Information on surface physical conditions, though not as extensive as desirable, is more adequate than data on subsurface characteristics. A brief discussion of the information available for use in later hydrologic data analysis is presented in the following sections.

2.1.—HYDROGEOLOGY

To a large extent, marine terraces control the present-day topography. These terraces have formed some watershed boundaries and significantly affect the ground-water hydrology of the Ahoskie Creek area because they have a high infiltration rate that reduces direct surface runoff. This reduction makes large quantities of water available for recharge of the Yorktown Formation, which lies directly below these Pleistocene terraces. The low permeability rate and the high water table of the Yorktown Formation impede vertical flow, causing water within the surficial terraces to move laterally toward the channels.

2.1.1.—Stratigraphy

The sediments of the Coastal Plain that were deposited on crystalline basement rocks form a definite ground-water boundary. The crystalline rocks are approximately 400 feet below the surface in the headwater area of Ahoskie Creek and 600 feet or more below the surface in the area of the city of Ahoskie (*8*). The sediments form a wedge, thickening toward the coast, and are derived from the weathering and erosion of the crystalline rocks of the Blue Ridge and Piedmont provinces. They were deposited under marine conditions, with the exception of some of the Quaternary sediments.

Elevation of land masses, retreat and encroachment of the seas, weathering, and erosion have caused the deposition of sediments to be discontinuous throughout the Southern Coastal Plain. The general stratigraphic section of the formations found in the Coastal Plain of North Carolina is shown in table A-1, extracted from Mundorff (*10*). However, only Quaternary surficial deposits and Yorktown, Beaufort, undifferentiated Upper Cretaceous, and Tuscaloosa subsurface formations were encountered in the investigation of the Ahoskie Creek watershed. Surface outcrops consist of Yorktown and Quaternary sands, silts, clays, and degraded limestones. The Quaternary sediments range in thickness from a few inches to several feet.

Subsurface investigations, drilling, and resistivity measurements were limited to 200 feet below the present land surface. Cretaceous sediments were encountered in all wells drilled in the Ahoskie Creek watershed.

2.1.1.1.—CRETACEOUS SYSTEM

The Tuscaloosa Formation, encountered in wells 1, 3, and 8 (fig. 2.1), has a dip varying from 15 to 20 feet per mile, strikes, in general, N. 50° E., and is composed of tan to red arkosic sands and interbedded clays. Hematite is a common accessory mineral. The origin is marine to nonmarine, indicating a near-shore depositional environment. Depth measurements of ground-water wells indicate that this formation does not receive any, or at least little, ground-water recharge within this area. Ground-water observation well 8 is screened in this aquifer (table A–7).

Undifferentiated Upper Cretaceous sedi-

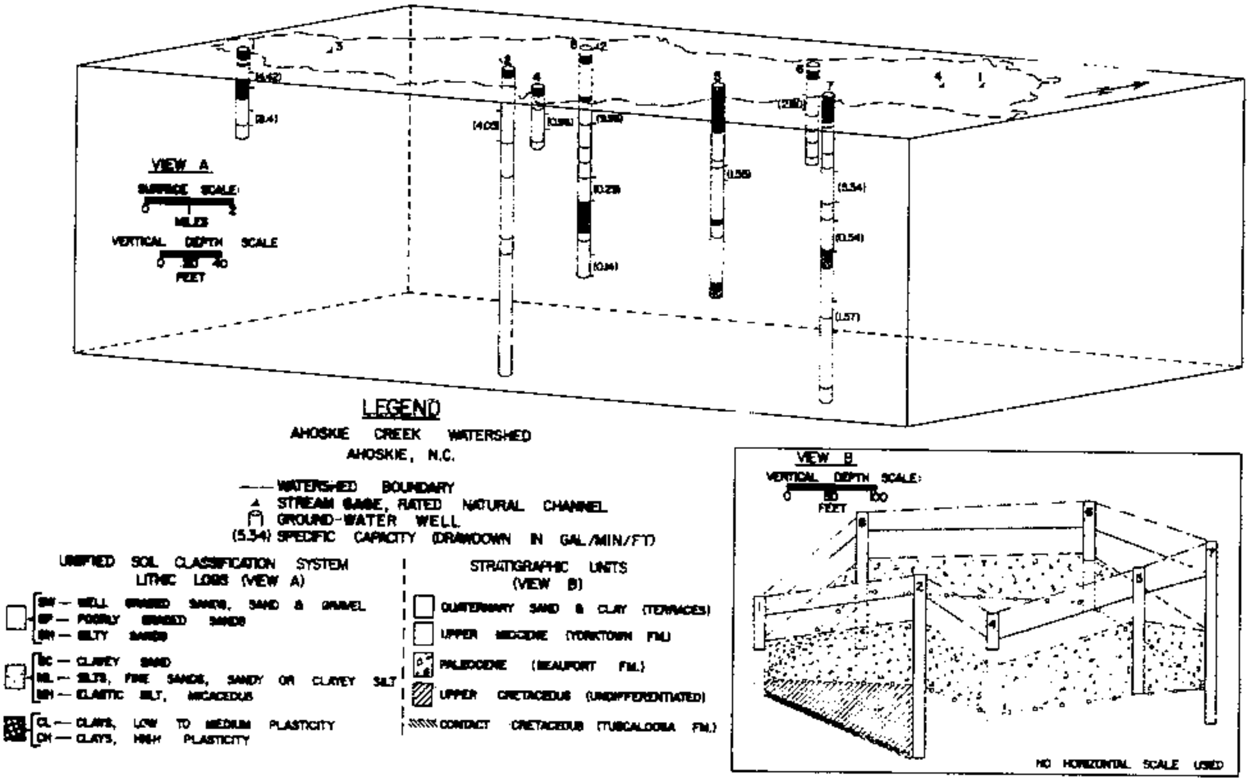

FIGURE 2.1.—Stratigraphic map, Ahoskie Creek watershed.

ments and Black Creek and Peedee Formations overlie the Tuscaloosa. These sediments, encountered in all wells drilled, dip from 6 to 8 feet per mile in a southeasterly direction and strike, in general, N. 30° E. These Upper Cretaceous shallow-water marine shelf deposits are composed of dark-gray to black interbedded clays, sands, and marls with glauconite and are predominantly lenticular. Rising land masses, weather, and erosion during the Laramide Orogeny altered these sediments a great deal.

2.1.1.2.—TERTIARY SYSTEM

2.1.1.2.1.—Paleocene Series

The Beaufort Formation was unconformably deposited on the undifferentiated Upper Cretaceous sediments after the sea inundated the area. The strike of the formation is N.15°W. and dips from 2 to 3 feet per mile (fig. 2.2). The composition varies from green glauconitic sands and gray argillaceous sands to sandy silt and clay deposited under marine conditions. Resistivity curves indicate that the formation in the Ahoskie Creek area has a relatively low porosity, and so the water-bearing potential is low. None of the ground-water wells are seated in this formation. At the close of the Paleocene epoch the seas either retreated or the landmass was elevated, or both, and this formation began to undergo erosion and weathering that probably continued through the Eocene age, preventing the deposition of the Castle Hayne limestone. Or, the Castle Hayne deposited was so thin that it was removed by the erosional period at the end of the Eocene and early Miocene epochs.

2.1.1.2.2.—Miocene Series

No sediments of the Eocene Age were recognized in the subsurface investigations: the Yorktown of the Miocene Age lies unconformably on the Beaufort and underlies the entire watershed, receiving some ground-water recharge in the area. It also provides some base flow to the channels during low-flow periods. The erosional period in the early Miocene removed the Pongo River Formation, or possibly the seas did not transgress inland far enough

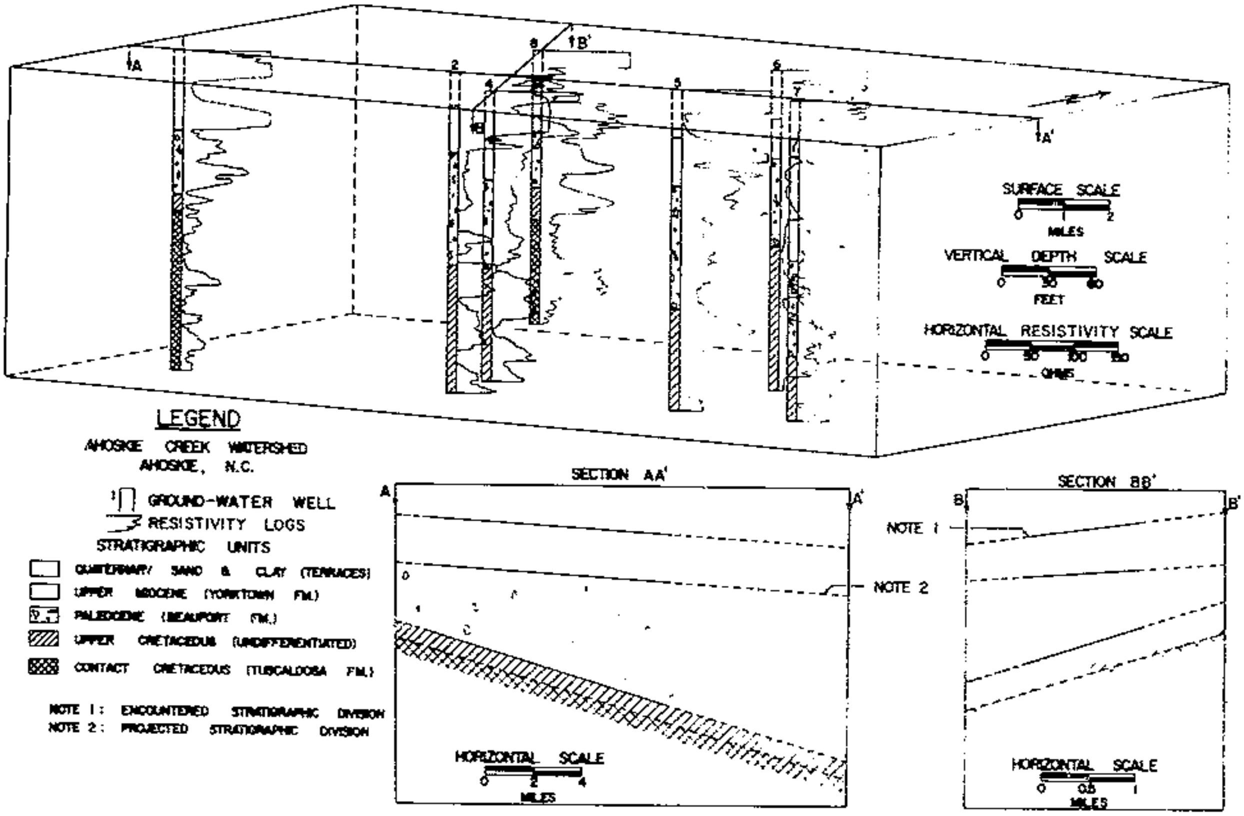

FIGURE 2.2.—Electrical resistivity map, Ahoskie Creek watershed.

to permit deposition into the Pongo River. The Yorktown was deposited under marine conditions and is composed of fine to medium, gray quartz sands interbedded with blue to gray silt and clay. Light-colored sand, shell beds, and marls occur in the upper part of the formation, which strikes N.65° W. and dips approximately 6 feet per mile in a northeasterly direction. The deposit of the Yorktown in this area was probably in an embayment or area of subsidence that caused the local change in dip from the expected easterly dip to the measured northeasterly dip. Wells 2, 5, and 7 (table A–7) are screened in this formation (fig. 2.1). The Yorktown in the area of well 2 outcrops at the surface and receives direct recharge. The channels were dug into the Yorktown in the upper (above gaging station No. 3) and lower watershed areas. The channel in the mid-reaches of the watershed did not intercept the Yorktown; rather, it cut into the Quaternary sediment and alluvial flood-plain deposits. Recharge in the upper watershed, which acts as a highland swamp, is low probably due to the sealing of the formation by fine depositional material. In the area where the improved channel system intercepts the Yorktown, ground-water recharge might possibly be increased during certain seasons of the year. Such recharge would permit the utilization of the aquifer reservoir system by providing storage during the early wet season and delivering a base flow during the dry, or low-flow, season.

2.1.1.2.3.—Post-Miocene Series

The post-Miocene surficial deposits are aqueous, are underlain by light-colored, fine- to coarse-grained sands occurring with interbedded clays, and vary in thickness from 20 to 40 feet, thickening to the east. Two Pleistocene terraces, the Penholoway (70 to 75 feet) and the Talbot (40 to 45 feet), are discernible within the watershed. Lying unconformably on the Yorktown Formation, they undoubtedly affect the recharge of the Yorktown, and possibly the recharge of deeper formations. Wells 1, 4, and 6 are screened in the terrace deposits (table A–7). The terraces also influence the direct runoff and the shallow subsurface lateral flow to the channels. As in the case with the Yorktown, the channels cut into these Quaternary sediments could permit the utilization of the storage capacity of this phreatic aquifer, making additional storage available during the high-runoff period and permitting the ground water to return later as base flow.

2.1.2.—Ground Water

The eight wells (fig. 2.1) were cased for ground-water observations (table A–7). Washed, fragmented samples were taken, electric resistivity (ER) logs were run to a depth of 200 feet at each site and specific capacity tests were made at selected depths. Electric resistivity logs were compared with lithic logs and specific capacity tests (fig. 2.2). In general, the ER logs provide information indicating the depth of the maximum porosity that would be expected within each formation. They also point out the zones that act as aquicludes, that is, zones of low porosity.

Well-stage recorders (analog) were installed during September 1967, and continuous records of the ground-water tables were obtained. The wells were screened for measurements of ground-water tables in the Quaternary surficial sands (three wells), Yorktown Formation (three wells), and the Tuscaloosa Formation (one well).

2.2.—SOILS

Soils of the Ahoskie Creek watershed, primarily derived from moderately fine-textured sediments, have fine sandy loam or silt loam surface soils and firm, slowly permeable clay subsoils. Permeability of most surface soils is moderate and that of subsoils is predominantly slow. Internal drainage is slow in most areas and medium in some. Ninety-five percent of the surface slopes are less than 2 percent, 96 percent of the total area is in erosion class 1, and more than 85 percent of the area falls into land capability classes I and II.

TABLE 2.1.—*Land use in the Ahoskie Creek, N.C., watershed*

[Percentage of area]

Land-use category	Year	
	1955	1970
Crops	32.6	30.8
Forest	62.7	63.0
Pasture	2.2	3.0
Idle	.9	.6
Urban	1.6	2.6

Basic soils data for all the major soils within each of the four subwatersheds are presented in tables A–2 through A–5. Information available includes the percentages of total area and the internal drainage characteristics for each soil; average depths, structure, and permeability for topsoil, subsoil, and substratum for each major soil type; and land-capability classes, erosion classes, and land-surface slopes for each drainage area (*1*).

2.3.—LAND USE

The first land-use study was conducted in 1960 with 1955 aerial photographs,[1] and land use was reevaluated in April 1974 with 1970 aerial photographs.[2] The Ahoskie Creek watershed has remained primarily an agricultural and woodland area for a long time. Forests and crops continue to occupy over 60 percent and 30 percent of the total area, respectively. The most significant change between 1955 and 1970 was a slight decrease in row crops and a slight increase in urban area (table 2.1).

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[1] Watershed work plan, Soil Conservation Service, Ahoskie Creek watershed, December 1960.

[2] Personal communication from Sidney F. Gray, geologist, Soil Conservation Service, April 28, 1974.

SECTION 3.—CHANNEL CHARACTERISTICS

For a long time, channels in the Ahoskie Creek watershed were virtually nonexistent, a condition largely responsible for frequent flooding. Channel improvement was necessarily a major factor in the plan to reduce flooding and provide proper drainage of agricultural lands. Approximately 22.1 miles of Ahoskie Creek, of which 17.6 miles were within drainage area W–A1, were dredged, and approximately 43.6 miles of lateral drainage were provided. Main channels were designed on the basis of the formula $Q=45A^{5/6}$ (*20*). This design was calculated to move runoff from a 2–5 year frequency storm within 24 hours.

Design of the channels to provide adequate safe removal of floodwater called for an average excavation depth of about 7 feet and bed widths ranging from 4 feet in the upper reaches to 42 feet at station W–A1 and 50 feet at the downstream terminus of the channel improvement. Bed slopes ranged from 0.0003 to 0.0008, and channel side slopes were 1 to 1.

All data on channel stability have not yet been evaluated, but a list of samples collected and results of tests performed, as well as available data on change in channel cross-sectional areas and carrying capacity, are presented in table A–6.

3.1.—CHANNEL AGGRADATION AND DEGRADATION

After channel excavation was completed in July 1964, 12 cross sections were selected as channel-stability study sites. Seven of these are in the vicinity of site W–A2, and five are approximately 1 to 1.5 miles upstream from site W–A1. Each of these cross sections was monumented to facilitate the periodic resurveys necessary to determine channel-geometry changes. In June 1969, an additional six cross sections were selected in curved channel segments in the vicinity of site W–A1. Survey data on the first 12 sites, located in reasonably straight stream reaches, include measurements as designed and as constructed, as well as several subsequent survey results. For the six sections at the curved sites, data are not available on measurements as constructed.

Data analyses were made for two time segments: from construction to October 1969 and from October 1969 to December 1972. The first could be considered a time of channel adjustment following construction, and a greater degree of stability should be expected in the later period. Two representative cross sections

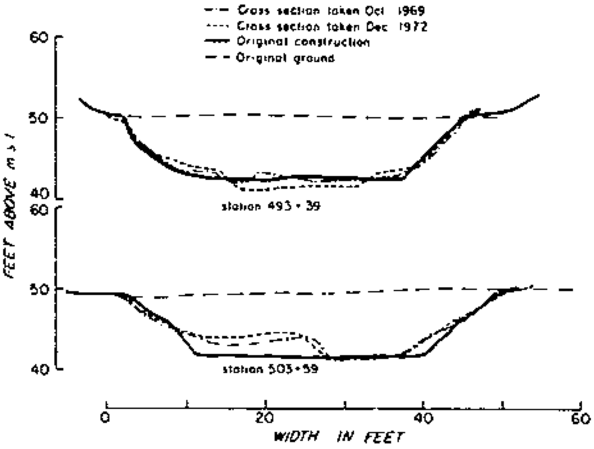

FIGURE 3.1.—Representative channel cross sections, upstream reach of Ahoskie Creek.

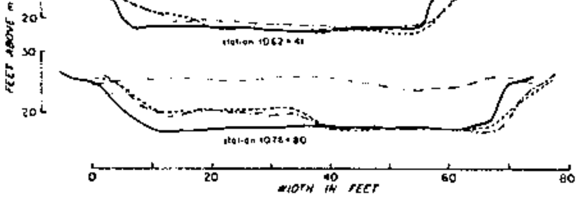

FIGURE 3.2.—Representative channel cross sections, downstream reach of Ahoskie Creek.

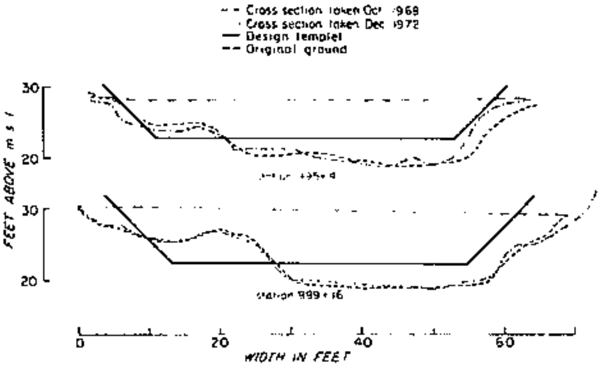

FIGURE 3.3.—Representative channel cross sections, curved reach of Ahoskie Creek.

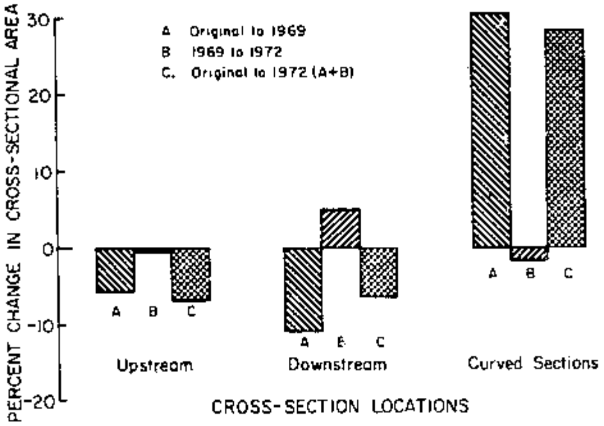

FIGURE 3.4.—Percentage of change in channel cross-sectional area, three reaches in Ahoskie Creek.

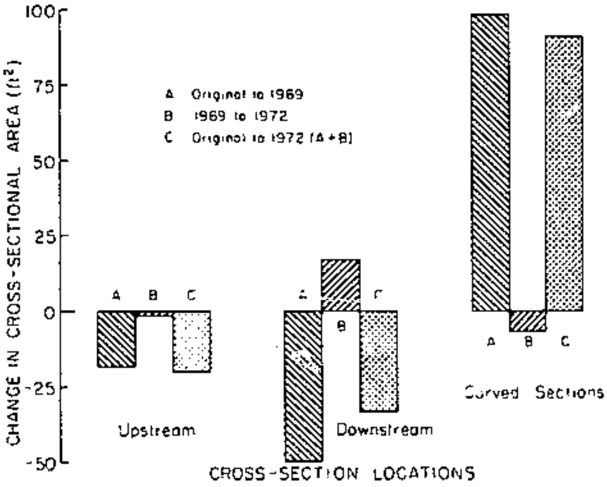

FIGURE 3.5.—Area changes in channel cross-sectional area, three reaches in Ahoskie Creek.

from each of the three groups were chosen for analysis and illustration (figs. 3.1–3.3). Data from each pair of cross sections are averaged and presented as one result.

Within the first period there was a great amount of scour in the curved sections and a

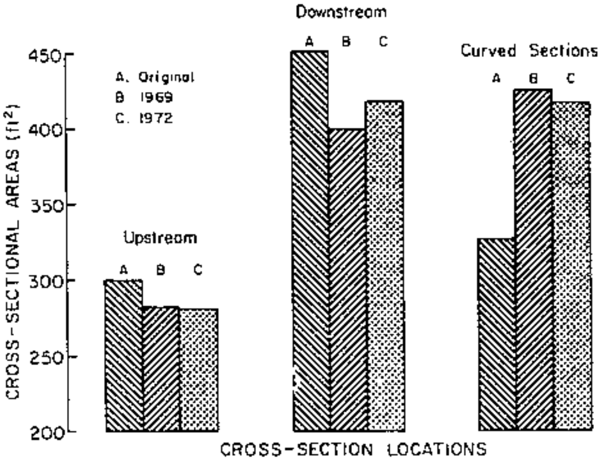

FIGURE 3.6—Channel cross-sectional areas, three reaches in Ahoskie Creek.

TABLE 3.1.—*Cross-sectional areas of six representative channel stations*

[Square feet]

Channel station	Area		
	Original	1969	1972
493+39	290.78	292.53	297.55
503+59	309.89	272.23	264.57
1,062+41	398.00	358.55	404.22
1,076+80	503.80	443.33	431.83
995+41	272.40	365.00	354.50
999+16	381.00	485.73	482.40

TABLE 3.2.—*Changes in cross-sectional areas of six representative channel stations*

[Square feet]

Channel station	Change in area		
	Original to 1969	1969 to 1972	Original to 1972
493+39	+1.75	+5.02	+6.77
503+59	−37.66	−7.66	−45.32
1,062+41	−39.45	+45.67	+6.22
1,076+80	−60.47	−11.50	−71.97
995+41	+92.60	−10.50	+82.10
999+16	+104.73	−3.33	+101.40

small but distinct amount of fill in the straight reaches (fig. 3.4). Apparently, a portion of the material that eroded in curves was moved to straight portions and deposited there. Cross-sectional area increased over 30 percent in the curved portion and decreased nearly 6 and 11 percent in the two straight study reaches, respectively.

This pattern changed significantly during the 1969–72 period. A slight amount of fill occurred in the curved portions, with cross-sectional area decreasing 1.78 percent. There was essentially no change in the upstream segments within the straight reaches, and scour increased the cross-sectional area approximately 5 percent in the downstream segments. For the entire period the straight reaches lost slightly over 6 percent of their cross-sectional area, and the curved segments increased about 28 percent in cross-sectional area.

Figure 3.5 shows changes in average cross-sectional area for the three reaches for the first period, the second period, and total time. The average cross-sectional areas for the three reaches for each survey are illustrated in figure 3.6. Survey data are summarized in tables 3.1–3.3.

Based on these studies it is apparent that extreme changes in channel geometry may occur immediately after excavation, especially in channel curves. However, as disturbed material is removed from banks and bed, a degree of stability will slowly return, gradually increasing as protective vegetation begins to spread. But, should this vegetation be allowed to grow unimpeded over a long period of time, channel capacity might be severely reduced in the future.

In regard to channel-bed and bank stability at monumented cross sections, it should be noted that channel banks have failed to maintain originally designed slopes. Most have sloughed off to a somewhat flatter slope than the intended 45 degrees, and, consequently, channel-top widths are now generally greater than when first constructed. Bed widths vary: some have increased and some have decreased.

TABLE 3.3.—*Percentage of change in the cross-sectional areas of six representative channel stations*

Channel station	Average percentage of change		
	Original to 1969	1969 to 1972	Original to 1972
493+39; 503+59	−5.78	−0.54	−6.14
1,062+41; 1,076+80	−10.96	+5.08	−6.36
995+41; 999+16	+30.74	−1.78	+28.38

In the straight-channel reaches channel thalwegs have remained at approximately the same point within a given cross section. However, the thalweg may appear on opposite sides of the channel at different cross sections, indicating a meandering pattern of low flow. Thalwegs in curves, of course, always appear near the outside of the respective curve and will change only to the extent that constant scour gradually expands the curvature of the channel.

3.2.—CHANNEL CONVEYANCE CAPACITY

In a study to determine the effectiveness of maintenance programs on drainage channels in eastern North Carolina, Swicegood and Kriz made observations on the carrying capacities of channels in the Ahoskie Creek watershed

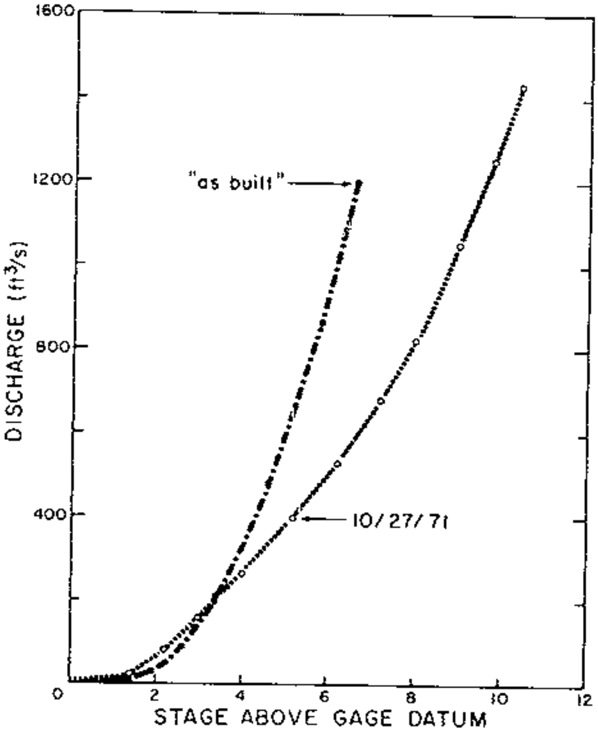

FIGURE 3.7—Stage-discharge relationships, watershed W A1.

(*22*). They reported that from 1965, after completion of the channelization, until 1971 there was a loss in water-carrying capacity for Ahoskie Creek channels, especially for high discharges. They also say that vegetation is principally responsible for the decreases in channel capacity at higher discharges.

These findings, significant from the standpoint of the hydraulic performance of these channels, led to a closer look at the change in stage-discharge relationships for these channels because of the inherent hydrologic implications. Rating tables furnished by the U.S. Geological Survey for gaging stations below the four study areas were examined for additional information on changes in channel capacity during the study period.

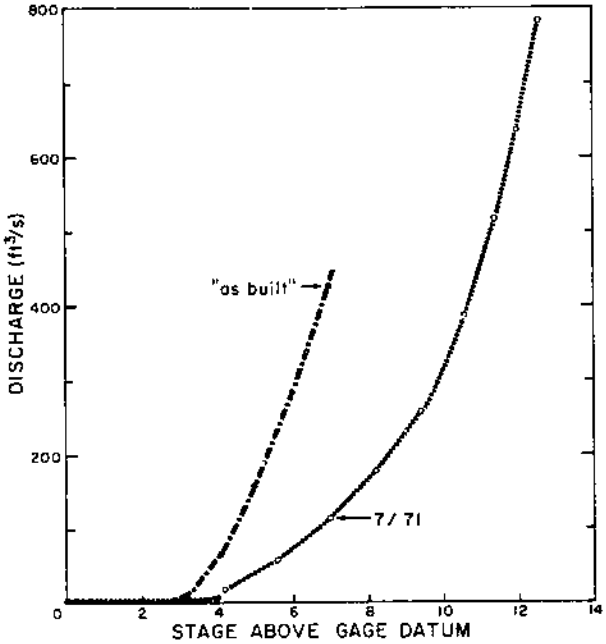

FIGURE 3.8.—Stage-discharge relationships, watershed W–A2.

TABLE 3.4.—*Stage-discharge relationships for selected discharges, as-built and 1971 conditions, watersheds W–A1, W–A2, and W–A3*

Watershed	Q (ft³/s)	Stage (ft) As-built	Stage (ft) 1971
W–A1	10	1.4+	1.1
W–A1	100	2.7	2.4+
W–A1	300	3.8+	4.3+
W–A1	600	5.0	6.7+
W–A1	1,000	6.1+	8.8+
W–A2	10	3.1+	3.9+
W–A2	100	4.4+	6.7
W–A2	200	5.3+	8.5+
W–A2	400	6.8+	10.7
W–A3	10	1.5+	4.4
W–A3	50	2.6+	7.2
W–A3	100	3.6	(¹)
W–A3	350	7.9+	(¹)

¹ Rating curve does not extend this far.

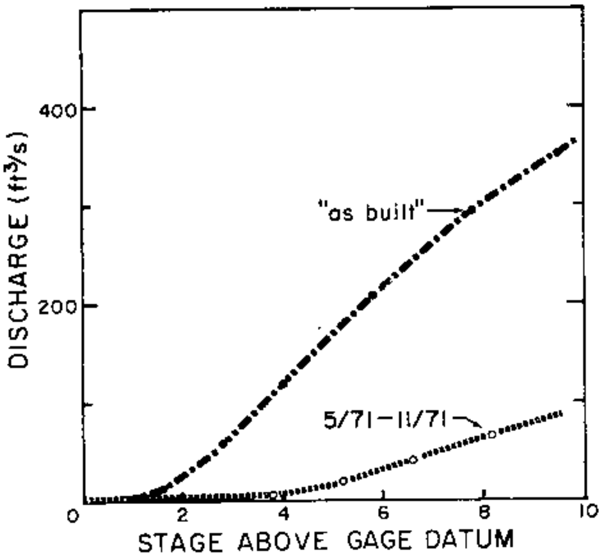

FIGURE 3.9.—Stage-discharge relationships, watershed W–A3.

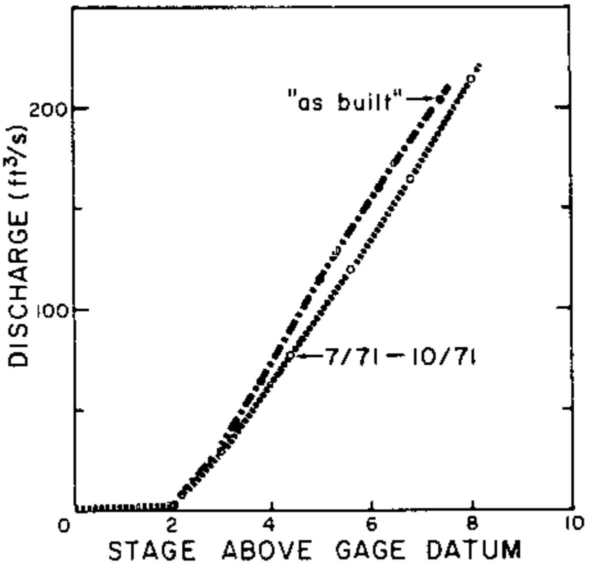

FIGURE 3.10.—Stage-discharge relationships, watershed W–A4.

Figures 3.7–3.10 show USGS rating curves for each of the study-area measurement sections. The as-built rating refers to the first rating after construction of the channels, and the 1971 date refers to the last rating during the study. Measurement-section channels for W–A1, W–A2, and W–A3 have incurred appreciable reductions in carrying capacities, particularly in the upper ranges of flow rates.

For the measurement section on watershed W–A1, carrying capacity has been reduced at stages above 3 feet and increased at stages below 3 feet. This difference is perhaps indicative of a slight channel degradation at this site.

For the sections at the outlets of watersheds W–A2 and W–A3, carrying capacities have been reduced significantly, and zero-flow gage heights have increased, indicating that channel aggradation has occurred in these upper reaches.

The channel capacity at W–A4 has changed little during the study. A single-barrel culvert located at this site is probably the hydraulic control that has resulted in a relatively stable rating at this station for the study period.

Figures 3.11–3.14 show flow rates for selected stages as a percentage of the as-built flow rates for W–A1 to W–A4, respectively, for the study period. These figures illustrate the magnitude of the reduction in channel capacities incurred by the sections at W–A1, W–A2, and W–A3 at high flow rates.

The change in channel capacity may affect the hydrologic performance of the watershed because of the change in channel storage, which directly affects flow routing. In this regard, the increase or decrease in the stage (indicative of the increased or decreased channel storage) for a given flow rate is of interest. Table 3.4 shows the overall change in stage from the as-built rating to the 1971 rating for selected flows on watersheds W–A1, W–A2, and W–A3.

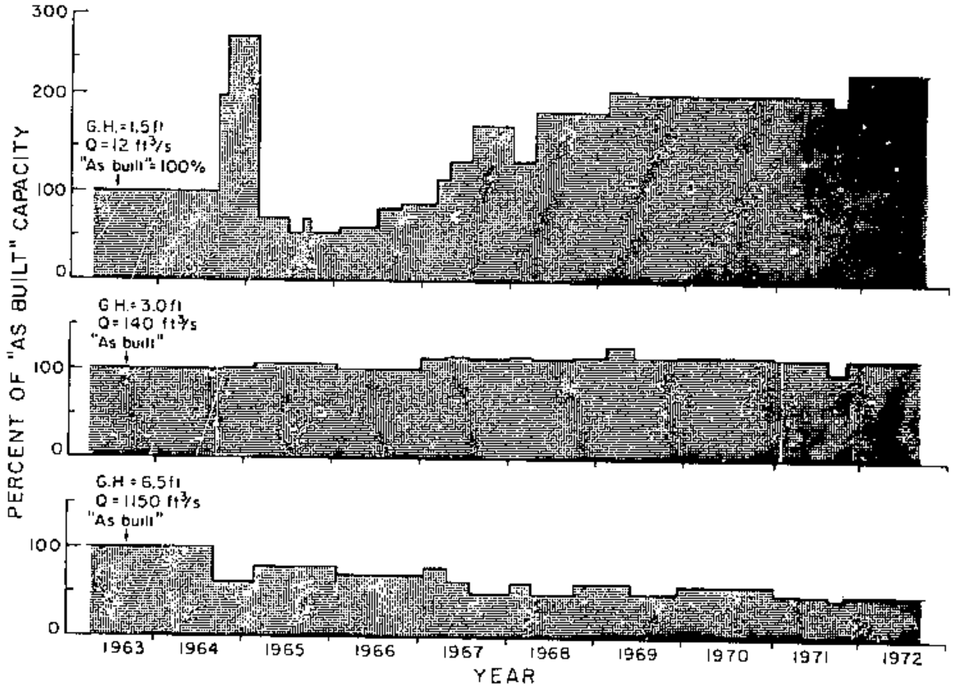

FIGURE 3.11.—Discharge rates as a percentage of as-built capacity for selected stages, watershed W–A1 (1964–72).

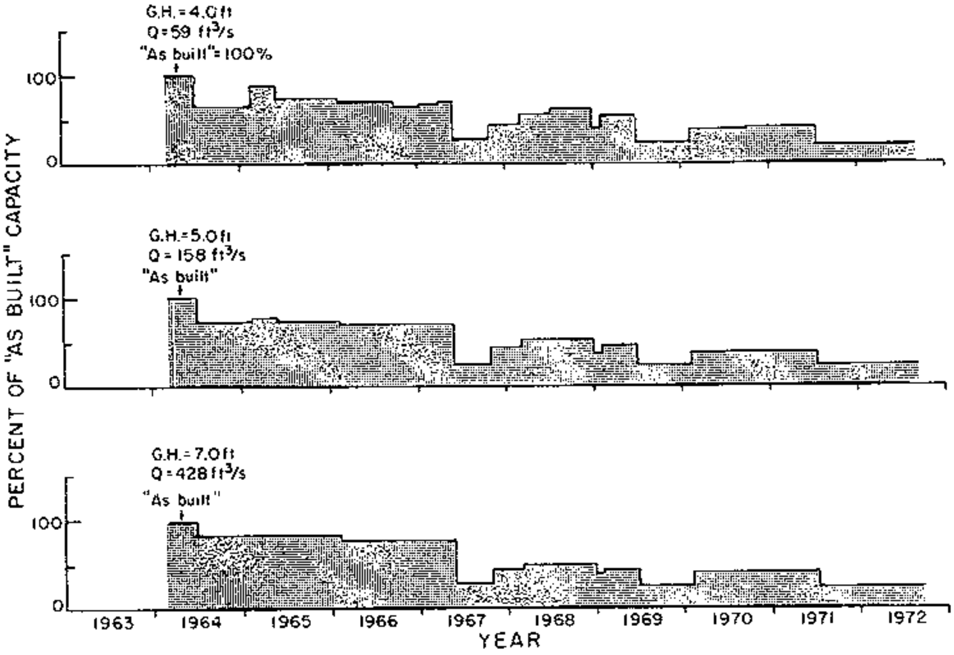

FIGURE 3.12.—Discharge rates as a percentage of as-built capacity for selected stages, watershed W–A2 (1964–72).

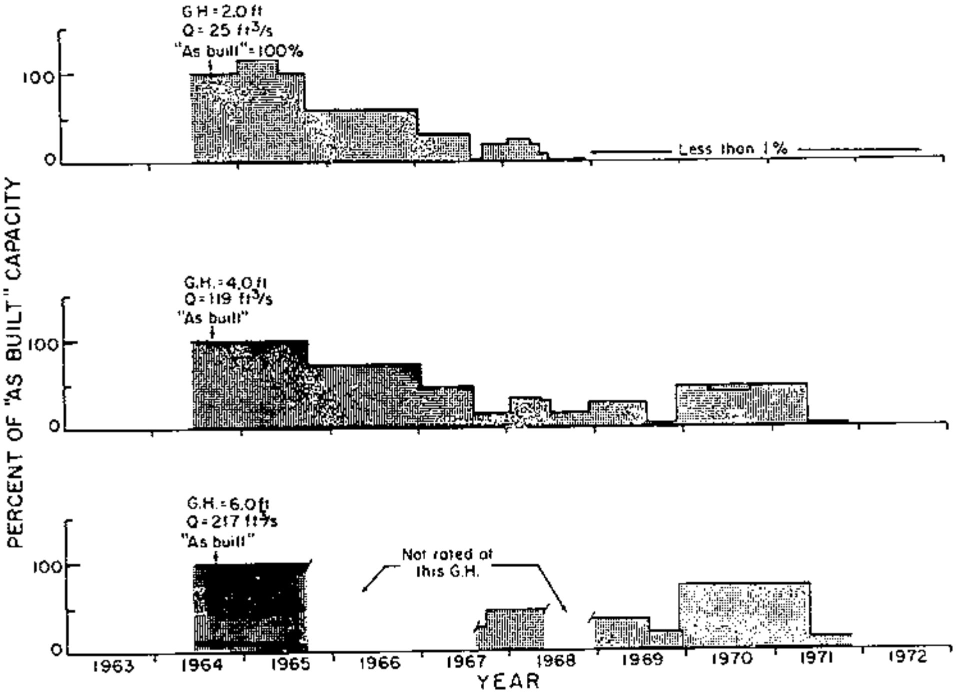

FIGURE 3.13.—Discharge rates as a percentage of as-built capacity for selected stages, watershed W–A3 (1964–72).

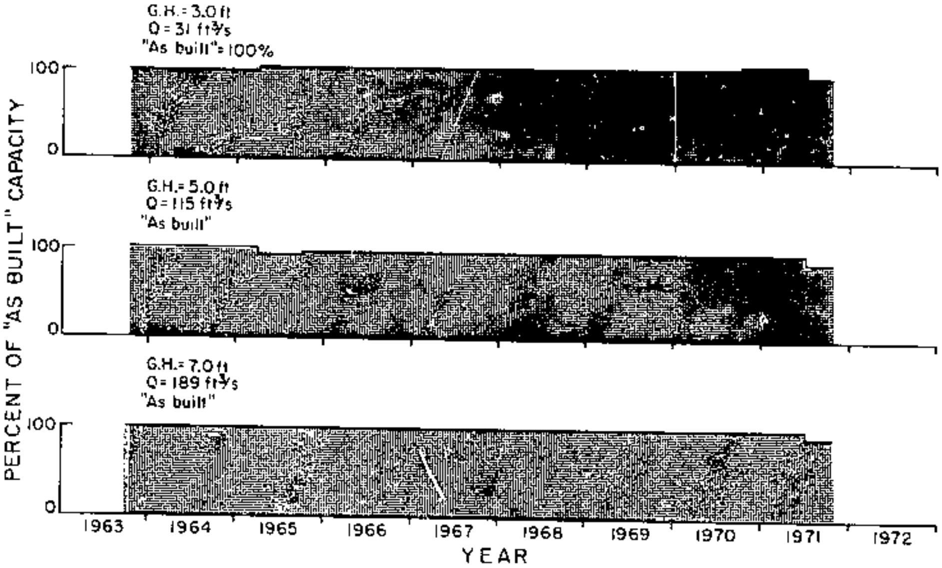

FIGURE 3.14.—Discharge rates as a percentage of as-built capacity for selected stages, watershed W–A4 (1964–72).

SECTION 4.—BASIC DATA AND REPRESENTATIVENESS

4.1.—RECORDS AVAILABLE AND DATA CONVERSION

The hydrologic and geohydrologic data are the continuously observed time-dependent information: precipitation depths, stream stages, and ground-water elevations. These basic data, collected in the Ahoskie Creek watershed by the cooperating agencies (sec. 1.1.4), were supplemented in this study, where available, from other sources. SCS, in addition to providing actual data collection, served as a clearinghouse and furnished the incoming analog chart records to the appropriate locations for data reduction and conversion.

SCS collected rain-gage charts and made them, along with USGS tipping-bucket charts, available to the North Carolina State University Biological and Agricultural Engineering Department for tabulation and conversion. Also, SCS sent observation charts on ground-water wells to ARS for tabulation and conversion. USGS provided copies of stream-stage charts, rating tables, and mean daily discharge data to SCS. SCS sent copies to ARS. ARS made necessary tabulations and data conversion.

ARS obtained climatic data from the U.S. Weather Bureau and additional precipitation data from a nearby cooperative observer location (*26*).

4.1.1.—Precipitation

ARS established a network of seven weighing-recording rain gages in May 1964. SCS maintained the network from May 1964 through September 1973. USGS operated three tipping-bucket gages at stream-gaging locations from July 1964 through September 1973. Rain-gage locations are shown on the watershed map, figure 1.1. E. H. Wiser, under a cooperative agreement,[1] made breakpoint tabulations and punched the data onto cards. Breakpoint data were available for use in special analyses to be reported in later sections. Daily watershed average rainfall, determined by the Thiessen method (*5*), has been published (*1–3*). Summaries of data are given in the appendix of this report. Table A–8 shows monthly maximum 15- and 30-minute and 1-, 2-, 6-, and 24-hour rainfall amounts at rain gage 3 for July 1964 through December 1972. Monthly and annual totals of weighted rainfall for watersheds W–A1, W–A2, W–A3, and W–A4 are given in tables A–9, A–10, A–11, and A–12, respectively, for the period July 1964 through December 1972.

In March 1904, J. T. Elliott established a cooperative-observer standard rain gage in Eagletown, N. C. (fig. 1.1). The Elliott family collected rainfall data up to 1973, and Alice Elliott made these data available to ARS. Monthly data for the period of March 1904 through December 1972 are given in table A–13, though data for some months are not currently available. Information on daily rainfall, with the observation time at 6:00 p.m., was made available for the period of January 1, 1950, through December 31, 1972. Table A–14 shows monthly maximum daily rainfall amounts for the Elliott Station from January 1950 through December 1972. Monthly precipitation data are also available for Scotland Neck, N.C. (fig. 1.1) for the period 1904 through 1972 (*26*).

4.1.2.—Streamflow

In January 1950, USGS established a stream-gaging station on Ahoskie Creek at Ahoskie, N.C. (watershed W–A1). Mean daily discharge data have been published for January 1950 through September 1964 (*23, 24*). USGS, under a cooperative agreement with SCS, maintained gaging stations at Ahoskie Creek at Ahoskie (W–A1), at Ahoskie Creek at Minton's Store (W–A2), at Ahoskie Creek near

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[1] Cooperative agreement No. 12–14–7001–90, between ARS and North Carolina State University.

Rich Square (W–A3), and at an Ahoskie Creek tributary at Poor Town (W–A4).

USGS identification and descriptive data for July 1964 through September 1973 for the four gaging stations, as published (*23*, *24*), are given in tables A–15, A–16, A–17, and A–18. Monthly summaries of streamflow volume for the four watersheds are also given in tables A–15, A–16, A–17, and A–18.

Breakpoint tabulations of streamflow were made for all watersheds for all storms that produced as much as 0.50 inch of rainfall or resulted in 0.50 foot of rise in stream stage. Breakpoint rainfall and streamflow data have been published for selected events (*1–3*). Annual maximum instantaneous streamflow rates and volumes for selected time intervals for the four watersheds are given in tables A–19 through A–22, monthly maximum instantaneous rates of streamflow in tables A–23 through A–26, and monthly maximum mean daily discharge in tables A–27 through A–30. USGS maintained and made available data for crest gages at selected sites in the Ahoskie Creek watershed during the period of July 1964 through September 1973.

4.1.3.—Ground Water

In 1966, eight ground-water observation wells were drilled with rotary equipment with reverse circulation (fig. 1.1). Washed fragmented samples were analyzed, and driller logs and electrical resistivity logs were made at each site. Geologic interpretation of logs and samples were made (sec. 2.1.1.). Four locations, wells 1, 3, 4, and 6, were selected for observation in the Quaternary surficial sands; three locations, wells 2, 5, and 7, for observation in the Yorktown Formation; and one location, well 8, for observation in the Tuscaloosa Formation. (See sec. 2.1.1. for structural and stratigraphic descriptions.) The wells were plugged below the respective aquifers, screened through the aquifer thickness, cased, and plugged above the aquifer. Pumping tests were made to determine transmissivity, storativity, drawdown, and recovery rates of each formation. Data are given in section 2.1.2.

Water-level recorders were installed in September 1967 and maintained by SCS. Breakpoint tabulations of ground-water surface elevations were made by ARS, and mean daily ground-water surface elevations were determined for October 1967 through September 1973. The aquifer at well 1 was partially sealed during the drilling and was not fully responsive to water-level changes until it was reworked in September 1969. Well 3 was not responsive to water-level changes, and so record collection was discontinued in August 1971. The ground-water data are summarized in table A–31, which gives monthly maximum and minimum water-surface elevations for wells 1, 2, 4, 5, 6, 7, and 8. The monthly summaries for well number 1 are for October 1969 through December 1972, and for all other wells January 1968 through December 1972.

4.2.—PRECIPITATION REPRESENTATIVENESS FOR RECORD PERIODS

Reliability and applicability of hydrologic analyses are determined by the climatic representativeness of the period during which the data were obtained. Concepts and methodologies are not generally affected, but quantification of relationships and processes may be seriously biased if precipitation is abnormally high or low for the observation period. Relatively long durations of hydrologic data collection are necessary to minimize effects of the biases. During a short period, there is less opportunity for "average" or extreme occurrences: correct evaluation of watershed-treatment effects is highly dependent upon a representative climatic experience. Since hydrologic systems in nature are nonlinear, small treatment effects may be exaggerated or eliminated between two nonrepresentative periods of rainfall. Part of this report is directed towards a determination of the effects of channel improvement on the hydrologic characteristics of the Ahoskie Creek watershed. It is essential that some evaluation is made to determine the precipitation representativeness of the periods of data collection before and after channel improvement.

No known standards of comparison or techniques exist for adequately determining the normalcy or representativeness of precipitation for any period. Neither is there such a thing as "average" or "normal" precipitation, although a period is often described as "below normal" or "above normal." The terms "normal" or "average" refer to the total population, that is, some infinitely long period. The duration of a hydrologic study merely represents a sample. Statistically designed experiments usually establish control of most variables so that resulting data provide statistics from which inferences can be drawn about the populations. Precipitation is so highly variable in time and space that no established norm can adequately represent the population. The degree of representativeness of the climatic population by the sample is highly subjective, and the methods of comparison vary with the investigator.

One of the few published methods for tests of normalcy of precipitation was made by Potter (*11*). The tests included certain frequency analyses. However, frequency analyses for short record periods may be highly biased, and so alternative methods of investigation were considered.

The determination of excessive storms requires recording rain-gage data (*28*). This information is not always available, as is the case in the present study for the before-treatment period. Streamflow data are available for the period 1950–62, before treatment, and the period 1965–72, after treatment, but only daily point-rainfall data are available for the pretreatment period before 1965. The long-term cooperative-observer gage at the Elliott Station near Eagletown was used as the reference location in the representative tests. The monthly rainfall totals are given in table A–13.

TABLE 4.1.—*Monthly rainfall means and standard deviations for three periods, Elliott Station, N.C.*

Month	1904–72		1951–62		1965–72	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
January	3.64	1.513	3.98	2.122	3.64	1.060
February	3.86	1.689	4.34	1.478	3.93	1.294
March	3.78	1.424	3.76	.805	3.45	1.172
April	3.25	1.632	3.18	1.524	2.71	1.097
May	3.74	1.923	3.76	1.880	4.55	2.036
June	4.49	2.050	3.77	1.801	4.24	1.385
July	6.18	2.797	5.66	3.326	5.50	2.158
August	4.99	3.097	6.21	3.253	5.12	2.841
September	4.42	3.056	4.22	3.495	3.19	1.539
October	3.02	2.161	3.70	3.132	3.51	2.447
November	2.93	1.882	3.43	1.487	2.52	1.144
December	3.46	1.516	3.11	.944	2.85	1.478
Annual	47.57	7.229	49.12	5.908	45.78	5.249

The first step in the determination of the representativeness of the rainfall for the periods of record was to compare monthly means for the before- and after-treatment periods with those of the long-term record. The comparative means are shown in figure 4.1. Average January and February rainfall for the pretreatment period is slightly above the long-term values, and that of the posttreatment period is slightly below the long term. During March and April the pretreatment averages are only slightly below the long term, but the posttreatment averages are well below the long term. During the remaining months, the comparisons were highly erratic, especially from May through September, the months when most of the rainfall results from convective thunderstorms. In May and June, rainfall during the posttreatment period was well above that of the pretreatment period, and in July it was similar before and after but well below the long term. The August, September, and November averages during the pretreatment period were approximately 1 inch greater than those of the posttreatment period. The annual comparison in figure 4.1 shows that the pretreatment period was "wetter than normal" and that the posttreatment period was "drier than normal."

The standard deviation of monthly amounts was determined for each month in order to

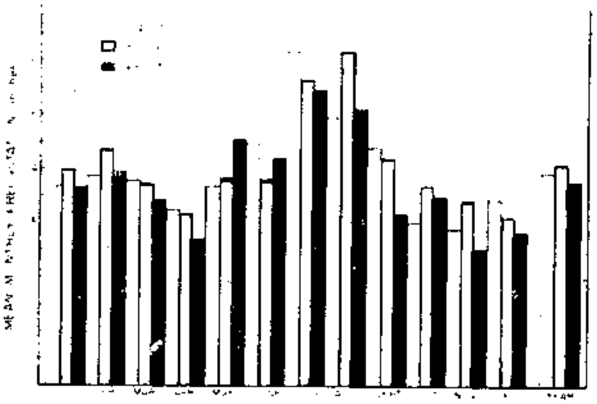


FIGURE 4.1.—Mean monthly rainfall amounts by record periods, Elliott Station (1904–72).

obtain a measure of the dispersion about the mean. In table 4.1, the standard deviations for each period are compared with the long-term standard deviations. In general, the dispersion during the pretreatment period compares reasonably well with the long term, but during the posttreatment period the dispersion indicates less than a normal spread of values.

However, means and standard deviations may not provide sufficient information about the precipitation of the respective periods. Extremes may be better indicators of the hydrologic characteristics for the periods of record. Monthly rainfall data for the Elliott Station are shown in figure 4.2. The significant points to be made concern the extremes for the before- and after-treatment periods, 1951–62 and 1965–72, respectively. In all months except May and December, the first, second, and third largest monthly values occurred before treatment. This does not necessarily reflect successive months. The lowest monthly totals

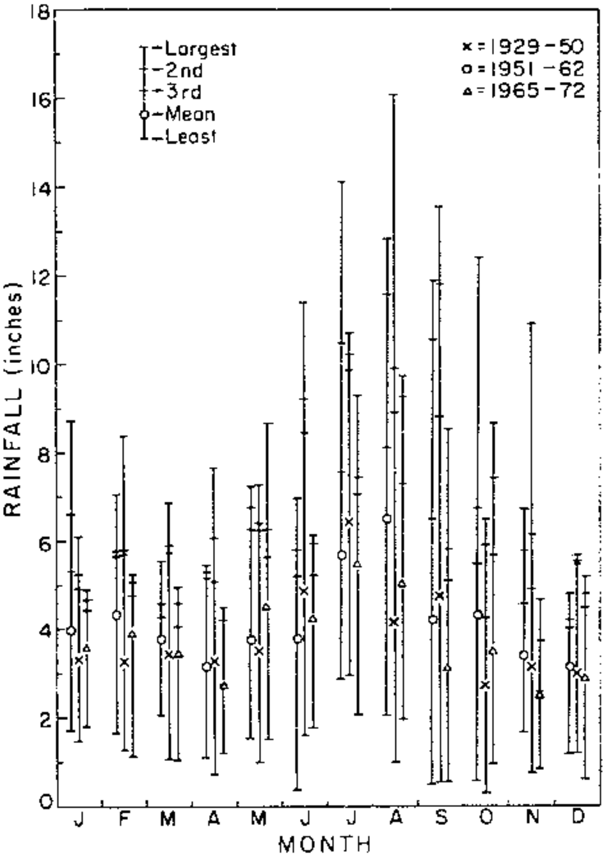


FIGURE 4.2.—Monthly rainfall amounts, Elliott Station (1929–72).

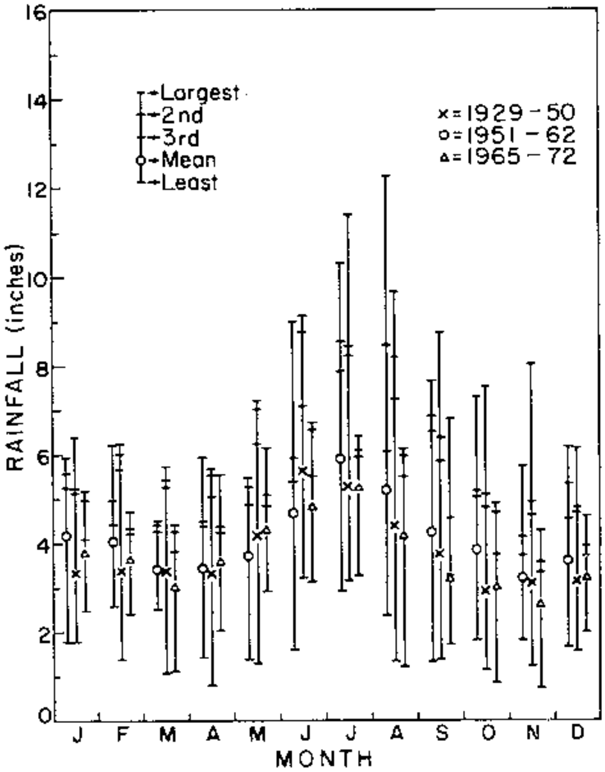


FIGURE 4.3.—Mean monthly rainfall as averaged for 2 months, beginning with month shown, Elliott Station.

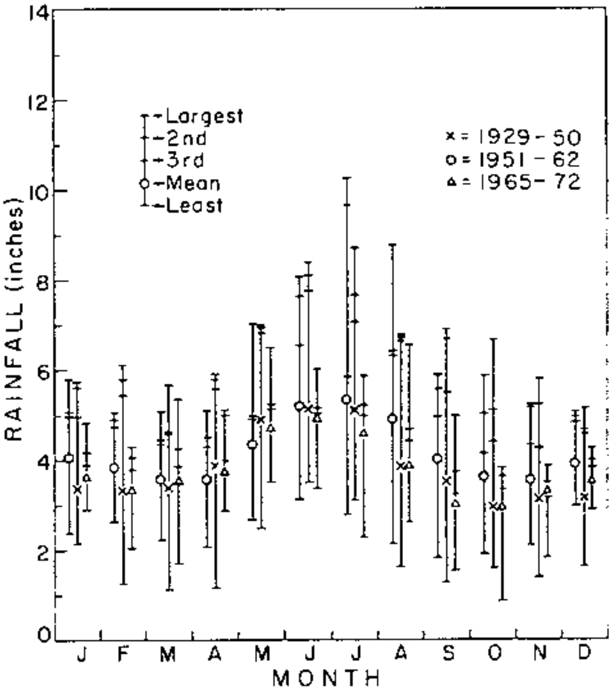


FIGURE 4.4.—Mean monthly rainfall as averaged for 3 months, beginning with month shown, Elliott Station.

occurred before treatment in January, May, June, and October. All-time record-high amounts occurred before treatment in January, July, and November, and after treatment in May.

Month-by-month comparisons of rainfall do not give a complete expression of streamflow potential, because antecedent rainfall is not considered, and so moving averages of sequential monthly rainfall were determined for 2, 3, 4, 5, and 6 months. Moving averages by month are shown in figures 4.3–4.7 for the before- and after-treatment periods, as well as the long term (1929–50). The figures show that for all moving-average schemes the spread of values in the before-treatment period compares favorably with that of the long term. However, the after-treatment period shows less spread and is generally low in amount.

A comparison of extremes of monthly moving averages shows that the all-time 2-month record high occurred in August–September during the before-treatment period. The 2-month moving averages were higher before treatment than after treatment for all months except May–June. For 3-month moving averages, all were higher before treatment except March–May, with the all-time high in July–September. Similar comparisons exist for 4- and 5-month moving averages, and for 6-month moving averages the before-treatment period has the higher values for all months.

Time distributions of rainfall are not adequately represented by monthly totals or by monthly moving-average schemes. Miller and Frederick published a so-called monthly normal number of days with rainfall greater than 0.5, 1.0, 2.0, and 4.0 inches (*9*). Daily rain-

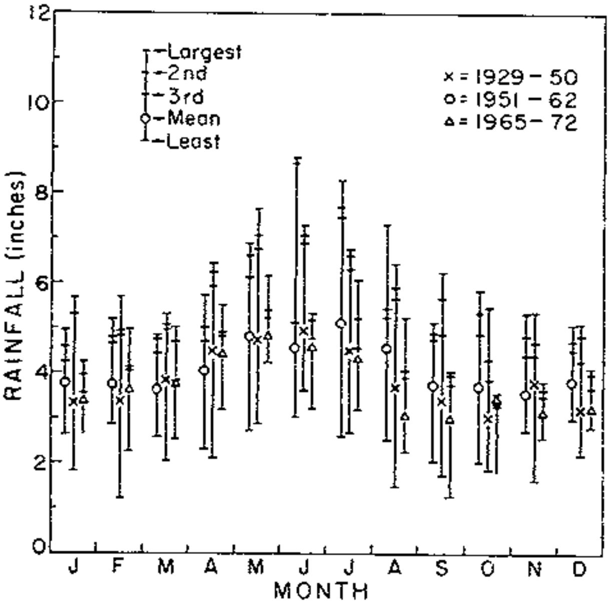


FIGURE 4.5.—Mean monthly rainfall as averaged for 4 months, beginning with month shown, Elliott Station.

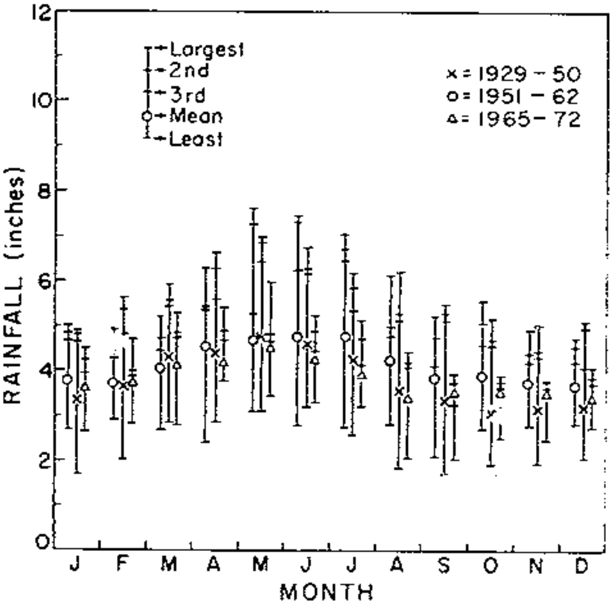


FIGURE 4.6.—Mean monthly rainfall as averaged for 5 months, beginning with month shown, Elliott Station.

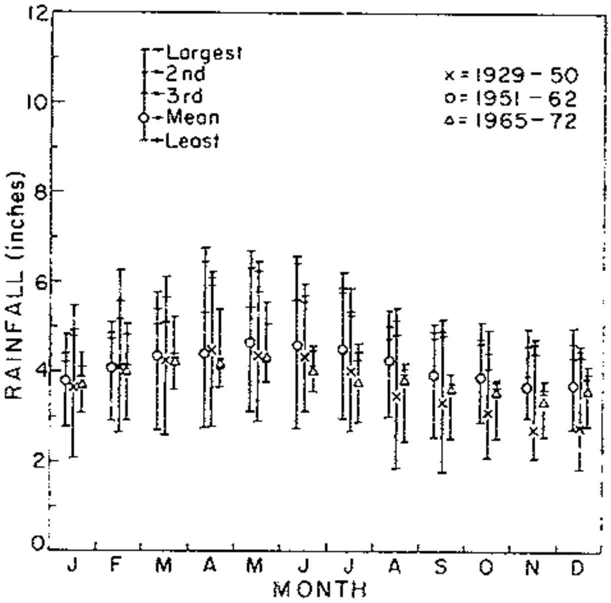


FIGURE 4.7.—Mean monthly rainfall as averaged for 6 months, beginning with month shown, Elliott Station.

TABLE 4.2.—*Normal number of 24-hour periods and observed number of calendar days with rainfall greater than or equal to the various amounts shown, Elliott Station*

Amount of rainfall (in)	Normal[1] or observation period	Month												Total
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Rainfall>trace	1950–63	7.3	7.6	8.1	7.1	8.1	7.9	9.4	7.9	5.9	5.2	5.7	5.6	86
Do	1964–72	7	6.9	7.2	6.6	8.1	7.6	10.4	8.3	6.2	6.3	5.8	6.1	87
Do	1950–72	7.2	7.3	7.8	6.9	8.1	7.7	9.8	8.1	6	5.7	5.7	5.8	86
Rainfall≥0.10	1950–63	6.1	7.2	7.2	5.9	6.8	6.7	8.0	7.3	5.3	4.6	5.4	5.0	75
Do	1964–72	6	5.8	5.9	5.4	6.4	5.7	8.8	7.2	4.7	4.8	4.6	5.1	70
Do	1950–72	6	6.7	6.7	5.7	6.7	6.3	8.3	7.3	5	4.7	5.1	5	73
Rainfall≥0.25	1950–63	4.2	5.2	4.9	3.8	4.4	5.0	5.4	5.4	3.8	3.4	3.6	4.2	53
Do	1964–72	4.7	4.9	4.3	3.3	4.4	4.3	6.1	5.1	3.1	3.7	3.2	3.6	51
Do	1950–72	4.4	5.1	4.7	3.6	4.4	4.7	5.7	5.3	3.5	3.5	3.5	4	52
Rainfall≥0.50	normal	3.0	3.0	3.0	2.8	3.2	3.2	4.4	4.5	3.3	2.4	2.5	2.9	38.2
Do	1950–63	2.7	3.4	2.7	1.8	2.3	2.6	3.5	3.4	2.4	2.4	2.1	2.6	32
Do	1964–72	2.7	3.3	2.3	1.7	2.7	2.7	3.7	3.3	1.9	2.6	1.7	1.9	30
Do	1950–72	2.7	3.3	2.6	1.8	2.5	2.7	3.6	3.4	2.2	2.4	2	2.3	32
Rainfall≥1.00	normal	1.0	1.0	1.0	1.0	1.1	1.4	2.3	2.6	2.0	1.0	1.0	.9	16.3
Do	1950–63	1	1.1	.5	.6	1	.9	1.6	2.1	1.3	1.1	1.2	.9	14
Do	1964–72	1	1.4	1	.6	1.4	1.5	1.8	1.8	1.2	1.3	.6	1	14
Do	1950–72	1	1.3	.7	.6	1.2	1.2	1.7	2	1.3	1.2	1	.9	14
Rainfall≥2.00	normal	.19	.05	.15	.2	.2	.4	.8	.8	.7	.4	.2	.3	4.4
Do	1950–63	.07	.07	.07	0	.14	.07	.43	.36	.50	.21	.14	0	2
Do	1964–72	.22	0	.11	.13	.33	.44	.33	.67	.56	.22	0	.11	3.2
Do	1950–72	.13	.04	.09	.09	.22	.22	.39	.48	.52	.22	0	.04	2.5
Rainfall≥4.00	normal	.001	.001	.001	.01	.01	.08	.1	.05	.01	.01	.01	.001	.28
Do	1950–63	0	0	0	0	0	0	0	.14	.14	0	0	0	.29
Do	1964–72	0	0	0	0	0	.12	0	0	0	0	0	0	.11
Do	1950–72	0	0	0	0	0	.04	0	.09	.09	0	0	0	.22

[1] Miller, J. F., and Frederick, R. H. (*9*).

fall records from the Elliott Station were utilized to determine the number of comparative occurrences each month for the before-treatment and after-treatment periods for comparison with the published normals (table 4.2). For the 0.5-inch amount, the before- and after-treatment periods are similar throughout the year, and the observed occurrences are well below the normal for all months except February. For 1.0 inch, there was considerable difference between the periods on a month-to-month basis, although the annual total is the same for both periods. Observed occurrences were generally lower than normal. Comparisons for the 2.0-inch amount are similar to those for 1.0 inch. Because of the infrequent occurrence of daily rainfall amounts greater than 4.0 inches, single occurrences in short records cause erratic results, but in general both periods were below normal.

The numbers of days with amounts greater than a trace, 0.10, and 0.25 inch are also shown in table 4.2. There are no published data for comparison, and so the tabulated data were used to compare record periods. Although the annual number of occurrences of each amount is comparable for both periods, there are considerable differences from month to month. Rain gage 3 in the network of recording gages was selected for similar comparisons for the after-treatment period, with the same general results as for the Elliott Station (table 4.3).

As previously stated, there is no good method of determining the normality or abnormality of a period of rainfall. However, it is necessary to draw conclusions for establishing applicability of other analyses. In general, the posttreatment period was slightly below "normal" and the pretreatment period was about "normal." The differences cannot be quantified and exceptions exist for some time spans within each period. Table 4.4 gives a summary of normalcy by month and year.

TABLE 4.3.—*Normal and observed number of 24-hour periods, 1964–72, with rainfall greater than or equal to the various amounts shown, rain gage 3, Ahoskie Creek*

Amount of rainfall (in)	Normal[1] or observed	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Rainfall>trace	observed	7.8	7.1	6.4	6.8	7.8	7.2	9.6	9.1	5.6	5.4	5.1	7.2	84
Rainfall≥0.10	do	6.5	6.4	5.4	5.0	6.4	6.1	8.1	7.6	5.3	4.6	4.2	6.1	71
Rainfall≥0.25	do	3.9	5.1	4.1	3.4	4.4	4.1	6.4	5.3	3.4	3.2	3.1	3.9	50
Rainfall≥0.50	normal	3.0	3.0	3.0	2.8	3.2	3.2	4.4	4.5	3.3	2.4	2.5	2.9	38.2
Do	observed	2.2	3.1	2.4	1.4	3.2	2.4	5	3.2	2.6	2	1.4	2.1	30.6
Rainfall≥1.0	normal	1.0	1.0	1.0	1.0	1.1	1.4	2.3	2.6	2.0	1.0	1.0	.9	16.3
Do	observed	.9	1.8	1	.5	1.6	1.6	2.4	1.7	7	1.3	.8	.9	15
Rainfall≥2.0	normal	.19	.05	.15	.2	.2	.4	.8	.8	.7	.4	.2	.3	4.4
Do	observed	.12	0	.12	.12	.25	.44	.55	.33	.55	.55	0	.11	2.8
Rainfall≥4.0	normal	.001	.001	.001	.01	.01	.08	.1	.05	.01	.01	.01	.001	.28
Do	observed	0	0	0	0	0	.11	.11	0	.11	.11	0	0	.44

[1] Miller, J. F., and Frederick, R. H. (*9*).

TABLE 4.4.—*Monthly and annual summary of normalcy of precipitation, Elliott Station*

Measurement	1951–62 Below normal	1951–62 Near normal	1951–62 Above normal	1965–72 Below normal	1965–72 Near normal	1965–72 Above normal
			January			
Mean			*		*	
Std. dev.			*	*		
Occurrences≥0.5 in		*			*	
Occurrences≥1.0 in		*			*	
Occurrences≥2.0 in			*		*	
Occurrences≥4.0 in		*			*	
Summary			X		X	
			February			
Mean			*		*	
Std. dev.		*		*		
Occurrences≥0.5 in			*			*
Occurrences≥1.0 in		*				*
Occurrences≥2.0 in		*		*		
Occurrences≥4.0 in		*			*	
Summary		X			X	
			March			
Mean		*		*		
Std. dev.	*			*		
Occurrences≥0.5 in	*			*		
Occurrences≥1.0 in	*				*	
Occurrences≥2.0 in	*				*	
Occurrences≥4.0 in	*			*		
Summary	X			X		

TABLE 4.4.—*Monthly and annual summary of normalcy of precipitation, Elliott Station*—Continued

Measurement	1951–62			1965–72		
	Below normal	Near normal	Above normal	Below normal	Near normal	Above normal
			April			
Mean		•		•		
Std. dev.		•		•		
Occurrences ≥0.5 in	•			•		
Occurrences ≥1.0 in	•			•		
Occurrences ≥2.0 in	•			•		
Occurrences ≥4.0 in	•			•		
Summary	X			X		
			May			
Mean		•				•
Std. dev.		•				•
Occurrences ≥0.5 in	•				○	
Occurrences ≥1.0 in		○				•
Occurrences ≥2.0 in	○					•
Occurrences ≥4.0 in	○				○	
Summary		X				X
			June			
Mean	•			•		
Std. dev.	•			•		
Occurrences ≥0.5 in	•			•		
Occurrences ≥1.0 in	•				○	
Occurrences ≥2.0 in	•				•	
Occurrences ≥4.0 in	•				•	
Summary	X			X		
			July			
Mean	•			•		
Std. dev.			○	•		
Occurrences ≥0.5 in	○			•		
Occurrences ≥1.0 in	○			•		
Occurrences ≥2.0 in	•			○		
Occurrences ≥4.0 in	○			•		
Summary	X			X		
			August			
Mean			•		•	
Std. dev.			○	•		
Occurrences ≥0.5 in	•			•		
Occurrences ≥1.0 in	•			•		
Occurrences ≥2.0 in	•			•		
Occurrences ≥4.0 in			○	•		
Summary			X	X		
			September			
Mean		•		•		
Std. dev.			•	•		
Occurrences ≥0.5 in	•			•		
Occurrences ≥1.0 in	•			•		
Occurrences ≥2.0 in	•			•		

TABLE 4.4.—*Monthly and annual summary of normalcy of precipitation, Elliott Station*—Continued

Measurement	1951–62 Below normal	 Near normal	 Above normal	1965–72 Below normal	 Near normal	 Above normal
			September—Continued			
Occurrences≥4.0 in		∘		•		
Summary		X		X		
			October			
Mean			•			•
Std. dev.			∘			•
Occurrences≥0.5 in		∘			∘	
Occurrences≥1.0 in		∘				•
Occurrences≥2.0 in	•			•		
Occurrences≥4.0 in	∘			•		
Summary		X			X	
			November			
Mean			•	•		
Std. dev.	•			•		
Occurrences≥0.5 in	∘			•		
Occurrences≥1.0 in		∘		•		
Occurrences≥2.0 in		∘		•		
Occurrences≥4.0 in	•			•		
Summary		X		X		
			December			
Mean	•			•		
Std. dev.	∘				•	
Occurrences≥0.5 in		∘		•		
Occurrences≥1.0 in		∘			•	
Occurrences≥2.0 in	∘			•		
Occurrences≥4.0 in		∘			•	
Summary		X			X	
			Annual			
Mean			∘	•		
Std. dev.	•			•		
Occurrences≥0.5 in	∘			•		
Occurrences≥1.0 in	∘			•		
Occurrences≥2.0 in	∘			•		
Occurrences≥4.0 in		∘		•		
Summary		X		X		

SECTION 5.—DATA SUMMARIZATION

5.1.—PRECIPITATION

Precipitation characteristics treated in this section are analyzed strictly from the viewpoint of precipitation as an independent process. Consideration is not given to interrelations with and interpretations toward analyses of the streamflow and ground-water components of the study. Emphasis is placed on those precipitation characteristics that are significant in water-resources planning and design.

5.1.1.—Frequency of Daily Precipitation

Although maximum storm rainfall does not always result in maximum streamflow, extreme rainfall events generally result in large streamflow rates or volumes and are of particular interest for design purposes. Daily rainfall is a consistently defined time unit of rainfall and is often used in hydraulic design, especially drainage design.

In frequency analyses using annual series, considerable data are often disregarded. For example, the second, third, and fourth largest values of a variable during a year may be considerably larger than the annual maximums for other years. Such differences can be perplexing when working with relatively short-term records.

Snyder developed a method for fitting distribution functions by nonlinear least squares (*14*). The method eliminates the problems of empty classes, outliers, and plotting position, which are particularly common in short-term hydrologic variables. Snyder and Wallace developed the three-parameter log-normal distribution as a functional variate transform of an embedded-normal distribution (*19*), and it has been used widely in hydrologic data frequency analysis. The mean of the embedded normal and two parameters in the transform function were evaluated by nonlinear least squares. When so defined and evaluated, the three-parameter log-normal distribution is a good device for generating values of stochastic variables. The log-normal probability density function is given by

$$p(v) = [\sqrt{2\Pi}\, k(v-o)]^{-1} \exp\left\{-\tfrac{1}{2}\left[\frac{\ln(v-o)}{k} - m\right]^2\right\}, \qquad (5.1)$$

and the variate transform function is given by

$$\ln(v-o) = kx. \qquad (5.2)$$

In equations 5.1 and 5.2, x is the variate of the embedded-normal distribution of unit variance, m the mean, v the value of the variate, and o and k mathematical parameters. Three parameters, o, k, and m, are evaluated by nonlinear least squares applied to historical data.

Snyder developed a procedure for considering parameters o and k seasonally continuous and cyclic over a year (*17*). The procedure provides for the evaluation of the parameters at selected points with the determination of intermediate values by interpolation techniques (*13*). The procedure was adapted to analyze 12 monthly distributions of a variate simultaneously, and so monthly maximums of a variate could be treated over the year. Snyder used the techniques to fit monthly maximum daily rainfall amounts and generate several 100-year sets of monthly values (*16*). By fitting historical data and optimization of the parameters, monthly values were generated for 12 months by means of the fitted parameters.

Monthly maximum daily rainfall amounts for the Elliott Station are given in table A–14 for 1950 through 1972. The nonlinear least squares method of fitting the log-normal distribution was applied to the monthly maximum rainfall data. Parameters o, k, and m in the log-normal distribution were optimized by the method of least squares. Parameters o and k were optimized at three points during the year, with intermediate points determined by interpolation techniques (*13*). Optimization of the parameters resulted in a correlation of 0.884

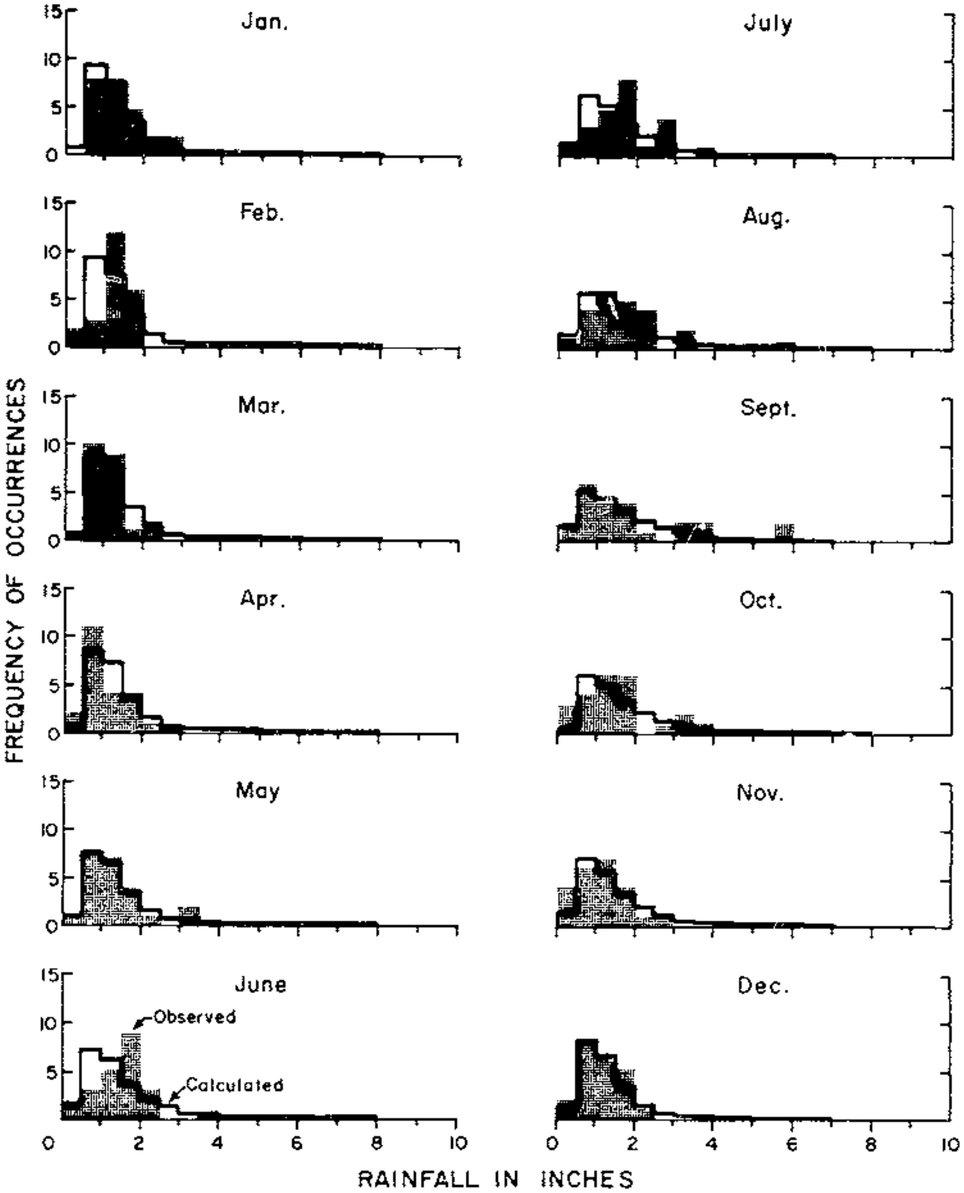


FIGURE 5.1.—Observed and calculated histograms, monthly maximum daily rainfall, Elliott Station (1950–72).

between observed and predicted values. Observed and calculated histograms are shown in figure 5.1.

Optimized parameters were used to generate ten 100-year sets of values for each month and then the 10 largest values were abstracted from each set for each month. Since the parameter functions are seasonally continuous, quarter points were selected for the presentation of the values. The 10 largest values from each of the 10 sets are shown in figures 5.2–5.5, for January, April, July, and October, respectively.

The data show a rather narrow range for return periods up to about 25 years, but the range increases considerably to the 100-year return period, demonstrating the relative reliability of estimating the values for long recurrence intervals from short-term data. The 22-year observed maximums are also shown on the figures for the four months.

The most significant point of this frequency analysis is that there is not a single value of estimated daily rainfall for any return period, but rather a range of values. This fact should be

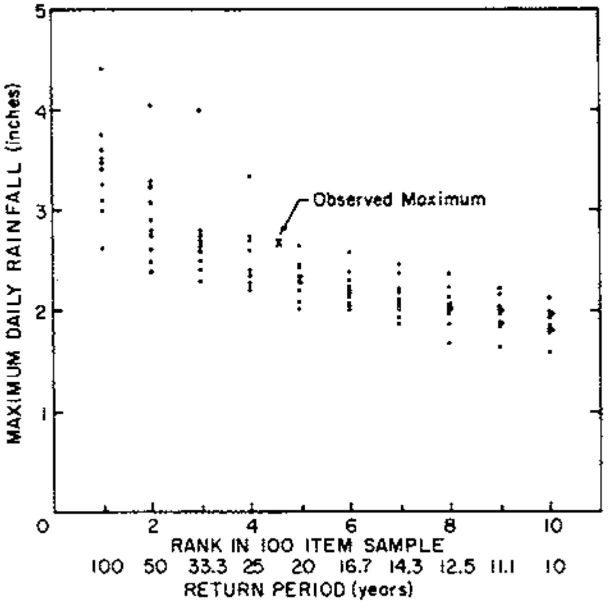


FIGURE 5.2.—Maximum generated daily rainfall, 10 maximums from ten 100-year samples, Elliott Station, January.

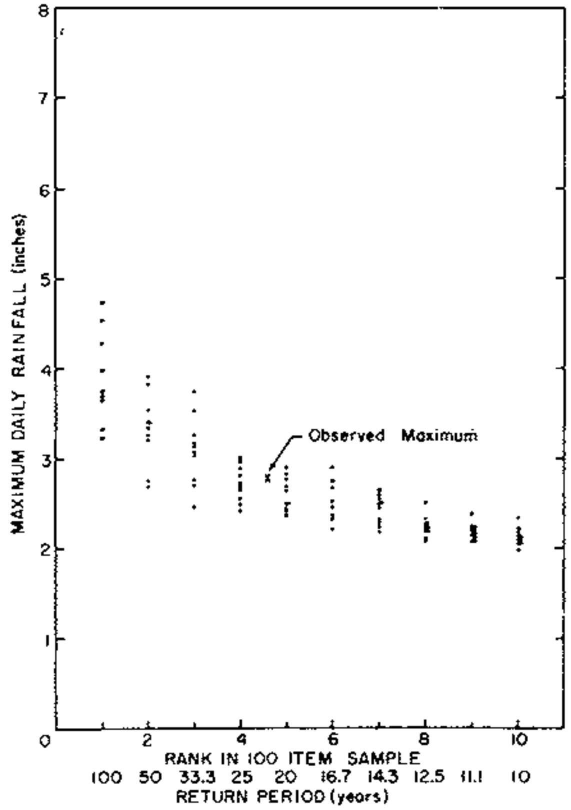


FIGURE 5.3.—Maximum generated daily rainfall, 10 maximums from ten 100-year samples, Elliott Station, April.

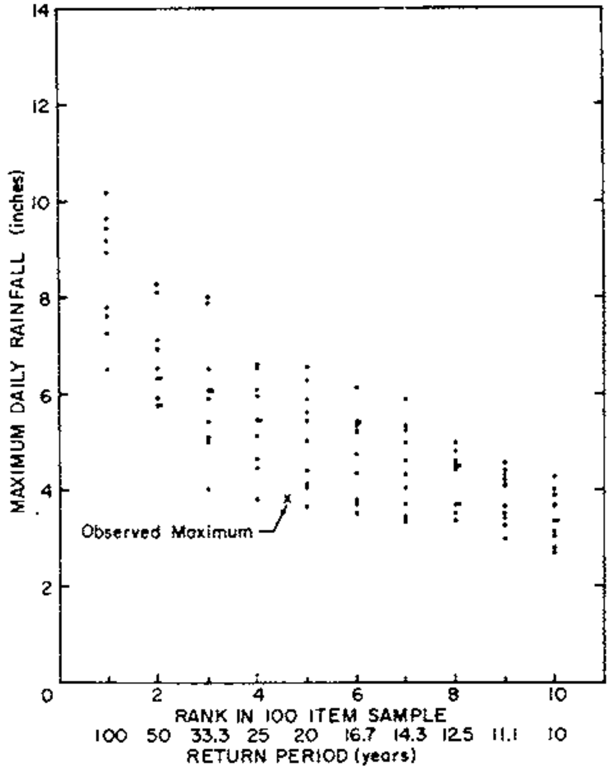


FIGURE 5.4.—Maximum generated daily rainfall, 10 maximums from ten 100-year samples, Elliott Station, July.

kept in mind when estimating future rainfall events from historical records.

5.1.2.—Areal Distribution of Precipitation

Design-storm rainfall amounts are normally taken from point-rainfall records or published U.S. Weather Bureau maps based on point-rainfall analyses (*27*). Basin rainfall for hydraulic-structures design is normally determined by reduction of point-rainfall estimates by some predetermined factor dependent upon the climatic region. SCS developed criteria for reducing map rainfall to areal rainfall for three climatic regions: Pacific Coastal, humid and subhumid, and arid and semiarid climates (*25*). Little data are available from rain-gage networks to determine reduction ratios, but the rain-gage network in the Ahoskie Creek watershed provides some data for estimating point-to-area relationships. Because the period of record is relatively short, the data are not sufficient for the desired analysis.

Two criteria were used in selecting storms for point-area analysis: (1) all storms, irrespective of duration, with maximum observed point rainfall equal to or greater than 2.00 inches, and (2) separation of storms into general winter (October 1 through April 30) and summer (May 1 through September 30) seasons. The number of storms was different for each watershed. A total of 60 summer and winter storms were selected for watershed W–A1, where maximum point rainfall ranged from 2.00 inches to 12.60 inches. Maximum Thiessen weighted rainfall ranged from 4.85 inches for watershed W–A1 to 8.70 inches for watershed W–A4. The 2-inch point rainfall is equivalent to approximately a 1-year 6-hour amount given in U.S. Weather Bureau Technical Paper 40 (*27*), and the 12.60 inches is greater than the 100-year 24-hour amount given. Of the 21.60-inch total, 12.50 inches was recorded in approximately 14 hours as measured at a tipping-bucket gage.

Ratios of areal rainfall to point rainfall were determined for each watershed by season for each storm irrespective of storm duration (fig. 5.6). The data reflect a large range of ratios for each watershed, especially during the summer season. Figure 5.6 also shows the types of rainfall mechanism in each season. The summer convective thunderstorms are generally more variable than storms associated with frontal movement in the winter.

Because the maximum ratios, for design purposes, would be more significant in providing safety factors, envelope curves were drawn through the uppermost points for each watershed each season. There is no significant difference between the seasonal lines up to approximately 40 square miles. Although there is a large gap between watersheds W–A2 and W–A3, the logarithmic scale of the area permitted the drawing of relatively smooth lines for each season. The data show that a ratio of 1.0 should be used for an area up to approximately 10 square miles. The summer and winter lines begin to diverge at 40 squares miles, with a significant difference in the ratios for the 57-square-mile watershed, W–A1.

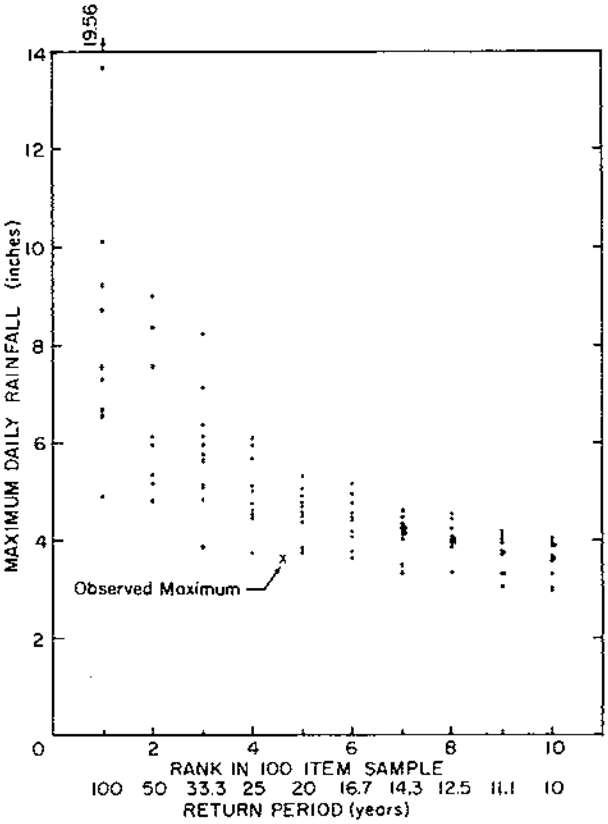


FIGURE 5.5.—Maximum generated daily rainfall, 10 maximums from ten 100-year samples, Elliott Station, October.

For purposes of comparison, the SCS curve for the humid and subhumid areas (*25*) was drawn on figure 5.6, showing a ratio of the areal rainfall to the map rainfall of unity for a 10-square-mile area. Map rainfall represents point rainfall determined from U.S. Weather Bureau Technical Paper 40 (*27*). The ratios drop off rapidly to approximately 0.86 for a 50-square-mile area, the largest difference between the SCS curve and the envelope curves determined from the Ahoskie Creek data occurring in the region of 30 to 40 square miles, with the SCS curve being considerably lower.

The maximum point-rainfall storm of 12.60 inches resulted in ratios ranging from 0.34 for the 57-square-mile watershed, W–A1, to 0.70 for the 2.60-square-mile watershed, W–A4. As indicated above, this storm has a long-term average recurrence probability.

The Ahoskie Creek rain-gage-network data show that the ratios of areal to point rainfall should not be less than 0.90 for areas less than 60 square miles. These data are representative of the mid-Atlantic near-coast areas.

5.1.3.—Time Distribution of Storm Precipitation

The conventional treatment of storm rainfall generally considers dimensionless plots of ratios

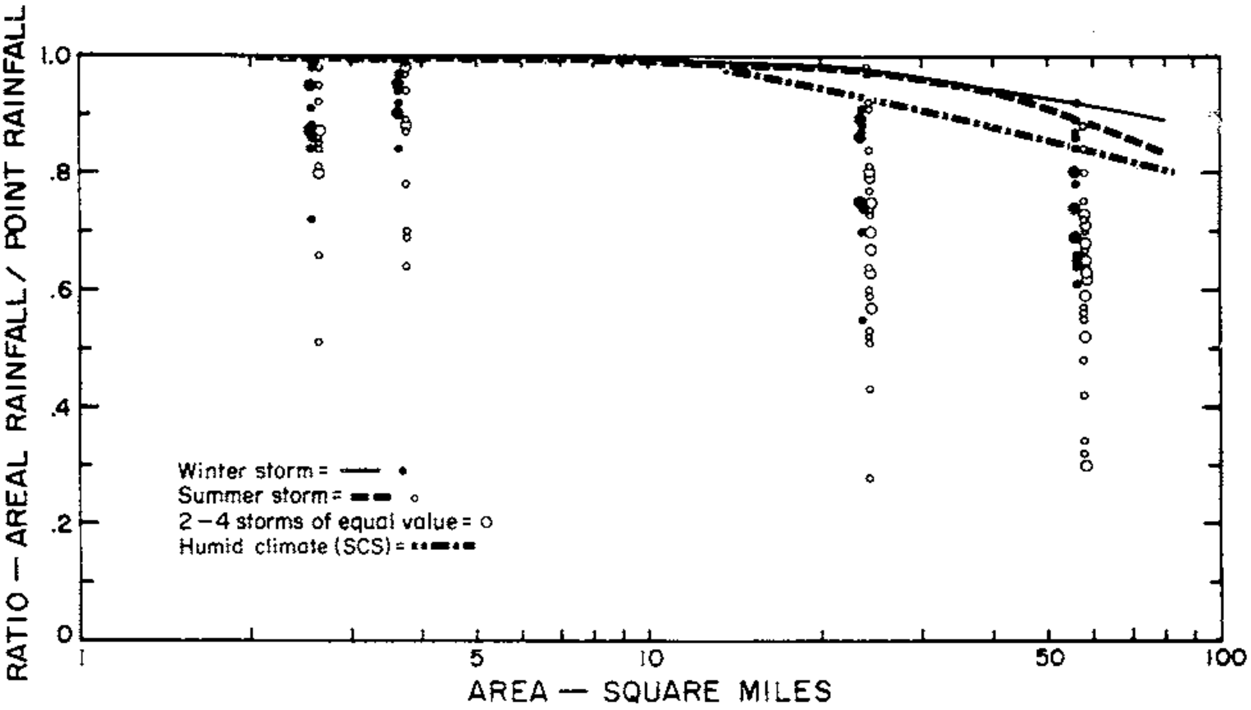


FIGURE 5.6.—Relationship between ratio of areal rainfall and point rainfall and area, Ahoskie Creek.

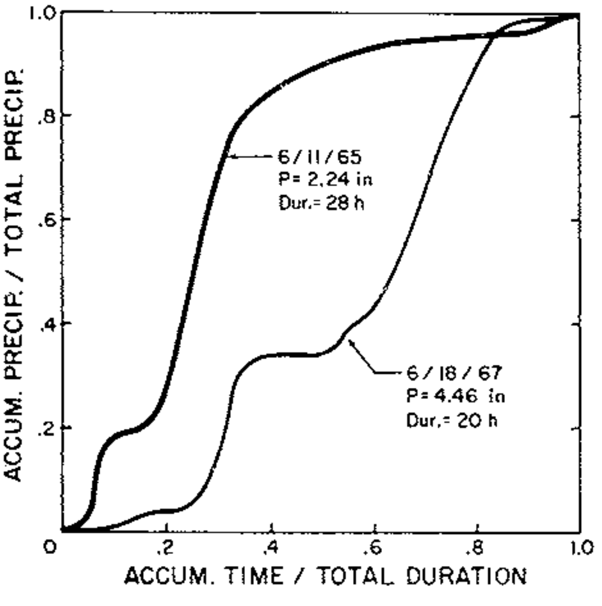


FIGURE 5.7.—Dimensionless plot of storm-rainfall distribution, summer storms, watershed W–A1.

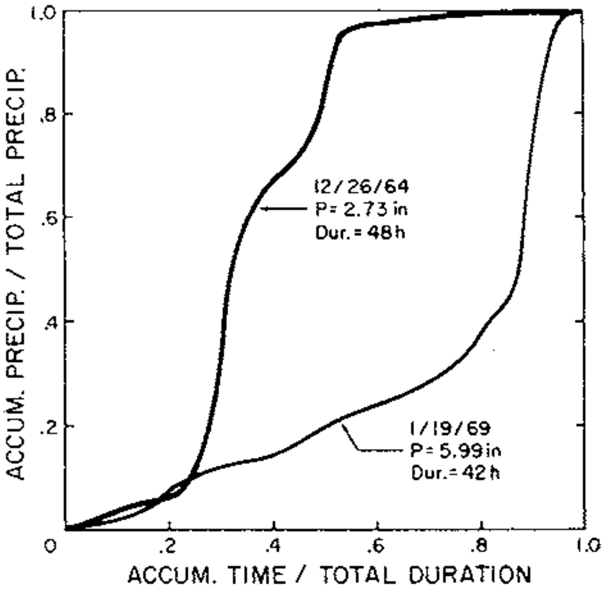


FIGURE 5.8.—Dimensionless plot of storm-rainfall distribution, winter storms, watershed W–A1.

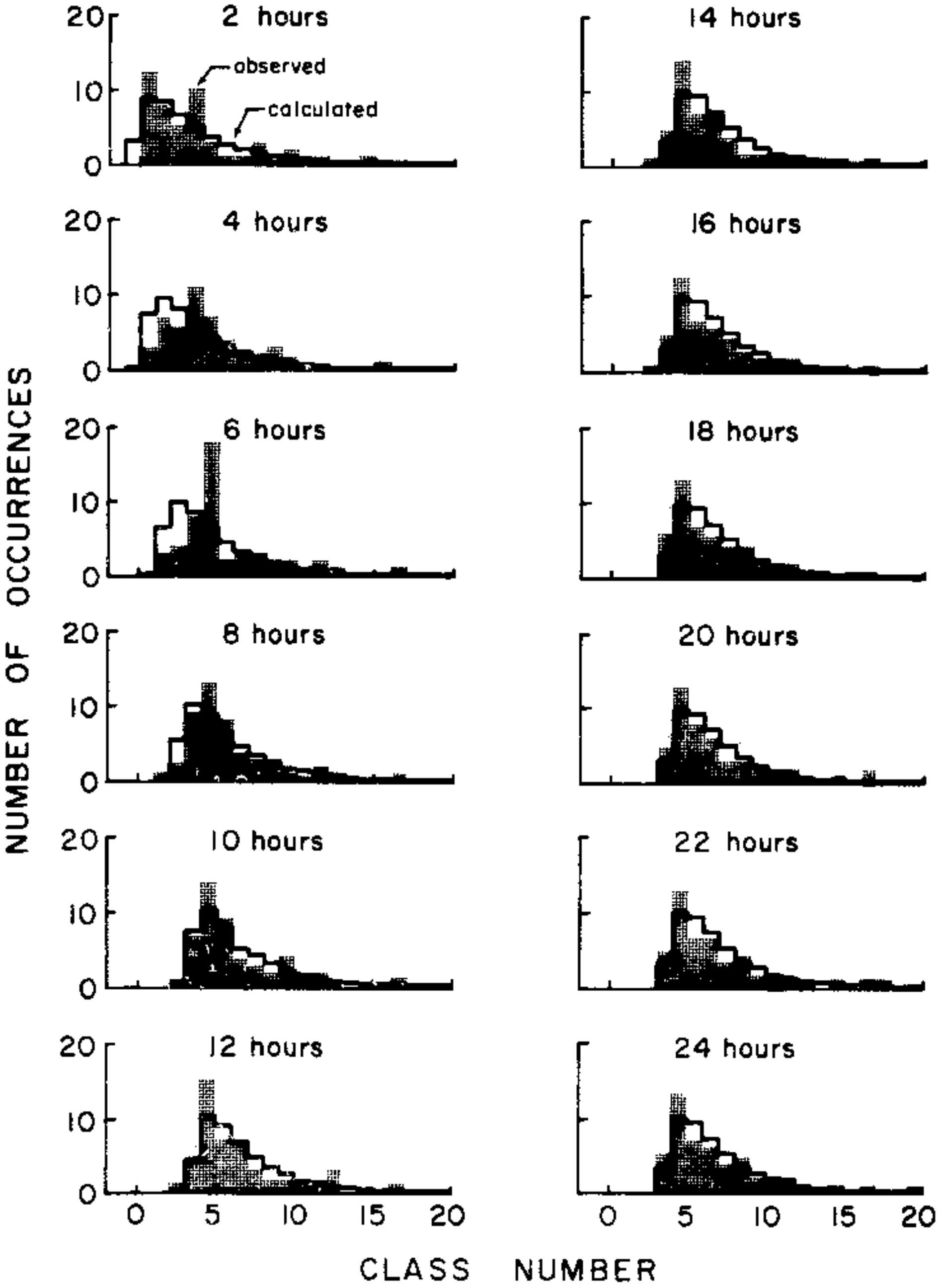


FIGURE 5.9.—Observed and predicted histograms for 24-hour rainfall at 2-hour intervals, 0.25-inch-class width, summer storms, Ahoskie Creek rain gage 3.

of accumulated precipitation to total storm precipitation, and accumulated time to total storm duration. Significant historical storms are used to determine seasonal patterns that characterize storm types. This type of analysis generally results in selection of a significant storm pattern to be applied to maximized rainfall amounts for time distribution.

In the present Ahoskie Creek study, storms with rainfall equal to or greater than 2.0 inches, irrespective of duration, were selected for analysis. Dimensionless plots were made and compared to determine if seasonal trends existed. Figures 5.7 and 5.8 show dimensionless plottings that illustrate the diversity of curves for summer and winter storms, respectively, by weighted rainfall for watershed W–A1. Since different hydrologic consequences will result

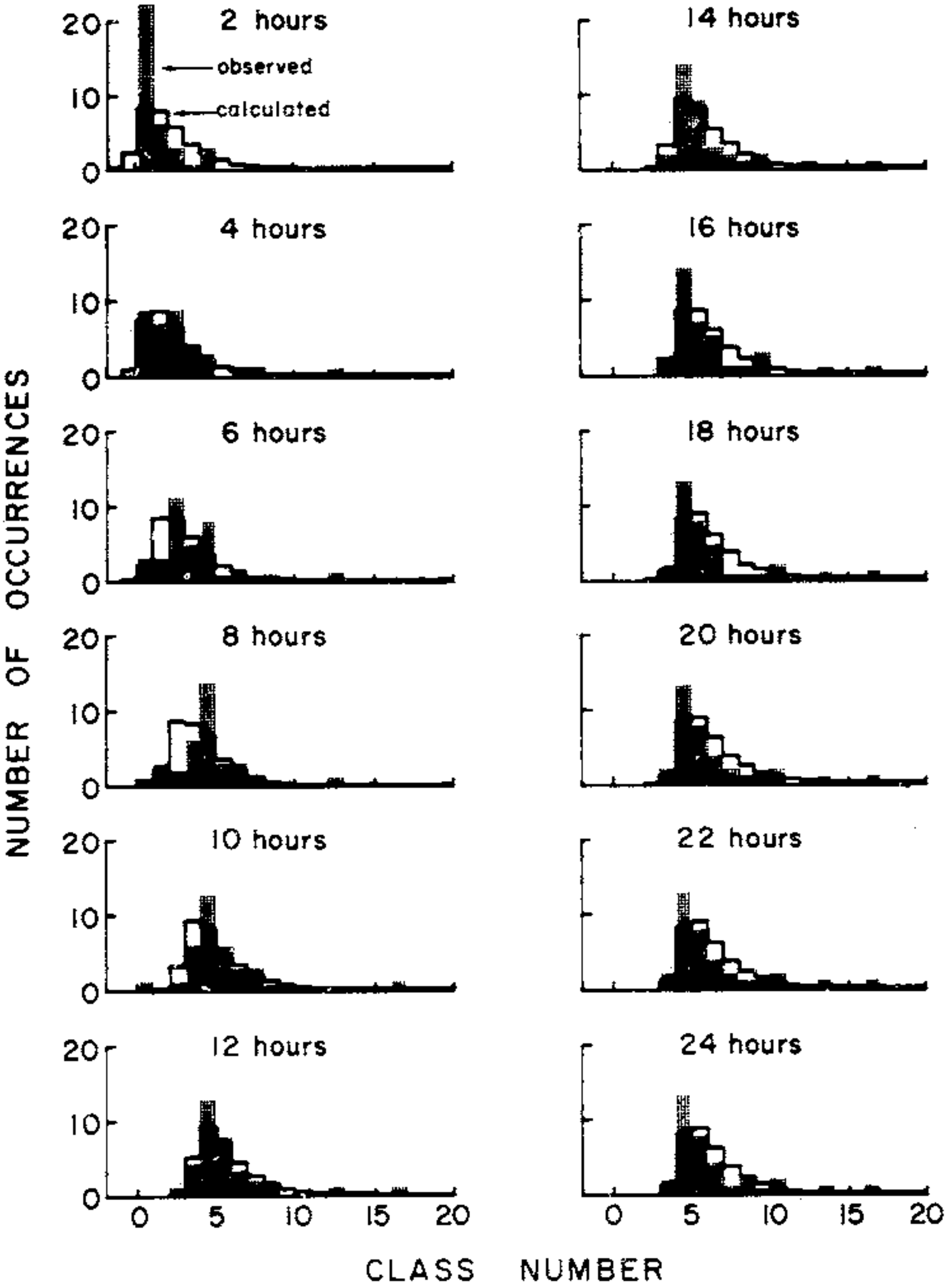


FIGURE 5.10.—Observed and predicted histograms for 24-hour rainfall at 2-hour intervals, 0.25-inch-class width, winter storms, Ahoskie Creek rain gage 3.

from each storm pattern, much is left to be desired for determining the appropriate storm pattern for hydrologic design and test purposes. Seasonal or storm differences could not be differentiated in the analysis.

An alternative procedure was investigated for analyzing time distribution of storm rainfall (*6*). Because rainfall amounts at successive time increments for selected storms provide frequency distribution for each time interval chosen, a number of distributions can be developed throughout a storm. Application of the log-normal distribution for hydrologic variables was given in section 5.1.1, as well as the concept of seasonal continuity of frequency distribution parameters. Now, instead of a frequency-distribution parameter of a hydrologic variable being continuous over a year, the function can be considered to be continuous over the duration of a storm.

The cyclic functions for parameters o and k in the log-normal distribution could not be used in this analysis. Time-dependent functions were conceptualized as

$$o_i = LCL - a_1 e^{-a_2 (i-1)^2} \tag{5.3}$$

and

$$k_i = \frac{b_1}{i} + b_2, \tag{5.4}$$

where o and k are the distribution parameters, i is the ith interval from 1 to 12, LCL is the lower class limit corresponding to the minimum rainfall for selected storms, and a_1, a_2, b_1, and b_2 are mathematical coefficients evaluated by fitting historical data.

Point-rainfall data were used in the study with rain gage 3 (fig. 1.1) of the Ahoskie Creek network selected for analysis. The record period was from July 1964 through December 1972. All storms with rainfall equal to or greater than 1.0 inch in 24 hours were selected and considered at 2-hour intervals. Two seasons were examined to consider differences in storm types: (1) summer, May 1 through September 30, and (2) winter, October 1 through April 30.

Accumulated rainfall amounts were used to develop histograms at 2-hour intervals for the 24-hour duration. A class width of 0.25-inch was chosen in this study. Twelve histograms were developed for each season. The storm selection criteria resulted in 50 summer storms ranging from 2.00 to 5.00 inches, and 35 winter storms ranging from 2.00 to 4.50 inches.

The nonlinear-least-squares method of fitting the log-normal distribution was applied to the storm data for optimization of the function relationships for parameters o and k and the parameter m for each season. Correspondence between the observed and the fitted histograms resulted in correlation coefficients of 0.873 and 0.841 for summer and winter storms, respectively. The observed and the fitted histograms are shown in figure 5.9 for the summer season and in figure 5.10 for the winter season. The agreement between the observed and the fitted histograms is relatively close, considering that the fit is for the 12 distributions simultaneously and not any single time interval.

As in the case with the frequency analysis of daily rainfall, this method is particularly adapted to the generation of synthetic data. The optimized parameters from the fitting technique and random-number generation were used to determine synthetic storm data. The data represent cumulative rainfall amounts at 2-hour intervals. Data sets were generated for 50 storms each for the summer and the winter (tables 5.1 and 5.2).

The tables show that the storms are not all of 24-hour duration and that there are periods without rainfall, conditions similarly characteristic of the historical data. Compared with the historical data, the generated data appear realistic. These data provide synthetic time-distributed storm rainfall for design and analysis.

5.2.—STREAMFLOW

Treatment of streamflow variables in this section is made purely on the basis of streamflow presentation. The section is intended to provide information and analyses of a specific variable without any reference to interrelationships with precipitation or ground-water components. These interrelations are treated in later sections. Methodologies presented in earlier sections are cross-referenced without duplicating the details.

5.2.1.—Streamflow Volumes for Selected Time Intervals

Annual maximum peak rates and volumes for selected time intervals are given in tables A–19 through A–22 for watersheds W–A1, W–A2, W–A3, and W–A4, respectively, for 1964 through 1972. As noted in section 4.1.2, the recording of streamflow at W–A2, W–A3, and W–A4 began July 1, 1964, and records are available for W–A1 for all of 1964. Since the greatest peak and volumes of 1964 occurred at W–A1 in October, it is believed that annual maximums for the other three watersheds also occurred in October.

The time intervals selected for this study coincide with those of the hydrologic data published by ARS (*1–3*). Volumes are given for 1, 2, 6, and 12 hours, and 1, 2, and 8 days. Units for volume are in inches and for peak rates are in inches per hour.

The data in tables A–19 through A–22 reveal that the 1-hour volume has the same magnitude as the peak rate for all watersheds for all years. Obviously, a peak would not be sustained for

TABLE 5.1.—*Rainfall of fifty 24-hour synthetic summer storms, at 2-hour intervals, Ahoskie Creek rain gage 3*

[Inches]

Storm	Period											
NO.	1	2	3	4	5	6	7	8	9	10	11	12
1	1.44	1.44	1.44	1.44	1.45	1.62	1.62	1.62	1.62	2.82	2.82	2.62
2	1.58	1.58	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.40	3.40
3	.26	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	2.58	2.58	2.58
4	.59	.74	.74	.91	1.28	1.45	1.92	1.98	1.98	1.98	1.98	1.98
5	2.28	2.28	2.28	2.28	2.28	2.39	2.61	2.61	2.61	2.61	2.61	2.61
6	1.32	1.32	1.32	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
7	1.32	1.48	1.48	1.48	1.48	1.51	1.51	1.51	1.51	1.51	1.66	1.66
8	.13	1.20	1.20	1.20	1.87	2.35	2.35	2.35	2.35	2.35	2.35	2.35
9	.34	.45	.51	1.02	1.02	1.66	1.66	1.66	1.66	1.87	1.87	1.87
10	.58	.79	.79	.79	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.87
11	.86	.86	.86	1.17	1.17	1.93	1.93	1.93	1.93	1.93	2.32	2.32
12	.42	1.45	1.45	1.45	1.45	1.45	1.72	1.72	1.72	1.75	1.75	1.99
13	.94	.94	.94	.94	1.82	1.82	1.82	2.28	2.52	2.52	2.52	2.52
14	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51
15	1.25	1.25	1.25	1.25	1.66	1.66	1.66	3.07	3.07	3.07	3.07	3.07
16	1.37	1.37	1.37	1.37	1.37	1.37	1.37	2.51	2.51	2.51	2.51	3.27
17	.28	.40	.40	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.71
18	.27	.53	.53	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.85
19	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.23	2.23	2.23	2.23
20	1.11	1.11	1.11	1.40	1.40	2.04	2.04	2.04	2.04	2.04	2.04	2.04
21	.37	.37	1.09	1.65	1.65	1.65	1.65	1.83	1.83	1.83	1.83	1.83
22	.88	.88	.88	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
23	.70	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
24	.30	1.28	1.28	1.28	1.28	2.19	2.19	2.19	2.19	2.19	2.19	2.19
25	.91	.91	.91	2.74	2.74	2.74	2.74	2.74	2.74	2.74	2.74	2.74
26	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19
27	.55	.55	.55	.81	1.15	1.20	2.50	2.50	2.50	2.50	2.50	2.50
28	.29	.74	.74	.80	1.19	1.48	1.48	1.80	1.80	1.80	1.80	1.80
29	.47	.55	1.08	1.23	1.41	1.41	1.41	1.41	1.85	1.85	1.85	1.85
30	.01	.23	1.41	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
31	.26	.48	.48	.57	1.95	1.95	1.95	1.95	2.37	2.37	2.37	2.37
32	1.13	1.13	1.13	1.13	1.59	1.59	1.59	1.59	1.59	1.59	1.99	1.88
33	.75	.75	.75	1.23	1.23	1.23	1.55	1.55	1.55	1.55	3.38	3.38
34	1.27	1.27	1.27	1.27	1.46	1.46	1.46	1.46	1.79	1.79	1.79	1.79
35	.53	.98	1.29	1.29	1.29	1.29	1.29	3.13	3.13	3.13	3.13	3.13
36	1.38	1.38	1.38	1.38	1.90	1.50	1.50	1.77	1.77	1.77	1.77	1.77
37	.63	.63	.63	.78	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54
38	.20	.38	.38	.85	2.35	2.35	2.35	2.35	3.40	3.40	3.40	3.40
39	.14	.17	1.30	1.87	1.87	1.87	1.87	1.87	2.65	2.65	2.65	2.65
40	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83
41	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03
42	1.80	1.80	1.80	1.80	1.80	1.80	2.08	2.08	2.08	2.08	2.08	2.14
43	.38	1.08	1.18	1.18	1.18	1.49	1.49	1.90	1.90	1.90	1.90	1.90
44	.30	.63	.69	1.26	1.26	1.26	1.26	1.58	1.58	1.58	1.58	1.58
45	.43	1.48	1.95	1.95	1.95	1.95	3.20	3.20	3.20	3.20	3.20	3.20
46	.56	.56	.82	1.49	1.49	1.49	2.69	2.69	2.69	2.69	2.69	2.69
47	.26	.27	.58	.58	.74	.81	.95	2.05	2.05	2.05	2.05	2.05
48	.08	.44	.44	1.39	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
49	1.66	1.66	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	2.14	2.14
50	.80	.80	2.18	2.18	2.18	2.92	2.92	2.92	2.92	2.92	2.92	2.92

TABLE 5.2.—*Rainfall of fifty 24-hour synthetic winter storms, at 2-hour intervals, Ahoskie Creek rain gage 3*

[Inches]

Storm	Period											
NO.	1	2	3	4	5	6	7	8	9	10	11	12
1	1.66	1.66	1.66	2.70	2.70	2.70	2.70	2.70	2.70	3.77	3.77	3.77
2	1.96	1.96	1.96	1.96	1.96	1.96	2.25	2.25	3.86	3.88	3.88	3.88
3	.24	.24	1.49	1.76	2.12	2.53	2.53	2.53	2.53	2.77	2.77	2.77
4	.48	1.79	1.79	1.79	1.79	1.79	2.55	2.55	2.55	2.55	2.55	2.55
5	2.14	2.14	2.89	2.89	2.89	6.30	6.30	6.30	6.30	6.30	6.30	6.30
6	.34	3.34	3.34	3.34	3.34	10.66	10.66	10.66	10.66	10.66	10.66	10.66
7	.71	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76
8	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	5.10	5.10	5.10	5.10
9	.44	.49	.88	1.31	1.32	1.39	1.97	1.97	1.97	1.97	1.97	1.97
10	1.02	1.02	3.68	5.36	5.36	5.36	5.36	5.36	5.36	5.36	5.36	5.36
11	.62	.62	1.08	1.90	1.90	1.90	1.90	1.90	1.90	1.90	2.60	2.60
12	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
13	.47	.47	.91	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58
14	1.75	1.75	2.80	2.80	2.80	2.80	2.80	2.80	2.80	4.73	4.73	4.73
15	2.80	2.80	2.80	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.58
16	.07	.11	5.30	5.30	5.30	5.30	5.30	5.30	5.30	5.30	5.30	5.30
17	3.56	3.56	3.56	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73
18	.36	.36	1.27	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
19	1.71	1.71	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
20	.21	.80	.80	3.49	3.49	3.49	3.49	3.49	3.49	3.49	6.41	6.41
21	3.61	3.61	3.61	7.09	7.09	7.09	7.09	7.09	7.09	7.09	7.09	7.09
22	1.26	1.26	1.26	1.26	1.26	1.77	1.99	1.99	2.05	5.00	5.00	5.00
23	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89
24	.47	.47	.47	1.08	1.71	1.85	1.85	1.85	2.03	2.03	2.03	2.38
25	.74	.82	1.93	1.93	1.93	2.23	2.23	2.23	2.23	2.75	2.75	2.75
26	1.46	1.56	1.56	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41
27	.74	.74	.83	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34
28	.21	.49	.49	1.32	1.82	1.82	4.85	4.85	4.85	4.85	4.85	4.85
29	1.32	1.32	1.32	1.32	1.32	3.95	3.95	3.95	6.96	6.96	6.96	6.96
30	.12	.59	1.45	1.49	1.49	1.75	2.33	2.33	2.33	2.33	2.39	2.39
31	.21	.88	.95	1.00	1.02	1.65	2.30	2.30	2.50	2.50	3.16	3.16
32	1.82	1.82	1.82	1.82	1.82	2.13	2.13	2.13	2.35	2.35	2.35	2.35
33	.44	.44	.86	1.09	1.09	1.62	1.62	1.62	1.95	1.95	1.95	1.95
34	.65	.65	.67	1.44	2.11	2.11	2.20	2.20	2.35	2.91	2.91	7.76
35	5.24	5.24	5.24	5.24	5.24	5.24	5.95	5.95	5.95	5.95	5.95	5.95
36	.78	.78	.78	1.12	1.75	1.75	8.88	8.88	8.88	8.88	8.88	8.88
37	.21	.42	.67	1.54	1.54	1.54	3.31	3.31	3.31	4.01	4.01	4.01
38	1.59	1.59	1.59	1.59	1.59	1.65	1.65	1.65	1.65	2.21	2.21	2.21
39	.67	1.56	1.62	1.62	1.62	1.74	1.74	3.14	3.14	3.14	3.14	3.14
40	1.13	1.13	1.17	1.17	1.21	3.37	3.37	3.37	3.37	3.37	4.44	4.44
41	1.65	1.65	1.65	1.65	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95
42	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79
43	.71	1.74	1.74	2.93	2.93	9.64	9.64	9.64	9.64	9.64	9.64	9.64
44	.24	.44	1.06	1.78	1.78	1.78	1.78	3.55	3.55	3.55	3.55	3.55
45	.33	.45	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71
46	.46	.89	.89	2.26	3.16	3.16	3.16	3.16	3.16	4.18	4.18	4.18
47	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36	4.36
48	.97	.97	3.30	3.30	3.30	3.30	3.30	4.18	4.18	4.18	4.18	4.18
49	.77	2.08	2.08	2.08	2.08	2.26	2.26	2.26	2.26	2.26	2.26	2.26
50	.56	1.25	1.25	1.25	1.72	1.72	1.72	4.03	4.03	4.03	4.03	4.03

long periods, but rounding off of the relatively small peak values results in the same values rounded to hundredths. The tables also reveal that the 2-hour volumes are exactly twice the 1-hour volumes for all watersheds for all years, except 1972 for W–A1, 1966 for W–A2, 1967 for W–A3, and 1969 and 1972 for W–A4. These exceptions are due to rounding, and for all practical purposes the 1-hour volumes in inches are equivalent to the instantaneous peak in inches per hour. Likewise, the 2-hour volumes are twice the 1-hour volumes.

Ratios of observed volume to extrapolated volume were determined for 6, 12, and 24 hours according to the following formulas:

$$\frac{\text{6-h observed}}{3\times 2\text{ h observed}},\qquad \frac{\text{12-h observed}}{2\times 6\text{ h observed}},\quad\text{and}$$

$$\frac{\text{24-h observed}}{2\times 12\text{ h observed}}.$$

Ratios were determined for all watersheds for all years, and averages were determined for each watershed for each time interval (fig. 5.11). The points do not fit the smooth lines on the semilog paper, and therefore straight lines were drawn to connect the points. The plotted points do show influence of size of area, as expected. Ratios for 2-day and 8-day volumes were considerably lower with less consistency than shown in figure 5.11. These data indicate that Coastal Plain watersheds larger than about 60 square miles, with improved channels, produce long-duration flat hydrographs. Daily volumes are essentially equal to 24 times the instantaneous peak discharge. The influence of area on hydrograph shape can be inferred from the data in the figure.

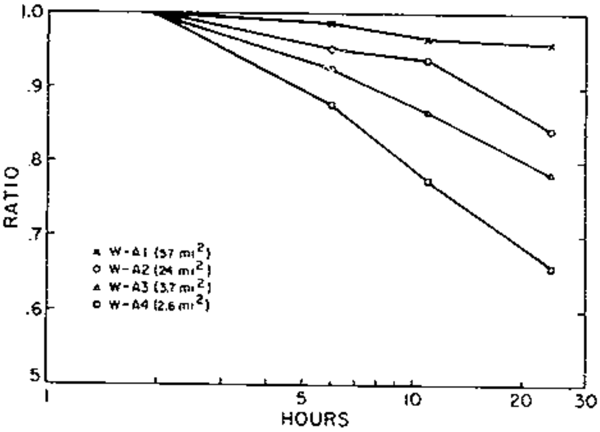


FIGURE 5.11.—Ratios of observed to extrapolated discharge for selected time intervals, Ahoskie Creek.

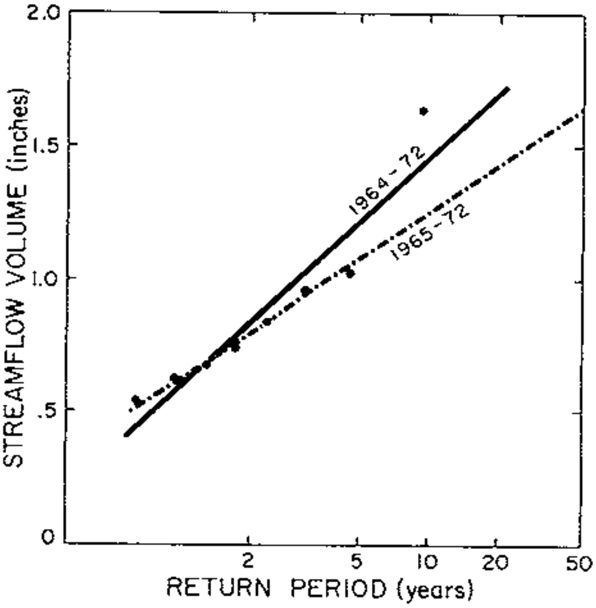


FIGURE 6.12.—Fisher-Tippett type I distribution, annual maximum 1-day streamflow, watershed W–A1 (1964–72).

Streamflow volumes for 24-hour periods are significant in hydraulic design. Frequency analysis of historic annual series is one method of estimating flood volumes for various return periods. Several methods of frequency analysis and several distributions have been used in hydrology. The Gumbel procedure for fitting the Fisher-Tippett type I distribution (*12*) was used to fit the annual series of 24-hour streamflow for watershed W–A1, for 1964 through 1972. The data were plotted on Gumbel extreme value paper (fig. 5.12). As indicated by the dashline, 7 of the 8 years closely approximate a straight line. However, the 1964 annual maximum was 60 percent larger than the second highest value, and the least-squares line for all data is greatly different from the line for 7 years. The one extreme point, which often may occur in a short period of record, shows why short-term records do not provide good estimates for design purposes.

The solid line in figure 5.12 shows that the 1964 storm would have an estimated average recurrence interval of approximately 17 years. An extension of the dashline would indicate the 1964 storm had an approximate 50-year recurrence interval. This comparison shows that the short-term records for Ahoskie Creek do not justify frequency analysis.

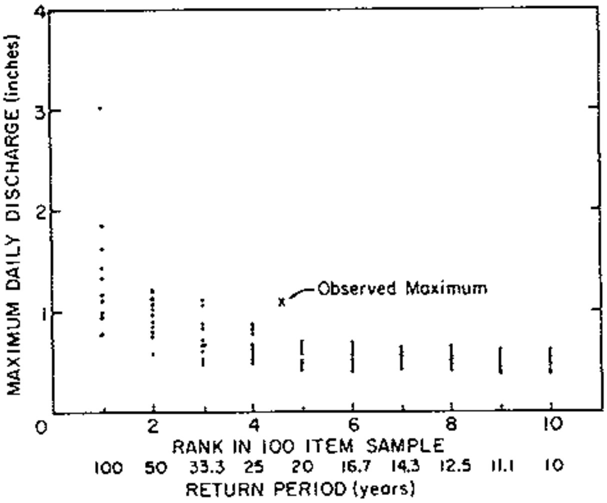


FIGURE 5.13.—Generated maximum daily discharge for January, 10 maximums from 10 samples of 100 items, watershed W–A1.

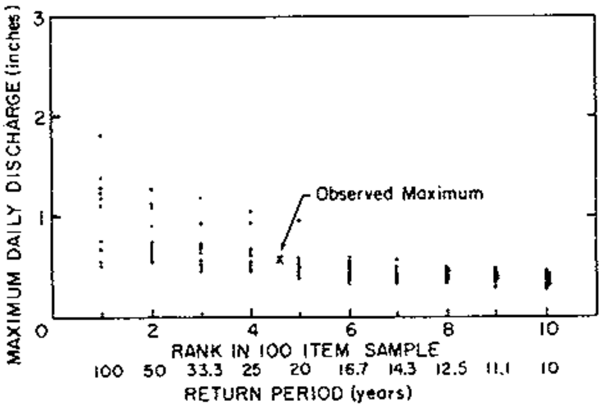


FIGURE 5.14.—Generated maximum daily discharge for April, 10 maximums from 10 samples of 100 items, watershed W–A1.

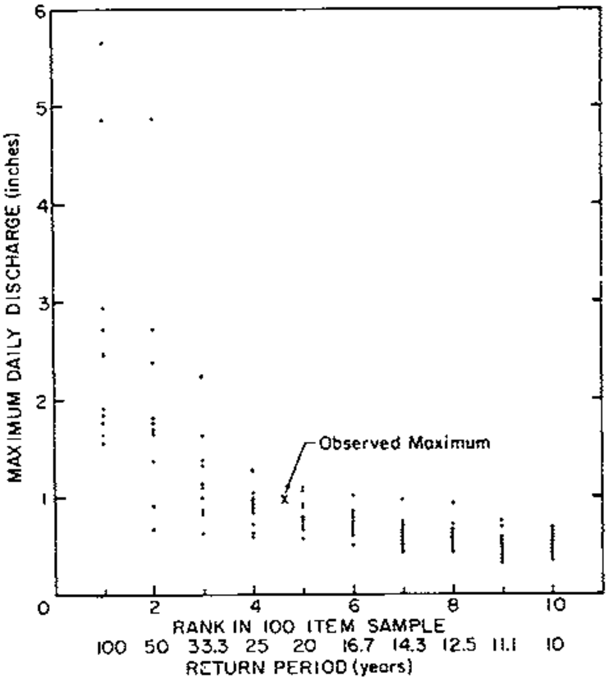


FIGURE 5.15.—Generated maximum daily discharge for July, 10 maximums from 10 samples of 100 items, watershed W–A1.

An alternate method of frequency analysis was used to study daily streamflow volumes. The nonlinear-least-squares method of fitting the log-normal distribution was presented in section 5.1.1, as well as the concept of seasonally continuous cyclic functions of distribution parameters. By means of the seasonally continuous functions, monthly data could be analyzed, as opposed to the normally used annual series.

The 22-year, 1951 through 1972, record for watershed W–A1 was used with the fitting and generation techniques. Monthly maximum mean daily discharge values (table A–27), expressed in volume, were used in the study. The data were fitted and parameters optimized with a correlation coefficient of 0.940, which is good, considering that the fitting was simultaneous over the 12 months, as opposed to a best fit for any individual month.

The optimized parameters were used with the generating technique, and ten 100-year sets of monthly streamflow volumes were determined. The 10 largest values in each set for each month were abstracted, ordered by rank, and plotted. Since the distribution parameters *o* and *k* are seasonally continuous cyclic functions, four months were selected to represent the results: January, April, July, and October, which correspond to the quarter-point selections in daily rainfall analyses (sec. 5.1.1). The generated data for the four months are shown in figures 5.13–5.16.

In viewing the figures, three points should be made. First, these data were generated with parameters from a 22-year record. The figures show little spread in the data representing return periods up to 25 years, but for longer return periods the data ranges increase. Second, the observed maximums are plotted at the 22-year return period since it is rank 1 in a 22-year record. This does not imply that it represents a 22-year return period. The third and most

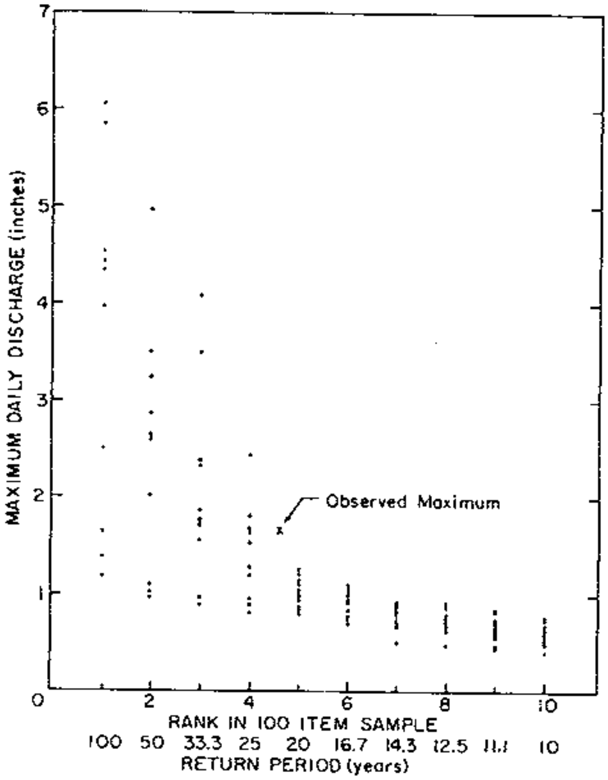


FIGURE 5.16.—Generated maximum daily discharge for October, 10 maximums from 10 samples of 100 items, watershed W–A1.

significant point is that there is not a single value for any one return period, that is, neither a 100-year volume nor a 10-year volume exists. Instead, there is a range of values for any return period, in the figures shown, 10 values for each return period. These values would be different if 10 more sets of 100-year data were generated. Planners and designers who use frequency data should note this point. These studies point out the value of long-term data for frequency analysis. The 9-year data, after the channelization of the Ahoskie Creek watershed, are insufficient for frequency study.

5.2.2.–Frequency of Peak Flow Rates

Annual maximum instantaneous peak rates are given in tables A–19 through A–22 for watersheds W–A1, W–A2, W–A3, and W–A4, respectively. Tables A–23 through A–26 give the monthly maximum instantaneous peaks for the four watersheds, and tables A–27 through A–30 contain the monthly maximum mean daily discharge for each of the watersheds.

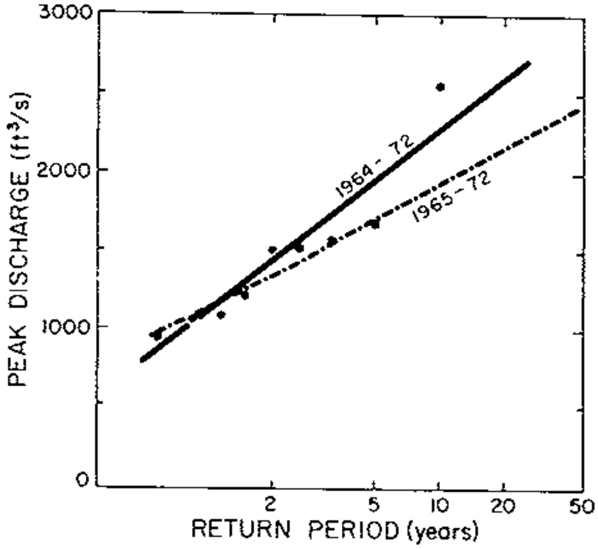


FIGURE 5.17.—Fisher-Tippett type I distribution, annual maximum peak discharge, watershed W–A1 (1964–72).

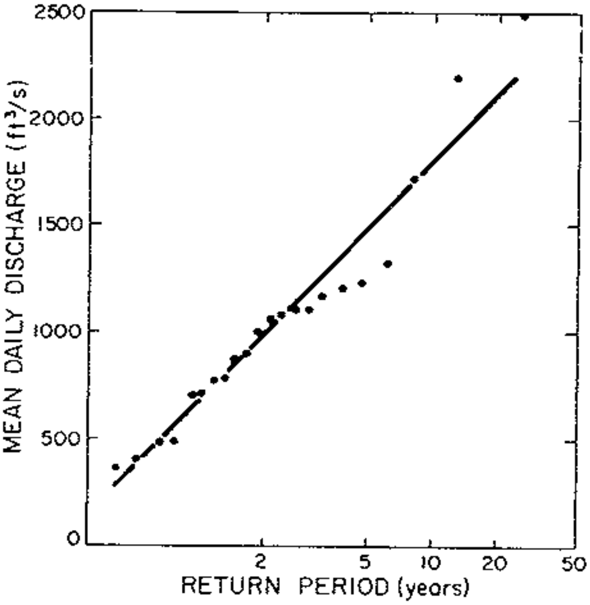


FIGURE 5.18.—Fisher-Tippett type I distribution, annual maximum mean daily discharge, watershed W–A1 (1951–72).

Design of many hydraulic structures is determined by the peak discharge rate expected for some average recurrence interval. In section 5.2.1, Gumbel's simplified procedure (*12*) was applied to the short-term annual maximum 1-day volumes for watershed W–A1, as well as to the annual maximum instantaneous rates of

(*Continued on page 44.*)

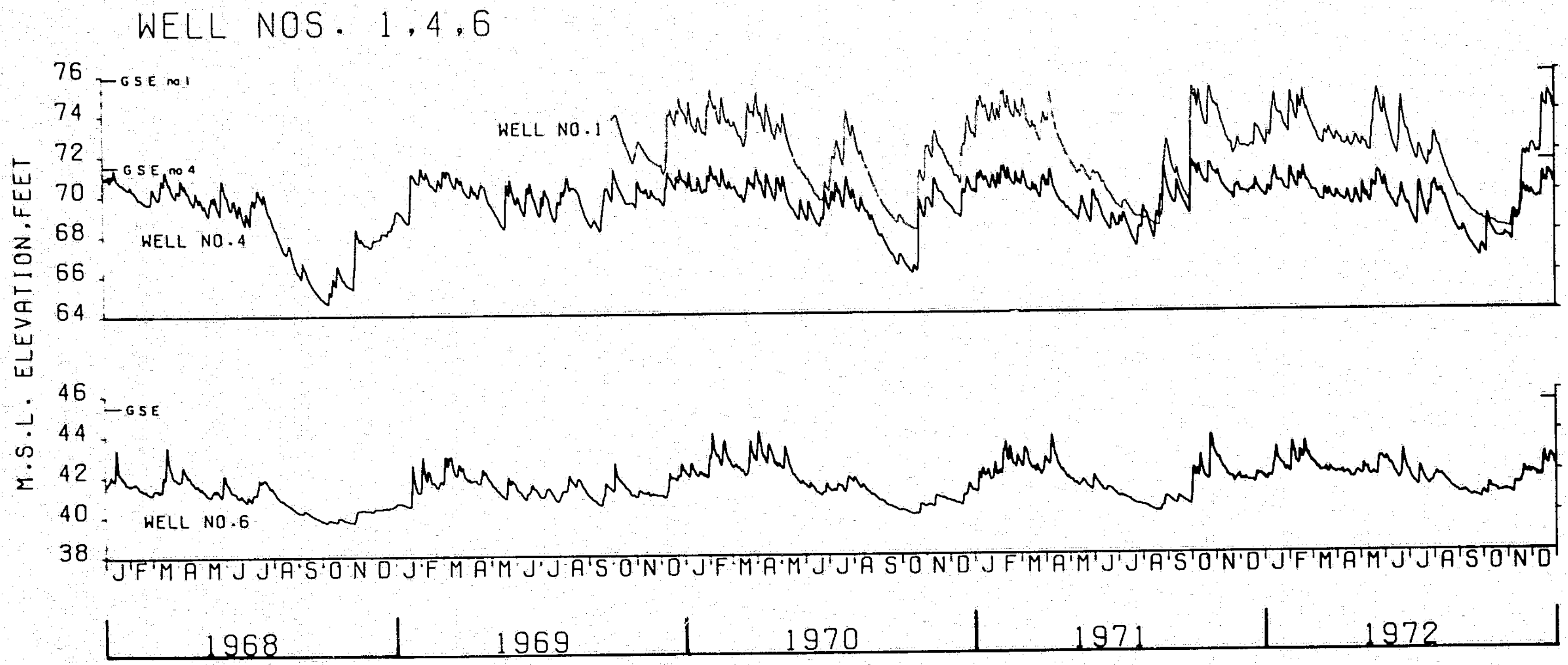


Figure 5.19.—Ground-water hydrographs, Quaternary aquifer (1968–72).

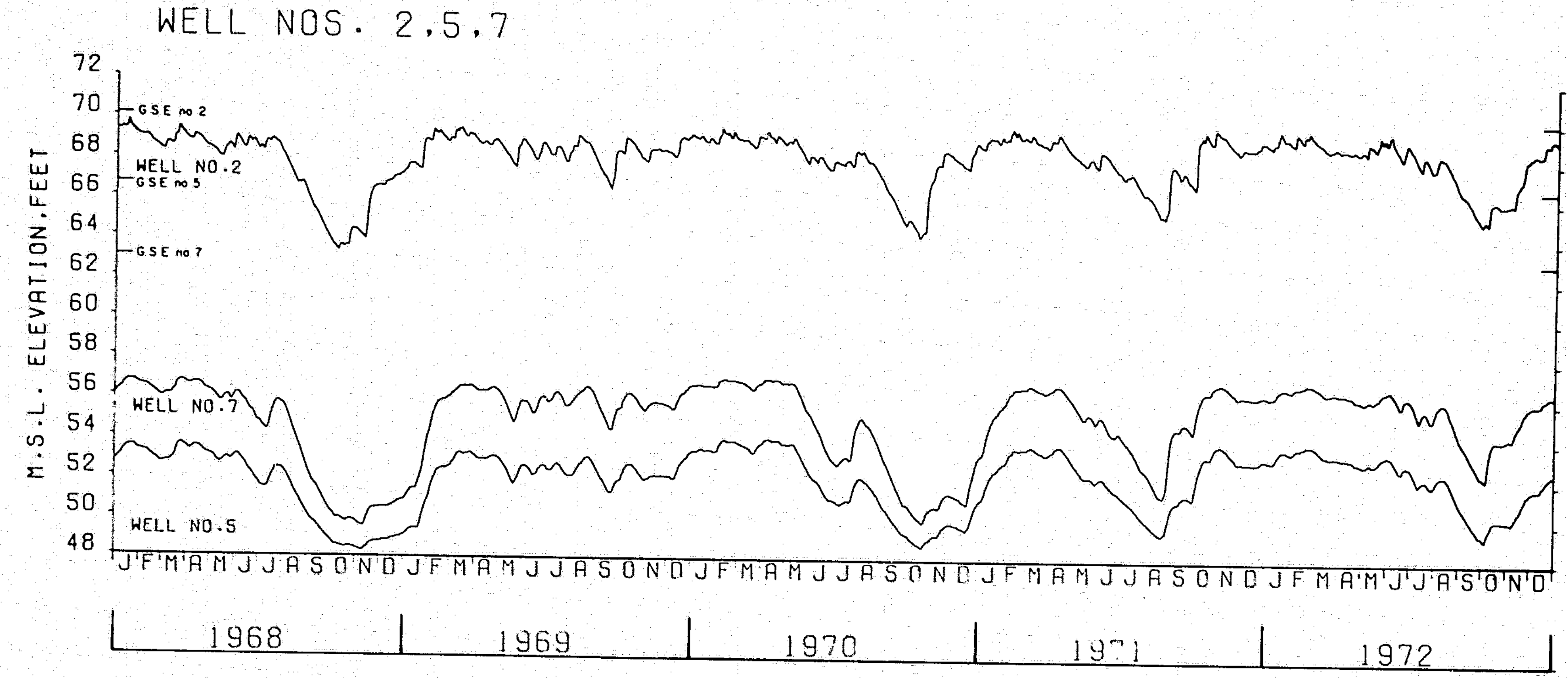


FIGURE 5.20.—Ground-water hydrographs, Yorktown aquifer (1968–72).

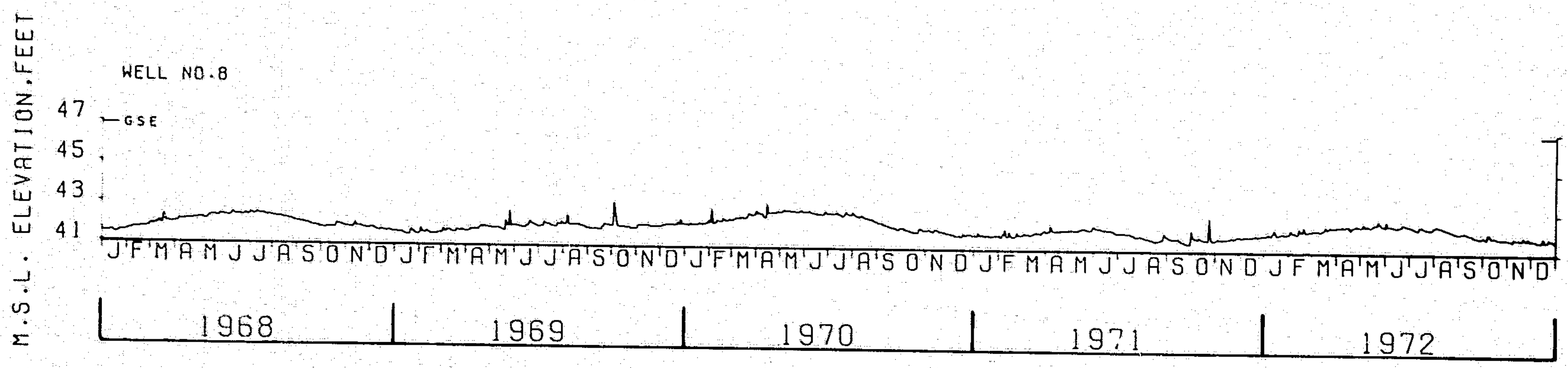


FIGURE 5.21.—Ground-water hydrographs, Tuscaloosa aquifer (1968–72).

discharge for the watershed. The data are shown in figure 5.17 for 1964 through 1972. The short-term peak-rate data did not fit the extreme value distribution as shown in the figure, but this was expected from the discussion of the relationships between peak rates and 1-day volumes in section 5.2.1. Just as with the volume data, the 1964 annual peak discharge would have different projected recurrence intervals depending upon how the data were used. The 1964 peak rate was 52 percent greater than the second largest peak for 1964 through 1972. The peak-producing event in 1964 was a tropical storm, and thus actually represents a different population than do the other storms.

Instantaneous peak-discharge data are not readily available for 1951 through 1963 for watershed W–A1, but mean daily-discharge data are published for the period (*23*, *24*). Monthly maximum mean daily-discharge data are shown in table A–27 for watershed W–A1 for 1951 through 1972. The 22 annual maximums were plotted on Gumbel extreme value paper (fig. 5.18). The data approximate a straight line more closely than the short-term values (fig. 5.17). Again, the 1964 storm is the largest and plots above the regression line. However, another tropical storm in 1960 produced the second largest mean daily discharge in the 22-year record. The 1964 storm discharge is only 13 percent greater than that of the 1960 storm. Extension of the least-squares line of figure 5.18 would indicate a return period of approximately 50 years for the 1964 storm and 24 years for the 1960 storm. The value of long-term records for frequency analysis is emphasized by the relative results shown in figures 5.17 and 5.18.

In view of the findings in the frequency analysis of short-term peak-rate data for watershed W–A1, frequency analyses were not made for watersheds W–A2, W–A3, and W–A4. Tables A–20, A–21, and A–22 reveal extremes for these watersheds similar to those of W–A1.

5.3.—GROUND WATER

The Quaternary deposits (surficial Pleistocene) receive direct recharge from precipitation and show a quick ground-water response. The recharge and recession pattern of the wells in the surficial aquifer shows in general a similarity to well 2 (Yorktown), which receives direct recharge from precipitation. The general seasonal pattern of the recharge and recession for the surficial materials and the Yorktown is similar. Well 1 shows the greatest water-table fluctuation. The shallow wells are recharged to within 6 to 8 feet of the ground surface throughout the year, and for two-thirds of the time they are recharged to within 2 or 3 feet of the ground surface (fig. 5.19). In other words, this aquifer could hold but little more ground water in storage, and the effective recharge head on the Yorktown could be raised only a few feet.

The Yorktown Formation does not show as pronounced a response to individual storms as do the Quaternary sediments. Well 2 in this formation shows the quickest response (fig. 5.20). This well is updip from wells 5 and 7, and recharge occurs directly to the Yorktown rather than through the surficial-Pleistocene deposits. The Yorktown wells recharge during early winter, and in general are totally recharged by midwinter. Recession begins in early to midsummer, reaching a low in September and October. The yearly fluctuations for well 2 varied from 6.4 feet in 1968 to 3.0 feet in 1969, well 5 varied from 5.4 feet in 1968 to 4.2 feet in 1969, and well 7 varied from 7.2 feet in 1968 to 5.7 feet in 1969 (fig. 5.20). The maximum monthly decline occurred in September 1968 in all three wells, and the maximum recharge occurred in October and November 1971 (fig. 5.20). In general, the Yorktown maximum and minimum monthly stages closely parallel each other. The ground-surface elevation of well 2 (table A–7) is 70.1 feet above mean sea level. Because the Yorktown in this area is not confined, the ground-water table cannot exceed this elevation without free water standing on the surface. The relation between downdip wells 5 and 7 and updip well 2 shows that the aquifer is recharged first in the area of well 2 during the early winter recharge period.

Water-table fluctuations in the Tuscaloosa were minor. The maximum stage change for the entire period was 2 feet (fig. 5.21). Recharge does not start until February and continues slowly until May, which is later than the shallower overlying aquifers. In the wet year, 1969, the recharge of this aquifer was not significantly different from the years before and after. Apparently, the greatest recharge in this area, approximately 1 foot, was in 1970, which was a drier year than 1969. It is inferred, therefore, that this aquifer does not receive significant ground-water recharge in the Ahoskie Creek area. No ground-water wells were cased in the Beaufort Formation, and so it is not known if this formation received recharge in this area.

Average values of specific capacity by aquifers (fig. 2.1) were 1.98 gal/min/ft drawdown for the Quaternary surficial sands, 4.31 gal/min/ft for the Yorktown, 0.29 gal/min/ft for the undifferentiated Upper Cretaceous, and 1.4 gal/min/ft for the Tuscaloosa. In general, the Yorktown Formation specific capacity values were fairly high, indicating that recharge can occur. This recharge is partially controlled in many areas of the watershed by the overlying Quaternary sands and clays, but where they are absent recharge occurs directly to the Yorktown. The specific capacity and storage available within the Yorktown further controls recharge: when the storage is not available, as during the wet season, recharge cannot occur.

Quaternary sediments also have a fairly high specific capacity, making water available for the recharge of the deeper aquifers and providing ground water for return to streamflow. However, they cannot recharge more ground water to the Yorktown and deeper aquifers than the available unsaturated storage. These Quaternary sediments often have been removed, or the thickness reduced by erosion, or never deposited. The Yorktown in these cases receives direct recharge. Specific capacities for the deeper formations below the Yorktown are generally lower than for the shallower formations.

5.3.1.—Ground-Water Response to Precipitation

Within the shallow sediments, ground-water response to precipitation always occurs within 2 days. Well 4 shows a greater elevation response to individual storms and a more pronounced seasonal variation than do wells 1 and 6. Well 6, which is closer to the channel, does not show a great range of response, and the maximum range of the water table is much less. Wells 1 and 4 respond similarly.

The Yorktown Formation outcrops at the ground surface in the upper watershed in the area of well 2 and dips at a rate of approximately 6 feet per mile. Well 2 shows a response to individual storms, recharging to within a foot of the ground surface every year during the study. Only during late summer, when rainfall is low and evapotranspiration is high, does the water table drop (maximum 5 feet). Wells 5 and 7 show only a seasonal response and a delayed response to well 2. Because well 5 is approximately 5 miles downdip, the elevation is approximately 30 feet lower, delaying the response to precipitation.

The Tuscaloosa (well 8) shows neither a seasonal nor an individual storm response, and does not receive any recharge in the Ahoskie Creek area. The recharge area lies to the west.

The time lag between the day of rainfall and the day of well hydrograph peak was determined for all wells in the study area. Linear correlations of the lag times were made between wells in the same aquifer and between aquifers. Linear correlation coefficients of lag times between wells in the Quaternary aquifer were greater than coefficients between wells in the Yorktown aquifer (table 5.3).

Wells 4 and 6 are in the shallow phreatic aquifer, and the total aquifer thickness of these two wells is approximately equal. They should respond at about the same time and have a high correlation coefficient, the only difference being rainfall distribution between the well sites. Since the Yorktown wells are in a semiartesian aquifer and since wells 5 and 7 are downdip from well 2, the correlation coefficients for these wells are, as expected, lower than those of wells 4 and 6. The higher correlation coefficient between wells 2 and 4 results from the Yorktown outcropping at the surface and receiving direct recharge in the area of well 2.

The analyses of the lag times between precipitation and ground-water hydrograph peaks

TABLE 5.3.—*Well response within and between aquifers*

Comparison	Well Nos.	Correlation coefficients
Within aquifers:		
Yorktown	2,[1]5	0.7641
Do	2,7	.6852
Quaternary	4,6	.8224
Between aquifers	2,4	.9438
Do	5,4	.6500

[1] Correlation coefficient of well 5 to 2 hydrograph peak.

clearly show the difference in response between the two aquifers. Analysis by calendar quarter shows that the Quaternary aquifer response lags precipitation by 1 to 2 days and that the Yorktown aquifer lags precipitation by 2 to 4 days (fig. 5.22). Well 2 in the Yorktown shows a quicker response than wells 5 and 7, which are downdip in the Yorktown. Well response to weighted rainfall for watershed W–A1 is similar to the response to weighted rainfall for watershed W–A2, except during the fourth quarter.

The monthly response shows that the greatest ground-water lag is in October and November, with a second high-lag period in April and May (fig. 5.23). All wells are located at distances such that the recharge or ground-water response in the wells is not affected by the channel system. This means that the runoff that occurs in the period between the time of precipitation and the time of ground-water response probably is not in any case available for aquifer recharge. The streamflow during the time less than the lag is primarily composed of direct runoff plus the ground water that returns as streamflow from the shallow aquifer in the immediate area adjoining the channels. None of the wells are located in the immediate area of the channels.

5.3.2.—Ground-Water Response to Streamflow

Hydrograph peaks of ground-water wells lag behind the peaks of the streamflow hydrographs. The relative response of the wells with respect to streamflow shows the distinction between aquifers, as did the well response to precipitation. Peaks of ground-water wells in the Quaternary lag streamflow peaks by less than 1 day, and in the Yorktown by between 1 and 3 days (fig. 5.24). This time is less than the lag for precipitation. Downdip response in the Yorktown is shown better on the monthly plot (fig. 5.25) than on the quarterly plot. The greatest lag is in October and May, and the least lag during the wet seasons.

5.4.—DURATION AND MOVING AVERAGES

Duration studies are based upon data arranged in order of rank. The term duration has evolved primarily from streamflow studies.

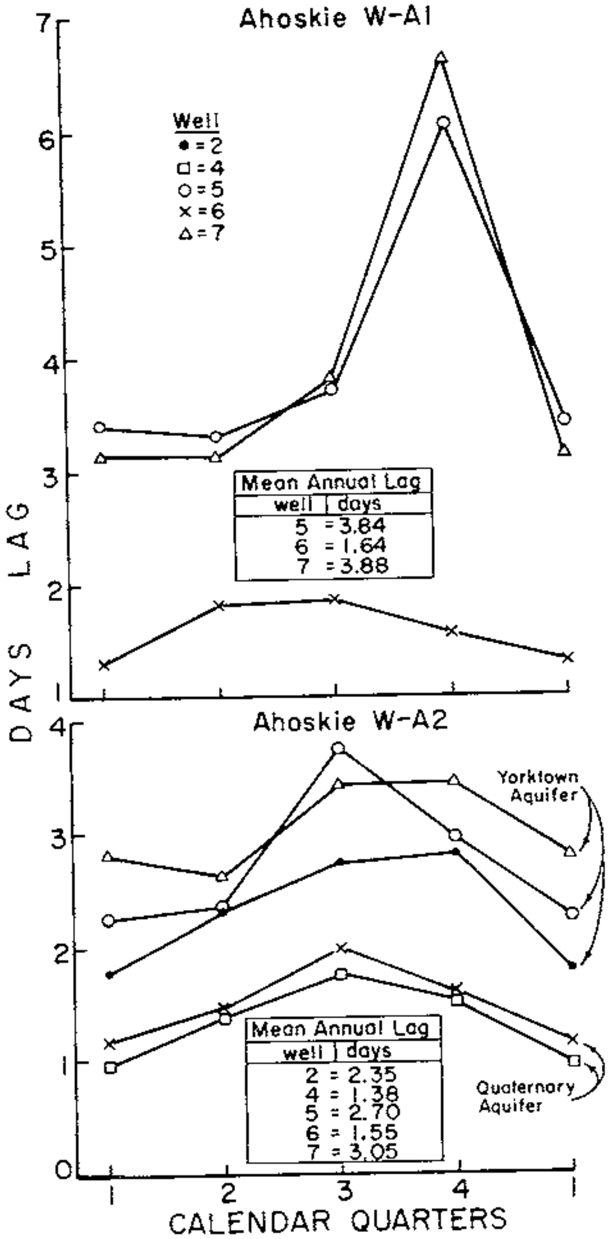


FIGURE 5.22.—Time lag from rainfall to ground-water peaks, by calendar quarter.

Duration implies the length of time flow is above or below a selected amount. In practice, duration is normally limited to a study of the recorded extremes of the highest or lowest flows. With selected data in ranked order, comparisons can be made by rank across different data sets. Ranked values may highlight differences across watersheds or changes with time in a particular watershed.

Duration studies are closely allied to statisti-

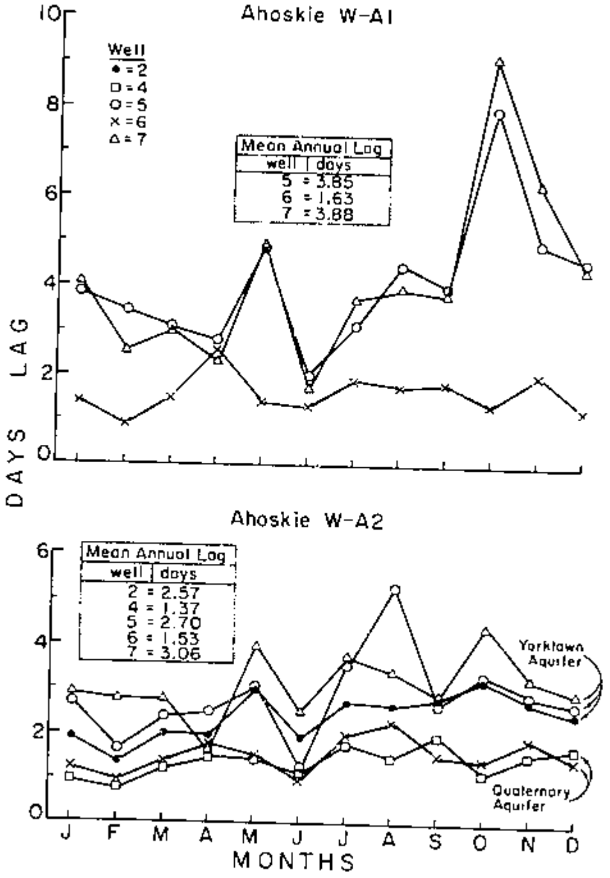


FIGURE 5.23.—Time lag from rainfall to ground-water peaks, by month.

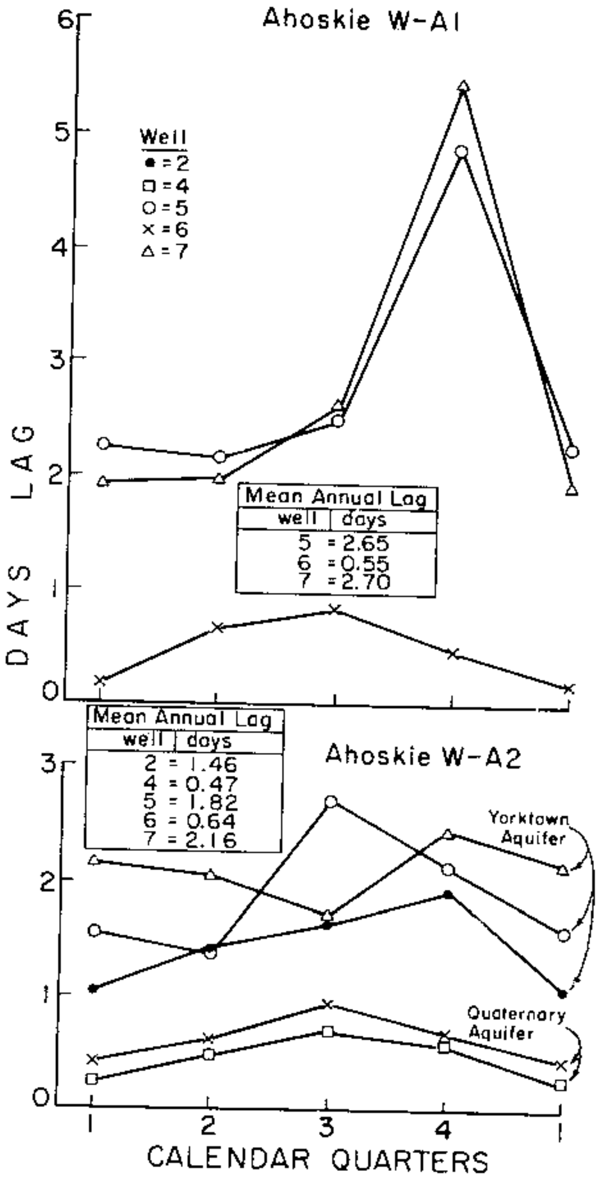


FIGURE 5.24.—Time lag from streamflow to ground-water peaks, by calendar quarter.

cal frequency analysis. If the data were grouped into classes, the probability of occurrences could be determined. Duration studies emphasize the comparisons of extremes in recorded data without assigning specific probabilities to future expectation. When so organized, duration studies can be directed toward meteorological data, as well as toward hydrologic and geohydrologic data.

Because data placed in rank order for duration studies lose their individuality with regard to the time of occurrence, moving averages are more suited to the portrayal of time trends than are rank numbers. Moving averages must be defined with regard to the time over which the average is computed, and with regard to the location within the record. Time location can mean the placement within the total length of record, or the relative placement, such as within the year. The relative placement was used in this report to define seasonal patterns.

The unit of data was a 5-day average, and a year of record is made up of 73 sequential units of data. Averages can be computed for longer periods from the 5-day averages. In this report averages were computed for each 5-day increment to 30 days. Each of the 73 periods making up a year serves as the beginning period for either duration or moving-average studies, and so for each data set a total of 438 (6×73) durations were computed. Also plotted were 18 seasonal moving-average graphs that used the mean and the median of the durations for each of the 73 annual beginning periods.

Since the total number of duration and moving-average computations is too large for presentation in this report, only the 5-day periods near January 1, April 1, July 1, and October 1 and the averaging periods of 5, 10, and 30 days are included. Duration and moving-average studies for precipitation, for streamflow, and for ground-water elevation will be presented on this basis.

In the following sections two basic record periods are considered. The period of June 1, 1951, through December 31, 1962, will be considered pretreatment for rainfall and streamflow, and the period of July 1, 1964, through December 31, 1972, will be considered posttreatment. Pretreatment rainfall data are limited to the Elliott Station, pretreatment streamflow data are limited to watershed W–A1, and data on ground-water stages are available only for 1968 through 1972 in the posttreatment period.

5.4.1.—Precipitation

In the following section "precipitation duration" is used in the same context as "streamflow duration." No meaning of length of rain during a storm is implied. The precipitation data presented in this section are mean daily values for the 5-day unit.

5.4.1.1.—DURATION

The point rainfall from the cooperative-observer gage, Elliott Station (fig. 1.1), and the watershed weighted rainfall were used in the duration studies. A total of six data sets were studied: (1) Elliott Station (point), June 1, 1951, through December 31, 1962, (2) Elliott Station (point), July 1, 1964, through December 31, 1972, (3) watershed W–A1 (weighted), July 1, 1964, through December 31, 1972, (4) watershed W–A2 (weighted), July 1, 1964, through December 31, 1972, (5) watershed W–A3 (weighted), July 1, 1964, through December 31, 1972, and (6) watershed W–A4 (weighted), July 1, 1964, through December 31, 1972.

In order to compare streamflow data for the period before and after channelization, it was necessary to use consistent precipitation data for the two periods (data sets 1 and 2 above). To compare watersheds W–A1, W–A2, W–A3, and W–A4, it was necessary to use data sets 3 through 6. Tables 5.4 through 5.7 summarize the 5-, 10-, and 30-day averaging periods for the six data sets for the selected beginning periods. January represents the period during which evapotranspiration is low, ground water is recharging, and streamflow is increasing. April has moderate evapotranspiration, high ground water, and high streamflow. July is the time of high evapotranspiration, depleting ground water, and decreasing streamflow. October is the period of moderate evapotranspiration, depleted ground water, and low streamflow.

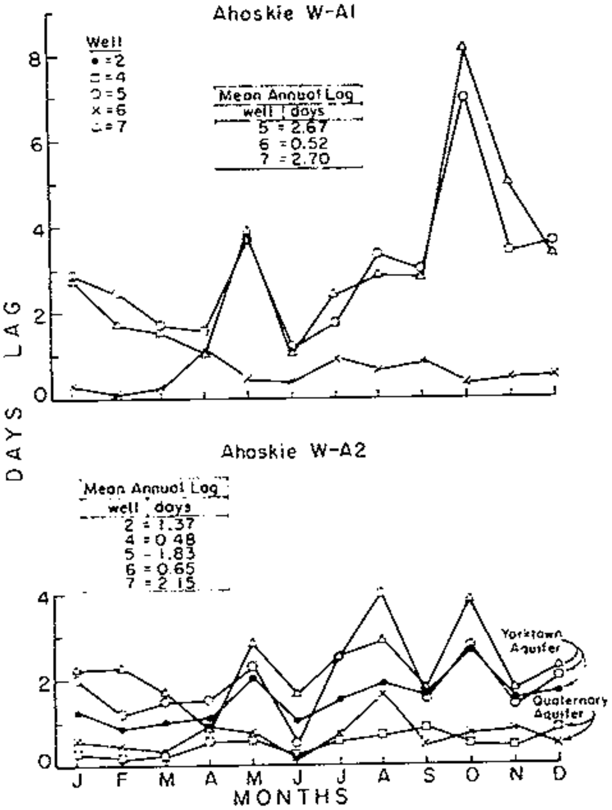


FIGURE 5.25.—Time lag from streamflow to ground-water peaks, by month.

Interpretation of the precipitation-duration tables will be limited to the low-rainfall extremes because the hydrologic records are too short to smooth the erratic occurrences of high-rainfall extremes. Small differences in average daily amounts may be significant in considering low-rainfall extremes. Most emphasis will be placed on the 30-day averaging period.

Table 5.4 shows that rainfall was greater before treatment than after treatment for the averaging period beginning January 1. For example, in the 30-day averaging period the low-

(*Continued on page 53.*)

TABLE 5.4.—*Precipitation duration by ordered averages, period beginning January 1*

[Mean daily value in inches]

Rank	Elliott Station 1951–62	Elliott Station 1964–72	W–A1 (1964–72)	W–A2 (1964–72)	W–A3 (1964–72)	W–A4 (1964–72)
			5-day averaging period			
1	0.210	0.172	0.142	0.152	0.162	0.148
2	.146	.138	.138	.142	.144	.136
3	.106	.082	.106	.074	.090	.116
4	.106	.046	.054	.042	.052	.072
5	.040	0	.028	.034	.032	.028
6	.030	0	0	0	0	0
7	.020	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	...	...	...	...	...
11	0	...	...	...	...	...
			10-day averaging period			
1	0.275	0.251	0.158	0.182	0.204	0.154
2	.163	.139	.137	.137	.142	.145
3	.123	.107	.116	.121	.126	.115
4	.096	.099	.081	.080	.087	.089
5	.095	.069	.059	.061	.059	.058
6	.073	.064	.053	.037	.045	.050
7	.066	.019	.016	.012	.016	.022
8	.047	0	0	0	0	0
9	.024	...	...	...	...	...
10	.020	...	...	...	...	...
11	0	...	...	...	...	...
			30-day averaging period			
1	0.292	0.178	0.172	0.175	0.170	0.174
2	.209	.169	.155	.165	.168	.131
3	.162	.143	.117	.117	.123	.125
4	.142	.116	.111	.106	.118	.113
5	.105	.104	.092	.091	.088	.102
6	.093	.098	.089	.084	.084	.078
7	.090	.048	.049	.049	.050	.062
8	.069	.046	.041	.044	.047	.035
9	.060	...	...	...	...	...
10	.059	...	...	...	...	...
11	.057	...	...	...	...	...

TABLE 5.5.—*Precipitation duration by ordered averages, period beginning April 1*

[Mean daily value in inches]

Rank	Elliott Station		W–A1 (1964–72)	W–A2 (1964–72)	W–A3 (1964–72)	W–A4 (1964–72)
	1951–62	1964–72				
			5-day averaging period			
1	0.370	0.440	0.268	0.234	0.224	0.356
2	.306	.256	.128	.146	.146	.176
3	.106	.038	.116	.124	.110	.120
4	.082	.020	.068	.058	.044	.082
5	.056	.014	.020	.020	.020	.016
6	.046	0	0	0	0	0
7	.046	0	0	0	0	0
8	0	0	0	0	0	0
9	0	...	...	...	...	...
10	0	...	...	...	...	...
11	0	...	...	...	...	...
			10-day averaging period			
1	0.258	0.275	0.198	0.194	0.193	0.258
2	.220	.179	.191	.171	.170	.208
3	.091	.091	.116	.126	.112	.159
4	.090	.062	.077	.077	.087	.074
5	.072	.053	.052	.056	.054	.049
6	.063	.041	.039	.043	.050	.042
7	.041	.011	.039	.034	.039	.041
8	.033	.007	0	0	.010	0
9	.033	...	...	...	...	...
10	.008	...	...	...	...	...
11	0	...	...	...	...	...
			30-day averaging period			
1	0.223	0.184	0.156	0.149	0.144	0.190
2	.143	.140	.104	.105	.120	.117
3	.116	.124	.096	.103	.117	.112
4	.113	.088	.095	.099	.095	.106
5	.111	.087	.083	.072	.068	.076
6	.082	.044	.050	.048	.055	.072
7	.078	.044	.030	.034	.042	.041
8	.076	.040	.029	.027	.032	.027
9	.071	...	...	...	...	...
10	.046	...	...	...	...	...
11	.025	...	...	...	...	...

TABLE 5.6.—*Precipitation duration by ordered averages, period beginning July 1*

[Mean daily value in inches]

Rank	Elliott Station 1951–62	Elliott Station 1964–72	W–A1 (1964–72)	W–A2 (1964–72)	W–A3 (1964–72)	W–A4 (1964–72)
	5-day averaging period					
1	0.538	0.372	0.388	0.490	0.516	0.380
2	.434	.296	.238	.194	.282	.294
3	.124	.280	.204	.192	.242	.214
4	.080	.176	.198	.174	.204	.180
5	.060	.152	.160	.172	.198	.176
6	.050	.142	.142	.132	.174	.170
7	.048	.122	.136	.132	.108	.084
8	.016	.106	.014	0	0	.020
9	.014	0	0	0	0	0
10	0	...	...	...	...	...
11	0	...	...	...	...	...
12	0	...	...	...	...	...
	10-day averaging period					
1	0.311	0.399	0.379	0.331	0.348	0.478
2	.305	.279	.311	.329	.314	.363
3	.276	.244	.235	.261	.280	.256
4	.269	.200	.199	.202	.265	.256
5	.225	.197	.195	.159	.224	.216
6	.167	.196	.157	.142	.192	.192
7	.110	.113	.134	.123	.173	.120
8	.094	.071	.018	.009	.013	.027
9	.087	.002	.009	.008	.007	.010
10	.078	...	...	...	...	...
11	.062	...	...	...	...	...
12	.049	...	...	...	...	...
	30-day averaging period					
1	0.336	0.267	0.269	0.272	0.275	0.338
2	.210	.248	.253	.235	.261	.264
3	.164	.235	.246	.235	.245	.237
4	.162	.222	.234	.226	.183	.218
5	.156	.155	.216	.188	.179	.210
6	.143	.141	.170	.138	.147	.200
7	.133	.124	.155	.135	.134	.189
8	.123	.114	.124	.120	.101	.173
9	.113	.067	.057	.050	.045	.063
10	.103	...	...	...	...	...
11	.098	...	...	...	...	...
12	.098	...	...	...	...	...

TABLE 5.7.—*Precipitation duration by ordered averages, period beginning October 1*

[Mean daily value in inches]

Rank	Elliott Station		W–A1	W–A2	W–A3	W–A4
	1951–62	1964–72	(1964–72)	(1964–72)	(1964–72)	(1964–72)
	5-day averaging period					
1	0.528	1.220	1.236	1.182	1.174	1.310
2	.432	.426	.748	.692	.628	1.068
3	.390	.314	.322	.338	.312	.232
4	.132	.294	.242	.238	.242	.196
5	.040	.216	.110	.126	.152	.084
6	.014	.188	.108	.122	.136	.066
7	0	.060	.006	.016	.088	0
8	0	.014	0	0	0	0
9	0	0	0	0	0	0
10	0	...	...	...	...	...
11	0	...	...	...	...	...
12	0	...	...	...	...	...
	10-day averaging period					
1	0.439	0.708	0.692	0.668	0.675	0.724
2	.375	.652	.589	.600	.583	.552
3	.245	.314	.377	.349	.316	.522
4	.222	.278	.338	.276	.267	.412
5	.195	.182	.164	.164	.181	.167
6	.118	.147	.092	.087	.096	.098
7	.066	.095	.055	.063	.076	.042
8	.062	.094	.054	.061	.068	.033
9	.037	.030	.003	.008	.044	0
10	.024	...	...	...	...	..
11	.020	...	...	...	...	..
12	0	...	...	...	...	...
	30-day averaging period					
1	0.425	0.398	0.381	0.371	0.377	0.375
2	.226	.266	.246	.247	.238	.224
3	.176	.178	.140	.140	.137	.222
4	.146	.166	.137	.127	.133	.165
5	.116	.124	.134	.122	.119	.115
6	.092	.111	.120	.119	.112	.105
7	.088	.056	.048	.058	.070	.033
8	.085	.042	.031	.029	.032	.023
9	.080	.032	.025	.026	.028	...
10	.053	...	...	...	...	...
11	.033	...	...	...	...	...
12	.014	...	...	...	...	...

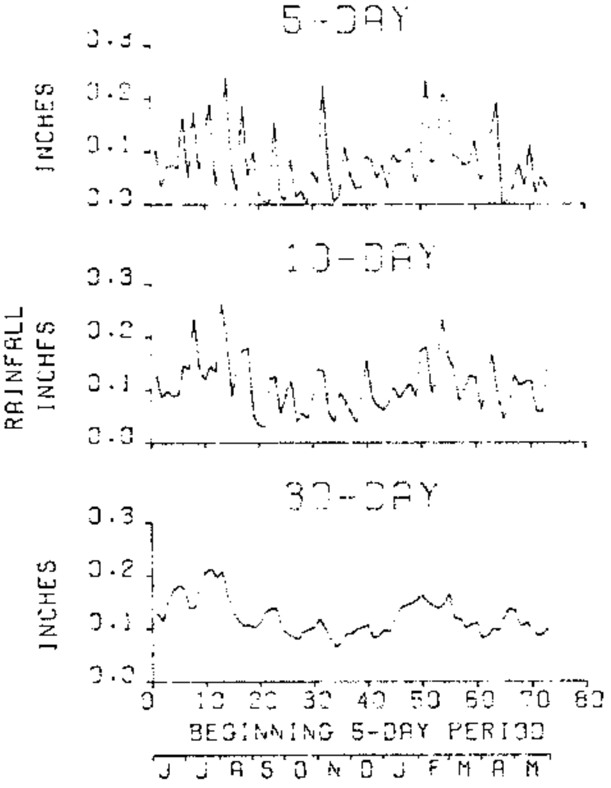


FIGURE 5.26.—Median 5-, 10-, and 30-day rainfall, Elliott Station (1951–62).

est mean daily value was 0.057 inch before treatment. Two values during the 8 years of record after treatment were below this amount, but the median values are not greatly different. Also, the first-rank value of 0.292 inch before treatment appears disproportionately high. Little difference can be noted between the Elliott Station and watershed average rainfall in the 30-day averaging period, as is also the case with the 10- and 5-day averaging periods. However, the number of years with zero rainfall in this particular 5-day period prevents simple comparisons.

In table 5.5, the 30-day averaging period beginning April 1 also shows more rainfall before treatment than after treatment. Before treatment, the two lowest amounts were 0.046 inch or less; after treatment 3 out of 8 years were 0.044 inch or less, and median values again do not differ greatly. Point rainfall and rainfall at watershed W–A4 appear high for the 5-day and 10-day averaging periods, but for 30-day averaging the values for all watersheds are more uniform.

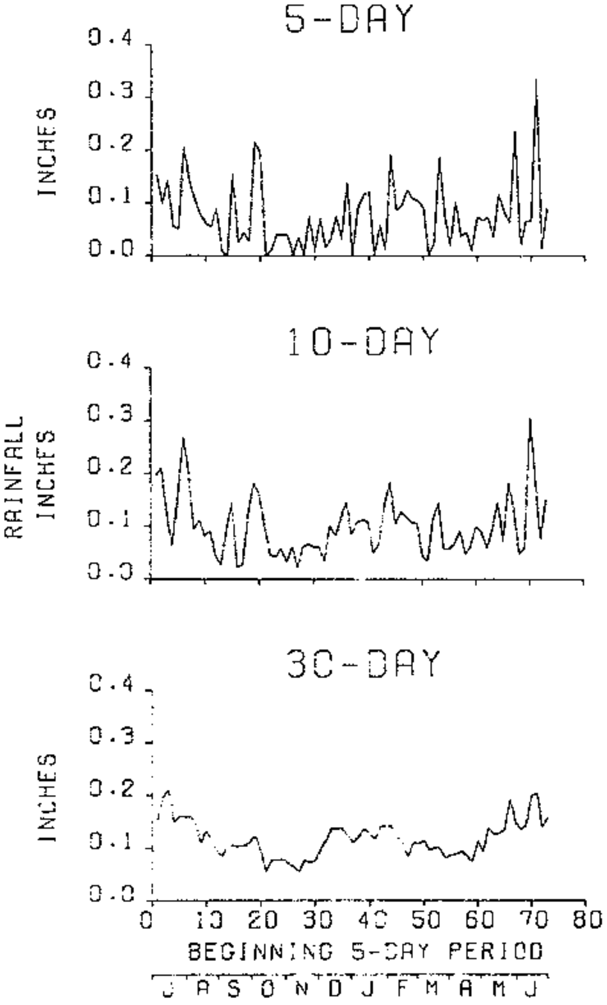


FIGURE 5.27.—Median 5-, 10-, and 30-day rainfall, Elliott Station (1964–72).

In table 5.6, the pretreatment and the posttreatment rainfall amounts for July seem about the same. The median value for posttreatment is slightly higher, but this value is balanced by the low value of 0.067 inch for the driest year. Precipitation on watershed W–A4 is high compared to the average of the other areas and compared to the point rainfall at the Elliott Station.

Table 5.7, showing precipitation averages for October, contains a large range of values from wet to dry years in both before- and after-treatment periods at the Elliott Station. The 30-day averaging period shows that the median value is higher for the posttreatment period but not much different in the drier years. Averages are nearly the same for all watersheds and the point rainfall at the Elliott Station.

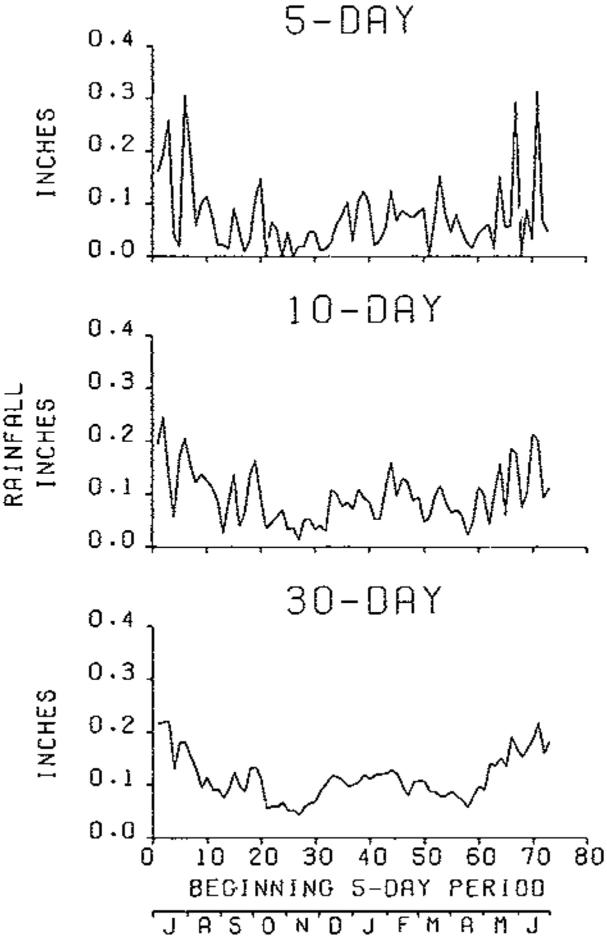


FIGURE 5.28.—Median 5-, 10-, and 30-day rainfall, watershed W–A1 (1964–72).

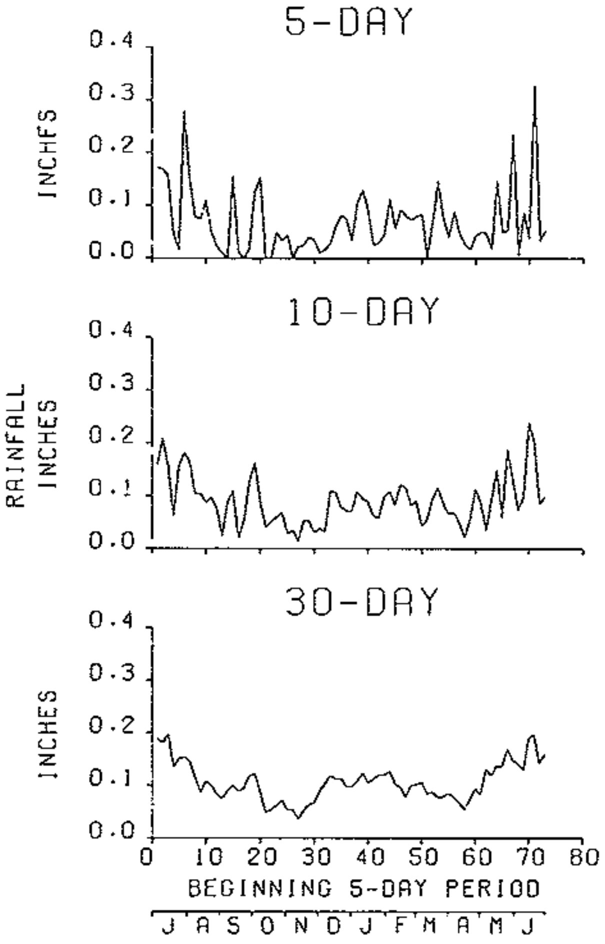


FIGURE 5.29.—Median 5-, 10-, and 30-day rainfall, watershed W–A2 (1964–72).

5.4.1.2.–MOVING AVERAGES

Tabulated duration data cannot be presented for all seventy-three 5-day periods of the year, but a clear depiction of the season-to-season progression of precipitation can be given graphically. Such graphs, showing median values for each duration for the 73 annual periods, and for 5-, 10-, and 30-day averaging, were plotted for the 6 data sets listed in section 5.4.1.1.

Figures 5.26 and 5.27 show pretreatment and posttreatment moving-average precipitation values for the Elliott Station. Five- and ten-day averaging periods are too short to smooth the natural random occurrence of rainfall, but the 30-day averaging produces acceptably smooth values. These averaging periods confirm that rainfall was lower during the posttreatment period: winter and summer highs of precipitation, as well as the autumnal low of precipitation, were all lower.

Figures 5.28–5.31 contain the moving averages of precipitation averaged over each watershed in the posttreatment periods. All four watersheds show similar seasonal patterns and consistent magnitudes. Comparison of these figures with figure 5.27, point rainfall for the same period, reveals some differences. Although the seasonal patterns are identical, winter and spring rains are higher at the Elliott Station. The summer high and autumnal low of precipitation are about the same for the network of gages and for the Elliott Station.

5.4.2.–Streamflow

Streamflow-duration and moving-average studies were used to establish base-streamflow values and seasonal variability of flows. Differences in base flows before and after channelization on watershed W–A1 can be investigated, and differences for the four

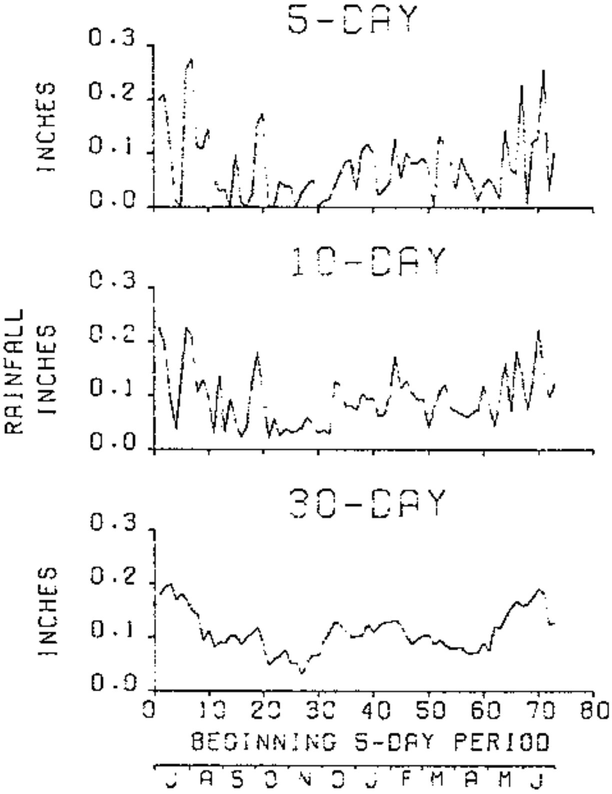


FIGURE 5.30.—Median 5-, 10-, and 30-day rainfall, watershed W–A3 (1964–72).

watersheds can be noted for the period of record after channelization.

5.4.2.1.—DURATION

Five streamflow records were processed for duration studies. The total number of duration data sets calculated was 2,190, resulting from 6 averaging periods for 73 different beginning periods for the 5 streamflow records. Only a few of these will be discussed.

Tables 5.8 through 5.11 show 5-, 10-, and 30-day durations for the eight streamflow records with the averaging periods beginning near January 1, April 1, July 1, and October 1. The April and October durations are near the seasonal high and seasonal low, respectively, of base flow. The January and July durations are in transitional times between high and low base-flow periods.

Watershed W–A1 has experienced lower base flows in the dormant season after channelization (tables 5.8 and 5.9). For example, in January prior to channelization only four out of twelve 5-day average flow values were below 30 ft³/s, and after treatment five out of nine values were less than 30 ft³/s. In April, 3 out of 11 years had 5-day flows less than 60 ft³/s before channelization, and after channelization five out of eight values were below 60 ft³/s.

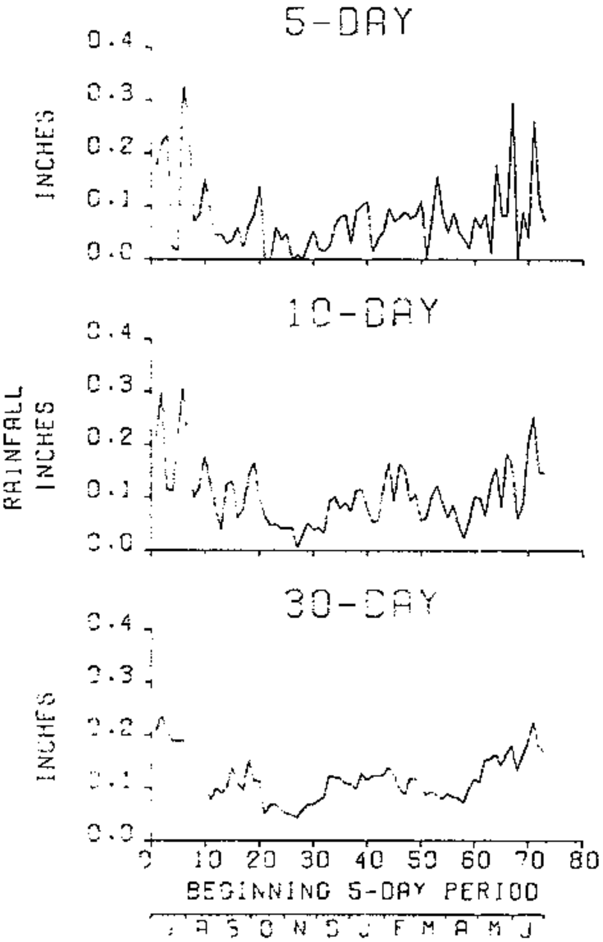


FIGURE 5.31.—Median 5-, 10-, and 30-day rainfall, watershed W–A4 (1964–72).

In summer and autumn, the before-to-after relationship in watershed W–A1 is reversed (tables 5.10 and 5.11): base flows are higher after channelization. In July, 7 out of 12 years had 5-day flows of 3.7 ft³/s or less before channelization, and the lowest value in 9 years after channelization was 7.3 ft³/s. In October, 8 out of 12 years had flows of 3.5 ft³/s or less before channelization, and after channelization the lowest value in 9 years was 3.9 ft³/s. Similar before-to-after relationships may be noted in the 10-day and 30-day durations.

Tables 5.8 through 5.11 show only one difference in duration characteristics for the four

(*Continued on page 58.*)

TABLE 5.8.—*Flow duration, beginning January 1*

[Cubic feet per second]

Rank	W–A1		W–A2	W–A3	W–A4
	1951–62	1964–72	(1964–72)	(1964–72)	(1964–72)
	5-day averaging period				
1	165.6	332.4	101.8	25.14	4.82
2	127.2	238.8	58.2	12.64	3.70
3	117.6	134.2	54.4	10.16	2.46
4	105.6	79.6	33.6	3.42	1.78
5	93.4	26.2	11.8	.63	.46
6	44.0	25.0	11.0	.29	.28
7	38.2	23.2	7.3	.09	.21
8	36.6	13.2	4.6	.06	.19
9	18.8	6.0	1.8	.00	.10
10	15.3	...	...	...	...
11	9.9	...	...	...	...
12	5.0	...	...	...	...
	10-day averaging period				
1	232.6	208.1	62.4	14.82	3.25
2	199.1	155.3	47.5	8.29	2.29
3	178.5	111.8	39.6	7.83	2.14
4	88.6	42.9	32.0	1.28	.58
5	80.0	26.4	9.6	.89	.46
6	46.0	21.5	9.0	.20	.24
7	45.4	14.6	5.2	.10	.23
8	36.3	6.6	2.0	.01	.12
9	34.4	...	...	...	...
10	10.0	...	...	...	...
11	4.4	...	...	...	...
	30-day averaging period				
1	236.9	210.8	81.1	12.84	6.28
2	183.2	145.4	57.1	6.81	2.98
3	177.2	118.7	43.3	5.52	2.38
4	142.8	98.1	33.4	4.98	2.14
5	131.4	93.6	31.3	3.76	1.51
6	114.0	79.4	29.2	2.87	1.06
7	63.6	44.6	16.1	.72	.86
8	49.3	10.7	3.4	.03	.22
9	47.8	...	...	...	...
10	30.3	...	...	...	...
11	7.5	...	...	...	...

TABLE 5.9—*Flow duration, beginning April 1*

[Cubic feet per second]

Rank	W–A1		W–A2	W–A3	W–A4
	1951–62	1964–72	(1964–72)	(1964–72)	(1964–72)
	5-day averaging period				
1	325.4	203.8	95.4	12.04	9.36
2	272.6	162.8	60.0	6.46	5.86
3	193.0	88.0	32.2	4.76	1.64
4	160.0	47.2	18.4	1.90	.94
5	126.0	46.0	13.4	1.44	.82
6	121.4	32.2	11.1	.93	.54
7	100.4	30.4	9.4	.66	.34
8	63.0	20.4	6.3	.38	.34
9	36.8	...	...	...	...
10	36.6	...	...	...	...
11	30.6	...	...	...	...
	10-day averaging period				
1	206.7	285.7	103.8	14.99	8.93
2	195.4	131.2	49.0	5.45	4.15
3	170.8	67.4	24.8	3.22	1.22
4	140.1	48.9	15.2	1.84	1.17
5	121.2	45.0	13.9	1.67	.96
6	99.1	38.1	13.3	1.26	.68
7	96.4	27.5	10.1	.56	.36
8	84.3	18.1	5.7	.30	.29
9	76.0	...	...	...	...
10	29.2	...	...	...	...
11	28.8	...	...	...	...
	30-day averaging period				
1	168.0	212.5	75.8	11.30	5.71
2	166.2	119.8	45.4	5.98	2.98
3	139.1	75.2	27.4	4.42	1.97
4	106.3	54.6	22.4	2.48	1.22
5	96.2	42.1	16.5	1.66	.76
6	85.8	37.9	11.9	1.54	.76
7	83.7	21.7	7.8	.30	.29
8	82.4	14.2	4.5	.15	.25
9	72.3	...	...	...	...
10	59.4	...	...	...	...
11	16.9	...	...	...	...

TABLE 5.10.—*Flow duration, beginning July 1*

[Cubic feet per second]

Rank	W–A1		W–A2	W–A3	W–A4
	1951–62	1964–72	(1964–72)	(1964–72)	(1964–72)
	5-day averaging period				
1	149.4	72.6	75.8	4.72	0.92
2	74.4	25.2	6.9	.28	.52
3	25.6	18.0	5.9	.12	.48
4	19.1	15.2	5.8	.12	.45
5	17.6	15.1	5.0	.12	.23
6	3.7	13.8	3.9	.05	.20
7	.7	12.2	3.5	.05	.12
8	.7	10.5	2.8	.04	.11
9	.6	7.3	2.6	.03	.05
10	.4	...	...	...	...
11	0	...	...	...	...
12	0	...	...	...	...
	10-day averaging period				
1	99.5	139.5	82.2	6.30	10.75
2	57.4	79.4	29.7	3.62	.81
3	20.7	20.3	10.1	.82	.80
4	13.4	19.8	7.4	.11	.47
5	13.2	16.0	5.2	.11	.39
6	12.2	14.4	5.0	.08	.21
7	3.9	13.2	4.7	.06	.17
8	1.3	12.8	3.7	.05	.11
9	.8	11.8	2.2	.04	.05
10	.8	...	...	...	...
11	.6	...	...	...	...
12	0	...	...	...	...
	30-day averaging period				
1	42.5	104.8	45.7	8.72	5.34
2	38.7	81.7	30.4	3.14	2.48
3	33.7	81.2	28.3	2.58	1.84
4	13.7	63.1	21.9	.44	1.42
5	6.2	47.4	9.3	.33	1.05
6	5.4	26.7	8.6	.18	.89
7	4.7	23.0	6.3	.11	.46
8	3.2	9.8	3.9	.03	.32
9	1.5	9.7	1.8	.03	.09
10	.8	...	...	...	...
11	.4	...	...	...	...
12	0	...	...	...	...

TABLE 5.11.—*Flow duration, beginning October 1*

[Cubic feet per second]

Rank	W–A1		W–A2	W–A3	W–A4
	1951–62	1964–72	(1964–72)	(1964–72)	(1964–72)
	5-day averaging period				
1	78.4	392.1	140.9	8.49	32.48
2	58.0	62.0	27.1	3.72	12.40
3	37.4	40.2	26.5	1.12	.92
4	5.5	10.6	3.6	.16	.52
5	3.5	9.7	3.4	.08	.19
6	1.2	8.9	2.9	.05	.14
7	.3	7.3	2.7	.02	.14
8	.3	7.2	2.7	0	.10
9	.2	3.9	1.0	0	.08
10	.1	...	...	...	...
11	.1	...	...	...	...
12	0	...	...	...	...
	10-day averaging period				
1	55.8	629.0	199.4	31.96	19.28
2	40.4	417.8	126.4	15.27	16.11
3	34.3	310.6	118.0	8.80	12.58
4	17.0	26.8	4.0	.09	.79
5	13.7	8.8	3.0	.05	.28
6	3.3	8.2	2.8	.04	.21
7	1.2	7.6	2.8	.03	.14
8	.7	6.0	2.7	.02	.12
9	.4	4.7	1.9	0	.10
10	.2	...	...	...	...
11	0	...	...	...	...
12	0	...	...	...	...
	30-day averaging period				
1	242.4	296.6	94.3	12.36	11.89
2	57.6	253.4	81.5	7.80	5.60
3	22.8	117.2	51.0	5.37	5.24
4	20.0	19.4	5.4	.15	.42
5	17.8	10.2	5.4	.07	.19
6	17.5	8.4	2.7	.05	.17
7	1.3	7.3	2.6	.02	.16
8	1.2	7.3	2.5	.02	.12
9	.4	6.3	2.0	.01	.11
10	.3	...	...	...	...
11	.1	...	...	...	...
12	0	...	...	...	...

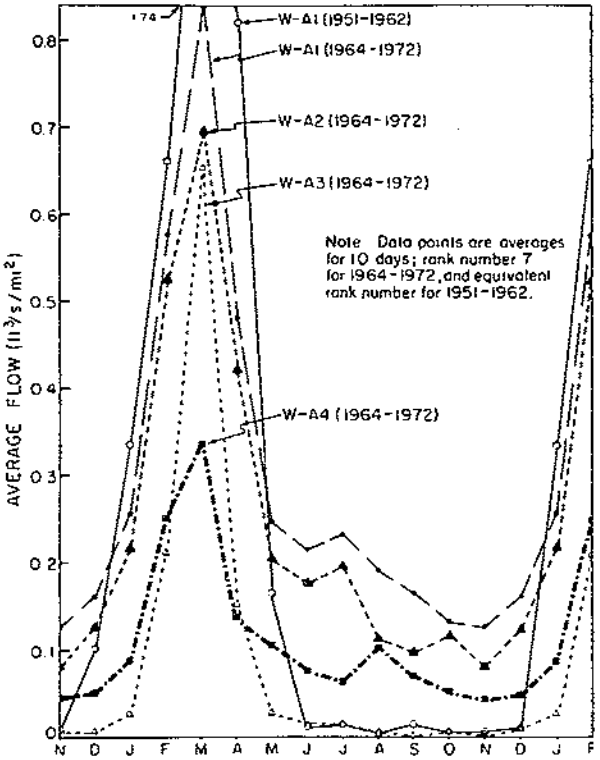


Figure 5.32.—Seasonal variability of low-flow duration.

watersheds after channelization: watershed W–A3 had disproportionately low base flows for January, July, and October. In April, on the other hand, base flows appear relatively high. Additional duration data sets were selected to emphasize watershed W–A3 duration characteristics.

Duration data sets containing the first day of each calendar month were abstracted from the total number computed, and a 10-day averaging period was chosen. From these durations the flow with rank number 7 was noted for the four watersheds with posttreatment records. A flow with equivalent rank number in the 11- or 12-year record was computed by interpolation for watershed W–A1 before treatment. These beginning-of-month values were then divided by the size of the associated drainage area to produce unit-area flow rates (fig. 5.32).

The seasonal reversal of before-to-after baseflow relationships in watershed W–A1 is readily apparent, as well as the high base flows from watersheds W–A1, W–A2, and W–A4 after channelization for the months of June through December. Watershed W–A1 before channelization and watershed W–A3 show low unit-area flows during these months. All five streamflow records show that the highest base flows occur in March, and the unit-area flow from W–A3 is about equal to that of W–A2. Watershed W–A3, after channelization, is apparently a miniature of the entire drainage system, W–A1, before channelization (fig. 5.33). The improved channel extends only part way into watershed W–A3. Because no lateral drains were constructed and because no roadways, where drainage improvements might have been made, cross the area, watershed W–A3 is substantially unchannelized, compared to watersheds W–A1, W–A2, and W–A4.

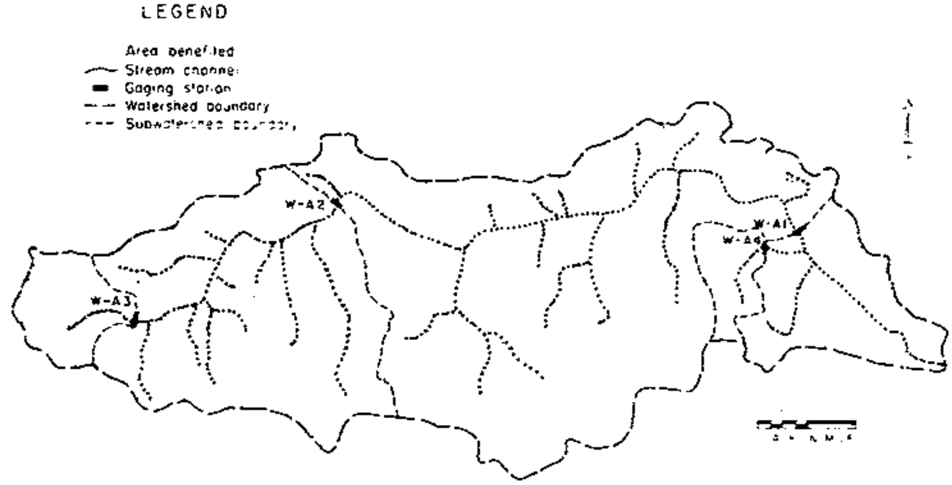


Figure 5.33.—Ahoskie Creek watershed map with improved channels and benefited areas.

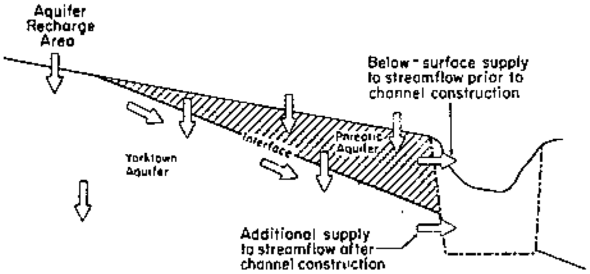


FIGURE 5.34.—Schematic of altered flow regime.

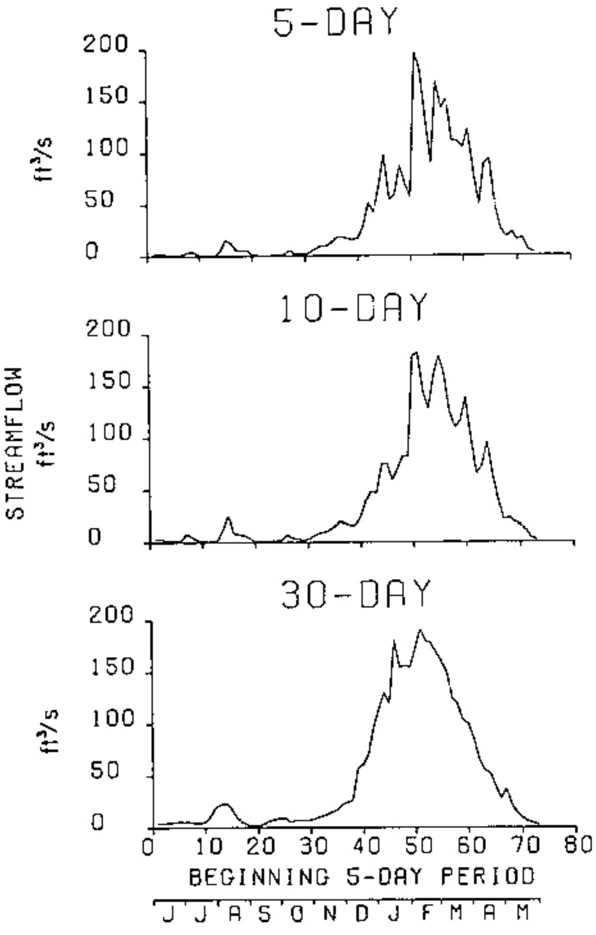


FIGURE 5.35.—Median 5-, 10-, and 30-day streamflow, watershed W–A1 (1951–62).

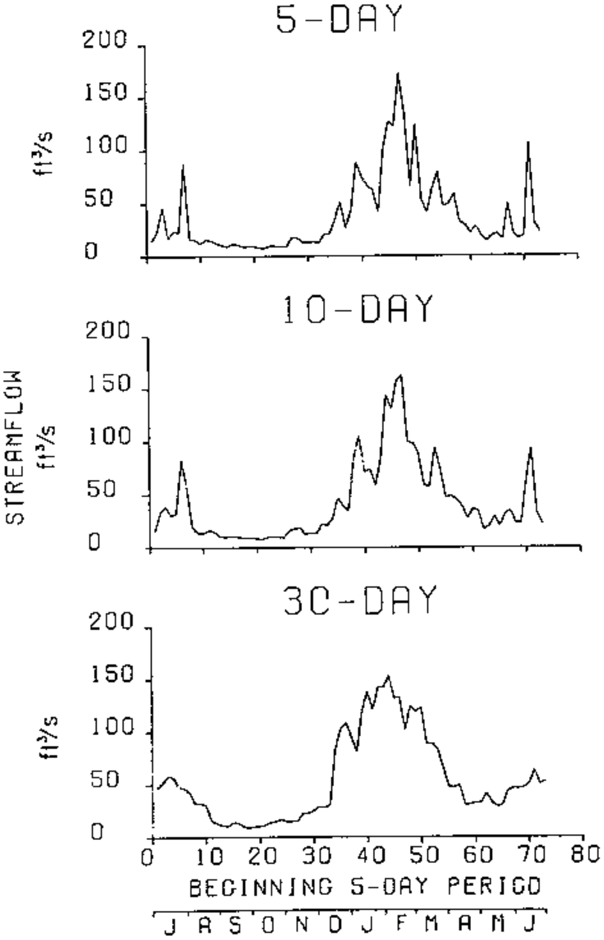


FIGURE 5.36.—Median 5-, 10-, and 30-day streamflow, watershed W–A1 (1964–72).

An interpretation of the flow-duration curves reveals a change in flow regime caused by channel construction (fig. 5.34). Since base flows during the high-flow season on watersheds W–A1, W–A2, and W–A4 are reduced, it is likely that watershed storage of water is increased. With improved surface and subsurface drainage, this increase in storage can only take place in the underlying aquifers. Release of this deeper storage to streamflow is relatively slow, compared to drainage of the surface materials. This delayed release from aquifer storage provides for the increased base flow from June through December. The increased streamflow from June through December cannot be explained by variation in rainfall, since post-treatment rainfall at the Elliott Station was shown to be less than during the pretreatment period.

The hydrologic records are insufficient to provide positive information on high-flow durations because the random occurrences of large rain events cause inconsistencies in short hydrologic records. For example, the highest 5-day flow beginning July 1 for area W–A1 for 1964 through 1972 was 72.6 ft³/s. When the averaging time is increased to 10 days, the highest flow increased to 139.5 ft³/s, nearly double,

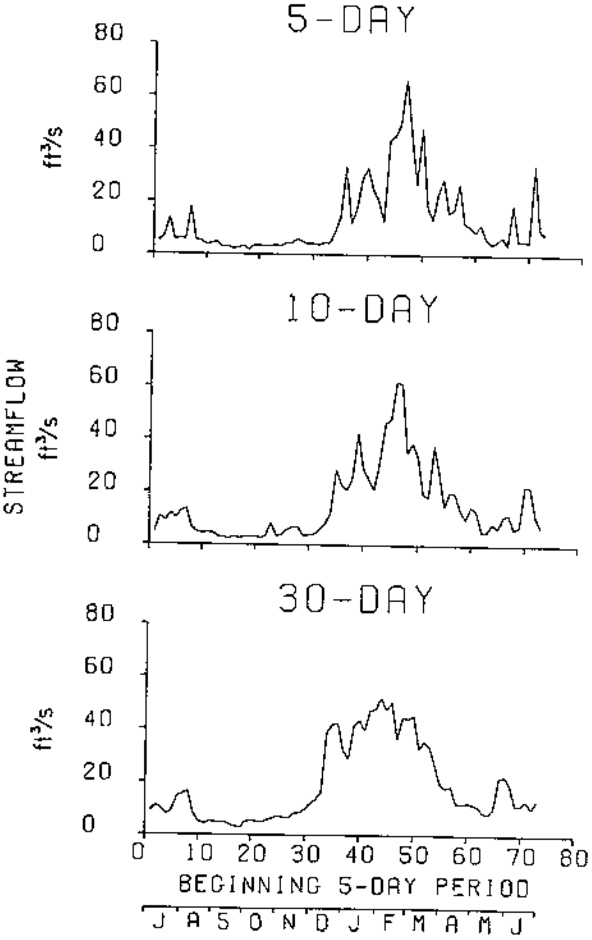


FIGURE 5.37.—Median 5-, 10-, and 30-day streamflow, watershed W–A2 (1964–72).

because of an extreme storm during the second 5-day period in July 1969. Likewise with W–A4, the highest 5-day flow was only 0.92 ft³/s, and yet the highest 10-day flow increased more than ten times to 10.75 ft³/s.

5.4.2.2.–MOVING AVERAGES

Moving averages provide a more complete picture of seasonal variability of streamflows than are given by selected durations. Durations are rank-ordered flows at a particular season, but moving averages are constructed from the mean or median values of the duration sets and represent all the flows rather than the extremes. Moving averages with 5-, 10-, and 30-day averaging times are presented in figures 5.35 through 5.39, each figure being based on one of the five streamflow records available. Only the medians of the ranked flow for the different averaging times are shown because the arithmetic means were found to fluctuate too much to be useful. This fluctuation is caused by the random presence of high extremes of rainfall during the short hydrologic record of only 8 years.

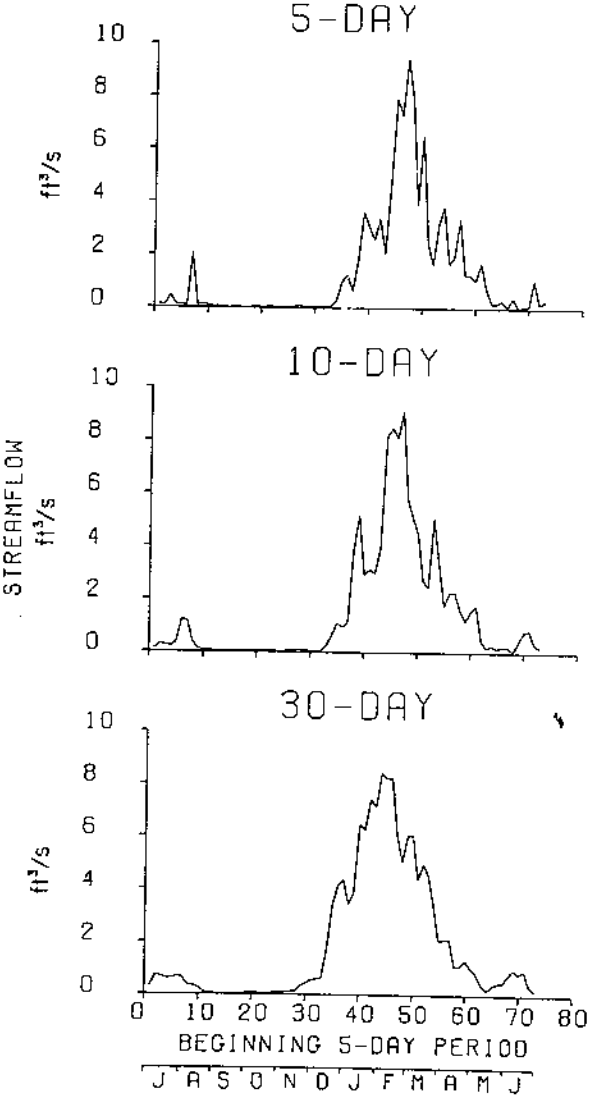


FIGURE 5.38.—Median 5-, 10-, and 30-day streamflow, watershed W–A3 (1964–72).

Figure 5.35 shows the median values of flows for three averaging times for watershed W–A1 before channelization with the beginning of the averaging times set at each of the 73 periods of the year. The year starts with June 1. The median flows reach a low value near June 1 and apparently decrease no further during the growing season. Seasonal increase begins about 125 days after June 1, or about the middle of September. Highest values reflect random

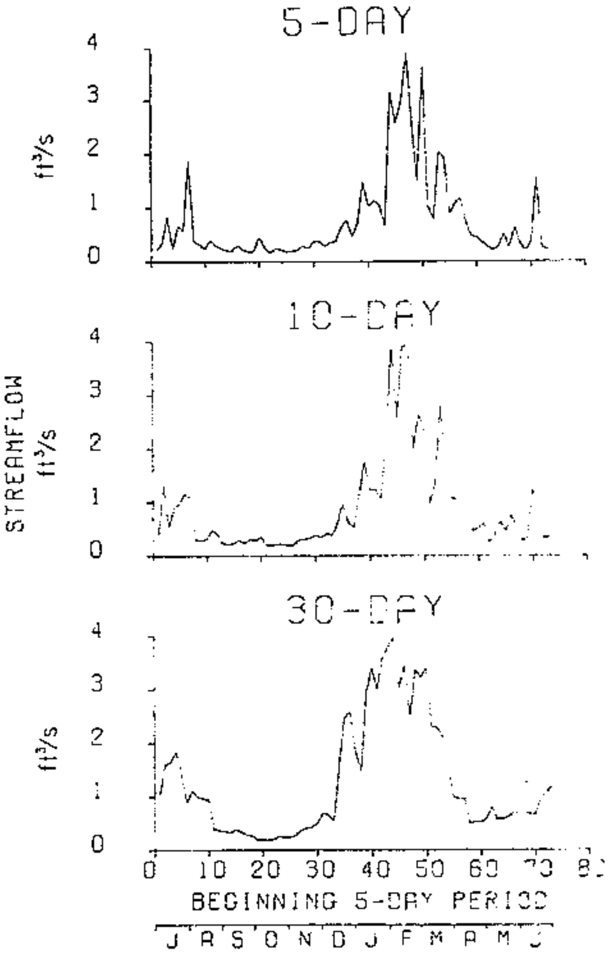


FIGURE 5.39.—Median 5-, 10-, and 30-day streamflow, watershed W–A4, (1964–72).

fluctuations, and occur during February for 30-day averaging. The shorter averaging times show larger fluctuations.

Figure 5.36 gives median values of flow for the three averaging times for watershed W–A1 following channelization. In this figure the year starts with July 1. Comparison of data in figures 5.35 and 5.36 gives the seasonal inversion of base flow before and after channelization, as noted in the duration studies. Median flows are lower after channelization during the dormant season, but higher during the growing season. Also, median flows generally decrease from July 1 until the recharge season begins, a recession that implies drainage of water from aquifer storage. No such implication is possible before channelization. The concept of improved deep storage caused by channelization, presented in the stream duration studies, is supported by the moving-average study.

Figures 5.37–5.39 show moving-average streamflow values for watersheds W–A2, W–A3, and W–A4. The recession of the median values is evident on watersheds W–A2 and W–A4, though not so pronounced as on watershed W–A1 after channelization. Watershed W–A3 flows are near zero, showing little seasonal recession. The moving-average studies support the thesis that flow during low-flow periods on watersheds W–A1, W–A2, and W–A4 is supplied by an underlying aquifer intercepted by the channels.

5.4.3.—Ground Water

5.4.3.1.—DURATION

Well data were placed in ranked order to provide a means of comparison within aquifers and between aquifers. Duration data were computed for 5-, 10-, and 30-day averaging periods; and records for ground-water stages for 5 years, 1968 through 1972, from seven wells were processed. Records for well 1 cover 1970 through 1972. The four averaging periods near January 1, April 1, July 1, and October 1, respectively, will be discussed.

Ranked averages for the Quaternary wells (1, 4, and 6) show little difference from year to year, except in October (tables 5.12–5.15). In this month the highest and lowest years differed by 6.08 feet for well 4 and by 2.28 feet for well 6 for the 5-day averaging period. The average stage was the highest in 1969 and lowest in 1968 for all shallow wells.

The Yorktown showed the same general pattern as the Quaternary sediment. The period beginning October 1 showed the most variation (table 5.15): values ranged from approximately 4.14 feet in well 5 to 5.12 and 6.07 feet in wells 2 and 7, respectively, for the 30-day averaging period. The highest stage was in 1969 and the lowest in 1968. Well 2, which lies in the surface outcrop area of the Yorktown, shows less variation (a maximum of 1.33 feet) during the record period than wells 5 and 7, which range from 4 to 5 feet. These ranges indicate that enough water was available during all four selected study periods (1, 19, 38, and 56) to maintain a minimum of water-table fluctuation at well 2. The water table was within 2.6 feet of the ground surface at all times.

(*Continued on page 64.*)

TABLE 5.12.—*Ground-water-well duration, beginning January 1*

[Feet above mean sea level]

Rank	Quaternary well—			Yorktown well—			Tuscaloosa well [7]8
	[1]1	[2]4	[3]6	[4]2	[5]5	[6]7	
	5-day averaging period						
1	73.80	70.93	42.02	69.32	53.35	56.62	42.12
2	73.00	70.58	41.83	69.11	53.11	56.30	42.03
3	72.48	70.47	41.77	69.03	52.87	56.16	41.85
4	...	69.94	41.69	69.00	52.81	55.93	41.62
5	...	69.09	40.63	67.58	49.15	50.96	41.49
	10-day averaging period						
1	73.94	70.92	42.15	69.33	53.37	56.63	42.12
2	73.77	70.63	41.81	69.13	53.07	56.27	41.90
3	72.66	70.28	41.77	69.01	52.93	56.25	41.87
4	...	70.02	41.54	68.90	52.17	54.92	41.61
5	...	69.10	40.62	67.64	49.24	51.12	41.48
	30-day averaging period						
1	73.93	70.81	42.18	69.29	53.40	56.60	42.14
2	73.53	70.54	42.06	69.21	53.34	56.51	41.92
3	73.41	70.39	41.96	69.04	53.24	56.48	41.77
4	...	70.34	41.78	69.00	52.05	54.72	41.57
5	...	69.54	40.90	67.96	49.62	51.84	41.50

[1] Records for years 1970 to 1972 only; ground surface elevation: 75.9 ft above m.s.l.

[2] Ground surface elevation: 71.5 ft above m.s.l.

[3] Ground surface elevation: 45.5 ft above m.s.l.

[4] Ground surface elevation: 70.1 ft above m.s.l.

[5] Ground surface elevation: 66.7 ft above m.s.l.

[6] Ground surface elevation: 63.0 ft above m.s.l.

[7] Ground surface elevation: 46.9 ft above m.s.l.

TABLE 5.13.—*Ground-water-well duration, beginning April 1*

[Feet above mean sea level]

Rank	Quaternary well—			Yorktown well—			Tuscaloosa well [7]8
	[1]1	[2]4	[3]6	[4]2	[5]5	[6]7	
	5-day averaging period						
1	74.49	71.03	43.70	69.34	53.90	56.88	42.74
2	73.56	70.49	42.32	68.92	53.33	56.53	42.32
3	72.71	70.17	41.92	68.80	53.30	56.45	42.00
4	...	69.99	41.78	68.76	53.28	56.42	41.96
5	...	69.78	41.74	68.71	52.98	56.34	41.68
	10-day averaging period						
1	74.16	70.76	43.38	69.26	53.94	56.91	42.70
2	74.04	70.47	42.42	69.02	53.37	56.55	42.33
3	72.59	70.38	42.02	68.89	53.35	56.47	42.05
4	...	70.14	41.93	68.75	53.26	56.46	41.94
5	...	69.71	41.75	68.72	52.94	56.31	41.73

See footnotes at end of table.

TABLE 5.13.—*Ground-water-well duration, beginning April 1*—Continued

[Feet above mean sea level]

Rank	Quaternary well—			Yorktown well—			Tuscaloosa well [7]8
	[1]1	[2]4	[3]6	[4]2	[5]5	[6]7	
	30-day averaging period						
1	73.67	70.44	42.98	69.09	53.89	56.87	42.71
2	73.08	70.19	42.54	69.00	53.50	56.53	42.33
3	72.44	70.14	41.85	68.76	53.32	56.48	42.11
4	...	70.13	41.82	68.72	53.16	56.34	41.98
5	...	69.64	41.81	68.68	52.96	56.34	41.82

[1] Records for years 1970 to 1972 only; ground surface elevation: 75.9 ft above m.s.l.
[2] Ground surface elevation: 71.5 ft above m.s.l.
[3] Ground surface elevation: 45.5 ft above m.s.l.
[4] Ground surface elevation: 70.1 ft above m.s.l.
[5] Ground surface elevation: 66.7 ft above m.s.l.
[6] Ground surface elevation: 63.0 ft above m.s.l.
[7] Ground surface elevation: 46.9 ft above m.s.l.

TABLE 5.14.—*Ground-water-well duration, beginning July 1*

[Feet above mean sea level]

Rank	Quaternary well—			Yorktown well—			Tuscaloosa well [7]8
	[1]1	[2]4	[3]6	[4]2	[5]5	[6]7	
	5-day averaging period						
1	72.02	69.91	41.47	68.71	52.49	55.88	42.70
2	71.67	69.82	41.19	68.25	52.40	55.80	42.45
3	69.34	69.68	41.09	68.25	51.43	54.43	42.30
4	...	68.72	41.04	67.86	51.22	54.21	42.04
5	...	68.39	40.82	67.24	50.80	52.76	41.88
	10-day averaging period						
1	72.01	70.02	41.41	68.75	52.51	56.03	42.72
2	71.83	69.93	41.29	68.42	52.28	55.55	42.45
3	69.38	69.82	41.28	68.07	51.48	54.44	42.27
4	...	68.60	41.18	67.88	51.13	54.08	42.06
5	...	68.55	40.81	67.31	50.82	52.87	41.88
	30-day averaging period						
1	72.51	70.02	41.52	68.52	52.36	55.88	42.70
2	71.81	69.59	41.46	68.31	52.14	55.48	42.41
3	69.01	69.56	41.45	68.08	52.00	55.16	42.30
4	...	69.23	41.05	68.06	51.17	53.50	42.04
5	...	68.17	40.63	67.04	50.75	53.47	41.83

[1] Records for years 1970 to 1972 only; ground surface elevation: 75.9 ft above m.s.l.
[2] Ground surface elevation: 71.5 ft above m.s.l.
[3] Ground surface elevation: 45.5 ft above m.s.l.
[4] Ground surface elevation: 70.1 ft above m.s.l.
[5] Ground surface elevation: 66.7 ft above m.s.l.
[6] Ground surface elevation: 63.0 ft above m.s.l.
[7] Ground surface elevation: 46.9 ft above m.s.l.

TABLE 5.15.—*Ground-water-well duration, beginning October 1*

[Feet above mean sea level]

Rank	Quaternary well—			Yorktown well—			Tuscaloosa well [7]8
	[1]1	[2]4	[3]6	[4]2	[5]5	[6]7	
				5-day averaging period			
1	74.86	70.82	42.02	68.81	52.20	55.79	42.68
2	68.52	69.70	40.78	67.09	51.22	54.56	41.99
3	68.46	66.94	40.74	65.16	49.33	52.30	41.83
4	...	66.60	40.16	64.93	49.15	50.59	41.77
5	...	64.74	39.74	63.39	48.58	50.00	41.57
				10-day averaging period			
1	74.71	70.63	41.87	68.88	52.40	55.96	42.34
2	68.44	70.52	41.39	68.12	51.63	55.02	41.95
3	68.42	67.69	40.99	65.53	49.50	52.72	41.91
4	...	66.44	40.11	64.77	49.06	50.46	41.80
5	...	64.80	39.78	63.46	48.56	49.97	41.65
				30-day averaging period			
1	74.32	70.77	41.98	68.93	52.64	55.93	42.07
2	69.20	70.00	41.42	68.50	52.37	55.89	41.92
3	68.30	67.72	40.98	65.88	49.97	53.68	41.86
4	...	67.18	40.17	65.17	48.91	50.26	41.85
5	...	65.47	39.81	63.81	48.50	49.86	41.70

[1] Records for years 1970 to 1972 only; ground surface elevation: 75.9 ft above m.s.l.

[2] Ground surface elevation: 71.5 ft above m.s.l.

[3] Ground surface elevation: 45.5 ft above m.s.l.

[4] Ground surface elevation: 70.1 ft above m.s.l.

[5] Ground surface elevation: 66.7 ft above m.s.l.

[6] Ground surface elevation: 63.0 ft above m.s.l.

[7] Ground surface elevation: 46.9 ft above m.s.l.

There are some differences, related to changes of available seasonal storage, in the general pattern of response of the Quaternary and Yorktown aquifers. The ranges of the high and low values for each quarter have been plotted for three wells: 2, 5, and 6 (fig. 5.40). The range for the Yorktown wells was the smallest during April and the greatest during October, showing that storage approached a maximum value each year during April and had a small variation below this maximum. In contrast, a large variation was observed in October, caused by the year-to-year difference in the amount of rainfall. During the depletion period, well 6 in the Quaternary does not show this pronounced seasonal pattern; rather, it tends to be erratic, probably reflecting random-rainfall inputs directly in the surficial material.

The Cretaceous ground-water elevation changes were less than 1 foot for any period, showing little, if any, recharge in this area.

5.4.3.2.—MOVING AVERAGES

Graphs showing medians for 5-, 10-, and 30-day averaging periods were plotted for all wells. The 5- and 10-day periods show more fluctuations caused by individual recharge periods than do the 30-day averages. The 30-day plots show a uniform seasonal change for the ground-water recharge and recession. Wells 1, 4, and 6 (figs. 5.41–5.43) show the response of the ground-water table to precipitation of the shallow phreatic sediments. Recharge begins in mid-September and continues until shortly after the first of the year, when the aquifer is fully recharged, the water table being approximately 1 foot from the ground surface in wells 1 and 4 and approximately 3 feet in well 6. With increased evapotranspiration and slightly lower rainfall, recession begins about the middle of April and continues until recharge begins in September, flattening slightly from the first of

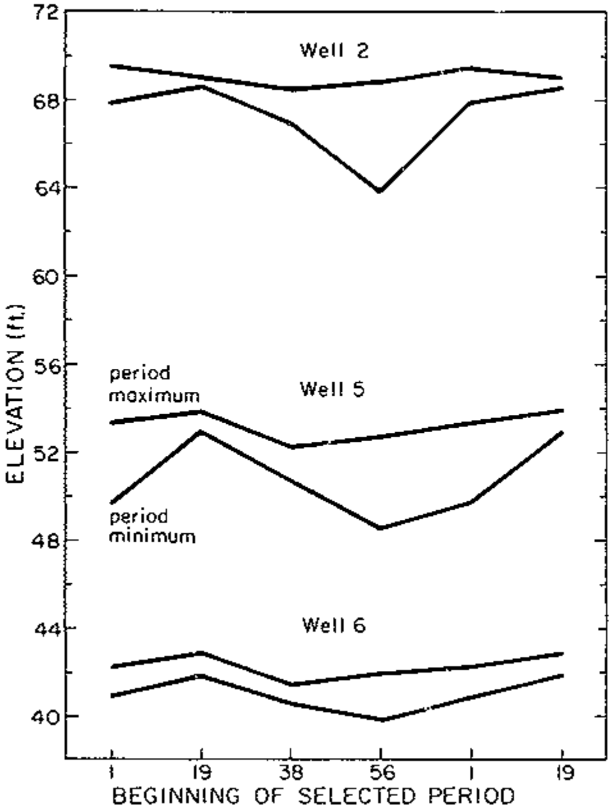


FIGURE 5.40.—Annual cycle of ground-water elevations.

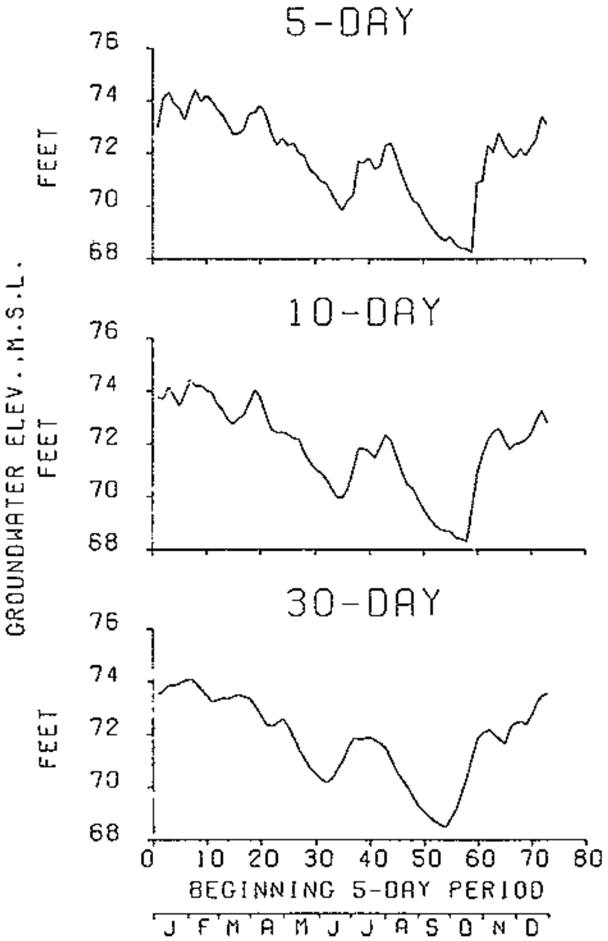


FIGURE 5.41.—Median 5-, 10-, and 30-day ground-water elevations, well 1 (1970–72).

June until mid-July. Well 1 shows the greatest water-table fluctuation, 4 feet, but the record period for this well is short and does not include 1968, the year with lowest rainfall. Direct comparisons, during similar time periods, cannot be made with the other shallow aquifer wells because wells 1 and 4 are located near the watershed boundary. Also, the large seasonal variation from high to low water levels in these wells reflects large variations in soil water in the uplands. Well 6, topographically lower, shows less variation, possibly reflecting both downslope drainage of water and generally higher soil-water levels nearer the streams.

The Yorktown wells (2, 5, and 7) do not show as much short-term fluctuation as do the Quaternary sediments (figs. 5.44–5.46). Recharge and recession, even in the 5- and 10-day-average plots, are more uniform and do not show response to individual storm events. The total range in elevation throughout the year is greater, in general, in the Yorktown than in the shallow sediments. Recharge begins in October and continues fairly uniformly until about mid-February in wells 5 and 7. Well 2 is fully recharged earlier than wells 5 and 7, by about the first of the year, and shows a more pronounced response to individual storms because it is updip and receives direct recharge. Recession begins in all the Yorktown wells except 2 in mid- to late-March and is fairly uniform, flattening slightly from mid-June to mid-August. Major recession at well 2 begins about mid-August, with a slight recession from mid-March to mid-August. The low occurred in the Yorktown wells in October. When well 2 is recharged, the water table is less than 1 foot below the ground surface, indicating that the aquifer in the vicinity of well 2 is almost fully recharged at a much earlier date than the other two wells downdip. This high water table was maintained during the first 3 to 4 months of the year. If the aquifer is recharged to within 1 foot of the surface, it can be inferred that the present channel system in the watershed

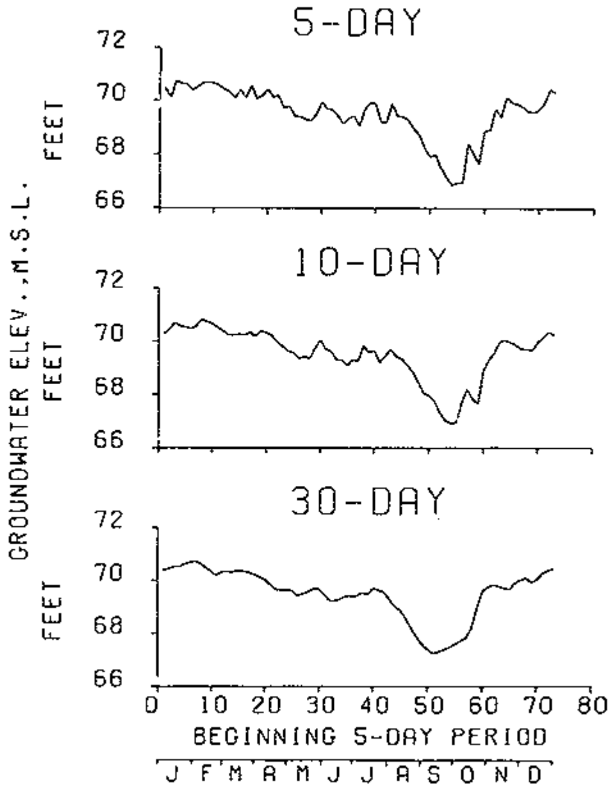


FIGURE 5.42.—Median 5-, 10-, and 30-day ground-water elevations, well 4 (1968–72).

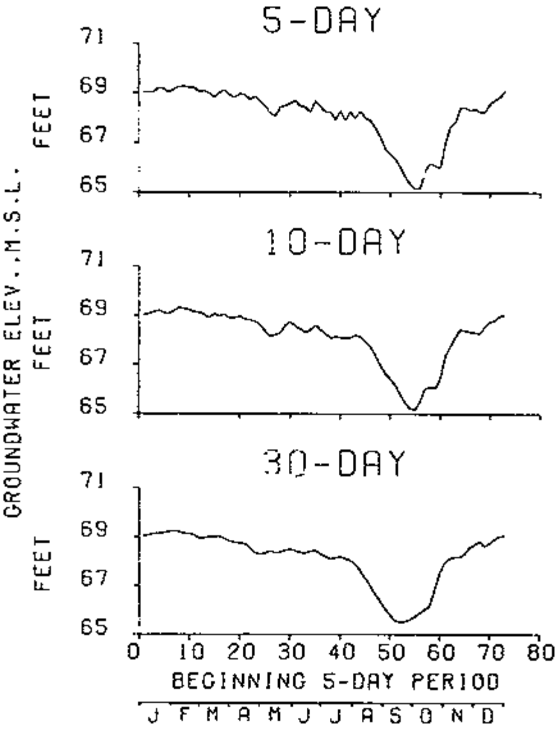


FIGURE 5.44.—Median 5-, 10-, and 30-day ground-water elevations, well 2 (1968–72).

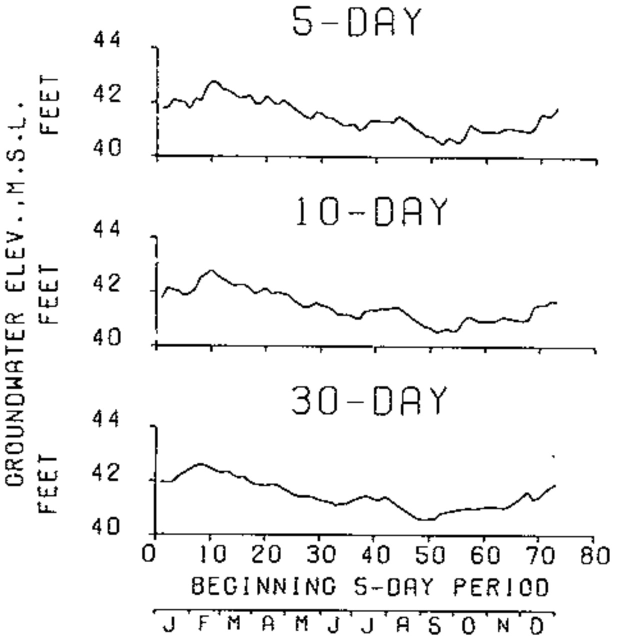


FIGURE 5.43.—Median 5-, 10-, and 30-day ground-water elevations, well 6 (1968–72).

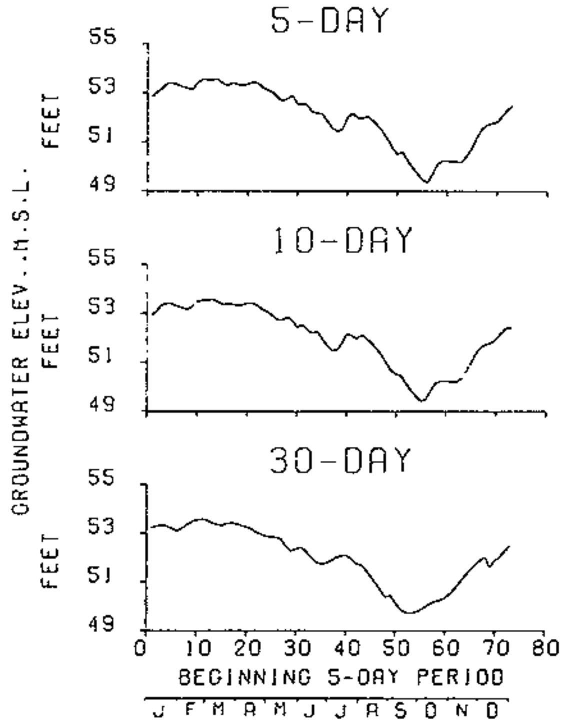


FIGURE 5.45.—Median 5-, 10-, and 30-day ground-water elevations, well 5 (1968–72).

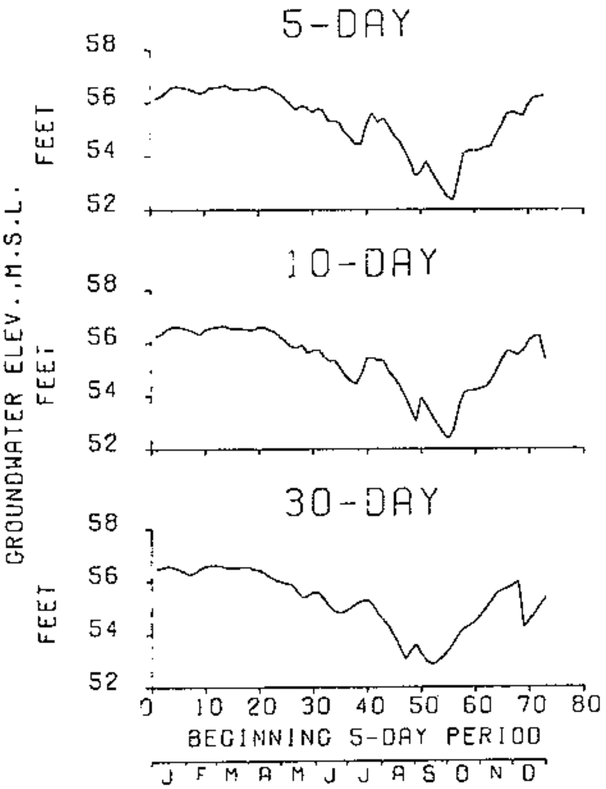


FIGURE 5.46.—Median 5-, 10-, and 30-day ground-water elevations, well 7 (1968–72).

has little effect on recharge during this period. When the aquifer is fully recharged, it cannot take any more precipitation into storage. Rather, any precipitation during this period would be expected to be conducted from the watershed as runoff in the channels and not go to ground-water recharge. In mid-April, evapotranspiration starts to increase and ground-water recession begins, and the increased rainfall in June and July causes a flattening of the recession curve.

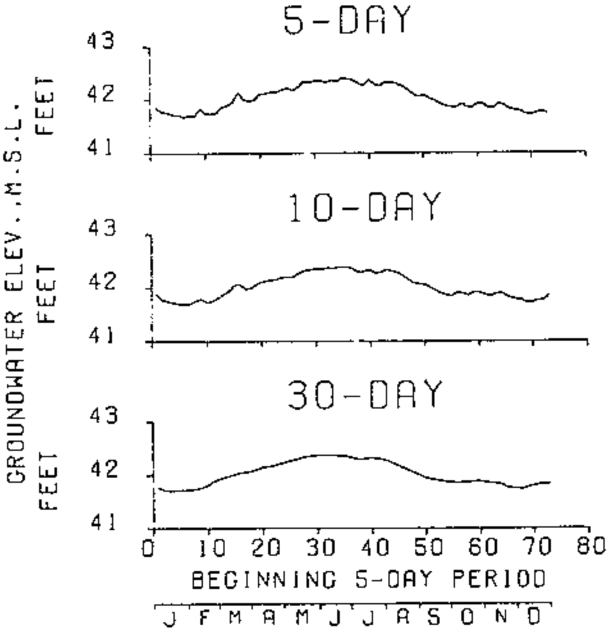


FIGURE 5.47.—Median 5-, 10-, and 30-day ground-water elevations, well 8 (1968–72).

The Tuscaloosa recharge begins about the first of February and continues until about the first of May (5-day period No. 25) at a uniform rate (fig. 5.47). Recession begins about the first of July (5-day period No. 35) and continues until the end of September. Recharge for the Tuscaloosa occurs during the recession period of the Yorktown and shallow surface sediments. Total water-table fluctuation is approximately 1 foot, and little, if any, recharge of the Tuscaloosa Formation occurs in the Ahoskie area. Recharge occurs west of the watershed, delaying downdip response and Tuscaloosa recharge until February.

SECTION 6.—ANALYSES AND INTERPRETATIONS

6.1.—WATER-YIELD ANALYSES

Water-yield analysis is concerned with the volume of water leaving a drainage area and the distribution of this volume in time. In practice, distribution normally means the seasonal variability of flow volumes, although it may mean the change in volumes over a sustained period, such as a year. In the following analyses the seasonal variability of flow will be emphasized. The year will be broken into monthly or 5-day periods, and seasonal variability of flow will be documented as the annual march of monthly or 5-day subtotals of flow.

Results of yield analysis are useful for planning the utilization of water as a resource for irrigation, for recreation, or for domestic use. These quantities form an information base for design of water-storage structures.

6.1.1.—Long-Period Streamflow

Long period is here defined to mean the length of time used to define a base unit of data, such as volume of streamflow for a month or a year. It is not to be confused with long term, which implies some change, effect, or activity measured during an extended length of time. Long-period streamflow response to precipitation was first defined by considering annual quantities to smooth the data and reveal long-term trends. Figure 6.1 shows that for watershed W–A1 changes in annual precipitation during the period of record resulted in similar changes in streamflow. Figures 6.2–6.4 show that the direction of changes is not always the same for watersheds W–A2, W–A3, and W–A4, especially during 1966–68. Furthermore, the volumes of annual streamflow are compar-

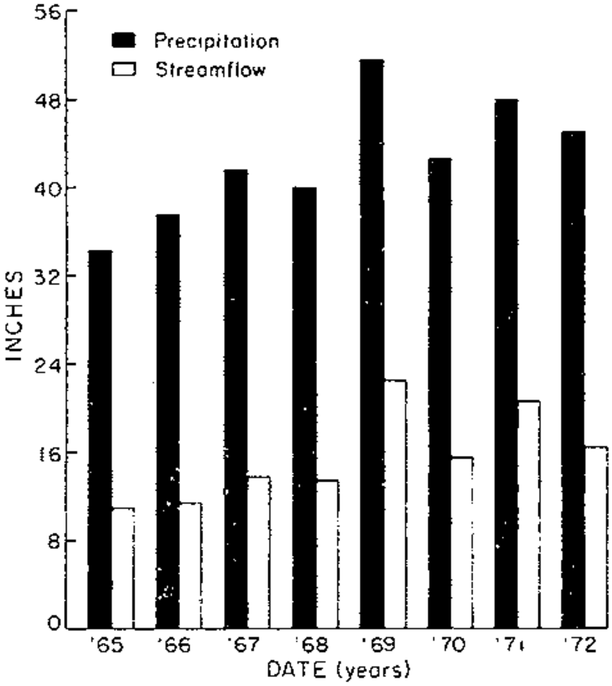


FIGURE 6.1.—Annual precipitation and streamflow, watershed W–A1 (1965–72).

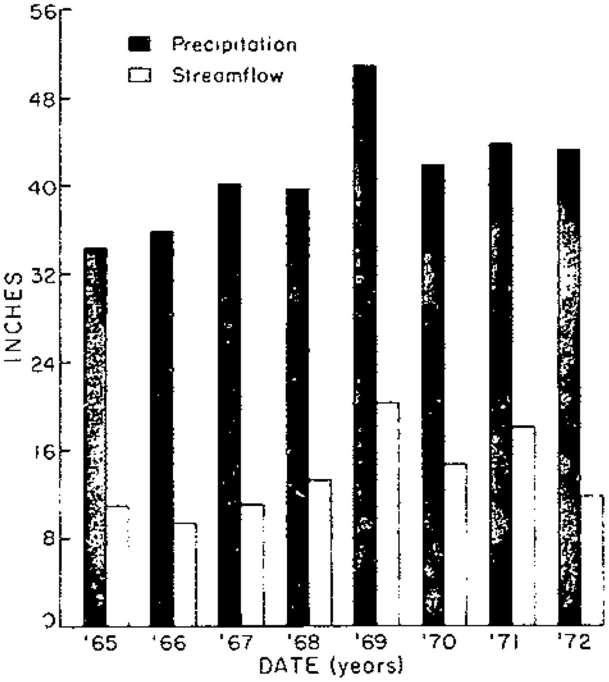


FIGURE 6.2.—Annual precipitation and streamflow, watershed W–A2 (1965–72).

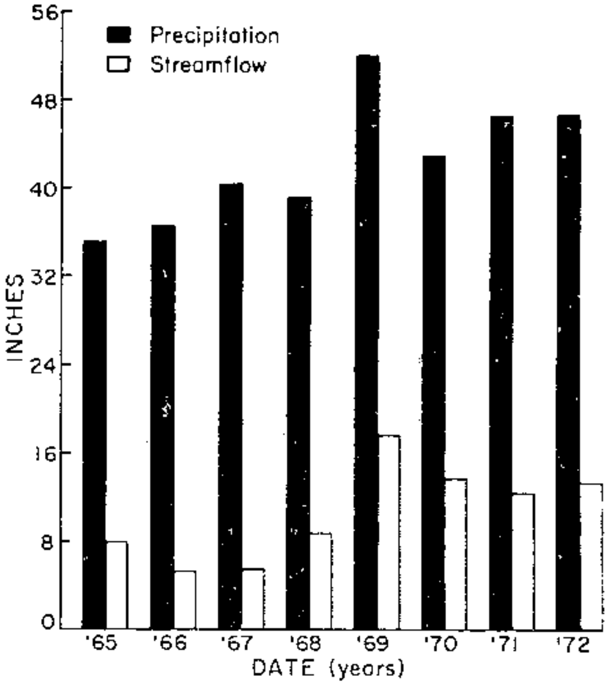


FIGURE 6.3.—Annual precipitation and streamflow, watershed W–A3 (1965–72).

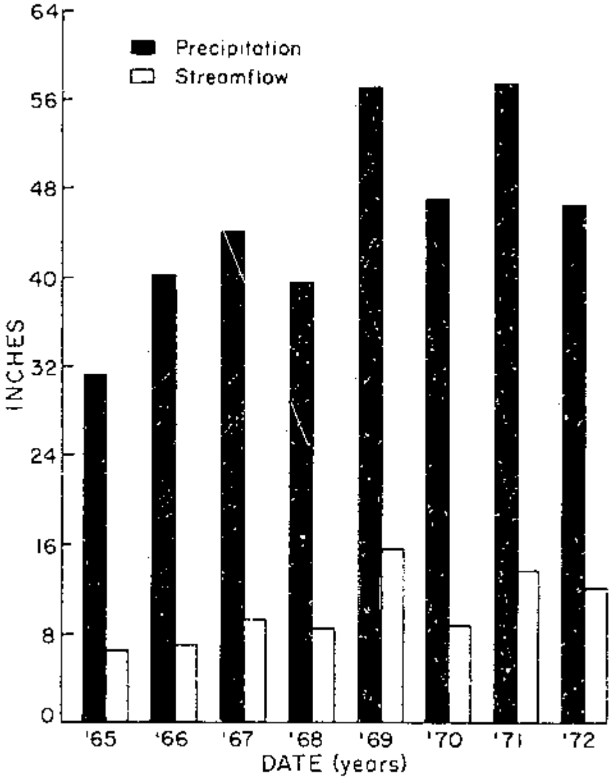


FIGURE 6.4.—Annual precipitation and streamflow, watershed W–A4 (1965–72).

able for watersheds W–A1 and W–A2, but annual volumes are significantly less for watershed W–A3 and particularly for watershed W–A4. The relationship between streamflow as a percentage of precipitation and size of area is shown in table 6.1. Watersheds W–A1 and W–A2 are similar, and watersheds W–A3 and W–A4 are similar, but the data indicate a considerable difference between the two pairs: W–A1, W–A2 and W–A3, W–A4.

Precipitation and streamflow by quarters of the year were also considered for detection of trends in the data. Figures 6.5–6.8 show such quarterly data for the four watersheds for 1964–72. These figures show that for all four watersheds precipitation in the first quarter produces the highest proportion of streamflow. This high proportion is produced by the combined effects of low evapotranspiration, fully recharged shallow aquifers, and near-maximum soil-water storage. For watershed W–A1, an average of 65 percent of the precipitation occurred as streamflow during the first quarter of the year, compared with 36 percent on an annual basis (table 6.1). Similar high percentages exist for the first quarter for all watersheds. Quarterly comparisons for all watersheds show variability in the second through fourth quarters: third quarter rainfall is generally high, with small percentages of runoff that reflect the evapotranspiration and ground-water recharge periods. Quarterly percentages show seasonal trends of evapotranspiration, ground-water recharge, soil drainage, and summer convective storms with small volumes (table 6.2).

In addition to the seasonal trend, table 6.2 shows differences among the drainage areas. During the first and second quarters the percentages of precipitation that become stream-

TABLE 6.1.—*Average annual precipitation and streamflow by watershed*

Watershed	Area (mi²)	Average annual— Precipitation (in)	Streamflow (in)	Streamflow (percentage of precipitation)
W–A1	57	42.47	15.38	36.4
W–A2	24	41.22	13.34	32.3
W–A3	3.7	42.27	10.39	24.1
W–A4	2.6	45.28	10.50	23.2

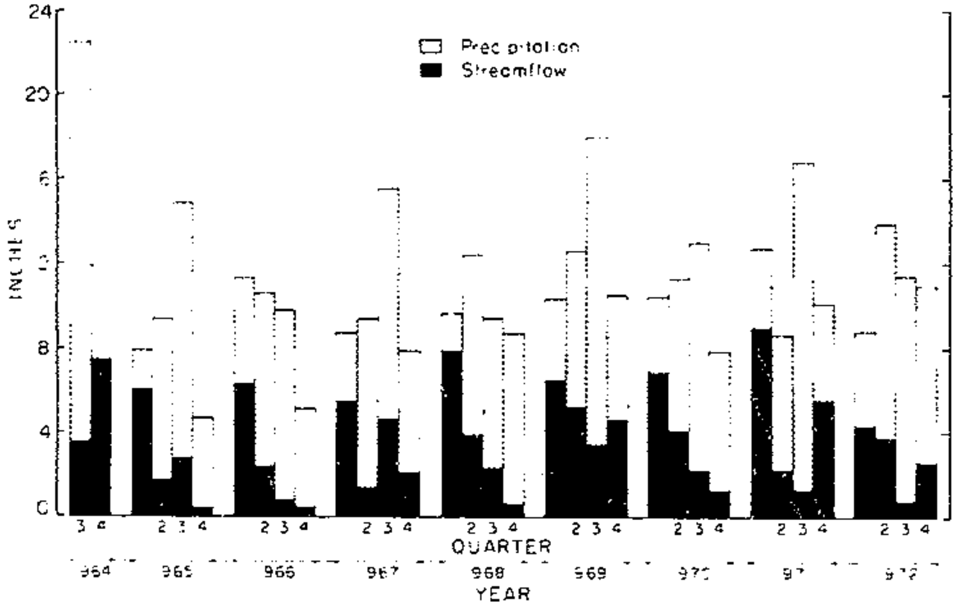


FIGURE 6.5.—Quarterly precipitation and streamflow, watershed W–A1 (1964–72).

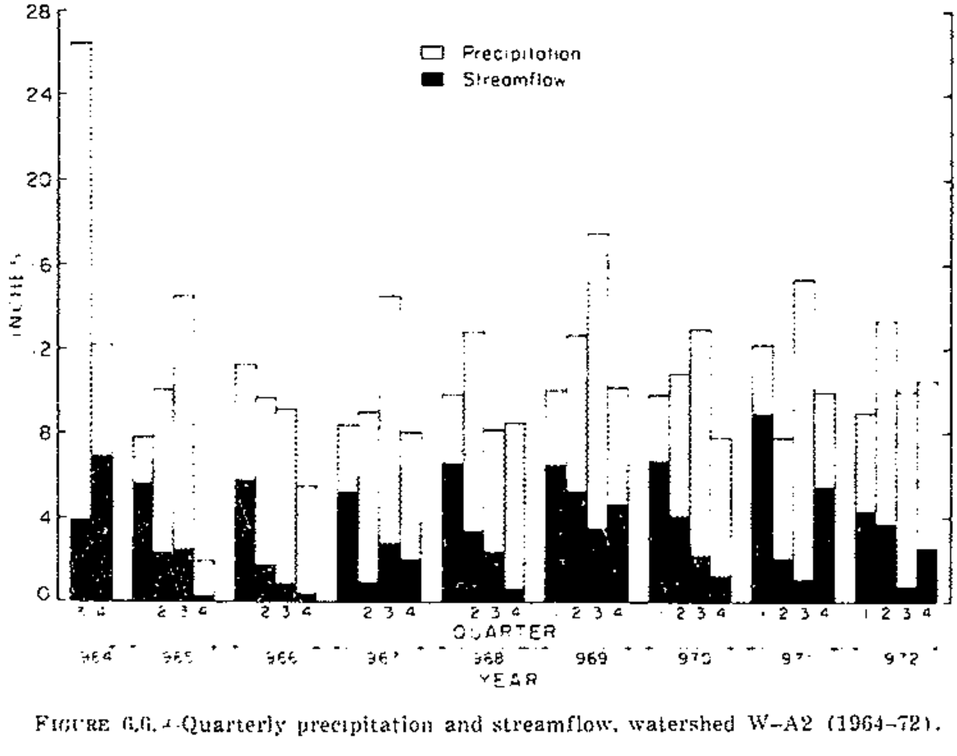


FIGURE 6.6.—Quarterly precipitation and streamflow, watershed W–A2 (1964–72).

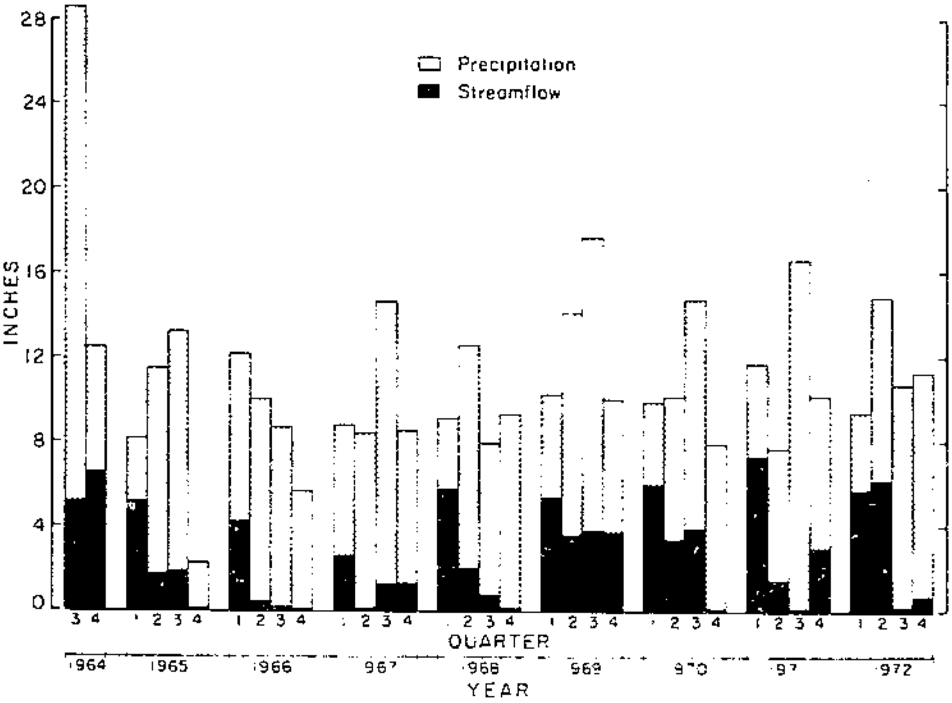


FIGURE 6.7.—Quarterly precipitation and streamflow, watershed W–A3 (1964–72).

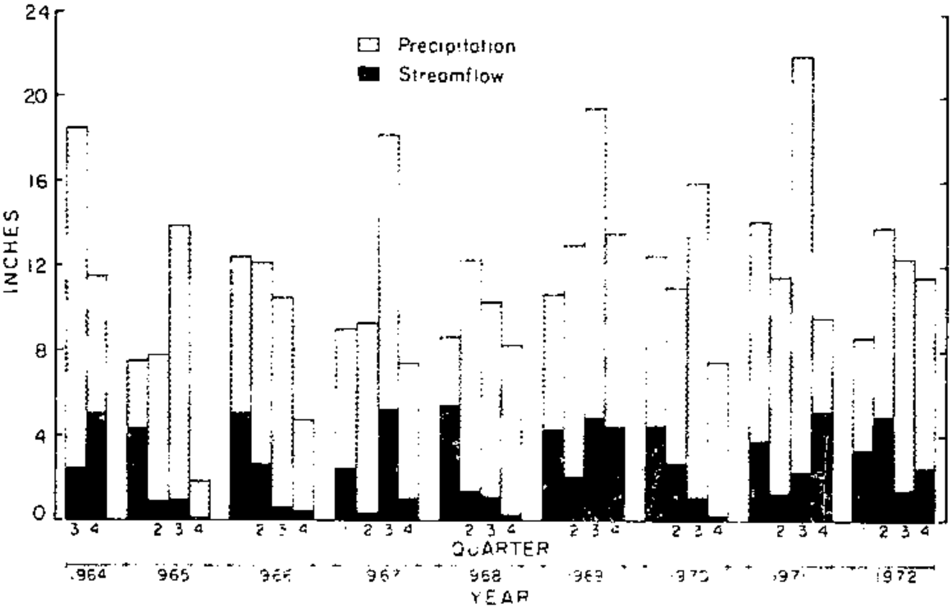


FIGURE 6.8.—Quarterly precipitation and streamflow, watershed W–A4 (1964–72).

flow are higher for watersheds W–A1 and W–A2 than for W–A3 and W–A4. Since W–A1 and W–A2 are downstream, hence lower, they may receive water from outcrops of the Yorktown Formation. In section 5.4.2.1., where streamflow-duration analyses were presented, the relationship between size of drainage area and rate of base flow was noted. The streamflow percentages in table 6.2 confirm this relationship. Table 6.2 also confirms the disproportionately low flow from W–A3 during the third and fourth quarters of the year.

TABLE 6.2.—*Average quarterly streamflow as a percentage of average quarterly precipitation*

Watershed	Area (mi^2)	Streamflow (percentage of precipitation in quarter)			
		1	2	3	4
W–A1	57	65	28	17	20
W–A2	24	63	27	16	28
W–A3	3.7	53	22	12	14
W–A4	2.6	40	18	15	22

Monthly totals of precipitation and streamflow were studied for details of variability of their relationship with season and with drainage area. Because of the scattering of the data, linear regression lines were fitted to each month to reveal the seasonal trends by smoothing. Regression lines for January and October do not fit into the overall seasonal trend. One point, labeled "A" in figure 6.9, shows an extremely low monthly streamflow for the observed precipitation, because each of the 2 months prior to the January in question had less than 1 inch of precipitation. Point A caused the large shift in the January line. Points B and C for October have abnormally high streamflow for the observed precipitation, because the Septembers prior to both October values had high precipitation volumes. These three points, because of the unusual antecedent precipitation and streamflow, resulted in regression lines that did not fit into the "normal"

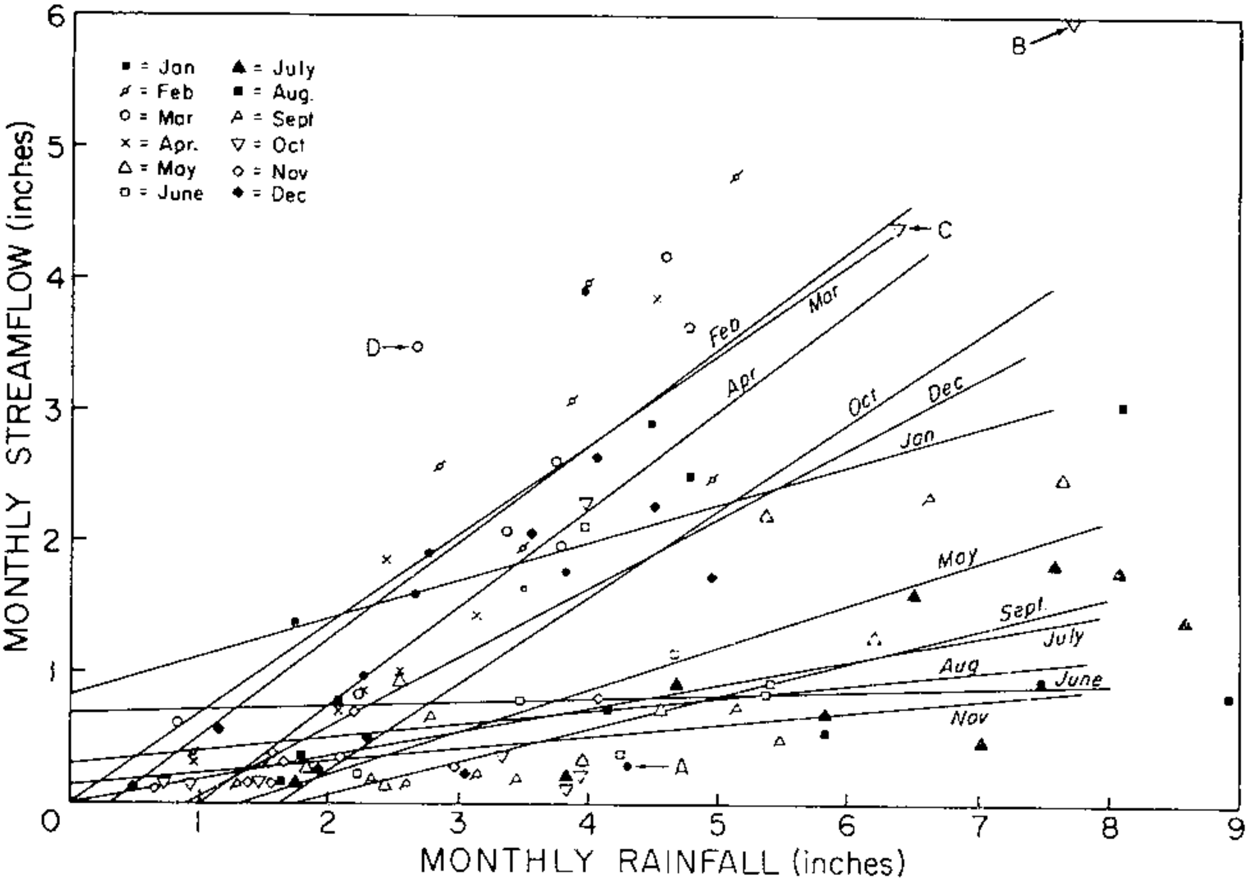


FIGURE 6.9.—Relationship between monthly precipitation and streamflow volumes, watershed W–A1 (1964–72).

seasonal trend. Point D indicates more streamflow than precipitation for a particular March record. Although this discrepancy may be due to error, such as a gage malfunction, it may be correct, since streamflow can exceed rainfall during periods of high carryover of stored water.

The general seasonal trend by months and the extreme antecedent monthly conditions led to further analyses of monthly data. Snyder (*17*) developed procedures and computer programs for analyzing monthly rainfall and streamflow data. The procedures utilize seasonally continuous cyclic functions for greater smoothing of the erratic data. The methods presented are as follows:

(1) Relating current-month streamflow to antecedent-month streamflow by

$$Q_m = a + bQ_{m-1}. \tag{6.1}$$

(2) Relating current-month streamflow to current-month precipitation by

$$Q_m = a + bP_m. \tag{6.2}$$

(3) Relating current-month streamflow to current-month precipitation plus antecedent-month streamflow by

$$Q_m = a + bP_m + cQ_{m-1}. \tag{6.3}$$

The procedures developed by Snyder (*17*) also include the log transform of the data with the above three equations. The regression lines of figure 6.9 were evaluations of equation 6.2 for the 12 separate calendar months.

Because of the scattering of the data, a modification of equation 6.3 was applied to the entire data set from the postchannelization period. Elliott Station precipitation data were used. The intent was to compare results with results of similar analysis of prechannelization data. Hopefully, such a comparison would reveal the effect of channelization on the rainfall-streamflow relationships.

TABLE 6.3.—*Optimized regression coefficients by month for equation 6.3, watershed W–A1*

$[Q_m = a + bP_m + cQ_{m-1}]$

Month	Coefficient		
	a	*b*	*c*
January	−2.004	1.006	0.344
February	−1.365	.861	.261
March	−.572	.608	.171
April	.193	.359	.106
May	.222	.221	.102
June	−.399	.246	.201
July	−1.562	.366	.374
August	−2.748	.523	.545
September	−3.443	.654	.639
October	−3.461	.774	.622
November	−3.092	.906	.539
December	−2.539	.999	.433

The coefficients *a*, *b*, and *c* of equation 6.3 are made continuous cycle functions of time through all months. The functions are optimized simultaneously through all months. The continuous nature of this cyclic structure of the coefficients is based on continuous parabolic interpolation (*13*). A total of nine parameters, three for each of the coefficients *a*, *b*, and *c*, are evaluated in applying this modification of equation 6.3 to any data set. Interpolation on the derived parameters gives values for each calendar month (table 6.3).

The optimized coefficients in the table were used with observed monthly precipitation in equation 6.3 to calculate monthly streamflow volumes. The correlation coefficient between calculated and observed monthly streamflow was 0.779, denoting that approximately 61 percent of the total variance was explained by the regression model. The relatively poor fit of the model indicates that it is probably not worthwhile to calibrate the regression model with pretreatment data to determine channelization effects on monthly streamflow. That is, treatment effects are probably obscured by the poor fit of the equation.

The coefficients in table 6.3 should be examined in comparison with figure 6.9, for the *a* and *b* coefficients relate to the regression lines of the figure.

The coefficient *b* in table 6.3 may be compared in a general way with figure 6.9. This coefficient represents the slope of the lines after additional smoothing imposed by seasonal continuity and after adjustment by flow of the antecedent month. The tabular data indicate that the months of November through March have the highest proportions of precipitation becoming streamflow, thus agreeing with the slopes of the lines in the figure, except for November and January. The January data were discussed earlier. The lowest relationship occurs in April through June, when the positive *c* coefficients for all months indicate positive relationships between monthly streamflow and

1-month antecedent streamflow. The strongest antecedent relationships occur in August through November, particularly in September and October. The October data were discussed earlier. The weakest antecedent relationships occur in February through June, particularly in April and May.

In view of the low correlation for the linear relationship, the data were transformed logarithmically, and a linear relationship was applied to the transformed data. But the transformation did not improve correlation: a correlation coefficient of 0.775 was determined, indicating that approximately 60 percent of the variance is explained by the transformation of data. Again, further effort is not justified for watershed W–A1. Because of the low correlation coefficients for watershed W–A1, similar analyses for watersheds W–A2, W–A3, and W–A4 are not justified.

The relationships between annual, quarterly, and monthly precipitation and streamflow have provided some significant information about the watersheds. However, the relationships are not sufficiently precise to discriminate between prechannelization and postchannelization flow regimes. It is possible that streamflow for shorter time periods would have a better relationship to precipitation in the period. Therefore, analyses based on a 5-day water-yield model are presented in the following section.

6.1.2.—5-Day Streamflow

The streamflow in any period depends primarily upon the rainfall in that period and in previous periods, and upon the water that can be retained in and on the watershed. The amount retained will vary seasonally with incident solar energy, because this energy controls evapotranspiration from the soil reservoir of water. The delivery of flow from rainfall in previous periods will also depend upon the amount of water stored in the watershed.

In order to separate the effects of the various watershed processes on observed streamflow, it is necessary to formulate and quantify conceptual models. Such a model was developed to utilize 5-day volumes of rainfall as input and 5-day volumes of streamflow as output, the time of year being an additional implicit input.

Model structure.—Figure 6.10 is a block diagram of the 5-day water-yield model, which is made up of three submodels. A seasonally cyclic function is used to compute the storage capacity of the watershed for every 5-day period in a sequence: any rain in excess of the storage capacity becomes streamflow. A characteristic function describes the pattern of release of water to streamflow for an idealized watershed

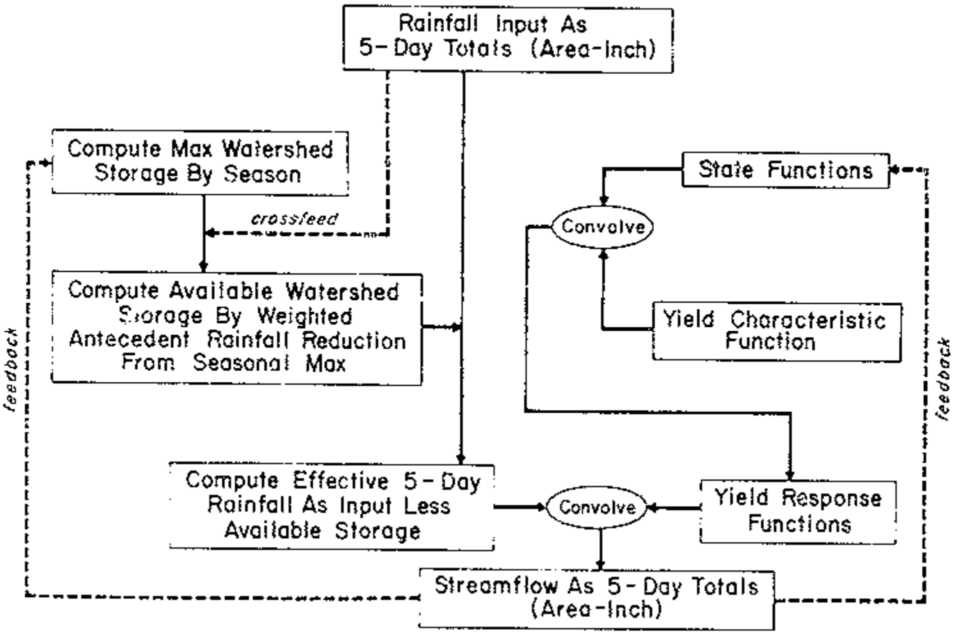


FIGURE 6.10.—Block diagram of 5-day water-yield model.

of zero storage. The state function, describing the wetness of the watershed, modifies the characteristic function to an actual pattern of release, a different pattern for every 5-day period. The excess rainfall amounts are distributed by their respective response patterns, and the summation of these distributed amounts is the prediction of streamflow.

Characteristic function.—The characteristic function describes, by definition, the hypothetical release of water to streamflow, if this release is not modified by travel through the channels and aquifers of the watershed. The computational form is shown in figure 6.11. This submodel is essentially form-free: before data analysis, the basic release pattern for a watershed is unknown, but by solving empirically for three parameters, nature provides the form. The exponential tail of the characteristic function is a modification of an earlier form. The exponential recession should allow close match to actual streamflow recessions during low-flow periods.

State function.—The state function "routes" the characteristic function to the outlet of the watershed, thereby changing it to a yield-response function. Flow typically passes through a wet watershed faster than through a dry one. If streamflow is used as an index of the wetness, the shape of the yield-response functions can be controlled by "feeding back" previously calculated flow volumes. The presently used form of the feedback parameter, m_t, is

$$m_t = b_1 RO_{t-1} + b_2, \tag{6.4}$$

where RO_{t-1} is the runoff in the 5-day period previous to the one being calculated. The statistical parameters, b_1 and b_2, are evaluated from data.

The state function is dependent on parameter m_t, as shown in

$$S(T)_i = \frac{1}{T_i^{m_t}}, \tag{6.5}$$

where $i=1, 2, 3$. This equation says that three values of $S(T)$ are computed as reciprocals of time, with the time exponentially scaled by the feedback parameter, m_t. Since these three values are the unscaled routing coefficients, scaling is required to make the sum of the three routing coefficients equal to unity, as in

$$s(T)_i = \frac{S(T)_i}{\sum_i S(T)_i}, \tag{6.6}$$

where $i=1, 2, 3$.

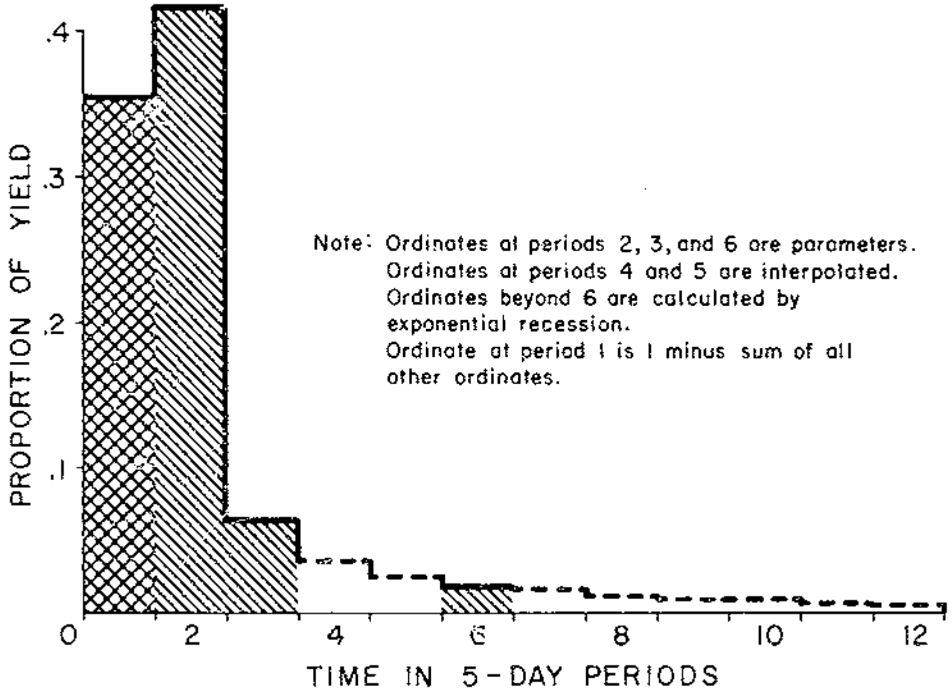


FIGURE 6.11.—Computational form of the water-yield-model characteristic function.

The characteristic function and the state function are convolved to produce the unit-yield functions.

Seasonal-storage function.—The seasonal-storage function is defined as the ability of the watershed to receive rainfall without releasing it to streamflow. Rain on the watershed that does not become streamflow must eventually go to deep seepage or back to the atmosphere through evapotranspiration. The storage function is made a function of the season of the year on the assumption that evapotranspiration serves as the major control on storage available.

Storage is computed in two steps, as illustrated in figure 6.12. First, a cyclic-interpolation function is specified as a parametric function of season: parameters 6 through 10 are spaced uniformly at an interval at 14.6 five-day units. This parametric function, which must be empirically evaluated, can be regarded as the maximum storage capacity of the watershed at any time of the year. Second, this maximum rate is decreased by streamflow and by antecedent rainfall, and the diminished storage is termed available storage.

Rainfall in excess of available storage is water held in temporary storage until it becomes streamflow. The unit-yield functions described earlier define how the water is released from this temporary storage to streamflow. The computational process is convolution of the rainfall excess values with the unit-yield functions.

Rainfall not in excess of the storage available at the time is assumed to go into storage—is by definition dead storage—and never becomes streamflow. Since storage is diminished by rainfall, the storage recovers as the time from the last rain increases. The rate of recovery is one of the empirically derived parameters of the model.

Parameter optimization.—The water-yield model contains 11 parameters that must be evaluated from recorded data: 6 of the parameters define the seasonal-storage function, 3 define the characteristic function, and 2 define

TABLE 6.4.—*Arrangement of data in 4-year sets*

Watershed—			
W–A1[1,2]	W–A2[2]	W–A3[2]	W–A4[2]
1951–54E	...	...	...
1955–58E	...	...	...
1959–62E	...	...	...
1965–68E	...	...	...
1969–72E	...	...	...
1965–68N	1965–68N	1965–68N	1965–68N
1969–72N	1969–72N	1969–72N	1969–72N

[1] E = Elliott Station precipitation.

[2] N = network precipitation.

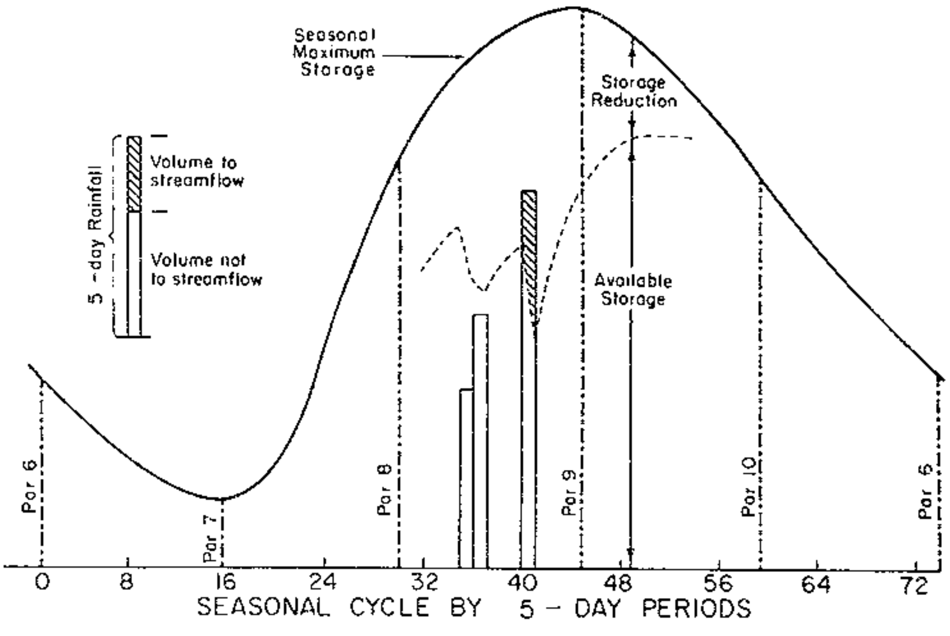


FIGURE 6.12.—Schematic of the seasonal-storage function.

the state function. Values of the parameters must be obtained by some numerical method of producing a "best match" between the model and the data. The method of optimization used for the water yield was nonlinear least squares combined with multivariate components regression (*4*).

Data were organized for optimization into 4-year blocks. Table 6.4 shows the arrangement of 4-year sets for which optimum values of the parameters were obtained. The sequence of five parameter sets for watershed W–A1 with Elliott Station (E) precipitation was used for possible detection of effects of channelization. For these five data sets with only one rain gage, optimization of the model could not be precise, but the use of this single station provided a consistent input in the before and after comparisons. More precise values should result from using the watershed average of 5-day rainfall computed from the network of raingages. Two 4-year data sets with network precipitation were available from each of the four watersheds. Interpretation of results from these data sets should serve to document effects of physiographic differences.

The optimized (best-fit) values of the parameters for all data sets are listed in table 6.5. The meaning of these values will be developed below. A major inconsistency may be noted in the storage parameters for the watershed W–A1, 1965–1968E, data set, but all other sets appear consistent. A minor statistical failure in the model produced the values of zero for parameter 3 for both data sets for watershed W–A4.

The characteristic function illustrated in figure 6.11 is given in detail in table 6.6. With this

TABLE 6.5.—*Optimized parameters for water-yield model*

Watershed	Data set	Correlation coefficient	State parameters		Characteristic parameters		
			1	2	3	4	5
W–A1	1951–54E	0.928	−0.7628	10.646	0.3962	0.0982	0.0264
	1955–58E	.849	−1.2652	9.988	.4187	.0646	.0196
	1959–62E	.852	−.9840	10.120	.5145	.0052	.0044
	1965–68E	.799	−1.1977	9.116	.2232	.0005	.0004
	1969–72E	.737	−1.2068	8.902	.1214	.0005	.0004
	1965–68N	.876	−1.2275	9.020	.1745	.0083	.0051
W–A2	1965–68N	.880	−1.1658	8.912	.1052	.0050	.0040
W–A3	1965–68N	.834	−1.1374	8.765	.1803	.0130	.0087
W–A4	1965–68N	.866	−1.1800	9.150	0	.0051	.0040
W–A1	1969–72N	.816	−1.2096	8.913	.2676	.0076	.0051
W–A2	1969–72N	.829	−1.2340	8.706	.1113	.0052	.0040
W–A3	1969–72N	.842	−1.1806	8.353	.1203	.0169	.0078
W–A4	1969–72N	.748	−1.2042	9.191	0	.0047	.0042

Watershed	Data set	Maximum-storage parameters					Available storage parameter 11	Residual error (in)
		6	7	8	9	10		
W–A1	1951–54E	0.1515	0.1340	0.4078	0.5863	0.4389	0.8327	0.119
	1955–58E	.1281	.0828	.3119	.6569	.3714	.8029	.214
	1959–62E	.1157	.0560	.3631	.6352	.4681	.8930	.242
	1965–68E	.1056	.0355	.2554	.3405	.2098	.1513	.194
	1969–72E	.1870	.0371	.3941	.4636	.3356	.8504	.242
	1965–68N	.1912	.0537	.3359	.3964	.2747	.8171	.156
W–A2	1965–68N	.2159	.0674	.3511	.4244	.3081	.8471	.134
W–A3	1965–68N	.2604	.0913	.4220	.4496	.4451	.8024	.129
W–A4	1965–68N	.2668	.1431	.3367	.4163	.2596	.7864	.136
W–A1	1969–72N	.0991	.0324	.2322	.4237	.2818	.7738	.207
W–A2	1969–72N	.1685	.0478	.3011	.5647	.3716	.8592	.179
W–A3	1969–72N	.2348	.0934	.3497	.6208	.5856	.8982	.182
W–A4	1969–72N	.1515	.1184	.2477	.3797	.2400	.6964	.207

structure and the values of parameters 3, 4, and 5 from table 6.5, the numerical values for each characteristic function ordinate were calculated (tables 6.7 and 6.8). These ordinates are the proportions of flow passing the stream gage from rain occurring during period one.

Table 6.7 illustrates the most significant change in streamflow detected by data analysis. The five characteristic functions in this table show the pattern of yield before and after channelization. The three functions prior to channelization show that 20 to 35 percent of flow passed the stream gage during the period in which the rain fell, and from 40 to 50 percent of flow occurred in the second 5-day period. Following channelization, about 70 to 80 percent of flow took place in the first period, and

TABLE 6.6.—*Detailed structure of characteristic function*

5-day period	Ordinate of characteristic function	Calculation of ordinate
1	*C*1	([1])
2	*C*2	Par 3.
3	*C*3	Par 4.
4	*C*4	(Par 4+2•Par 5)/3.
5	*C*5	(Par 4+8•Par 5)/9.
6	*C*6	Par 5.
7	*C*7	Exponential recession from Par 5; recession multiplier is e^{-b}, where $b=(\text{Par }4-\text{Par }5)/12\cdot\text{Par }5$.
8	*C*8	
9	*C*9	
10	*C*10	
11	*C*11	
12	*C*12	
13	*C*13	
14	*C*14	
15	*C*15	

[1] Area for $T=2$ to $T=6=\sum_{i=2}^{i=6} C_i$, area for $T=7$ to $T=\infty=(\text{Par }5\cdot e^{-b})/b$; from continuity of mass, $C1=1.0-\sum_{i=2}^{i=6} C_i-(\text{Par }5\cdot e^{-b})/b$.

TABLE 6.7.—*Yield characteristic functions using Elliott Station rainfall*

[Watershed W–A1]

5-day period	Proportions of flow for data period—				
	1951–54	1955–58	1959–62	1965–68	1969–72
1	0.3042	0.3552	0.1968	0.7267	0.8286
2	.3962	.4187	.5145	.2232	.1214
3	.0982	.0646	.0052	.0005	.0005
4	.0503	.0346	.0047	.0004	.0004
5	.0344	.0246	.0045	.0004	.0004
6	.0264	.0196	.0044	.0004	.0004
7	.0210	.0162	.0043	.0004	.0004
8	.0168	.0134	.0043	.0004	.0004
9	.0134	.0110	.0042	.0004	.0004
10	.0107	.0091	.0041	.0004	.0004
11	.0085	.0075	.0041	.0004	.0004
12	.0068	.0062	.0040	.0004	.0004
13	.0054	.0051	.0040	.0003	.0003
14	.0043	.0042	.0039	.0003	.0003
15	.0034	.0035	.0038	.0003	.0003
Multiplier	.7972	.8259	.9850	.9794	.9794

TABLE 6.8.—*Yield characteristic functions using network rainfall*

5-day period	Proportion of flow for watershed—			
	W–A1	W–A2	W–A3	W–A4
	1965–68			
1	0.7084	0.6738	0.5746	0.8108
2	.1745	.1052	.1803	0
3	.0083	.0050	.0130	.0051
4	.0061	.0043	.0101	.0044
5	.0055	.0041	.0092	.0041
6	.0051	.0040	.0087	.0040
7	.0048	.0039	.0086	.0039
8	.0046	.0038	.0084	.0038
9	.0044	.0038	.0083	.0037
10	.0041	.0037	.0082	.0036
Multiplier	.9491	.9794	.9848	.9773
	1969–72			
1	0.5846	0.7033	0.7629	0.5174
2	.2676	.1113	.1203	0
3	.0076	.0052	.0169	.0047
4	.0059	.0044	.0108	.0044
5	.0054	.0041	.0088	.0043
6	.0051	.0040	.0078	.0042
7	.0049	.0039	.0071	.0041
8	.0047	.0038	.0064	.0041
9	.0045	.0037	.0058	.0040
10	.0043	.0036	.0053	.0040
Multiplier	.9600	.9753	.9074	.9901
	Average of the 2 periods			
1	0.6465	0.6886	0.6688	0.6641
2	.2210	.1082	.1503	0
3	.0080	.0051	.0150	.0049
4	.0060	.0044	.0104	.0044
5	.0054	.0041	.0090	.0043

flow in the second period decreased to 12 to 22 percent. The variability within the before and after functions is seen to be less than the difference between the before and after functions (fig. 6.13).

The eight characteristic functions in table 6.8 reveal little information about the differences in yield for the four watersheds. All characteristic functions show that most flow occurs in the same 5-day period in which the rain falls, and that lesser flows occur in the second period. An abrupt change takes place in the third period, and beyond this sustained flows are small. Watershed W–A4 is different because it has zero proportion of flow yielded in the second period.

TABLE 6.9.—*Calculation of state function for data set W–A1, 1959–62, Elliott Station*

State function	Previous period runoff			
	PPR=0		PPR=1.5 in	
	Equation 6.5	Equation 6.6	Equation 6.5	Equation 6.6
S1	1.0	0.9403	1.0	0.9792
S2	.0538	.0506	.0193	.0189
S3	.0097	.0091	.0019	.0019
Total	1.0635	1.0000	1.0212	1.0000

Computational notes: $m = \text{Par } 1 \cdot (6.0 - \text{PPR}) + \text{Par } 2$ (equation 6.4), where PPR is the runoff in immediate antecedent period. For PPR=0: $m=4.216$ (dry watershed). For PPR=1.5 in: $m=5.692$ (wet watershed).

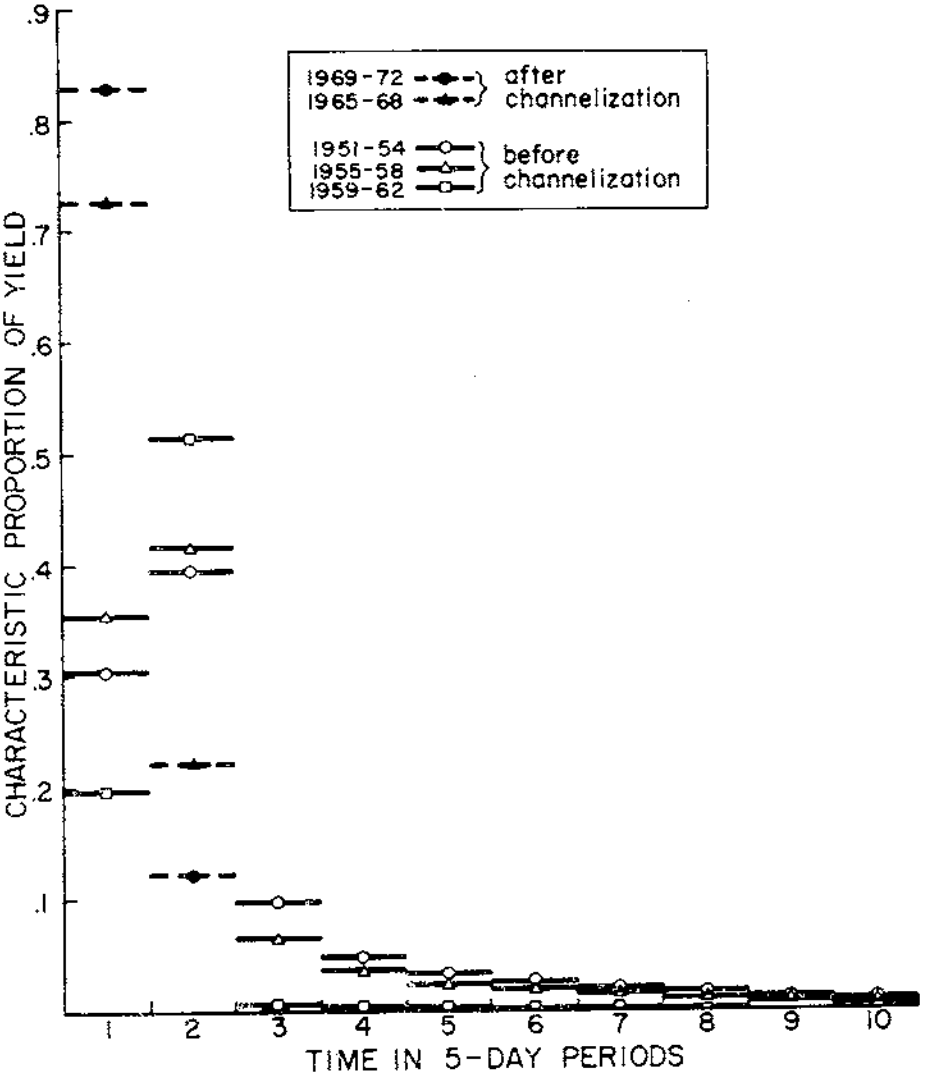


FIGURE 6.13.—Comparison of characteristic functions, watershed W–A1, before and after channelization.

TABLE 6.10.—*Calculation of unit-yield function for data set W–A1, 1959–62, Elliott Station*

[Convolution with characteristic]

5-day period	Characteristic function	Coefficients for PPR=0			Unit yield	Coefficients for PPR=1.5 in			Unit yield
		0.9403	0.0506	0.0091		0.9792	0.0189	0.0019	
1	0.1968	0.1851	...	...	0.1851	0.1927	...	...	0.1927
2	.5145	.4838	0.0100	...	.4938	.5038	0.0037	...	.5075
3	.0052	.0049	.0260	0.0018	.0327	.0051	.0097	0.0004	.0152
4	.0047	.0044	.0003	.0047	.0094	.0046	.0001	.0010	.0057
5	.0045	.0042	.0002	.0000	.0044	.0044	.0001	.0000	.0045
6	.0044	.0041	.0002	...	.0043	.0043	.0001	...	.0044
7	.0043	.0040	.0002	...	.0042	.0042	.0001	...	.0043
8	.0043	.0040	.0002	...	.0042	.0042	.0001	...	.0043
9	.0042	.0039	.0002	...	.0041	.0041	.0001	...	.0042
10	.0041	.0039	.0002	...	.0041	.0040	.0001	...	.0041

For pertinent computational notes, see notes to table 6.9.

TABLE 6.11.—*Calculation of storage and effective precipitation*

5-day period	Interpolation function (1)	Runoff (2)	Maximum storage (3)	Precipitation (4)	Available storage (5)	Effective precipitation (6)	Soil intake (7)	Weighted intake (8)
152	...	0.212	...	...	...	...	...	...
153	0.0501	.345	0.491	1.00	0.079	0.921	0.079	...
154	.0436	1.674	.421	1.56	.070	1.490	.070	...
155	.0380	1.195	.316	1.35	.011	1.339	.011	...
156	.0333	.543	.293	0	.063	0	0	...
157	.0298	.764	.281	1.25	.104	1.146	.104	...
158	.0275	.389	.254	.12	.100	.020	.100	0.180
159	.0267	1.206	.257	1.64	.077	1.563	.077	.186
160	.0275	.288	.242	0	.056	0	0	.131
161	.0300	.174	.291	.53	.160	.370	.160	.223
162	.0344	.198	.338	.24	.115	.125	.115	.261
163	.0411	.149	.403	.67	.142	.528	.142	.295
164	.0511	.531	.493	.64	.198	.442	.198	.365
165	.0608	.0325	.576	.52	.211	.309	.211	.433
166	.0733	1.170	.709	1.54	.276	1.264	.276	.549
167	.0871	.179	.769	0	.220	0	0	.398
168	.1020	.080	1.002	0	.604	0	0	.290
169	.1178	.059	1.168	.17	.879	0	.170	...

Computational notes: (1) from parameters 6 through 10 (table 6.5). (2) Runoff observed or computed. (3) (1) × (10.0 − previous runoff), for example, 0.0501 (10.0 − 0.212) = 0.491 and 0.0436 (10.0 − 0.345) = 0.421. (5) (3) − previous weighted intake, for example: 0.257 − 0.180 = 0.077 and 0.242 − 0.186 = 0.056. (6) (4) − available storage. (7) The smaller of (4) or (5). (8) Weighted intake of 6 previous periods: weighting multiplier is parameter 11 of model (0.77382), for example: $0.079p^6+0.070p^5+0.011p^4+0.000p^3+0.104p^2+0.100p=0.180$ and $0.070p^6+0.011p^5+0.000p^4+0.104p^3+0.100p^2+0.077p=0.186$.

The consistency of the derived results can be emphasized by averaging the ordinates of the functions for the two periods. In table 6.8, these averages are noted for the first five 5-day periods. In these averages the proportion of flow yielded in the first periods varies only from about 0.65 to 0.69; period 2 is transitional; and periods 3 and beyond contribute little to streamflow. The slight variability of proportionate flow in the first period might be a result of a consistent ratio of surface water to ground-water flow for all watersheds.

Parameters 1 and 2 in table 6.5 are used to quantify the state function (equations 6.4–6.6) and to calculate unit-yield functions from the characteristic functions. For illustrative purposes, calculations for one parameter set are shown in tables 6.9 and 6.10. The computed yield functions, together with the characteristic function, are plotted in figure 6.14. The yield functions differ only slightly from each other and from the characteristic. The actual yield of streamflow changes little with the wetness state of the watershed. Table 6.5 shows that parameters 1 and 2 vary little for all data sets. The conclusion is that the Ahoskie watersheds are essentially linearly responsive in yield.

Following the schematic in figure 6.12, the computation of storage and effective precipitation are shown in table 6.11. Essentially, the storage available to hold incoming rainfall is calculated, and rain in excess of this amount is effective in the generation of streamflow. The noneffective rain enters the soil profile and decreases the storage available. Between rains the storage recovers because of evapotranspiration and deep seepage.

The calculations in table 6.10 are for illustrative purposes only. It is difficult to summarize storage and streamflow for all data sets. Consequently, figures 6.15–6.28, showing rainfall, storage, and runoff for the 4-year period analyzed, were prepared.

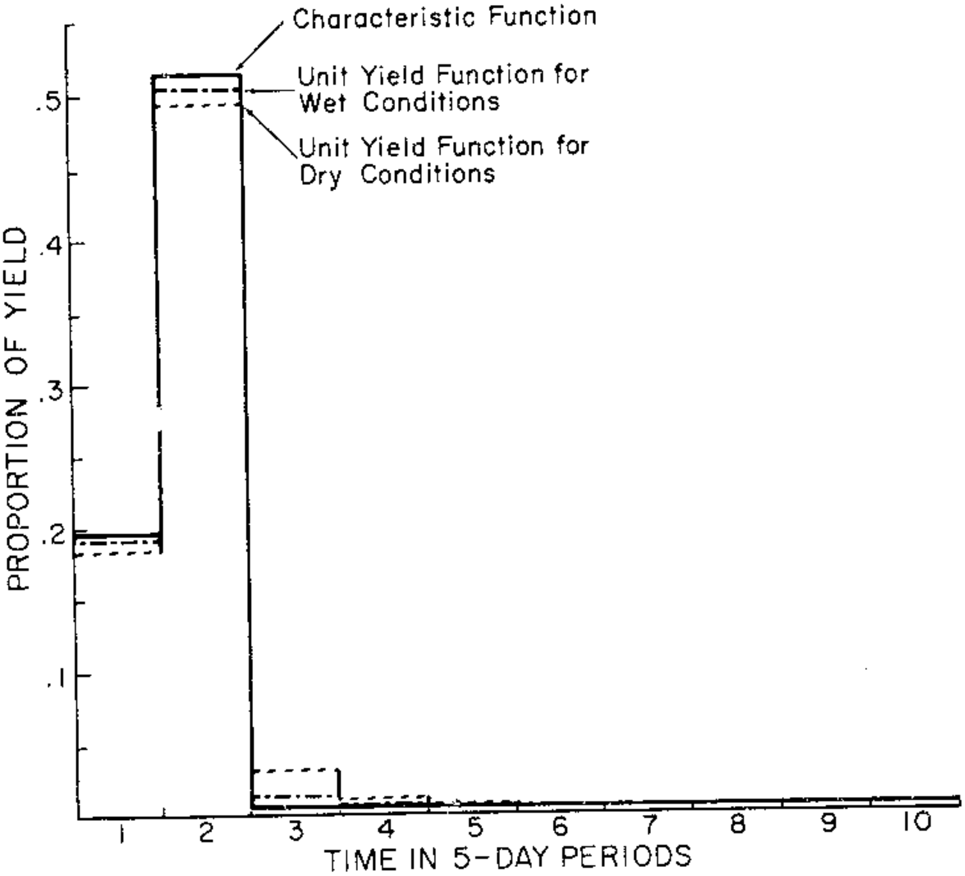


FIGURE 6.14.—Comparison of characteristic and yield functions for wet and dry conditions, watershed W–A1.

6.1.3.—Prediction for Treatment Effect

The effect of channelization can be studied only by means of the streamflow records at watershed W–A1, for the other three stream gages were installed after channelization. The only rainfall records prior to channelization are from the Elliott Station. These data were used with the water-yield model to see whether treatment effects were detectable. Elliott Station rainfall, from January 1, 1951, through December 31, 1972, was assembled in 5-day subtotals, and continuous 5-day volumes of streamflow were then predicted. Volumes were predicted twice, once with parameters from the 1959–62E data set in table 6.5, and again with parameters from the 1969–72E data set. The 22-year series of yield data, rainfall, storage, and runoff were then plotted mechanically. Both predictions were plotted and compared with observed runoff. Two additional charts based on the two predicted series were also plotted mechanically: one chart was made up of accumulated values of observed runoff and the predicted runoff, and the other was a continuous plot of the errors between predicted and observed runoff for both predicted series.

All charts were examined for evidence of the effects of channelization. Continuous time plots of the predicted values should show a discontinuity if an effect is present. No such discontinuities were detected, and neither were time trends evident in the accumulated data. Treatment effects may be present in the predictions, but they were obscured by natural variability of the rainfall data.

The effect of channelization upon the characteristic yield of runoff from watershed W–A1 was shown in figure 6.13. Such a changed pattern of yield is the changed response to an individual 5-day precipitation value. Actual streamflow past a gaging point is a cumulative value from a long antecedent series of such precipitation values. The cumulative values of runoff also obscure the change in pattern of yield.

The most noticeable difference in model behavior for the 22-year series of predictions with two sets of parameters was in the seasonal-storage functions. Maximum and available storages in the summer are higher using the before-treatment parameters than when using the after-treatment parameters in the model. Based on this observation an additional attempt was made to show the effects of treatment on runoff.

Effective precipitation was tabulated for 12 consecutive 5-day periods for the summer and winter seasons for both series of predictions. Totals for the 60 days were then compared with observed runoff for the same 60 days (figs. 6.29 and 6.30).

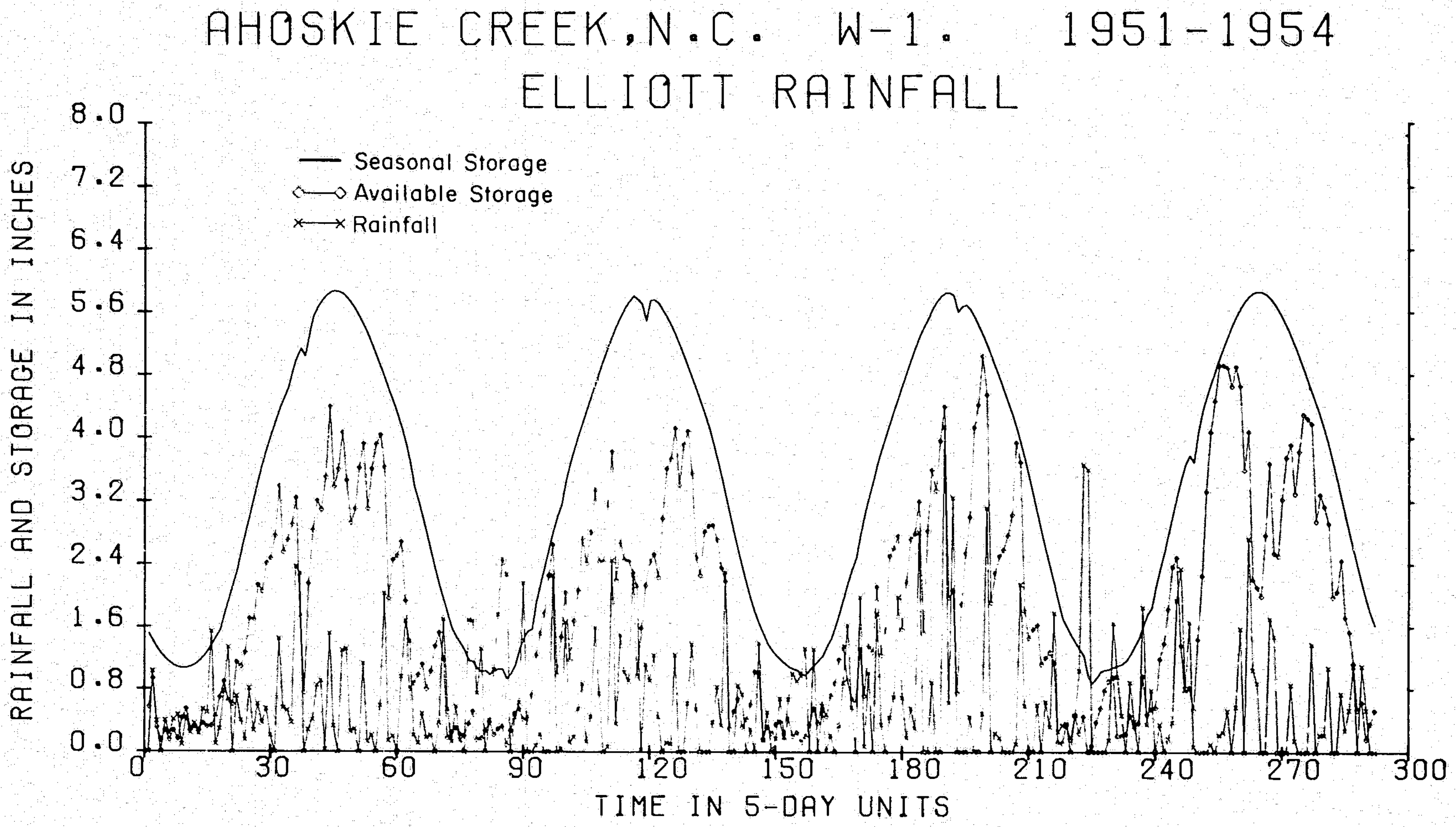
During the winter the predictions using the "before" set of parameters and the "after" set of parameters are essentially the same: both sets of predictions agree reasonably well with the observed values.

During the summer the predictions using the "before" set of parameters are considerably smaller than the predictions using the "after" set of parameters. For the years after channel construction, 1965 through 1972, the predictions are in agreement with observed values of runoff. However, in 1955 and 1960 excessive rain at the Elliott Station caused the model to predict high runoff amounts compared to the observed.

Table 6.12 was prepared to average some of the year-to-year irregularities in figures 6.29 and 6.30. Runoff totals in the 60-day periods for 12 years prior to construction and 8 years after construction are tabulated, and observed totals as well as predicted totals with the "before" and "after" parameters are given. Both summer and winter predicted totals using "before" parameters are closer to the observed totals for the years 1951 through 1962 than are the predictions with "after" parameters. Conversely, for both summer and winter, predicted totals using "after" parameters are closer to the observed totals for the years 1965 through 1972 than are the predictions with "before" parameters. This consistency of prediction lends some credibility to the values of the seasonal-storage parameters of the model.

The total values of the runoff using the "after" parameters are considerably more than those of the "before" parameters for the summer season. If these total differences are divided by the number of years, the values of 0.99 inch per year and 1.18 inches per year are obtained. The water-yield model applied to the rainfall record prior to construction indicates that about 1 inch of additional runoff per year would have occurred in the summer season, if

(*Continued on page 113.*)


AHOSKIE CREEK,N.C. W-1. 1951-1954
ELLIOTT RAINFALL
Seasonal Storage
Available Storage
Rainfall
RAINFALL AND STORAGE IN INCHES
8.0
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0
0
30
60
90
120
150
180
210
240
270
300
TIME IN 5-DAY UNITS

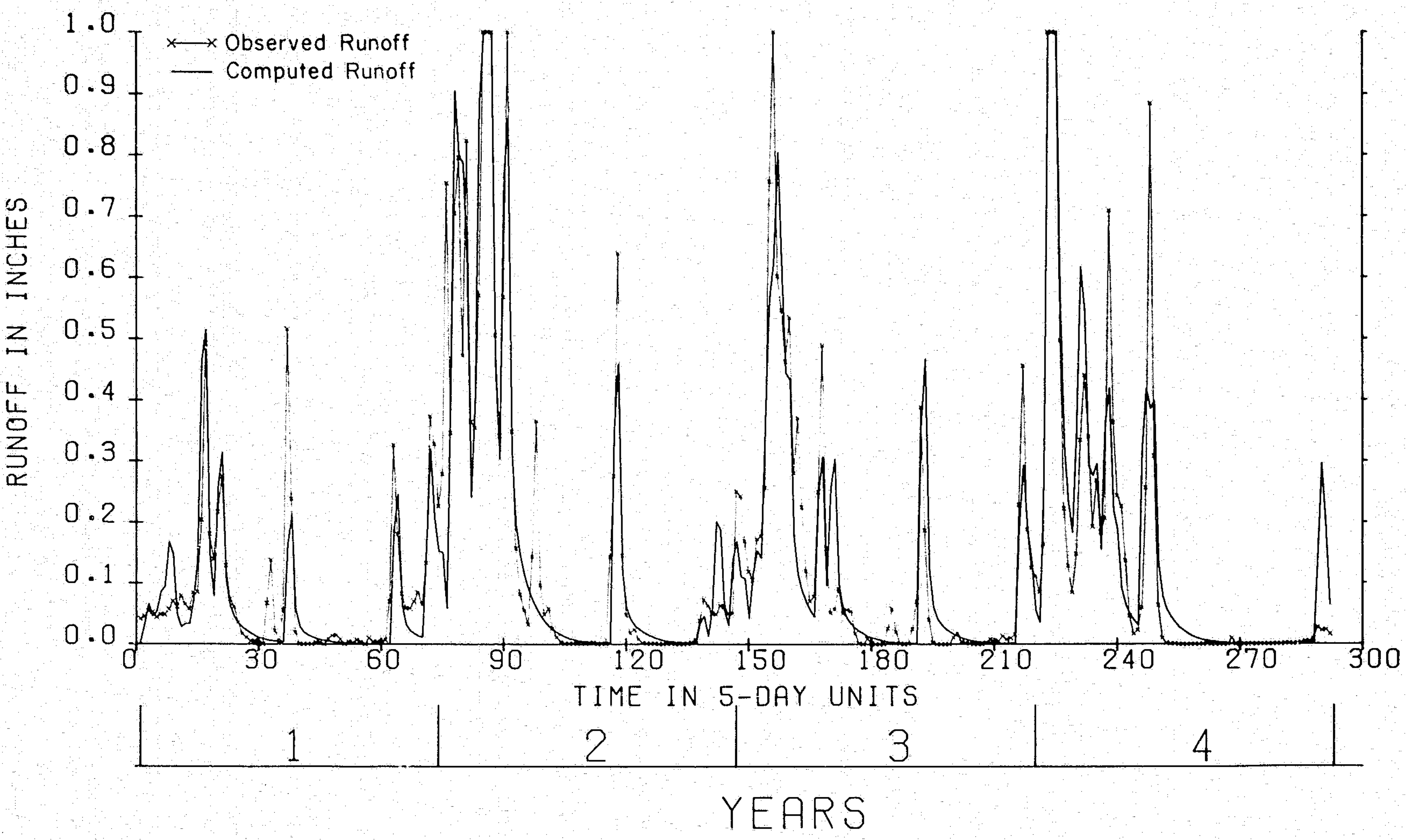
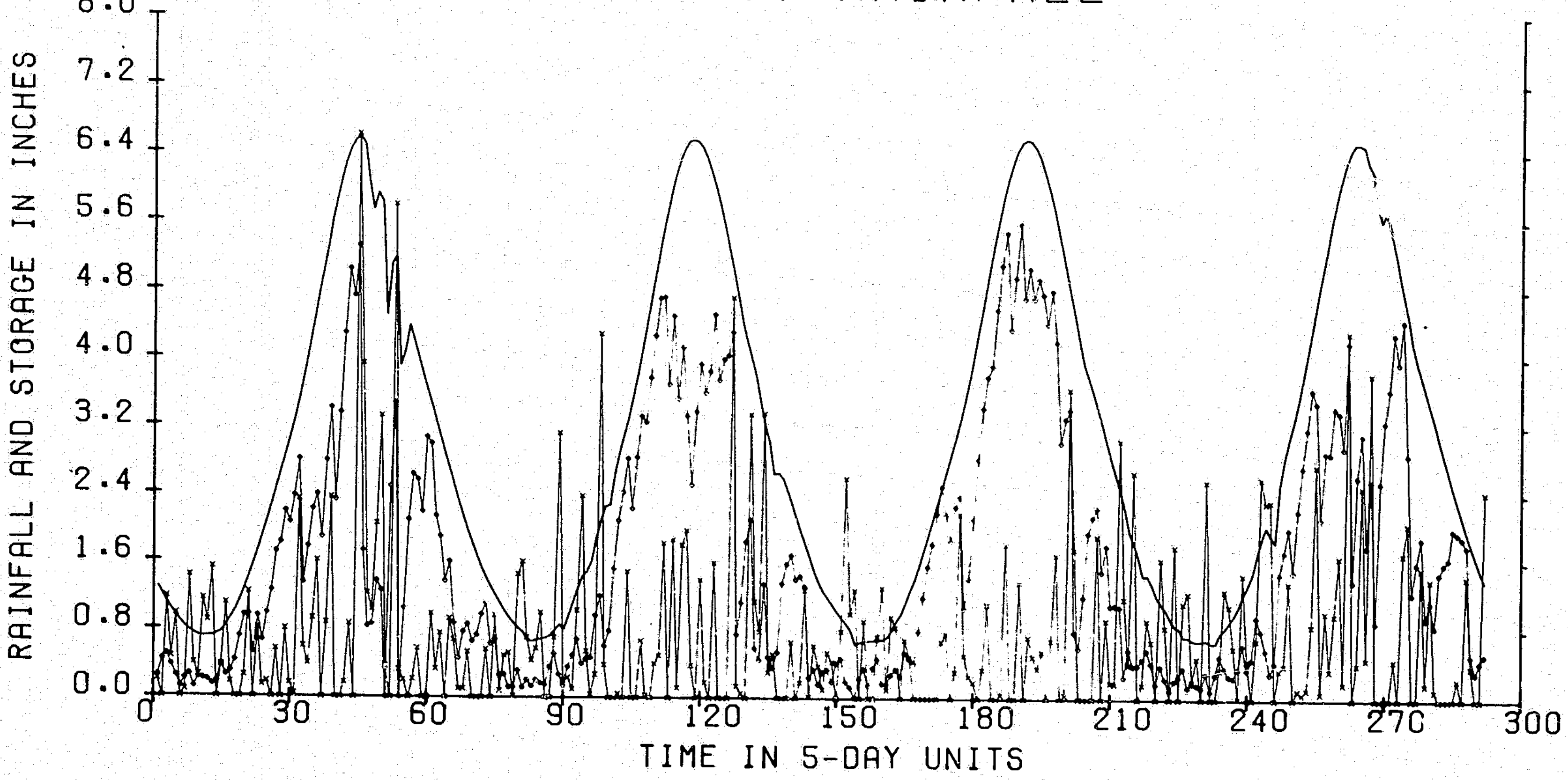


FIGURE 6.15.—Water-yield analysis, watershed W-A1, Elliott rainfall (1951–54).



AHOSKIE CREEK, N.C. W-1. 1955-1958
ELLIOTT RAINFALL

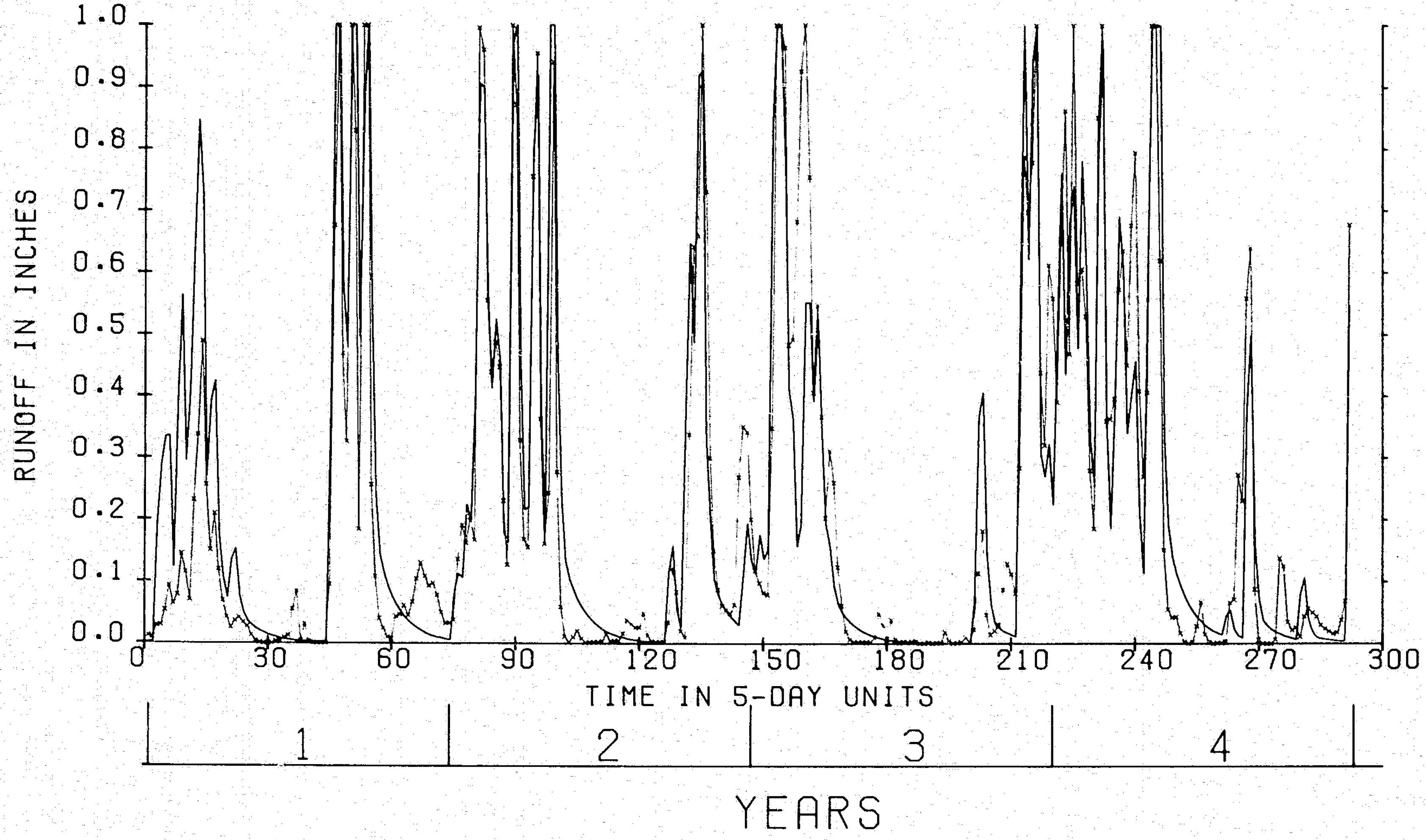
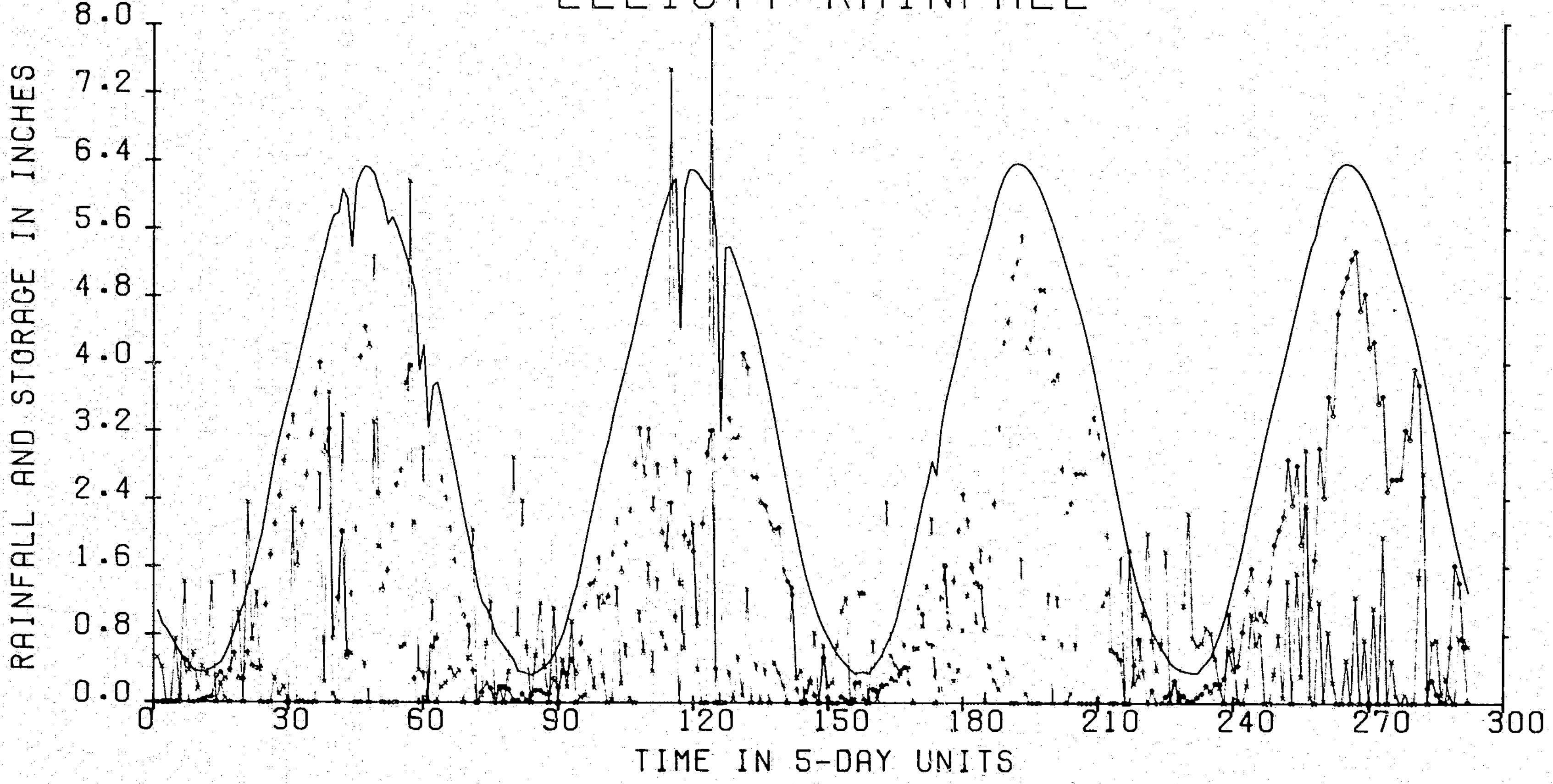


FIGURE 6.16.—Water-yield analysis, watershed W–A1, Elliott rainfall (1955–58).

AHOSKIE CREEK, N.C. W-1. 1959-1962
ELLIOTT RAINFALL



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THE HYDROLOGY AND HYDROGEOLOGY OF AHOSKIE CREEK WATERSHED, NORTH
2 OF 2

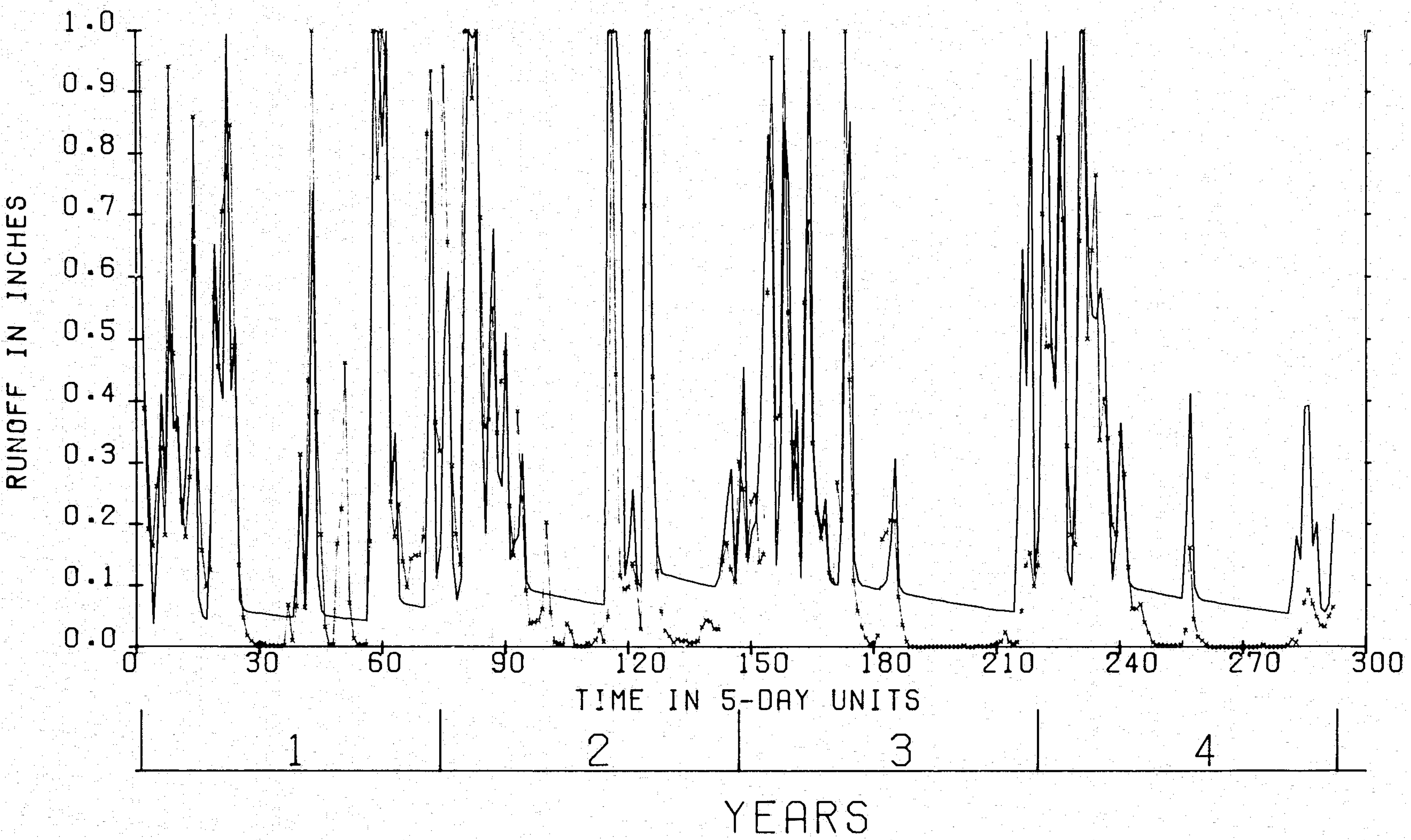
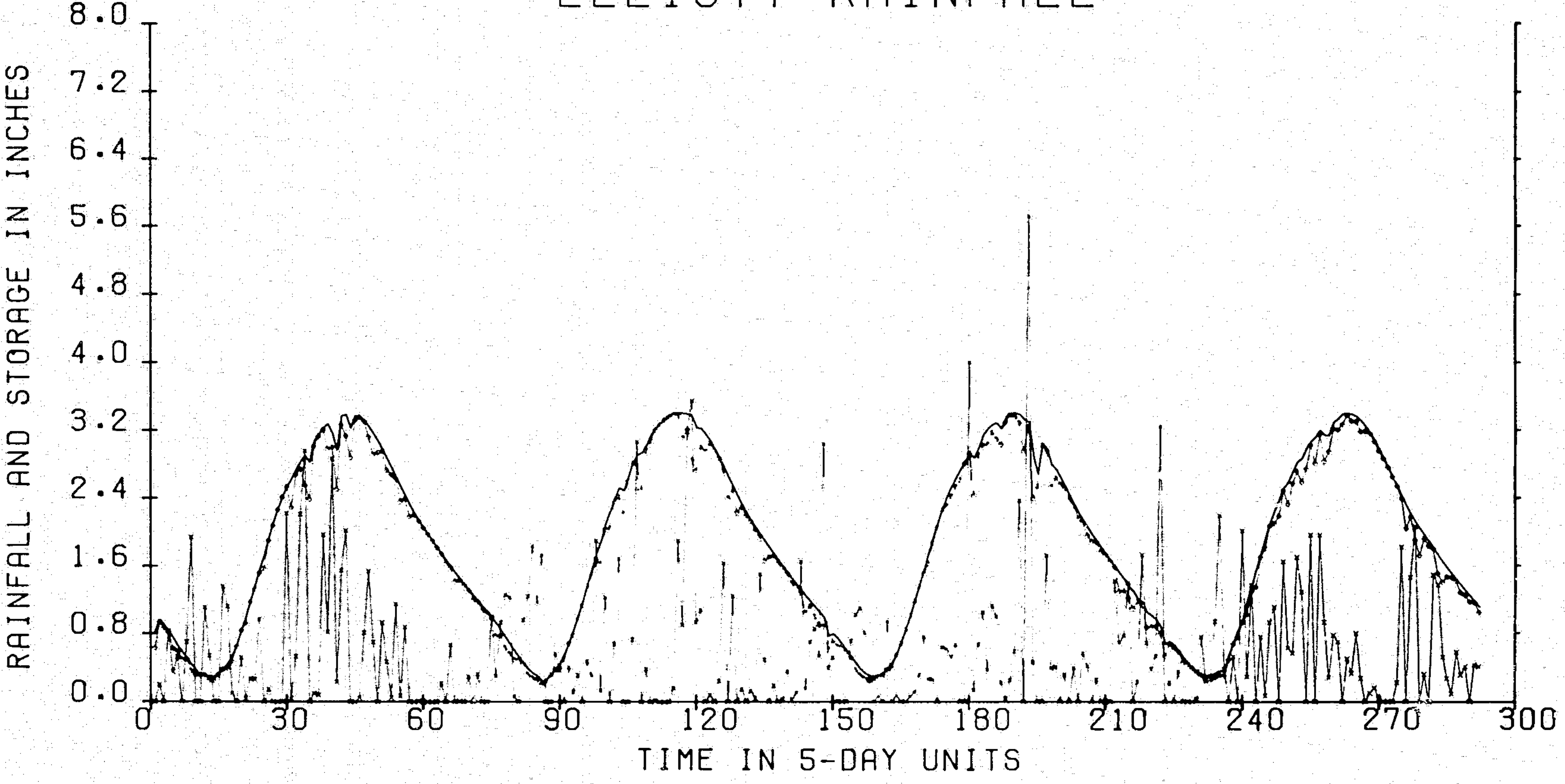


FIGURE 6.17.—Water-yield analysis, watershed W-A1, Elliott rainfall (1959-62).

AHOSKIE CREEK, N.C. W-1. 1965-1968
ELLIOTT RAINFALL



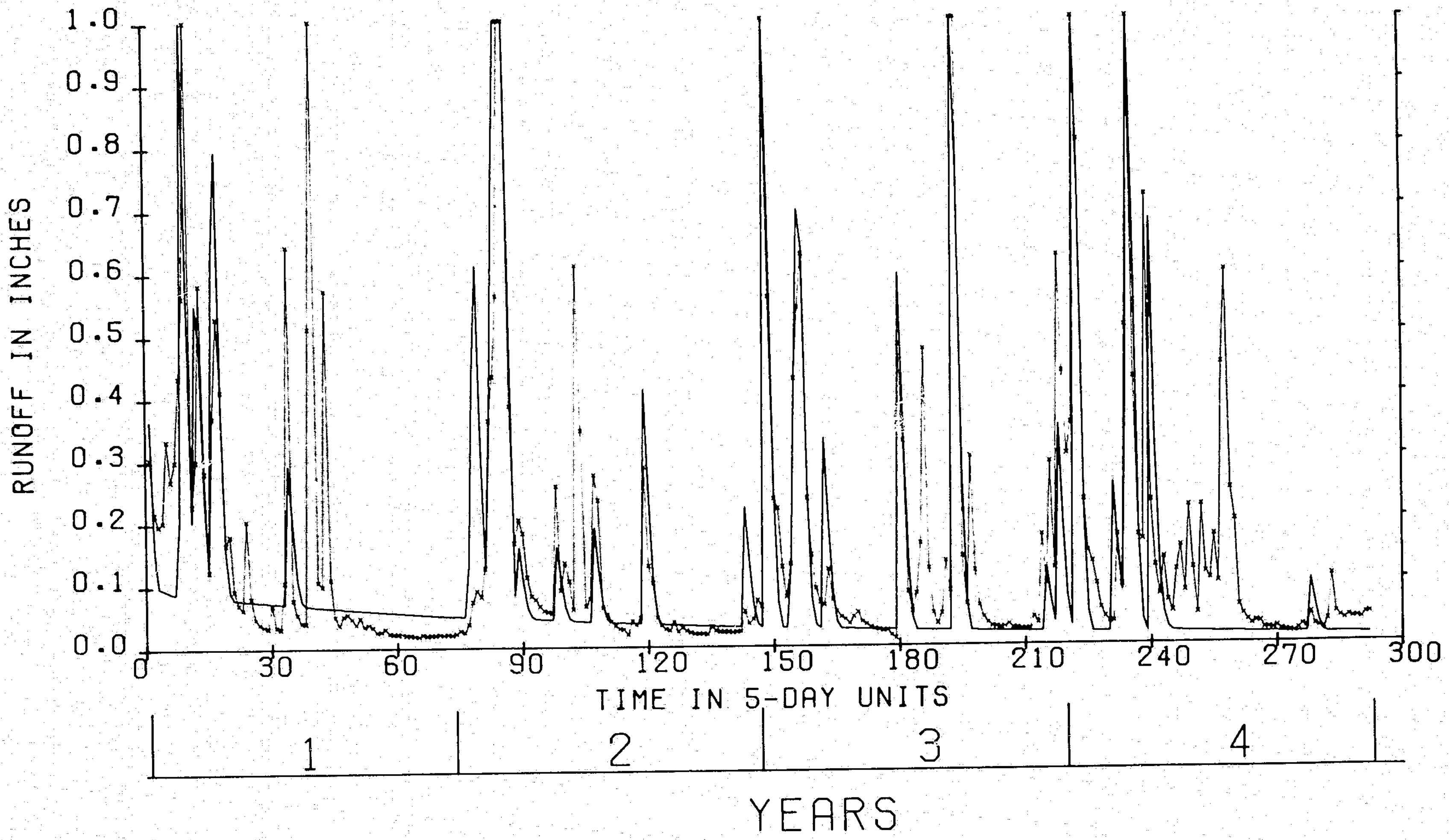
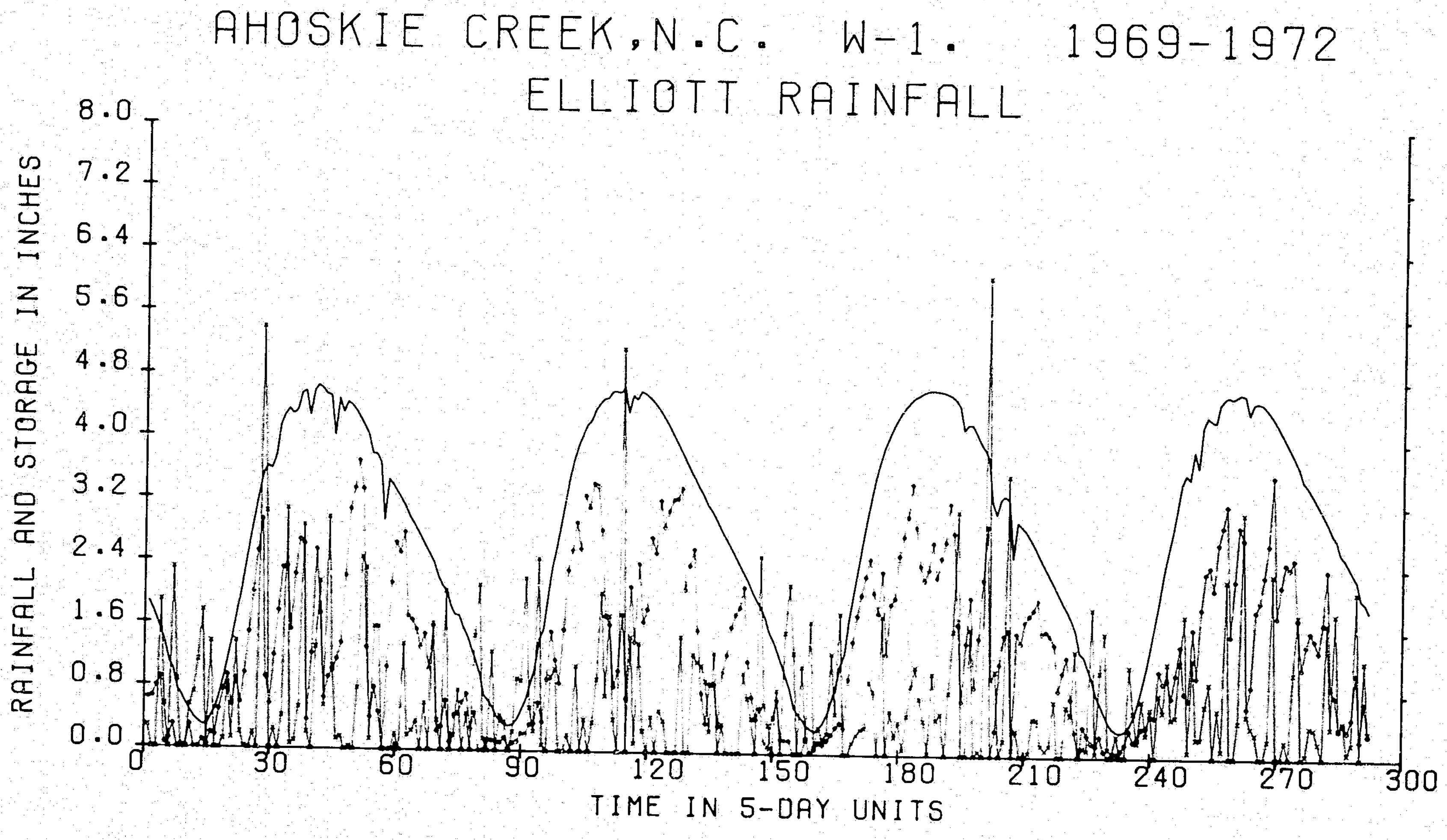


FIGURE 6.18.—Water-yield analysis, watershed W–A1, Elliott rainfall (1965–68).


AHOSKIE CREEK, N.C. W-1. 1969-1972
ELLIOTT RAINFALL
RAINFALL AND STORAGE IN INCHES
8.0
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0
0
30
60
90
120
150
180
210
240
270
300
TIME IN 5-DAY UNITS

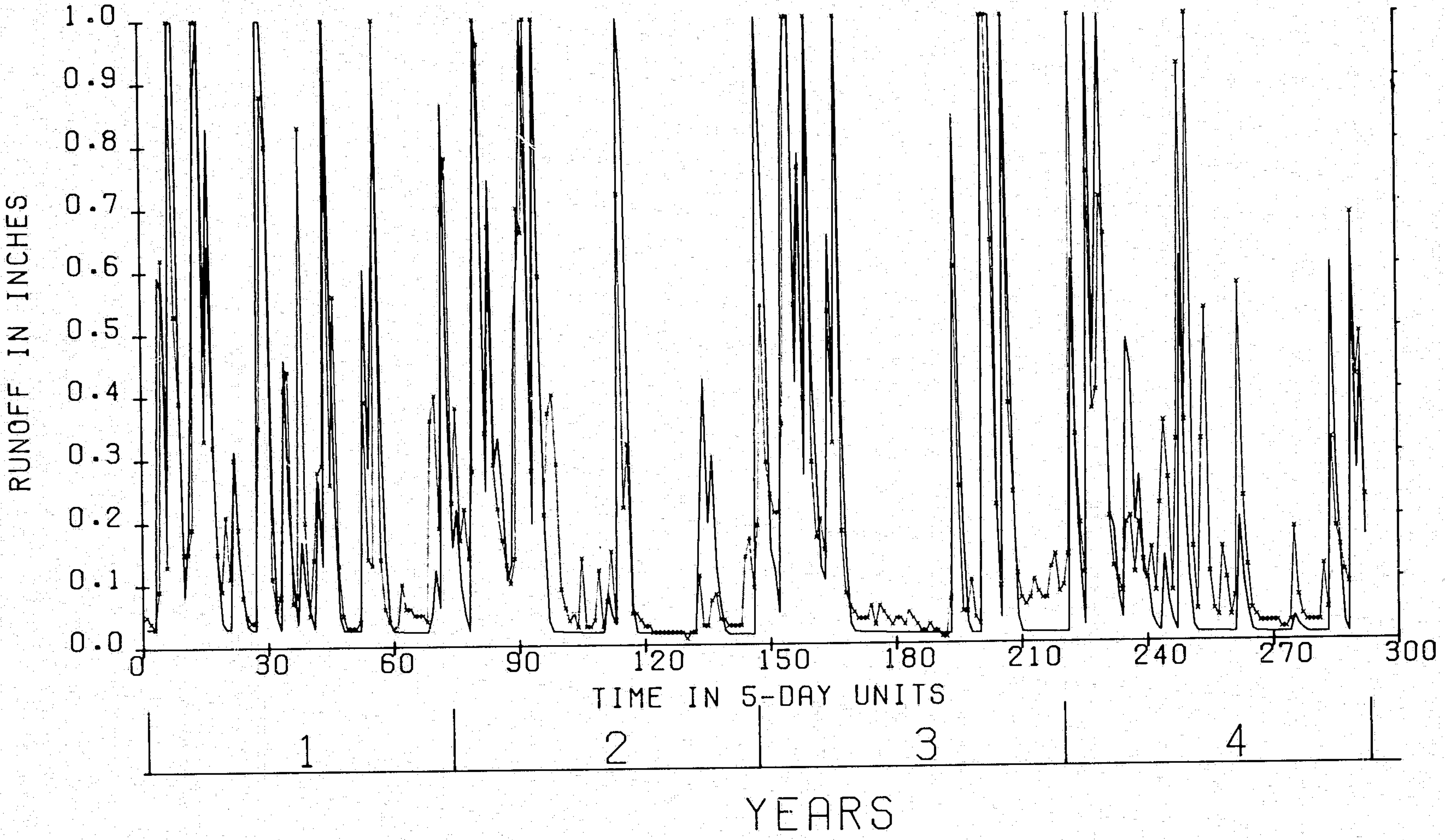
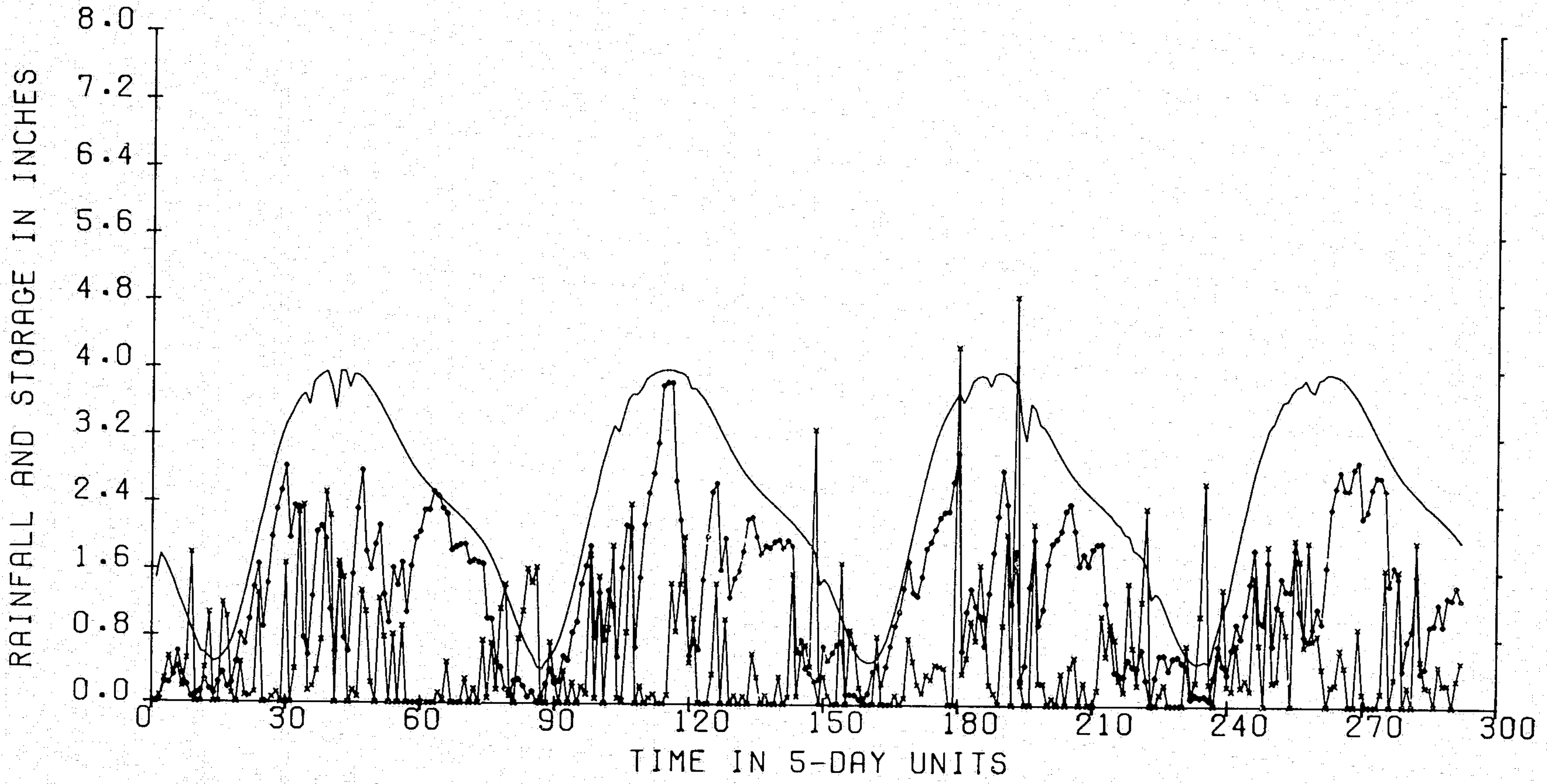


FIGURE 6.19.—Water-yield analysis, watershed W–A1, Elliott rainfall (1969–72).

AHOSKIE, N.C. W-1 1965-1968

NETWORK RAINFALL



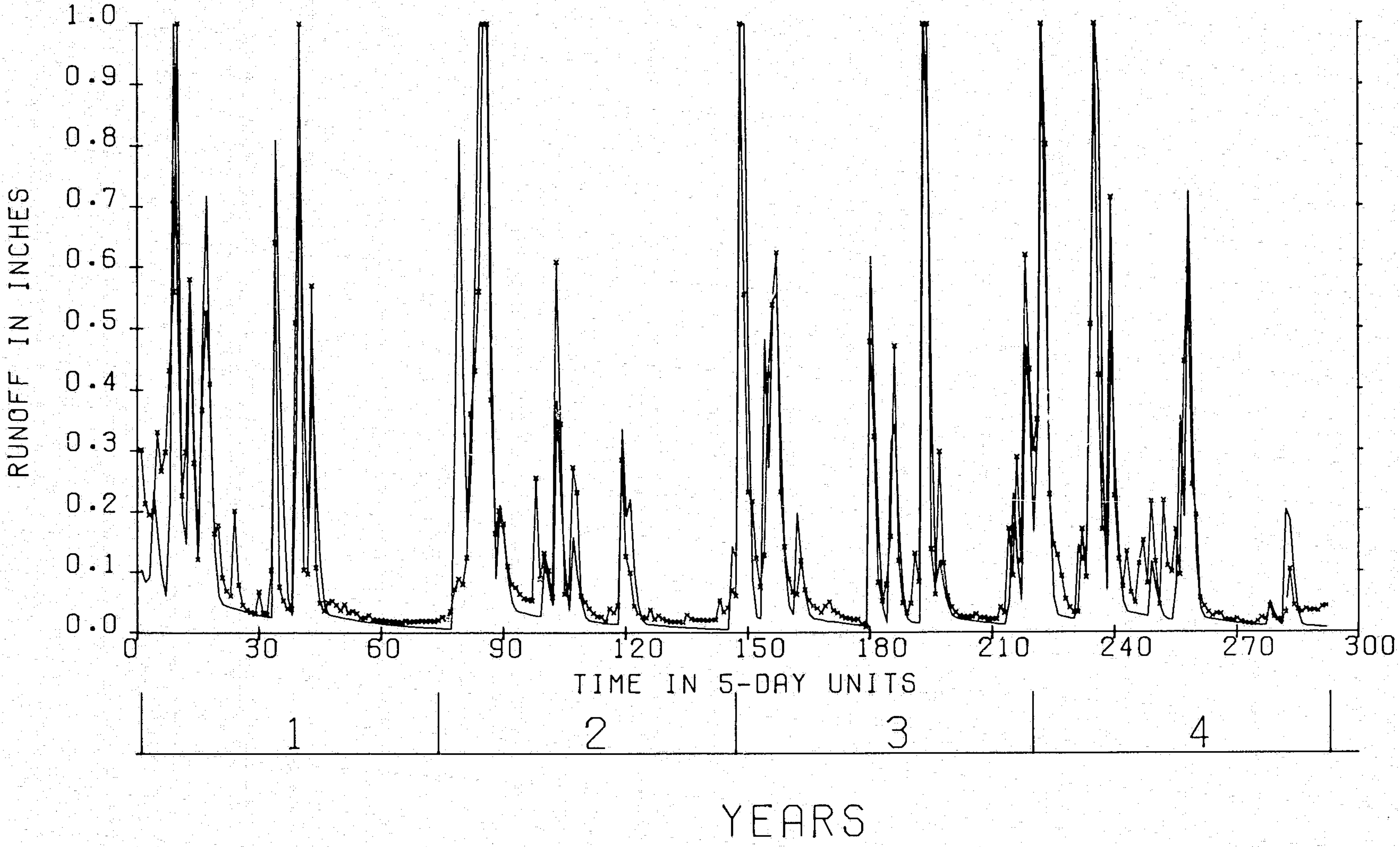
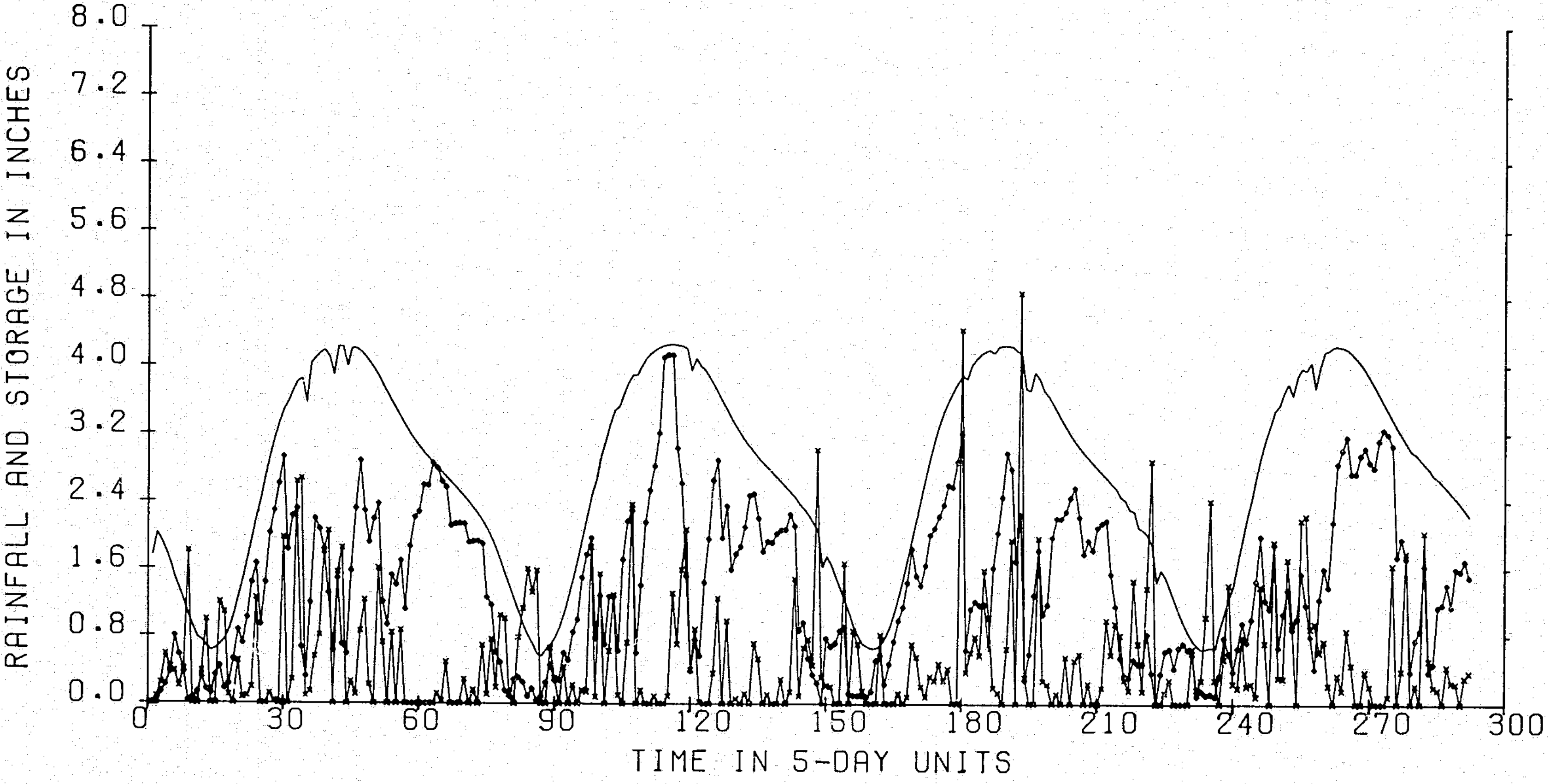


FIGURE 6.20.—Water-yield analysis, watershed W–A1, network rainfall (1965–68).



AHOSKIE, N.C. W-2 1965-1968

NETWORK RAINFALL

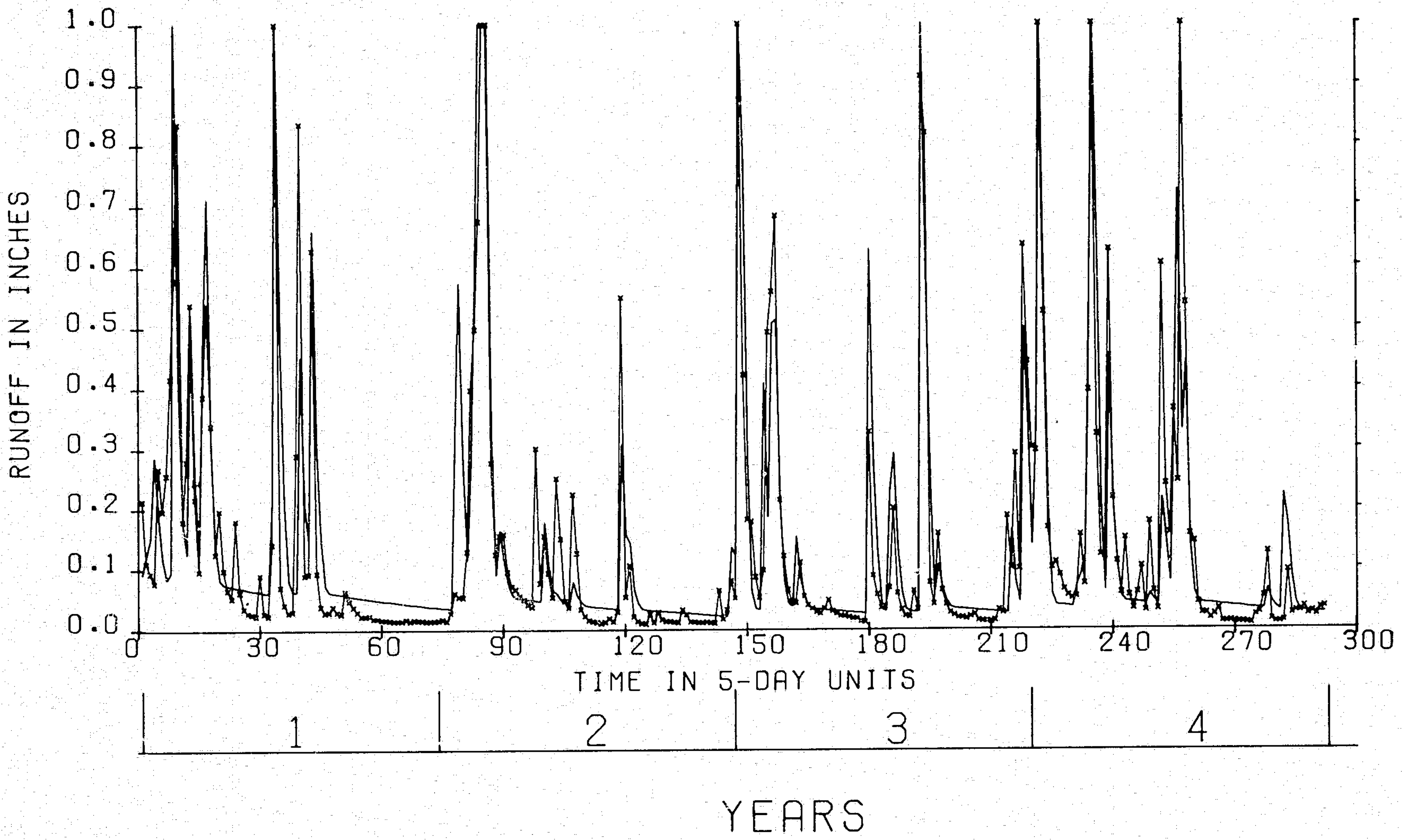
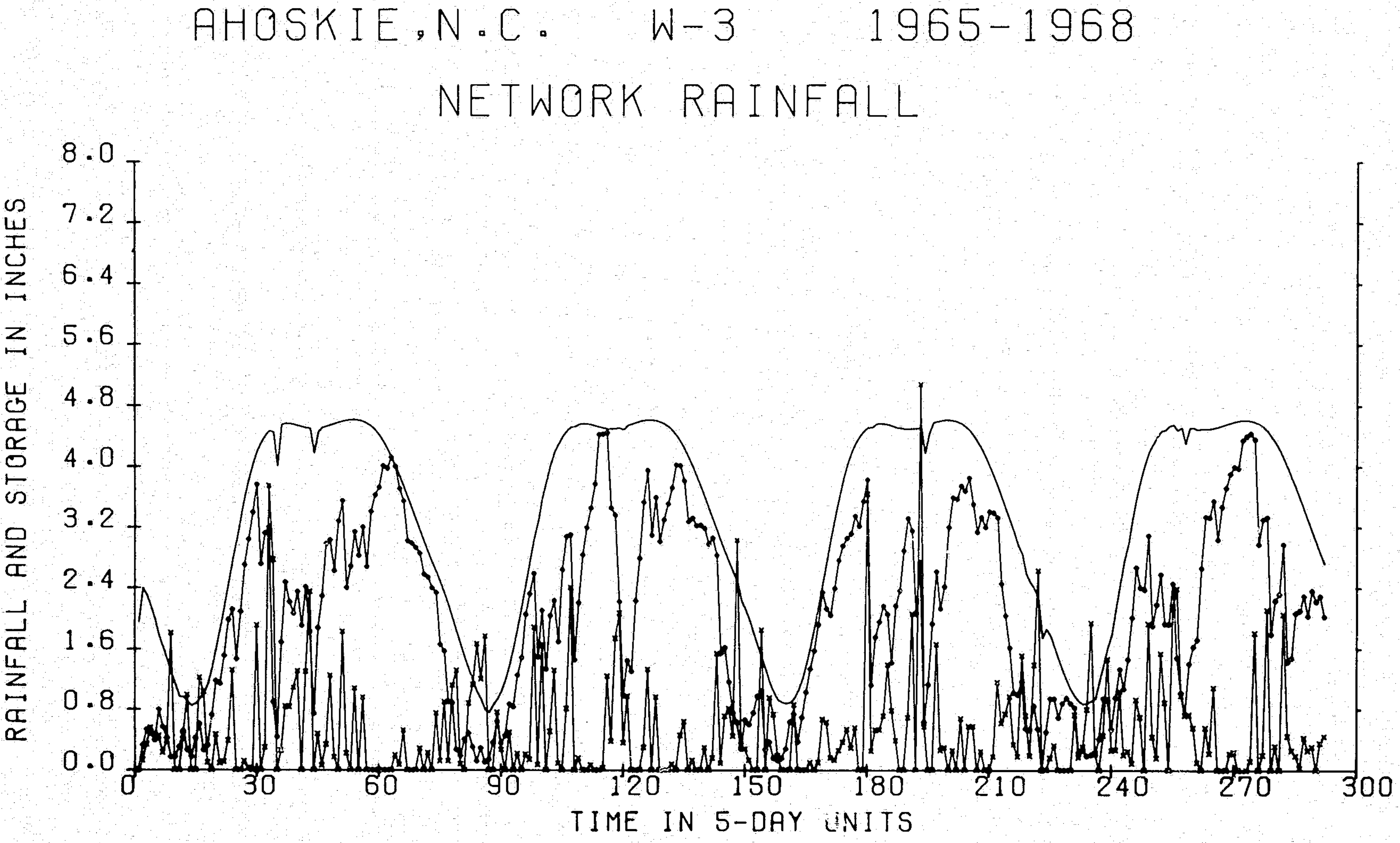


Figure 6.21.—Water-yield analysis, watershed W–A2, network rainfall (1965–68).



AHOSKIE,N.C. W-3 1965-1968

NETWORK RAINFALL

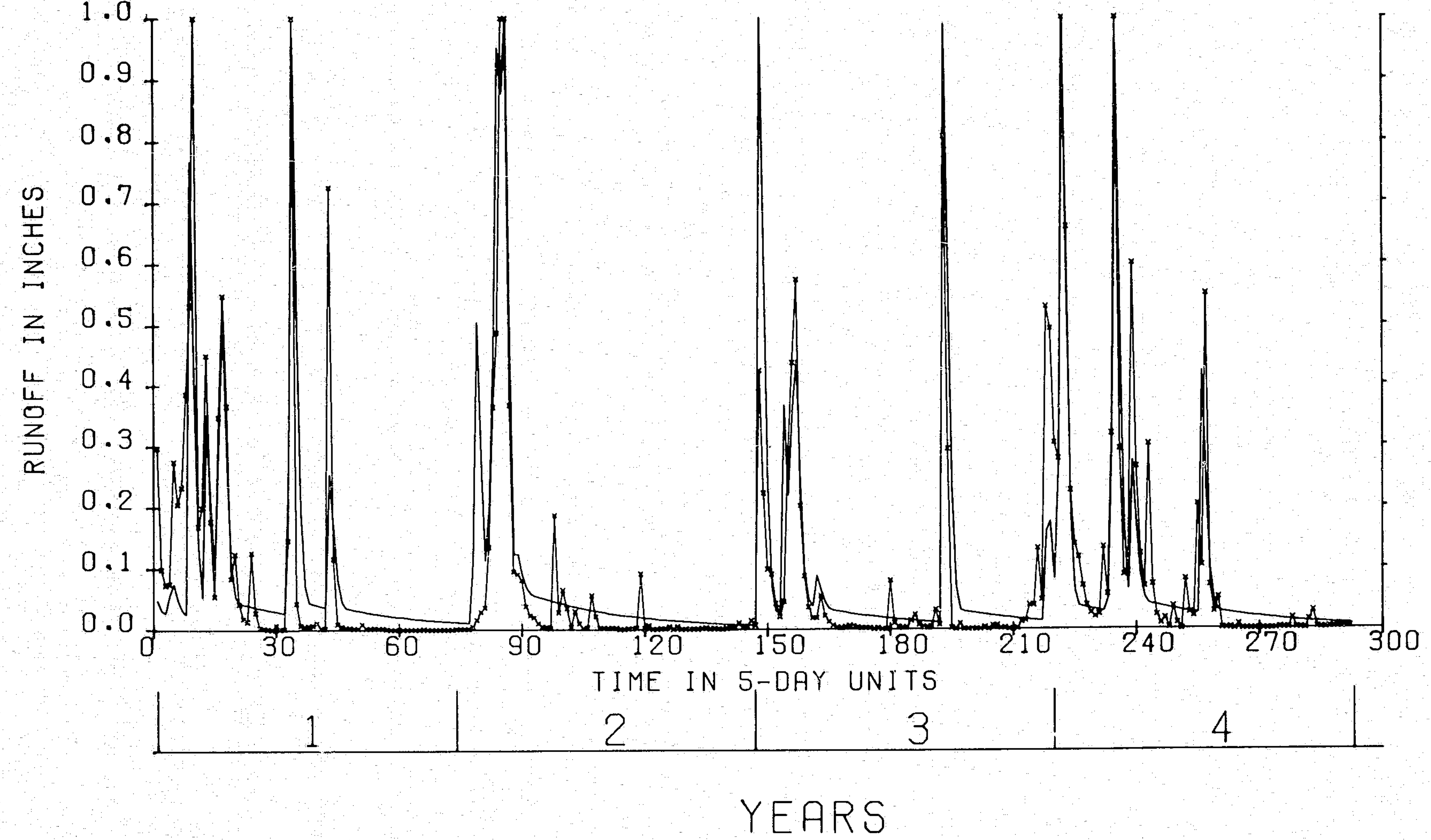
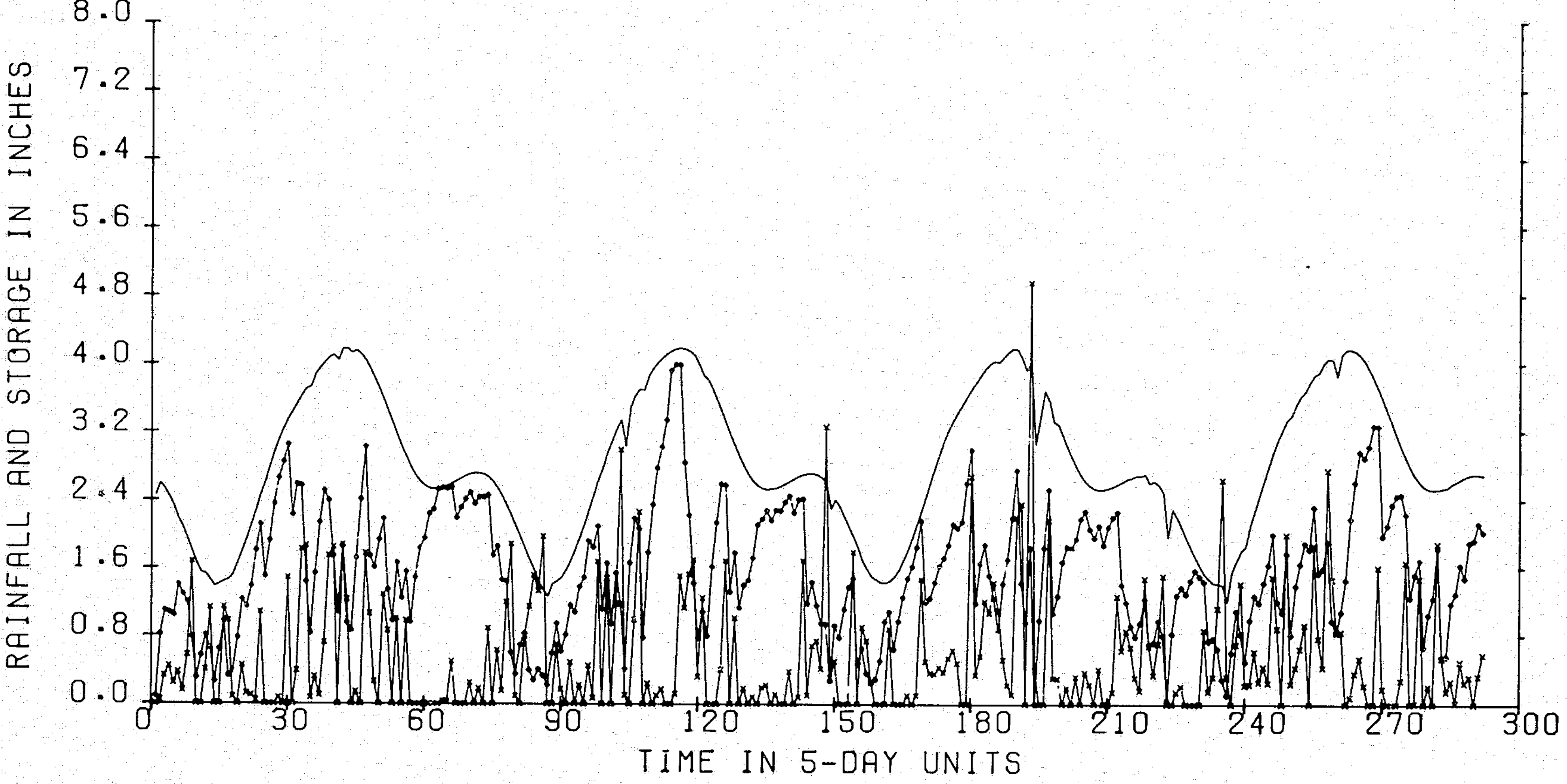


Figure 6.22.—Water-yield analysis, watershed W–A3, network rainfall (1965–68).

AHOSKIE, N.C. W-4 1965-1968

NETWORK RAINFALL



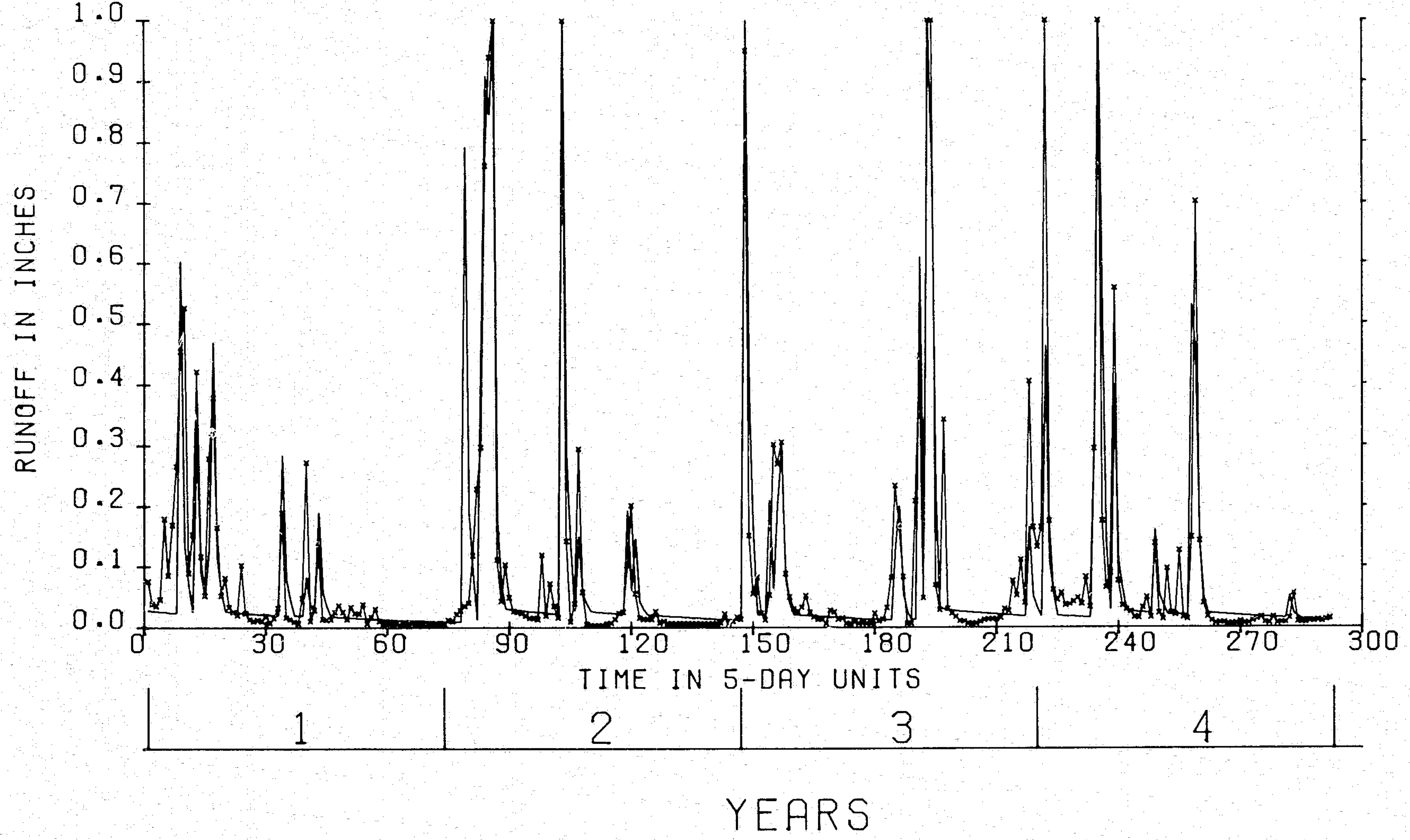
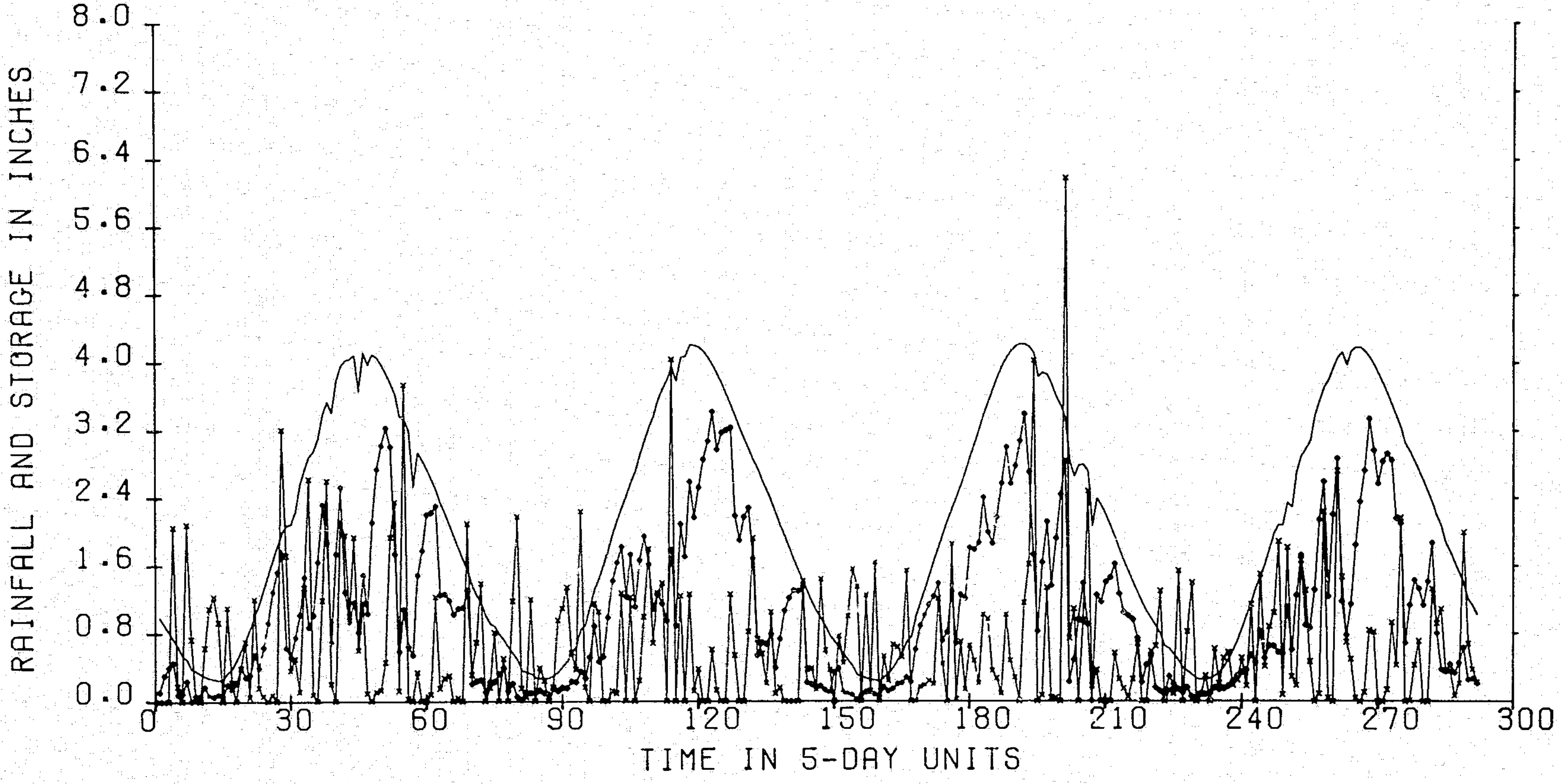


FIGURE 6.23.—Water-yield analysis, watershed W–A4, network rainfall (1965–68).



AHOSKIE, N.C.   W-1   1969-1972

NETWORK RAINFALL

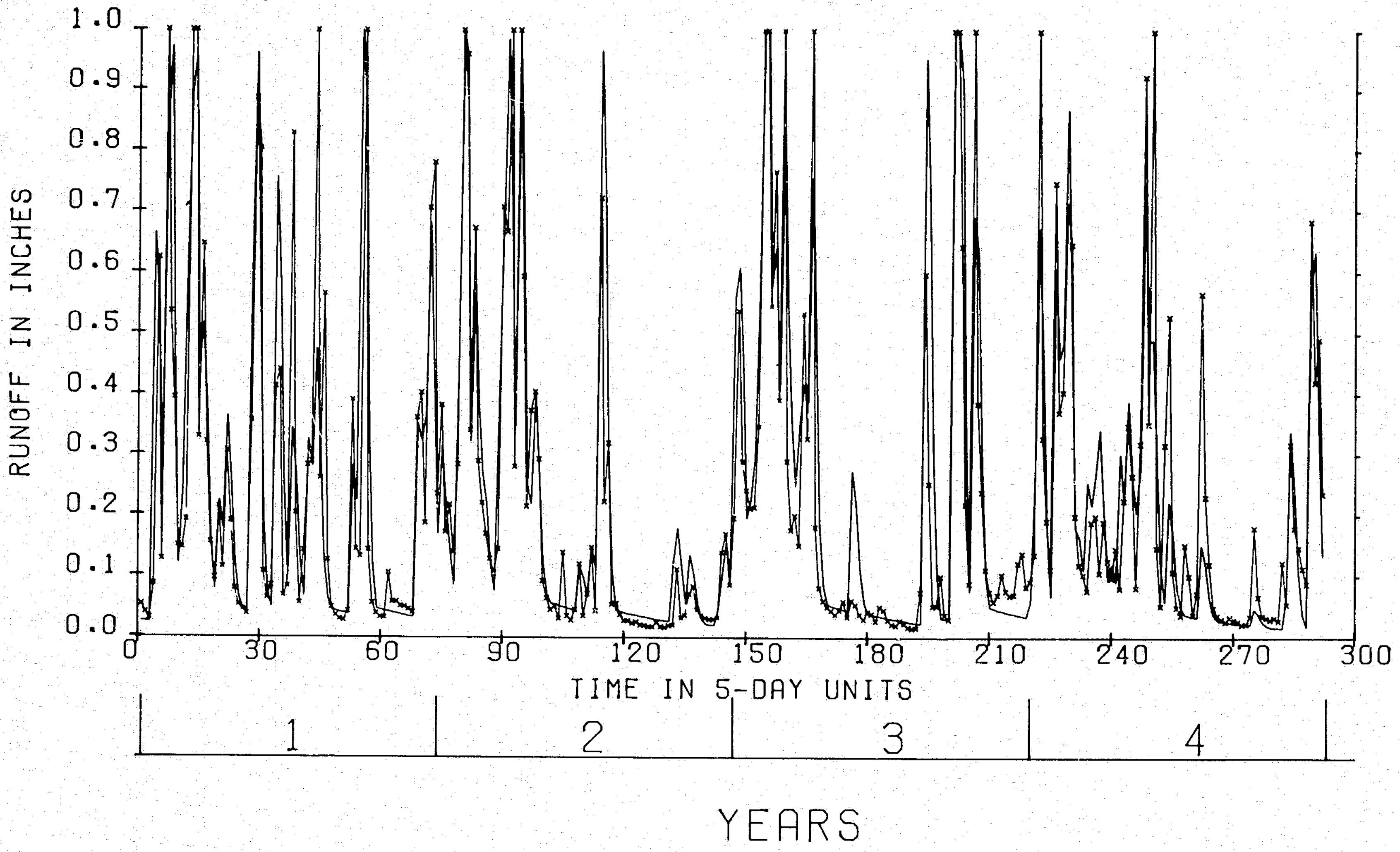
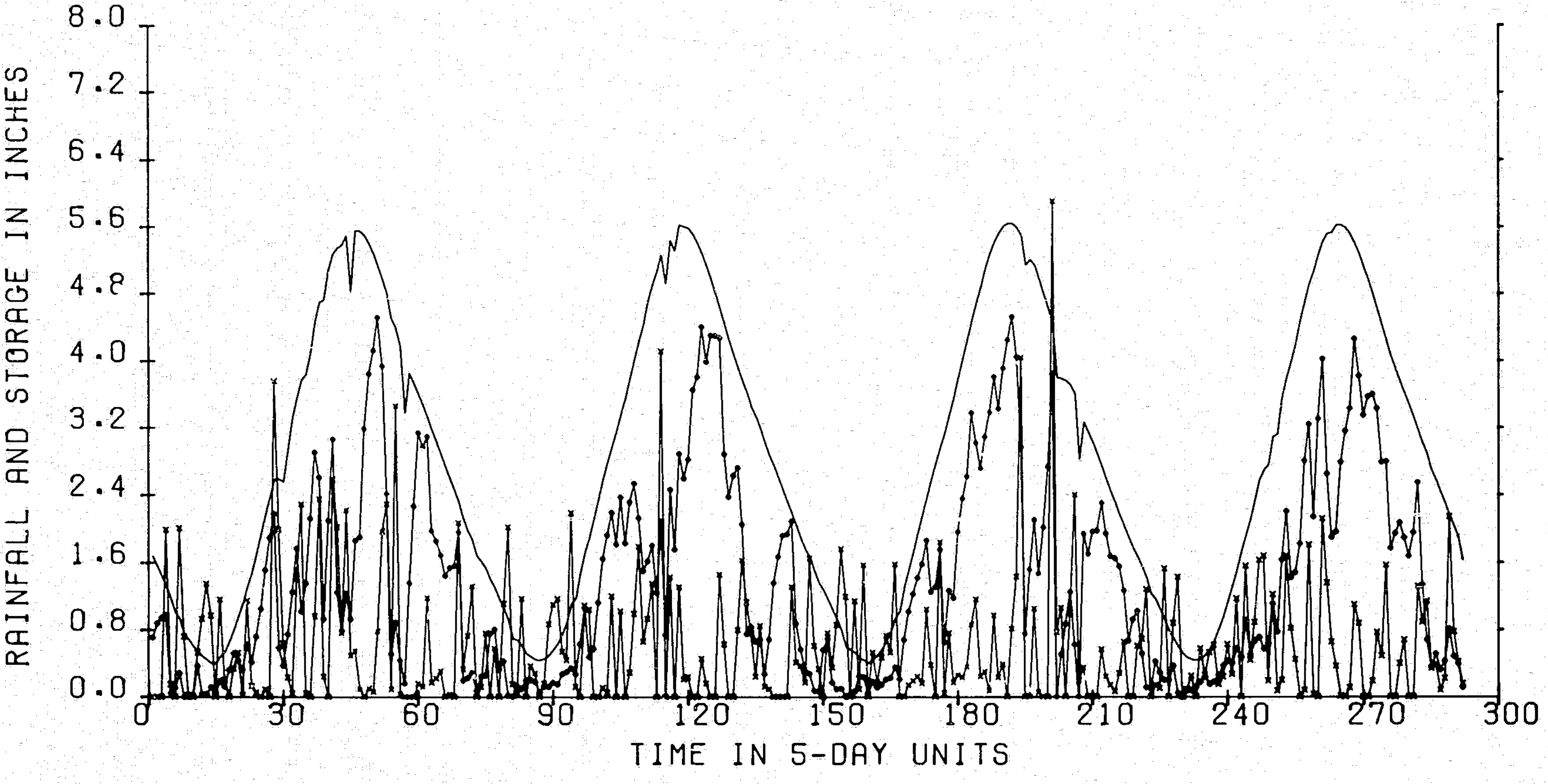


FIGURE 6.24.—Water-yield analysis, watershed W–A1, network rainfall (1969–72).

AHOSKIE, N.C. W-2 1969-1972

NETWORK RAINFALL



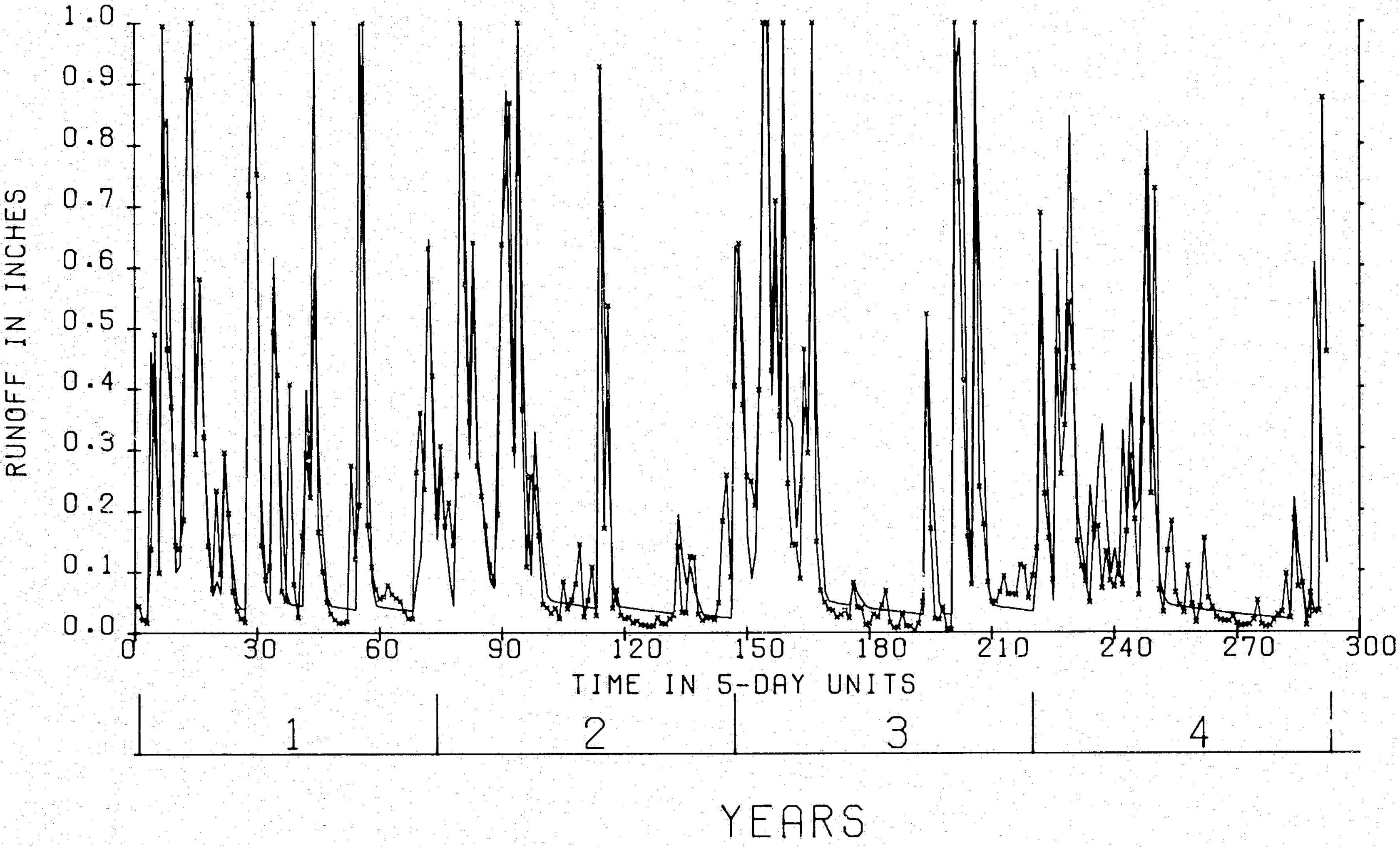
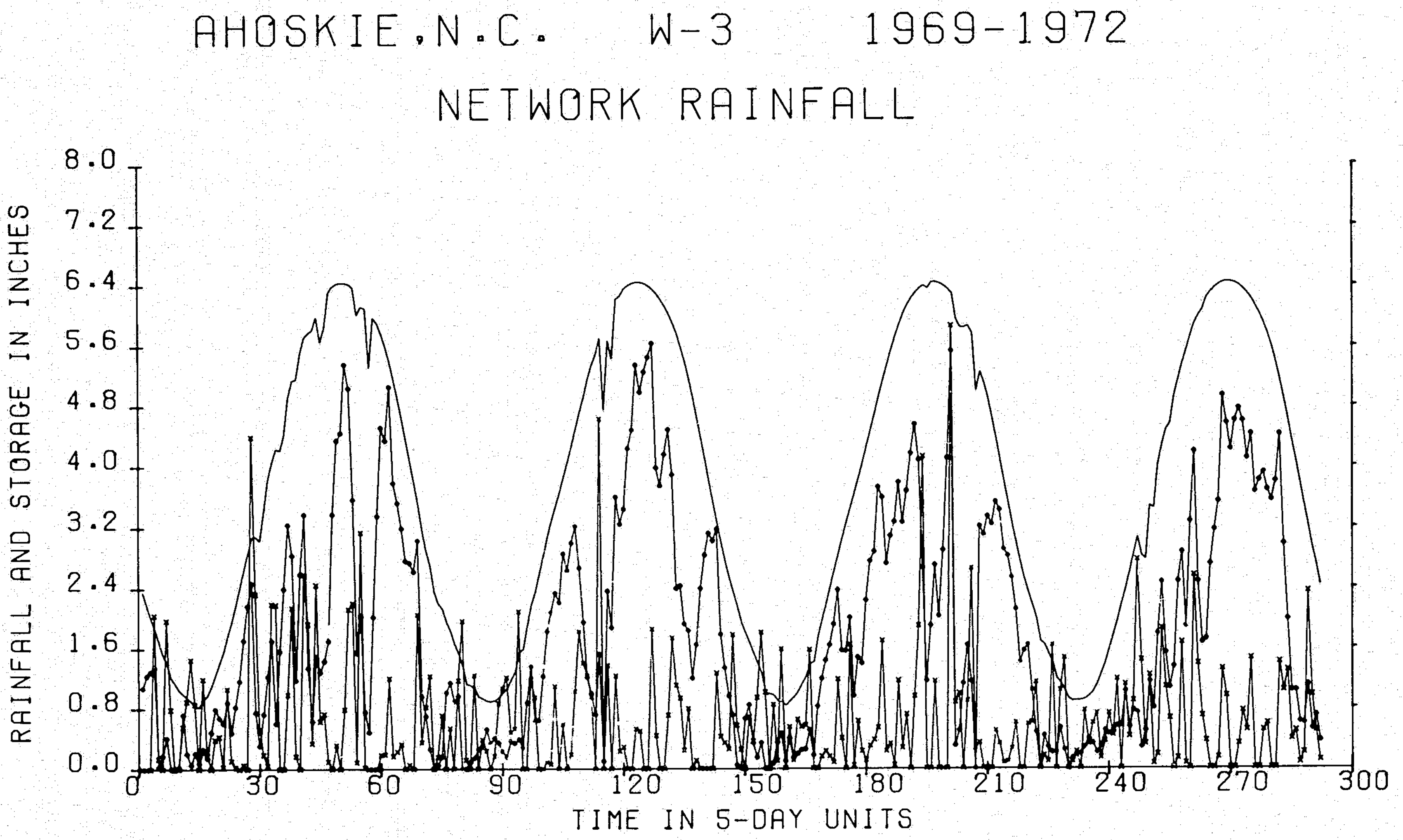


FIGURE 6.25.—Water-yield analysis, watershed W–A2, network rainfall (1969–72).


AHOSKIE, N.C.   W-3   1969-1972
NETWORK RAINFALL
RAINFALL AND STORAGE IN INCHES
8.0
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0
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60
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270
300
TIME IN 5-DAY UNITS

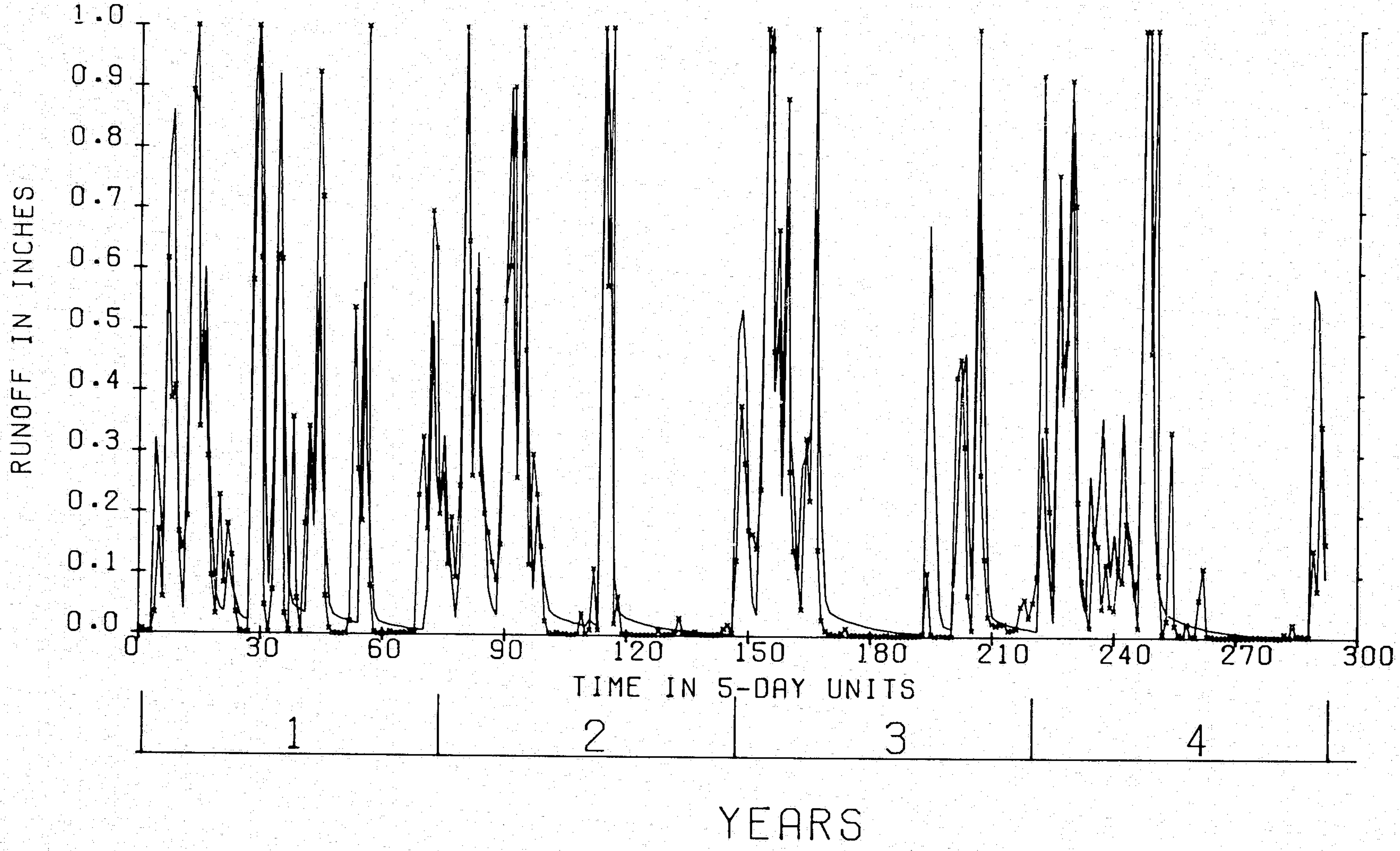
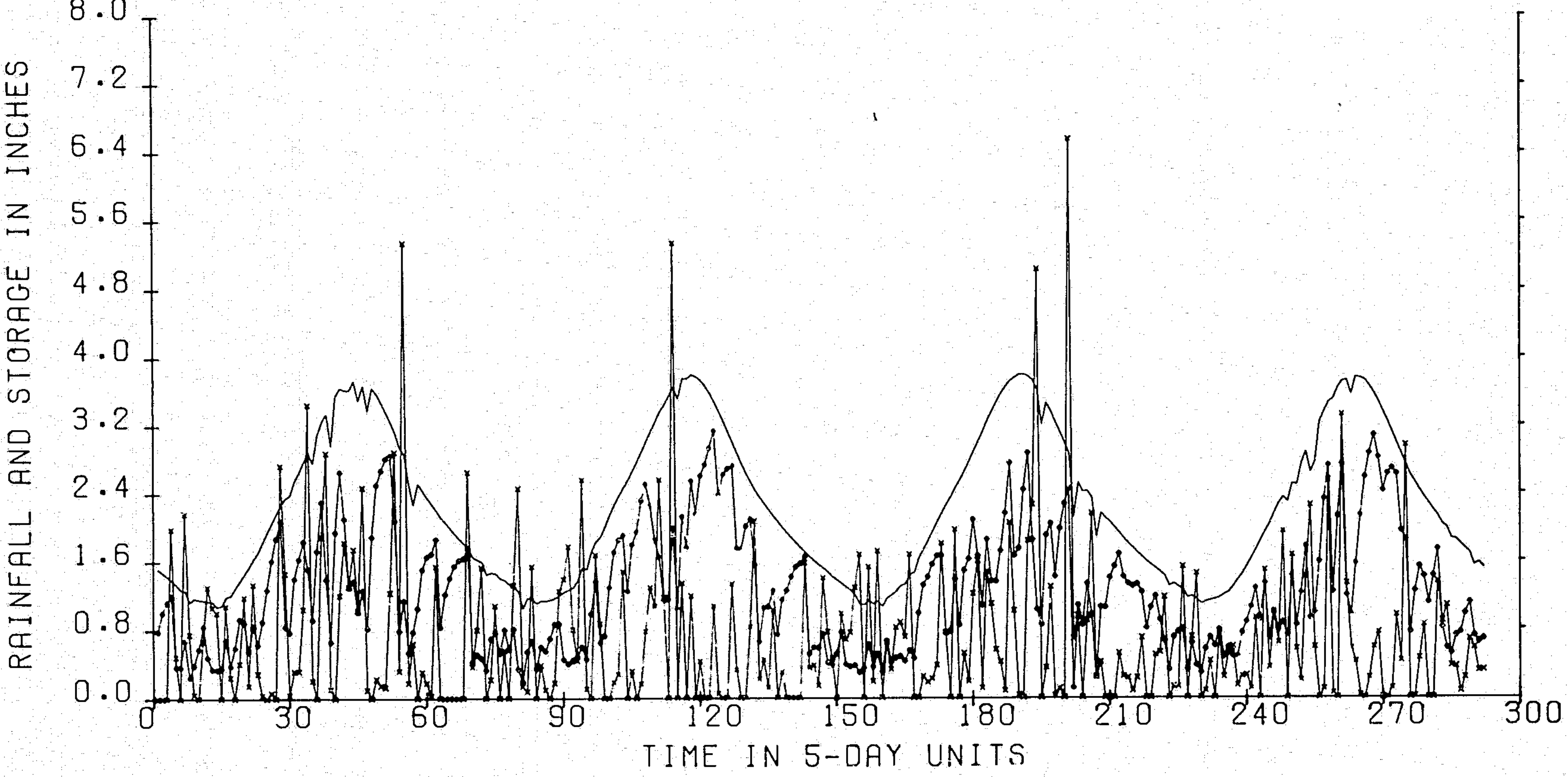


FIGURE 6.26.—Water-yield analysis, watershed W–A3, network rainfall (1969–72).

AHOSKIE, N.C. W-4 1969-1972

NETWORK RAINFALL



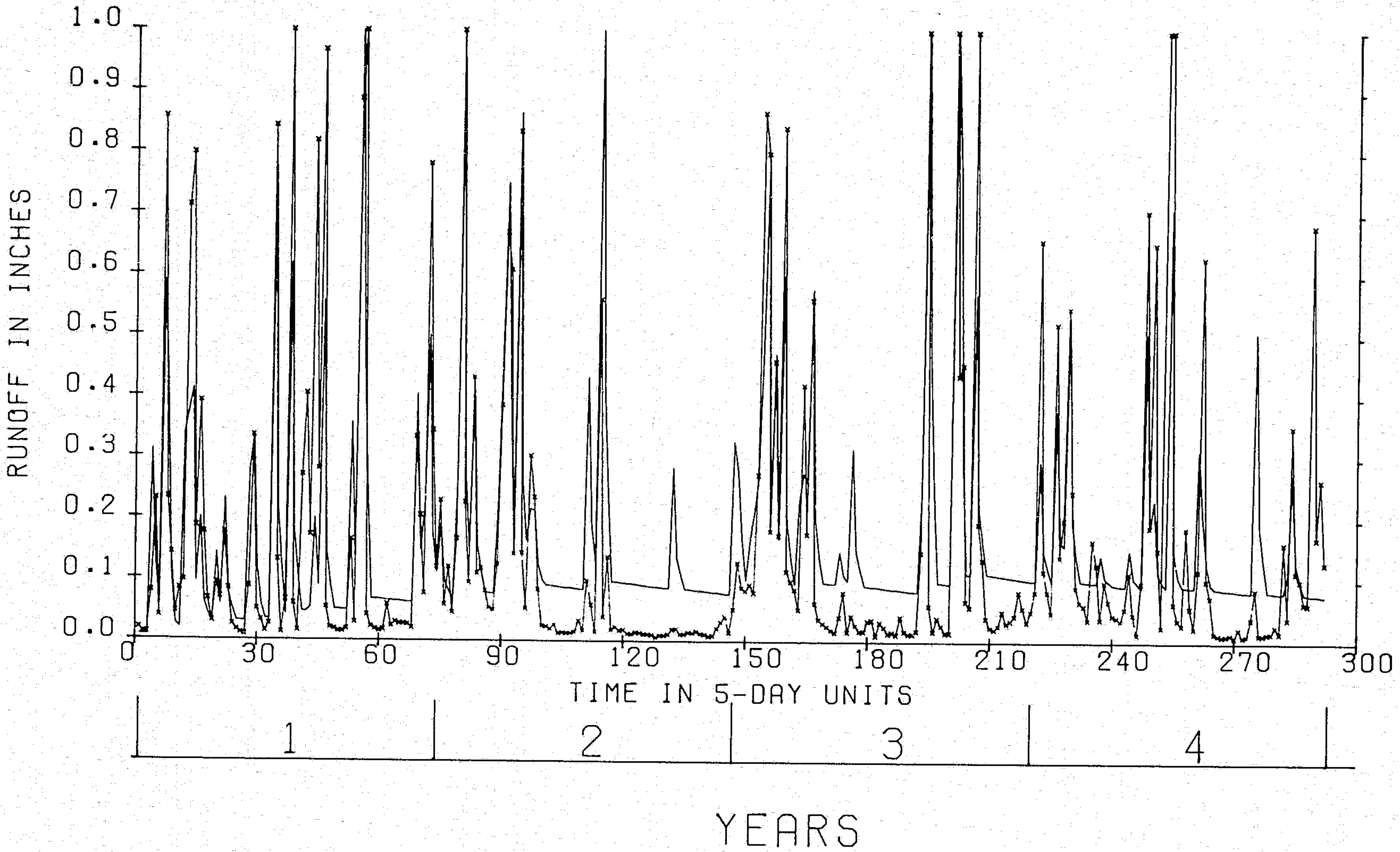
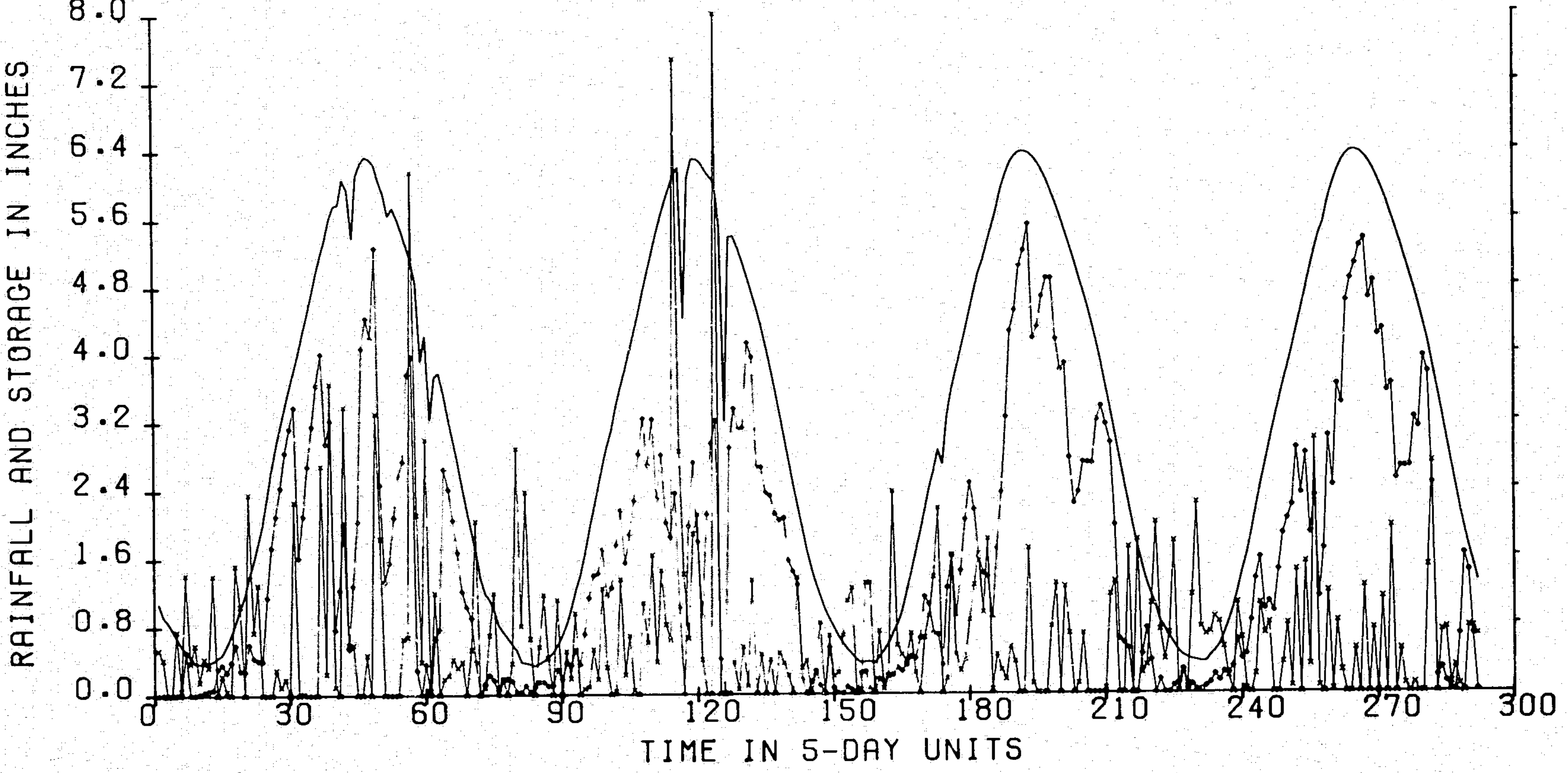


FIGURE 6.27.—Water-yield analysis, watershed W–A4, network rainfall (1969–72).

AHOSKIE CREEK, N.C. W-1. 1959-1962
ELLIOTT RAINFALL



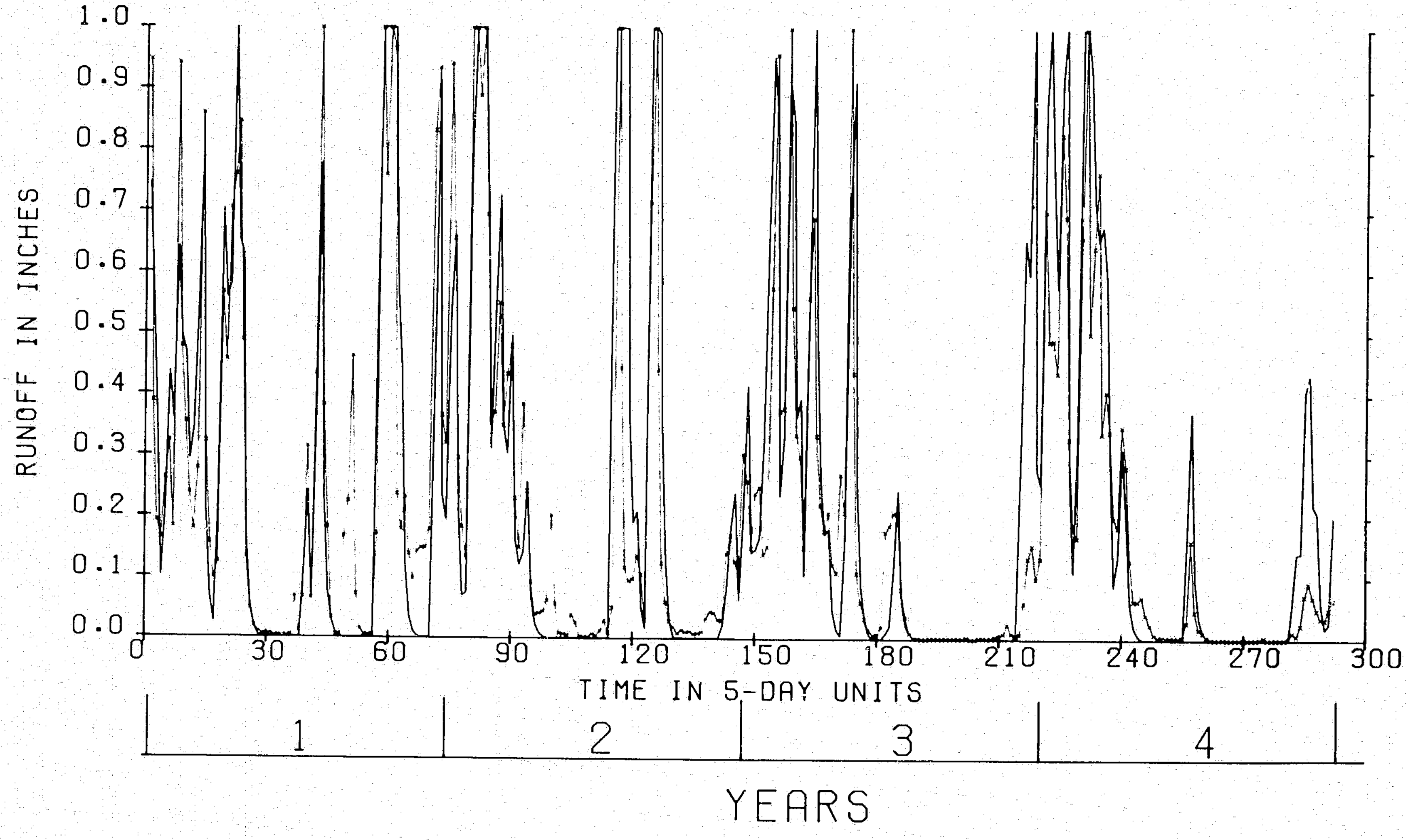


FIGURE 6.28.—Water-yield simulation, watershed W-A1, Elliott rainfall (1959–62).

TABLE 6.12.—*Summary of changes in seasonal water yield*

[Inches]

Runoff	Winter		Summer	
	1951–62	1965–72	1951–62	1965–72
Predicted, using "before" parameters	49.6	26.5	33.4	8.9
Predicted, using "after" parameters	48.9	27.4	45.3	18.3
Observed	51.8	29.5	18.7	15.3
"Before" minus observed	−2.2	−3.0	14.7	−6.4
"After" minus observed	−2.9	−1.1	26.6	3.0
"Before" minus "after"	.7	−.9	−11.9	−9.4
Change per year	.06	−.11	−.99	−1.18

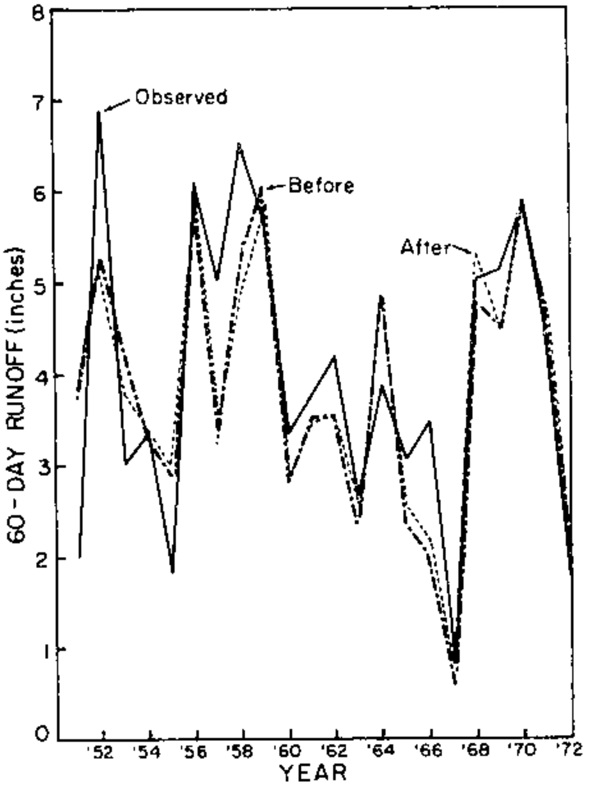


FIGURE 6.29.—Comparison of predicted and observed winter seasonal yield.

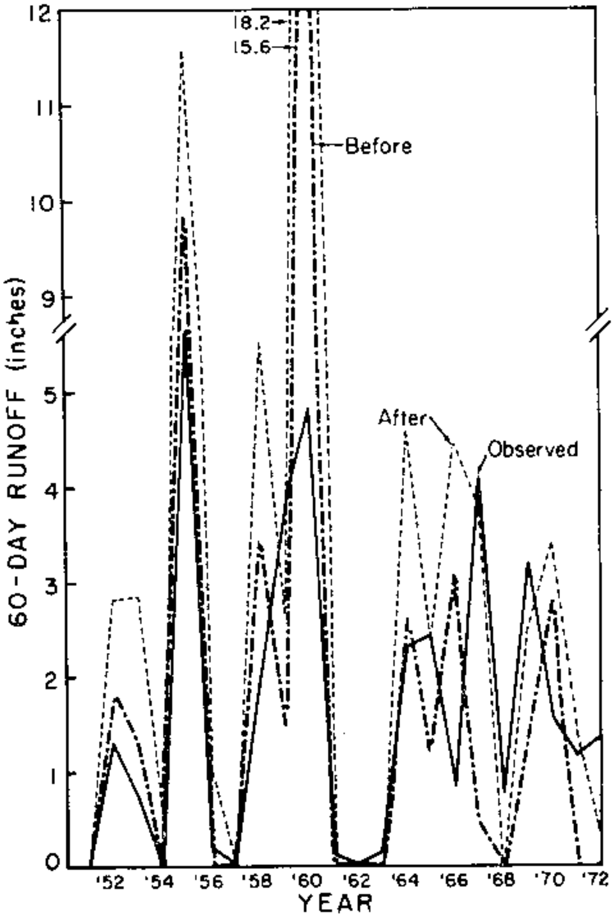


FIGURE 6.30.—Comparsion of predicted and observed summer seasonal yield.

the channels had then been constructed. The same model applied to the rainfall record after construction indicates that slightly in excess of 1 inch less runoff per year would have occurred in the summer season, if the channels had not been constructed.

The average change per year during the winter season is small, and the averages also are inconsistent, showing both a slight decrease and a slight increase in runoff following channelization.

6.2.—STORM ANALYSIS

Storm analysis deals with watershed response to rain during individual storm events. Such event analysis must deal with two aspects of response: (1) the volume of water delivered to streamflow in relation to the volume of input, and (2) the characteristic timing of the response.

6.2.1.—Rainfall-Streamflow-Storage Volume Relations

Streamflow measured in the surface channels in the Coastal Plain physiographic area represents combined contributions over and through the soil mantle. Several subjective methods of hydrograph separation are given in the literature (*7*), but, since the methods require subjective judgments, total streamflow is considered the most feasible element for analysis.

Criteria were established to select storms for streamflow-volume analysis. All storms were selected for which there was at least a 0.5-foot rise in stage or a rise resulting from a 0.5-inch rainfall. These criteria resulted in numerous small-volume storms, as well as those with large volumes. Breakpoint tabulations of the stream stage were made for all selected storms.

Streamflow response to precipitation results in storm hydrographs superimposed upon recession flow from previous rainfall. Storm-volume calculations were made by extrapolating the antecedent recession beneath the total hydrograph by

$$q_t = q_0 e^{-bt^m}, \tag{6.7}$$

where q is discharge, t is time, and b and m are parameters evaluated from three points on the antecedent recession (*18*). Extrapolated recession rates were subtracted from the total hydrograph discharge rates, and the volume calculations were continued to an arbitrary point well out on the total hydrograph recession. The recession equation (6.7) was then applied with appropriate parameters determined from the total hydrograph recession. The volume in the storm hydrograph tail was determined by integrating the two recession equations to infinity and subtracting the respective volumes. This computed difference was added to the volume previously determined to give the total storm volume.

Watershed-storm-rainfall volumes were determined from daily rainfall weighted by the Thiessen method. Some storms selected for analysis had broken rainfall patterns. In those cases in which the storm rainfall could not be decisively determined, the storms were eliminated from the analysis.

Streamflow response to precipitation is dependent upon the degree of wetness, or volume of water in storage, in the watershed at the time the storm occurs. The literature contains several procedures used to determine antecedent precipitation or antecedent soil moisture. In section 6.1, 5-day water-yield analysis, a procedure was described to determine the available storage in the watershed. The available storage was determined for the beginning of each 5-day period throughout the record period for each watershed. Although the beginning of each 5-day period did not necessarily coincide with the day on which individual storms occurred, the available storage values computed in the 5-day water-yield analysis were obtained to represent storage indexes for each storm event selected. These data, storm runoff volumes, Q, storm precipitation volumes, P, and available storage indexes, ASI, constitute the data for the storm rainfall-runoff-storage relationship analysis.

Calculations of the three components were made for each of the four watersheds. It should be pointed out that the short record period resulted in few large volume storms, and that the methods of calculations do not result in exact values of the three components. Although the data are known to contain some degree of error, there is sufficient evidence to justify determination of the interrelations.

Computed storm-rainfall volumes, runoff volumes, and available storage indexes were plotted for watersheds W–A1, W–A2, W–A3, and W–A4 (figs. 6.31–6.34). ASI values were

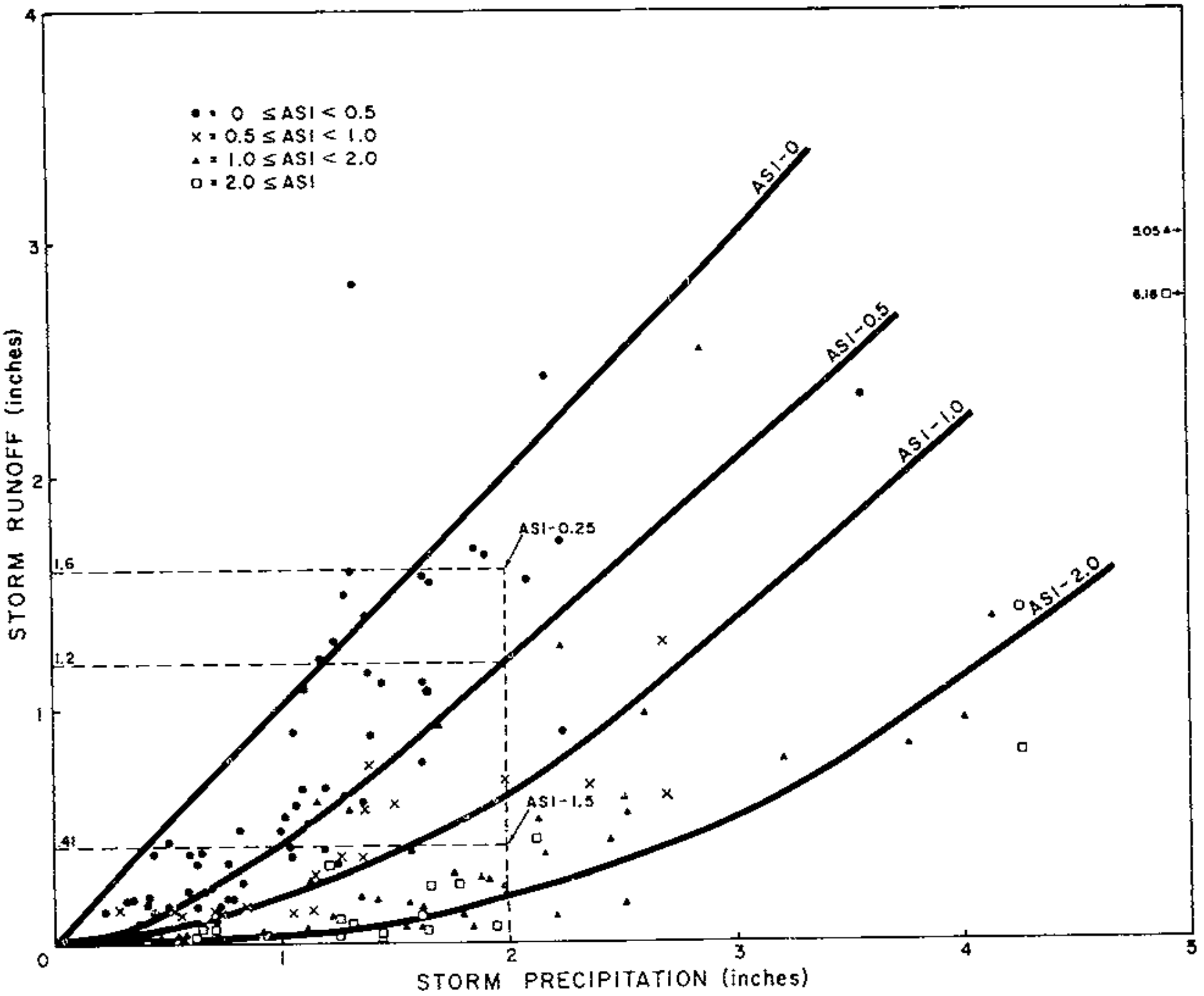


FIGURE 6.31.—Storm rainfall-streamflow-storage relationships, watershed W–A1.

arbitrarily grouped as follows: 0<ASI<0.50, 0.50<ASI<1.0, 1.0<ASI<2.0, and 2.0<ASI. The categories represent watershed available storage conditions ranging from low available storage to high available storage, or wet antecedent conditions to dry antecedent conditions.

To illustrate application of these *P–Q*–ASI relationships, assume that watershed W–A1 is at an ASI of 1.5 (the midpoint value for 1.0<ASI<2.0) and receives 2 inches of rainfall. From figure 6.31 a resultant runoff volume of 0.42 inch is determined.

The similarity of function between the rainfall–runoff–available-storage-index relationships and the SCS antecedent moisture condition (AMC) technique for determining storm runoff should be noted. For comparison of results obtained using the two techniques, the following example is presented.

At the midpoint of the 2.0<ASI grouping (which represents a low antecedent moisture condition such as AMC I) for W–A1, a rainfall volume of 2.0 inches produces a runoff volume of 0.10 inch. According to figure 10.1 of section 4, Hydrology, "SCS National Engineering Handbook" (*25*), the corresponding watershed curve number (CN) is 62. From table 10.1 in the handbook, it may be determined that a CN of 62 for AMC I corresponds to a CN of 91 for AMC III (a wet antecedent condition). By means of the SCS procedure and figure 10.1, a runoff volume of 1.20 inches is predicted for W–A1 in a wet antecedent condition (AMC III) with 2 inches of rainfall. By means of the *P–Q–*

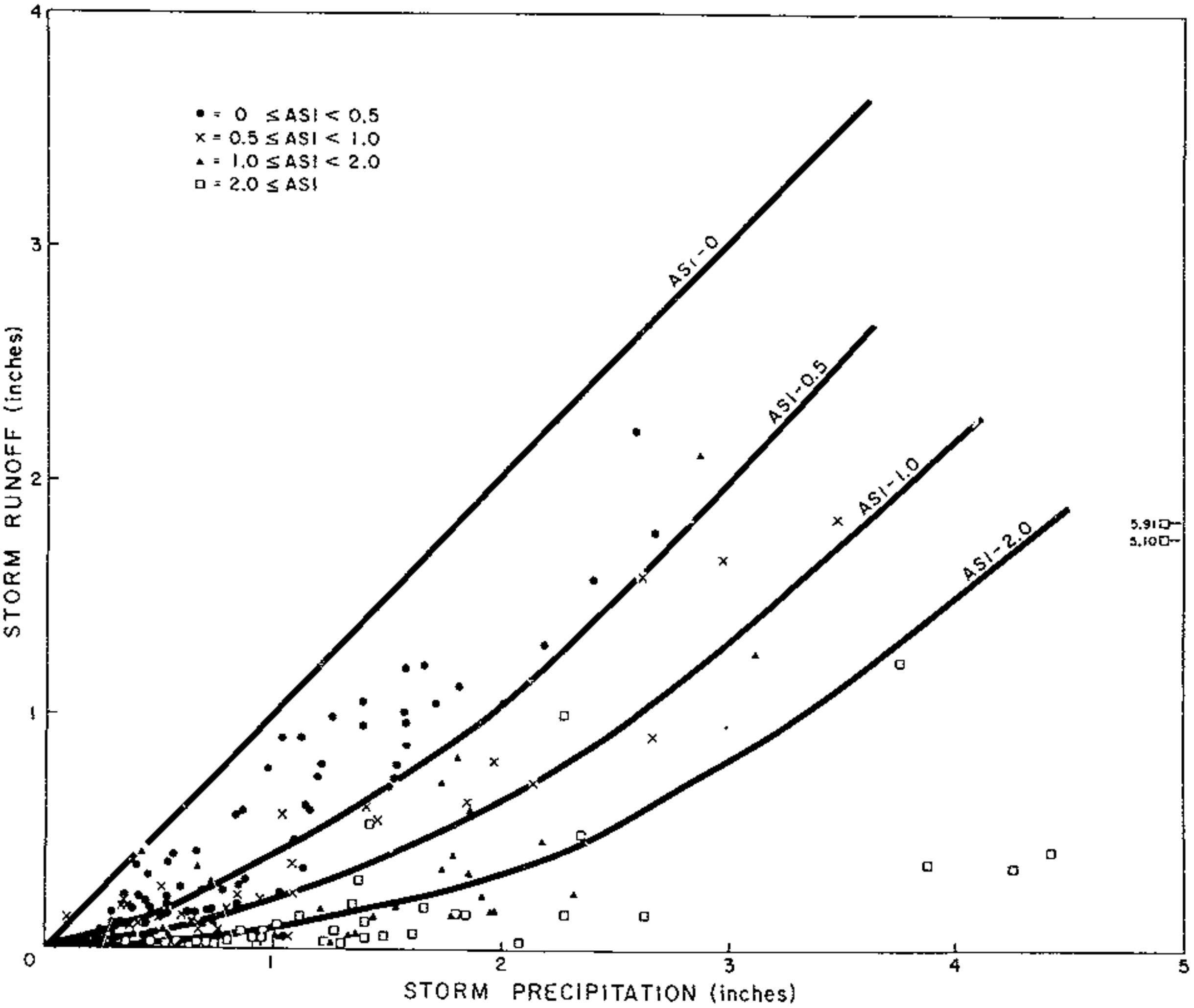


FIGURE 6.32.—Storm rainfall-streamflow-storage relationships, watershed W–A2.

ASI relations of W–A1 (fig. 6.31), for an available storage index of 0.5 (low available storage), the same runoff volume of 1.20 inches is determined.

With the above procedure, CN and runoff volumes were determined for each of the other watersheds in an AMC III state, for comparisons with ASI determined values. Results are tabulated in table 6.13. On W–A4, good correspondence was again observed between the SCS technique and the ASI based technique, but correspondence was less satisfactory for W–A2 and W–A3.

Runoff volumes were also computed for ASI values of 0.25, which represents a lower storage availability and hence a greater percentage runoff. ASI values of less than 0.25 were computed for runoff events on each of the study water-

TABLE 6.13.—*SCS curve number and storm-runoff volumes, watersheds W–A1, W–A2, W–A3, and W–A4*

[Precipitation = 2.00 inches]

	Watershed—			
	W–A1	W–A2	W–A3	W–A4
Storm runoff				
Q (AMC I)	0.10 in	0.17 in	0.13 in	0.14 in
SCS CN (AMC I) ..	62	66	64	65
SCS CN (AMC III) .	91	92	92	92
SCS $\hat{Q}$ (AMC III) ..	1.20 in	1.25 in	1.25 in	1.25 in
$\hat{Q}$ (ASI = 0.50)	1.20 in	1.04 in	1.00 in	1.18 in
$\hat{Q}$ (ASI = 0.25)	1.60 in	1.52 in	1.50 in	1.59 in

Abbreviations: Q = storm runoff volume. $\hat{Q}$ = calculated value of Q. CN = curve number. AMC = antecedent moisture condition. ASI = available storage index.

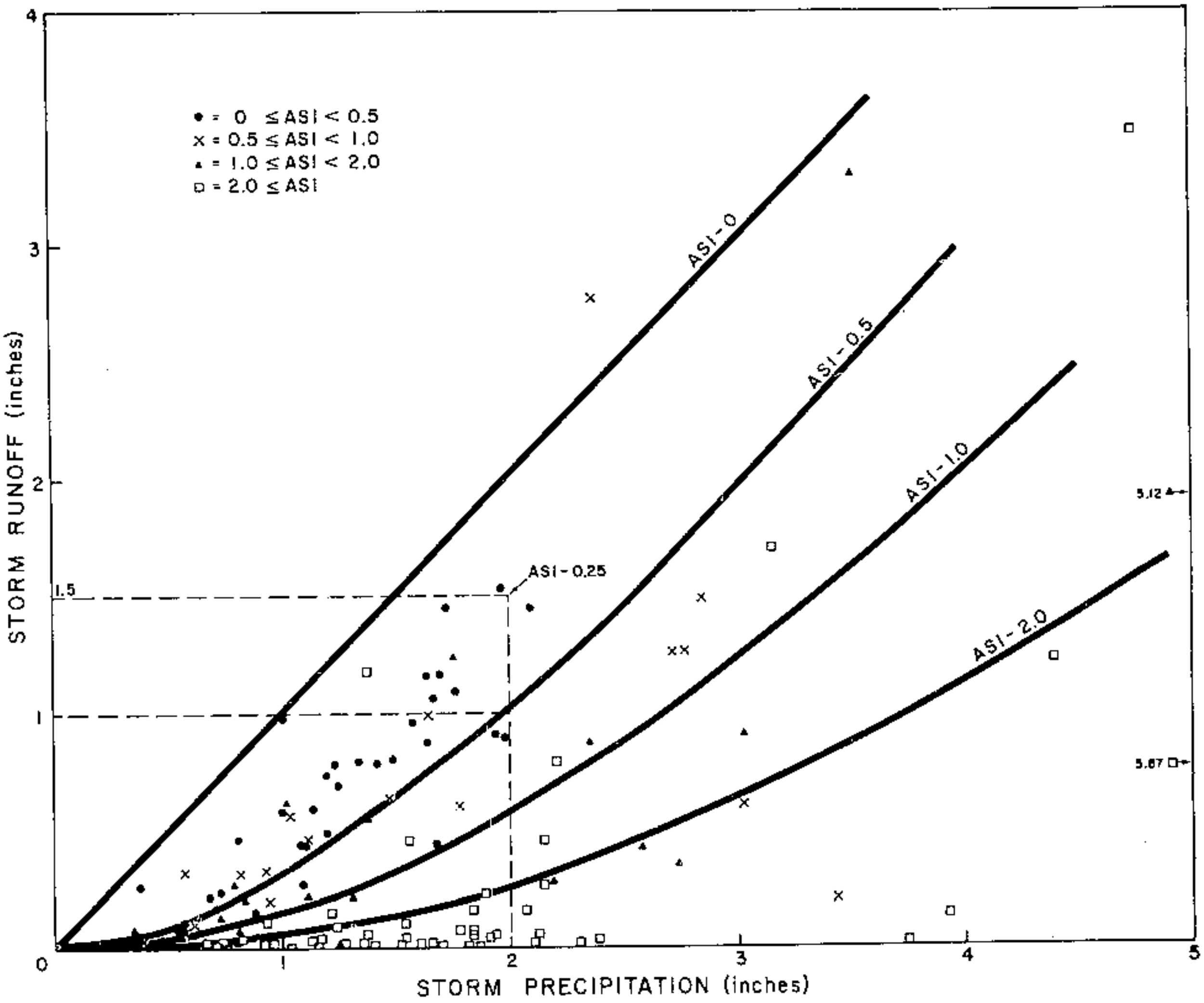


Figure 6.33.—Storm rainfall-streamflow-storage relationships, watershed W–A3.

sheds except W–A4, and so an ASI of 0.25 represents a realistic field condition. It may be noted in table 6.13 that for ASI=0.25, predicted runoff volumes exceed the maximum SCS predicted values (for AMC III) by 20 to 33 percent.

The available storage index is a byproduct of the development of the 5-day water yield model. The ASI technique for adjusting predicted runoff volumes based on watershed available storage conditions results in a continuum of values and provides a greater range of values than the SCS three-value (AMC I, II, and III) procedure.

In view of the greater flexibility and the potential application of the ASI technique, additional study could prove worthwhile. It should be repeated that the data used in developing these *P–Q*–ASI relationships represent a relatively short period with few large storms. The following section presents a method of dealing with the limited data period by optimizing parameters over a sequence of storms.

6.2.2.—Rainfall to Streamflow Response Time

The relationships between the timing of rainfall input and the streamflow output for the four watersheds were determined by means of a storm-hydrograph model previously reported (*15*). This model was altered slightly for efficient use in optimization techniques (fig. 6.35).

Model structure.—The model is composed of three submodels, each of which is parametri-

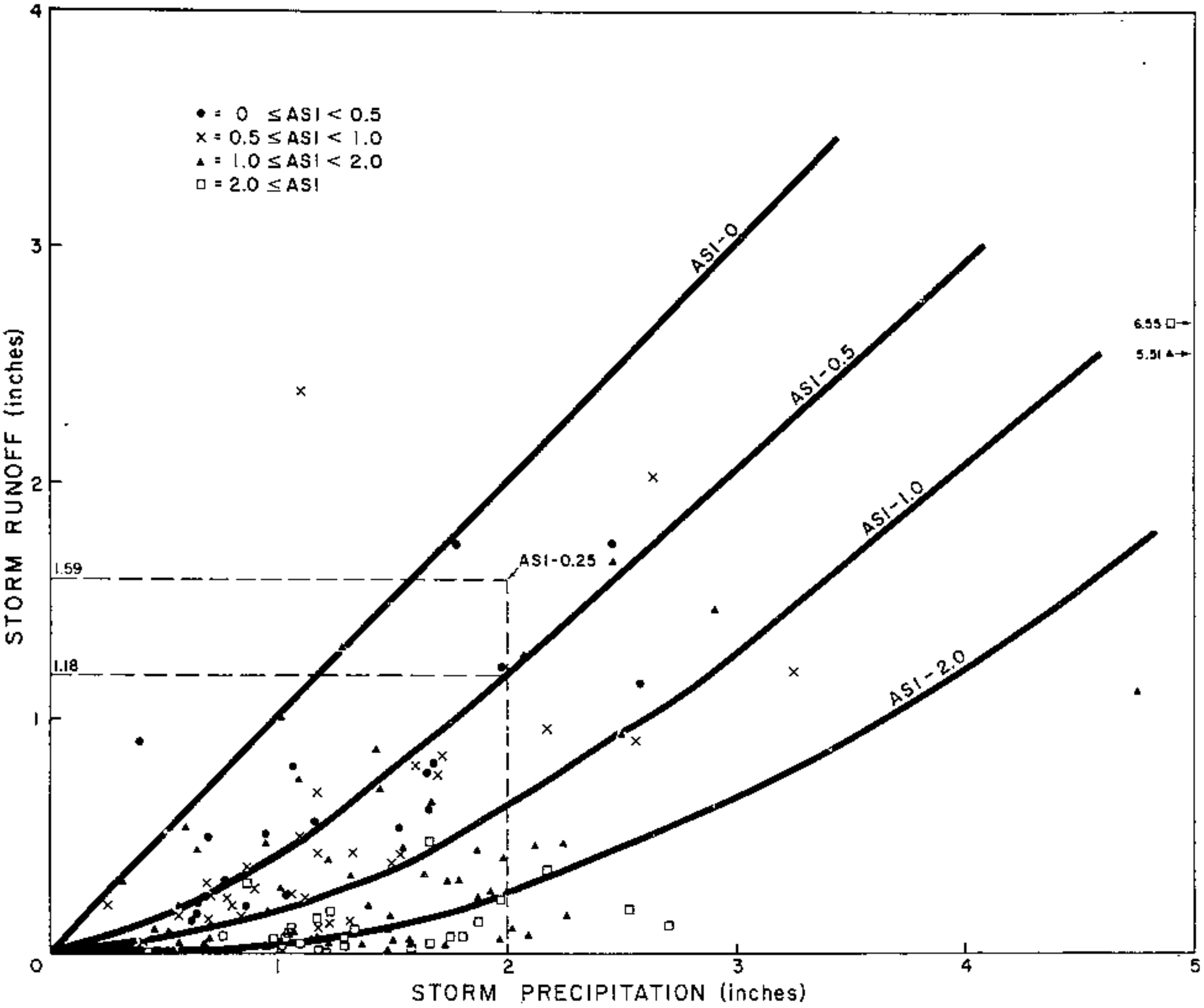


FIGURE 6.34.—Storm rainfall-streamflow-storage relationships, watershed W–A4.

cally defined. The parameters are numerically evaluated as discussed later. Details of the retention function are given in figure 6.36. The retention as computed is to be regarded as capacity for retention; actual volume of water retained depends upon the amount of rain. The mathematical formulation of the function is given as a finite difference equation:

$$r_{t+\Delta t}=r_t-b\left(\frac{P_{\Delta t}+20.0-r_t}{P_{\Delta t}+20.0-RL}\right)\left(\frac{P_{\Delta t}-RL}{P_{\Delta t}+RL}\right)(r_t-RL)\,\Delta t. \qquad (6.8)$$

In this equation r_t is the rate of retention at time t, Δt is the incremental unit of time,

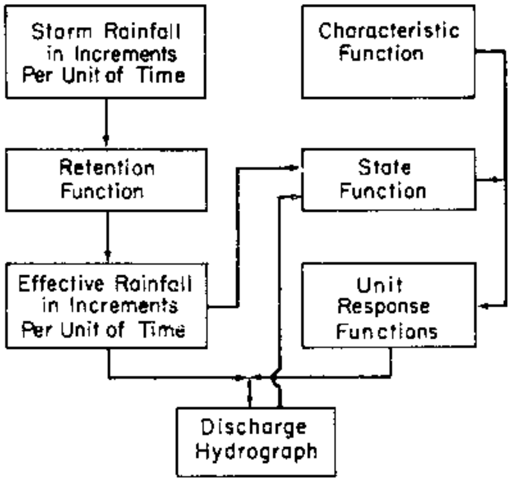


FIGURE 6.35.—Schematic of model for storm-hydrograph analysis.

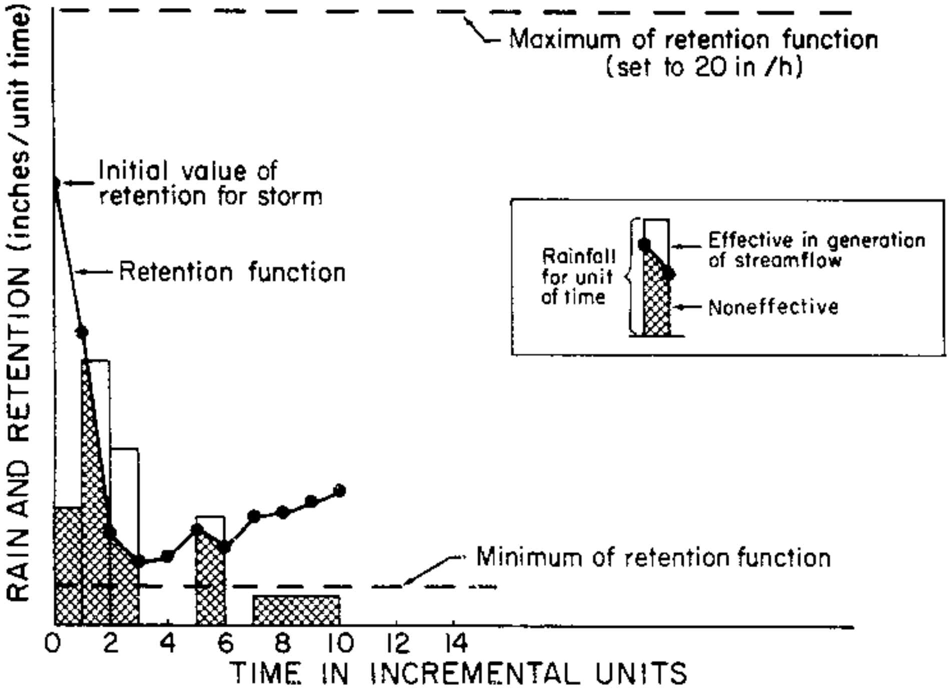


FIGURE 6.36.—Watershed retention function.

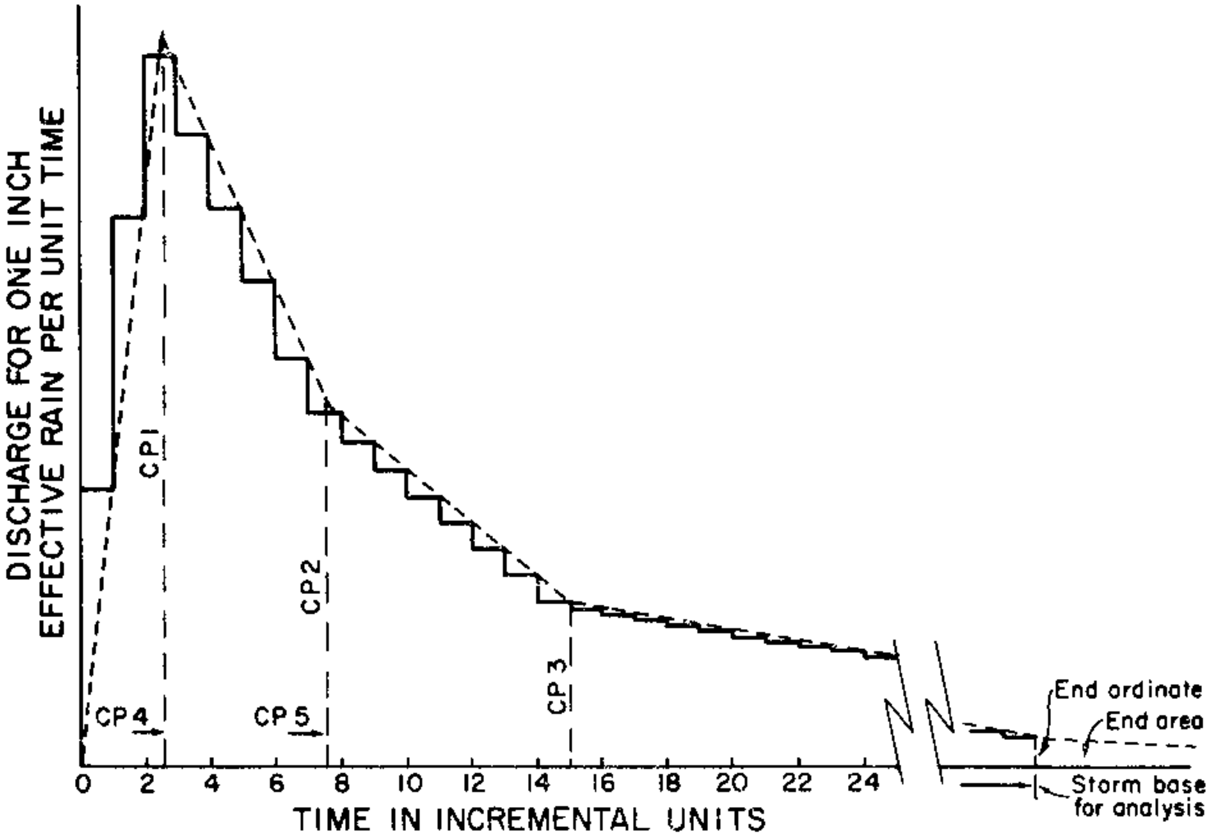


FIGURE 6.37.—Watershed characteristic function.

$r_{t+\Delta t}$ is the retention rate after time lapse Δt. The precipitation in time Δt is $P_{\Delta t}$ in inches per hour. The maximum rate of retention was set at 20.0 inches per hour, and the minimum rate is RL in inches per hour. The coefficient b is a mathematical shape parameter of the retention function. Three terms in the function were designated "parameters of fit" for evaluation by optimization techniques: (1) the value of the functions at time zero, the beginning of the storm; (2) the minimum rate of retention, RL; and (3) the shape parameter b. Any portion of any rainfall increment in excess of the retention function is defined as the effective portion for flow generation. Although the effective volumes are measured in watershed inches, these volumes are not assumed to be uniformly distributed over the watershed. Such nonuniform distribution is given by the characteristic function.

Construction of the characteristic function is shown in figure 6.37. The characteristic is a step function defined on a set of five parameters that outline a boundary with a maximum value $CP1$ at time $CP4$. An angle point of height $CP2$ is located at time $CP5$, and an additional angle point is located at time twice $CP5$. An end ordinate of the boundary marks the base of the storm hydrograph to be used in analysis. The boundary so outlined marks the height of the steps of the characteristic function at the end of each time increment. The five terms $CP1$ through $CP5$ are the characteristic "parameters of fit." The end ordinate is computed as that value needed to make the area under the characteristic equal to 1 watershed-inch of volume. A small triangular end-area with height equal to the end-ordinate and with base equal to the storm base is included.

The previous section described the characteristic function as a structure for optimization from observed hydrographs. Conceptually, the characteristic function is a volume-distribution function. Such distribution can be regarded as the time-transform of a watershed map of potential runoff. Consider placing a square grid over a map of the watershed, calculating the effective rain for each square of the grid for a significant storm rainfall of duration equal to one time increment, and computing travel time from the center of each grid square to the outlet. Lastly, form a type of statistical histogram by accumulating the amounts of effective rain by classes of travel time, the width of each class being equal to one unit of time increment. Following construction the histogram must be rescaled to equal 1 watershed-inch.

The next step in the sequence of watershed processes follows from the conceptual definition of the characteristic function. As each burst, or time increment, of effective rain is established by the retention function, the characteristic function describes the distribution of source areas. The next step is to move the water from the source areas through the channels to the watershed outlet.

Movement of water through the channels can be expected to vary with the amount of water in storage in the channel system. Velocities are greater for channels flowing nearly full than for channels nearly empty. Average velocities may decrease for overtopped channels with water moving slowly over wide flood plains. These changing velocities as water moves through varying levels of channel storage cause variation in timing of response to rainfall as observed at the outlet. The state function is a parametric approach to the effect of storage, or the state of wetness, on stream response.

The recession of streamflow following the peak of a storm hydrograph closely follows a descending exponential curve. Conceptually, such a curve is produced by the drainage of a reservoir with the rate of outflow proportional to the volume of water stored in the reservoir. These considerations lead to the choice of an exponential form for the state function of the hydrograph model. Use of this function will be equivalent to routing the characteristic function through channel storage.

The state function, written to express a storage-routing process that varies with the volume of storage, must be based on some index of storage. This index, shown as a function of time during the storm, is calculated by

$$I(t) = SP1 + SP2(WQ_t/DA + (1-W)P_{\Delta t}/\Delta t). \qquad (6.9)$$

In equation 6.9, $SP1$ and $SP2$ are the parameters to be determined empirically by optimization; Q_t/DA is the discharge per unit of drainage area at the beginning of a time increment; $P_{\Delta t}/\Delta t$ is the precipitation during the increment, converted to depth per unit of time; and W is an external weighting term. For any watershed, W can be set to any value from 0 to 1: for a value of zero the storage index is based entirely on rainfall or input storage, and for a value of 1 the storage index is based entirely on streamflow or output storage. Intermediate values produce a composite storage based on both input and output.

The state function, based on the storage index, is expressed by

$$S(\Upsilon) = I(t) \cdot \exp\left(-I(t) \cdot \Upsilon\right). \qquad (6.10)$$

Equation 6.10 is the state function continuous in Υ, the relative time within the function. For discrete routing, or convolution, in steps equivalent to the time increment, sequential segments of the area under $S(\Upsilon)$ are used as routing coefficients. These segments of area can be computed by integration as shown in

$$a(\Upsilon) = \int_{\Upsilon-1}^{\Upsilon} S(\Upsilon)\, d\Upsilon. \qquad (6.11)$$

The action of the model in representing watershed processes can now be summarized as follows: the characteristic function is routed to the watershed outlet by the coefficients calculated by equation 6.11. The routed characteristic is the unit response to rainfall in one time increment. Since the state function varies with storage during each time increment of rainfall duration, a different unit response is calculated for each increment of rain. Second-stage routing of the sequential volumes of effective rainfall, each by its own unit response function, yields the storm discharge hydrograph.

Parameter optimization.—The storm-hydrograph model outlined above is based on a total of 10 empirically determined mathematical parameters, each of which serves a specific purpose in establishing a numerical representation of the watershed process. The retention function contains three parameters, the characteristic function five, and the state function two. The values of the parameters can be expected to vary to some degree from storm to storm, because of errors in recording instruments, undetected changes in streamflow rating tables, and differences between computed and true rainfall in the drainage basin.

A computer program was written to determine values of the 10 model parameters simultaneously from several storms. Practical considerations of program size and running time required that the number of storms for simultaneous optimization be kept relatively small. The program written allows use of seven storms as a maximum. Each storm can have a different base of up to 60 time increments and a different duration of up to 25 increments of rainfall. The program searches for best values of all the parameters until the squared differences between the computed and observed discharge ordinates for all storms are minimized simultaneously.

Special treatment was necessary for one parameter. Initially an antecedent index of wetness was calculated for each storm, and this index was scaled to initial retention by one parameter of the retention function. This method failed because the antecedent index was not accurate enough to yield true initial conditions for the storms. Consequently, the initial retentions were externally adjusted after each five iterations of the optimization routines. A printer plot of all storms after five iterations gave rainfall, retention, and predicted and observed discharge hydrographs. Any storm with too much runoff had its initial retention increased, and any storm with too little runoff had its initial retention decreased. Following this, another five iterations of optimization were performed, and the process was continued until correlation coefficients reached approximately 0.95. Only relative initial retentions were adjusted externally. These values were still parametrically optimized. All nine remaining parameters, including the remaining two in the retention function, were optimized internally with no external controls.

Selection of events for optimization.—The dates of all events on all watersheds with storm rainfall in excess of 2 inches were tabulated. After this list was purged of all events with actual or suspected gage malfunction, the residual list was surprisingly small. It had been anticipated that several data sets could be assembled, each set consisting of about seven storms. These sets were to be designated as summer and winter, large storms and small storms, wet conditions antecedent to the storm and dry conditions antecedent to the storm. However, it was impossible to form such storm groupings from the small residual storm lists. Only one summer and one winter list was prepared and optimized for each watershed. The dates of storms used in optimization of the model are shown in table 6.14. For some lists

TABLE 6.14.—*Storm dates for multiple-event analysis*

Watershed	Summer storm dates						
	1964			1965			May 29, 1966
	Aug. 3	Aug. 31	Sept. 12	June 11	June 15	July 15	
W–A1	...	...	X	...	...	X	...
W–A2	X	...	X	X	...	...	...
W–A3	...	X	X	...	X	...	...
W–A4	X	...	X	...	...	...	X

Watershed	1967		1969			1971	
	June 18	Aug. 10	May 18	June 18	Sept. 20	Aug. 22	Aug. 26
W–A1	X	...	X	...	X	...	X
W–A2	X	...	X	...	...	...	...
W–A3	...	...	X	...	X	...	...
W–A4	...	X	...	X	...	X	...

Watershed	Winter storm dates								
	1964		Jan. 7, 1967	1968		1969			
	Oct. 3	Dec. 25		Jan. 13	Mar. 16	Jan. 19	Jan. 31	Feb. 1	Oct. 2
W–A1	...	X	X	...	...	X	...	X	...
W–A2	X	X	X	X	X	...	...	...	X
W–A3	...	X	X	X	...	...	...	...	X
W–A4	X	X	X	...	X	...	X	...	...

Watershed	1970				Oct. 22, 1971	Dec. 13, 1972
	Feb. 2	Mar. 30	Apr. 13	Oct. 22		
W–A1	X	...	...	X	...	X
W–A2	...	...	X	...	...	...
W–A3	X	...	...	...	X	...
W–A4	...	X	...	...	...	...

TABLE 6.15.—*Optimized values of parameters and correlation coefficients for streamflow-response model, summer and winter storms, Ahoskie Creek watersheds*

Watershed[1]	Number of storms	Retention parameters		Characteristic function[2]					State function parameters		Storage (*W*)	Correlation coefficient
		Shape	Minimum retention	*CP*1	*CP*2	*CP*3	*CP*4	*CP*5	*SP*1	*SP*2		
						Summer						
W–A1	6	0.0500	0.0619	1921	719.0	86.3	2.09	8.18	0.0352	0.549	0.6	0.97
W–A2	5	.5124	.0389	895	260.0	65.8	1.00	4.91	.0620	.057	.6	.83
W–A3	5	.0931	.0024	147	31.4	13.5	1.00	8.63	.0025	1.695	.5	.98
W–A4	6	.8853	.0538	226	206.0	17.9	1.91	4.76	−.2775	14.754	.5	.96
						Winter						
W–A1	7	0.0994	0.0056	2142	852.0	70.6	1.00	10.28	0.0024	0.592	0.5	0.97
W–A2	7	.3240	.0248	1099	231.0	45.7	1.00	7.48	.1017	−.142	.6	.95
W–A3	6	.2000	.0143	119	55.3	25.8	1.80	8.57	.1568	11.747	.75	.96
W–A4	6	.2318	.0020	175	39.8	11.7	2.57	7.98	.0716	6.437	.6	.93

[1] Time increment is 1 hour for watershed 4, 2 hours for other watersheds.

[2] See figure 6.37.

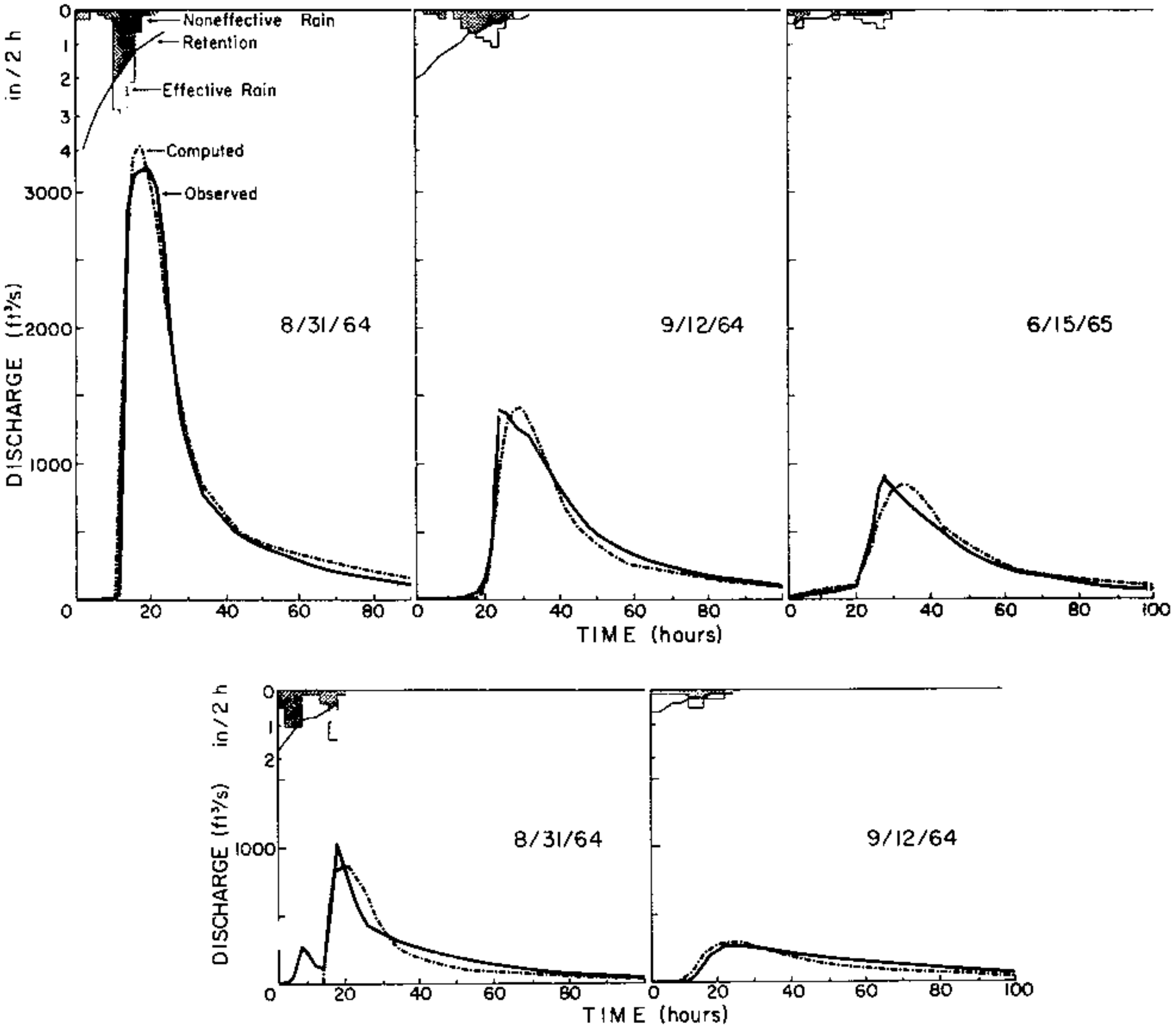


FIGURE 6.38.—Computed and observed hydrographs, summer storms, watershed W–A3.

only five storms were available and had to be used without regard for varying storm and antecedent conditions. Consequently, the derived storm parameters are not considered completely satisfactory.

Table 6.15 shows the derived values of the model parameters. The parameter for the initial value of the retention function is not shown, since, as explained above, initial values for individual storms had to be externally adjusted. The high values of the correlation coefficients in table 6.15 give assurance that the model is capable of representing streamflow response to various rainfall patterns. Essentially, this means that single sets of parameters can represent multiple patterns, and figure 6.38 illustrates this capability of the model. The correspondence between computed and observed hydrographs is shown for the five summer storms on watershed W–A3, as well as the determination of effective rain by the retention function. Correspondence is good except for minor irregularities.

Most values of the parameters in table 6.15 are hydrologically acceptable, but the results for watershed W–A2 are considered suspect. Difficulty was experienced in getting near-optimum values of the parameters. The relatively low value of 0.83 for the summer storms, and the physically impossible value of −0.142

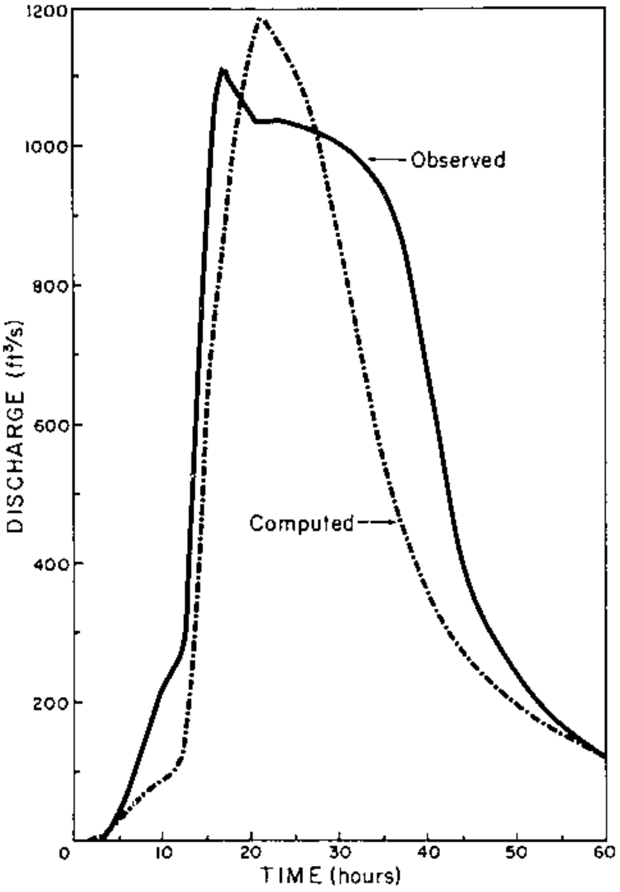


FIGURE 6.39.—Computed and observed hydrographs, watershed W–A1, February 2, 1970.

for parameter *SP*2 of the state function are reasons for suspicion. The negative value of *SP*2 would mean that response becomes sluggish with a high-storage index. Aside from watershed W–A2, the parameters for the characteristic and state functions, which combine to produce the unit-response functions, are fairly consistent. The timing of streamflow following rainfall, therefore, appears to be established to some degree. However, variability is great among the retention function parameters. The values for any watershed, summer or winter, are not irrational, and cannot be arbitrarily rejected. The variability of the parameters is probably a result of insufficient data and the need to include all available storms on the lists. Given more data and the possibility of establishing lists of storms with similar properties, the volumetric parameters would probably be more consistent.

A further example of the difficulty experienced with storm analysis is illustrated in figure 6.39, in which the computed and the observed hydrographs for the storm of February 2, 1970, are superimposed. Whereas the calculated hydrograph shows a rise to a relatively narrow single peak, the observed hydrograph shows a faster rise to peak, followed by a broad segment of nearly constant high flow. The observed hydrograph shape might have been caused by backwater, but this possibility has been eliminated by means of reanalysis of stage-discharge measurements.[1] The occasionally broad flat-topped hydrograph shape could also be caused by surface or subsurface runoff from portions of the watershed that contribute only intermittently to streamflow. The presence of such source areas, not adequately accounted for in the determination of drainage area, would also offer some explanation for the high storm-runoff volumes in relation to rainfall in figure 6.31. However, available information is not sufficient to establish an accepted explanation.

In brief, the approach to storm analysis presented above appears feasible, for a parametric model can be optimized across several storms simultaneously. The parameters so obtained are average values for all storms and have the extreme advantage of any statistical averaging process. Use of this modeling technique on multiple storms requires a sufficient quantity of precise data, and the averaging process can be used advantageously only when storm lists can be prepared to emphasize a particular property. Storms vary in many ways, by antecedent moisture conditions, by complexity of rainfall pattern, and by maximum intensity of input rainfall. The manner in which each of these conditions affects the model parameters should be determined by using lists of storms that are homogeneous in the effects being studied. Results of multiple-event analysis in this study show that lag times from rainfall input to streamflow output are readily determined, but analyses for the determination of precise volumes of runoff were less successful.

The elements necessary for the improved prediction of runoff volume have been identified. The retention function must be calibrated in

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[1] Personal communication, Ralph C. Heath, district chief, U.S. Geological Survey, Raleigh, N.C., February 25, 1975.

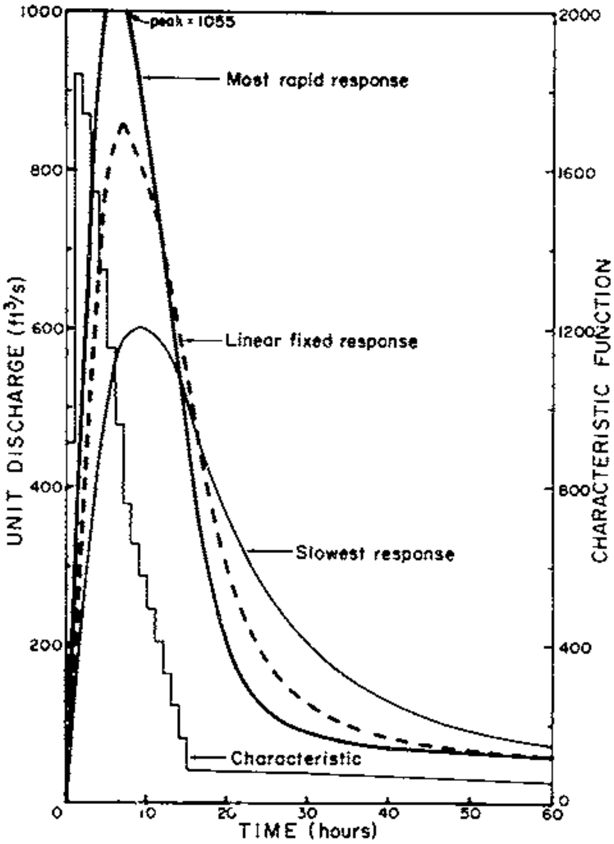

FIGURE 6.40.—Characteristic and selected response functions for summer storms, watershed W–A1.

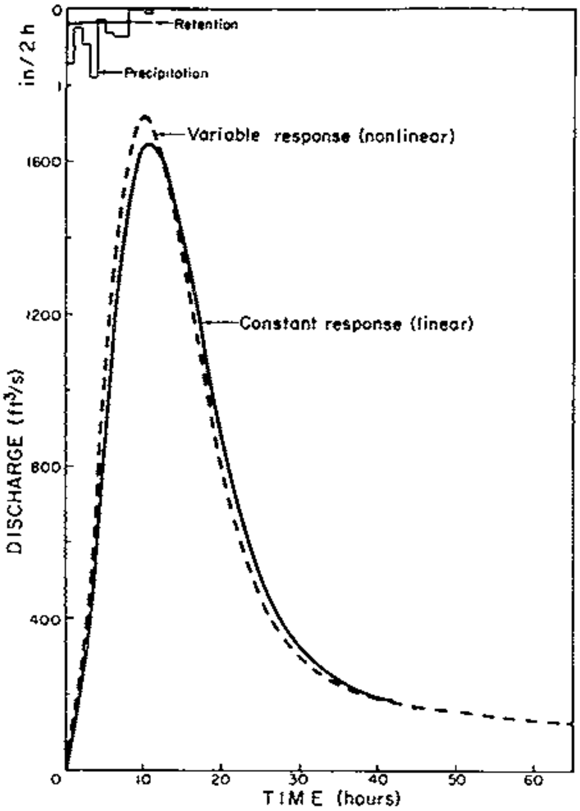

FIGURE 6.41.—Simulated hydrograph with variable response for summer storms, watershed W–A1.

two parts: the shape of the function throughout the duration of storm rainfall can be obtained by multiple storm analysis of adequate data, but the initial value of the function must be obtained by some other procedure. The use of the index of available storage from the 5-day water-yield model showed promise when used in the separate analysis of storm-rainfall volumes and storm-runoff volume. Additional research, with data from a project designed for the purpose, should produce a method of integrating all the necessary elements for solution of the problems of initial storm condition.

6.2.3.—Prediction of Storm Hydrographs

Because all storms cannot be presented and because many details of the unit-response functions for each rainfall increment for each storm must be omitted, the use of the information in table 6.15 will be demonstrated by predicting storm hydrographs for a synthetic rainfall. The same rains were used on each of the four watersheds, adjusting only for the size of the drain-

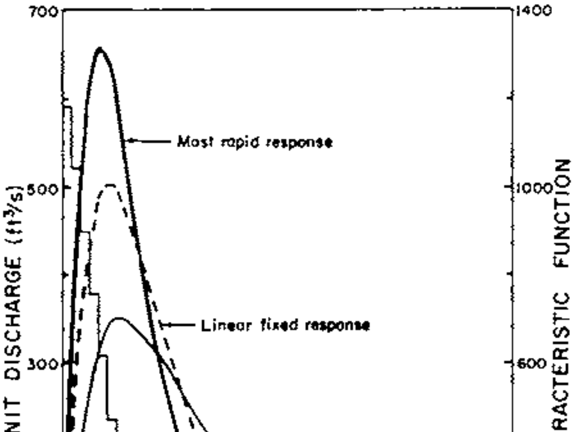

FIGURE 6.42.—Characteristic and selected response functions for summer storms, watershed W–A2.

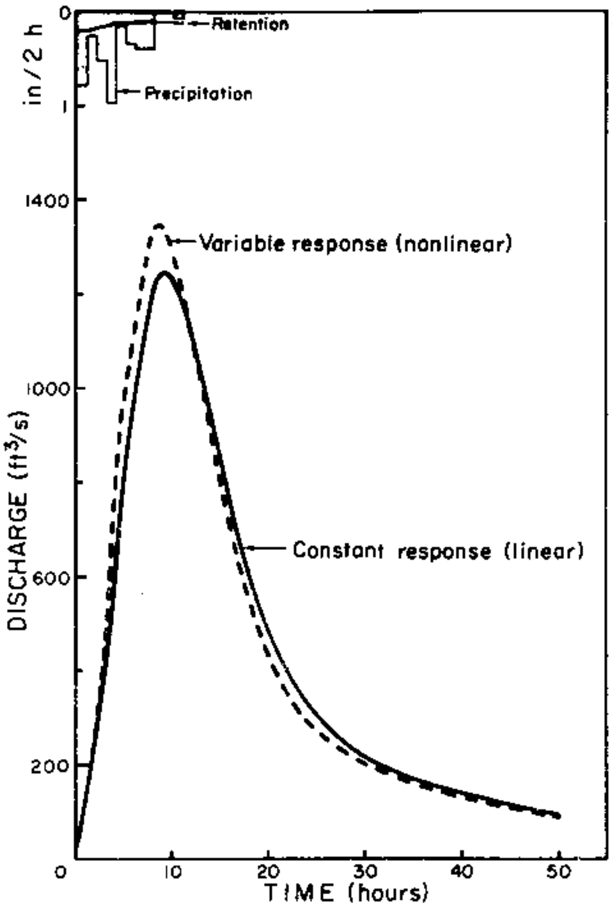

FIGURE 6.43.—Simulated hydrograph with variable response for summer storms, watershed W–A2.

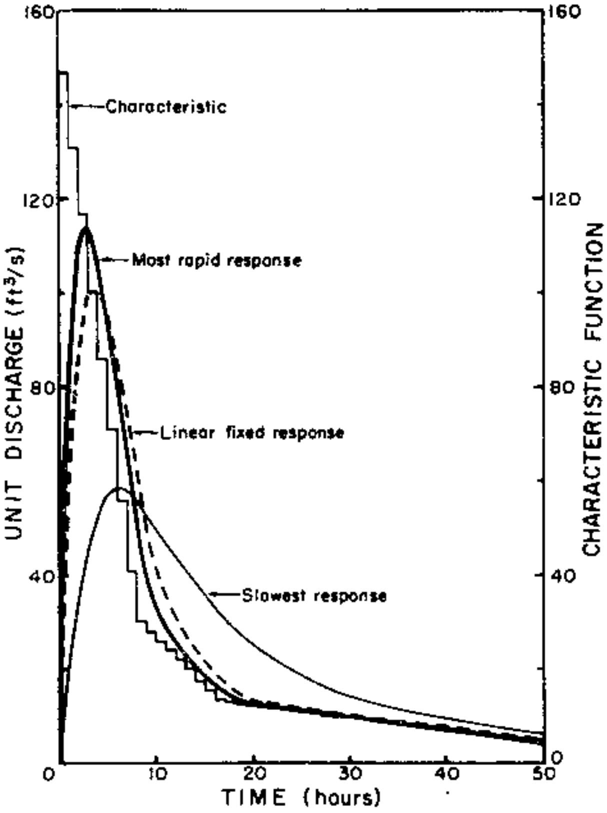

FIGURE 6.44.—Characteristic and selected response functions for summer storms, watershed W–A3.

age area. A summer-storm hydrograph and a winter-storm hydrograph were generated for each watershed. Constructional details of these eight predicted storms are shown in figures 6.40–6.55.

Stochastically simulated storm rains were taken from tables 5.1 and 5.2, and an average pattern of storm-rainfall increments was determined for the first 10 storms in each table. As an example, for watershed W–A1, these calculated values are shown at the top of figures 6.41 and 6.49. Parameters of the model were set to the numerical values in table 6.15 with some exceptions. The initial value of retention was set to 0.10 inch per hour for summer storms and to 0.05 inch per hour for winter storms. The value of the shape parameter of the retention function was set to 0.2 in place of the large values for certain of the analyses in table 6.15. Also, the characteristic function for watershed W–A2 was modified by comparison with the other watersheds, because of the difficulty experienced in optimization for the watershed.

Hydrographs of streamflow can be generated for any given set of storm-rainfall increments and any given set of numerical values of 10 parameters. A computer program using the identical model structure as the method for deriving optimum values of parameters from recorded storms was prepared. However, the cumbersome and complex mathematical routines for optimization were eliminated from the hydrograph simulation program.

Outputs from the hydrograph-simulation program include the average value of the retention function for each time increment of rainfall, the resultant effective rainfall, the characteristic function, the unit-response function for each increment of rainfall duration, and the hydrograph. Figures 6.40, 6.42, 6.44, and 6.46 contain the characteristic functions and selected response functions for summer storms for the four watersheds. Figures 6.48, 6.50, 6.52, and 6.54 show these functions for the

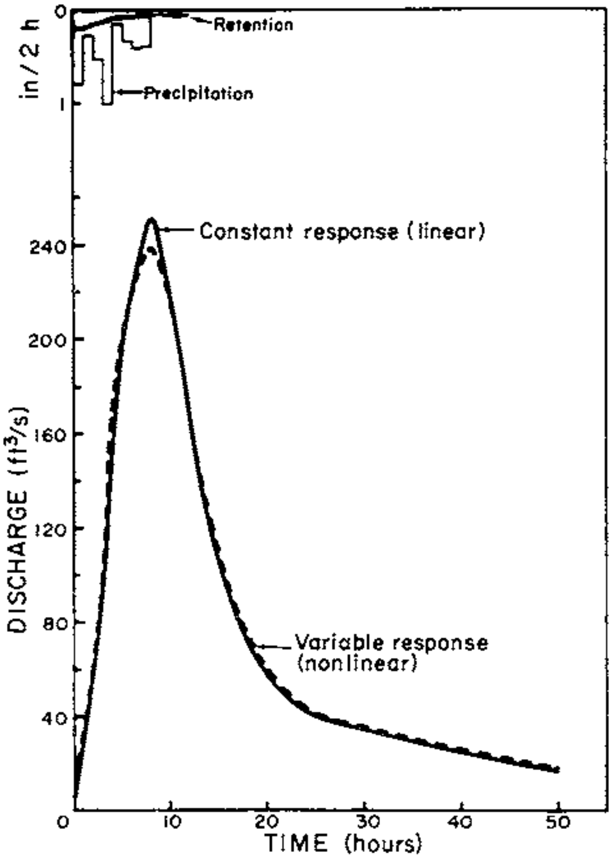

FIGURE 6.45.—Simulated hydrograph with variable response for summer storms, watershed W–A3.

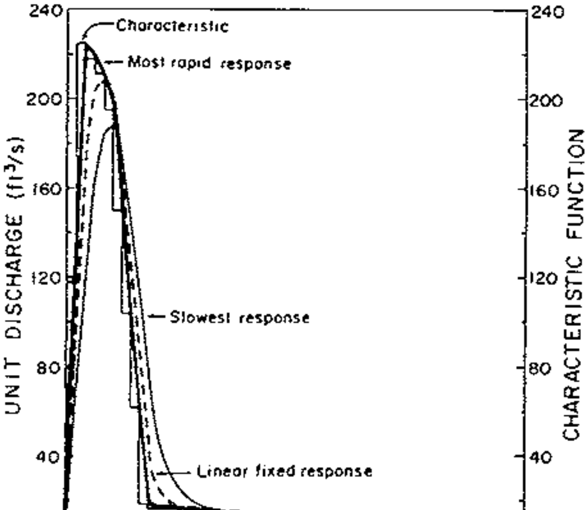

FIGURE 6.46.—Characteristic and selected response functions for summer storms, watershed W–A4.

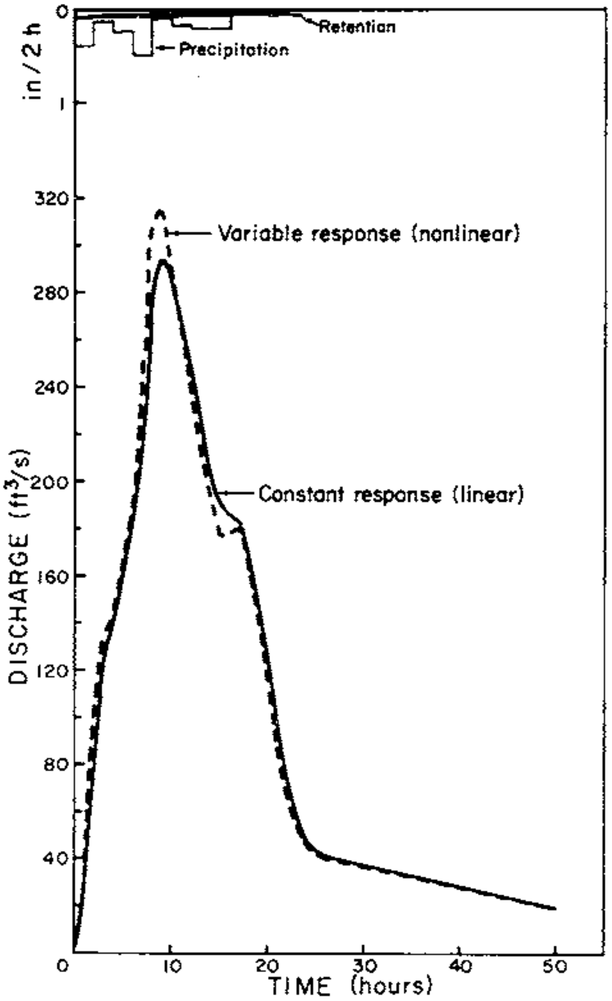

FIGURE 6.47.—Simulated hydrograph with variable response for summer storms, watershed W–A4.

winter storms. The two response functions selected for plotting were the ones with the highest peak and the lowest peak, or the most rapid response to rainfall and the slowest response to rainfall. Since the response functions are actually the transformed characteristic function following routing through a variable channel storage, the response of the watershed to rainfall is nonlinear.

A storm hydrograph was computed for both the summer and the winter simulated rains on each of the four watersheds (figs. 6.41, 6.43, 6.45, 6.47, 6.49, 6.51, 6.53, and 6.55). The retention function was held the same for both linear (constant) response and nonlinear response.

The nonlinear-response functions show that the watersheds act differently under various

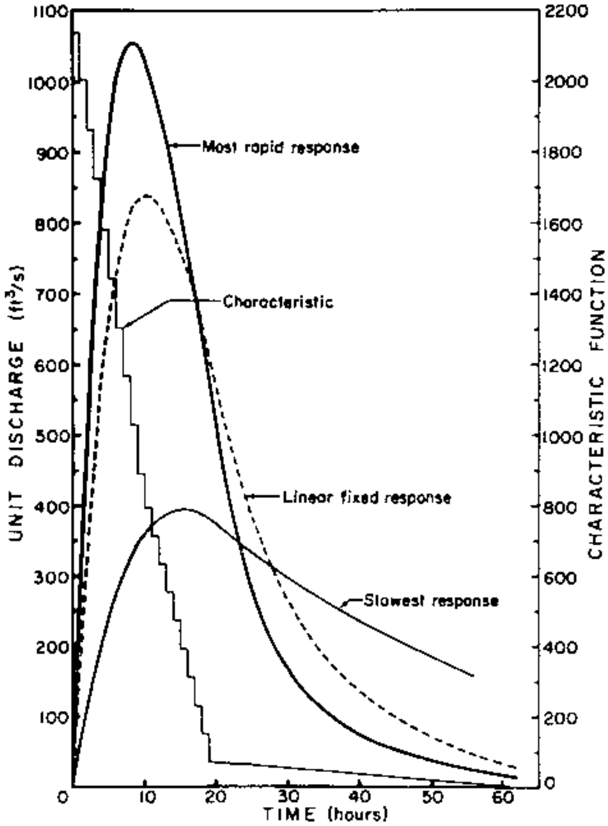

FIGURE 6.48.—Characteristic and selected response functions for winter storms, watershed W–A1.

amounts of storage. For example, the peak of the most rapid response for watershed W–A1 in winter is 1,058 ft³/s, and the peak of the slowest response is 400 ft³/s. If rain falling in a 2-hour period produced 1 inch of effective rainfall, these peak response values would also be the peak hydrograph values. In other words, predicted peak flows might vary up to two and one-half times, depending upon the value of the storage index.

Comparison of the hydrographs for nonlinear and linear response shows only small differences compared to the differences in the response functions, and this slight difference in the storm hydrographs cannot be generalized. The differences shown are only for the particular storm patterns that had been stochastically simulated. By chance, three major bursts were generated for both storms. Differences between nonlinear and linear response were minimized by the split rainfall. Also, since the particular linear response used in these calculations is based on median values of the storage

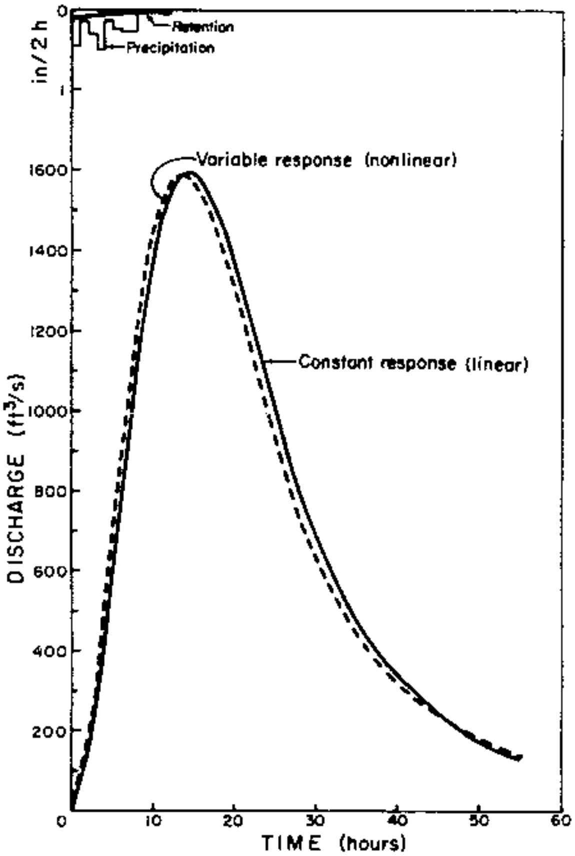

FIGURE 6.49.—Simulated hydrograph with variable response for winter storms, watershed W–A1.

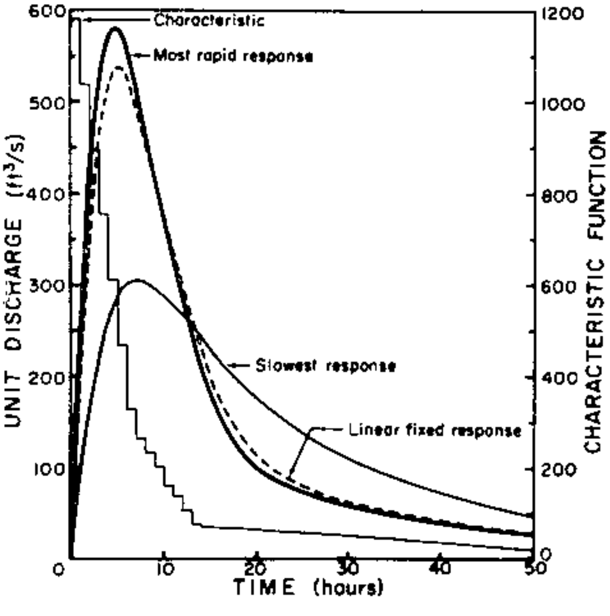

FIGURE 6.50.—Characteristic and selected response functions for winter storms, watershed W–A2.

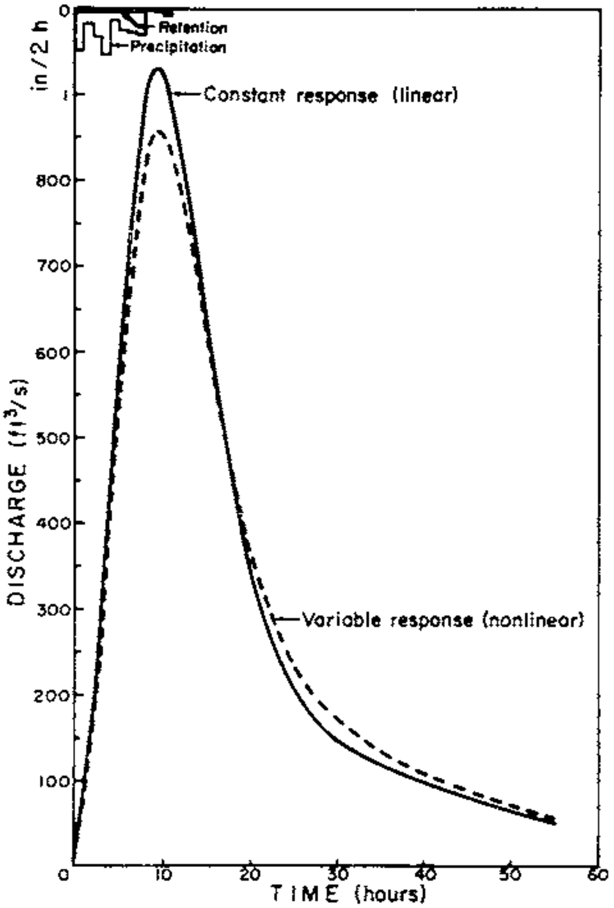

FIGURE 6.51.—Simulated hydrograph with variable response for winter storms, watershed W–A2.

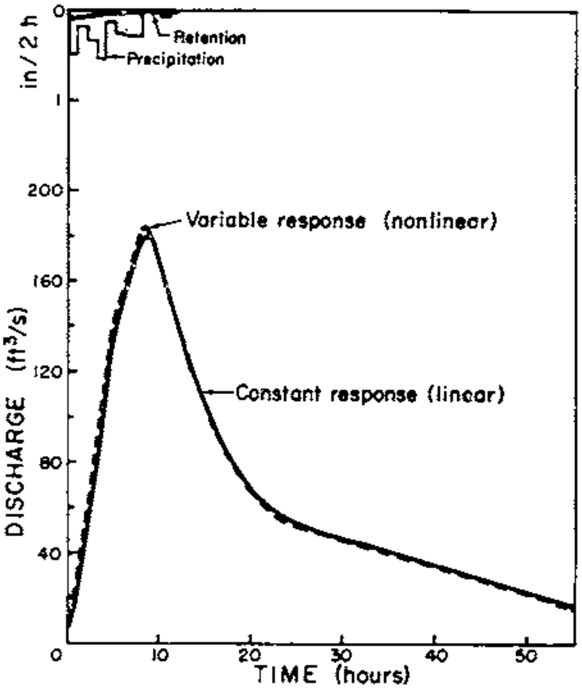

FIGURE 6.53.—Simulated hydrograph with variable response for winter storms, watershed W–A3.

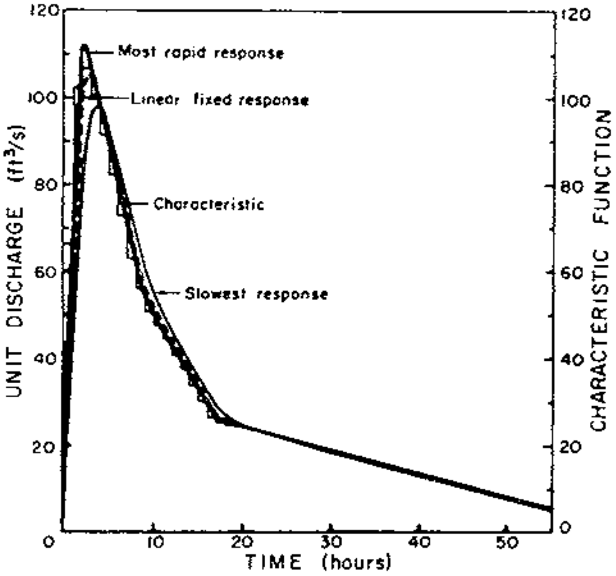

FIGURE 6.52.—Characteristic and selected response functions for winter storms, watershed W–A3.

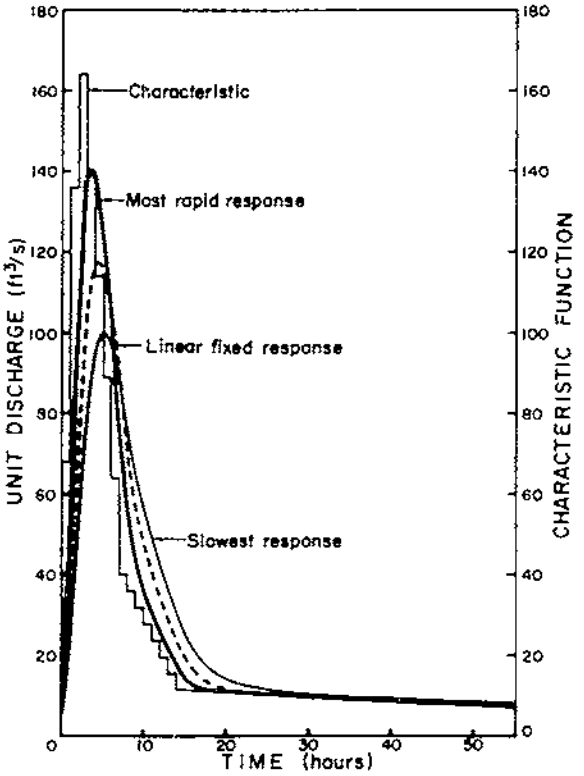

FIGURE 6.54.—Characteristic and selected response functions for winter storms, watershed W–A4.

index, an almost infinite number of combinations of rainfall patterns and response patterns is possible. The effect of nonlinearity cannot be estimated for all combinations. Conservative design procedure would seem to require the calculation of storm hydrographs based on nonlinear response, since these in general will produce somewhat higher peak flows.

The effect of channelization upon the storm hydrograph cannot be determined, for recorded hydrographs are available only from watershed W–A1 before channelization. Also, hourly rainfall data are available only after the recording gages were installed in 1964. Such hourly data would be necessary to establish the watershed response to rainfall prior to channelization.

6.3.–RECESSIONS

Streamflow during recessions, that is, during periods of little or no rain, represents a minimum dependable future supply of water from natural storage. Water management might become much more efficient if low flow rates could be predicted with reasonable accuracy. Estimates of recession characteristics will facilitate the forecasting of allowable withdrawals from streams for irrigation and the prediction of volumes available for pollution abatement. Although the recession of streamflow following storm periods has been studied for a long time, quantitative mathematical expressions for accurate prediction of flow during recession periods are still lacking. Consequently, a convolutional model of streamflow recession has been formulated and tested (*29*). The model also serves as an integral part of the water-yield model discussed earlier, providing a means for streamflow analysis between storms.

The recession model has been modified slightly to predict ground-water recessions. Although the excellent results obtained in predicting streamflow recessions have not been equaled in predicting ground-water recessions, fairly good results have been obtained. Further model development and refinement are expected to produce a satisfactory prediction procedure.

6.3.1.–Streamflow

Streamflow recession generates a sequence of flow volumes by days for the period desired (*29*). Three inputs are required: (1) volume for first day of recession, (2) one parameter, *b*, that defines a routing function, and (3) five parameters that define a characteristic function. The parameters, which are related to the initial rate of flow and to the size of the drainage area, are determined by optimization with historical streamflow records.

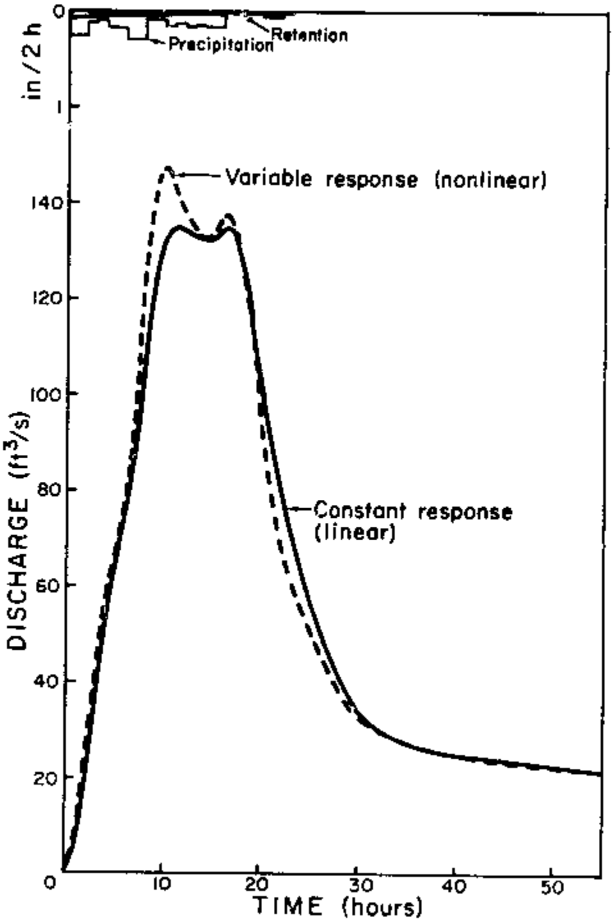

FIGURE 6.55.—Simulated hydrograph with variable response for winter storms, watershed W–A4.

USGS streamflow records from the four Ahoskie gaging stations were utilized in testing the recession model. Forty to fifty recessions, ranging from 10 to 29 days in duration, were selected from each drainage area, and the model was fitted to each recession to obtain values of the parameters. Relationships between parameter values and V_1, the first flow, were then evaluated. Similarly, relationships between the parameter values and the area, with V_1 held constant, were evaluated. Results confirmed the expected patterns of definite relationships between the parameter values and the initial

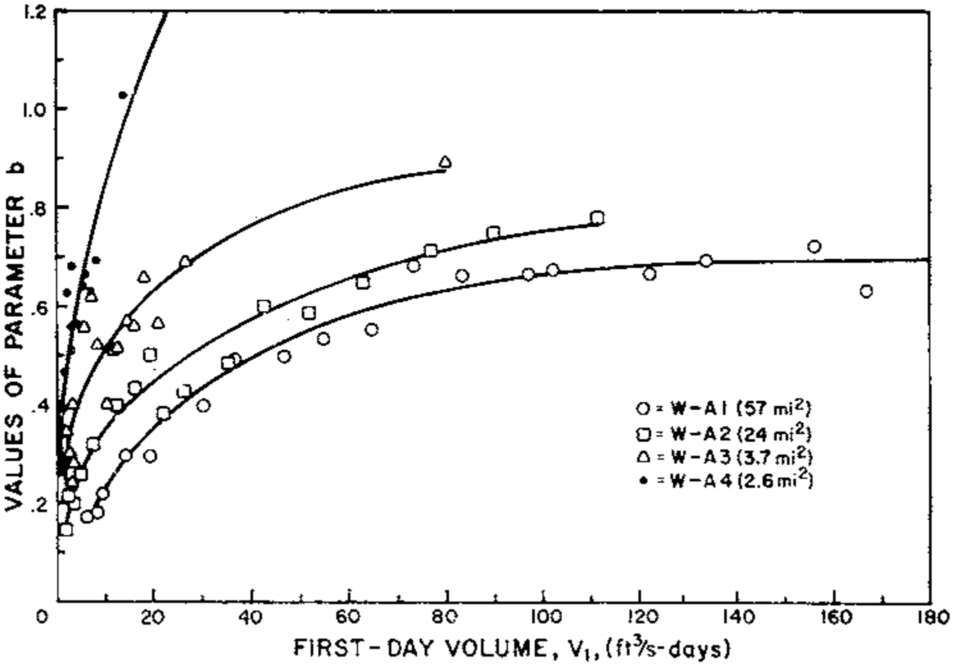

FIGURE 6.56.—Parameter b vs V_1 for watersheds W–A1, W–A2, W–A3, and W–A4.

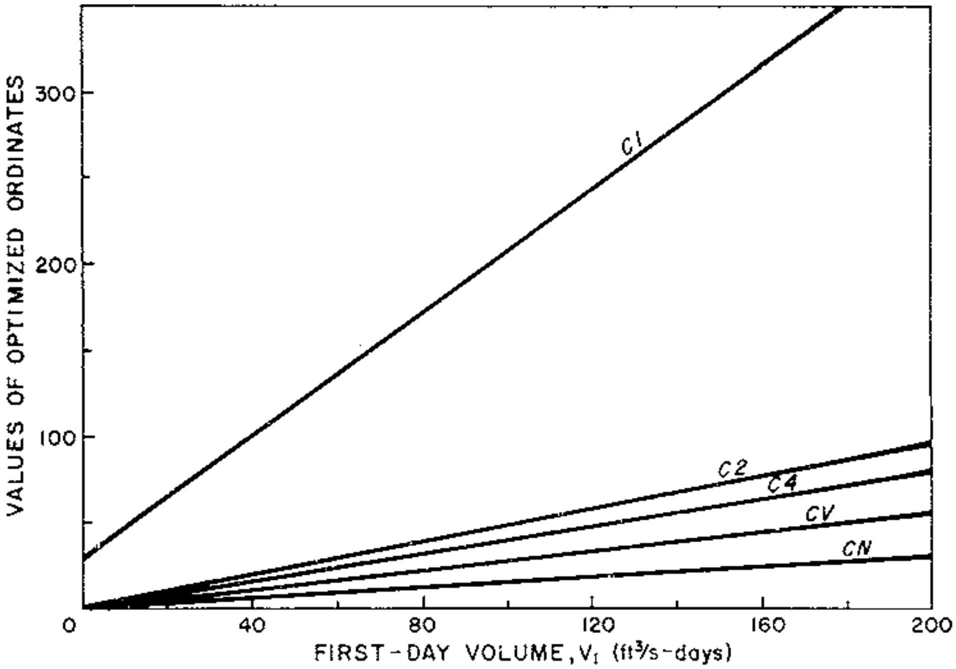

FIGURE 6.57.—Derived values of characteristic hinge points versus initial flow, watershed W–A1.

flow rate and the size of the drainage area. Most important, results were cast into consistent quantified forms that provide, by means of optimization procedures, the maximum correspondence between the recession model and the historical recession flow rates.

The relationship of b (parameter 1) to the initial discharge rate and to the size of the drainage area is shown in figure 6.56. As the drainage area decreases, the values of b increase. For example, at a V_1 value of 20 sfd (second-foot-day), b increases from 0.325 for W–A1 to 0.433 for W–A2, to 0.655 for W–A3, to over 1.0 for W–A4. Also, parameter values increase consistently with increasing values of V_1 for each drainage area. The smaller the area, the more rapid the increase in parameter values with increasing discharge.

Parameters 2 through 6 define the ordinates of the characteristic function. The value of the optimized ordinates of the characteristic functions for the test recessions for watershed W–A1 are shown in figure 6.57. In contrast to the values of b, parameters defining ordinates of the characteristic function increase linearly with increasing values of initial discharge, V_1. Although only data for W–A1 are shown in the figure, results were similar for the other drainage areas.

Values of $C1$ in figure 6.57 are much greater than those of $C2$ through CN. A decrease can be noted in ordinates $C2$ through CN, though the differences are relatively small. Unlike $C1$, these ordinates all appear to have the same value of zero at zero discharge. In figure 6.58, the ordinate $C1$ is plotted against V_1 for all four drainage areas. This ordinate is primarily dependent on V_1 and secondarily dependent on area in the Ahoskie drainages. This area dependency appears to be significant and consistent.

The close correspondence between the calculated volumes and the observed volumes for a recession is shown in figure 6.59. The calculated values fluctuate slightly from the observed values, but this may be expected since the

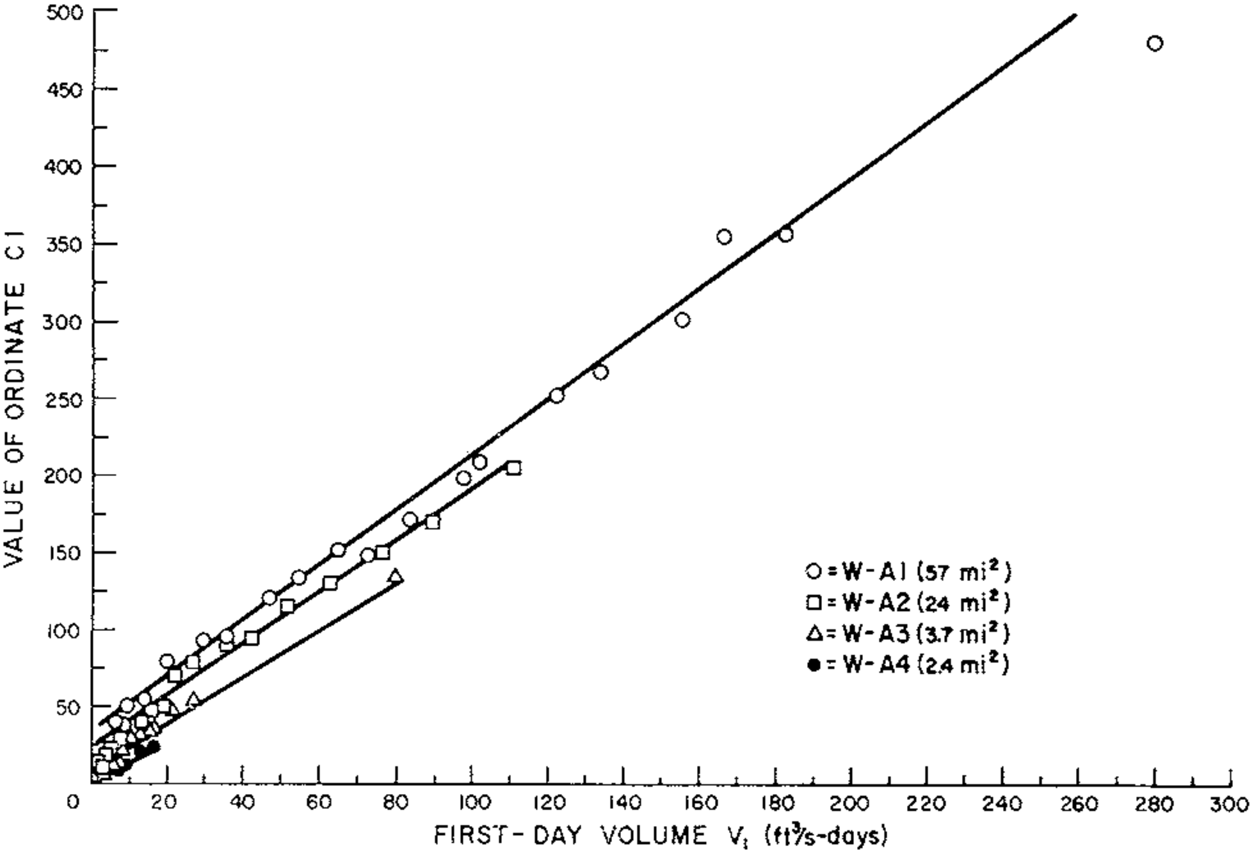

FIGURE 6.58.—Characteristic ordinate C_1 versus initial flow, V_1, for watersheds W–A1, W–A2, W–A3, and W–A4.

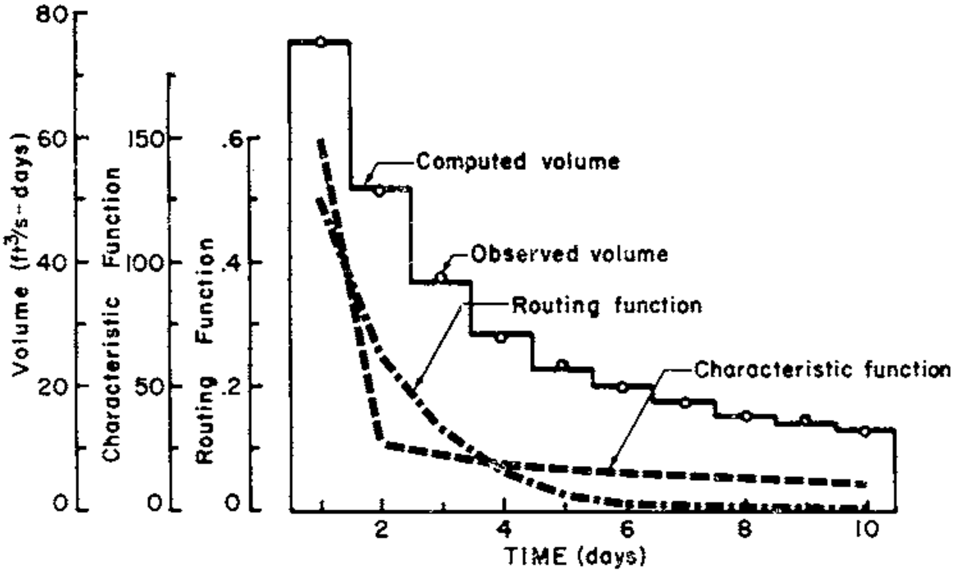

FIGURE 6.59.—Correspondence of optimized and observed 10-day recession, $N=10$ days.

TABLE 6.16.—*Ground-water recessions, minimum and maximum well stages and parameter values*

Well	Stage		Parameter—							
			[1]1		[2]2		[1]3		[1]4	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1	68.35	74.98	0.40043	0.51709	207.19	185.92	68.18	73.92	68.16	72.32
2	64.35	69.69	.31329	.44818	239.23	193.00	64.15	69.40	63.50	68.92
4	65.82	71.30	.35267	.44662	221.49	198.00	65.50	70.60	65.16	69.93
5	48.51	53.87	.22132	.30374	244.30	207.04	48.40	53.84	48.29	53.10
6	39.91	43.84	.24995	.33919	180.48	152.68	39.82	42.42	39.68	42.42
7	49.90	56.90	.25102	.33597	224.80	199.37	49.80	56.92	49.51	56.29
8	41.73	42.84	.30366	.31992	160.15	154.98	41.59	42.64	41.46	42.59

[1] Parameter values increase with increasing discharge.

[2] Parameter values decrease with increasing discharge.

mathematical computations proceed in a smooth consistent manner, which may not occur in a natural flow event. However, the daily differences are generally small and tend to be compensatory, allowing for a close approximation of the total volume for the entire recession period. For convenience, the values of the characteristic and routing functions are also shown.

6.3.2.—Ground Water

The techniques developed in streamflow analysis and prediction were extended to ground-water recessions, but two modifications of the model were necessary. Reduction to only four parameters improved results, as well as slightly reducing the mathematics performed by the computer: parameter 1 still defines a routing function and the other three parameters define a characteristic function.

Whereas all parameter values of the streamflow-recession model increased with increasing values, this was true only for parameters 1, 3, and 4 of the ground-water-recession model. The values of parameter 2 decreased with increasing ground-water elevation. This reversed behavior is unexplainable at this time.

Ground-water recessions in the Ahoskie drainage area have proven to be difficult to model, because of the small difference between the peak and the end of a given recession. As shown in table 6.16, for all recessions studied,

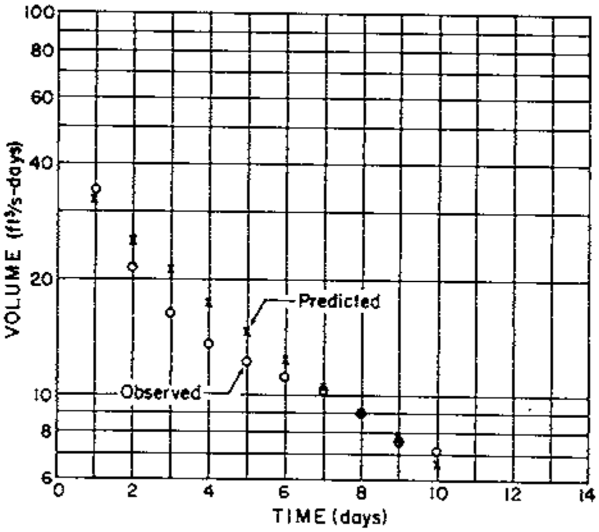

FIGURE 6.60.—Predicted and observed recessions, watershed W–A1, October 8–18, 1972.

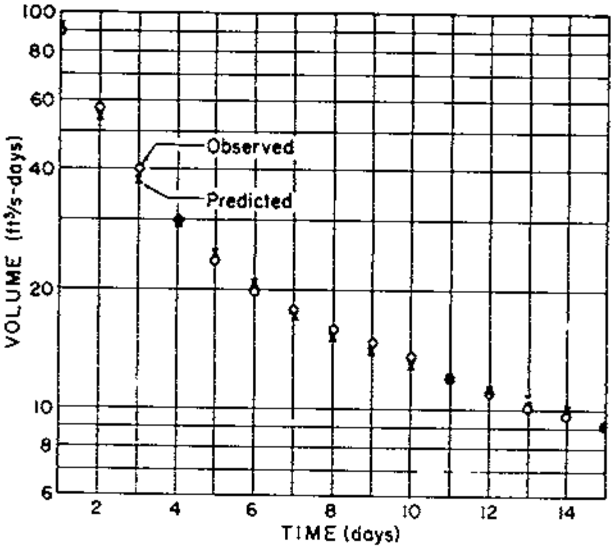

FIGURE 6.61.—Predicted and observed recessions, watershed W–A2, March 10–24, 1972.

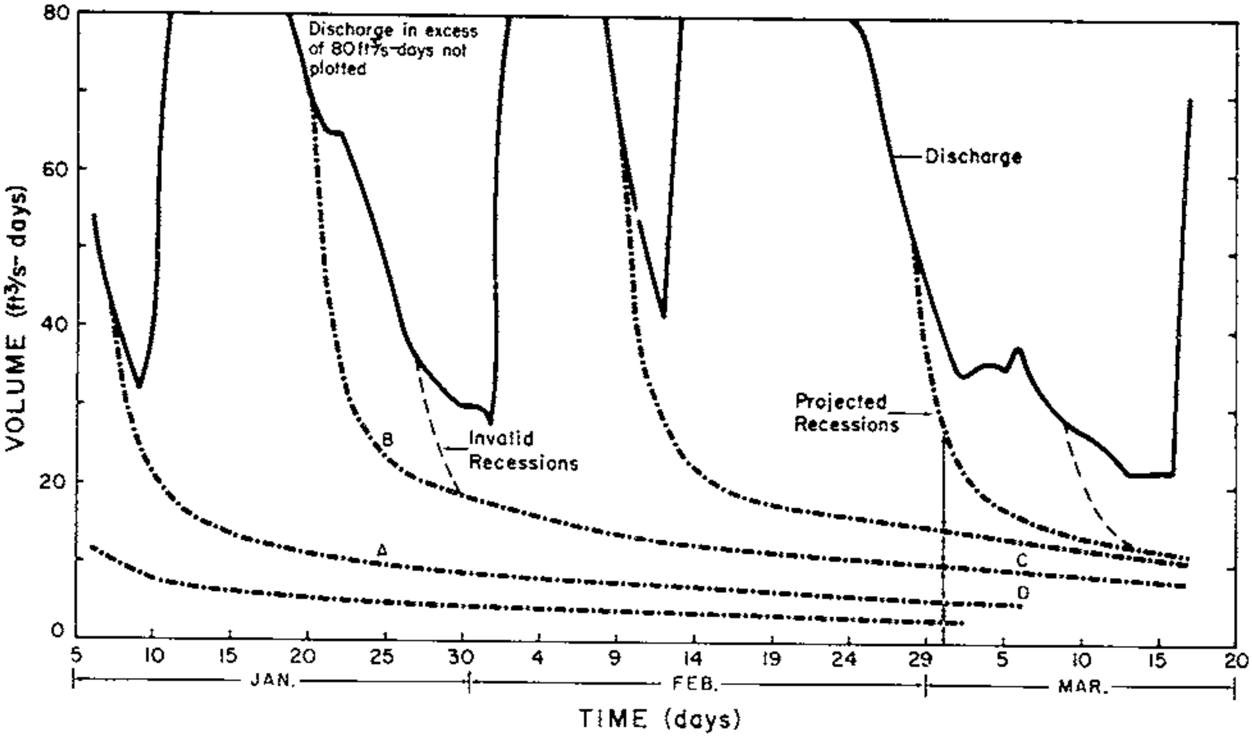

FIGURE 6.62.—Successive predicted recessions during recharge period, watershed W–A1.

the greatest change in stage was only 7 feet (well 7). In addition to showing the minimum and the maximum stages, table 6.16 also shows the minimum and the maximum values of the four parameters for the seven wells. It is apparent from these data that the minimum and the maximum values of parameter 3 closely approximate the minimum and the maximum well stages, respectively. Parameter 4 values are just slightly less than those of parameter 3.

Results achieved with the ground-water-recession analysis have been less satisfactory than

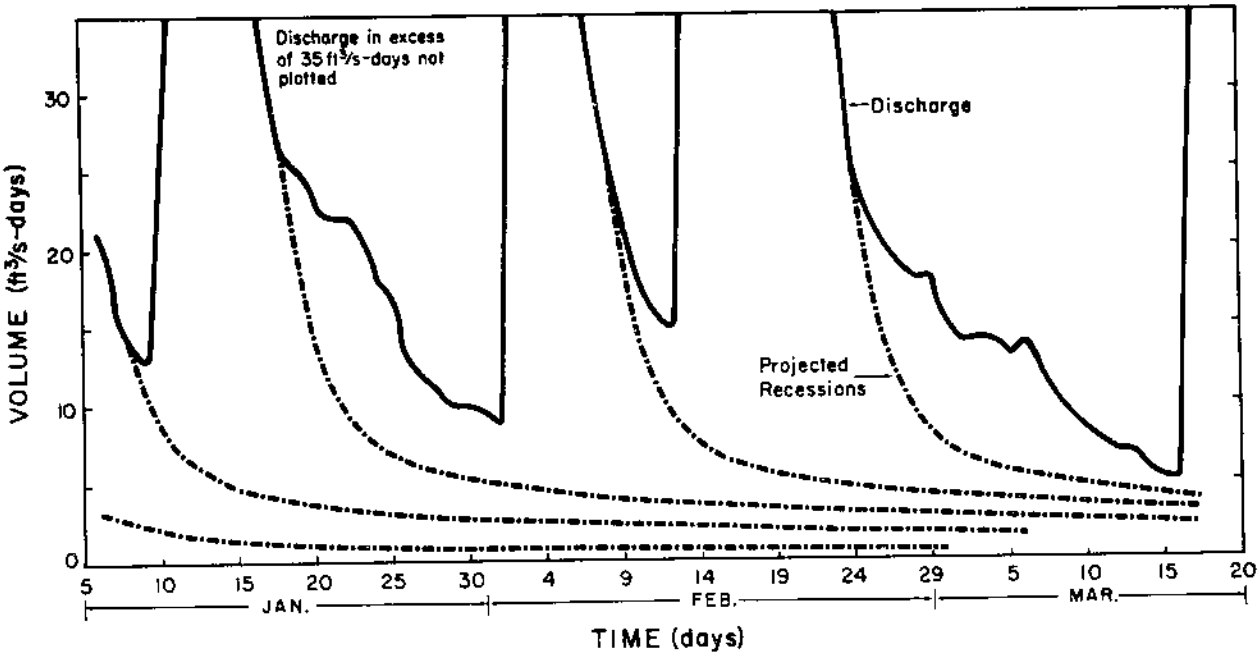

FIGURE 6.63.—Successive predicted recessions during recharge period, watershed W–A2.

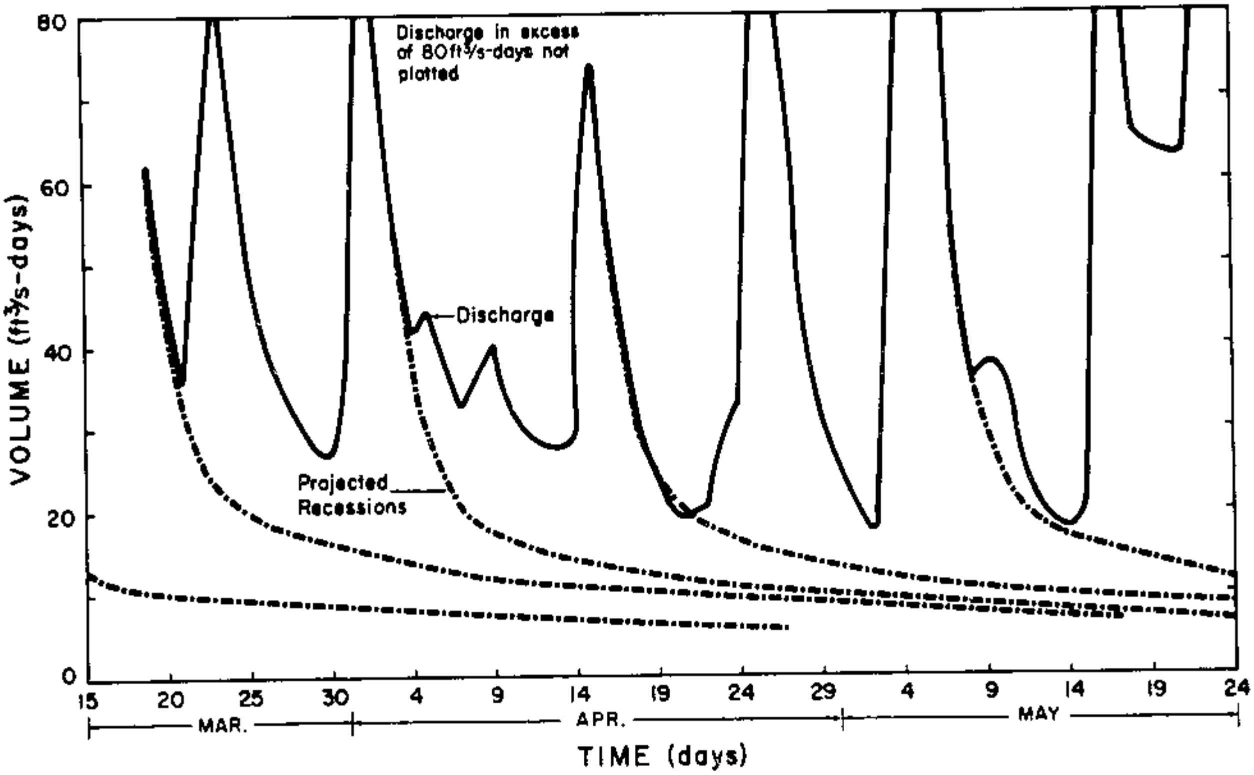

FIGURE 6.64.—Successive predicted recessions during nonrecharge period, watershed W–A1.

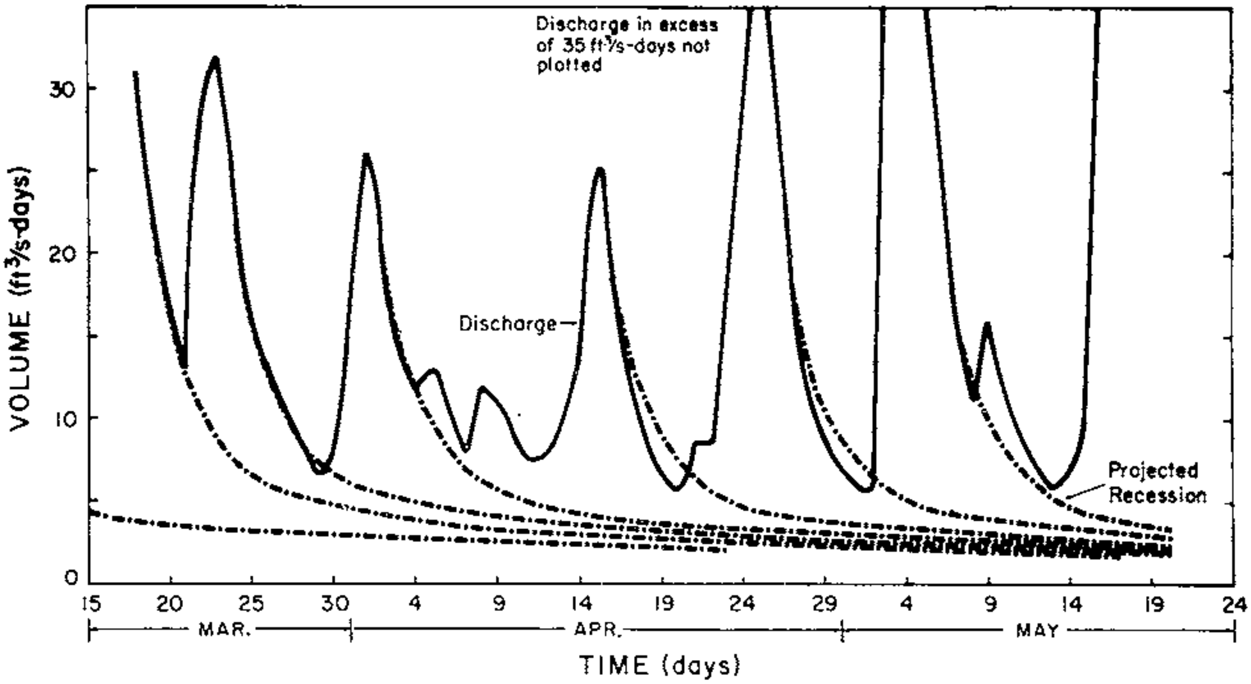

FIGURE 6.65.—Successive predicted recessions during nonrecharge period, watershed W–A2.

those obtained with the streamflow-recession model, indicating that this model requires further development and testing before being applied in prediction.

6.3.3.—Prediction

Verification testing of the model had three primary objectives: (1) to match predicted recessions with observed data, (2) to demonstrate recessions that may and those that may not receive significant contributions from ground-water recharge, and (3) to extend recessions from consecutive storms in order to separate the recession-flow volumes attributable to each storm period, thus facilitating a more complete and accurate hydrograph analysis. Flow data that had not been used in model development were utilized in testing.

Figures 6.60 and 6.61 illustrate the closeness of the fit of the predicted recessions of 10 and 15 days, respectively, as well as the smoothness of the predicted recessions. Recession analysis is used to define the portion of runoff that does not occur as rapid runoff and that may derive from ground water. This capability makes recession analysis a vital component of the water-yield model discussed earlier. Figures 6.62 and 6.63 depict a series of runoff events of watersheds W–A1 and W–A2, respectively, in which the several recessions separate periods of significant recharge. Recessions for a number of consecutive storms are each projected ahead for 60 days. In these figures, the volume of flow represented by the area between any two consecutive recession curves comes from ground water recharged during the associated storm.

In contrast, figures 6.64 and 6.65 illustrate a series of runoff events for the same watersheds in which there is little recharge during the events. The recessions are extended for 60 days in the same manner as in the preceding two figures. However, the successive recession curves tend to converge, indicating that little recharge occurred during the storms.

Also illustrated in figures 6.62–6.65 is the ability to separate flow at any given point or for a desired period into those portions attributable to specific storms. For example, in figure 6.62, the flow volume on March 1 may be readily subdivided into contributions from five distinct major storm events. Further, a total recession volume such as ABCD may be assumed to result from the rainfall causing the hydrograph rise beginning January 10. This method of flow subdivision may be applied to

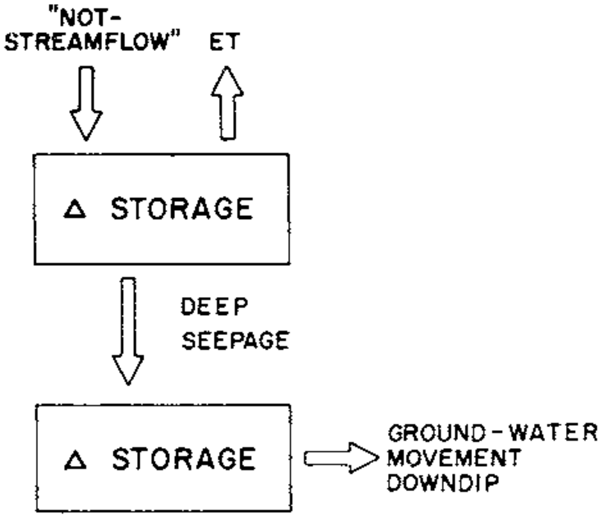

FIGURE 6.66.—Schematic of ground-water-response model.

any period desired. Although the recessions in these figures were computed for 60 days, they may be readily extended.

The beginning points of the calculated recessions in figures 6.62–6.65 were chosen on the true recessions of major events. These were the types of events used in quantification of parameters and therefore the logical types to use in verification. Recessions calculated with initial points on minor storms lying on the recessions of major storms are not valid. Such invalid calculations are illustrated by the dashlines beginning on January 27 and March 9 in figure 6.62.

6.4.—GROUND-WATER SIMULATION MODELING

A parametric ground-water (well-response) model was formulated as a complement to the 5-day water-yield model to put together an integrated hydrologic model package. Initially, a 2-tier model was developed (fig. 6.66). Input to the model is the "not streamflow" portion of the precipitation from the 5-day water-yield model, that is, the portion of the precipitation not moving past the stream gage. The "not streamflow" was partitioned into ET—the change in storage in the first layer (surficial aquifer)—and deep seepage to the Yorktown aquifer. The input to the deeper aquifer was divided into the change in aquifer storage (indicated by ground-water-well elevation) and ground-water movement downdip.

The conceptual model was programed and run on a trial basis. Simulation using 4 years of climatic data, with some parameter manipulation, produced generally satisfactory predicted well response. However, the modeling effort is still in the developmental stage, and results are insufficient to warrant presentation.

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APPENDIX.—DATA SUMMARY

TABLE A–1.—*Geologic units and their water-bearing characteristics in the Greenville and Ahoskie Creek, N.C., areas*

System	Series	Formation and Members		Description	Hydrologic Properties
Quaternary	Pleistocene and Recent	Surficial Deposits (P) 1/		Light colored fine to coarse-grained sheet sand with interbedded clay. Occasional marl and shell beds are present.	Supplies groundwater to shallow dug and driven wells. Small yield per well but has excellent water-bearing properties. Water contains large amount of iron and may be corrosive.
Tertiary	Miocene	Upper	Yorktown formation (P)	Light colored sandy shell beds and marls in upper part. Lower part consists of blue-gray marl & shell beds, & massive interbedded clay	Lenticular sand and shell beds supply small to moderate amounts of water for domestic and farm use. In northeastern section of the Greenville area this aquifer is under artesian pressure.
		Middle	Rocks of Calvert Age (A)	Brown to chocolate-colored phosphatic sands and sandy silts containing collophane and quartz with shell-limestone.	Not extensively developed as an aquifer. Running sands, which clog screens is a common complaint of well drillers. Potential yield and quality good.
	Eocene	Middle and Late Claiborne & Jackson	Castle Hayne limestone (A)	White to gray sand and marl. Sandy calcitic and dolomitic shell-limestone prominent. Glauconite, pyrite, and phosphate occurs as accessories.	Calcareous sands and shell limestones, supply water to artesian wells. High permeability and large potential yield throughout. Good municipal and industrial supply. Water generally hard and may contain H_2S.
	Paleocene	Midway Age	Beaufort formation (P)	Variable in composition ranging from green glauconite sands to gray argillaceous sands. Pyrite occurs as a common accessory.	Supplies small to moderate amounts of artesian water. Water is soft, high in sodium bicarbonate, and may contain excessive fluoride.

TABLE A-1.—*Geologic units and their water-bearing characteristics in the Greenville and Ahoskie Creek, N.C., areas*—Continued

Cretaceous	Upper Cretaceous	Navarro Age 2/	Pedee formation (P)		Dark-gray coarse-grained glauconite sands in upper part. Drab black massive marine clays in lower part.	Sand beds are good aquifers and supply municipal, industrial, domestic and farm use. Water is good quality.
		Austin and Taylor Age 2/	Black Creek Formation	Snow Hill Marl member (P)	Black to gray interbedded clays and marls. Marls are locally indurated to form impure shell-limestones.	Supplies fair to moderate amounts of water to domestic and farm wells.
				Unnamed member (P)	Gray to black micaceous sands and clays, thinly bedded to massive; variable amounts of lignite, marcasite, and glauconite. Cross bedding is prominent.	Sand beds in the formation yield large supplies to industrial, municipal, domestic, and farm wells. Contains some saline water.
		Woodbine & Eagle Ford Age	Tuscaloosa formation (P)		Tan, red, and gray arkosic sands and interbedded clays. Hematite is a common accessory mineral. Massive to lenticular aspect in all sections.	A good aquifer. Some saline water, otherwise it is good quality.
	Lower Cretaceous	Trinity Age	Sand and Clay (?)		Green clay and tan sand. Mica is common.	Contains saline water.

1/ P - Present in the Ahoskie Creek Watershed area
A - Absent in the Ahoskie Creek Watershed area

2/ All the Upper Cretaceous formations are grouped together and are reported in this report as undifferentiated.

TABLE A–2.—*Soil description, erosion classes, and land capability classes, watershed W–A1*

LOCATION: Hertford, Bertie, and Northampton Counties, North Carolina; approximately 3/4 mile southwest of Ahoskie; Chowan River Basin.

AREA: 36,480 acres. (57.0 sq. miles)

SLOPES:

Slope-Percent	0-2	2-6	6-10
Percent of area	95	4	1

SOILS: Derived from moderately fine textured sediments.

		Topsoil			Subsoil		Substratum		
Type	Percent of area	Avg. depth (in.)	Structure	Permeability	Structure	Permeability	Avg. depth to(in.)	Permeability	Internal drainage
Coxville fine sandy loam, silt loam	41	8	Weak fine granular	Moderate	Moderate medium subangular blocky	Slow	38	Slow	Slow
Lenoir fine sandy loam, silt loam	22	7	Weak fine granular	Moderate	Moderate medium angular blocky	Slow	36	Slow	Slow to very slow
Craven fine sandy loam	15	12	Weak fine granular	Moderate	Moderate medium subangular blocky	Slow	42	Slow	Medium
Chastain clay loam	8	9	Moderate medium subangular blocky	Moderate	Moderate medium angular blocky	Slow	60	Slow	Slow to very slow
Marlboro fine sandy loam	4	9	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderately slow	32	Moderately slow	Medium
Duplin fine sandy loam	3	8	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderately slow	34	Moderately slow	Medium
Dunbar fine sandy loam	2	15	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderately slow	30	Moderately slow	Slow
Caroline fine sandy loam	2	12	Weak fine granular	Moderate	Moderate medium angular blocky	Slow	31	Slow	Medium
Norfolk loamy fine sand, sandy loam	2	12	Weak fine granular	Moderate	Weak medium subangular blocky	Moderate	36	Moderate	Medium
Faceville fine sandy loam	1	10	Weak fine granular	Rapid	Moderate medium subangular blocky	Moderate	28	Moderately slow	Medium

EROSION:

Erosion class	1	2
Percent of area	96	4

LAND CAPABILITY:

Class	I	II	III	IV	V
Percent of area	5	23	63	8	1

TABLE A-3.—*Soil description, erosion classes, and land capability classes, watershed W–A2*

LOCATION: Hertford, Bertie, and Northampton Counties, North Carolina; approximately 5 miles northwest of Aulander; Chowan River Basin.

AREA: 15,360 acres (24.0 sq. miles)

SLOPES:

Slope-Percent	0-2	2-6
Percent of area	97	3

SOILS: Derived from moderately fine textured sediments.

Type	Percent of area	Topsoil			Subsoil		Substratum		
		Avg. depth (in.)	Structure	Perme-ability	Structure	Perme-ability	Avg. depth to(in.)	Perme-ability	Internal drainage
Coxville fine sandy loam, silt loam	48	8	Weak fine granular	Moderate	Moderate medium subangular blocky	Slow	38	Slow	Slow
Lenoir fine sandy loam, silt loam	24	7	Weak fine granular	Moderate	Moderate medium angular blocky	Slow	36	Slow	Slow to very slow
Craven fine sandy loam	10	12	Weak fine granular	Moderate	Moderate medium subangular blocky	Slow	42	Slow	Medium
Chastain clay loam	4	9	Moderate medium subangular blocky	Moderately slow	Moderate medium angular blocky	Slow	60	Slow	Slow to very slow
Marlboro fine sandy loam	4	9	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderate	32	Moderate	Medium
Duplin fine sandy loam	3	8	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderate	34	Moderate	Medium
Norfolk loamy fine sand, sandy loam	3	12	Weak fine granular	Moderate	Weak medium subangular blocky	Moderate	36	Moderate	Medium
Dunbar fine sandy loam	2	15	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderate	30	Moderately slow	Slow
Caroline fine sandy loam	1	12	Weak fine granular	Moderate	Moderate medium angular blocky	Slow	31	Slow	Medium
Faceville fine sandy loam	1	10	Weak fine granular	Rapid	Moderate medium subangular blocky	Moderate	28	Moderately slow	Medium

EROSION:

Erosion class	1	2
Percent of area	99	1

LAND CAPABILITY:

Class	I	II	III	IV
Percent of area	5	18	72	5

TABLE A–4.—*Soil description, erosion classes, and land capability classes, watershed W–A3*

LOCATION: Northampton County, North Carolina, approximately 3 miles southeast of Rich Square; Chowan River Basin.

AREA: 2,368 acres (3.70 sq. miles)

SLOPES: 100% of area in 0-2% class

SOILS: Derived from moderately fine textured sediments.

		Topsoil			Subsoil		Substratum		
Type	Percent of area	Avg. depth (in.)	Structure	Perme-ability	Structure	Perme-ability	Avg. depth to(in.)	Perme-ability	Internal drainage
Coxville fine sandy loam, silt loam	70	8	Weak fine granular	Moderate	Moderate medium subangular blocky	Slow	38	Slow	Slow
Lenoir fine sandy loam, silt loam	20	7	Weak fine granular	Moderate	Moderate medium angular blocky	Slow	36	Slow	Slow to very slow
Chastain clay loam	4	9	Moderate medium subangular blocky	Moderately slow	Moderate medium angular blocky	Slow	60	Slow	Slow to very slow
Craven fine sandy loam	2	12	Weak fine granular	Moderate	Moderate medium subangular blocky	Slow	42	Slow	Medium
Marlboro fine sandy loam	2	9	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderate	32	Moderate	Medium
Caroline fine sandy loam	2	12	Weak fine granular	Moderate	Moderate medium angular blocky	Slow	31	Slow	Medium

EROSION:

Erosion class	1	2
Percent of area	99	1

LAND CAPABILITY:

Class	I	II	III	IV
Percent of area	2	4	90	4

TABLE A–5.—*Soil description, erosion classes, and land capability classes, watershed W–A4*

LOCATION: Hertford County, North Carolina; approximately 2 miles southwest of Ahoskie; Chowan River Basin.

AREA: 1,664 acres (2.60 sq. miles)

SLOPES:

Slope-Percent	0-2	2-6
Percent of area	89	11

SOILS: Derived from moderately fine textured sediments.

Type	Percent of area	Topsoil			Subsoil		Substratum		Internal drainage
		Avg. depth (in.)	Structure	Permeability	Structure	Permeability	Avg. depth to (in.)	Permeability	
Coxville fine sandy loam, silt loam	36	8	Weak fine granular	Moderate	Moderate medium subangular blocky	Slow	38	Slow	Slow
Craven fine sandy loam	25	12	Weak fine granular	Moderate	Moderate medium subangular blocky	Slow	42	Slow	Medium
Lenoir fine sandy loam, silt loam	18	7	Weak fine granular	Moderate	Moderate medium angular blocky	Slow	36	Slow	Slow to very slow
Duplin fine sandy loam	4	8	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderate	34	Moderate	Medium
Dunbar fine sandy loam	4	15	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderate	30	Moderately slow	Slow
Caroline fine sandy loam	4	12	Weak fine granular	Moderate	Moderate medium angular blocky	Slow	31	Slow	Medium
Bibb fine sandy loam	4	28	Weak medium granular	Moderate	Structureless	Moderately slow	40	Slow	Slow
Marlboro fine sandy loam	3	9	Weak fine granular	Moderate	Moderate medium subangular blocky	Moderate	32	Moderate	Medium
Norfolk loamy fine sand, sandy loam	2	12	Weak fine granular	Moderate	Weak medium subangular blocky	Moderate	36	Moderate	Medium

EROSION:

Erosion class	1	2
Percent of area	92	8

LAND CAPABILITY:

Class	I	II	III	IV	V
Percent of area	3	40	53	0	4

TABLE A–6.—*Soil tests on samples from Ahoskie Creek watershed*[1]

Sample No.	Station	Channel side	Depth (ft)	Sample type[2]	Unified class	Mechanical analysis	Atterberg limits		Dry density (g/cm³)	Specific gravity	Dispersion (percent)	Shear unconfined compression	Permeability (ft/day)	Linear shrinkage (percent)	X-ray diffraction analysis	Kaolinite (percent)	Montimorillonite (percent)
							Lower	Plasticity index									
1	1,062+41	R	8.3–9.3	UD	SM	x	(3)	(3)	1.59	2.66	...	...	0.18	25.2	...	...	...
2	1,062+41	R	6.2–8.0	UD	CL	x	28	10	1.61	2.67	90	688	...	24.7	...	...	...
3	1,065+92	R	6.0–8.0	UD	CL	x	28	10	1.56	2.66	26	538	...	26.4	...	...	...
4	1,076+80	R	6.0–8.0	UD	CL	x	37	14	1.46	2.59	68	1,625	.0085	29.9	...	...	...
5	1,000+41	L	6.0–7.5	UD	SM	x	(3)	(3)	1.35	2.62	...	...	...	35.9	...	...	...
6	999+16	L	17.0–18.7	UD	SM	x	(3)	(3)	1.39	2.69	...	...	...	34.6	...	...	...
7	996+66	L	5.0–6.4	UD	MH	...	...	...	...	...	...	...	...	...	...	...	...
8	995+41	L	5.0–6.1	UD	SM	x	(3)	(3)	.36	2.41	50	...	...	...	...	...	...
9a	995+41	L	9.3	UD	CL–ML	x	23	5	1.50	2.65	...	325	.02	28.9	...	...	...
9b	995+41	L	11.5	UD	SP–SM	x	(3)	(3)	1.47	2.63	...	...	...	30.0	...	...	...
10	503+59	L	3.6–5.2	UD	CL	x	37	15	1.20	2.55	80	813	...	44.1	...	...	...
11	503+59	L	6.5–8.5	UD	SM	x	(3)	(3)	1.80	2.67	...	...	...	18.1	...	...	...
12	503+59	L	13.4–15.7	UD	SP–SM	x	(3)	(3)	1.58	2.65	...	...	...	25.6	...	...	...
13	488+39	R	6.5–8.6	UD	CL–ML	x	23	7	1.74	2.67	85	825	.0046	20.0	...	...	...
14	493+39	R	5.0–7.3	UD	MH	x	80	35	.93	2.37	80	675	...	68.9	...	...	...
15	493+39	R	9.6–11.5	UD	SP–SM	x	(3)	(3)	1.52	2.66	...	...	...	28.1	...	...	...
16a	222+07	L	8.5	UD	SC–SM	x	19	4	1.77	2.68	64	288	...	19.2	...	...	...
16b	222+07	L	10.6	UD	CH	x	59	29	1.50	2.69	69	1,225	...	29.6	...	...	...
17	1,097+18	L	6.5–8.4	UD	SM	x	(3)	(3)	1.48	2.65	...	...	...	29.8	...	...	...
18	1,150+84	R	6.5–7.9	UD	MH	x	68	18	.37	2.20	67	...	...	...	...	...	...
19	1,074+76	L	9.5–11.5	UD	SC–SM	x	19	5	1.45	2.63	62	...	...	31.0	...	...	...
20	499+59	L	8.0–9.0	UD	CL–ML	x	22	6	1.77	2.68	...	...	...	19.2	...	...	...
21	488+39	R	4.2–5.9	D	CH	x	53	26	...	...	...	...	...	...	...	...	...
22	493+39	R	5.5–6.0	D	MH	x	76	37	...	...	...	...	...	...	...	...	...
23	1,048+60	L	1.8–3.0	D	ML	x	48	19	...	...	...	...	...	...	...	...	...
24	936+15	L	6.6–8.5	D	CL	x	45	20	...	...	...	...	...	...	...	...	...
25	499+59	L	9.6–13.2	D	CL–ML	x	25	7	...	...	...	...	...	...	...	...	...
26	996+66	L	13.0–14.0	D	ML	x	29	6	...	...	...	...	...	...	...	...	...
27	499+59	L	4.0–5.0	D	CL–ML	x	22	6	...	...	...	...	...	...	...	...	...
28	1,074+76	L	3.7–5.8	D	MH	x	62	29	...	...	...	...	...	...	...	...	...
29	499+59	L	4.5–5.2	D	CL	x	26	8	...	...	...	...	...	...	...	...	...
30	996+16	R	12.0–13.0	D	CL	x	46	21	...	...	...	...	...	...	...	...	...
31	996+66	L	3.5–4.0	D	MH	x	58	22	...	...	...	...	...	...	...	...	...
32	1,150+84	R	12.0–12.5	D	SW–SM	x	(3)	(3)	...	...	...	...	...	...	...	...	...
33	1,074+76	...	(4)	D	SP	x	(3)	(3)	...	...	...	...	...	...	...	...	...
34	1,065+92	...	(4)	D	SP	x	(3)	(3)	...	...	...	...	...	...	...	...	...
35	499+59	...	(4)	D	SP	x	(3)	(3)	...	...	...	...	...	...	...	...	...
36	222+07	L	1.5–10.0	D	CH–MH	x	54	25	...	...	...	...	...	...	x	65	35
37	222+07	R	4.4–9.0	D	CL	x	49	23	...	...	...	...	...	...	x	50	25
38	366+50	R	2.5–3.0	D	MH	...	...	...	...	...	...	...	...	...	x	65	30
39	366+50	R	...	D	CL	...	...	...	...	...	...	...	...	...	x	50	50

40	999+16	R	...	D	CL	...	...	...	...	...	...	...	...	...	x	45	55
41	935+00	L	2.0–3.0	D	MH	...	...	...	...	...	...	...	...	...	x	60	40

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[1] Samples taken and analyzed by SCS. [2] D=disturbed; UD=undisturbed. [3] Nonplastic. [4] Bedload.

TABLE A–7.—*Ground-water wells, Ahoskie Creek watershed*

[Feet]

Well	Aquifer	Elevation		
		Ground surface (m.s.l.)	Depth screened below ground surface	Elevation of screen (m.s.l.)
1	Surficial	75.9	15–20	60.9–55.9
2	Yorktown	70.1	39–44	31.1–26.1
[1]3	Surficial	58.2	28–33	30.2–25.2
4	Surficial	71.5	23–28	48.5–43.5
5	Yorktown	66.7	54.5–59.5	12.2–7.2
6	Surficial	45.5	15–20	30.5–25.5
7	Yorktown	63.0	50–55	13.0–8.0
8	Tuscaloosa	46.9	145–150	98.1–103.1

[1] Records discontinued; well not responding.

TABLE A–8.—*Monthly and annual maximum rainfall amounts by selected time intervals, rain gage 3, Ahoskie Creek watershed, 1964–72*

Month	Rainfall-measuring interval											
	15-minute		30-minute		1-hour		2-hour		6-hour		24-hour	
	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches
	1964											
June	13	0.53	13	0.68	13	0.88	13	0.88	13	1.03	13	1.12
July	9	.63	9	1.00	9	1.05	9	1.05	28	1.44	28	2.00
August	29	.90	3	1.35	3	1.81	3	1.85	3	2.35	3	2.73
September	11	.36	11	.40	13	.55	13	.99	13	2.10	12	3.75
October	4	.15	4	.21	4	.35	4	.56	4	1.13	4	2.08
November	20	.21	20	.24	20	.27	11	.54	25	1.00	25	1.00
December	26	.40	26	.68	26	.95	26	1.14	26	1.68	26	2.65
Annual Maximum	Aug. 29	.90	Aug. 3	1.35	Aug. 3	1.81	Aug. 3	1.85	Aug. 3	2.35	Sept. 12	3.75
	1965											
January	17	0.20	17	0.22	17	0.30	17	0.35	30	0.40	30	0.60
February	25	.22	25	.25	25	.38	14	.50	14	.85	14	1.30
March	17	.32	17	.45	17	.45	4	.65	17	.75	17	.87
April	27	.25	27	.50	27	.70	27	.75	27	.85	27	1.70
May	27	.35	27	.47	27	.65	27	.76	27	1.13	27	1.35
June	11	.17	11	.23	11	.37	11	.68	11	1.28	11	1.65
July	11	1.00	11	1.76	11	2.95	11	3.43	11	4.05	10	4.35
August	22	.80	22	.95	22	.95	1	.88	1	1.10	10	1.10
September	11	.38	11	.45	11	.60	11	.77	11	.85	11	.85
October	7	.25	7	.25	7	.25	7	.39	7	.80	7	1.00
November	22	.05	21	.10	21	.10	22	.15	22	.25	21	.60
December	25	.08	25	.12	25	.21	25	.22	12	.31	12	.31
Annual Maximum	July 11	1.00	July 11	1.76	July 11	2.95	July 11	3.43	July 11	4.05	July 10	4.35
	1966											
January	27	0.25	27	0.25	27	0.25	26	0.27	22	0.66	22	1.25
February	28	.15	28	.30	28	.50	28	.64	28	1.10	24	1.70
March	4	.34	19	.50	4	.67	4	.98	4	1.38	4	1.60
April	14	.12	14	.14	14	.15	4	.20	4	.25	4	.35
May	29	.70	29	1.04	29	1.09	29	1.34	29	1.45	14	1.60
June	19	.12	19	.25	19	.39	10	.52	19	1.10	16	1.60
July	30	.35	30	.35	30	.59	30	.95	30	1.14	30	1.41
August	15	.98	15	1.45	15	1.71	15	1.83	15	1.89	15	2.06
September	28	.51	28	.54	28	.60	19	.56	19	1.10	19	1.73
October	10	.12	10	.17	1	.25	1	.25	1	.37	1	.37
November	1	.52	1	.72	1	.74	1	.80	1	.80	1	.80
December	13	.10	13	.20	13	.35	13	.65	13	1.47	13	1.63
Annual Maximum	Aug. 15	.98	Aug. 15	1.45	Aug. 15	1.71	Aug. 15	1.83	Aug. 15	1.89	Aug. 15	2.06
	1967											
January	8	0.27	8	0.45	8	0.62	8	1.10	8	2.52	7	3.45
February	9	.08	9	.14	9	.22	9	.30	9	.65	9	1.00
March	21	.04	21	.07	21	.10	21	.20	21	.50	21	.85
April	22	.51	22	.63	22	.67	22	.67	22	.67	22	.67
May	28	.37	28	.48	28	.48	28	.48	28	.48	28	.58
June	18	.90	18	1.48	18	2.33	18	2.33	18	3.10	18	3.75
July	15	.69	15	.93	15	.93	15	.93	15	1.00	15	1.50

See footnotes at end of table.

TABLE A–8.—*Monthly and annual maximum rainfall amounts by selected time intervals, rain gage 3, Ahoskie Creek watershed, 1964–72*—Continued

Month	Rainfall-measuring interval											
	15-minute		30-minute		1-hour		2-hour		6-hour		24-hour	
	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches
						1967—Continued						
August	21	.58	21	.68	21	.73	11	.42	21	1.50	21	2.15
September	10	.18	10	.35	10	.49	10	.62	10	1.03	9	2.08
October	25	.90	25	1.02	25	1.02	25	1.02	25	1.02	25	1.02
November	23	.14	23	.21	23	.31	23	.42	24	.47	23	.58
December	22	.18	22	.35	22	.44	22	.63	22	1.13	22	1.25
Annual Maximum	June 18	.90	June 18	1.48	June 18	2.33	June 18	2.33	June 18	3.10	June 18	3.75
						1968						
January	14	0.30	14	0.39	14	0.57	14	0.79	13	1.10	13	1.80
February	2	.08	2	.14	2	.25	29	.27	29	.55	29	.65
March	17	.30	17	.56	17	.71	17	1.00	17	1.56	17	3.00
April	24	.24	5	.30	5	.50	5	.62	5	1.45	5	1.75
May	12	.88	12	1.12	12	1.15	5	.56	12	1.15	26	1.70
June	27	.93	27	1.40	27	1.63	6	1.90	27	2.05	27	2.05
July	27	.63	19	.70	11	1.07	3	1.26	3	1.65	3	1.87
August	14	.28	14	.28	14	.28	14	.35	14	.35	14	.35
September	6	.75	6	.75	6	.80	6	.88	6	.90	6	.90
October	19	.43	7	.50	7	.96	7	1.20	18	1.05	19	1.58
November	10	.18	10	.21	10	.35	10	.62	10	1.04	9	1.33
December	28	.13	28	.19	28	.22	22	.32	28	.35	28	.79
Annual Maximum	June 27	.93	June 27	1.40	June 27	1.63	June 6	1.90	June 27	2.05	Mar. 17	3.00
						1969						
January	19	0.05	19	0.09	19	0.14	20	0.25	20	0.48	20	1.41
February	23	.09	1	.16	1	.24	23	.50	1	1.01	1	1.50
March	7	.11	7	.13	6	.23	7	.40	6	.90	1	1.65
April	5	.16	18	.24	18	.29	18	.35	18	.35	5	.75
May	19	.52	19	.72	25	1.04	25	1.38	19	1.38	19	1.40
June	2	.55	2	.55	2	.55	19	.75	19	.80	18	1.65
July	6	.88	6	1.76	6	2.31	6	2.35	6	2.40	6	3.45
August	3	.53	3	.54	3	.55	15	.59	3	.90	3	1.65
September	17	.66	17	1.10	17	1.10	17	1.10	17	2.80	17	3.00
October	2	.70	2	.97	2	1.48	2	2.42	2	3.10	2	4.20
November	19	.10	19	.12	2	.24	2	.50	2	1.18	1	1.25
December	10	.27	10	.39	10	.50	10	.90	10	.90	10	1.15
Annual Maximum	July 6	.88	July 6	1.76	July 6	2.31	Oct. 2	2.42	Oct. 2	3.10	Oct. 2	4.20
						1970						
January	30	0.17	30	0.38	30	0.43	30	0.50	29	0.74	29	1.15
February	9	.15	3	.19	3	.37	17	.58	3	1.35	3	1.70
March	31	.22	31	.33	31	.42	31	.71	31	1.28	30	1.45
April	26	.14	14	.28	14	.55	14	1.04	13	1.05	13	2.03
May	26	.25	26	.31	26	.46	26	.55	26	.80	25	1.35
June	21	.80	21	.81	5	1.59	5	1.58	5	1.85	26	1.90
July	10	.70	30	.85	30	1.00	7	.90	30	1.00	30	1.05
August	10	.15	23	.26	23	.40	8	.40	10	.66	10	1.15
September	4	.35	4	.35	27	.38	27	.53	27	1.05	27	1.50

See footnotes at end of table.

TABLE A-8.—*Monthly and annual maximum rainfall amounts by selected time intervals, rain gage 3, Ahoskie Creek watershed, 1964–72*—Continued

Month	Rainfall-measuring interval											
	15-minute		30-minute		1-hour		2-hour		6-hour		24-hour	
	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches	Day[1]	Inches
	1970—Continued											
October	16	.25	16	.45	16	.75	22	.90	23	1.47	22	2.45
November	10	.55	10	.63	10	.80	10	.94	10	1.18	10	1.55
December	16	.14	16	.20	16	.34	16	.56	16	1.15	16	1.50
Annual Maximum	June 21	.80	July 30	.85	June 5	1.59	June 5	1.58	June 5	1.85	Oct. 22	2.45
	1971											
January	5	0.20	5	0.24	5	0.33	5	0.49	5	0.95	5	1.13
February	22	.50	22	.70	22	.78	22	1.03	22	1.22	13	1.30
March	19	.30	15	.35	15	.36	15	.42	3	.52	3	1.47
April	6	.09	6	.14	6	.19	6	.33	6	.74	6	1.45
May	13	.20	13	.36	13	.42	13	.63	13	.92	13	1.25
June	15	[2].31	15	[2].69	15	[3].95	(4)	(4)	15	[3].95	15	[3]1.12
July	2	.60	2	.81	2	1.02	2	1.12	2	1.22	2	1.22
August	22	.88	22	1.05	22	1.37	8	.43	22	1.67	22	1.67
September	12	.34	12	.60	12	.73	12	.98	12	1.25	30	[5]5.00
October	23	[6].31	23	[6].43	23	[6].47	1	1.12	23	[6]1.25	22	[7]2.93
November	24	.35	24	.39	24	.44	24	.50	24	.49	24	.49
December	20	.04	20	.08	20	.18	20	.25	20	.23	20	.45
Annual Maximum	Aug. 22	.88	Aug. 22	1.05	Aug. 22	1.37	July 2	1.12	Aug. 22	1.67	Sept. 30	5.00
	1972											
January	13	0.32	13	0.45	13	0.55	13	0.71	13	1.07	13	1.23
February	19	.11	19	.18	19	.28	19	.41	1	.85	1	1.44
March	16	.19	16	.22	16	.28	16	.31	16	.59	16	.75
April	4	.27	4	.29	4	.30	4	.30	24	.54	24	.59
May	31	1.06	31	1.68	31	2.40	31	2.41	31	2.84	31	2.84
June	19	.50	17	.70	17	1.27	17	1.83	17	1.90	17	1.90
July	25	.85	25	.91	25	.92	28	1.10	12	1.86	12	2.39
August	2	.60	2	.62	2	.62	2	.65	2	.62	2	1.05
September	28	.42	28	.63	28	1.00	28	.99	27	1.00	27	1.07
October	6	.43	6	.81	5	1.21	6	1.70	6	2.30	5	2.54
November	8	.39	8	.72	8	.87	8	1.11	8	1.21	8	1.21
December	13	.15	13	.23	13	.37	13	.67	12	1.27	12	1.27
Annual Maximum	May 31	1.06	May 31	1.68	May 31	2.40	May 31	2.41	May 31	2.84	May 31	2.84

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[1] Day of occurrence shown is the day at the beginning of the time interval.

[2] Intensity record lost at rain gage 3; record at rain gage 6 used for intensity adjusted to rain gage 3 daily total.

[3] Intensity record lost at rain gage 3; record at rain gage 6 used to determine daily amounts occurring within time span shown.

[4] No record.

[5] 24-hour period carried over into October 1.

[6] Intensity record lost at rain gage 3; record at rain gage 7 used for intensity adjusted to rain gage 3 daily total.

[7] Intensity record lost at rain gage 3; record at rain gage 7 used to determine daily amounts on October 22 and 23 occurring in a 24-hour period.

TABLE A–9.—*Monthly and annual Thiessen weighted precipitation, watershed W–A1*

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1964	...	...	...	...	...	...	7.01	8.92	6.58	6.38	1.55	4.03	(34.47)
1965	1.74	2.83	3.38	2.06	1.85	5.37	7.58	4.15	3.10	.92	.65	.46	34.09
1966	4.29	4.96	2.66	.95	6.20	3.47	1.72	5.81	2.30	.69	1.35	3.06	37.46
1967	4.45	3.47	.81	1.50	2.41	5.40	4.67	8.10	2.76	1.41	1.52	4.96	41.46
1968	3.96	.97	4.74	3.11	4.56	4.56	6.49	1.65	1.24	3.83	2.98	1.88	39.97
1969	2.24	3.49	4.57	2.56	5.37	4.65	8.07	4.79	5.11	3.98	2.07	4.49	51.39
1970	2.65	3.97	3.78	4.49	2.53	4.25	8.59	1.79	2.58	3.92	1.63	2.32	42.50
1971	3.81	5.10	3.72	2.42	3.95	2.21	3.83	7.47	5.42	7.69	1.20	1.14	47.96
1972	2.76	3.84	2.22	2.27	7.61	3.94	5.82	2.09	3.40	3.32	4.06	3.57	44.90
Average	3.24	3.58	3.24	2.42	4.31	4.23	5.98	4.97	3.61	3.57	1.89	2.87	42.47

TABLE A–10.—*Monthly and annual Thiessen weighted precipitation, watershed W–A2*

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1964	...	...	...	...	...	...	7.04	11.75	7.61	6.42	1.63	4.16	(38.61)
1965	1.80	2.69	3.37	2.10	2.12	5.81	6.77	4.31	3.39	.89	.64	.64	34.32
1966	3.92	4.84	2.54	.95	5.49	3.25	1.49	5.66	2.01	.76	1.64	3.13	35.68
1967	4.18	3.37	.81	1.45	2.02	5.53	4.15	7.77	2.58	1.65	1.42	4.95	39.98
1968	4.53	.93	4.46	3.18	4.26	5.45	5.64	1.83	.68	4.04	2.91	1.61	39.52
1969	2.14	3.28	4.61	2.22	6.48	4.02	8.15	4.11	5.29	3.65	2.03	4.45	50.43
1970	2.57	3.75	3.58	4.38	2.40	4.09	8.47	1.78	2.74	4.09	1.53	2.26	41.64
1971	3.89	4.85	3.47	2.44	3.66	1.82	3.77	6.73	4.75	7.68	1.16	1.14	45.36
1972	2.82	3.93	2.24	2.46	7.59	3.24	4.98	1.57	3.43	2.65	4.08	3.80	42.79
Average	3.13	3.46	3.14	2.40	4.25	4.15	5.61	5.06	3.61	3.53	1.89	2.88	41.22

TABLE A–11.—*Monthly and annual Thiessen weighted precipitation, watershed W–A3*

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1964	...	...	...	...	...	...	7.34	14.03	7.27	6.26	1.57	4.65	(41.12)
1965	2.09	2.75	3.34	2.38	2.06	7.08	5.37	4.48	3.30	.96	.80	.52	35.13
1966	4.41	4.88	2.80	1.07	5.54	3.38	1.34	5.52	1.83	.84	1.53	3.31	36.45
1967	4.22	3.72	.86	1.50	2.31	4.54	3.68	8.40	2.48	1.84	1.59	5.08	40.22
1968	4.37	1.06	3.66	3.58	3.80	5.18	5.48	1.87	.58	4.44	2.95	1.84	38.81
1969	2.19	3.33	4.65	2.06	7.31	4.63	7.83	4.25	5.54	3.35	2.19	4.47	51.80
1970	2.59	3.73	3.58	4.30	2.20	3.64	9.63	1.76	3.33	4.31	1.34	2.29	42.71
1971	3.81	4.54	3.45	2.54	3.48	1.69	4.28	7.71	4.63	8.11	1.17	1.03	46.44
1972	2.61	4.24	2.64	2.86	8.17	3.88	5.61	1.39	3.86	2.55	4.61	4.18	46.60
Average	3.29	3.53	3.12	2.54	4.35	4.25	5.62	5.49	3.65	3.62	1.97	3.04	42.27

TABLE A–12.—*Monthly and annual Thiessen weighted precipitation, watershed W–A4*

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1964	...	...	...	...	...	...	6.54	7.06	4.84	6.13	1.26	4.12	(29.95)
1965	1.45	2.77	3.33	1.79	1.56	4.48	6.30	4.21	3.42	.98	.56	.43	31.28
1966	4.76	4.89	2.85	1.23	7.43	3.50	1.90	5.93	2.73	.63	.90	3.29	40.04
1967	4.48	3.68	.88	2.17	3.16	3.94	5.30	9.92	2.96	.92	1.82	4.79	44.02
1968	2.70	1.08	4.97	3.18	4.94	4.12	7.11	1.20	2.07	3.37	2.85	2	39.59
1969	2.48	3.64	4.69	3.40	4.30	5.34	7.92	6.64	4.95	5.70	2.52	5.35	56.93
1970	3.18	4.61	4.70	5.59	2.82	2.56	11.37	1.73	2.84	3.53	1.49	2.45	46.87
1971	4.47	5.26	4.40	2.82	5.14	3.63	5.89	9.95	6.08	7.18	1.19	1.24	57.25
1972	2.43	3.77	2.52	1.69	7.10	5.02	6.45	2.14	3.62	4.28	4.04	3.19	46.25
Average	3.24	3.71	3.54	2.73	4.56	4.07	6.53	5.42	3.72	3.64	1.85	2.98	45.28

TABLE A–13.—*Monthly and annual rainfall, Elliott Station, Northampton County, N.C.*[1]

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1904	...	...	[2]5.06	0.89	4.16	3.41	4.51	7.33	2.37	1.90	3.83	5.00	38.46
1905	2.72	4.75	2.50	5.45	2.48	5.73	7.08	3.66	3.58	2.17	.81	4.97	45.90
1906	3.19	5.38	5.65	1.46	2.98	5.02	7.98	10.98	1.65	3.46	.87	3.00	48.16
1907	1.10	4.36	5.68	4.20	4.75	6.06	5.35	4.03	2.43	1.10	5.47	5.30	49.83
1908	4.73	5.37	5.37	1.88	3.83	7.74	9.75	7.55	1.47	2.68	1.47	3.23	54.99
1909	2.15	2.75	2.10	7.22	4.10	14.38	2.13	5.88	1.00	1.55	.82	3.08	47.16
1910	3.15	2.96	2.15	4.64	5.04	8.71	3.85	9.40	.73	3.20	1.06	3.71	48.60
1911	3.66	3.02	4.85	3.60	1.41	1.59	6.95	8.90	2.04	2.95	5.72	3.72	48.41
1912	3.12	3.62	4.90	4.20	2.13	5.96	3.93	5.96	4.40	.91	2.50	5.34	46.97
1913	4.04	3.31	4.92	.65	3.73	5.69	8.55	1.34	6.80	4.10	1.60	2.70	47.43
1914	2.62	5.17	3.45	2.22	2.35	3.40	5.08	1.41	3.62	2.00	3.74	5.70	40.76
1915	6.25	3.42	3.54	2.69	7.15	6.05	3.14	3.53	3.30	2.70	1.75	3.46	46.97
1916	3.28	4.42	2.81	2.78	5.30	5.45	8.70	6.55	3.70	3.39	1.54	3.68	51.60
1917	4.31	3.22	4.88	4.06	3.31	7.33	10.11	6.23	9.14	4.20	.64	2.81	60.24
1918	4.51	.95	2.37	6.58	3.88	2.64	5.13	2.60	4.04	1.30	1.95	4.31	40.26
1919	3.45	3.76	2.90	2.15	6.00	5.54	13.08	3.97	1.18	3.41	.22	2.40	48.06
1920	3.87	6.80	6.40	6.40	1.43	4.15	8.75	3.07	2.52	.45	5.27	7.60	56.71
1921	3.38	2.70	3.15	4.66	5.84	1.42	3.10	2.06	4.52	.85	3.03	3.63	38.34
1922	4.60	6.95	7.10	2.79	(3)	(3)	12.52	7.02	.40	4.44	.73	6.70	(53.25)
1923	2.26	4.93	6.65	6.25	1.32	.94	6.40	6.12	6.95	1.90	1.56	1.29	46.57
1924	4.96	5.00	3.17	2.98	4.87	3.96	5.75	9.00	10.82	.96	1.32	3.48	56.27
1925	4.77	2.78	3.50	1.01	2.15	5.53	3.68	1.32	1.75	2.90	3.06	3.41	35.86
1926	3.27	3.92	2.97	2.99	2.24	4.13	2.13	2.31	1.16	1.96	5.65	5.40	38.13
1927	.65	1.21	1.20	3.47	1.15	4.28	3.67	6.12	(3)	4.38	(3)	(3)	(26.13)
1928	(3)	(3)	(3)	5.05	(3)	7.65	7.29	5.78	10.41	(3)	.56	5.34	(42.07)
1929	4.88	5.53	3.37	1.02	5.34	6.40	6.62	2.87	13.49	4.10	2.34	2.72	58.68
1930	3.71	1.44	1.41	.85	1.10	5.53	5.79	.96	2.24	1.83	4.80	5.11	34.77
1931	2.18	2.74	1.66	5.09	4.97	3.61	5.25	4.89	3.49	.30	(2)	4.41	(38.59)
1932	4.47	3.34	4.52	1.94	2.34	9.16	3.02	5.54	3.98	4.98	2.90	5.51	49.70
1933	2.07	3.31	2.49	3.16	3.88	2.86	9.09	2.98	1.89	3.20	1.29	1.50	37.72
1934	1.98	5.62	5.78	4.83	6.26	4.65	6.59	2.79	11.78	1.04	3.66	1.56	56.54
1935	3.05	2.68	5.25	4.59	3.48	2.16	10.67	4.15	5.32	.78	4.28	2.19	48.60

See footnotes at end of table.

TABLE A-13.—*Monthly and annual rainfall, Elliott Station, Northampton County, N.C.*[1] —Continued

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1936	5.28	4.01	5.61	4.45	(3)	5.36	7.96	3.15	4.15	5.88	3.73	5.64	(55.22)
1937	6.66	1.60	3.20	7.68	1.00	3.31	3.16	4.04	6.28	2.75	3.39	1.55	44.62
1938	2.20	1.95	2.71	3.19	3.14	11.40	6.19	2.08	8.73	2.99	2.27	2.67	49.52
1939	4.56	8.33	3.75	6.05	1.62	8.45	9.86	7.01	2.91	3.15	2.70	1.93	60.32
1940	2.70	2.64	2.32	3.29	3.92	1.52	6.90	16.03	3.27	.58	3.91	1.22	48.30
1941	1.95	1.87	3.48	3.15	1.18	6.29	6.63	2.30	.52	2.40	1.02	3.17	33.96
1942	1.54	2.22	5.87	.73	1.12	1.58	5.34	8.86	4.85	6.47	1.03	5.02	44.64
1943	4.54	1.88	4.89	2.67	5.99	5.75	6.35	2.32	2.13	1.65	.70	3.63	42.50
1944	4.30	5.68	6.85	4.74	2.06	3.94	5.02	2.32	6.84	1.27	4.85	2.65	50.52
1945	2.28	5.27	1.30	1.44	2.71	2.64	10.22	3.11	4.70	1.19	2.62	5.50	42.98
1946	3.92	3.75	1.07	4.90	6.40	6.09	8.07	2.61	3.73	2.13	4.75	1.48	48.90
1947	4.38	1.30	3.58	3.73	4.60	5.70	4.59	2.68	5.65	4.08	6.14	2.06	48.49
1948	4.92	5.59	3.61	4.32	5.47	3.16	4.35	5.59	5.30	4.22	10.87	5.13	62.53
1949	1.66	4.04	3.66	2.51	7.29	6.82	6.70	9.87	3.57	4.02	1.96	2.37	54.47
1950	2.98	1.28	3.17	1.30	3.17	4.84	9.11	2.31	4.01	3.58	.72	2.08	38.56
1951	2.05	1.65	3.56	3.37	2.82	6.94	3.10	4.73	1.76	3.48	4.53	2.96	40.95
1952	4.85	7.01	5.50	2.57	3.43	2.99	7.65	6.74	1.46	2.55	3.85	3.27	51.87
1953	1.75	4.82	2.08	5.38	3.30	4.45	4.19	8.02	4.07	.52	3.33	3.70	45.61
1954	8.77	1.80	4.56	1.56	7.20	.32	2.94	7.85	1.01	1.82	2.65	2.74	43.32
1955	2.80	4.08	3.36	2.43	1.74	5.83	4.25	12.78	11.81	1.96	2.77	1.19	55.00
1956	2.07	5.72	4.24	4.78	4.26	2.16	6.18	4.63	6.43	6.71	3.41	2.44	53.03
1957	4.87	4.54	3.89	1.16	1.73	3.45	2.95	2.92	4.40	3.69	6.68	4.82	45.10
1958	4.25	5.61	3.31	5.20	6.72	3.90	4.28	11.50	.46	5.46	1.75	4.24	56.68
1959	1.76	3.17	3.36	5.45	1.52	1.36	10.50	4.16	2.89	12.40	2.36	3.05	51.98
1960	5.30	4.53	3.24	1.84	3.15	3.82	14.10	6.45	10.49	2.34	1.60	2.31	59.17
1961	2.63	4.67	4.21	2.42	6.24	4.86	3.68	2.72	2.07	2.76	2.52	4.06	42.84
1962	6.67	4.50	3.83	1.95	2.96	5.17	4.06	2.01	3.78	.69	5.75	2.58	42.95
1963	3.23	3.84	2.97	1.67	2.02	3.33	.65	1.81	6.97	.64	4.86	2.91	34.90
1964	4.32	4.58	3.48	3.03	1.53	3.48	6.67	7.28	8.48	7.35	1.82	5.24	57.26
1965	1.91	3.17	3.70	2.06	2.37	5.92	7.44	4.81	2.91	.96	.89	.64	36.78
1966	4.71	5.20	2.74	1.63	5.63	4.19	2.08	9.65	2.32	1.19	2.57	3.48	45.39
1967	4.48	3.89	1.07	1.24	2.85	5.21	3.71	9.19	2.84	1.39	2.37	4.82	43.06
1968	4.39	1.15	4.04	4.55	4.17	6.15	4.65	1.90	.51	5.66	3.74	2.14	43.05
1969	2.72	3.72	4.95	2.65	8.62	3.90	7.05	4.85	5.71	3.34	2.25	4.52	54.28
1970	2.89	3.97	4.62	4.28	2.39	3.72	9.32	2.35	2.40	4.06	2.27	2.16	44.43
1971	4.98	5.59	3.84	2.70	4.16	1.78	4.68	6.02	5.07	8.62	1.33	1.06	52.83
1972	3.02	4.75	2.65	2.54	6.23	3.02	5.07	2.21	3.74	2.84	4.70	4.01	44.78
	Mean												
	3.59	3.86	3.77	3.34	3.69	4.76	6.16	5.12	4.34	2.94	2.91	3.52	48.00
	Number of months												
	67	67	68	69	66	68	69	69	67	66	66	67	

[1] Data provided by family of J. T. Elliott, Woodland, N.C. [2] Record began. [3] Data not available.

TABLE A-14.—*Monthly maximum daily rainfall, Elliott Station*

[Inches]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1950	0.72	0.46	0.70	0.50	0.50	1.78	1.88	0.92	1.23	1.82	0.28	0.62
1951	.90	.47	.84	1.25	.73	1.66	.75	1.32	.81	1.44	1.42	.90
1952	1.68	1.76	2.16	1.20	1.38	1.10	1.50	1.24	.93	1.06	1.30	.56
1953	.59	1.00	.66	1.80	1.58	1.98	2.66	1.92	3.12	.24	2.14	1.78
1954	1.98	1.65	.96	.79	1.75	.22	1.58	1.24	.54	1.38	.88	1.10
1955	1.17	1.15	1.09	.73	.55	1.80	1.99	5.92	5.60	.98	.92	.56
1956	.96	.98	.43	1.50	3.14	.86	1.81	1.27	1.52	3.34	1.95	.62
1957	1.26	1.04	.97	.54	.66	1.56	1.80	1.36	1.68	1.75	1.63	1.91
1958	1.63	1.30	1.02	1.38	1.43	2.06	1.45	2.22	.46	1.70	1.40	1.43
1959	.75	1.23	.95	1.80	.93	1.34	2.79	1.91	.73	3.60	1.20	1.25
1960	2.77	1.50	1.15	.96	.97	1.16	3.78	1.84	6.00	1.34	.48	1.37
1961	.83	1.09	1.50	.55	2.11	.94	1.01	.95	.78	1.25	1.31	1.17
1962	1.70	1.64	.89	.57	1.05	1.19	1.12	1.20	1.95	.50	2.70	.77
1963	1.08	1.15	.76	.95	.58	1.15	.21	.47	3.76	.40	1.68	.93
1964	1.15	1.44	2.05	2.77	.57	1.52	1.33	3.07	3.55	2.93	.88	2.04
1965	.83	1.41	.94	.97	1.60	2.21	2.67	2.02	.93	.88	.67	.33
1966	.99	1.84	1.50	.36	1.81	1.69	1.83	3.53	1.30	.87	1.50	1.65
1967	2.70	1.02	.94	.76	.64	4.00	.62	2.01	1.72	.57	.69	1.73
1968	1.43	.76	1.79	1.54	1.43	1.70	1.86	.63	.22	1.75	1.41	.43
1969	1.37	1.43	1.23	.82	3.03	1.79	2.83	2.43	2.45	1.57	1.35	1.62
1970	1.35	1.35	1.68	2.45	1.09	2.02	1.52	1.38	1.47	1.25	.67	1.02
1971	2.29	1.60	1.06	1.68	1.13	.50	.90	1.71	3.40	3.21	.38	.55
1972	1.35	1.61	1.15	.58	1.30	.61	2.25	.85	1.25	1.70	1.71	1.47

TABLE A-15.—*Monthly and annual streamflow, watershed W-A1*

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1950	1.97	0.83	1.07	0.32	0.21	0.15	2.47	0.20	0.49	0.05	0.06	0.14	7.96
1951	.26	.32	.99	.79	.07	.36	.59	.03	.03	.02	.68	.94	5.08
1952	2.83	4.00	5.49	.71	.46	.01	.01	1.13	.02	(1)	.16	.29	15.11
1953	.97	2.90	1.83	.97	.29	.01	.09	.63	.02	.01	.04	.91	8.67
1954	5.43	1.07	1.50	1.53	1.39	.05	(1)	.01	(1)	(1)	.01	.09	11.08
1955	.21	.55	1.44	.22	.04	.10	.08	2.19	6.43	.26	.39	.43	12.34
1956	.71	3.16	3.19	2.25	1.34	.04	.03	.17	.10	1.45	2.52	1.01	15.97
1957	1.01	4.69	3.78	.86	.02	.12	.01	.02	.02	.36	1.18	3.80	15.87
1958	3.66	2.20	3.57	2.26	4.46	.09	.07	1.52	.20	.32	.22	.75	19.82
1959	2.05	2.04	1.66	3.39	.19	.02	1.30	1.45	.78	5.46	.97	2.34	21.65
1960	2.34	5.45	2.16	.82	.33	.07	1.27	2.33	5.18	.69	.12	.54	20.70
1961	1.20	3.19	2.48	1.03	2.29	.27	.60	(1)	(1)	.01	.05	.41	11.54
1962	2.96	2.71	2.80	1.07	.19	.02	.24	(1)	(1)	(1)	.17	.28	10.45
1963	1.83	1.95	2.09	.32	.07	.15	.05	.05	.69	.11	.26	.80	8.37
1964	2.44	2.66	2.07	1.48	.18	.15	.47	.83	2.30	4.40	.37	2.66	20.01
1965	1.38	2.56	2.06	.68	.27	.83	1.84	.72	.19	.13	.10	.11	10.87
1966	.25	2.47	3.43	.34	1.26	.78	.18	.56	.16	.12	.13	.25	11.15
1967	2.89	1.96	.60	.27	.17	.93	.93	3.05	.64	.17	.16	1.74	13.51
1968	3.89	.36	3.62	1.43	.74	.75	1.60	.17	.10	.15	.27	.23	13.30
1969	.97	2.63	4.19	.99	2.20	1.16	1.77	2.48	.68	2.28	.36	2.48	22.20
1970	1.59	3.97	1.95	3.87	.95	.39	1.39	.36	.12	.21	.30	.49	15.58
1971	1.76	4.78	2.60	1.86	.29	.21	.19	.94	.45	6.00	.69	.57	20.34
1972	1.89	3.05	.81	.85	2.49	2.10	.70	.78	.17	.38	.82	2.07	16.11
Average	1.93	2.59	2.44	1.23	.87	.38	.69	.85	.82	.96	.44	1.01	14.25

[1] Trace.

Notes: USGS Station Description: 02053500 Ahoskie Creek at Ahoskie, N.C. (Chowan River Basin).

LOCATION: lat. 36°16′50″, long. 77°00′00″, Hertford County, on right bank 10 ft downstream from bridge on State Highway 350, 0.5 mile upstream from Seaboard Coast Line Railroad bridge, and 0.8 mile southwest of Ahoskie.

DRAINAGE AREA: 57 mi^2, approximately.

PERIOD OF RECORD: January 1950 to December 1972.

GAGE: Water-stage recorder. Datum of gage is 17.46 ft above mean sea level (Soil Conservation Service bench mark). Prior to Jan. 4, 1963, at present site at datum 4.00 ft higher. Jan. 20, 1950 to May 24, 1951, nonrecording gage.

REMARKS: Records good. Entire basin above station channelized since July 1964. Excavation begun downstream in July 1962 and reached the station in December 1962.

TABLE A–16.—*Monthly and annual streamflow, watershed W–A2*

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1964	...	...	1.93	1.59	0.18	0.17	0.41	0.64	2.87	3.79	0.36	2.78	...
1965	0.99	2.49	2.15	.72	.27	1.35	1.44	.79	.23	.12	.09	.09	10.73
1966	.20	2.81	2.86	.32	.99	.56	.09	.77	.09	.09	.11	.22	9.11
1967	2.65	2.04	.48	.21	.14	.52	.44	1.91	.37	.12	.10	1.76	10.74
1968	3.48	.40	2.76	1.28	.49	1.50	2.12	.13	.06	.25	.19	.18	12.84
1969	.82	2.23	3.45	.97	2.01	1.30	1.15	1.90	.50	2.38	.32	1.94	19.98
1970	1.39	3.52	1.98	3.04	.57	.43	1.66	.39	.10	.25	.37	.64	14.34
1971	2.23	4.53	2.18	1.69	.25	.16	.18	.76	.23	4.48	.55	.48	17.71
1972	1.41	2.17	.68	.64	2.08	1.01	.36	.25	.10	.14	.47	1.96	11.27
Average ..	1.65	2.52	2.05	1.16	.89	.78	.87	.84	.51	1.29	.28	1.12	13.34

Notes: USGS Station Description: 02053450 Ahoskie Creek at Mintons Store, N.C. (Chowan River Basin).

LOCATION: lat. 36°16′46″, long. 77°09′28″, Hertford County, on right bank at downstream side of bridge on State Highway 305, 1.5 miles southeast of Mintons Store, and 3 miles upstream from Fort Branch.

DRAINAGE AREA: 24 mi², approximately.

PERIOD OF RECORD: February 1964 to December 1972.

GAGE: Water-stage recorder. Datum of gage is 40.00 ft above mean sea level (Soil Conservation Service bench mark).

REMARKS: Records fair. Entire basin above station channelized since February 1964. Recording rain gage located at gage.

TABLE A–17.—*Monthly and annual streamflow, watershed W–A3*

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1964	...	...	...	...	...	...	0.13	0.82	4.17	3.54	0.11	2.91	...
1965	1.01	2.34	1.86	0.39	0.04	1.33	.03	.82	.02	(1)	(1)	0	7.84
1966	.02	1.94	2.31	.06	.34	.08	.01	.10	.01	(1)	(1)	.03	5.17
1967	.89	1.52	.27	.03	.02	.10	.06	1.15	.01	.02	.02	1.28	5.37
1968	3.56	.28	1.91	1.47	.15	.37	.78	.01	0	.02	.05	.02	8.60
1969	.28	1.86	3.22	.69	2.50	1.38	1.16	1.74	.85	1.61	.02	2.07	17.37
1970	1.25	3.08	1.71	3.10	.41	.04	3.12	.76	.01	.04	.03	.04	13.59
1971	1.33	4.25	1.82	1.48	.03	.01	.01	.12	.03	2.56	.28	.18	12.11
1972	1.73	3.53	.55	.59	4.15	1.50	.17	.05	.01	.01	.04	.73	13.06
Average ..	1.26	2.35	1.71	.98	.96	.60	.61	.62	.57	.87	.06	.81	10.39

[1] Trace.

Notes: USGS Station Description: 02053400 Ahoskie Creek near Rich Square, N.C. (Chowan River Basin).

LOCATION: lat. 36°14′52″, long. 77°14′12″, Northampton County, on right bank 150 ft upstream from culvert on Secondary Road 1100, 1.8 miles downstream from Seaboard Coast Line Railroad bridge, and 3.5 miles southeast of Rich Square.

DRAINAGE AREA: 3.7 mi², approximately.

PERIOD OF RECORD: June 1964 to December 1972.

GAGE: Water-stage recorder. Datum of gage is 57.62 ft above mean sea level (Soil Conservation Service bench mark).

REMARKS: Records fair. Entire basin above station channelized. Excavation was completed in July 1964. Recording rain gage located at station.

TABLE A-18.—*Monthly and annual streamflow, watershed W-A4*

[Inches]

Year	Month												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1963	...	...	...	...	...	...	...	...	...	0.03	0.27	0.73	...
1964	2.08	2.27	1.38	0.83	0.10	0.05	0.25	0.77	1.45	2.78	.20	2.02	14.18
1965	.59	2.02	1.77	.39	.12	.35	.47	.31	.18	.10	.05	.05	6.40
1966	.15	2.64	2.28	.14	1.93	.58	.05	.53	.11	.05	.04	.08	6.96
1967	1.28	1.01	.24	.11	.06	.07	.61	4.29	.47	.06	.11	.86	9.17
1968	2.59	.25	2.61	.81	.28	.30	1.07	.05	.06	.07	.10	.07	8.27
1969	.40	1.42	2.37	.48	.52	1.06	2.35	2.28	.26	2.41	.20	1.77	15.52
1970	.79	2.41	1.38	2.09	.42	.10	.90	.12	.07	.08	.08	.13	8.56
1971	.60	2.64	1.63	.88	.22	.13	.14	1.30	.86	4.54	.32	.29	13.56
1972	1.05	1.73	.52	.32	1.59	2.94	.83	.46	.10	.18	.76	1.40	11.88
Average ..	1.06	1.82	1.58	.67	.58	.62	.74	1.12	.40	1.03	.21	.74	10.50

Notes: USGS Station Description: 02053510 Ahoskie Creek tributary at Poor Town, N.C. (Chowan River Basin).

LOCATION: lat. 36°16′29″, long. 77°00′38″, Hertford County, on left bank 12 ft upstream from culvert on Secondary Road 1105, 1 mile southeast of Poor Town, and 1 mile upstream from mouth.

DRAINAGE AREA: 2.6 mi², approximately.

PERIOD OF RECORD: October 1963 to December 1972.

GAGE: Water-stage recorder. Datum of gage is 30.86 ft above mean sea level (Soil Conservation Service bench mark).

REMARKS: Records good. Entire channel above and below station channelized and improved in December 1962. Recording rain gage located at station.

TABLE A–19.—*Annual maximum peak discharge and volumes for selected time intervals, watershed W–A1*

Year	Peak discharge		Volume													
			1-hour		2-hour		6-hour		12-hour		1-day		2-day		8-day	
	Date	Rate[1]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]
1964	Oct. 5	0.07	Oct. 5	0.07	Oct. 5	0.14	Oct. 5	0.42	Oct. 5	0.83	Oct. 5	1.65	Oct. 5	3.02	Oct. 3	4.15
1965	July 16	.04	July 16	.04	July 16	.09	July 16	.26	July 16	.51	July 15	.84	July 15	1.03	July 11	1.70
1966	Mar. 4	.05	Mar. 4	.05	Mar. 4	.09	Mar. 4	.27	Mar. 4	.54	Mar. 4	1.03	Mar. 4	1.57	Feb. 28	3.22
1967	Jan. 8	.04	Jan. 8	.04	Jan. 8	.08	Jan. 8	.25	Jan. 8	.49	Jan. 8	.97	Jan. 8	1.48	Aug. 21	2.65
1968	Jan. 14	.05	Jan. 14	(3)	Jan. 14	(3)	Jan. 14	(3)	Jan. 14	(3)	Jan. 14	(3)	Jan. 14	(3)	Jan. 14	(3)
1969	Feb. 2	.03	Feb. 2	.03	Feb. 2	.06	Feb. 2	.17	Feb. 2	.28	Feb. 2	.54	Feb. 2	.93	Feb. 2	1.52
1970	Feb. 3	.03	Feb. 3	.03	Feb. 3	.06	Feb. 3	.19	Feb. 3	.38	Feb. 3	.74	Feb. 3	1.42	Jan. 30	2.55
1971	Feb. 13	.03	Feb. 13	.03	Feb. 13	.06	Feb. 13	.18	Feb. 13	.35	Feb. 13	.68	Oct. 23	1.17	Sept. 30	2.65
1972	June 1	.03	June 1	.03	June 1	.05	May 31	.15	May 31	.31	May 31	.62	May 31	1.06	May 26	1.29

[1] Area-inches/hour.

[2] Area-inches.

[3] Missing record.

TABLE A–20.—*Annual maximum peak discharge and volumes for selected time intervals, watershed W–A2*

Year	Peak discharge		Volume													
			1-hour		2-hour		6-hour		12-hour		1-day		2-day		8-day	
	Date	Rate[1]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]
1964	Oct. 5	0.08	Oct. 5	0.08	Oct. 5	0.17	Oct. 5	0.50	Oct. 5	0.97	Oct. 5	1.64	Oct. 4	2.37	Oct. 3	3.06
1965	July 15	.05	July 15	.05	July 15	.10	July 15	.27	July 15	.49	June 16	.62	June 16	.83	Feb. 12	1.29
1966	Mar. 4	.06	Mar. 4	.06	Mar. 4	.11	Mar. 4	.31	Mar. 4	.54	Mar. 4	.87	Mar. 4	1.24	Feb. 26	2.49
1967	Jan. 8	.07	Jan. 8	.07	Jan. 8	.15	Jan. 8	.43	Jan. 8	.78	Jan. 8	1.23	Jan. 8	1.57	Jan. 8	2.12
1968	Jan. 14	.05	Jan. 14	.05	Jan. 14	.10	Jan. 14	.31	Jan. 14	.61	Jan. 14	1.15	Jan. 13	1.80	Jan. 12	2.32
1969	May 25	.04	May 25	.04	May 25	.09	May 25	.26	May 25	.50	May 24	.92	May 24	1.34	May 19	2.66
1970	Feb. 3	.04	Feb. 3	.04	Feb. 3	.08	Feb. 3	.23	Feb. 3	.42	Apr. 13	.80	Apr. 13	1.04	Jan. 30	1.52
1971	Oct. 24	.05	Oct. 24	.05	Oct. 24	.10	Oct. 23	.29	Oct. 23	.55	Oct. 23	.97	Oct. 23	1.45	Sept. 30	1.92
1972	May 31	.03	May 31	.03	May 31	.06	May 31	.16	May 31	.31	May 31	.50	May 31	.65	Dec. 14	.99

[1] Area-inches/hour.

[2] Area-inches.

TABLE A–21.—*Annual maximum peak discharge and volumes for selected time intervals, watershed W–A3*

Year	Peak discharge		Volume													
			1-hour		2-hour		6-hour		12-hour		1-day		2-day		8-day	
	Date	Rate[1]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]
1964	Oct. 5	0.12	Oct. 5	0.12	Oct. 5	0.24	Oct. 5	0.67	Oct. 5	1.24	Oct. 5	1.88	Oct. 4	2.57	Oct. 4	3.49
1965	June 16	.04	June 16	.04	June 16	.08	June 16	.23	June 16	.41	June 16	.69	June 16	1.00	Feb. 11	1.42
1966	Mar. 4	.04	Mar. 4	.04	Mar. 4	.08	Mar. 4	.22	Mar. 4	.38	Mar. 4	.65	Mar. 4	.99	Feb. 26	2.15
1967	Aug. 23	.03	Aug. 23	.03	Aug. 23	.05	Aug. 23	.14	Aug. 23	.23	Aug. 23	.36	Aug. 22	.61	Aug. 20	1.10
1968	Jan. 14	.08	Jan. 14	.08	Jan. 14	.17	Jan. 14	.49	Jan. 13	.88	Jan. 13	1.29	Jan. 13	1.67	Jan. 13	2.37
1969	May 24	.06	May 24	.06	May 24	.12	May 24	.34	May 24	.58	May 24	.84	May 24	1.14	May 19	2.30
1970	Feb. 3	.07	Feb. 3	.06	Feb. 3	.13	Feb. 3	.34	Feb. 3	.55	Feb. 3	.84	Feb. 3	1.07	Feb. 1	1.80
1971	Feb. 7	.05	Feb. 7	.05	Feb. 7	.10	Feb. 7	.26	Feb. 7	.42	Feb. 7	.66	Feb. 7	1.00	Feb. 7	1.72
1972	May 18	.05	May 18	.05	May 18	.10	May 18	.29	May 18	.52	May 18	.86	May 18	1.30	May 18	3.28

[1] Area-inches/hour.

[2] Area-inches.

TABLE A–22.—*Annual maximum peak discharge and volumes for selected time intervals, watershed W–A4*

Year	Peak discharge		Volume													
			1-hour		2-hour		6-hour		12-hour		1-day		2-day		8-day	
	Date	Rate[1]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]	Date	Amt.[2]
1964	Oct. 5	0.12	Oct. 5	0.12	Oct. 5	0.24	Oct. 5	0.64	Oct. 5	0.99	Oct. 5	1.28	Oct. 4	1.59	Oct. 4	1.83
1965	July 15	.04	July 15	.04	July 15	.08	July 15	.18	Feb. 14	.32	Feb. 14	.49	Feb. 14	.82	Feb. 13	.95
1966	May 30	.16	May 30	.16	May 30	.32	May 29	.82	May 29	1.01	May 29	1.01	May 30	1.19	Feb. 28	1.98
1967	Aug. 22	.11	Aug. 22	.11	Aug. 22	.22	Aug. 21	.54	Aug. 21	.76	Aug. 23	.92	Aug. 23	1.64	Aug. 21	3.48
1968	Jan. 14	.13	Jan. 14	.13	Jan. 14	.26	Jan. 14	.73	Jan. 13	1.20	Jan. 13	1.66	Jan. 13	2.01	Jan. 13	2.49
1969	Oct. 2	.16	Oct. 2	.16	Oct. 2	.31	Oct. 2	.93	Oct. 2	1.68	Oct. 2	2.05	Oct. 2	2.22	Oct. 1	2.42
1970	Feb. 3	.13	Feb. 3	.13	Feb. 3	.26	Feb. 3	.68	Feb. 3	.98	Feb. 3	1.15	Feb. 2	1.38	Feb. 1	1.77
1971	Oct. 23	.09	Sept. 30	.09	Sept. 30	.18	Sept. 30	.50	Sept. 30	.84	Sept. 30	1.55	Sept. 30	2.03	Sept. 30	2.56
1972	June 17	.17	June 17	.17	June 17	.33	June 17	.86	June 17	1.21	June 17	1.33	June 17	1.41	June 17	2.47

[1] Area-inches/hour.

[2] Area-inches.

TABLE A-23.—*Instantaneous peak discharges, watershed W-A1*

[Cubic feet per second]

Year	Month Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1964	...	...	...	...	...	...	603	1,150	1,470	2,550	63	1,960
1965	156	1,200	522	138	98	965	1,580	800	67	21	(1)	6.8
1966	66	289	1,680	28	1,240	550	44	520	39	11	16	57
1967	1,520	452	(1)	189	(1)	865	367	1,400	320	16	(2)	515
1968	(2)	52	1,500	690	167	337	557	36	(2)	45	99	17
1969	543	1,060	1,010	156	855	660	556	706	351	(2)	68	817
1970	103	1,210	895	1,000	373	262	598	[3]27	13	171	95	115
1971	582	1,080	832	945	55	61	78	601	96	949	121	90
1972	735	722	116	131	731	960	374	514	28	345	366	769

[1] No peak occurred during month. [2] No record. [3] Partial record.

TABLE A-24.—*Instantaneous peak discharges, watershed W-A2*

[Cubic feet per second]

Year	Month Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1964	...	...	...	...	...	...	261	104	1,120	1,340	44	1,120
1965	(1)	401	217	[2]38	[2]111	667	756	523	131	13	(3)	(3)
1966	42	675	872	12	279	259	8.3	714	17	23	40	71
1967	1,160	221	24	14	4.4	383	77	515	86	13	14	279
1968	794	(3)	596	289	99	347	439	31	(3)	109	119	56
1969	214	458	340	57	653	353	191	571	141	786	58	320
1970	142	693	474	660	101	98	430	30	27	153	83	86
1971	405	578	430	480	53	32	100	241	24	768	42	39
1972	338	204	37	40	436	182	65	42	3.2	21	107	369

[1] No record. [2] Partial record. [3] No peak occurred during month.

TABLE A-25.—*Instantaneous peak discharges, watershed W-A3*

[Cubic feet per second]

Year	Month Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1964	...	...	...	...	...	...	52	18	339	295	[2]2.5	200
1965	25	51	28	16	6.2	99	7.4	91	14	.54	(1)	(1)
1966	1.8	70	99	(1)	16	20	.62	55	2.2	2.5	2.3	6.7
1967	98	19	8.0	(1)	(1)	64	3.3	37	1.5	.82	1.0	29
1968	198	4.0	55	34	2.3	40	34	2.2	(1)	2.4	2.4	(1)
1969	10	40	36	2.8	145	56	39	75	30	123	.57	57
1970	19	159	53	124	14	10	[2]66	6.4	2.0	8.2	.60	2.1
1971	28	[2]123	49	58	1.1	.09	.36	12	.26	65	(1)	2.8
1972	53	61	7.2	9.8	127	13	29	32	1.3	(1)	58	84

[1] No peak occurred during month. [2] Partial record.

TABLE A–26.—*Instantaneous peak discharges, watershed W–A4*

[Cubic feet per second]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1964	...	...	...	...	...	...	29	3	13	5	25	26
1965	5.4	53	31	8.2	3.3	32	65	22	8.4	6.3	(1)	(1)
1966	(2)	87	191	(1)	274	47	2.7	61	3.2	(1)	(1)	3.0
1967	130	18	2.1	(1)	1.0	1.8	58	200	60	(1)	(1)	(2)
1968	216	4.5	178	2.6	13	47	183	(1)	2.6	2.2	7.0	(1)
1969	18	113	[3]34	5.0	74	149	184	101	13	260	3.7	116
1970	14	219	119	141	25	12	72	1.3	1.4	13	1.7	7.2
1971	7.8	90	53	54	9.7	17	21	125	157	155	6.4	3.6
1972	72	46	6.6	3.0	126	287	73	43	[3]16	[3]3.7	32	96

[1] No peak occurred during month. [2] No record. [3] Partial record.

TABLE A–27.—*Monthly maximum mean daily discharge, watershed W–A1*[1]

[Cubic feet per second]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1950	375	75	191	65	33	80	410	96	232	7.1	5.1	13
1951	18	25	184	93	15	175	206	12	6.6	8.5	122	121
1952	380	875	818	134	142	1.3	4.7	230	8.1	.6	46	34
1953	95	356	223	194	42	11	31	124	17	2.3	5.9	178
1954	1,060	178	155	256	362	25	.4	6.5	1.0	.5	1.5	17
1955	30	89	164	25	10	41	37	380	1,330	60	43	36
1956	65	447	713	438	378	8.5	12	18	44	239	500	112
1957	335	767	427	108	2.5	19	2.6	22	7.5	77	268	556
1958	404	371	698	268	1,080	28	27	371	117	52	18	474
1959	442	375	323	433	60	3.0	420	600	209	1,110	143	478
1960	371	411	189	146	80	22	1,460	1,390	2,200	16	17	57
1961	110	525	346	114	708	83	103	.6	.7	3.3	19	54
1962	410	480	264	116	28	4.5	63	.8	.5	2.2	30	23
1963	488	192	218	32	8.3	52	3.0	4.2	400	8.6	63	136
1964	375	314	578	712	17	26	309	696	1,030	2,490	50	1,890
1965	143	828	415	118	56	462	1,230	522	28	14	6.6	6.6
1966	47	965	1,170	26	799	299	20	305	21	9.5	10	32
1967	1,200	350	67	20	13	714	264	1,120	188	14	20	385
1968	1,700	48	1,460	521	147	219	279	12	8.8	24	61	15
1969	439	824	810	137	750	453	477	688	294	1,000	46	644
1970	282	1,100	607	886	324	128	492	129	9.7	102	72	83
1971	357	767	786	700	33	19	36	450	200	906	101	83
1972	634	587	96	104	586	781	237	325	17	186	241	601

[1] The maximums listed represent the absolute maximums for the month irrespective of time of occurrence relative to storm peaks. A given maximum may have occurred on the last day of the month, and the storm maximum may have occurred on the first of the following month. Therefore, the successive monthly maximums may not be independent events. Low-flow maximums may have occurred on more than 1 day within the month.

TABLE A–28.—*Monthly maximum mean daily discharge, watershed W–A2*[1]

[Cubic feet per second]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1964	...	...	174	238	6.2	11	55	185	637	937	26	753
1965	60	244	154	50	23	365	292	198	20	5.1	2.8	2.3
1966	15	292	430	11	126	116	3.9	236	9.5	5.8	16	27
1967	664	168	26	9.8	4.4	190	44	335	48	5.0	8.4	199
1968	743	20	418	203	48	150	259	12	1.7	37	44	6.5
1969	139	299	271	52	581	208	134	389	89	701	14	218
1970	100	508	295	492	78	61	274	81	8.8	74	56	49
1971	215	431	270	279	24	10	32	134	67	468	30	27
1972	162	140	35	38	193	229	42	26	5.0	21	66	226

[1] The maximums listed represent the absolute maximums for the month irrespective of time of occurrence relative to storm peaks. A given maximum may have occurred on the last day of the month, and the storm maximum may have occurred on the first of the following month. Therefore, the successive monthly maximums may not be independent events. Low-flow maximums may have occurred on more than 1 day within the month.

TABLE A–29.—*Monthly maximum mean daily discharge, watershed W–A3*[1]

[Cubic feet per second]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1964	...	...	...	...	...	...	4.6	67	166	170	1.5	133
1965	9.7	41	25	5.0	1.4	61	.7	36	.7	.05	.05	0
1966	.5	40	51	.7	7.1	5.2	.05	6.1	.2	.3	.1	1
1967	25	18	3.5	.3	.1	7.9	1.2	36	.7	.4	.4	22
1968	125	3.6	34	27	1.9	12	16	.6	0	.87	2.2	.30
1969	6.0	24	31	6.7	78	36	32	60	25	76	.25	39
1970	14	55	34	67	12	3.4	70	44	.70	2.4	.34	.70
1971	12	56	32	35	.63	.07	.13	5.5	2.4	43	3.9	2.6
1972	31	47	6.5	7.5	65	58	7.0	4.1	.13	.12	1.6	9.7

[1] The maximums listed represent the absolute maximums for the month irrespective of time of occurrence relative to storm peaks. A given maximum may have occurred on the last day of the month, and the storm maximum may have occurred on the first of the following month. Therefore, the successive monthly maximums may not be independent events. Low-flow maximums may have occurred on more than 1 day within the month.

TABLE A-30.—*Monthly maximum mean daily discharge, watershed W-A4*[1]

[Cubic feet per second]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1963	...	...	...	...	...	...	...	...	...	0.1	4.3	6.1
1964	20	18	21	14	0.3	0.5	6.3	15	36	89	1.0	45
1965	3.5	22	16	3.9	.5	9.8	11	4.7	1.2	1.1	.2	.1
1966	1.0	47	54	.5	72	14	.5	6.6	1.0	.2	.1	.8
1967	.1	.1	.3	.1	.1	.1	.1	.1	.3	.2	.6	20
1968	97	1.2	82	20	5.3	4.3	37	.2	.3	.53	2.8	.24
1969	9.2	43	25	3.2	19	56	52	27	5.3	86	1.9	41
1970	8.4	79	40	48	8.4	1.2	16	1.1	.28	.69	.24	1.0
1971	5.6	37	29	18	3.1	1.1	1.6	51	51	83	3.4	2.3
1972	24	26	5.4	2.3	29	64	13	14	1.0	4.5	15	29

[1] The maximums listed represent the absolute maximums for the month irrespective of time of occurrence relative to storm peaks. A given maximum may have occurred on the last day of the month, and the storm maximum may have occurred on the first of the following month. Therefore, the successive monthly maximums may not be independent events. Low-flow maximums may have occurred on more than 1 day within the month.

TABLE A-31.—*Ahoskie Creek ground-water-well maximum and minimum monthly values*

[Feet]

Month	Well—													
	[1]1		[2]2		[3]4		[4]5		[5]6		[6]7		[7]8	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
	1968													
January	...	...	[8]69.7	69.0	[8]71.4	70.4	53.5	52.7	43.4	41.5	56.7	56.1	41.6	[9]41.4
February	...	...	69.0	68.3	70.6	69.6	53.3	52.6	41.7	41.1	56.6	55.9	41.8	46.1
March	...	...	69.5	68.5	71.3	69.8	[8]53.6	52.7	[8]43.5	41.2	[8]56.7	56.0	42.4	41.8
April	...	...	69.1	68.3	70.9	69.5	53.5	53.1	42.5	41.3	56.6	56.2	42.2	42.0
May	...	...	69.0	67.9	70.8	69.0	53.1	52.6	42.1	41.0	56.2	55.7	42.4	42.1
June	...	...	68.9	68.3	70.2	68.5	53.1	51.6	41.6	40.7	56.1	54.7	42.5	42.3
July	...	...	68.9	67.9	70.3	68.5	52.4	51.4	41.9	40.8	55.8	54.3	[8]42.5	42.3
August	...	...	67.8	65.8	68.6	66.2	52.3	50.1	41.2	40.2	55.5	52.3	42.3	42.1
September	...	...	65.8	63.6	66.7	64.9	50.0	48.8	40.3	39.8	52.2	50.2	42.1	41.8
October	...	...	64.4	[9]63.3	66.5	[9]64.6	48.7	48.4	40.0	39.7	50.2	49.7	42.0	41.7
November	...	...	66.6	63.9	68.4	65.3	48.8	[9]48.2	40.3	[9]39.7	50.5	[9]49.5	42.1	41.8
December	...	...	67.4	66.5	68.7	67.4	49.1	48.7	40.6	40.3	50.9	50.5	41.9	41.6
	1969													
January	...	...	68.9	67.4	71.1	68.6	51.0	[9]49.1	42.6	[9]40.5	54.2	[9]50.9	41.8	[9]41.5
February	...	...	69.4	68.8	[8]71.4	70.3	52.6	51.1	42.9	41.4	56.1	54.3	41.8	41.5
March	...	...	[8]69.5	68.8	71.3	70.1	53.3	52.6	[8]43.0	41.7	56.6	56.1	41.8	41.6
April	...	...	68.9	68.6	70.6	69.6	53.1	52.9	42.3	41.6	56.6	56.3	42.0	41.7
May	...	...	69.0	67.5	70.8	68.3	52.9	51.6	41.9	40.8	56.2	54.7	42.7	41.7
June	...	...	68.8	67.9	70.7	69.0	52.6	52.1	41.6	40.8	56.0	55.2	42.2	41.9
July	...	...	68.7	67.8	70.3	68.7	52.7	52.1	41.4	40.7	56.2	55.6	42.2	41.9
August	...	...	69.2	67.7	70.9	68.7	53.0	52.1	42.0	41.0	56.5	55.8	42.5	41.9
September	...	...	68.4	[9]66.5	70.4	[9]68.2	52.4	51.2	41.6	40.5	55.8	54.4	42.1	41.8
October	74.0	71.5	69.1	67.9	71.3	69.4	52.7	51.9	42.6	40.9	56.2	55.3	[8]43.2	41.9
November	72.7	71.4	68.6	67.9	70.7	69.4	52.1	51.9	41.2	40.9	55.8	55.3	42.1	41.9
December	[8]74.8	[9]71.0	69.3	68.1	71.3	69.4	[8]53.3	51.9	42.5	40.9	[8]56.6	55.4	42.4	42.0

See footnotes at end of table.

TABLE A–31.—*Ahoskie Creek ground-water-well maximum and minimum monthly values* —Continued

[Feet]

Month	Well—													
	[1]1		[2]2		[3]4		[4]5		[5]6		[6]7		[7]8	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
	1970													
January	74.6	72.9	69.2	68.8	71.1	70.1	53.5	53.3	43.0	41.8	56.7	56.5	42.3	42.1
February	[8]75.2	73.5	[8]69.6	69.0	[8]71.4	70.3	54.0	53.4	44.1	42.4	[8]57.0	56.6	42.9	42.2
March	74.5	72.3	69.2	68.6	70.9	69.6	53.8	53.3	43.7	41.9	56.8	56.4	42.8	42.3
April	75.0	72.7	69.4	68.8	71.3	69.7	[8]54.0	53.7	[8]44.1	42.3	56.9	56.7	[8]43.2	42.5
May	74.0	71.0	69.2	67.8	70.9	68.7	53.8	52.2	43.4	41.5	56.8	55.2	42.9	42.8
June	70.9	69.6	68.2	67.6	70.1	68.4	52.2	50.9	41.6	40.9	55.1	52.9	42.9	42.7
July	74.1	70.1	68.5	67.8	70.9	69.2	52.0	50.8	41.9	41.1	54.8	52.7	42.8	42.6
August	73.4	70.1	68.5	66.8	70.2	68.2	52.1	50.7	41.8	40.7	55.1	53.1	42.8	42.3
September	69.9	68.5	66.7	64.7	68.0	66.4	50.6	49.3	40.7	40.2	53.0	50.7	42.3	42.0
October	71.1	[9]63.2	67.1	[9]64.2	69.7	[9]66.0	49.3	[9]48.7	40.5	[9]40.0	50.7	[9]49.9	42.1	41.8
November	73.1	71.4	68.5	67.4	70.7	69.2	49.8	49.1	40.9	40.4	51.3	50.6	42.0	41.8
December	73.8	70.4	69.0	67.6	70.8	68.8	50.9	49.5	41.5	40.4	53.2	50.8	41.8	[9]41.6
	1971													
January	74.8	72.7	69.3	68.7	71.1	70.0	52.9	51.0	42.5	41.1	55.8	53.2	41.9	41.7
February	75.1	73.6	69.7	69.1	71.3	70.4	53.6	52.9	43.5	41.9	56.6	55.8	42.0	41.6
March	74.7	72.5	69.4	68.7	71.1	69.7	53.7	53.3	43.3	41.9	56.7	56.4	42.0	41.7
April	75.0	71.7	69.5	68.3	71.2	69.2	53.7	52.8	[8]43.9	41.6	56.7	55.9	42.2	41.9
May	71.6	70.5	68.5	67.7	70.1	68.4	52.8	51.9	41.9	41.1	55.8	54.9	42.2	42.0
June	71.0	69.3	68.6	67.2	70.0	68.1	52.2	51.3	41.7	40.8	55.2	54.3	42.2	41.9
July	69.5	68.7	67.5	66.4	68.9	[9]67.3	51.2	50.0	40.9	40.4	54.2	52.5	41.9	41.7
August	72.6	[9]68.3	67.8	[9]65.2	71.2	67.7	50.4	[9]49.3	40.8	[9]40.1	53.9	[9]51.2	41.9	41.5
September	72.5	69.5	67.8	66.7	70.6	68.9	51.3	50.5	40.8	40.4	54.9	54.1	41.7	[9]41.4
October	[8]75.2	73.2	[8]69.8	68.2	[8]71.6	70.3	53.8	51.5	43.8	41.6	56.8	54.8	[8]42.7	41.6
November	74.3	71.8	69.5	68.5	71.0	69.6	[8]53.8	53.0	42.7	41.4	56.9	56.2	41.8	41.6
December	73.3	72.1	69.1	68.7	70.6	69.8	53.1	52.9	42.0	41.4	56.3	56.2	41.9	41.7
	1972													
January	75.1	72.2	69.7	68.8	[8]71.3	69.7	53.6	53.0	43.4	41.5	56.7	56.2	42.3	41.8
February	74.9	72.8	[8]69.7	69.0	71.3	70.0	[8]53.9	53.4	43.7	41.9	[8]57.0	56.6	42.4	41.9
March	73.3	72.3	69.1	68.6	70.2	69.4	53.8	53.3	42.5	41.8	56.8	56.4	42.4	42.1
April	72.9	72.1	68.8	68.6	70.1	69.3	53.2	53.0	42.1	41.6	56.5	56.1	42.4	42.1
May	[8]75.1	71.9	69.5	68.5	71.0	69.2	53.5	52.8	42.7	41.7	56.6	56.0	42.9	42.3
June	74.6	71.7	69.1	68.2	70.7	69.0	53.5	52.6	43.1	41.5	56.7	55.8	42.9	42.3
July	72.5	71.0	68.5	67.7	70.5	68.2	52.8	51.9	42.2	41.2	56.1	55.1	42.4	42.2
August	72.8	69.6	68.5	66.7	70.6	68.0	52.5	51.2	41.9	40.9	56.1	54.3	42.4	42.0
September	69.7	68.6	66.6	[9]65.0	68.2	66.6	51.0	49.5	41.0	[9]40.6	54.2	52.4	[8]43.0	41.8
October	68.5	68.1	66.2	65.1	68.8	66.8	50.3	[9]49.3	41.4	40.7	54.2	[9]52.2	42.1	41.8
November	72.1	[9]68.1	68.5	66.0	70.3	[9]67.4	51.7	50.1	42.2	40.8	55.9	54.3	42.0	41.7
December	74.9	71.7	69.4	68.5	71.0	69.5	52.5	51.7	43.1	41.6	56.5	56.0	42.1	[9]41.7

[1] Ground surface elevation: 75.9 ft. [2] Ground surface elevation: 70.1 ft. [3] Ground surface elevation: 71.5 ft. [4] Ground surface elevation: 66.7 ft. [5] Ground surface elevation: 45.5 ft. [6] Ground surface elevation: 63.0 ft. [7] Ground surface elevation: 46.9 ft. [8] Maximum yearly value based on a hundredth of a foot. [9] Minimum yearly value based on a hundredth of a foot.

TABLE A–32.—*U.S. Customary to metric conversions*

To convert		Multiply by—
From	To	
Inches	millimeters	25.4
Inches	centimeters	2.54
Feet	meters	.3048
Miles	kilometers	1.6093
Square feet	square meters	.0929
Square miles	hectares	259
Square miles	square kilometers	2.59
Square miles	acres	640
Acres	square miles	1.5625×10^{-3}
Acres	hectares	.4047
Cubic feet	cubic meters	.028317
Cubic feet per second	acre-feet per day	1.9835
Cubic feet per second	cubic meters per second	.0283
Gallon per minute	liter per minute	3.7848
°F	°C	5/9(°F−32)

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