THE TENNESSEE VALLEY AUTHORITY'S SMALL WATERSHED RESEARCH

by

Carl D. Eklund
Tennessee Valley Authority
Knoxville, Tennessee

INTRODUCTION

The Tennessee Valley Authority, when created by Congress in 1933, was directed to promote the development of all the resources of the Tennessee River Basin. The forests, minerals, lands, and water were to be considered as a whole and their interrelation respected.

The Valley had suffered a century and a half of man's abuse during its settlement period. Forests had been cleared for agriculture. Erosion and poor land management took its toll and more clearing followed. Timber harvesting early in the 19th century cleared thousands of acres of submarginal land and left little to protect the soil. By 1933, when TVA was created, forest acreage had been reduced from 26 million to 14 million acres. Seven million acres were suffering from erosion and two and one-half million acres were eroded almost beyond reclamation.

It was against this background of 150 years of abuse that TVA started its watershed research program. It was evident that reclamation work needed to begin immediately. It was also important that the impact of these reclamation activities upon the water resource be determined and used for future planning. Thus the mandate given TVA to develop the Valley's resources led to the establishment of watershed research projects with a variety of specific objectives, but all included the general objective of studying the interrelation of the water resource with the other natural resources of the Valley.

Since TVA is a resource development agency, its watershed research is necessarily directed toward application, although basic research has been included at some projects in an effort to determine the reasons for certain hydrologic responses.

The purpose of this paper is to describe briefly some of TVA's small watershed research projects--their objectives and the principal results where these are available. The projects discussed herein follow generally in order of their establishment, or as the findings on early projects or the new requirements of TVA's development programs led to the need for special watershed research. Figure 1 shows the location of selected watershed projects within the Tennessee Valley.

SINGLE-PURPOSE WATERSHEDS

White Hollow Watershed

The White Hollow watershed is typical of TVA's early, single-purpose watersheds. It is the only remaining active one of the first three research watersheds established in 1934.

White Hollow is located in northeast Tennessee between the Clinch and Powell River arms of Norris Reservoir. The 1,715-acre watershed, acquired by TVA in its land acquisition program for Norris Reservoir, was considered typical of the Appalachian Valley region. Nearly all the land had been under cultivation at one time; even areas in forest had been subjected to grazing or burning. Soils were severely eroded with numerous active gullies. The topography of the watershed is fairly rugged; there is a range in elevation of 600 feet. More than 70 percent of the soils are rated as fifth class by the U. S. Department of Agriculture, being steep, cherty, silt loams. Cultivation in 1934 was limited to the ridge tops and the flatter slopes.

The acquisition of the area by TVA and the subsequent placing of the watershed under a program of forestry management afforded the opportunity of studying the effect upon runoff and soil erosion of changes in the vegetal cover on a watershed taken out of cultivation.

During the three decades in which measurements have continued on the White Hollow project, many useful results have been obtained. A report in 1961[1] documented the changes that have taken place. A 1936 survey indicated that 66 percent of the land was in forest cover but this land was understocked; there was little humus or litter because of fire or grazing. The remainder of the area was abandoned land mostly in broom sedge; 40 percent was in some stage of erosion. Beginning in 1934 and 1935 intensive erosion control and tree planting operations were carried out. Natural forest reproduction was quite extensive. By 1956 the protective cover was complete.

Reforestation has resulted in considerable changes to the hydrology of White Hollow. The storm hydrograph has been completely altered. Figure 2 illustrates the differences in the discharge hydrograph from comparable summer storms in July 1938 and June 1962. Peak discharges for summer storms have been reduced to only 5 to 27 percent of former values. Winter storm peaks have also been reduced, although not so much. Storm runoff for both seasons now occurs at lower rates and for much longer periods as a result of the delay of runoff by improved cover conditions. Soil loss from the watershed has been substantially reduced. Annual sediment loads are now only 4 percent of those in 1935.

Changes in forest cover are usually associated with a change in water yield. Eschner and Satterlund (1965),[2] for example, indicated a decrease in water yield with an increase in forest cover over a 39-year

period. Hewlett and Hibbert (1961)[3] and others have shown increases in water yield after forest cutting. In White Hollow watershed no significant change has been noted in water yield. This is attributed to the relationship between the watershed surface and soil characteristics and the underlying limestone formations.[4] The water in the soil available for evapotranspiration apparently has not been changed as a result of the increased forest cover. Overland flow is retarded by the improved ground cover and infiltrates through the shallow soils into the fractured underlying limestone, where it is unavailable for evapotranspiration. Water from this source emerges in springs and stream channels. Thus the only effect of the increased forest cover upon White Hollow has been the retarding of runoff with no significant change in water yield.

With stabilization of the watershed essentially achieved and a near-maximum improvement of the watershed hydrology attained, the next logical objective in the study was to determine the effect of a high-level management program aimed at the optimum production of timber, wildlife, and water. This second phase was initiated in 1965. A logging road network, designed to minimize siltation and other disturbance of the stream, has been constructed. Selective cutting of pulpwood and hardwood is in progress and wildlife feeding areas have been established.

Pine Tree Branch Watershed

In 1941 the Pine Tree Branch watershed was established in west Tennessee within the Mississippi Embayment physiographic province. The objectives of this study were the same as those for White Hollow; only the soils and location were different. Pine Tree Branch was considered representative of a large area of erodible, sandy soils in the western part of the Basin. Geologically the watershed is in the Ripley formation of sandy, unconsolidated material that is underlain at a depth of about 150 feet by the Selma clay stratum which restricts further downward movement of water. Deep seepage moves west along the stratum and out of the Tennessee Valley. The soils and geology have an important bearing upon the water-yield characteristics of the area.

In 1941 the 88-acre watershed was marked by deep gullies and sheet erosion, about a fourth of the watershed was in scrub forest, half the land was idle, and the remainder in cultivation, chiefly corn and cotton.

After a five-year calibration period an intensive erosion-control and reforestation program was carried out in 1946-1948. Simple woven-wire check dams were built in the gullies, locust trees were planted in the gullies, and all of the open areas were planted in pine. By early 1950 about 15 percent of the watershed, principally the severely eroded areas, still had less than 50 percent cover. Supplemental treatment on these areas resulted in progressive improvement of the cover.

The effect of this treatment upon the watershed hydrology has been dramatic. A comprehensive report in 1962[5] showed that water yield was

reduced 3 to 6 inches per year. Reductions in surface runoff volumes accounted for all of these changes; ground-water runoff volumes have remained unchanged. As in White Hollow watershed, the streamflow hydrograph has been altered considerably. Peak discharges for both winter and summer storms have been markedly reduced. Peak rates of comparable large to moderate storms were reduced by 70 to 90 percent. The time distribution pattern of surface runoff indicates a considerable reduction in overland velocities as a result of the improved land cover. Soil loss from the watershed has decreased progressively since initiation of the treatment programs, dropping by 96 percent from 24 to 1.1 tons per acre per year.

The second phase of this project began in 1963 when about two miles of logging roads were constructed and allowed to stabilize. In 1966 and 1967 the first selective cutting of pulpwood and sawtimber returned $1700. Timber remaining on the watershed will be held as growing stock. Total return from timber sales over a 45-year period will be about $60,000. Continued hydrologic measurements will establish the effect of this first and subsequent timber sales.

The White Hollow and Pine Tree Branch projects indicated that reclamation programs restoring abused land to productivity could at the same time achieve highly desirable improvement of the hydrology. Later single-purpose watershed studies had different goals, including more basic hydrologic research, yet still with the overall objective of studying the effects of management practices upon the water resource.

The Western North Carolina Watershed Research Project

The Western North Carolina Watershed Research Project was established in 1949 as a cooperative study with North Carolina State University. Its basic objective was to develop a better understanding of water-plant-soil relationships. It is the only watershed study in which agricultural covers alone are considered and which is carried out under a statistical design. Hydrologic instrumentation is sufficient to study the complete hydrologic cycle. Thus the project was designed to promote basic hydrologic research, to develop methods of measuring and separating the effects of the numerous variables, and to explain the reasons for the results obtained.

The six small watersheds which have been included in this study are located near Waynesville and Asheville, North Carolina. They range in size from about 4 to 6 acres and are typical of the small steep areas of the region which are in cultivation. The project was concerned with determining the change in physical properties of the soils when subjected to 4 major crops: corn, wheat, improved moderately grazed pasture, and heavily grazed pasture. These soil changes, correlated with accompanying changes in the hydrologic response, are to be evaluated and were intended to furnish guidelines for improved farm programs beneficial to the water resource.

At the beginning of the project it was intended to base the studies upon paired watersheds. This original concept was found to be invalid because the watershed pairs could not be related. In lieu of the paired-watershed concept, a 4 x 4 statistical Latin square design was adopted under which cover treatments were assigned to each of four watersheds so that each crop followed every other crop once during the life of the project. This design permits the separation of both period and watershed effects and a more precise estimate of cover treatment differences.

The project has covered a transition period in data analysis from simple methods early in the project to the present use of complex computer techniques. The intensive appraisal of hydrologic data from these small watersheds has led to a better understanding of the soil-plant-water interrelations. From the Waynesville project has come the concept of partial watershed area contributions to runoff.[6] Recent studies of interflow on one of the watersheds have expanded this concept, and added to the better understanding of the mechanics of storm runoff. In addition, studies of evapotranspiration, soil moisture and temperatures, physical soil data, and varying land use have contributed to the overall results. The final evaluation of this project must await the completion of cover treatment on two of the four watersheds in the Latin square design. Many of the research findings have been presented in annual project reports[7] or technical publications. The project has been one of TVA's most valuable. Here basic research studies have provided the data needed to develop analytic techniques and have led to a better understanding of watershed hydrology which has been applied in all subsequent watershed studies.

North Fork Citico Creek Watershed

The North Fork Citico Creek watershed study is located in the high-rainfall region of the mountainous Cherokee National Forest. It is a cooperative project of TVA, the U. S. Forest Service, and the Tennessee Game and Fish Commission, established to determine the effects of a high-standard, multiple-use management program upon the hydrology and stream biology. The best national forest management practices will be utilized in developing the timber, wildlife, and recreation resources of the 7-square-mile watershed. The study will have value both as a demonstration and as a study. It is intended to answer such questions as: What effect does carefully managed timber harvesting have upon the water resource of a heavily forested mountain watershed? Can recreation be enjoyed and wildlife maintained without damaging water quality and quantity?

Hydrologic measurements include precipitation, streamflow, suspended sediment, air and water temperatures, and relative humidity. Stream biology observations are made to determine the existing food-chain structure and fish life is sampled in the lower 2-mile reach of the stream.

The project began in 1960 and has gone through a 5-year calibration period. Currently, a system of logging roads is being constructed, and the first timber sale has been negotiated. The project cannot be evaluated at present, but it should provide useful guidelines for future multiple-use programs which must be developed to meet the increasing demands placed upon forest resources.

RESOURCE DEVELOPMENT WATERSHEDS

Since the Tennessee Valley Authority was directed to develop all the resources of the Valley, it could not overlook the desperate economic situation of a large percentage of the people in the region. The human resource was in need of development along with the land and water resources. Early research watersheds or areas, aimed at multi-resource development, were initiated. All of these identified water as the unifying resource for developmental activities and reflected TVA's concern that control of the large rivers must be complemented by a program for resolving water resource problems on the land in cooperation with the local people.

The Chestuee Creek Watershed Project

The Chestuee Creek project, located in middle-east Tennessee, was one of several projects wherein TVA worked with local people and agencies " . . . in an intensive, integrated effort to develop the resources of the region . . . to provide optimum crop and forest production; optimum utilization of water. The measurement of the effect of such adjustments upon water action; and the raising of income levels would be reflected in improved educational, health, recreational, and government services." During the 18-year life of the project, at least a portion of these objectives were realized. Land-use changes from row crops to pasture and forest, and increased income levels on test-demonstration farms, were achieved. Accompanying these were reductions of 45 to 70 percent in the sediment in the streams and a decrease of about 10 percent in storm runoff and peak discharges. However, more important than these were the lessons learned. An evaluation report on the Chestuee Creek project[8] observed that " . . . . The values of the Chestuee program are diffused among all of the watershed programs that followed this initial experiment . . . . Many lessons were learned in Chestuee that made later adaptations of area development programs more successful. . . . In Chestuee many efforts were made to meet the complex problems of administering a program that sought unity of direction, maximum participation of resource interests and sound intergovernmental, interagency relationships. . . . a great many organizations had their first experience with broadly based area development, with working together toward common objectives in a limited space."

The findings of the Chestuee Creek Project and other early developmental areas prepared the way for the creation of TVA's Tributary Area Development Program. This broad program is aimed at the comprehensive resource development of large watersheds within the Valley. A description of this total program has been documented in various forms.[9]

In two of these areas, Beech River in west Tennessee and Yellow Creek in north Mississippi, hydrologic measurements of rainfall, streamflow, and suspended sediment were included. These measurements were to be used in planning improved land-use practices. However, in Beech River the reverse process occurred. Renovation of abused land through reforestation and improved agricultural practices took place and an attempt was made to detect the effects of these measures upon streamflow and suspended sediment. The results in this 305-square-mile area were not so dramatic as those achieved on Pine Tree Branch, located within Beech River watershed. Only a decrease in sediment loads was detected. The failure to detect significant changes in hydrologic responses is not suprising. Research findings had been expected from a project not designed to produce this level of results. Land-use changes could not be controlled since all of the watershed was in private ownership. The detailed information needed to relate changes on the land to changes in streamflow at a given gage was not measured. The hydrologic measurements were valuable, however, in the design of a water control system for the watershed. This system of seven multipurpose reservoirs, one detention dam, and some 80 miles of improved channels is designed to limit crop season flooding to an average of once in five years. Continued hydrologic measurements are being secured to ascertain the effectiveness of the water control system.

The Parker Branch Watershed

The Parker Branch research watershed, near Asheville in western North Carolina, was initiated in 1952 as another cooperative project with North Carolina State University. This study was established to resolve some of the problems and questions left unanswered by earlier developmental watersheds. Early projects had not defined potentials for the agricultural resource adjustments, or the implications of major adjustments on farm or rural economies, or ways to achieve development goals and the implications of major land-use changes on the water resource. The Parker Branch study was therefore established as a research project with specific objectives, control measurements, and a definite schedule.

In 1952 the 1000-acre watershed was typical of many low-income rural areas of the South. Abused land, subsistence farming, poor management, and reliance upon non-farm income all contributed to the problems. An intensive technical, managerial, and financial assistance program was initiated to determine (1) the extent to which farm income could be raised by total resource use, (2) the associated changes in farming operations, including financial investments and farm consolidation as well as land-use adjustments, and (3) the resulting changes in watershed hydrology.

The results of the Parker Branch project are included in a comprehensive project report.[10/] The study was an outstanding success from almost any aspect. During the 10-year span of the project, net farm income increased fourfold while average family income from all sources increased 50 percent. Land-use changes involved a substantial shift

from idle or forest lands to pasture and alfalfa. Farm consolidations and farm management changes largely eliminated absentee ownership and increased productivity. Private investments in livestock, buildings, and equipment were almost double the public financial investment in land renovation, seed, and fertilizer made to accelerate land-use and farm management changes.

Significant changes also occurred in the water resource. Improved cover conditions permitted increased infiltration, reduced summer storm runoff, and improved ground-water levels. Peak runoff rates during the summer were reduced about 55 percent. Retardation of runoff was most pronounced for small- to moderate-sized intense storms. The land-use adjustments were not effective in reducing runoff during many winter storms and occasional summer storms which occurred when infiltration capacities were lowered by saturated soil conditions. Sediment transport from the watershed was reduced 71 percent.

The Parker Branch project thus linked the water resource to land use on a research level. It demonstrated that the optimizing of farm income using a total resource development approach is consistent with soil and water conservation. It also showed that there are definite limits to the extent to which land use can influence the water resource. Although the overall changes in the water resources at Parker Branch were significant, many winter floods and a few summer floods were unaffected by the land-use adjustments.

The Parker Branch project included the study of two alternate resource development programs in order to compare their effect upon net farm income with that actually observed. The first, using only an increase in the level of technology with no organizational changes, would have raised farm income an estimated 114 percent. The second alternative, emphasizing soil and water conservation, would have increased net farm income 214 percent. The total resource development program used resulted in an actual 343 percent increase in farm incomes.

The alternate programs could not be coupled with estimates of corresponding changes in the hydrologic response. Analytic procedures to provide such estimates were not available; hence, this facet of the Parker Branch study could not be explored. This lack of a prediction method to evaluate alternate land-use programs in terms of hydrologic response led to additional hydrologic research aimed at providing such methods.

The Upper Bear Creek Experimental Project

The Upper Bear Creek Experimental Project, initiated in 1962, is located in northwestern Alabama. This project is designed specifically for the formulation and numeric evaluation of methods for transferring hydrologic data. A procedure termed area-stream factor correlation (ASFAC) is the mathematical model to be developed. This procedure

requires detailed knowledge of the interrelationships between the characteristics of the watershed and the flow in the stream draining it.

To provide data for use in the model the basic 143-square-mile watershed has been subdivided into several sets of subwatersheds, each with different land-use patterns. (Figure 3). Hydrologic instrumentation includes 12 stream gages and a network of 44 rain gages. The streamflow and rainfall data are used to generate the stream factors: the runoff volumes, and a distribution function. The area factors--land use, soils, topography, etc.--are obtained by periodic surveys in both dormant and growing seasons.

The results of this study should permit (1) the transferring of hydrologic data from headwater areas downstream to larger drainage areas, (2) the estimation of changes in the water resource that will occur as a result of land-use adjustments, either real or proposed, and (3) the simulation of hydrologic response on ungaged watersheds.

In addition to the above objectives, the project also provides for cooperative research in forest management with the U. S. Forest Service, open-channel hydraulic studies, water quality investigations, and studies of suspended sediment yield. Descriptions of the project and related investigations have been included in more detailed reports.[11/] [12/]

To date, a considerable effort at this project has been devoted to the building of mathematical models using observed data and the developing of associated computer programs. Upon completion of the model development, the area-stream factor correlation will begin in which the measured watershed characteristics will be linked with the streamflow. Once the area-stream factor link is accomplished, and this will require verification of the model over a wide range of data, the area factors alone can be used to estimate streamflow on ungaged watersheds or to predict varying hydrologic response under alternate land-use programs. The methods and techniques to be developed at the Upper Bear Creek project will provide a useful tool for the planning of water resource development as well as means of synthesizing streamflow data needed for the design of water control systems.

SUMMARY

In summary, TVA watershed research has covered a wide range of investigations. Single-purpose watersheds, typified by White Hollow and Pine Tree Branch, have demonstrated that reclamation work on abused land could benefit the water resource while returning the land to productivity. The western North Carolina project provided the basic hydrologic research needed to explain the varying hydrologic responses observed and led to the recognition of the heterogeneous nature of a watershed and the concept of partial-area runoff contribution. The North Fork Citico Creek project will provide answers to questions as to how mountainous, forested

areas can be managed to utilize timber and wildlife resources and develop recreation potentials, yet provide the needed protection for the water resource.

Resource development watersheds--Chestuee Creek and Beech River--have indicated that improvements in the water resource can result from multi-resource development programs, but dramatic results on these larger areas are difficult to achieve because the development of human resources as well as land resources is involved. The Parker Branch project defined resource development potentials and showed that high rural income goals can be achieved and are compatible with soil conservation practices and improved hydrologic response.

The Upper Bear Creek project has not yet produced significant results, but has pointed out the shortcomings of many of the conventional approaches to water resource development. More important, it promises a mathematical linking of streamflow and watershed characteristics.

In the immediate future TVA small watershed research will include a study of the effects of area coal strip mining and follow-up reclamation work on the water resource. We are presently considering a watershed study designed for the investigation of the movement of nitrate fertilizer by runoff. Future water resources research by TVA will, as in the past, be applicable to its on-going program of comprehensive resource development.

REFERENCES

1. "Forest Cover Improvement Influences upon the Hydrologic Characteristics of White Hollow Watershed, 1935-1958," Report No. O-5163, TVA, Knoxville, Tennessee, May 1961.

2. "Forest Protection and Streamflow from an Adirondack Watershed," Eschner, Arthur R., and Satterlund, Donald R., Presented at the Forty-Sixth Annual Meeting of the AGU, 1965.

3. "Increases in Water Yield after Several Types of Forest Cutting," Hewlett, John D., and Hibbert, Alden R., Quarterly Bulletin, IASH, Louvain, Belgium, September 1961.

4. "Effects of Forest Cover upon the Hydrologic Characteristics of a Small Watershed in the Limestone Region of East Tennessee," Sodemann, Paul C., and Tysinger, Jones E., TVA, Knoxville, Tennessee, October 1965.

5. "Reforestation and Erosion Control Influences upon the Hydrology of the Pine Tree Branch Watershed, 1941-1960," TVA, Knoxville, Tennessee, 1962.

6. "What is Watershed Runoff?" Betson, Roger P., Forty-Fourth Annual Meeting, AGU, April 1963.

7. "Cooperative Research Project in Western North Carolina," Annual Reports, TVA, Knoxville, Tennessee.

8. "Chestuee Creek Watershed Project--Evaluation Report," TVA, Knoxville, Tennessee, October 1964.

9. "Tributary Area Development," TVA, Knoxville, Tennessee, 1965.

10. "Parker Branch Research Watershed," Project Report 1953-1962, TVA, Knoxville, Tennessee, 1963.

11. "Upper Bear Creek Experimental Watershed--Research in Area-Stream Factor Correlation," Water Resource Research Paper No. 4, TVA, Knoxville, Tennessee, 1964.

12. "The Upper Bear Creek Experimental Project," 1962-1964 and 1964-1965, TVA, Knoxville, Tennessee.

Acknowledgment: Much of the material used in preparing this paper was obtained from an unpublished report, "A Study in the Development of Watershed Research in TVA--1967," by Roger P. Betson, Head, Hydrologic Research and Analysis Staff, Hydraulic Data Branch, TVA.

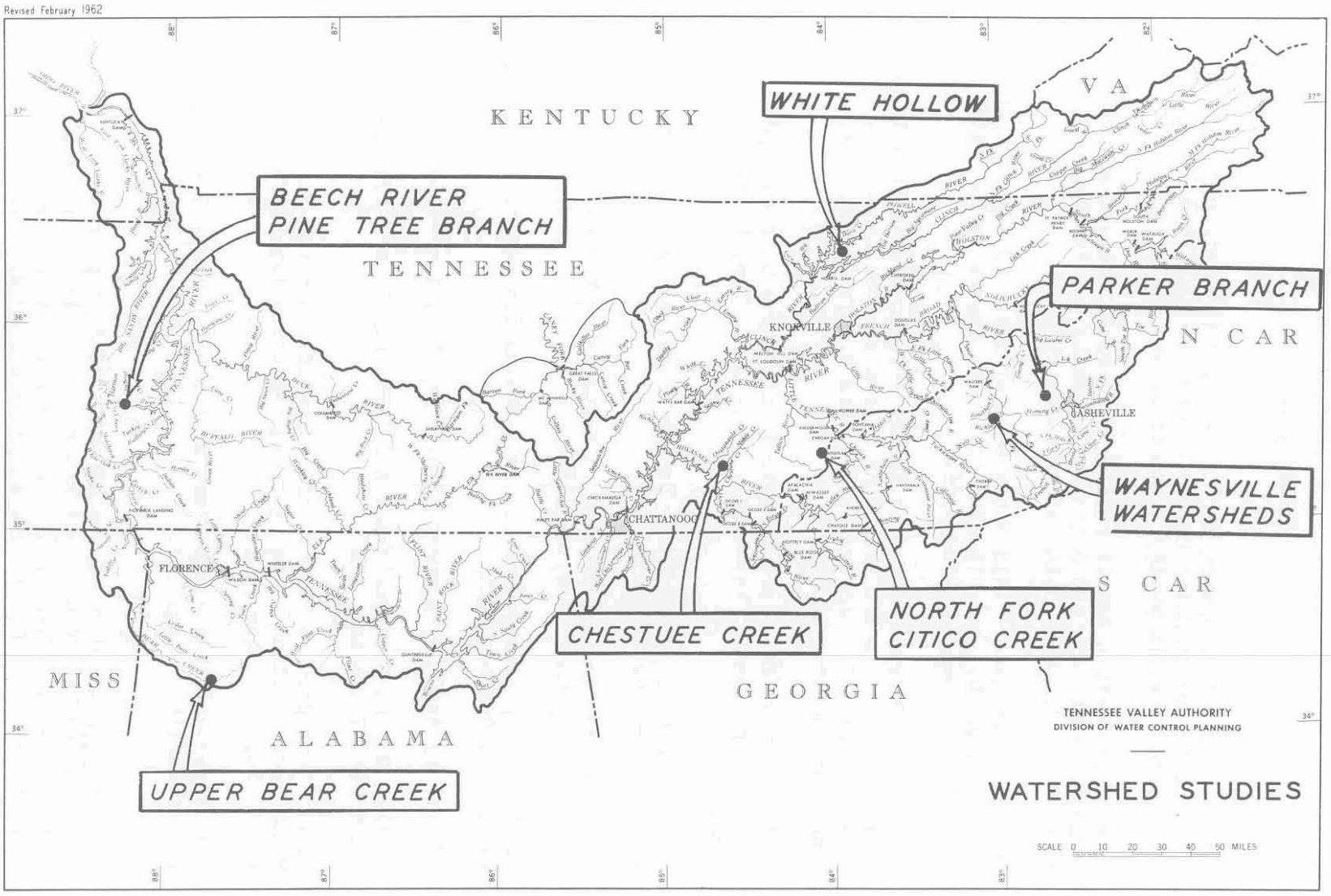

Revised February 1962
WHITE HOLLOW
BEECH RIVER
PINE TREE BRANCH
PARKER BRANCH
WAYNESVILLE
WATERSHEDS
CHESTUEE CREEK
NORTH FORK
CITICO CREEK
UPPER BEAR CREEK
KENTUCKY
TENNESSEE
VA
N CAR
S CAR
MISS
ALABAMA
GEORGIA
KNOXVILLE
CHATTANOOGA
FLORENCE
ASHEVILLE
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
WATERSHED STUDIES
SCALE 0 10 20 30 40 50 MILES

FIGURE 1

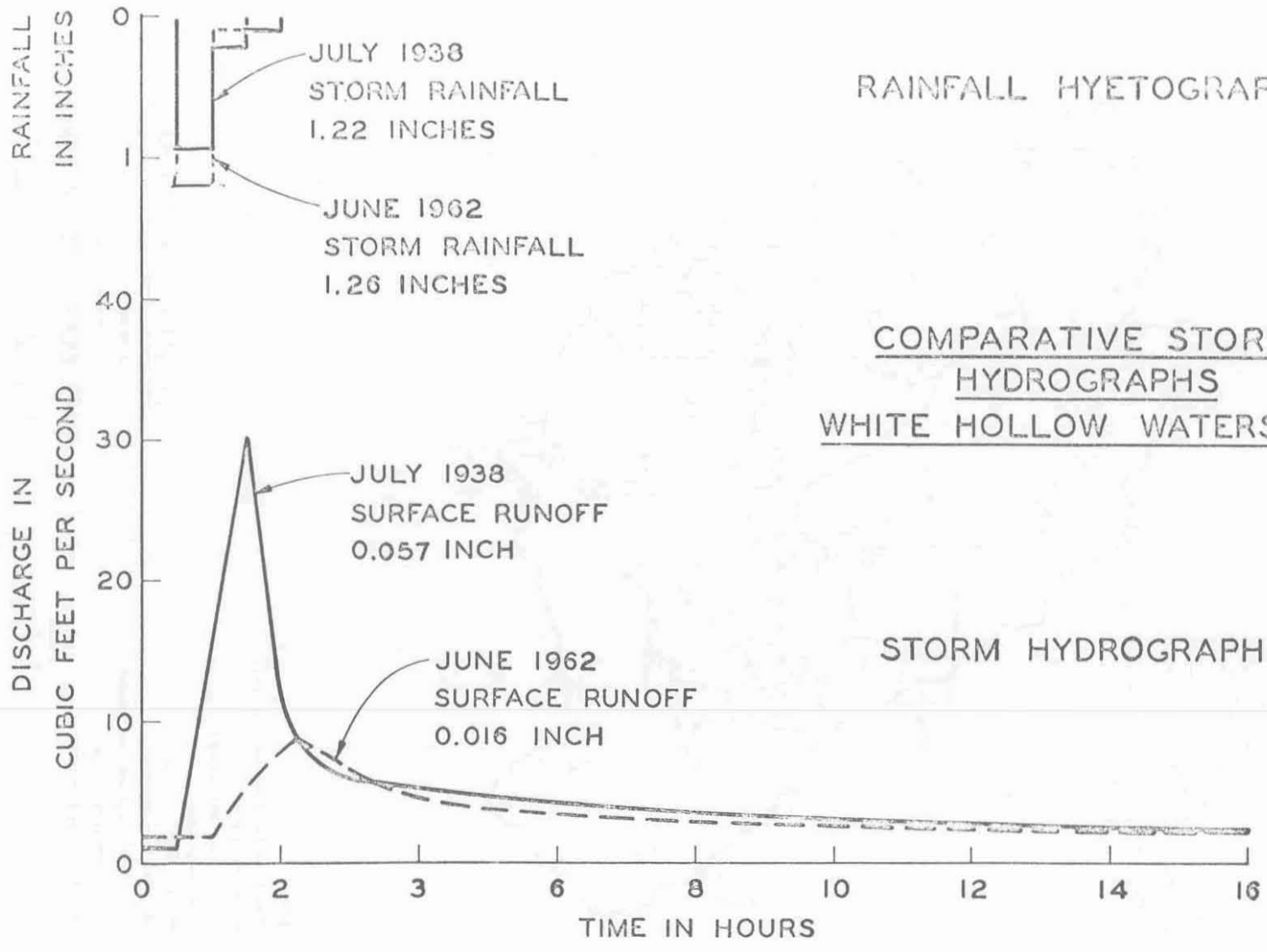
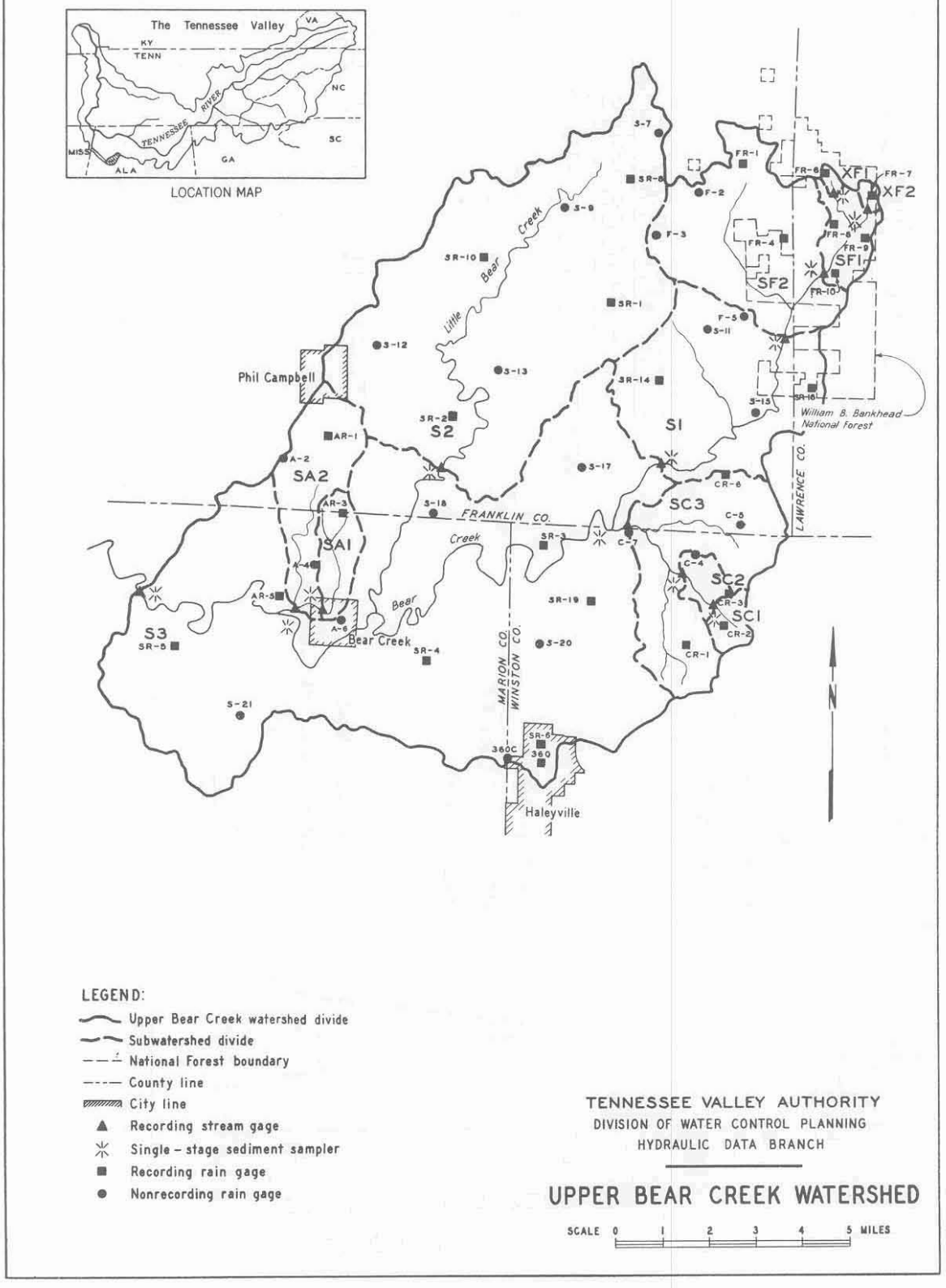

RAINFALL IN INCHES
0
1
JULY 1938
STORM RAINFALL
1.22 INCHES
JUNE 1962
STORM RAINFALL
1.26 INCHES
RAINFALL HYETOGRAPHS
COMPARATIVE STORM
HYDROGRAPHS
WHITE HOLLOW WATERSHED
DISCHARGE IN CUBIC FEET PER SECOND
40
30
20
10
0
JULY 1938
SURFACE RUNOFF
0.057 INCH
JUNE 1962
SURFACE RUNOFF
0.016 INCH
STORM HYDROGRAPHS
0
2
3
6
8
10
12
14
16
TIME IN HOURS

FIGURE 2

FIGURE 3


The Tennessee Valley
VA
KY
TENN
NC
TENNESSEE RIVER
SC
MISS
ALA
GA
LOCATION MAP
Phil Campbell
Bear Creek
Little Bear Creek
FRANKLIN CO.
MARION CO.
WINSTON CO.
LAWRENCE CO.
William B. Bankhead National forest
Haleyville
S1
S2
S3
SA1
SA2
SC1
SC2
SC3
SF1
SF2
XF1
XF2
N
LEGEND:
Upper Bear Creek watershed divide
Subwatershed divide
National Forest boundary
County line
City line
Recording stream gage
Single - stage sediment sampler
Recording rain gage
Nonrecording rain gage
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH
UPPER BEAR CREEK WATERSHED
SCALE 0 1 2 3 4 5 MILES