THE ROLE OF TVA RESERVOIRS IN REDUCING FLOOD CRESTS ON THE LOWER OHIO AND MISSISSIPPI RIVERS

by

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INTRODUCTION

The closure of Kentucky Dam in August 1944 forged the most effective link in the TVA chain of flood control projects to aid in controlling floods on the lower Ohio and Mississippi Rivers. Since that time Kentucky Dam, assisted by the other projects in the TVA system, has reduced the crest of over 50 floods on the lower Ohio and Mississippi Rivers and has prevented direct flood damages totaling over $43,000,000. Table I shows the significant floods on the lower Ohio and Mississippi Rivers since closure of Kentucky Dam, the amount of crest reduction by TVA regulation, and estimates of dollar value of damages prevented by these operations.

The Tennessee Valley is one of the wettest regions in the nation, and devastating floods have figured prominently in the region's colorful history. When TVA was created by an Act of Congress on May 18, 1933, one of the primary duties that it was specifically assigned was "to control the destructive floodwaters in the Tennessee River and Mississippi River Basins." Today, 37 years later, an integrated water control system consisting of 44 hydro projects is operated under the direction of TVA and two additional major multiple-purpose TVA projects are under construction (Plate 1). The total flood control storage reservation of the system on January 1 of each year exceeds 12 million acre-feet of which 4 million acre-feet is reserved in Kentucky Reservoir alone.

The principal flood control function of Kentucky Reservoir is the reduction of flood crests on the lower Ohio and Mississippi Rivers in the vicinity of Paducah, Kentucky, and Cairo, Illinois. Other TVA reservoirs are operated to supplement the storage capacity of Kentucky Reservoir as much as possible, consistent with their need for flood control within the Tennessee Valley. TVA regulation can reduce the crest of great Ohio and Mississippi River floods as much as 2 to 4 feet at Cairo, Illinois, and by lesser amounts downstream on the Mississippi River as far as the mouth of the Red River (Plate 2). This stage reduction capability is equivalent to increasing the height of hundreds of miles of downstream levees protecting 6 million acres of productive land, which is estimated to increase the value of these lands by $150,000,000. TVA regulation also aids in reducing the depth and frequency of flooding on an additional 4 million acres of land not protected by the levee system.

THE TENNESSEE VALLEY

The Tennessee River drains a 40,900-square-mile area which is very favorably situated for the occurrence of heavy and widespread storms. The terrain of the Tennessee Valley varies from the mountainous regions along the eastern rim--where mountain tops rise over 6,000 feet above mean sea level--to the rolling hills of middle Tennessee and the broad valleys and relatively flat areas of the western basin (Plate 3). In its course from Knoxville to the mouth at the Ohio River, the Tennessee River flows a distance of 650 miles and falls 500 feet. At the mouth of the Tennessee River the flood plain generally is slightly above elevation 300.

Hydrology of the Tennessee Basin

The mean annual rainfall over the Tennessee River Basin is about 52 inches, but annual means have varied from a low of 38 inches to a high of 65 inches. Some locations in the mountainous southeastern section show annual averages in excess of 90 inches, while other areas within the basin average less than 40 inches. Rainfall is fairly well distributed throughout most of the year (Plate 4). Mean monthly amounts vary from slightly less than 3 to about 5-1/2 inches, with March usually the month of heaviest precipitation.

Mean annual runoff from the basin is about 43 percent of the annual precipitation, or about 22 inches, and has varied from a low of about 10 inches to a high of 33 inches. The natural river flow at Kentucky Dam has varied from a maximum of 500,000 cubic feet per second in 1897 to a minimum of 4,500 cfs in 1925, with an average annual flow of 65,300 cfs for the period between 1886 and 1968.

Although rainfall in the Tennessee Valley is well distributed throughout the year, streamflow records show a strong seasonal pattern in which the high flows of the winter and spring months stand out clearly (Plate 4). Occurrence of great Valley-wide floods would be expected to fit the seasonal runoff pattern. This is illustrated by Plate 5 which shows the distribution of floods at Chattanooga by months of the year. It shows that all of the large floods have been limited to the period from late December to early April, following the seasonal runoff pattern.

Relation of Kentucky Dam to the Ohio and Mississippi Rivers

Kentucky Dam is located 22.4 miles above the mouth of the Tennessee River which is near Paducah, Kentucky, and 68.9 miles above the mouth of the Ohio River at Cairo, Illinois (Plate 3). Due to this favorable location of Kentucky Dam, regulation of Tennessee River discharges by Kentucky Dam is effective on the lower Ohio and Mississippi Rivers almost without diminution. Although the drainage area of the Tennessee River is less than 5 percent of the Mississippi River Basin above Columbus, Kentucky (Plate 6), the contribution of the Tennessee River discharges to Mississippi River floods has usually been a substantial amount. The highest known contribution, 30.6 percent, occurred in the 1897 flood, which was the highest known flood on the lower Tennessee River. During the great February 1937 flood, 7-1/2 years before Kentucky Dam was closed, the Tennessee River contributed about 12 percent of the discharge to the flood crest of the Mississippi River at Cairo. The actual amount of reduction of a flood crest at Cairo effected by operation of TVA reservoir system will vary with each flood, depending on the relative magnitude of the flows in the Tennessee, Ohio, and Mississippi Rivers; the available flood storage space; and the requirements for reduction on the lower Ohio and Mississippi Rivers.

OBJECTIVES OF FLOOD CONTROL OPERATIONS

Eastern Tennessee Valley Above Chattanooga

Within the Tennessee Valley by far the greatest potential urban damage from floods is at Chattanooga, located just above the narrow constriction that divides the Valley into rather distinct upper and lower portions (Plate 3). The existing TVA reservoir system provides almost complete protection to large areas below the tributary dams, and a substantial degree of protection to the areas below the main river dams. Chattanooga, however, is the focal point for major flood control operations within the Tennessee Valley, for it is the location of greatest preventable damage in the basin.

Western Tennessee Valley, Ohio and Mississippi Rivers

The principal use of flood control storage in the Tennessee River reservoirs below Chattanooga is to regulate floods (1) below each of the dams on the Tennessee River and (2) on the lower Ohio and Mississippi Rivers. Paducah, Kentucky, and Cairo, Illinois, are locations of particular interest in flood damage prevention on the lower Ohio River. The primary objectives in the operation of TVA reservoirs for regulation of floods on the lower Ohio and Mississippi Rivers are (1) to safeguard the Mississippi River levee system, (2) to reduce the frequency with which the Birds Point-New Madrid floodway is put to use, and (3) to reduce the frequency and magnitude of flooding of land not protected by the levee system (Plate 7).

Certain locations on the lower Mississippi River have been selected as main control points and critical stages were determined for each location as a guide to regulation of releases from the Tennessee River. In general, these critical stages are those above which the danger of floods breaching or overtopping protection works is imminent or damages to unprotected areas becomes serious. The control points and the critical stages at these points are as follows:

Location	Critical Stage
Cairo, Illinois	54 feet during winter season 40 feet during cropping season (end of April to end of November)
Birds Point-New Madrid Floodway	57 feet on the Cairo gage
Tiptonville-Obion Extension Levee	52.5 feet on the Cairo gage

Thus, the Cairo, Illinois, gage has been selected as an index of flooding on the lower Ohio and Mississippi Rivers.

Although nominal flood stage at Cairo is 40 feet, and some flooding of highways and railroads occurs at stages below 50 feet, flooding becomes more extensive at a stage of about 53 feet. Initial studies of Kentucky Reservoir operation for floods of record prior to addition of Corps of Engineer reservoirs in the upper Mississippi, Missouri, and Ohio Basins indicated that 54 feet was the practical minimum stage to which the more severe winter season floods could be reduced with the storage available. With the beginning of the cropping season, about the first of April, lower stages cause damages by delaying preparation of agricultural lands and the planting of crops, and by actual destruction of crops. While control of summer season floods to a stage of 40 feet is desirable, initial analysis of past floods indicated 44 feet to be the minimum practical stage for reduction of severe summer season floods. With the addition of the Corps reservoirs, floods lower than these critical stages can be regulated.

OPERATING PRINCIPLES AND OBJECTIVES

Planning for Flood Control

An important and controlling element in planning the dams and reservoirs was the seasonal character of major Valley-wide floods in the Tennessee Valley. The record, extended back about 150 years through historical high water marks--though not entirely complete--indicates that the large destructive, Valley-wide floods occur during a more or less well-defined period of about four months (Plate 5). This flood period extends from about the last half of December to the first part of April. The greater incidence of winter floods results from a more frequent occurrence of heavy, persistent precipitation at the same time that vegetation is dormant and ground conditions favor a high rate of runoff.

In the Tennessee Valley, largest reservations for controlled detention of flows are provided in the flood season--January, February, and March. At both Paducah and Cairo, on the Ohio and Mississippi Rivers, floods occur later than on the Tennessee River, extending through April into May and June.

Functions of Two Types of Reservoirs

The 10 large flood storage reservoirs on the tributaries to the Tennessee River have a relatively large capacity with respect to flood volumes--equivalent to 6.4 inches over their drainage areas on March 15--and therefore are operated to store all, or almost all, of the flood inflow. The eight main Tennessee River reservoirs, which have a flood storage reservation, have a relatively much smaller flood storage capacity--equivalent to an average of about 1.8 inches over their drainage areas, excluding Kentucky--and therefore are operated to accelerate the pre-flood flows downstream, thereby reserving their flood control storage for use in reducing the flood crest, when optimum benefit can be achieved through use of the limited flood storage space.

Development of Operating Principles and Objectives

During 37 years of planning, constructing, and operating the TVA hydro projects, 10 flood control operating principles and objectives evolved. Five of these principles and objectives relate to operations of the reservoirs for flood control within the Tennessee Valley, especially for the reduction of flood stages at Chattanooga. The other five principles, which relate especially to operations for flood control in the lower Tennessee Valley and on the lower Ohio and Mississippi Rivers, are listed below.

1. The flood control operation of the Tennessee River reservoirs below Chattanooga is primarily for the reduction of flood heights along the upper reaches of those reservoirs and to supplement Kentucky Reservoir operations.

2. The flood control operation of Kentucky Reservoir is primarily for the reduction of flood heights along the lower Ohio and Mississippi Rivers.

3. Throughout the flood season a storage reservation of 21 feet is provided in Kentucky Reservoir. This reserved space is sufficient for the retention of only a limited portion of the flow in the Tennessee River and therefore the available storage capacity, as far as possible, must be held for use when the peak flow of the Ohio arrives at the mouth of the Tennessee.

4. The objective in the use of the reservoir system for flood control is primarily for the regulation of damaging floods, and the available capacity is to be reserved for that purpose.

5. Data on rainfall and streamflow will be collected continuously during the progress of all storms and utilized as a guide to daily detailed operation. Successful reservoir control will require not only adherence to the general principles, but also close attention to and prompt allowance for the daily developments.

The successful regulation of a flood requires careful coordination of the operation of the tributary and mainstream reservoirs. It also requires that the prescribed flood storage space be held in reserve during the entire flood season, except when used for regulating floods.

RESPONSIBILITY FOR FLOOD CONTROL ON THE OHIO AND MISSISSIPPI RIVERS

Section 7 of the Flood Control Act of December 22, 1944, provides that ". . . in case of danger from floods on the lower Ohio and Mississippi Rivers the Tennessee Valley Authority is directed to regulate the release of water from the Tennessee River into the Ohio River in accordance with such instructions as may be issued by the War Department." This statute assures that the flood control operations of Kentucky Reservoir are integrated with the flood flows on the Ohio and Mississippi Rivers, which are under the control of the Corps of Engineers. The Division Engineer, Ohio River Division, has been designated formally by the Secretary of Defense as the representative of the Defense Department responsible for issuance of instructions to TVA for regulating releases from the Tennessee River when danger from floods exists on the lower Ohio and Mississippi Rivers.

Development of Joint Operations Manual

Cooperative arrangements between TVA and the Corps of Engineers to regulate flows from the Tennessee River during floods on the lower Ohio and Mississippi Rivers have been in effect since 1945. A joint manual entitled "Regulation of Releases From the Tennessee River During Ohio and Mississippi River Floods Periods" was issued in 1957 through the cooperative efforts of TVA engineers and the Corps of Engineers and was revised in 1963. This manual presents a summary of the detailed working arrangements and procedures developed by the engineering staffs of TVA and the Corps of Engineers. The following paragraph, extracted from that manual, details the working arrangements now in use.

Working Arrangements

Normally the Kentucky Reservoir operation schedule for flood periods is determined by the Tennessee Valley Authority with a view to providing optimum flood regulation consistent with physical limitations on operation of the project. The proposed schedule of releases is reviewed by the Mississippi River Commission and the Ohio River Division. If, in the opinion of either office, a deviation from the operating schedule proposed by the Tennessee Valley Authority is desirable, the proposed deviation is coordinated between the two offices and then is discussed with the Tennessee Valley Authority via telephone by the Ohio River Division. Taking into consideration any reservoir storage or dam operation factors which might affect the desired regulation, a revised schedule of releases is agreed upon. This schedule is confirmed by the Tennessee Valley Authority by teletype to the Ohio River Division and is relayed by the division office to the other offices concerned.

Cumberland River - Barkley

The Nashville District, Corps of Engineers, is responsible for flood control operations on the Cumberland River. Barkley Dam, a Corps of Engineers project located 30.6 miles above the mouth of the Cumberland River, became fully effective for flood control in February 1966, providing about 1,500,000 acre-feet of flood storage during the flood season. An ungated navigation canal connecting Kentucky and Barkley Reservoirs was opened in June 1966 (Plate 8). Because of this interconnecting canal, Kentucky and Barkley Reservoirs must be regulated as a unit. Cooperative arrangements between TVA and the Nashville District, Corps of Engineers, insure the carefully coordinated operations of these reservoirs at all times. During flood control operations by Kentucky and Barkley Reservoirs, TVA water control engineers and Corps of Engineers personnel of the Nashville District and the Ohio River Division are in frequent contact, coordinating all flood control operations and predictions.

OPERATIONS

Ideal Operation

The so-called "ideal" method of operation of the reservoirs for flood control, where reservoirs do not have sufficient capacity to retain the entire runoff from a storm, implies the best possible use of the storage available for the maximum reduction of flood stages at critical locations below the reservoirs.

To accomplish this result, it would be necessary to have in advance of the storm complete chronological knowledge of the discharge of the stream that would occur at various locations. Since any such degree of accuracy in weather forecasting does not appear to be attainable in the foreseeable future, there seems to be no point in anticipating such favorable results. Although it is true that the possibilities of this method of operation can be computed from records of past floods to determine the limiting reductions of stage, the results are apt to be misinterpreted as those which should have been obtained but were not because of incompetence of the operators.

Operating Concepts in Use

Although the basic concepts of flood control operation can be established by recognition of objectives and study of past experience, the operation of a large, multiple-purpose reservoir system cannot be reduced to fixed routine procedures to be followed for all floods. No two floods are exactly alike. Distribution, duration, and intensity of storms vary; available space is never identically distributed; and downstream requirements change. It is necessary to deviate in the day-to-day pattern of control followed from one flood to another, while still adhering to the same basic principles.

Current flood control operating procedures are based on two different operating concepts: (1) A set of rules has been developed, based on analysis of prior events, which can be used in the decision-making process with a minimum of current analysis; and (2) the predictive process, in which emphasis is placed on current analysis of all available information, is used to modify the established rules and thus, hopefully, optimize the operations.

Operating Guide. At the present time operation of Kentucky Reservoir is in accordance with an operating guide which calls for retention of flood flows in the reservoir when forecasts indicate that certain designated stages at Cairo will be exceeded. Operations under the guide are varied as necessary to meet anticipated conditions of weather and crest stage at Cairo, peak volume above various Cairo stages, flow in the Tennessee River, and available reservoir storage. Maximum level at Kentucky Dam for storing floodwater is elevation 375 from December through May. Normally, from June through November the maximum water level at the dam is limited, if possible, to elevation 365, recognizing that flooding easements in the Kentucky Reservoir above elevation 365 are limited to the period December through May.

Because of the complexity of the problem, development of uniformly applicable guides for flood control operations of the reservoirs in the Ohio-Mississippi system has not been completed. Research has been conducted for the formulation of numerical solutions of flood routing problems with a view to application of digital computers in the solution. Studies are under consideration under the leadership of the Reservoir Control Center in the Ohio River Division Office, to develop a comprehensive computer program to handle the total basin-wide analysis.

Predictive Process. Researchers have acknowledged the role of the predictive process in the day-to-day operation of control facilities. A knowledge of current and anticipated streamflows is essential for the efficient operation and control of the reservoir system. Current forecasting and routing procedures in use by TVA accurately predict flows based on current and observed hydrologic data. Meteorological uncertainties, however, still present a problem. Although we are able to measure and predict rather well the behavior of water after it reaches the earth's surface, the ability of meteorologists to define the atmospheric portion of the hydrologic cycle leaves much to be desired.

Under a memorandum of agreement between TVA and the ESSA Weather Bureau, the Knoxville Weather Bureau Airport Station furnishes quantitative forecasts of precipitation for the Tennessee and Cumberland River valleys on a regular daily schedule, with additional forecasts as frequently as changing weather conditions warrant. The regular forecast covers a period of 48 hours and, in addition, gives an outlook for the following 72 hours. TVA's long experience with quantitative precipitation forecasts shows that verification of the predicted amounts of rainfall for the whole five-day period is seldom obtained. ESSA Weather Bureau meteorologists, however, are still trying to achieve this goal. Thirty-day outlooks in weather also are furnished semimonthly by the Weather Bureau and include quantitative forecasts of total precipitation for the period. These long-range forecasts have not been accurate enough to use in advance planning, however.

Quantitative forecasts of precipitation are considered in scheduling discharges at each dam in the system. Streamflow forecasts based on predicted rainfall are made frequently to serve as a guide in planning reservoir operations should the weather forecast verify

Operations for Flood Control - Ohio and Mississippi Rivers

The operation of the TVA reservoir system for flood control on the Ohio and Mississippi Rivers follows the pattern of (1) drawdown of Kentucky Reservoir below normal level, (2) storage of Tennessee River flows for crest reduction on the lower Ohio and Mississippi Rivers, and (3) post-flood drawdown of the reservoirs to flood control levels (Plate 9).

Pre-Flood Drawdown. Prior to construction of Kentucky Dam, natural flood flows from valley storage in the lower Tennessee River often coincided with peak flows on the Ohio River, augmenting peak stages on both the lower Ohio and Mississippi Rivers. The object of making early flood releases from Kentucky and Barkley Reservoirs is to accelerate the Tennessee and Cumberland flood waves downstream before the arrival of the Ohio River flood crest at the mouth of those streams. The additional storage capacity provided in these reservoirs by the advance drawdown of the reservoirs is then available for retention of flows in the Tennessee and Cumberland Rivers that would otherwise coincide with peak flows on the Ohio River. The drawdown at Kentucky and Barkley Dams is limited to a minimum headwater of elevation 346 or a tailwater at Pickwick Landing Dam of elevation 355, the minimum levels to meet navigation requirements at these locations. The drawdown is further limited to hold the total volume under the water surface profile at not less than the flat pool volume at normal headwater elevation 354, thus insuring sufficient water to return to normal minimum pool level. During the precrest drawdown period, the resulting Cairo stages will usually be greater than the natural stages would have been, but reservoir detention capacity will have been saved for use at the time when it can produce the greatest reduction of the Ohio River crest.

Storage for Crest Reduction. When the flood crest on the Ohio and Mississippi Rivers can be defined with reasonable accuracy with respect to time and stage, selection of the target stage to which it is anticipated the flood can be held is made by the Corps of Engineers. Gradual reductions in releases from Kentucky Dam (and at Barkley Dam) then are made as the crest approaches, and releases are regulated as needed to obtain the maximum practical crest reduction. The amount of the reduction in discharge from Kentucky Dam will vary with each flood, depending on the flow in the Tennessee River; the weather outlook; the available storage space; and the requirements for reductions measured by stages at Cairo, which in turn depend on the season of the year. On some occasions, as in 1958, 1960, 1961, and 1968, TVA has reduced Kentucky discharge to zero for two or three days to achieve maximum Cairo stage reductions.

Post-Flood Drawdown. Post-flood drawdown of Kentucky Reservoir to regain flood control storage space usually starts as soon as practicable after the Cairo crest is reached and the stage has begun to fall. In smaller floods, drawdown usually is started after Cairo has fallen about a foot. Releases from Kentucky Dam gradually are increased, and are made at a rate calculated to maintain a flat or slowly falling Cairo stage, provided flood stages below Cairo will not be increased thereby. As a general rule, the amount of discharge from the dam will depend upon the volume of storage to be released, the time of the year, the possibility of succeeding Mississippi River floods, and the previous high releases. Usually the reservoir will be returned to normal level in from 10 days to two weeks after storing has ended, depending on the volume of surplus water to be discharged.

Problems Affecting Operations for Flood Control

Changing the flow of a stream--either increasing low flows or reducing high flows by means of reservoirs--presents a wide variety of problems, most of which are due to public reaction to any change of whatever nature, even though it may be beneficial. These problems, both temporary and continuing in nature, often affect flood control operations. All special operations to relieve the numerous emergency situations, however, have been subordinated to the overall plan of operation for obtaining maximum flood control benefits.

One of the most difficult problems constantly facing water control engineers is the misunderstanding of flood control by the public. People push their activities down to the new regulated levels, even building homes there. They refuse to believe that when a flood of major proportions occurs, even the regulated flow below the dams will be so high that it will cause serious damage in the new zone of activity. Rapid changes in stages below the dams--especially during each flood control operation--also cause many complaints. Most complaints result from a lack of knowledge of flood easement provisions and of flood control operations. In spite of many newspaper articles, talks, legal decision, magazine articles, and books covering the subject, many individuals remain uninformed. Efforts to educate the public and increase awareness of potential flood hazards must continue.

BENEFITS ACHIEVED

Any discussion of the benefits achieved from flood control operations usually becomes involved with the various categories of benefits--paimary, secondary, and incidental--and with accounting principles. Details of the categories and accounting principles used by TVA can be found in a TVA report entitled "Floods and Flood Control." A brief synopsis of the results of the evaluations is all that will be presented here.

Flood Control Benefits

The accumulated flood control benefits of $540,000,000, from the TVA reservoir system through January 1969, are now nearly three times the $191,000,000 investment in the flood control system and about seven times the $81,000,000 accumulated flood control expense.

To determine the value of flood control, TVA made a comprehensive study and report (1936) of the value of reduction of flood stages on the lower Ohio River from Paducah to the mouth at Cairo and on the Mississippi River from Cairo to the mouth of the Red River (Plate 2). Primary tangible benefits include preventable flood damages to some 4,000,000 acres in the unprotected and backwater areas. Secondary benefits are largely the estimated increase in land values of some 6,000,000 acres already protected by the levee system, but which receive greater security from floods because of upstream reservoir control. The 4,000,000 acres lie in the unprotected areas of western Kentucky and Tennessee, western Mississippi and eastern Louisiana, and in the backwater areas of the St. Francis, White-Arkansas, and Yazoo Rivers.

The estimated average annual flood damages preventable by the TVA reservoir system on the lower Ohio and Mississippi Rivers is $2,869,000. Damages actually prevented through 1969 since closure of Kentucky Dam, some 25 years ago, amount to $43,000,000, or an average of about $1,720,000 per year--substantially less than the estimate for the long-term period of record, 117 years at Cairo. Justification of the higher estimate of preventable damages must await a large regional flood.

Stage reductions at Cairo due to TVA regulation reached 3.1 feet in May 1958 and in April 1965 (Table I). The largest savings in damages from regulation of a flood on the lower Ohio and Mississippi Rivers resulted during the flood of May 1958 (Plate 10). Although the observed stage of 43.1 feet was relatively low, the averted damages were estimated at almost $8,000,000 because of its occurrence during the crop season.

Incidental Benefits

Incidental benefits to other water use programs are achieved as a result of storing floodwater during the operation of the reservoir system for its primary purposes--navigation, flood control, and power. Municipal and industrial water supplies have been greatly enhanced in quantity and quality. The release of previously stored floodwater during periods of low flows also contributes to the improvement of navigation on the Mississippi River and to the prevention of salt water intrusion into the Mississippi from the Gulf of Mexico.

FUTURE DEVELOPMENTS

Electronic Data Processing

Until recently the daily operating analysis of the reservoir system was largely dependent on manual computations. Today the electronic computer is being used to process large volumes of data with far greater speed and accuracy than is humanly possible. Improvements in data processing through use of the computers will make possible more rapid predictions of flows and will produce some increase in the accuracy of predictions. In the future the engineers who are operating and managing the flood control system will be able to evaluate several alternatives and then make their decisions more rapidly, thus operating with some increases in efficiency.

Improved Meteorological Forecasts

The most critical need at this time to permit significant improvements in flood control operations, is for accurate, timely, and reliable long-range weather predictions. Meteorological forecasts now used by TVA give relatively reliable quantitative predictions of precipitation for two days at the most. Three additional days predictions are also received, but their accuracy leaves much to be desired. Beyond that 5-day period lies a no-man's land as far as usefulness in planning future reservoir operations.

The lack of reliable long-range weather predictions is especially critical during flood control operations at Kentucky Dam. During the major flood season in the Tennessee Valley, weather systems generally move across the Valley each three to five days, with each system containing the possibility of producing increased flows. Emptying Kentucky Reservoir to recover normal flood control storage space usually requires 10 to 14 days after a major flood control operation. Thus, three or more precipitation cycles are likely to occur before the normal flood control storage space is recovered.

Maximum Utilization of Flood Storage Space

Utilizing all available storage space could provide maximum reduction in the crest of floods on the lower Ohio and Mississippi Rivers, but prudent operation dictates reserving some space for contingencies--especially the uncertainties of the next weather systems. Water control engineers recognize the possibility that one of the weather systems moving across the Valley during the emptying of Kentucky Reservoir could produce heavy precipitation of a magnitude that would require additional flood control operations to regulate the flows. The probability of such an occurrence is not as remote as might be imagined. In many instances the outstanding floods on the Tennessee and Ohio Rivers have resulted from the cumulative effect of an extended sequence of storms. The greatest flood of record on the lower Tennessee River resulted from rains spread over 21 days in March 1897. A similar sequence of storm events occurred in January 1937, resulting in the disastrous record-breaking flood which swept the Ohio River Valley during the latter part of January and early February. Such a sequence of events has been observed in lesser degrees of severity and duration several times in the period of record, and a recurrence must be considered as highly probable. It is certainly reasonable to expect that, when the maximum flood occurs, the maximum rain will be preceded by showers and followed by appreciable rain after about a three-day interval.

Should flood-producing rains occur when all or most of the flood storage space is already full, there would be little opportunity to regulate flood flows. Thus, a follow-up storm of lesser magnitude could require higher discharges and produce a higher flood crest than the larger primary storm. Extrapolating the tendency to reserve some flood storage space to its logical extreme, it is probable that--under present operating procedures--when the 100-year flood occurs not all of the flood control storage space will be utilized.

Significant increases in the efficiency of utilization of the complete flood storage space will have to await the development of the technology required to make accurate, timely, and reliable long-range weather predictions. When highly reliable quantitative and qualitative precipitation forecasts become available for two-week or more periods, then the managers of the flood control system may be able to utilize all available flood storage space in the regulation of flows and reduction of flood crests--filling the reservoirs, if need be, to the very top.

CONCLUSION

Effectiveness of Past Operations

TVA reservoirs have a significant role in reducing flood crests on the lower Ohio and Mississippi Rivers. They have effected crest reductions of over 3 feet and will be able to effect greater crest reductions in the future during larger regional floods. Direct flood damages already prevented total over $43,000,000, and additional protection is afforded to 6 million acres of productive land protected by downstream levees. Even though these past accomplishments are impressive, in the future there will be demands for increased effectiveness in flood control operations. Meeting these demands will require improved meteorological forecasts and the development of even more effective operating procedures.

Justification of Operations

A truism recently expressed so well in a recent paper by John T. Mitchell, Jr., Chief of the Corps' Ohio River Division Reservoir Control Center, is worthy of repetition here. "Those who are actively engaged in the day-to-day solution of practical water management problems or scheduling of reservoir operations are being required to justify each action in ever increasing detail." This is especially true of flood control operations.

Water control engineers directing the operation of the TVA reservoir system must have available to them a detailed analysis of their situation in the Tennessee River Basin plus an analysis that blends the solution of TVA problems into solution of the broader Ohio-Mississippi River problems. Such analysis is necessary in the decision-making process and for use in explaining or justifying operating actions.

Mr. Mitchell further stated: "Those who are actively engaged in the operating process are well aware of the questions asked by the public or the using organization. Few things do more to weaken confidence in an operating organization than resort to justification of operation decisions by reference to nebulous rules. It is becoming increasingly evident that the same can be said of implication that an action was impersonally and irrevocably directed by computer."

In light of this statement, the present flood control operating procedure seems to have considerable merit. The present procedure relies on the refined judgment of capable, experienced water control engineers, using all available data, equipment, and the most modern techniques to obtain the best solution. The public should be secure in its knowledge of the continued cooperation by men of different organizations, who strive, in good faith, to achieve the maximum amount of good with the tools at their disposal, yet who also strive not to place current operations in even greater danger by risking everything to gain little additional benefit. The public should also be assured of our continuous vigilance in the operation of the water control system and of the continuing diligent efforts to improve the effectiveness of flood control operations.

Evolution of More Effective Operating Procedures

The development of current flood regulation procedures and the publication of the Joint Operations Manual were long steps on the road to effective flood control. The failure to complete development of uniformly applicable guide rules for flood control releases from all reservoirs in the Ohio-Mississippi Basins should not be criticized, for the problem is one of extreme complexity. Even the most advanced computer package available today would be taxed beyond its capacity in the analysis of the possible alternative operations of the existing combined reservoir systems, now approaching 100 dams. The capacity of computers will be increased and they will be used for the rapid analysis of more data and more alternative solutions to aid the engineer-managers in decision making. This engineering aid, however, will never replace the judgment of a well-prepared, experienced, conscientious professional engineer.

The managers of the flood control systems must continue to operate to achieve maximum benefits with available flood storage space. Some unused space must be reserved, however, for regulation of possible increases in flows from the future, unknown weather systems. Development of reliable, long-range quantitative precipitation prediction capabilities would allow system operations to approach the maximum efficiency of the "ideal method of operation." As demands on the water control systems increase, it will become of increasing importance to operate with an efficiency approaching the ideal method. At the present state of the art, however, when considering the advisability of utilizing additional flood storage space for the current regulation, the decision still has to be made: "Will the increased current benefit be equal to or greater than the increased risk of greater damages?"

CAIRO STAGE REDUCTIONS AND PREVENTED FLOOD DAMAGES ALONG THE LOWER OHIO AND MISSISSIPPI RIVERS

Year	Month	Cairo Stage - Feet(2) Actual	Cairo Stage - Feet(2) Without Tenn. River Regulation	Reduction (Feet)	Damages Prevented
1945	Mid-March	53.92	55.4	1.48	
	Late March	53.9	54.3	0.4	$ 970,000
	April	53.7	54.3	.6	
	May	44.3	-	(1)	
	June	44.7	-	(1)	
1946	January	52.13	53.5	1.37	500,000
	February	45.9	46.3	.4	
1947	January	41.0	42.9	1.9	480,000
	April	47.12	48.0	.88	
	May	45.8	-	(1)	
	June	45.1	-	(1)	
1948	February	46.8	48.7	1.9	
	March	45.6	46.1	.5	1,600,000
	Early April	51.6	53.4	1.8	
	Late April	47.9	49.0	1.1	
1949	January	50.7	51.3	.6	
	February	49.3	50.5	1.2	200,000
	April	46.8	46.9	.1	
1950	January	55.35	57.2	1.85	
	February	55.91	57.1	1.19	1,800,000
	April	46.8	47.3	.5	
1951	February	49.02	49.0	0	
	Mid April	47.5	47.5	0	
	Late April	46.2	46.7	.5	0
1952	February	47.7	-	(1)	
	March	50.7	51.2	.5	400,000
	May	44.0	-	(1)	
1953	None				
1954	None				
1955	March	50.1	50.9	.8	580,000
1956	February	40.1	41.0	.9	0
	February	43.7	45.8	2.1	700,000
	March	40.7	42.3	1.6	
1957	February	45.7	47.2	1.5	4,870,000
	April	43.8	46.8	3.0	

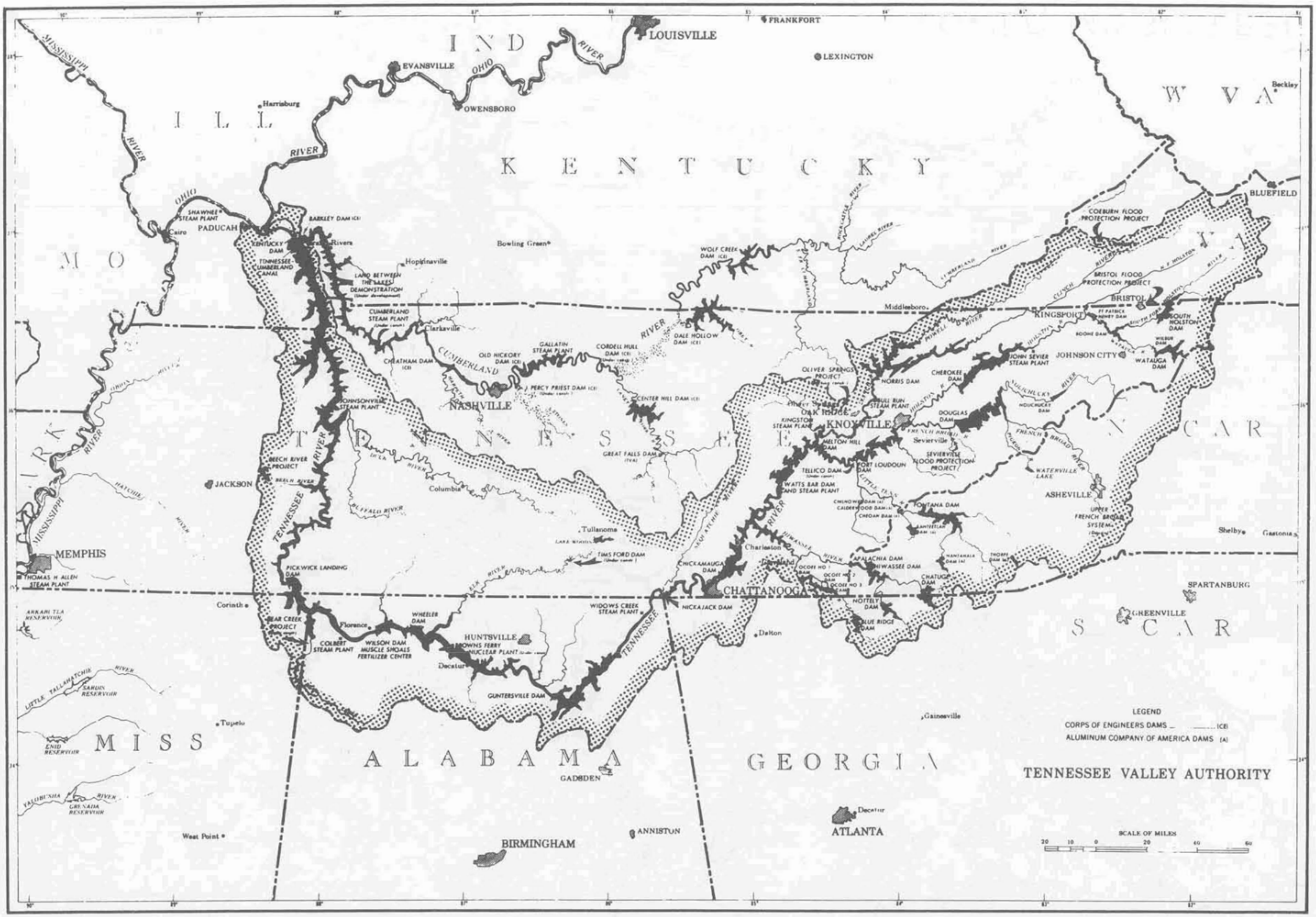
(1) No detailed estimates available.
(2) Flood stage is 40 feet.

Year	Month	Cairo Stage - Feet Actual	Cairo Stage - Feet Without Tenn. River Regulation	Reduction (Feet)	Damages Prevented
1958	May	43.1	46.2	3.1	$ 8,000,000
	July	43.8	44.8	1.0	
1959	Feb.	38.3	40.5	2.2	50,000
	Feb.	40.3	41.6	1.3	
1960	April	47.4	50.1	2.7	4,500,000
1961	March	49.8	51.9	2.1	
	April	40.5	42.0	1.5	
	April	40.3	41.5	1.2	4,150,000
	May	54.5	55.0	0.5	
1962	Feb.	42.4	42.4	0	
	March	50.5	51.7	1.2	
	April	50.2	51.4	1.2	2,530,000
	April	48.4	49.2	0.8	
1963	March	51.5	53.9	2.4	4,010,000
1964	March	48.2	50.4	2.2	
	April	40.2	40.7	0.5	3,250,000
	May	41.6	42.1	0.5	
1965	Feb.	40.0	40.5	0.5	
	April	47.4	50.5	3.1	1,150,000*
	May	40.2	40.6	0.4	
1966	Feb.	41.9	43.2	1.3	634,000*
	May	41.6	42.9	1.3	
1967	March	42.0	43.3	1.3	1,017,000*
	May	43.6	45.3	1.7	
1968	March	39.5	41.3	1.8	
	April	41.3	42.8	1.5	1,402,000*
	June	43.9	45.5	1.6	
1969	Feb.	47.4	47.7	0.3	337,000*
	April	44.8	46.0	1.2	
Total					$43,130,000

*Determined by U. S. Corps of Engineers.

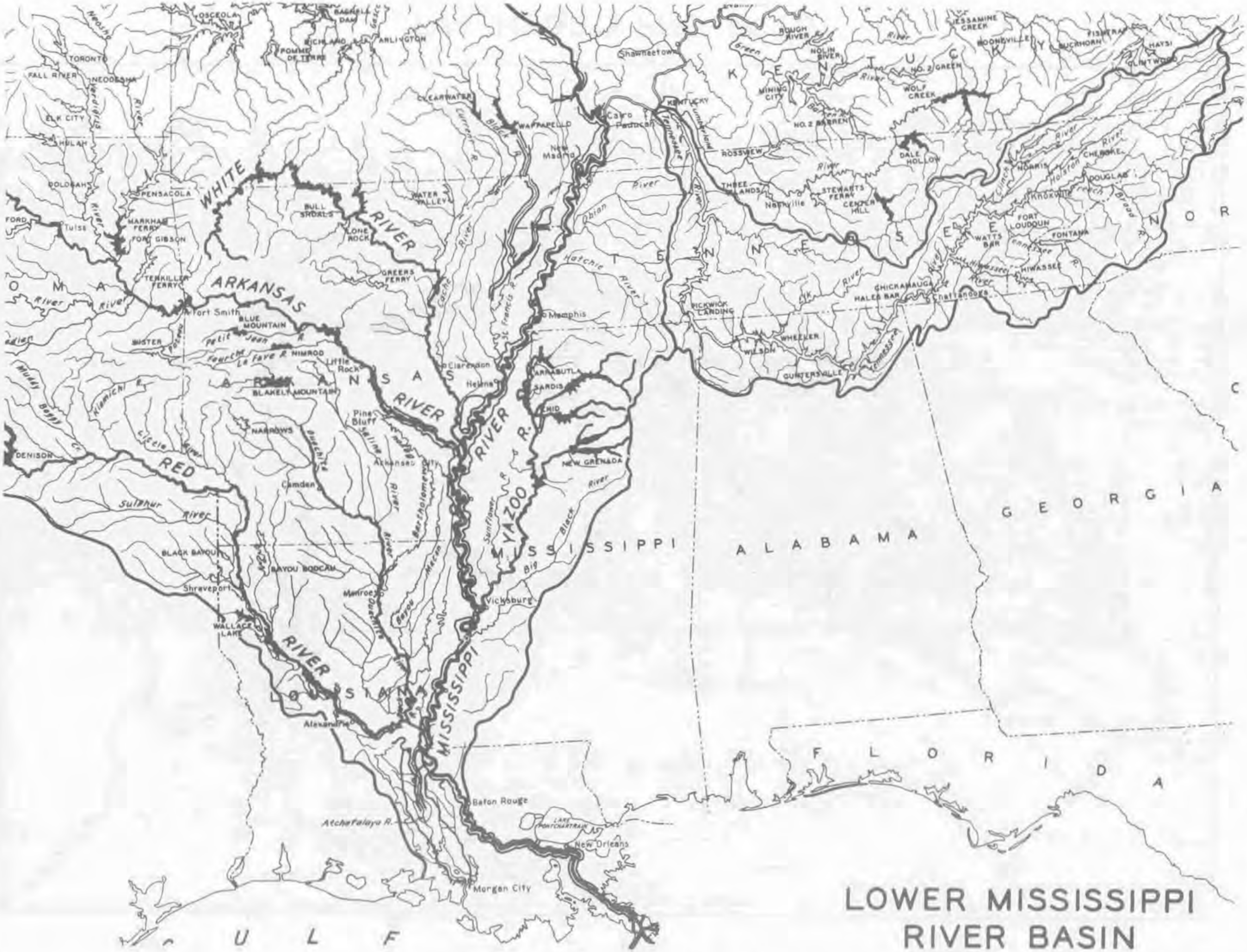
July 1969

TABLE NO. I



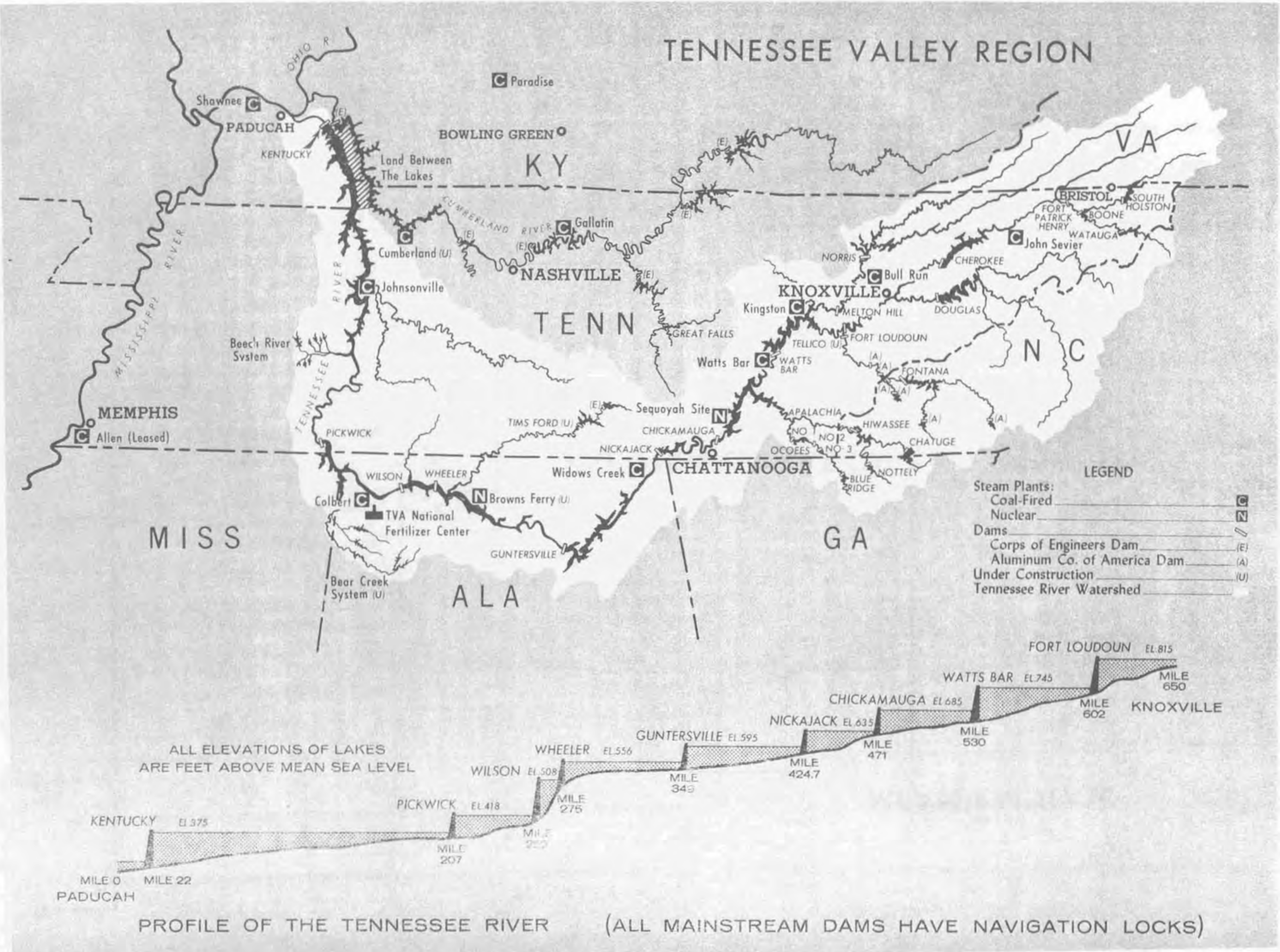
TVA HYDRO PROJECTS

PLATE I

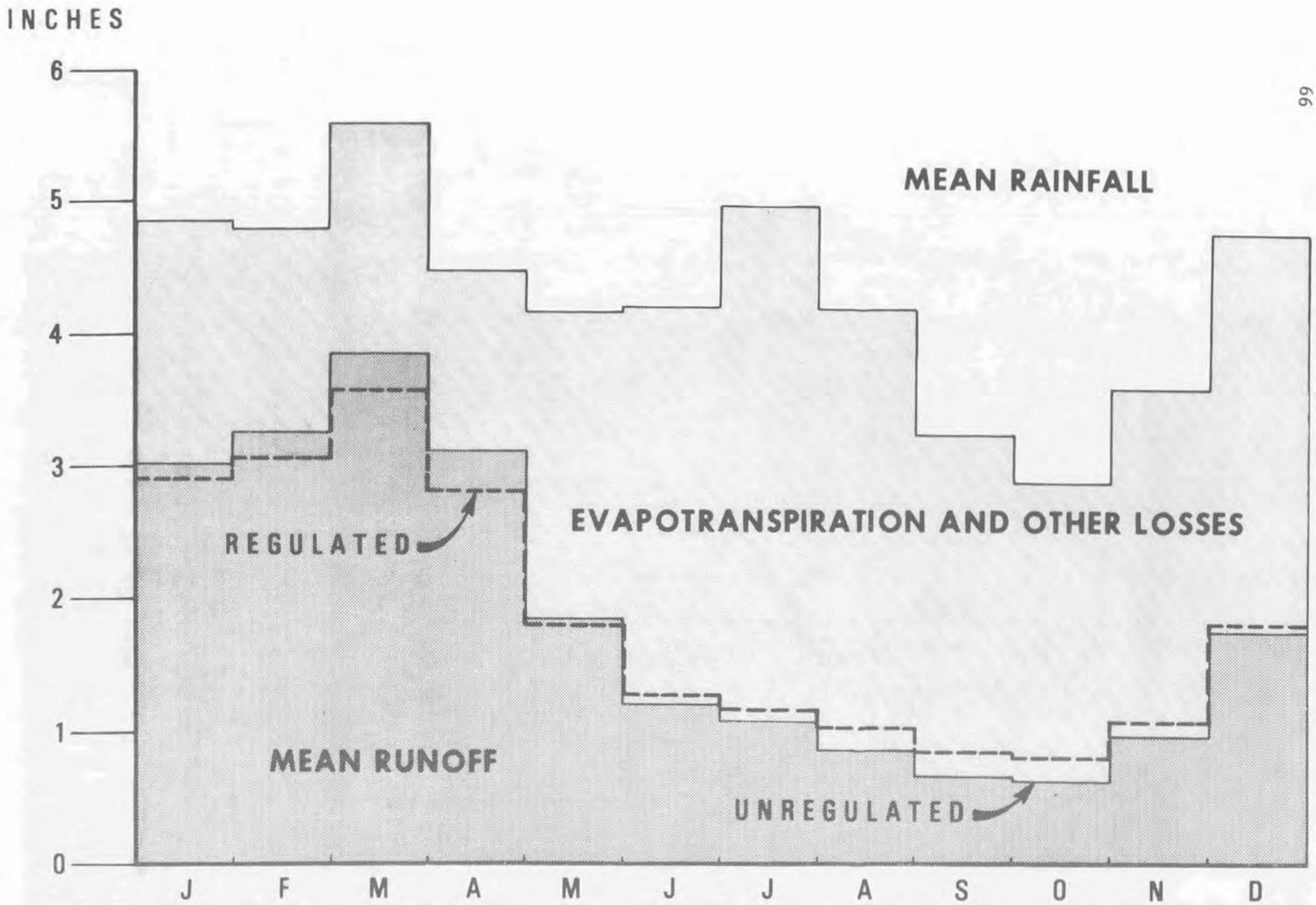


LOWER MISSISSIPPI RIVER BASIN

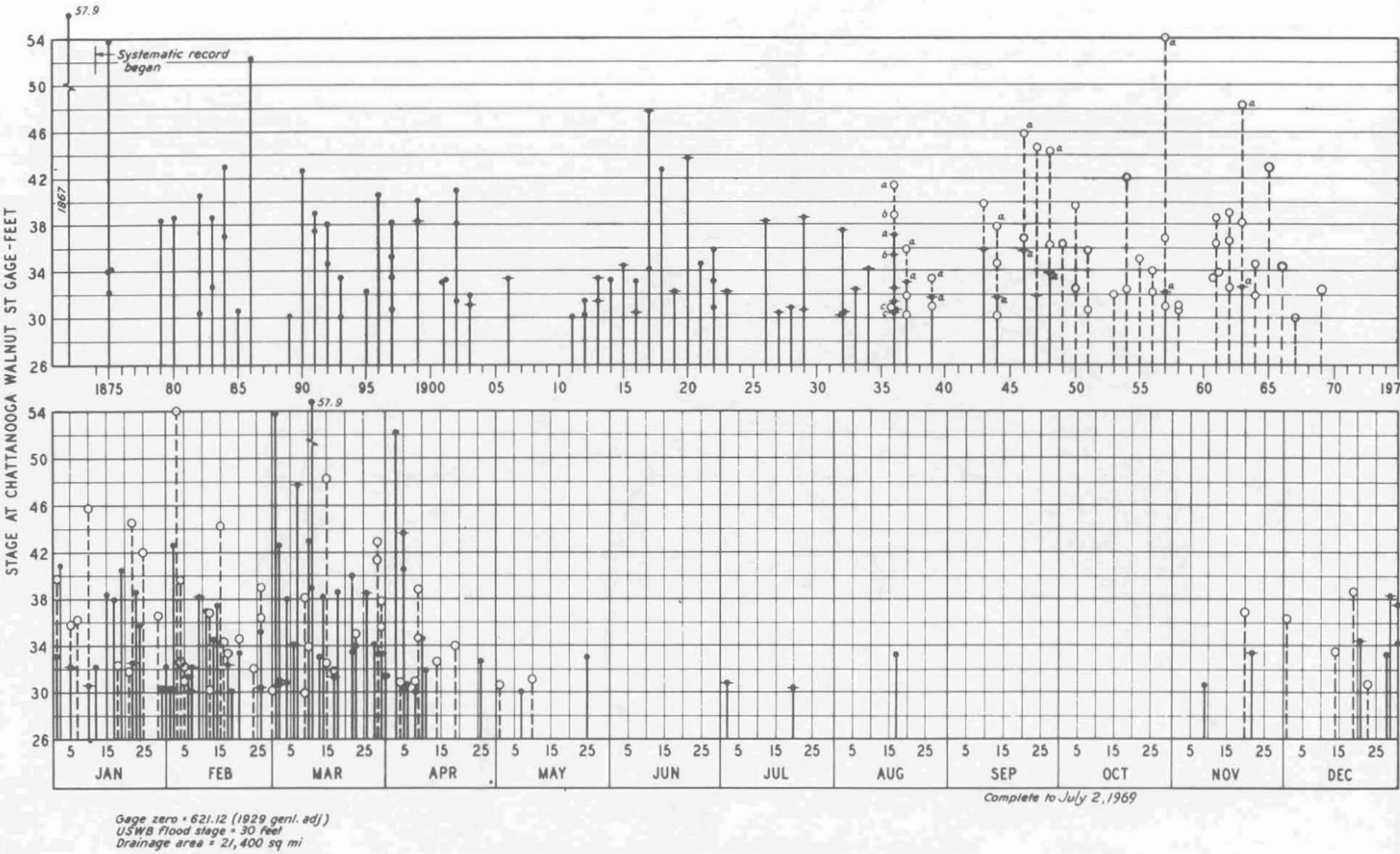
PLATE 2



TENNESSEE VALLEY REGION
Paradise
Shawnee
PADUCAH
OHIO R
KENTUCKY
BOWLING GREEN
Land Between The Lakes
KY
VA
CUMBERLAND RIVER
Gallatin
Cumberland (U)
NASHVILLE
Johnsonville
TENN
MISSISSIPPI RIVER
TENNESSEE RIVER
Beech River System
MEMPHIS
Allen (Leased)
BRISTOL
SOUTH HOLSTON
FORT PATRICK HENRY
BOONE
WATAUGA
John Sevier
NORRIS
CHEROKEE
Bull Run
KNOXVILLE
Kingston
MELTON HILL
DOUGLAS
GREAT FALLS
TELLICO (U)
FORT LOUDOUN
Watts Bar
WATTS BAR
FONTANA
N C
Sequoyah Site
APALACHIA
HIWASSEE
TIMS FORD (U)
CHICKAMAUGA
NICKAJACK
OCOEES
NO 1
NO 2
NO 3
CHATUGE
PICKWICK
WILSON
WHEELER
Widows Creek
CHATTANOOGA
NOTTELY
BLUE RIDGE
Colbert
Browns Ferry (U)
TVA National Fertilizer Center
MISS
GA
GUNTERSVILLE
Bear Creek System (U)
ALA
LEGEND
Steam Plants:
Coal-Fired
Nuclear
Dams
Corps of Engineers Dam (E)
Aluminum Co. of America Dam (A)
Under Construction (U)
Tennessee River Watershed
FORT LOUDOUN EL 815
WATTS BAR EL 745
MILE 650
CHICKAMAUGA EL 685
MILE 602
KNOXVILLE
NICKAJACK EL 635
MILE 530
GUNTERSVILLE EL 595
MILE 471
MILE 424.7
ALL ELEVATIONS OF LAKES ARE FEET ABOVE MEAN SEA LEVEL
WHEELER EL 556
WILSON EL 508
MILE 349
MILE 275
PICKWICK EL 418
KENTUCKY EL 375
MILE 207
MILE 0
MILE 22
PADUCAH
PROFILE OF THE TENNESSEE RIVER
(ALL MAINSTREAM DAMS HAVE NAVIGATION LOCKS)



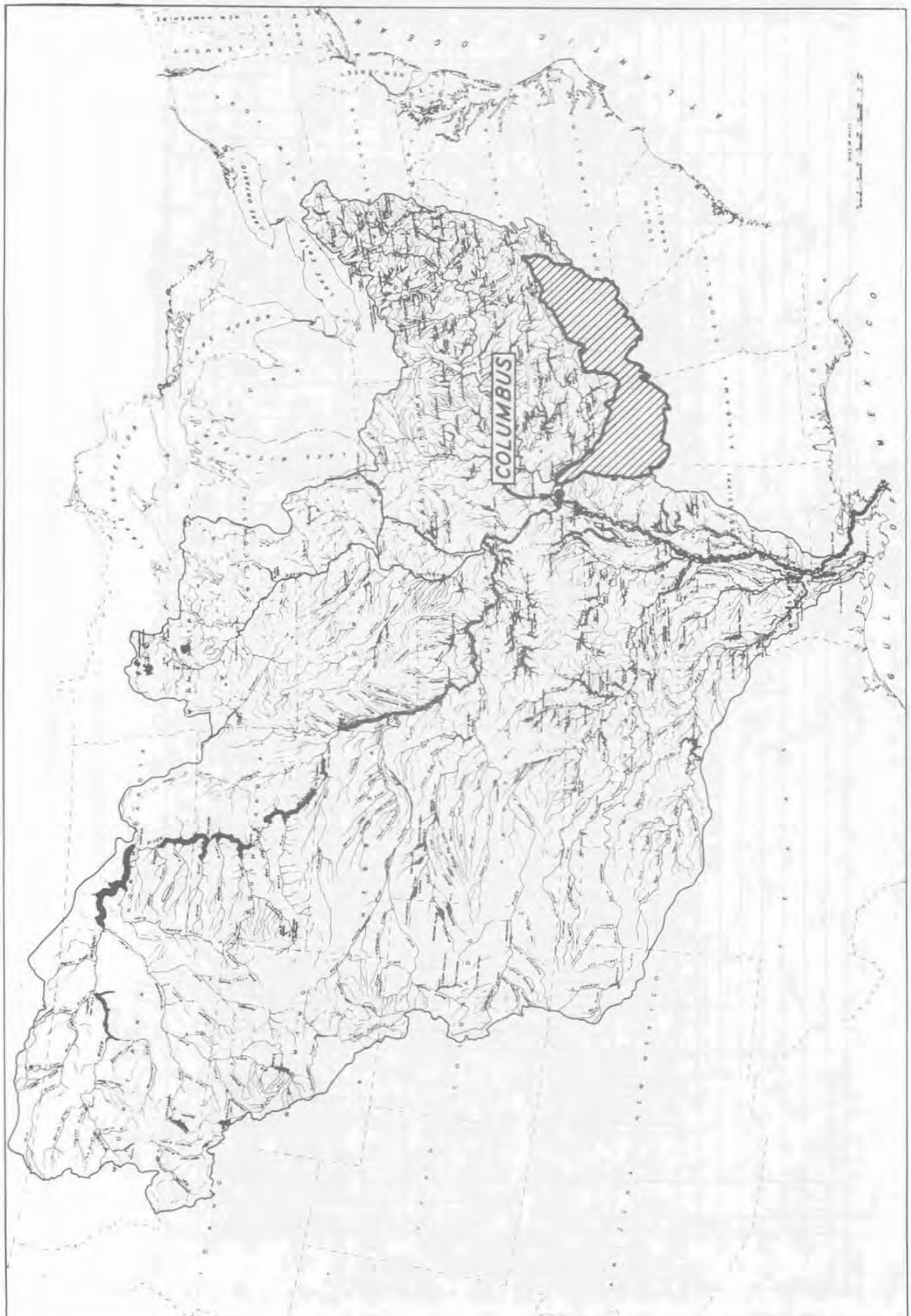
TENNESSEE VALLEY MONTHLY RAINFALL AND RUNOFF



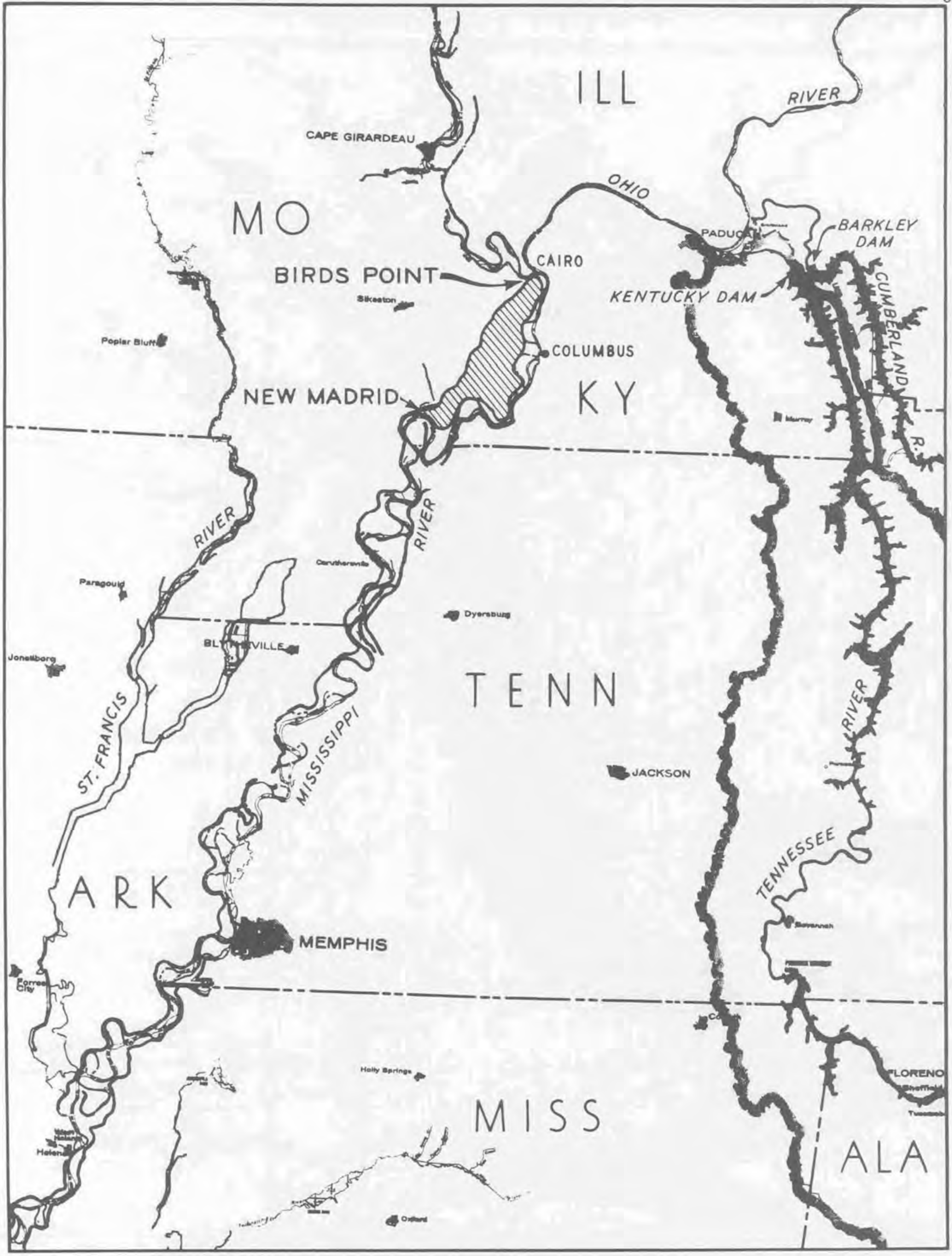
TENNESSEE RIVER AT CHATTANOOGA, TENNESSEE

DISTRIBUTION OF FLOODS

PLATE 5



MISSISSIPPI RIVER BASIN



BIRDS POINT - NEW MADRID FLOODWAY & MISS. RIVER LEVEE SYSTEM

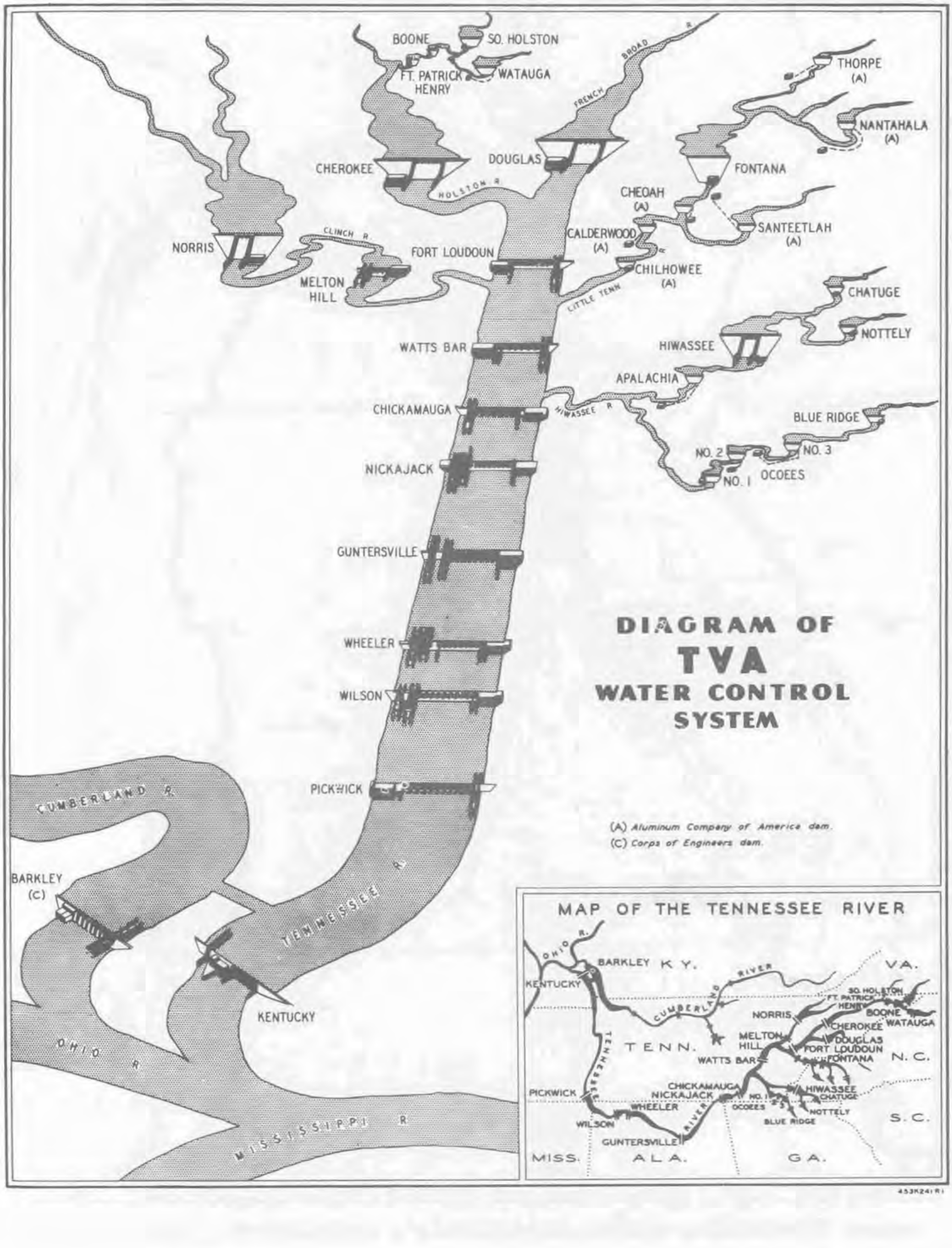
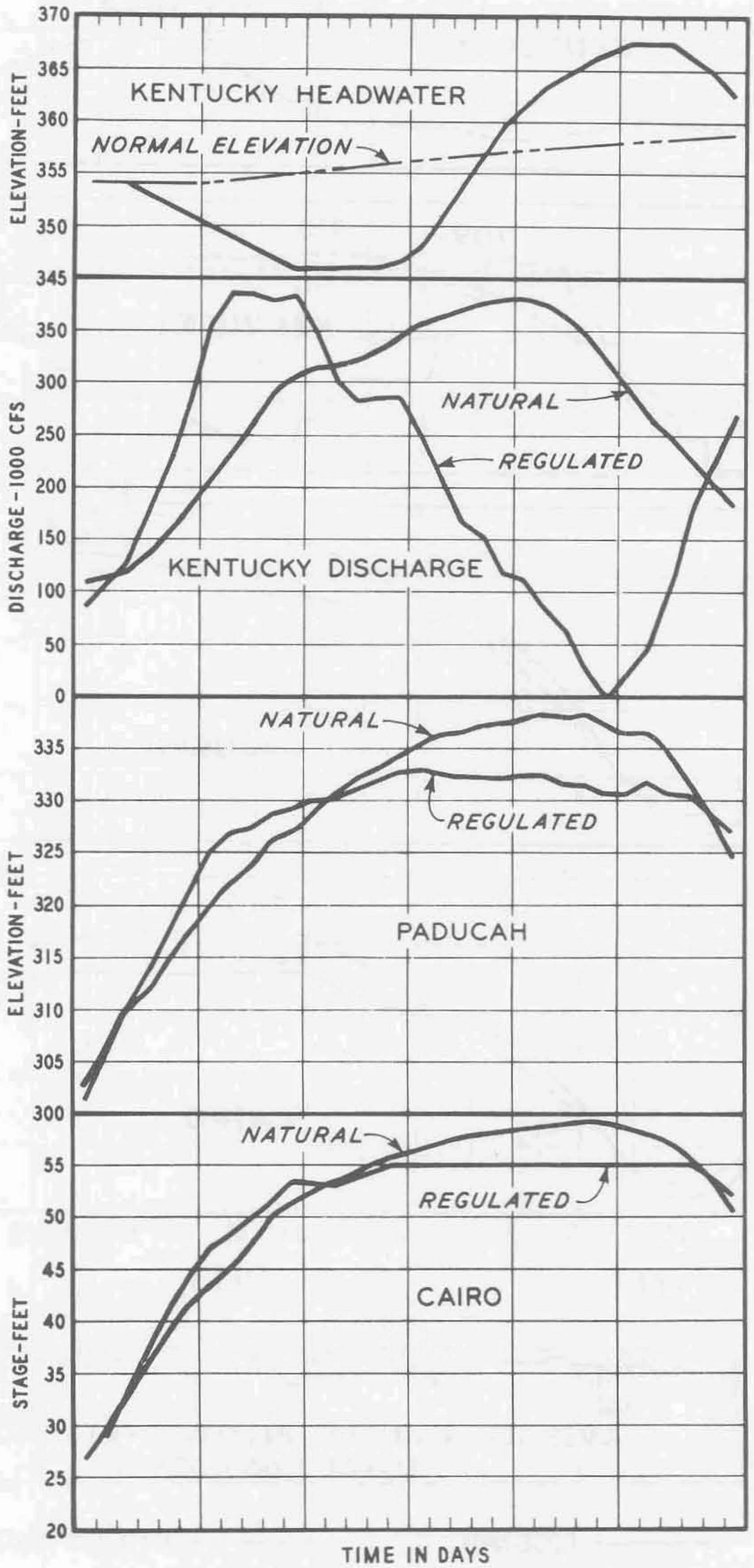
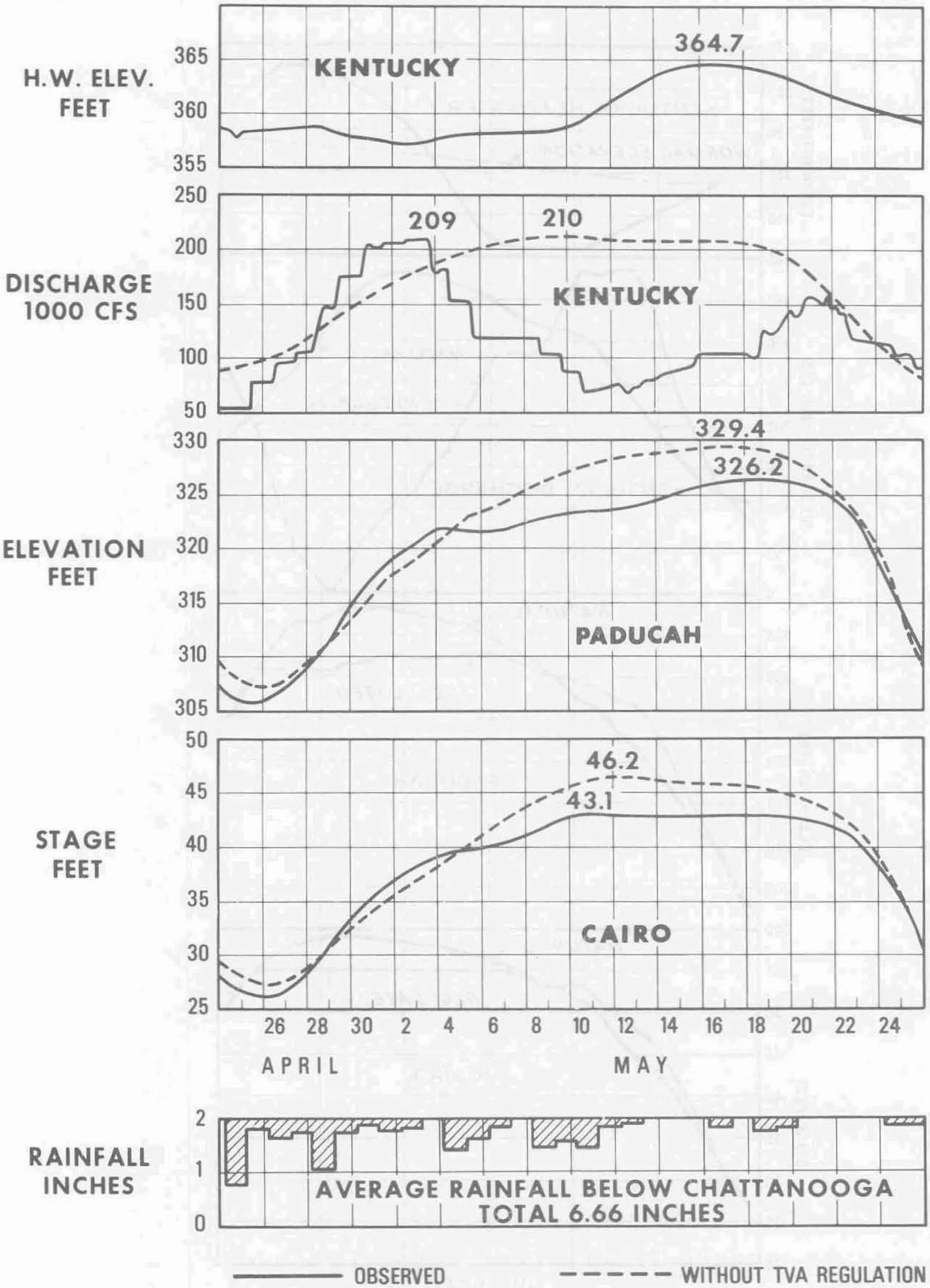


DIAGRAM OF
TVA
WATER CONTROL
SYSTEM
BOONE
SO. HOLSTON
FT. PATRICK HENRY
WATAUGA
FRENCH BROAD R.
THORPE (A)
NANTAHALA (A)
CHEROKEE
DOUGLAS
HOLSTON R.
FONTANA
CHEOAH (A)
CALDERWOOD (A)
SANTEETLAH (A)
CHILHOWEE (A)
NORRIS
CLINCH R.
FORT LOUDOUN
MELTON HILL
LITTLE TENN
CHATUGE
NOTTELY
HIWASSEE
WATTS BAR
APALACHIA
HIWASSEE R.
CHICKAMAUGA
BLUE RIDGE
NO. 2
NO. 3
NO. 1
OCOEES
NICKAJACK
GUNTERSVILLE
WHEELER
WILSON
PICKWICK
CUMBERLAND R.
BARKLEY (C)
TENNESSEE R.
KENTUCKY
OHIO R.
MISSISSIPPI R.
(A) Aluminum Company of America dam.
(C) Corps of Engineers dam.
MAP OF THE TENNESSEE RIVER
OHIO R.
BARKLEY
KY.
VA.
KENTUCKY
CUMBERLAND RIVER
SO. HOLSTON
FT. PATRICK HENRY
BOONE
WATAUGA
NORRIS
CHEROKEE
DOUGLAS
MELTON HILL
FORT LOUDOUN
FONTANA
TENN.
WATTS BAR
N. C.
TENNESSEE
CHICKAMAUGA
NICKAJACK
HIWASSEE
CHATUGE
PICKWICK
NO. 1
OCOEES
NOTTELY
WHEELER
RIVER
BLUE RIDGE
S. C.
WILSON
GUNTERSVILLE
MISS.
ALA.
GA.

453K241R1



TYPICAL KENTUCKY RESERVOIR FLOOD CONTROL OPERATION FOR LOWER OHIO AND MISSISSIPPI RIVERS



EFFECT OF TVA RESERVOIR OPERATIONS ON FLOOD STAGES AT PADUCAH AND CAIRO

APRIL 24—MAY 25, 1958

<u>Table I</u>

Cairo Stage Reductions and Prevented Flood Damages Along the Ohio and Mississippi Rivers

<u>Plates</u>

1. TVA Hydro Projects (map)
2. Lower Mississippi River Basin (map)
3. The Tennessee Valley Region (map)
4. Rainfall and Runoff by Months, Tennessee Valley (Bar Graph)
5. Distribution of Floods at Chattanooga, Tennessee, by Months (graph)
6. Mississippi River Basin (map)
7. Birds Point-New Madrid Floodway and Levee System, Cairo to Memphis (map)
8. Diagram of TVA Water Control System (showing Barkley Canal)
9. Effect of Reservoir Operation on Flood Stages at Paducah and Cairo (showing drawdown, storage, and return to normal level of Kentucky vs. effect of operation on stages at Paducah and Cairo)
10. Kentucky Reservoir Flood Control Operation for Lower Ohio and Mississippi Rivers - May 1958

ACKNOWLEDGMENTS

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The following references were used in obtaining the material necessary for preparation of this paper. In several instances, where the writer's clarity and style of expression could obviously not be improved upon, material has been bodily extracted from the references. Some references were utilized as an aid to better expression of the philosophy and professional concepts involved in flood control operations, rather than for their direct treatment of the subject matter.

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