

MULTIPLE PURPOSE RESERVOIR OPERATION  
TENNESSEE RIVER SYSTEM

By

Clarence E. Blee

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# Multiple-Purpose Reservoir Operation of Tennessee River System

## Part I. Seasonal Control of Flow

By CLARENCE E. BLEE, M. AM. SOC. C.E.

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ONE has but to review a record of the dams and reservoirs constructed throughout the country during the past decade and to examine the list of those proposed for construction in the near future, to be impressed by the comparatively large number of multiple-purpose structures included. Another noteworthy trend, particularly with respect to projects having to do with flood control, is toward the development of a complete drainage area by a series of reservoirs. Thus an increasing number of engineers are becoming interested in the subject of multiple-purpose operation of reservoir systems, not only from the standpoint of operating procedure as such, but also from that of the effect of such operation on the planning and design of the structures comprising such a system.

Something of a pioneering effort in this field is the system of reservoirs on the Tennessee River and its tributaries, operated by the Tennessee Valley Authority since 1936 for the multiple purposes of navigation, flood control, and power, and now including 26 installations. Having no precedent for the multiple-purpose operation of such a system, the engineers of the Authority have had to develop methods and techniques to cope with the situation and to meet the problems which have arisen. A discussion of the procedures developed for the operation of the Tennessee River system and of the results obtained may, therefore, be of interest.

The watershed of the Tennessee River comprises 41,000 sq miles, about half of which is covered by forest growth (Fig. 1). The headwaters of the river are in the mountains of eastern Tennessee, of western Virginia and North Carolina, and of northern Georgia. These mountains include the Blue Ridge and Smoky Mountain ranges, which rise to an elevation of over 6,500 ft. The main river begins just above Knoxville, Tenn., at the confluence of the Holston and French Broad. The normal elevation of the river surface at Knoxville is about 800 ft above sea level, and at Paducah about 300 ft. Of the 500 ft of drop, some 100 ft are concentrated at Muscle Shoals, and the remainder are fairly well distributed over the river, but with the flatter gradients below Pickwick Dam (Fig. 2).

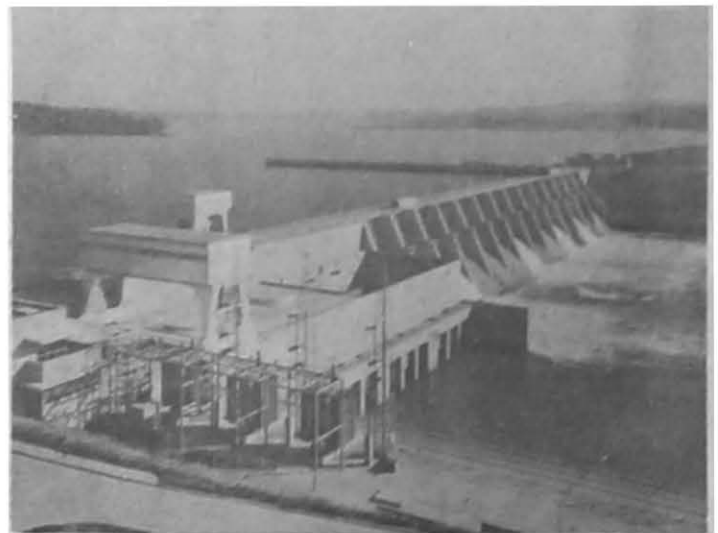
Mean annual precipitation for the Tennessee River basin as a whole is approximately 52 in., varying from about 37 in. in dry years to 63 in. in wet years. The mean annual rainfall over limited mountainous areas near the headwaters may be as high as 85 in., whereas over other areas in sheltered valleys it may be as low as 40 in.

*FROM one of the most highly developed river systems in the world comes this record of how a river's flow can be utilized to benefit multiple purposes. On the Tennessee River 26 multiple-purpose reservoirs are operated as a unit, so regulating the flow as to produce a minimum discharge of about 30,000 cu ft per sec where, under natural conditions, the discharge had ranged from 5,000 to 475,000 cu ft per sec. Benefits that accrue are many. Over two million kilowatts of generating capacity are made available. The navigable channel has been extended up river 650 miles to Knoxville. Coordinated operation of flood gates has removed the threat of serious floods. Other benefits tangible and intangible are numberless. In this paper, which is presented in two parts, Mr. Blee tells how the TVA system is operated. The paper has been adapted from an address presented before a joint session of the Hydraulics and Waterways Division at the Annual Meeting.*

The storms which produce general, valley-wide precipitation and which are potential sources of major floods, are the Gulf storms which enter the Valley from the western end with a generally southwest-northeast storm track. These occur between mid-December and the first of April. West Indian hurricanes, occurring between June 1 and October 15, occasionally strike along the northern part of the easterly boundary of the watershed and move generally in a northeasterly direction. These storms produce intense precipitation over the limited areas traversed.

Snow storage of precipitation does not play an important part in the runoff from the Valley as a whole. Snow occurs to a depth of a few inches in all parts of the Valley and may reach a depth of several feet in the high mountains, but even in the mountains it stays on the ground for comparatively short periods.

As now constructed, the system of dams and reservoirs designed to develop and control the waters of the Tennessee Valley consists of 9 dams on the main river and 12 dams on tributary streams. Under an agreement with the Aluminum Company of America, TVA also directs the operation and water dispatching of that company's five plants on the Little Tennessee River, so that the 26 installations operate as one system. The Tennessee River and its tributaries thus become one of the most highly developed river systems in the world.



FORT LOUDOUN DAM ON THE TENNESSEE--A TYPICAL TVA MAIN-RIVER PROJECT

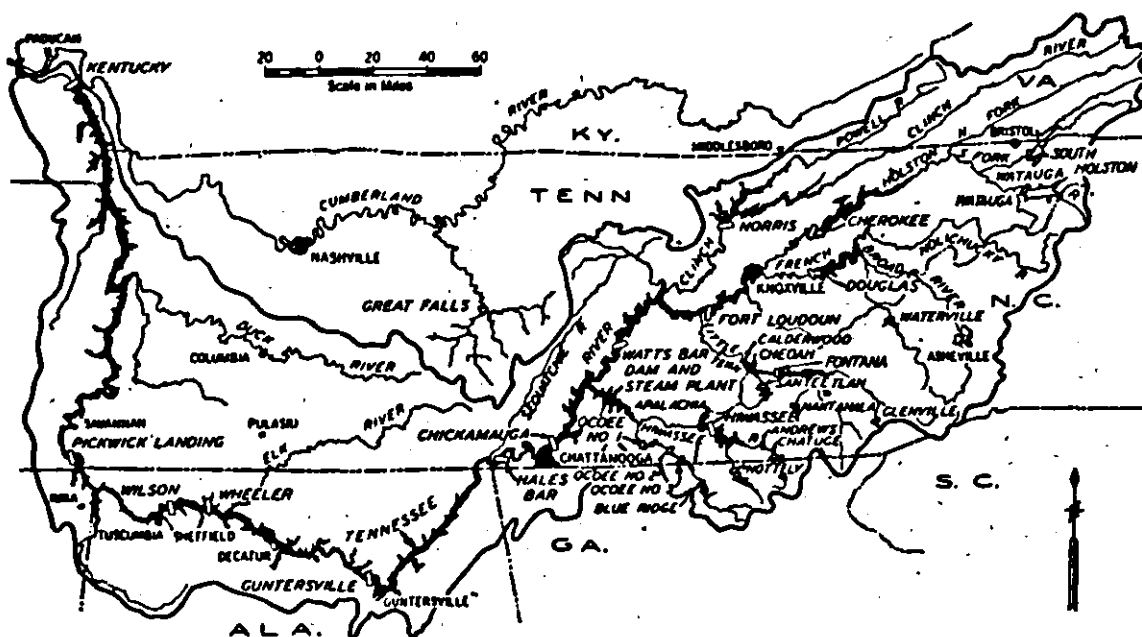


FIG. 1. THE TENNESSEE RIVER SYSTEM

produce power for war production. In these cases there was a commitment that such plants would be operated primarily for power as long as the power was necessary for war production. As soon as this power is no longer necessary to meet the requirements of war production, these plants will be placed on multiple-purpose operation under the appropriate rule curves.

In establishing the storage space to be reserved for flood control, recognition is given to the fact that the flood season in the Tennessee Valley is

The combined gross storage capacity of the reservoirs is 21,000,000 acre-ft, of which 13,000,000 acre-ft are usable within normal operating levels. The continuous length of the slack-water navigation channel extending from Paducah, Ky., to Knoxville, Tenn., with a navigable depth of 9 ft, is 650 miles. The present total installed hydroelectric generating capacity of the 28 plants amounts to over 2,000,000 kw. In addition, the Authority has available steam-electric generating capacity totaling 450,000 kw, which may be used to supplement the supply from the hydro plants.

Data as to present capacities refer to projects completed or under active construction. Fontana Dam was closed in November 1944; the first unit went into operation in January 1945 and the second unit went into operation in March 1945, completing the installation planned for the present. The fourth and last unit of the Watts Bar Steam Plant started operating in April. The first three units at Kentucky Dam are in operation, and the fourth will go on the line in the fall of 1945. The use of the Kentucky Reservoir for flood-control storage was limited this season, as the reservoir relocation work had not been entirely completed.

In taking up the subject of water control as applied to the operation of this river system, it may be observed that this subject has two phases: (1) long-range or seasonal control, and (2) short-range or day-to-day control.

Long-range control is that which is required to provide the proper reservation of storage space for flood control and to determine the general method of operating for power production to meet the forecast power load. In the case of the provision for flood control storage, a chart or rule curve is prepared for each reservoir showing the limiting elevations above which the reservoir is not to be filled throughout the flood season except in controlling a flood. These limitations are established by the flood-control requirements assigned to the particular reservoir as part of the designed requirements for the whole system.

Normally they would remain constant, except for some change in the basic assumptions or a change from one stage in the development of the system to another. There has been one departure from this procedure, and that concerns certain plants authorized specifically to

limited to a definite period. Systematic stream-flow records covering the past 70 years, and historical records extending our knowledge to cover a period of more than 100 years, are available. Such records demonstrate that major floods on the Tennessee River are confined to the period between the latter part of December and the first of April. Intense precipitation may be caused in the summer months by West Indian hurricanes striking along the eastern edge of the basin or by local thunder-storms, but neither of these involves sufficient areas to produce a major flood on the main river (Fig. 3).

FLOOD-CONTROL STORAGE ABOVE CHATTANOOGA

The locality in the Tennessee Valley most vulnerable to flood damage is the city of Chattanooga. A repetition of the flood of 1867—the largest flood of record—would, if uncontrolled, submerge the business and industrial district up to a depth of about 20 ft, causing very serious and extensive damage. Therefore above Chattanooga the operation of the reservoir system is directed primarily toward the protection of that city, but it also benefits lands and other communities along the tributaries and main river, as well as on the lower Ohio and Mississippi. The system of reservoirs as now constructed provides over 4,000,000 acre-ft of storage for flood control as of March 15, 1945, in the tributary reservoirs above Chattanooga, as indicated in Table I.

In addition there is a flood storage capacity of some 815,000 acre-ft in the main-river reservoirs above Chattanooga. This, combined with the storage in the tributary reservoirs, affords a total flood-control storage of approximately 4.5 in. of runoff from the entire watershed of 21,000 sq miles above Chattanooga. This storage is

TABLE I. PROPOSED STORAGE FOR FLOOD CONTROL AS OF MARCH 15 IN TRIBUTARY RESERVOIRS ABOVE CHATTANOOGA

Project	DRAINAGE AREA Sq Miles	FLOOD CONTROL CAPACITY	
		Acro-Ft	In. of Runoff
Norris (Clinch River)	2,912	1,377,000	8.9
Cherokee (Holston River)	3,429	807,000	4.4
Douglas (French Broad River)	4,541	1,020,000	4.2
Fontana* (Little Tenn. River)	1,443	577,000	7.5
Hiwassee† (Hiwassee River)	968	406,000	7.9
		4,187,000	

\* Drainage area excludes that of Nantahala and Glenville reservoirs.  
† Includes Nottely and Chatuge reservoirs.

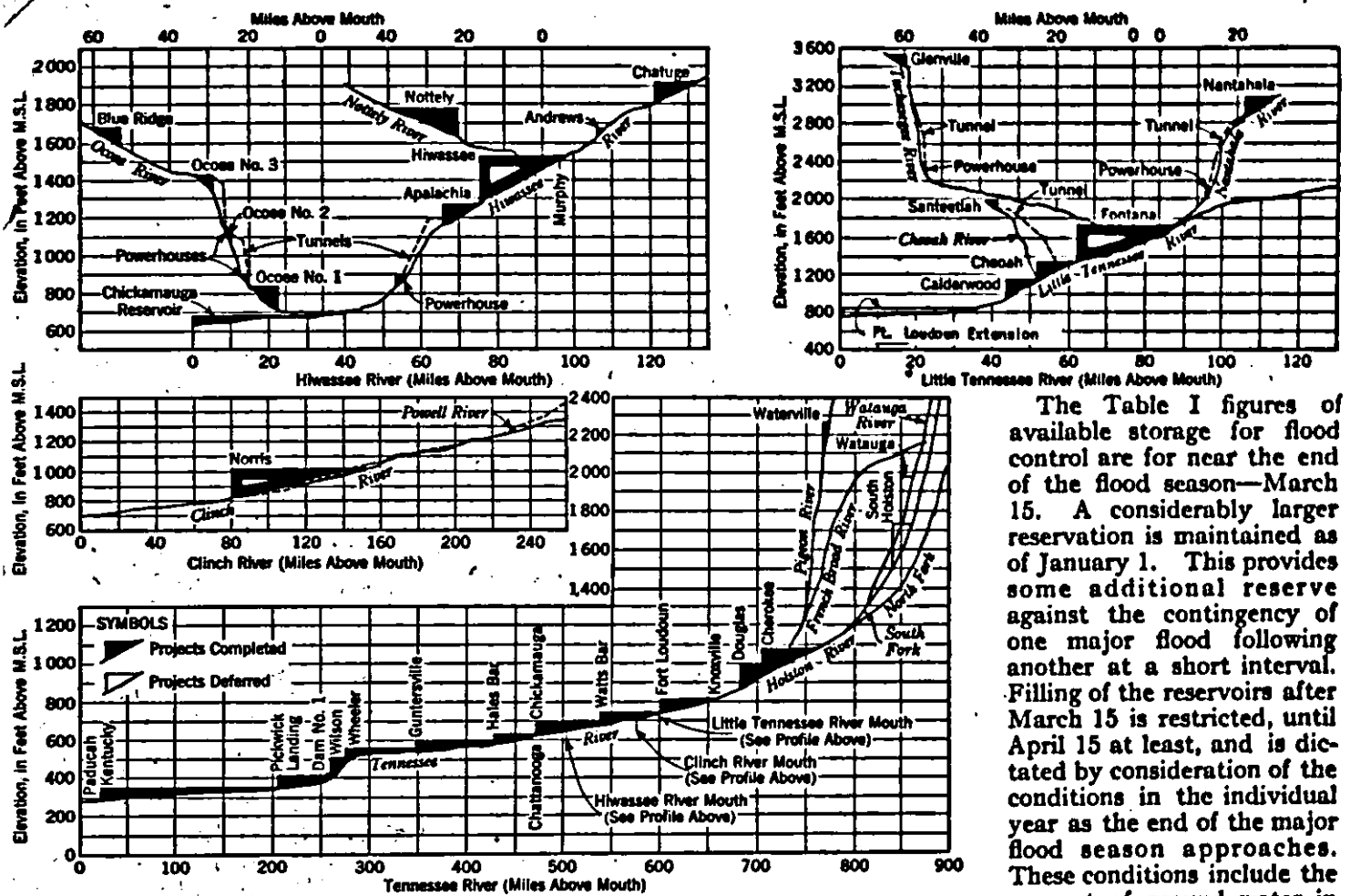


FIG. 2. PROFILE OF THE TENNESSEE RIVER SYSTEM

The Table I figures of available storage for flood control are for near the end of the flood season—March 15. A considerably larger reservation is maintained as of January 1. This provides some additional reserve against the contingency of one major flood following another at a short interval. Filling of the reservoirs after March 15 is restricted, until April 15 at least, and is dictated by consideration of the conditions in the individual year as the end of the major flood season approaches. These conditions include the amount of ground water in the soil, the progress of the season as indicated by vegeta-

sufficient to control the largest floods of record to such an extent as to greatly reduce the damage that would otherwise result at Chattanooga. Furthermore, the reduction in flood crest resulting from the operation of the reservoirs makes it feasible to protect Chattanooga by a system of levees against the occurrence of a probable flood considerably larger than the flood of record.

In the use of the reservoir system for flood control, the objective is to regulate the substantial floods only. The science of weather forecasting has made notable advances in recent years but as yet cannot furnish completely dependable data as to the duration of a storm. Consequently each flood must be treated as if it might develop into a major flood. This means that available storage capacity should not be used up in regulating the smaller floods, but must be held in reserve so far as possible for the control of major floods.

tion, and the stream flow and weather conditions prevailing in the last half of March.

Below Chattanooga the reservoirs on the main river have a combined flood-control storage of about 5,000,000 acre-ft, including the 4,000,000 acre-ft behind Kentucky Dam, which is located practically at the mouth of the Tennessee River. This latter storage is in a particularly strategic position for assisting in the control of floods on the lower Ohio River and on the Mississippi River below Cairo. Studies indicate that with the complete system of reservoirs on the Tennessee and its tributaries, the 1937 flood crest on the Mississippi would have been reduced approximately 2 ft at Cairo and that reductions of 2 to 3 1/2 ft would have been made in other important floods.

WATER CONTROL FOR POWER PRODUCTION

This discussion of long-range or seasonal control has so far been devoted largely to flood control. The long-range control for hydroelectric power production is something of a complement to the flood-control operations, starting in where the latter leave off. As a guide to reservoir operations, a master guide curve is prepared each year, based on the predicted power load or range of loads for the year. This curve is an envelope of a number of curves, each showing the amount of hydro energy which should have been in storage during certain critical dry years of record in order to carry the designated load with all the steam-electric plants on the TVA system operated to capacity. In general, when the energy actually in storage in the reservoirs is above this curve, no steam or purchased energy is essential; when the stored energy is below the curve, the need of supplying all available supplementary energy is indicated.

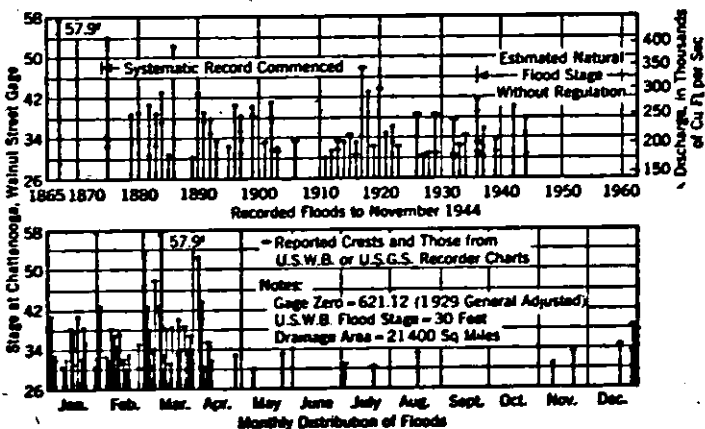


FIG. 3. DISTRIBUTION OF FLOODS AT CHATTANOOGA, TENN.

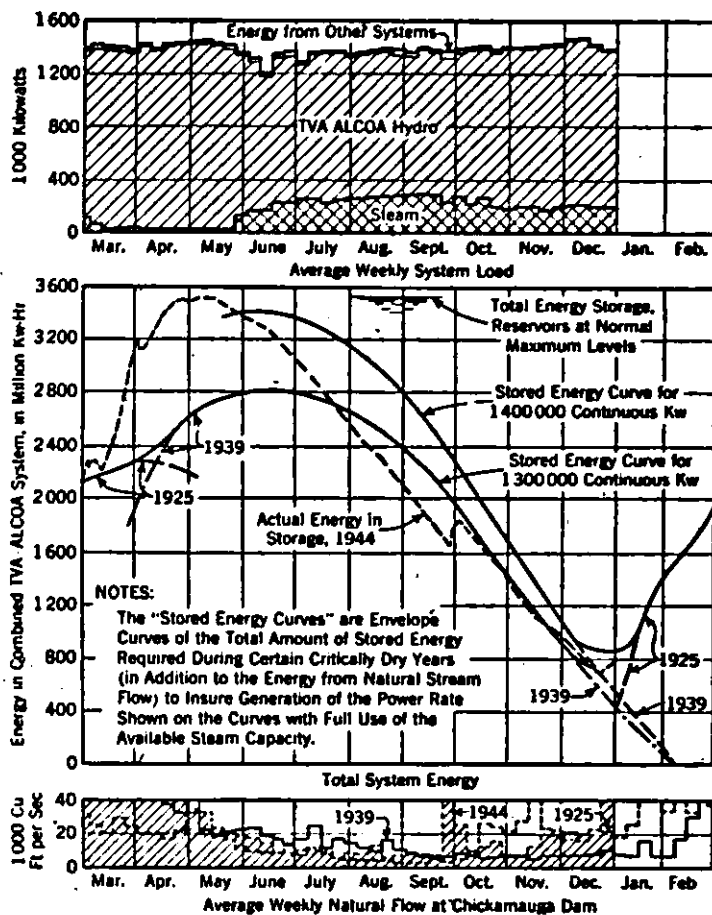


FIG. 4. OPERATING GUIDES FOR 1944 ON COMBINED TVA-ALCOA SYSTEM

This statement, however, oversimplifies the situation. Questions of economy are involved in addition to the ability to carry the load. The supplementary power comes from various sources, with widely varying unit costs. Obviously it is desirable to use the low-cost energy as far as possible, but this means starting its use early, and then it may develop that the corresponding stored energy will be subsequently lost by spilling. The questions of when to start supplementary steam-electric power and how much to use are largely matters of judgment, and the curves are only guides. Factors that must be considered include the probabilities of various patterns of dry years occurring, the extent to which the load might be curtailed or additional supplementary energy obtained in an emergency, and the current runoff and ground-water conditions.

Data as to actual load, energy in storage, and stream-flow conditions are plotted on the curve as they develop. This presentation of the data not only gives a good record but also affords a basis for forming judgment as to operating procedures. The master guide curve and operating record for the 1944 season are shown in Fig. 4. It will be noted that during the summer the energy in storage was drawn down considerably below that called for by the guide curve. In this particular case, the decision to avoid the use of the more inefficient steam plants, which would have been required to build up the amount of energy in storage to that called for by the curve, was influenced by the fact that a considerable block of the load was not being furnished as firm power and so could be curtailed. Also it was probable that additional power could be purchased to meet a deficiency if such an emergency should occur.

In addition to the master guide curve, curves are prepared for each reservoir to indicate the desirable dis-

tribution of the storage among the reservoirs. The Tennessee River, with sites for storage dams toward the headwaters at relatively high elevations, is well adapted to an integrated operation whereby the power load is carried largely by the main-river plants during the wet season, while the storage dams on the tributaries are shut down to permit filling. Then in the dry season the storage dams are drawn upon heavily, generating power at the plants located at each dam and utilizing the released water through all the downstream plants. Water from the Fontana Reservoir will ultimately be used through a total of 13 plants having a combined gross head of about 1,400 ft. The system had, of course, to be planned and designed for integrated operation, with provision for the requisite installed capacity, and with the necessary transmission lines to accommodate this method of operation.

Navigation is one of the primary objectives of the TVA, but since the main-river dams giving slack-water navigation to Knoxville have been completed, very little in the way of special operating procedure at the reservoirs is required for the benefit of navigation. During the earlier stages of the development and, in fact, until the completion of Kentucky Dam, the operating requirements under conditions of open-channel navigation were quite exacting.

#### MALARIA CONTROL, AN IMPORTANT FUNCTION

Malaria control is not one of the objectives specifically named in the Tennessee Valley Authority Act, but it has become an important function of the Authority. The building of an extensive system of reservoirs in a region to which malaria is endemic necessarily introduces the problem of controlling the breeding of the malaria-bearing mosquito (*Anopheles quadrimaculatus*) in and along the shores of the lakes. (See "Engineering Aspects of Mosquito Control—TVA," by W. G. Stromquist, CIVIL ENGINEERING for October 1944.) This becomes a problem of reservoir control and must be coordinated with other operating requirements.

In the case of the reservoirs on the main river, the desirable water-level regulation for malaria control is to fill the reservoir to the maximum elevation in the early spring, hold the water at this level for a short period, then drop it to the normal upper operating level. This tends to strand floating debris and to inhibit vegetable growth around the margin of the reservoir. Then, during the mosquito-breeding season (which extends from about May 15 to October 1 in this region), the water levels are subjected to cyclical fluctuations of about a foot at one-week intervals, combined with a gradual water-level recession. Water-level fluctuation is one of the most effective methods of combating the production of mosquitoes, as it strands the eggs and larvae and also draws them out from the protective vegetation, exposing them to their natural enemies. On the large storage reservoirs it is not feasible to fluctuate the water, but the extensive drawdown keeps the edge of the water away from vegetation and on a clean shore.

Supplemental means of mosquito control are also employed, including the application of larvicides by spraying from boats or dusting from airplanes. It has been found that thorough initial clearing, with re-shrubbing of a marginal strip just before impoundment, pays good dividends in reducing the annual cost of larvicidal treatment. In certain localities, it has proved economical to dike and dewater large shallow areas. Again, flat, irregular shore areas have been treated by cut-and-fill excavation to produce a straight, steeply sloping shore.

# Multiple-Purpose Reservoir Operation of Tennessee River System

## Part II. Day-to-Day Control of Flow

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**W**ATER control on the Tennessee Valley Authority system is centralized in the office of the Chief Engineer at Knoxville, directly under the supervision of an engineer in the Water Control Planning Department. This administrative device has the advantages of establishing a unified control of water operations for all purposes, and of placing that control in a department which is familiar with the planned methods of operation for the system.

Under the established policy of the Tennessee Valley Authority, the operation of the reservoirs is conducted for the benefit of the following objectives: navigation, flood control, power, and malaria control, as well as other miscellaneous and minor purposes. While the superior rights of navigation and flood control are recognized at all times, every attempt is made to coordinate the requirements of the various programs so that the needs of each may be met in so far as possible without injury to the others. Unified control is a prime necessity in operating a system such as that of the Tennessee Valley Authority, with its multiple functions.

### FORECASTING STREAM FLOW

To supply information on rainfall and stream flow throughout the watershed, an extensive network of precipitation and stream-gaging stations is maintained. About 150 key stations on this network normally report each morning by telephone or telegraph to the central forecasting office in Knoxville. During flood periods, 90 additional stations send in reports, and all stations make reports at more frequent intervals if certain predetermined criteria as to amount of rainfall and rate of rise of streams are exceeded. From each of the dams information is transmitted to the office of the Chief Dispatcher of the Department of Power Operations, giving reservoir elevations and the rate of water discharge. This information, for the entire system, is forwarded to the Knoxville office by teletype.

To report the amounts of rainfall and the stages of streams in locations remote from telephone or telegraph lines, the Authority has developed rain and stream gages which automatically report their information each two hours by radio signals. There are now 22 rain gages and 15 stream gages of the radio type installed on the system. These radio gages have proved very reliable in operation and have

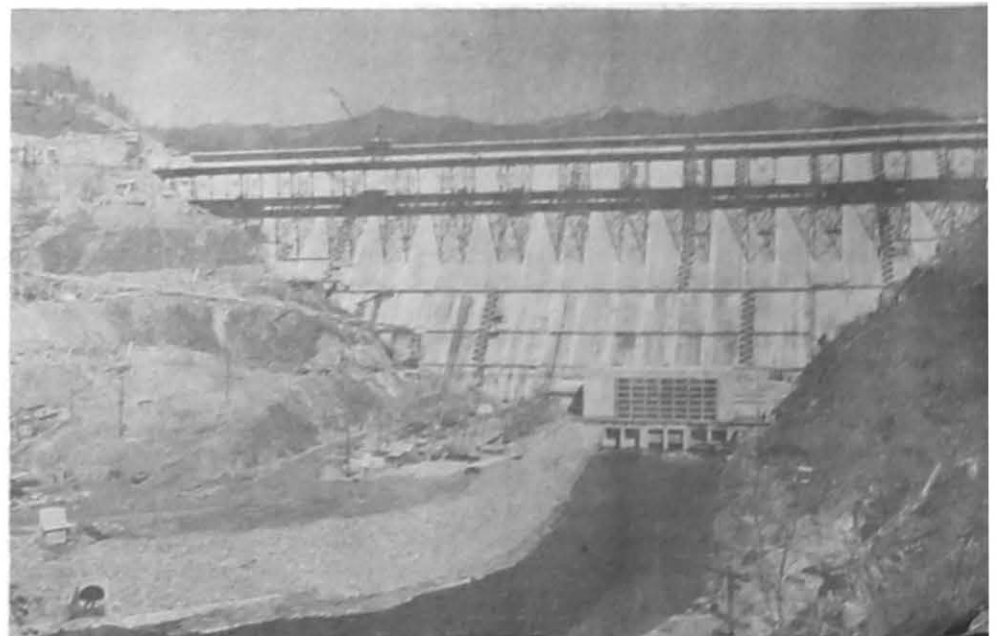
**E**FFECTIVE short-range control of river flow requires the accumulation of considerable data. On the highly developed TVA System, extensive records are kept of rainfall and stream gaging, weather, ground-water conditions, and a dozen or more other pertinent factors. Operating problems develop rapidly during a flood and complete data must be available at all times. Thus a routine must be worked out that will supply the needed data. This article by Mr. Blee is the second part of his discussion on the operation of the TVA system of reservoirs. The first part, which appeared in the May issue, covered long-range or seasonal flow-control problems. The material for these articles was presented in an address before a joint session of the Hydraulics and Waterways Divisions at the Society's Annual Meeting in New York.

been invaluable in furnishing information from the mountainous regions of the watershed—information which is most essential for predicting runoff.

In connection with stream-flow forecasting, the TVA is using quantitative weather forecasts furnished by the U.S. Weather Bureau under a cooperative agreement whereby the Bureau makes special forecasts twice daily covering the Tennessee Valley and its major subdivisions. About 8 a.m. an early-morning preliminary forecast is received which is based on conditions as of the preceding midnight. This is followed up about 11 a.m. by a final forecast giving predicted weather conditions for three to five days in advance, and amounts of rainfall expected in the various subdivisions of the Valley for two days in advance.

Daily information normally starts to come into the Knoxville office about 6 a.m. As rainfall records are received, they are written on an outline map showing the rainfall and river gaging stations (Fig. 1). This information, in conjunction with preliminary weather forecasts, stream-flow data, and reservoir information, is grouped according to tributary drainage basins and is then analyzed by engineers assigned to specific parts of the system. Runoff is estimated for the current day and for the three days in advance. It has been found preferable to base the primary forecasts of runoff on the rain which has actually fallen to date.

These estimated runoffs are reviewed in connection with the amount of rainfall forecast, the storage existing in each reservoir, and the needs for power production. Then decisions are reached about noon as to how the reservoirs shall be operated. A daily bulletin is then



FONTANA DAM AND POWER HOUSE—  
NO. 1 UNIT WAS PUT ON THE LINE IN JANUARY,  
AND NO. 2 UNIT IN MARCH 1945

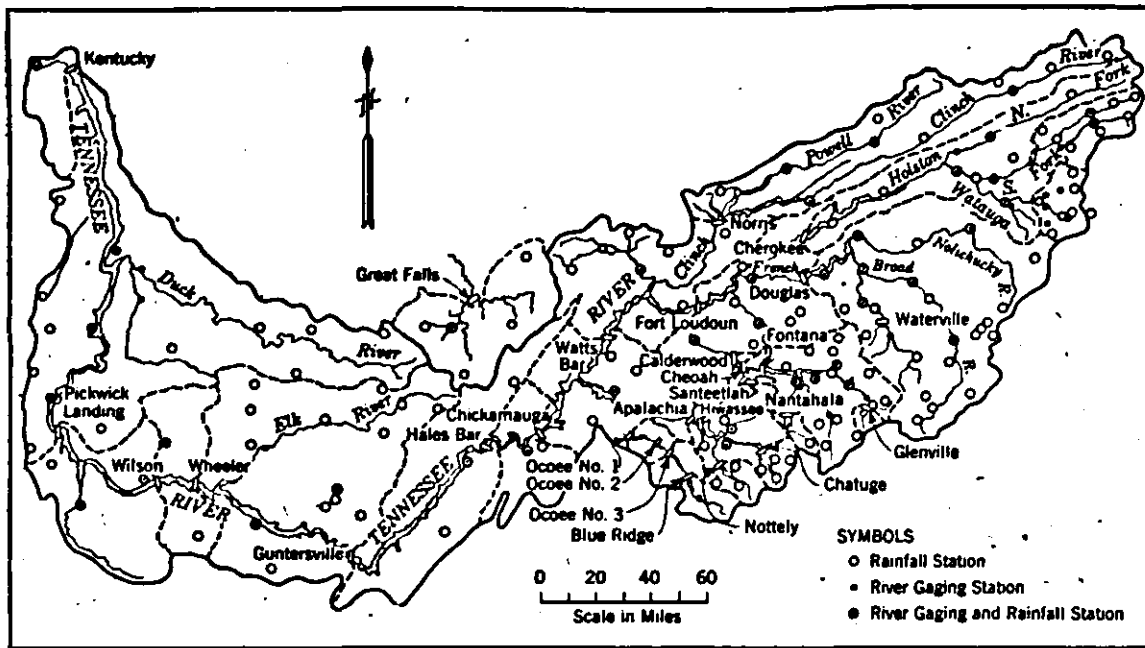


FIG. 1. RAINFALL AND RIVER RECORDING STATIONS IN THE TVA SYSTEM

issued giving: the current inflow, discharge, elevation, and the change in elevation from the previous day for each reservoir; the discharge, stage, and change of stage at key points on the main river and tributaries throughout the Valley; the forecast inflow, discharge, and elevation at each reservoir for three days in advance.

In selecting the proper factor to convert rainfall into runoff, good judgment gained by experience and based on extensive data is required. Taking the watershed as a whole, the mean annual rainfall is 52 in. and the corresponding runoff is 23 in., giving a ratio of runoff to rainfall of 44%. This ratio varies considerably in the various sections of the Valley, and there is a striking seasonal variation in the relation of runoff to precipitation even for the average monthly figures, as is shown in Fig. 2. The runoff from individual storms or locations is affected by many factors such as conditions of the soil surface, depth to ground water, rate of precipitation, soil cover, and state of growth of vegetation. The surface runoff from a prolonged storm in the wet season may be as high as 75% of the rainfall, while the corresponding runoff from a short storm with equal intensity of rainfall, but at the end of a dry period, may not be more than 25% of the rainfall. This is one reason why summer storms do not result in more severe floods.

Several references have been made to the influence of ground water on the available supply of water. This has in the past been recognized in a qualitative way but the Authority's engineers have recently been attempting to estimate the available ground water in storage so that it may be depended upon with something like the reliance that is placed upon water stored in surface reservoirs. The soil of the Valley is in general fine grained and not particularly favorable for the storage and giving up of ground water.

Moreover, there is a wide variation in the ground-water characteristics of different basins in the Valley. The 2,912 sq miles tributary to Norris Reservoir has been found to contribute a maximum of 2.7 in. of ground water, amounting to 420,000 acre-ft, while the corresponding figure for Fontana Reservoir with its deeper soil cover is 8 in., yielding 670,000 acre-ft from 1,571 sq miles. The methods developed for estimating the amount of ground water in storage are interesting, but space does not permit a detailed description of them. Basically they depend upon the hypothesis that the rate of flow

from ground-water sources is an index of the amount of ground water in storage.

In routing floods through a system formed by a series of reservoirs it is necessary to take account of a number of factors. One of these is the rate of travel of transitory waves through both open channels and reservoirs. The results and conclusions from a series of experiments carried out on the Tennessee River system to determine such rates of travel, and to compare them with the theoretical values computed from

formulas, are well presented in the paper, "Translatory Waves in Natural Channels," by J. H. Wilkinson, M. Am. Soc. C.E., in the June 1944 PROCEEDINGS of the Society. While the actual rates of travel are affected by a number of variables, the velocity in open channels is in the order of 3 to 5 miles per hour, while that in a reservoir is in the order of 15 miles per hour.

Another factor which must be recognized in manipulating a series of reservoirs is the variation, with rate of discharge, of the amount of water under profile storage. As the rate of flow increases, the gradient of the back-water curve steepens, thus increasing the amount of water in the reservoir as compared with the flat pool storage on which capacities are generally based. At

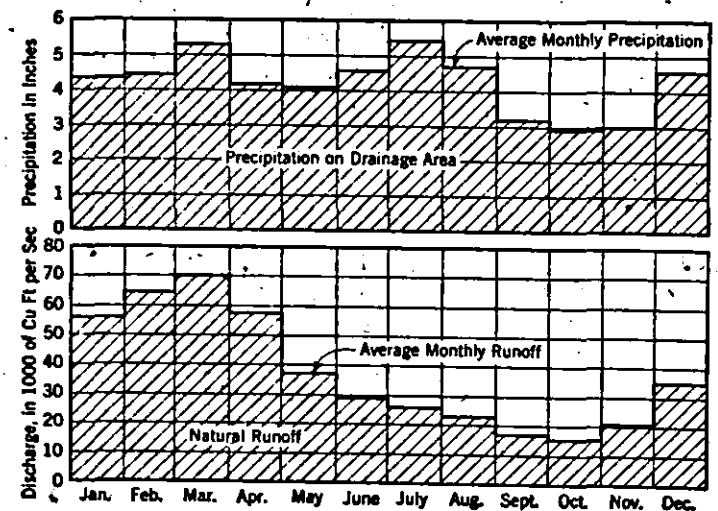


FIG. 2. MONTHLY VARIATIONS IN PRECIPITATION AND RUNOFF FOR TENNESSEE RIVER BASIN AS RECORDED AT CHATTANOOGA

Wheeler Reservoir during the 1942 flood, when the discharge into and out of the reservoir was 220,000 cu ft per sec, the volume under profile storage was 1,410,000 acre-ft, whereas the level pool storage is 1,131,000 acre-ft, an increase of 279,000 acre-ft.

This variation in storage with conditions of flow may be an asset or it may be a liability. When discharge rates are being increased, as is generally the case in the earlier stages of a flood, the reservoir is able to absorb more stored water than it would under flat pool conditions, at the same time holding a constant level at the



ge dam. While this is advantageous, it must be remembered that as the inflow is reduced, the profile tends to flatten, and the decreasing amount of storage results in a surplus of water which must be taken care of.

In operating for the reduction of flood peaks on the lower Ohio and on the Mississippi below Cairo, the obvious strategy is to discharge as much water as possible from the Tennessee system ahead of the peak on the Mississippi at Cairo, and then hold back the water originating in the Tennessee basin until the peak at Cairo has passed. As was mentioned in the previous installment, Kentucky Reservoir, with its large flood-control storage located near the mouth of the Tennessee River, is in a particularly favorable position with respect to such operations. Also, with the main Tennessee River converted into a continuous series of dams and reservoirs, even the storage reservoirs on the upstream tributaries can be made quickly effective on the Ohio by manipulation of the intervening reservoirs.

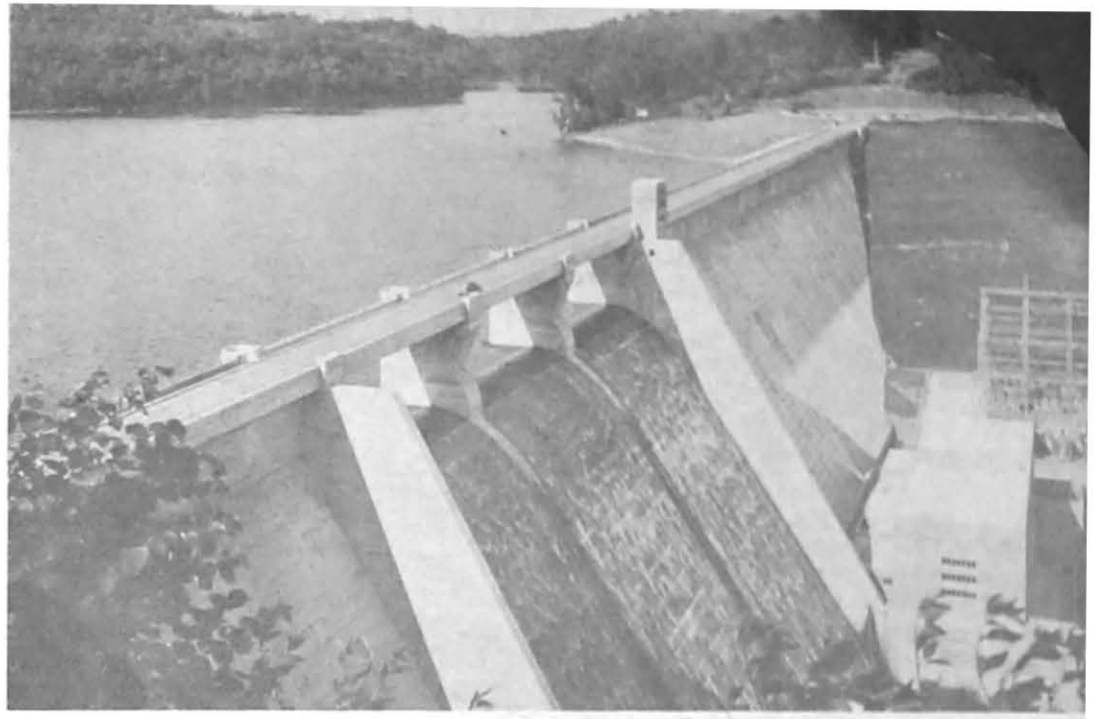
In operating the reservoirs above Chattanooga to assist in reducing flood peaks on the lower Ohio and Mississippi, and in reducing major floods at Chattanooga, the flexibility of the operations is limited by the rate of flow which can be discharged past Chattanooga without damaging the city. Construction of levees and other protective works at Chattanooga, which has been recommended to supplement the control afforded by the reservoir system and so protect the city from floods greater than the flood of record, would remove this limitation.

In handling floods, centralized control and prompt decisions are essential. One of the most important factors in successfully controlling a major flood by a large system of reservoirs such as the Tennessee River system, and routing the flood waters past critical points, is timing. Timing is of the utmost importance and the accomplishment of this necessitates accurate data as to hydraulic factors, adequate means of controlling the release of water, and the prompt issuance and execution of instructions governing the control operations by those intimately familiar with the details of behavior of the system under control.

#### RELATION TO CONTROL OF THE MISSISSIPPI

When a large river system such as the Tennessee is tributary to another river—in this case, the Mississippi through the Ohio—it is highly desirable that the discharge from the tributary river, at the time of a major flood on the main stem, be coordinated with the control planned for the main river. Those exercising the control on the main stem are concerned with the amount and the time of occurrence of discharges at the mouth of the tributary into the main river. The obtaining of these desired discharges from a large tributary such as the Tennessee can best be assured by a control of operations which is centralized in the agency responsible for the planning and development of that river system.

With the multiple objectives prescribed by the Tennessee Valley Authority Act, the many projects making up the reservoir system, and the intricate operating problems, the control necessarily becomes a function for



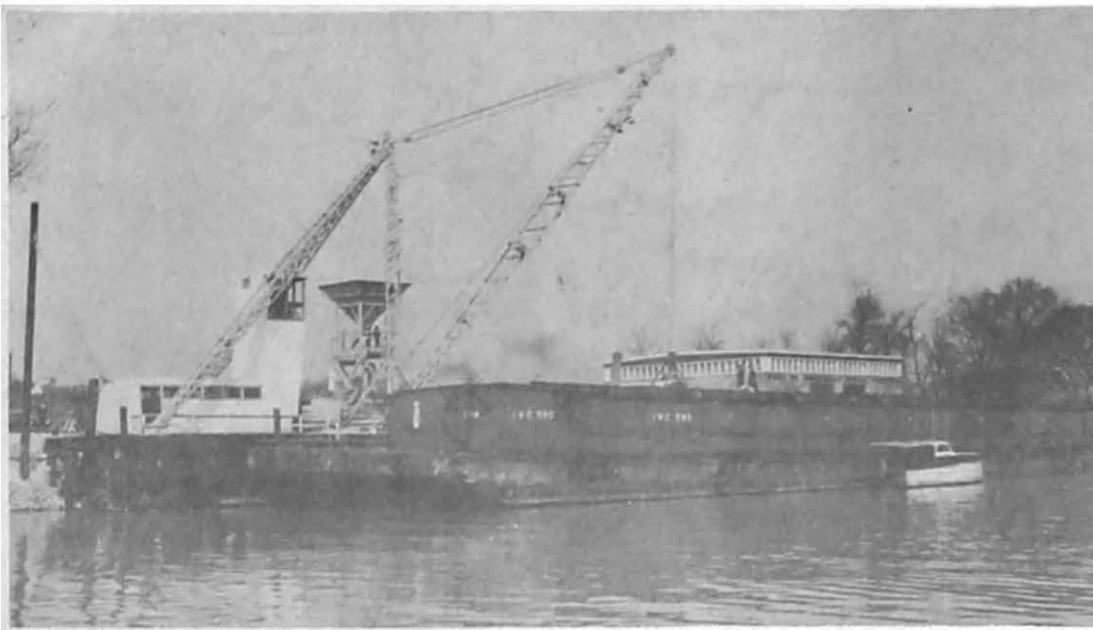
NORRIS DAM ON THE CLINCH RIVER IS TYPICAL OF DAMS ON TRIBUTARIES OF THE TENNESSEE

localized authority. In meeting the statutory obligation of the Authority to contribute to the control of floods on the Mississippi River, it has been the practice of the Authority's engineers, at times of expected floods, to exchange information with the Office of the Division Engineer of the Corps of Engineers. Actual and predicted discharges are compared, and the discharges to be released at the mouth of the Tennessee are coordinated with that office. This cooperation makes it possible to reduce flood peaks most effectively on the lower Ohio and Mississippi rivers. Recently this arrangement has been formalized by an amendment to the current Flood Control Act which directs that, in case of danger from floods on the Lower Ohio and Mississippi rivers, the Tennessee Valley Authority is 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.

#### MECHANICS OF WATER CONTROL

In carrying out the mechanics of water control for the Tennessee Valley system, written instructions or memoranda are issued periodically by the Water Control Engineer, setting up operating requirements and limitations in advance. In the case of a flood or other emergency, instructions are given by telephone and confirmed by memorandum. All instructions are issued to the Superintendent of Power Operations and transmitted by him through the Load Dispatcher to the power stations at the dams concerned, where the actual gate operations are performed by the power-house crews. The reliable and positive transmission of instructions, particularly in times of flood, is an important matter. And it must be borne in mind that during an exceptional flood ordinary means of communication, such as commercial telephone and telegraph lines, are liable to be interrupted at the time when they are most needed.

On the TVA system there is a power-generating station located at, or a short distance from, practically every dam, and the communication facilities developed for load dispatching are used for transmitting instructions for water control. Each power house is connected with the main lines of the commercial telephone system by substantially built extensions. In addition, communication is provided by a carrier-current telephone system



UNLOADING CARGO OF WHEAT FROM ST. LOUIS AT KNOXVILLE TERMINAL  
Navigation Is an Objective of TVA Reservoir System

which operates by radio transmission, following channels afforded by high-voltage transmission circuits.

With respect to the design of the structures forming a part of the Tennessee River system, there are but few features which are peculiar to the method of operation. All the tributary storage dams are provided with sluiceways or low-level outlets as a means of discharging water when the reservoir level is below the spillway crest, and when wasting of water is required to maintain or restore space for flood control storage. Precautions are taken to insure the reliable operation of spillway gates, but such measures would be taken with any dam of equal importance.

#### TYPES OF MULTIPLE-PURPOSE PROJECTS INVOLVING FLOOD CONTROL

The most important factor in the successful operation of a multiple-purpose water-control system is that the system shall have been planned and designed for the method of operation to be carried out. There are three different methods of approach or conceptions as to the design of multiple-purpose projects involving flood control: (1) the idea that a reservoir must at all times be kept empty for flood control; (2) the view that there must be a designated portion or definite layer of the reservoir reserved for flood control and another portion for other of the multiple uses, with no common use of the same space; (3) the view that the same space in a reservoir may be used both for flood control and for other purposes at different seasons of the year.

Each of these conceptions has its proper place and each has been successfully and economically employed. The first is essentially the detention-basin type of development and can have little if any other use than for flood control. The reservoirs of the Miami Conservancy District in Ohio are an example of this type of project. In studying the flood control problem of the Upper French Broad River in the Tennessee Valley, the Authority's engineers have tentatively proposed the use of detention-type reservoirs for such a project. Here the stream-flow distribution is not favorable for power development; economical sites for reservoirs of large capacity are not available; and the record indicates that major floods may be expected in any season of the year.

The second-water that of reserving index of portion or layer and reservoir for flood control—has been used in the design of a number of multiple-purpose projects. The Norfolk Dam, recently constructed in Arkansas by the Corps of Engineers, is an example of this method of approach to multiple-purpose operation. The planning of the Watauga and South Holston projects in the northeastern end of the Tennessee Valley is based on reserving exclusively for flood control the space above a certain fixed elevation in each reservoir. In the case of these projects, the topography and the lack of development in the area are such that reservoirs of com-

paratively large storage capacity may be obtained at reasonable cost, but damaging floods may occur in any season of the year.

The third method—that of utilizing the same space in a reservoir for flood control during one season and for other purposes during another—is the method generally used as the basis of planning and design for the system of water control in the Tennessee Valley as now constructed. The following conditions favorable to such a method of multiple-purpose operation are present to a high degree in the Tennessee Valley:

1. Major floods are consistently confined to a definite flood season.
2. Topographic conditions and the extent of improvement in the reservoir areas are such as to favor relatively large storage capacities at moderate cost.
3. The annual runoff cycle is such as to favor the required degree of filling of the reservoirs after the end of the flood season.

The important thing, and the point which I wish to stress here, is that in considering a multiple-purpose project, all available basic data must be assembled and the proposed method of operation determined by an engineering analysis directed toward serving the desired purposes in the most economical manner. This problem is like other engineering problems where we have certain controlling conditions which can be determined and appraised, and also certain objectives which must likewise be appraised and balanced one against another, so that the solution arrived at will fit all the factors involved.

In planning the reservoirs forming the Tennessee River System, the engineers of the Tennessee Valley Authority have studied the controlling conditions and have adopted the methods of multiple-purpose operation that most economically produce reliable flood control, adequate navigation facilities, and substantial power production. The operation of the system has been carried out over the past several years as planned. During that time a number of moderately large floods have occurred and have been successfully controlled. No extremely large floods have been experienced, but the planned reservations of reservoir space for flood control have been maintained, and such a flood may be awaited with confidence that it will be controlled as planned.

**PRINCIPAL FEATURES OF WATER CONTROL PROJECTS  
IN THE  
TENNESSEE RIVER BASIN**

PROJECT	DATE OF FIRST USE	RIVER	** MAX. HEIGHT (FEET)	OVERALL CREST LENGTH (FEET)	MAX. SPILLWAY CAPACITY (CFS)	VOLUME OF CONCRETE (CU. YDS.)	VOLUME EARTH AND/OR ROCK FILL (CU. YDS.)	POWER #		LOCK		AREA AT TOP OF GATES (ACRES)	TOTAL VOLUME BELOW TOP OF GATES (ACRE FEET)	USEFUL <sup>h</sup> CONTROLLED STORAGE (ACRE FEET)	LENGTH <sup>c</sup> OF SHORE LINE (MILES)	BACKWATER LENGTH (MILES)	MAXIMUM CONTROLLED POOL LEVEL (EL.)	MINIMUM EXPECTED POOL LEVEL (EL.)	AVERAGE TAILWATER LEVEL (EL.)
								INSTALLED OR UNDER CONSTRUCTION KW	ULTIMATE CAPACITY (KW)	SIZE (FEET)	MAX. LIFT (FEET)								
Kentucky	1944	Tennessee	206	8412	1,300,000	1,355,000	4,063,400	160,000	160,000	110x600	73	261,000	6,002,600	4,010,800	2,200	184.3	375	354	310
Pickwick Landing	1938	Tennessee	113	7715	750,000	630,300	2,966,000	144,000	216,000	110x600	63	46,800	1,091,400	418,400	496	50.1	418	408	362
Lock & Dam No. 1	1926	Tennessee	20	220	x	x	x	0	0	60x297	8	x	x	0	5	2.6	x	x	x
Wilson	1925	Tennessee	137	4862	765,000 <sup>a</sup>	1,259,400	0	335,200	436,000	60x300	92 <sup>f</sup>	15,900	562,500	52,500	154	15.5	507.88	504.5	414
Wheeler	1936	Tennessee	72	6342	687,000	626,200	0	129,600	259,200	60x360	52	68,300	1,151,800	348,900	1063	74.1	556.3	550	507
Guntersville	1939	Tennessee	94	3979	625,000	289,700	813,900	72,900	97,200	60x360	45	70,700	1,018,700	162,900	962	82.1	595.44	593	557
Hales Bar	1914	Tennessee	83	2315	600,000	x	x	51,100	99,700	60x267	38	6,100	135,100	11,800	100	39.9	631	629 <sup>m</sup>	598
Chickamauga	1940	Tennessee	129	5800	600,000	491,800	2,635,800	81,000	108,000	60x360	55	39,400	705,300	329,400	810	58.9	685.44	675	635
Watts Bar	1942	Tennessee	112	2960	550,000	480,200	1,173,000	150,000	150,000	60x360	70	43,100 <sup>d</sup>	1,132,000 <sup>d</sup>	377,600 <sup>d</sup>	783 <sup>d</sup>	72.4	745	735	682
Fort Loudoun	1943	Tennessee	122	4190	380,000	575,000	1,783,000	0	0	60x360	80	15,500	386,500	109,300	368	55.0	815	807	739
Fort Loudoun Ext.	e	Little Tenn	100	3120	86,400	65,000	2,035,000	64,000	128,000	60x360	80	17,600	455,000	130,000	268	33	815	807	739
Apalachia	1943	Hiwassee	150	1308	153,000	448,500	0	75,000	75,000	60x360	70	1,123	58,570	35,730	31	9.8	1280	1240	840 <sup>r</sup>
Hiwassee	1940	Hiwassee	307	1287	150,000 <sup>b</sup>	793,000	14,200	57,600	115,200	60x360	70	6,280	438,000	364,700	180	22	1526.5	1415	1272
Andrews <sup>p</sup>	1924	Hiwassee	50	385	x	x	x	1,800	1,800	60x360	70	x	283	x	x	1.5	x	x	x
Chatuge	1942	Hiwassee	144	2850 <sup>1</sup>	39,000	21,900	2,347,400	0	x	60x360	70	7,150	247,800	229,300	132	13	1928	1860	1804
Ocoee No. 1	1912	Ocoee	135	840	45,000	160,000	0	18,000	18,000	60x360	70	1,900	91,300	33,100	18	7	837.65	816.9	724
Ocoee No. 2	1913	Ocoee	30	450	x	0	0	19,900	19,900	60x360	70	x	x	0 <sup>k</sup>	x	0	1106.2	x	843 <sup>r</sup>
Ocoee No. 3	1943	Ocoee	110	612	100,000	111,000	82,000	27,000	27,000	60x360	70	606	14,440	9,370	24	7	1435	1413	1119 <sup>r</sup>
Blue Ridge	1931	Toccoa	167	1000	55,000	x	1,500,000	20,000	20,000	60x360	70	3,290	197,500	183,000	60	10	1690	1590	1543
Nottely	1942	Nottely	184	2300 <sup>2</sup>	48,000	17,700	1,552,300	0	x	60x360	70	4,290	184,400	184,000	106	20	1780	1640	1612
Norris	1936	Clinch	265	1860	240,000 <sup>b</sup>	1,002,300	181,700	100,800	100,800	60x360	70	40,200	2,567,000	2,281,000	800	72 Clinch 56 Powell	1034	930	826
Calderwood**	1930	Little Tenn	230	897	260,000	x	0	121,500	121,500	60x360	70	538	41,160	4,090	x	8	1087.5	1079.5	872 <sup>r</sup>
Cheoah**	1919	Little Tenn	230	770	200,000	x	0	76,000	95,000	60x360	70	640	35,670	7,260	x	10	1276.6	1263.6	1087.6
Fontana	1944	Little Tenn	480	2385	218,000 <sup>b</sup>	2,795,000	100,000	135,000	202,500	60x360	70	10,670	1,444,300	1,157,300	274	29	1710	1525	1278
Santeetlah**	1928	Cheoah	200	1150	92,000	x	0	45,000	45,000	60x360	70	2,850	156,000	131,000	85	x	1939.8	1864.8	1275 <sup>r</sup>
Nantahala**	1942	Nantahala	250	1042	59,000	x	1,829,000	43,200	43,200	60x360	70	1,605	137,300	124,900	x	4.6	3012.1	2882.1	2007 <sup>r</sup>
Glenville**	1941	Tuckasegee	150	900	56,000	x	458,000	21,600	21,600	60x360	70	1,462	71,110	66,670	x	4.5	3491.7	3416.7	2275 <sup>r</sup>
Douglas	1943	French Broad	202	1705 <sup>3</sup>	330,000 <sup>b</sup>	548,200	622,800	60,000	120,000	60x360	70	31,600	1,514,100	1,419,700	556	43	1002	920	873
Marshall <sup>p</sup>	1910	French Broad	x	x	x	x	x	3,000	3,000	60x360	70	x	x	x	x	x	x	x	x
Greenville <sup>p</sup>	1913	Nolichucky	x	x	x	x	x	10,560	10,560	60x360	70	930	16,000	8,050	x	x	x	x	x
Waterville <sup>p</sup>	1930	Big Pigeon	200	870	60,000	124,200	0	108,000	108,000	60x360	70	340	25,280	20,500	x	5.5	2258	2175	1397 <sup>r</sup>
Cherokee	1942	Holston	175	6760 <sup>4</sup>	288,000 <sup>b</sup>	681,400	3,240,300	60,000	120,000	60x360	70	31,100	1,565,400	1,473,100	463	59	1075	980	925
South Holston	e	S Fork Holston	290	1550	105,000	90,500	5,958,000	0	50,000	60x360	70	9,100	783,000	660,000	241	25	1742	1616	1490
Wilbur <sup>p</sup>	1912	Watauga	x	363	25,000	x	x	3,700	x	60x360	70	61	x	427	3	1.5	1644.5	1637.5	1585
Watauga	e	Watauga	318	900	62,000	65,300	3,533,000	0	50,000	60x360	70	7,100	677,000	627,000	117	17	1975	1815	1650
Great Falls*	1916	Caney Fork	92	800	150,000	x	x	31,860	31,860	60x360	70	2,280	54,500	49,400	120	22	804.9	762	655 <sup>r</sup>

\* Not in Tennessee Valley  
 \*\* Property of Aluminum Company of America; operation coordinated with TVA system  
 x No definite figure available  
 xx From deepest excavation on base line to roadway or deck  
 1 Saddle dam and spillway, 1,480 ft additional  
 2 Saddle dam, 340 ft additional  
 3 Saddle dam, 3,670 ft additional  
 4 Saddle dam, 1,770 ft additional

a Not maximum capacity, but capacity at 20.5 foot head  
 b Includes capacity of discharge conduits  
 c At clearing line elevation  
 d Includes Little Tennessee area above proposed Fort Loudoun Extension Dam  
 e Construction deferred, features shown are for proposed projects  
 f Two lifts

g Based on rated capacity  
 h From maximum controlled level to minimum expected pool level  
 k Reservoir silted  
 m Minimum for navigation to Chattanooga  
 n Except during drawdown in advance of floods at main-river plants  
 p Privately owned plant  
 r At remote powerhouse

Chief Engineer's Office  
July 1, 1945