

A PROPOSED STEAM BASE LOAD POWER PLANT

at

HARRIMAN, TENNESSEE

by

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FOREWORD

1. Purpose of Thesis.
2. Need for a base load plant in East Tennessee.
 - (a) Growth of Industries.
 - (b) Inadequate water power
3. Location recommended in University of Tennessee Engineering Experiment Station. Bulletin Number 5.
4. Acknowledgements of assistance and sources of information.
 - (a) National and State Geological Bulletins.
 - (b) Bulletins of University of Tennessee Engineering Experiment Station.
 - (c) Periodicals: "Power"; "American Institute of Electrical Engineer's Journal".
 - (d) Personal acknowledgement to Professors Woolrich and Switzer.
 - (c) Manufacturer's Bulletins.

Definitions

Introduction

1. What is a base load power plant?
2. Detailed discussions of steam base load power plants are needed in East Tennessee.
 - (a) Growth of power consuming industries.
 - (b) Growth in the production of power.

- (c) Forecasts for the future.
- 3. Detailed description of how the study was conducted.
 - (a) Study of power needs.
 - (b) Study of power supply.
 - (c) Base load power plant needs.
 - (d) Survey of Harriman.
 - (1) Water supply. (a) Quantity. (b) Quality. (c) Temperature
 - (2) Coal supply
 - (a) Mines.
 - (b) Transportation facilities.
 - (3) Electrical distribution facilities.
 - (e) Summary of Conclusions.

CHAPTER I

The Necessary Conditions for a Base Load Power Plant.

- 1. Coal.
 - (a) Bountiful supply.
 - (b) Regular supply
 - (c)
 - (1) More than one available mine.
 - (2) More than one available field.
 - (c) Cheapness of supply.
 - (d) Quality of supply.
- 2. Water.
 - (a) Necessity.
 - (b) Quantity.
 - (c) Quality.
 - (1) Temperature range.
 - (2) Chemical content.
- 3. Need.
 - (a) Basic.
 - (b) Electrical transmission lines.

CHAPTER II

The Favorable Conditions that Harriman has to Offer.

- 1. Coal.
 - (a) Fields.
 - (1) Mines.
 - (b) Economical Transportation.
 - (1) Railroads.

2. Water.

- (a) Quantity.
- (b) Quality.
 - (1) Chemical content.
 - (2) Temperature range.

3. Need:

- (a) Industrial development.
- (b) Electrical transmission lines.

CHAPTER III

Conclusions

1. A plant should be built.

- (a) Type.
- (b) Size.

APPENDIXES

"A"

Discharge of the Emory River at Harriman, Tennessee.

"B"

Atmospheric conditions at Harriman, Tennessee.

Summary of Conclusions

It would be feasible to construct and operate at Harriman, Tennessee, a base load plant of 70,000 kilowatt base capacity, and 105,000 peak capacity. To generate this power there should be installed:

- 3 - 30,000 K.W. condensing turbines
- 1 - 15,000 K.W. condensing turbine
- 14 - 1250 B.H.P. Water tube stoker-fired boilers with superheaters.
- 3 - 330,000 lb. per hr. jet condensers.
- 1 - 165,000 lb. per hr. jet condensers.
- Surface condensers of a total capacity of 1,255,000 lb. per hr.

A spray system on the river of 1756 nozzles, capacity of each being fifty gallons per minute at 10 lb. pressure.

Open feedwater heaters of a total capacity of 1,255,000 lb. per hr.

The boilers should produce at the turbines, steam at 200 lbs. (gage) superheat 218.1°F., total heat 600°F.

This, with all the necessary **auxilliary equipment** will, in the opinion of the writer, based on a study of the conditions and the opinions and suggestions of the authorities given in the introduction and throughout the text, will easily and efficiently deliver the rated capacity of the proposed plant.

FOREWORD

The purpose of this thesis is to make a survey of the conditions existing at Harriman, Tennessee, that are favorable to the establishing of a base load power plant either in the city or near it.

At this time Eastern Tennessee is taking great strides forward in an industrial way. Manufacturing plants and other industries are continuously and rapidly being moved into this territory and others are being developed. These various industries must be supplied with adequate power. This section is rich in its abundance of potential water power, but this can be developed only slowly and will not be able to supply the demand as rapidly as it is rising. This will be shown later so as not to leave any doubt as to the necessity of several base load steam power plants in the territory.

Professors J.A.Switzer and W.R.Woolrich have made a general survey of the whole of East Tennessee, and extended into Kentucky, Alabama and North Carolina; in their report "The University of Tennessee Engineering Experiment Station Bulletin No.5", they show the need of steam plants and recommend several locations as possible sites. Among these places is Harriman, Tennessee; they recommend a plant there of about 75,000 or 100,000 Kilowatts.

The writer takes up the investigation where they left it off, and makes a detailed study of the site as a possible location.

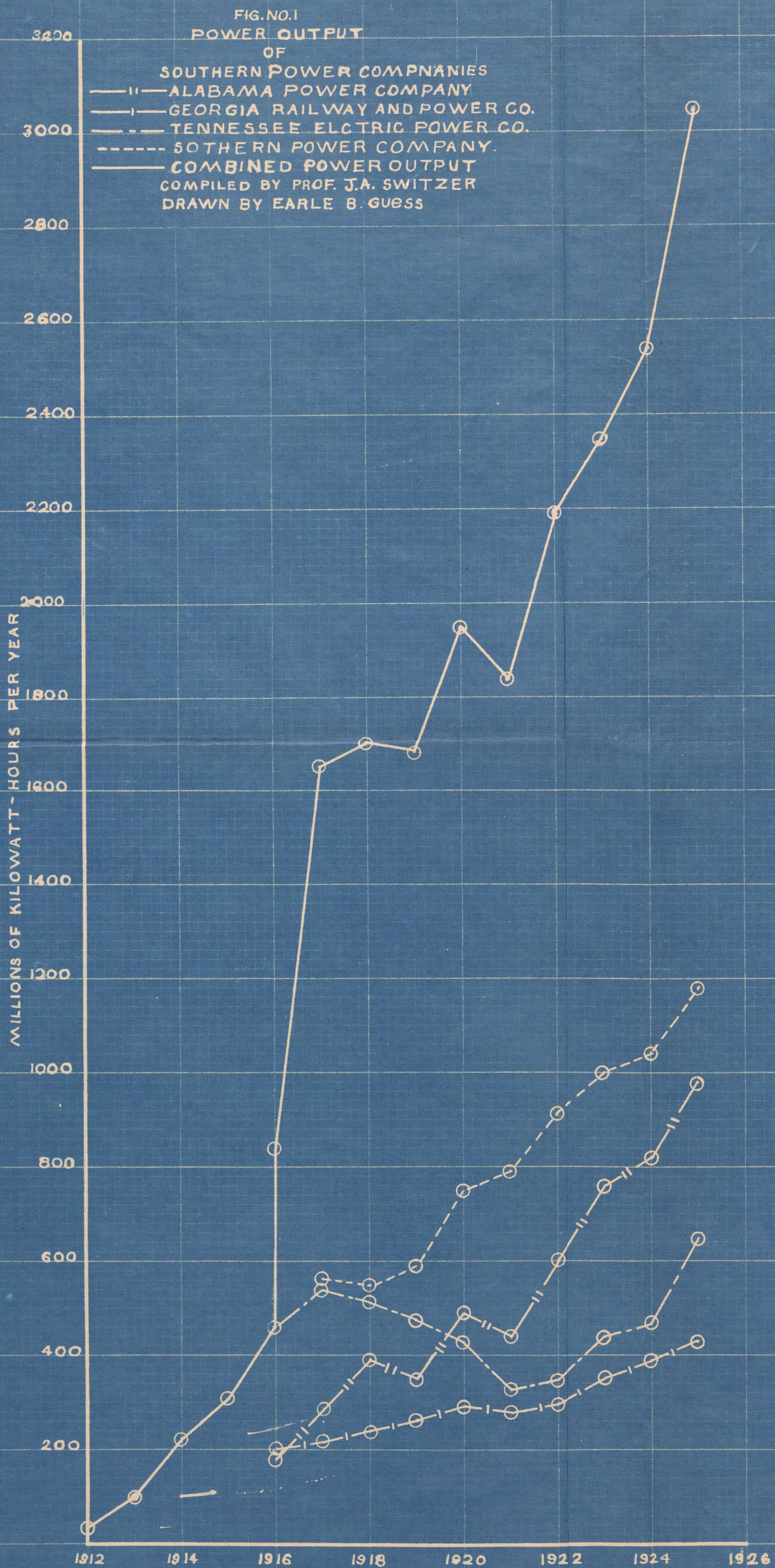
The survey is not a personal one, as the writer has never been on the field, but has made an investigation and study of State and National Geological Bulletins covering^{the} period of 1904-1926, and Bulletins of the University of Tennessee Experiment Station. These gave him an adequate knowledge of existing conditions. He made a study of the requirements and proposed plans of base load plants in "Professional Paper", "Power", "A.I.E.E. Journal" and Gebhardt's text on steam engineering. Other than these, he made use of catalogs and bulletins sent him by various manufacturers.

Greatly indebted does the writer feel toward Professor Woolrich, who not only helped in the collecting of data, but directed, advised, and assisted him. Also is he indebted to Professor Switzer, who assisted in getting the correct flow of the Emory River. It was these two gentlemen who published the "University of Tennessee Experiment Station Bulletin No.5" which was the nucleus on which this thesis is founded. Others whom the writer wishes to thank are the gentlemen of the United States Geological Survey Offices in Chattanooga, Mr.J.I.Widmeyer of the Knoxville Station of the United States Weather Bureau, Mr.R.C. Walzl of the Harriman Water and Light Department, and others who may be mentioned from time to time. All of the gentlemen have been very kind in helping him get the information needed.

INTRODUCTION

What is a Base Load Power Plant? The average layman knows of only two types of power plants, the steam plant and the hydro plant, and to him power is power and it is always the same. But by study into the subject, we find that though that classification exists, it is not the principal one. This is the day of central power stations. To quote the "University of Tennessee Engineering Experiment Station Bulletin Number 5," the isolated steam plant is already superannuated, and will soon be superseded." Today the Southern Appalachian section is covered by one of, if not the greatest net-work of 110,000 volt transmission lines. These lines are owned and supplied with power by the Southern Power Company, Alabama Power Company, the Tennessee Electric Power Company, the Georgia Railway and Power Company, Watauga Power Company and numerous smaller companies. These are all more or less interconnected for mutual benefit. Their power generating plants consist of both steam and hydro-electric stations. But back to the original question, what is a base load plant? These companies find that their loads are not constant, but will vary greatly with the hours of the day, the days of the month and the months of the year. This variation amounts to little to the small isolated plant and can be cared for easily, but the variation on these interconnected lines amounts to thousands of kilowatts. The peak or heavy loads are cared for to a great extent by interconnection. The peak load not coming on all the plants at the same time, they are able to assist one another, but yet there is great variation. The companies are forced to supply the necessary power at all times. They find by a study of load requirements that there is a definite load that is always needed at all seasons of the year and hours of the day, this continuous load is their base load. Power plants that supply power for this load are base load plants, or according to the "United States Geological Survey Professional Paper 123", "A Base Load Plant is a plant designed to carry that part of the load that is practically continuous."

In the last quarter of a century the industries of the State of Tennessee have grown enormously, but from all indications the growth has just begun. Not only are new manufacturing plants opening in the State, but large numbers of those of the over industrialized sections of the North and East are moving their plants to the South. They see the great supply of native white labor in the mountain districts, the abundance of natural resources, both mineral and agricultural, the large number of sights for large power plants, both hydro and steam, and realize that the climatic conditions are most favorable for steady year around employment and production. The Piedmont Sections of the coast states have, up to the last few years, received most of these plants, but now they are coming more and more to East Tennessee. Not only are they grouping around the two large cities of the section, Chattanooga and Knoxville, but are scattering out into the smaller communities, such as Kingsport, Cleveland,



Elizabethton and Erwin. The percent of increase in manufacturing is rising rapidly in the State. This can be seen somewhat by a study of the 1925 Report of the Bureau of Census. This shows that the value of the produce has increased from \$92,749,129.00 in 1899 to \$556,253,162.00 in 1919; there being an increase of 48.7 per cent during the five years from 1899 to 1904 and one of 162.3 per cent from 1914 to 1919. The capital stock invested did not increase in quite as large a percent; there being one of 62.2 during the period of 1899 to 1904 and one of 94.0 per cent from 1914 to 1919. The majority of these plants are power consuming and effect the power load greatly, but the above figures are, for several reasons, not really true indexes to the growth of the demand for power in the State. One of the principal reasons being that they do not cover the last seven years, during which time the greater part of the real permanent growth has taken place; then, while the value of products and capital stock are more or less indexes to industries, they are rather variable and not considered to be the best authorities. Therefore the curve in Figure 1, Page 8, which were obtained from Prof. J.A. Switzer, are presented to show the increase in power output during the period 1912 to 1925. This is not the increase in plant capacity, but the actual output. There are four curves showing the output of the four largest companies supplying East Tennessee, and then one showing the total. It will be noticed that during the years 1915 to 1921 the Tennessee Light and Power Company output went up to a peak and returned. This was due to the fact that the Aluminum Company of America bought power from them during those years. In 1917 they began to cut in on their own plant and had cut in completely in 1921. It will be noted that except for that one break all the curves rise with a rather regular and slightly increasing slope. It may seem rather presumptuous to some people to base a prediction of the future on a period of only twelve years, but authorities, such as the gentlemen of the University of Tennessee Engineering Experiment Station, Major Harold C. Fisk, United States Army District Engineer of the District of East Tennessee, and those connected with the State and National Geographic Survey, as well as the power companies themselves are all agreed that the demand curve will continue to rise with a probable increase in slope. If the demand curve rises the supply curve must rise, and if the supply curve rises that of the production must also. That will mean that the power companies of the section will have to increase their capacities, for of the four principal companies previously named, all are operating only within a small capacity factor and all are drawing up plans for the enlargement of their system. The Utilities Commission of the State are forcing them to do so. Most of these plans are for the erection of hydro electric plants. That is very good, for at the present time there is a large amount of potential water power in the section and it will give power at a rather cheap rate if properly developed. But there is a limit to these developments, for the best sights are rapidly being taken. Mr. Frank Baum has said that within a period of twenty years, all of the water power of the United States will have been developed.

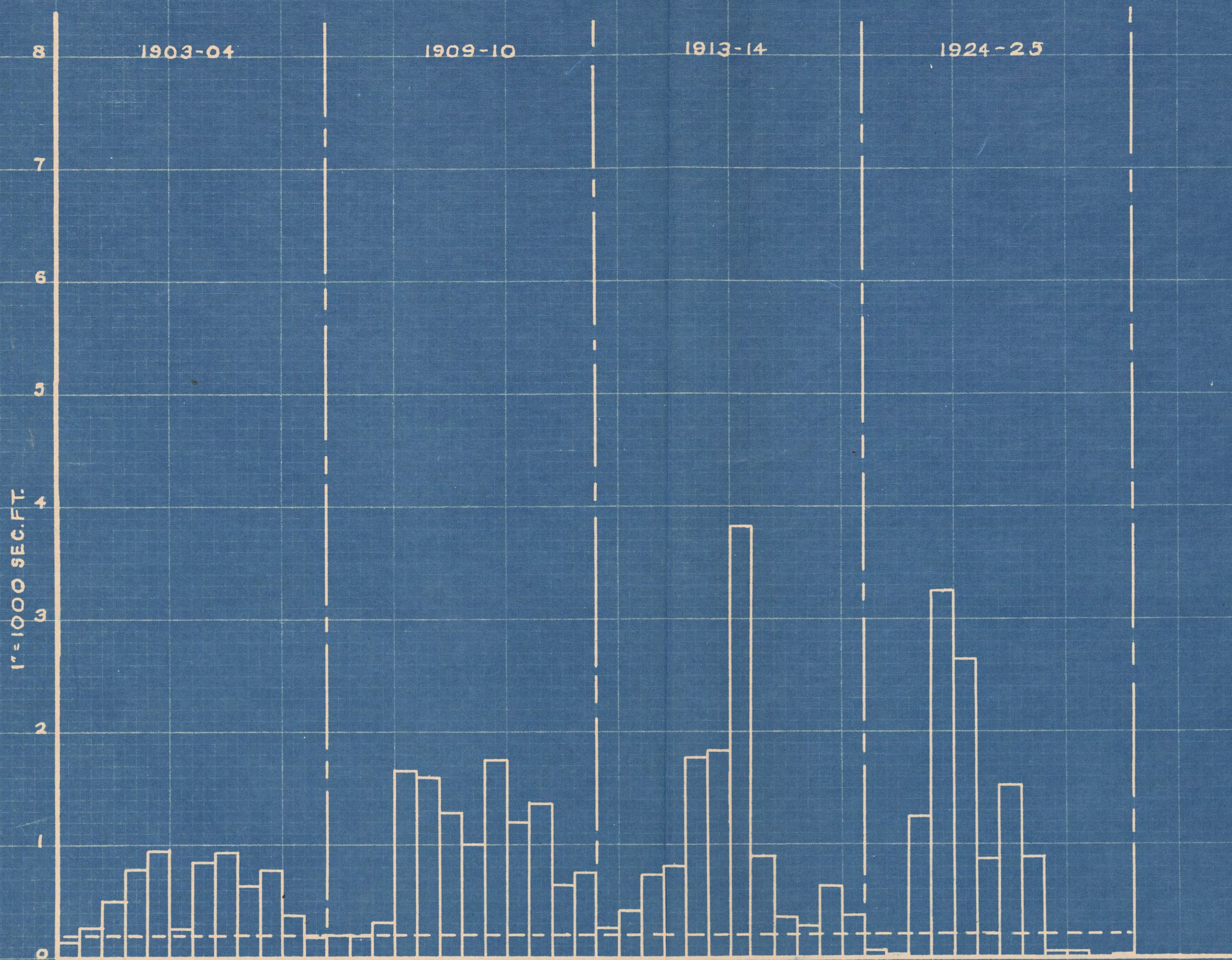


FIG. NO. 2.

HYDROGRAPH SHOWING DISCHARGE OF THE EMORY RIVER DURING THE FOUR DRYEST YEARS OF THE PERIOD 1903-1925

——— MEAN MONTHLY DISCHARGE

----- MEAN WORKING DISCHARGE-ASSUMED.

DRAWN BY-EARLE B. GUESS

At the present rate it seems that all the really profitable sites of this section will have been taken before then. Be the time when it may, it is not far off and plans must be made for the future. A disadvantage to the hydro-electric power is that it fluctuates greatly with the stream flow and the streams vary to a great extent with the seasons, and it so happens that as a rule the streams are lowest when the demand for power is greatest. In the curves shown in Figure 1, the base load increases as rapidly as the total, if not more so. That means that the primary or low water power must be equal to the base load. It has been the practice in this section to make their principle source of power the hydro-electric plant, and to supplement this with steam plants. But as the better hydro sites are taken and the load increases, there is a growing need in East Tennessee for steam base load plants to insure to the consumers a steady supply of power at all times; the peaks being taken care of by the hydro-electric plants. Some of the power companies are realizing this and are looking for suitable sites for such plants.

In preparing this paper a study of the industrial growth of the whole Southern Appalachian section, East Tennessee in particular, was made. The material obtainable was rather limited as the larger part of the growth took place in the last few years, and it's use as indexes was affected by the World War, which threw things into an abnormal condition. The greatest help came from the "University of Tennessee Engineering Bulletin No.5," and curves lent to the writer by Professor J.A.Switzer. Also personal information given him by Professor W.R.Woolrich and other Professors of the University. A study of power production was made at the same time, they being parallel. A careful study of the "United States Geological Survey Professional Paper 123", was made. From it was gotten the general characteristic qualifications, and needs of a base load plant, particular attention being paid to steam plants. The recommendations given in the conclusion are largely based on those set forth in this paper. The most important study was the survey of Harriman; this was not done by personal investigation on the ground, but by study of United States and Tennessee Geological maps, reports, and the "Tennessee Geological Survey Bulletin Number 34". There was no way of determining the actual discharge of the Emory River over any period of time; so a comparative hydrograph with the Clinch River at Clinton was calculated and drawn as shown in Appendix "A" Page 25. To then arrive at the discharge that could be depended on, and on which calculations could be made was largely arbitrary. The writer, after consultation with Professor Woolrich, decided to take the four dryest years of the period 1903-04 to 1924-25 as a basis on which to work. These were 1904-05, 1909-10, 1913-14 and 1924-25. A separate hydrograph of these years are shown in Figure 2, Page 10. The basic discharge was then taken as the highest discharge that was available for eighty per cent of the forty-eight months in question:

48 X 0.80 = 38.4 (Call) 39 months during which
flow must be available.
48 - 39 = 9 Months, during which flow may
not be available.

It was found there were ten months where the discharge was below 200 Sec. ft.:

October and September of 1903-04
October and November of 1909-10
October, November, June, July, August and September of 1924-25.

But that for September 1904 and October 1909 were 192 second feet, this being so close to 200, and in view of the fact that twenty per cent of 48 was taken as 9, whereas it is really 9.6, the writer assumed 200 second feet to be his basis flow. He was unable to get a definite report on the quality of the Emory River water or was it so he could make a chemical analysis himself; but he consulted Professors W. R. Woolrich, J. A. Switzer and W.E. Grainger, all of whom had made studies of the water; the two former in connection with power projects and the latter in his chemical laboratories. All of them report it to be remarkably free from those minerals which cause hardness and corrosion, and that it is ideal for power purposes. The other feature of the water supply is its temperature. The only obtainable data was the readings taken during the month of April 1926. This was of no value as April is one of the months of highest water, and lowest temperature and it is the high temperature that is needed in this investigation. Therefore, the writer had to accept the estimate of the United States Geological Survey Offices in Chattanooga. This was 79° F. The conditions concerning the coal supply were found by locating the accessible mines on the third edition of the "Geological Map of Tennessee;" in doing this, not only was the distance from Harriman noted, but transportation facilities, both rail and water. On the same map was located the high tension lines passing near Harriman, over which the generated power could be conducted to points of distribution. This was checked by a map published by the Tennessee Light and Power Company. The air temperatures^{and} relative humidity were gotten from the Knoxville office of the United States Weather Bureau covering a period of 67 years, 1855-1922; these, though taken at Knoxville are approximately the same as those that might have been taken at Harriman and are assumed in this writing, to be so. They were used in the calculation of the cooling pond. The method used to calculate the amount of steam which the 200 second feet of stream flow would condense, and the amount of power that that amount of steam would generate are those set forth by G.F. Gebhardt in his sixth edition of "Steam Power Plant Engineering". The method of cooling pond calculations are also found there. The water rate assumed for the turbines is one that the writer chose after a study of water rates as set forth as being typical by Mr. Gebhardt in the same Volume.

CHAPTER I

The Necessary Conditions for Steam Base Load Power Plants.

In the introduction there was given a definition for a base load power plant and something of the characteristics of one. To repeat: "A Base Load Plant is a plant designed to carry that part of the load that is practically continuous". If the load is to be practically continuous, the supply must be absolutely continuous. The capacity of the plant must never fall below the base load for which it is supposed to care. It may carry peak loads also if conditions are favorable, and there is no danger of putting the plant under a strain which might cause it to be unable to carry the base at some future time. The base load plants are the skeleton on which large power systems are built. The base plants may be so combined with variable load plants as not to be distinguishable; but in this case, each variable load plant has a base load on which it rates its operation, and the sum of these base load capacities forms the basis of the system.

The necessary conditions for a plant to deliver a continuous supply of power may be grouped under three heads: the need or load, the natural conditions, and the plant equipment. The plant equipment will not be treated in this Chapter at all, except to say that enough reserve and duplications must be had so as to reduce the possibility of a forced capacity below base requirements to a minimum and the probability to absolute zero. A further discussion will be given in Chapter III, under recommendations.

To quote the "University of Tennessee Engineering Experiment Station Bulletin Number 5", "The requirements for a steam base load power plant are: a coal mine, a river and more coal mines." These are the two most essential things; first, there must be coal and plenty of it. The consumption of a plant of 100,000 Kilowatts or over, is enormous, something like 240 tons a day per 100,000 Kilowatts, varying with its quality and efficiency of the plant. Therefore, there must be a bountiful supply available. Not only must it be bountiful, but it must be regular. Of course, a plant cannot shut down for the lack of coal if it can be possibly prevented. Neither can one afford large storage bins if they might be eliminated, for their cost is great, the handling of the coal expensive and there is danger of spontaneous combustion. Therefore, what is desired for a plant of this kind is at least one coal mine within a convenient distance, and so located that its coal can be easily gotten to the plant either by rail or water. Where this is the case, coal costs are greatly reduced. The above could be classed as an absolute necessity, for a large plant of this kind would

never be built where it was not the case. But that is not all, what more is desired is that there be more such mines, and if possible have various means of transportation. This is not only to insure sufficient quantity, but regularity of supply. If for any reason one mine or means of transportation therefrom, shuts down there will be others, so that the regular supply will not be curtailed in the least. This can be carried still further; if it should be possible, it would be very desirable to locate a base load plant where it would be convenient to more than one field. The reasons for this are the same as for wanting more than one mine. "Coal Strikes" operate largely by fields. It is their strikes largely, that threaten the regularity of the supply of coal to the plant. It is not likely that there would be a strike in more than one field at a time. Therefore, if a plant is conveniently located to more than one field it is more than likely that it can get its supply from one of the others, thus insuring a regular, bountiful supply. The next phase of the coal situation is the matter of cost, for coal is the principle operating expense of a plant and the expenses must be kept as low as possible. But if a plant has the preceding requirements, the latter need not bother it greatly, for if it has a regular, bountiful supply from more than one mine it is more than likely that the cost at the mine will be comparatively cheap. And though it was not specifically mentioned, it was implied that it was desirable that the plants and mines be rather close together, if that be the case, the transportation charges, which are about as important as the cost at the mine, if not more so, is small. The quality of the coal is largely a problem of the designer. Most any of the marketable coals are satisfactory for base load plants, provided the proper fuel burning equipment is used for that particular coal. It is true that coal of high heat value, high fusion point and low per cent of ash, are somewhat more desirable, but not necessary.

Next to coal in importance to the base load power plant is condensing water, in fact, in some ways it is of more importance, for conditions are getting very critical when an operator can not get coal from somewhere, but if he has not sufficient water on hand there is no possible way to get it supplied, and this will mean a great drop in the plant's capacity. Therefore, such a plant should be located on a river supplying plenty of water. Not only should there be plenty of it, but it should be of low temperature and contain nothing that is injurious to the condenser or boiler. The vacuum or back pressure is directly proportional to the temperature of the condensing water, therefore, it is very desirable that it be low; especially is this true where the quantity of water is limited, for the higher the temperature, the more water that has to be used to prevent trouble and injury to the equipment. It is necessary that it be free from, or at least low in sulphates, chlorides and nitrates of lime, magnesia and iron, which cause hardness and produces a scale. Also some waters contain alkalies or acids which cause corrosion. It is indeed desirable that it be free of such, and absolutely necessary that it not be strong with them.

If all the above conditions exist, there is no doubt but that an up-to-date, modern plant of large base load capacity could be easily built; but what would be the use of such a plant if there was no means by which the power could be used? One of the first things to consider in the contemplation of erecting a base load plant is, is there a need for the power which is to be supplied? If so, where is the need, is it local, and is there already existing adequate means of distribution? Base load plants are usually connected to extensive systems of lines. If that be the case, where can the proposed plant tie in to the system? Is there adequate lines passing near the proposed site? All these questions must be answered. If there is not a high tension line fairly close to the proposed site it might be more profitable to select another site, for the erection of transmission lines is very expensive. But where all of the above conditions exist there is an ideal location for a base load steam power plant.

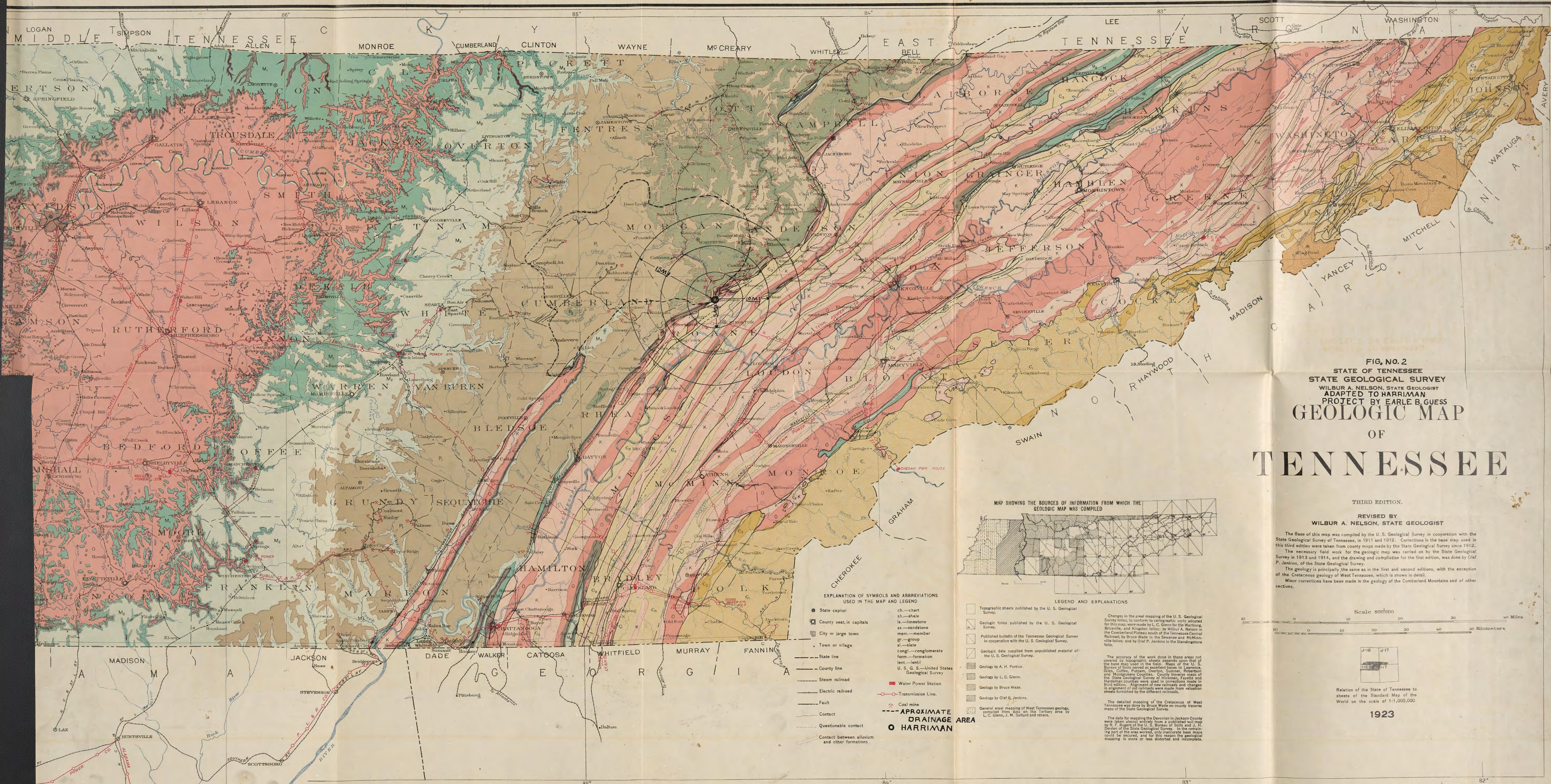
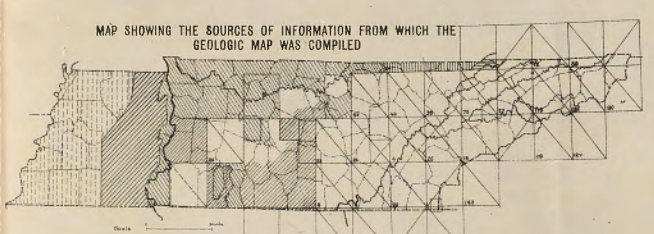


FIG. NO. 2
STATE OF TENNESSEE
STATE GEOLOGICAL SURVEY
WILBUR A. NELSON, STATE GEOLOGIST
ADAPTED TO HARRIMAN
PROJECT BY EARLE B. GUESS
GEOLOGIC MAP
OF
TENNESSEE

THIRD EDITION.

REVISED BY
WILBUR A. NELSON, STATE GEOLOGIST

The base of this map was compiled by the U. S. Geological Survey in cooperation with the State Geological Survey of Tennessee, in 1911 and 1912. Corrections in the base map used in this third edition were taken from county maps made by the State Geological Survey since 1912. The necessary field work for the geologic map was carried on by the State Geological Survey in 1913 and 1914, and the drawing and compilation for the first edition, was done by Olaf P. Jenkins, of the State Geological Survey. The geology is principally the same as in the first and second editions, with the exception of the Cretaceous geology of West Tennessee, which is shown in detail. Minor corrections have been made in the geology of the Cumberland Mountains and of other sections.



- EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED IN THE MAP AND LEGEND
- State capital
 - County seat, in capitals
 - City or large town
 - Town or village
 - State line
 - County line
 - Steam railroad
 - Electric railroad
 - Fault
 - Contact
 - Questionable contact
 - Contact between alluvium and other formations
- ch—chert
ls—limestone
ss—sandstone
m—member
gr—group
sl—state
congl—conglomerate
form—formation
lent—lentil
U. S. G. S.—United States Geological Survey
- Water Power Station
- Transmission Line
- Coal mine
- APPROXIMATE DRAINAGE AREA OF HARRIMAN

- LEGEND AND EXPLANATIONS
- Topographic sheets published by the U. S. Geological Survey.
 - Geologic folios published by the U. S. Geological Survey.
 - Published bulletin of the Tennessee Geological Survey in cooperation with the U. S. Geological Survey.
 - Geologic data supplied from unpublished material of the U. S. Geological Survey.
 - Geology by A. H. Purdie.
 - Geology by L. C. Glenn.
 - Geology by Bruce Wade.
 - Geology by Olaf P. Jenkins.
- Changes in the areal mapping of the U. S. Geological Survey folios, to conform to cartographic units adopted for this map, were made by L. C. Glenn for the Wartburg, Bricville, and Kingston folios; by Wilbur A. Nelson in the Cumberland Plateau south of the Tennessee Central Railroad; by Bruce Wade in the Sevier and McMinnville folios; and by Olaf P. Jenkins in the Standingstone folio.
- The accuracy of the work done in those areas not covered by foliographic sheets depends upon that of the base map used in the field. Maps of the U. S. Bureau of Soils served as excellent bases in Lawrence, Giles, Coffey, Putnam, Overton, Sumner, Robertson and Montgomery Counties. County traverse maps of the State Geological Survey of Hickman, Fayette and Hardeman counties were used in corrections made in third edition. Alignment of new railroads and changes in alignment of old railroads were made from valuation sheets furnished by the different railroads.
- The detailed mapping of the Cretaceous of West Tennessee was done by Bruce Wade on county traverse maps of the State Geological Survey.
- The data for mapping the Devonian in Jackson County were taken almost entirely from a published soil map by R. J. Rogers of the U. S. Bureau of Soils and J. H. Dorden of the State Geological Survey. In the remaining part of the area worked, only inaccurate base maps could be secured, and for this reason the geological mapping is more or less distorted and incomplete.

Scale 600,000

0 10 20 30 40 Miles

0 10 20 30 40 Kilometers



Relation of the State of Tennessee to sheets of the Standard Map of the World on the scale of 1:1,000,000.

1923

CHAPTER II

Favorable Conditions which Harriman has to Offer.

Harriman, Tennessee, a small town on the Emory River, 166 miles from Nashville, 50 miles from Knoxville, and 80 miles from Chattanooga has, within certain limits, more of the necessary and desirable conditions favorable for a base load plant than can hardly be found at any one point. There is existing there to a more or less extent every one of the desirable and necessary conditions discussed in Chapter I. It is located on the intersection of four separate railways, each of which pass through a different coal field. These railways are: The Southern's main lines from Knoxville to Cincinnati; The Tennessee Central from Nashville to Harriman; The Louisville and Nashville from Corbin, Kentucky, to Chattanooga, and a small road of the Southern System, the Harriman and Northeastern, which runs from Harriman to Petros and on to the State mines. As stated, each of these carriers pass through a separate coal field. On the map of Figure 3 Page 15, are concentric circles drawn around Harriman; these circles are drawn to scale with a radii of 5, 10 and 15 miles. Within the five mile radius there are seven mines, in the ten mile radius are fourteen, and in the fifteen mile radius there are forty-one. Every one of these, except two, are situated on one of the railways going right into Harriman. As the radius increases the number of mines increases rapidly, for there are several other larger fields on these same roads. So there is a bountiful supply, and as it is scattered among four separate fields it is very unlikely that the time will come when it will be so that all the necessary coal can not be had. And if all the railway operators went on strike, the coal could be brought by trucks if need be. All of these fields are in Tennessee, but if in the case of an emergency it was necessary, coal could be easily gotten from the fields of Kentucky, which are not far distant and which are connected to Harriman by the Southern, and Louisville and Nashville main lines. Therefore, in regards to coal it is ideally located.

The other main essential for a base load plant is also there; the Emory River passes around the town. The stream is not a large one, and it's discharge fluctuates quite a bit, but it has been found, after a careful study of a period of a little more than twenty-two years, that it can be depended on for a flow of 200 second feet. Of the twenty-two years, eleven had months whose mean discharge was never below the 200 second feet, four that had one, three that had two, one that had three, one that had four and two that had even six months below. During most of these months, however, it was only slightly below. Therefore, it seemed proper to consider the working flow as 200 second feet, provided adequate consideration is given to the fluctuation in all calculations that may be made. The quality of the water is unusually good.

The chemical composition can not be given exact, but it is known that it is almost completely free from those minerals which cause corrosion and scaling of boilers and equipment, and its low temperature is about 70°F.

There is no question but what the power generated could be profitably disposed of. The town is right in the heart of the section of East Tennessee that is making such great strides forward industrially, and of which one authority has said "the Power Companies are today twenty per cent behind the power market requirements." It lies within the triangle formed by Knoxville, Chattanooga and Nashville, and is surrounded with small towns that are advancing rapidly. The town itself has not yet grown much industrially, but it stands to reason, being located as it is, between Knoxville, Chattanooga, Nashville and Cincinnati, and having four railways, three of them main lines, that if it is given a half chance that it will step right to the front. Its big need is power. It even has, within easy reach, a means of transmuting its power to those places where it is needed most. Running within five miles of the town is the 110,000 volt line of the Public Light and Power Company; this line connects at Lenoir City with the high tension double lines of the Tennessee Electric Power Company, running through Knoxville, Cleveland and Chattanooga. Also the Tennessee Electric Power Company line through Petros, Coal Creek and Knoxville passes within about fifteen miles of the city.

All these conditions are extremely favorable for a steam base load plant, the quantity of regular water being the limiting feature of the size plant that could be operated there.

CHAPTER III

A Suitable Plant for Harriman, Tennessee.

It has been shown that Harriman is a most suitable location for a base load plant; the one limitation being the amount of the regular discharge of the Emory River. This being the limiting condition, all calculations and recommendations have to be made with that as a basis.

The working discharge assumed by the writer, (as shown in the introduction) is 200 second feet. He realized when he made the assumption that account would have to be taken of the times when it did not amount to that much, so he is making provisions in his recommendations by including a system for cooling the water passing through the condensers and using it over and over indefinitely as needed.

The discharge was converted from second feet to pounds per hour as follows:

Discharge = 200 second feet.
Temperature = 70° F.
Density of water at 70° F. = 62.
 $200 \times 62 \times 60 \times 60 = 44,650,000$ lb. water per hr.

The following operating conditions were assumed and calculated for the turbines:

Steam pressure at turbine throttle = 300 lbs.
per square inch (gage)
Total temperature of steam = 600° F.
Superheat = 218.1° F.
Turbine exhaust pressure (absolute) = 1.5 inches
of mercury.
 $e =$ Mechanical efficiency of turbo-generator = 0.95
 W = Water rate = 11 pounds per kilowatt hour.
 H_1 = Initial heat content = 1322.2 (Goodenough)
 A = Heat converted into work, B.t.U. per lb. steam.
 $A = \frac{3415}{e W} = \frac{3415}{0.95 \times 11} = 326.8$
 H'' = Heat content of exhaust.
 H_r = Heat lost due to radiation; (negligible)
 $H'' = H_1 - H_r - A$
 $H'' = 1322.2 - 326.8 = 995.4$
 t_s = Temperature of vapor at exhaust pressure =
91.75 °F. (Goodenough)

Either surface or jet condensers may be used. It is customary, however, to use the surface type in the larger plants on account of their economy in the use of power for pumping, and the keeping of the condensate clean for recirculation.

The surface condenser requires more cooling water, however, so the writer calculated the amount of power that can be generated with the available condensing water with both types.

The Surface Condenser.

$t' =$ Temperature of condensate.

$t_s - t' = 3^{\circ} \text{ F.}$ (assumed)

$t' = t_s - 3 = 91.75 - 3 = 88.75^{\circ} \text{ F.}$

$t_o =$ Temperature of cooling water $= 70^{\circ} \text{ F.}$
(Temperature of river water)

$t'' =$ Temperature of discharged cooling water.

$t_s - t'' = 11^{\circ} \text{ F.}$ (assumed)

$t'' = 91.75 - 11 = 80.75^{\circ} \text{ F.}$

$R =$ pounds of cooling water required per lb. of steam.

$$R = \frac{H'' - t' + 32}{t'' - t_o}$$

$$R = \frac{995.4 - 88.75 + 32}{80.75 - 70} = 88.7 \text{ lb.}$$

$$\frac{44,650,000}{88.7} = 512,000 \text{ lb.} = \text{amount of steam}$$

that the working flow of the river will condense when used in a surface condenser.

$$\frac{512,000}{11} = 46,600 \text{ K.W.} = \text{amount of power that can be generated with the above steam.}$$

46,600 K.W. is the capacity of a plant using surface condensers on the Emory River at Harriman when the river is flowing at the rate of 200 second feet.

The Jet Condenser.

All values are the same except that $t_s - t''$ is assumed to be only 5° F. in this case, therefore:

$$t'' = 91.75 - 5 = 86.75^{\circ} \text{ F.}$$

$$R = \frac{H'' - t'' + 32}{t'' - t_o}$$

$$R = \frac{995.4 - 86.75^{\circ} + 32}{86.75 - 70} = 56.1 \text{ lbs.}$$

$$\frac{44,650,000}{56.1} = 796,000 \text{ lb.} = \text{amount of steam}$$

that the working flow of the river will condense when used in jet condensers.

$$\frac{796,000}{11} = 72,300 \text{ K.W.} = \text{amount of power that can be generated with the above steam.}$$

72,300 K.W. is the capacity of a plant using

jet condensers on the Emory River at Harriman when the river is flowing at the rate of 200 second feet.

These calculations show that with the installation of surface condensers, as is the custom, the base load capacity of the plant would be cut down to 45,000 kilowatts, whereas, if jet condensers are used it can be very safely rated at 70,000, a clear gain of 35,000 kilowatts. The excess power required to operate the jet condensers would amount to an extremely slight fraction of the gain in capacity. With these facts in mind and knowing the first cost of jet condensers are comparatively low, the writer would suggest that the base load rating be made 70,000 kilowatts, and a low level jet condenser be installed with each turbine. He is also mindful of the fact that for eight or more months of the year the supply of water is sufficient to operate the plant at full capacity with surface condensers. Therefore, he also recommends that surface condensers be installed with a total capacity equal to the full capacity of the plant; so that when there is a sufficient supply of water the plant might effect that saving of power which would be possible with their use instead of those of the jet type.

With the base load taken as 70,000 kilowatts and the water rate as eleven pounds per kilowatt hour, the total condensate will be 770,000 pounds. With the use of the jet condensers it would require $770,000 \times 56.1$ or 43,197,000 pounds of cooling water. This would give a total of 43,967,000 pounds exhausted from the condenser per hour.

The lowest discharge of the Emory River during the twenty one years studied was in September 1925, when it was 5.08 second feet or 1,134,000 pounds per hour. It is extremely improbable that it will ever fall below that; so it can be taken as an absolute minimum discharge. Therefore, 43,967,000 - 1,134,000 or 42,833,000 pounds per hour is the greatest amount of water that a cooling system will be called upon to cool. The temperature of this water is 86.75°F. and it is desired to reduce it to as close to 70°F. as possible.

$$43,833,000 \text{ lb. per hr.} = \frac{43,833,000}{60} \times \frac{7.481}{62} = 87,800 \text{ gallons per minute to be cooled below } 86.75^\circ\text{F.}$$

The average wet bulb temperature for the months of June, July and August is 70.6°F. This is the lowest possible degree to which the water can be cooled by means of a spray pond, which the writer believes to be the best system under existing conditions. The temperature can, however, be brought very close to this temperature. The writer, following the recommendations of manufacturers, recommends that 1756 nozzles, having a capacity of fifty gallons per minute at a pressure of ten pounds per square inch, be placed in the river above the intake pipe. They should be grouped into rows from twenty to twenty five feet apart and two or three feet between nozzles. This will not only bring the temperature of the water down very close to the low limit, but it then allows it to mix with the water coming down the stream, thereby reducing the temperature still more.

With this equipment, it is the writer's opinion that there will never be any danger of the temperature of the condensing water rising above 72°F. or of the supply falling below that required for the base load of 70,000 kilowatts.

The turbine equipment to insure a continuous base load of 70,000 kilowatts, will of necessity, be quite a bit larger than the actual 70,000. It will have to be so arranged that should any one unit have to be shut down, the remaining units will be capable of carrying the base load. It is considered the best practice by leading engineers to use units of about 30,000 kilowatts in plants of this nature; therefore, the writer would advise that two 30,000 kilowatt and one of 15,000 be installed to carry the base load and auxiliaries. Then as a spare unit, another one of 30,000 kilowatts. This last will replace any unit that may have to be shut down, and in times of high water, the peak load of the plant can be run up to 105,000 kilowatts.

The boiler equipment of the plant must be such that the plant can be run at full capacity when desired. This would require that enough steam be generated under the conditions assumed on Page 16, to supply the four turbines under a total load of 105,000 kilowatts. At the water rate of eleven pounds per kilowatt hour this requires:

$$105,000 \times 11 = 1,155,000 \text{ pounds of water converted into steam.}$$

A Assuming that the water enters the boilers from the feedwater heaters at 210°F., 32.79 pounds of water per hour is equivalent to one boiler horse power. (Taken from Babcock and Wilcox tables.) Therefore:

$$\frac{1,155,000}{32.79} = 35,000 = \text{Boiler horse power required.}$$

It is considered good practice to operate boilers under this type of load at 200 percent rating; therefore, the rated boiler horse power required equals:

$$\frac{35,000}{2.00} = 17,500$$

This capacity may be divided into any number of standard size boilers with about equal first cost and efficiency; the writer, however, would recommend that fourteen 1250 horse power boilers be installed. This, when all boilers are in operation, would carry the peak load at 200 per cent rating, and with one boiler out of operation it would carry it at 463 per cent, which is not unusual for peak loads, and the plant will seldom operate at the full peak load for which the calculations have been made. If desired, however, there might be installed another boiler as a lay-by boiler, making a total of fifteen 1250 horse power boilers.

APPENDIX "A"

Discharge of the Emory River at Harriman, Tennessee.

As there was no available discharge data for the Emory River at Harriman, and only for five and one-half years at any point on the river, the discharge, except for the five and one-half years, was obtained by means of a comparative hydrograph with the Clinch River at Clinton, Tennessee. The transformation ratio being worked out from the discharge of the two rivers from the known years and the drainage areas. All the data was gotten from the Tennessee Geological Bulletin Number 34, and prints obtained from the United States Geological Survey, except the drainage area of the Emory River at Harriman. This was obtained by planimetering the area between Deermont and Harriman on a United States Geological Survey topographic reconnaissance map, and adding it to the area at Deermont as given in Bulletin Number 34. That for the five known years was gotten by multiplying the discharge per square mile of drainage area at Deermont by the total drainage area at Harriman.

The data and calculations are as follows:

Drainage area at Deermont, Tennessee	702 Sq.Mi.
Drainage area between Deermont & Harriman	92 Sq.Mi.
Drainage area at Harriman, Tennessee.	794 Sq.Mi.

Drainage area of the Clinch River at Clinton is 3090. Sq.Mi.

$$\begin{array}{l} \text{The ratio of Emory drainage area to the Clinch} \\ \text{drainage area} = \end{array} \quad \frac{794}{3090} = 0.257$$

<u>Clinch River</u>		<u>Emory River</u>	
Year	Mean yearly discharge in sec. ft. per sq.mi.	Year	Mean yearly discharge in sec. ft. per sq.mi.
1920-21	1.33	1920-21	1.58
1920-22	1.89	1921-22	2.51
1922-23	1.85	1922-23	2.25
1923-24	<u>1.60</u>	1923-24	<u>1.67</u>
	6.67		8.01
Mean for 1920-24 = $\frac{6.67}{4} = 1.67$		Mean for known period = $\frac{8.01}{4} = 2.00$	
The ratio of the Emory discharge, sec.ft. per sq. mi.. to the Clinch discharge, sec. ft. per sq.mi. =		$\frac{2.00}{1.67} = 1.197$	
Transformation ratio = $0.257 \times 1.197 = 0.308$			

The Mean Monthly Discharge

Month	Clinch River 1903-04	Emory River 1903-04	Clinch River 1904-05	Emory River 1904-05
Oct.	390	121.	331	102.
Nov.	855	263.	528	163.
Dec.	1680	518.	3410	1050.
Jan.	2600	801.	4840	1490.
Feb.	3000	924.	8910	2744.
Mar.	7780	240.	6250	1925.
Apr.	2720	837.	3430	1057.0
May	2990	920.	5480	1689.0
June	2070	638.	1500	462.0
July	2510	773.	1870	576.
Aug.	1170	360.	2190	674.
Sept.	624	192.	1240	384.

Mean Yearly Discharge

549.

1026.

	1905-06	1905-06	1906-07	1906-07
Oct.	1190	366	3410	1050
Nov.	702	216	7430	2290
Dec.	4100	1263	4990	1537
Jan.	6540	2013	5910	1820
Feb.	3290	1013	5620	1730
Mar.	4940	1520	10500	3233
Apr.	5410	1665	6820	2100
May	3130	964	4790	1475
June	1250	385	9490	2923
July	2610	804	2070	638
Aug.	5000	1540	2320	714
Sept.	3120	961	2830	871

Mean Yearly Discharge

1059

1698

	1907-08	1907-08
Oct.	1070	330
Nov.	7870	2428
Dec.	4250	1310
Jan.	8490	2614
Feb.	9410	2900
Mar.	9510	2930
April	7460	2298
May	3860	1188
June	2290	706
July	1560	480
Aug.	1470	453
Sept.	1280	394

Mean Yearly Discharge

1503

Month	Clinch River 1908-09	Emory River 1908-09	Clinch River 1909-10	Emory River 1909-10
Oct.	613	189	625	192
Nov.	1190	366	470	145
Dec.	5470	1685	1010	311
Jan.	7250	2232	5290	1630
Feb.	10700	3298	5190	1600
March	11500	3540	4160	1282
April	5270	1624	3250	1000
May	7650	2356	5760	1775
June	6840	2106	3540	1090
July	6660	2050	4370	1346
Aug.	4200	1294	2050	631
Sept.	836	257	2410	742

Mean Yearly discharge

1551.

979

	1910-11	1910-11	1911-12	1911-12
Oct.	496	1528	2560	789
Nov.	282	87	2780	856
Dec.	2240	690	4980	1535
Jan.	7590	2338	5850	1800
Feb.	10700	3300	7880	2428
March	82100	2526	14700	4528
April	13000	4007	15300	4720
May	4370	1346	7730	2380
June	949	292	2230	687
July	1040	320	2740	844
Aug.	738	227	2670	823
Sept.	731	225	1650	508

Mean Yearly Discharge

1470

1825

	1912-13	1912-13	1913-14	1913-14
Oct.	950	293	897	276
Nov.	1000	308	1340	413
Dec.	3590	1105	2390	736
Jan.	17000	5240	2700	832
Feb.	6420	1976	5760	1773
March	14800	4560	5880	1810
April	3990	1230	12400	3820
May	4480	1380	2940	906
June	3410	1050	1060	327
July	1350	416	911	281
Aug.	1170	361	2080	641
Sept.	682	210	1190	367

Mean Yearly Discharge

1511

1015

Month	Clinch River 1914-15	Emory River 1914-15	Clinch River 1915-16	Emory River 1915-16
Oct.	1620	499	5140	1584
Nov.	725	223	5100	1571
Dec.	6960	2143	11700	3604
Jan.	10800	3327	13400	4127
Feb.	7420	2287	8280	2550
March	3860	1189	6510	2005
April	22530	779	5150	1586
May	2430	748	2000	616
June	3170	976	3340	1028
July	5370	1654	4880	1503
Aug.	2790	859	5960	1835
Sept.	2320	715	1240	382
Mean Yearly Discharge		1283.		1866.
	1916-17	1916-17	1917-18	1917-18
Oct.	1380	425	1530	471
Nov.	1030	317	1160	357
Dec.	4820	1485	1210	373
Jan.	14900	4590	12000	3700
Feb.	11500	3542	8870	2732
March	27000	8320	5250	1617
April	5750	1771	7220	2224
May	2160	666	4650	1433
June	2050	631	2100	648
July	3850	1186	1960	604
Aug.	3060	943	1450	446
Sept.	1890	582	1980	610
Mean Yearly Discharge		2038		1268
	1918-19	1918-19	1919-20	1919-20
Oct.	1930	595	3350	1032
Nov.	4760	1467	3160	973
Dec.	5890	1815	8000	2464
Jan.	11800	3636	8360	2576
Feb.	4550	1402	9180	2830
March	8180	2520	13200	4066
April	3740	1152	10000	3080
May	6980	2150	3180	980
June	2680	826	5000	1540
July	1190	367	2250	694
Aug.	990	305		
Sept.	493	152		
Mean Yearly Discharge		1366.		

Actual Discharge of the Emory River

Month	Discharge No.Mi.	Mean Discharge	Discharge No.Mi.	Mean Discharge
	1920	1920-		
Aug.	4.53	3600.0		
Sept.	1.50	1191.0		
Mean Yearly Discharge		2086.0		

80.5

Month	1920-21	1920-21	1921-22	1921-22
Oct.	0.114	8.05		
Nov.	0.215	170.8	0.081	64.4
Dec.	3.33	2645.0	1.51	1200.0
Jan.	2.85	2263.0	1.87	1485.0
Feb.	4.99	3963.0	3.59	2850.0
Mar.	2.36	1875.0	3.53	2803.0
April	3.05	2423.0	7.01	5565.0
May	0.830	659.5	6.28	4989.0
June	0.133	105.7	2.34	1860.0
July	0.766	608.5	1.98	1572.0
Aug.	0.430	341.5	0.809	642.5
Sept.	0.214	170.0	0.944	750.0
Oct.			0.311	247.0
Mean Yearly Discharge		1275.5		2002.3

Month	1922-23	1922-23	1923-24	1923-24
Oct.	0.035	27.9	0.014	11.1
Nov.	0.105	83.4	0.046	36.5
Dec.	3.82	3031.0	1.81	1436.0
Jan.	3.35	2660.0	3.97	3150.0
Feb.	6.35	5040.0	3.93	3120.0
March	5.70	4525.0	2.79	2215.0
April	2.46	1954.0	2.92	2319.0
May	3.08	2447.0	3.52	2795.0
June	1.01	802.0	0.667	530.0
July	0.413	328.0	0.205	162.9
Aug.	0.722	577.0	0.106	84.2
Sept.	0.128	101.7	0.097	77.0
Mean Yearly Discharge		1798.1		1328.0

Month	1924-25	1924-25	1925-	1925-
Oct.	0.058	46.2	1.72	1366.0
Nov.	0.017	13.5	3.18	2523.0
Dec.	1.580	1255.0	1.72	1366.0
Jan.	4.100	3258.0		
Feb.	3.320	2638.0		

Month	1924-25	1924-25	1925-	1925
March	1.090	866.0		
April	1.920	1525.0		
May	1.090	866.0		
June	0.051	40.5		
July	0.058	46.0		
Aug.	0.0091	7.23		
Sept.	0.0064	5.08		
Mean Yearly Discharge		880.54		

Mean Discharge for Period 1903-1925 1435.29 Sec.Ft.

APPENDIX "B"

Atmospheric Conditions at Harriman, Tennessee.

There is no United States Weather Bureau at Harriman, Tennessee, so there was no means of getting accurate data on atmospheric conditions there. Knoxville is only fifty miles distant, however, and Mr. J.I. Widmeyer of the Bureau at Knoxville told the writer that he would be perfectly safe in assuming that the mean atmospheric conditions at Harriman are the same as those at Knoxville; so all the following data is really that observed in Knoxville, but it will be assumed to be true for Harriman:

Mean Temperatures for
each month for the per-
iod 1855-1922- Degrees
Fahrenheit.

Mean relative Humidity
for each month for the
period 1888-1910

Jan.	38.4	77
Feb.	41.9	72
Mar.	48.7	70
Apr.	58.0	65
May	67.2	70
June	74.0	75
July	77.1	76
Aug.	76.2	79
Sept.	70.6	77
Oct.	59.9	75
Nov.	47.9	74
Dec.	40.3	77
Mean for Period	58.4	74

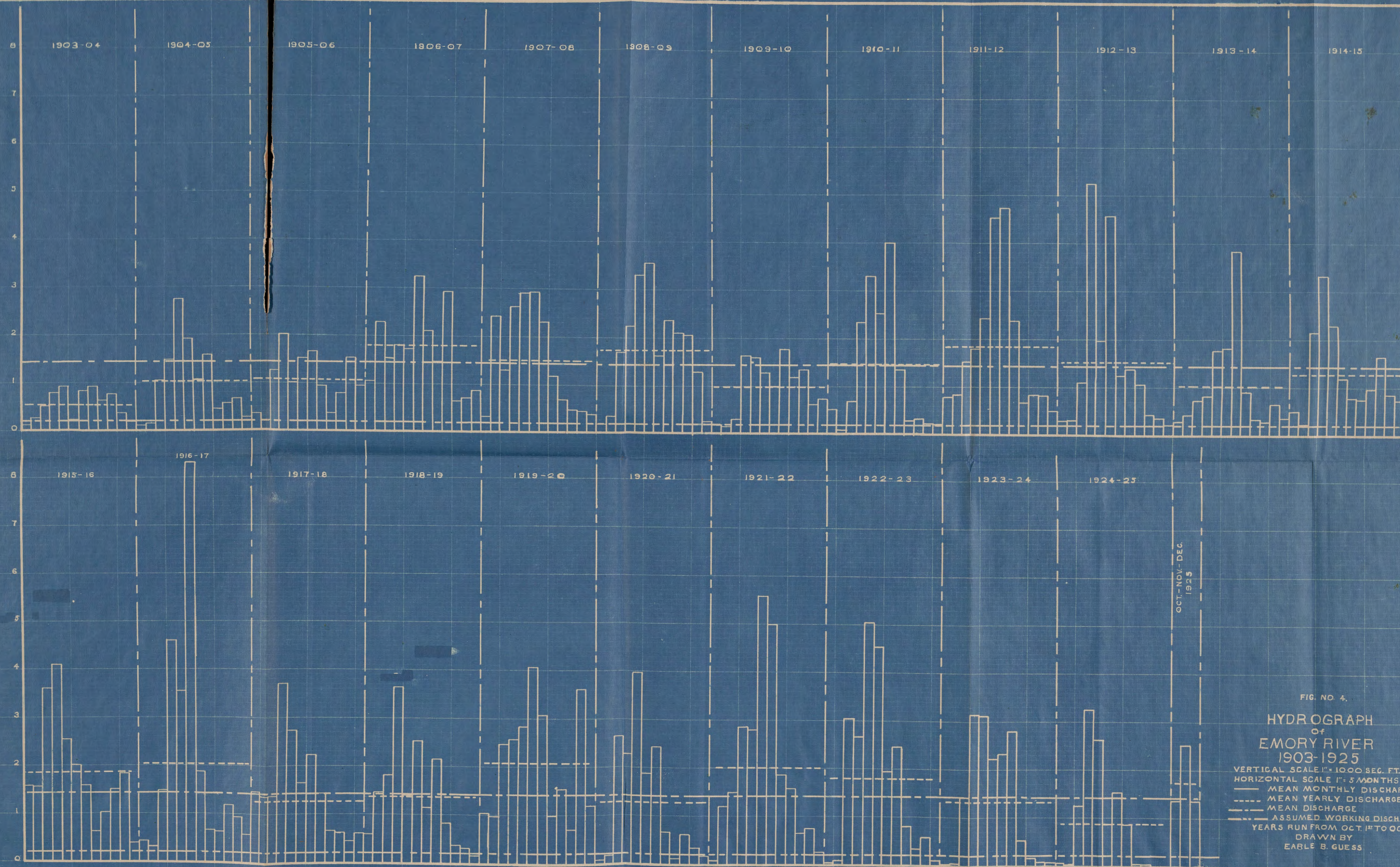


FIG. NO. 4.
 HYDROGRAPH
 of
 EMORY RIVER
 1903-1925
 VERTICAL SCALE 1" = 1000 CUB. FT.
 HORIZONTAL SCALE 1" = 5 MONTHS
 ——— MEAN MONTHLY DISCHARGE
 - - - MEAN YEARLY DISCHARGE
 . . . MEAN DISCHARGE
 - - - ASSUMED WORKING DISCHARGE
 YEARS RUN FROM OCT. 1ST TO OCT. 1ST
 DRAWN BY
 EARLE S. GUESS

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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