HAMMERMILL BOND

THESIS

"A PRELIMINARY INVESTIGATION OF A POWER SITE ON THE TENNESSEE RIVER NEAR KNOXVILLE"

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and

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Under

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An investigation along this line is commonly made by a number of experts, each familiar with the particular work entrusted to him. All such investigations, to be of full value, should be made under the direction of some one able to fully appreciate the necessary extent and character of such investigations, and to correlate and determine the influences of various factors and their mutual relations. The investigations necessary for a full understanding of the project and the procedures which should be followed, may be summarized in essentially their logical order as follows:

First: The determination of the market and the probable nature and distribution of the load. The present cost of power and the price at which power can be sold.

Second: The water supply and its variations. The possibilities of pondage and storage and the necessity and cost of auxiliary power.

Third: The physical character of the power site. The foundations, the plant payout, the resultant head, the local materials of construction, and the extent of the necessary transmission

to convey the power of its market.

Fourth: The preliminary estimate of cost. This should be made very liberal and should contain estimates for contingencies amply sufficient to meet such uncertainties as are involved in the project.

Fifth: The legal rights, including riparian rights, flowage and reservoir rights; permits and franchises; rights-of-way for transmission; rights of condemnation; and the extent and influences of state and federal control on both project and prices.

Sixth: The methods and cost of financing the project, and the feasibility of floating the necessary stock and securities.

Seventh: A report on the project covering a full and complete consideration of Items I to 6 and their relations to one another.

Eigth: The design of the plant, and the structures necessary for storage and control of waters.

Ninth: The construction.

Tenth: Operation and maintenance.

In this Preliminary Investigation for a Power Site on the Tennessee River above Knoxville, it was found that time would not permit for a thorough examination of all of the details necessary for a complete report on such a project. The investigation is wholly concerned with the physical character while further investigation will have to be made as to the determination of the market and the probable distribution of the load; legal rights and the means of financing. The distance which a dam on the Tennessee would

back water was so great that it was impossible for two men to completely survey in such a short time and also get together the necessary data of stream flow and make all of the computations for a complete report of a large power plant. This survey was only made possible by the use of the U. S. G. S. maps and some profiles and maps of the Holston and French Broad Rivers plotted in 1899 and 1900 by Major Dan Kingman of the U. S. Engineers. The rainfall and flow of the river was obtained from data of the U. S. G. S. showing the discharge of the river at the gauging station at Knoxville.

The Location

A reconnaissance survey of the Tennessee River was made from the County Bridge at Knoxville to the junction of the French Broad and the Holston about four miles above the bridge. The Tennessee Marble crosses the river at two places in this distance but neither place was in any way suitable for a dam site. A dam at a point above the bridge would overflow the car tracks of the Knoxville Railway and Light Company and also flood considerable property, including several manufacturers and the Island Home Farm. Gaps in the hills above this point would also allow the water to pass out over a large section of country probably circling down on parts of Knoxville. Further investigation was not made of this site.

A point three quarters of a mile below the junction of the rivers, at first sight, appeared to be an excellent location for a dam. One side of the river was bordered by a high cliff nearly a hundred feet in height with almost vertical walls. A

gradual slope on the other side showed a ten percent rise from the river banks to an elevation of about sixty feet above the river.

Upon examination of the cliff it was found to be of Tellico Sandstone which is very hard, the nose of the cliff at a point where a dam could be built shows that it has stood the river in flood stage almost without wear for several years. The dip of the stratum is impervious and is an excellent rock for making water tight connections with the dam which is essential and one of the principles of dam construction.

This site seemed to be the only place at which an economical dam could be built so a survey was begun at once with this location in view. It was decided that an investigation of three dams, twenty, twenty-five, and thirty feet in height would be made. Thirty feet was the limiting heighth since the slope of the river was so gradual that it did not seem profitable to build a dam any higher due to the rich country that would be flooded. A dam forty feet in height would flood several marble quarries, a marble mill, and a lime kiln almost at the immediate site of the dam. It is possible that walls could be built to protect the properties but our investigation was limited to a dam thirty feet in height.

Geology of the Section.

The country through which the French Broad and the Holston Rivers flow is about the same. The topographical features are very rugged and rocky. Both rivers, as shown on the map, wind their way down to the Tennessee River in very much the same way and the bends are almost identical. The French Broad is the larger river of the

two although at first glance they look to be about the same size. The slope of the rivers are about the same both falling thirty feet in a little over fourteen miles. This shows that the level of the country is about the same and the formations through which they pass are of about the same resistance to erosion.

This country is in the middle stage of the cycle of erosion or the stage of maturity. This is shown by the way in which the hills are cut and are being eroded, hardly any level lands are to be found along the course. The bending of the stream and the many small shoals are indicative that this section is in the stage of maturity.

The marble formations are the most prominent of this section. Lime stone covers the entire area as shown by the many sink holes and hollows that are to be seen. This is a very poor country in which to build a dam due to these formations. In a country of this kind one would expect to find many underground caverns, crevices, and strams through which the water would flow if obstructed by a dam. Experience shows that it is risky to build a dam in a country where so many sinks occur. There is no sure way in which all of these sinks and their depth can be determined. Observations after a very heavy rainfall will help in deciding the magnitude of such a sink by observing the rapidity with which the water disappears in the sinks.

The Survey.

We had very little material with which to begin such an extensive investigation. A Government map of the territory was available but since it was plotted on 100 ft. contours it was of

little value to us. This map plotted before 1900 and by close observation we discovered that it was incorrect so it was practically of no value whatever.

We started out to run in all of our lines from the dam site taking the elevations and contours as we went. The topography of the country was such that we had to go up three small valleys before we had advanced any considerable distance up the river. An effort was made to get elevations up the rivers but no elevations were to be had. We did not know just how far up the rivers we would have to go, and surveying through woods and over hills and cliffs was a slow process. After we had gone some distance up the French Broad we found a map in Professor Switzer's office showing the profile of both rivers, just what we needed. These maps were made by Major Dan Kingman of the U. S. Engineers in 1899 and 1900 and enough points were plotted on the river to be reliable and for sufficient use in a preliminary investigation.

The profiles showed that a dam thirty feet high would back water 14.75 miles up the French Broad and 14.5 miles up the Holston. This caused us to abandon the continuation of a stadia survey over the entire area for the whole course covered 30 miles. It would take a party of engineers several weeks to complete a survey of both banks of the rivers, a course of some sixty miles, through all kinds of obstructions such as large bluffs, hills, and wooded areas. We had to limit our survey to an accurate survey near the dam site showing five foot contours of the valleys and streams which would be affected by any of the dams. The remainder of the investigation of the flooded area was made by means of the hand

level, pace scale, and the Kingman maps. We were able to locate ourselves on any point of the river and by taking the elevation of approximate low water shown on the profile we could determine the thirty, twenty-five and twenty foot contours with a hand level in the field, and place them on an enlarged map. Of course this necessarily allowed for a certain error but in some ways it would be compensating. Contours were plotted at intervals of five feet showing the flooded area of a twenty, twenty-five, and thirty foot dam respectively with an allowable flood stage of five feet over the dam. The flood stage of the river now as shown by the leaves and cornstalks in the trees is several feet over this but with a long spilway it is not likely that it will exceed this although the dam was designed for a crest of ten feet flood stage. A more thorough investigation might show that it would be necessary to include floodgates in the design of the dam.

Flood Area.

A dam twenty feet high backs water up the Holston River 10.6 miles covering 430 acres, and 9.5 miles up the French Broad covering an area of 538 acres making a total of 966 acres. The net area flooded after the area of the river has been deducted is 233 acres.

The back water of a twenty-five foot dam will end at a distance of 12 miles up the Holston covering an area of 616 acres, and 12.25 miles up the French Broad covering an area of 985 acres totaling 1601 acres. The net area flooded is 708 acres.

A thirty foot dam will back water to a point 14.5 miles up the Holston covering an area of 815 acres, while the French

Broad backs water 14.75 miles up covering an area of 1240 acres totalling 2055 acres, the net area of which is 1011 acres.

Most of the flooded area is good rich land but as there is some along the banks which is rocky and wooded, a close estimate of the average cost of the flooded land is $100 per acre. The figures below show the flooded area and the cost of the land.

Height of dam	Flooded area	Cost at $100 per acre
20	233	$23,300
25	708	70,800
30	1011	101,000

A curve is drawn showing the increase of the flooded area with an increase in the heighth of the dam.

A portion of the highway is flooded and a survey of a probable route and the changed distance will have to be made before an estimate of the cost of flooding this road can be made. Part of the road at Huffaker's Ferry is flooded but this right could probably be bought for $5,000 from the county as a bridge is located a few hundred yards above the ferry and the change could be made very easily.

The marble mills, a lime kiln and a marble quarry would be flooded in a high flood stage by a dam thirty feet high and damage of this will have to be computed before the actual cost of the flooded area can be ascertained. The tracks to the marble mills are on an elevation just above the thirty foot contour and they would also be flooded, by high water. It is possible to change the road to a level higher up with a slight increase in grade which would not effect greatly the load to be carried as the track is only a spur to the mill and no very heavy loads are carried over this particular portion of the track. However, a detailed investi-

gation will have to be made before this cost can be obtained.

Four small houses at the dam site and two more near the road would have to be bought. These houses are not worth more than $4000.

Cross Section at Dam Site.

In order to determine approximately the volume of concrete in a dam it was necessary to make a cross section of the river at the dam site. Soundings were taken at places in the river, the distance from the shore being determined by transit on the bank sighting on a standia rod in the boat. Elevations were taken along the slope up the bank so that the entire cross section of the dam site could be had. We could not ascertain just how far down the sand-stone stratum ran but in all probability a good rock formation may be found underneath the stream. This is evident from the geology of the section. The outcrop of rocks on the hillside shows that a stratum of rock extended across the river at one time and the cross section of the stream bears this out, the shape being worn as though cut in rock.

This information is not at all sufficient for the construction of a dam at this site. No reputable engineer builds a dam on any stream without first having explored the foundation by core drills and making sure that his foundation is impervious. The upward pressure caused by impervious stratum will wreck dams. A drill should never operate through a pervious stratum.

THE HYDROGRAPH.

The quantity of water flowing in a stream at any time, which is more briefly termed "stream flow" or "run-off", depends primarily on the rainfall. On account of the great variation in the stream flow, the data are best studied in graphical form. The accompanying hydrograph is such a curve, the flow in cubic feet per second at Knoxville being plotted as ordinates against time as abscissas. The data used in the making of these curves were obtained from bulletins issued by the United States Geological Survey for the years plotted. The rating curves were gotten from the same source.

"In order to fully appreciate the power value of the stream, the character and extent of it's daily fluctuations must be known or estimated. Averages for the year, monthly averages and estimates for the average power have ordinarily been taken as a basis for power estimates but they are more or less misleading, unsatisfactory and uncertain, for the reason that such averages include extremes, the maximum of which are often unavailable for water power purposes without more extensive storage than is ordinarily available. The maximum and minimum flow which affect the power of the stream not only through the quantity flowing, but also through the head as well, are of the utmost importance for a broad consideration of a water power developement. So also is the knowledge of the various stages of the flow, and the lenght of time that each will prevail. Such knowledge demands daily observations or estimates of daily flow, which can be present-

ed best by the hydrograph." (Mead Page 140)

The gauge was established at Knoxville in 1900 but we could get no data before Jan. 1, 1902. The observations were discontinued Dec. 31, 1911 on account of dredging operations which so affected the cross-section of the river that the rating curves could not be depended upon. This leaves us a ten year period to observe, containing the year 1904, said to be the driest year in a long period.

While this gauge was not actually at the dam site, it is on the Tennessee river four miles below the site and no streams of any consequence enter the river between the gauge and the site. This being the case the accompanying hydrograph is the actual not the comparative hydrograph. Thus we have an actual hydrograph to study, plotted rom reliable data from the United States Geological Survey.

The Relation of Stream Flow and Storage to Power Developed.

The hydrograph which has been presented before shows the stream flow day by day. This discharge hydrograph may be converted into a power hydrograph by merely changing the coordinates. Various elements must be considered in determining the scale of this power hydrograph and the scale will be different for each height of dam considered, 20 foot, 25 foot and 30 foot. The formula for horse power being -

$$H.P. = \frac{Q\ H\ e}{8.8}$$

the scale may be calculated. We have Q from the discharge hydrograph. H is the head on the plant.

In considering the head on the plant it must be remembered that the proposed development is of comparatively low head on a stream in which the flow is at times very large, reaching at infrequent intervals, discharges as high as 100,000 second feet. In power developments under low heads, the fluctuation in head has almost or quite as much influence on the continuous power that can be economically developed from a stream as the minimum flow itself.

"The hydraulic gradient of a stream varies with the quantity of water flowing. At times of low water the fall available in almost every portion of its course is greater than is necessary to assume the flow between given points and frequent rapids result which are commonly the basis for water power developments. As the flow increases, however, a higher gradient and greater

stream section is necessary in order to pass the greater quantity of water, and the rapids and small falls gradually become obscured or disappear entirely under larger flows. Water power dams concentrate the fall of the river that is unnecessary to produce flow during conditions of low and moderate water, and when the gradient of the water surface and the cross-section of the stream are increased to accommodate the larger flow, the fall at such dams is frequently greatly reduced."(Meade page 186) This is based on the assumption that the cross-section of the river is practically the same above the dam as below. As a matter of fact, the cross-section below our proposed dam site widens out considerably, the river being a little short of 500 feet wide at the site and widening out almost immediately to 1000 feet or more as it passes through the city of Knoxville. There are also many rapids below the dam, thus showing that the fall of the river is steep enough to take care of the water below the dam.

This rapid run-off of tail water would be a very great advantage because in keeping tail water low during times of large flow, the effect of loosing head in flood times as has just been spoken of, will be avoided to a great extent.

To proceed with our calculations, however, average heads must be estimated. The fact that the entire fall of the dam may not be obtained due to the design of the dam, must also be taken into account, so the following heads were taken. With a 30 foot dam and a 20 foot intake, 27 feet; with a 25 foot dam and

a 20 foot intake, 22 feet; and with a 20 foot dam and a 15 foot intake, 17 feet.

The value of e will vary according to the design of the installation but we based our calculations on figures from good engineering practice. The following figures were obtained from Prof. J. A. Switzer as a conservative estimate of the efficiencies to be expected in the various parts of the installation:

Turbines 91 per cent

Generators 93 per cent.

Transformers 97 per cent

Transmission 97 per cent.

It might be explained right here that as the dam site is almost within the limits of the city of Knoxville, the transmission line will necessarily be short. We estimate that a three mile line will be ample to reach the power house of the Knoxville Railway and Light Company.

Combining the above efficiencies we get an efficiency of practically 80 percent. Hence, taking these figures we may calculate the horsepower of 10,000 second feet for each dam.

Height of dam.	Intake	Average head.	H.P. of 10,000 second feet.
30 foot	20	27	24,600
25 foot	20	22	20,000
20 foot	17	17	15,500

To investigate the possibilities of 30 ft, 26 ft and 20 ft dams, the survey was made and from it we have the 20 foot, 25 foot and 30 foot contour lines based on average water level

(the gauge reading 4 feet on the Gay Street bridge at Knoxville, three miles below the site of the dam). Knowing these, the river was divided up into 1000 feet sections, then end areas were calculated and the volume of water that would be stored between 25 and 20 feet, should a dam of 25 foot be constructed, and also between 20 and 30 feet should the 30 foot dam be constructed. The summation of all of these volumes then gave the total storage between the 30 foot and 20 foot levels and of the lower half gives the storage between the 25 and 20 foot levels. This former, it will be seen, is the exact amount of storage that can be drawn down from a 30 foot dam with the intake placed at the 20 foot level and the latter will be the storage which can be drawn down from a 25 foot dam with the intake at 20 feet. These intakes were assumed for the purposes of calculation and are values very near those which would be used in actual constinction. The area of the river in its present bed was calculated so that the amount of land flooded by each dam could be gotten and from this the drawdown of a 20 foot dam with a 15 foot intake was estimated. These calculations are tabulated in Table 1 and the results are

Height of dam	30 ft	25 ft	+20 ft + - (estimated)
Storage on French Broad acre ft	9090	3807.5	600
Storage on Holston acre feet	6427.5	2615.	400
Total Storage. acre feet	15,512.5	6427.5	1000

To see just what best use of the storage could be made a mass diagram is suggested by Rippl (page 172 Meade. Water Power Engineering) was worked up from the hydrograph to study the conditions. During the period under observation 1902-1912, the

observed flow of the stream for each month was taken and the summation of these monthly flows, added one to the other, consecutively, were plotted in the mass curve in which the abscessa of each point represents the total time from the beginning of the period; and the ordinate, the total quantity of water available during the same interval.

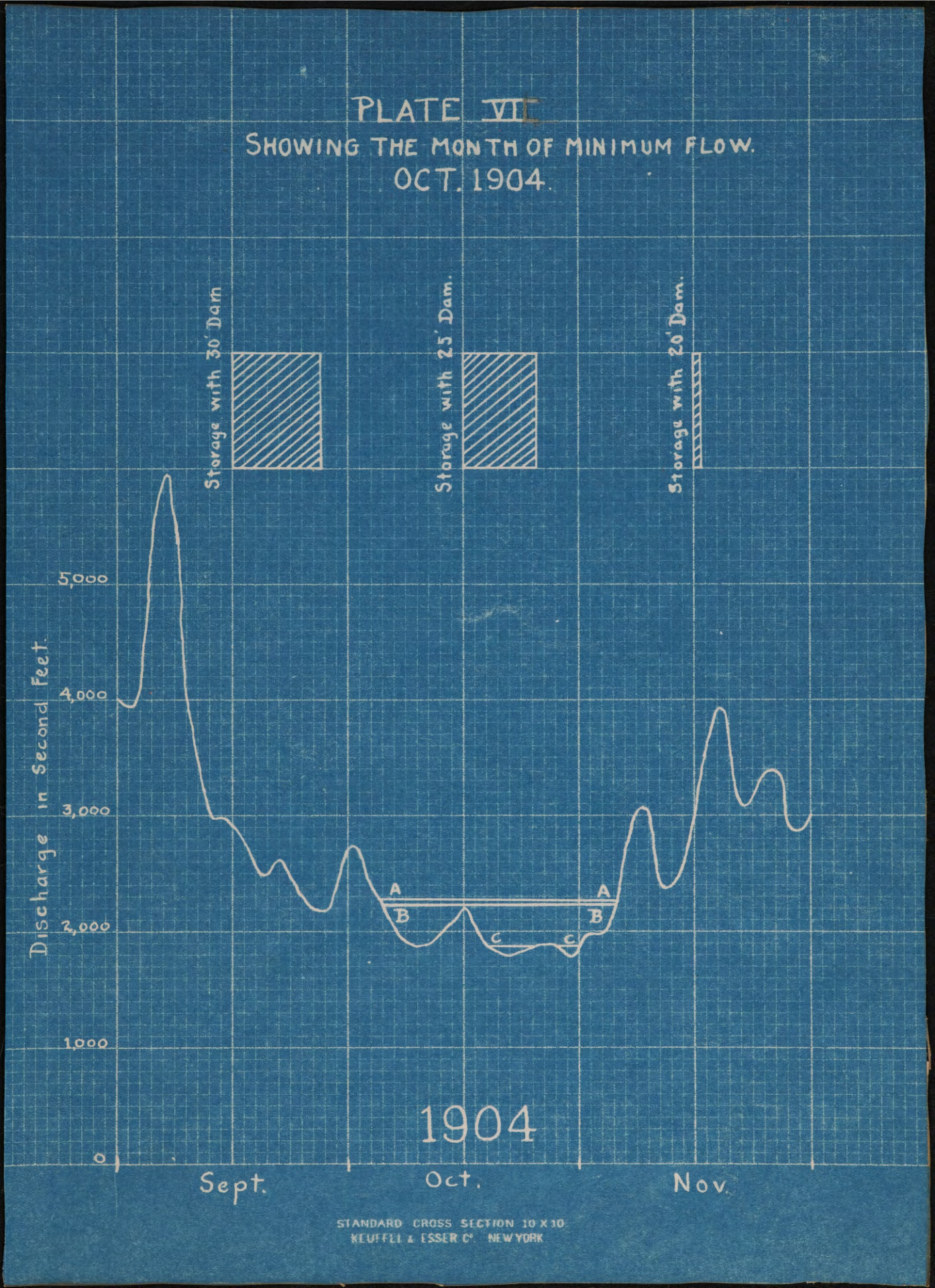
In a similar manner the curve of consumption can be plotted. For most purposes this can be considered a straight line as the variation in the use of power from season to season is a refinement not usually warranted, unless the uses to which power is to be put at various times of the year is well established. The ordinate between the supply and any demand line then represents the total surplus from the beginning of the period considered, and when the inclination of the supply line is less than that of the demand line, the yield of the drainage area is less than the demand and a reservoir is necessary.

As our heights of dams were limited by valuable lands, marble quarries, railroads and highways, we found that our storage was so small as compared with the runoff of the stream that the Rippl method of calculation could not be used. Our storage plotted to such a scale could not be seen. However we can study our storage and power that can be developed with the storage and without auxiliary power during the dryest period of our observation, September, October and November of 1904. Plate VII. is the hydrograph of these months plotted to a larger scale.

PLATE VII

SHOWING THE MONTH OF MINIMUM FLOW.

OCT. 1904.



STANDARD CROSS SECTION 10 X 10
KEUFFEL & ESSER Co. NEW YORK

On it also are blocks which represent the storage obtainable with various dams. These storages are used to fill in the valleys of the dry season as shown and by using this storage during these months the guaranteed, or rather the very probable, minimum flow is thereby raised. By reference to Plate VI it will be seen that, without storage, the minimum flow will be 1800 second feet. However when the storage which would be had with a 30 foot dam is taken into account the flow line will be raised to 2310 second feet, line AA on the plate VI . Thus is water added when it will count most.

Taking into account the storage behind a 25 foot dam as seen by line BB on plate VI, the flow line under these conditions can be raised to 2250 second feet by the storage thus afforded. The storage behind the 20 foot dam is very small, but it is enough as seen by line CC to raise the line to 1900 second feet. Thus we have the flow that can be utilized at all times for power purposes and therefore the power the installations could be counted on to develop continuously 24 hours a day, 365 days in the year.

Height of dam.	Flow.	Horse Power
30'	2310	5628
25'	2250	4500
20'	1900	2945

By further reference to the hydrographs it will be seen that during this ten year period only four times does the flow of

river become as low as this and then never for any length of time. At other times the flow may go as high as 100,000 second feet or may hold a flow of over 10,000 second feet for a long period. It would be a violation of all laws of conservation, as Prof. J. A. Switzer points out in his address before the American Electrochemical Society, to base the capacity of the development on the absolute minimum stream flow. "But," he goes on to say, "the selection of the proper value for Q is a matter of no little difficulty..... The value of Q proper to rise in any case is a function of many variables. Are we 'conservative' only if we base our calculations on the absolute minimum flow? Or shall we use 'the mean monthly minimum for the average year'. Or again (as is customary with the United States Geological Survey in making estimates of water power), the minimum flow for the six high water months? The answer depends on many considerations on the probable load factor of the plant, on the cost of coal (and so of auxiliary stream power), on the amount of storage at the proposed plant, on the amount of storage at other and tributary developments, on the ratio between the cost of dam and cost of generating equipment, and on other factors which no doubt suggest themselves....."

It is obvious that inasmuch as this thesis deals with the survey of the would-be flooded areas or the French Broad and Holston rivers, too much time cannot be given to the weighing of these different factors. It must be remembered, however, that this project is located in the heart of a coal mining region, that there is much possibility of additional storage obtained by the building of other dams higher up on

both rivers and that the cost of a dam at this point would in all probability be very reasonable. In weighing these factors, it was decided that the best value of Q to take would be the one used by the United States Geological Survey "the minimum flow for the six highwater months". These six months were taken as the period from February 10 to August 10,1906. The minimum flow during this period was 8,000 second feet. The flow of 8,000 second feet being the capacity of our plant auxiliary power must be furnished during times of deficient flow. The table below shows the capacity of the plants at the three given heads and the capacity of the auxiliary power in order that the plant might be furnishing its customers all the time.

Height of dam.	Capacity of Plant.	Necessary Capacity of Auxiliary.
30'	19,680	14,022
25'	16,000	11,500
20'	12,400	9,455

In arranging for this auxiliary power it might be well to study just how much it is to be used. It might be said at the beginning based on the accompanying hydrograph, the auxiliary would have been called on for its full capacity only four times in the ten years. Below is given the data showing how much of the ten year period under observation the plant would have been actually operating, most of the time with a low output and occasionally at full capacity.

Length of Time the Proposed Auxiliary Would Operate.

(Based on the ten years of hydrograph)

	Date	Total time for year.	Percent of year
1902	July 18 - Nov.24	126	34.6
1903	Aug. 8 - Dec. 31	142	39.0
1904	Jan. 1 - 22		
	Jan. 27 - Feb. 8		
	Feb. 13 - 21		
	June 6 - 28		
	July 13 - Dec. 28	229	62.2
1905	Sept. 1 - Dec. 2	92	25.2
1907	Oct. 9 - Nov. 10	32	8.8
1908	Sept. 9 - Oct. 24	45	12.3
1909	Aug. 22 - Dec. 31	128	35.2
1910	Jan. 1 - 6		
	Mar. 17 - Apr. 17		
	Sept. 14 - Dec. 31	142	39.0
1911	May 18 - Dec. 22	200	54.9

Percent of ten years 31.3

By the average we see that the plant would only be operating for 31.3 percent of the time and at full capacity only 57 days in ten years or 1.5 percent of the time. These figures assume a unity load factor.

To save money, we would suggest that if possible, a company, such as an electro-chemical company, be induced to establish a plant near-by so that the auxiliary plant could be used to furnish power to it when it is not supporting the hydroelectric power. The electro-chemical company could use this secondary power and shut down in case the entire auxiliary capacity is

required for the installation.

It will be seen, therefore, that these dams investigated, under the conditions we specify, would develop 19,680 horsepower, 16,000 horsepower, and 12,400 horsepower, respectively, considering the load factor as unity.

As a matter of fact, a market such as Knoxville affords would have a load factor of about 50 percent. The installed capacity of the plant would then be double the amount specified above to take care of the peak load.

Cost of the Dam.

An approximate cost of the different heights of dams for which this investigation was made has been based on the assumption that an impervious rock wou ld be struck within five feet below the bed of the river.

Mead, in discussing the principles of dam construction has the following to say: (Mead's Water Power Engineering, Page 610)

First: They must have suitable foundations to sustain the pressure transmitted through them, which be either impervious or rendered practically so.

Second: They must be stable against overturning.

Third: They must be safe against sliding.

Fourth: They must have sufficient strength to withstand the strains and shocks to which they are subjected.

Fifth: They must be practically watertight.

Sixth: They must hav essentially watertight connections with their bed and banks, and, if the bed and banks are pervious,

with some impervious stratum below the bed and within the banks of the stream.

Seventh: They must be constructed so as to prevent injurious scouring of the bed and banks below them.

Even if solid rock is not to be found at five feet the dam, according to Mead, could be built upon proper pile foundation with the proper cut off precaution.

A solid masonry dam was selected since the raw material is so near at hand. All of the hard stone necessary for the construction of the gravity type day may be had within a radius of a quarter of a mile. The railroad facilities are good for the transporting of all machinery used in construction and for delivering all equipment for the power house. A spur track runs within three hundred yards of the sight on one side and a branch line of the Southern is located about a half mile's distance on the other side of the river.

The construction of a dam with a vertical overfall, unless provision made for the admission of air, will result in the formation of a partial vacuum below the sheet, and a certain extra resultant head due to the same. The vertical overfall is also frequently objectionable, on account of the action of the falling water on the bed of the stream immediately adjacent to the dam, and on the foundation of the dam itself. It is frequently desirable to give the lower face of the dam a curved outline, in order to guide the water smoothly over the dam, and deliver it approximately tangentially to the stream bed.

Mr. Vagman has worked out a number of dams of different heights, of the O. G. type, with the curve of the dam above the parabolic path that the water would make in a free fall with the initial horizontal velocity corresponding to the depth of water on the dam. He has computed the volume of concrete per linear foot in cubic yards of each size of dam. These points fall on a smooth curve plotted between height of the dam and the volume of concrete P. L. F. With this curve it is possible to determine the volume P. L. F. in cubic yards of any size dam within the limit of Mr. Vagman's computations.

The volume of the three dams was taken from the enclosed curve. For example, the 20 ft dam has to be thirty feet high over a section of 70 ft. The 30 ft. mark is located on the diagram and following the parallel line to the curve and then over to the line marked volume, the volume of this dam is found to be 29 cu. yards P.L.F. 70 x 29 = 2,030 cu yds for this section. The other sections are found accordingly and are shown in the following tables:

Volume of solid masonry dams from curve showing volume Per Linear Foot for masonry dams.

Height of 20' Dam.	Length of Section	Volume per linear foot.	Volume of section
30	70	29	2030
40	120	42.5	5100
50	280	58	16230
20	120	17.5	2100
10	40	7.5	300.
			25760 Cubic Yds.

Height of 30' Dam	Length of Section	Volume per linear foot.	Volume of section
40	70	42.5	2975
50	120	58	6860
60	280	77	21550
30	120	29	3480
20	70	17.5	1225
15	50	11.5	575
			36665 Cubic Yds.
Height of 25' Dam			
35	70	36	2520
45	120	51	6120
55	280	67.5	18800
25	120	22.5	2700
15	70	11.5	805
			30945 Cubic Yds.

The cost of the dam was estimated at $18 per cubic yard of concrete. Professor Dougherty said that a dam now would cost about $20 per cubic yard in place but since the raw materials are all at hand on this place and they can be bought cheaply and handled with little cost, it was thought that $18 would be a conservative estimate of the cost.

Costs of dams.

Ht. of Dam.	Volume (cu. yds)	Cost at $18 per cu yd.
20	25,560	$460,000
25	30,940	557,000
30	36,625	660,000

Curves are shown plotted between height of dam and volume of concrete, and between height of dam and cost.

SUMMARY

To sum up then we have the figures of the power developed and the cost of the dams not including the installation of the machinery for the heights of the dams considered.

Height of Dam	Area Flooded	Cost of Flooded area	Power Developed	Cost of Dam.
20'	233 Acres	$ 23300	12400	$ 460,000
25'	708	70800	16000	557,000
30'	1011	101000	19680	660,000

TABLE I

Calculation of Storage between 25ft.-30ft. and 20ft.-25ft. Contours

Sta.	Width 30'	Width 25'	Mean	Vol.	Width 20'	Mean	Vol.
A	704	649	676	124.8	612	630	97.0
B	1600	1400	1500	178.8	1200	1400	137.8
C	1700	1500	1600	203.0	1200	1350	146.0
D	2100	1800	1950	172.0	800	1200	114.8
E	1200	900	1050	123.0	700	800	97.5
1	1200	1000	1100	104.6	800	900	87.2
2	800	650	725	77.0	600	625	68.8
3	650	600	625		550	575	87.7
4	1400	1300	1350	113.1	700	1000	12300
5	1850	1300	1570	169.8	1000	1150	126.1
6	1500	1400	1450	173.1	900	1050	107.3
7	900	850	875	133.1	800	825	74.6
8	600	500	550	87.7	450	475	53.0
9	550	500	525	61.8	400	450	56.0
10	650	600	625	66.2	450	525	57.4
11	700	550	625	71.8	400	475	56.0
12	700	600	650	73.2	400	500	60.1
13	650	600	625	71.8	500	550	58.7
14	600	550	575	68.9	400	475	54.6
15	600	550	575	66.1	400	475	50.2
16	500	450	474	60.4	350	400	47.1
17	350	300	325	45.9	300	300	40.1
18	400	375	387	40.9	350	362	38.1

Sta.	Width 30'	Width 25'	Mean	Vol.	Width 20'	Mean	Vol.
19	400	375	387	44.3	350	362	41.5
20	400	375	387	44.3	350	362	41.5
21	400	375	387	44.3	350	362	41.5
22	400	375	387	44.3	350	362	41.5
23	600	500	550	53.7	450	475	48.2
24	700	500	600	66.1	500	450	55.3
25	800	600	700	74.6	400	550	574
26	600	500	550	71.6	350	425	56.6
27	600	450	525	61.5	350	400	47.3
28	500	450	475	50.0	300	375	51.8
29	600	500	550	58.8	450	475	48.6
30	650	500	575	57.4	350	375	51.8
31	500	400	450	64.7	350	425	45.9
32	600	500	550	58.8	400	450	47.3
33	650	450	550	63.1	250	350	45.9
34	650	500	575	64.7	350	425	44.5
35	500	400	450	58.8	300	350	44.5
36	500	400	450	51.6	300	350	40.1
37	500	400	450	51.6	250	325	38.8
38	500	450	475	53.0	250	350	38.8
39	900	700	800	73.2	300	500	48.6
40	700	550	625	81.7	300	425	53.0
41	900	600	750	79.0	450	525	429
42	900	800	850	91.8	600	700	70.2
43	600	500	550	80.4	300	525	70.2

Sta.	Width 30'	Width 25'	Mean	Vol.	Width 20'	Mean	Vol.
44	600	550	525	61.8	350	400	53.0
45	600	400	500	58.6	300	350	42.9
46	800	600	700	68.7	300	450	45.9
47	1200	900	1050	100.3			3807.5
48	1500	1100	1300	134.3			Acre Feet.
49	900	800	850	128.8			
50	600	500	550	80.4			
51	600	450	525	615			
52	650	550	600	64.5			
53	650	500	575	67.5			
54	500	400	550	58.8			
55	600	350	525	47.3			
56	700	400	550	58.8			
57	750	300	525	60.6			
58	600	400	500	58.8			
59	600	300	450	54.3			
60	600	450	525	56.0			
61	600	450	525	60.2			
62	450	300	375	51.7			
63	500	350	425	45.9			
64	500	300	400	47.3			
65	400	250	325	41.6			
66	350	300	325	37.2			
67	400	250	325	37.2			

Sta.	Width 30'	Width 25'	Mean	Volume
68	450	300	375	
				40.2
69	400	250	325	
				40.2
70	500	250	375	
				40.2
71	350	250	300	
				386
72	350	250	300	
				34.4
73				

5562.5 Acre Feet

The above is the storage on the Tennessee and French Broad Rivers. Below is the storage on the Holston River.

Sta.	Width 30'	Width 25'	Mean	Vol.	Width 20'	Mean	Vol.
100	1000	800	900	106.3	600	700	80.2
101	1100	800	950	117.2	600	700	84.5
102	1200	1000	1100	128.7	550	775	89.0
103	1300	1000	1150	128.7	550	775	81.6
104	1300	900	1100	150.0	400	650	86.0
105	1800	1250	1525	159.0	450	850	91.6
106	1500	1000	1250	1590	500	750	83.0
107	1600	1000	1300	145.9	400	700	83.0
108	1000	900	950	129.0	600	750	73.1
109	700	650	675	93.0	400	525	
110	700	550	625	74.3	300	425	56.9
111	900	700	800	81.6	450	575	57.3
112	650	450	550	77.5	250	350	53.0
113	1100	900	1000	88.5	600	750	62.8

Sta.	Width 30'	Width 25'	Mean	Vol.	Width 20'	Mean	Vol.
114	1500	800	1150	122.8	400	600	77.2
115	550	400	475	93.0	300	350	54.5
116	450	400	425	51.4	350	375	41.5
117	600	500	550	56.6	350	425	45.9
118	450	350	400	54.2	200	275	40.1
119	500	350	425	47.2	300	325	30.0
120	350	250	300	41.5	150	200	35.8
121	500	450	475	44.5	400	425	45.9
122	550	450	500	56.0	300	375	44.5
123	600	450	525	58.7	350	400	34.4
124	500	400	450	56.0	300	350	42.5
125	500	350	425	50.2	300	300	37.4
126	500	400	450	50.2	350	375	38.8
127	450	350	400	48.7	250	300	38.8
128	450	400	425	47.3	350	375	38.8
129	400	350	375	45.9	300	325	40.1
130	350	300	325	40.1	250	275	34.4
131	400	300	250	38.8	250	275	31.4
132	450	300	375	41.5	200	250	30.0
133	300	250	275	37.2	200	225	27.8
134	400	300	375	37.2	300	325	31.4
135	400	300	350	41.5	250	275	34.4
136	350	250	300	37.2	250	250	30.0
137	450	300	375	38.8	300	300	31.4
138	500	400	450	47.3	300	350	37.2

Sta.	Width 30'	Width 25'	Mean	Vol.	Width 20'	Mean	Volume
139	350	300	325	44.5	300	300	37.2
140	300	250	275	344	250	250	34.4
141	300	250	275	31.4	250	250	30.0
142	400	350	375	372	300	325	31.4
143	400	300	350	41.5	250	275	30.0
144	450	350	400	42.9	250	300	33.1
145	400	350	375	44.2	250	300	35.8
146	450	350	400	44.2	250	300	34.4
147	400	350	375	44.2	250	300	34.4
148	500	400	350	47.3	300	350	34.4
149	350	250	300	42.9	250	250	28.7
150	400	300	350	37.2	275	275	30.0
151	350	300	325	38.8	275	275	31.4
152	400	250	325	37.2	250	250	30.0
153	400	350	375	40.1	300	325	33.1
154	450	300	375	41.3	300	300	35.8
155	400	300	350	41.5	300	300	34.4
156	400	300	350	40.2	300	300	34.4
157	450	250	300	37.2	250	250	31.4
158	350	200	275	33.1	200	200	25.9
				3527.5 Acre Feet			2615. Acre Feet

Total 30ft.-25ft.

3527.5

5562.5

9090.0 Acre feet

Total 20ft.-25ft.

2615.0

3807.5

6422.5 Acre feet

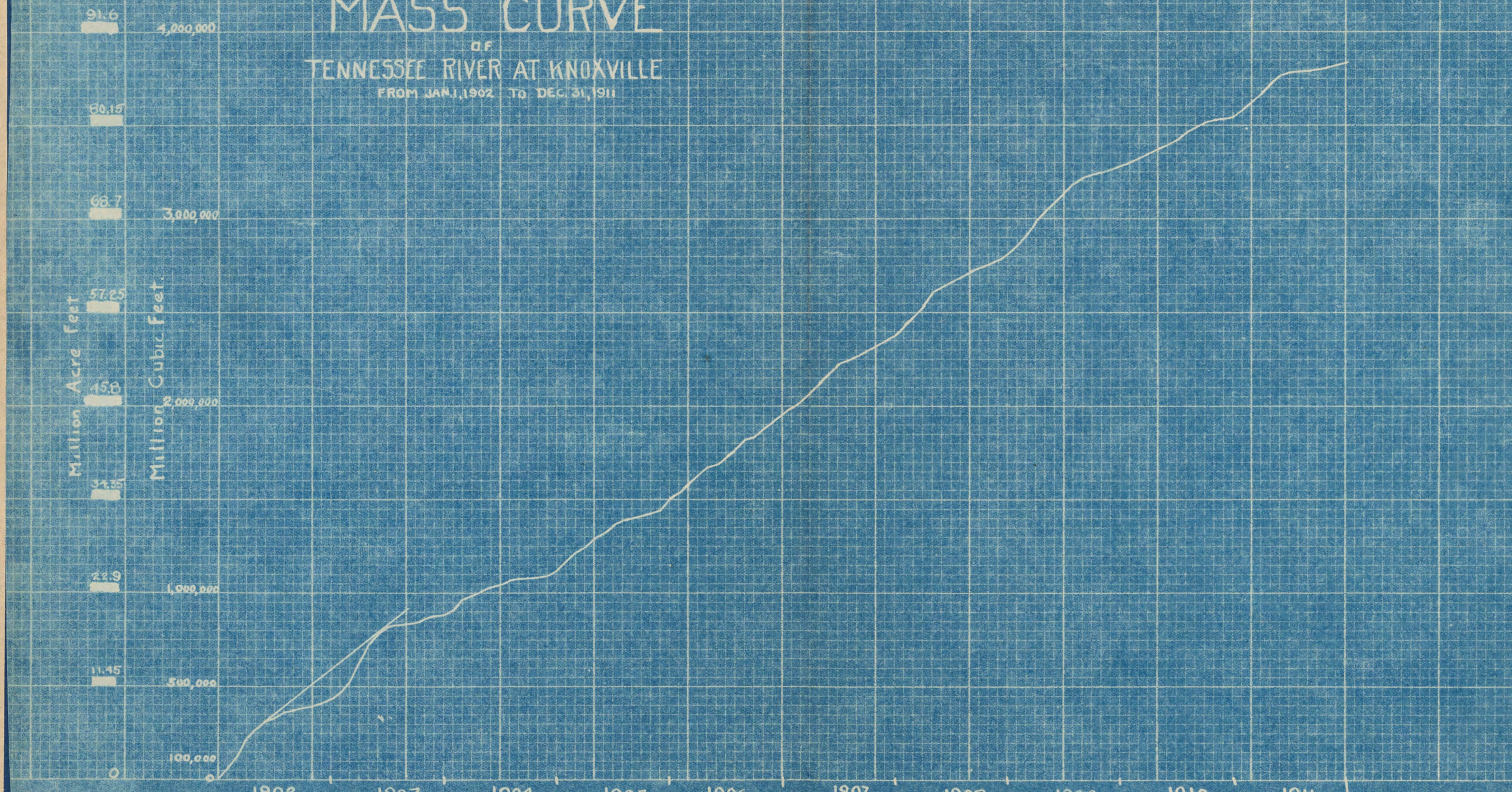
PLATE VII

MASS CURVE

of

TENNESSEE RIVER AT KNOXVILLE

FROM JAN. 1, 1902 TO DEC. 31, 1911

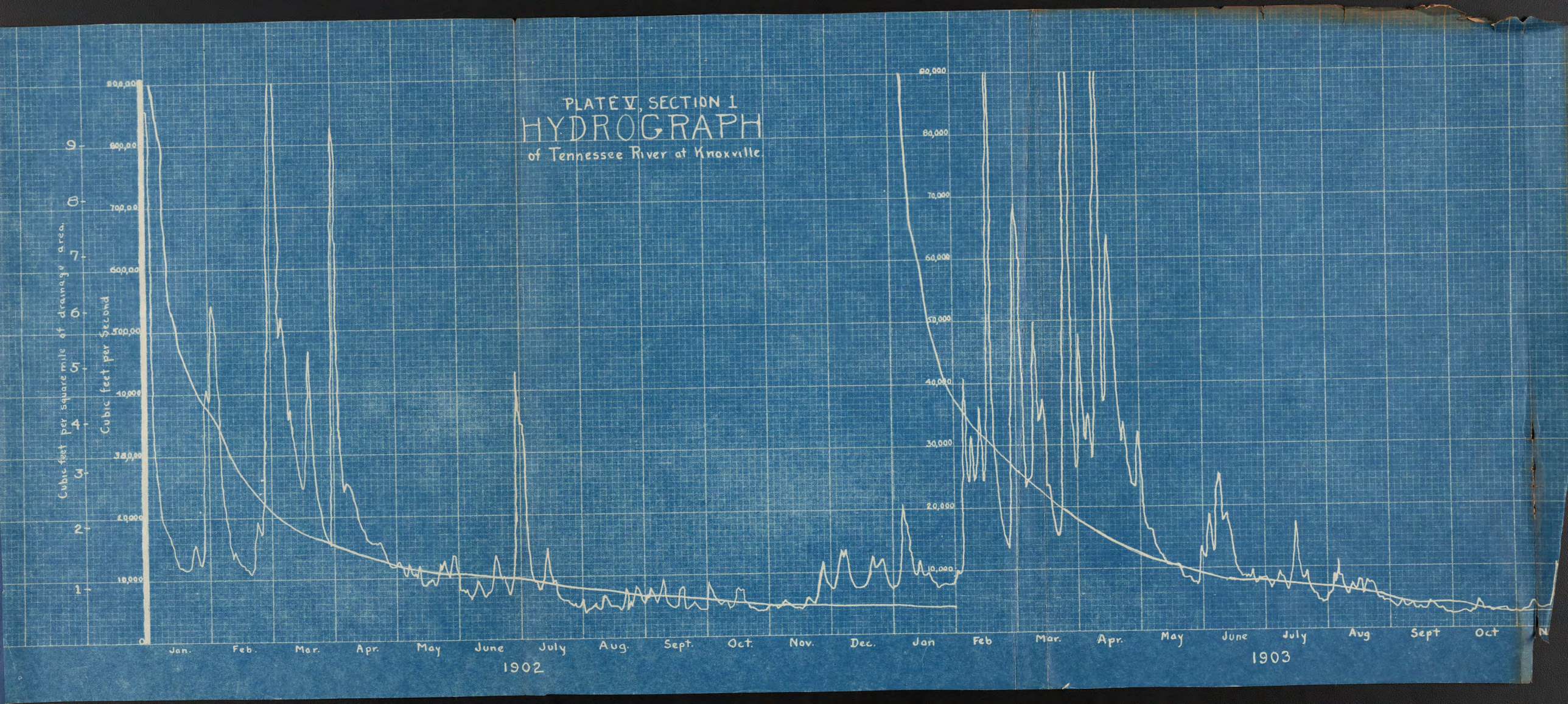


STANDARD CROSS SECTION 10 X 10.
KEUFFEL & ESSER C° NEW YORK.

PLATE V, SECTION 1

HYDROGRAPH

of Tennessee River at Knoxville



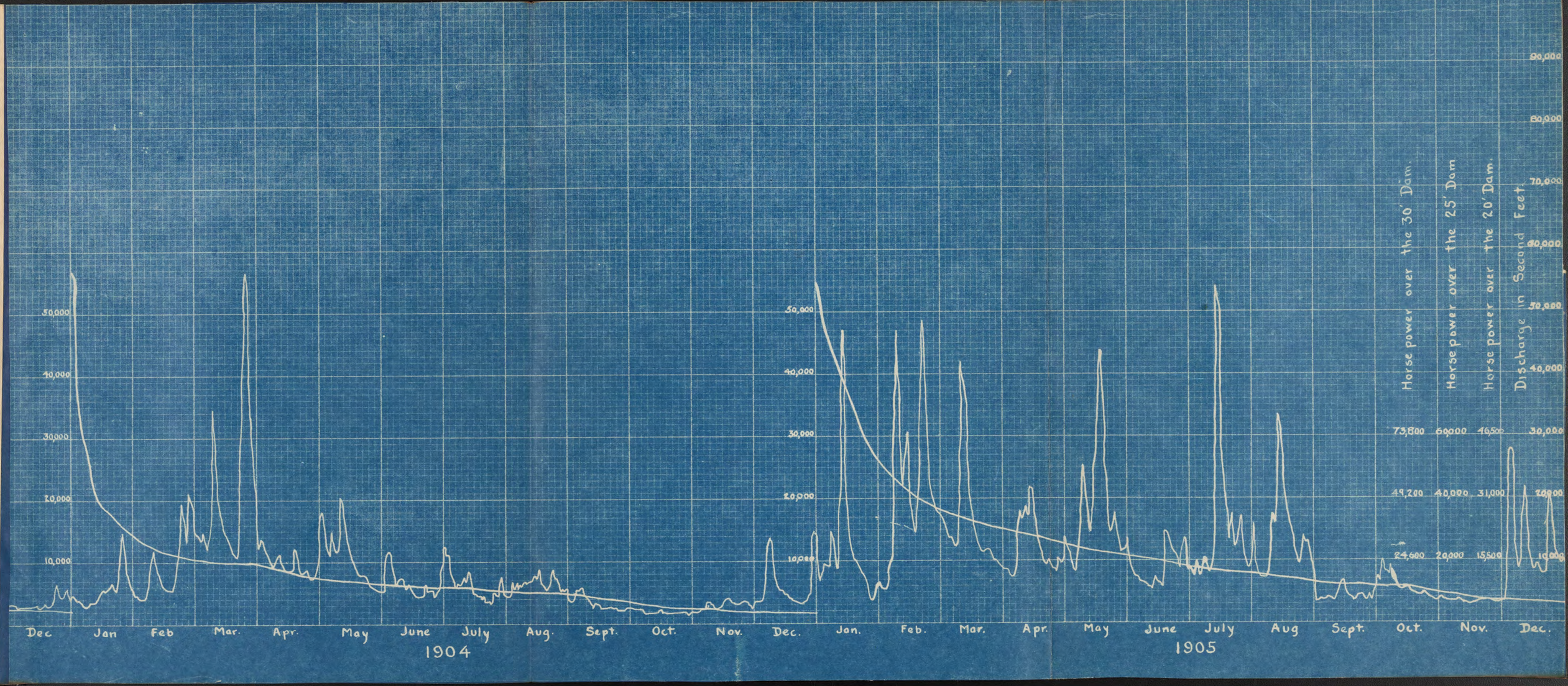
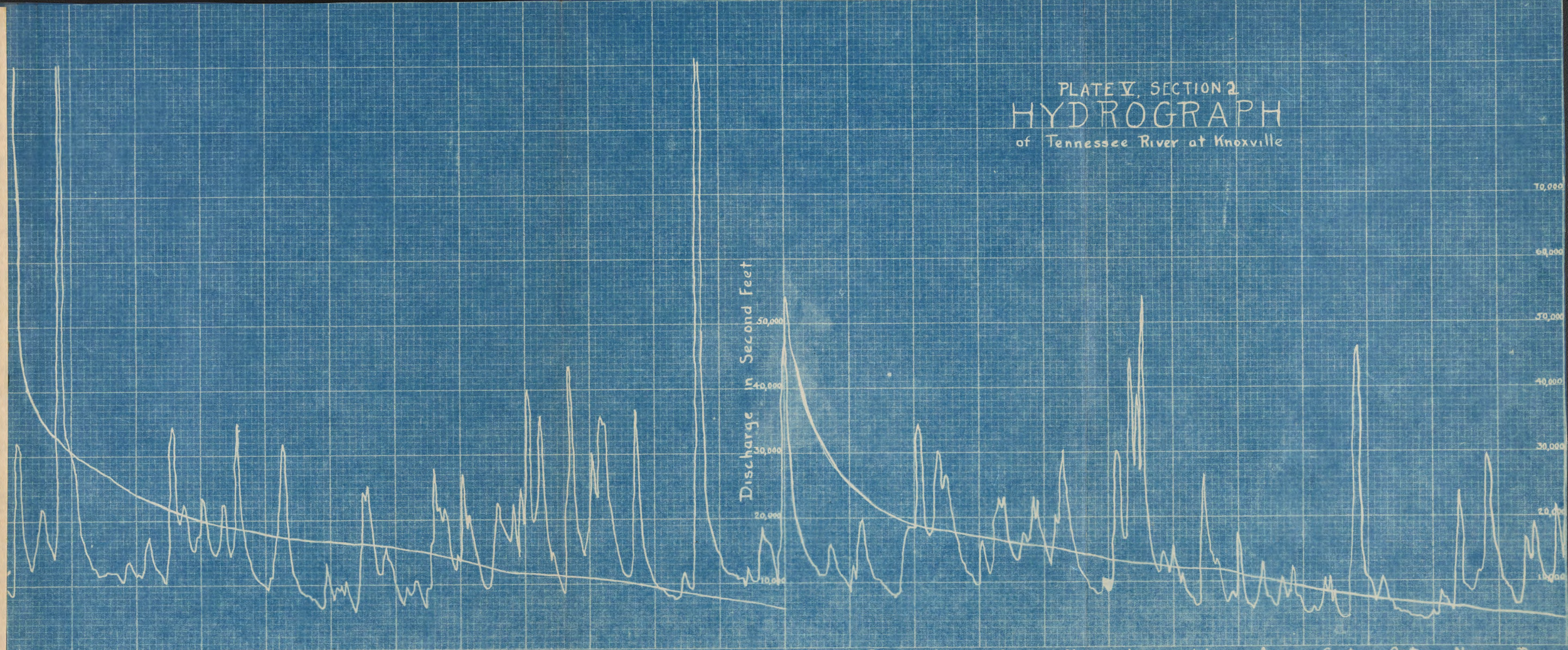

50,000
40,000
30,000
20,000
10,000
Dec
Jan
Feb
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
1904
50,000
40,000
30,000
20,000
10,000
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug
Sept.
Oct.
Nov.
Dec.
1905
Horse power over the 30' Dam.
Horse power over the 25' Dam
Horse power over the 20' Dam.
Discharge in Second Feet.
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
73,800 60,000 46,500
49,200 40,000 31,000
24,600 20,000 15,500

PLATE V, SECTION 2

HYDROGRAPH

of Tennessee River at Knoxville



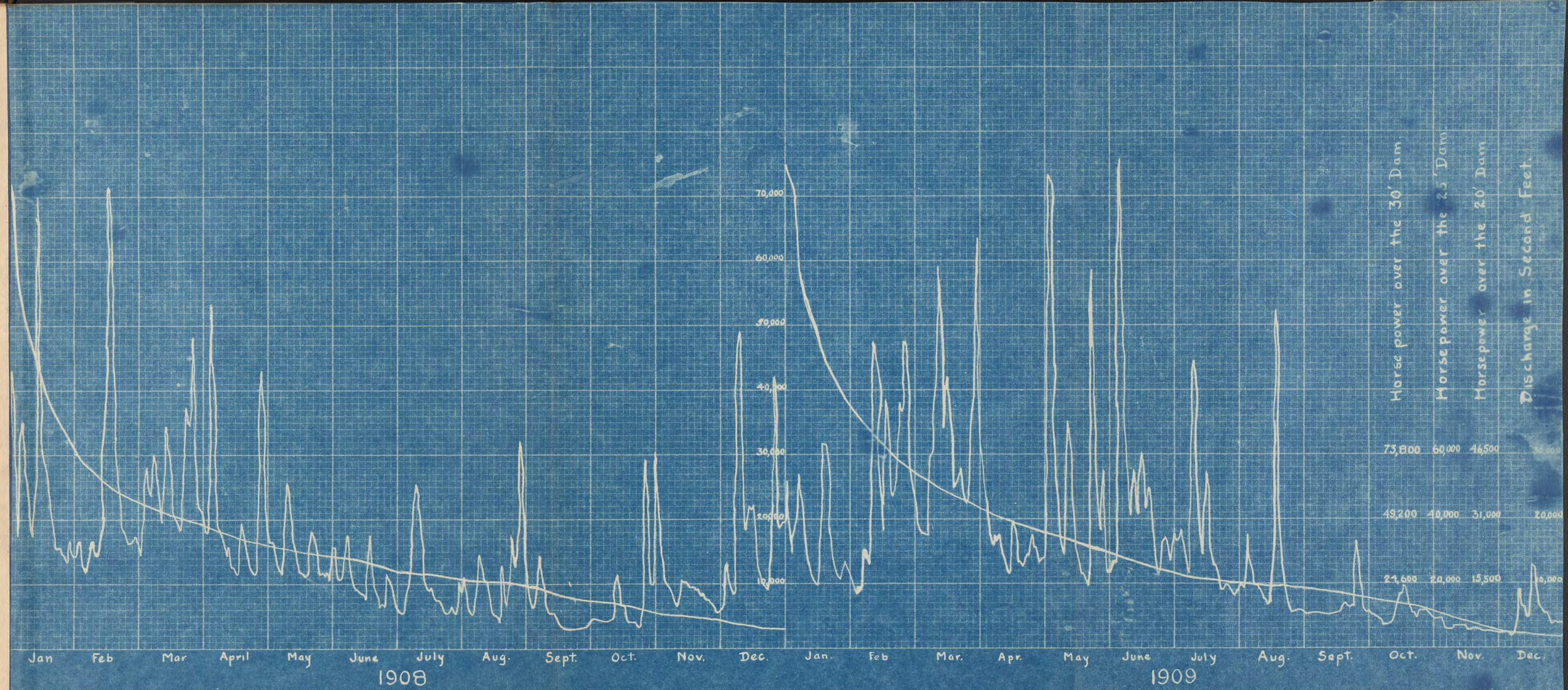
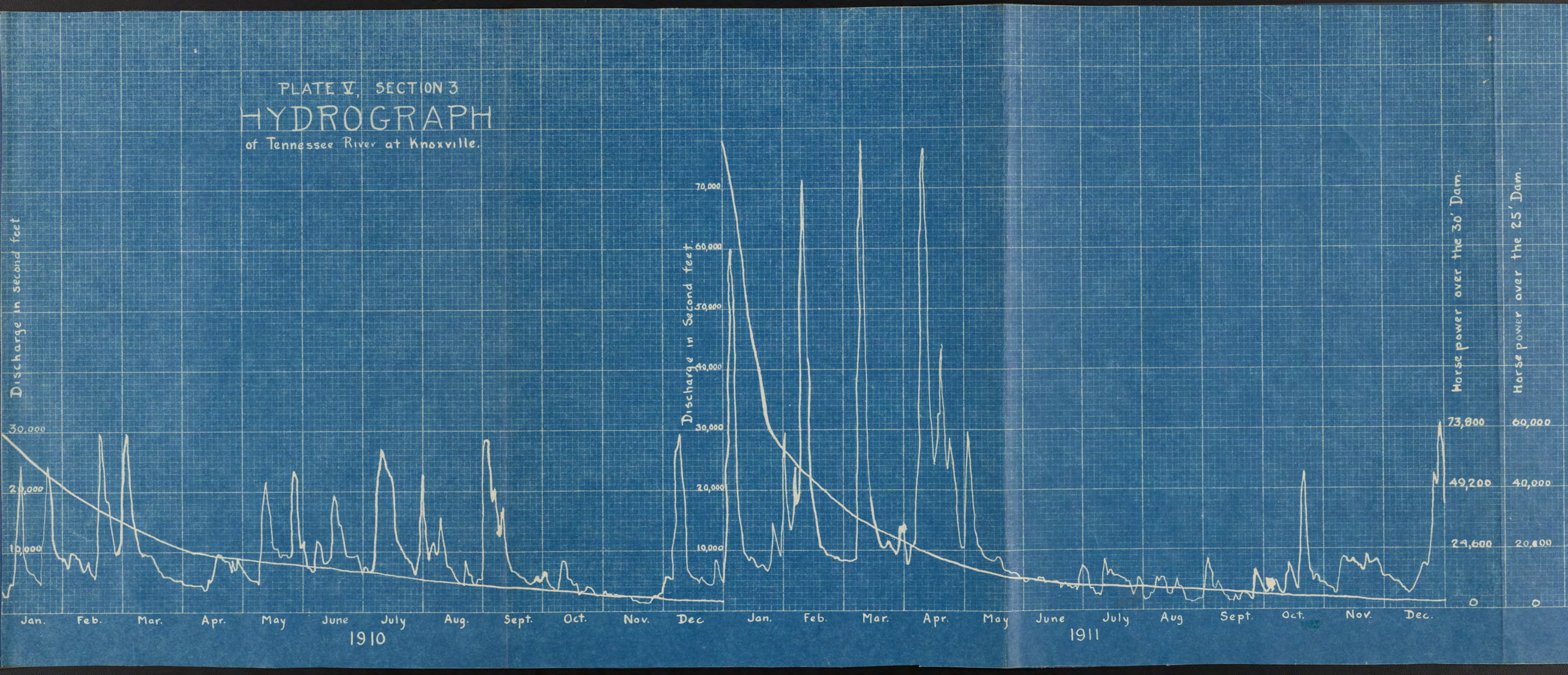
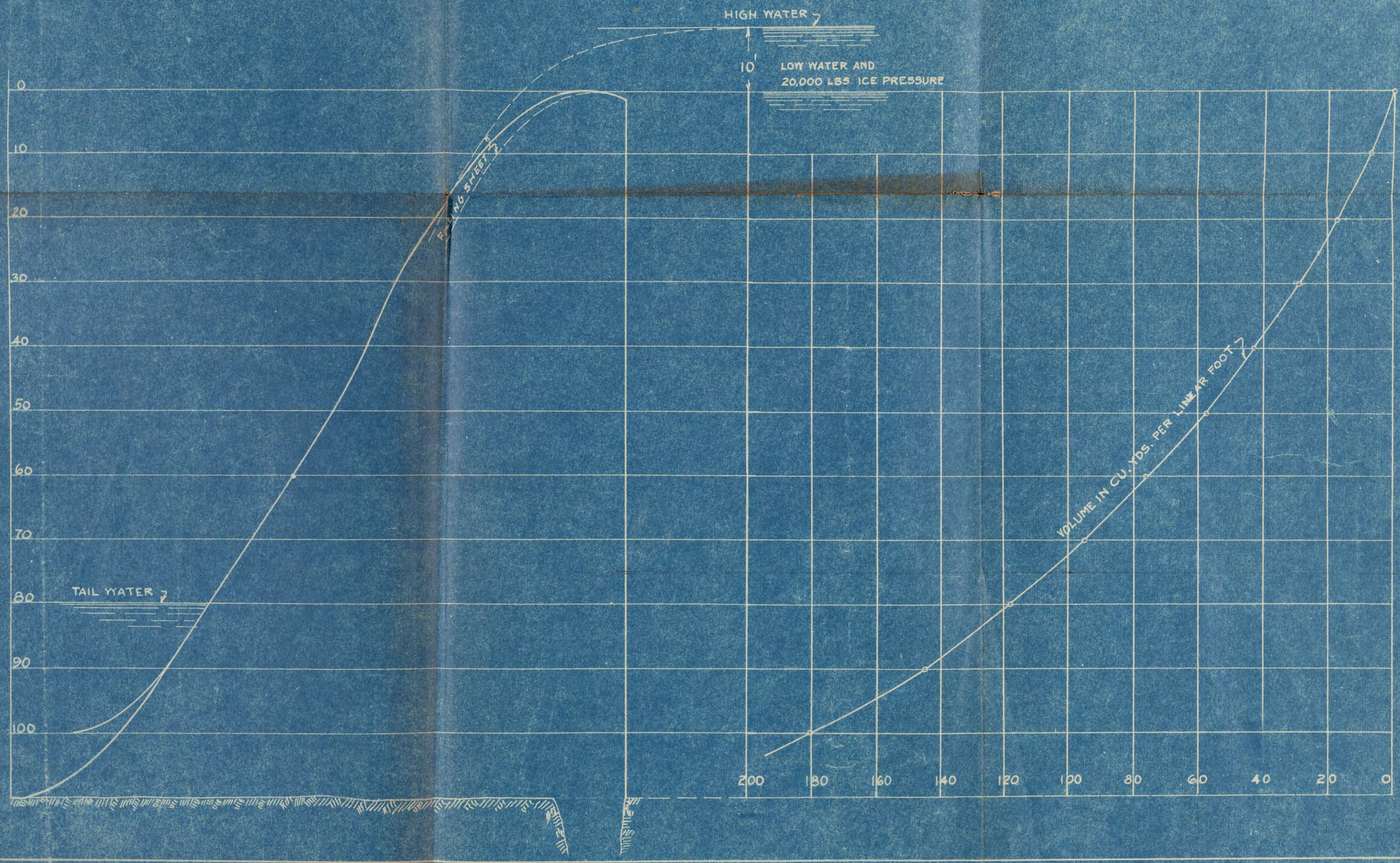

70,000
60,000
50,000
40,000
30,000
20,000
10,000
Horse power over the 30' Dam.
Horsepower over the 25' Dam.
Horsepower over the 20' Dam.
Discharge in Second Feet.
73,800 60,000 46,500
49,200 40,000 31,000 20,000
24,600 20,000 15,500 10,000
Jan Feb Mar April May June July Aug. Sept. Oct. Nov. Dec.
1908
Jan. Feb Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
1909

PLATE V, SECTION 3

HYDROGRAPH

of Tennessee River at Knoxville.




HIGH WATER
10'
LOW WATER AND
20,000 LBS. ICE PRESSURE
0
10
20
30
40
50
60
70
80
90
100
TAIL WATER
SHEET PILING
200
180
160
140
120
100
80
60
40
20
0
VOLUME IN CU. YDS. PER LINEAR FOOT