

PRELIMINARY DISCUSSION OF ECONOMIC
VALUE OF A POSSIBLE HYDRO-ELECTRIC
DEVELOPMENT ON TENNESSEE RIVER NEAR
KNOXVILLE

by

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T A B L E
of
C O N T E N T S

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INTRODUCTION

This thesis is concerning a proposed site on the Tennessee River about three miles above Knoxville. The thesis is to lead up to the point where the matter of costs of such a project can be worked up.

The Tennessee river is well known as being very flashy. From government bulletins it was found that most of these flood flows come suddenly and do not stay long. The relation of the power to the flow is shown by curves.

This project is of very unusual character, due to the fact that the head will be high when the flow is low and low when the flow is high. The extreme variation in head made a very interesting study.

THE SITE

The proposed dam site is about one mile down the river from the junction of the French Broad and Holston rivers. The French Broad had a drainage area of approximately 5000 square miles and the Holston a drainage area of about 4000 square miles, or a total of 9000 square miles.

The dam site is situated at Cave Springs, has one side bordered by a cliff of rock about 80 or 90 ft. in height, nearly vertical, while the other side is about 60 feet high, coming up to this height on a gradual slope. The rock is of the very hard tellico sandstone and water tight connections might readily be made because of this impervious material.

A cross section of the river at this site is plotted
PLATE I.

DAM

The flood flows of the Tennessee river being very great (although very rare) changed the design of the dam somewhat. The fact that there is a marble quarry at the forks of the river (EL. 860) and the Southern railway tracks along the banks of the Holston, makes it necessary to keep the headwater below this contour. Since the load up to this contour would have to be bought, the water might as well cover it so the best plan would be to hold the head water level constant and this would be as high as possible.

To take care of the flood flows, Taintor gates or Ston-ey gates are proposed. The concrete dam height 20 feet, and on top of this a 25 foot Taintor or Stoney gate, would give a total head of 45 feet, which would be the highest head that could be

had on the plant. Whenever a flow comes so that the water starts to pour over the gates, they should be opened, at least one at a time, so as to keep the water level below the 860 contour. The elevations are as follows:

Crest of dam 830

Crest of Taintor gates 855

This dam site was proposed by McGregor Smith and studied in a thesis two years ago, but a better site is possible because the length of spillway is too short. The spillway should be as long as possible to take care of the flood flows. The shores of the river on the upstream side of the dam are not any wider and on the down stream side, if you were to go a hundred feet or so, you would come to another fork in the river and the land around the vicinity is practically level having no means of empounding water by means of a dam.

SPILLWAY

The spillway should be of sufficient capacity to discharge any flood flow that might occur. At first a spillway length of 500 feet was considered, with 25 foot taintor or Stoney gates. The fact that when the flood flows occur, the dam will be submerged, brings in some difficulty because the discharge over a submerged weir is not as great as that of an open weir. The quantity of water discharged over 500 foot dam with 25 foot head on upstream side and the weir submerged 15 feet will be, using an approximate formula

$$Q = L \sqrt{Z} (3.4 Z + 4.4 H) \text{ or}$$

$$Q = 500 \sqrt{10} (3.4 \times 25 + 4.4 \times 15) =$$

$$Q = 155,000 \text{ sec. feet}$$

To drill a tunnel to take care of the excess water would be too expensive and impractical, because the tunnel would have to be of very large diameter to take care of the water, for example, at maximum flood, the greatest head that could be had on the tunnel would be ten feet and assuming the maximum theoretical velocity of 25 feet per second.

$$Q = A V \text{ or}$$

$$A = \frac{Q}{V} = \frac{50000}{25}$$

This would give a radius of 25 feet or 50 foot diameter. This would be very expensive to build, and it would be cheaper to excavate and lengthen the spillway.

Making the length of spillway 650 feet, we would be able to discharge apprx. 200,000 sec. feet for submerged weir with maximum floods.

$$Q = L \sqrt{Z} (3.4Z + 4.4H)$$

$$Q = 650 \sqrt{10} (3.4 \overline{10} + 4.4 \overline{15})$$

To save space to be used for spillway length, the power house is to be placed with its length perpendicular to the axes of the dam.

The flood flow of the Tennessee river (maximum recorded is 200,000 sec. feet. A contract could be made with the marble company so that if a flood should ever occur with a discharge of more than 200,000 sec. feet and floods out their business, the power company would see to it that their business is put back into operation after the flood. A sinking fund could be started to take care of this debt should it ever occur.

There never has been a flood of more than 200,000 sec. feet recorded, but from a curve (PLATE VII) given in Russell & Turnean "Public Water Supplies," showing the relation between flood discharge and drainage area, the maximum flood is calculated as 240,000 sec. feet. (The curve given in appendix is a reproduction of the one given in the book)

BACKWATER

The backwater conditions could not be looked into very accurately because of lack of necessary maps and lack of time to make an extensive survey. A survey of this kind would take many months. The U. S. Government is making a detailed survey of this river and its tributaries, at present, but no data could be obtained for public use. The water would be backed up approximately 17 miles on the Holston and 18 miles on the French Broad. The approximate amount of land to be bought is 1600 acres. This value was taken from a curve plotted from data taken from another thesis. Points were obtained from heights of dam of 20, 25, and 30 feet and the curve extrapolated to height of 45 feet.

DRAWDOWN

With height of dam of 45 feet, the amount of acres covered was found to be 4900. This was arrived at by an approximate method since no other way was available. From the other thesis, the amount of acres covered were plotted and the curve interpolated. For example

Height dam 30 ft.		
Back water French Broad		
14.75 miles		1240 acres
Back water Holston		
14.5 miles		<u>815</u> acres
	Total	2055 acres

Three points for 20, 25 and 30 foot dam were plotted and the curve interpolated, the contour levels as ordinates and the acres covered as abscissae. This curve is called the acres covered curve. From this curve the draw down curve was drawn. The mean value of the acres covered between the two consecutive five foot contours multiplied by the depth (five feet) will give the amount of drawdown in acre feet. Points were obtained from different calculations and the draw down curve plotted with acre feet as abscissae and the height of contour levels or height of water as ordinates.

This draw down curve could only be used during low water times when the water level gets below the top of the taint-gates. From our duration of head curves a ten foot draw down seems to be the maximum, to keep within the economical limits.

RATING CURVES

A rating curve is a curve drawn with the height of gauge reading in feet as ordinates and the discharge in sec. feet as abscissae. These readings are usually checked every two years because of the change in river bed. Our rating curves were made at the gauging station at the Gay Street Bridge, Knoxville, Tenn., and it is assumed that there is no appreciable difference between this and our site, three miles away.

The rating curves were obtained from government bulletins, readings taken over a period of 1901-1909. "It should be kept in mind that any single observation of the flow of a stream represents a totally inadequate and unsatisfactory criterion for water power consideration". Our readings were taken over a period of about nine years. It appears tho, that all these years show flows of different varieties which seem to be very typical conditions of the flow.

HYDROGRAPH.

A hydrograph is a curve constructed for the study of a stream flow and its influences on water power, with the ordinates as daily flow in cubic feet per second and the element of time as abscissae. One type of hydrograph would show the fluctuations of one day to the next over a period of one month or year. From a hydrograph a duration curve can be drawn. Our data came from the pamphlets let out by the U. S. Geological Survey.

DURATION CURVES

Duration curves are curves drawn with the percent of time as abscissae and the head, flow or power as ordinates. They are drawn from the same figures that the hydrographs are drawn

from except that in drawing the duration curves the values of the flow are taken in order of their magnitude and not as they occur, as is the case with the hydrograph.

PRIMARY POWER

Since the flow of the Tennessee river gets very low at times 1800 second feet the primary power available is very low without storage facilities. The Tennessee river, French Broad and Holston affords hardly any storage whereby water could be stored from one wet season and used during a dry season keeping the primary power higher than that of the natural minimum of the stream. The matter of using auxiliary power to increase the primary power will be discussed later.

Primary power is that power which is available and can be promised to customers at all times. The flow of the river most of the time is greater than the quantity of primary power calculated but this power generated above the primary power cannot be guaranteed at all times and is called secondary power.

SECONDARY POWER

Secondary power is that power which can be generated only when there is demand for it and a plenty of water to generate it. Secondary power cannot be guaranteed and therefore sells at a much lower price. The continuity of this power is, as a rule not guaranteed, and the right is reserved to cut off such supply upon reasonable notice.

Secondary power is usually available for 9 months in each year and furnished longer if the flow of water in the stream keeps up to a value necessary to supply it.

AUXILIARY POWER

The development of a power site usually also involves the consideration of an auxiliary power source such as a storage reservoir or a steam plant. In our case a storage reservoir is out of the question, so our only other solution is steam power. If secondary power can be sold without an auxiliary steam plant, the amount of secondary power which may be developed economically depends only upon whether or not the price received for such power will cover the interest and profit on the investment. The capacity of the steam plant or the amount of secondary power to be developed depends upon the cost of the steam power.

The function of an auxiliary plant is to convert at least a part of the secondary power which would be available only part of the year, into primary power available at all times, thus increasing the sale value.

The question now is for what capacity shall it be built? To get the best economy out of a steam station it must operate at practically a constant load corresponding to full load of one or more units. To get best economy out of a water power station with water available during low water periods, the highest water level, obtainable must be maintained at all times. During low water when the minimum stream flow capacity and steam power capacity combined are not sufficient to carry the peak load, the steam plant can be operated at constant load using the water power during the peaks and storing the water during the balance of the time.

With the auxiliary power the total plant can supply a load continuously throughout the year which is equal to that which the water power yields at ordinary stage of flow, the aux-

iliary equipment being operated during the periods of low water only. The cost of this auxiliary power may be a little more than the price received for it during the time of production, it is the amount of power produced that brings an income for a whole year, while the auxiliary costs continues only for a short time.

INTERCONNECTION

The advantage of interconnection with some other plant would be that the operation may be so improved that a most efficient and reliable service can be rendered to customers of all the systems. During either flood or low water times, at the plant there is a shortage of head which reduces the amount of power. Now at this time there may be a surplus of power at some other station and they would like to sell some, which would be the most economical to do, because they would be wasting water. This power when generated could help out the peaks in our plant, only if our peak came during their valley load. When two companies are interconnected while one is carrying the peak loads of the other, this second one can build up their pondage.

DISCUSSION

The duration curve on the flow of the river shows the maximum of about 45000 sec. ft. at 5 per cent of the time with 25000 sec. ft. 25 per cent time and 7500 sec. ft. 75% and 1800 sec. ft. 100% of the time. The head curves shows that the head is inversely to the flow of the river, with a small flow we have the largest head, but the power increases with the decrease in head.

All three of the duration curves were plotted to the same sheet so that one can find out the performance of the plant

at any flow of the river immediately. All are plotted with the abscissae the percent of time. Although the percent is reversed for the head so as to make the head duration curve fit right. For any percent of time you can find out the flow head and power by reading the intersection of a vertical line through the percent of time. The flow head and power scales are off at the left (ordinates). Example: If you want to know what the characteristics at 40 percent of the time on lower scale at 40 percent read vertically to flow curve, point N. and horizontally, read discharge or 14,200 - vertically from N to P intersection of head curve read 41.4 ft., go vertically to power curve at P read 53200 horse power. This amount of power is taken with the turbine efficiency of 80 percent, (constant, which is not the actual performance of the turbines. The actual may be higher as they are manufacturing turbines with higher efficiencies).

The amount of primary power from waterpower is 5970 KW or 52,400,000 K W hrs. per year. If we only guarantee this, we need no steam power but if we agree to guarantee the power that we get from water 50 per cent of the time we would need auxiliary power to supplement this water power to make firm power all the year. For 50% of the time water gives 152,000,000 K W hrs. per year. To make this firm power all the year we need an auxiliary plant with generating capacity of 63,000,000 KW hrs. per year, making a total of 215,000,000 KW hrs. for water and steam combined.

In table IV column (5) shows the number of K W hrs. developed by water at a certain percent of the year. Col. (6) shows the amount of auxiliary power that will have to be generated to make up for the deficiency in water power for the other percent of

the year. The last column shows the total amount of firm power.

From this table or the curves drawn from this table the most economical design of auxiliary steam station and capacity could be figured. The usual design is to design the hydroelectric plant with a capacity that would utilize the amount of flow that occurs 50 percent of the year and design the steam plant to furnish the required amount to generate the deficiency caused by the smaller flows of the stream.

The most economical design of plant will be determined by the overhead and stand by losses, whether the increase in income will pay the interest and depreciation, etc., of the idle steam plant.

CONCLUSION

This study will have to be carried on before a definite design of plant can be worked out. To make this plant a paying proposition, it would have to be interconnected with some other system, on account of the flashyness of the river, causing wide variations in head on the plant. It must be understood that this study is not a complete one, the matter of detail was not entered into thoroughly.

It was considered that a market for power was available since there are quite a few towns nearby who would buy power. It can be said that with interconnection this would make an ideal site for a water power plant.

APPENDIX

DATA FOR DRAW-DOWN CURVES I

HEAD	ACRES COVERED	ACRES COVERED by EACH CONTOUR	DRAW-DOWN ACRE-FEET
45	4100		0
40	3400	18750	18750
35	2740	15350	34100
30	2055	11987	46087
25	1420	8687	54775
20	980	6000	60775
15	660	4100	64875
10	400	2650	67525
5	190	1475	69000
0	0	475	69475

MEAN MONTHLY FLOWS

II

	<u>1902</u>	<u>1903</u>	<u>1904</u>	<u>1905</u>	<u>1906</u>	<u>1907</u>	<u>1908</u>	<u>1909</u>
Jan.	23144	9923	5545	12280	25300	15100	26200	17100
Feb.	24500	30952	9377	22740	14400	12100	23400	26000
Mar.	43999	38605	21770	15940	17100	19800	26700	32500
Apr.	19652	42133	10420	12430	17200	17200	20900	16100
May	10620	11664	10430	17710	12800	14200	14500	24000
June	10952	12904	6516	9000	12600	22600	10500	23500
July	10020	7757	6095	15500	13500	11600	9830	16100
Aug.	5818	6217	6323	14050	18400	8330	10800	11000
Sept.	5869	3299	3258	5745	21200	10300	5540	66450
Oct.	5425	2793	1968	4354	20300	6110	8590	5290
Nov.	5763	4216	2852	3443	20700	12600	9460	2990
Dec.	9500	3867	6309	12600	15800	13900	19300	5050

POWER HYDROGRAPH

III

% TIME	DISCHARGE	HEAD	HORSE- POWER 100% EFF.	HORSE- POWER 80% EFF.
0				
3	35000	37.5	149000	1190000
5	25000	38.4	122000	97800
7	26400	39.0	117000	93400
10	24700	39.3	110500	88500
15	22500	39.7	101600	81200
20	20500	40.	91200	72800
25	19000	40.3	87000	69400
30	17000	40.8	78800	63000
35	15500	41.1	72400	57800
40	14500	41.4	68300	54500
45	13000	41.7	61700	49500
50	12200	42.	58300	46500
55	11200	42.3	53700	42900
60	10000	42.5	48300	38600
65	9000	42.8	43700	34900
70	8200	43.1	40200	32100
75	7200	43.38	35400	28300
80	6300	43.6	31200	24900
85	5200	44.0	26000	20700
90	4400	44.4	22000	17700
95	3500	45.0	17900	14300
100	2000	46.0	10480	8360

DATA ON CAPACITIES OF POSSIBLE WATER POWER AND STEAM POWER
PLANTS AND TOTAL AMOUNT POSSIBLE FIRM POWER.

% Time	Possi- ble HP Output	Requir- ed aux. Power to make firm	Possi- ble KW Output	Requir- ed KW aux. to make power firm	KW hrs. per year generated by water power with in- stalled capacity indicated by Col. I	KW hrs. per yr. to be gen- erated by steam to guar- antee firm power	Firm Power that can be guaran- teed 5+6 -
100	8000	0	5970	0	52400000	0	52400000
95	14500	6500	10800	4850	90000000	2130000	92130000
90	17800	9800	13300	7320	105000000	3200000	108200000
85	20800	12800	15500	9560	115000000	6300000	121300000
80	25000	17000	18600	12700	130500000	11100000	141600000
75	28400	20400	21200	15200	139000000	16600000	155600000
70	32200	24200	24000	18100	147000000	23800000	170800000
65	35000	27000	26100	20200	148500000	31000000	179500000
60	38000	30000	28300	22400	149000000	40000000	189000000
55	43000	35000	32000	26200	154000000	51800000	205500000
50	46500	38500	34700	28800	152000000	63000000	215000000
45	49500	41500	36900	31000	145000000	74600000	219600000
40	54000	46000	40200	34400	141000000	90500000	231500000

The figures are based on 100% load factor.

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.

NAME

TITLE

J. A. Switzer
Prof. Hyd & San. Eng.

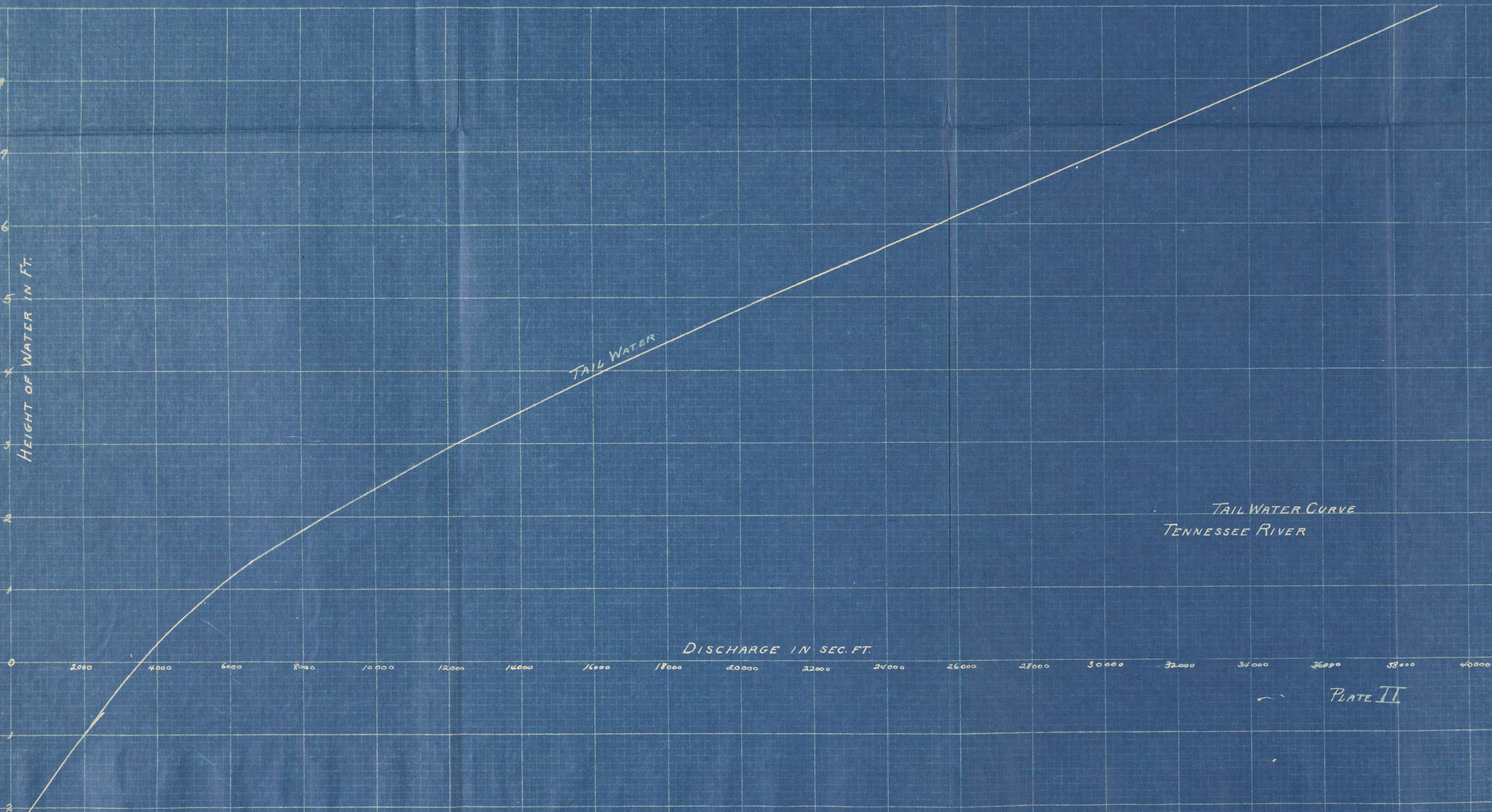
HEIGHT OF WATER IN FT.

TAIL WATER

TAIL WATER CURVE
TENNESSEE RIVER

DISCHARGE IN SEC. FT.

PLATE II



55

50

45

40

35

30

25

20

15

10

5

0

HEIGHT OF WATER IN FT.

HEAD WATER CURVE

TAIL WATER CURVE

DISCHARGE IN SEC. FT.

PLATE 1

9

10000

20000

30000

40000

50000

60000

70000

80000

90000

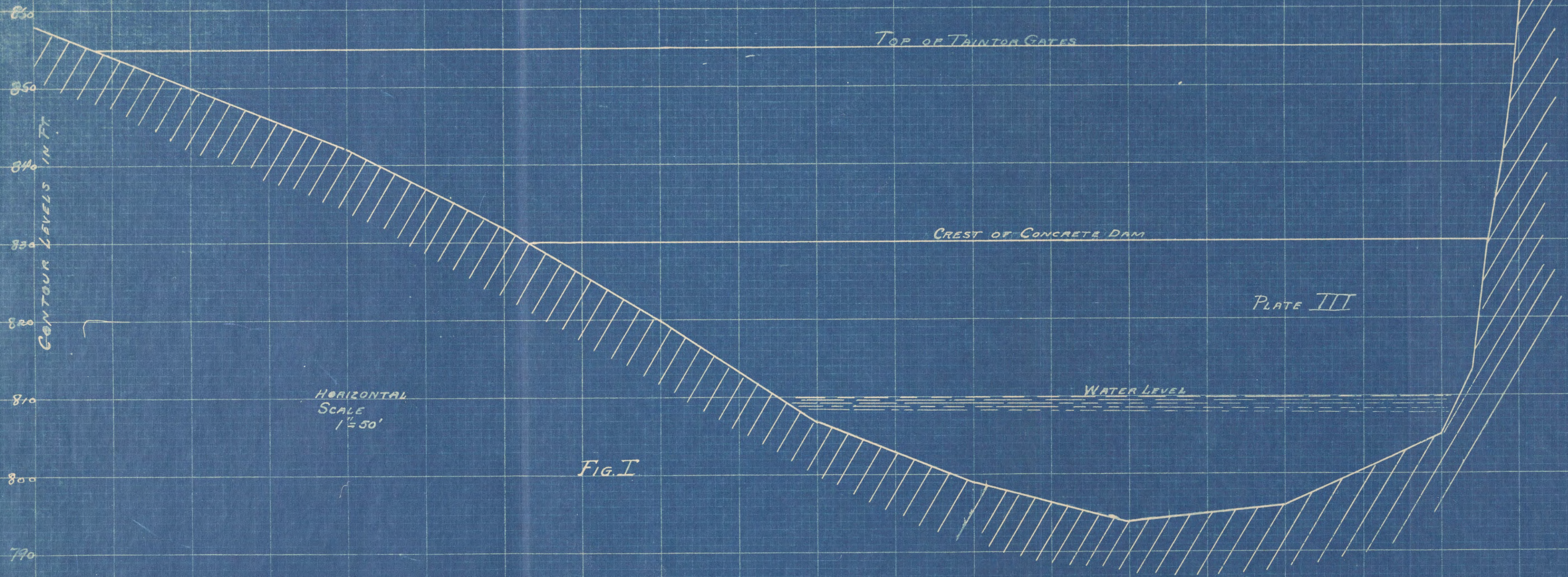
100000

120000

140000

160000

180000



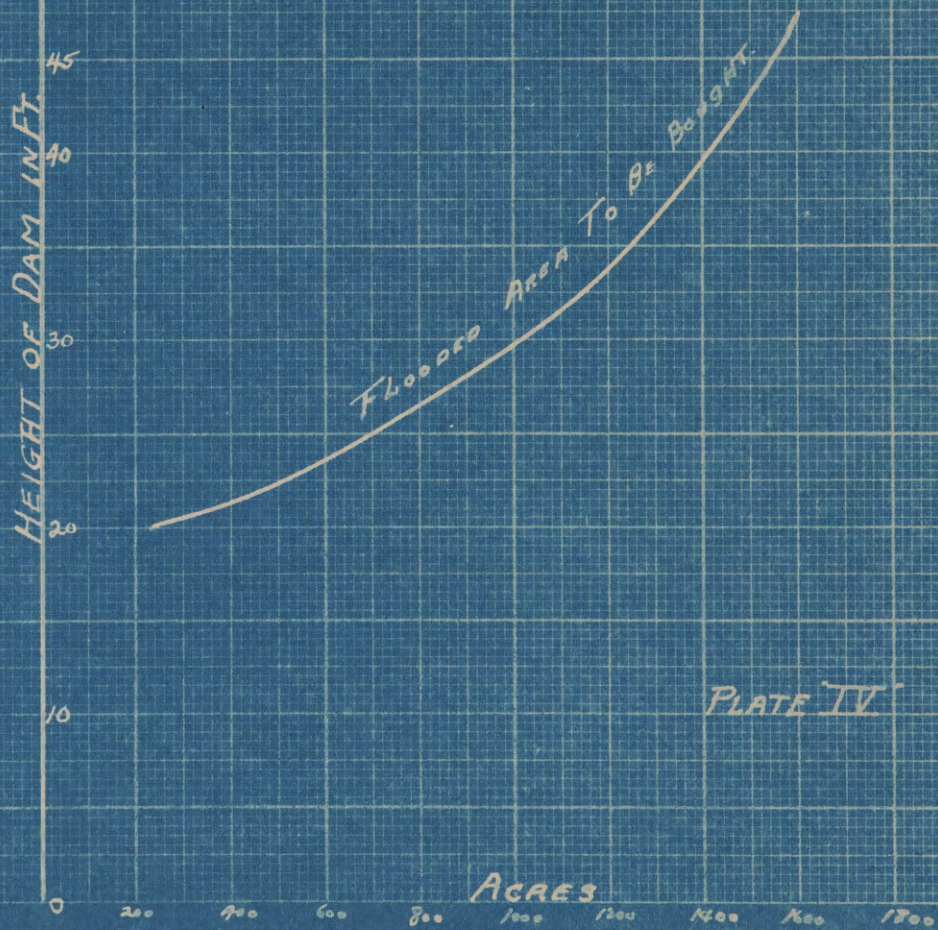
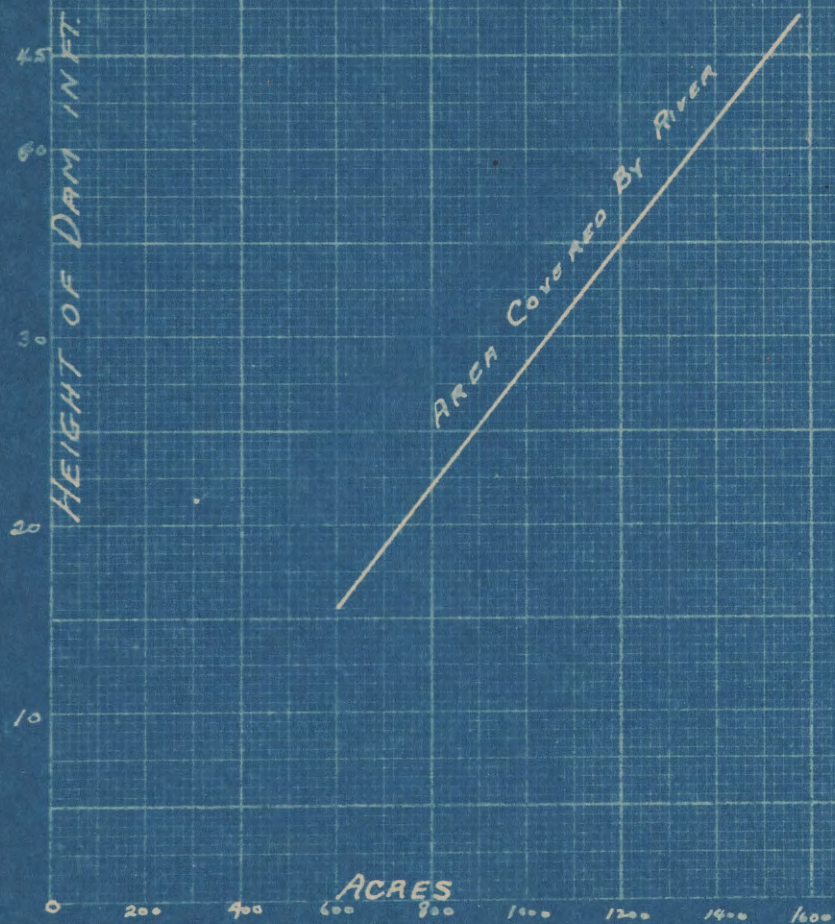


PLATE IV

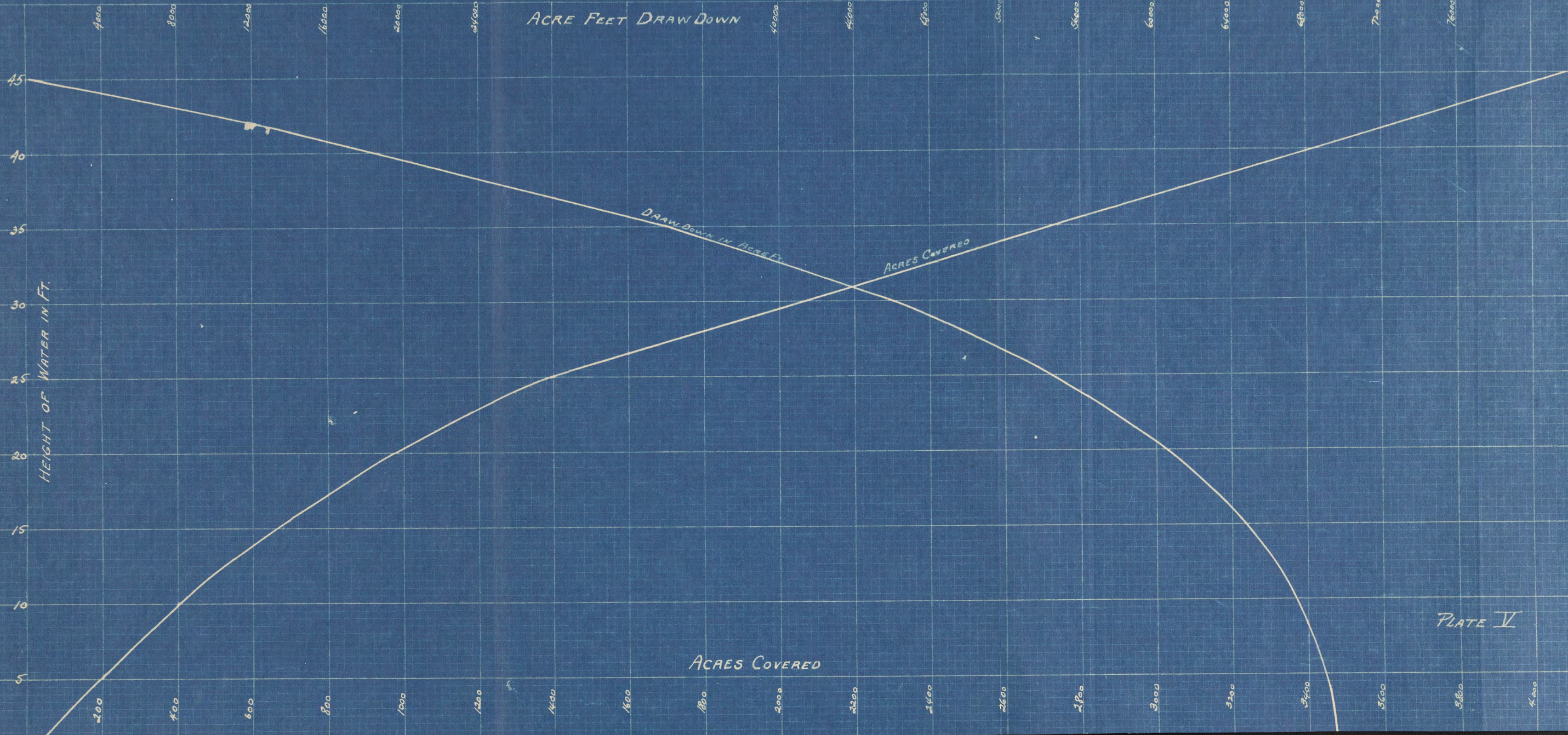


PLATE V

HYDROGRAPH
OF
MEAN MONTHLY FLOWS
OF
TENNESSEE RIVER AT CAVE SPRINGS
KNOXVILLE, TENN.
DURATION FLOW CURVE

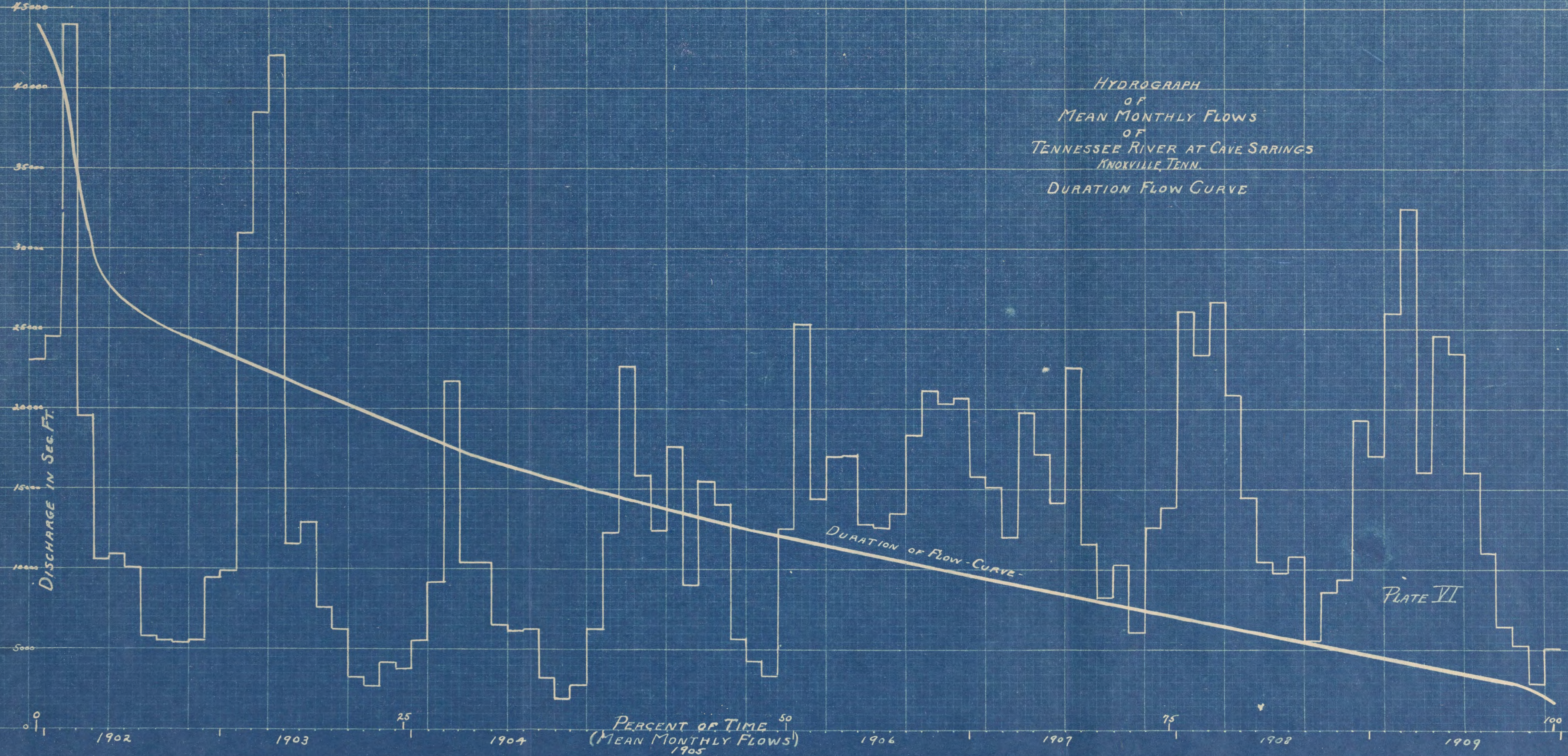


PLATE VI

CURVE SHOWING
RELATION BETWEEN
FLOOD DISCHARGE AND DRAINAGE AREA
(KUTCHLING)

DISCHARGE IN SEC. FT.

PLATE VII

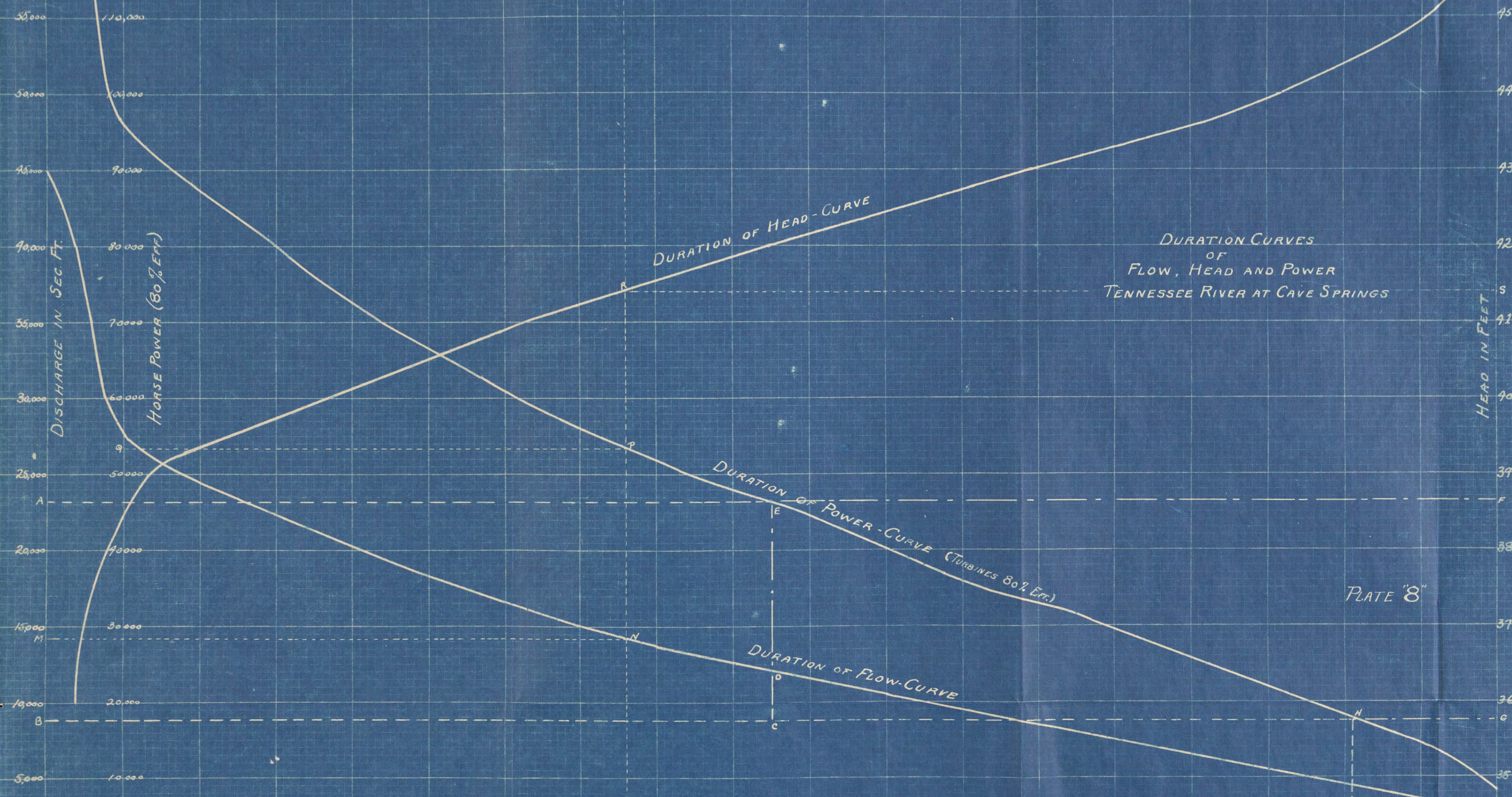
DRAINAGE AREA SQ. MILES

0 500 1000 1500 2000 3000 4000 5000 6000 7000 8000 9000

280
260
240
220
200
180
160
140
120
100
80
60
40
20

100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0

PERCENTAGE OF YEAR DURING WHICH VARIOUS HEADS ARE MAINTAINED



(TEN YEAR PERIOD)
 PERCENTAGE OF YEAR DURING WHICH VARIOUS FLOWS AND THE CORRESPONDING AMOUNTS OF POWER WERE MAINTAINED

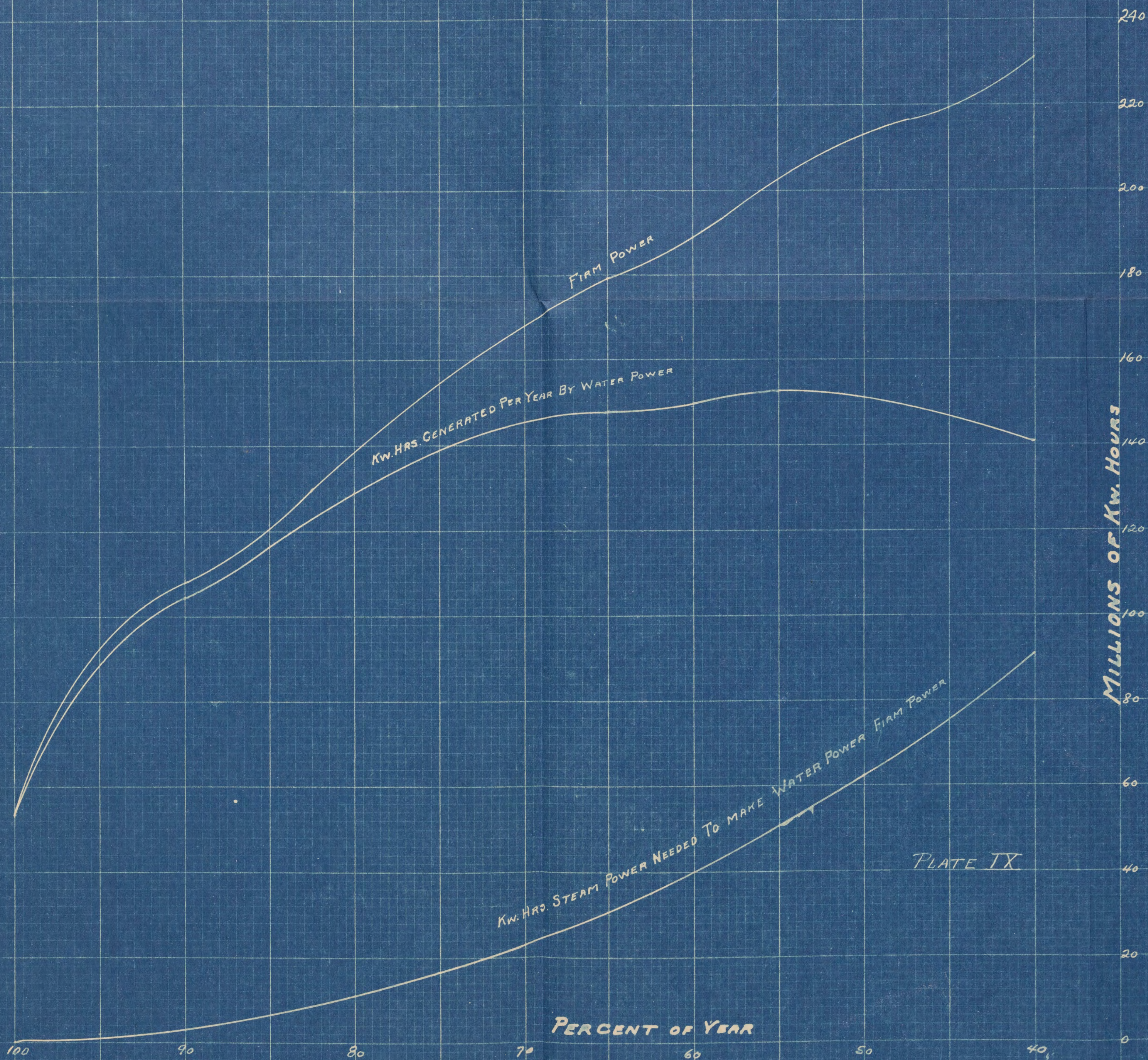


PLATE IX