MICHIGAN STATE COLLEGE
OF
AGRICULTURE AND APPLIED SCIENCE

THESIS

HYDRAULICS OF THE COLUMBIA RIVER

SUBMITTED FOR
CIVIL ENGINEER DEGREE

1926

E. H. COLLINS

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T H E S I S

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SYNOPSIS

Recently, considerable experimental data concerning the flow of the Columbia River was obtained. These data were extensive and accurate enough to check up the constants commonly used in the various slope formulas to compute the flow of rivers. The experimental data consisted of the reading of several gages along approximately 25 miles of the river. The actual flows observed ranged from 25,000 c.f.s. to 345,000 c.f.s. Quite reliable data were also obtained from local residents concerning a flow of 700,000 c.f.s., the largest flood known. Various cross-sections were sounded and contoured. The flow was measured at a standard U.S.G.S. stream gaging station having a well defined rating curve. Having the values of flow, slope, hydraulic radius and area known, coefficients of standard slope formulas were computed and the results are discussed.

FIELD DATA

The Columbia River, above the point where these experiments were conducted, has a drainage area of about 35,000 square miles. The average flow at this point is greater than that of the Colorado and Yukon rivers, about equal to the Frazer, Missouri and Nile rivers and somewhat less than the Danube, St. Lawrence and Ohio rivers. The path of the Columbia River parallels mountain ranges which are closely related to great folds and faults. The valley between these ranges varies in width from one-quarter to two miles in width. The river has cut a channel thru the valley with banks, in general, 50 to 75 feet above flood-water. The range in stage from low-water to flood-water is about 25 feet. There are no high falls in the river. The slope in general is gradual. Occasionally the banks are rock canyons about half the general width of the river. At these places the river either falls over a rock dike or passes thru a very deep crevice. Between these points the width of the river, in general, is about 1500 feet. The bed is composed of water-worn boulders which are fairly large. During flood the river carries silt and alternately forms and washes out sand and gravel bars. At low-water it appears it should be classed even lower than Torrential stream by Kutter, while at high-water it would be classed as Earth having stones and weeds occasionally.

Plate I shows the location of all gages and sections and the stream gaging station.

RIVER GAGES

River gages were placed at each section noted. These were staff gages made of pieces of 2" x 6" and fastened either to standing trees or cedar posts placed solidly in the ground. The gage boards were painted white. The foot mark elevations were stenciled with black paint and each tenth of a foot was marked with a saw cut. A line of check levels was run the full length of the 25 miles of the river. Periodically, each foot in the slope gages and one mark on the vertical gages were checked with an engineer's level from a local B.M. placed near each gage. Fortunately no gages were found in error. These gages were all read once daily by the same observer. They were read from early spring thru the flood months and continued until late in the fall when the flow had reached close to the minimum.

CROSS-SECTIONS

The cross-sections were taken at low-water by sounding the river with a lead weight and taking topography of the bank with an engineer's transit.

GAGING STATION

The gaging station is well located on a straight stretch of the river where the stream line flow is not disturbed except at extremely low water. The gagings were made from a cable stretched across the river. A small Price current meter was used to measure velocity. The meter had been rated by the U.S.G.S. at Washington, D. C. Standard U.S.G.S. methods of stream gaging were used. Plate II is a copy of the rating curve. A staff gage at the rating station was read twice daily.

It will be noted on Plate I that there is some inflow from the Kettle River between the gaging station and the gage sections. Previously, a rating station had been maintained on the Kettle River by the U.S.G.S. The gage at this station was still in existence. Readings of this gage were taken periodically. The flow of the Kettle River was deducted from the flow of the Columbia River at the gaging station to obtain the flow of the Columbia River past the gages used in this discussion.

COMPUTATIONS

All gage readings were plotted for each gage. Any blunders by the observers were thus discovered and discarded.

The sections were plotted to natural scale. The wetted perimeter was measured with a map measurer. The area was planimetered. Curves of both R and A were plotted for each section. For the purpose of this discussion flows of 48,000; 100,000; 150,000; 200,000; 250,000; 300,000; 350,000 and 700,000 c.f.s. have been chosen. The profiles for these flows, as observed in the field, are plotted in Plate III. The hydraulic characteristics of these sections for the flows mentioned above are shown in the appendix. Plate XVI in the appendix also shows some typical sections with their values of A and R.

Two methods were used in working up the data. As an example of these methods consider for the moment sections 16, 17 and 18. One method was tried where the areas and hydraulic radii of sections 16 and 17 were averaged and the slope taken as observed between sections 16 and 17. However, it was found better to take the area and hydraulic radius of section 17 and the average of the slopes 16 to 17 and 17 to 18.

Vaules of roughness coefficient (n) both in Kutter's formula

$$V = \frac{41.6 + \frac{1.811}{n} + \frac{0.00281}{S}}{1 + \left(41.6 + \frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}} \sqrt{R\ S}$$

and Manning's formula

$$V = \frac{1.486}{n} R^{2/3} \quad S^{1/2}$$ were next computed.

PROBLEM

The title of this thesis "Hydraulics of the Columbia River" was taken because apparently there is little data available on this subject. Data were discussed with members of the United States Geological Survey. They had some scattered data on a few large rivers. However, none of it seemed to show any definite laws such as are shown in this discussion. A large amount of data have been presented on small streams and small artifical canals but none on large rivers or canals. Also, some fifty so-called slope formulae have been presented to calculate the flow of streams, etc. Most of these formulae are rather complicated and, strange to say, Kutter's formula, which is probably used more extensively than any other, is the most complicated. It is believed that so-called "nature" does her work in the simplest way. The problem then is to present the hydraulic characteristics of flow in large rivers with particular reference to the flow of the Columbia River and discuss their relations as set forth in what are commonly called slope formulae.

DISCUSSION

As the experimental data obtained on the Columbia River appears to be the best it will be discussed first.

On Plate IV values of Kutter's and Manning's coefficient "n" have been plotted for all sections for flows of 48,000 c.f.s. and 100,000 c.f.s. Values at higher flows were not plotted because there was very little variation. It can be seen from these results that Manning's coefficient is not so sensitive as Kutter's when other than stream line flow exists. In other words, bends, rapids or other disturbances in the stream do not effect Manning's formula as much as it does Kutter's. In general the two values follow closely except where there were rapids in the river as at sections 19-22 and 26. Above section 26 there is a narrow deep gorge. The wide variation at this section is undoubtedly due to whirls, boils and eddies from the stream above.

On Plates V to XIII, the variation of the roughness coefficient "n" for each section is shown for all stages. Seven of the twelve sections show fairly consistent variations. The other sections (13-14-20-21-23) are erratic. The reason for this is, that in the vicinity of these sections were either bends, rapids or other disturbances which broke the slope of the stream between points of observation. In most cases several intermediate sections would have been necessary to isolate each change in slope. Had these observations been taken it is believed that the curves for all sections would be similar. It may be noted that both Manning's and Kutter's coefficients check closely especially at the higher flows.

Of the sections showing consistent variations, section 16 is probably the best section. All the physical characteristics of the river from section 15 thru section 16 to section 17 were favorable to expect good results from a slope formula. The various characteristics of this section are plotted in detail on Plate XIV. On this plate flow in c.f.s. has been plotted as abscissae and V, R, R, S, n, C and K as ordinates. The experimental data plots in smooth curves that warrant some study. It may be seen from these curves that the general laws as stated by Kutter in 1885, are substantiated. These general laws are stated as follows;

C INCREASES

1. With the increase of hydraulic radius R and most rapidly when r is small.

2. With the decrease of resistance to flow (coefficient of roughness n).

3. With a decrease of slope S.

It appears that Items 1 and 2 might be called axiomatic. Item 3, however, has been much discussed. In Kutter's original discussion he found conflicting results from the experiments he discussed. It might be stated that in these experiments the slope was small as compared to the slopes in the Columbia River data. Plate XV shows some similar data regarding the Mississippi River above Carrollten, Louisiana taken from Table 9 in "Calculation of Flow in Open Channels" by Ivan E. Houk of the Miami Conservancy District. These curves show an increase and decrease of C with an increase of S. The slope in general is about one-tenth that of the Columbia River data.

The value K, shown in both plates XIV and XV, was derived as follows:

Starting with the well known assumption of a solid of water sliding down a trough of uniform slope and moving with a constant velocity, use (F) for force due to friction tending to retard this solid; (W) weight of solid; (A) cross-sectional area; (L) length; (w) weight per unit volume; (K) is coefficient of fluid friction; (p) is the wetted perimeter; (V) is velocity; (R) is the hydraulic radius; (S) is slope and (g) is force of gravity.

Then $$W = L\,A\,w$$

and $$F = K\,P\,L\,w\,\frac{V^2}{2\,g}$$

Then the energy over-coming the friction is equal to

$$L\,A\,w\,\frac{h}{L}$$

$$\text{or } L\,A\,w\,\frac{h}{L} = K\,p\,L\,w\,\frac{V^2}{2\,g}$$

$$V^2 = \frac{2\,g\,A\,h}{K\,p\,L}$$

Since $S = \dfrac{h}{L}$ and $R = \dfrac{A}{p}$

we may with $V = \sqrt{\dfrac{2\,g\,R\,S}{K}}$

or $\qquad V = 8.025\sqrt{\dfrac{R\,S}{K}}$

Chezy's formula is $V = C\sqrt{R\,S}$

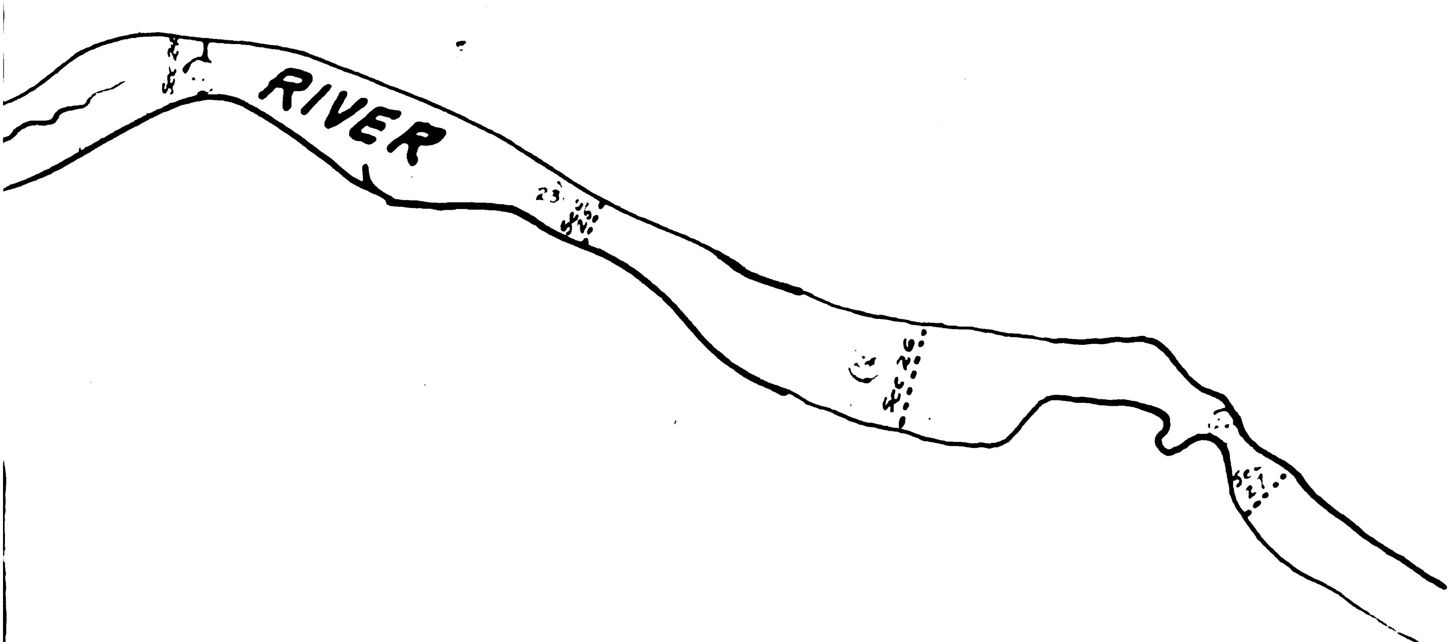
Then in other words $C = 8.025\sqrt{\dfrac{1}{K}}$

It should be noted that this value (K), as shown on the above curves, shows practically the same variations as the coefficient of roughness friction (n).

CONCLUSIONS

It appears that all slope formulae are empirical. Kutter has spent more time and used more experimental data in developing his formula, hence it has had more weight with engineers in general and rightly so. It is probable that the accuracy of the experimental data used by Kutter was poor. This combined with the fact that his data on large canals and rivers was meagre led him to some wrong conclusions regarding slope. On the Columbia River with practically ten times the slope Chezy's coefficients(c) are practically equal. The correction Kutter introduced for slope was undoubtedly absorved by a slight change of his values of (n). Manning's formula appears to be just as good as Kutter's under ideal conditions and better under poor conditions. It is believed that the

value K, which has been discussed, would have given as accurate results as any formula. It is the simplest form of constant that could be used. Kutter's formula has given good results when checked up for local conditions as any formula would, but when used in one locality with constants derived by comparison with a supposedly similar locality has been erratic. It is like the case of estimating the runoff of one drainage area by comparison with another which seldom can be relied on except for a very rough estimate.



COLUMBIA RIVER GAGES

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HYDRAULICS OF COLUMBIA RIVER

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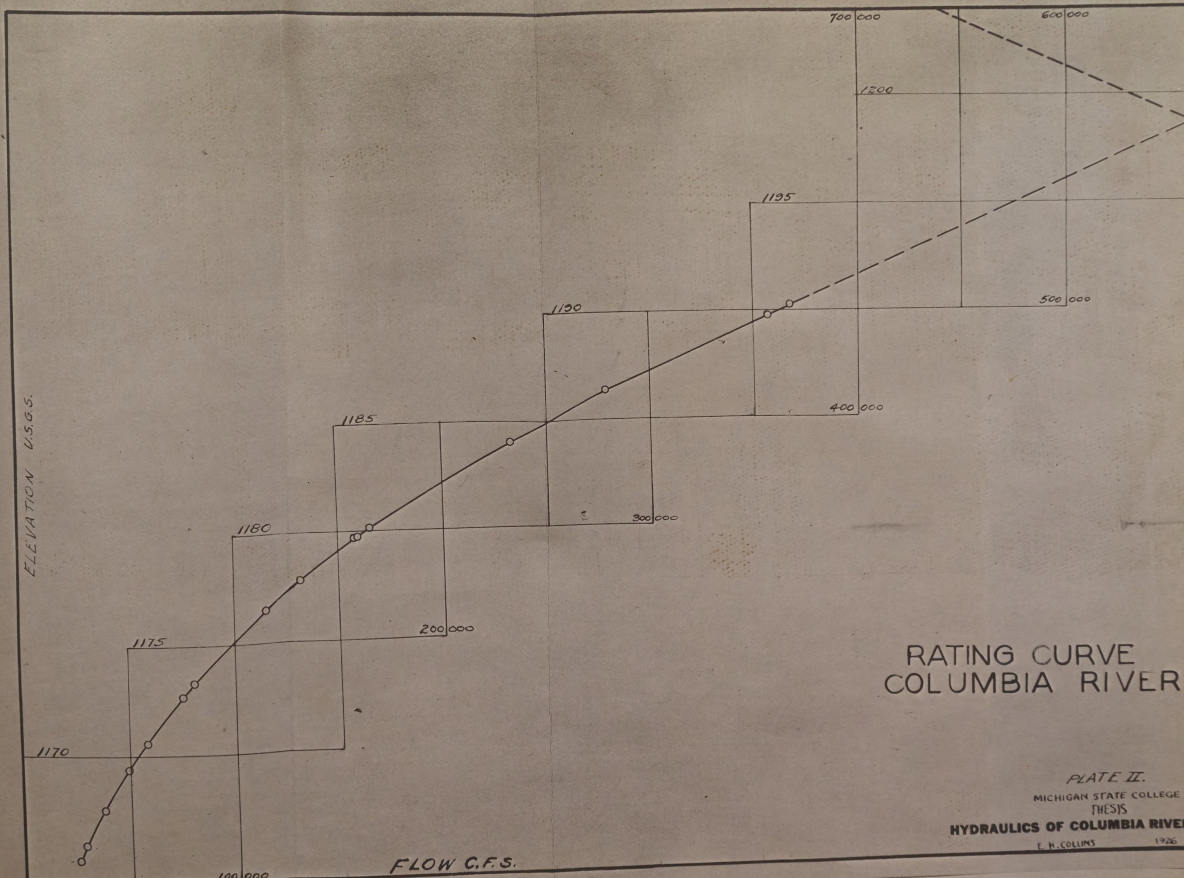
PLATE I.


700 000
600 000
1200
1195
500 000
1190
400 000
1185
300 000
1180
200 000
1175
1170
100 000
ELEVATION U.S.G.S.
FLOW C.F.S.
RATING CURVE
COLUMBIA RIVER
PLATE II.
MICHIGAN STATE COLLEGE
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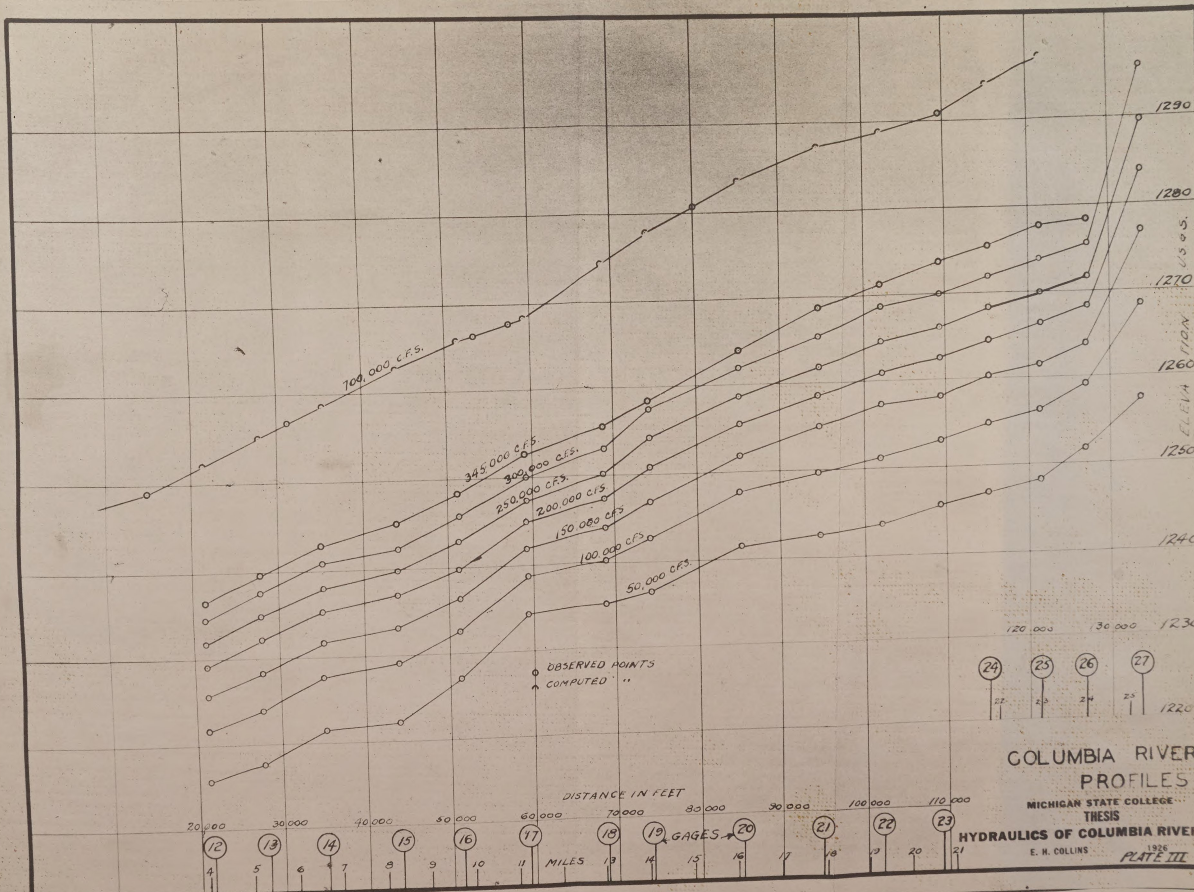
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS
1926



COLUMBIA RIVER PROFILES

MICHIGAN STATE COLLEGE
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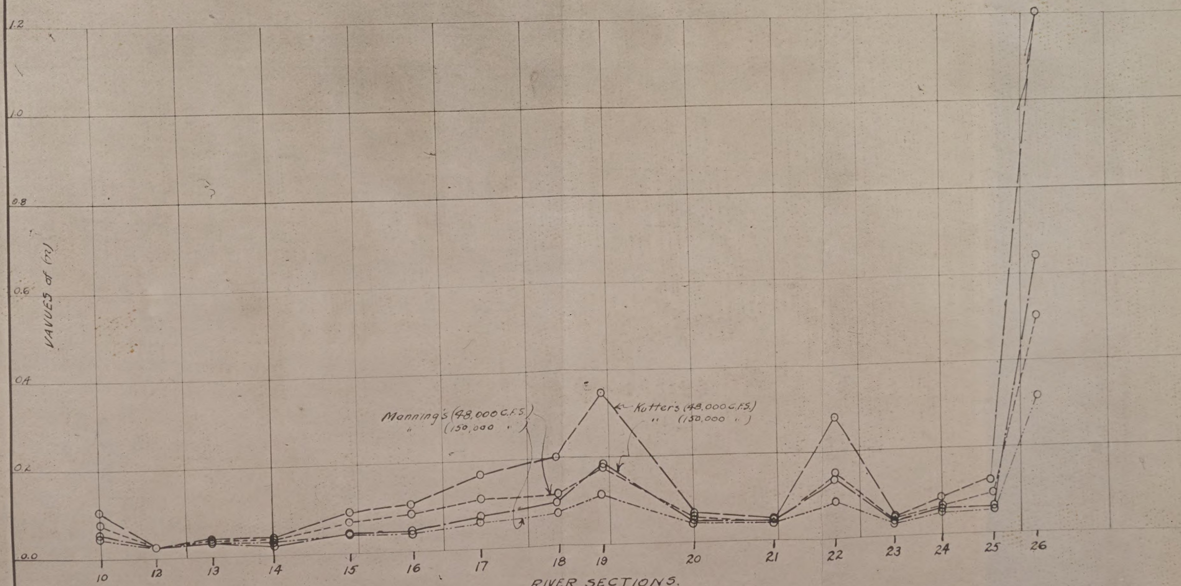
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS 1926
PLATE III



FACTOR "n"
ALL SECTIONS

MICHIGAN STATE COLLEGE
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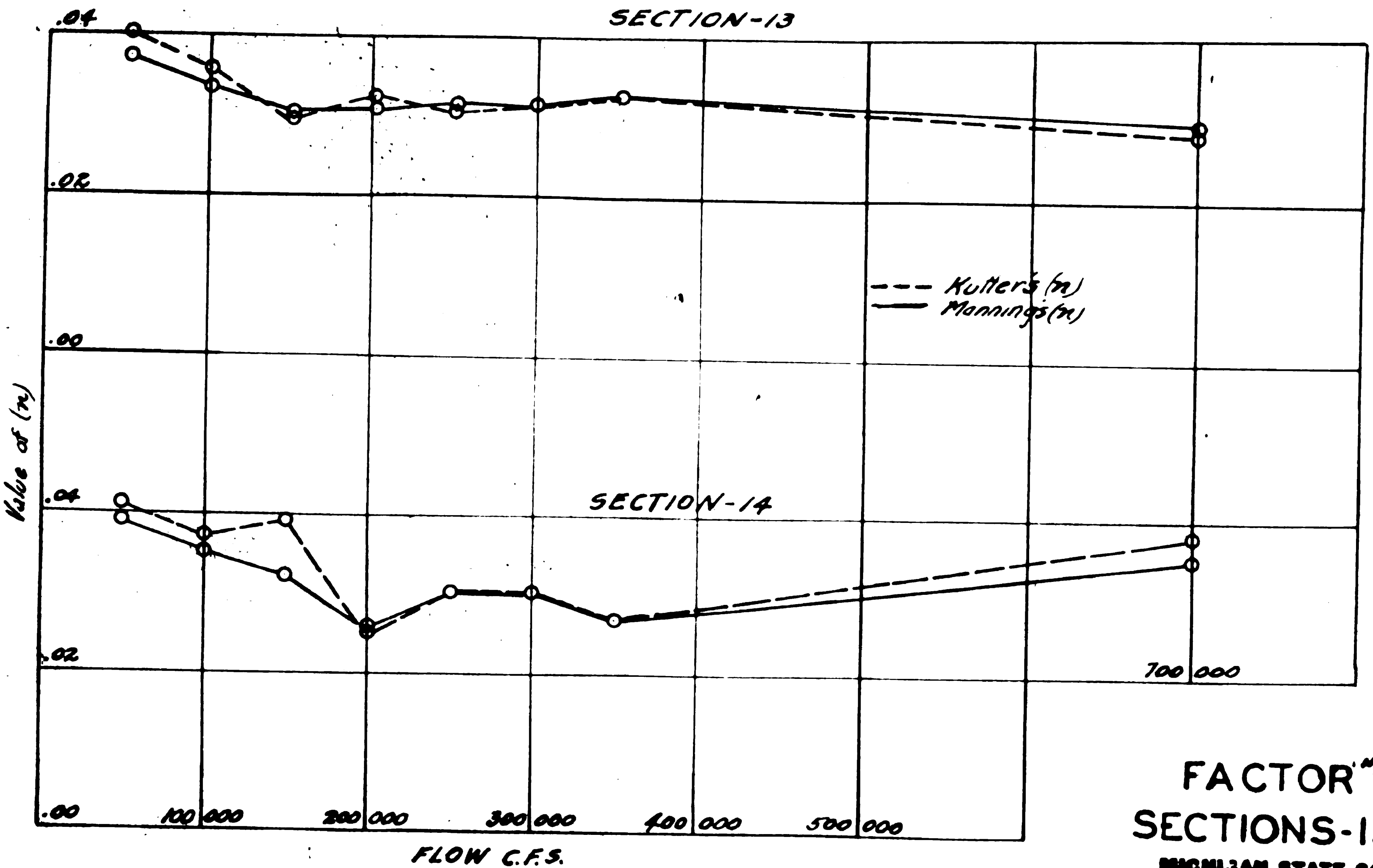
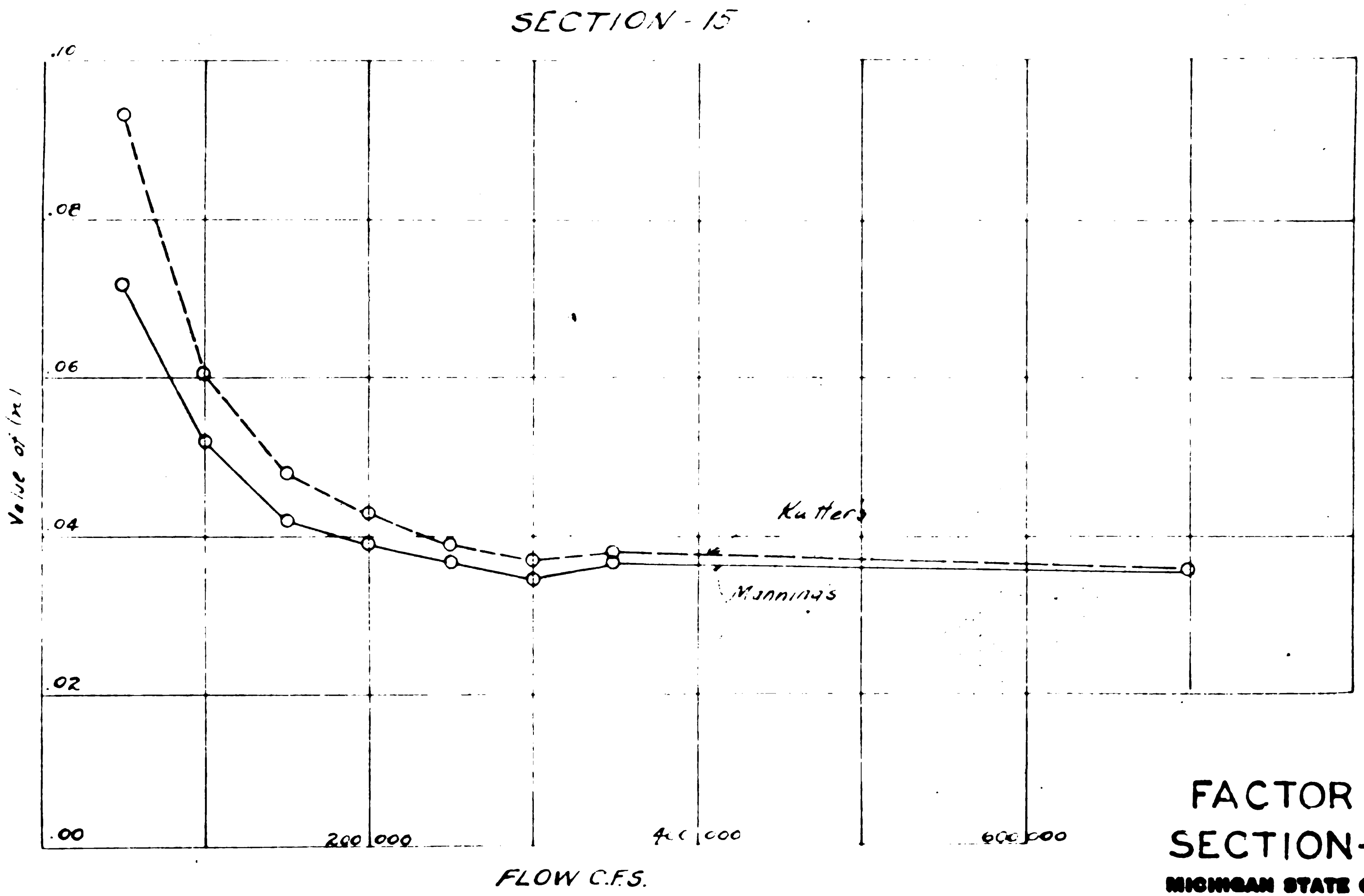
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS 1926

PLATE IV.



FACTOR "n"
SECTIONS-13-14
MICHIGAN STATE COLLEGE
THESIS
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS [illegible]

PLATE V.



FACTOR "n"
SECTION - 15

MICHIGAN STATE COLLEGE
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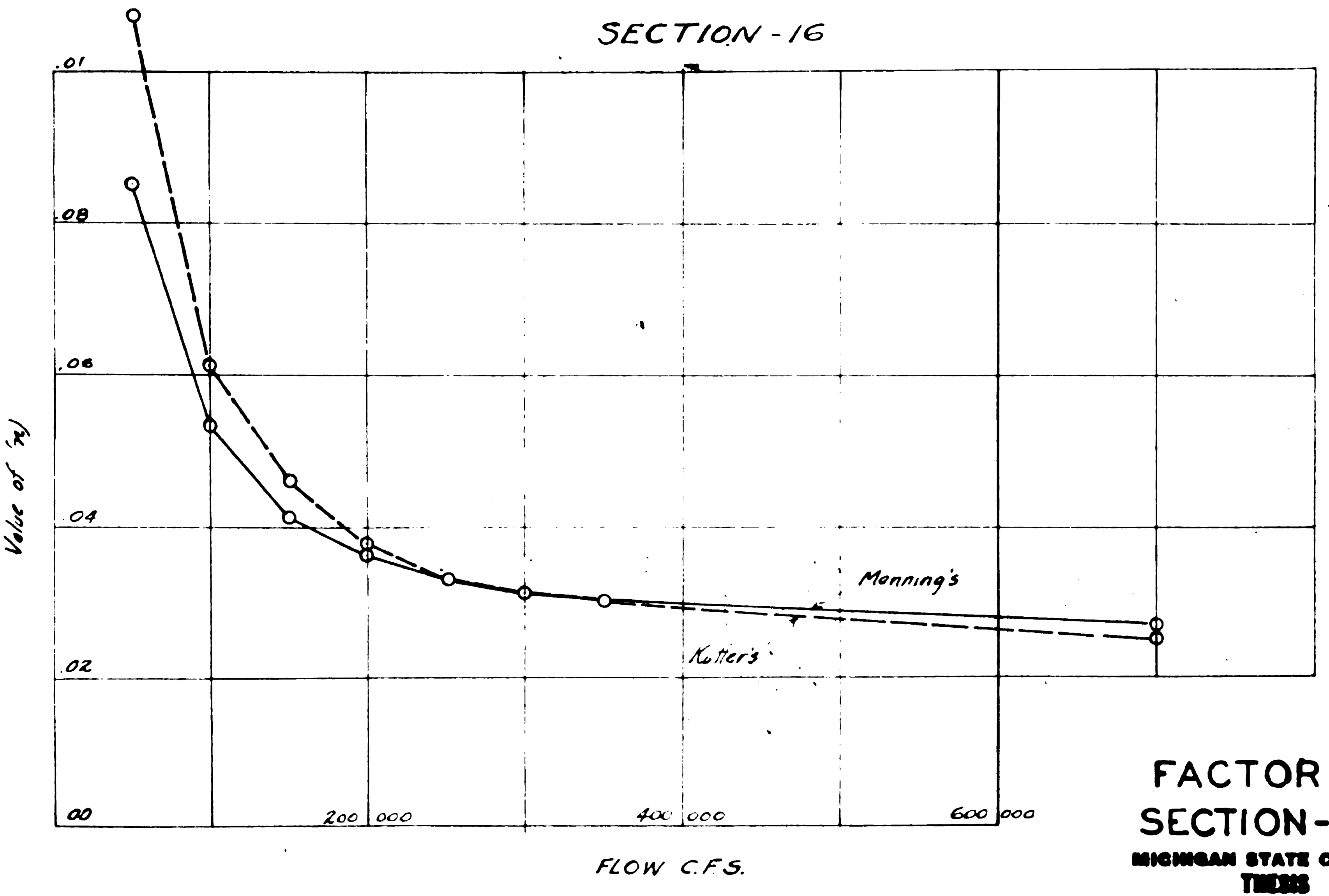
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS [illegible]

PLATE VI.



FACTOR "n"
SECTION-16

MICHIGAN STATE COLLEGE
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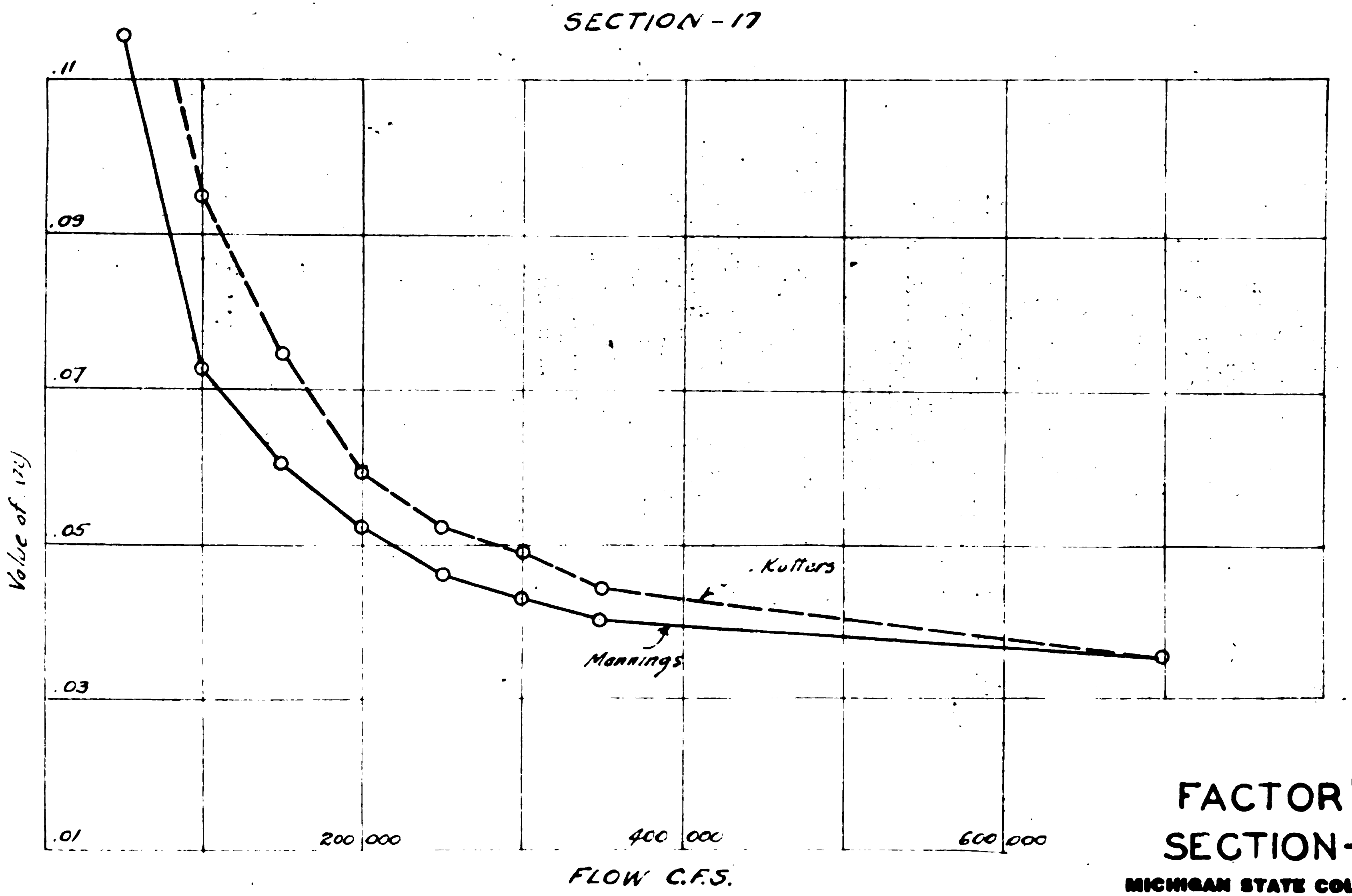
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS 1926

PLATE VII.



FACTOR "n"
SECTION - 17
MICHIGAN STATE COLLEGE
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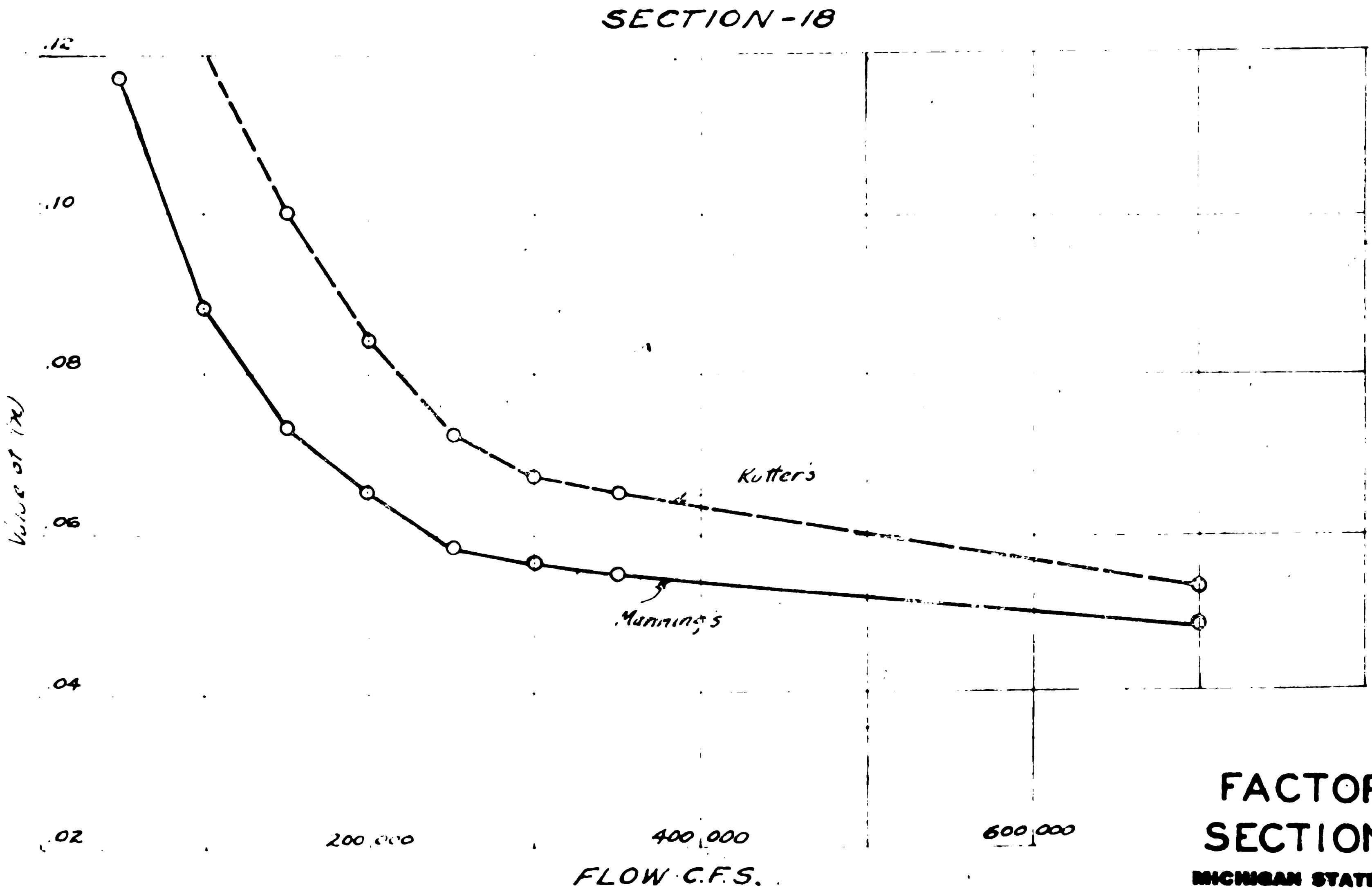
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS 1920
PLATE VIII.



FACTOR "n"
SECTION-18

MICHIGAN STATE COLLEGE
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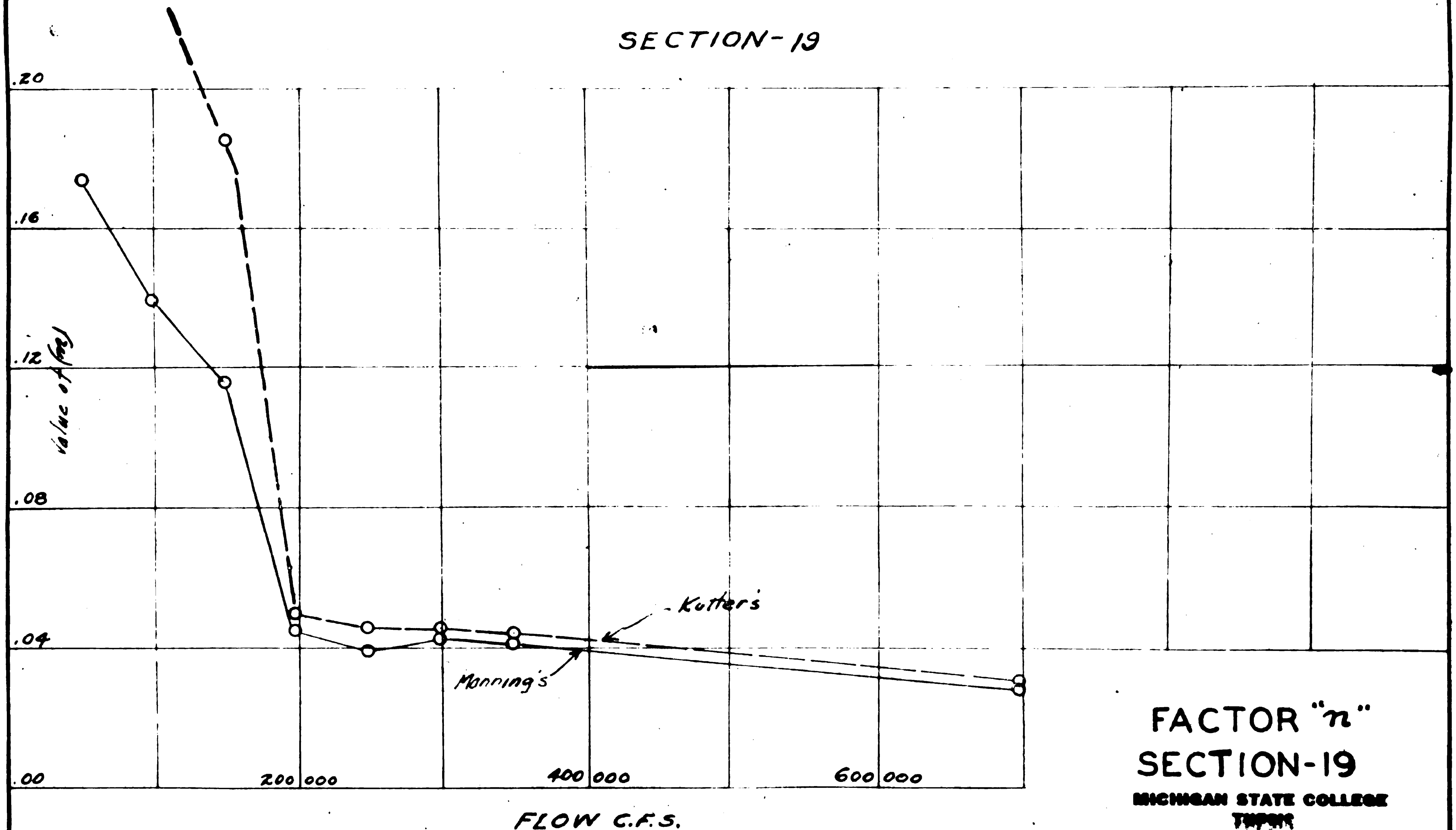
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS [illegible]

PLATE IX.



FACTOR "n"
SECTION-19
MICHIGAN STATE COLLEGE
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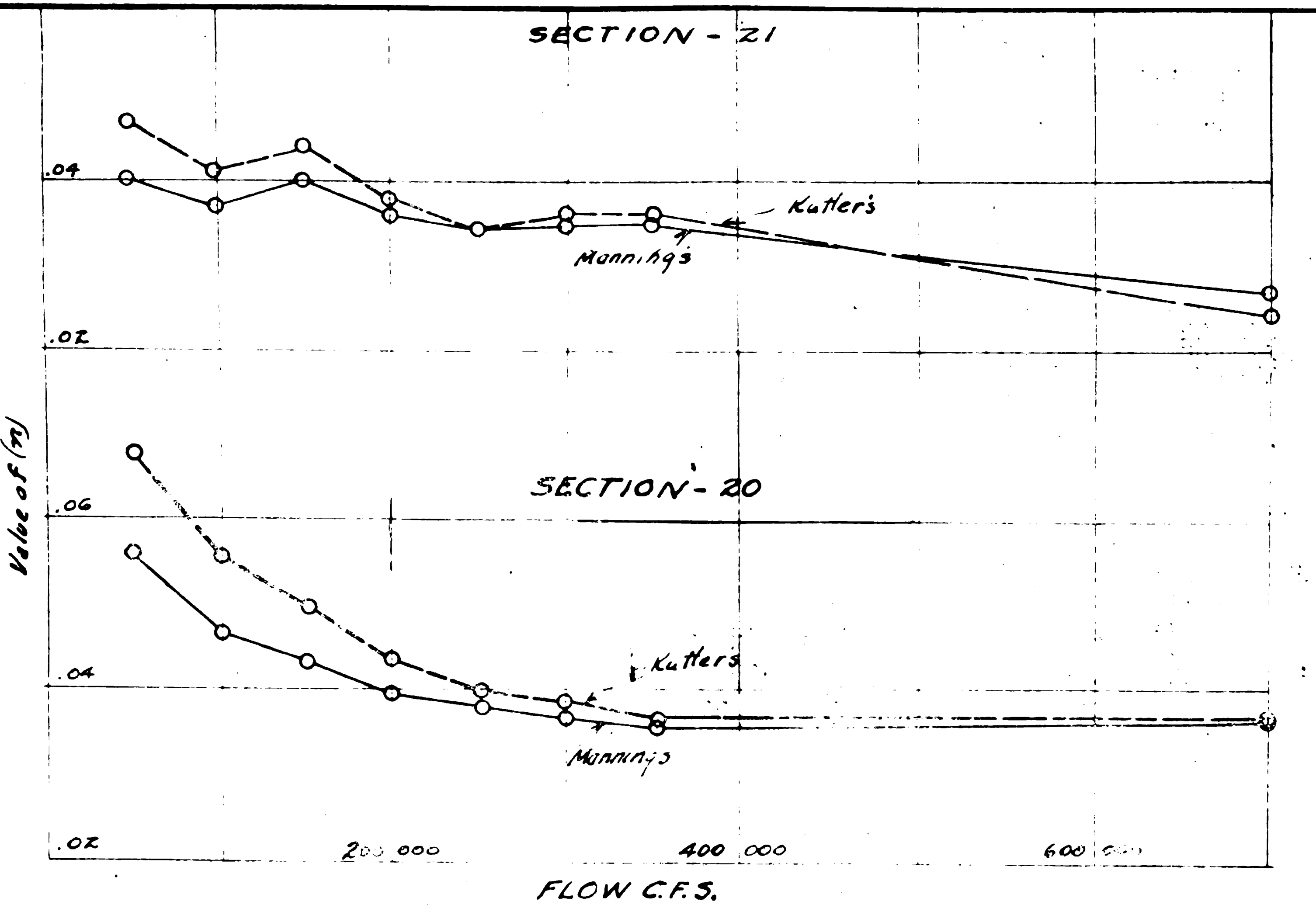
HYDRAULICS OF COLUMBIA RIVER

PLATE X.



FACTOR "n"
SECTIONS-20-21

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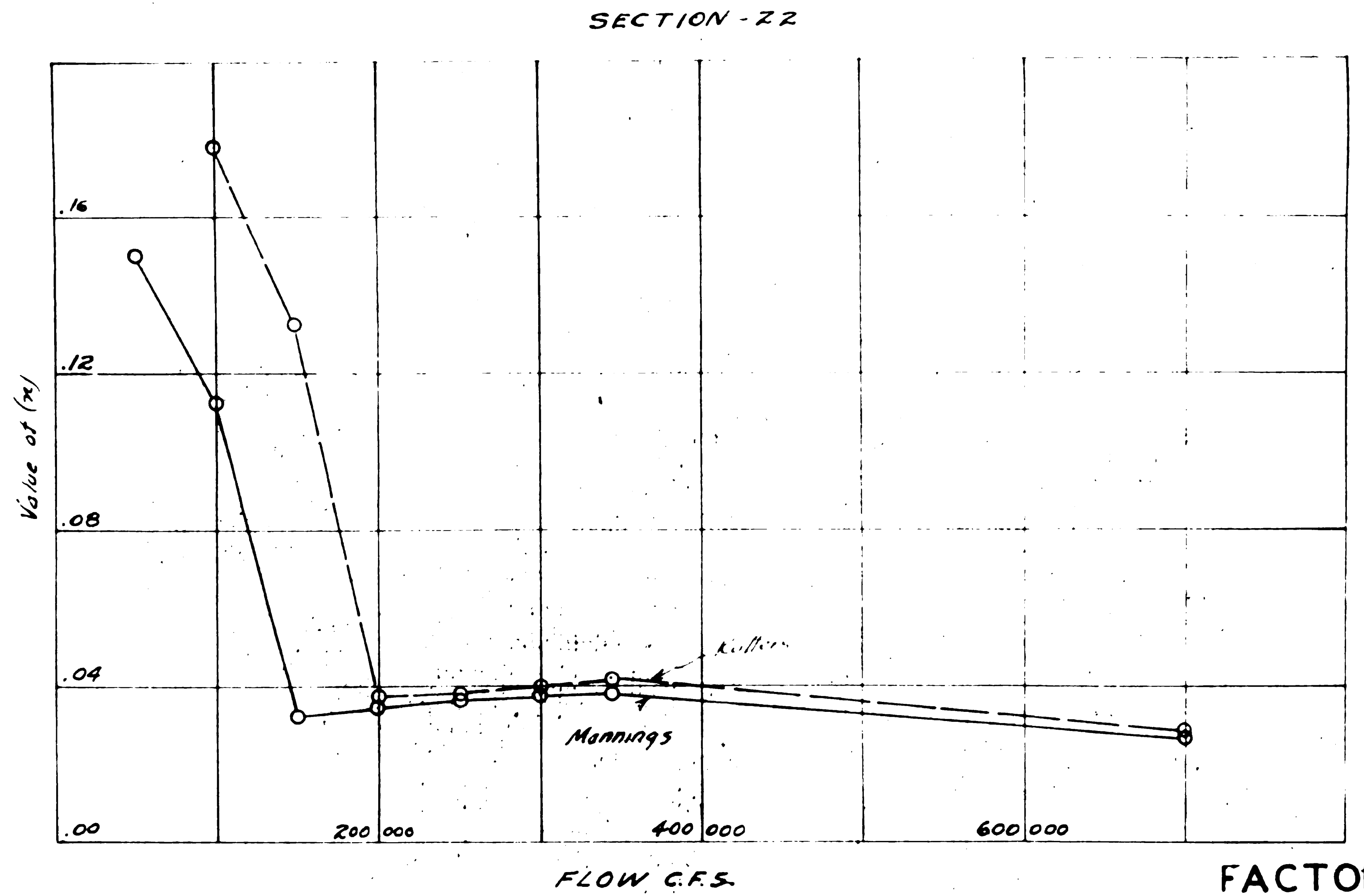
PLATE XI.



FACTOR "n"

SECTION-22

MICHIGAN STATE COLLEGE

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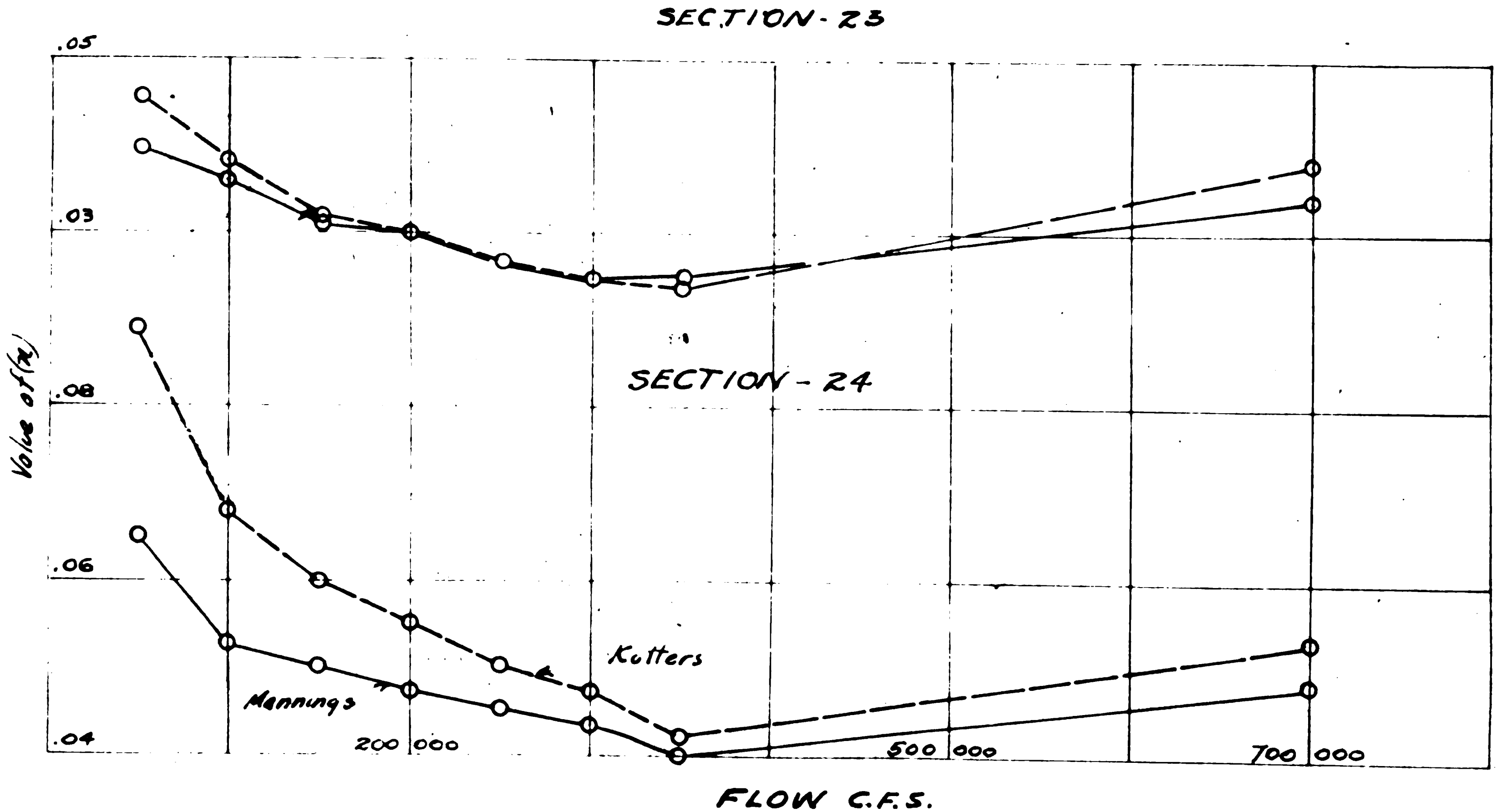
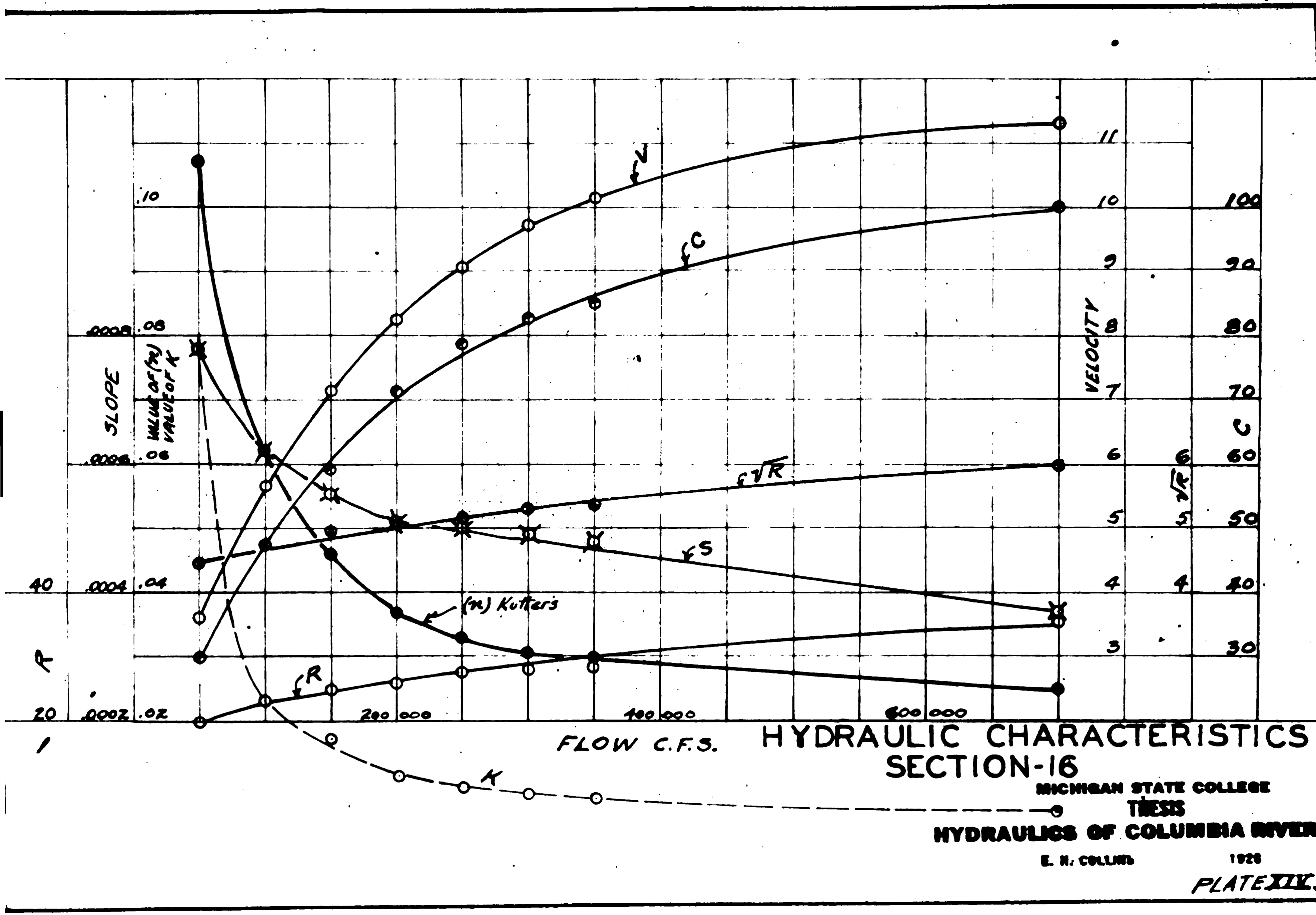
HYDRAULICS OF COLUMBIA RIVER

E. H. COLLINS 1926 PLATE XII

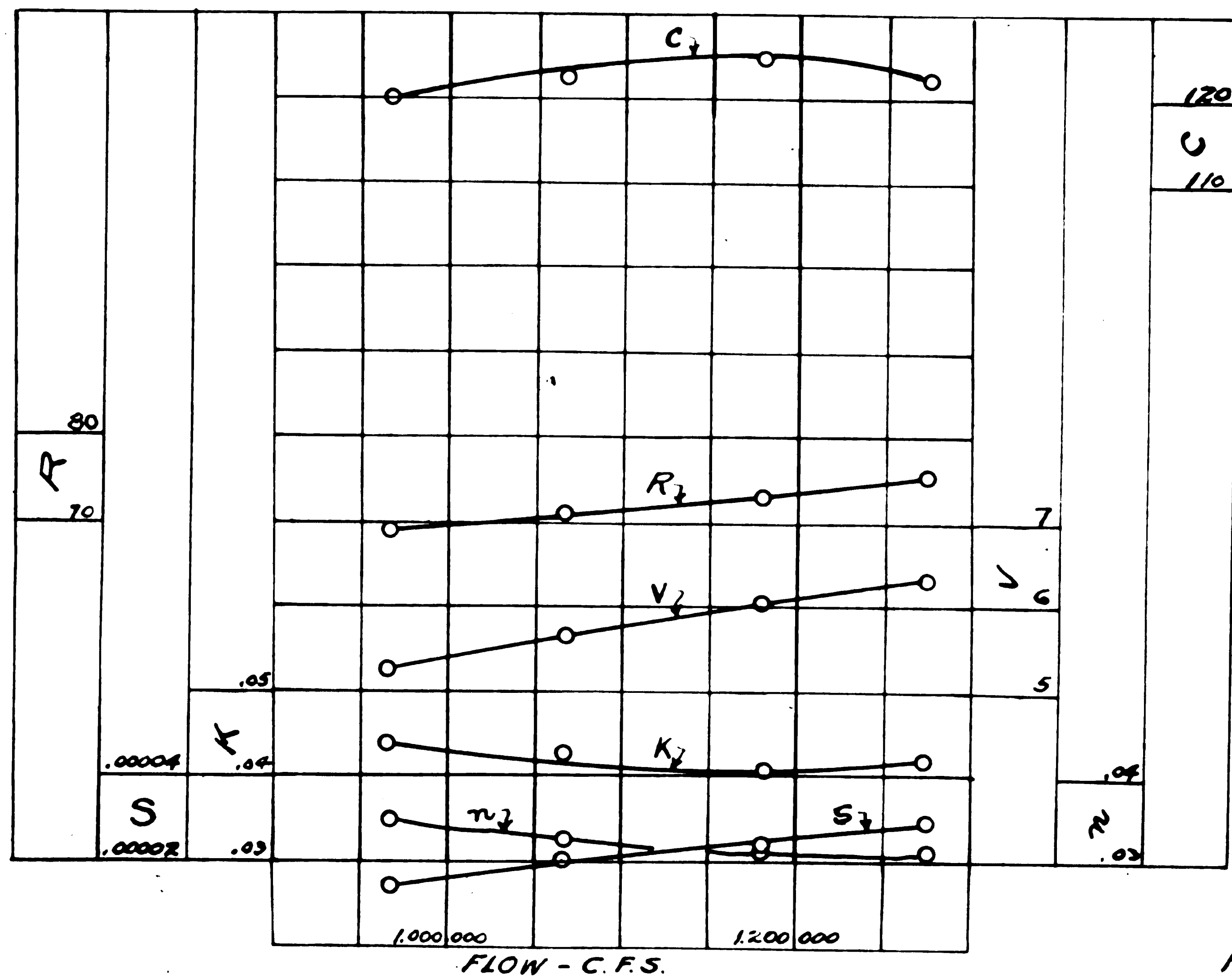


FACTOR "n"
SECTIONS-23-24
MICHIGAN STATE COLLEGE
THESIS
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS 1928
PLATE XIII.



HYDRAULIC CHARACTERISTICS
SECTION-16

MICHIGAN STATE COLLEGE
THESIS
HYDRAULICS OF COLUMBIA RIVER
E. H. COLLINS 1926
PLATE XIV.



HYDRAULIC CHARACTERISTICS
MISSISSIPPI RIVER

PLATE XV.
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HYDRAULICS OF COLUMBIA RIVER
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APPENDIX

COLUMBIA RIVER - HYDRAULIC CHARACTERISTICS

48,000 C. F. S.

Sect.	Distance Ft.	Elevation of water surface	Difference in eleva- tion - ft.	Area Sq. Ft.	Velocity Ft/Sec.	Hydraulic Radius Ft.	Slope between sections	Slope at sections	n_M	n_K
12		1215.80		11,750	4.08	9.8				
	6890		1.95				.000283			
13		1217.75		10,750	4.46	13.0		.000425	.038	.041
	6970		3.95				.000567			
14		1221.70		13,250	3.63	12.0		.000320	.039	.041
	8800		0.65				.000074			
15		1222.35		16,750	2.87	19.5		.000369	.072	.093
	7230		4.80				.000665			
16		1227.15		13,250	3.63	19.5		.000780	.085	.107
	7960		7.13				.000895			
17		1234.28		21,000	2.28	22.5		.000491	.115	.168
	9270		0.82				.000088			
18		1235.10		25,750	1.86	37.75		.000172	.117	.202
	5590		1.43				.000256			
19		1236.53		33,500	1.43	31.50		.000356	.173	.347
	10780		4.92				.000456			
20		1241.45		15,250	3.15	19.00		.000281	.056	.068
	9680		1.04				.000107			
21		1242.49		13,800	3.48	24.75		.000120	.040	.047
	7310		0.97				.000133			
22		1243.46		34,000	1.41	31.50		.000205	.150	.279
	7470		2.07				.000277			
23		1245.53		12,000	4.00	18.00		.000248	.040	.046
	5670		1.27				.000220			
24		1246.80		16,750	2.86	25.75		.000219	.065	.089
	6200		1.35				.000218			
25		1248.15		16,800	2.86	24.40				

COLUMBIA RIVER - HYDRAULIC CHARACTERISTICS

100,000 C. F. S.

Sect.	Distance Ft.	Elevation of water surface	Difference in elevation - ft.	Area Sq.Ft.	Velocity Ft/Sec.	Hydraulic Radius Ft.	Slope between sections	Slope at sections	n_M	n_K
12		1221.70		19,500	5.13	15.70				
	6890		2.40				.000348			
13		1224.10		17,000	5.88	16.20		.000267	.034	.036
	6970		3.75				.000538			
14		1227.85		20,000	5.00	16.00		.000443	.035	.037
	8800		1.15				.000131			
15		1229.00		22,750	4.40	25.25		.000334	.052	.061
	7230		3.65				.000505			
16		1232.65		17,600	5.68	22.80		.000318	.053	.061
	7960		5.95				.000747			
17		1238.60		25,250	3.96	26.75		.000626	.072	.094
	9270		1.55				.000167			
18		1240.15		29,000	3.45	39.80		.000457	.088	.127
	5590		2.47				.000442			
19		1242.62		40,250	2.48	35.50		.000304	.138	.231
	10780		5.08				.000471			
20		1247.70		20,750	4.82	24.00		.000456	.047	.056
	9680		1.90				.000196			
21		1249.60		18,250	5.48	30.00		.000333	.037	.041
	7310		1.50				.000205			
22		1251.10		43,000	2.32	38.00		.000200	.112	.178
	7470		1.83				.000245			
23		1252.93		17,500	5.72	23.40		.000225	.036	.038
	5670		1.77				.000312			
24		1254.70		23,000	4.35	30.25		.000278	.053	.068
	6200		1.40				.000226			
25		1256.10		22,600	4.42	30.50				

COLUMBIA RIVER - HYDRAULIC CHARACTERISTICS

150,000 C. F. S.

Sect.	Distance Ft.	Elevation of water surface	Difference in elevation - ft.	Area Sq. Ft.	Velocity Ft/Sec.	Hydraulic Radius Ft.	Slope between sections	Slope at sections	n_M	n_K
12		1225.80		25,000	6.00	19.50				
	6890		2.60				.000377			
13		1228.40		21,800	6.88	18.50		.000429	.031	.034
	6970		3.35				.000481			
14		1231.75		25,000	6.00	19.00		.000323	.032	.027
	8800		1.45				.000165			
15		1233.20		26,700	5.62	28.70		.000293	.042	.030
	7230		3.05				.000422			
16		1236.25		21,000	7.15	24.40		.000559	.041	.049
	7960		5.55				.000697			
17		1241.80		30,000	5.00	28.75		.000459	.060	.048
	9270		2.05				.000221			
18		1243.85		31,800	4.72	40.20		.000388	.073	.046
	5590		3.10				.000555			
19		1246.95		45,500	3.30	38.00		.000509	.115	.074
	10780		5.00				.000464			
20		1251.95		24,500	6.12	27.80		.000387	.044	.100
	9680		3.00				.000310			
21		1254.96		22,300	6.73	33.50		.000301	.040	.184
	7310		2.14				.000293			
22		1257.10		26,500	5.66	25.50		.000200	.032	.050
	7470		0.80				.000107			
23		1257.90		21,800	6.88	26.75		.000256	.031	.044
	5670		2.30				.000406			
24		1260.20		27,500	5.46	34.50		.000308	.050	.132
	6200		1.30				.000210			
25		1261.50		27,000	5.56	35.00				

COLUMBIA RIVER - HYDRAULIC CHARACTERISTICS

200,000 C. F. S.

Sect.	Distance Ft.	Elevation of water surface	Difference in elevation - ft.	Area Sq. Ft.	Velocity Ft/Sec.	Hydraulic Radius Ft.	Slope between sections	Slope at sections	n_M	n_K
12		1229.10		30,000	6.67	22.50				
	6890		2.95				.000428			
13		1232.05		26,000	7.70	21.00		.000432	.031	.033
	6970		3.05				.000437			
14		1235.10		29,700	6.74	22.00		.000216	.026	.025
	8800		1.70				.000194			
15		1236.80		30,000	6.67	32.00		.000300	.039	.043
	7230		2.95				.000408			
16		1239.75		24,250	8.25	25.75		.000516	.036	.037
	7960		4.97				.000624			
17		1244.72		31,750	6.30	32.50		.000454	.052	.059
	9270		2.63				.000284			
18		1247.35		34,700	5.76	40.50		.000451	.065	.084
	5590		3.45				.000618			
19		1250.80		27,250	7.34	27.25		.000578	.044	.049
	10780		4.70				.000437			
20		1255.50		28,000	7.14	31.50		.000374	.040	.044
	9680		3.00				.000310			
21		1258.50		25,000	8.00	36.00		.000312	.036	.038
	7310		2.30				.000315			
22		1260.80		30,500	6.56	29.00		.000260	.035	.037
	7470		1.52				.000204			
23		1262.32		26,250	7.60	27.70		.000276	.030	.030
	5670		1.98				.000349			
24		1264.30		31,500	6.35	38.00		.000320	.047	.055
	6200		1.80				.000291			
25		1266.10		30,500	6.56	38.50				

COLUMBIA RIVER - HYDRAULIC CHARACTERISTICS

250,000 C. F. S.

Sect.	Distance Ft.	Elevation of water surface	Difference in elevation - ft.	Area Sq. ft.	Velocity Ft/sec.	Hydraulic Radius Ft.	Slope between sections	Slope at sections	n_M	n_K
12		1231.70		34,000	7.36	25.00				
	6890		3.25				.000465			
13		1234.95		30,000	8.35	24.00		.000444	.032	.031
	6970		2.95				.000423			
14		1237.90		33,500	7.48	24.50		.000317	.030	.030
	8800		1.75				.000211			
15		1239.65		33,000	7.60	34.50		.000319	.037	.039
	7230		3.10				.000428			
16		1242.75		27,500	9.10	26.70		.000499	.033	.033
	7960		4.55				.000570			
17		1247.30		35,000	7.16	35.00		.000430	.046	.052
	9270		2.70				.000291			
18		1250.00		36,750	6.80	40.70		.000496	.058	.072
	5590		3.93				.000701			
19		1253.95		30,500	8.20	29.50		.000560	.038	.045
	10780		4.52				.000420			
20		1258.45		31,000	8.08	34.50		.000374	.038	.040
	9680		3.18				.000329			
21		1261.63		27,000	9.27	38.00		.000350	.034	.034
	7310		2.72				.000372			
22		1264.35		35,000	7.16	32.00		.000286	.036	.037
	7470		1.50				.000201			
23		1265.85		29,800	8.40	27.40		.000290	.027	.027
	5670		2.15				.000379			
24		1268.00		35,000	7.16	41.00		.000331	.045	.050
	6200		1.76				.000284			
25		1269.76		33,500	7.48	41.50				

COLUMBIA RIVER - HYDRAULIC CHARACTERISTICS

300,000 C. F. S.

Sect.	Distance Ft.	Elevation of water surface	Difference in elevation - ft.	Area Sq. Ft.	Velocity Ft/Sec.	Hydraulic Radius Ft.	Slope between sections	Slope at sections	n M	n K
12		1234.45		38,500	7.80	28.00				
	6890		3.30				.000480			
13		1237.75		33,500	8.95	26.50		.000453	.032	.032
	6970		2.97				.000426			
14		1240.72		37,500	8.00	27.30		.000320	.030	.030
	8800		1.88				.000214			
15		1242.60		36,000	8.35	37.00		.000313	.035	.037
	7230		2.98				.000413			
16		1245.58		31,000	9.67	27.70		.000484	.031	.031
	7960		4.42				.000555			
17		1250.00		37,500	8.00	37.50		.000434	.043	.049
	9270		2.90				.000313			
18		1252.90		39,500	7.60	43.50		.000529	.056	.067
	5590		4.40				.000746			
19		1257.30		34,500	8.70	32.00		.000577	.042	.045
	10780		4.40				.000408			
20		1261.70		34,000	8.82	37.50		.000380	.037	.039
	9680		3.40				.000352			
21		1265.10		30,000	10.00	41.00		.000395	.035	.036
	7310		3.20				.000438			
22		1268.30		39,500	7.60	35.50		.000309	.037	.039
	7470		1.35				.000181			
23		1269.65		34,000	8.80	27.00		.000271	.025	.025
	5670		2.05				.000362			
24		1271.70		38,500	7.80	44.00		.000336	.044	.047
	6200		1.92				.000310			
25		1273.62		37,000	8.10	44.50				

COLUMBIA RIVER - HYDRAULIC CHARACTERISTICS

350,000 C. F. S.

Sect.	Distance Ft.	Elevation of water surface	Difference in elevation - ft.	Area Sq. Ft.	Velocity Ft/Sec.	Hydraulic Radius Ft.	Slope between sections	Slope at sections	n_M	n_K
12		1236.80		42,000	8.34	30.50				
	6890		4.25				.000616			
13		1241.15		38,200	9.17	29.20		.000458	.033	.033
	6970		2.10				.000301			
14		1243.25		42,000	8.34	29.50		.000258	.027	.027
	8800		1.90				.000216			
15		1245.15		39,000	9.00	39.00		.000375	.037	.038
	7230		3.13				.000434			
16		1248.28		34,500	10.15	28.50		.000479	.030	.030
	7960		4.17				.000524			
17		1252.45		40,200	8.70	39.20		.000416	.040	.044
	9270		2.85				.000308			
18		1255.30		41,500	8.45	45.50		.000601	.055	.065
	5590		5.00				.000894			
19		1260.30		37,500	9.35	34.00		.000582	.040	.043
	10780		4.00				.000371			
20		1264.30		37,000	9.46	40.00		.000377	.036	.037
	9680		3.70				.000383			
21		1268.00		32,000	10.95	43.20		.000434	.035	.036
	7310		3.55				.000486			
22		1271.55		43,500	8.05	36.50		.000524	.039	.041
	7470		1.35				.000181			
23		1272.90		39,500	8.86	26.70		.000308	.025	.024
	5670		2.03				.000358			
24		1274.93		41,500	8.45	46.70		.000894	.040	.042
	6200		1.57				.000253			
25		1276.50		39,400	8.88	46.50				

COLUMBIA RIVER - HYDRAULIC CHARACTERISTICS

700,000 C. F. S.

Sect.	Distance Ft.	Elevation of water surface	Difference in eleva- tion - ft.	Area Sq. Ft.	Velocity Ft/Sec.	Hydraulic Radius Ft.	Slope between sections	Slope at sections	n_M	n_K
12		1252.00		66,500	10.53	44.00				
	6890		3.00				.000435			
13		1255.00		55,500	12.72	41.50		.000468	.030	.029
	6970		3.50				.000502			
14		1258.50		62,000	11.29	42.50		.000478	.035	.038
	8800		4.00				.000454			
15		1262.50		57,000	12.27	54.70		.000434	.036	.036
	7230		3.00				.000415			
16		1265.50		62,000	11.29	35.70		.000364	.027	.025
	7960		2.50				.000314			
17		1268.00		57,500	12.17	49.00		.000480	.036	.036
	9270		6.00				.000646			
18		1274.00		58,500	11.96	60.00		.000636	.048	.053
	5590		3.50				.000626			
19		1277.50		49,700	14.08	40.30		.000577	.030	.028
	10780		5.70				.000528			
20		1283.20		58,500	11.96	52.00		.000460	.037	.037
	9680		3.80				.000392			
21		1287.00		48,500	14.43	59.00		.000298	.027	.024
	7310		1.50				.000205			
22		1288.50		66,000	10.60	49.00		.000236	.029	.027
	7470		2.00				.000268			
23		1290.50		76,500	9.15	35.50		.000442	.034	.038
	5670		3.50				.000617			
24		1294.00		61,000	11.46	63.30		.000550	.045	.053
	6200		3.00				.000483			
25		1297.00		58,500	11.96	61.50				

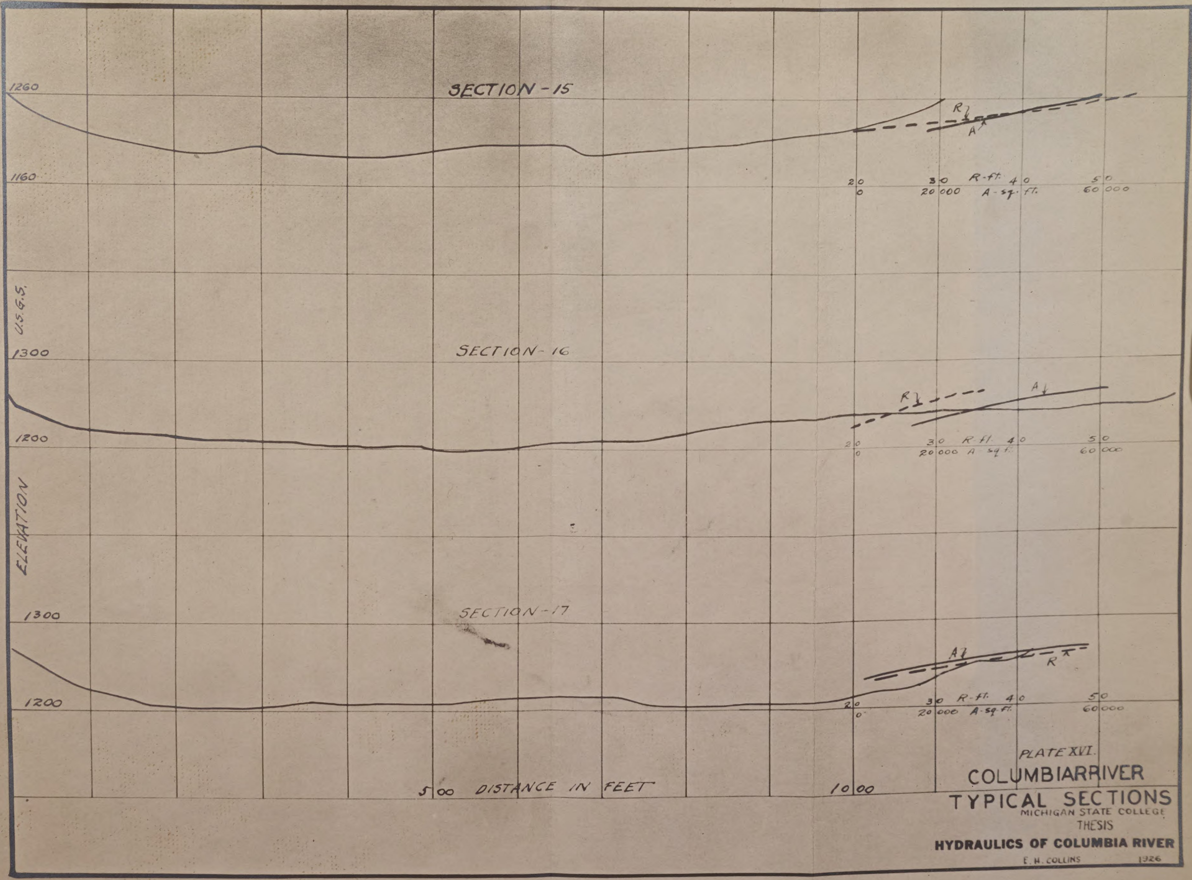

PLATE XVI.

COLUMBIA RIVER

TYPICAL SECTIONS

MICHIGAN STATE COLLEGE

THESIS

HYDRAULICS OF COLUMBIA RIVER

E. H. COLLINS 1926