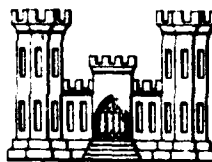


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SYLLABUS

The data gathered in the 1971 Hydrographic Survey of the Missouri River by the U.S. Army Corps of Engineers, Omaha District, were studied to determine the relationships between the physical features (i.e., area, control structures, and bend geometry) to the hydraulic parameters (i.e., average velocity, shear velocity, and resistance to flow). Recommendations concerning data collection are presented.

The results of the analysis show that resistance to flow is directly proportional to flow area and the hydraulic radius, whereas it is indirectly proportional to the velocity. The effects of the bend geometry (radius of curvature, length of bend, and central angle of bend) on the resistance to flow seem to be masked out by effects of the major sand bars, by training works constructed along the reaches, and by changes in the bed roughness. A steady increase in the size of bed material is present for the whole reach studied, indicating possible changes in the resistance to flow. Also, potential points or problem areas in terms of navigation depth and local aggradation can be found through inspection of the six plates prepared from the data.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Letter on file

A

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PLATES 1-6	Included separately

PURPOSE

The purpose of this investigation is to:

- (1) Evaluate and relate the hydraulic parameters of the Missouri River from Sioux City, Iowa to Rulo, Nebraska to the physical features of the channel such as channel width, control structures, and bend geometry; *and*
- (2) Offer recommendations regarding further data collection and computational programs.

The data supplied for analysis includes:

- (1) Tabulation of Calculated Hydraulic Parameters,
 - (2) 1971 Hydrographic Survey, *and*
 - (3) Water Temperature Data.
- 

DESCRIPTION

This study utilizes the basic data provided by the Omaha District of the Corps of Engineers. The basic data include a tabulation of calculated hydraulic parameters which is displayed in the appendix, and the maps and data of the 1971 hydrographic survey of the Missouri River.

To more clearly ascertain the actual effects of the physical features of the channel (control structures, width, area, and bend geometry) on the hydraulic parameters involved with the channel flow (average velocity, shear velocity, resistance to flow, etc.), a comprehensive set of figures were made whereby selected basic data and computed parameters were plotted as a function of river mile from Sioux City, Iowa to Rulo, Nebraska. These figures clearly illustrate the interaction between the alignment of the channel, the water surface slope, characteristics of the bed material, top width of the channel, the cross sectional area of the flow in the channel, the hydraulic radius of the channel, the average velocity in the channel, the shear velocity in the channel, and the resistance to flow in the system as denoted by Manning's resistance coefficient (Plates 1-6). Each parameter on the plates has its own vertical scale whereas the horizontal scale is marked every five miles and is the same for all parameters. Each point on the figures corresponds to the average value of the respective parameter for the river reach beginning at the river mile represented by that point and ending at the mile represented by the next point downstream. Thus each point indicates the beginning of the bend or crossing and represents the value of that parameter for that reach which ends at the location of the next point.

In addition to the view of the trends and effects offered by the plates, four figures were prepared to show the effect of bend area, central angle, length, and radius of curvature on flow resistance. All bends in the study length were measured for θ , L_b , and R_c , and those values along with the area of the bends A_c were plotted against flow resistance as shown in figures 1-4.

RESULTS OF THE INVESTIGATION

The data utilized in this report were collected for the whole system over a sufficiently short period of time so that the discharge remained essentially constant (from 48,000 to 52,000 cfs). This condition allows an excellent opportunity to study the variation in the hydraulic parameters over a relatively long reach of river.

Referring to Plates 1-6, many interesting and important points pertinent to the understanding of the river mechanics of the system are found. Study of the plates indicates that where the area of the water cross section is small, the hydraulic radius and resistance to flow are correspondingly small, whereas the velocity is correspondingly large. In this regard, Plates 1-6 give considerable positive and useful evidence showing how the hydraulics of the system relate to the geometry of the system. Additional positive points resulting from analysis of Plates 1-6, as well as identification of problem areas and work that should be done as a follow-up, will be identified in the conclusions.

Although Plates 1-6 give considerable evidence of the interaction of the geometric and hydraulic properties of the system, some limitations of comparison appear as one tries to determine the relationships between resistance to flow and the geometry of bends. Figures 1, 2, and 3 have been prepared to show the relationship of resistance to flow as represented by u/u_* to radius of curvature, central angle, and length of bends. The only conclusion to be made from Figures 1, 2, and 3 is that there is no close correlation between the resistance to flow and the radius of curvature, central angle, and length of bends in this system. There appears to be a greater variation in resistance to flow due to changes in the hydraulic parameters such as area and slope. Figure 4 shows the close correlation between area and resistance to flow.

In attempting to relate the control structures to hydraulic parameters, specifically to structure density and the form resistance, a scattering of

points indicated that the data provided no positive relationship. Structure density is a vague term which is hard to uniformly quantify, since varying types of control structures exist along the length of the river and their influence is difficult to single out. Also, other factors of form resistance such as bed forms and bar formations exert an influence on form resistance. Because of the interaction of many variables on the form resistance and the fact that structure density is hard to quantify, a relationship between control structures and form resistance is not evident in the data.

CONCLUSIONS

The data compiled for the Missouri River offers a comprehensive look at the mechanics of flow in the reach covered by the data. Such comprehensive data over a long reach of river for essentially constant discharge gives an excellent opportunity to determine how such critical variables as resistance to flow, shear velocity, average velocity, hydraulic radius, area, top width, and grain size vary in such a system. More specifically, (1) by referring to Plates 1-6 it is obvious that where the cross sectional area of the water is relatively small, the resistance to flow is relatively small, the hydraulic radius is relatively small, and the average velocity is relatively larger. Conversely, where the cross sectional area of the water is larger, the forms of bed roughness have increased the resistance to flow and the average velocity is consequently smaller.

(2) Studying the effects of radius of curvature, length, and internal angle of each bend, it is difficult to find any correlation between these variables and the resistance to flow. With the data available to us it is our conclusion that such geometric factors as length, internal angle, and radius of curvature of bends do have an effect on resistance to flow, but in this instance their effects are masked by changes in the bed roughness, by the effect of major sand bars, and by revetment and training works constructed along the reaches. It is possible that additional analysis could determine which parameters are most sensitive under various flow conditions and at what point bend geometry could become an important influence of flow resistance.

(3) An interesting observation of the characteristics of the bed material is that both the D65 and D35 sizes of the bed material increase with river distance throughout the reach from Sioux City to Rulo. The increase in size of bed material is approximately 25 percent for the reach. This is an extremely interesting phenomenon and with additional study should

be related to changes in resistance to flow, sediment transport, the form of bed roughness, and velocities in the system.

(4) Studying Plates 1-6 enables one to compare key variables with the planned geometry of the system, and it is easily ascertained where potential problem areas may exist in terms of navigation depth, local aggradation, and so forth. Inspection of the plates shows specific bends and crossings which have abrupt changes in the average values of parameters such as area, flow resistance, velocity, and hydraulic radius which reflect on the ability of that reach to transport sediment and maintain desired cross-sectional characteristics. For example, reaches with larger areas and lower velocities have lower transport capabilities which may indicate possible aggradation areas accompanied by a less stable cross-section and possible navigation problems. Areas vulnerable to additional degradation may be found where relatively higher velocities exist along reaches with smaller relative cross sectional areas.

(5) It should be stressed that with the data available and some additional sediment transport analysis, it is possible to compute the sediment transport for each sub-reach throughout the total system. Having done these computations one could quite adequately determine source and sink areas of sediment along the whole system, which should correlate extremely well with navigation problems, channel changes, and need for dredging.

Based upon the analysis of this report, it is desirable to make certain recommendations concerning additional computational programs and additional data or hydraulic parameter analyses which would possibly aid in further evaluation.

It would be extremely worthwhile to expand the data collected for this study to include similar data measured at other discharges and temperatures of flow. This additional information would provide better insight to the variation of resistance to flow with stage or discharge and also help evaluate

the effects of temperature on resistance to flow, stage, and bed forms in the river system.

Sediment transport in the system was not a part of the study. However, sediment transport is an essential and important part of the river system that should be considered in future study. In this regard, it would be extremely worthwhile to study the transport capability of the river system, reach by reach, and put this together so that one has an understanding of the transport of the total system. Possibly by putting computed bed material transport on Plates 1-6, additional insight to the problem could be obtained. This would become even more valuable should data similar to that provided for this report be collected at different discharges. If such data were taken, it would give extremely important information on the variability of transport throughout the system for different discharges. This could be useful from the viewpoint of planning future channel changes and studying navigation problems in greater detail.

Another function related to the transport capacity of the river is ψ . Study of this function should reveal potential aggradation and degradation problems and also give some insight to bed configuration and resistance to flow.

APPENDIX

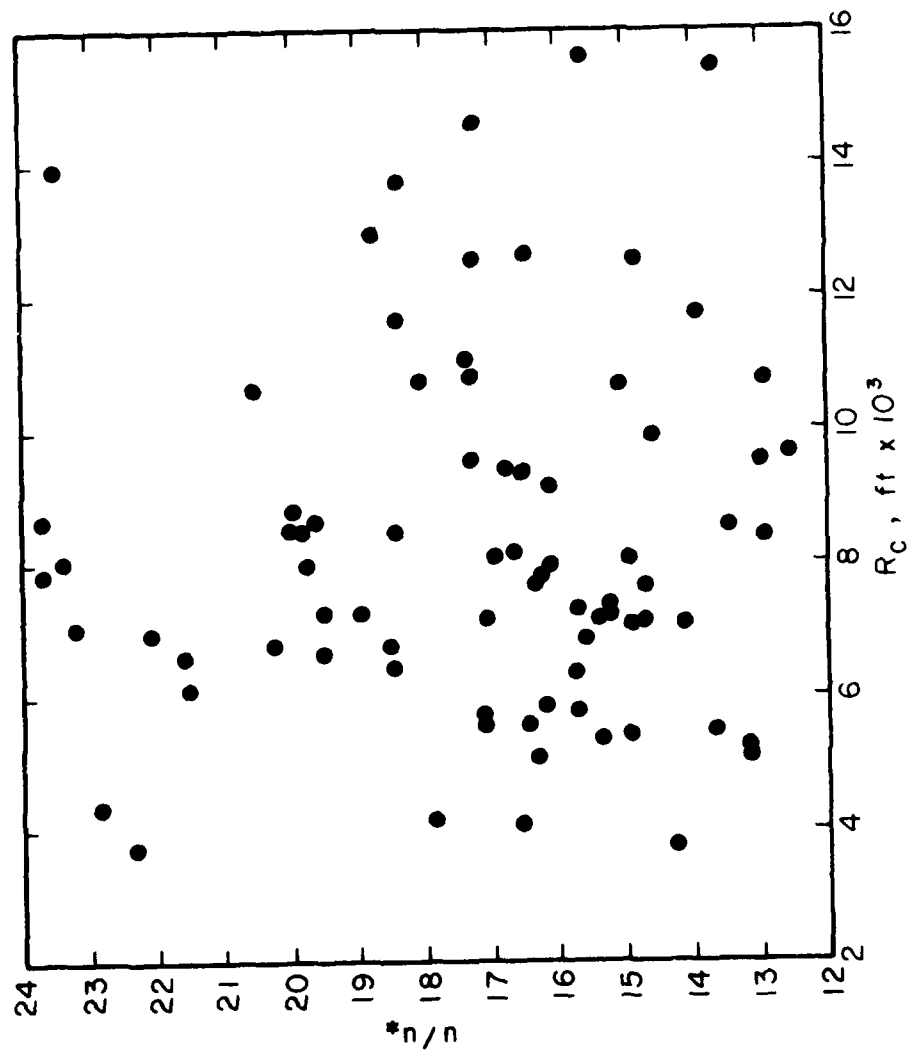


FIGURE 1. RELATIONSHIP BETWEEN RADIUS OF CURVATURE AND FLOW RESISTANCE

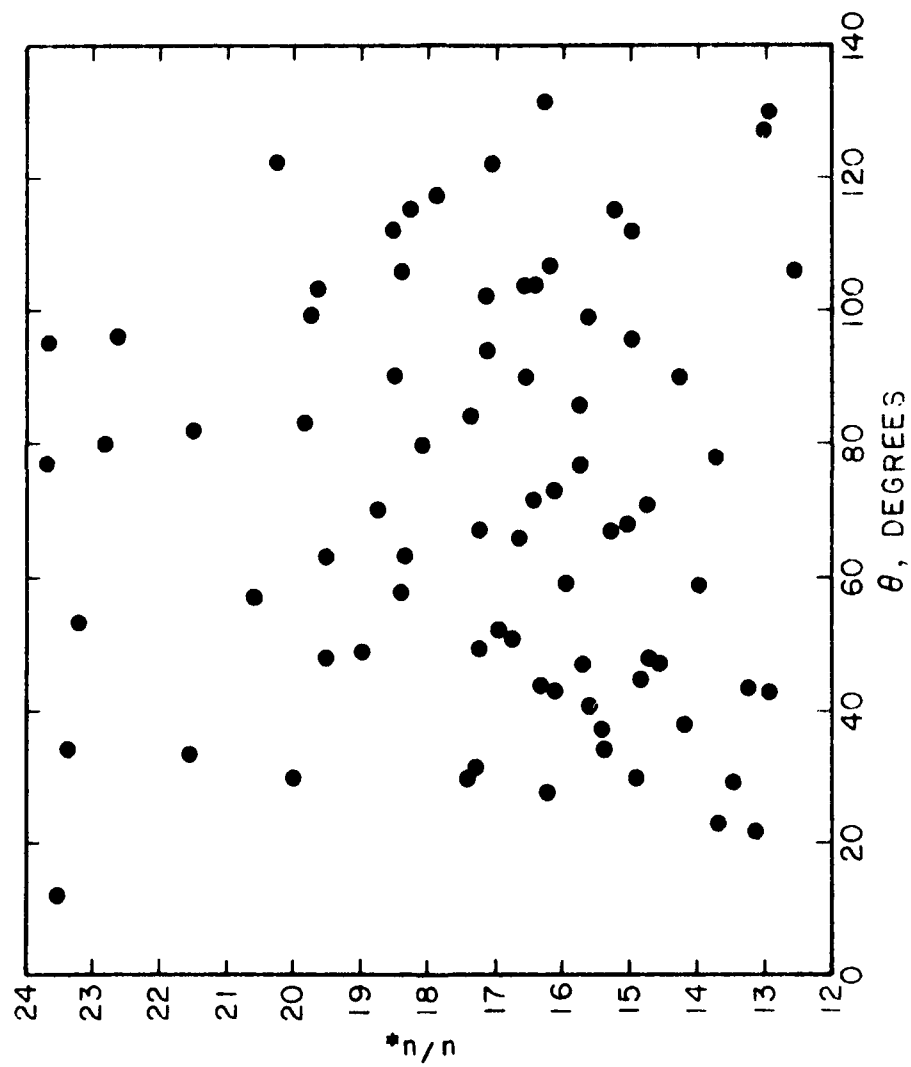


FIGURE 2. RELATIONSHIP BETWEEN CENTRAL ANGLE AND FLOW RESISTANCE

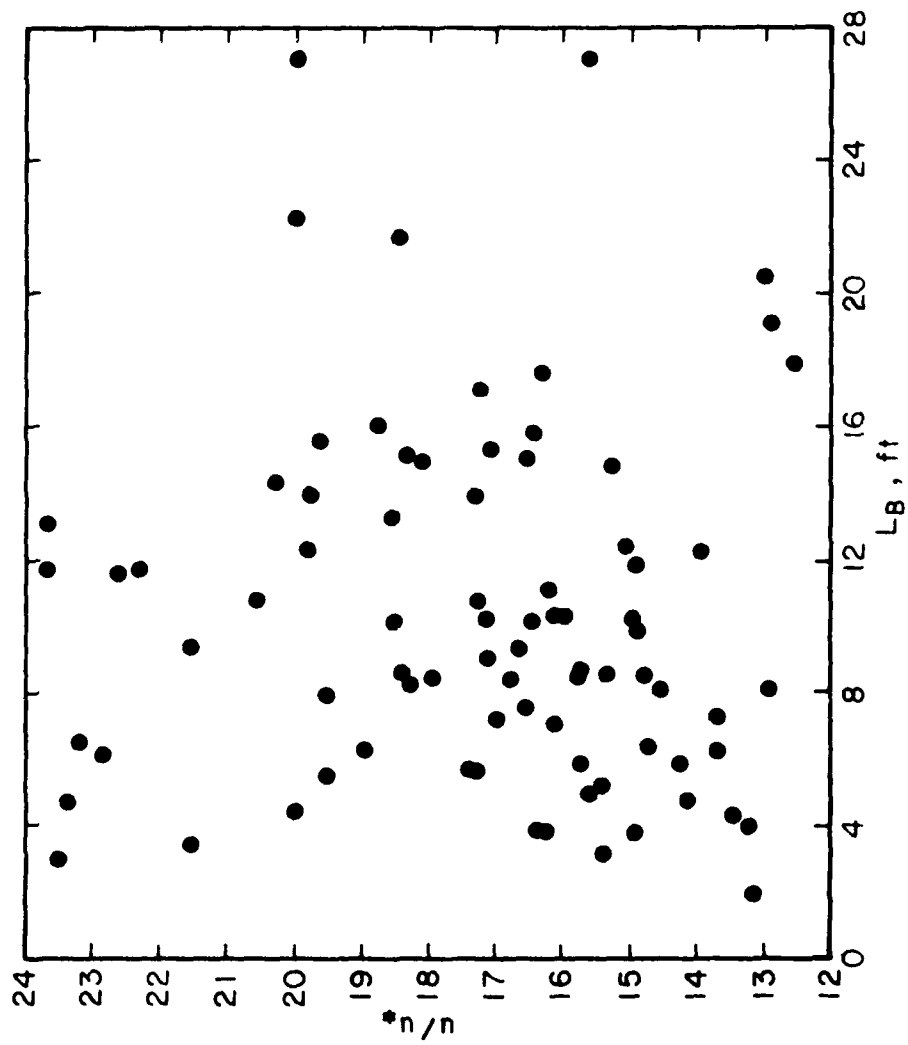
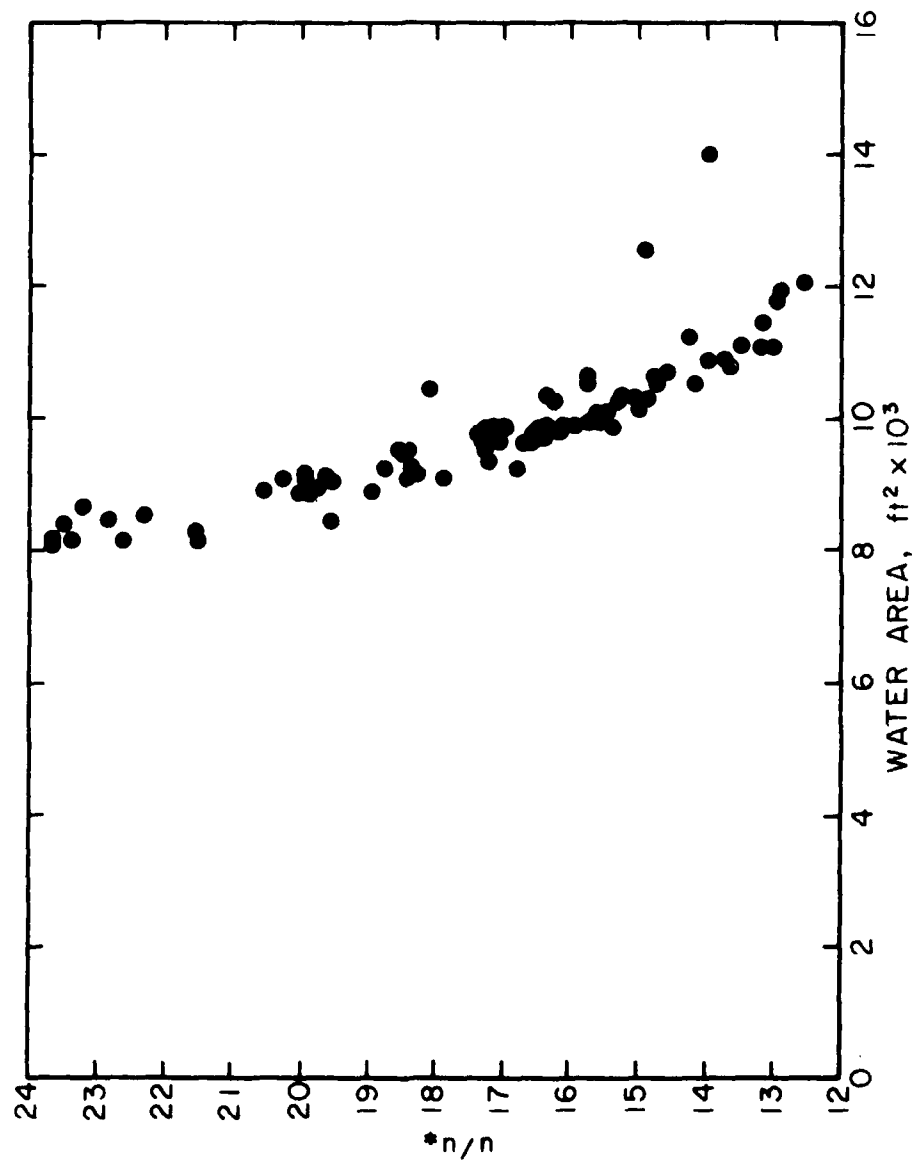


FIGURE 3. RELATIONSHIP BETWEEN LENGTH OF BEND AND FLOW RESISTANCE



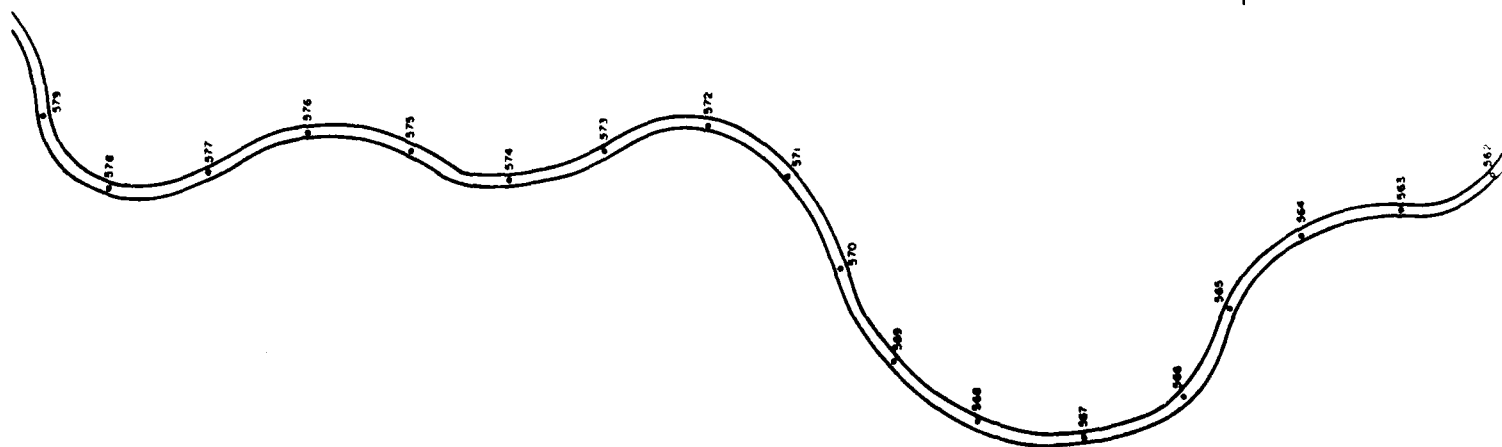
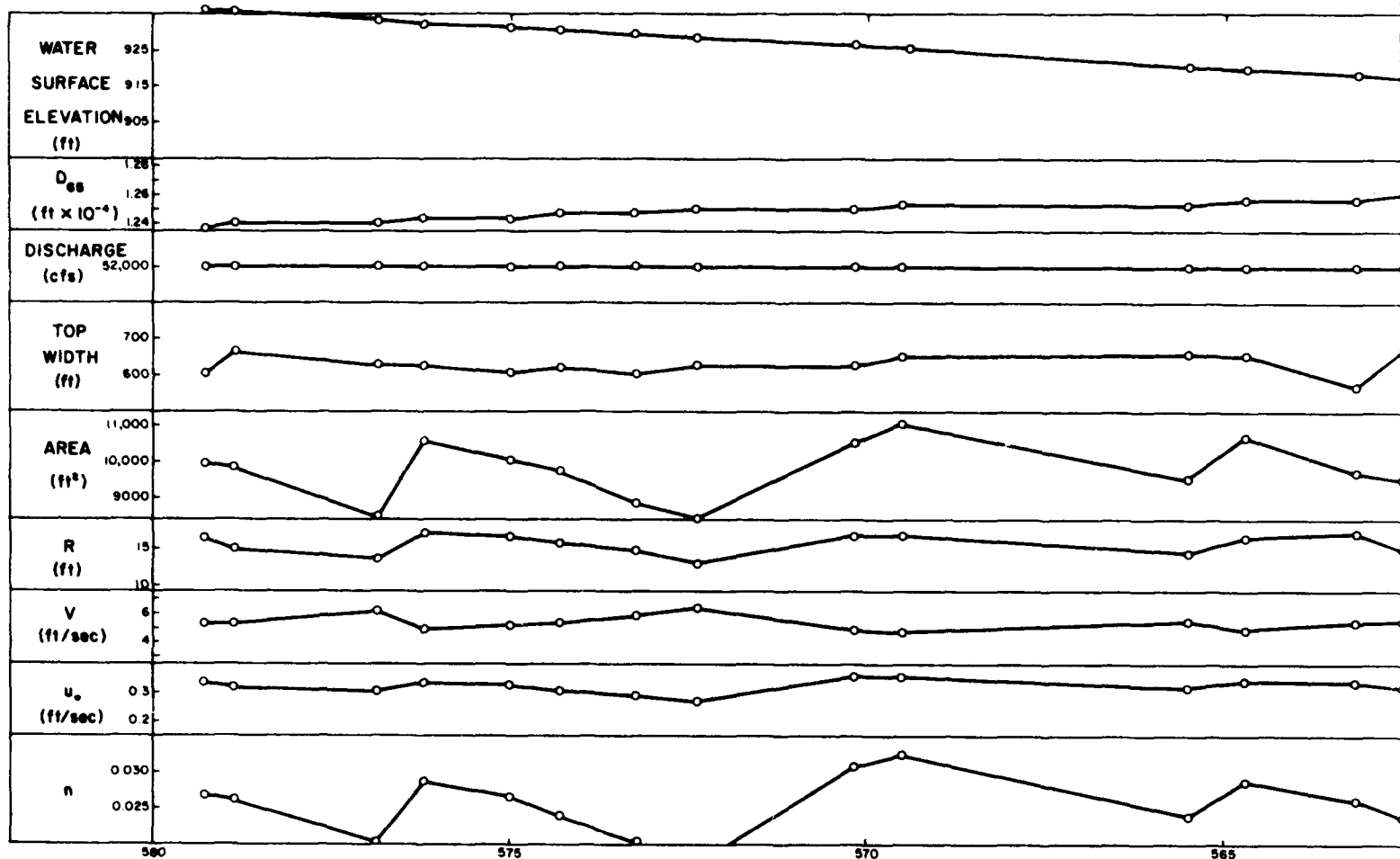
RIVER MILE UP	RIVER MILE DOWN	SLOPE FT/FT	CFS	N	14 FT	AREA SQ FT	U	AR2/3	K	VIL F/S	WIND MPH	TOTAL WIND MPH
753.74	753.33	C-000189	48000	0.0276	1707	13933	9.95	64720	3447653	3.48	27.74	127.54
753.50	752.86	C-000194	48000	0.0295	1332	14167	10.64	65156	3448842	3.39	27.43	127.43
753.65	752.15	C-000187	48000	0.0322	1556	12544	10.42	61370	3437453	3.53	27.43	127.43
753.80	751.56	C-000193	48000	0.0321	860	13161	13.94	73871	3438666	4.02	26.71	127.43
753.95	751.33	C-000194	48000	0.0326	756	11767	15.69	73741	3417269	4.66	26.71	127.43
754.10	749.24	C-000197	48000	0.0344	1922	11846	10.64	56411	3428060	4.13	21.17	127.43
754.25	748.94	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
754.40	748.64	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
754.55	748.34	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
754.70	748.04	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
754.85	747.74	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
755.00	747.44	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
755.15	747.14	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
755.30	746.84	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
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755.90	745.64	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
756.05	745.34	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
756.20	745.04	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
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757.25	742.94	C-000197	48000	0.0344	723	10877	14.83	56411	3428060	4.13	21.17	127.43
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757.55</												

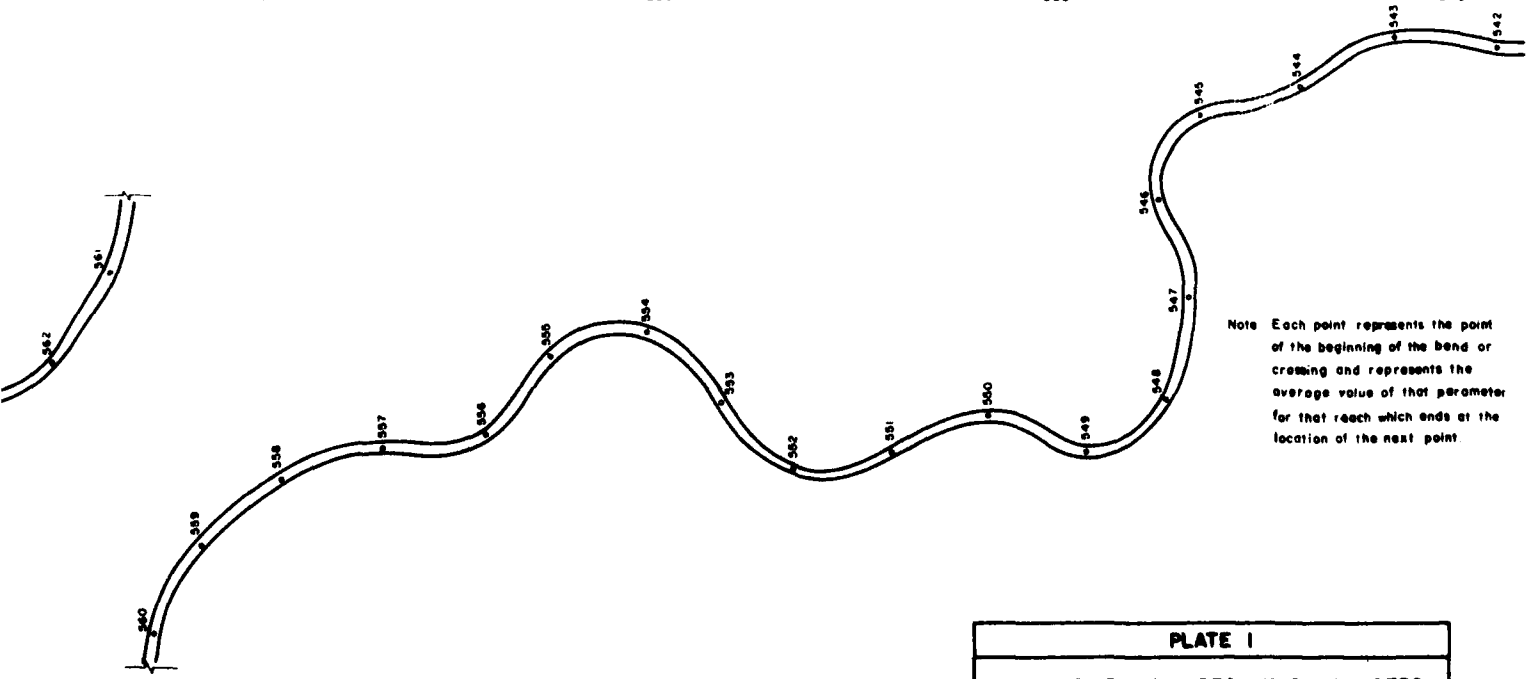
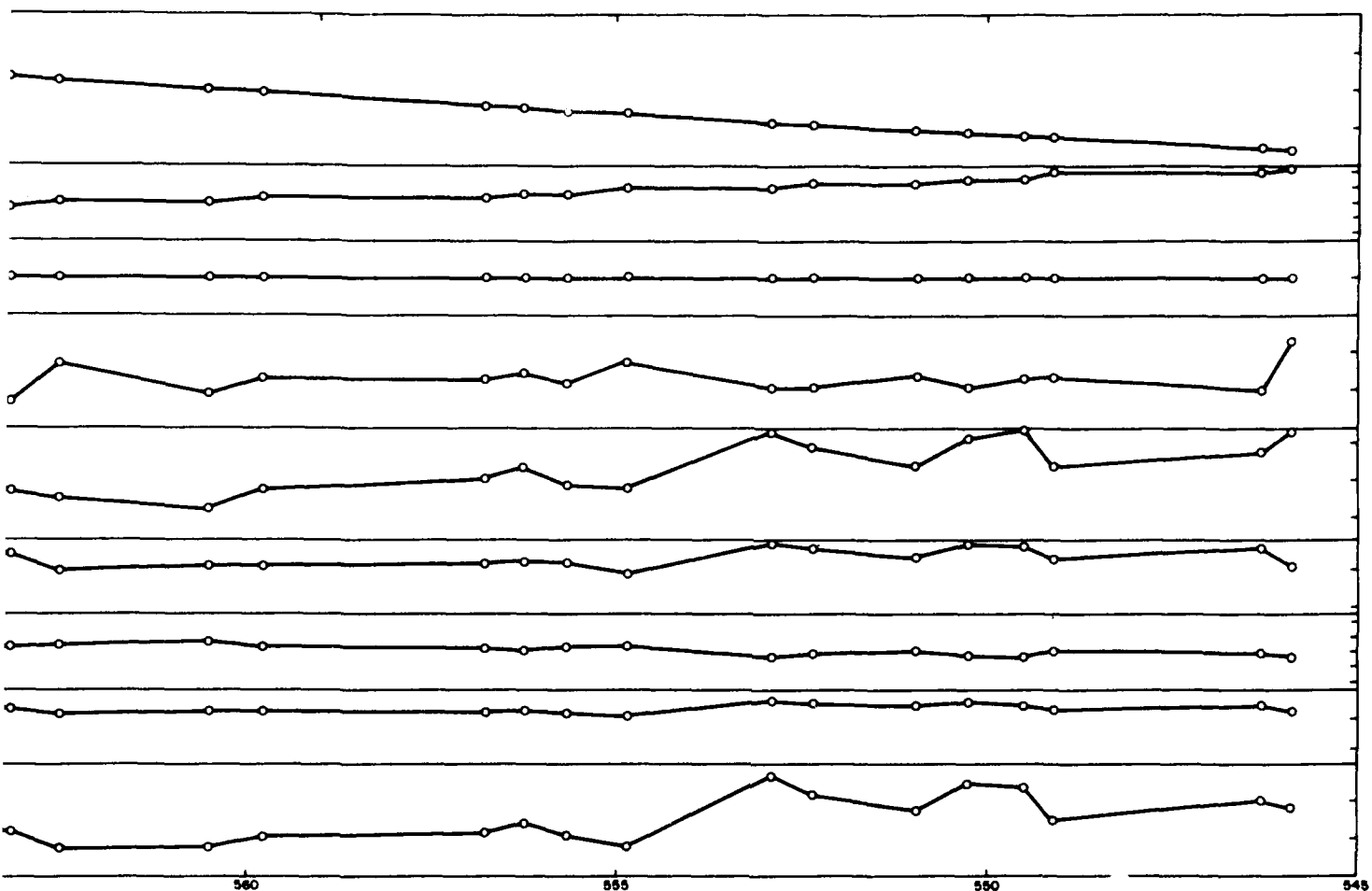
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THE UNIVERSITY OF CHICAGO

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W.S.	W.S.	W.S.	DJS	Up	Mo.	Uo.	TAU	R1	R1	R1/R2	W1/W2	N1	N1/N2	1/2011	V1/V2	P21
W/S	W/S	W/S	FT.	F/S	F/S	F/S		FT	FT							
937.76	937.76	937.76	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
937.80	937.80	937.80	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
937.84	937.84	937.84	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
937.88	937.88	937.88	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
937.92	937.92	937.92	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
937.96	937.96	937.96	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.00	938.00	938.00	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.04	938.04	938.04	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.08	938.08	938.08	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.12	938.12	938.12	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.16	938.16	938.16	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.20	938.20	938.20	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.24	938.24	938.24	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.28	938.28	938.28	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.32	938.32	938.32	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.36	938.36	938.36	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.40	938.40	938.40	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.44	938.44	938.44	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.48	938.48	938.48	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.52	938.52	938.52	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.56	938.56	938.56	0.001201	0.283	0.197	0.203	0.156	7.49	7.95	0.485	0.515	0.0131	1.92	0.672	19.52	1.10
938.60	938.60	938.60	0.001201	0.283	0.197	0.203	0.1									





Note Each point represents the point of the beginning of the bend or crossing and represents the average value of that parameter for that reach which ends at the location of the next point.

PLATE I
MISSOURI RIVER HYDRAULIC PARAMETERS
(FROM 1971 HYDROGRAPHIC SURVEY)

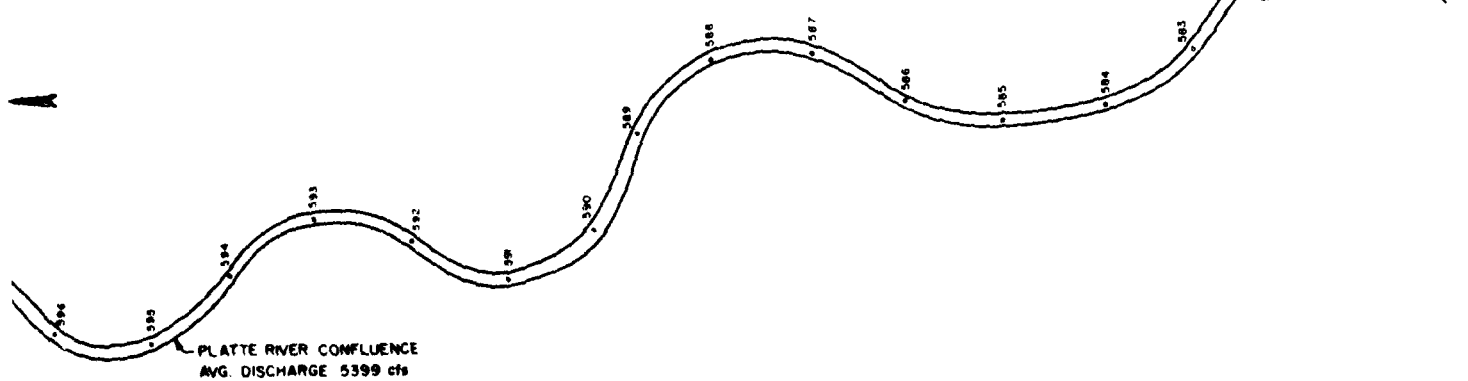
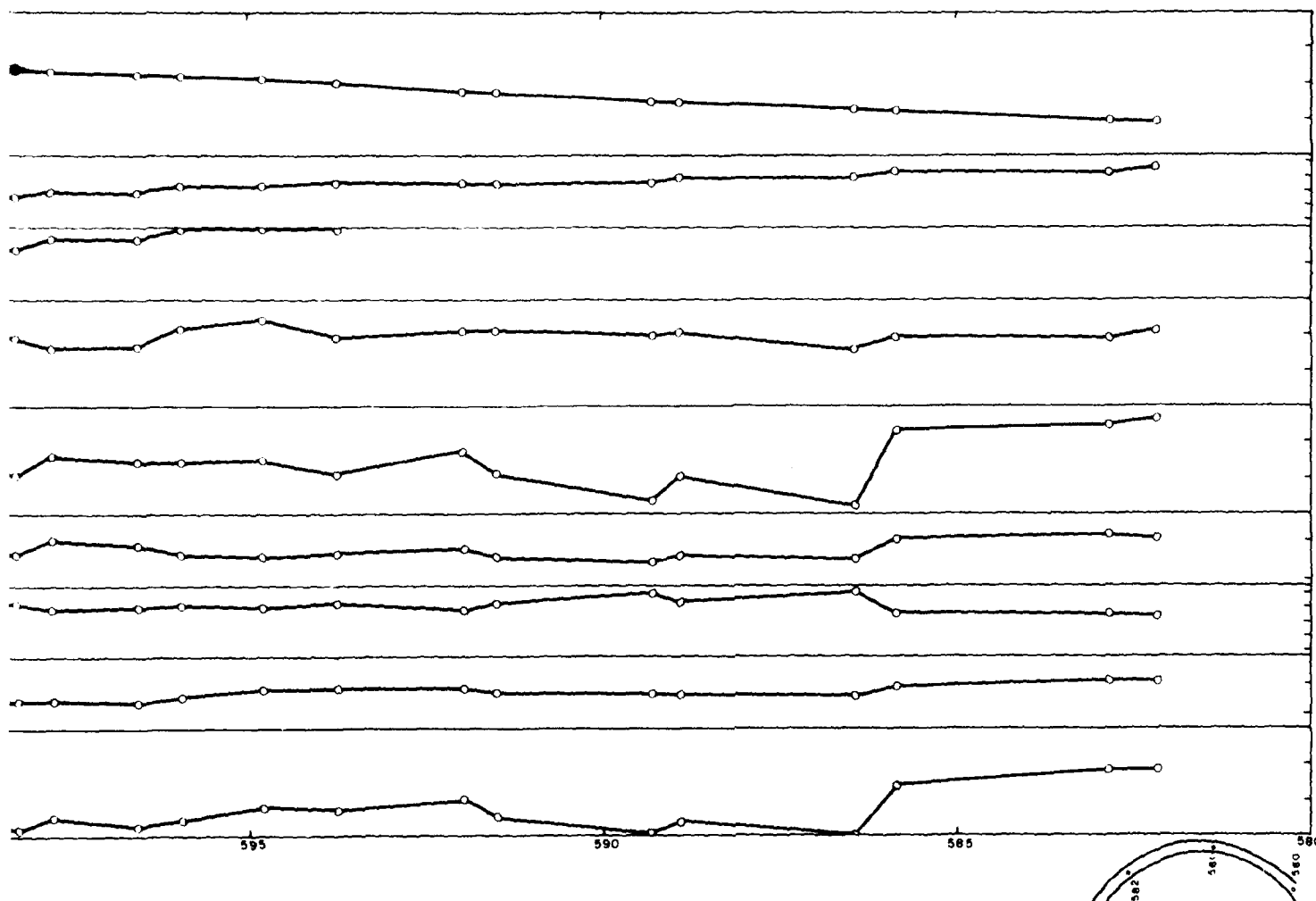
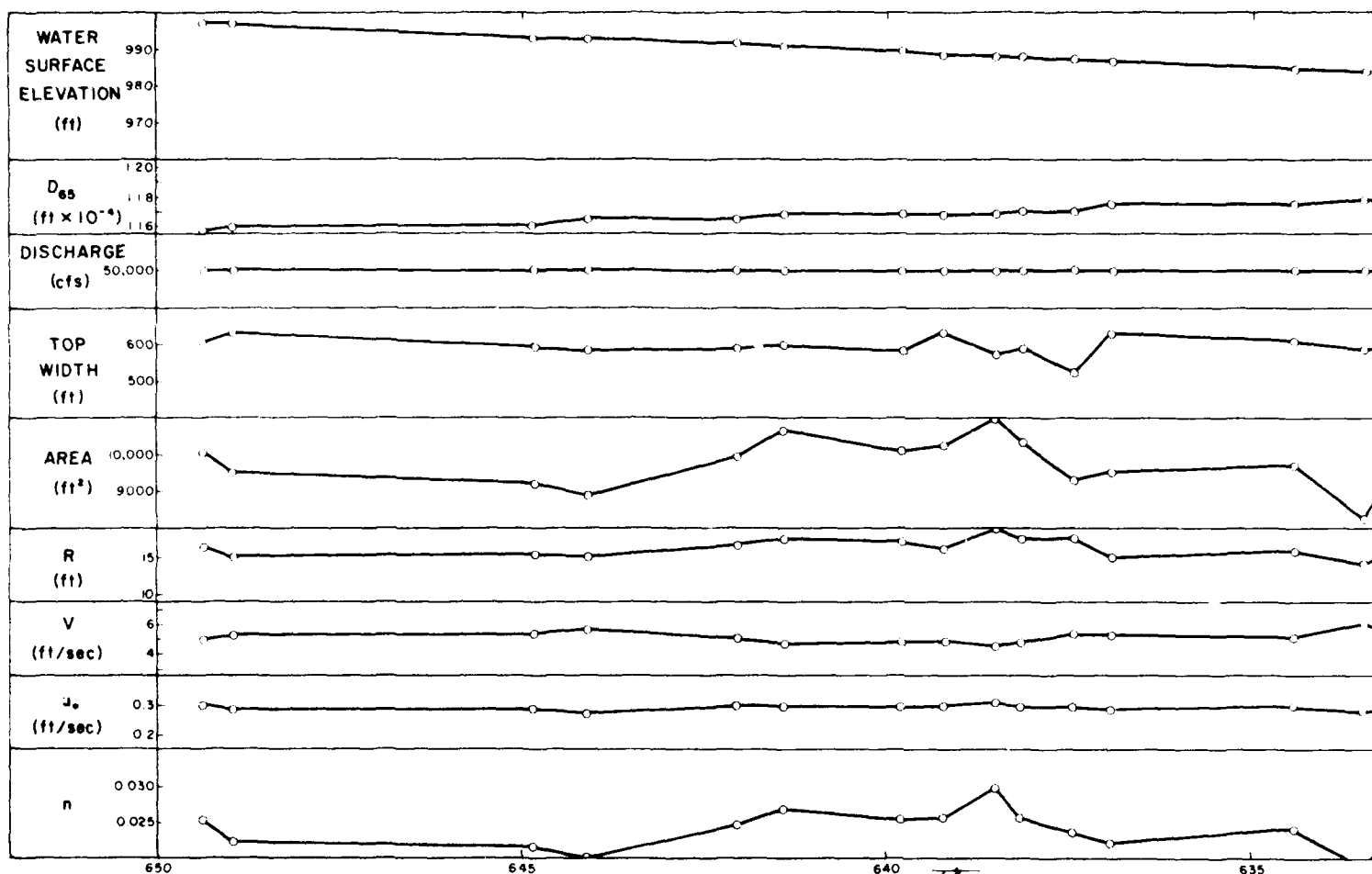
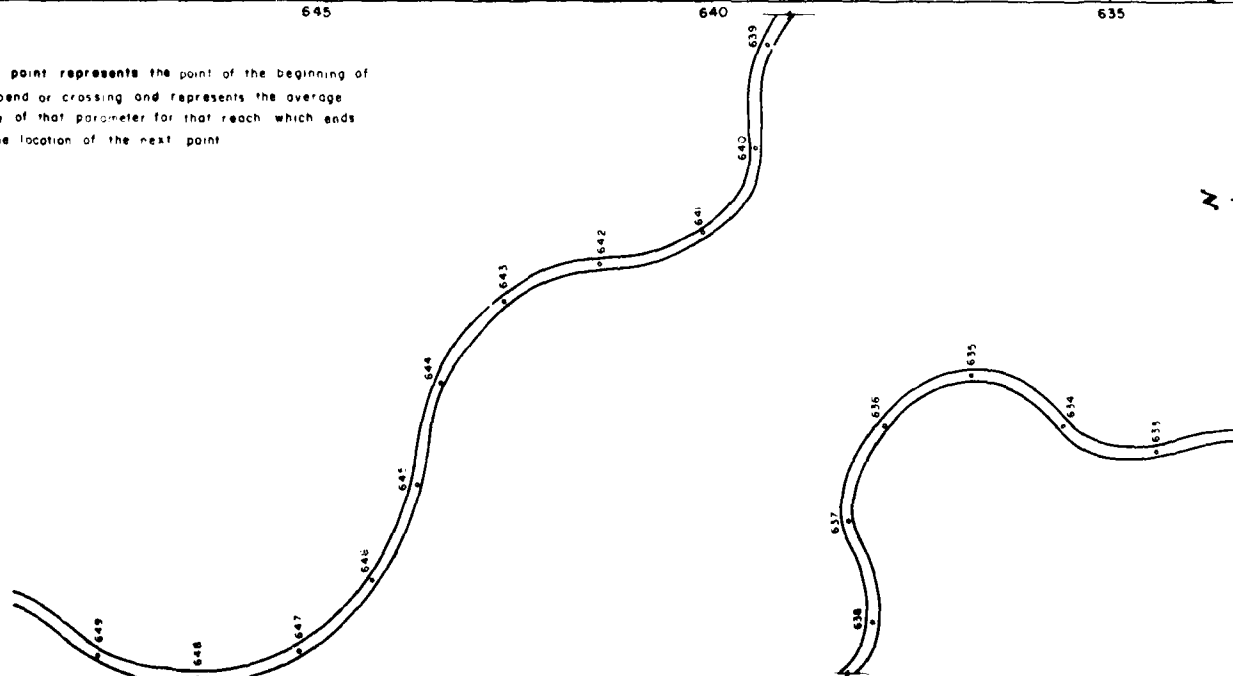


PLATE 2

MISSOURI RIVER HYDRAULIC PARAMETERS
(FROM 1971 HYDROGRAPHIC SURVEY)



Note Each point represents the point of the beginning of the bend or crossing and represents the average value of that parameter for that reach which ends at the location of the next point



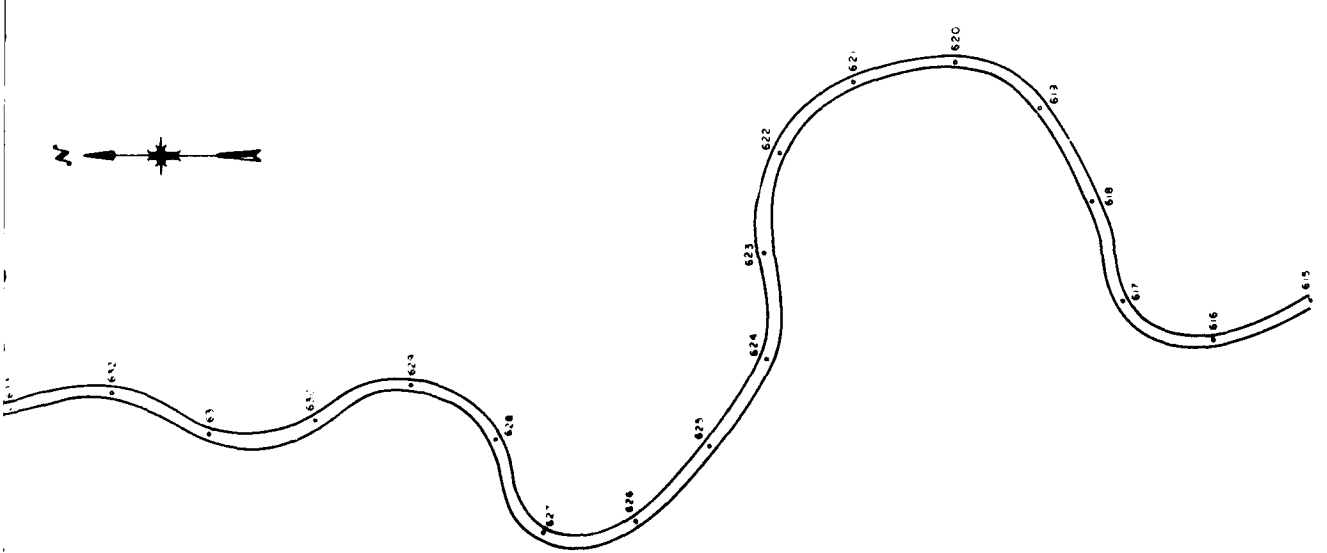
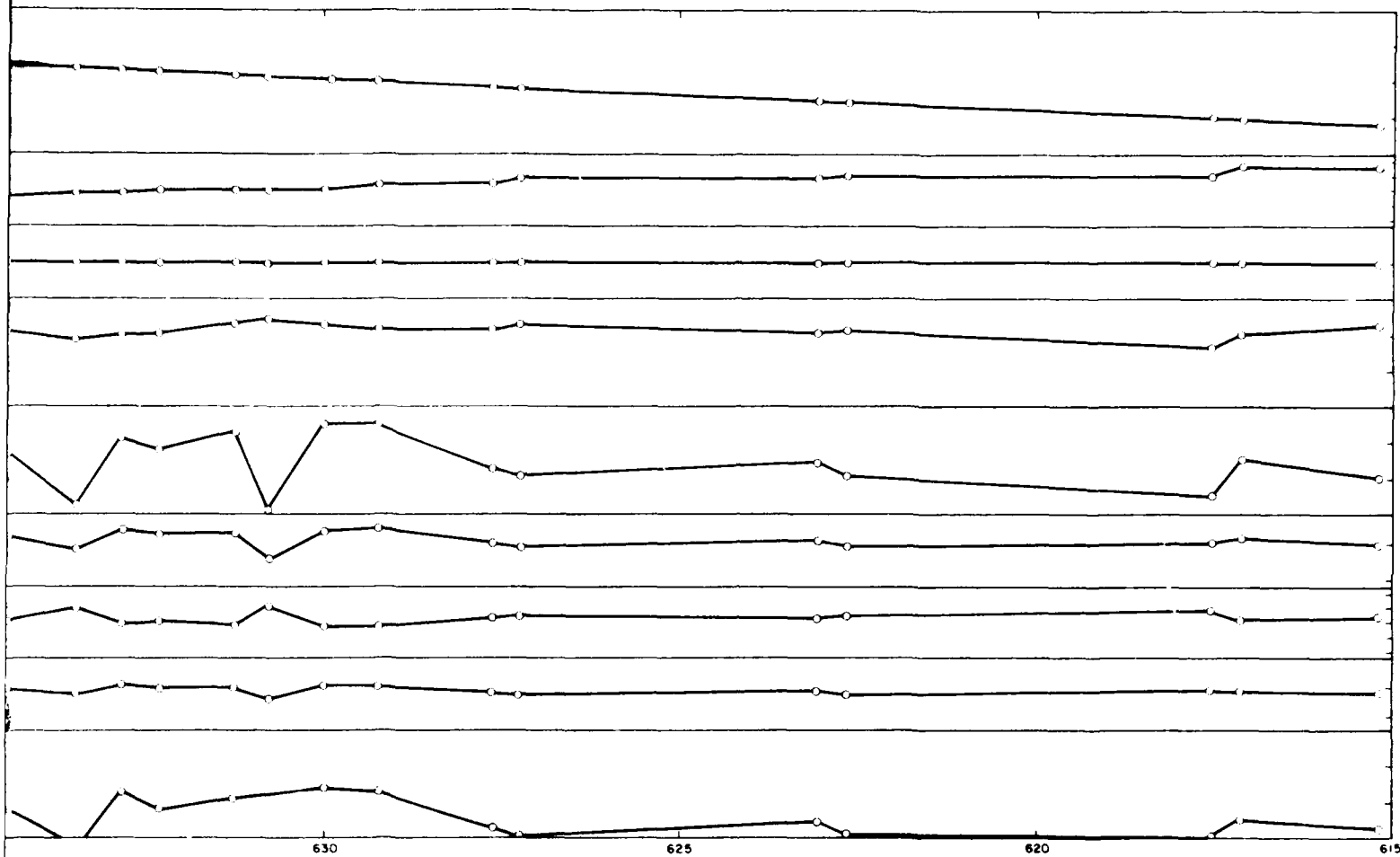
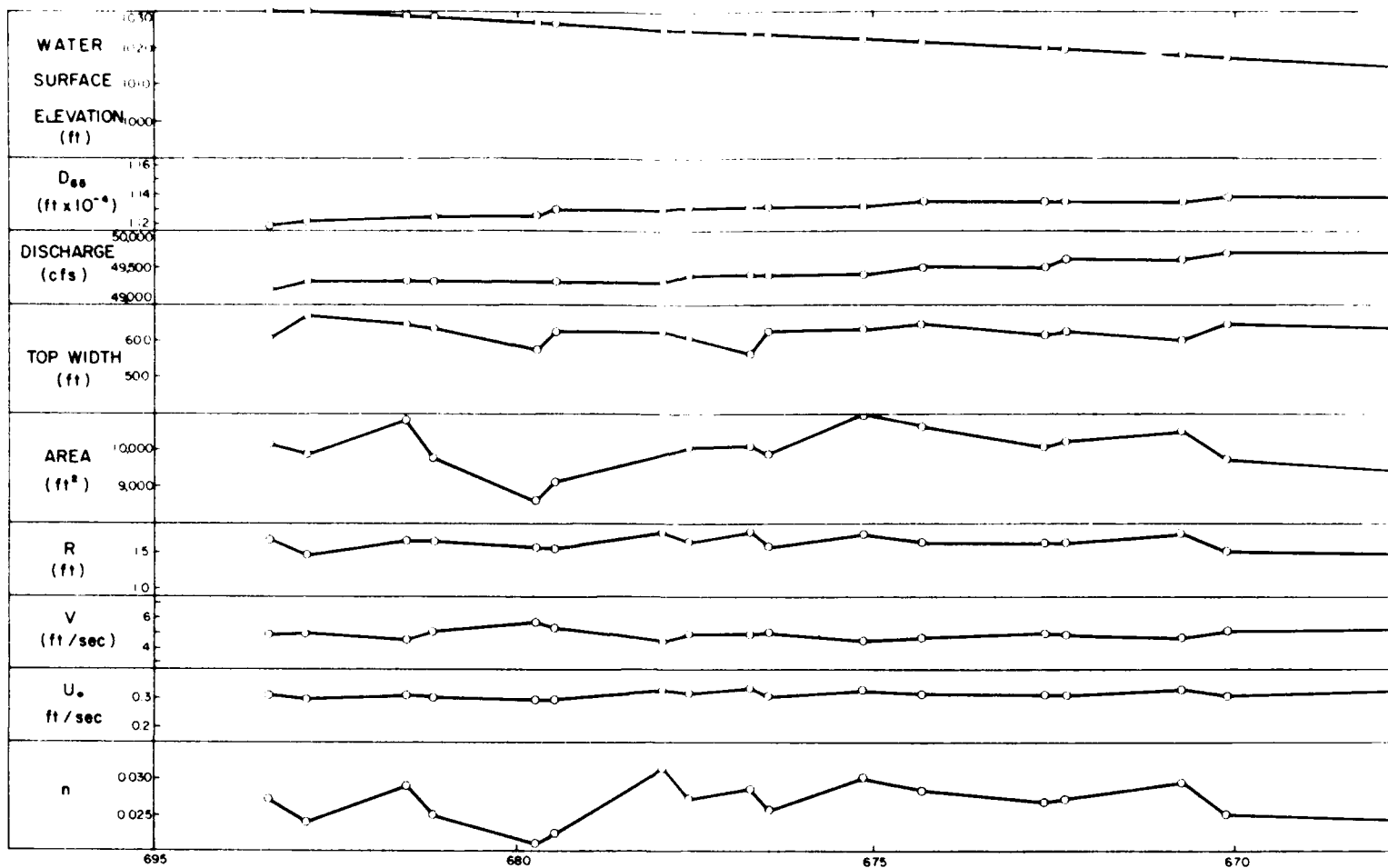
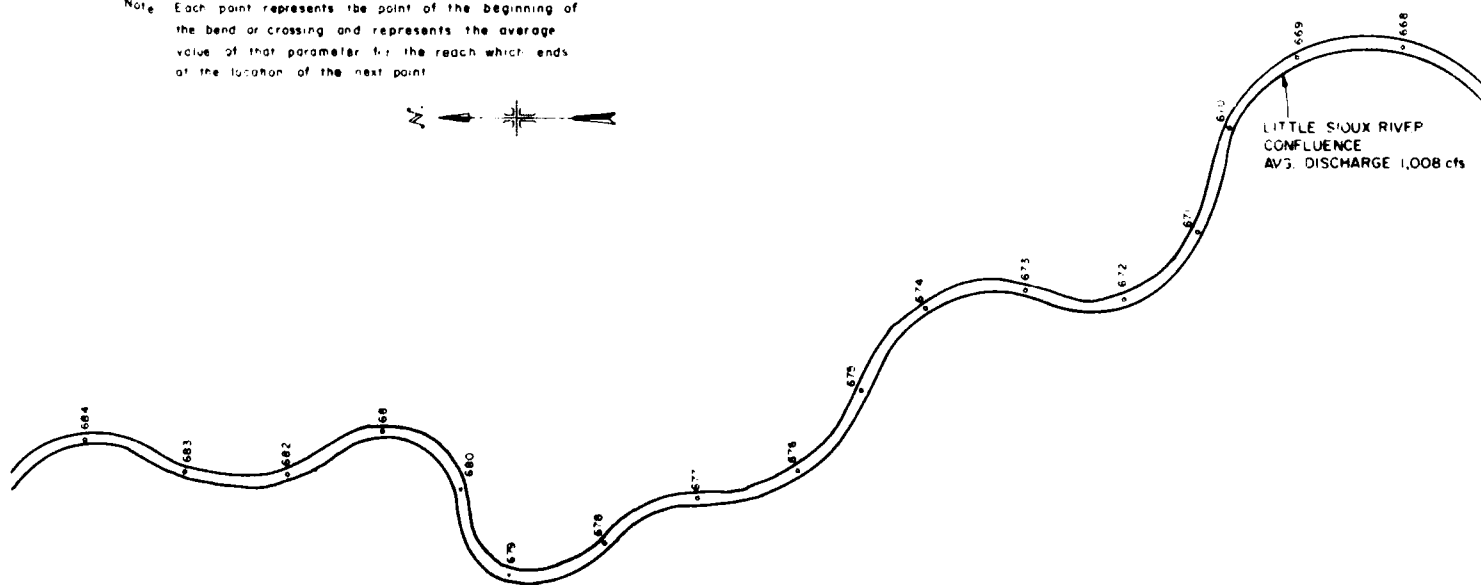


PLATE 3

MISSOURI RIVER HYDRAULIC PARAMETERS
(FROM 1971 HYDROGRAPHIC SURVEY)



Note: Each point represents the point of the beginning of the bend or crossing and represents the average value of that parameter for the reach which ends at the location of the next point.



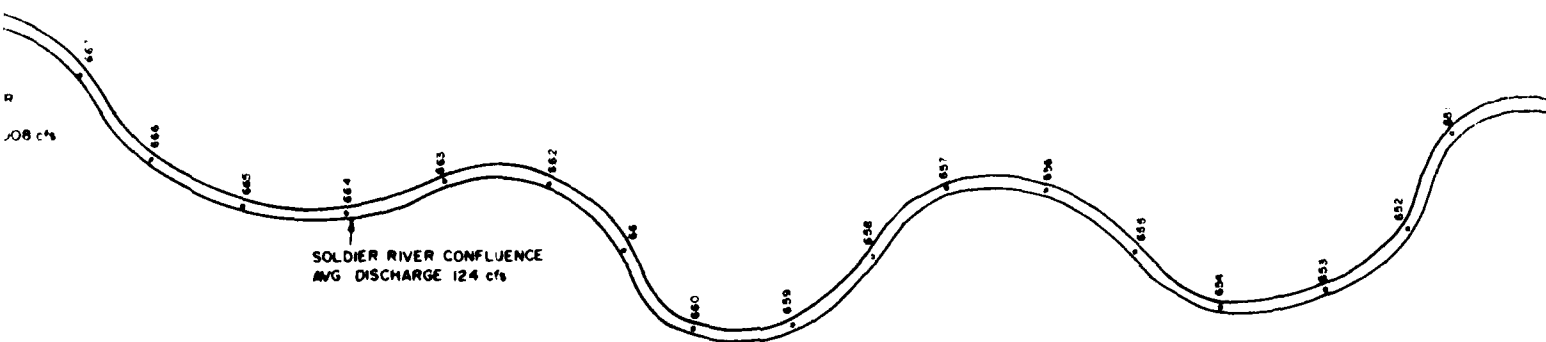
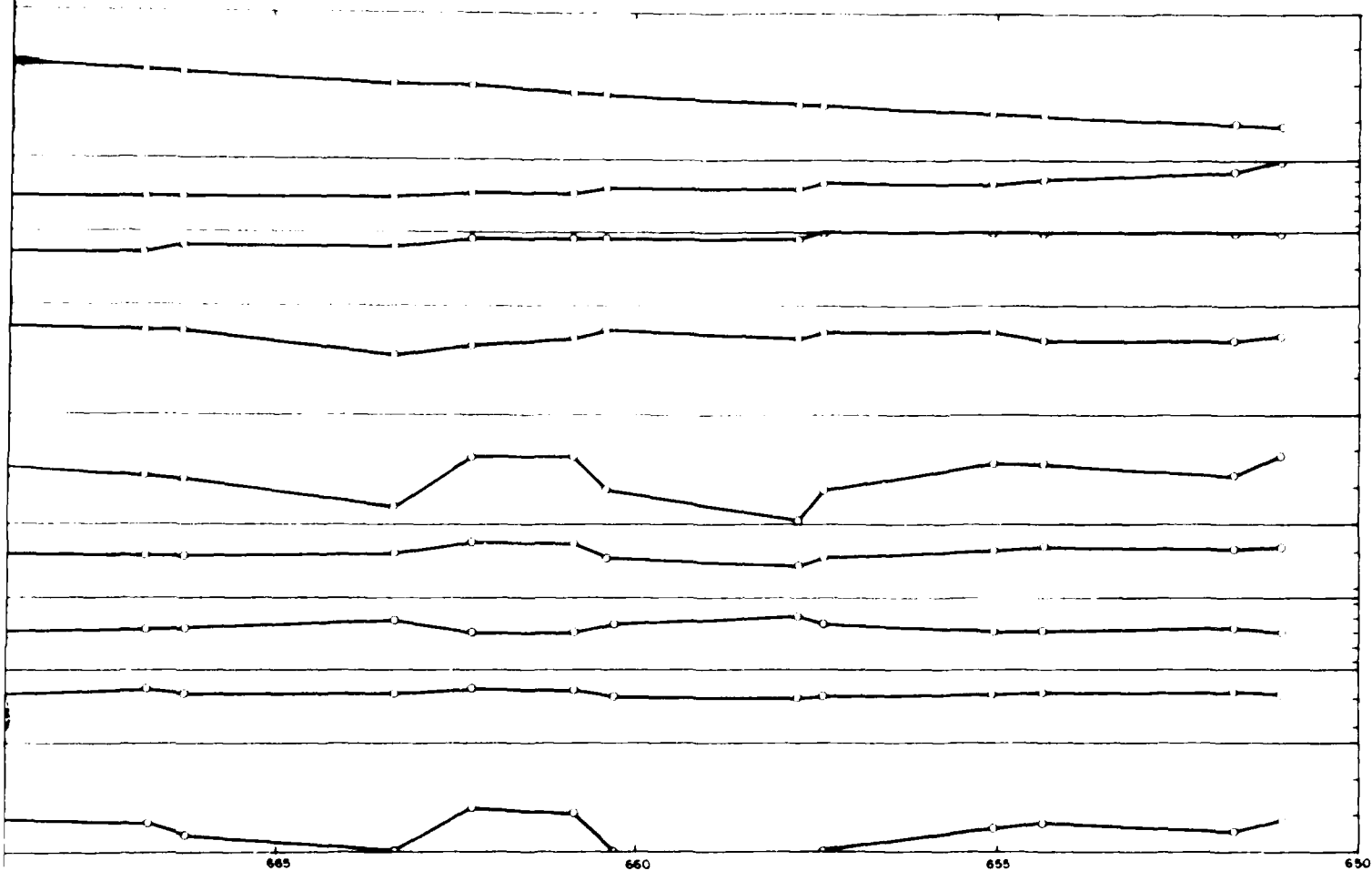
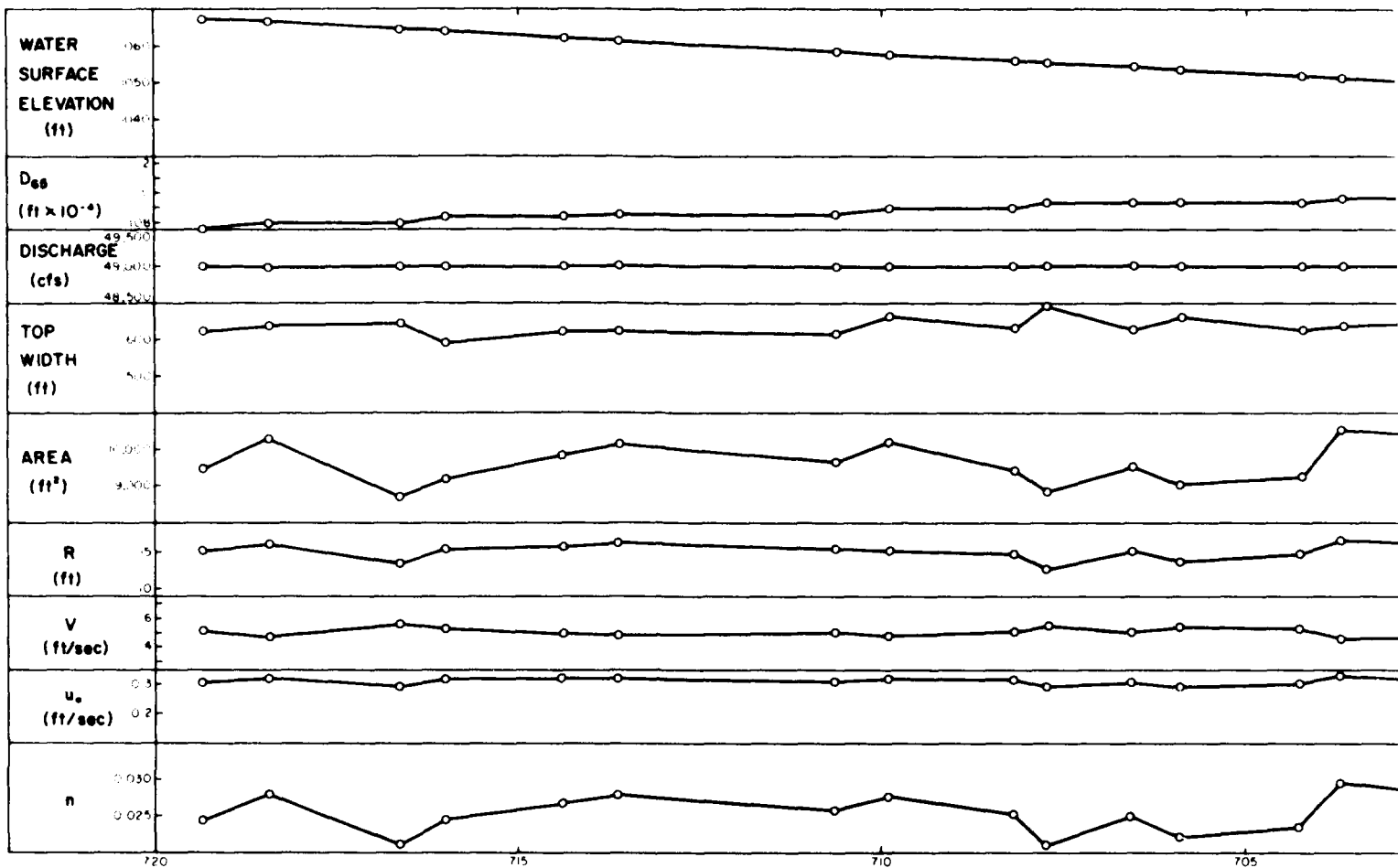
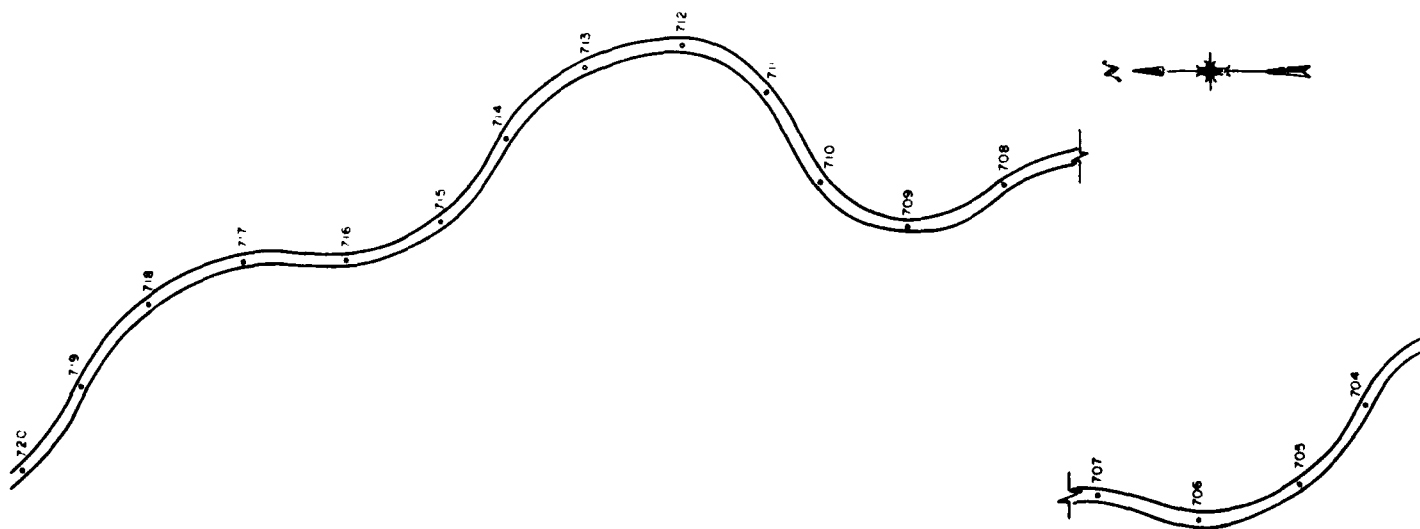


PLATE 4

MISSOURI RIVER HYDRAULIC PARAMETERS
(FROM 1971 HYDROGRAPHIC SURVEY)



Note: Each point represents the point of the beginning of the bend or crossing and represents the average value of that parameter for that reach which ends at the location of the next point.



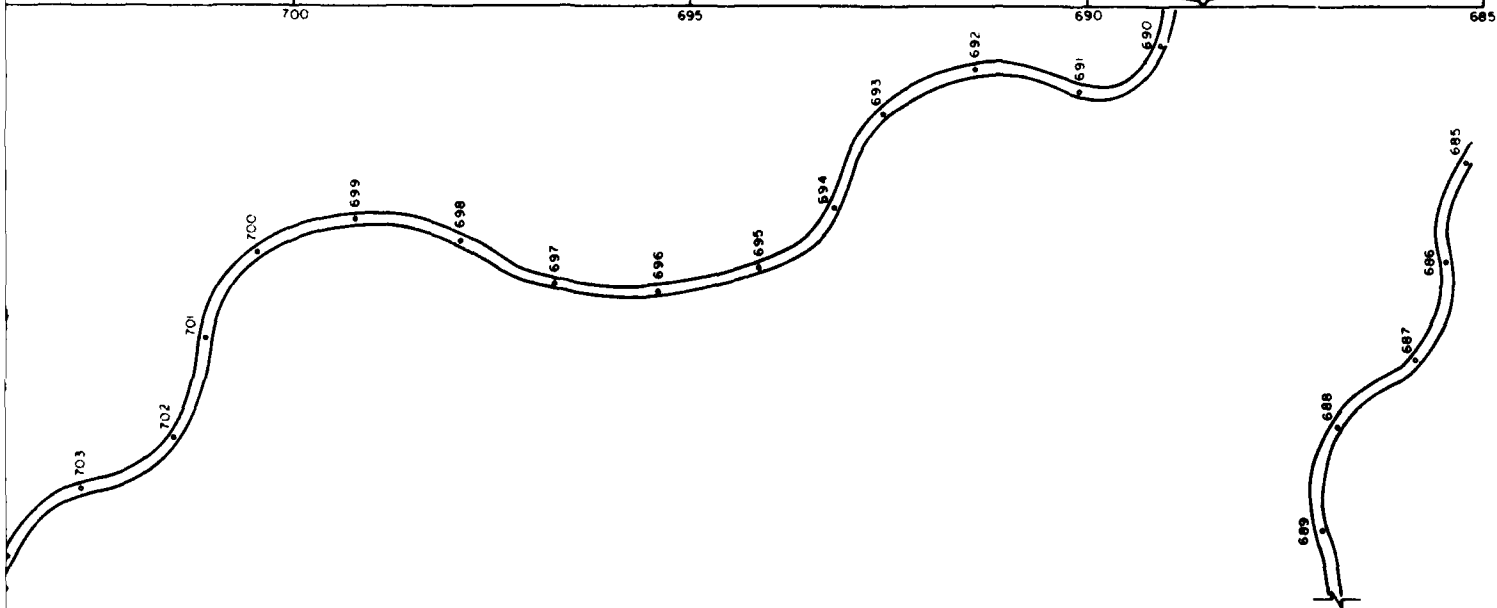
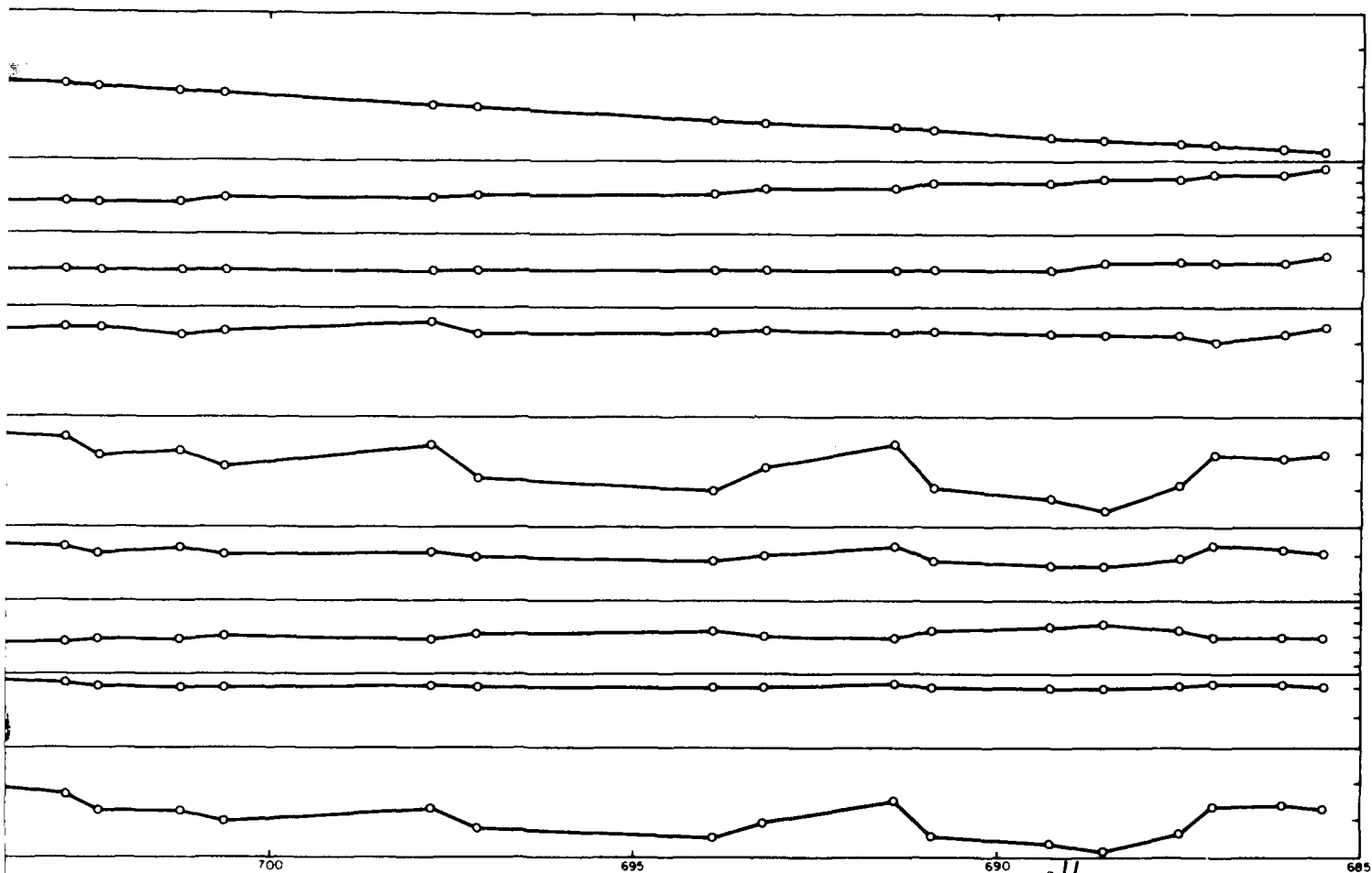
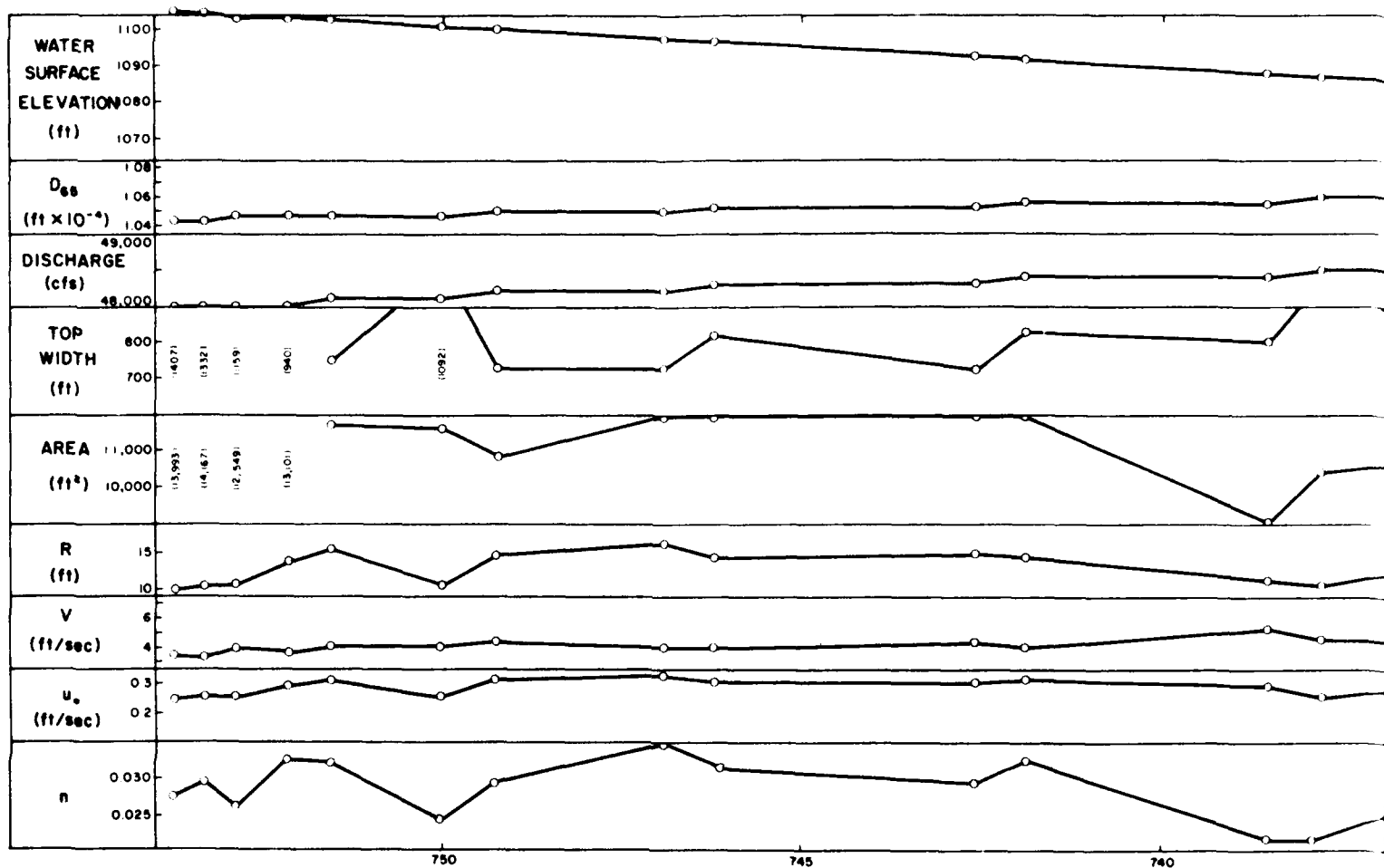


PLATE 5

MISSOURI RIVER HYDRAULIC PARAMETERS
(FROM 1971 HYDROGRAPHIC SURVEY)

2



Note: Each point represents the point of the beginning of the reach or crossing and represents the average value of that parameter for that reach which ends at the location of the next point.