GEOMETRIC STABILITY ANALYSIS OF AN ALLUVIAL RIVER

by

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INTRODUCTION

The subject of fluvial hydraulics in an alluvial river is a very difficult one because every variable is constantly changing at each place in space and at each point in time. Many empirical equations have been written and these become exponentially more complicated as each additional variable is considered. Any river is a complicated interrelationship of these many variables, and the river engineer is at a loss to recognize all of the variables and to know what degree of dependence to place on each of them.

The numerous variables may be grouped into six classifications; (1) Time, (2) Geologic, (3) Hydrologic, (4) Geometric, (5) Hydraulic, and (6) Man's Activities. Time is the only real independent variable when we consider the geologic timetable; however, in an engineering timetable, the geologic and hydrologic variables and at times some of man's activities may be considered independent. Lane (1957)(3) states, "The present river is the result of past geology. All the present physical factors of quantity of flow, sediment load, and the slope of the alluvial valley as well as the characteristics of the material of which it is composed are the result of past and present geology. An understanding of the geological aspects will help in future control of the river." The geologic variables are inherited from some previous time period in a state of dynamic equilibrium - - they may be undergoing a slow geologic change but from an engineering standpoint, they are not changing. These variables are (a) the general relief of the drainage basin, (b) the slope of the river valley, (c) the type, size, cohesion, specific gravity, wear resistance and distribution of the bed and bank material, and (d) the type and depth of the suballuvial formations.

The hydrologic variables are: (a) the discharge and type of hydrograph which are controlled by the magnitude, intensity, duration, distribution and season of rainfall, (b) temperature, (c) vegetal cover and the intensity of cultivation and grazing, (d) the permeability and the infiltration rate of the soils, (e) the surface erosion and bank caving, (f) ice condition and (g) the total sediment load. These hydrologic variables are to a slight degree dependent on the geologic variables and to a lesser degree on man's activities, but for purposes of river engineering they are considered independent.

The degree of dependence of man's activities varies because they may be of past or future projects and may be permanent or constantly changing. These variables may include but are not limited to (a) location and type of past work, (b) location and type of future work, (c) variations caused in the hydrograph and sediment load, (d) allocation of funds (e) future needs and uses of the river system, (f) time to do the job, emergency or well thought-out project, (g) availability of men, equipment and material, (h) type of material available locally, (i) construction and installation problems and procedures, (j) access to job site, and (k) weather and river condition during construction.

Next in line of dependence are the geometric variables, they are the result of the hydrologic and geologic conditions on the river, i.e., they are the result of the interaction between water discharge, the quantity and character of the sediment discharge, and the composition of the bed and bank material. The geometric variables are (a) depth, (b) width, (c) sinousity, (d) radius of curvature, (e) degree of curvature of bends, (f) width of the meander belt, (g) distance between meander loops, (h) the distance between bar formations (i) general alignment,(j) the longitudinal profile of the river channel (k) the shape of riffles and bars, and (l) the shape factor of the channel cross section, bed forms and stream reach.

The hydraulic variables are the most dependent. These factors are constantly changing in order to bring the entire system into a state of equilibrium. The hydraulic variables are (a) slope, (b) roughness of bed form, (c) velocity, (d) turbulence, (e) tractive force, (f) fall velocity of the bed and bank material, (g) the sediment bedload, (h) stream power, (i) Froude Number relations, (j) hydraulic radius, (k) seepage forces in the bed and banks and, (l) the viscosity of the suspended sediment-water load.

If we are to understand the characteristics of a river and if we are to be able to properly engineer controls, we should first understand the effects of these related sciences; however, in some instances it need not be quite that complicated. We should understand how the geologic and hydrologic variables combine to give us the river as we find it in its natural condition. Man may force a river into an unnatural condition, but because the most independent variables do not change in engineering time, the river will always attempt to return to its natural condition. By utilizing this fact we can guide and direct a river, letting it do most of the work, thereby controlling it in a geometric pattern that is natural for each particular reach.

From an engineering standpoint the only independent variables we need to consider are discharge, valley slope, and the material in the bed and banks of the river, as well as man's activities. As these change from reach to reach the geometry of the stream will change, and with this knowledge for each drainage basin a set of relationships can be derived for all the geometric properties. The hydraulic variables will continually change and adjust to conform to the geometric pattern for each reach. Therefore, if we build-in proper geometric characteristics in accord with the independent variables for each reach, the hydraulic variables will adjust to keep the system in balance.

Every geometric variable is a function of the discharge. To determine which discharge to use, from all the literature on the subject, could be very discouraging. Actually the channel is formed by all flows. From a flow-duration curve and from a knowledge of sediment movement we might eventually determine a dominant discharge. But why not look closely at natures results of this illusive factor. If a stream is poised or graded or nearly so, and if we can obtain surveys, maps, and aerial photos over a reasonable period of time, we can directly measure all geometric variables. We need not concern ourselves with the scientific cause of the rivers characteristics but only that the end result, as we find it, can be controlled and that the plan and profile geometry can be altered within some envelope of values.

The regime formulas as derived by various authors may be used as a guide. However, if we are to use this method of analysis of a river, then these must be refined to fit each drainage basin and possibly each reach of every stream, especially where tributary flow is significant and where there are pronounced geologic variations.

Maddock (1969)[(7)] states, "Nine equations are required for the complete solution of the problems of flow in alluvial channels. The equations do not exist and probably never will. Therefore it is not possible, and probably never will be possible, to provide a precise answer to all flow problems. The question is, what is needed to provide approximate answers to the problems?"

A thorough knowledge of all sciences related to an alluvial river would be to the engineers's advantage, but it may be possible to properly engineer river stabilization with a limited knowledge and by using the consulting services of the greatest engineer of all times - - NATURE!

We need to determine whether the stream is braided or meandering, poised, graded, aggrading or degrading. A poised or graded condition implies that a general overall equilibrium exists between the major factors controlling river activity. Even though a river may be poised, it's alluvial plain may be aggrading or degrading in various reaches, and this may change as man's activities begin to affect the river's regime. A complete knowledge of all factors would be helpful and even necessary in a large project. But what about the underfunded and/or understaffed project, the small one that cannot afford a full study, or the remote project with little or no information available or the emergency job where quick decisions must be made? On these projects you still need to be reasonably sure of your design.

VARIABLES TO BE CONSIDERED

This type of analysis applies specifically to poised or graded, meandering, alluvial streams. A complete knowledge of all variables would be advantageous but in a geometric analysis the following should be considered:

1. Depth
2. Width
3. Sinousity
4. Radius of curvature
5. Degree of central angle of bend
6. Width of a meander belt
7. Distance between meander loops
8. Spacing of bars
9. General alignment
10. Longitudinal profile of the river channel
11. Shape of riffles and bars
12. The shapefactor of the channel cross section, bed forms and stream reach.
13. Discharge hydrographs
14. Sediment discharge capacity
15. Soil conditions
16. Valley slope

All of these variables are important; however, in making an analysis with limited time and data, and if we consider that the stream as we find it is a result of all previous flow conditions, then the above list could be shortened to:

1. Depth
2. Width
3. Distance between bars
4. General alignment
5. Valley slope

DISCUSSION OF VARIABLES

The data used in this study was taken from two hydrographic surveys of the Mississippi River made prior to major construction of river controls and from two hydrographic surveys made after river control began. The first two surveys were made by the Mississippi River Commission during a period from 1876 to 1880 and from 1911 through 1915 with part of the river surveyed in 1921. The last two surveys were made in 1962 and in 1969. The above surveys were chosen so that the geometric variables could be measured and compared both in a natural and in a semicontrolled condition.

As already stated, all variables are complexly interrelated and thus it is impossible to discuss one independently of all others; however, an explanation of the variables is needed. Therefore, the geometric variables considered in this study are discussed in relation to the stabilization of a river.

DEPTH AND WIDTH

There is an ultimate depth that any meandering, alluvial river will scour. This ultimate depth may be reached without the benefit of armor plating and is a function of the discharge, sediment load, time the river remains at a particular place, erodibility of the bed and bank material, width, radius of curvature, size of bed material, fall velocity of material being transported and slope.

Depth of crossings and pools depends mostly on the discharge plus the erodibility of the bed and bank material and energy slope. If the bed and bank material is composed of easily eroded material, then more energy will be expended in bank caving and thus more meandering rather than in scouring out pools and crossings to greater depths. Consequently, depth is directly dependent on time. The longer a pool is held in one position by a cohesive or non-erodible bank, the deeper it is scoured, approaching an optimum depth.

Tables 1 and 2 give the average and limiting low water depths and widths for four surveys of the Mississippi River. It was noted that the natural river, as shown in the 1876-80 and 1911-15 surveys, maintained relatively constant depths and widths for each reach. As long as good widths were maintained in a particular part of the river then good depths followed.

It was also observed when studying the natural river that for the same depth and width, radius of curvature varied widely. Consequently, it was deemed that width control is much more important than radius of curvature in determining depth.

TABLE NO. 1

DEPTHS VS WIDTHS

SURVEY	NO.	POOL DEPTH AVG.	POOL DEPTH LIMITS MIN.	POOL DEPTH LIMITS MAX.	POOL WIDTH AVG.	POOL WIDTH LIMITS MIN.	POOL WIDTH LIMITS MAX.
1876 - 80							
MD (MEMPHIS DIST.)	107	49	20	80	2200	1400	5300
VD (VICKSBURG DIST.)	76	70	35	110	2000	1300	3400
NOD (NEW ORLEANS DIST.) to 900 M.B.C.	32	122	90	160	1900	1400	2400
1911 - 15 & 1921							
MD (8% reveted)	99	56	30	95	2000	1000	4300
VD (10% reveted)	78	70	35	110	1800	1200	3000
NOD to 900 M.B.C.	31	120	90	160	1900	1500	2600
1962							
MD (63% reveted)	55	62	34	100	2200	1300	3600
MD (Non-reveted)	32	43	24	75	2800	2200	3600
VD (67% reveted)	45	76	45	110	1900	1400	3000
VD (Non-reveted)	22	70	40	90	2200	1500	3600
1969							
VD (67% reveted)	41	71	50	110	1800	1400	3000
VD (Non-reveted)	20	50	30	90	2400	1200	3600

TABLE NO. 2

DEPTHS VS WIDTHS

SURVEY	NO.	CROSSING DEPTH AVG.	CROSSING DEPTH LIMITS MIN.	CROSSING DEPTH LIMITS MAX.	CROSSING WIDTH AVG.	CROSSING WIDTH LIMITS MIN.	CROSSING WIDTH LIMITS MAX.
1876 - 80							
MD	106	15	1	27	3500	1700	5500
VD	76	23	10	46	2950	1600	5000
NOD to 900 M.B.C.	30	42	34	60	2700	2100	3200
1911 - 15 & 1921							
MD	98	13	5	30	3450	2000	5400
VD	78	21	5	39	3200	2100	4800
NOD to 900 M.B.C.	31	43	22	60	2700	2200	3100
1962							
MD (reveted)	32	13	1	45	3750	2500	4800
MD (Non-reveted)	57	10	1	28	4150	2600	5800
VD (reveted)	13	17	5	30	3200	2800	3800
VD (Non-reveted)	55	19	5	40	3250	2000	5000
1969							
VD (reveted)	16	28	10	40	2800	2100	3600
VD (Non-reveted)	45	19	5	38	3400	1800	4700

SINUOSITY AND SLOPE

Sinuosity is necessary but the amount is not too critical as long as slopes are compatible and bar sequence and distances are maintained in a geometric form which will accommodate the various water and sediment discharges. By measuring the geometric properties of a river, a wide variation of slopes will be encountered; however, it will be found for each reach of each river that the slope can vary within certain limits and that the hydraulic variables of the river will adjust to maintain good depths and alignment.

The water surface slopes at high flows will be approximately the same as the top bank slopes and will have less variation than low water slopes. Chart 4 shows the agreement between the two slopes. This is in agreement with the fact that it is the high flows that build the top banks and natural levees.

Valley slopes are a result of geology which in some cases may be a rock formation acting like a weir, a soil condition that is more easily erodible, or a tributary with an excessive sediment load. Valley slope was determined by finding the slope of the axis of the meander belt.

Chart 5 shows the relationship between top bank slope and valley slope. As can be seen, there is not a good relationship between the two; however, there is a definite division between the divided and undivided reaches. As a result of studying this chart, one could possibly consider limited cutoffs on a particular reach of a river, with some specific valley slope, which would not cause the top bank (high water) slope to exceed the limiting slope between divided and undivided flow.

Throughout each change in the valley slope the river will adjust its lengths by becoming more or less sinuous in order to obtain a slope which will be compatible to the hydraulic variables needed throughout the reach for sediment and water transport. However, it must be kept in mind that these two factors are greatly influenced by the type of bed and bank material. Lane (1955)[(2)] and Leopold and Langbein (1962)[(5)] point out that a stream reacts quickly to any change and that it will return to a state of equilibrium in a short time. Nevertheless, it must be remembered that this is not geologic equilibrium since geologically, equilibrium is never reached.

In its natural state, the Mississippi River accomodated any valley slope up to 0.6 feet/mile by adjusting its sinuosity and hydraulic variables. When the valley slope exceeded 0.6 feet/mile, the river tended to take on the characteristics of a braided stream, see Chart 6. This slope may have been partially influenced by soil conditions. Also, braiding may occur when the valley slope exceeds 0.6 feet/mile because the river is unable to build controls to maintain a single channel for the existing water and sediment transport.

It is believed, that on any stream, there are tolerable limits of water surface slope, and that within these limits the hydraulic variables will adjust to maintain good geometric characteristics. On the Mississippi River these limits were found to vary up to 0.45 feet/mile for the low water slope, and to 0.60 feet/mile for the high water slope. When realigning a channel or making cutoffs, the river should adjust more quickly if these limits are not exceeded.

RADIUS OF CURVATURE

This could be an extraneous parameter either for measuring stability or as a criterion of depth. There are so many factors that determine the shape of a river bend, i.e., hard points of rock or various types of clay deposits, that the depth of a pool will depend more on the length of time that the river maintains that position with little or no bank scour. Whenever we stop a bank from moving and thus stop the introduction of new material, the river will strive to attain its optimum depth. Many authors have stated that the radius of curvature and the depth of the pool are inversely related. This is only partially true because the shorter radius usually indicates a more cohesive material and the depth attained is a factor of time. Thus relatively long radius bends, if held in one position over a long period of time, will have deep pools. In a bend of any radius that is within the normal range of radii for the river discharges, a pool will be maintained as long as the width is held within limits and the arc is smooth and of uniform radius. As already stated, the Mississippi River in its natural state maintained good depths as long as good widths were maintained irregardless of the radius.

A bar will build on the convex side of a bend as long as the arc is uniform. The arcs formed by the convex and concave side, as well as the thalweg should be concentric. When the radius of the arc of the concave bank is disrupted the pool ends and the crossing begins.

Two consecutive bends with different radii can occur in the same direction with no intervening alternate bar, provided the straight section between then is less than half the normal distance between bars. A shoal will occur approximately halfway between the bends and on the same side of the river as the two pools.

DEGREE OF CURVATURE OF BENDS

The degree of the central angle is not critical but should be held under 180° to eliminate the threat of a natural cutoff developing. A good pool and good point bar formation will be maintained as long as the central angle is within reason and the radius of the bend is uniform.

WIDTH OF MEANDER BELT

This is important only in indicating what limits of meander might be expected in an uncontrolled river and possibly could give an indication of the amount of meander to be expected in any time period.

DISTANCE BETWEEN MEANDER LOOPS

This parameter is important only in showing the high water channel alignment and in pinpointing the distance between point bars.

SHAPE OF RIFFLES AND BARS

A study of these is important in order that the dimensions and shape of dike fields can be determined. These fields will perform best if they fit the natural contours and flow lines of the channel. Any bar will tend to shape itself to the configuration of the concave bank. This configuration is dependent on the erodibility of the soil and the hydrograph of flow, i.e., the flow which determines the point of most frequent attack.

All bar formations, point, alternate and middle bars, are formed by the same process and tend to have similar spacing along the channel. The mechanical process that forms all bars is a result of secondary flow, i.e., helicodial flow and centrifugal forces causing circular flow in bends. Middle bars are built in a channel which is too wide; excess width is caused by banks being too easily erodible and/or slopes too steep.

DISTANCE BETWEEN BAR FORMATIONS

In stabilizing any reach of any river, except for very localized protection, this parameter is one of the most important to determine and understand. When a river is locked into a set position and alignment, the natural process of meandering is stopped and thus the sediment transport along with the magnitude and locations of scour and deposition may be altered.

All bar formations, point, alternate and middle bars, tend to have similar spacing along the channel. The distance between bar formations was measured between the apex of the bars. The apex is usually found opposite or immediately upstream of the deepest point in the pool; however, in a non-eroding stabilized river the deepest part of the pool may be found a considerable distance downstream. This spacing is dependent primarily on the discharge and to a lesser degree on the type of bed and bank material. Charts 7 and 8 seem to indicate that over long reaches average distance between bars is independent of water surface slope. The slope may affect bar spacing only when it becomes too steep and the river takes on the characteristics of a braided stream. The distance sequence will be broken in a stable channel when a bend occurs with a long uniform radius and a large central angle. The bar builds uniformly on the convex side as long as there is a smooth concave bank of uniform radius. Two such bends in sequence could easily double the normal distance between the apex of the bars.

In the 1876-80 and 1911-15 survey of the natural river, it was found that 51 percent of the bars in the Vicksburg District were between 4.0 and 6.0 miles apart, and 50 percent of the bars in the Memphis District were between 3.6 and 5.6 miles apart, see chart 9. In the Vicksburg District, the bar spacing for the 1969 survey varies as follows:

3 Stable Reaches	4.0 to 7.3 miles apart
6 Unstable Reaches	2.5 to 4.0 miles apart

8 Transition Reaches 2.0 to 5.0 miles apart

The longer distance between bars is generally associated with bends that have smooth concave banks of uniform radius. The point bar associated with this bend will be continuous as long as the curve maintains a uniform radius. If this occurs, a bar up to twice the normal length could develope. Normally the distance between point and alternate bars is as follows:

Vicksburg District below Arkansas River	4.6 miles
Memphis District above Arkansas River	4.2 miles

In checking the 1968 and 1969 navigation maps of the Mississippi River it was found that 71 percent of all bars in the Vicksburg District and 53 percent of all bars in the Memphis District fit the above spacings. The bars that were formed at different spacings were generally associated with extremely wide channels with revetment on both banks and/or with dike fields spaced irregularly along the channel.

The fact that bars occur at regular intervals in stable channels has been observed by other authors as well. Leopold, Wolman and Miller (1964, pp. 203, 206-207)[6] state - "A straight or nonmeandering channel characteristically has an undulating bed and alternates along its length between deeps and shallows, spaced more or less regularly at a repeating distance equal to 5 to 7 widths. The same can be said about meandering channels, but this seems more to be expected because the pool or deep is associated with the bend, where there exists an obvious tendency to erode the concave bank. The similarity in spacing of the riffles in both straight and meandering channels suggest that the mechanism which creates the tendency for meandering is present even in the straight channel."

"This spacing of pools and bars was also noted by Stuart in his work on the ecology of salmon and trout, he had found that water flowing through the gravel of a riffle provides aeration essential to the incubation of fish ova (Stuart, 1953, p. 408). Being concerned with the effect of diversion and realignment of certain gravel streams in Scotland on their ability to maintain trout, Stuart noted that new stream beds dredged by a dragline were, when just constructed, of uniform depth and without pools and riffles. With the aim of producing the usual pool and riffle sequence, he directed the operator of the dragline to leave piles of gravel on the stream bed at intervals appropriate to riffles - that is, 5 to 7 widths apart. After a few flood seasons these piles had been smoothed out and presented to the eye a picture that in all respects appeared natural for a pool and riffle sequence. Moreover, the riffles so formed have been stable over a number of years of subsequent observation."

LONGITUDINAL PROFILES:

The geometry of the channel is a result of all discharges over a long period of time. The channel's top bank elevation is a result of flooding which builds the natural levee; therefore, the top bank elevation versus distance along the channel will give an indication of the high water slope as shown in chart 4. The low discharges will form a more sinuous path between top banks of the channel and will flow around the bars formed mostly by high discharges. Sediment movement occurs at all stages; however the higher discharges move the bulk of the sediment and are more influential in forming the channel.

Water surface profiles of high and low stages, before construction, will give an indication of the variations in slope. After construction, similar profiles will indicate where and to what degree the channel is changing. By close observation of profiles and the geometry in specific reaches, it is possible to derive relationships of the variation in slope to which the stream will adjust. This will give limits that can be tolerated by the hydraulics of the stream in the event that shortening of the channel is necessary by cutoffs and realignment. Charts 10 and 11 are comparisons of low water slopes before and after major river control began. The two early surveys on chart 10 were adjusted to a discharge of 155,000 c.f.s. which is approximately the same discharge as the later surveys of 154,000 c.f.s. on chart 11. Chart 10 shows that the early river had aggradation below Red River Landing and degradation between Arkansas City and Vicksburg; however, most of the river had a constant stage discharge relationship in the two surveys. Chart 11 shows the effect of the cutoffs and bank revetment in the late river. The channel bed is going through a change throughout the entire reach; the channel is appreciably deeper due to the effect of stabilization.

DISCHARGE HYDROGRAPH AND SEDIMENT DISCHARGE

These parameters are important since they show when water and sediment discharge will be at a high or low and what magnitude can be expected. The design of structures must take into account the high sediment floods as well as all other flows. Since sediment will be moved primarily at high flow, it may be important to show if floods will occur over long or short periods and if the rise and fall will be sharp or gradual.

SOIL CONDITION

Knowledge here will give indications as to the bearing qualities of the soil for piles and other structures. Also, the types of failures that may occur in the banks can be anticipated, and thus, the banks can be sloped for better stability.

GENERAL ALIGNMENT AND STABILIZATION PROCEDURES

Channels which need to be realigned due to instability, excessive curvature, or the need to protect property should be laid out on topographic maps and aerial photographs, taking into account the conditions that exist both above and below the area of planned improvement. Channels in erosion resistant material are invariably narrow and deep while those in erosive materials are wide and shallow, see chart 12. By following this natural phenomenon, the artificial hardening of the banks by stabilization permits the general narrowing and consequently deepening of the channel in compliance with natural laws.

Reveted banks and controlled widths will build a more efficient channel which will pass flood flow much easier with a minimum increase in stage. Velocities are higher in deep channels and thus can accommodate a higher flow. However, a stabilized river can no longer meander; therefore, the natural progressive movement of the whole system of bars, pools, and shoals is stopped. Consequently, widths must be controlled and banks stabilized in proper alignment plus provision must be made for permanent bars to build at proper intervals as nature shows us. Structures designed to stabilize bars must also be designed to contain the bed sediments, scoured in channel deepening, in permanent storage facilities spaced in proper geometric sequence down the channel. Caution needs to be exercised in the design of revetment due to the fact that a revetted channel may scour to its ultimate depth. This may cause the revetment to fail unless provision has been made to counteract such action.

Leliavsky (1954, p. 143)[4] states, "There is, however, a strong current of opinion against this line of approach, for a solid, artificial bank-protection must of necessity introduce a foreign element into the natural process of the formation of a river channel, and thereby upset its basic laws. To use a parable, we may say that by building an unerodible, solid structure in the natural channel of an alluvial river, we are introducing a dead element into a live body, and therefore, the behavior of this body in its natural state cannot be used for a prognosis of the effect of the dead element, which must be studied as such, in special experiments." This statement is not entirely correct because the characteristics would be changed only if the channel was locked into an unnatural condition and/or if the intensity and duration of discharge were altered. By studying the river in its natural regime, a set of geometric parameters with tolerable limits can be developed that can be built into the channel so that there will be a minimum of maintainence.

In a meandering river, the point bar will build up to the highest elevation in that part of the valley and the material thus stored will remain there until an upstream meander loop cuts through it. In a stabilized river, the high water will flow over the point bar and tend to keep it scoured to a lower elevation and at the same time try to build the bar toward the concave bank thus making a narrower and deeper channel. A channel thus formed is poor for navigation and will tend to undermine any bank protection. In this case, deep groins in the pool and/or longitudinal structures on the convex bank may be considered. The resulting effect will be the tendency for the pool to move back toward the center of the channel and thus reduce attack on the concave bank.

Top bank control by high water restrictions should also be considered in order to keep a more uniform top bank width and to control sediment transport at all stages. The width of the river will necessarily vary with valley slope and type of channel cross sections.

Some channel improvement may call for making cutoffs. When cutoffs are considered the river slopes should also be considered so that slopes leading to braided type channels will not be encountered. As discussed previously, limited cutoffs may possibly be considered, however, the main trouble with cutoffs is that they often disrupt sinuosity and the sequence of alternating bars. This distruption may lead to a problem area if a proper sequence cannot be built back into the area of the cutoff. This pool-bar sequence will reestablish itself as soon as the next well formed point or alternate bar shows up downstream. This could mean that the mechanics of sediment transport and flow are continually regenerated.

Channel improvements should be accomplished in the following order, working in a downstream direction and letting the river do most of the work:

(1) Begin any realignment or control at a fixed hard point.

(2) Realign a river where possible to build in more depth and curvature in bends. A smooth transition from one curve to the next, such that the tangent of each thalweg radius will coincide at the crossing, produces the best alignment and stability.

(3) Plan areas of deposition according to normal bar spacing for each individual reach of the river.

(4) Any structure should be designed and located to take advantage of secondary currents and should be built in stages or steps which take the best advantages of the work the river can do.

(5) Any future work should be done with the above in mind except where flood protection is in danger.

Anding (1970, p. 64)[(1)] states that , "With an understanding of the controlling variables and basic principles of the river, we should be able to properly design for a planned ultimate alignment; the types of structures listed below.

(1) Control structures for bendways and around point bars to afford proper widths and depths. These structures would be planned to provide increased overall roughness at low stages and decreased roughness and resistance to flow at high stages as required for more uniform slopes and transport of water and sediment.

(2) Control structures for crossings and straight reaches designed to afford reduced roughness and proper contraction to provide increased depths and flatter slopes at low stages and steeper slopes and more uniform channel characteristics at high stages.

(3) Control structures for divided flow reaches designed to develop either the bendway channel or the chute channel as desired.

(4) Supplementary training structures designed to improve the channel characteristics adjacent to existing revetments or dikes. This

may be accomplished by increasing the overall roughness where a wider and shallow channel is required and decreasing the roughness and contracting the channel to provide a narrower and deeper channel."

CONCLUSIONS

In any problem concerning alluvial rivers, experience and engineering judgement are of prime importance and in many instances will be the final determining factors. E. W. Lane (1957)(3) states, "There is a nearly infinite variety of river forms, if considered in detail. No river is exactly like any other river and no part of any river is exactly like any other part of the same river. This is because river forms are the result of a great many factors, and the same combination of these factors is never exactly repeated. However, river forms are the results of physical laws and if the conditions controlling the shape of any part of a river are exactly reproduced then the same form of a river will result. Certain factors influencing river forms are more effective than others, and when similar combinations of these major factors occur, roughly, similar rivers are produced." Consequently, proper geometric analysis will give many clues that will enhance the stabilization of the river with a minimum of maintenance.

As a result of the geometric analysis done on the Mississippi River, it is believed that there is an optimum depth to which any stream will scour and that there is a specific spacing of bars and pools that is dependent on the discharge. Consequently, in any channel improvement project, the general alignment of the natural channel must be studied in order to determine the geometric relationships that need to be conserved. The bars must be locked into natural deposition areas, the widths must be controlled, and there must be smooth transitions from pools to crossings and back to pools in order for the improved channel to operate properly.

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CLASSIFICATION OF VARIABLES

1. TIME
2. GEOLOGIC
3. HYDROLOGIC
4. GEOMETRIC
5. HYDRAULIC
6. MAN'S ACTIVITIES

POTAMOLOGY STUDIES

MISSISSIPPI RIVER

VARIABLES FOR GEOMETRY ANALYSIS

APRIL 1970

CHART I

VARIABLES TO BE CONSIDERED

1. DEPTH
2. WIDTH
3. SINUOSITY
4. RADIUS OF CURVATURE
5. DEGREE OF CENTRAL ANGLE
6. WIDTH OF THE MEANDER LOOP
7. DISTANCE BETWEEN MEANDER LOOPS
8. SPACING OF BARS
9. GENERAL ALIGNMENT
10. LONGITUDINAL PROFILE OF RIVER CHANNEL
11. SHAPE OF RIFFLES AND BARS
12. THE SHAPE FACTOR OF THE CHANNEL CROSS SECTION, BED FORMS AND STREAM REACH
13. THE DISCHARGE HYDROGRAPH
14. SEDIMENT DISCHARGE
15. SOIL CONDITIONS
16. VALLEY SLOPE

POTAMOLOGY STUDIES

MISSISSIPPI RIVER

VARIABLES FOR GEOMETRY ANALYSIS

APRIL 1970

CHART 2

MINIMUM VARIABLES

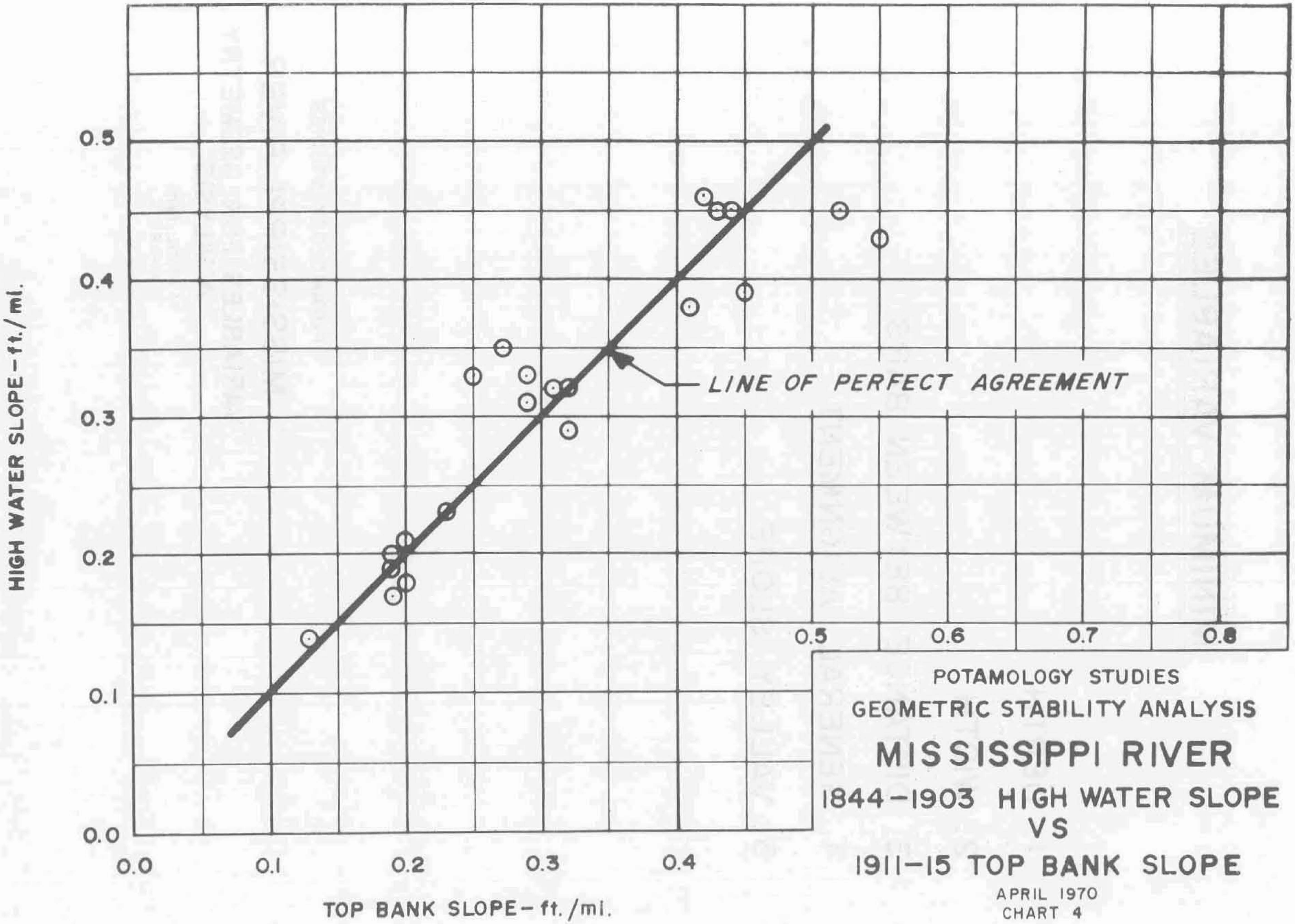
1. DEPTH
2. WIDTH
3. DISTANCE BETWEEN BARS
4. GENERAL ALIGNMENT
5. VALLEY SLOPE

POTAMOLOGY STUDIES

MISSISSIPPI RIVER

VARIABLES FOR GEOMETRY ANALYSIS

APRIL 1970
CHART 3



POTAMOLOGY STUDIES

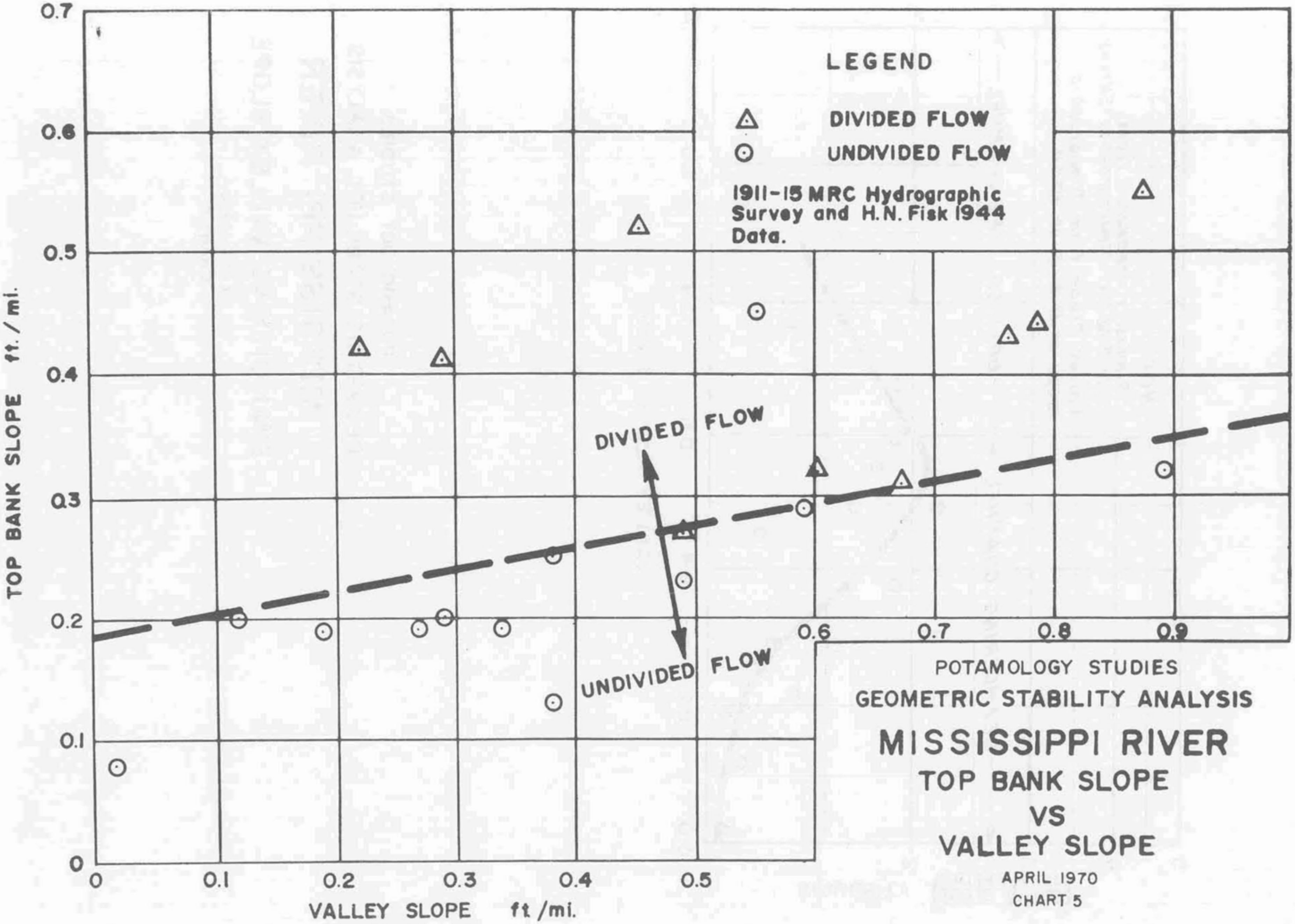
GEOMETRIC STABILITY ANALYSIS

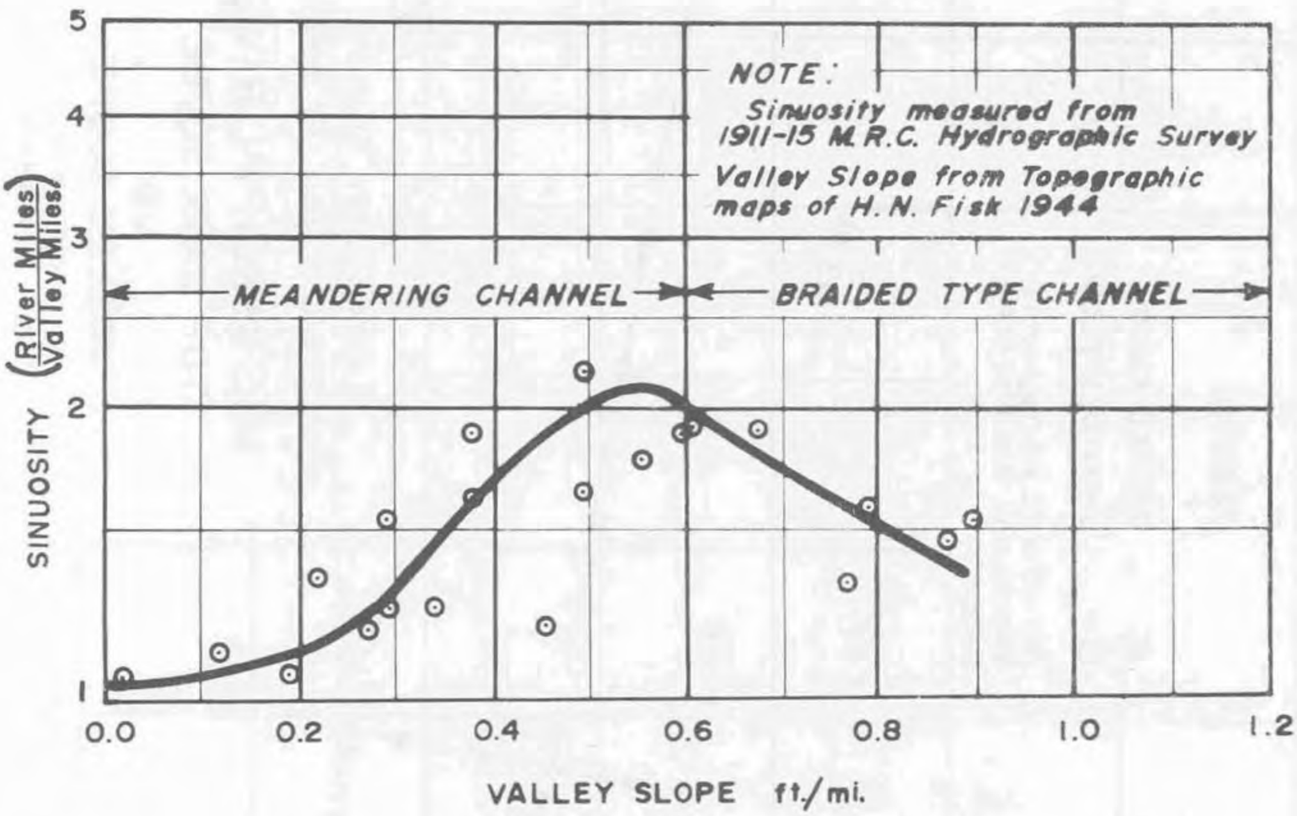
MISSISSIPPI RIVER

1844–1903 HIGH WATER SLOPE VS 1911–15 TOP BANK SLOPE

APRIL 1970

CHART 4


LEGEND
DIVIDED FLOW
UNDIVIDED FLOW
1911-15 MRC Hydrographic Survey and H.N. Fisk 1944 Data.
DIVIDED FLOW
UNDIVIDED FLOW
TOP BANK SLOPE ft. / mi.
VALLEY SLOPE ft /mi.
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
POTAMOLOGY STUDIES
GEOMETRIC STABILITY ANALYSIS
MISSISSIPPI RIVER
TOP BANK SLOPE
VS
VALLEY SLOPE
APRIL 1970
CHART 5



POTAMOLOGY STUDIES

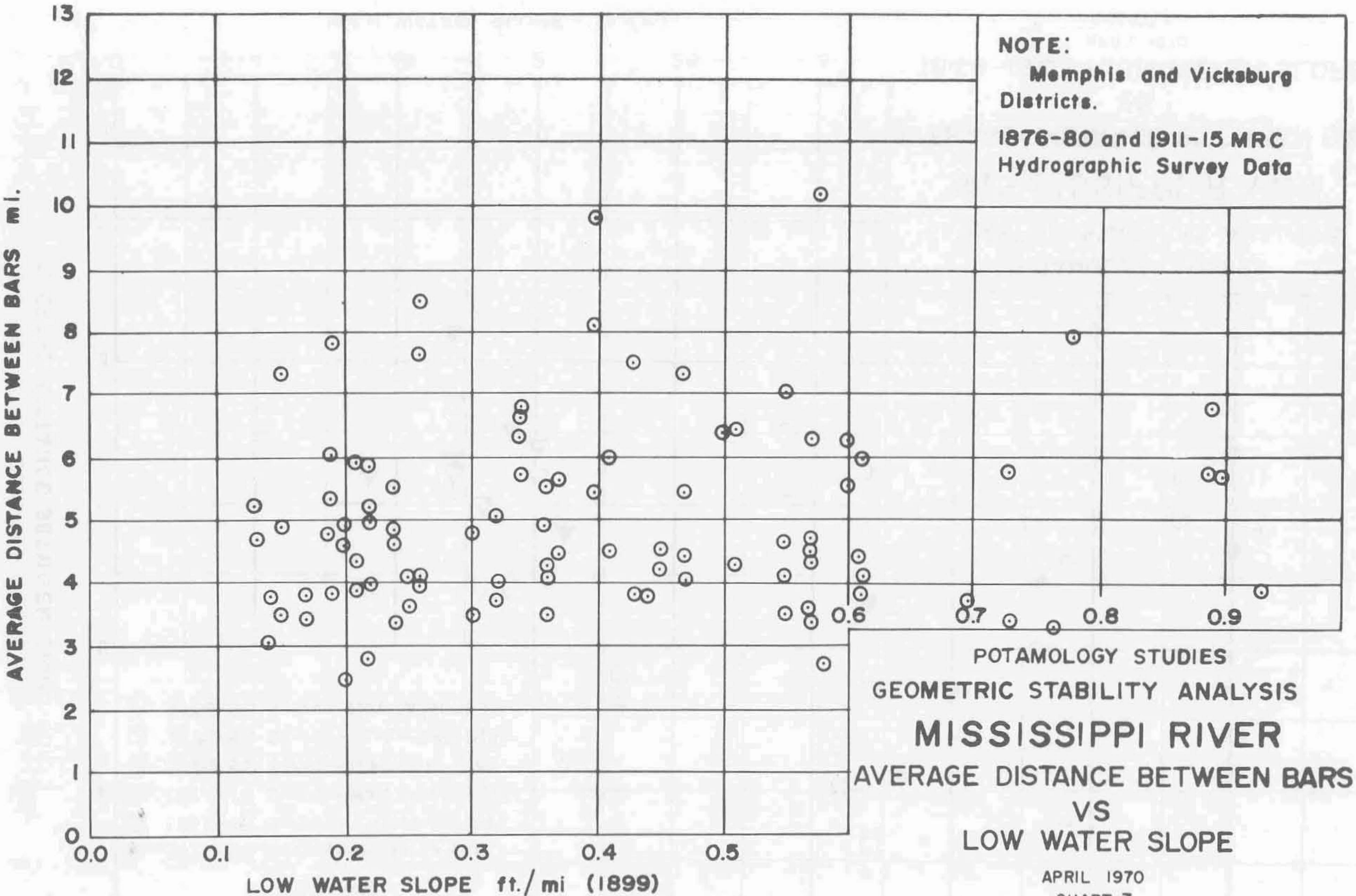
GEOMETRIC STABILITY ANALYSIS

MISSISSIPPI RIVER

SINUOSITY VS. VALLEY SLOPE

APRIL 1970

CHART 6



POTAMOLOGY STUDIES

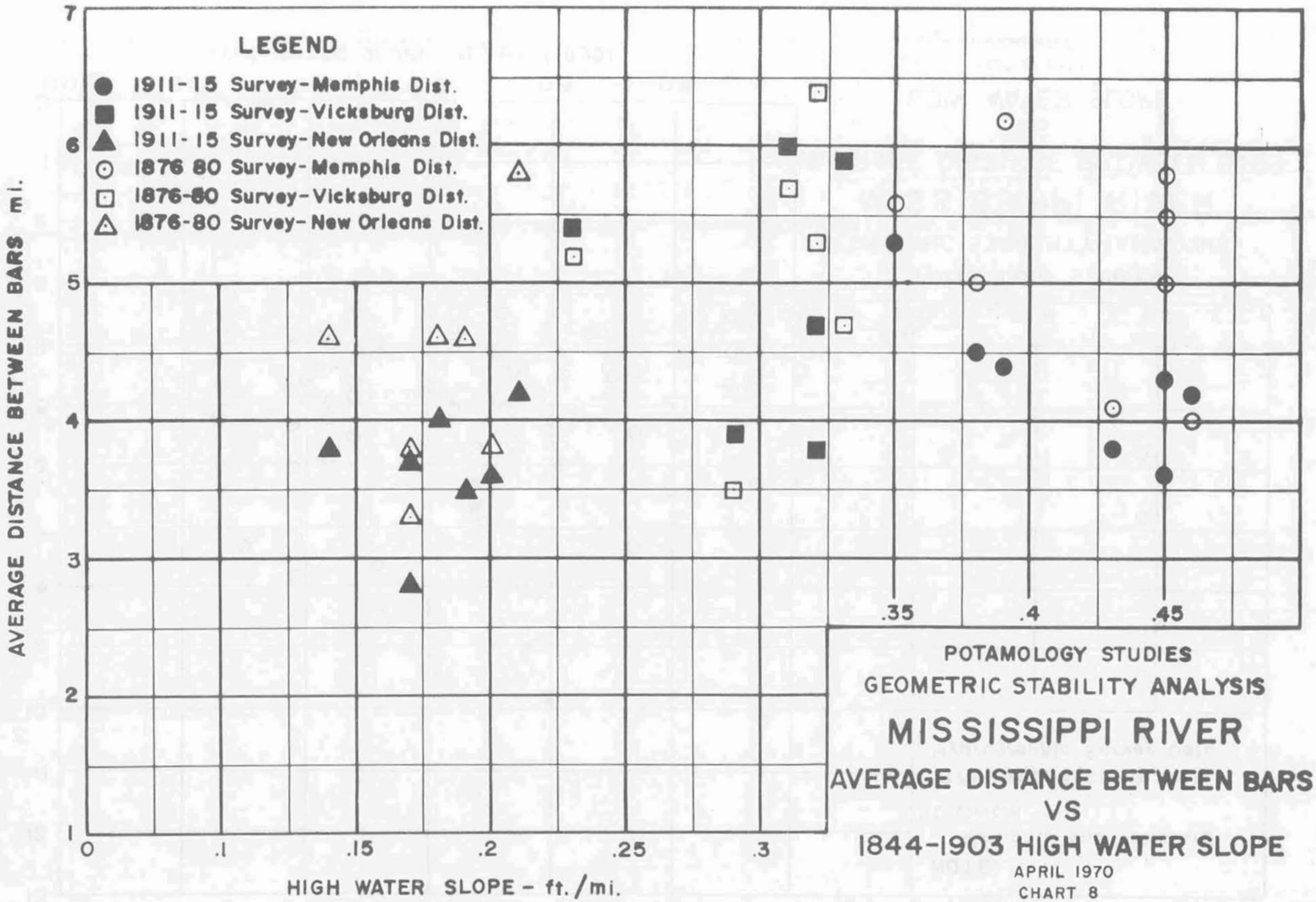
GEOMETRIC STABILITY ANALYSIS

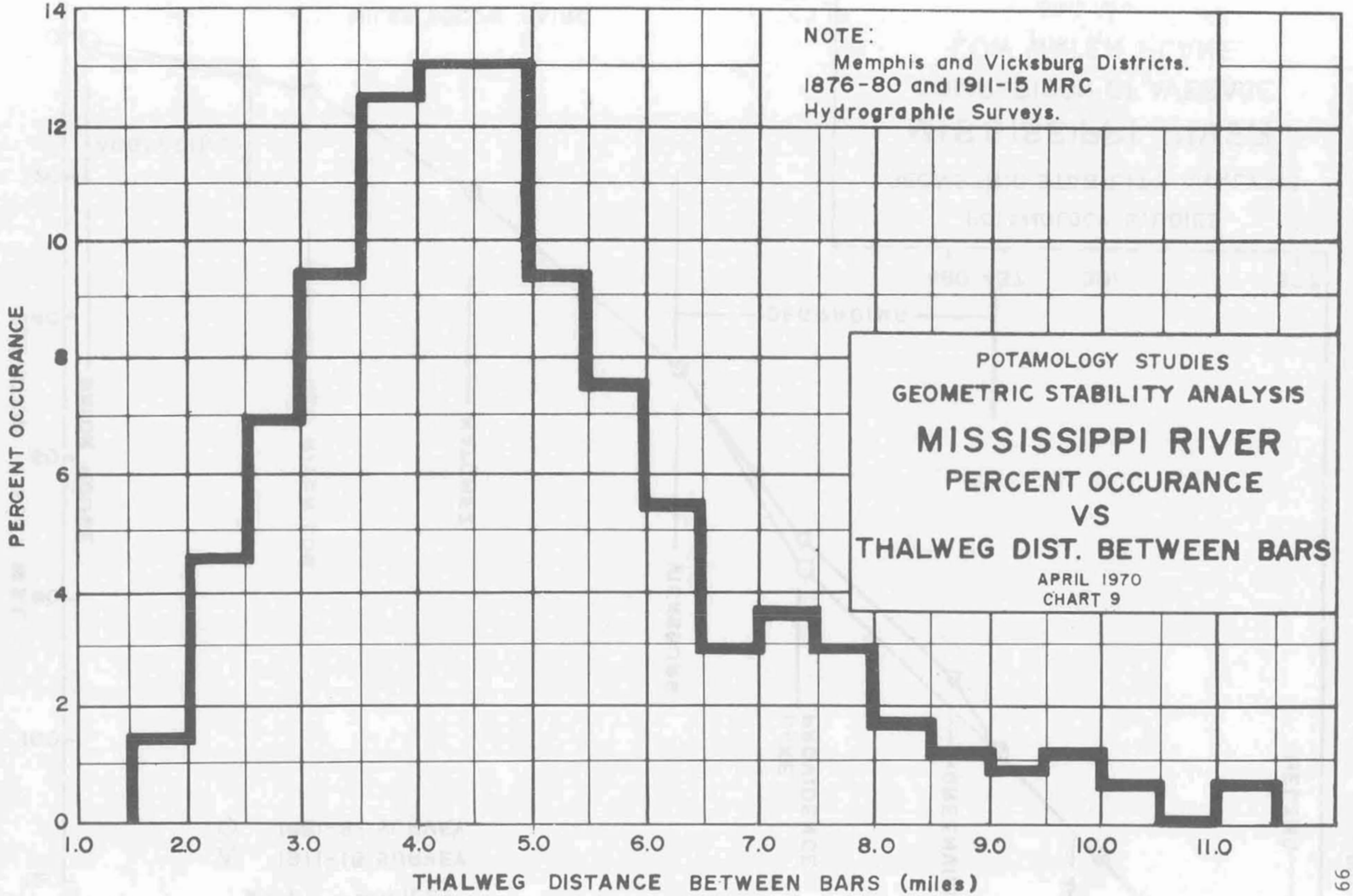
MISSISSIPPI RIVER

AVERAGE DISTANCE BETWEEN BARS VS LOW WATER SLOPE

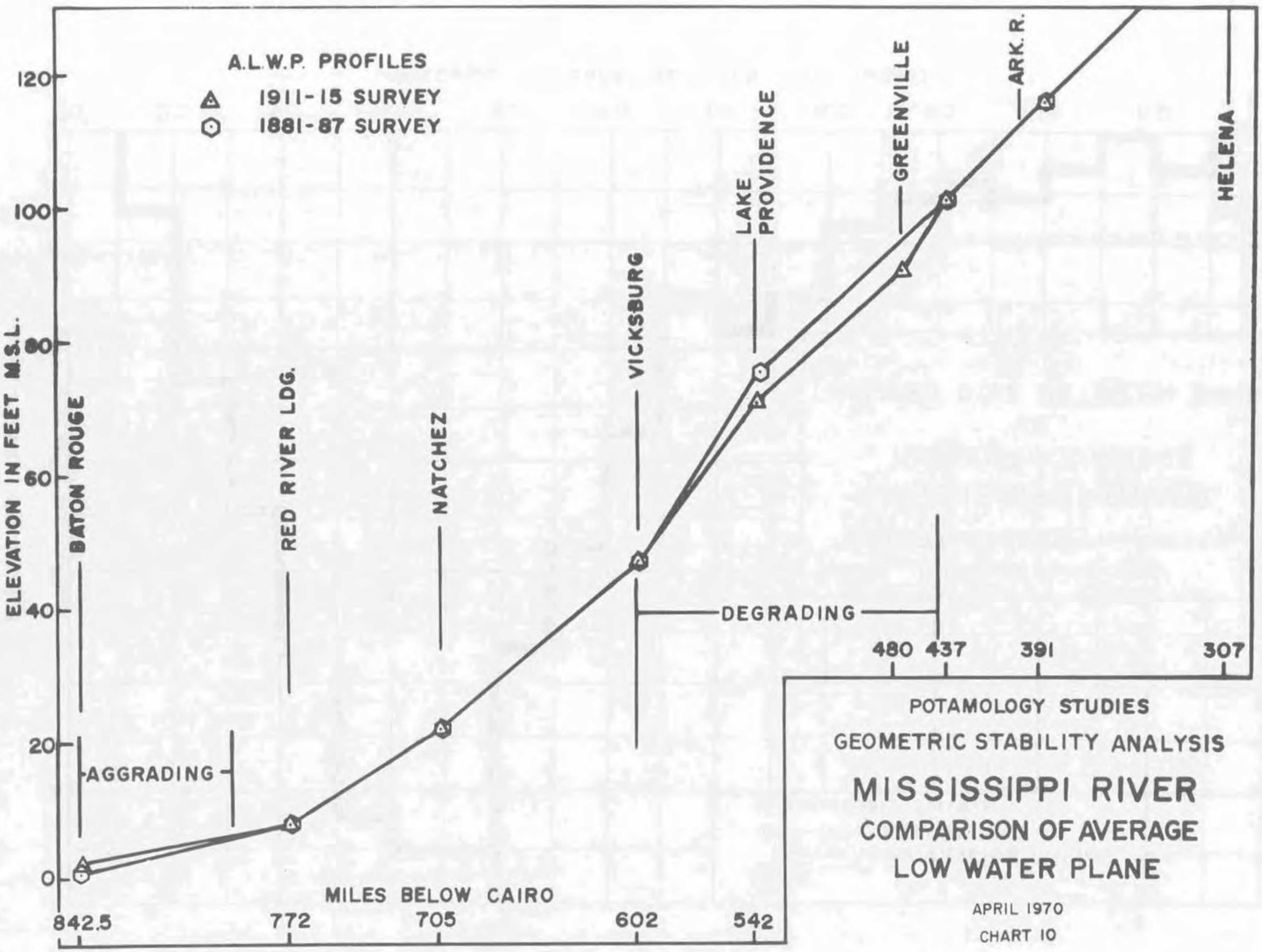
APRIL 1970

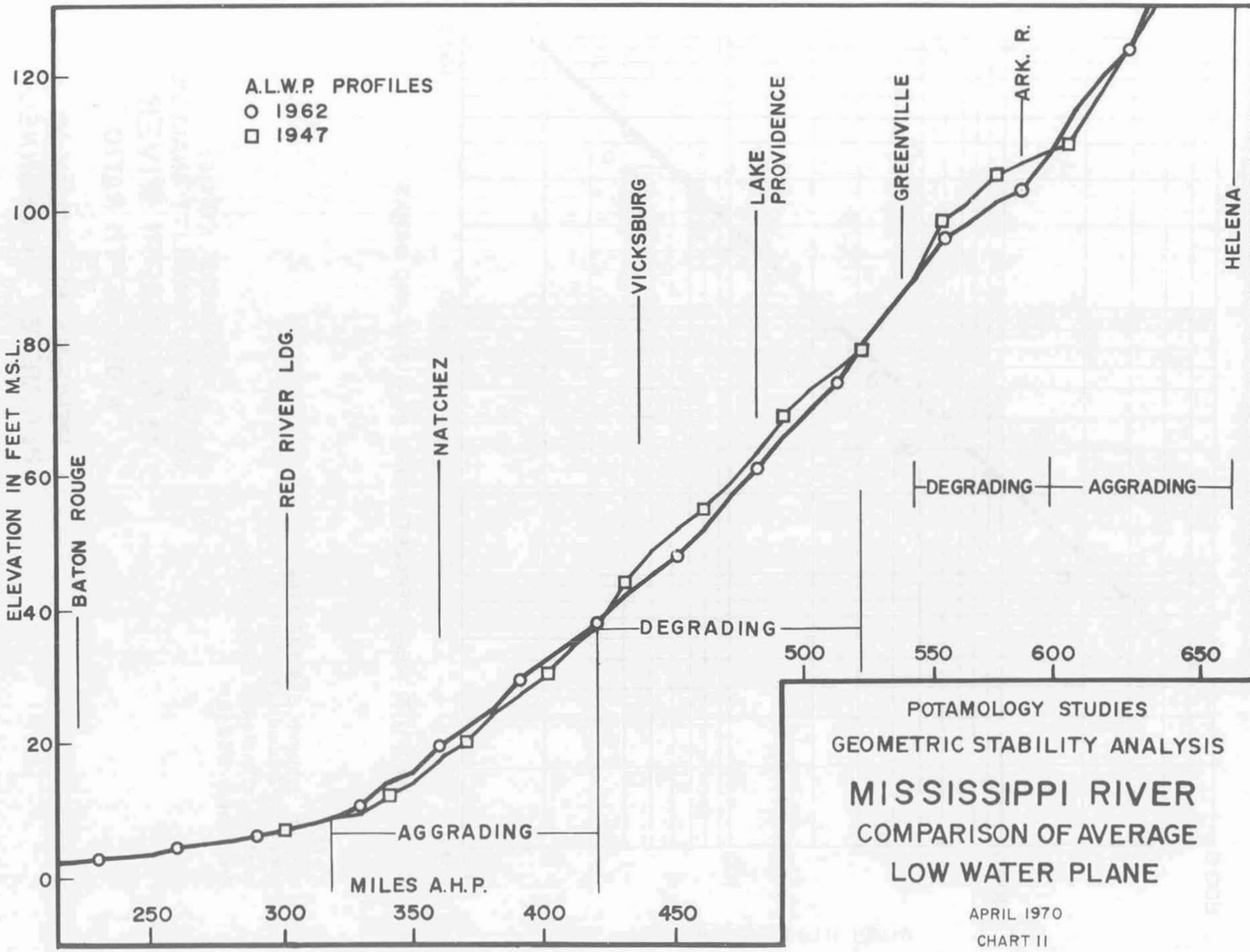
CHART 7

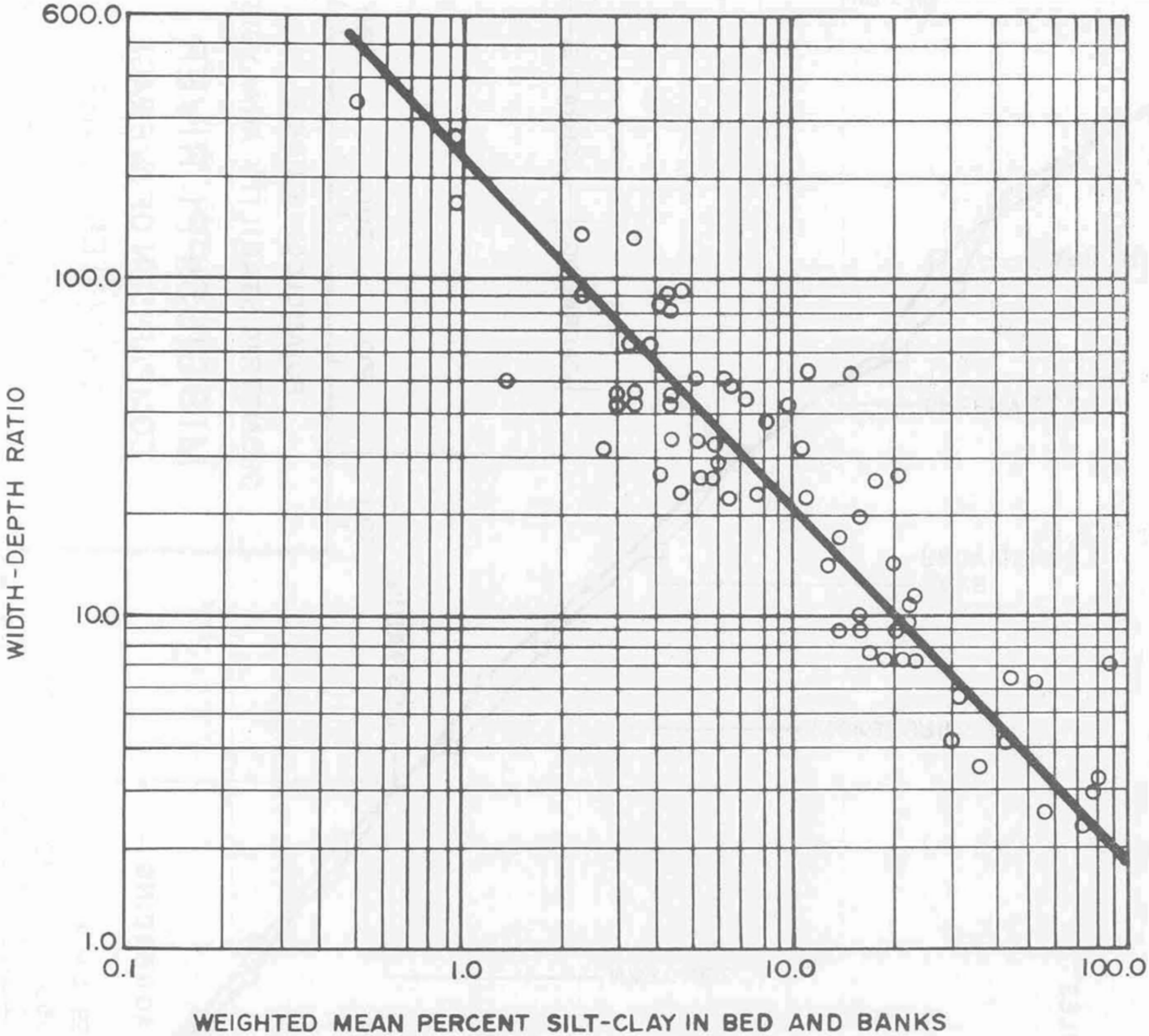

LEGEND
1911-15 Survey-Memphis Dist.
1911-15 Survey-Vicksburg Dist.
1911-15 Survey-New Orleans Dist.
1876 80 Survey-Memphis Dist.
1876-80 Survey-Vicksburg Dist.
1876-80 Survey-New Orleans Dist.
AVERAGE DISTANCE BETWEEN BARS mi.
HIGH WATER SLOPE - ft./mi.
1
2
3
4
5
6
7
0
.1
.15
.2
.25
.3
.35
.4
.45
POTAMOLOGY STUDIES
GEOMETRIC STABILITY ANALYSIS
MISSISSIPPI RIVER
AVERAGE DISTANCE BETWEEN BARS
VS
1844-1903 HIGH WATER SLOPE
APRIL 1970
CHART 8



NOTE:
Memphis and Vicksburg Districts.
1876-80 and 1911-15 MRC
Hydrographic Surveys.
POTAMOLOGY STUDIES
GEOMETRIC STABILITY ANALYSIS
MISSISSIPPI RIVER
PERCENT OCCURANCE
VS
THALWEG DIST. BETWEEN BARS
APRIL 1970
CHART 9
PERCENT OCCURANCE
0
2
4
6
8
10
12
14
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
THALWEG DISTANCE BETWEEN BARS (miles)


A.L.W.P. PROFILES
1911-15 SURVEY
1881-87 SURVEY
ELEVATION IN FEET M.S.L.
120
100
80
60
40
20
0
BATON ROUGE
RED RIVER LDG.
NATCHEZ
VICKSBURG
LAKE PROVIDENCE
GREENVILLE
ARK. R.
HELENA
AGGRADING
DEGRADING
MILES BELOW CAIRO
842.5
772
705
602
542
480
437
391
307
POTAMOLOGY STUDIES
GEOMETRIC STABILITY ANALYSIS
MISSISSIPPI RIVER
COMPARISON OF AVERAGE
LOW WATER PLANE
APRIL 1970
CHART 10


A.L.W.P. PROFILES
O 1962
□ 1947
ELEVATION IN FEET M.S.L.
0
20
40
60
80
100
120
BATON ROUGE
RED RIVER LDG.
NATCHEZ
VICKSBURG
LAKE PROVIDENCE
GREENVILLE
ARK. R.
HELENA
AGGRADING
DEGRADING
DEGRADING
AGGRADING
MILES A.H.P.
250
300
350
400
450
500
550
600
650
POTAMOLOGY STUDIES
GEOMETRIC STABILITY ANALYSIS
MISSISSIPPI RIVER
COMPARISON OF AVERAGE
LOW WATER PLANE
APRIL 1970
CHART II



NOTE:
From Schumm, S.A. 1960 The Shape of Alluvial Channels in relation to Sediment Type: USGS, Prof. Paper 352-B.

POTAMOLOGY STUDIES
GEOMETRIC STABILITY ANALYSIS
MISSISSIPPI RIVER
WIDTH-DEPTH RATIO
VS
PERCENT SILT-CLAY IN
PERIMETER OF CHANNEL
APRIL 1970
CHART 12