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Channel straightening by cut-offs, with special reference to the Mississippi River

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CHANNEL STRAIGHTENING BY CUT-OFFS

WITH SPECIAL REFERENCE TO THE MISSISSIPPI RIVER

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, in the Department of Mechanics and Hydraulics, in the Graduate College of the State University of Iowa.

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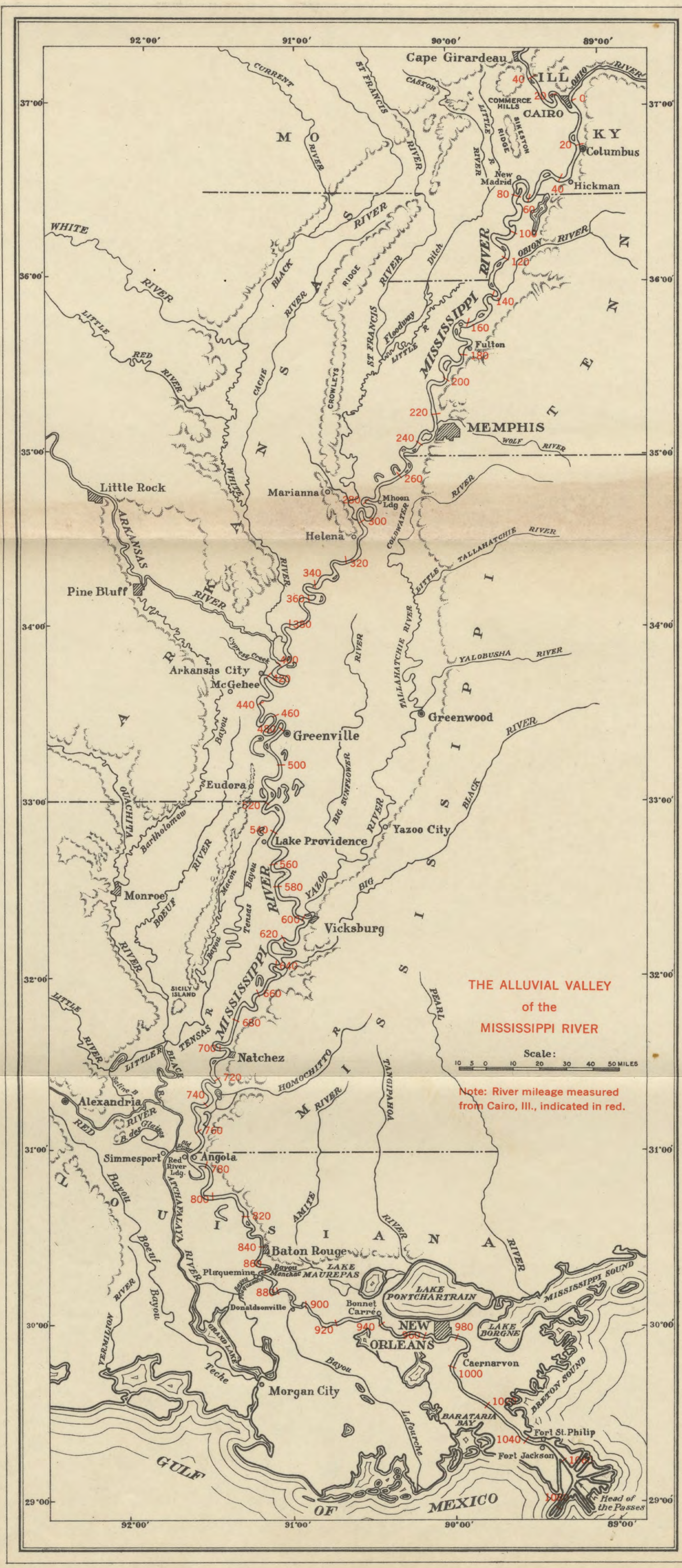
THE ALLUVIAL VALLEY
of the
MISSISSIPPI RIVER
Scale:
10 5 0 10 20 30 40 50 MILES
Note: River mileage measured from Cairo, Ill., indicated in red.
Cape Girardeau
ILL
CAIRO
KY
Columbus
Hickman
New Madrid
MO
Memphis
Marianna
Helena
Little Rock
Pine Bluff
Arkansas City
McGehee
Greenville
Greenwood
Eudora
Lake Providence
Yazoo City
Monroe
Vicksburg
Natchez
Alexandria
Simmesport
Angola
Baton Rouge
Plaquemine
Donaldsonville
Bonnet Carre
NEW ORLEANS
Caernarvon
Morgan City
Fort St. Philip
Fort Jackson
Head of the Passes
LAKE PONTCHARTRAIN
LAKE MAUREPAS
LAKE BORGNE
BRETON SOUND
MISSISSIPPI SOUND
BARATARIA BAY
GULF OF MEXICO
MISSISSIPPI RIVER
ARKANSAS RIVER
WHITE RIVER
ST FRANCIS RIVER
YAZOO RIVER
RED RIVER
ATCHAFALAYA RIVER
OHIO RIVER

A C K N O W L E D G M E N T

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A great deal of necessary information was supplied through the efforts of Mr. J. G. Jobes, Associate Engineer, also of the Experiment Station, to whom the author wishes to make grateful acknowledgment for his courtesies at this time.

C O N T E N T S

I. INTRODUCTION TO THE STUDY OF CUT-OFFS

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I. INTRODUCTION TO THE STUDY OF CUT-OFFS

1. Historical Background.

From the earliest times of recorded history man has attempted to control the courses and currents of streams. Control works were erected by the ancient Egyptians, the Chinese, and other primitive people. The art, as opposed to the science, of river engineering has progressed far from its crude beginnings. We have modern regulatory structures such as the large retarding basins of the Miami Conservancy District, the systems of locks and dams which maintain navigable depths on many of our inland waterways, the Panama Canal, etc. as outstanding examples of the art of engineering. The science of river engineering, on the other hand, is neither as old nor as far advanced as its counterpart. The study of river hydraulics has been pursued only a few centuries and its development has been relatively slow. The mass of factors and influences which govern the flow of streams are so complex, and accurate field observations of hydraulic phenomena are so difficult to obtain, that man has been baffled in his endeavor to reduce current behavior to set laws or fixed formulae. The practice of river hydraulics is therefore largely empirical.

The following statement illustrates another reason for the slow-paced development of river hydraulics:

> "Study shows that while different rivers possess similar hydraulic characteristics, each river combines these characteristics in an individual manner. As a result, each river

> must be considered as a separate problem, complete in itself and peculiar to itself. The Mississippi, which projects itself across the North American continent and which drains almost one-half of the area of the United States, exhibits through its many reaches almost the entire gamut of river phenomena." *

Captain A. A. Humphreys and Lieutenant H. L. Abbott, both of the Corps of Engineers, U. S. Army, made the first scientific study of the Mississippi in their Delta Survey. The report on the survey,** submitted in 1861, was a distinct contribution to river hydraulics. No further comprehensive or detailed study of the Mississippi was attempted until the Mississippi River Commission was created in 1879. Since the formation of that body, collection of data has progressed on a sound basis, and thorough studies of practical hydraulic phenomena have been constantly projected. In 1930 the U. S. Waterways Experiment Station was built at Vicksburg, Mississippi, with the primary mission of investigating general and specific hydraulic problems arising in conjunction with the improvement of the Lower Mississippi. In the laboratory of the Experiment Station many tests have been instituted and are at present being conducted from which invaluable information has been gained concerning the mechanics of flow in open channels. The reports from this laboratory are among the most

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* "Improvement of the Lower Mississippi River for Flood Control and Navigation," p. 75. Prepared by Major D. O. Elliott for the Mississippi River Commission.

** "Report on the Physics and Hydraulics of the Mississippi River."

important contributions made to the scientific knowledge of the hydraulics of river flow that have been made in this country since Humphreys' and Abbott's report on the Delta Survey.

Among other investigations, the U. S. Waterways Experiment Station ran several exhaustive tests on cut-offs. These tests were particularly notable because they indicated that some of the traditional theories regarding the effects of cut-offs were in error.

This paper will attempt to present some of the theories on cut-offs that different authorities have advocated; to analyze these theories and the manner in which they have influenced river control methods on the Mississippi; and to discuss, in view of the most recent data available, what are believed to be the true effects of cut-offs on the Mississippi River.

2. Formation of Cut-offs by Nature.

Cut-offs occur in nature in two separate and distinct ways.* Occurrence of a cut-off may be caused by either one of the two methods described below, or by a combination of both.

1) One method involves erosion of the banks of a neck by the currents of the stream when it is within banks. A meandering stream frequently bends back on itself in such a manner that two points on the stream which may be several miles distant from each other, as distance is measured along the

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* Thomas & Watt, "The Improvement of Rivers," p. 236-7.

banks, are actually only a fraction of a mile apart across the narrowest part of the neck which has been formed. If conditions are such as to direct the currents against the neck, either on its upstream or downstream side, or on both sides, erosion is likely to occur. Eventually the bank will be cut, allowing part of the stream to pour through the opening across the neck. As the distance across the neck is considerably less than around the bend, while the fall is the same, the water which passes through the new channel will have an increased velocity. As the scouring ability of a current varies directly as a function of its velocity, the fast moving water passing through the new passage will erode a progressively larger channel. Unless a resistant layer of earth is encountered, the cut-off channel will enlarge itself until the entire flow of the river passes through it.

As soon as part of the flow has been diverted into the new channel there is an immediate retardation of that part of the flow which as yet must go around the longer, old channel. This retarding of its velocity, and the eddies which are created, cause the water to drop part of the silt load which it is carrying, and a bar is started in the old channel just below the mouth of the cut-off channel. Another bar may be formed at the foot of the old channel due to deposits of material eroded in the cut. Both of these bars impede the flow of water around the old channel and aid in forcing increasingly greater amounts of it through the cut-off channel. As a rule the bars are in time built up until they completely separate the old channel from the remainder of the stream. Thomas and Watt cited instances in which flood overflows built up closing bars to a height of forty feet. Entrances to the old channel were so completely hidden by the high bars that from steamers passing along the river no evidence of the former channel could be seen.* The old channel, having been dammed at both ends, becomes a lake. On account of their curved shape, these lakes left as the results of cut-offs are often referred to as oxbow or horseshoe lakes.

2) The second method in which cut-offs are formed in nature involves out-of-bank flow. In some cases a river may double back on itself until a narrow neck exists and yet, with normal stages, there will be no threat of a cut-off. This may be due either to the resistance of the banks to erosion, or to the absence of strong currents impinging on the banks at the neck. In times of flood a stream may be forced out of its banks and across the top of an unprotected neck. The increased velocity resulting from the sudden fall may cause considerable erosion unless the surface is exceedingly resistant to scour. The river may fall in time to prevent a channel being cut, but the scouring action will recur when high enough stages are again reached. Sometimes, however, one high water period will be sufficient for the currents to cut out a channel across the neck. Once a channel has been cut which allows water to flow through at normal river stages, the development of the

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* Thomas & Watt, op. cit. p. 27-29.

cut-off proceeds in the manner outlined above in describing the first method of cut-off formation.

Along the Mississippi River surface scour has been impeded and the potential occurrence of cut-offs prevented by the presence of a hard, resistant, stratum of clay on the many protruding necks. These layers of clay are unique in some respects. They are not continuous over any great distance, nor is there any regularity to their occurrence. The frequent recurrence and semi-circular shape of these clay strata give rise to the belief that they owe their origin to cut-offs of an earlier period. Ox-bow lakes formed by ancient cut-offs along the river have very slowly and gradually silted up into strips of clay land. Sediment from floods and other fine material deposited in these lakes have completely filled them until they are no longer lakes. The fineness of the particles and the slow process of sedimentation has caused the earth which fills the lakes to be very hard and almost impervious to erosion.

When, in the course of its meandering, the river encounters one of these clay strata, it experiences great difficulty in cutting through the clay deposit. If the deposit is on a neck of the stream, it may prevent the occurrence of a cut-off due to overbank flow, as was described above. It is just as effective in preventing bank scour by the currents when the river is within banks unless a more erodible material underneath is scoured out, causing the layer of clay to break off in large chunks.

In order to check the natural formation of cut-offs, erosion of the neck must be prevented. This is accomplished by directing the current away from the neck by means of groynes, or by covering the attacked bank with revetments. Over-bank scour is combatted with spur dikes run out on the neck from the main levee system. (The tops of the dikes obviously should be higher than flood levels). An attempt was made to hold Leland Neck on the Mississippi River against over-bank scour by building a permeable dike along the neck. The attempt, however, met with failure as the cut-off was not prevented.

3. Formation of Artificial Cut-offs.

Some writers and engineers prefer to call only natural cut-offs by the name "cut-off", classifying such phenomena by the term "channel shortening" if they are induced artificially. In this paper both the natural and artificial elimination of bends will be referred to as cut-offs.

Practice in making artificial cut-offs varies with the locality, the material through which the cut-off channel is cut, the depth of the channel below the bend, and with other factors. Therefore no one method is universally followed. For example, the practice in Holland, as evidenced by cut-offs made in 1868 on the Wijk River * was to dig the cut-off channel to full width, allowing the current to scour the bottom to such

* Hubrecht, W. H., "On Cutting Off a Bend of the Lower Rhine," p. 304-7, Proc. Inst. C. E.

a depth as would accommodate the flow. The present practice on the Lower Mississippi River, for reasons to be discussed later, * is to dig a pilot channel across the neck at the place where the cut-off is desired. The pilot channel is not cut to either full depth or width. ** It merely trains the current, and helps to start the flow. A third method, recommended by some authorities, is to dredge the cut-off channel to full depth and width before the current is turned into it. Theoretically the third method would be the most desirable, but practical considerations often dictate the use of one of the first two methods.

Lieutenant H. D. Vogel, Director of the U. S. Waterways Experiment Station at Vicksburg, Mississippi, stated in a letter to the writer that in his opinion a deliberate channel shortening should always be made by dredging tangentially from the curve above the neck to the bend below the neck, rather than by cutting a channel across the narrowest point of the neck. Reference to PLATE IX will demonstrate the reasonableness of this argument. If the cut-off channel is made at the narrowest point on the neck, the current will have to make several curves that could be eliminated by cutting tangentially from bend to bend. The curves in the channel will

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* See below: Part II, Section 4 (b).

** On the Tisza River in Hungary pilot channels were cut to only one-third of the width desired. See Szilagy, "Flood Control on the Tisza River," The Military Engineer, Vol.24, 1932, p. 623.

throw the current against the banks, causing erosion, and will allow the channel to develop toward the point of the bend which was eliminated. Eventually the old channel may be nearly all reclaimed. A cut-off channel which is cut tangentially usually does not have a tendency to migrate, and it is more likely to deliver the stream to the channel below in a direction more conducive to a good get-away.

A number of cut-offs on the Mississippi have been made tangentially, with exceptions in the cases of Leland Neck and Diamond Point cut-offs* where it was not practical to follow this method.

4. Precautionary Measures.

Certain precautions are advisable in shortening river channels by the elimination of bends. Many authorities recommend excavation of a new channel to its full size before the stream is diverted into it. Advocates of this measure maintain that if only a pilot channel were constructed and if the stream were allowed to excavate the remainder, the material scoured out would be deposited at the foot of the cut-off in the form of a bar, and would later have to be removed by dredging.

On the Mississippi River, however, the above procedure is not followed. It has been found the excessive cost of dredging prohibits digging the channel to full section. Inasmuch as cut-offs are made across a point there is usually a

* q. v. Part II, Section 4 (b).

deep pool at each end ofthe cut-off channel. Hence there is little probability of the eroded material forming a bar at the foot of the cut-off which would be an impediment to navigation. In case a bar should form near the foot of the cut-off, the cost of opening a channel through the deposited material ordinarily would be less than the cost of excavating the cut-off channel to full section. For these reasons the general policy on the Mississippi River is to dig pilot channels only and allow the stream to enlarge the channels to the necessary capacity.

As cut-offs give new angles of attack to the currents, revetments are frequently necessary to prevent bank erosion above and below the cut-off. If erosion of this kind is not averted the river will soon carve new sinuosities, and the advantage gained from the shortening will be lost.

5. Advantages of Cut-offs.

The general conclusion that advantages are to be gained by eliminating river bends is not admitted by all authorities.

> "One school of extremists will maintain that every bend should be artificially cut across to provide a straightened river, never considering the detrimental effects that may follow such a disturbance of the natural regimen or the fact that new meanders will quickly develop tending to reclaim for

> the river its original length unless enormous sums of money are expended for bank revetments. Another school of thought, almost equally extreme, leans toward the belief that cut-offs must be prevented in every case at any cost, if disaster is to be avoided. The latter belief is often founded upon a more or less natural, but nevertheless unreasonable, assumption that a decreased stage in one reach must be compensated for by an increased stage in another." *

Somewhere between these two extreme views lies the truth. Certainly in some instances a cut-off would be advantageous. It is not a panacea for all river ills, and probably might have no place at all on certain particular streams. Where slopes and bed materials are of such characteristics as to allow the changes caused by cut-offs, they may be very usefully and profitably used.

One writer states ** that it is expedient to eliminate tortuous bends by cutting direct channels across necks in reaches where gentle currents prevail. Navigation would benefit by such channel straightening because by the elimination of bends the channel would be made shorter and easier to navigate.

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* Vogel, H. D., "The Military Engineer," Vol.XXIV, 1932, p.333.

** Vernon-Harcourt, L.F., "Rivers and Canals," p. 56.

The same writer believed that the increase in the slopes occasioned by the decrease in lengths would induce swifter currents, which by their scouring action would maintain the desired depth and width of the cut-off channel section.

Mr. Etcheverry* thought cut-offs were desirable where they might be employed to increase the capacity of streams. Thus if the capacity of a river bend should be less than the capacity of the remainder of the stream, he recommended elimination of the bend by digging a channel of greater capacity across the neck. Or, if the carrying capacity of a stream was being increased by dredging or other means, a cut-off might properly be made providing it would be cheaper to dig the cut-off than to increase the capacity of the stream all the way around the bend. Mr. Etcheverry stated further that cut-offs should be attempted only in hard material which is not subject to rapid erosion, since the increased velocities and changed direction of the current are apt to prove disturbing to the regimen in alluvial soil. He would allow cut-offs in alluvial streams only if floods were infrequent and of short duration in that locality.

In 1931 Mr. J. F. Coleman, a consulting engineer of New Orleans, stated his belief that cut-offs have a place in the improvement of the Mississippi River. ** The benefits which Coleman believed could be derived from river shortening

* "Land Drainage and Flood Protection," p. 236-40.

** "Mississippi River - A National Flood Problem," Civil Engineering, Vol. 1, 1931, p. 401-4.

on the Mississippi lay principally in the rectification of slopes and in the general improvement of the channel into a more efficient hydraulic conduit. Irregular slopes, broken into very short sections which vary frequently from practically nothing to as much as six inches per mile, and great differences in cross-sectional area at various points (on account of the lack of uniformity in the distances that levees are set back) have transformed the river into a conduit which is by no means efficient. This deficiency in carrying capacity is especially in evidence when the river is out of its banks, the time when carrying capacity is most important. Coleman believed that slopes could be made more uniform and the capacity of the river increased by a proper use of cut-offs. He cautioned that before making an attempt to smooth out the slopes a study should be made of critical velocities and the slopes which would produce these velocities.

On some streams the plan might be feasible to allow cut-offs to occur naturally in order that the stream may adjust itself to a more stable condition. On the hypothesis that nature abhors a straight line, many people have concluded that the more circuitous and crooked a stream may be, the nearer it approaches an ideal natural condition. On the Mississippi River in particular, nature has not been allowed to take its full course in adjusting the channel. In many places where cut-offs would have occurred naturally, artificial preventative measures have been employed which have precluded shortening of the channel, and the river has been left in an unstable condition. A section of the Red River above Shreveport may be cited to show the effects of a treatment which is in direct contrast to that employed on the Mississippi before 1929. Due to lack of funds nothing was done to prevent cut-offs on a reach of the Red River which formerly had many bends. Over a period of years many cut-offs have occurred in this reach, straightening the channel to a marked extent. As a result the channel has become stabilized, with a lowering of both the high and low water levels, yet with an accompanying increase of navigable depth at low water. Thus, in this reach of its course the Red River, unhampered and unaided by artificial means, has improved its navigability and reduced its flood hazard. Since nature has indicated a tendency towards cut-offs along the Mississippi, it seems logical to assume that conditions would probably be improved if this tendency were aided rather than retarded. *

Cut-offs which shorten the length of a river channel make it possible to reduce the extent of the levees necessary to confine the flood flow. As levees are expensive to build and maintain, it may be possible to effect sizeable savings by reducing their length.

Finally, and perhaps most important of all the advantages of bend elimination, cut-offs reduce the stages of the river above the mouth of the cut. Humphreys and Abbott,**

* Coleman, op. cit. p. 403.

** Humphreys & Abbott, op. cit. p. 396.

as well as many engineers who have written on the subject in recent years, expressed the opinion that flood heights would be raised as much, or nearly as much, below the cut-off, as they would be reduced above it. Investigations with models at the U. S. Waterways Experiment Station at Vicksburg and observations of actual cut-offs on the Mississippi have shown that stages above a cut-off are lowered, but that there a re no permanent changes in stages below. These observations indicate that cut-offs may be useful as a flood protection measure without fear of benefiting the country above the cut at the expense of the country below.

(It will be shown in Section 8 below that the effect of a cut-off on stages, as set forth above, may be different on an unleveed stream where a contrary set of conditions obtain.)

6. Disadvantages of Cut-offs.

The first exhaustive study of the Mississippi River was made by two officers of the Corps of Engineers, U. S. Army, Captain A. A. Humphreys and Lieutenant H. L. Abbott. The results of this study are contained in their "Report on the Mississippi River." * Some authorities give this work credit for being the first advancement made in the science (as opposed to "art") of river hydraulics made in

* Published in 1861; also published under the name, "Report on the Physics and Hydraulics of the Mississippi River."

this country. These two men, by the theories explained in their report, did much to mold policies of river control on the Mississippi for many years.

While the system of diminishing the natural resistance opposed to the flow of water in channels by cutting off river bends had been advocated by many, and had even been applied on the Mississippi by both state and federal governments, Humphreys and Abbott did not endorse the practice. * They concluded that any cut-off would reduce the water level above and raise the level below by an approximately equal amount. This conclusion was arrived at after the authors had studied the effects of Shreve's (1831) and Raccourci (1848) cut-offs on the 1851 flood as compared with the 1828 flood. From their observations and assumptions they concluded that the two cut-offs lowered stages several feet above the upper cut-off, but that the stages below Raccourci were raised a corresponding amount. Mathematical formulae were derived which gave results in very close agreement with their observations. In view of these results, which to them seemed apparent, Humphreys and Abbott concluded that cut-offs would not be useful in reducing floods, whether the cuts were made singly or in groups, since any advantage gained in lowering stages at one point would be offset at points downstream where levels were raised.

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* Humphreys & Abbott, op. cit. p. 396-402.

Objection is raised * to several unsubstantiated and rather questionable assumptions made by Humphreys and Abbott in arriving at their conclusion concerning the elevation of water levels downstream as the result of cut-offs. In their analysis of the affect of Shreves and Raccourci cut-offs on the 1851 flood, these writers assumed:

1) that the flood of 1851 was equal in magnitude to that of 1828; (although no record of discharge was obtained at various points to prove it, and no assurance was given as to similarity in the rate of progress of flood waves.)

2) that the discharge from Red River was the same in 1851 and 1828;

3) that a uniform slope may be taken as existing from the head of the cut-offs to Baton Rouge.

There is another error which possibly may have entered the calculations of Humphreys and Abbott, as well as those of other earlier writers. Virtually every major flood on the Mississippi River has been accompanied by crevasses in the levees all along the river. ** The exact dates of many of the earlier crevasses are not known. Since a crevasse would

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* Paper I, U.S. Waterways Experiment Station, Apr.15,1932, p. 56

** For a detailed list of crevasses see House Document 798, 71st Congress, 3rd Session, p. 125-37.

affect stages both above and below the cut-off, it is entirely possible that comparisons made between two floods may have been thrown off considerably by the occurrence of a crevasse which the writer did not know of and therefore could not consider.

If a stream is not leveed, lowering the stages in one section may tend to pull in water from overbank storage, thereby increasing the discharge at points below. Humphreys and Abbott maintained that on the Mississippi River, which had levees, stages below a cut-off would be raised, not because of any increase in discharge, but because of the new direction taken by the current on leaving the foot of the cut-off channel. As a result of this change in course, the swiftest water would refuse to run in the deepest part of the channel , and would, moreover, make it impossible for the channel to carry the discharge of the river without a raise in water surface elevation.

Humphreys and Abbott believed that the bed material of the river was of such hard, non-erosive clay, that the current would require a long period of time to adjust itself to the new channel and that consequently the injurious effect of the cut-off would be lasting. More recent investigations have proven that the bed material of the Mississippi is not the non-erosive blue clay described by Humphreys and Abbott, but an alluvial deposit, easily eroded by the action of the river current. The present trend of thought is toward the opinion that any raising of stages below a cut-off is merely temporary and will quickly disappear as the river adjusts itself by scouring a new deepwater channel.

Writing on cut-offs in later years, Col. C. W. Kutz in 1927,* Col. C. McD. Townsend in 1922,** Gen. Lytle Brown in 1931,*** and C. G. Forshey in 1876,**** all asserted that cut-offs on the Mississippi would cause permanently higher stages to exist below the cuts. The first three named apparently based their conclusions on the observations and deductions made by Humphreys and Abbott. Forshey alone made his own field observations. He differed from the three other writers in his belief that for a certain distance below a cut-off there would even be an actual reduction in gage heights, although farther downstream water levels would be raised. No explanation was offered for this phenomenon.

So convinced was General Brown of the harmful effects of cut-offs on the Mississippi River that he stated it would be worth while to spend as much as $500,000 for protective works to prevent the threatened break-through across Leland Neck in the Greenville Bends. Later in his article Gen. Brown modified his stand to the extent of stating that he was

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* "The Work of the Mississippi River Commission," Proc. A. S. C. E., 1927, p. 2492.

** "The Hydraulic Principles Governing River and Harbor Contruction," p. 118-20.

*** "Flood Control & Channel Maintenance on the Lower Mississippi River, " Civ. Engineering, Vol. 1, 1931, p. 819.

**** "Cut-offs on the Mississippi River - Their Effects on the Channel Above and Below," Trans. A. S. C. E. Vol. 5, 1876, p. 317-22.

willing for some experimenting to be done with cut-offs on the Mississippi River, provided that laboratory tests were first made of the section of the river where cut-offs were contemplated, and adequate precaution taken to insure against bank erosion. As General Brown was at that time Chief of Engineers, U. S. Army, his attitude toward cut-offs was important in shaping policies to be carried out on the Mississippi.

John W. Alvord and Charles B. Burdick * in their treatment of cut-offs stated that although the object of cut-offs is to carry floods at reduced gage heights, channel shortenings might cause greater heights at a given place downstream by lowering water levels above the cut and thereby preventing floods which otherwise would have occurred there. It is apparent that if the increased velocity and lowering of stages upstream are enough to carry the entire discharge within banks, water which otherwise would overflow the banks and be held temporarily in valley storage, is carried through the cut-off and on downstream. The channel below will then be called upon to carry more water than it had to accommodate before the cut-off was made. Since there is no increase in the velocity of the current for any appreciable distance below the foot of the cut-off, the channel below will have a larger discharge, but no increase in velocity. To compensate

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* "Relief from Floods," p. 99-103.

for the greater discharge below, the cross-sectional area must be enlarged, a process which can only be accomplished by the stream rising to a higher stage.

The effect of valley storage on stages below will be at a minimum in cases analogous to the proposed cut-off on the Scioto River within the city limits of Columbus, Ohio. The natural storage to be eliminated, while very important in view of the damage it could do the city, is negligible when compared to the flood discharge of the Scioto. Therefore the cut-off will not appreciably affect downstream stages.

On the other hand, the maximum effect of valley storage on downstream stages would obtain if a series of cut-offs were used to straighten a stream which meandered through a wide, swampy valley. Straightening such a stream would greatly increase its capacity. Floods, which previously caused water to stand for a considerable length of time over most of the valley, might be carried within banks by the improved channel. As a result the channel below the cut-offs would have a much greater discharge to handle, and stages would be raised correspondingly.

On a leveed stream on which floods do not overflow the levees, and on unleveed streams with stages below bankfull, there is no overbank valley storage. Therefore the decrease in surface elevation above the cut-off will not cause an increase in discharge, nor a rise in gage heights below.

A second objection to cut-offs which is often raised is that the attendant increase in slopes causes swifter currents. On a stream with considerable velocity any increase in flow might prove a serious difficulty to upstream navigation.

J. L. Van Ornum * saw an even more serious objection to the increased slopes, namely, that they would produce violent fluctuations in velocity, with accompanying instability both up and down stream. To illustrate how serious may be the consequences of changes in velocity, with accompanying disturbances in the regimen, Van Ornum described the disastrous effects of a system of cut-offs made on the Tisza River, a stream which flows through Czecho-Slovakia, Jogo-Slavia and Hungary and empties into the Danube.

In the middle of the nineteenth century a program of flood protection was started on this stream which was unique in its extensive use of cut-offs. Between 1846 and 1867 the length of the river was reduced from 758 miles to 477 miles. A total of 112 cut-offs were made aggregating 85 miles in length. The levee line was greatly shortened and the size of the levees decreased. Such extensive shortening could not be made in most streams, or their stability would be destroyed, but was permissible in this case because of the gradual slopes which prevailed. The Tisza is probably the only river in the world combining such inconsiderable velocity with such long winding bends. Slopes, which varied from 1.3 inches per mile to five inches per mile, increased by

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* "The Regulation of Rivers," pp 87, 310-12.

the cut-offs to values varying from 1.7 to 7.8 inches per mile. Between Tojak and the Danube, a river distance of 340 miles, the slope is unusual in that after the cut-offs were made, it reached a value of only 2.36 inches to the mile. According to Van Ornum the extensive cut-offs relieved the upper end of the valley only to the detriment of the lower part. Flood heights were reduced at the upper end, but the waters came down faster, causing partial engorgement when approaching regions where natural conditions have not yet been modified to accelerate flow. Subsequently, (in 1879), the city of Szeged was subjected to the greatest flood in its history. The greatly increased velocity, added Van Ornum, produced a second ill effect in the consequent erosion of banks as the river tried to resume its original widely-curving course and to regain its lost length.

It is of note that Julius Szilagy, * writing in 1932 on flood control of the Tisza River, made no mention of the detrimental effects caused by this extensive use of cut-offs. On the contrary he stated that before the cut-offs were made, much of the lower part of the valley was inundated from February to July, and that often during this period some of the cities were approachable only by boats. The fact that this condition has been rectified since the cut-offs were made would lead to the conclusion that Van Ornum's statement concerning the damage caused by the cut-offs is at least open to

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* "Flood Control on the Tisza River," in "The Military Engineer, Vol. 24, 1932, p. 623-26.

question.

The fact that the city of Szeged was subjected to the greatest flood in its history in 1879 does not necessarily prove that cut-offs relieved the upper part of the Tisza Valley to the detriment of the lower end, as Van Ornum assumed. First it should be determined whether the precipitation was less, or no greater, during that flood period than in others analogous to it. The effect of the levee system should also be explained. If, during the period of improvement, when the 85 miles of cut-offs were being made, there was any extension of the levee line, this prolongation would account for the presence of a greater volume of water at points below, just as with the extension of levees up the Mississippi River progressively higher flood stages have been noted at New Orleans and other points on the lower Mississippi. The original plan for improving the Tisza Valley, as prepared by Paul Vasarhely, who first pointed out the regularity of lfow, called for a system of levees as well as a system of cut-offs.* It is therefore not unreasonable to infer that the levee system was extended during the period between 1846 and 1867.

Van Ornum stated that natural conditions on the lower part of the Tisza had not been modified to accelerate flow. This being the case, an increased discharge, from no

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* Szilagy, op. cit. p. 623-26.

matter what cause, would make for higher stages. In adjusting itself to its new bed, a stream is quite likely to pile up at the foot of a new cut-off. This accumulation, however, has usually been found to be only temporary, and disappears as the stream cuts out a channel for itself.

B. F. Thomas and D. A. Watt * also objected to cut-offs on streams with steep slopes, but they offered no objection to shortening streams having moderate slopes, provided the cut-off channel was made in such a manner as to cause a minimum disturbance where it left and re-entered the old channel, and provided the banks above and below were properly protected against erosion caused by new current directions.

Cut-offs, by giving the current greater velocities, and by forcing the stream to take new directions, may cause considerable erosion and bank caving. According to William Starling ** sections of a stream which have been stable for many years may be thrown into a greatly disturbed condition by one or more cut-offs. Instability is especially likely to occur if the stream has a movable bed. Forshey *** stated that Terrapin Neck (Mile 576) and Palmyra (Mile 621****) cut-offs caused the points of attack of the current to be

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* "The Improvement of Rivers," p. 62.

** "The Floods of the Mississippi River," p. 53.

*** Forshey, op. cit. p. 317-22.

**** Throughout this paper references to river miles indicate distances below Cairo, Illinois.

changed over a considerable reach of the Mississippi River. The result was extensive and disastrous bank caving in a previously stable section of the river. Whole plantations were destroyed, levees were attacked, parts of cities were undermined and old points scoured away, while new points and sand bars were built up.

John Lathrop Mathews * agreed with Starling and Forshey that cut-offs cause currents that tear away the banks and upset the regimen of the stream. He added that in his opinion cut-offs bring about no permanent reduction in the length of a river, because when one bend is eliminated the increased currents cause other bends to be lengthened until equilibrium is restored between the velocity and the resistance of the banks to erosion.

As a result of Centennial Cut-off (1876) which occurred twenty-six miles above Memphis, Hopefield Bend, immediately above the same city, receded between 1100 and 1800 feet in six years. An enormous bar which formed on the city-side of the river at Memphis was another result of the same cut-off. Just below the bar the river was diverted towards the shore and in time undermined a railroad, warehouses, and other valuable property.**

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* "Remaking the Mississippi," p. 84-6.

** Thomas & Watt, op. cit. p. 236.

According to Fred H. Tibbetts * bends in a river are never accidents of nature, but are a natural adjustment of the river's length in order to balance grade and velocity under normal flows (including flood flows) so that the erosive power of the river is in equilibrium with the erosive resistance of the material through which it flows. Since cut-offs eliminate bends, Tibbetts believed they would increase velocities and accelerate bank attack. The sudden development of such attacks on banks in sections which have previously been stable is a menace to the levee system, and is doubly dangerous since it is practically impossible to foresee and prepare for such an attack in advance. Therefore Tibbetts would permit an extensive cut-off project only in case bank protection had been completed in advance, or if large quantities of protective material ready to be installed immediately, where needed, were on hand at the time the cuts were made.

In 1911 Tibbetts opposed a flood protection plan for the Sacramento River which included a large number of cut-offs. One of these cut-offs was made, and immediately an attack began at a point where valuable warehouses and steamer landings made it necessary to hold the river bank. As a result of this experience the plans to make other cut-offs on the Sacramento were subsequently abandoned.

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* "Flood Control on Alluvial Rivers," Engineering News-Record, Vol. 107, 1931, p. 520-24.

Concentration of tributary flow may be a result of cut-offs. Streams that have the mouths of their tributaries close together, (as in the case of fan-shaped drainage basins), are more likely to be flooded than if the mouths of the tributaries were farther apart. If the peak discharge from one branch does not have time to flow off before the onrush from another tributary arrives, the channel of the main stream will be called upon to carry at one time the maximum discharges of the two (or more) branches - a feat which it may not be able to accomplish without overflowing. Shortening a stream with cut-offs, by actually decreasing the distance between the mouths of the tributaries, and by giving the currents higher velocities, has the effect of bringing the tributary entrances much closer together. Hence a storm of short duration that normally would cause no flooding, may, after cut-offs are made, cause the main stream to overflow its banks. It is important, therefore, to investigate the location of tributary entrances and the length of time it takes the flood peaks of the tributaries to reach the main stream, before undertaking plans for a system of cut-offs.

Still another disadvantage of cut-offs is the possibility that a city or town located on a river bend may be left inland to decay. Several small towns on the Mississippi River have suffered this fate. * In 1876 Centennial

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* Thomas & Watt, op. cit. p. 27-8.

Lake Cut-off left Vicksburg on an oxbow lake. The upper end of the lake silted up rapidly, and had dredging not been resorted to, the lower end would also have been closed. It was finally necessary to divert the Yazoo River into Centennial Lake in order to keep open a navigable passage between Vicksburg and the Mississippi. When the cut-off across Leland Neck is completely developed, Greenville, Mississippi, will be left on an oxbow lake. Whether or not extensive dredging will be necessary to keep one end of this lake open for a shipping channel remains to be seen.

To summarize, the disadvantages which may accompany cut-offs are:

1) Increased slopes.
2) Increased velocities.
3) Instability of regimen.
4) Higher stages due to concentration of flow.
5) Elevation of stages below the cut-off.
6) Change in points of attack by currents.
7) Accelerated bank attack.
8) Separation of river towns from the stream.

As was brought out above, this writer does not agree with the opinion that all these disadvantages are likely to accrue, especially on leveed streams such as the Mississippi River.

In a paper published by the U. S. Waterways Experiment Station at Vicksburg, Mississippi, there appears the following statement, which refers to the discussions on cut-offs made by Humphreys and Abbott, Forshey, and Ellet:

> "The conclusions of these early writers are based on fragmentary and inaccurate data, and can not be regarded as either authoritative or conclusive." *

7. Individual Nature of Streams.

C. E. Grunsky, in discussing the aspects of flood control, said:

> "Each river has a character of its own. The topographic and orographic features of watersheds do not correspond, nor even the relative extent and character of soil and plant cover. Furthermore the rainfall on which runoff so largely depends is never the same on any two watersheds. Moreover, there can in such circumstances never be an exact duplication of valley building by any two rivers, no matter how similar they may otherwise be in their general characteristics. This

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* Elliott, op. cit. p. 62.

> is an important fact which differentiates the study of river phenomena from such engineering studies as those relating to the use of steam or the generation and transmission of electric energy, or the properties of building materials.
>
> "Yet there are certain fundamental principles readily understood, though not always properly applied, which guide the engineer in planning works for river regulation or river control." *

Grunsky's general statement regarding the individual nature of streams should always be borne in mind, and especially must the varied characteristics of streams be considered in a study of cut-offs. Many properties of streams, the materials which compose their banks, and the valleys through which they flow are of vital importance in determining whether cut-offs on these streams are to be beneficial or detrimental. No blanket approval or condemnation of cut-offs can be given. One reach on a river might be susceptible to treatment by cut-offs and another reach on the same river of such a nature that cut-offs in it would prove upsetting to the

* "Some Aspects of the Flood Control Problem," The Military Engineer, Vol. 24, 1932, p. 337.

regimen. Lieutenant H. D. Vogel, U. S. Waterways Experiment Station, Vicksburg, stated in a letter to the writer that while a cut-off at Yucatan, in a lazy reach of the Mississippi, might be excellent in every way, a similar cut-off at Slough Bend (near New Madrid) in a reach of steep slopes, would be very difficult to handle.

Steep slopes and high velocities are only two of the many factors that must be considered in determining the feasibility of cut-offs. The characteristics of the soil will influence the amount of erosion and bank caving which may follow a cut-off, as well as the length of time required for the current to adjust itself to new directions. Erodibility of the banks will also limit the amount of length which the river will regain after it has been shortened. The presence or absence of levees will affect the amount of valley storage and consequently the extent to which discharges are increased by cut-offs. If the stream is unleveed, a cut-off, by lowering stages above, may draw in water from over-bank storage, thereby increasing the discharge and gage heights below.

The size of a stream and the width of the valley through which it passes, bring in one of the economic aspects of river control. If the value of the property to be protected is less than the sum it is economically feasible to spend on protection by levees, cut-offs may be employed as a cheaper method of control, according to G. W. Pickels.*

* "Drainage and Flood Control Engineering," p. 292-311.

The same authority explains that the amount of river shortening depends somewhat on the general shape of the drainage area, and the size and location of tributaries. Any shortening brings the mouths of tributaries below the cut-off closer to the mouths of those above the cut. This condition tends to make the drainage area more fan-shaped, and may thereby cause higher flood peaks, especially in small drainage areas subject to flashy rises.

The foregoing illustrates the point that cut-offs are affected by so many factors that they are not well suited to a too inclusive treatment. Each cut-off should be treated as a law unto itself. Before any river shortening is attempted a thorough study should be made of all the conditions existing in the locality which may be effected by the shortening. Model studies are very useful in this connection, as many of the natural conditions of the prototype may be reproduced in a model, and the behavior of the prototype may be very accurately determined before the cut-off is actually made. While model studies are useful as aids, they should not be relied upon entirely where observations of the prototype can also be made.

8. The Manner in which Cut-offs Affect Stages Above and Below.

Ever since Humphreys' and Abbott's report was published many engineers have believed that cut-offs caused not only lower stages in the river above, but also a raising of the stages below. The effects of cut-offs on a leveed stream have been discussed elsewhere in this paper.* The effects on an unleveed stream are quite different, however, and are therefore explained briefly here.

G. W. Pickels ** explained the effects of cut-offs on the stages of an unleveed stream about as follows (See PLATE VIII) : Assume that the channel has been shortened by a cut-off to one-third its former length and that the velocity has been doubled by the increased slope and smaller roughness factor. Consider first the case of a steady inflow at B and the stream within its banks. The amount of water to be carried at each section is the same. Therefore, if the cross-sectional area of the channel is constant through the length shown, it is readily seen that through the cut-off the stage will be lowered due to the increased velocity. A to F is known as the drop-off section and is convex upward. The maximum velocity is reached at F. The length A - F depends on all the hydraulic elements of the old and new channels, so A may be many miles upstream. GE, the "backwater curve", is concave upward. DE is relatively short as compared to BA. The stage at D will be less than at A. Since the cut-off is short F and G will probably overlap. The effect then of a single cut-off with steady, within bank flow, is to lower the stage within the cut-off and for a certain distance above and below it, with no increase in the

* Supra, Section 5, p. 15 et seq.

** Op. cit. p. 292-311.

the stage or the discharge below the cut-off.

Next consider unsteady flow, since steady flow seldom exists. Assume channel at A at bank-full stage, with the stream out of its banks above A. From A to E stages are reduced, so are below bank-full stages. Below E the stream will be below bank-full but will reach bank-full if water at A remains at that stage.

If the flood continues to rise, the cut-off channel will eventually run full. Above F and below G the stream will be higher than between F and G, hence out of its banks. The flood will be slightly higher below E than if no cut-off existed, since the valley storage around the old winding channel has been eliminated. Flood flows reach E quicker than previously also, therefore E is subject to overflow by storms of brief duration.

If the flood rises higher, even F-G is flooded, but not as much as other parts of the river unless the flood is so great that the channel discharge is negligible in comparison with the total discharge. The flood below G is worse than if no cut-off existed, due to the amount of lost valley storage above.

It must be remembered that A, F, G and E are not fixed points. With a rising stream both the "drop-off" and "backwater" curves are shortened.

With a series of cut-offs the unimproved channel between the cuts will be flooded about the same as land below a single cut-off and for substantially the same reasons.

Going downstream the amount of lost natural storage will increase, hence the flooded areas will suffer to a progressively greater extent. To prevent this flooding the channels between cut-offs should be given greater slopes, a result which may be accomplished by beginning at the mouth of the stream and lowering the grades through the cuts, thereby increasing grades above the cuts. The final grade should be about constant.

It is seen that unless the lower end of the channel is improved all the way to the mouth of the stream, the upper end will be benefited only at the expense of the lower. It follows that channel straightening alone as a method of improvement can be applied extensively only in the case of small streams.

The above remarks are meant to apply only to streams that are not leveed.

9. Changes in Length of River Channels.

The question as to whether cut-offs cause any permanent reduction in the length of a river channel is a controversial one. A few authorities believe that cut-off shortenings may be retained, but the majority opinion is toward the belief that the increased velocity occasioned by cut-offs will cause erosion which eventually will regain for the river its lost length.

Szilagy believed that not all the extensive shortening on the Tisza River in Hungary, previously described, * would be permanent. ** Bank erosion has progressed more rapidly on the Tisza since the cut-offs were made, because of the greater kinetic energy imparted to the current. Especially in its upper reaches the river has proceeded to move laterally, and to form new and abrupt bends. To protect the riparian land owners from the attacks of the current, Szilagy recommended a system of bank stabilization as the best method to curb the tendency of the stream to erode its banks.

William Starling *** also thought that if a cut-off occurred the increase in slope would immediately cause erosion, and that eventually both the slope and length of channel would be restored in that section of the river. He cited the action of the Mississippi in the vicinity of Vicksburg, where, in 1876, Centennial Lake Cut-off reduced the channel length about six miles. By 1892, sixteen years later, surveys showed that in the fifty miles of river adjacent to the cut-off, four of the six miles had been regained. He also mentioned the fact that over a period of many years the total river distance from Cairo to the Gulf of Mexico has changed very little despite the many shortenings made by cut-offs. This fact led Starling to conclude

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* Supra, Section 6, p. 27 et seq.
** Szilagy, op. cit. p. 623-26
*** Op. cit. p. 53.

that the river will maintain certain lengths and slopes along its entire course as well as in its individual reaches.

Major L. E. Lyons made a study of the changes in length of the lower Mississippi River * which induced him to believe that the channel was gradually getting longer. He thought an ultimate length should be adopted for the lower river. This chosen length should not be exceeded, since to do so would flatten slopes and also add resistance to flow in the additional miles of sinuous channel through which the stream would have to pass.

To attain this ultimate length he recommended a system of river training in which possible cut-offs, recession of bends, advance of points, and other similar natural changes would be allowed to develop and proceed to previously selected positions or limits where stabilization might be effected in accordance with a plan admitting of these natural changes and having in view the predetermined length which was not to be exceeded.

Major Lyons' study of the river points out what a variable length it maintains, changing constantly in its overall length, and even to a greater extent in the lengths of short reaches. TABLE A, taken from his article, shows the changes in lengths of various sections of the river for periods of approximately 34 years. In case the period between the surveys was more or less than 34 years, the proportionate

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* "Changes in Length of the Lower Mississippi," The Military Engineer, Vol. 24, 1932, p. 458-62.

part of the change for a 34-year interval was calculated, for purposes of comparison. This table shows an increase in river miles from Cairo to the Gulf of 54.3 miles, or nearly 5%, between 1881 and 1914 - an average increase of about 1.6 miles per year. All except three of the sections along the river lengthened during this period. The largest decrease was between St. Joseph (Mile 660) and Natchez (Mile 710). This shortening was a result of Waterproof Cut-off in 1884, which shortened the channel 11.4 miles. By 1914 between St. Joseph and Natchez 4.9 miles of this lost length had been regained. It can be seen that the most stable sections of the river lie between Baton Rouge (Mile 846) and the Gulf of Mexico, while the most unstable are between New Madrid (Mile 60) and Red River Landing (Mile 775). In the latter section the length changed from 698.0 to 743.6 miles, an increase of 45.6 miles, or 6.5% of its length, in 34 years. The largest changes occurred in two sections lying between Lake Providence (Mile 540) and St. Joseph, Missouri. The combined length of these two sections changed from 104.4 miles to 130.0 miles between 1881 and 1914. This 25.6 mile increase is a change of 25.5% in 34 years.

Of the 54.3 mile increase in the Lower Mississippi, 26 miles or 47.9% of the whole, took place between Lake Providence and St. Joseph. In the period covered, two major shortenings occurred; the Waterproof Cut-off (Mile 680) in 1884, and Albemarle, or Newman, Cut-off (Mile 567) in

1912.*

Many cut-offs are known to have occurred of which there are no records except the oxbow lakes which are left on both sides of the present channel as testimony. TABLE C gives a list of those lakes which are well defined; in many cases they are of large dimensions and retain the form of the river bed for long distances. (Of course there are many other oxbow lakes which are not included in TABLE C. As they are small and narrow, due to sedimentation, their origin is uncertain.) Before the construction of levees the river overflowed its banks with great frequency, and the repeated sedimentation occurring in these periods of overflow would have filled the lakes listed in TABLE C more completely than is the case if they had been of very ancient origin. Hence these lakes, while not assumed to have occurred within the last 100 years, are believed to be of a comparatively recent origin.

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* While Major Lyons considers Abemarle a cut-off, it is not generally so considered, and is not listed by the Mississippi River Commission in its list of true cut-offs. Before 1912 the river split at Newman Towhead, with the main part of the flow taking the longer route around the towhead, and the remainder going through a chute inside the towhead. In 1912 the entire flow shifted to the chute, and the old channel silted up at the ends. Although shifting of the main channel to a chute may shorten the length of a channel, this action is not usually classed as a cut-off in the strict sense of the word because of the frequency with which it occurs. Whereas Bordeaux Chute Cut-off (Mile 279), 1874, is listed as a cut-off by the M.R.C., it is omitted by Major Lyons, showing that opinions vary as to whether the shifting of the main channel to a chute behind an island is a true cut-off.

TABLE B is a list of cut-offs that occurred between 1830 and 1930, based on Major Lyons' definition of what comprises a cut-off. It will be noted that Bordeaux Chute, 1874, is not among them. He drew attention to the fact that eleven cut-offs took place between 1830 and 1876, and only two in the 54 years from 1876 to 1930, with none after 1912. He thought it possible that other cut-offs, of which there is no record, may have occurred between 1830 and 1876.

Major Lyons thought that if improvements had not prevented erosion the river length might have increased even more than it did. However, it must be remembered, that although improvements have prevented the river from increasing its length, these same improvements have very effectively checked the formation of cut-offs which would have shortened the channel.

Major Lyons appears to stand with the minority in his views on the changes in length of the Lower Mississippi. TABLE E taken from "Paper I of the U. S. Waterways Experiment Station, Vicksburg, Mississippi," shows that according to Mississippi River Commission Maps, the distance from Cairo to Fort Jackson, Louisiana lengthened only 12.2 miles between 1882 and 1916. Although these 34 years cover practically the same 34-year period that Major Lyons considered, he found a 50.4 mile increase over the same reach. The Mississippi River Commission maps show an increase of 16.2 miles over this reach between 1882 and 1929. This discrepancy illustrates a point which was mentioned in a letter to this writer from the office of the U. S. Waterways Experiment Station:

> "Whether the river tends to regain or retain the shortening due to a cut-off depends entirely on what one is attempting to show, and upon the choice of surveys and reaches. However, if one adds up all the shortenings due to cut-offs and sees the great reduction in length, and then sees that the length is approximately the same, it is obvious that there is a strong tendency for an uncontrolled alluvial river to regain what might be called its normal length."

The writer of an article entitled "New Plans for the Mississippi" * attempted to discredit the theory that rivers regain length lost by cut-offs and expressed his view that the doctrine was based on insufficient proof. His contention was as follows:

> "The doctrine found support in the fact that the measured length of the river at different periods of time, years apart, when its course was quite different, appeared to total closely the same number of miles; and

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* Engineering News-Record, Vol. 110, 1933, p. 798.

> the further fact that whenever a cut-off occurred, shortening the channel by say 20 miles, new meanderings soon developed on either side of the cut-off, again increasing the length by about the same 20-mile amount. These facts are the sole foundation for the doctrine mentioned. No other reasons to support it appear to exist; but it has been an article of faith along the river."

The writer then attempted to prove the folly of the theory by pointing out that Shreves and Raccourci Cut-offs caused a total shortening of 34 miles. Of this distance only five miles had been regained by 1882, and only 9.4 miles by 1929.

One instance could neither prove nor disprove the theory. However, a better general idea of the way the Mississippi tends to regain its lost length may be gained by a study of TABLES E, D, and F. In TABLE E the Ross Survey of 1765 cannot be considered as accurate, when judged by present day standards. It has been carefully adjusted to traces of old portions of the river channel which appear on recent, accurate maps. In this way it is believed that the mileages shown are approximately correct. The mileages given for 1820 were obtained from the Young Survey of that year, adjusted to contemporary Land Office Survey bank lines, as these surveyed bank lines appear on present accurate topographic maps of the Alluvial Valley. Therefore distances as shown for 1820 are believed to be reasonably correct. The maps of the Mississippi River Commission used in TABLE E are accurate surveys measured by present day standards. TABLE E therefore represents the best data available on channel length changes on the lower river.*

TABLES D and E give the following information:

<u>Cairo - Columbus:</u> No cut-offs have occurred in this reach. Its length has changed only a mile in a period of 164 years, and is now the same as it was in 1882.

<u>Columbus - New Madrid:</u> Another very stable section which has experienced no recorded cut-offs. Since 1882 the channel has lengthened .9 of a mile.

<u>New Madrid - Fulton:</u> Although Needham's Cut-off (1821) shortened this distance by 11 miles, by 1882 the reach was three miles longer than in 1820, despite the effect of the cut-off. In 1929 it was 3.7 miles longer than in 1882.

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* Elliott, op. cit. p. 71-2.

Fulton - Memphis: In 1876 this section was shortened 15 miles by Centennial or Devil's Elbow Cut-off. The cut-off caused the opening of Fogleman's and Beef Island Chutes below, a development which shortened the channel an additional 15 miles - for a total decrease of 30 miles. In 1882, six years later, this reach so increased its length that it was only 4.9 miles shorter than in 1820. However, by 1929, it had shortened again until it was 13 miles shorter than in 1820.

Summary, Cairo to Memphis: The entire reach from Cairo to Memphis lengthened 2.4 miles between 1820 and 1882 in spite of the two cut-offs. In 1929, however, this reach was 4.5 miles shorter than in 1882.

Memphis - Helena: Commerce and Bordeaux Chute Cut-offs in 1874 shortened this reach by 17 miles. All of this except 2½ miles had been regained by 1882. In 1929 the reach was 4 miles longer than it had been before the cut-offs, or 6.5 miles longer than in 1882.

<u>Helena - Arkansas City:</u> Three cut-offs have occurred in this reach; Montezuma between 1796 and 1817, Horse Shoe in 1848, and Napoleon in 1863. In 1765 the reach was 127.9 miles long, and in 1820 it was 128.4 miles long despite the 11 miles shortening due to Montezuma Cut-off. The shortening between 1820 and 1882 amounted to a total of 19 miles, yet in 1882 the length was only 3.4 miles shorter than in 1820. Between 1882 and 1929, with no cut-offs the reach shortened 6.8 miles.

<u>Arkansas City - Greenville:</u> No cut-offs have occurred in this reach. Its length has consistently increased from 27.2 miles in 1765, to 32.0 miles in 1820, to 40.0 miles in 1882, and finally to 44.0 miles in 1929.

<u>Greenville - Lake Providence:</u> Grand Lake Cut-off shortened this reach 10 miles sometime between 1796 and 1817, yet in 1820 the reach was 1.7 miles longer than in 1765. Bunch's Bend Cut-off in 1830 and American Cut-off in 1858 shortened the channel an additional 23 miles. By 1882 nine of

these 23 miles had been regained. Between 1882 and 1929 only .1 of a mile more was regained.

Lake Providence - Vicksburg: Three cut-offs have also occurred in this reach. Yazoo Cut-off in 1799 shortened the channel 12 miles, yet in 1820 the reach was only 3 miles shorter than in 1765. Terrapin Neck Cut-off in 1866 and Centennial Lake Cut-off in 1876 shortened the reach a total of 22 miles. In 1882 the reach was only 11 miles shorter than in 1820. By 1929 an additional 1.1 miles had been regained.

Summary, Memphis - Vicksburg: Eleven cut-offs occurred in this 380 mile reach between 1796 and 1876, three before 1820 with a total shortening of 33 miles, and 8 since 1820 with a shortening of 81 miles. Yet the reach was 7 miles longer in 1820 than in 1765, and only 9.1 miles shorter in 1882 than in 1820. By 1929, with no additional cut-offs, the channel lacked only .8 of a mile of regaining its 1820 length.

Vicksburg - St. Joseph: This reach was shortened 19 miles by Palmyra or Davis Island Cut-off in 1867. In 1882 the reach was only 14 miles shorter than in 1820, and by 1916 had increased in length 11.6 more miles. However, between 1916 and 1929 the reach was shortened by 7.6 miles.

St. Joseph - Natchez: Between 1765 and 1820 this reach lengthened from 39.0 to 46.0 miles. It had lengthened 6 more miles by 1882. In 1884 Waterproof Cut-off shortened it 12 miles, but by 1916 it was only 8.7 miles shorter than it had been in 1882. Between 1916 and 1928 the length increased only 2.2 miles, which shows that compensatory lengthening in this reach has been neither rapid nor great.

Natchez - Bayou Sara: Three cut-offs have occurred in this reach: Homochito Cut-off in 1776 shortened the reach 13 miles; Shreves in 1831 and Raccourci in 1848 shortened it 15 and 19 miles, respectively. In spite of Homochito Cut-off the reach was 4.2 miles longer in 1820 than in 1765. The 34-mile shortening made by Shreves and Raccourci Cut-offs has not been compensated for in any such rapid manner. In 1882 the channel was 29 miles shorter than in 1820. There is no apparent explanation for the complete compensation of the channel shortening occasioned by Homochito Cut-off since no such action followed Shreves and Raccourci Cut-offs only a few miles away. The explanation may lie in errors which were made in the 1765 measurements of the channel length in this section. If, however, those measurements were correct, and the compensation for Homochito Cut-off did occur, this occurrence is but another indication of the individual peculiarities of cut-offs.

Bayou Sara - Fort Jackson: No recorded cut-offs have occurred in this comparatively stable reach, which had a length of 226.7 miles in 1765, 239.0 miles in 1820, 239.2 miles in 1882 and 243.1 miles in 1929.

Summary, Vicksburg to Ft. Jackson: Five cut-offs have occurred in this reach since 1765. In 1776 Homochito shortened the reach 13 miles, yet in 1812 it was 22 miles longer than in 1765. Between 1820 and 1882 cut-offs caused a shortening of 53 miles, but in 1882 the reach was only 36.3 miles shorter than in 1820. In 1884 Waterproof Cut-off shortened the channel 12 miles, but in 1916 the reach was 8.7 miles longer than in 1882. With no cut-offs in the period 1916 to 1929, the channel shortened 3.9 miles.

SUMMARY, CAIRO TO FORT JACKSON: Along the total length of the lower river 13 cut-offs have occurred since 1765, with a combined shortening amounting to 218 miles. Yet in 1929 the river was but 8.2 miles longer than in 1765. Four of these cut-offs, with a combined shortening of 46 miles occurred in the 1765 - 1820 period, yet in 1820 the river was 8.2 miles longer than it had been in 1765. Thirteen cut-offs shortened the river a total of 160 miles between 1820 and 1882, yet in 1882 the channel was only 50 miles shorter than in 1820. Waterproof Cut-off in 1884 was the only cut-off to occur in the 1882 - 1929 period. It caused a shortening of 12 miles, yet in 1916 the river was 12.2 miles longer than in 1884. Between 1916 and 1929 the river gained an additional four miles.

In TABLE F the Lower Mississippi has been divided into thirteen reaches. This table shows the amount of shortening caused by cut-offs which occurred in each reach during each of the periods discussed above, and to what extent compensatory lengthening took place.

From the foregoing discussion of the lengthening which invariably occurred after cut-offs had shortened the channel, it is clearly seen that the total shortening made by cut-offs is not permanent. In some cases lengthening took place which was more than the number of miles of shortening. In other cases the two distances were about equal and in still others only a small part of the shortening was regained. Always, however, some compensation occurred. It is possible that the 1765 and 1820 surveys were not exact and that the inaccuracies in them account partially for the seemingly strange behavior of the river. Only one cut-off occurred between 1882 and 1929. Accurate maps at the beginning and end of this period make it possible to determine precisely how compensatory lengthening has taken place in this case. Definite conclusions can not, however, be based on one observation. Deductions must, therefore, include reference to the large number of cut-offs which occurred during an earlier period when the maps were less accurate than they are at present. Although the result in the case of a single reach or a single cut-off may be slightly in error, broad conclusions based on the behavior of the whole river are believed to be approximately correct. Note that in either case the compensatory lengthening sometimes more than balanced the shortening, whereas at other times the original length of the channel was only partially regained.

In considering the examples given above, it must be remembered that the channel length changes given in TABLE V are the cumulative results of all changes occurring over relatively long periods of time, and therefore cannot be attributed entirely to the direct effects of cut-offs.

10. Summary.

The foregoing pages have brought out some of the varied, and often opposing, beliefs concerning cut-offs. At one time it was believed that cut-offs would be a very useful method of improving the Mississippi River for flood control or for navigation. Several early cut-offs which were followed by disastrous bank caving and erosion, and the adverse report of Humphreys and Abbott, were instrumental in bringing about a reversal of this belief. There followed a period in which no cut-offs were made on the Mississippi and none were allowed unless the cost of preventing the cut-off was prohibitive. The opponents of cut-offs could mention several distinct disadvantages which appeared certain to result. There were few advocates of cut-offs on the Mississippi, for even Caleb G. Forshey and other such men, who had at one time been proponents of river shortening, turned against the practice.

From the time it was organized in 1879 until 1928 the Mississippi River Commission was definitely opposed to any policy contemplating the use of cut-offs. As a result Waterproof Cut-off in 1884 was the only cut-off which occurred during this period, and it was neither contemplated nor desired. However, for reasons to be discussed later,* after 1928 the policy of the Mississippi River Commission concerning cut-offs was reversed and since that time several bends have been eliminated on the Lower Mississippi River. The reasons for the change in policy, a short history of past cut-offs on the Mississippi, a description of the present cut-off project, and some of the results obtained from model studies on cut-offs at the U. S. Waterways Experiment Station at Vicksburg will be taken up in Part II of this report.

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* Part II, Section 3.

II. CUT-OFFS ON THE MISSISSIPPI RIVER

1. Introduction.

Cut-offs are characteristic phenomena of alluvial streams. The Lower Mississippi is an alluvial stream known to have been subjected to the formation of cut-offs since the earliest times of which there is any record of the river. Moreover the numerous ox-bow lakes in the valley along both banks testify to the innumerable cut-offs which occurred even before there were written records of the Mississippi.

Reference to any map will show that the river is a series of bends and reverse curves. A series of maps showing the same sections of the river, but made at intervals of years, clearly indicates the tendency of the loops formed by the sinuosities of the stream to grow longer. (See PLATE XX -a, b, c and d). Under conditions favorable to the process, these loops advance a great distance, forming a point or neck several miles long. The land areas encompassed by the river in such bends are usually rounded at their extremity, and at this point may have considerable width. Near the base, however, these "peninsulas" may be left with very narrow necks. Thus the river may carve a course for itself around a bend in such a manner that the river distance between a point on the upstream side of the neck and one opposite it on the downstream side may be as much as twenty miles, whereas the actual land distance between these two points, across the narrow neck, may not be over half a mile. If the neck is attacked on either side, or on both sides, it becomes increasingly narrow and a "break-through" may eventually result. Since the fall via this short channel is the same as in the channel around the bend, velocities through the chute will be relatively high. Hence the chute will scour out a channel until the entire discharge of the river takes this shorter course. In most cases both ends of the old channel then silt up, leaving an oxbow lake. This sequence of changes describes the usual process involved in the formation of a natural cut-off.

Overbank flow is another method by which natural cut-offs are formed on the Mississippi River. In the foregoing description of a cut-off it will be noted that the formation was not aided by any overbank flow across the neck. Such flow occurs, however, when the stream gets high enough out of its banks to flood a narrow neck which has been formed by an enlongated bend. Again the fall across the neck is the same as around the bend, while the distance is considerably less. The high velocities thus induced tend to scour out a channel across the neck. The river may recede before the channel has been cut completely through, but eventually successive high water periods will cause a channel to be cut, and the river will abandon the longer old course in favor of the shorter, steeper, cut-off channel.

Before the day of levees along the Mississippi, flood stages were of course much lower than they are at the present time, and consequently there was much less overbank flow. As the banks were heavily timbered, scour across a neck even when the river was out of banks was not extensive. For these reasons some authorities believe that overbank flow had little to do with the formation of the earlier cut-offs. Levee construction has greatly changed this condition until the scouring across necks has become very important. If cut-offs are to be prevented in undesirable localities, it often becomes necessary to construct spur dikes and permeable dikes longitudinally along these peninsulas. Great "blue holes" are frequently scoured out as the high water takes the short cut across the neck. The "blue hole" left on Leland Neck of the Greenville Bends after the 1929 Flood was 80 feet deep, 2600 feet long and 600 feet wide. It is estimated that two and one half million cubic yards of earth were scoured out of this hole by this one flood.* These "blue holes" may make it impossible or impracticable to hold the neck against the attacks of the river. As will be seen later in this paper,** the Mississippi River Commission finally decided to allow the formation of a cut-off at Leland Neck.

The two processes enumerated above describe the methods by which cut-offs are naturally formed. Quite frequently local inhabitants, and occasionally river authorities, see fit to apply the appelation of "cut-off" to lesser channel

* Elliott, op. cit. p. 247.
** Section 2, Section 4-b; below.

changes such as the reopening or enlargement of old chute channels, or the break-through of the river into old oxbow lakes, and similar phenomena. The Mississippi River Commission does not consider these changes true cut-offs and does not include them in their list of cut-offs which have occurred since 1700. (See TABLE D). Some authorities even go so far as to eliminate from consideration the dredged channels across the necks of bends, maintaining the view that such changes are not really cut-offs but "channel shortenings". There is certainly some basis for this contention inasmuch as a cut-off is usually a break-through at the narrowest point of a neck, whereas a channel shortening is properly made by dredging tangentially from the bend above the neck to the bend below it. (See PLATE IX.) The distinction will readily be seen. In the eyes of the Mississippi River Commission, however, the difference is not great enough to cause them to list artificial cut-offs separately.

TABLE D lists cut-offs which are known to have occurred on the Lower Mississippi River between 1700 and 1932. Of the twenty given, nineteen occurred after 1765. It is very probable that several others of which there is no record took place in the period between 1700 and 1765. The profusion of oxbow lakes along the river testify to the number of unrecorded cut-offs of comparatively recent date. An accurate determination of all cut-offs since 1765 is possible as complete maps of the river have existed since that time.

In "The Improvement of the Lower Mississippi River"* it is explained that while much misinformation concerning cut-offs on the lower river exists in the popular mind, there is a paucity of real information having to do with these phenomena. The uninformed, or misinformed, layman usually pictures a cut-off as a grand spectacle which occurs almost instantaneously, and is followed by violent and stupendous changes in the river. This erroneous impression is at least partly the fault of early writers who based their conclusions on inaccurate data. From the explanation given above it is evident that cut-offs as a rule occur in no such manner. Of course the relative speed with which a cut-off is formed depends on such conditions as the volume of flow, the distance across the neck as compared with the distance around the bend (which, in turn, will influence the velocity), and the character of the soil through which the channel is made. The actual formation of the initial cut-off channel may develop very rapidly, but the set of conditions favorable to this break-through was much longer in forming. Likewise a considerable length of time is required for the cut-off channel to be enlarged enough to accommodate the entire discharge of the river, for the ends of the old channel to silt up, and for the other readjustments coincident with the completion of the cut-off. Thus, far from being an instantaneous change, a cut-off takes as much as several years, or more, to be completely formed. The very fact that cut-off formation is such a gradual process

* Elliott, op. cit. p. 60 ff.

accounts in a large degree for the lack of accurate information concerning the phenomena. Too many of the earlier writers were prone to judge the complete effects by what they observed in a very limited time. There is no doubt that much of the fragmentary data available to them was very inaccurate. Gathering complete data on cut-offs requires an exhaustive study rather than casual field observation.

The fact that the policy of the Mississippi River Commission until 1929 was to prevent all cut-offs along the lower river accounts partly for the lack of definite information on the subject. Although a comprehensive study of cut-offs would have been expensive, because of the time involved and the magnitude of the phenomena, had even a few such investigations been conducted, the records of same would today be a storehouse of interesting and significant information. However, no cut-offs were allowed to occur between 1884 and 1929, hence there was no opportunity to study their effects.

2. History and Description of Some of the Important Mississippi River Cut-offs.

A description of some of the most important recorded cut-offs that have occurred along the Mississippi River will now be given. Much of the following data was found in "The Improvement of the Lower Mississippi River for Flood Control and Navigation,"* a comprehensive outline of the history of the

* PP. 64 - 70.

improvements on the Lower Mississippi, covering a period of more than one hundred years. The report was published in 1932 by the Mississippi River Commission, and contains what is believed to be the latest thought on river control as well as the most authentic account of the history of flood control and navigation on the Mississippi River.

<u>Shreves and Raccourci Cut-offs</u> ** (PLATES XIX AND XVIII)

Both of these cut-offs were artificially made for the purpose of improving navigation in the reach of the Mississippi adjacent to Red River Landing and in the lower part of Red River. The junction of the Red, Atchafalaya and Mississippi Rivers as it existed in 1805 is shown in PLATE XIX. During the early years of the nineteenth century the lower Red River was shoaling badly and a bar was building up in the Mississippi below the mouth of Red River. As these conditions seriously interfered with navigation, it was decided to make a cut-off across the neck of Turnbull Bend in an attempt to improve the channels of both the Red and the Mississippi. The theories on which this hope was founded are not stated. Since Captain Shreve, the father of the Mississippi River steamboat, was one of the active proponents of the idea, the cut-off was named for him. Shreve's Cut-off was made in 1831, shortening the river channel by

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** Unless otherwise stated, credit for the descriptions of these enumerated cut-offs is due to "The Improvement of the Lower Mississippi River for Flood Control and Navigation."

fifteen miles.

This cut-off did not justify the hopes of its sponsors regarding its effectiveness in eliminating shoaling. The zone of shoaling was merely shifted to a new locality, downstream from its former position. Instead of working as a benefit to navigation, the cut-off proved to be an impediment. Upper and Lower Old River offered two channels through which Red River might discharge. The discharge was not great enough to maintain two channels and difficulty has been experienced since 1831 in maintaining a navigable entrance to Red River. This difficulty has been augmented from time to time by the shifting of Red River from one of these channels to the other. At one time a dam was started between the mouth of Red River and the point at which the Atchafalaya debouches, in an effort to force the flow from Red River to take the Upper Old River channel. The idea was abandoned however, and at the present time Lower Old River is the main entrance to the Atchafalaya and Red.

In spite of the fact that Shreve's Cut-off demonstrated the ineffectiveness of a cut-off as a means of navigation improvement in this reach, a second cut-off was made four miles below, at Raccourci Bend, in an attempt to relieve the situation. (See PLATE XVIII). Raccourci Cut-off, made by the State of Louisiana in 1848, is described clearly and completely by Caleb G. Forshey thus: A canal 20 feet wide by one mile in length was cut across the neck in 1848. Logs and driftwood floated in and clogged the passage, so that the river did not actually go through. In 1849 the banks were cleared back 100 feet on each side of the canal, the depth of the canal was increased so as to cut through the strata of clay into sand, and gunpowder was used to blast the bottom. As soon as the water entered the canal, a boat with a rapidly revolving wheel was sent in to agitate the water and induce scour on the earth loosened by the blasts. To quote Mr. Forshey:

> "The scene is described as one of terrific grandeur as the widening reached the lofty forest. The falling of trees and the whirl and boil of eddies was truly sublime. In two hours time it was a river. The Natchez, Capt. Tom Leathers [commanding], with some degree of recklessness, put her head into the tide, steamed through the rushing current and terrible tempest of falling cypresses." *

Raccourci Cut-off shortened the river channel by an additional 19 miles, but failed to improve the condition of the channel above.

Shreves and Raccourci Cut-offs were failures as navigation improvements, but reference to PLATE XX-d shows

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* C. G. Forshey, Trans. Am. Soc. C. E., Vol. 5, 1876, p. 318.

that they did not cause any pronounced channel changes in the vicinity. By 1929 only five miles of the 34 miles of shortening had been regained.

The effects of the two cut-offs on floods is a mooted question. As has already been mentioned, * Humphreys and Abbott, as well as Professor Caleb G. Forshey, attempted to show that flood heights were lowered above the cut-offs while raised below them. The reports of these men were based on data of doubtful accuracy and completeness, and therefore cannot be relied upon absolutely. The modern view of the effect of these cut-offs is expressed in the following statement:

> "Although the cut-offs were attended by local readjustments of the channel, there is no conclusive evidence that they themselves have appreciably affected flood heights." **

The enlargement which subsequently occurred on the Atchafalaya cannot be attributed to the effects of these cut-offs, as the enlargement of this stream was due primarily to the removal of the "rafts" which tended to choke the channel, and to the development of the Atchafalaya levees. Shreve's Cut-off was probably a benefit to the Atchafalaya problem in that it interposed the inefficient Old River channel between the Atchafalaya and Mississippi, and directed the Mississippi away from the Atchafalaya to such

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* Part I, Section 6; supra.
** Elliott, op. cit. p. 69.

an extent that a break-through is now hardly a possibility. Had Shreve's Cut-off not been made, it is very probable that when the Atchafalaya began to expand after the removal of the "rafts", a very serious diversion of the Mississippi would have occurred.

Palmyra or Davis Island Cut-off. (PLATE XV).

Palmyra or Davis Island Cut-off, which occurred naturally in February 1867, is located about 621 river miles below Cairo, or about 15 miles below Vicksburg. As indicated in the figure, the east bank was cut through, and the river shortened by nineteen miles. The ends of the old channel then silted up, leaving the oxbow lake which became known as Palmyra Lake. The increased currents above the cut-off caused Diamond Point and Newton Bend to move rapidly downstream. * In 1874 Diamond Point was hardly more than a slight protuberance in the east bank of the river. By 1883 the bend around the point had cut far into the west bank, and at the same time had progressed downstream until the distance between the bank of the river at Diamond Point and the upper end of Palmyra Lake was only a mile and a half. By 1904 this distance had decreased to one hundred feet, and on April 15 of that year the neck was broken through, allowing the river to flow into Palmyra Lake.

* This particular reach of the river is a striking example of channel meandering.

Locally the break-through was called Killakranka Cut-off, but it was not a true cut-off since the river was merely cutting through to an old, abandoned channel. The lower end of Palmyra Lake was reopened, with part of the flow taking this channel, while the remainder continued to take the channel around Sargent Point. The lengths of the two channels were approximately the same - about 13 miles. The normal discharge was not great enough to maintain both channels, hence deterioration was inevitable.

At first the river had a tendency to keep to the east of Davis Island, but later began to shift to the Palmyra Lake Channel. By 1929 it had ceased to flow east of Davis Island and the lower end of this channel had already started silting. The recently dredged Diamond Point Cut-off, discussed later in this paper,* will again bring the current back to the east channel.

Commerce Cut-off. (PLATE XIII).

Commerce Cut-off occurred May 10, 1874, about forty miles downstream from Memphis, Tennessee. A narrow neck on the right bank of the river was overtopped by high water. The shortening which resulted from the cut-off amounted to ten miles. According to contemporary accounts the channel across the neck developed very rapidly. The

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* Section 4-b, below.

second day after the break-through occurred, a steamboat is reported to have passed through the new channel, and by the third day the channel is said to have been 800 yards wide.*

As an immediate result of the cut-off, Ashley Point, which is some five miles downstream, was attacked and began to erode immediately. The full force of the current was thrown into the bend below the point and as a result Bordeaux Chute, just below this bend, began to enlarge, continuing to expand until it became the main channel of the river. The channel was thereby shortened another seven miles. Considerable erosion occurred along this reach of the river as a result of the two shortenings. (See PLATE XIII). Commerce Cut-off, which caused a great amount of bank caving and extensive property damage, is an excellent example of the destructive action which may result from the radical channel changes sometimes induced by cut-offs.

<u>Centennial or Devil's Elbow Cut-off.</u> (PLATE XII).

Centennial Cut-off occurred March 26, 1876, cutting through a neck on the east bank of the Mississippi about 44 miles above Memphis. It shortened the main channel of the river 15 miles. On PLATE XII is illustrated the course of

* Elliott, op. cit. p. 64.

the river in 1874. The stream made a deep bend in the west bank and then curved sharply back to the east in getting around Brandywine Island. When Centennial Cut-off occurred, the current west of Brandywine Island was reversed and the flow was forced down Fogleman's Chute, an old chute channel cut across the bend. Fogleman's Chute rapidly enlarged until it soon became the main channel, while the channel to the east of Brandywine Island silted up. The changing of channels gave the current a new direction below the mouth of Fogleman's Chute, with the result that a few years later the old chute behind Beef Island was re-opened. Like Fogleman's Chute, this soon became the main channel. The combined shortenings due to Centennial Cut-off and the reoccupation of Fogleman's and Beef Island Chutes totaled 30 miles. However, by 1882, six years after the cut-off, the river distance from Fulton down to Memphis was 54.6 miles, or only 4.9 miles less than in 1820. Compensatory lengthening of the channel in order to partially offset the shortening provides the reason for close agreements in river lengths.

Indirect results ofthe cut-off were observed in the recession of Hopefield Point, opposite Memphis, (from 1100 to 1800 feet), the formation of shoals in Memphis Harbor, and the undermining of railroad and warehouse property in the lower part of the city. *

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* Thomas & Watt, op. cit. p. 236.

Centennial Lake Cut-off. (PLATE XIV).

This cut-off occurred April 27, 1876. The river at this point formerly made a deep bend eastward. The city of Vicksburg was situated on the east bank of the river, immediately south of the bend. When the river broke through the long peninsula opposite the lower part of the city, all the wharf front, warehouses, elevators, etc. were left on a lake in which the remains of the peninsula appeared as an island. Damage from the cut-off was reported to have been very great,* with effects felt for a hundred miles up and down stream. The immediate effect of the six-mile shortening was the formation of Delta Point opposite Vicksburg. Subsequently the attacks of the current against this point forced it to recede rapidly, and at the same time caused Reid-Bedford Bend below Vicksburg to be greatly accentuated. Before 1930 the current followed this bend around the west side of Racetrack Towhead. However, in that year the channel on the east side of the towhead was re-opened and became again the main river channel. Another change occasioned by the cut-off was the gradual shifting of the entire river downstream, away from the city.

Centennial Cut-off was noteworthy in its effect upon Vicksburg Harbor. Vicksburg, which was on the main

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* Annual Report of the Mississippi River Commission, 1884. p. 286-7. H. Ex. Doc. # 64, 48th Congress, 2nd Session.

river channel before the cut-off, had a harbor which had remained substantially unchanged since the earliest records. However, after the cut-off, the harbor was left on a rapidly silting oxbow lake. By 1877 the deterioration had assumed such alarming proportions that a Board of Engineer Officers was convened to study the situation and devise a plan of improvement. The board* recommended -

1) that Delta Point be protected by revetment;

2) that a bar dike be built off the southwest end of Delta Island;

3) that the innerharbor be dredged out; and

4) that the Yazoo River be diverted into the lake in order to prevent the harbor from silting up again.

In 1900 the Yazoo River was diverted through an old channel of the Mississippi into theeast end of Lake Centennial. The diversion has been effective in helping to keep open an entrance to Vicksburg Harbor.

The Yazoo River has been affected by cut-offs for many years. Before 1799 it flowed into a bend of the Mississippi which that year was converted into an oxbow

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* Annual Report of the Chief of Engineers, 1878, Part I, Appendix L, p. 638-40.

lake by Yazoo Cut-off. In 1876 the river was flowing into the Mississippi through Yazoo Lake. The diversion canal now carries the discharge of the Yazoo into Lake Centennial and past Vicksburg into the Mississippi.

It is of interest to note that during the Vicksburg Campaign of the Civil War, General Grant attempted an artificial cut-off across the neck of Vicksburg Bend in an effort to move part of his army below the city without having to run the Confederate batteries at Vicksburg. * He was not successful in his attempt to induce a cut-off, but the remains of the canal he had dug are still visible. This canal was in no way responsible for the formation of Centennial Lake Cut-off in 1876.

<u>Waterproof Cut-off.</u> (Plate XVII).

Waterproof Cut-off ** occurred between May 7 and 11, 1884, about 21 miles above Natchez and 680 river

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* M. F. Steele, "American Campaigns," Washington, U. S. Inf. Assoc. p. 401.

** Note: This cut-off is also described under the name of "King's Point Cut-off" in the Annual Report of the Miss. River Com., 1884, p. 286-7, found in H. Ex. Doc. # 64, 48th Congress, 2nd Session, Set 2296.

miles below Cairo. It shortened the river 12 miles. Previously the river at this point had flowed around a neck, six miles long and from three-quarters of a mile to a mile in width, known as Coles Point. (See PLATE XVII.) Waterproof, like Palmyra Lake Cut-off, sixty miles upstream, is an example of the slow rate at which cut-offs develop in this section of the river. In 1774 Coles Point neck was about one mile wide. By 1874 it had narrowed to one-half this width, but had not been permanently cut despite the fact that about the year 1855 a ditch 50 feet wide by 20 feet deep had been dug across the neck in an unsuccessful attempt by local interests to induce an artificial cut-off. A court injunction caused work on the ditch to be stopped, but during each high water period after the construction of the ditch, part of the discharge went through it. There was no evidence of the formation of a cut-off until May 1884, when the river was at flood stage. On May 7th it was noticed that both banks of the old ditch were caving rapidly. Caving continued as the channel widened, until by May 11th the cut-off was complete. On May 25th, 839,000 second feet were passing through the cut-off while the discharge of the old channel was only 370,000 second feet.

Immediate effect of the cut-off was felt at Kempe Bend, a few miles above, where rapid caving began. The concave bank began to recede, and continued to do so until it was halted by revetments in 1899. The recession at Kempe Bend amounted to approximately one mile between 1882 and 1913. Both ends of the lake formed by Waterproof Cut-off have silted up; in fact the entire lake itself has almost done the same.

The effects of Waterproof Cut-off have not been violent. Erosion occurred at Kempe Bend above and at Giles or Cowpen Bend below. Caving was active at the latter point before 1884, however, so the present condition there is not entirely due to the action of the cut-off. Six gages, from which records are available, were located in the vicinity of the cut-off. These records show very little difference in the rates of fall of the four gages located above the cut-off after its occurrence, and show that the depression upstream was not pronounced. The Natchez gage, 21 miles below, rose slightly after the cut-off, but this increase was almost identical with a rise which occurred simultaneously at Red River Landing. Records after May 20th are said to show that the rise at Red River Landing was even more sustained than that at Natchez. *

To summarize: the effects of Waterproof were neither marked nor severe. Except for the slight depression in stages upstream from the cut-off, no perceptible stage changes resulted from the channel shortening.

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* Elliott, op. cit. p. 68.

The Greenville Bends. (PLATE X).

Although no cut-offs occurred in this reach of the river until after the adoption, in recent years, of a new policy concerning cut-offs by the Mississippi River Commission, it is fitting that this famous stretch of the Mississippi be considered here. Cut-offs have been imminent at more than one of the Greenville Bends during the last century. (See PLATE XX-a). Only the constant vigilance of engineers in protecting the necks with dikes and revetments has prevented cut-offs from breaking through Leland and Tarpley Necks.

The Greenville Bends comprise about 40 miles of river length, between river miles 445 and 485 (below Cairo). They consist of four large loops which include Georgetown, Rowdy, Miller, Spanish Moss, Bachelor and Walnut Bends, and Ashbrook, Linwood, Tarpley and Leland Necks. The city of Greenville, on Bachelor Bend, is the only important habitation located on the Greenville Bends. The average mean low-water slope through this section of the river is only 0.205 feet per mile, while the average for the entire reach from Cairo to Red River Landing is 0.35 feet per mile.* Meandering such as has occurred here is characteristic of flat slopes. Reference to PLATE XX-a will show that the bends have migrated downstream and that the curvature of the bends has been accentuated since

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* Elliott, op. cit. p. 70.

1765. The narrowing is especially marked at Linwood and Ashbrook Necks.

Ashbrook and Leland Necks have been protected from overbank scour by spur dikes extended from the base levees. (See PLATE X.) In pursuance of a fixed policy against cut-offs, the Mississippi River Commission has had constructed a number of bank revetments in this reach. The necks have become so narrow and flood heights so great, that each year it becomes increasingly difficult to prevent cut-offs along this tortuous section. Had protective works been started earlier, the task would have been made much less expensive.

The effects of overbank scour are plainly evident from the great blue holes on Tarpley and Leland necks. On the latter these holes have defied all attempts to arrest their progress. A spur dike 6,250 feet long, built on Leland Neck in 1903, was extended 3,000 feet in 1907, and another 4,000 feet in 1927. In 1929 when the blue hole had spread from the downstream side to within 300 feet of the upstream side, a permeable dike 5,000 feet long was built as an arm to the remains of the other extensions in an effort to hold the neck. The river succeded in flowing across the neck , when on June 3, 1933, the high water broke through the dike. Since the stage had begun to recede a cut-off did not occur. The fact that the dike was breached demonstrated that all attempts to prevent a cut-off at Leland Neck must meet with failure. At last, in July 1933, a cut-off channel was dredged across the neck. It so happened that earlier in 1933 plans for a cut-off had been considered for this neck, (as will be discussed later),* but the breaking through of the river in June made it advisable to take action sooner than had been planned. Since a cut-off here was inevitable, it was safer to dredge a pilot channel in order to control the time and place of the cut-off than to leave these important factors to chance.

To quote an editorial on the new cut-off:

> "To old river residents the passing of the Greenville Bends will appear as the loss of a most picturesque feature of the river. To river engineers it means the conclusion of one of the most fascinating battles of a generation - to maintain the old tradition of the sanctity of channel courses as they had endured during recorded history. Fortunately the Bends, except for the city of Greenville, mean little for human habitation, and Greenville will merely be put on a spur of the river instead of being on the main channel. The disadvantage is theoretical

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* Section 4-b, below.

> rather than actual, as proved by the little economic effect on Vicksburg when similarly isolated by the Centennial [Lake] Cut-off of 1876. The passing of the Greenville Bends, famous since navigation of the river by white men began, is unlikely to cause other than sentimental regrets." *

Contrary to the view taken above, in the opinion of this writer, a cut-off at Leland Neck will not mean the passing of the Greenville Bends. Bachelor Bend will no longer be part of the main channel. However, as the mouth of the cut-off channel is about at Mile 472, there will still be a loop of the river to the east below Spanish Moss Bend before the main channel swings west to enter Walker Bend. The number of bends in this reach will not be reduced by the cut-off. A new bend around Leland Point will replace Bachelor Bend; the other parts of the Bends will remain practically as they now exist.

It is reasonable to believe that the present Bachelor Bend will become an oxbow lake, with both ends silting up. Such action is the normal procedure, and there is nothing to indicate a departure from that action here. While the location of Greenville is analogous to

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* Engineering News-Record, Vol. 111, 1933, p. 361.

that of Vicksburg in 1876, at the time of Centennial Lake Cut-off, outside influences are not the same. Vicksburg would have been left on a lake entirely unconnected with the river, had not a channel been maintained by dredging the lower end of Lake Centennial. The amount of silting was so great that the Yazoo River was diverted into the lake in 1901. The outflow of the Yazoo has prevented bars from closing the lower end of Lake Centennial. At Greenville there appears to be no stream available to divert into what will become Bachelor Bend Lake. Therefore, if Greenville is to remain on a spur of the Mississippi, it is probable that extensive and persistent dredging operations will be necessary to maintain an entrance to Greenville Harbor.

3. Change in Policy Regarding Cut-offs.

On January 8, 1933 a powder blast blew away a bank of earth between two dredged cuts across the neck of Diamond Point, ten miles below Vicksburg, Mississippi. This blast completed the first planned cut-off made on the Mississippi River since Raccourci Cut-off in 1849, and was an epoch-making event in the history of the river channel control problem. The occasion definitely marked a new attitude towards the problem on the part of the Mississippi River

Commission. For nearly a century the prevention of cut-offs had been one of the first principles of river control on the Mississippi, a general policy which had been followed by the Mississippi River Commission since its organization in 1879.

It is true that Waterproof and Yucatan Cut-offs, which occurred in 1884 and 1929 respectively, were not planned cut-offs, but neither of them was seriously opposed. In fact, Yucatan Point Cut-off may be said to have first indicated that a change in the attitude of the Mississippi River Commission towards cut-offs was imminent.

The Commission had not in 1929 definitely changed its policy. Revetments had been placed in an attempt to hold Yucatan Point, the narrow neck dividing the Mississippi and Big Black Rivers, but the work of protecting the neck was never completed. In 1929 General Jackson, President of the Mississippi River Commission, ordered the work on revetments stopped, and in the fall of that year the river broke through into the channel of the Big Black River. Yucatan Cut-off was thus allowed as an experiment - even so, such a radical experiment had not been permitted on the Mississippi in many years. This step was particularly bold since no laboratory studies had been made to determine what results might be expected. No previous cut-off furnished an unerring precedent, as both Commerce and Centennial Cut-offs in the Memphis reach had been followed by disastrous bank caving and channel readjustment, whereas Waterproof, Palmyra and other cut-offs had developed without violent changes in the regimen.

Inasmuch as Yucatan Point is located between Waterproof and Palmyra Cut-offs, it might have been argued that the proposed cut-off could be expected to develop in much the same manner. The way a cut-off forms and the nature of ensuing changes in the channel are determined to a great extent by the bed and bank material. The material in which the river flowed at Yucatan should be expected to differ little from that at Palmyra and Waterproof, on either side of Yucatan. But so many other factors, some of them unknown, affect cut-offs that even if the bed material were the same, it would be impossible to predict accurately the results which would occur after the formation of the cut-off. For example, Shreves and Raccourci Cut-offs developed along lines entirely different from those taken by Fausse River Cut-off, yet all three occurred within a forty-mile reach of the river. (See "Changes in Lengths of River Channels", Part I, Section 9, supra.)

From the foregoing it will be seen that the Mississippi River Commission had reason to hope that calamitous consequences would not follow the development of Yucatan Cut-off, but had no assurance that this hope would be a reality. Therefore the decision to allow Yucatan

Cut-off was a radical change in the traditional policy which had been to hold all necks at any cost.

Permitting the formation of Yucatan Cut-off was, nevertheless, a passive, though radical measure. It was a step forward, but it did not indicate that the Mississippi River Commission was definitely committed to a policy advocating the use of cut-offs. The actual dredging of Diamond Point Cut-off in 1933 was, on the other hand, a very positive move which explicitly showed that the long period of cut-off prevention had ended and that henceforward cut-offs were to have an authentic part in plans for controlling the river channel.

Between 1929 and 1933 Yucatan Cut-off was observed to develop slowly and in an orderly manner with none of the dire and destructive results attributed by many writers to cut-offs. This circumstance encouraged the belief that no serious changes in the river regimen should be expected to follow. The successful outcome of a single cut-off was not enough, however, to convince the Mississippi River Commission of the advisability of cut-offs all along the stream. The U. S. Waterways Experiment Station at Vicksburg, through the use of model tests, brought out facts concerning the nature of cut-offs which gave the river engineers confidence in their plans. By means of the model studies a fairly accurate idea could be obtained of how proposed cut-offs would function. These experiments bore out the predictions of the engineers who had believed cut-offs could safely be made on the lower river, and were probably the most important factor in settling the issue of channel straightening in the minds of the Mississippi River Commission. Today the Commission, having reversed the tradition of more than fifty years, is definitely launched on a policy of channel rectification.

4. Practical Application of Model Studies of Cut-offs on the Lower Mississippi River.

(a) Experiments made prior to the initiation of the construction program.

After the disastrous 1927 flood on the Mississippi River a flood control plan was adopted which embodied the following points: *

1) Elevation of levees to about three feet above their 1914 grade line along both sides of the river from Cairo to New Orleans in order to carry a flood discharge ranging from 2,250,000 sec.-ft. at Cairo to 3,000,000 sec.-ft. in the lower river.

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* "New Plans for the Mississippi," Engineering News-Record, Vol. 110, 1933, p. 796. See also House Document 798, 71st Congress, 3rd Session, "Control of Floods in the Alluvial Valley of the Lower Mississippi River."

2) The construction just above New Orleans of Bonnet Carre spillway, capable of discharging 250,000 sec.-ft. of flood flow into Lake Pontchartrain.

3) The construction of three by-pass floodways outside the leveed width of the river to carry excess flood-flow which the leveed river could not accommodate. These floodways are -
(a) Bird's Point - New Madrid Floodway,
(b)The Boeuf Floodway (Tensas Basin), and
(c) The Atchafalaya River.

Congress allocated $200,000,000 to carry out the above mentioned plans, with an additional $100,000,000 for stabilization of the river channel. The methods of stabilization were not specified, but were left to be developed by the Mississippi River Commission through subsequent studies and experience.

Much of the construction contemplated under the plan outlined above has been completed. Work on the Boeuf Floodway was suspended when the inhabitants in the ten by fifty mile strip applied for an injunction to restrain the building ofthe floodway levees. The case finally went to the U. S. Supreme Court where it was decided against the inhabitants of the basin. No work could be done on the floodway during the litigation, but now that the case is settled and work can be resumed, the Chief of Engineers, U. S. Army, and the Mississippi River Commission are attempting to find some means by which the entire flood discharge can be carried between the main river levees from themouth of the Arkansas to Red River so that the Boeuf Floodway may be discarded.

A number of pressing demands created need for a laboratory in which broad studies of river hydraulics could be explored. One of the first problems which needed investigation was that of river stabilization, for which Congress had allocated a large fund. Later there arose the problem of increasing the flow capacity of the river in order to eliminate the Boeuf Floodway. There have been and will continue to be countless other phases of river hydraulics confronting engineers on the Mississippi which require laboratory studies, if the slow and extremely costly methods of trial and error are to be avoided. The Mississippi River Commission was quick to realize this fact. Early in 1929 land was acquired near Vicksburg, Mississippi and an organization planned for what was to be the U.S. Waterways Experiment Station. Construction on the station started in 1930 and on December 25th of that year the water first overflowed the spillway of the supply reservoir.

Among the first of the laboratory studies made by the Experiment Station were tests to determine the extent to which channel straightening might be employed in solving the broad problem of stabilization, slope rectification and capacity expansion. Although straightening channels by cut-offs had been opposed for many years by river engineers, it had become increasingly difficult to protect all necks from the erosive attacks of the currents. In 1929 the river cut through Yucatan Neck, and at the same time was threatening to repeat the process at Leland and Tarpley Necks of the Greenville Bends, as well as at other points along the lower river. In still other sections the cost of preventing shortening had become so great that cut-offs appeared warranted even though they might be followed by erosion, bank caving and channel meandering. Obviously, the extremely tortuous reaches of the river were not efficient conduits. In a few concentrated sections slope irregularities had decreased the river capacity causing higher flood stages. These facts made it desirable to determine to what extent cut-offs could aid in improving flow conditions on the Mississippi. The laboratory of the Experiment Station furnished the facilities for model studies of the contemplated changes before such revolutionary alterations were deliberately tried on the river channel.

Observation of the effects of Yucatan Cut-off and of the results obtained by model studies emphasized the lack of much data essential to a technical study of the river, and the previous total neglect of many controlling factors influential in the river's behavior.* The findings which resulted from the Yucatan Bend study and the laboratory experiments both clearly indicated that some direct errors concerning cut-offs had become fixed beliefs. Chief among these errors was the belief that the lowered stages which occurred above a cut-off were offset by correspondingly higher surface elevations below. Tests demonstrated that -

a) Any increase in stages downstream is due either to the temporary effect of reservoir action of upstream areas, or to a transitory channel stricture below;

b) The increase in water surface height below the cut-off disappears gradually as the new channel develops;

c) Lowering of the flow line above the cut-off is, however, permanent;

d) The effect of (c) is at a maximum just above the cut, with stages lowered in decreasing amounts to a point from 50 to 100 miles upstream.

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* "New Plans for the Mississippi," Engineering News-Record, Vol. 110, 1933, p. 798.

The discovery of one fallacy concerning cut-offs led to the belief that there might be other errors of equal importance in the conclusions arrived at by earlier investigators. Therefore in experimental studies it was deemed necessary to go back to first principles, placing no reliance on any prior beliefs or supposed facts.

Model tests were begun at the Experiment Station immediately upon its completion. Two models were constructed, one with a horizontal scale of 1 : 4800 and a vertical scale of 1 : 360, and the other with horizontal and vertical scales of 1 : 2400 and 1 : 120 respectively. * The latter model, which was built out of doors, is the largest river model ever built.** It represents 275 miles of river length and is wide enough to include overflow areas. (See PLATES XXII and I to VII inclusive.) The lower limit of the model is at Mile 765, just above the mouth of Old River, the upper limit at Mile 490, or immediately below the Greenville Bends. The smaller, indoor model overlaps the upper end of the large model, extending from Mile 500, upstream, to Mile 390, well above the Greenville Bends and Caulk Point.

The first studies of river shortening at the Experiment Station employed these two models to determine

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* Paper I, U.S. Waterways Experiment Station, April 15, 1932, p. 3.

** "Straightening by Channel Cut-offs" Engineering News-Record, Vol. 110, 1933, p. 839.

the effects of ten cut-offs between the mouths of Arkansas and Old Rivers. With the single exception of Yucatan, at the time of the experiments all ten were proposed, not actual, shortenings. Cut-offs were made in the model at the following points:

1.	Caulk Point	Mile 405
2.	Ashbrook Neck	Mile 445
3.	Tarpley Neck	Mile 458
4.	Sarah Island	Mile 518
5.	Point Lookout	Mile 545
6.	Willow Point	Mile 562
7.	Diamond Point	Mile 612
8.	Yucatan Point	Mile 637
9.	Natchez (Giles Bend)	Mile 690
10.	Esperance Point	Mile 704

In addition to these studies, a special investigation was made of all necks in the Greenville Bends, which included model tests of Linwood and Leland as well as the tests of Ashbrook and Tarpley Necks just listed. The effects of cut-offs across these necks were studied separately and in all possible combinations. The experiments indicated that any cut-off made either at Caulk Point or within the Greenville Bends would produce such a lowered elevation upstream as to impair the efficiency of a fuse-plug levee located above the Bends. Leland Neck Cut-off, which will be discussed in (b) below, was dredged in June 1933 because a break-through at this point appeared inevitable, although laboratory tests showed that a cut-off would induce heavy silt deposits at the lower end of the old river channel a few miles below Greenville. *

This same series of experiments illustrated that each of three proposed cut-offs between Lake Lee and Vicksburg - at Sarah Island, Point Lookout and Willow Point - would produce upstream lowering but, that one - at Sarah Island - would not be effective and its usefulness incommensurate with its cost. Moreover, it was found that tangential cuts would cause velocities in excess of those permitting safe navigation. Alternate channels at these two points, it was thought, would cause practically the same lowering upstream and have less tendency towards the immediate re-formation of bends. In the models, however, the three cut-offs did not lower stages enough to prevent the overtopping of levees in this section. For example, at Mile 490.7 (See TABLE H) a flood of the same magnitude as that of 1927 would be lowered only 0.7 feet by the cut-offs; whereas a lowering of 6.8 feet at this point is necessary to prevent overtopping of the project levees. Nowhere in the Lake Lee - Vicksburg reach did the model cut-offs induce lowering

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* For a more detailed account of these experiments see "Experiments to Determine the Effects of Various Cut-offs in the Greenville Bends," Appendix II, Paper I, U. S. Waterways Experiment Station, April 15, 1932.

sufficient to carry within the project levees a discharge equivalent to the 1927 flood (2,472,000 c.f.s.), although they did cause a reduction of gage heights of nearly 4.5 feet at some places. Since it appeared from model study that these cut-offs would not produce the desired amount of stage lowering, they were considered neither practical nor economical, and were therefore rated as undesirable by the U. S. Waterways Experiment Station.

Of the cut-offs below Vicksburg, the one at Yucatan Point was an accomplished fact at the time when these studies were made. It was found that tangential cuts could be made at Diamond Point, Natchez and Esperance Point, with a not too unreasonable amount of dredging and without immoderate increases in velocity. No harmful effects seemed likely to result from a cut-off at Diamond Point. In fact the experiment indicated that the cut would be beneficial in lowering backwater in the Yazoo Basin and in improving channel conditions in the vicinity of Davis Island.

The cut-off at Natchez (Giles Bend) , as seen in the model, caused excessive velocities upstream with erosion tendencies that appeared likely to endanger the safety of Vidalia, immediately below Natchez. On account of this fact a cut-off was not recommended in this already stable reach. As any cut-off below Natchez, according to laboratory experiments, appeared valueless, the one at Esperance Point was deemed inadvisable.

Complete tests on the ten proposed cut-offs led to the general conclusion that in upstream reaches stages would be lowered by the cuts, while below, except where reduced by the next downstream cut-off, stages would show no change in elevation. Hence before it would be possible to utilize the increased capacity of the channel upstream, it would be necessary to raise levees downstream enough to accommodate the greater discharge. The experiments also indicated that during the formative period of the cut-off bars were quite likely to form below the downstream end, but that they were moved aside by falling stages or by the low water flow. In all the tests it was observed that rapid silting occurred in both ends of the abandoned old channel.

Specifically the results obtained from model tests showed that if the ten cut-offs were made, the discharge of 2,008,000 c. f. s., contemplated under the 1927 Flood Control Plan, could be increased to something more than 2,400,000 c.f.s. without causing a rise on the Arkansas City gage; but the project levees would have to be raised by the amount shown in Column 6, TABLE H. Foundation conditions between Arkansas City and Red River Landing are such that the project elevation of the levees is already considered extremely high.

TABLE H * shows the effects, for several discharge rates, of cut-offs on river gages in the immediate vicinity, as determined from the model tests.

(b) The cut-off program on the Lower Mississippi River.

In TABLE G appears a list of cut-offs which have occurred on the Mississippi since 1929, with the dates the water first flowed through the cuts, their lengths, location and other data.

Although Yucatan, or Big Black Cut-off, was neither planned nor assisted in its development, the river engineers had adequate warning that the Mississippi was threatening to break through into the Big Black River above Yucatan Point. (See PLATES XVI & XXII.) Little was done to prevent the impending change, however, and in the latter part of 1929 the first cut-off on the Mississippi since Waterproof Cut-off in 1884 was allowed to occur. Channel changes at this point since 1765 are illustrated in PLATE XX-b. Between 1864 and 1875 channel changes in this reach caused what was locally known as Grand Gulf Cut-off. It was not a true cut-off, but the enlargement of an old chute behind an island just below

* From Paper I, U.S. Waterways Experiment Station, April 15, 1932, p. 9-11.

the mouth of the Big Black. The main channel shifted to the enlarged chute leaving a horsehoe lake to mark the outline of the old bend, as the ends of the previous course gradually silted up. The town of Grand Gulf, a former river port, was left inland by this change. *

Yucatan was not formed in the usual manner of cut-offs. Before 1929 the Big Black River emptied into the Mississippi near the downstream side of the neck formed by Yucatan Bend. Bank cavings on both streams, a few miles above the mouth of the Big Black, had caused the channels of each to gradually approach the other. When it was seen that a break-through was inevitable, a mattress was placed across the channel of the Big Black below the point of impending failure. It was hoped that this mattress would impede the enlargement of the channel, and thereby prevent the Mississippi from abandoning completely its course around Yucatan Bend. However, after the Mississippi broke through into the Big Black the channel of the latter immediately began to enlarge until both ends of the mattress were flanked. As no subsequent effort was made to prevent the cut-off from becoming the main channel, it has gradually enlarged. By the end of 1931 about 40% of the discharge passed through the cut-off. A rise on the river in the early part of 1932, the first rise of any consequence since the break-through, caused

* For further description of Grand Gulf "Cut-off" see Annual Report of the Chief of Engineers, U.S. Army, 1881.

erosion to proceed at a rapid rate, and by April 1932, 60% of the river discharge went through. By the early part of 1934 the upper end of Yucatan Bend had silted up to such an extent that it was possible to walk across the closing bar.

Yucatan Cut-off has developed without any subsequent cataclysms in river regimen. The new channel was scoured out in a slow and orderly manner, and no evidence of serious bank attacks has been noted either up or downstream. Any changes in the vicinity are no more marked than other local variations which are constantly taking place along the river. Comparison of several high-water profiles for the same stage indicate the water levels above have been slightly depressed while stages below have been raised a little. This latter condition is accounted for by minor channel deterioration below the cutoff where detritus from the cut has been deposited. Present thought indicates that this channel stricture is only transitory and that the current will soon erode a channel of adequate cross-section to carry the discharge without any stage increase below.

After the occurrence of Yucatan Cut-off model studies were made at the U. S. Waterways Experiment Station to determine the feasibility of channel straightening in several other tortuous reaches of the river. The results of these tests have already been described in this paper.* PLATE XXII shows the locations of the ten proposed cut-offs, as well as the positions of the eight cut-offs which have been dredged since laboratory tests were started. It will be noticed that of the ten proposed cut-offs, none have been made at Caulk Point, Ashbrook or Tarpley Neck, Sarah Island, Point Lookout or Esperance Point. Besides the shortening at Yucatan, which occurred naturally, cut-offs have been dredged at Leland Neck, Marshall, Willow, Diamond and Glasscock Points, and at Giles Bend. (See TABLE G.) Of these the Experiment Station at Vicksburg reported favorably only those at Diamond Point and Yucatan. However the motivating object of tests made at the Experiment Station has been to determine a means for eliminating overflow through Boeuf Basin. Cut-offs were therefore not recommended:

1) If they failed to increase the channel capacity;

2) If they were extremely expensive to dredge; or

3) If they caused undesirable currents and erosion.

No model studies were made of the cut-offs at Glasscock, Worthington or Marshall Points until after

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* Sub-section (a), supra.

dredging had been started in nature, hence no recommendations were made concerning the feasibility of the cut-offs. Results of tests made of these cut-offs will be briefly described later in this paper. *

Although it was apparent that cut-offs, used alone, were not enough to warrant the discard of a floodway through Boeuf Basin, nevertheless, the Mississippi River Commission determined to dredge seven cut-offs between Greenville and Angola. Channel straightening has been employed in each of these seven instances in order to take advantage of the local lowering of stages above the cut, to smooth out slope irregularities, or to obtain better, shorter routes for navigation.

The general method of digging the cut-off channel was to dredge a pilot channel about 300 feet wide by 30 feet deep across the neck. Dredges worked from either end of the cut towards the middle. When only a narrow dike of earth remained, the dredges were withdrawn and explosives used to remove the last impediment to the flow. It was hoped that the current would enlarge these pilot channels to full size. In most cases scouring has done this, but it now appears that additional dredging will be necessary in order to secure complete development of the cut-off at Glasscock Point and of those above Vicksburg.

Diamond Point Cut-off, about ten miles below Vicksburg, was first opened on January 8, 1933. If Yucatan

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* Sub-section (c), below.

is considered a planned cut-off, Diamond Point was second in the series of eight channel shortenings which have recently been completed. It is notable as the first artificially made cut-off which has occurred on the Mississippi since Raccourci, in 1848. * The pilot channel, originally dredged to a width of 300 feet and a depth of 30 feet, by June 1, 1933 had enlarged until it was 800 feet wide and was carrying 366,000 c.f.s., or about one-third of the river flow. ** (See PLATE V.) By the spring of 1934 the channel was still only 40% developed, a condition which illustrates the gradual nature of the transformation. Natural adjustments have been given time to occur and no perceptible increase in bank caving has been noted to result from the swifter currents upstream.

No cut-off was planned at Leland Neck until a definite decision was reached concerning the Boeuf Floodway and the fuse plug levee in the vicinity of Arkansas City. However, on June 3, 1933, high water broke through the permeable dike on Leland Neck. As the river was receding at that time, no cut-off was formed. This penetration of the dike showed that future floods would form a cut-off unless large expenditures were made to repair and strengthen the dike. Therefore the decision was made to dredge a channel across the neck so that the time and

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* Forshey, in Vol. 5, Trans. Am. Soc. C. E., 1876, lists Terrapin Neck (1866) as an artificial cut-off, though it is not so considered by the Miss. River Commission.

** "Straightening by Cut-off Channels," Engineering News-Record, Vol. 110, 1933, p. 841.

place of the cut-off might be controlled. Dredging operations were begun immediately and the pilot channel was completed during July of 1933. By September 1st of that year approximately one-third of the river discharge was going through the new channel. In the spring of 1934 sufficient silting had occurred in the ends of the old river channel to interfere with navigation and boats were regularly going through the cut-off.

Plans for a cut-off at Tarpley Neck are as yet indefinite. It is possible that it would have been cut had not immediate action at Leland Neck been necessary. Simultaneous cut-offs at both necks would not be expedient, but it is this writer's opinion that a cut-off across Tarpley Neck may later become desirable as a means of keeping Greenville, Mississippi a river port. Should both ends of the old channel left by Leland Cut-off become closed by silt, a cut-off at Tarpley Neck would introduce the current into the oxbow lake formed at Leland Neck, and reopen the lower end to navigation. If this suggested cut-off follows normal procedure, the channel into Spanish Moss Bend around Carter Point will be closed by a bar, thereby causing Leland Cut-off to become inoperative.

The cut-offs at Giles Bend (Cowpen Point) and Glasscock Point, which were opened to flow on May 25 and March 26, 1933, respectively, were made primarily to obtain better and shorter routes for navigation. Straight, tangential cuts were made across both points. The former shortens the channel 11.1 miles and the latter 10.8 miles. As an incidental feature these cut-offs are expected to smooth out the irregular profile, thereby increasing the total channel capacity of the reach containing the two cut-offs. The pilot channels across Glasscock and Cowpen Points developed so slowly that the discharge of the Mississippi did not go through these cut-offs during the 1933 low-water season.

The cut-off at Willow Point was opened to flow on April 8, 1934. It is analogous to the two cut-offs just described in that it is more of a channel rectification measure than a true loop elimination. The length of the channel was shortened 7.7 miles by the cut-off. A greater shortening could have been obtained had a tangential cut been made across Willow Point. Since doing so would have entailed the removal of considerably more earth, and also would have caused excessive velocities and bank erosion, it was decided to dredge a curved pilot channel in the location indicated on PLATE XXII. Sufficient time has not elapsed to show definitely how this channel will enlarge itself. It is the opinion in some quarters that it will have a strong tendency to develop towards the old channel, if it develops at all.

Neither Marshall Point nor Worthington Point Cut-offs greatly reduced the length of the river channel. The former, opened to flow on March 12, 1934, shortened the channel 4.2 miles; and the latter, opened to flow on Dec. 25, 1933, caused a shortening of 4.3 miles. Pilot channels were not dredged tangentially in either case because they would have been longer and more expensive to cut. The development of neither cut-off has progressed far to date, but it will be of interest to follow their development and compare it with that of the tangential cut-offs at Yucatan, Cowpen and Glasscock Points.

(c) Model studies since the initiation of the actual construction program.

In a paper entitled "Model Studies of Cut-offs and Channel Improvements Performed by the U. S. Waterways Experiment Station," dated August 16, 1933, there appears a summary of the tests made on cut-offs along the Mississippi which at that time had actually been dredged or were in the process of being cut. Since extensive field work had been done, data were available concerning the completed cut-offs. It was therefore possible to compare results obtained from the model with actual field observations. The models, according to this report, proved their ability to reproduce, on a small scale and in a relatively short period of time, changes which had occurred in nature before the tests were made. Consequently they were considered "indispensable as a means of predicting future effects which involve such a multiplicity of factors that they defy exact computation."

TABLE 1-A lists the model studies of cut-offs on the Mississippi and gives the scales, geographic limits, and types of the models. "Fixed bed" indicates a bed of cement mortar; "movable bed" indicates a bed molded of some erodible material.

TABLE 1 - A

Name of Study	Model Characteristics			
	Type	Horizontal scale	Vertical scale	Areas included in model
Cut-off studies				
Leland Neck Worthington Point Willow Point Marshall Point	Fixed bed	$\frac{1}{2400}$	$\frac{1}{120}$	Miss. River, Mile 396 to Mile 603; Yazoo basin incl. within limits of backwater from Miss. River.
Cut-off studies				
Diamond Point Yucatan Point	Movable bed	$\frac{1}{1000}$	$\frac{1}{100}$	Miss. River, Mile 559 to Mile 655
Cut-off studies				
Giles Bend Glasscock Point	Movable bed	$\frac{1}{1000}$	$\frac{1}{100}$	Miss. River, Mile 650 to Mile 760

The cut-offs at Leland Neck, Worthington Point, Willow Point, and Marshall Point were tested both in a partially and a fully developed state. TABLES 2-A and 3-A

TABLE 2-A

Effects of Partially Developed Cut-offs at Leland Neck (Mi. 472.0 - 483.5), Worthington Pt. (Mi. 505.7-513.3), Willow Pt. (Mi. 564.0 - 578.0), and Marshall Pt. (Mi. 587.0 - 593.0), on Water Surface Elevations.

Gage	Mile	Indicated effects of the cut-offs, in feet, on water surface elevations for discharges now passing Vicksbg. gage at stage:		
		55 feet	50 feet	40 feet
HW #111	399.2	-0.3	-0.8	-0.7
Arkansas City	436.7	-1.0	-1.3	-1.2
HW #99	467.4	-1.5	-1.9	-1.8
→ HW #95	490.7	-0.7	-1.0	-1.2
HW #93	502.7	-1.2	-1.2	-1.3
→ HW #89	523.0	-0.9	-0.9	-1.1
Lake Providence	543.0	-1.5	-1.5	-2.0
→ HW #82	560.2	-2.3	-2.5	-3.8
→ Vicksburg	601.8	-1.3	-1.8	-2.0

→ Cut-offs.

TABLE 3-A

Effects of Fully Developed Cut-offs at Leland Neck, Worthington Pt., Willow Pt., and Marshall Pt., on Water Surface Elevations.

Gage	Mile	Indicated effects of the cut-offs, in ft., on water surface elevations for discharges now passing Vicksburg gage at stage of:		
		55 feet	50 feet	40 feet
HW #111	399.2	-0.4	-0.8	-0.5
Arkansas City	436.7	-1.3	-1.8	-1.1
HW #99	467.4	-3.3	-3.1	-2.6
→ HW #95	490.7	-2.5	-2.8	-2.6
HW #93	502.7	-3.1	-3.3	-2.8
→ HW #89	523.0	-2.0	-2.0	-1.5
Lake Providence	543.0	-4.0	-3.9	-3.2
→ HW #82	560.2	-6.9	-7.3	-8.2
→ Vicksburg	601.8	-2.7	-3.6	-3.7

→ Cut-offs.

show the effects of these cut-offs on different river stages. Fully developed cut-offs downstream were assumed to cause the lowering shown at Vicksburg.

TABLE 4-A shows the effects of fully developed cut-offs at Yucatan and Diamond Points on water surface elevations as determined by the model. (See PLATES XV and XXII for the location of these cut-offs.)

Experiments were first made on the Diamond Point Cut-off channel molded to the section as dredged in nature. At Yucatan the channel was similarly molded to sections that existed in nature as shown by the 1932-33 survey. In the model the right bank of the cut-off at Diamond Point eroded, tending to form a new bend. It became necessary to hold this bank after the channel reached an advanced state of development. A bar formed at the lower end of the channel which required dredging to prevent further shoaling. However, tests indicated that both the cut-off and the channel around Newtown Bend, immediately below, would develop rapidly when the upper end of Palmyra Lake was closed. It was also shown that this development would occur if intensive dredging was employed downstream from the cut-off. As the channel across Diamond Point was enlarged by nature, extensive bank caving occurred. It was not believed that this caving would cause excessive filling below the mouth of the cut, but that it might cause a crossing bar within the cut which would require dredging. There was also a tendency for a blanket bar to form along the concave side of Newtown Bend, but as this bar progressed downstream, the end of Sargent Point, on the opposite bank, gradually eroded, leaving a good navigable channel in prolongnation of the axis of the cut-off.

The channel across Yucatan Point developed in the model with little change from the alignment it has taken in nature. In the model, the upper end of the oxbow lake formed by the cut-off filled appreciably, a part of the material having eroded from Diamond Point Cut-off upstream. In nature, the closing of the upper end of the oxbow lake was so complete by the early part of 1934 that a man could walk across the closing bar without getting his feet wet. A bar also formed along the left bank at the foot of the cut-off, but a good navigable channel was left at all times both through and below the cut-off.

Cut-off channels at Giles Bend and Glasscock Point were molded of erodible material to the sections as dredged in nature, and then allowed to develop to their final form. Giles Bend developed along the same general lines as did Yucatan Cut-off, described above. A bar formed along the left bank at the lower end of the pilot channel, but a navigable channel was left open.

The channel across Glasscock Point did not develop appreciably during the tests. The dredged cut widened, but a pronounced fill occurred in the pilot channel

TABLE 4-A

Effects of Fully Developed Cut-offs at Diamond Pt. (Mi. 613.6 - 626.0), and Yucatan Point (638.3-648.0), on Water Surface Elevations.

Gage	Mile	Indicated effects of the cut-offs, in ft., on water surface elevations for discharges now passing Vicksburg gage at stage of: 55 feet	50 feet	40 feet
HW #80	574.9	-1.9	-3.3	-3.6
Vicksburg	601.8	-2.1	-5.1	-6.8
HW #74	609.4	-3.1	-5.7	-7.7
→ HW #73	617.9	-3.6	-5.5	-7.6
HW #72	624.9	-1.5	-3.2	-5.0
HW #71	631.7	-3.1	-5.0	-6.2
→ # 6	637.0	-3.7	-5.2	-5.7
#10	649.4	-0.3	-1.2	-1.4
HW #68	653.1	-0.0	-0.4	-0.6

→ Cut-off.

TABLE 5-A

Effects of Fully Developed Cut-offs at Giles Bend (Mi. 689.5 - 704.1) and Glasscock Point (Mi. 722.5 - 736.7) on Water Surface Elevations.

Gage	Mile	Indicated effects of the cut-offs, in ft., on water surface elevations for discharges now passing Natchez gage at stage of: 55 feet	50 feet	40 feet
St. Joseph	662.4	-3.3	-3.2	-3.5
HW #66	670.0	-4.4	-3.7	-3.6
HW #64	681.4	-5.8	-5.8	-5.4
→ HW #62	687.8	-6.4	-6.2	-5.9
Natchez	705.7	-2.0	-3.1	-3.0
HW #59	710.4	-3.5	-4.1	-4.2
HW #58	716.7	-3.9	-4.9	-5.2
→ HW #57	720.9	-3.8	-4.5	-5.3
HW #54	736.7	-0.1	-0.1	-0.5

→ Cut-off.

which was not removed even during the higher stages. Further tests showed that extensive dredging would be required in the pilot channel to secure full development.

The effects of these two cut-offs, fully developed, on river stages are presented in TABLE 5-A.

III SUMMARY OF DEVELOPMENTS IN

CHANNEL STRAIGHTENING ON THE LOWER MISSISSIPPI RIVER

Fausse River Cut-off in 1722 marked the first chapter in the recorded history of cut-offs on the Lower Mississippi River. The complete history of channel shortening, however, antedates this cut-off by many years, perhaps by centuries. The countless horseshoe lakes, most of which are older than the oldest maps of the alluvial valley, provide ocular evidence of the numerous occasions on which the river in its constant meandering has cut across narrow necks and left, entirely disconnected from the remainder of the stream, many lakes, which were formerly bends of the river.

The first maps of the Mississippi, which were made by the Ross Survey in 1765 and the Young Survey in 1820, are not considered absolutely accurate. It is known that a cut-off occurred at Montezuma between 1796 and 1812, at Grand Lake between 1796 and 1817, at Yazoo in 1799, and at Homochito in 1776, but it is not definitely established that these were the only cut-offs in the 1722-1820 period. Inasmuch as the Land Office made bank surveys of the Mississippi about 1820 and as accurate Mississippi River Commission maps have existed since 1882, all major channel changes since 1820 are known. (The complete list of known cut-offs which occurred before 1930 are given in TABLE D.)

During the first half of the nineteenth century the use of cut-offs was generally sanctioned on the Mississippi, though the literature of the period indicates that in the opinions of a strong minority, they were not highly esteemed as a method of channel straightening. Nevertheless, Shreves and Racocurci Cut-offs were artificially induced before 1850 and three others were allowed to occur during this period.

In the decade which followed, Humphreys and Abbott made their survey of the "Physics and Hydraulics of the Mississippi," in the report on which they expressed unqualified disapproval of channel shortening. Between 1874 and 1876 Centennial, Commerce and Bordeaux Chute Cut-offs occurred naturally in the vicinity of Memphis. All three were followed by disastrous and far-reaching results. Although several other cut-offs which occurred during the 1850 - 1880 period in other reaches of the river had none of the deleterious features of the three near Memphis, the prejudice against cut-offs increased. No concerted attempt was made to prevent their natural formations, but none were artificially cut. (Grant's unsuccessful efforts to induce a cut-off at Vicksburg, during the Civil War, were instigated purely for military purposes.)

In 1879 control of the Mississippi was centralized in the Mississippi River Commission. This body may be said to have inherited a policy opposed to artificial river shortening. As a result, Waterproof in 1884, was the only cut-off which occurred from 1879 until 1929.

By 1929 conditions existed on the Mississippi which favored reinstatement of the doctrine of channel straightening. In at least two instances the problem of holding narrow necks against cut-offs had become extremely costly - and almost impossible. Moreover, the desire to increase the flood capacity of the channel between Arkansas City and Old River in order to discard Boeuf Floodway also made for an open-minded policy concerning the practicability of cut-offs. That cut-offs, natural or artificial, should have occurred soon was beyond doubt. In 1929 the Mississippi broke through into the Big Black River, and the first cut-off in nearly half a century was an accomplished fact. Eventually others would have been cut, but it might have taken several years for a policy of action to be developed. The results of the model tests at the U. S. Waterways Experiment Station added confidence and direction to the new thinking, and thereby hastened the formulation and execution of the program.

Since Yucatan Cut-off in 1929, seven additional cut-offs have been dredged. To borrow the words of the Engineering News-Record: "A program of river straightening exceeding all precedent and approaching all but extravagant previous speculation has been inaugurated on the Mississippi."

What the future of this program will be can only be a conjecture. Present indications point toward an orderly development of the recent cut-offs between Greenville and the mouth of Old River. There have been no demands for cut-offs below Angola, Louisiana, and on account of erosion conditions, none are being considered at present above Helena, Arkansas.

With models at the U. S. Waterways Experiment Station to check each step in the development of the eight cut-offs which have been completed, and with accurate and complete field data on the cut-offs collected regularly by river engineers, a thorough and scientific investigation of the formation and effects of cut-offs on the Mississippi will be possible. The results of these combined studies will be a distinct contribution to the knowledge of river hydraulics. Those interested in this branch of science will follow with keen interest developments on the Mississippi for the next few years.

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TABLE ..A......

Section	Date of Surveys		Years Between Surveys	Mid-stream Distances in Miles				Total Distance below Cairo	
	Earlier Surveys	Later Surveys		Earlier Surveys	Later Surveys	Increase or Decrease	34-yr. Increase	Earlier Surveys	Later Surveys
Cairo to Columbus	1883-84	1911	29	21.3	21.7	0.4	.47	21.3	21.7
to New Madrid	1883-85	1911	29	49.0	50.1	1.1	1.29	70.3	71.8
to Cotton Wood Point	1883-85	1911-12	30	53.3	59.1	5.8	6.57	123.6	130.9
to Fulton	1883-85	1912-13	31	52.1	53.3	1.2	1.32	175.7	184.2
to Memphis	1877-84	1912-13	37	55.3	54.2	-1.1	-1.01	231.0	238.4
to Mhoon Landing	1877-84	1912-13	37	45.7	48.1	2.4	2.22	276.7	286.5
to Helena	1883-84	1912-14	32	33.8	38.6	4.8	5.10	310.5	325.1
to Sunflower Landing	1883-84	1913-14	32	46.3	49.1	2.8	2.98	356.8	374.2
to White River	1881-82	1913-14	34	41.7	40.5	-1.2	-1.20	398.5	414.7
to Arkansas City	1881-83	1913-14	34	45.5	47.8	2.3	2.30	444.0	462.5
to Greenville	1881-82	1913-14	34	40.1	46.1	6.0	6.00	484.1	508.6
to Lake Providence	1881-82	1913-14	34	63.0	63.0	0.0	0.00	547.1	571.6
to Vicksburg	1881-83	1913-14	34	54.9	66.4	11.5	11.50	602.0	638.0
to St. Joseph	1882-83	1913-14	33	49.5	63.6	14.5	14.53	651.5	701.6
to Natchez	1882-83	1913-14	33	51.5	44.9	-6.6	-6.80	703.0	746.5
to Red River Landing	1882-83	1913-14	33	65.3	68.9	3.6	3.71	768.3	815.4
to Bayou Sara	1882-83	1909-10	29	35.2	36.1	0.9	1.05	803.5	851.5
to Baton Rouge	1883	1909-10	28	33.6	34.2	0.6	.73	837.1	885.7
to Plaguemine	1883	1909-18	36	20.2	20.6	0.4	.38	857.3	906.3
to Donaldsonville	1883	1909-10	40	32.1	32.6	0.5	.43	889.4	938.9
to College Point	1893-94	1921-22	30	17.8	17.9	0.1	.11	907.2	956.8
to New Orleans	1893-94	1921-22	30	54.2	54.3	0.1	.11	961.4	1011.1
to Fort Jackson	1893-94	1921-22	30	82.9	83.6	0.7	.79	1044.3	1094.7
to Head of Passes	1893-94	1921-22	30	20.3	20.6	0.3	.34	1064.6	1115.3
to Gulf of Mexico	1857-72	1922	66	13.6	16.2	2.6	1.34	1078.2	1131.5
				1,078.2	1,131.5	62.2	63.27		
						-8.9	-9.01		
						53.3	54.26		

NAME OF CUT-OFF	MILES BELOW CAIRO (1916)	YEAR OF CUT-OFF	YEARS BETWEEN SUCCESSIVE CUT-OFFS
1. FAUSSE RIVER	814	1722	.....
2. HOMOCHITO	752	1766	54
3. YAZOO LAKE	595	1800	24
4. NEEDHAM'S	135	1821	21
5. BUNCH'S	525	1830	9
6. SHREVE'S	771	1831	1
7. RACCOURCI	774	1848	17
8. HORSESHOE	320	1848	0
9. AMERICAN	496	1858	10
10. NAPOLEON	400	1863	5
11. TERRAPIN NECK	576	1866	3
12. DAVIS	632	1867	1
13. COMMERCE	268	1874	7
14. CENTENNIAL (DEVIL'S ELBOW)	205	1876	2
15. CENTENNIAL LAKE	601	1876	0
16. WATERPROOF	680	1884	8
17. ALBEMARLE	567	1912	28

TABLE B MAJOR LYONS' LIST OF MISSISSIPPI RIVER CUT-OFFS, 1722-1912, SHOWING THE NUMBER OF YEARS BETWEEN SUCCESSIVE CUT-OFFS.

NAME OF LAKE	LOCATED BETWEEN
1. HORN LAKE	MEMPHIS AND MHOON LANDING.
2. HORSE SHOE LAKE	MEMPHIS AND MHOON LANDING.
3. OLD RIVER LAKE	MEMPHIS AND MHOON LANDING.
4. MOON LAKE	HELENA AND SUNFLOWER LANDING.
5. SWAN LAKE	SUNFLOWER LANDING AND WHITE RIVER.
6. CONCORDIA BAYOU	SUNFLOWER LANDING AND WHITE RIVER.
7. LAKE BOLIVAR	WHITE RIVER AND ARKANSAS RIVER.
8. LAKE VERMILLION	WHITE RIVER AND ARKANSAS RIVER.
9. MACON LAKE	ARKANSAS RIVER AND GREENVILLE.
10. LAKE CHICOT	GREENVILLE AND LAKE PROVIDENCE.
11. LAKE WASHINGTON	GREENVILLE AND LAKE PROVIDENCE.
12. GRAND LAKE	GREENVILLE AND LAKE PROVIDENCE.
13. LAKE PROVIDENCE	GREENVILLE AND LAKE PROVIDENCE.
14. LAKE ST. JOSEPH	VICKSBURG AND ST. JOSEPH.
15. LAKE BRUIN	VICKSBURG AND ST. JOSEPH.
16. LAKE ST. JOHN	ST. JOSEPH AND NATCHEZ.
17. LAKE CONCORDIA	ST. JOSEPH AND NATCHEZ.

TABLE C LIST OF SOME OF THE MORE IMPORTANT OXBOW OR HORSESHOE LAKES ON THE MISSISSIPPI RIVER BELOW MEMPHIS.

TABLE D

LIST OF CUT-OFFS ON THE MISSISSIPPI RIVER BELOW CAIRO.

(MISSISSIPPI RIVER COMMISSION DATA)

NAME OF CUT-OFF	MILES BELOW CAIRO	BANK THROUGH WHICH CUT WAS MADE.	YEAR IN WHICH CUT-OFF OCCURRED.	REDUCTION IN RIVER LENGTH
NEEDHAM'S..........	135	WEST	1821	11 MILES
CENTENNIAL OR DEVIL'S ELBOW.....	204	EAST	1876	15
COMMERCE...........	270	EAST	1874	10
BORDEAU CHUTE......	279	EAST	1874	7
MONTEZUMA..........	314	WEST	1796-1812	11
HORSE SHOE.........	320	WEST	1848	9
NAPOLEON OR BEULAH LAKE.......	400	WEST	1863	10
AMERICAN...........	497	WEST	1858	11
GRAND LAKE.........	517	EAST	1796-1817	10
BUNCHS BEND........	524	EAST	1830	12
TERRAPIN NECK......	576	WEST	1866	16
YAZOO..............	596	WEST	1799	12
CENTENNIAL LAKE....	601	WEST	1876	6
DAVIS OR PALMYRA...	623	EAST	1867	19
YUCATAN BEND.......	638	EAST	1929	10
WATERPROOF.........	680	WEST	1884	12
HOMOCHITO..........	753	WEST	1776	13
SHREVES............	771	EAST	1831	15
RACCOURCI..........	775	EAST	1848	19
FAUSSE RIVER.......	814	EAST	1722	21

STATION	ROSS MAP 1765	MAPS OF ABOUT 1820	MISS. RIVER COM. MAPS		
			1882	1916	1929
CAIRO, ILL............	0.0	0.0	0.0	0.0	0.0
COLUMBUS, KY..........	20.8	21.8	21.6	21.6	21.6
NEW MADRID, MO.......	63.3	66.0	70.3	71.0	71.2
FULTON, TENN.........	161.7	168.1	175.4	175.4	179.0
MEMPHIS, TENN.........	224.6	227.6	230.0	227.0	225.5
MHOON LANDING, MISS...	271.3	275.0	276.3	273.2	271.1
HELENA, ARK...........	300.6	306.6	306.5	307.1	308.5
MOU. WHITE RIV. ARK...	386.0	386.0	393.2	391.7	396.4
ARKANSAS CITY, ARK....	428.5	435.0	438.3	436.7	443.5
GREENVILLE, MISS......	455.7	467.0	478.3	480.2	487.5
LAKE PROVIDENCE, LA...	532.0	545.0	542.3	543.0	551.6
VICKSBURG, MISS.......	603.0	613.0	599.3	601.8	609.7
ST. JOSEPH, LA........	657.5	676.0	648.3	662.4	662.7
NATCHEZ, MISS.........	696.5	722.0	700.3	705.7	708.2
ANGOLA, LA............	776.8	797.5	765.3	771.4	775.4
BAYOU SARAH, LA.......	820.3	850.0	799.8	807.8	812.1
BATON ROUGE, LA.......	849.0	884.0	833.3	842.4	846.4
PLAQUEMINE, LA........	866.0	902.7	854.1	862.8	866.8
DONALDSONVILLE, LA....	896.0	935.2	885.4	895.4	899.6
COLLEGE POINT, LA.....	913.8	953.2	904.5	913.1	917.2
CARROLLTON, LA........	964.3	1005.0	957.0	966.7	970.8
FT. JACKSON, LA.......	1047.0	1089.0	1039.0	1051.2	1055.2

TABLE E. COMPARISON OF MILEAGES ALONG MISSISSIPPI RIVER BELOW CAIRO, ILLINOIS. (MISS. RIVER COMMISSION DATA.)

	LENGTH 1765	SHORTENING 1765-1820	LENGTH 1820	SHORTENING 1820-1882	LENGTH 1882	SHORTENING 1882-1929	LENGTH	
							1916	1929
CAIRO - COLUMBUS	20.8		21.8		21.6		21.6	21.6
COLUMBUS - NEW MADRID	42.5		44.2		48.7		49.4	49.6
NEW MADRID - FULTON	98.4		102.1	11	105.1		104.4	107.8
FULTON - MEMPHIS	62.9		59.5	15	54.6		51.6	46.5
MEMPHIS - HELENA	76.0		79.0	17	76.5		80.1	83.0
HELENA - ARKANSAS CITY	127.9	11	128.4	19	131.8		129.6	135.0
ARKANSAS CITY - GREENVILLE	27.2		32.0		40.0		43.5	44.0
GREENVILLE - LAKE PROVIDENCE	76.3	10	78.0	23	64.0		62.8	64.1
LAKE PROVIDENCE - VICKSBURG	71.0	12	68.0	22	57.0		58.8	58.1
VICKSBURG - ST. JOSEPH	54.5		63.0	19	49.0		60.6	53.0
ST. JOSEPH - NATCHEZ	39.0		46.0		52.0	12	43.3	45.5
NATCHEZ - BAYOU SARA	123.8	13	128.0	34	99.5		102.1	103.9
BAYOU SARA - FT. JACKSON	226.7		239.0		239.2		243.4	243.1
	1047.0	46	1089.0	160	1039.0	12	1051.2	1055.2

TABLE F LENGTHS OF REACHES OF THE LOWER MISSISSIPPI RIVER IN CERTAIN YEARS, WITH THE NUMBER OF MILES OF SHORTENING DUE TO CUT-OFFS WHICH OCCURRED IN EACH REACH.

CUT-OFF	DATE	MILES BELOW CAIRO 1915 SURVEY (MILES)	DISTANCE ACROSS POINT C/L TO C/L OF RIVER (MILES)	DISTANCE AROUND BEND (MILES)	REDUCTION IN RIVER LENGTH (MILES)	LENGTH OF CUT. TOP BANK TO TOP BANK (MILES)	H.W. FALL ACROSS POINT 1929	L.W. FALL ACROSS POINT
LELAND NECK	JUNE 3 1933	472.0-483.5	1.3	11.3	10.0	3,900	4.3	3.4
WORTHINGTON POINT	DEC. 25 1933	505.7-513.3	3.8	8.1	4.3	17,600	3.7	1.6
WILLOW POINT	APR. 8 1934	564.0-578.0	4.7	12.4	7.7	22,000	4.0	3.7
MARSHALL POINT	MAR. 12 1934	587.0-593.0	3.1	7.3	4.2	13,000	2.2	2.2
DIAMOND POINT	JAN. 8 1933	613.6-626.0	2.6	14.6	12.0	9,175	2.2	4.2
YUCATAN POINT	FALL 1929	638.3-648.0	2.6	12.2	9.6	11000 in 1929 8500 in 1933	3.7	1.3*
GILES BEND **	MAY 25 1933	689.5-704.1	2.9	14.0	11.1	10,000	4.6	2.8
GLASSCOCK POINT **	MAR. 26 1933	722.5-736.7	4.8	15.6	10.8	20,8000	3.2	2.4

TOTAL REDUCTION IN RIVER LENGTH..........................69.7

* AFFECTED BY SLOPE ADJUSTMENTS WHICH HAVE TAKEN PLACE SINCE THE CUT-OFF OCCURRED.
** LOW WATER DISCHARGE DID NOT GO THROUGH THESE CUT-OFFS DURING THE 1933 LOW WATER SEASON.

TABLE G

RECENT CUT-OFFS ON THE LOWER MISSISSIPPI RIVER.

1	2	3	4	5	6	7	8	9	10
		Q=2,008,000cfs		Q= 2404000 c.f.s.		Q=2,472,000 c.f.s.			
RIVER MILE	H. W. GAGE.	A	B	C	D	E	F	G	H
405.0	110	165.9	160.1	166.9	1.0	173.1	167.3	-5.8	1.4
414.4	8*	165.3	159.2	166.4	1.1	172.5	166.8	-5.7#	1.5
→ 429.75	Chicot Ldg.	161.4	154.6	161.4	0.0	167.8	161.7	-6.1	0.3
a 442.9	104	157.8	147.5	154.5	-3.3	164.6	155.2	-9.4	...
→ 448.75	103	155.6	147.5	154.5	-1.1	162.8	155.2	-7.6	...
460.2	101	151.3	147.3	154.2	2.9	159.8	154.5	-4.3#	3.2
→ 467.5	99	150.6	147.3	154.2	3.6	158.1	154.5	-3.6#	3.9
g 476.2	98	147.7	147.3	154.2	6.5	155.2	154.5	-0.7#	6.8
484.2	97	145.2	145.2	151.6	6.4	152.7	152.7	0.0	7.5
488.6	96	143.4	142.7	149.5	6.1	150.6	149.8	-0.8	7.2
490.7	95	142.6	141.5	147.5	4.9	149.4	148.7	-0.7	6.1
497.0	94	140.2	138.9	145.6	5.4	147.8	146.7	-1.1	6.5
507.6	92	136.4	134.8	141.9	5.5	144.2	142.9	-1.3	6.5
517.0	90	131.6	129.9	135.0	3.4	138.0	136.3	-1.7	4.7
→ 525.0	89	130.9	129.2	133.9	3.0	137.5	134.6	-2.9#	3.7
532.1	87	127.3	125.7	130.0	2.7	132.9	130.7	-2.2	3.4
537.6	86	124.7	122.8	128.1	3.4	131.3	129.2	-2.1	4.5
543.0	Lake Prov.	122.9	120.4	126.5	3.6	129.7	127.2	-2.5	4.3
551.5	84	121.4	117.1	123.1	1.7	128.7	124.3	-4.4#	2.9
→ 560.2	82	118.5	115.3	120.4	1.9	125.3	121.7	-3.6	3.2
→ 574.9	80	112.7	112.5	117.4	4.7	118.0	118.1	0.1	5.4
583.7	78	110.5	108.8	113.8	3.3	115.6	115.0	-0.6	4.5
592.2	77	107.3	105.3	110.2	2.9	112.8	111.5	-1.3	4.2
601.8	Vicksburg	106.3	103.5	108.9	2.6	111.8	110.0	-1.8	3.7
606.3	75	102.3	99.3	103.3	1.0	106.1	104.1	-2.0	1.8
611.0	O-1*	101.3	97.6	101.6	0.3	105.4	102.3	-3.1	1.0
617.9	73	100.4	97.2	100.8	0.4	104.4	101.4	-3.0#	1.0
→ 622.0	PL**	98.4	96.6	100.4	2.0	103.0	100.9	-2.1#	2.5
627.0	O-2*	98.4	97.2	101.1	2.7	103.3	101.7	-1.6	3.3
638.0	O-3*	97.1	94.8	98.6	1.5	102.0	99.3	-2.7	2.2
→ 640.7	70	96.3	93.9	98.1	1.8	101.4	99.0	-2.4#	2.7
649.0	O-4*	92.9	92.2	96.3	3.4	98.3	97.2	-1.1	4.3
653.1	68	91.7	90.8	94.3	2.6	96.4	95.0	-1.4	3.3
657.2	67	90.5	89.7	93.8	3.3	95.8	94.5	-1.3	4.0
662.4	St. Jos.	89.4	88.3	92.4	3.0	94.7	93.4	-1.3	4.0
670.0	66	86.1	84.5	88.8	2.7	91.9	89.9	-2.0	3.8
675.2	65	84.9	82.0	87.6	2.7	91.3	89.0	-2.3	4.1
681.4	64	84.1	81.5	86.5	2.4	90.5	87.7	-2.8	3.6
687.8	62	82.0	78.5	83.4	1.4	88.8	84.7	-4.1	2.7
→ 693.7	61	79.8	76.9	82.4	2.6	86.7	83.8	-2.9#	4.0
699.5	60	78.5	76.0	82.1	3.6	85.3	83.4	-1.9#	4.9
705.7	Natchez	74.0	72.3	76.1	2.1	79.0	76.9	-2.1	2.9
710.4	59	72.6	70.7	73.9	1.3	76.5	74.6	-1.9	2.0
716.7	58	71.6	69.1	73.2	1.6	76.1	73.9	-2.2#	2.3
→ 720.9	57	71.1	69.3	72.8	1.7	75.5	73.8	-1.7#	2.7
726.2	56	69.6	68.4	72.4	2.8	74.0	73.6	-0.4#	4.0
730.9	55	68.8	69.2	72.4	3.6	73.5	73.5	0.0	4.7
736.7	54	68.3	68.3	72.2	3.9	73.1	73.1	0.0	4.8
744.4	53	66.7	66.7	70.9	4.2	71.8	71.8	0.0	5.1
750.2	52	65.6	65.6	70.1	4.5	71.2	71.2	0.0	5.6
754.5	51	65.2	65.2	69.8	4.6	70.8	70.8	0.0	5.6
759.2	50	63.7	63.7	68.6	4.9	69.7	69.7	0.0	6.0

a. Arkansas City, Ark. at river mile 436.7 g. Greenville, Miss. at river mile 489.2
* Model Gages. ** Palmyra Lake Model Gage. → Cut-offs.

A. Stages for adopted project discharge of 2,008,000 c.f.s. in feet M. G. L.
B. Stages after cut-offs for project discharge of 2,008,000 c.f.s. in feet M. G. L.
C. Gage readings obtained after modification of the model by cut-offs and raising levees.
D. Increase in stages above project elevations for discharge of 2,404,000 c.f.s. (all cut-offs open) D = C—A
E. Stages in feet M. G. L. before cut-offs with discharge of 2,472,000 c.f.s. Levees raised to carry 1927 flood.
F. Stages in feet M. G. L. after cut-offs with discharge of 2,472,000 c.f.s. Levees raised to carry 1927 flood.
G. Difference in feet produced by cut-offs for 1927 flood. G = E—F
H. Increase in stages above project elevations for 1927 flood after cut-offs. (in feet) H = F—A

TABLE H

EFFECTS OF CUT-OFFS ON RIVER STAGES.

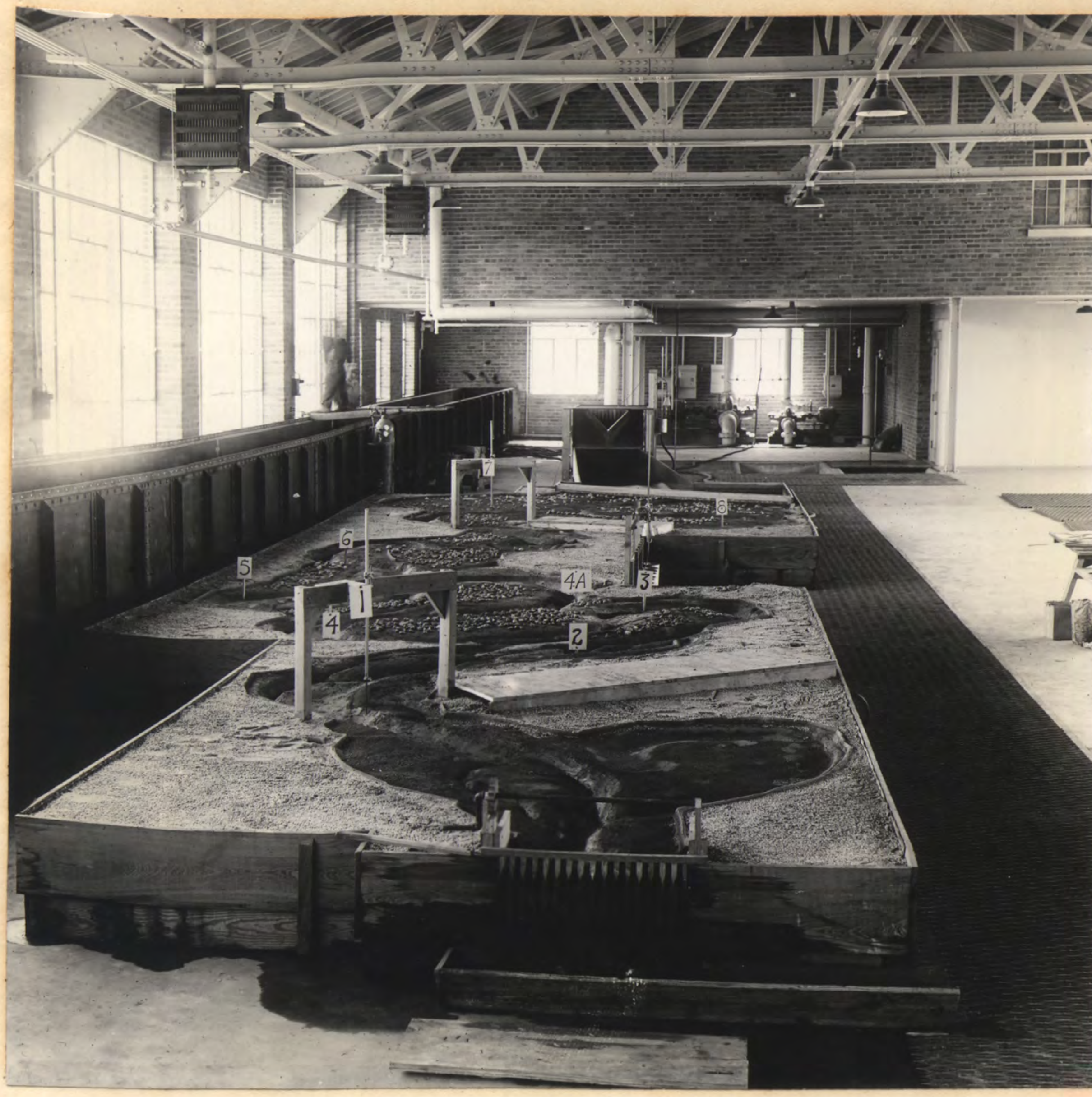


PLATE I. GENERAL VIEW OF THE GREENVILLE BENDS MODEL, U.S. WATERWAYS EXPERIMENT STATION, VICKSBURG, MISS. MODEL SCALES: 1:4800 HORIZONTAL, 1:360 VERTICAL.

PLATE II GENERAL VIEW OF FIXED-BED, OUTDOOR MODEL, U. S. WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI. HORIZONTAL SCALE 1 : 2400; VERTICAL SCALE 1 : 120. MODEL USED TO INVESTIGATE EFFECTS OF PROPOSED DREDGED CUT-OFFS BELOW LAKE LEE. UPPER LIMIT AT MILE 484, LOWER LIMIT AT MILE 762.7 .

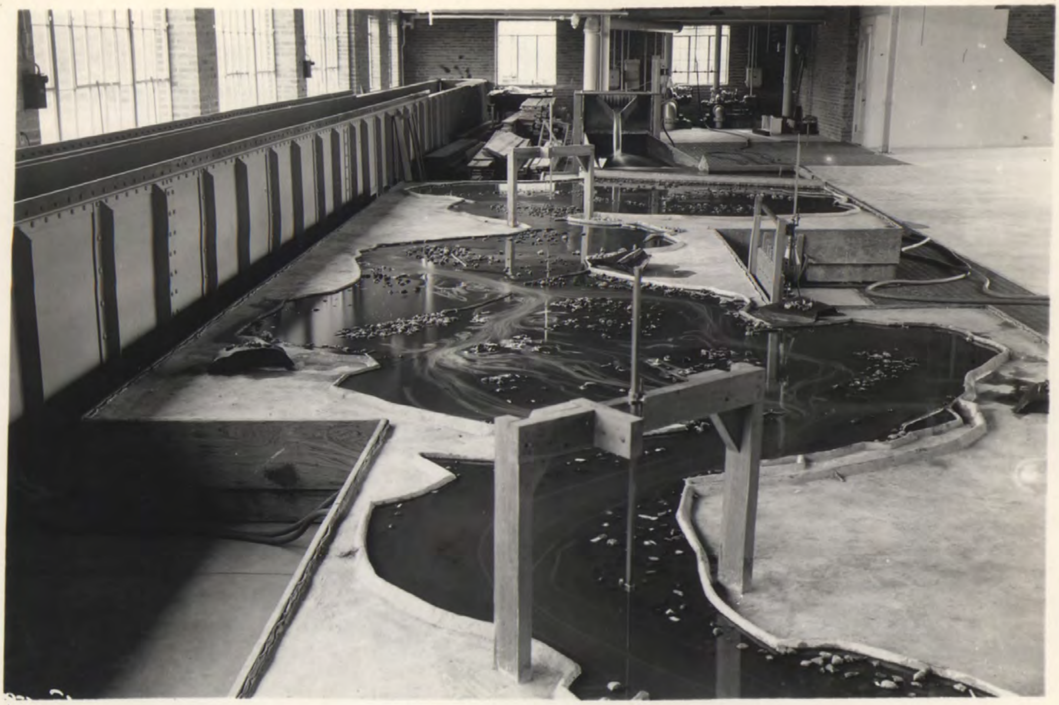


PLATE III GREENVILLE BENDS MODEL, U.S. WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI. MODEL SCALES: 1 : 4800 HORIZONTAL, 1 : 360 VERTICAL. VIEW SHOWING TURBULENCE PRODUCED BY CUT-OFFS AT ALL FOUR NECKS IN THE GREENVILLE BENDS.

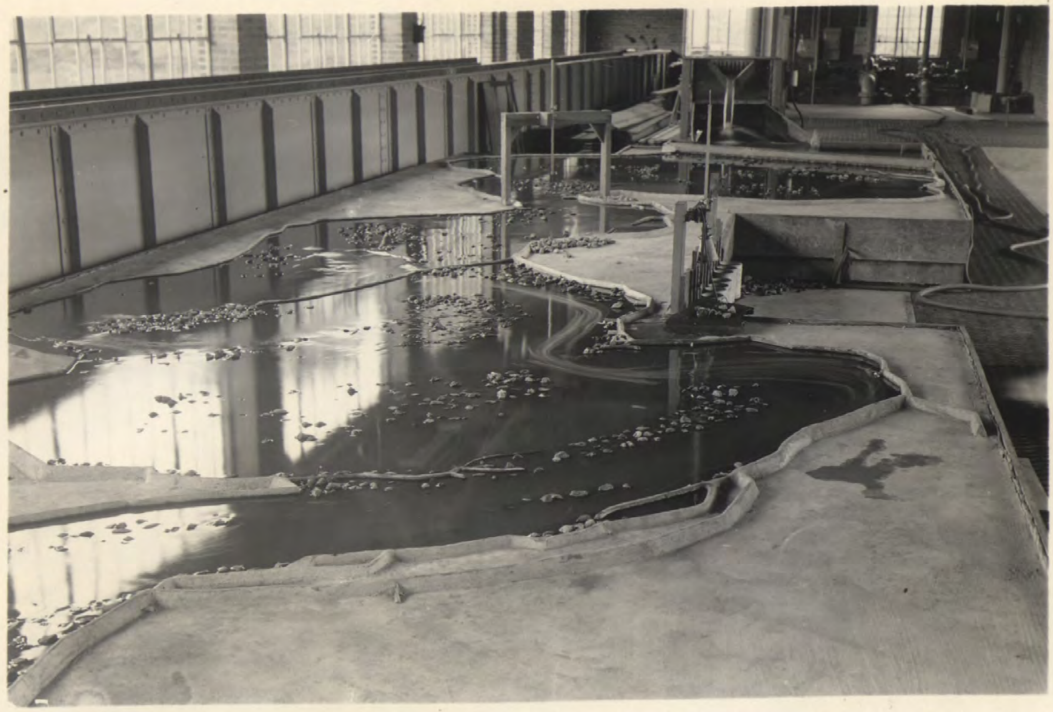


PLATE IV GREENVILLE BENDS MODEL, U. S. WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI. MODEL SCALES: 1 : 4800 HORIZONTAL; 1 : 360 VERTICAL. VIEW SHOWING DIRECTION OF CURRENTS AFTER A CUT-OFF AT TARPLEY NECK.

PLATE V PHOTOGRAPH OF AERIAL MOSAIC TAKEN ON JUNE 19, 1933 SHOWING DIAMOND POINT CUT-OFF. THE STAGE OF THE MISSISSIPPI WHEN THIS PHOTOGRAPH WAS TAKEN WAS 43.9 FEET ON THE VICKSBURG GAGE. APPROXIMATELY 32% OF THE RIVER DISCHARGE IS SHOWN PASSING THROUGH THE CUT-OFF.

PLATE VI GREENVILLE BENDS MODEL, U. S. WATERWAYS EXPERIMENT STATION. MODEL SCALES: 1 : 4800 HORIZONTAL; 1 : 360 VERTICAL. VIEW SHOWING BAR FORMATION ON DOWNSTREAM SIDE OF TARPLEY NECK AFTER CUT-OFF. (SIMILAR BAR FORMATION HAS BEEN NOTED AT DIAMOND POINT AND YUCATAN POINT CUT-OFFS IN NATURE.)

PLATE VII GREENVILLE BENDS MODEL, U. S. WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI. MODEL SCALES: 1 : 4800 HORIZONTAL; 1 : 360 VERTICAL.

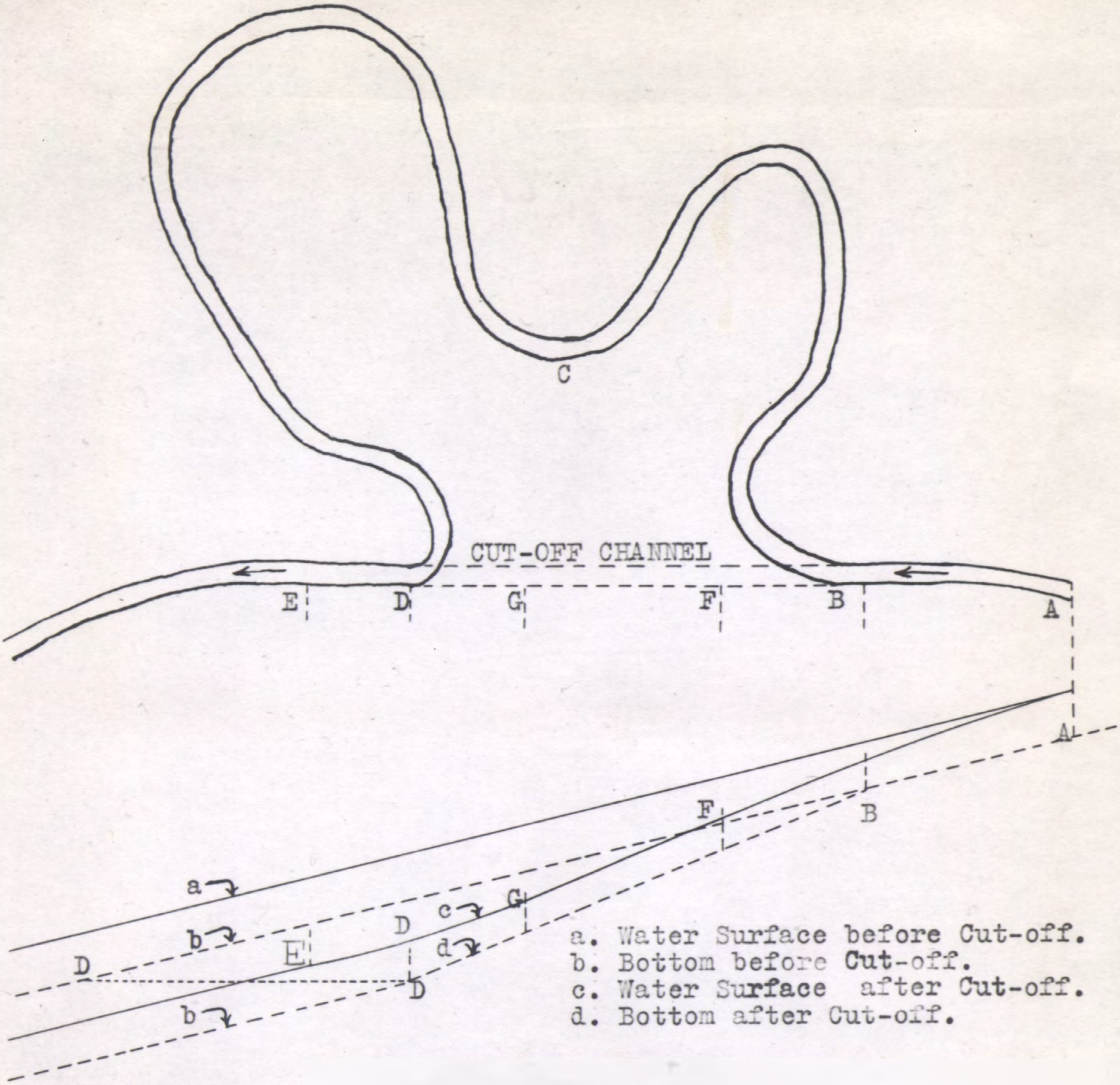
A. CUT-OFF ACROSS TARPLEY NECK.

B. BAR FORMED BELOW CUT-OFF.

C. SILTING AT LOWER END OF NEWLY FORMED OXBOW LAKE.

D. SILTING AT UPPER END OF NEWLY FORMED OXBOW LAKE.

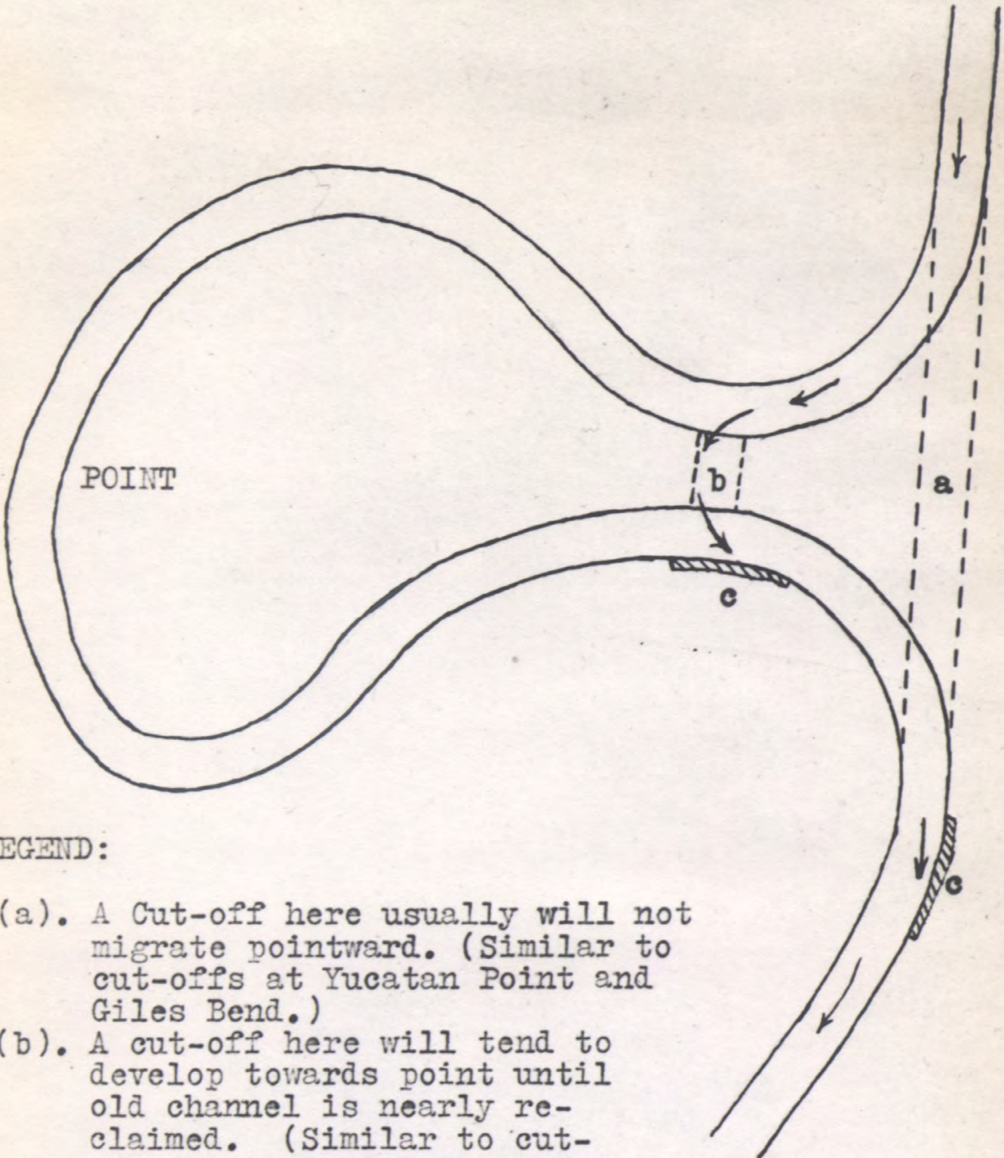
E. CHUTE ACROSS POINT CHICOT WHERE EROSION MAY BE EXPECTED.



a. Water Surface before Cut-off.
b. Bottom before Cut-off.
c. Water Surface after Cut-off.
d. Bottom after Cut-off.

PLATE VIII.

CHANGE IN PROFILE OF CHANNEL CAUSED BY SINGLE CUT-OFF.

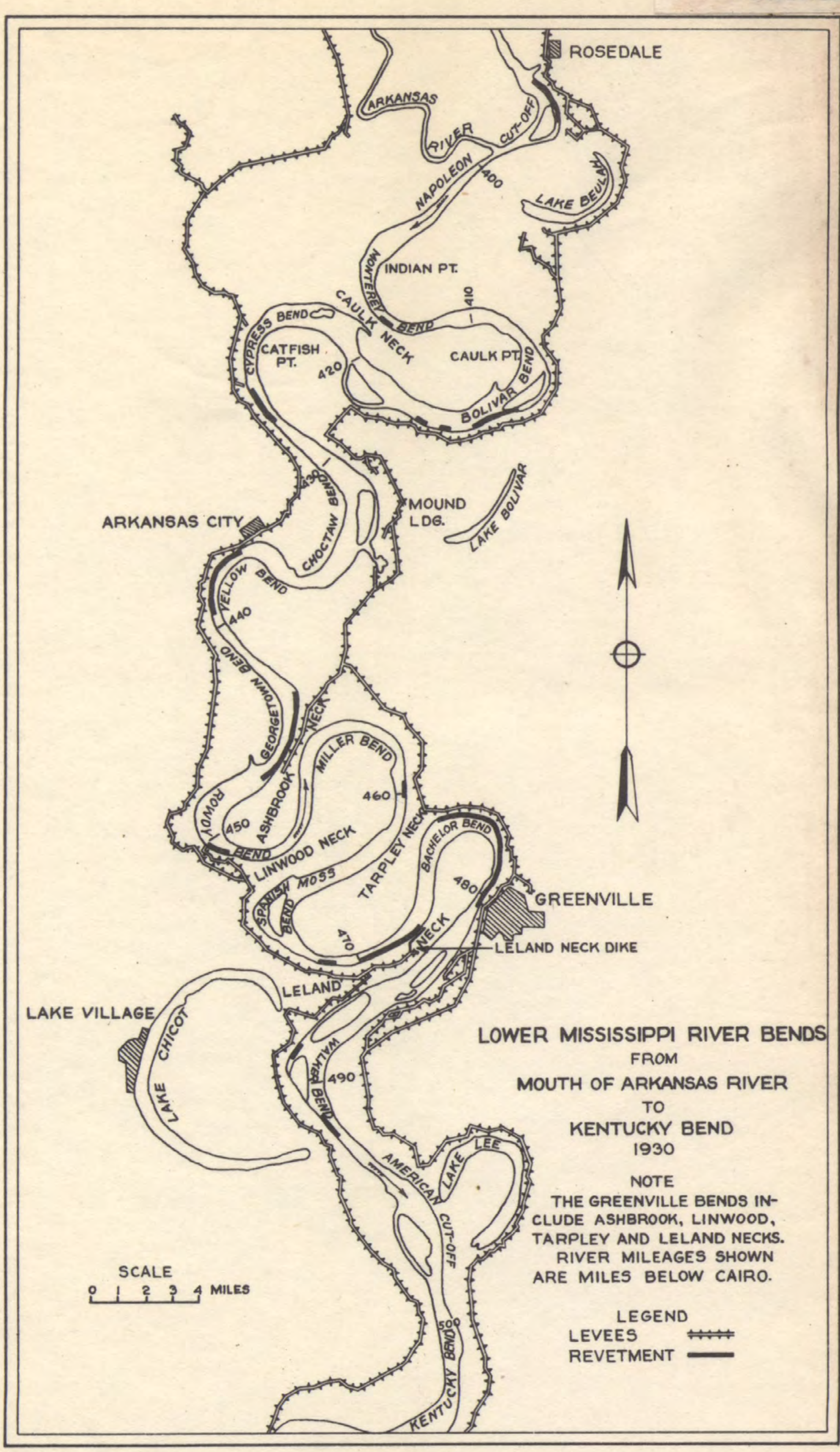


LEGEND:

(a). A Cut-off here usually will not migrate pointward. (Similar to cut-offs at Yucatan Point and Giles Bend.)
(b). A cut-off here will tend to develop towards point until old channel is nearly reclaimed. (Similar to cut-offs at Diamond Point and Leland Neck.)
(c). Bank attack here.

PLATE IX. SHOWING TWO METHODS OF MAKING ARTIFICIAL CUT-OFFS.

PLATE X



LOWER MISSISSIPPI RIVER BENDS
FROM
MOUTH OF ARKANSAS RIVER
TO
KENTUCKY BEND
1930

NOTE
THE GREENVILLE BENDS INCLUDE ASHBROOK, LINWOOD, TARPLEY AND LELAND NECKS.
RIVER MILEAGES SHOWN ARE MILES BELOW CAIRO.

LEGEND
LEVEES
REVETMENT

Plate XI

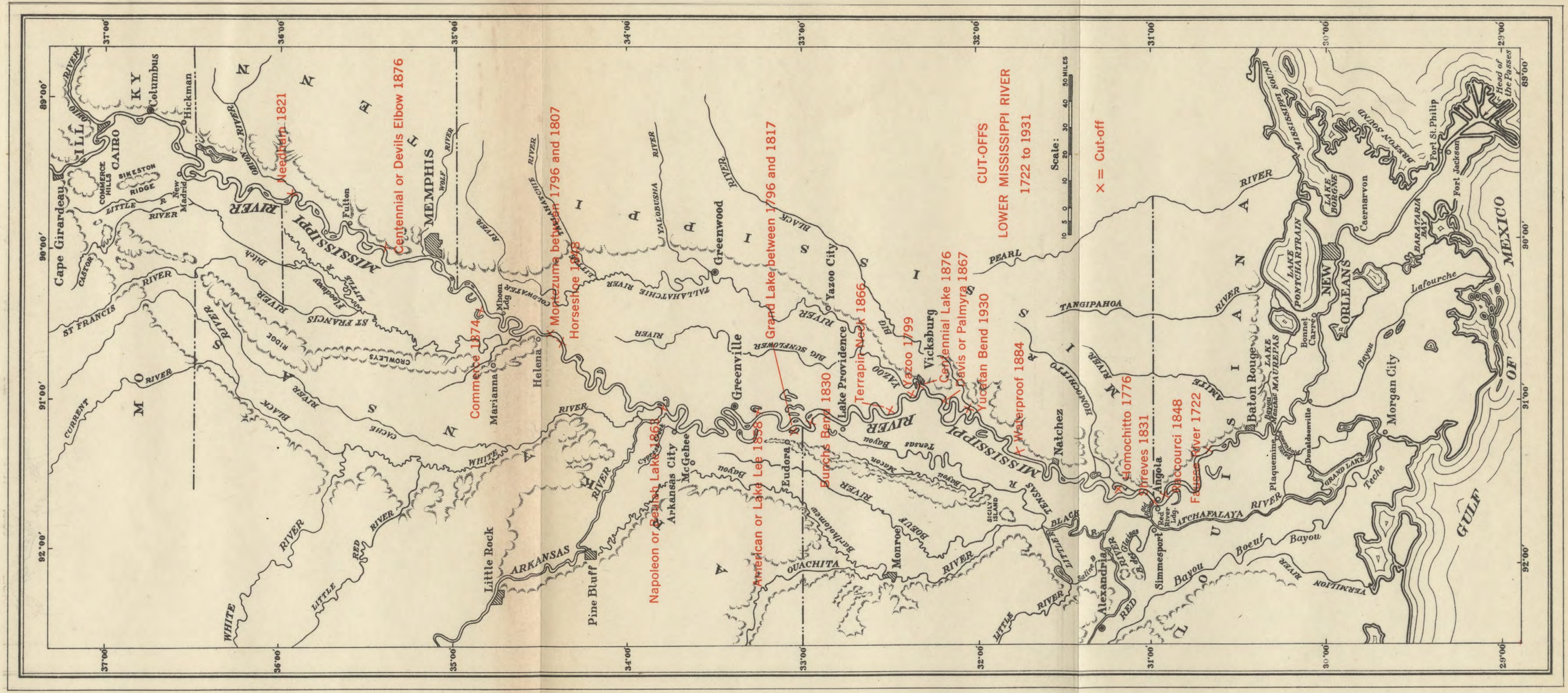
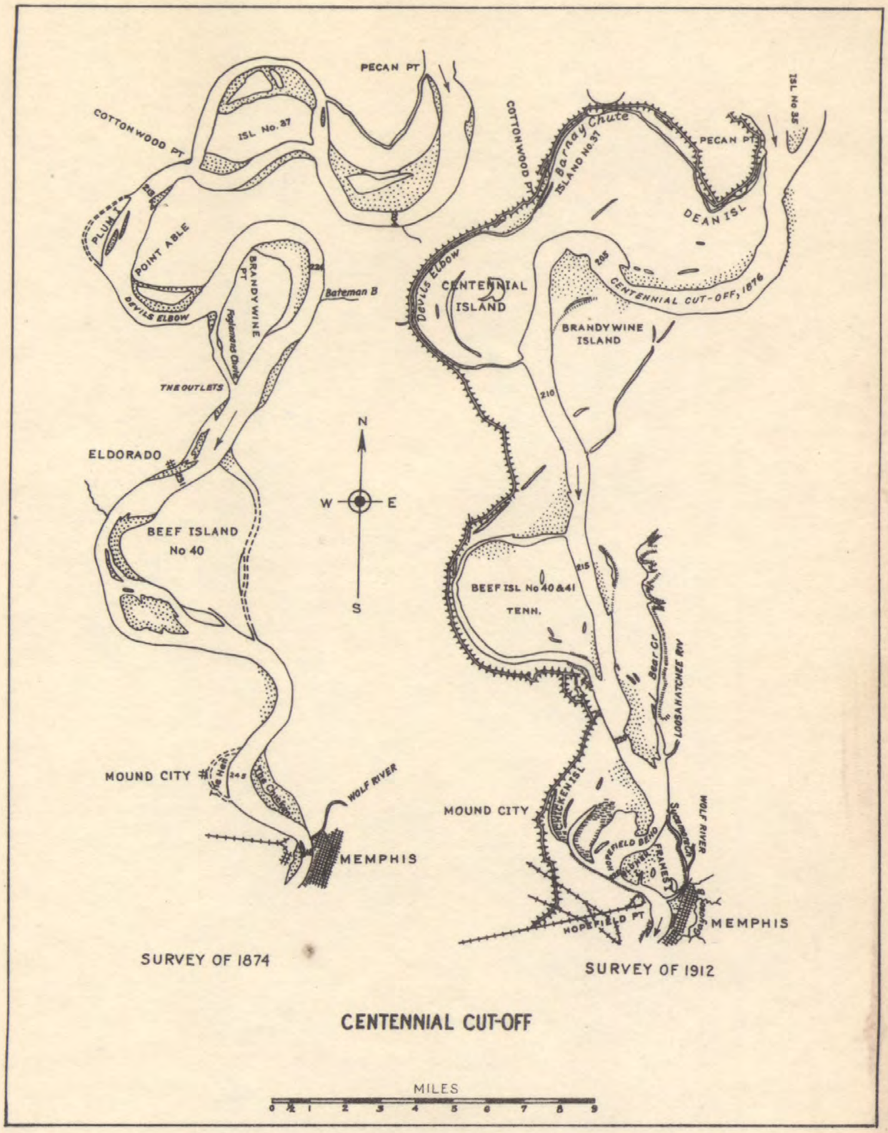
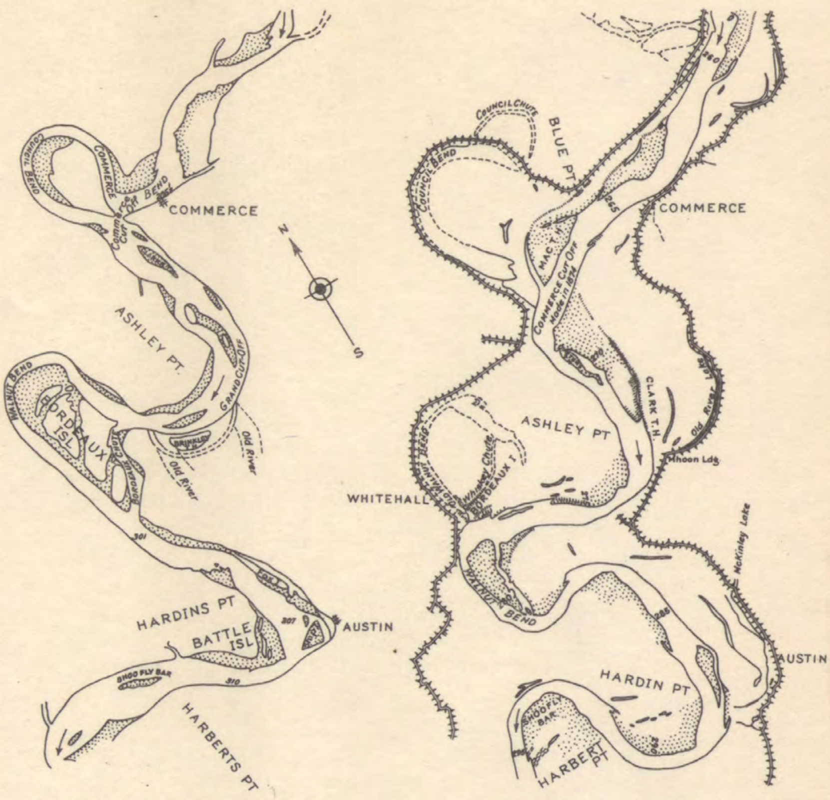

CUT-OFFS
LOWER MISSISSIPPI RIVER
1722 to 1931
x = Cut-off
Scale: 50 MILES
Needham 1821
Centennial or Devils Elbow 1876
Montezuma between 1796 and 1807
Horseshoe 1848
Commerce 1874
Grand Lake between 1796 and 1817
Napoleon or Beulah Lake 1863
American or Lake Lee 1858
Bunchs Bend 1830
Terrapin Neck 1866
Yazoo 1799
Centennial Lake 1876
Davis or Palmyra 1867
Yucatan Bend 1930
Waterproof 1884
Homochitto 1776
Shreves 1831
Raccourci 1848
Fausse River 1722
MISSISSIPPI RIVER
MEMPHIS
Vicksburg
Natchez
Baton Rouge
NEW ORLEANS
Little Rock
Pine Bluff
Helena
Greenville
Greenwood
Yazoo City
Lake Providence
Alexandria
Monroe
Morgan City
Cape Girardeau
Cairo
Columbus
Hickman
New Madrid
GULF OF MEXICO

Plate XII



CENTENNIAL CUT-OFF

Plate XIII



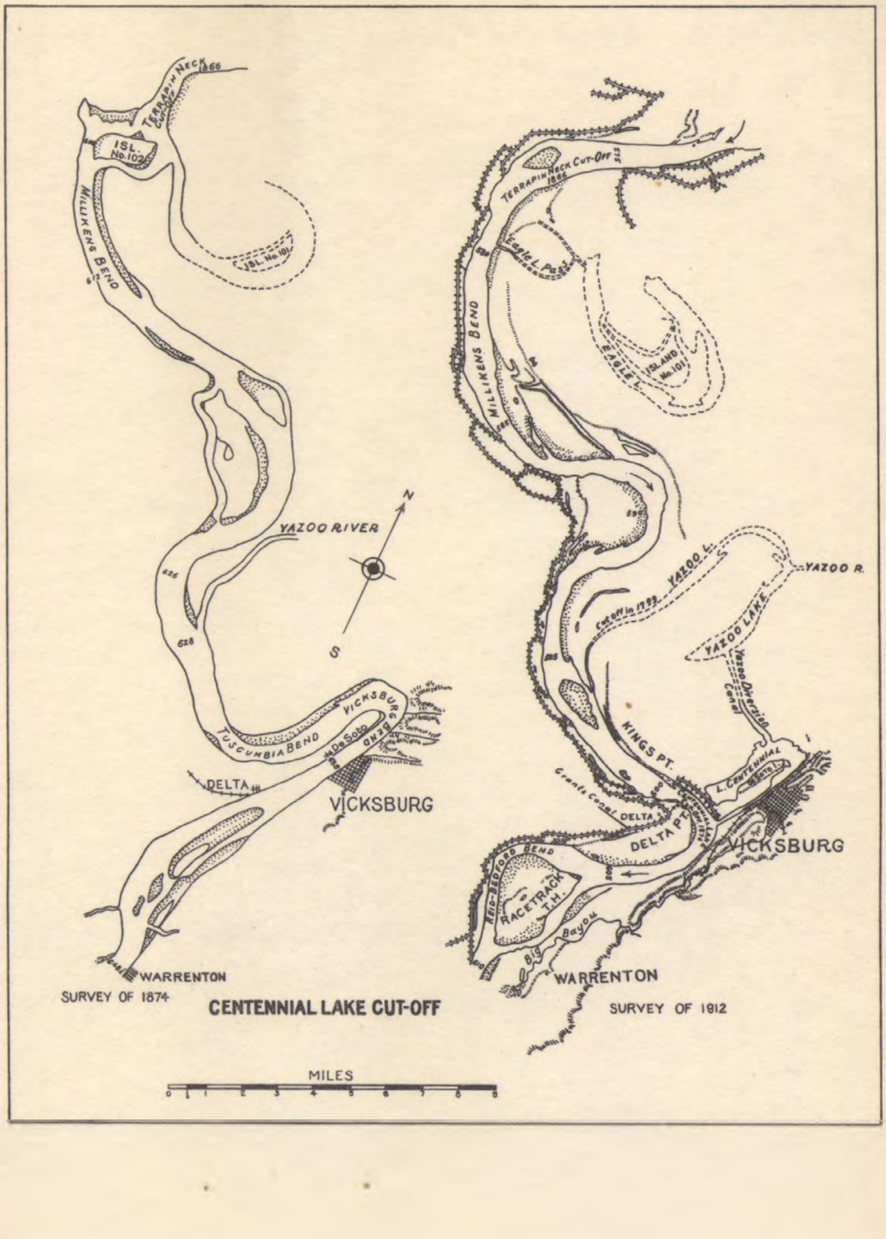
SURVEY OF 1874

SURVEY OF 1912

COMMERCE CUT-OFF

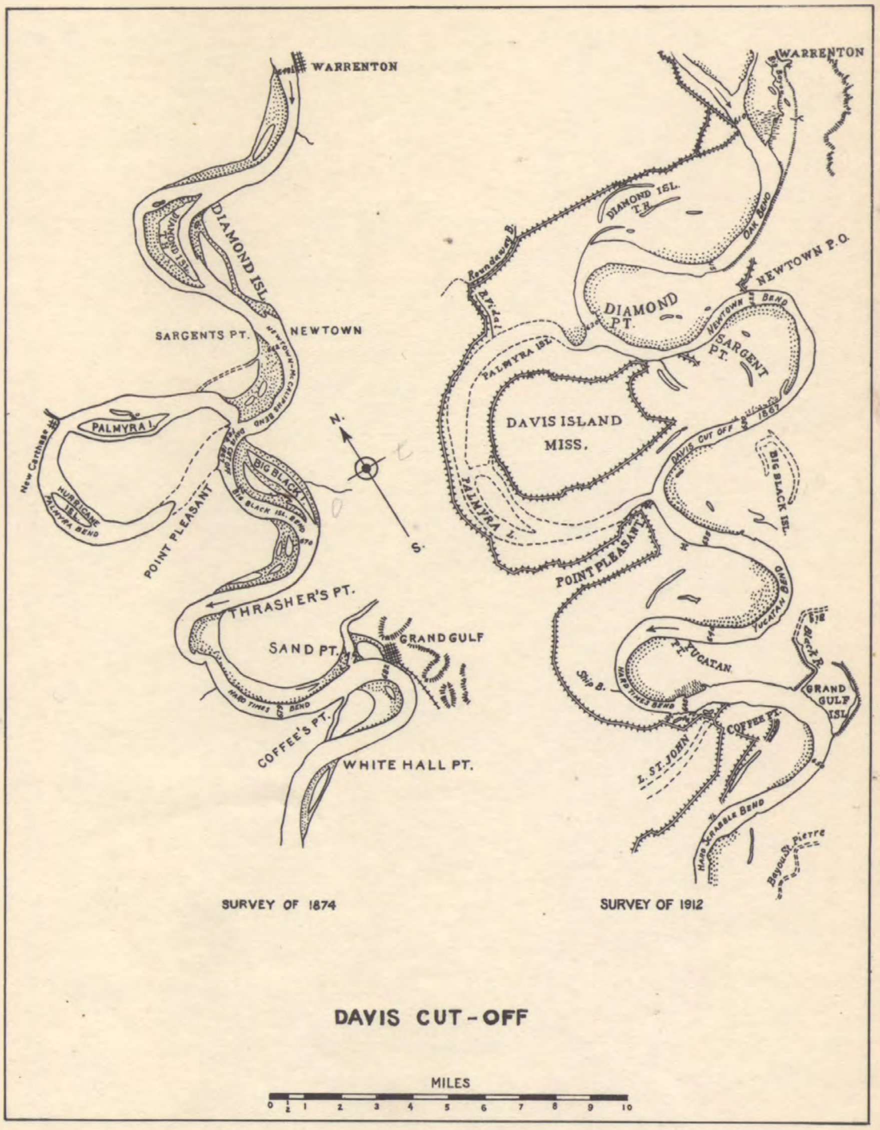
MILES
0 ½ 1 2 3 4 5 6 7 8 9

Plate XIV



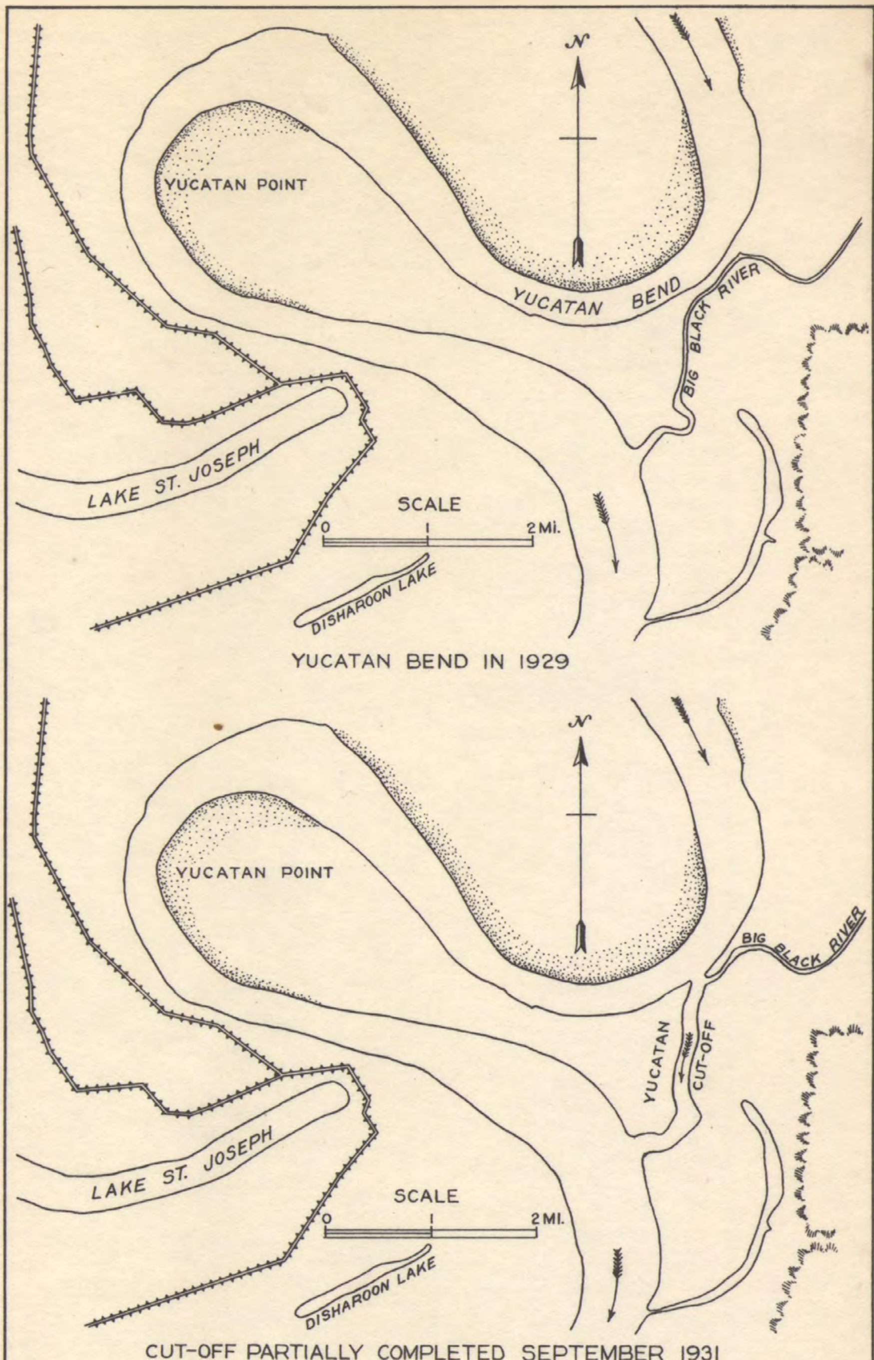
CENTENNIAL LAKE CUT-OFF

Plate XV



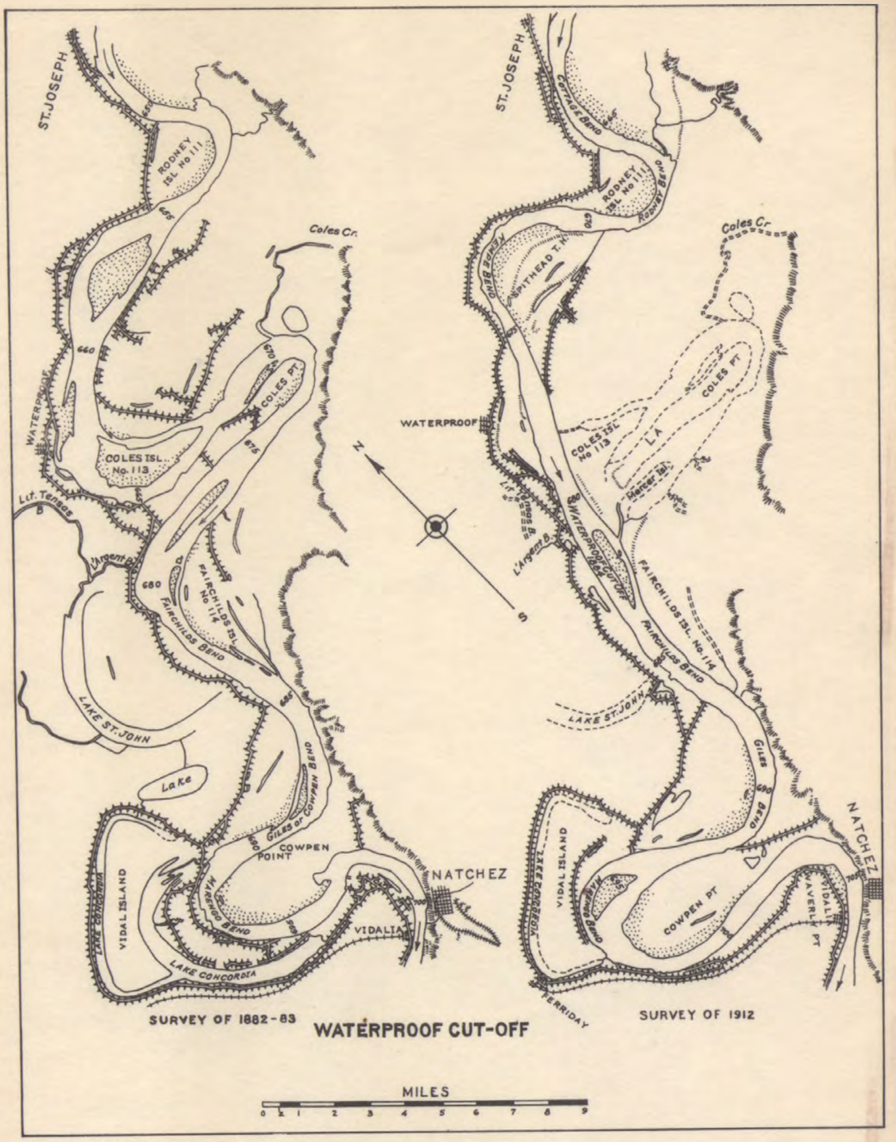
DAVIS CUT-OFF

Plate XVI



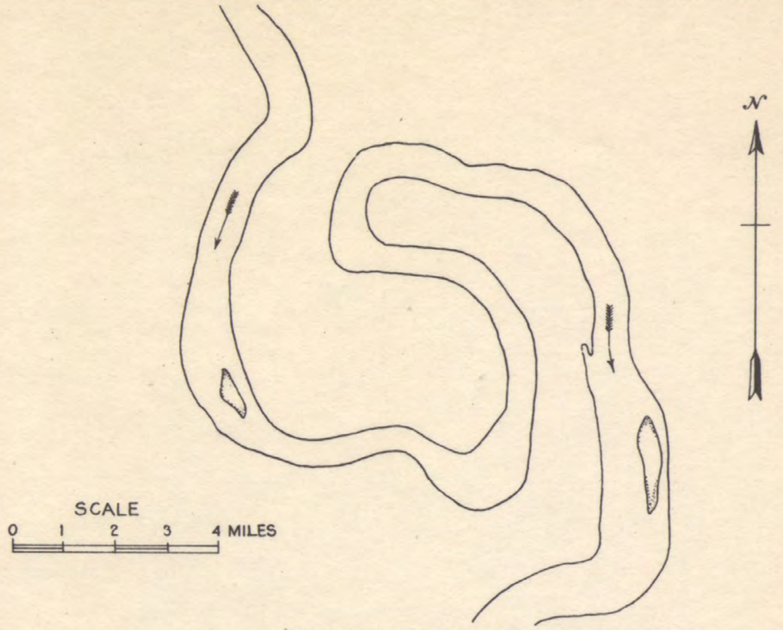
YUCATAN CUT-OFF
1930

Plate XVII

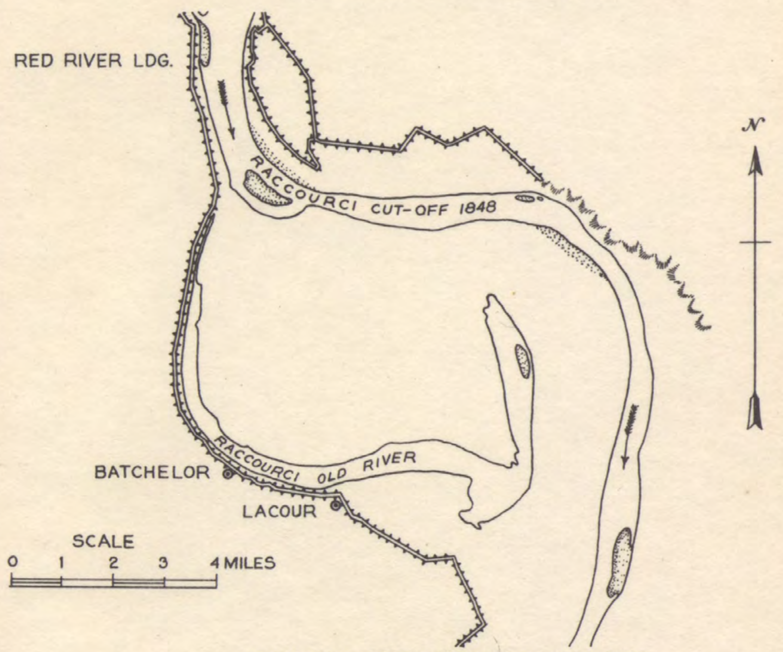


WATERPROOF CUT-OFF

Plate XVIII



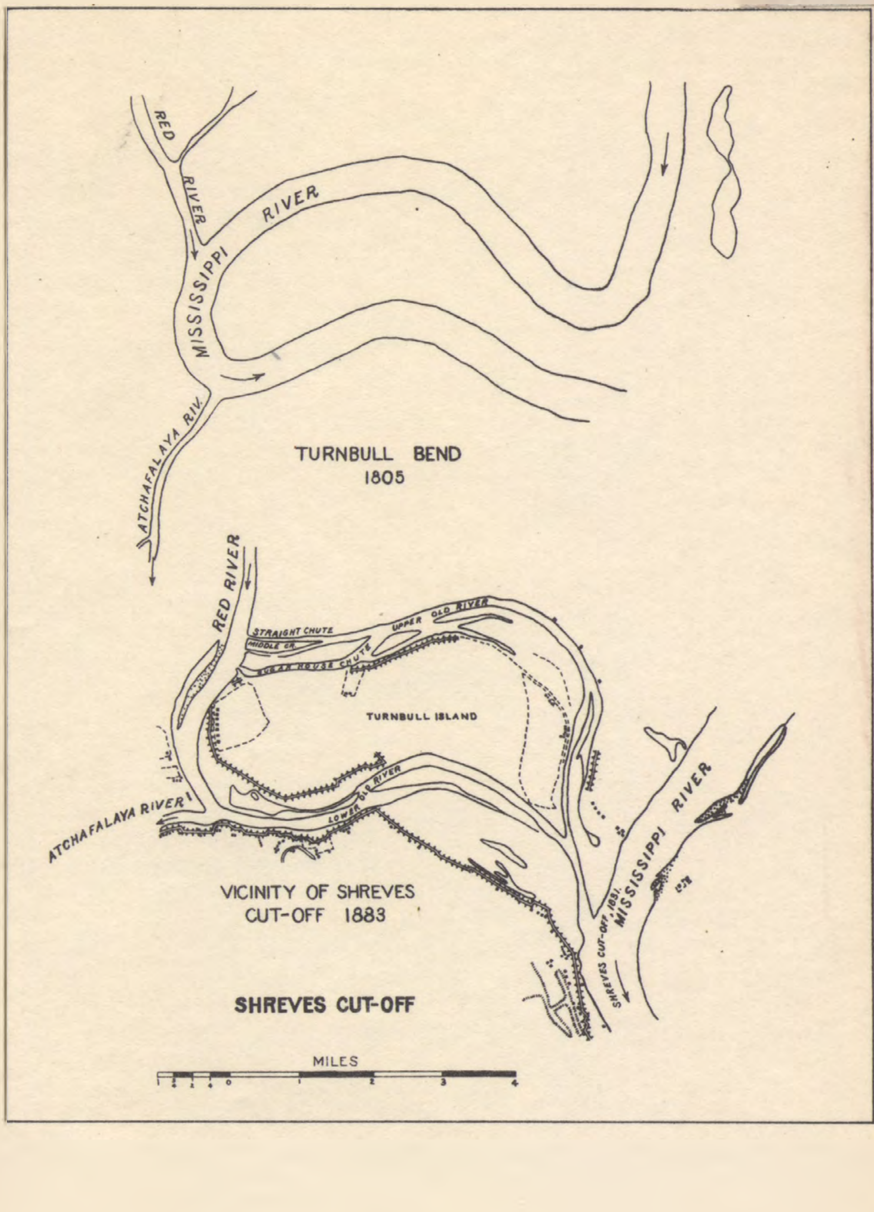
RACCOURCI BEND IN 1820



VICINITY OF RACCOURCI CUT-OFF
1930

RACCOURCI CUT-OFF
1848

PLATE XIX



SHREVES CUT-OFF

PLATE XX-a

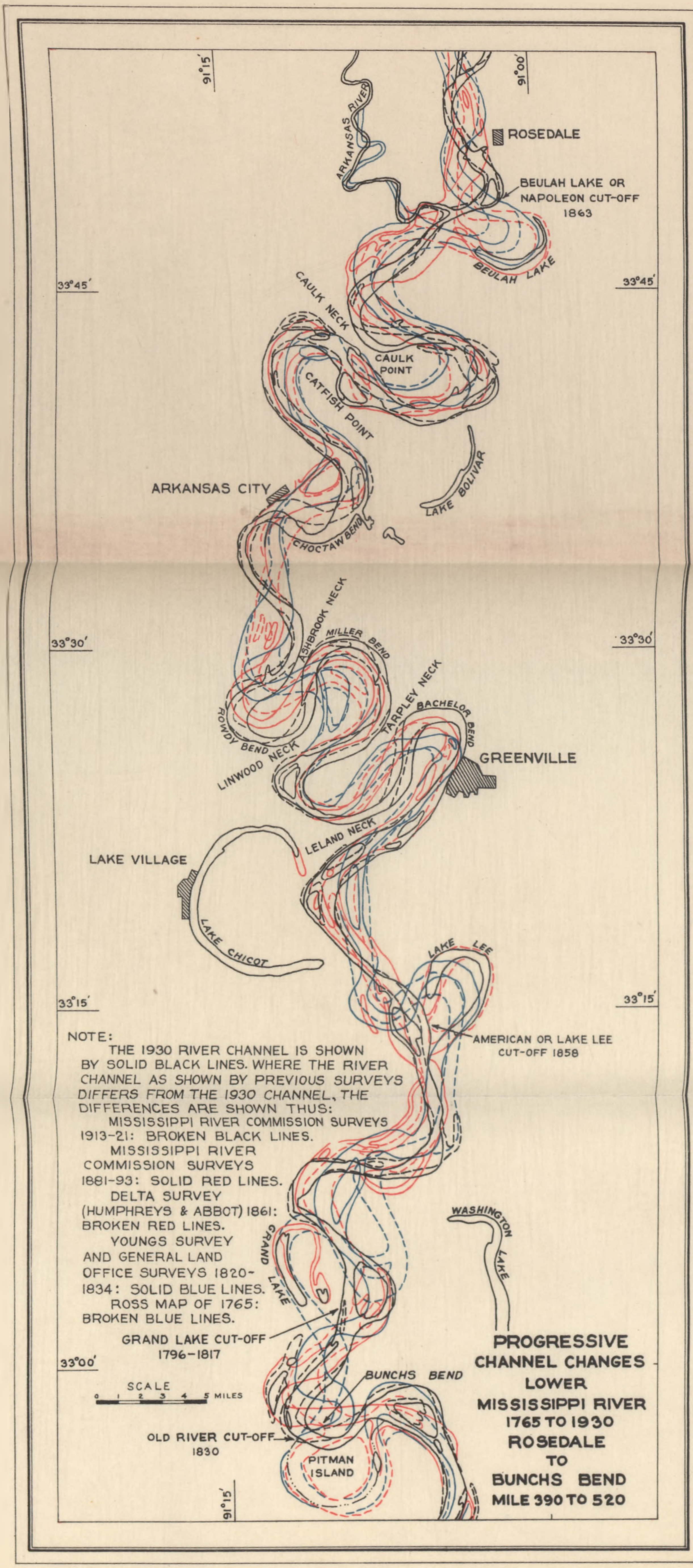

91°15'
91°00'
ROSEDALE
ARKANSAS RIVER
BEULAH LAKE OR
NAPOLEON CUT-OFF
1863
BEULAH LAKE
33°45'
33°45'
CAULK NECK
CAULK
POINT
CATFISH POINT
LAKE BOLIVAR
ARKANSAS CITY
CHOCTAW BEND
ASHBROOK NECK
MILLER BEND
33°30'
33°30'
TARPLEY NECK
BACHELOR BEND
ROWDY BEND NECK
LINWOOD NECK
GREENVILLE
LELAND NECK
LAKE VILLAGE
LAKE CHICOT
LAKE LEE
33°15'
33°15'
AMERICAN OR LAKE LEE
CUT-OFF 1858
NOTE:
THE 1930 RIVER CHANNEL IS SHOWN
BY SOLID BLACK LINES. WHERE THE RIVER
CHANNEL AS SHOWN BY PREVIOUS SURVEYS
DIFFERS FROM THE 1930 CHANNEL, THE
DIFFERENCES ARE SHOWN THUS:
MISSISSIPPI RIVER COMMISSION SURVEYS
1913-21: BROKEN BLACK LINES.
MISSISSIPPI RIVER
COMMISSION SURVEYS
1881-93: SOLID RED LINES.
DELTA SURVEY
(HUMPHREYS & ABBOT) 1861:
BROKEN RED LINES.
YOUNGS SURVEY
AND GENERAL LAND
OFFICE SURVEYS 1820-
1834: SOLID BLUE LINES.
ROSS MAP OF 1765:
BROKEN BLUE LINES.
WASHINGTON LAKE
GRAND LAKE
GRAND LAKE CUT-OFF
1796-1817
33°00'
SCALE
0 1 2 3 4 5 MILES
BUNCHS BEND
OLD RIVER CUT-OFF
1830
PITMAN
ISLAND
91°15'
PROGRESSIVE
CHANNEL CHANGES
LOWER
MISSISSIPPI RIVER
1765 TO 1930
ROSEDALE
TO
BUNCHS BEND
MILE 390 TO 520

PLATE XX-b

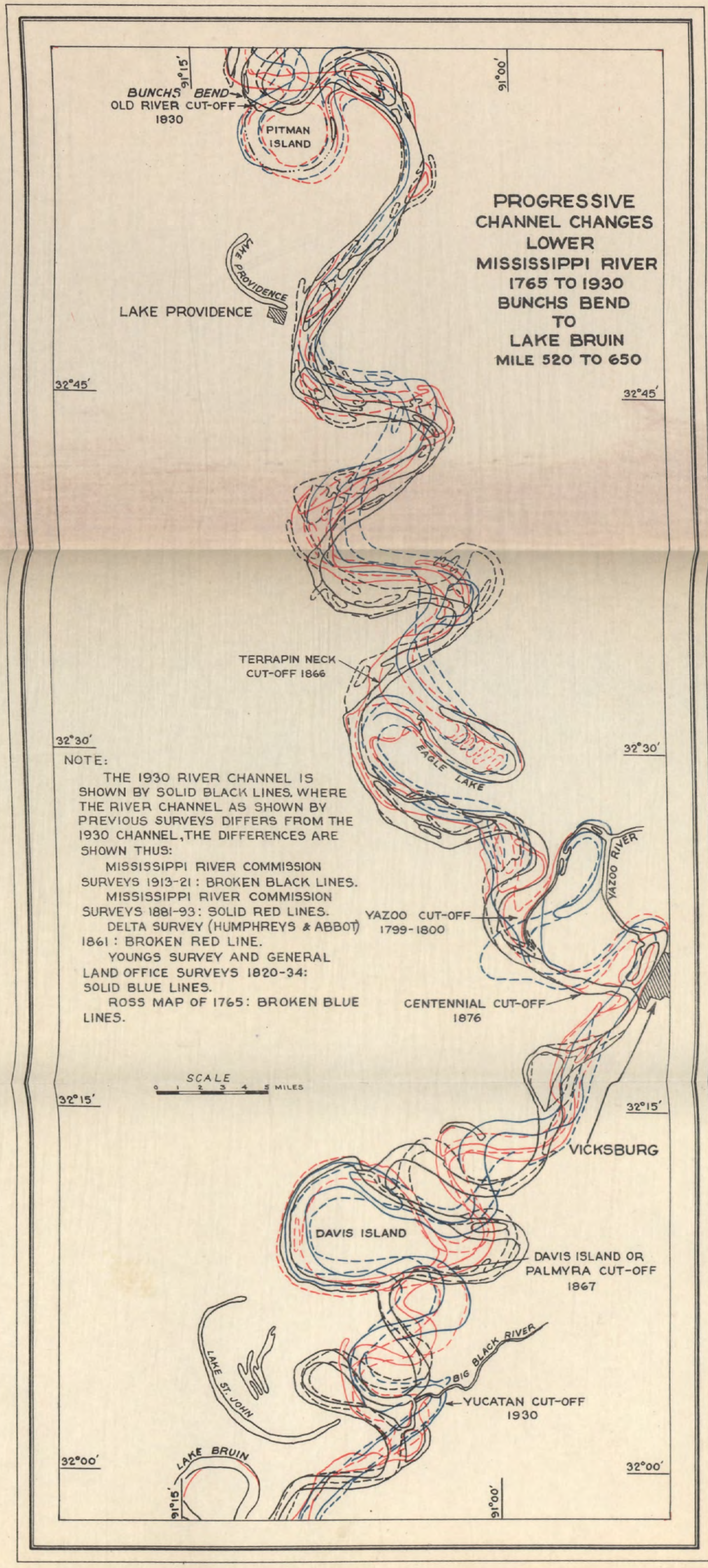

PROGRESSIVE
CHANNEL CHANGES
LOWER
MISSISSIPPI RIVER
1765 TO 1930
BUNCHS BEND
TO
LAKE BRUIN
MILE 520 TO 650
BUNCHS BEND
OLD RIVER CUT-OFF
1830
PITMAN
ISLAND
LAKE PROVIDENCE
LAKE PROVIDENCE
TERRAPIN NECK
CUT-OFF 1866
EAGLE LAKE
YAZOO RIVER
YAZOO CUT-OFF
1799-1800
CENTENNIAL CUT-OFF
1876
VICKSBURG
DAVIS ISLAND
DAVIS ISLAND OR
PALMYRA CUT-OFF
1867
BIG BLACK RIVER
YUCATAN CUT-OFF
1930
LAKE ST. JOHN
LAKE BRUIN
91°15'
91°00'
32°45'
32°30'
32°15'
32°00'
NOTE:
THE 1930 RIVER CHANNEL IS SHOWN BY SOLID BLACK LINES. WHERE THE RIVER CHANNEL AS SHOWN BY PREVIOUS SURVEYS DIFFERS FROM THE 1930 CHANNEL, THE DIFFERENCES ARE SHOWN THUS:
MISSISSIPPI RIVER COMMISSION SURVEYS 1913-21 : BROKEN BLACK LINES.
MISSISSIPPI RIVER COMMISSION SURVEYS 1881-93: SOLID RED LINES.
DELTA SURVEY (HUMPHREYS & ABBOT) 1861 : BROKEN RED LINE.
YOUNGS SURVEY AND GENERAL LAND OFFICE SURVEYS 1820-34: SOLID BLUE LINES.
ROSS MAP OF 1765: BROKEN BLUE LINES.
SCALE
0 1 2 3 4 5 MILES

PLATE XX-c

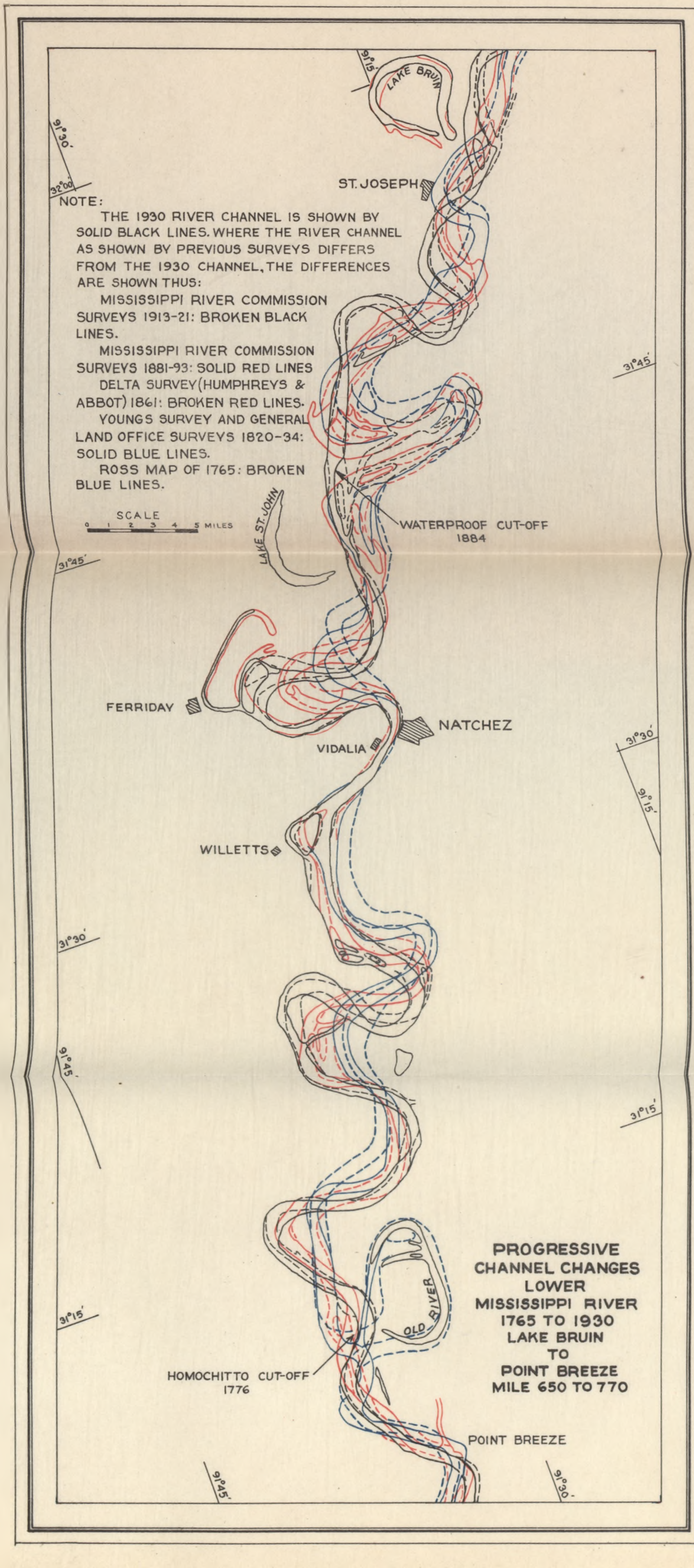
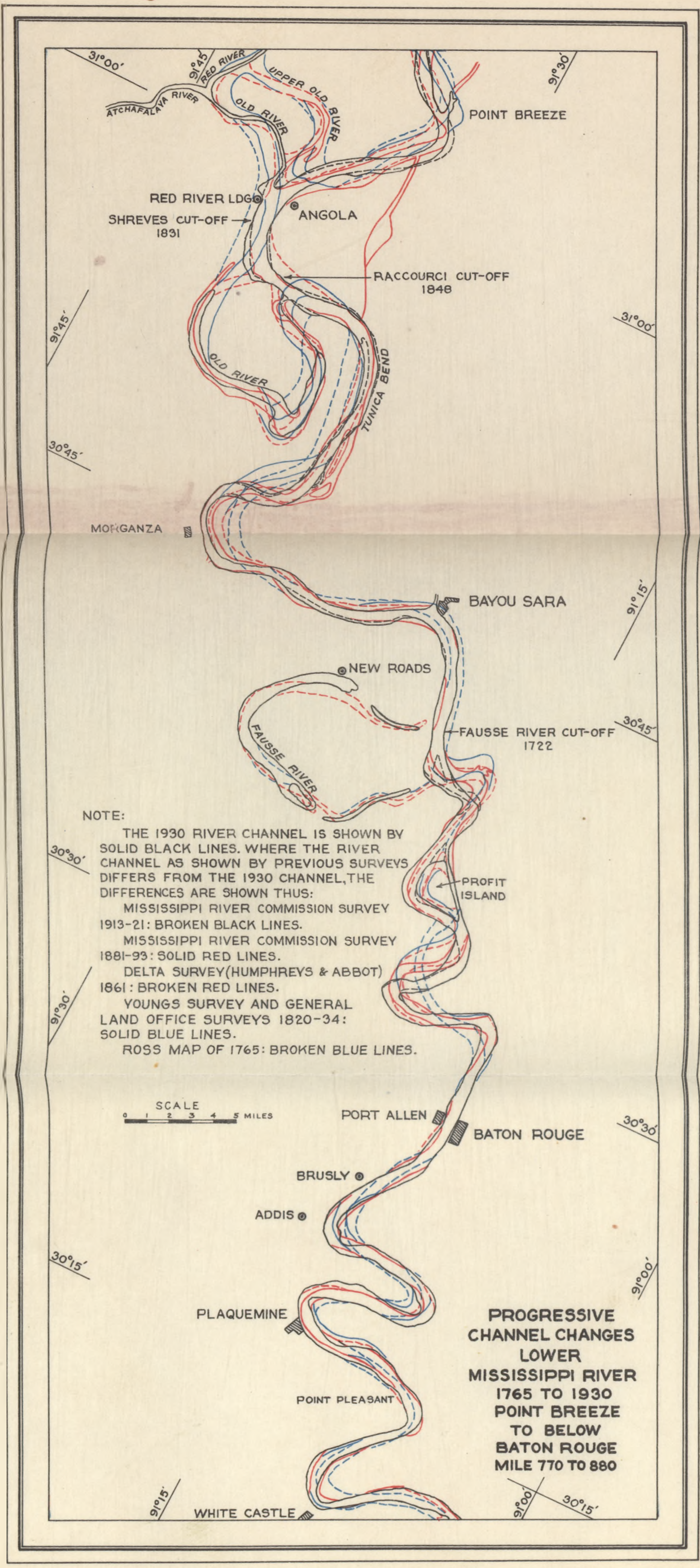
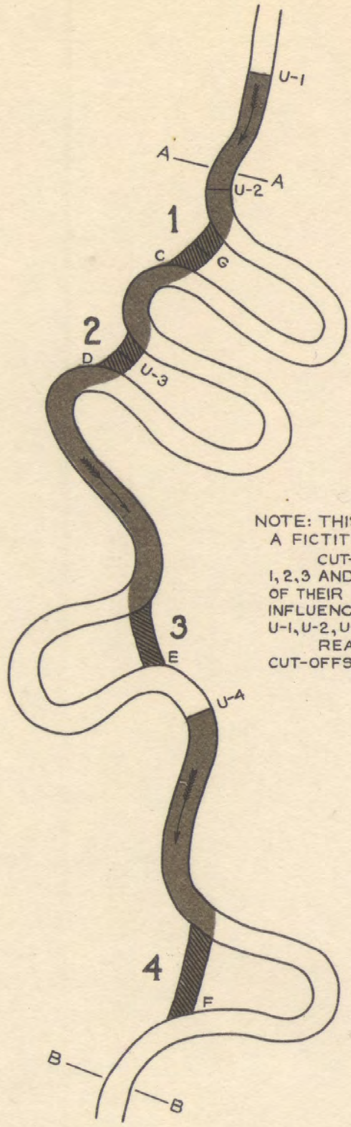

PROGRESSIVE
CHANNEL CHANGES
LOWER
MISSISSIPPI RIVER
1765 TO 1930
LAKE BRUIN
TO
POINT BREEZE
MILE 650 TO 770
NOTE:
THE 1930 RIVER CHANNEL IS SHOWN BY SOLID BLACK LINES. WHERE THE RIVER CHANNEL AS SHOWN BY PREVIOUS SURVEYS DIFFERS FROM THE 1930 CHANNEL, THE DIFFERENCES ARE SHOWN THUS:
MISSISSIPPI RIVER COMMISSION SURVEYS 1913-21: BROKEN BLACK LINES.
MISSISSIPPI RIVER COMMISSION SURVEYS 1881-93: SOLID RED LINES
DELTA SURVEY (HUMPHREYS & ABBOT) 1861: BROKEN RED LINES.
YOUNGS SURVEY AND GENERAL LAND OFFICE SURVEYS 1820-34: SOLID BLUE LINES.
ROSS MAP OF 1765: BROKEN BLUE LINES.
SCALE
0 1 2 3 4 5 MILES
LAKE BRUIN
ST. JOSEPH
WATERPROOF CUT-OFF
1884
LAKE ST. JOHN
FERRIDAY
NATCHEZ
VIDALIA
WILLETTS
OLD RIVER
HOMOCHITTO CUT-OFF
1776
POINT BREEZE
91°30'
32°00'
91°15'
31°45'
31°30'
91°15'
91°45'
31°15'
91°45'
91°30'

PLATE XX-d



PROGRESSIVE CHANNEL CHANGES LOWER MISSISSIPPI RIVER 1765 TO 1930 POINT BREEZE TO BELOW BATON ROUGE MILE 770 TO 880
NOTE:
THE 1930 RIVER CHANNEL IS SHOWN BY SOLID BLACK LINES. WHERE THE RIVER CHANNEL AS SHOWN BY PREVIOUS SURVEYS DIFFERS FROM THE 1930 CHANNEL, THE DIFFERENCES ARE SHOWN THUS:
MISSISSIPPI RIVER COMMISSION SURVEY 1913-21: BROKEN BLACK LINES.
MISSISSIPPI RIVER COMMISSION SURVEY 1881-93: SOLID RED LINES.
DELTA SURVEY (HUMPHREYS & ABBOT) 1861: BROKEN RED LINES.
YOUNGS SURVEY AND GENERAL LAND OFFICE SURVEYS 1820-34: SOLID BLUE LINES.
ROSS MAP OF 1765: BROKEN BLUE LINES.
SCALE
0 1 2 3 4 5 MILES
31°00′
91°45′
RED RIVER
ATCHAFALAYA RIVER
UPPER OLD RIVER
OLD RIVER
91°30′
POINT BREEZE
RED RIVER LDG
SHREVES CUT-OFF 1831
ANGOLA
RACCOURCI CUT-OFF 1848
91°45′
31°00′
OLD RIVER
TUNICA BEND
30°45′
MORGANZA
BAYOU SARA
91°15′
NEW ROADS
FAUSSE RIVER
FAUSSE RIVER CUT-OFF 1722
30°45′
30°30′
PROFIT ISLAND
91°30′
PORT ALLEN
BATON ROUGE
30°30′
BRUSLY
ADDIS
30°15′
91°00′
PLAQUEMINE
POINT PLEASANT
91°15′
WHITE CASTLE
91°00′
30°15′

Plate [redacted]XXI



NOTE: THIS PLATE REPRESENTS A FICTITIOUS RIVER REACH.

CUT-OFFS ARE NUMBERED 1, 2, 3 AND 4. THE UPSTREAM LIMITS OF THEIR RESPECTIVE ZONES OF INFLUENCE ARE DESIGNATED U-1, U-2, U-3 AND U-4.

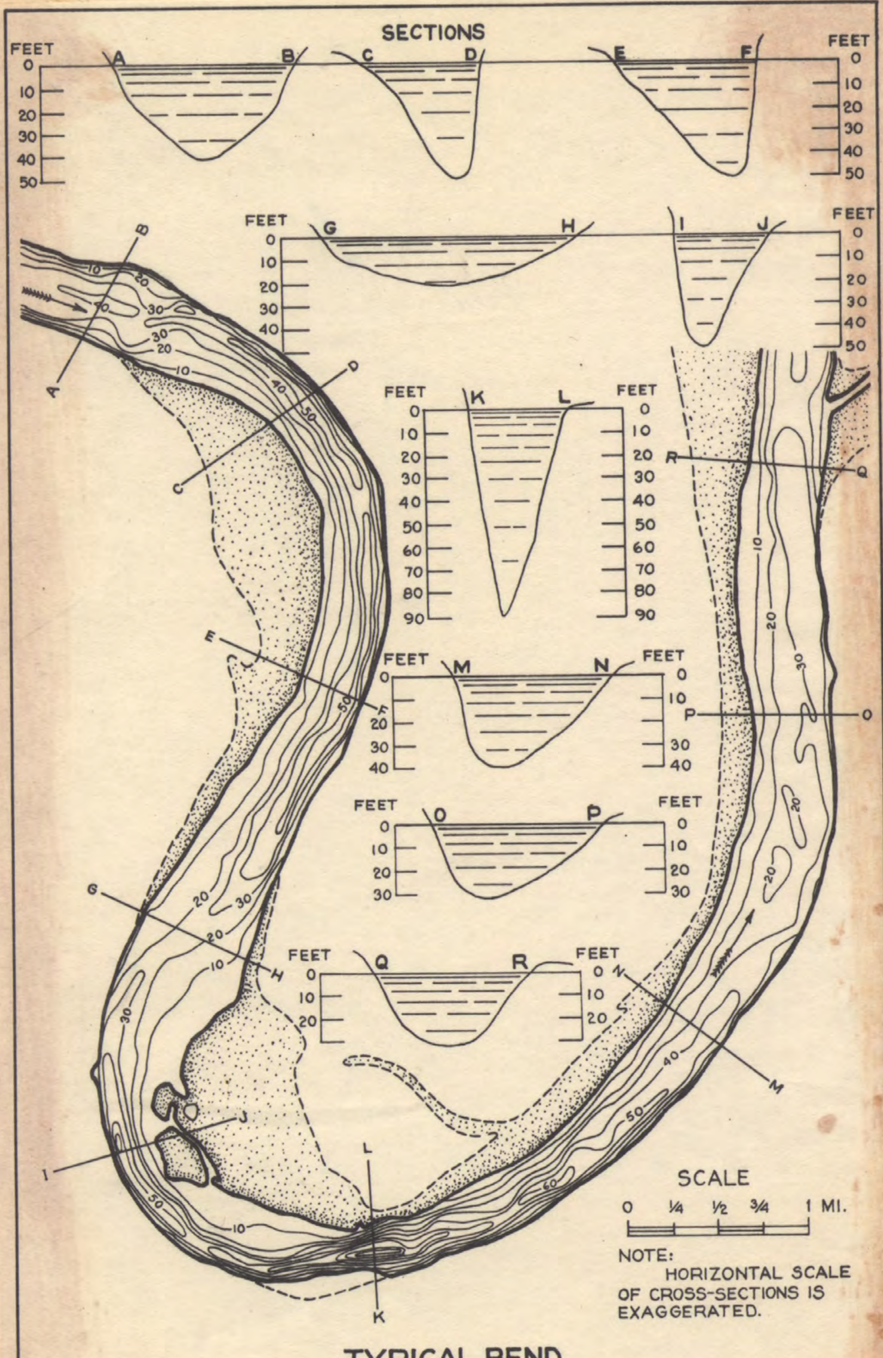
REACHES INFLUENCED BY CUT-OFFS ARE TINTED BLUE.

THE USE OF CUT-OFFS TO SHORTEN A RIVER CHANNEL

Plate XXII

Plate No.

PLATE XXIII



TYPICAL BEND
LOWER MISSISSIPPI RIVER
SHOWING
RELATIVE POSITIONS OF BARS & POOLS