69TH CONGRESS, 2d Session | COMMITTEE ON RIVERS AND HARBORS, HOUSE OF REPRESENTATIVES, U. S. | DOCUMENT No. 9

MISSISSIPPI RIVER BETWEEN THE OHIO RIVER AND ST. LOUIS

LETTER

FROM THE

CHIEF OF ENGINEERS, UNITED STATES ARMY

TRANSMITTING

REPORT OF THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS ON REVIEW OF REPORTS HERETOFORE MADE ON MISSISSIPPI RIVER BETWEEN THE MOUTH OF THE OHIO RIVER AND THE NORTHERN BOUNDARY OF THE CITY OF ST. LOUIS

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, December 17, 1926.

Hon. S. WALLACE DEMPSEY,
Chairman Committee on Rivers and Harbors,
House of Representatives.

DEAR SIR: 1. Referring to letter of the chairman of the Committee on Rivers and Harbors of the House of Representatives, dated March 28, 1924, inclosing a copy of a resolution of the committee requesting the Board of Engineers for Rivers and Harbors to review the project heretofore adopted by Congress for the improvement of the Mississippi River between the mouth of the Ohio and the northern boundary of the city of St. Louis, with a view to providing a permanent, navigable channel, with a minimum depth of not less than 9 feet and a minimum width of not less than 300 feet, with sufficient width of said channel around the bends in said river to afford convenient passage for tows of barges used on the Mississippi River, I inclose herewith the report of the board thereon, dated December 15, 1926.

2. This section of the Mississippi River is under improvement by the United States for the provision of a channel with a minimum width of 200 feet and a depth of 8 feet from the Ohio River to St. Louis, and thence 6 feet to the mouth of the Missouri River, to be obtained by regulating works and dredging. Between the time of the adoption of the project in 1910 and the end of the fiscal year 1925, $2,593,920 was expended for new work. Since that time allotments

of $3,500,000 have been made for new work. The estimated cost of the work in 1910 was $21,000,000, exclusive of amounts previously expended.

3. In 1925 there was a commerce on this section of the river of 1,400,000 tons, exclusive of car and general ferry traffic and of sand moved short distances. Inclusive of such traffic, the total commerce was nearly 9,000,000 tons. From an economic study, the district engineer estimates that with the completion of a dependable channel of 8 or 9 foot depth there would develop a commerce of 6,680,000 tons at a computed saving of $4,453,950.

4. This section of the Mississippi flows partly through an alluvial valley, in which the river channel meanders. The bed of the river is composed of various materials, from the extreme of ledge rock to the finest of silt. Large deposits of silt are brought in from the Missouri River, and its movement during floods has a controlling effect on the location and depth of channels at the crossings. The low-water flow at St. Louis is about 40,000 second-feet, not including water from Lake Michigan diverted through the Chicago Drainage Canal and the Illinois River. Improvements which have been made in the past, together with encroachments on the low-water channel, have resulted in a lowering of the low-water plane at St. Louis of about 6 feet since 1837. A material increase in velocity at Chain of Rocks has been one of the main effects.

5. The district engineer states that work which has been carried out has been successful in stabilizing many miles of the river. The method of improvement followed is the protection of banks, both natural and artificial, from erosion and contracting the streams by means of permeable dikes. Material brought down by the river accumulates at the dikes and builds up an artificial bank. He points out that careful engineering studies and actual works constructed have shown that the channel can be stabilized by contracting the river to an extent which approximates an average of the natural conditions. At many of the crossings where continuous dredging was necessary in the past the regulating works have provided an adequate channel where no dredging is now necessary. Although great benefits have resulted from the work already done, it is essential that additional regulating works and bank protection be carried to a point where a minimum of dredging is required and a stable channel is available at all times.

6. In the several sections of the river needing regulation the district engineer proposes to provide by means of permeable dikes the widths at the low-water, mean, and bank-full stages given in the following table:

	Length	Low water		Mean stage		Bank full	
		Width	Mean depth	Width	Mean depth	Width	Mean depth
	Miles	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
River des Peres to Grays Point	125.7	2,250	8	3,250	14.8	4,600	23.3
Commerce to Commercial Point	7.2	2,500	8	4,500	13.0	6,000	20.3
Commercial Point to Ohio River	32.2	2,000	8	3,500	14.0	4,800	24.9

These works will, he believes, provide a channel 9 feet deep and not less than 300 feet wide. The total estimated cost, including amounts made available since 1910, is $31,000,000. There has already been made available $6,100,000, leaving for future appropriation or allotment $24,900,000. The annual maintenance cost is estimated at $900,000, which is $300,000 greater than the present annual expenditure for that purpose. He recommends that the regulating works and revetment be completed and that dredging, which affords only temporary relief, be resorted to only when and to the extent that the needs of navigation then existing require. The division engineer concurs.

7. The board points out that this section of the Mississippi already carries a commerce of some magnitude. The development of transportation on the upper Mississippi River will probably add to this tonnage, and completion of the Missouri River improvement to Kansas City will add an appreciable traffic having its origin or destination on the lower river. A 9-foot channel has recently been recommended in the Illinois River, with a view to providing a through waterway of that depth from the Lakes to the Gulf. The board therefore concludes that the provision of a 9-foot depth in this section of the Mississippi is essential. In view of the results already obtained from the works thus far carried out and from a study of the plans proposed by the district engineer, the board believes that a continuation of the present method of improvement will provide the channel dimensions desired. It therefore recommends modification of the existing project for the Mississippi River between the mouth of the Ohio and the Missouri, so as to provide for a channel 9 feet deep and generally 300 feet wide, widened at the bends, up to the northern boundary of the city of St. Louis, by contraction works and bank revetment, together with such dredging as may be necessary, at an estimated cost of $31,000,000, including amounts expended and allotted since 1910, with $900,000 annually for maintenance. Funds should be made available as needed.

8. After consideration of the above-mentioned reports, I concur in general with the board.

9. The shoals in the section of the river between the mouth of the Ohio and St. Louis have been attacked successfully in the upper 100 miles of the section and a depth of 8 feet or more has been maintained almost continuously since January 1 of this year. Additional works are needed from time to time in the process of molding the stream so as to hold the channel in a permanent position. The shoals in the remaining 80 miles of the section are being similarly attacked. Part of the success in maintaining existing channels during the present year has been due to high water and other favorable conditions, but much of it can be credited to the works already constructed.

10. There is at present a 9-foot project for the Ohio and for the Mississippi River to the mouth of the Ohio, and the large and constantly increasing commerce on the river requires that a channel of this depth be extended to St. Louis. Congress is at the present time giving consideration in the pending river and harbor bill to the recommendation for a 9-foot channel in the Illinois River, and studies are being made by the War Department with a view to recommending a 9-foot channel from St. Louis to the mouth of the Illinois. It is very desirable that there be provided ultimately a continuous channel

of this depth from Chicago and St. Louis to New Orleans and Texas points.

11. The present project for the Middle Mississippi, which is the name usually applied to the section of the river covered in this report, provides for a channel 8 feet in depth and 200 feet wide to be provided at a cost estimated in 1910 at $21,000,000. Since that estimate was submitted, a total of $6,100,000 has been spent or allotted for new work. I believe that the balance, viz, $14,900,000, will be sufficient for all the new work necessary to protect caving banks and to remove shoals in the channel. There is a strong probability that a channel 9 feet deep and 300 feet wide can be secured by the works constructed and contemplated augmented by dredging. Some dredging, decreasing in amount as the construction of permanent works of improvement progress, will probably always be necessary, but dredging produced only temporary results, and should be reduced to a minimum.

12. It would appear unwise and unnecessary to authorize funds in excess of the amount now provided for by the existing project when the need therefor can not be definitely foreseen for some years to come, if at all. Costs have increased materially since 1910 and the estimate of $21,000,000 made at that time would ordinarily have to be increased materially to meet present day conditions. The economies that now seem possible are more pronounced when this fact is taken into consideration.

13. I recommend that the existing project, which provides for a channel 8 feet deep and 200 feet wide be changed so as to provide for a channel 9 feet deep and 300 feet wide, with additional width in bends, with no change in the cost authorized for the existing project. The annual cost of maintenance should be increased from $600,000 to $900,000.

Very truly yours,

EDGAR JADWIN,
Major General, Chief of Engineers.

WAR DEPARTMENT,
THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS,
Washington, D. C., December 15, 1926.

Subject: Mississippi River from the mouth of the Ohio to the northern boundary of the city of St. Louis.
To: The Chief of Engineers, United States Army.

1. This report is submitted in response to the following resolution, dated March 24, 1924:

Resolved, That the Board of Engineers for Rivers and Harbors, created under section 3 of the river and harbor act, approved June 13, 1902, be, and is hereby, requested to review the project heretofore adopted by Congress for the improvement of the Mississippi River between the mouth of the Ohio and the northern boundary of the city of St. Louis, with a view to providing a permanent, navigable channel, with a minimum depth of not less than 9 feet and a minimum width of not less than 300 feet, with sufficient width of said channel around the bends in said river to afford convenient passage for tows of barges for use upon the Mississippi River.

2. The existing project for the improvement of this section of the Mississippi River provides for a channel with a minimum width of

200 feet and a depth of 8 feet from the Ohio River to St. Louis, and 6 feet from St. Louis to the mouth of the Missouri River, to be obtained by regulating works and dredging as follows:

First. By regulating works, for closing sloughs and secondary channels, narrowing the river to a uniform width of about 2,500 feet at bank-full stage, building new banks where the natural width is excessive, and by protecting new and old banks from erosion where necessary to secure permanency.

Second. By dredging or other temporary expedients, pending the completion of the permanent improvement, so as to maintain each season the required low-water depth of channel. This project was originally adopted in 1881, was later superseded, and finally readopted in 1910. Between the latter date and the end of the fiscal year 1925, $2,592,920 was expended for new work. Allotments totaling $3,500,000 have been made since that time for new work. The estimated cost of the work, made in 1910, was $21,000,000, exclusive of amounts previously expended.

3. The commerce on this section of the river in 1925, exclusive of car and general ferry traffic and of sand moved short distances, was 1,004,000 tons. Inclusive of ferry and other local traffic the total was nearly 9,000,000 tons. An economic study was made by the district engineer, with a view to estimating the potential tonnage which might develop on the improved channel and the probable savings in transportation costs which would result. An analysis was made of all the freight moved in the Mississippi Valley in 1924 in directions favorable for transportation on the river. A computation of savings resulting from the diversion from rail to water of certain of this traffic was based in general on a comparison of the existing freight tariffs by rail and by river. Where river tariffs did not exist, they were constructed on the basis of 80 per cent of the port-to-port rail rate. The district engineer concludes from this study that a total of 6,680,000 tons of commerce may develop on the river at a computed saving of $4,453,950. No distinction has been made by the district engineer between the possibilities of an 8-foot and a 9-foot channel, it being believed that the principal feature affecting the development of a large tonnage is a dependable channel of navigable depth. Equipment already operating on the river is suitable for use on either an 8-foot or 9-foot project.

4. The middle Mississippi, as the section between the mouth of the Ohio and the mouth of the Missouri Rivers is generally known, has characteristics which largely resemble those of the Missouri. For 134 miles below St. Louis, the river flows through an alluvial valley generally 4 to 5 miles wide between the bluffs. In the 7-mile section between Grays Point and Commerce the river passes through a rock-bound gorge, from which it emerges into the wide deltalike valley of the lower Mississippi. The river stages are affected by the combined flow of the upper Mississippi and the Missouri, and by the retarding effect of the Ohio River, which varies with the stage. The bed of the river is composed of various materials from the extreme of ledge rock to the finest of silt. Vast deposits of silt are brought in from the Missouri River and its free movement during floods has a controlling effect on the location and depth of channels across the bars. The low-water flow at St. Louis is about 40,000 second-feet, not including the water diverted from Lake Michigan through the Chicago Drainage Canal and the Illinois River. Practically no sediment is carried

by the Upper Mississippi and Illinois Rivers. The average surface slope between the mouth of the Missouri and the mouth of the Ohio is 0.58 foot per mile. Improvements which have been made in the past and encroachments on the low-water channel have resulted in a lowering of the low-water plane at St. Louis since 1837 of about 6 feet. One of the effects of this change in water surface has been to increase the velocity at Chain of Rocks.

5. The improvement of this part of the Mississippi involves very careful engineering. The work so far carried on has been that of contracting the stream by means of permeable dikes or wing dams, and protecting the banks, both natural and artificial, from erosion. The accumulation at the dikes of material brought down by the river builds up an artificial bank, which in certain locations must be protected by revetments. The successful carrying out of an improvement of this nature necessitates, in general, connected works based upon some bank which has been already stabilized. Isolated structures can not be expected to stand up for any length of time, as they are subject to attack during periods of high water or on account of a change in local direction of flow.

6. The district engineer states that work which has recently been carried on has been successful in partially stabilizing the banks. It has been found wise to contract the low-water channel to a less extent than was considered necessary when the project of 1881 was adopted. Since that time careful engineering studies have been made and the actual works constructed have shown that the best results are obtainable by contracting the river only to an extent which approximates an average of the natural conditions. Sections which have too great a width must be narrowed. Changes in the alignment of the channel have been effective in reducing bank erosion and in turning the energy of the current to useful purposes. At many places where almost continuous dredging has been necessary in the past, an adequate channel is now available without dredging. For economical maintenance it is essential that regulating works and bank protection be carried out to a point where a minimum of dredging is required. Local conditions are such that dredging as generally performed in this section of the Mississippi provides temporary relief only. Suction dredges are used and the material excavated is deposited nearby in the river, no material being permanently taken from the waterway. With the river improved to an extent such that natural forces will maintain a channel, only a limited amount of dredging will be required.

7. The district engineer proposes to provide in the several sections of the river needing regulation, the widths at low water, mean, and bank-full stages indicated in the following table, by means of permeable dikes, sloping uniformly from low-water elevation to mean stage and from mean stage to bank-full elevation:

Subdivision of river	Length	Low water		Mean stage		Bank full	
		Width	Mean depth	Width	Mean depth	Width	Mean depth
	Miles	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
River des Peres to Grays Point	125.7	2,250	8	3,250	14.8	4,600	23.3
Commerce to Commercial Point	7.2	2,500	8	4,500	13.0	6,000	20.3
Commercial Point to Ohio River	32.2	2,000	8	3,500	14.0	4,800	24.9

His calculations, and the results of work already done, indicate to him that this plan will provide a channel 9 feet deep and not less than 300 feet wide. He divides the work into classes on the basis of necessary priorities, as follows:

(*a*) Structures required now to protect caving banks and to remove shoals in the channel, estimated to cost $12,600,000, less expenditures already made and funds available, leaving $6,500,000 yet to be provided.

(*b*) Structures required in the near future to complete regulation of the river, estimated at $9,700,000.

(*c*) Structures required, but not immediately, to complete the work, at an estimated cost of $8,700,000.

The total estimated cost, including funds made available since 1910, is $31,000,000, an increase of $10,000,000 over the estimate at that time for work still to be done. Of this sum there has already been made available $6,100,000, leaving for future appropriation or allotment $24,900,000. Annual maintenance of the work is estimated at $900,000; $600,000 for maintaining regulating works and $300,000 for dredging. This is $300,000 greater than the present annual expenditure for maintenance.

8. The rapid development of the lower Mississippi Valley and the Southwest assures, in the opinion of the district engineer, a growing demand for transportation in this region. For this purpose and to provide adequately for the traffic already existing a stable channel of reasonable dimensions at all river stages is demanded. He points out that failure to carry on the improvement of the middle Mississippi would eventually result in a controlling depth of 4 or 5 feet and in the destruction of valuable land, due to vagaries of the channel. He recommends:

(*a*) That the regulating works and revetment now being carried on be completed.

(*b*) That until the regulating works have been completed a channel 8 feet deep and generally 200 feet wide be maintained by dredging.

(*c*) That dredging be continued as needed to maintain a channel 9 feet deep and generally 300 feet wide, provided that a channel depth greater than 8 feet and a width greater than 200 feet should be provided only when the needs of navigation then existing are not adequately met by a channel of those dimensions.

(*d*) That all regulating works below St. Louis be completed before new works above St. Louis are undertaken.

The division engineer concurs.

9. This section of the Mississippi River already carries a commerce of some magnitude. Completion of the Missouri River improvement to Kansas City will add an appreciable tonnage, having its origin or destination on the lower river. Developments in transportation on the upper Mississippi River will probably still further add to the tonnage of the middle Mississippi. A 9-foot channel has recently been recommended in the Illinois River, with a view to providing a through waterway of that depth from the Great Lakes to the Gulf. All of these considerations point to the necessity for continued improvement of the section of the Mississippi under consideration and to provision of a channel of 9-foot depth. The results already obtained from the contraction works and bank revetments thus far placed, and a study of the plans proposed by the district engineer show that a continua-

tion of the present method of improvement is well adapted to provide the channel dimensions desired.

10. The board therefore recommends modification of the existing project for the Mississippi River between the mouth of the Ohio and the Missouri, so as to provide for a channel 9 feet deep and generally 300 feet wide, widened at the bends, up to the northern boundary of the city of St. Louis, by contraction works and bank revetment, together with such dredging as may be necessary, at an estimated cost of $31,000,000, with $900,000 annually for maintenance. On this basis, $24,900,000 remains to be provided. It is not improbable, however, that the project may be completed with less than this expenditure if adequate funds are made available as needed. The amount estimated by the district engineer for structures required in the future, $8,700,000 (*c*, par. 7), may not be required, at least for many years. The nature of the problem is such, due to uncertainties of flow and the natural instability of the river, that it is believed advisable to use as the estimated cost, $31,000,000. Particular emphasis is given to the necessity of providing funds in such amounts and at such times as needed.

For the board:

HERBERT DEAKYNE,
Brigadier General, Assistant Chief of Engineers,
Senior Member.

MISSISSIPPI RIVER BETWEEN MOUTH OF OHIO RIVER AND NORTHERN BOUNDARY OF ST. LOUIS, MO.

SYLLABUS

The district engineer recommends: Completing regulating works of present project; continuing dredging to maintain 8-foot channel of present project; after completion of regulating works, dredging to create channel 9 feet by 300 feet with additional width in bends for barge-tows accommodated by straight reaches; such 9-foot dredging only when required by navigation then existing, otherwise, dredging to maintain aforesaid 8-foot channel.

WAR DEPARTMENT,
UNITED STATES ENGINEER OFFICE,
St. Louis, Mo., May 14, 1926.

Subject: Review of the project for the improvement of the Mississippi River between the mouth of the Ohio and the northern boundary of the city of St. Louis.

To: The Chief of Engineers, United States Army, Washington, D. C. (Through the division engineer, western division.)

1. The following review of the existing project for the improvement of the Mississippi River between the mouth of the Ohio and the northern boundary of the city of St. Louis is submitted in accordance with a resolution adopted by the Committee on Rivers and Harbors of the House of Representatives, March 24, 1924 (par. 13 hereof), and with instructions from the Chief of Engineers, United States Army, April 1, 1924, as modified by letter of July 11, 1924, 7245 (Miss. R., Ohio R., St. Louis), and by first indorsement on letter of the Board of Engineers for Rivers and Harbors to the Chief of Engineers, July 15, 1925, 7245 (Miss. R., Ohio R., St. Louis)–9.

HISTORY OF PROJECT

2. The plans and projects originally adopted for the general improvement of this portion of the Mississippi River (between the mouths of Ohio and Missouri Rivers) have been somewhat modified but not radically departed from. The first Federal work toward improving the Mississippi, the destruction of snags and trees endangering navigation between New Orleans and the mouth of Missouri River, was authorized by act of Congress, May 24, 1824, the initial appropriation being $75,000. The snagging then inaugurated was interrupted during the Mexican and Civil Wars but was resumed in 1866 and has been continuous ever since. The first work in the nature of permanent improvement, "a pier to give direction to the current of the Mississippi River, near the city of St. Louis," was authorized in acts of Congress, July 4, 1836, and March 3, 1837, which appropriated a total of $50,000 therefor; and in 1844 the sum of $25,000 was appropriated for the benefit of navigation in St. Louis Harbor. The amounts expended under these old appropriations are not available for citation here.

3. The first project report pertaining to the general improvement of the river in this district was submitted to the Chief of Engineers, United States Army, by a board of Engineers April 13, 1872, for proposed works between the mouth of Meramec River and Alton, Ill. The board stated as its belief that the ultimate demands of commerce would require the low-water width of St. Louis Harbor to be not over 1,200 or 1,500 feet. The works, begun in 1872 and continued for a number of years, consisted of solid dikes and dams of brush and stone, to confine the low-water flow of the river to a single channel, and revetments of brush mattress and stone paving to hold and preserve the banks from erosion. Eight-foot navigation between the mouth of Ohio River and St. Louis and 6-foot navigation thence to the mouth of Illinois River were first recommended in a report by the district engineer on transportation routes to the seaboard January 20, 1875, these channels to be obtained in four years and total cost estimated at $7,159,200.

4. The present project, using revetments as in 1872 and permeable instead of solid dikes, was adopted in 1881; the plan being "to make the improvement continuous, working downstream from St. Louis, by reclaiming land and building up new banks, thus reducing the river to the approximately uniform width of about 2,500 feet. It is proposed by this means to secure a minimum depth of 8 feet. The depth is now liable to become as little as 4 feet in some places and less than 8 feet in every place where the width is greater than 2,500 feet. Alluvial banks are to be protected from erosion. This general statement of the proposed application of the appropriation is as specific as the nature of the case will admit of. The changeable character of the river renders it impracticable to give in advance the exact localities where works will be required." (Annual Report, Chief of Engineers, 1882, p. 1605.) The estimated cost of the improvement, as revised in 1883, was $16,397,500.

5. By the earlier appropriation acts, the 22-mile stretch of river between the mouths of the Missouri and Illinois rivers was included in the St. Louis district, 1872 to 1890, and in the Rock Island district after 1891. Acts between 1875 and 1905 directed certain expendi-

tures for works at several definitely specified and far-separated localities.

6. The project was modified by the sundry civil act of March 2, 1895, and the river and harbor act of June 3, 1896, which provided for continuing the improvement and for the construction, maintenance, and operation of movable jetties, dredge boats, and other suitable appliances for improving the low water channel, "with the view of ultimately obtaining and maintaining a navigable channel from St. Louis to Cairo not less than 250 feet in width and 9 feet in depth at all periods of the year except when navigation of the river is closed by ice." The river and harbor act of June 13, 1902, authorized the temporary transfer and operation in this district of one or more of the dredges used by the Mississippi River Commission below Cairo, Ill.; such dredging to be carried on as needed during a term of four years, with annual expenditures limited to $50,000. No advantage was taken of this opportunity.

7. In compliance with a resolution adopted by the Committee on Rivers and Harbors of the House of Representatives, the Board of Engineers for Rivers and Harbors submitted a report, November 12, 1903, as to whether, by dredging or otherwise, a suitable channel could not be established and maintained in this portion of the Mississippi River at less expense than in accordance with the existing project. Their report stated that a suitable channel was one of 8 feet depth and 200 feet width, with greater width where alignment was unfavorable, St. Louis to Cairo, and of 6 feet depth, mouth of Missouri River to St. Louis. That it was proacticable to secure such channel by means of contraction work and shore protection and that the cost of such works would be at least $20,000,000 in addition to expenditures already made, with annual maintenance thereafter at $400,000. The board (majority report) recommended dredging, instead of permanent works, as the principal means of improvement for a term of 3 years and an annual expenditure of $300,000 for permanent work until the results of the dredging were known; and that, after a trial of the more extended dredging, the project for establishing the channel should be revised in the light of experience thus gained. Congress, in the river and harbor act of March 3, 1905, adopted the recommendation of the board as to dredging and thereafter but little new construction was accomplished until 1910.

8. The river and harbor act of June 25, 1910, contained the following item:

> Improving Mississippi River from the mouth of the Ohio River to and including the mouth of the Missouri River: Continuing improvement in accordance with the plan adopted in eighteen hundred and eighty-one, which has for its object to eventually obtain by regularization works and by dredging a minimum depth of eight feet from the mouth of the Ohio River to Saint Louis, and of six feet from Saint Louis to the mouth of the Missouri River, and with a view to the completion of said improvement within a period of twelve years, five hundred thousand dollars.

It is to be noted in connection with the foregoing item that the earliest provision for dredging in this district is contained in the river and harbor act of June 3, 1896. The report of the board on examination and survey of waterway from Chicago to the Gulf, March 20, 1909, put the cost of completion of the project of 1881 at $21,000,000, no estimate of annual maintenance charges being included.

PRESENT PROJECT

9. The existing project for this part of the Mississippi is to contract the river to a width of about 2,500 feet, reclaiming land and building up the necessary artificial banks to create a channel 8 feet deep and 200 feet wide with increased width where alignment is unfavorable, St. Louis to mouth of Ohio River, and a channel 6 feet deep, St. Louis to mouth of Missouri River; these channel dimensions to be obtained by dredging where necessary to supplement or in the absence of the requisite works of contraction.

PROGRESS OF WORK

10. The interruptions to the work of contraction, due to reliance upon dredging, meager appropriations, or other reasons, have resulted in but one-third of the necessary works being completed. The scant appropriations during the war years did not even meet the needs of seasonal repair. Since 1910, when the project of 1881 was reverted to, and up to and including the fiscal year 1925 only $2,592,920 were expended for new work.

CONDITION OF WORK

11. The works of contraction and bank revetment now completed are rendering real service. The heaviest injuries to completed works have been due to unprotected structures left isolated by the interruption of work on supporting and contiguous structures. Ordinary seasonal deterioration is not heavy. In the vicinity of St. Louis the effect of continuous works is most evident. The obvious benefits in thus creating an excellent channel for navigation in this instance indicate the value of completed works. The works elsewhere are of much shorter length, and although their value is not so obvious as that of the structures noted, they have given positive benefits.

12. Dredging has been resorted to in cutting through river bars during the navigation season. The characteristic configuration of the bed of a river such as the middle Mississippi at low water makes the uninterrupted maintenance of a depth greater than the natural depth quite difficult, especially in stretches only partially or not at all improved. With slowly decreasing discharge of river, bars often will cut out naturally with drop in river stage and so maintain the present project depth. It is impracticable to maintain a dredging fleet sufficient in number of dredges to safeguard the required depth at each bar. The necessity frequently arises, in a rapidly falling river, of dredging a bar only after it has become obstructive to the 8-foot depth. The intermittency of full project dimensions when using dredges to increase the natural depth of a river is important in estimating the value of such a method of maintaining specified depths.

PRESENT REVIEW

13. This review is required by resolution of the Committee on Rivers and Harbors of the House of Representatives, March 24, 1924, reading as follows:

> * * * that the Board of Engineers for Rivers and Harbors, created under section 3 of the river and harbor act approved June 13, 1902, be, and is hereby, requested to review the project heretofore adopted by Congress for the improvement of the Mississippi River between the mouth of the Ohio and the northern boundary of the city of St. Louis with a view to providing a permanent, navigable channel, with a minimum depth of not less than 9 feet and a minimum width of not less than 300 feet, with sufficient width of said channel around the bends in said river to afford convenient passage for tows of barges for use upon the Mississippi River.

14. The channel dimensions to be considered in this review do not sensibly differ from those of the ultimate 9-foot channel authorized by Congress in 1896, nor from the "8-foot navigation" originally recommended in 1875, but they are larger than are authorized by the present project. The resolution specifies a channel increased in width by 50 per cent—from 200 to 300 feet; the depth across this wider channel is increased 1 foot—from 8 to 9 feet. It is also definitely specified that the new channel dimensions are to be carried to the northern boundary of St. Louis. No change in the present project north of St. Louis is contemplated by the resolution.

THE MISSISSIPPI RIVER

15. The Mississippi Basin receives drainage from 30 States and Canada (see project map, sheet 1), has an area of one and one-fourth million square miles, comprehending more than three-fifths of the arable resources of the United States, and has been characterized as the greatest single estate laid out for the habitation of man.

16. Rising in a number of small lakes in the vicinity of Lake Itasca, Minn., elevation 1,467, the Mississippi flows southwardly 2,466 miles into the Gulf of Mexico. The principal tributaries are the Illinois, a former outlet of the Great Lakes and remarkable for its gentle slope; the Missouri, with its immense basin, steep slope, and great volume of sediment carried, in reality the main stream, navigable to Fort Benton, 2,285 miles, and from its source to the Gulf, about 4,200 miles, the longest river in the world; the Ohio, 969 miles in length, in the zone of heavy rainfall and contributing to the Mississippi discharge about three times as much as the Missouri, although their basin areas are as 2 to 5; the Arkansas, 1,460 miles, with headwaters above elevation 7,000; and the Red, 1,275 miles, heavily charged with sediment, carrying much drift and discharge into the Atchafalaya and Mississippi. More than half of the Missouri Basin, all that part west of the one-hundredth meridian and above elevation 2,000, is arid or semiarid territory; the eastern portion of that basin and the upper Mississippi Basin receive moderate rainfall. Data pertaining to the Mississippi are condensed in the following table:

Station	Miles from Gulf of Mexico	Tributary entering above station	Drainage area down to station	Elevation		Average fall per mile, low water	Widths		Depth		Volumes (M cubic) feet per second [1]	
				High water	Low water		Bank full	Low water	Natural	Project	High water	Low water
			Square miles	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*		
St. Paul, Minn	1,937	Minnesota	35,800	703.9	681.6		800	260			117	1
Muscatine, Iowa	1,547	Wisconsin	99,400	550.3	529.0	0.391	2,400	1,800	2½	6	289	22
Grafton, Ill	1,297	Illinois	170,900	435.8	402.8	.505	3,000	2,700	3	6	398	25
St. Louis, Mo	1,258	Missouri	698,000	421.1	376.7	.689	2,000	1,500	3	6	1,146	24
Mouth of Ohio	1,079	Ohio	916,600	325.1	299.4	.396	3,700	2,350	3½	8	[2] 2,015	[3] 71
Helena, Ark	774	St. Francis	938,300	197.0	138.8	.420	3,900	2,150	4½	9	[3] 2,041	88
Vicksburg, Miss	479	Arkansas, Yazoo	1,138,300	101.0	[4] 39.7	.336	3,300	2,700	4½	9	1,626	97
New Orleans, La	108	Red	1,238,200	21.1	−1.7	.112	2,140	2,050	4½	9	1,388	135

[1] Observed maxima and minima.
[2] Discharge measured at Columbus, Ky., 20 miles below mouth of Ohio River.
[3] Maximum measured discharge of Mississippi (Mississippi, Atchafalaya, and crevasses) 2,300,000 cubic feet per second.
[4] Maximum range in stage of entire Mississippi River system, 69.1 feet, Ohio River, Cincinnati, Ohio.

Supplementing the widths given at the above stations, maximum bank-full widths are: St. Paul to mouth of Missouri River, 5,000 feet; thence to Cairo, 7,000 feet; thence to the Gulf, 10,500 feet. Typical low-water elevations and slopes in this great basin are shown in graph inset, sheet 15 of project map.

17. The middle Mississippi has characteristics which are a composite of those of the upper Mississippi and Missouri. From St. Louis to Grays Point, 134 miles, it flows in an alluvial valley generally 4 to 5 miles wide between bluffs; its character changes in passing through the 7-mile rockbound gorge from Grays Point to Commerce, and again when it emerges into the wide deltalike valley of the lower Mississippi. The upper Mississippi and the Missouri by their combined flow at the upper end and the Ohio by its variable retarding effect on discharge at the lower end control the stages of the middle Mississippi, as tributary drainage into this section of the river has but little effect.

18. The Mississippi River, in the condition that we know it, is closely associated in geologic history with the glacial age in North America. The continental ice cap in its extreme advance reached as far south as the Ohio. On its recession, the upper Mississippi and Illinois Rivers cleared of ice before the glacier occupying the valley of the Missouri had disappeared. For a time before the gorge of Niagara opened to pass the waters of the Great Lakes, drainage of the Great Lakes reached the Mississippi through the Illinois River. In a similar way the drainage from southern Canada poured into the upper Mississippi valley until the ice had receded to Hudson Bay and drainage to the north was possible.

19. As a result of these geologic actions and this period of glacial drainage, the bed of the upper Mississippi has been worn down by the erosive action of a much greater volume of water than that of present day ordinary tributary drainage. We find the average slope of the middle Mississippi steeper than that of the upper Mississippi and flatter than that of the Missouri. The Missouri River and valley is far behind the upper Mississippi in its geologic state of erosion, and the present steep slopes and heavily silt-laden waters of the Missouri are the consequence.

20. Speculation as to the stages of the river in preglacial, glacial, and postglacial periods is of some interest. The rock trough upon which the aluvial bed of this river rests may have been eroded in the preglacial period, but was certainly occupied by the ice of the later periods, and was enlarged, if not created, by these later movements of the ice. That the denser débris and much of the silt now contained in this rock trough was deposited there by overloaded glacial waters is evidenced by terminal moraines wherever glaciers were stationary for substantial periods of time. The highly swollen upper Mississippi during the period of inverted glacial drainage undoubtedly eroded the middle Mississippi to flatter slopes than those of the present river only to have the silt-laden Missouri throw another blanket of alluvium over the valley when the drainage of the Great Lakes and Canada had taken its present outlet.

21. This physical and geologic outline is here presented because of its bearing upon the improvements projected. The Missouri River bed and valley is subject to erosion and pours annually a vast quantity

of water-borne silt into this portion of the Mississippi. Assuming that the middle Mississippi is so formed physically that this silt is now passed to the Mississippi at Cairo without change in quantity, the design of works of improvement must consider deeply the retention of this characteristic capacity of the stream.

22. The energy which keeps this water in motion and creates the velocities that can retain and move on this burden of silt is derived from slope. Works of contraction must be such as not to change violently the natural cross-sectional areas and velocities. If contraction works of improvement create a section that is too narrow, excessive velocities occur and the stream bed is eroded. A drop in water surface and in slope is therefore to be expected with too great contraction. Such drops in low-water surface have already been noted locally upon the Missouri and in this portion of the Mississippi. The following detailed study of the Mississippi River, in the vicinity of St. Louis, was made by Assistant Engineer William M. Penniman.

ST. LOUIS HARBOR

23. Improvement has probably changed this section of the Mississippi River more than any other part of equal extent; the formerly broad, shallow stream having here been changed to one comparatively narrow and deep. In 1837, when Robert E. Lee commenced the improvement in this part of the river, its flood width was 6 miles and average width between banks fully 4,000 feet. The present bank-full width at Pittsburg Dike (mile 1.1) and Davis Street (mile 7.5) is only 1,500 feet, and the flood width at bridges is about 2,000 feet. Bank-full and low-water widths are generally 2,000 feet and 1,500 feet, respectively, as fixed by established harbor lines. The minimum navigable depth was originally 3½ to 4 feet; now, for a distance of 13 miles below the Merchants Bridge it is 10 feet, and this distance includes a stretch of 5 miles (3½ to 8½ miles below Eads Bridge) where it is 14 feet.

24. Although local navigation has in general benefited by this change, serious objections to such great contraction of the river, a contraction greatly increased in effect by the piers and abutments of four bridges, have long been known. The objectionable results from this unduly severe contraction of the river are:

(*a*) Local lowering of the low-water plane.

(*b*) Increased slope at low stages below Chain of Rocks (7 miles above the severe contraction), and increasing tendencies in the stretch of increased slope toward the formation of rapids obstructive to navigation.

(*c*) Reduced navigable depth over the Chain of Rocks.

(*d*) Local raising of the flood plane.

(*e*) Great increase in velocity and in erosion of river bed at high and flood stages.

(*f*) Production of depths greater than are necessary.

25. At St. Louis the stage of extreme low water has always occurred during abnormally cold winters when the stream was "gorged" or blocked with ice and had very little flow. Such lowest low water,

as observed since 1837 and referred to the present Market Street gauge, has fallen successively as follows:

1840—3.24 feet.
1843—2.8 feet (approximate) December 12–22.
1860—0.53 feet, December 27.
1863—minus 0.07 feet, December 21.
1895—minus 0.60 feet, January 27.
1900—minus 2.52 feet, January 2.
1917—minus 3.10 feet, December 30.

Although river stages caused by such abnormal conditions may not be fully comparable, they do, however, represent minimum volumes of flow that can not greatly differ and indicate, in this case, a progressive lowering of low-water plane and river bed, 1840 to 1917, of about 6 feet.

26. Considering the stages of annual lowest water for navigation from 1872 to 1925, at St. Louis, Chain of Rocks, and Grays Point (the first locality being of changeable, the second of more slowly changeable, and the last, 134 miles below St. Louis, of unchangeable cross-section), a comparison shows a steady lowering of the low-water plane at St. Louis, amounting to about 6 feet in those 54 years.

27. The discharge curves for the Mississippi River at St. Louis have been revised and reconstructed. (See Pl. V). The first complete curve is for the period 1866–1881, and the second for the period 1899–1917. An intermediate curve for low stages, 1895–1899, and a fourth curve for low stages, 1919–1926, are also shown. All authoritative gaugings of the river in the district (total number, 649) have been used in the construction of these curves; the observations distant from St. Louis having been coordinated to the Market Street gauge. The earliest gaugings were made in 1866, after several dikes had been built (Pittsburgh Dike, 1865) and Bloody Island (East St. Louis) had been joined to Illinois. Undoubtedly the plane of low water had begun to drop prior to the early sixties, as indicated by the record of extreme low water. While the data for the first curve were being obtained, more dikes were installed and the Eads Bridge was built 1870–1874. The Merchants Bridge was built 1889–90, and an extensive system of dikes on the Illinois side between the two bridges in 1891. A stage lower than extreme low water of 1863 was observed for the first time in 1895. Contraction of the central 5-mile stretch of the harbor was made still more continuous or sluicelike by two more bridges—McKinley and Municipal—built 1907 to 1911.

28. By the first curve, "standard low water" of 1881, or 4 feet on the St. Louis gauge, is shown to have had a volume of about 40,000 cubic feet per second. During the periods of the intermediate and second curves, that volume passed St. Louis at the 1½-foot and zero stages, respectively; the low-water plane had thus fallen 4 feet, 1881 to 1917. The fourth low-stage curve determined by the gaugings of recent years (1919–1926) serves as proof of a further drop in the low-water plane of about 2 feet. Lee's low water, 1837–1839, was equivalent to a stage of about 6¾ feet on the present Market Street gauge and a volume now estimated at 45,000 cubic feet per second. Thus the total lowering of low-water plane at the foot of Market Street, St. Louis, 1837 to 1926, or since the improvement was commenced, is about 8 feet.

29. "Standard low water" of 1881, "low-water plane" for district operations, and "low water for navigation" are practically synonymous terms; and "low water" is hereby defined as the surface plane of the low-water volume of 40,000 cubic feet per second at St. Louis, approximating gauge heights and elevations (sea level) as follows:

Station	River distance	Gauge height	Elevation	Fall per mile	Remarks
	Miles	*Feet*	*Feet*	*Feet*	
Chain of Rocks	10.4	75.0	388.9	.....	Cross section, partly stable.
Eads Bridge	.0	.....	.....	.....	
Market Street, St. Louis	.4	−2.0	377.8	1.03	Changeable cross section.
Grays Point	133.7	4.0	304.8	.55	Stable cross section.
Commerce	140.5	2.0	303.5	.19	Do.
Mouth of Ohio River	180.0	.....	274.0	.75	Elevation corresponds to 4 feet, Cairo gauge, Ohio River, 2¼ miles above mouth.

30. It is to be noted that the above defined low water is the natural minimum flow during the season of navigation, and includes no "added volume" or diversion of waters from Lake Michigan. An increment of 8,000 cubic feet per second will raise the low-water plane at St. Louis about 1 foot and, because of rise in river bottom with rise in stage, characteristic of the middle Mississippi, will increase the navigable depth about one-half foot.

31. The plane of low water over the Chain of Rocks has lowered about 2 feet because of the increased fall (par. 33) immediately below the higher parts of the rock underlying the channel; further increase in fall will cause further lowering of water surface and reduction of depth over the rock. An estimate made in 1910 for an 8-foot channel, St. Louis to mouth of Illinois River, contained an item for rock excavation, 138,000 cubic yards, at Chain of Rocks. (See H. Doc. No. 762, 63d Cong., 2d sess., p. 110.) This estimate was for the short stretch of river (miles 10 to 10.7) in the vicinity of the old intake tower and was derived from a contour map of the bedrock as determined from a large number of borings by the St. Louis Water Department in 1889. In 1912, when the new intake tower was located, additional boorings eastwardly from the towers indicated that the bedrock there was not at all obstructive to 9-foot navigation. This is confirmed by the accompanying map (Pl. I) and profile (Pl. III) which show an excellent channel down to mile 9½.

32. The higher portion of the 1866–1881 discharge curve has been connected by broken line with the estimated volume (1,350,000 cubic feet per second) for the flood of 1844, extreme high water, at its true gauge height, 41.3 feet. This same volume at a newly estimated gauge height of 46½ feet for extreme high water has been similarly connected with the higher portion of the second curve which is well determined by the flood observations at Chester and Thebes. It is reported that at the Merchants Bridge the flood of 1892 swept out a 25-foot deposit of alluvium, removing it to bedrock. The flood of 1903, 38 feet gauge, was normally 6 feet lower than the flood of 1844, but, at a point one-half mile above the Merchants Bridge, was only 6 inches lower than an authentic mark for 1844. Assuming that extreme high water will now pass the Eads Bridge at a gauge

height of 46½ feet, as seems probable from comparison of flood planes and volumes, and will remove the alluvium one-half way down to bedrock, the mean velocity will be 10 feet per second. If such a flood be of sufficient duration to sweep out all the alluvium—average depth, 52 feet—to bedrock, the resulting mean velocity will then be 8 feet per second. And in such a flood the arch footings of Eads Bridge, which were placed above high-water mark of 1844, will be submerged 5 feet.

33. The mean fall between Chain of Rocks and Grays Point is 0.58 foot (7 inches) per mile, for both low water of 1904 and extreme high water of 1844. In 1837, with river stage 12 feet above ordinary low water of that time (about 6¾ feet, Market Street gauge) the mean fall per mile between Cabaret and Arsenal Islands is published as 0.425 foot, (Lee); in the same stretch, in 1844, with stage about 1½ feet above ordinary low water, it was 0.65 foot (Cram). In 1872 the low-water plane throughout the harbor was almost uniform at 0.58 foot per mile. In 1904, the mean fall per mile at "Low Water" from Chain of Rocks to Bissell Point (mile 3.3 above Eads Bridge) was 1.16 feet; from Bissell Point to Market Street, 0.39 foot; from Market Street to Jefferson Barracks (mile 10.7), 0.24 foot; and thence to Waters Point (mile 21.5), 0.60 foot. In 1923 a fall of only 0.15 foot in 1 mile was observed near the foot of Arsenal Street (mile 3.2), river stage 1½ feet above low water. Winter of 1925–26, with river stage 4½ feet above low water, a fall of 0.17 foot per mile was observed in the central harbor and a fall of 2 feet in 1 mile just below Chain of Rocks.

34. A hydrographic survey embracing the harbor and extending northwardly to the mouth of Missouri River and southwardly to Jefferson Barracks, a distance of 28 miles, was made during the fall of 1925. This survey is shown on the accompanying map in two sheets, Plates I and II, scale 1 to 20,000, together with the bank lines of 1889 (the first general topographic map of the district) and the bank lines of a portion of the harbor in 1844. The map is supplemented with a slope profile, Plate III; a sheet of comparative cross sections, Plate IV; and the discharge curves, Plate V, hereinbefore mentioned. Plate III shows comparative thalwegs of river bed, the planes of significant floods and low waters, and a series of eight special-slope observations at medium low stages, at stations about 1 mile apart, 1925–26.

REFERENCES, ST. LOUIS HARBOR

Annual Report, Chief of Engineers, 1903, pages 1455–1462.
Annual Report, Chief of Engineers, 1909, pages 1603–1609.
House Document No. 772, Fifty-ninth Congress, first session, pages 3–20.
House Document No. 50, Sixty-first Congress, first session, pages 14, 60, and 72.
House Document No. 628, Sixty-third Congress, second session, page 5.
House Document No. 762, Sixty-third Congress, second session, page 110.

ELEMENTS OF PROBLEM

35. The problem of improving the middle Mississippi River involves the adjusting of any proposed regulating works in such manner as to accommodate to the end desired the varying and largely interdependent elements that give the river its present physical characteristics. As variations in one of these characteristic elements

will not only have its resultant effect on any of or all the others, and as these others in turn may then react on the feature originally chosen for consideration, a brief summation of these elements is pertinent.

(*a*) Material of river bed varies from the extreme of solid ledge rock to that of the finest silt. Deposits of alluvium are neither horizontally nor vertically uniform.

(*b*) Discharge is determined mainly by the upper Mississippi-Missouri flow in the ratio of 54 to 46 for mean discharge, with tributary local drainage as a minor factor. Volume of extreme high water is more than fifty times the observed minimum flow. At times high stages in the Ohio at its mouth tend strongly to retard the flow of the middle Mississippi.

(*c*) Surface slope of the river section as a whole is determined by the relative stages at the Missouri-Mississippi and the Ohio-Mississippi confluences. There are many departures from this general or mean slope. The greatest local variations in low-water slope occur in the alluvial stretches where bed and banks are unstable, and bars which act as temporary dams are constantly changing in height and position. Fairly constant low-water slopes, much gentler than mean slope, are maintained wherever banks are permanent or thoroughly stable and widths are not excessive; and in the adjacent stretches, where river is wider and bank alignment and bar position change but little, such slopes are steeper than mean slope.

(*d*) Silt content varies principally with the stage of the Missouri River, the upper Mississippi supplying but little silt. Except in the case of a cut-off or extensive local erosion of bed and banks, the amount of silt furnished by the middle Mississippi itself is comparatively small.

36. If any of the above-described elements could be made either a definite fixed factor, or a variable with a definitely known variation, the problem of regulation would be simplified to an extent depending on the relative influence of such factor in creating the varying conditions which are characteristic of this section of the river.

37. The most difficult work in regulation will be to accomplish the fixation of the stream bed, by that term including bottom and banks, and so to fix it with definite thalweg, varying but little for the various stages, as to ovbiate the irregular filling of the channel with a rising river, and to force the stream flow to cut its own channel in predetermined places on falling stages.

CROSS WEIRS

38. Cross weirs or sill dams have been proposed for the middle Mississippi, to hold cross sections at certain selected localities to desired dimensions and grade so that low-water plane, despite bed scour, may always be maintained at the same gauge height. The low-water flow might thus be confined in a section 500 feet wide by 18 feet deep. Objections to such severe narrowing, however, are:

(*a*) The rolls and eddies that would occur over and below the weirs and the strong tendency toward much greater depths below them.

(*b*) The loss of natural cross section for low-water volume, causing natural surface planes for greater volumes to be raised, probably 3 to 5 feet for mean to bank-full volumes; and

(*c*) The number of such weirs required, probably exceeding the number of natural bars that may become obstructive to 8-foot navi-

gation, about 50 between St. Louis and Grays Point and 10 thence to Cairo.

39. Another and probably better scheme of installing cross weirs would be to construct them in pairs 4 to 16 miles between pairs; the fall between the downstream weir of one pair and the upstream weir of the next pair below to be one-half of the mean fall; the weirs of each pair to be one-fourth as far apart as the pairs; and the fall within each pair to be three times the mean fall. The natural low-water plane between the weirs of each pair would thus be raised at the upstream weir and lowered at the downstream weir by the amount of mean fall between them. The fall within pairs would not be in excess of that already observed throughout considerable stretches of the river, and the lessened fall between pairs would be favorable to excellent navigation.

40. Tentative cross-sectional dimensions of river at weirs above Grays Point are 400 feet bottom width, 9½ feet below low water, with low-water mean-stage, and bank-full widths conforming to average natural widths at those stages, viz, 2,000 feet, 3,250 feet, and 4,600 feet. The channel current between the weirs of each pair would be about 3½ miles per hour at low water. The depth may, of course, be increased by decreasing the low-water width and altering the side slopes of the section.

41. The river between pairs of weirs, if regulated to low-water, mean-stage and bank-full widths of 2,000, 3,000, and 4,400 feet, respectively, would have a low-water depth of 14½ feet for a width of about 675 feet, and here the velocity of current in the channel would be reduced to about 1⅞ miles per hour.

42. Any doubt as to whether weirs would have beneficial and far-reaching effects on the regimen of the river could be dispelled by the construction of one or two pairs of such weirs.

Construction of cross weirs would involve:

I. A broad foundation of special construction laid according to required alignment and cross section and as nearly as practicable to profile grade of completed weir.

(*a*) Fills to be made as required by aid of permeable dikes in secondary channels and by solid dikes in the main channel. Fills may be effected in stages, accretion meantime taking place.

(*b*) Cuts necessary to place foundations, to be made by dredging or by induced scour.

II. The weir below low water to be brought to final transverse section, profile, and grade by means of piling, cribbed mattress, and riprap stone. Portions above low water to be revetted with riprap stone or concrete on the required slope and profile.

III. Bank protection to be placed as required upstream and downstream from the revetted ends of weirs.

The estimated cost of one such cross weir is:

Below low water, 2,000 linear feet, at $200	$400,000
Above low water, 2,600 linear feet, at $100	260,000
Contingencies	40,000
Total	700,000

43. It can not be predicted that any reduction in the extent of regulating works will occur as a result of the construction of one or a few cross weirs. On the other hand, the construction of an isolated

cross weir might be followed with the need for a number of additional cross weirs to maintain the project depth over the weir first constructed. The tentative depth of the cross weir below the low-water plane, 9½ feet, is so slightly in excess of the required depth that local variations in the low-water plane in the portion of river above or below the weir, if such surface plane is not also supported by cross weirs, might easily cause encroachment upon the project depth over the weir itself. Indeed, any project for the use of cross weirs in improving the middle Mississippi could easily be extended to supporting the entire surface slope upon a number of such weirs.

DAMS

44. Properly designed contraction works must make but little change in the existing river velocities. The only methods now known by which contraction works could create navigable depths greatly increasing those of the present project would be by decreasing the slope of the river by the use of fixed or movable dams. Nature of foundation, extent of silt carried, and excessive cost force leaving such structures out of consideration at this time. At the same time, sill dams, or submerged weirs, distributed at frequent intervals along the river to hold the slope approximately as at present, are only recommended as a means of supporting the surface slope in exceptional instances. As permanent works of improvement are extended on the Missouri River, the amount of silt brought into the Mississippi should decrease. A change in the silt content of the Missouri, and consequently in this portion of the Mississippi, and demands for increased depth or additional contraction create new conditions to which adjustment can only be made by taking out the excess slope by fixed or movable dams. Decreased amount of silt carried, or advance in engineering art, and the increased commercial development of the Mississippi Valley in the future may make the construction of either fixed or movable dams desirable.

METHODS OF IMPROVEMENT

45. Improvement of this part of the Mississippi has been carried on by contracting the stream and protecting its banks, which has accomplished partial regulation, and by dredging. The method of contraction was the building up of new banks, or accretions, by means of permeable dikes or wing dams. Revetments were used to protect both natural and artificial alluvial banks from erosion. Works executed in this way, if properly designed, are a permanent investment in the river. An inspection of the various works, some of them placed in 1838, impresses the observer that practically all have rendered good service and have improved the river. In some cases structures have been destroyed, but almost always because requisite maintenance was not given them, or because the structures were left isolated by postponing the installation of necessary contiguous and supporting works. As before stated, any change in the general regimen of the river to obtain greater depth must not reduce the velocity below that necessary to carry through this section of the river the great burden of silt brought into it by the Missouri; excessive velocity that would erode the stream bed, reduce the slope, and create

rapids above the contracted section must equally be avoided. In the light of increased knowledge of the physical characteristics and the balance of natural forces in the river, it is to be repeated and emphasized that practically all expenditures on properly designed works of contraction and of bank protection will be investment. This distinction is made as against the cost of dredging of the kind performed in this district, which is essentially an operating cost

46. Dredging as generally performed in this portion of the Mississippi River is subject to popular misunderstanding. The suction type of dredges used here cuts navigable channels across shoals in the steamer channel and deposits the excavated material near by in the river, and only as far from the main channel as the short discharge lines of the dredges will reach. No material is permanently taken from the waterway by this method. A very slight permanent improvement in the navigable condition of the main river perhaps follows, but the greatest part of the effect of this type of dredging is usually obliterated during the first considerable rise in the river. Dredging is, therefore, an operating expense similar to the expense incurred in railroad operation in maintaining pusher locomotives to double-head tonnage trains over steep grades. With the river not improved to such an extent as to maintain by natural forces a channel sufficient for the type of boats operating on the river, dredging is a necessity. This is the situation at the present time. The necessity for dreging will gradually decrease as works of permanent improvement approach completion. With the use of lighter draft barges and towboats, even with the present river, the amount of dredging would be less and might be avoided altogether. It is believed that dredging should be utilized, and then up to the requirements in depth as prescribed by the project only when necessitated by the drafts of barges or towboats operating on the river. When such operating demand does not exist all possible resources should be applied to contraction works, the eventual results of which will be to reduce dredging even if the project depth were increased.

SELECTION OF DESIGN

47. As regulating works of contraction and bank protection will be required with any method of improvement that may be adopted, it appears advisable to present a design for such regulating works that will disturb as little as possible the existing play of natural forces in the river. In this way the very substantial effects that tend to offset the erosion of the stream bed and flattening of the low-water surface slope can be determined. The chief effects that offset the changes noted are the increased resistance of the stream bed at greater depth and the shoaling of the deep pools in the natural stream bed. The first effect results in a partially fixed natural stream bed, and the second, by the increased frictional resistance of the river channel, tends to offset the loss of friction in the narrowed and deepened portion of the river.

48. It seems, therefore, the prudent plan to construct the regulating works now proposed, and during such construction and thereafter to observe carefully the low-water surface slope. Remedial action to hold up a seriously dropping surface slope can then be taken.

49. To more closely observe the surface slope of the middle Mississippi, gauges at about 10-mile intervals below St. Louis were read in 1925, and daily readings are now being taken. This precaution will early detect any significant change of surface slope during or following the construction of the proposed regulating works.

50. It would be consistent with the science of hydraulics to artificially flatten the slope through each portion of the river contracted. Works of contraction could then be designed with the interrelated slope, volume, and mean depth to give any desired depth of channel for navigation. The cost of the structures—weirs, fixed or movable dams—with certain reservations as to the stability of the latter, to create flatter slopes, militates against consideration of these structures. There is called for, then, the design of contraction works such as to create the depths at present necessary for navigation and yet not to cause excessive erosion.

PROPOSED REGULATING WORKS

51. In accordance with the above principles and based upon the extensive data and experience had upon the middle Mississippi, the design of the works of contraction required is next taken up.

52. The section adopted is one that meets the demand for a stabilized steamer channel and yet does not contract too sharply the natural widths of the river. The effects of the existing works of contraction, as well as the results of river gaugings, were made use of in determining the required contraction. The section chosen represents what may be termed a "gentle contraction."

53. Using all available data, a compilation was made of the cross sections of the river existing at various stages. The following table summarizes the result of this compilation. (Also see Sheet No. 2 of maps.)

TABLE I

Subdivision of river	Length	Low water		Mean stage		Bank full	
		Average width	Average depth	Average width	Average depth	Average width	Average depth
St. Louis (Market Street) to River des Peres	*Miles* 7.6	*Feet* 1,700	*Feet* 11.5	*Feet* 2,205	*Feet* 19.9	*Feet* 2,755	*Feet* 31.0
River des Peres to Grays Point	125.7	1,940	10.1	3,235	15.1	4,635	23.2
Grays Point to Commerce	6.9	2,085	12.9	2,720	19.2	3,005	30.3
Commerce to Commercial Point	7.2	2,585	7.8	4,550	12.6	6,070	20.8
Commercial Point to Ohio River	32.2	1,900	8.3	3,435	13.9	4,735	24.*

54. Omitting the subdivision through St. Louis Harbor and the gorge near Commerce, in both of which subdivisions no change in the existing river cross section is practicable or desirable, there are seen to be three subdivisions of the river remaining, each demanding a cross-section standard within the subdivision but varying somewhat between subdivisions. The three subdivisions are: First, St. Louis to Grays Point; second, Commerce to Commercial Point; and third, Commercial Point to Cairo.

55. Supported by the above compilation, and the considerable experience had in this district with contraction works, a cross sec-

tion for each of the subdivisions noted was selected. The section adopted for each of these three subdivisions is shown in the following table:

TABLE II

Subdivision of river	Length	Low water		Mean stage		Bank full	
		Width	Mean depth	Width	Mean depth	Width	Mean depth
	Miles	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
River des Peres to Grays Point	125.7	2,250	8	3,250	14.8	4,600	23.3
Commerce to Commercial Point	7.2	2,500	8	4,500	13.9	6,000	20.3
Commercial Point to Ohio River	32.2	2,000	8	3,500	14.0	4,800	24.9

56. These cross sections call for low-water widths of 2,250, 2,500, and 2,000 feet, respectively. The widths at mean stage and bank full are as nearly as practicable the means of the existing natural widths at those stages. All hurdles are designed to slope uniformly from low-water elevation to mean stage and to bank-full elevation at the river widths noted. This precaution is to be taken to accommodate stream flow in excess of low-water channel requirements. This principle requires the nonclosing of sloughs above mean stage in the portion of river below Commerce.

57. The contraction to be brought about by the regulating works proposed is a conservative one. The practical result of these works will be merely narrowing the abnormally wide sections of the river to the present mean widths. The project of 1881 contemplated contraction to a width of about 2,500 feet. Through St. Louis Harbor a contraction to a low-water width of 1,500 feet to 1,800 feet has been carried out. The contraction proposed causes much less change in the original condition of the river than either the project of 1881 or the work in St. Louis Harbor. Calling for very little change from the original condition of the river the equilbirium of natural forces in the river will be but slightly disturbed.

58. It is not possible to predict exactly the navigable depths which will result after completing works of the nature proposed. Based on the natural velocities obtaining in the present low-water cross sections, reasonable computations indicate that the cross sections formed by the proposed contraction works will give a mean depth of 8 feet at low water and a channel depth of 9 feet over a width of about 500 feet in each of the three-river subdivisions. These computations are based on the very conservative natural low-water volume for navigation of 40,000 cubic feet per second which includes no diversion whatever from Lake Michigan. (Par. 30.) So low a water has not occurred during navigation seasons of the last 22 years. (Reference is made to sheet No. 2 of the accompanying maps upon which are tabulated the natural cross sections and velocities through each subdivision of the river, together with the proposed cross sections and predicted velocities.)

59. It is therefore a fairly conservative conclusion that a channel 9 feet deep at low water and at the least 300 feet in width will result on completing the regulating works. In general it will not be necessary to carry on dredging operations to maintain such channel prior to completion of these works. Dredging is essentially an operating

charge and in the absence of traffic requiring the full dimensions of the now proposed channel should be restricted to the needs of traffic already on the river. The present channel, project depth of 8 feet and width of 200 feet, has developed a substantial traffic with boats and barges adapted to such channel; these dimensions therefore should be maintained during any improvement for a channel of larger dimensions. In the absence of contraction works, extensive dredging will be necessary in the future, as it has been in the past, to maintain this channel.

60. The following extract from report by Col. O. H. Ernst, Corps of Engineers, August 10, 1903, when the 1903 report of the Board of Engineers was under preparation, is thought to be as pertinent to the matter to-day as when written:

> A dredged channel which does not maintain itself is a very precarious foundation for trade. There is probably no place in the world where a dredged channel will have a briefer existence than in the uncontrolled part of the Mississippi River below the Missouri. * * * the cost * * * would certainly be large, and as it must be continuous and perpetual there is always the danger of that effort may be relaxed. This menace will, in my judgment, prevent a very extensive use of the deepened channel. * * * dredging * * * has what seems to me the fatal defect of being dependent upon never-ending effort. It is a temporary improvement adopted from compulsion and not from choice. * * * The plans and methods of construction introduced and developed under my direction between 1879 and 1886 have proved entirely successful. * * * To abandon them now for dredging is to abandon a certainty for an uncertainty.

61. The basic resolution of the Committee on Rivers and Harbors contains the language "with sufficient width of said channel around the bends in said river to afford convenient passage for tows of barges for use upon the Mississippi River." The main difficulty of handling large tows is due to the many sharp bends with strong cross currents in the low-water channel. The regulating works proposed aim at smooth easy curves for stream flow and navigation, and with compact cross section more uniform currents. In the absence of completed works it is impracticable to lay down any definite width necessary at bends in the river to facilitate the handling of large tows. Both in the construction of contracting works and in the performance of dredging, effort should be continued to avoid sharp turns in the steamer channel. The movement of bars often leaves a reef in such position that, with adverse currents and sharp change in direction of channel, it becomes practically impossible to swing a large tow about the reef without grounding, even though a channel of full project depth and width exists. The expedient is then forced in such instances of cutting down the reef by dredging and thus increasing the project width. Even with the regulating works completed, such emergency dredging will no doubt be occasionally required as in the past, although less frequently.

62. Until the regulating works below St. Louis are completed, dredging should be done to maintain a low-water channel 8 feet deep and 200 feet wide with sufficient width at bends to avoid the double-tripping of barge-tows accommodated by straight reaches; after the regulating works are completed, dredging should be done to the extent necessary to create a low-water channel 9 feet deep and 300 feet wide with similar additional width in bends for barge-tows; and it should also be provided in authorizing such channel that dredging to this maximum extent will be done only when necessary to meet the needs of the actual navigation then existing and that otherwise the aforesaid 8-foot channel will be maintained.

63. The regulating works necessary to contract the low-water cross section of the river and stabilize the banks are shown upon the maps submitted with this report. These structures have been planned as required by the present condition of the river. Changes in the channel may cause changes in the location of these works. However, the quantities obtained in thus planning the structures are reasonably accurate for the purpose of estimating costs. This review requires consideration of a 9-foot depth of channel from the mouth of the Ohio to the northern boundary of the city of St. Louis. Under the present project, the northern limit of the 8-foot channel is St. Louis which has a harbor front of 19 miles with but few facilities for navigation in the northern 8-mile portion; the Burlington elevator, just north of Merchants Bridge, has been for many years the actual northern limit of the 8-foot channel However, with the river fully regulated between the mouth of the Ohio and St. Louis, the additional harbor to be made available by regulation north of Merchants Bridge will be no doubt required by increased shipping on the river. Meanwhile, every resource should be applied to channel regulation south of St. Louis. The cost of completing the regulation between Merchants Bridge and the northern boundary of St. Louis is $500,000. While the quantities and cost of this latter work are included in the estimates here presented, the execution of such work is only of value after the completion of all regulating works south of St. Louis.

64. The works proposed are permeable dikes of piling (hurdles) driven through mattress foundations for channel contraction and revetments of mattress and paving for bank protection. The dikes serve to create the necessary accretions of silt to contract the river's width. At bends in alluvial banks, both natural and artificial, revetments are planned to stop erosion and occasionally similar revetment is necessary to protect artificial accretions in straight reaches.

65. In the execution of the work, progress should be made downstream, starting at one or more points in the river having stabilized banks. Great risks of loss exist in executing scattered works. Continuous work safeguards all structures and applies the aggregate influences of all the structures instead of the single influence of an isolated structure. Progress of work downstream moves bars ahead of the work.

66. The materials used in this work are wooden piling, brush, rough boards, and riprap stone. The amount of piling and brush required will give serious concern as the supply is diminishing. Substitution of concrete for both of these materials may be necessary for the completion of work on this portion of the Mississippi. A satisfactory supply of stone exists in the quarries and bluffs along the river.

67. The use of reinforced concrete piles in the channelward ends of timber dikes is now in an experimental stage in this district; the substitution of durable and nondecaying material for timber in such exposed positions may greatly reduce the number of revetments planned to protect the artificial banks when formed by the proposed dikes. If results from the use of concrete are as favorable as indicated, no substantial increase in first cost of works over the estimates given hereinafter need be looked for; on the other hand, a very substantial reduction in maintenance costs may be anticipated. In constructing permanent regulating works, wooden parts which will be exposed to channel attack should be kept submerged to lessen

deterioration and should not extend above extreme low water which is 3 to 4 feet below the low water defined in paragraph 29. Hence maintaining the elevation of the low water discharge and preventing a drop in its plane is a desideratum in practical regulation.

COST

68. The detailed location of regulating works required was made at the close of the working season of 1924. A further study was made recently of these proposed structures and the priority of the various proposed structures is suggested. Proposed structures are then presented in three classes of priority as follows:

A (red). Structures required now (1925) to protect caving banks and to remove shoals in the channel.

B (blue). Structures required in near or immediate future to complete regulation of river.

C (green). Structures required, but not immediately, to complete regulation of river.

The structures proposed in each class of priority are shown in the stated colors on separate inclosure.

69. A summary of the works proposed separated in the above priorities follows:

Priority	Linear feet		Cost		
	Hurdles	Revetments	Hurdles	Revetments	Total
A	120,400	145,770	$4,616,000	$4,373,100	$9,189,100
B	152,760	81,260	6,110,400	2,437,800	8,548,200
C	78,320	199,200	3,132,800	4,518,800	7,651,600
Total					25,388,900

70. The total cost to complete the works listed under each priority, with that of necessary additions to present plant for the expeditious performance of work is, then:

Priority A	$9,189,100
New plant	2,000,000
Total priority A	11,189,100
Priority B	8,548,200
Total priorities A and B	19,737,300
Priority C	7,651,600
Total project	27,388,900
Contingencies	3,611,100
Total cost	31,000,000

71. This involves an additional authorization for new work as follows:

Estimate for new work 1910	$21,000,000
Less new work performed (to date)	3,000,000
Balance	18,000,000
Increase in estimate, required to complete works	13,000,000
Total	31,000,000

POTENTIAL TRAFFIC

72. In the accompanying study of indicated commodity movements, freight rates and possible savings in freight costs by transportation on an improved middle Mississippi River, a total of 5,680,000 is predicted as the potential tonnage which may develop for such transportation at a computed saving of $4,453,950. This amount is obtained by analysis of the volume of freight now moving (1924) and the computation in the main is based on the application to that volume of the existing freight tariffs for both rail and river. In the few cases where for some commodities river tariffs did not exist they have been constructed on the basis of river rate equalling 80 per cent of the port-to-port rail rate, which has been the prevailing practice heretofore in determining river rates on the Mississippi.

73. The saving as thus shown in this study is the indicated saving to shippers, being based on the "selling price" of transportation and not on the "manufacturing cost"; for the same commodities a comparison of the possible savings resultant from utilization of river transportation when based on the production costs of transportation for the two methods of freight movement, would give a showing even more favorable to the river.

74. In this study no distinction is made between the possibilities of an 8-foot and a 9-foot depth of channel, as the basic rate for combined river and rail hauls is uniformly 80 per cent of the port-to-port rail rate regardless of the channel depth. As before stated, the rates used in this study are based on the selling price of the river transportation, hence can make no distinction between different channel depths, and therefore can not take into consideration the probably lessened cost to the purveyor of river transportation afforded by a 9-foot channel.

FINANCIAL ANALYSIS.

RETURN V. EXPENDITURE

75. In the following series of items, it is proposed to consider each element of possible income and show when possible the return from establishing and utilizing a stabilized river channel in the middle Mississippi:

	Return
Item 1. Potential freight savings. The determination of this amount is given in detail within the inclosed traffic study.	$4,453,950
Item 2. Direct saving in present freight movements. This estimate is based on the detailed computation of the actual carrying charges on the river and on competing railroads for the calendar year 1924.	410,000
Item 3. Protection of levees and other improvements on the alluvial plain. There are approximately 300,000 acres of land upon the alluvial plain of the Mississippi River between the mouths of Ohio and Missouri Rivers. All portions of the alluvial plain are subject to attack by the shifting channel of the uncontrolled Mississippi. No estimate of the value of the land and improvements on the alluvial plain is presented but such value is so large that it is at least desired to present the importance of these improvements and the protection which works of stabilization provide.	Not estimated.

Item 4. Invisible income from lowered freight rates..... Not estimated.

The railroad freight tariff in the lower Mississippi at present is somewhat lower in directions along the Mississippi River than in directions away from the river. This difference was very marked prior to 1922; since then many rates along the Mississippi River have been increased as much as 100 per cent. The total saving to shippers, in the past, by such depressed rail rates, has been vast and is even substantial now with the rail rates only slightly out of line along the Mississippi River. It is impossible to compute the amount of such invisible income but its extent is so great as to be notable and it is so recorded.

Item 5. Miscellaneous income..... Not estimated.

This is another type of income from a stabilized river channel which can not be reduced to value in dollars. The stabilization of the river enables large modern steam electric plants to be located, with assurance, along the river and thus serve as a foundation for industrial settlements. The various terminal facilities already existing will be safeguarded by a stabilized channel and stabilization, itself, encourages the construction of additional facilities. Recreational use of the river is encouraged and made safer by an easily followed steamer channel.

Expenditures

Item 1. Interest charges on new investment..... $1,240,000

This has been computed upon the new capital investment required to complete the regulating works as presented in this review.

Item 2. Annual dredging charges..... 300,000

The dredging performed at present is necessary to make a steamer channel 8 feet deep and 200 feet wide, and it is considered that, with the regulating works complete, a channel 9 feet deep and 300 feet wide can be maintained with no increase in present annual dredging cost.

Item 3. Maintenance charges, regulating works..... 600,000

This estimate is based upon the past experience of this district in maintaining regulating works.

76. This comparison is naturally based upon predictions, and, as noted, slurs over some items. It is believed that the income from the improved river has been underestimated. It is worth bearing in mind that the present annual expense required on the middle Mississippi, which is $300,000 for dredging and $300,000 for maintenance of regulating works, can hardly be omitted in view of the large public interests of navigation and other investments involved. Present maintenance charges are still high because many isolated structures still exist unsupported along the river and deterioration is largerly due to their lack of support. The additional expenditure to complete the regulating works really safeguards public expenditures already made in partially contracting the river.

CONCLUSION

77. The project presented, of contracting the middle Mississippi to fairly uniform width and stabilizing its banks, may not be the final work of molding this part of our great interior river to the demands of commerce. There are two extremes which limit possible effort upon this river: First, the present works of bank protection and contraction and the annual dredging operations might be entirely given up. This would result in a channel with a natural depth of about 4 feet and a main river shifting from time to time over the entire alluvial plain.

The river would break up into secondary channels of uncertain depths and would discourage all traffic. The alluvial land and all substantial improvements contiguous to the river would be in a most perilous situation. It is obvious that the interests involved would not permit the river to go back to the condition presented, that is, its original condition. Second, one-half of the surface slope may be taken from this part of the river to its great advantage by the construction of fixed or movable dams. Even with such exceedingly costly structures, and with the solution of the combined engineering and financial problems involved, works of contraction would be necessary. The present commercial needs of the Mississippi Valley do not justify, at this time, the construction of dams.

78. As an intermediate step, however, between the original river and what may be the final works upon this portion of the middle Mississippi, the project of works of contraction and bank revetment really only reiteration of previous projects, is presented. Such works will be required as a part of any project of improvement. Certain precautions must be taken against radically disturbing the surface slope of the river and the same may lead to the construction of a number of cross weirs to support the surface slope.

79. There is a strong tendency to lose sight of the really impressive tonnage now using the middle Mississippi. Through the year 1925, if one includes not only freight traffic by common, contract, and private carriers, but also freight carried on the ferries, and sand and gravel moved locally, a total of 9,000,000 tons is obtained as the quantity of freight afloat annually upon the middle Mississippi. When, in addition to this, there is considered the value of a stabilized river, in other respects not so conspicuous and not so dependent upon potential traffic, ample support is given for the expenditures required in completing the stabilization of the middle Mississippi.

80. The supplementary dredging to be performed, prior to the completion of the regulating works, should be adequate for the floating equipment using the river but should not exceed the dimensions of channel prescribed by the present project. After the completion of the regulating works dredging should be limited to what might be called the new natural channel. This channel, as nearly as can be predicted in view of the many interdependent elements entering into the problem, will be at least 300 feet wide and 9 feet deep. Dredging to create this ultimate channel should be done only when necessary to meet the needs of equipment then using the river; otherwise the channel dimensions of the present 8-foot project should be maintained. It is considered a grave mistake to authorize dredging for channel dimensions greatly exceeding those of the natural cross section of the river. To absorb resources in dredging for depths greatly in excess of natural depths at the expense of completion of the regulating works simply delays the ideal molding of the river to that form in which dredging costs are minimized.

81. The rapid development of the lower Mississippi Valley and the Southwest assures the growing demand for transportation in this region. However, to carry the commodities suitable for water transportation, either now or in the future, a stable channel of reasonable dimensions through all stages of river is demanded. The project presented gives this. The transportation need exists and will increase. The channel can be made satisfactory for navigation.

82. In compliance with law, it is reported that there are no questions of terminal facilities, water power, or other subjects so related to the project proposed that they may be coordinated therewith to lessen the cost and compensate the United States for expenditures made in the interests of navigation.

MAPS

83. There are submitted herewith the project maps in 16 sheets, scale 1:20,000, which show the works proposed, the condition of present works and numerous other features necessary to a full presentation of this review; graphical representation of the priorities cited in paragraph 68, in atlas form on reduced scale project maps; and the drawings described in paragraph 34, pertaining to the study of St. Louis Harbor.

RECOMMENDATIONS

84. For the improvement of Mississippi River between the mouth of Ohio River and the northern boundary of the city of St. Louis, it is recommended:

(*a*) That the regulating works of contraction and revetment be continued and completed.

(*b*) That prior to completion of regulating works, dredging be continued to maintain the present project channel, 8 feet deep and 200 feet wide with requisite increased width at bends.

(*c*) That after completion of regulating works, dredging be continued, as needed, to maintain a channel 9 feet deep and 300 feet wide with requisite increased width at bends: *Provided*, That dredging of channels deeper than 8 feet and wider than 200 feet be authorized only when the needs of navigation then existing are not adequately met by such 8-foot channel.

(*d*) That all regulating works between the mouth of Ohio River and St. Louis be completed before new works above Merchants Bridge are undertaken.

(*e*) That a new capital expenditure of $31,000,000 (increase of $13,000,000 over preceding estimate, 1910) be made for the improvement, covering regulating works and construction plant.

JOHN C. GOTWALS,
Major, Corps of Engineers,
District Engineer.

[First indorsement]

OFFICE DIVISION ENGINEER, WESTERN DIVISION,
St. Louis, Mo., June 24, 1926.

To: The Chief of Engineers, United States Army, Washington, D. C.
Subject: Review of project for improvement of Mississippi River between mouth of Ohio River and northern boundary of the city of St. Louis, Mo.

1. The recommendations of the district engineer are concurred in.

2. This report is the result of very thorough study based on many years' experience of the St. Louis engineer office in the regulation of the middle Mississippi, and the conclusions are well worth acceptance and thoughtful application to the problem of its improvement.

CHAS. L. POTTER,
Colonel, Corps of Engineers.

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