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FLOOD WATERS OF THE MISSISSIPPI RIVER

ARTICLE ON THE CONTROL, CONSERVATION, AND UTILIZATION OF THE FLOOD WATERS OF THE MISSISSIPPI BASIN
PREPARED FOR THE NATIONAL FLOOD COMMISSION BY THE RESEARCH SERVICE, INC.
WASHINGTON, D. C.

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SENATE RESOLUTION NO. 222

REPORTED BY MR. RANSDELL

IN THE SENATE OF THE UNITED STATES,
April 7, 1930.

Resolved, That the manuscript entitled "The Control, Conservation, and Utilization of the Flood Waters of the Mississippi Basin" prepared for the National Flood Commission by the Research Service, Inc., of Washington, District of Columbia, be printed as a Senate Document.

Attest:

EDWIN P. THAYER,
Secretary.

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PREFACE

Flood control is essential to the larger and permanent economic welfare of the people of the United States. Particularly is this true of the drainage basin of the Mississippi River and its tributaries.

The purpose of this report is to make clear the necessity for a national policy relating to the water resources of the country, treating them as an asset of great potential value, and not as a liability. Under this comprehensive plan, covering the many interrelated problems of streamflow regulation in aid of navigation, of impounding in aid of power and irrigation, of soil erosion, of ground water supply, of forestation, may be drawn and carried out, under able direction, by the trained bureaus of the Government.

Its purpose also is to show that in the absence of a comprehensive national policy, the flood-control work done in the past, while serving in dry weather and in seasons of moderate precipitation, has not only failed in seasons of great floods, but has made the situation worse and worse.

The lack of vision and knowledge of the ultimate effect of the work was fully demonstrated, not only by the flood devastation of 1927, but by the published reports in 1926, to the effect that "the improvement (of the Mississippi) is providing a safe and adequate channel for navigation and is now in condition to prevent the destructive effects of floods."

And by a statement made by the chairman of the Mississippi River Commission just prior to the first break in the levee at New Madrid, Mo., in 1927, to the effect that the levees were in such strong condition that they could and would hold all the water the tributaries would send down that year.

Closely following the New Madrid break there were some 250 independent breaks in the levee lines between Cairo and the Gulf.

One hundred years of disastrous experience has shown the futility of past methods, of accredited ideas, of individual bureau control, of patchwork, and of "levees only."

The problem is too big for any one bureau to handle.

It is too complex for Congress to solve by direct legislation.

Economists must first point the way, so that the engineers may have a definite and adequate goal to attain.

With a definite goal in mind, competent engineers can and will plan in such a way as to work with, instead of working against, nature.

To this end the full cooperation and active services will be required of the experts of the Agricultural Department on forestry, soil porosity, soil erosion, soil moisture; of the Interior Department on irrigation, drainage, and the conservation of natural resources; of the Power Commission on power; of the War Department on channel improvement and navigation; of the Department of Commerce on transportation, trade, and communications; of the States, localities, and business enterprise on cooperation and the sharing of costs.

Coordination is therefore necessary.

That means placing the project under the directing control of a coordinating head or commission, which, in addition to being competent, must be free from bureaucratic prejudice, precedent, and individuality.

Thereafter the work could proceed as appropriations were made available, the several projects to receive attention in the order of their importance.

In the past the process by which the country above was relieved of excessive flood waters was the process by which the country below was ruined.

Under the policy and program proposed, the upper country would be relieved by so utilizing surplus waters as to check and control flood formation.

Less water in flood form would then come down on the low country, and the problem there could then be solved by moderate levees and emergency outlets.

Under such a program there would be no place for "fuse-plug levees."

In the net result, such a program, carried to its logical conclusion, would change a natural resource of great scope from a liability into an asset.

The need for a new economic margin is fully apparent to every economist who knows that the far-reaching change in the world status of the United States—it has recently changed from a borrowing to a lending Nation, and from a seller of raw materials to a seller of the finished articles of commerce—entails new responsibilities and new needs.

If we would hold our advantage we must use, not waste. This applies particularly to our water supply. We must check soil erosion, restore the receding ground-water level, replant forests as old trees are cut out, put an end to devastating floods, regulate stream flow in aid of navigation, use surplus waters for power and irrigation.

In all the history of the world there has never before been so favorable an opportunity for profitable, wholesome enterprise and reciprocal trade as now exists between the Americas.

The United States has the money to finance American development outside its own borders, the machines and the genius to supply the manufactures needed, the capacity to purchase and absorb the raw materials the remainder of the New World can supply.

The southern Republics have mines, forests, lands in the greatest abundance. They are veritable storehouses of natural wealth. The time has come for their development.

They welcome immigration, enterprise, new capital.

If the United States is to function fully in this new era of larger opportunity it must put its house in order and capitalize its environment through economic refinements.

Its house can not be in order so long as uncontrolled drainage be permitted to wash away its most valuable soils, waste its natural power, moisture, and navigation, and, in the process, periodically destroy life and property on the grand scale.

There is confusion in the public mind which needs clearing away.

One group, opposed to water transportation, never tires of charging to inland water-moved commerce all the moneys invested in channel improvement, stream flow, regulation, harbor development, etc.

Another group insists on charging to the lowlands all the moneys invested in levees, spillways, diversion, etc.

Still another wants to charge directly against the dry lands irrigated all the moneys spent for the diversion of water from streams—and wet lands below—where it is not needed, to dry lands where it will serve a good purpose.

All are wrong. Every act incident to the control and use for beneficial purposes of the surplus drainage of the country will serve several wholesome purposes.

Source stream control will mean water for power and irrigation and, in the dry season, for stream flow in aid of a sustained water supply and all-the-year navigation channels. It will also mean reduced soil erosion and a restored ground-water supply, which will greatly extend the life of the Nation's agricultural economy. Finally, it will mean a greatly reduced, if not eliminated, flood and drainage problem for the lowlands.

The whole will bring increased economy and greater opportunity for the Nation as a whole.

The cost should properly be borne by the Nation for general benefits, and by the States, localities, and business enterprise for local, or direct benefits.

Business enterprise should build power dams and sell power for its own account. But such dams should be built to conform with a general plan.

The land benefited should pay for irrigation. But where power dams and irrigation works help regulate stream flow and check flood formation, the Government, in one form or another, should aid.

Drainage is the concern of the land requiring drainage. But all land is entitled to an outlet. Consequently the general plan should provide outlets for the country's regulated drainage.

Stream-flow regulation is a proper function of the General Government. But should any lands be so low as to require levees after stream-flow regulation shall have been effected, then the building and maintenance of such levees should become a concern of the owners of such lands.

Another matter about which the public are most hazy is as to who should point the way—set the goal—who should plan, and who should do the work.

No single bureau of the Government, no matter how expert it may be in its special field, is capable of doing all these things.

Economists with independent vision are needed as a preliminary step.

Engineers with imagination are needed next.

The genius of America's great enterprise is needed to consolidate, coordinate, and direct the work if the country's larger interests are to be served.

In its last analysis, the report shows that the national welfare requires that Congress adopt a national policy and create the means, first, for economists to point the way; next, for engineers to plan comprehensively; and, finally, for competent managers to coordinate and direct the work of turning the devasting forces of nature into a blessing for mankind, as the funds shall be provided.

The country's pioneer days have come to an end, and careless methods of treating fundamental problems of national economy no longer will serve. Business has changed its methods. Government must change its methods, too.

In this new era of enforced common sense, the Mississippi Valley—backbone and bread basket of the Nation—requires, for the good of the whole, first attention, after 100 years of hopeless muddling.

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FLOOD WATERS OF THE MISSISSIPPI RIVER

SUMMARY

"Working with nature" is the fundamental principle on which this plan for the control, conservation, and utilization of flood waters of the Mississippi Basin is based. The natural resources of the basin should be utilized to keep the flood stages down, and to eliminate the flood crests, especially in the lower Mississippi. In the development of this plan, all elements of the entire watershed from the headwaters near the Canadian border to the outlets of the main river in the Gulf of Mexico are comprehended. Hence the plan considers the physiographic features, such as forests and soil cultivation, and includes the various factors of improved levees, and existing channels, source stream control, diversion channels and emergency spillway outlets.

Source stream control involves systems of reservoirs in the basins of the Ohio, Missouri, White, Arkansas, and Red Rivers. This preliminary investigation indicates that available feasible sites will provide for the storage of 10,000,000 acre-feet on the Ohio River and its tributaries, of 15,000,000 acre-feet on the Missouri River, of 3,900,000 acre-feet on the upper Mississippi River, of 34,000,000 acre-feet in the Arkansas-White watershed, and of 6,460,000 acre-feet in the Red River Basin. The utilization of these combined systems of impounding reservoirs may make it possible, as indicated by data now available, to reduce flood stages, under conditions of a possible maximum flood, 11 feet at Cairo, Ill., 15 feet at Arkansas City, Ark., and 17 feet at the latitude of Old River, La.

Existing records and data indicate that there is opportunity for the construction of a practicable combined diversion channel and series of storage basins in the lowest swamp or marsh lands of the St. Francis, Tensas, and Atchafalaya Basins west of the main river and in the Yazoo Basin east of the river. This combined system west of the lower Mississippi can be utilized to remove about 300,000 second-feet (cubic feet per second) of flood waters from the Mississippi River at Cape Girardeau, Mo., and to also divert flood waters from the St. Francis, White, Arkansas, and Red Rivers and thus keep these waters from the channel of the main river in the case of excessive flood conditions in the southwest section of the basin, such as occurred in the flood of 1927.

An emergency flood outlet for bank-full stages in the lower Mississippi should be constructed at some point above New Orleans (such as Bonnet Carre) with a view to diverting surplus flood waters through a short flood way, and into Lake Pontchartrain.

This plan contemplates the provision for a possible maximum flood of 4,000,000 second-feet at the so-called bottleneck at the

latitude of Old River. The existing river channel, when the levees have been brought up to grade as provided for in the recent act of Congress (70th Cong., 1st sess.) will take care of 1,500,000 second-feet. A special diversion channel, intercepting and diverting the waters of the principal tributaries west of the Mississippi River, will take care of 850,000 second-feet and a possible additional 150,000 second-feet in the backwater areas. The source stream control reservoirs will take care of 1,250,000 second-feet and eliminate serious flood-crest conditions, particularly in the lower Mississippi Basin. The execution of this plan could be taken up in a series of steps, including the completion of the levee system, channel improvement, the building of the lower river spillway, the construction of the source stream control reservoirs which may be done simultaneously in the various watersheds of the principal tributaries, and the development of the diversion channels, commencing with the Atchafalaya Basin, which could be used as a relief spillway and flood way, before the diversion channels are built in the Tensas and St. Francis Basins.

The execution of this project will involve an expenditure of about $1,000,000,000 and require a period of from 10 to 15 years. The estimated benefits, including protection of life and property, the enhancement of the value of agricultural lands, and the income from power development and the utilization of the regulated channels for navigation, would justify the initial cost of the entire project, and during the next generation bring enduring welfare and prosperity to this great section of the United States.

Respectfully submitted.

THE RESEARCH SERVICE (INC.),
ALLEN B. MCDANIEL.

NOTE.—The unit of measurement of flowing water is the cubic feet per second abbreviated to second-feet. For stored water the unit is an acre-foot; that is, enough water to cover an acre to a depth of 1 foot, or 43,560 cubic feet. One cubic foot per second flowing for a day of 24 hours, or 86,400 seconds, is approximately equivalent to 2 acre-feet.

RECOMMENDATIONS

Any national policy governing flood control should be based on the recognition by the Federal Government of its obligation to maintain interstate commerce and to protect the lives and property of its citizens when the States fail in this duty. It is generally recognized to be the duty of the Federal Government to proceed with the repair, strengthening, and enlargement of the levee system, and such bank protection and channel improvement required to protect lives and property, and to provide a navigable channel as required by existing laws.

The further execution of a flood-control plan should be done by a commission properly authorized to administer a national flood policy in cooperation with the various States concerned. The States would operate under commissions appointed by and functioning under flood-control codes established by legislative statutes. The construction and administration of the reservoir, diversion channel, and spillways projects could be carried out on a cooperative basis, somewhat similar to the Federal-aid highways program, the Federal and State Governments sharing in the expense and administration of a predetermined policy and plan, which shall be established by act of Congress and ratified by the legislatures of the States concerned.

Immediate steps should be taken by the Federal Government, using its existing agencies—such as the Forest Service, the Geological Survey, the Weather Bureau, the Corps of Engineers, and the Mississippi River Commission—acting conjointly, to secure basic data, including topographic maps, stream measurements, flood-flow factors and conditions, and to do the necessary research on geologic, physiographic, hydrographic, and climatological conditions, especially in the lower river basin. All such material would be available for the use of the national flood commission, if and when created by act of Congress and appointed by the President. These data would supplement existing material, including that now being secured by the Army engineers in their river survey, by the Coast and Geodetic Survey, and by other Government agencies acting either under special authority or in the performance of routine duties.

I. Floods, Their Occurrence, Extent, and Periodicity

The recent excavations in the Mesopotamian Valley indicate some sedimental traces of a great flood which archeologists suggest may have been the deluge referred to in the Bible. However true this may be, recorded history is replete with an almost continuous series of disasters involving the loss of life and property due to unusual flood conditions in various parts of the world.

Floods may be caused by excessive rains, as was the case in Cuba in 1791, when 3,000 people were drowned; in 1813, when 4,000 people perished in Poland, and 6,000 people were lost in Silesia by unprecedented floods; and in 1903, 1913, 1922, and 1927 in the lower Mississippi River Basin; by the bursting of banks of rivers, lakes, and reservoirs as in the overflow of the Danube in 1811, the Yellow River in 1851, and the rising of the Seine in 1910; by the eruptions of the sea such as occurred in Japan in 684, at Catalonia, Spain, in 1617, and in the enlargement of the Zuyder Zee and other great floods in Holland.

A study of available flood records indicates that at intervals great floods occur over wide areas. Thus in 1726, 1852, and 1929 unusual flood and storm conditions obtained throughout Europe. Similarly, periodically great floods occur in one section of the world, such as the overflow of the Yellow River in China in 1851, the flood on the Hoang Ho River in 1887 when 900,000 people perished, the Yangtse flood in 1911 with a loss of life of 100,000, and the great floods of 1914 and 1915 in the West River Valley, accompanied with great life and property devastation and loss. In the United States, the recent great Mississippi River flood of 1927 recalls the previous series of floods that have occurred in this basin since the early account of Fernando de Soto's trip down the Mississippi in 1539:

> Then God, our Lord, hindered the work with a mighty flood of the great river, which, at that time—about the 8th or 10th of March (of 1543)—began to come down with an enormous increase of water, which in the beginning overflowed the wide level ground between the river and the cliffs; then little by little it rose to the top of the cliffs.[1]

[1] La Florida del Inca, by Garcilaso de la Vega, quoted by Glenn W Caulkins, Cashmere, Wash See Flood Control, compiled by Lamar T Beman

On the 18th of March of 1543, which that year was Palm Sunday, when the Spaniards were marching in procession, the river entered with ferocity through the gates of the town of Aminoya, and two days later they were unable to go through the streets except in canoes.

The flood was 40 days in reaching its greatest height, which was the 20th of April, and it was a beautiful thing to look upon the sea where there had been fields, for on each side of the river the water extended over 20 leagues of land and all of this area was navigated by canoes, and nothing was seen but the tops of the tallest trees.

On account of these inundations of the river the people build their houses on the high land, and where there is none, they raise mounds by hand, especially for the houses of the chiefs; the houses are constructed three or four stages above the ground, on thick posts that serve as uprights, and between uprights they lay beams for the floors, and above these floors which are of wood, they make the roof, with galleries around the four sides of the house where they store their food and other supplies, and here they take refuge from the great floods. The floods do not occur every year, but when in the regions where the rivers have their source there have been heavy snows the preceding winter with rains in the following spring; and thus the flood of 1543 was very great on account of the heavy snow the preceding winter. These floods occur every 14 years, according to what an old Indian woman told us, which can be verified if the country is conquered, as I hope it will be.

Considerable study has been given to the matter of the extent and nature of floods, but their causes and periodicity are still a matter of conjecture as far as underlying natural laws or relations are concerned.

A recent observer [2] points out the extraordinary climatic changes apparently due to the influence of ice flows and deflections of such currents in the oceans as the Humboldt, Guinea, and Benguella currents. For example, the outburst of ice between 1895 and 1897 from the Antarctic was accompanied with far-reaching climatic repercussion:

In India 1893 and 1894 were years of excessive rainfall, then in 1896 and 1899, came years of drought followed by widespread famine. In 1899–1900 upwards of 6,500,000 people were on famine relief for several months. Australia also suffered. In New South Wales and Queensland almost continuous drought prevailed from 1896 to 1902.[3]

Another observer [4] has made a study indicating the deflection westward of the Humboldt current in 1925, and causing abnormal rainfall along the arid coasts of Ecuador, Peru, and Chile. This condition has occurred periodically at intervals of about 34 years, which reminds one of the so-called Brückner cycle theory of great rainfall and flood conditions about every 35 years.

A recently developed theory of flood occurrence suggests great floods about 35 years apart and extraordinary floods or superfloods at intervals of about 100 years. However, the available data are not sufficient to substantiate this theory for any locality or section of the world. On the Mississippi River, for example, the superfloods have occurred in 1785, 1844, 1903, 1913, 1922, and 1927. It will be noted that there is an interval of 59 years between the first and second, and the second and third floods. But in more recent years this interval seems to have been reduced to five years. What will occur in 1962 (59 years from 1903) no one can foretell.

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[2] Otto Pettersson, the Geographical Review. January, 1929.

[3] Otto Pettersson, the Geographical Review. January, 1929.

[4] R. C. Murphy, Geographical Review, vol. 16, 1926, pp. 26–54.

II. Floods in the Mississippi River Basin

Floods in the Mississippi River Basin have become one of the great internal problems of this Nation as evidenced by the nation-wide attention and interest resulting from the latest great flood of 1927. The heart of this country, geographically, is the drainage basin of the Mississippi River, its tributaries, and their headwaters, an area of about 1,250,000 square miles, or approximately 41 per cent of the total area of the United States. The waters from 31 States pour into this basin, and in 1927 an area of 30,000 square miles was inundated. The devastation wrought by this last great flood included the death of several hundred persons, an additional 600,000 people were driven from their homes, and a property loss of about $270,000,000.

Floods occur in the Mississippi Basin every spring and, in more recent times, great floods occur at intervals of about five years. Floods of notable extent have been recorded in the years 1718, 1735, 1770, 1782, 1785, 1791, 1796, 1799, 1809, 1811, 1813, 1815, 1816, 1823, 1824, 1828, 1844, 1849, 1850, 1851, 1858, 1859, 1882, 1883, 1890, 1897, 1903, 1912, 1913, 1922, and 1927.

A study of the behavior of these floods indicates the normal flood conditions of the various tributaries as follows:

The upper Mississippi River undergoes a single annual rise that reaches its height about the middle of May and then drops gradually until the latter part of August. From this time on until January, there is a fairly uniform low stage, which is then followed by a gradual rise to the crest in May.

The Missouri River has generally a small winter swell due to rains and then a slight decline in stage until the middle of May, when a rapid rise occurs, reaching its crest about the middle of June. This rise is occasioned by rains together with melting snows on the headwaters. During the latter half of each year the fall is continuous and decreasing in rapidity as time goes on. The continued high water period at St. Louis shows the combined effect of these two independent rises, as the upper Mississippi rise is usually closely followed by the Missouri rise.

The Ohio River has a regimen that in recent years has greatly lengthened the flood period at Cairo due to its early rise. A rapid rise of the river starts in November and increases until January when a fall occurs. Then melting snows with rains on the headwaters occasion another rise in February and continues until a crest at Cairo is reached about the middle of March. This high stage often continues until the middle of April, when the fall begins slowly.

The Arkansas River starts a gradual rise in November and reaches the crest early in May. The flood stage generally continues for about a month, and then falls gradually until August. Ordinarily the flood discharge of the Arkansas follows the main flood crest down the Mississippi and has little effect on flood conditions on the lower river.

The Red River has a similar regimen to the Arkansas, with a flood stage from the first to the middle of May and low-water conditions the latter part of September. Like the Arkansas the high water of this river has little effect generally on the normal floods of the Mississippi. In 1927, however, floods from both the Red and

Arkansas Rivers occurred at a high stage of the lower Mississippi, and produced a crest which seriously threatened the safety of New Orleans.

These conditions of flood flows in the tributaries acting independently do not result in great or superfloods. The latter result from the unusual conditions of rainfall and run-off and the synchronizing of flood peaks from several main tributaries. Generally, the Missouri and upper Mississippi have coordinated flood stages. When the Ohio flood crest coincides with that of the Mississippi at Cairo, a great flood such as that of 1913 occurs. The White, Red, and Arkansas are erratic and rarely affect the flood stages on the lower Mississippi to any marked degree. The flood of 1927 was a notable exception.

On the lower Mississippi the average flood condition is described by a recent report by the United States Weather Bureau:

This year (1929) we are maintaining about the average condition in both the Ohio and lower Mississippi Rivers. The crest of a general Ohio River flood of good, although not dangerous, proportions will pass the mouth of the river March 20 or 21 with a crest stage at Cairo, Ill., close to 52 feet, 7 feet above flood line of 45 feet. It will pass Memphis, Tenn., about March 24 or 25 with a peak stage in the neighborhood of 41.5 feet, 6.5 feet above the flood stage of 35 feet, and Arkansas City, Ark., about March 28 with a crest between 53 and 54 feet, flood stage being at 48 feet.

The crest should reach Vicksburg, Miss., very near the end of the month with a crest of 51 feet or so, the flood line being at 45 feet. Below Vicksburg the flood wave will continue its leisurely course and, wind and weather permitting, should pass New Orleans toward the end of the first week in April, with a crest possibly a foot or two above the flood stage of 17 feet.[5]

Since the establishment of the Mississippi River Commission in 1879 the following notable floods have occurred:[6]

FLOOD OF 1882

In this flood the lower Mississippi was moderately high at the beginning of the year. During the early part of January the Mississippi at St. Louis, Cairo, and Memphis was falling slightly, while from the effects of the rains in the St. Francis, White, and Yazoo Basins the lower section was rising. Into this well-filled lower stretch of stream was precipitated the first Ohio rise, which kept the river quite full below Cairo until the second rise from the Ohio, principally from the upper Ohio, occurred, synchronizing with a sharp rise of the Mississippi at St. Louis.

FLOOD OF 1883

This flood was characterized by one great swell, which established a new high stage on February 27 at Cairo. The rise was brought about principally by an Ohio flood, which was aided somewhat by a rise in the upper Mississippi. This was a type of purely Ohio flood, the Ohio descending upon a rather low river below Cairo.

FLOOD OF 1890

The 1890 flood had three swells, principally from the Ohio. The peak was produced by a combination of heavy rains in the Ohio drainage and in the central valley. The Missouri, Arkansas, and Red Rivers played no part in the development of the flood.

FLOOD OF 1897

The genesis of this flood appears to have been as follows:

The lower Mississippi in the early part of February was at flood stage. Into it was poured a great flood from the Ohio. At the same time the alluvial bottom land had been filled by heavy rainfall. The river was brought to full flood by the middle of March. It was then maintained in flood chiefly by heavy rain-

[5] Dr. H. C. Frankenfield, United States Daily, Mar. 21, 1929.
[6] Referendum No. 31, U. S. Chamber of Commerce, Oct. 31, 1927.

fall over the central valley and Arkansas Basin, aided by high water in the upper Mississippi. The river was at flood height for nearly two months.

This flood overflowed nearly 14,000 square miles of the central valley. Losses resulted from many causes, among which may be enumerated the destruction of buildings, fences, levees, the drowning of stock, ruining of crops, and prevention of subsequent planting. A large area was flooded in the St. Francis Basin. The levees along the main Mississippi extended at this time a distance of 125 miles. The effect of leveeing the west bank of the Mississippi compelled the water to pass down from Cairo to Helena without relief into the St. Francis Basin. Below Helena the flood proved to be the most disastrous on record. The losses were principally property damage and loss of livestock. No loss of human life appears recorded.

FLOOD OF 1903

The flood of 1903 was another Ohio flood. The rise was practically continuous from Cairo to the Gulf, similar to the 1897 flood, with the exception that in the 1903 flood there was no rise of consequence above the mouth of the Ohio on the Mississippi. The Red and Ouachita Rivers contributed materially to the lower river stages. There was also during the flood and previously a heavy precipitation on the central alluvial bottom lands.

Since the 1897 flood the St. Francis system of levees had been extended from 125 to 175 miles along the west bank of the Mississippi. As a result, some 3,000 square miles additional of flood plain had been reclaimed from the river and the immense volume of water which had formerly found relief in this area was confined to the river channel, the direct consequence of which was an abnormal increase in the height of flood crest without an unusual increase in initial flood volume at Cairo.

FLOOD OF 1912

The annual rise of the lower Mississippi River in this year was accentuated by a severe storm from the southwest which moved northeastward over the lower Mississippi and Ohio Valleys attended by general and heavy rains. There were two crests in the Mississippi River at St. Louis which met high flood stages in the Ohio. Flood stage prevailed for 45 days in all. At New Orleans there was a single crest of 22 feet, which was 1.6 feet above the previous high-water record. This crest stage represented the maximum effect of wind and water and was as high as it could have been under any combination of existing circumstances. The flood losses were similar to those of other floods, the estimated total damage to property being $78,000,000, one-third of which was property exclusive of crops, and one-third crop damages.

FLOOD OF 1913

The flood of 1913 is generally considered the great flood of the Ohio. It was this flood which caused immense losses in the vicinity of Dayton, Ohio, and stimulated flood-prevention measures later taken by the Miami conservancy district. The river stages at St. Louis were considerably below previous records. Western tributaries were at moderate stage. Low crest stages occurred in the central valley toward the south due to breaks in the levees which occurred in the upper reaches below Cairo. The area overflowed, whether from crevasse water or backwater, was less in the 1913 flood than in the flood of 1912. Repairs to the 1912 breaks had not been wholly completed in many places when the 1913 flood occurred.

FLOOD OF 1922

The outstanding features of the 1922 flood are, first, the general distribution of the flood over all main tributaries, the only exception being in the Tennessee and Cumberland Rivers. So far as actual records or reported tradition show, the main stream and all its tributaries had never before been in general flood at the same time; second, the 1922 flood had unprecedentedly high stages in its lower reaches below the mouth of the Arkansas and White Rivers. Had the levees remained intact, the average stages of this flood would have been 1 foot higher over the previous records, according to Weather Bureau reports.

FLOOD OF 1927

The 1927 flood was similar in many respects to the 1922 flood. None of the major drainages, with the exception probably of the Arkansas and the central valley, can be charged with extreme flood conditions. The upper portions of the

Mississippi drainage, including the Missouri, upper Mississippi, and Ohio, contributed only in a small measure to the flood crest. However, heavy rains in their lower reaches brought all three streams into flood simultaneously, producing a record gauge height at Cairo and unprecedented flood conditions from there to the Gulf because of floods encountered from the western tributaries and in the central valley. The western tributaries, the central valley, lower reaches of the Missouri and the Tennessee and Cumberland Rivers are largely responsible for the 1927 flood, the greatest flood of the Mississippi of which we have any knowledge.

As will be noted, the flood of 1927 was the greatest in the lower Mississippi Valley of which there is record, and yet the upper tributaries were not in unusual flood nor contributed materially to conditions in the lower basin. It is within the limits of reason to assume the possibility of atmospheric conditions such as to bring about a gigantic flood condition with the synchronization of the flood waters of all the tributaries; namely, the simultaneous converging of floods from the Missouri, upper Mississippi, and the Ohio Rivers at Cairo and the subsequent addition of flood waters from the Red, White, and Arkansas Rivers.

III. Geologic History and Physical Character of Mississippi Basin

The Mississippi Basin is a heart-shaped area occupying practically 41 per cent of the central sections of the United States and discharging in a general southerly direction into the Gulf of Mexico.

The principal divisions of the Mississippi Basin are as follows:[7]

Basin	Area in square miles	Per cent of total area
Ohio	203, 900	16
Upper Mississippi	187, 850	15
Missouri	528, 850	43
Arkansas and White	186, 000	15
Red	90, 000	7
Lower Mississippi	54, 300	4
Total	1, 250, 900	100

The drainage basin is in general an immense plain, extending from the Allegheny Mountains on the east to the Rocky Mountains on the west, bounded on the north by the watersheds of the St. Lawrence and Saskatchewan Rivers, and on the south contracted to a narrow outlet between the Tombigbee and Pearl River drainage on the east and the Sabine River watershed of Louisiana on the west. The plain is broken by low ridges between the streams, and the Ozark Mountains of Arkansas and Missouri and the Black Hills of South Dakota.

The principal divisions of the basin, as noted above, show a clearly marked drainage system with several large tributary streams joining the main river like the branches of a tree. The major tributaries are the Ohio on the northeast, the upper Mississippi on the north, the Missouri on the northwest, and the White, Arkansas, and Red on the west. The Missouri joins the upper Mississippi just above St. Louis, the Ohio enters the Mississippi at Cairo, and lower down the White, Arkansas, and Red Rivers in turn between Memphis and Baton Rouge.

[7] Monthly Weather Review, Supplement No. 22, 1927.

An early student [8] of the Mississippi River assumed that the original delta plain commenced at the mouth of the Ohio River and that there originally existed a great falls of some 275 feet at that point, and similarly a falls or sharp descent at the chain of rocks above Commerce, Mo. This plain or embayment was about 600 miles long and had a slope of about 6 nches to the mile to the south. The breadth of the plain at the mouth of the Ohio was 50 to 60 miles and at the Gulf about 150 miles. The area was about 34,000 square miles, or approximate.y that of the State of Indiana. Over this plain Ellet estimated a river length of 1,178 miles and a high-water slope of 3¼ inches to the mile.

The modern geologic knowledge of the Mississippi Valley is exemplified in the Marbut [9] theory, which assumes that the Mississippi originally flowed west of Crowleys Ridge and did not join the Ohio until the two streams reached the lower end of that ridge near Helena, Ark. Later the Mississippi was diverted through gaps in Crowleys Ridge, probably as a result of capture by small tributaries of the Ohio River.

The early observers advanced the theory that the Mississippi River Valley as it now exists was built up like a true stream delta by river deposit, such as in the case of the Yellow River in China. Later students, however, believe that the original plain was formed by a great glacial river, which occupied a much wider space than the present stream. This great plain was tilted, subsequent to its formation by glacial water. This theory is substantiated by the discovery of sand dunes in the upper part of the alluvial valley near Poplar Bluff, marking the northern boundary of the ancient beach. Humphreys and Abbot and many subsequent observers have noted that a substratum of blue clay forms the real bed of the river from the mouth of the Ohio to the Passes. On this substratum rest the moving sand bars, alluvium and surface vegetation.

As the alluvial deposit varies from outcrops of blue clay in the Yazoo bottom and east of the Mississippi near Natchez to a thickness of 25 to 35 feet in the St. Francis and upper section of the Yazoo Basins, it is evident that the basin of the lower Mississippi was formed by the deposition of sedimentary matter and that the lower river has the general characteristics of an alluvial type of stream.

These sedimentary formations which underlie the present river basin were not deposited by this river. Over this plain the river has gradually made its course under conditions somewhat different from those that govern the flow of true delta streams. Evidence seems to indicate that the river channel has not materially changed for a long time. The overflows of the river in past centuries have built up an alluvial delta with banks adjacent to the river and sloping from 3 to 4 feet per mile for 5 to 6 miles inland from the river.

The channel shifts continually, due to current action at bends and cut-offs, but it has not been proved that the river length remained nearly a constant over a long period of time. There is reason to assume that the bluffs on the east side of the lower Mississippi Valley and those adjacent to Crowleys Ridge on the west side have been

[8] Ellet, Mississippi and Ohio Rivers.
[9] C. F. Marbut, the Evolution of the Northern Part of the Lowlands of Southeastern Missouri; Missouri University Studies, Vol. I, No. 3.

cut by the river. Hence it is fairly certain that the river has changed its course many times, flowing sometimes along one bluff, and sometimes along the other.

Below New Orleans, the river has gradually formed a true delta. It has been estimated [10] that 7,000,000,000 cubic feet of sediment are deposited annually in the Gulf of Mexico near the mouth of the Mississippi River. Humphreys and Abbot's reports on the Mississippi River give an estimate of 750,000,000 cubic feet, while a recent report [11] assumes about twice this amount. Ellet intimates that the Mississippi Delta has been gradually built out over a very long period of time and has slowly built up its general surface elevation very much as the records indicate in the case of the River Po in Italy, where, over a period of 2,000 years, the river has extended its outlet about 15 miles into the Adriatic Sea.

Authorities differ as to the original mouth or outlets of the Mississippi River. There are four possible outlets as indicated by existing principal divisions of the Delta region; the Atchafalaya Basin, the La Fourche Bayou, the present river channel and the Lake Pontchartrain district. The Atchafalaya Basin lies to the east of New Iberia and has an area of about 4,500 square miles. Between this basin and the present river channel lies Bayou La Fourche with an area of about 2,500 square miles. To the east of the river and north of New Orleans is the district including Lake Maurepas and Lake Pontchartrain with an area of about 2,300 square miles. These divisions of the Delta region are largely of interest as to their possible future modification and utilization to provide for the disposal of flood waters.

IV. Hydrology of the Mississippi River and Its Major Tributaries

RAINFALL

The character and extent of Mississippi floods are largely due to heavy rains over the central and lower valleys of the basin.

> Their magnitude will depend upon, first, the amount of rain in individual storms; second, their duration, that is, the recurrence of a sequence of storms following each other; and, third, the extent to which the rain storms synchronize in their distribution and time of occurrence with the downstream progress of the flood crests in the tributary and main rivers.[12]

The normal rainfall for the principal divisions of the Mississippi River Basin is given in the following table:

[10] Ellet, Mississippi and Ohio Rivers.
[11] The Mississippi River, a Review and Analysis, H. N. Sulliger.
[12] Monthly Weather Review, Supplement No. 29, 1927.

TABLE 1.—*Normal rainfall for Mississippi River basins*

[In inches]

Month	Upper Mississippi Basin	Missouri Basin	Ohio Basin	Arkansas Basin	Red Basin	Lower Mississippi Basin
January	1.51	.75	3.93	1.59	2.76	4.67
February	1.46	.66	3.35	1.48	2.67	4.12
March	2.14	1.26	4.34	2.13	3.46	4.85
April	2.86	2.23	3.83	2.98	4.48	4.81
May	5.10	3.28	3.97	3.69	4.45	4.44
June	4.08	3.43	4.29	3.30	3.74	4.23
July	3.44	2.86	4.46	3.16	3.39	4.37
August	3.32	2.55	4.01	3.14	3.26	3.99
September	3.20	2.30	3.09	2.60	2.80	3.25
October	2.40	1.58	2.95	2.19	2.89	2.98
November	1.83	.93	2.79	1.67	2.78	3.64
December	1.48	.80	3.71	1.57	3.33	4.54
Total	31.82	22.81	44.70	29.30	40.01	49.87

TABLE 2.—*Precipitation A and departure from normal B for six floods*

[In inches of water if spread over entire Mississippi drainage]

	1882				1903			
	Jan.	Feb.	Mar.	Total	Jan.	Feb.	Mar.	Total
A								
Grand division:								
Upper Mississippi	0.17	0.49	0.44	1.10	0.10	0.24	0.33	0.67
Missouri	.20	.55	.44	1.19	.23	.53	.47	1.23
Ohio	.94	.92	.73	2.59	.33	.86	.59	1.78
Arkansas and White	.24	.47	.31	1.02	.11	.50	.27	.88
Red	.35	.29	.20	.84	.13	.41	.26	.80
Lower Mississippi	.37	.31	.26	.94	.17	.33	.25	.75
Total	2.27	3.03	2.38	7.68	1.07	2.87	2.17	6.11
B								
Grand division:								
Upper Mississippi	−.04	+.29	+.14	+.39	−.11	+.04	+.03	−.04
Missouri	−.10	+.22	−.06	+.06	−.07	+.20	−.02	+.11
Ohio	+.29	+.39	+.02	+.70	−.32	+.33	−.12	−.11
Arkansas and White	+.03	+.25	−.01	+.27	−.10	+.28	−.05	+.13
Red	+.17	+.12	−.03	+.26	−.05	+.24	+.03	+.22
Lower Mississippi	+.16	+.12	+.04	+.32	−.04	+.14	+.03	+.13
Total	+.51	+1.39	+.10	+2.00	−.69	+1.23	−.10	+.44

	1912				1913			
	Feb.	Mar.	Apr.	Total	Jan.	Feb.	Mar.	Total
A								
Grand division:								
Upper Mississippi	0.16	0.30	0.50	0.96	0.24	0.20	0.48	0.92
Missouri	.45	.87	1.12	2.44	.35	.44	.68	1.47
Ohio	.37	.83	.83	2.03	.98	.37	.58	1.93
Arkansas and White	.31	.43	.50	1.24	.31	.24	.23	.78
Red	.13	.35	.29	.77	.22	.20	.15	.57
Lower Mississippi	.12	.34	.34	.80	.34	.21	.22	.77
Total	1.54	3.12	3.58	8.24	2.44	1.66	2.34	6.44
B								
Grand division:								
Upper Mississippi	−.04	+.00	+.08	+.04	+.03	+.00	+.18	+.21
Missouri	+.12	+.38	+.27	+.77	+.05	+.11	+.19	+.35
Ohio	−.16	+.13	+.21	+.18	+.33	−.16	−.13	+.04
Arkansas and White	+.09	+.11	+.05	+.25	+.10	+.02	−.09	+.03
Red	−.04	+.12	−.02	+.06	+.04	+.03	−.08	−.01
Lower Mississippi	−.07	+.12	+.12	+.17	+.13	+.02	+.00	+.15
Total	−.10	+.86	+.71	+1.47	+.68	+.02	+.07	+.77

TABLE 2.—*Precipitation A and departures from normal B for six floods*—Con.

	1922					1927				
	Jan.	Feb.	Mar.	Apr.	Total	Jan.	Feb.	Mar.	Apr.	Total
A										
Grand division:										
Upper Mississippi	0.16	0.31	0.35	0.53	1.35	0.15	0.15	0.40	0.64	1.34
Missouri	.29	.44	.89	1.48	3.10	.25	.28	.63	1.59	2.75
Ohio	.44	.41	.92	.66	2.43	.67	.54	.82	.95	2.98
Arkansas and White	.18	.21	.60	.62	1.61	.30	.16	.48	.69	1.63
Red	.19	.22	.40	.36	1.17	.17	.17	.29	.42	1.05
Lower Mississippi	.19	.21	.36	.16	.92	.16	.18	37	.33	1.04
Total	1.45	1.80	3.52	3.81	10.58	1.70	1.48	2.99	4.62	10.79
B										
Grand division:										
Upper Mississippi	−.05	+.11	+.05	+.11	+.22	−.06	−.05	+.10	+.22	+.21
Missouri	−.01	+.11	+.39	+.63	+1.12	−.05	−.05	+.14	+.74	+.78
Ohio	−.21	−.12	+.21	+.04	−.08	+.02	+.01	+.11	+.33	+.47
Arkansas and White	−.03	−.01	+.28	+.17	+.41	+.09	−.06	+.16	+.24	+.43
Red	+.01	+.05	+.17	+.05	+.28	−.01	+.00	+.06	+.11	+.16
Lower Mississippi	−.02	+.02	+.14	−.06	+.08	−.05	−.01	+.15	+.11	+.20
Total	−.31	+.16	+1.24	+.94	+2.03	−.06	−.16	+.72	1.75	2.25

The unusual precipitation conditions of great floods are shown in Table 2. It is interesting to note that measured by the comparative depths of water precipitated over the entire drainage basin, the relative order of magnitude of these six great floods of the last half century is 1927, 1922, 1912, 1882, 1913, and 1903. But direct comparison between such floods can not be properly made, as there are peculiar features that have modified results from time to time. For example, a comparison of the floods of 1882 and 1912 would have to take account of the fact that from Cairo south in 1882 the general levee system was relatively new, while in 1912 it was nearing completion. Furthermore a comparison of the floods of 1922 and 1927, while indicating about the same total equivalent precipitation, does not indicate the important part that the torrential rains of April, 1927, over the lower Arkansas Valley played in producing the excessive flood crests in the lower river.

It will be noted that the excessive rainfall during the height of the flood of March and April, 1927, was almost entirely within the lower river basin. Twenty-five inches or more of rain fell, during these two months in northern Alabama, part of Mississippi and southeast Louisiana. From 18 to 25 inches of rain fell over the rest of Mississippi, eastern Arkansas, and Louisiana, western Tennessee, and extreme southwest Kentucky. Fourteen to eighteen inches fell over another section of Tennessee, southwest Kentucky, southern Illinois, southeast Missouri, eastern Arkansas, and Louisiana. Ohio, Pennsylvania, West Virginia, eastern Kentucky, and Tennessee had from 6 to 10 inches of rainfall. This accounts for the unusually low stage of the Ohio. In 1913 the flood came largely from the Ohio, thus reversing the conditions of 1927.

RUN-OFF

Humphreys and Abbot and Greenleaf give the run-off as follows (as quoted in Supplement No. 29 of the Monthly Weather Review, 1927):

Ratio of discharge to precipitation

Basin:	Ratio
Ohio	0.30
Upper Mississippi	.28
Missouri	.15
Arkansas	.16
Red	.22
Lower Mississippi	.52
Entire basin	.25

In 1897 the Weather Bureau computed the normal annual precipitation to be 30.11 inches on the basis of a weighted average annual rainfall of water sufficient to cover the entire Mississippi watershed to a depth of 30.11 inches. Using 0.25 as the ratio of discharge to precipitation, the total annual discharge would be 502,174,900 acre-feet. The discharge figures for five floods are as follows:

Discharge in millions of acre-feet for five floods based upon an average ratio of run-off to rainfall of 0.25 and upon precipitation records for the months of January, February, March, and April

	1882	1912	1913	1922	1927
Upper Mississippi	12.4	18.0	17.3	25.4	25.0
Missouri	12.4	24.2	14.8	31.0	27.5
Ohio	35.3	41.0	38.4	48.3	59.6
Arkansas and White	9.3	13.6	8.0	17.3	17.4
Red	11.8	11.1	8.0	17.3	15.4
Lower Mississippi	26.0	27.9	26.6	31.6	36.0
Total	107.2	135.8	113.1	170.9	180.9

The run-off characteristics of the Mississippi Basin above Cairo are fairly well defined and have been changed but slightly by the works of man. Below Cairo, however, these elements are continually changing with the development of levees, cut-offs, spillways, and other artificial works, and will continue to change until a definite permanent program of flood control has become established.

Let us now consider the physical features as affecting the run-off for the various principal basins of the Mississippi River system:

The Ohio Basin lies largely along the western slopes of the Alleghany and Blue Ridge Mountains, where the Tennessee, Cumberland, Kentucky, Big Sandy, Great Kanawha, Little Kanawha, Allegheny, and Monongahela Rivers flow through steep, rugged, and generally heavily timbered country and into the Ohio. It is these streams which contribute a large part of the volume of water that results in the periodic floods on the Ohio and lower Mississippi Rivers. The watershed rainfall averages about 43 inches per annum and the run-off averages about 32 per cent. With the exception of the Wabash River which drains the northern plateau region between the Ohio River and the Great Lakes, the other principal tributaries flow largely through rather narrow, steep valleys with a relatively rapid run-off.

In the headwaters, this run-off is occasionally considerably augmented by melting snows in the late spring. Many of these tributaries furnish opportunity for flood control by retarding reservoirs, as in the case of the Miami conservancy district. The Tennessee River is being rapidly developed as a power stream, and this development helps to reduce variations in flow and flood heights more and more toward the annual mean. In the Ohio watershed, flood control studies have been made,[13] and much local benefit is anticipated from the construction of reservoirs.

The upper Mississippi Basin includes all that section of the river above the mouth of the Ohio River. This upper part of the Mississippi rises in a large group of lakes and ponds in northern Minnesota and flows through a rather flat country to the Falls of St. Anthony, which is the head of navigation and about 700 miles above the mouth of the Missouri River. This basin extends from the narrow divide that separates it from the Red River of the North easterly nearly to Lake Michigan. It is relatively low and level. In the upper reaches is the series of six reservoirs built at the headwaters for the purpose of aiding low-water navigation on the river below St. Paul. The capacity and cost of this system of reservoirs is given as follows:

Reservoir	Capacity, acre-feet	Cost	Cost per acre-foot
Lake Winnibigoshish	967, 170	$368, 200. 00	$0. 38
Leech Lake	743, 340	246, 800. 00	. 33
Lake Pokegama	120, 760	197, 000. 00	1. 63
Sandy Lake	72, 500	218, 000. 00	3. 00
Pine River Reservoir	177, 520	215, 500. 00	1. 21
Gull Lake	70, 970	77, 200. 00	1. 08
Total	2, 152, 226	1, 322, 700. 00	. 61

The effect [14] of the operation of these reservoirs in reducing the floods of the lower Mississippi was studied for each of the great floods of recent years with the following results:

1912: In this year the flood crest reached Cairo in the early part of April, and the operation of the Minnesota Reservoir system caused a reduction of about 1,100 cubic foot-seconds, or about one-fifth of an inch on the gage at Cairo.

1913: Flood crest reached Cairo early in April. The upper Mississippi was at a low stage at the time corresponding to this flood wave and the reservoirs were discharging water in order to maintain navigable depths. This resulted in increasing the flood discharge by about 230 cubic foot-seconds.

1916: Flood crest reached Cairo early in February. Conditions in upper Mississippi were similar to those in 1913, and operation of reservoirs increased the flood discharge about 250 cubic foot-seconds.

1922: This flood had two approximately equal crests at Cairo, the first late in March and the second late in April. The operation of the reservoirs reduced the earlier crests by 500 cubic foot-seconds and the later crests by 1,700 cubic foot-seconds, about one-third of an inch on the gage at Cairo.

1927: Flood crest reached Cairo just after the middle of April. Operation of reservoirs caused reduction of about 1,200 cubic foot-seconds, or slightly more than one-fifth of an inch on the gage at Cairo.

In 1912, 1922, and 1927, the reservoirs were storing the entire flow of the streams except the minimum that must be passed to prevent damage to navigation and power development. If they had been operated solely for the benefit of the

[13] Report of Flood Commission, Pittsburgh, Pa., 1911.
[14] Report on the Control of Floods of the Mississippi River by Means of Reservoirs, House Document No. 2, 1927.

Mississippi floods, they could have done no more without damage to these interests. In 1913 and 1916 they were contributing a small increase to the Mississippi floods in order to prevent loss to the navigation and power interests.

With a drainage area of 187,850 square miles, the average annual rainfall is about 35 inches and with a run-off of about 27 per cent.

The Missouri is the largest of the principal basins of the Mississippi watershed. It has an unusual variety of features from its northern extremity about 75 miles north of the Canadian boundary to the mouth of the river at St. Louis, and from the Rocky Mountains on the west easterly to the main river. The western part of the basin is mountainous and characterized by rugged ridges and spurs which supply a fairly regular and uniform run-off in the melting of the snow in the late spring. The rapid mountain streams pass through deep gorges where favorable storage opportunities are limited. From the base of the mountains extensive barren plains gradually merge into the wide, fertile farm areas of the Dakotas and Nebraska. The Missouri River is formed by the junction of the Jefferson, Madison, and Gallatin. The principal tributaries are the Yellowstone River in the upper section and the Platte and Kansas Rivers in Nebraska and Kansas. Investigations indicate that source stream control is possible on the headwaters; a feasible storage capacity of about 1,000,000 acre-feet on the Jefferson and a somewhat less amount on the Madison and Gallatin. The Missouri is a factor of less importance than the Ohio in the flood situation in the Mississippi basin. The great floods of the past have demonstrated the possibility of a flood from the Missouri either synchronizing with one from the Ohio, as occurred in 1858, or in prolonging the period of flood in the lower Mississippi basin by following closely after, as occurred in 1897. The entire watershed, draining an area of slightly more than one-half million square miles, has an average annual rainfall of about 20 inches and a run-off of nearly 12 per cent.

The Arkansas Basin just to the south of the Missouri Basin is similar in general topography and extends from the Rocky Mountains in Colorado and New Mexico to the main river. The river rises near Leadville, Colo., and passes through the mountains in a gorge near Canyon City. Flowing in a general easterly direction the river passes Pueblo and through an arid, sandy region. Beyond the mouth of the first principal tributary, the Cimarron, the river becomes winding and is broken by many sand bars and islands. Just below the junction of the Canadian River, the Arkansas passes through the Ozark Mountains. Emerging from this rugged country, the river enters the alluvial plain of the Mississippi Valley. In this section, the river is subject to overflow as occurred in 1927, and which affected communities as far west as Little Rock. In 1926, an Interstate Commission [15] made a report on a system of flood control by reservoirs in this basin.

The Red River Basin lies just to the south of the Arkansas Basin. The river rises in the region southeast of the Rocky Mountains in northwestern Texas and flows southeasterly across a barren gypsum desert and for several hundred miles forms the boundary between Oklahoma and Texas. After entering the northwest corner of Louisiana the river passes through many large swamps and bayous.

[15] Professional Engineer, July, 1927, Flood Control. E. E. Blake.

The Atchafalaya River runs due south from the Red about seven miles west of its junction with the Mississippi. It is probable that before the construction of levees, the Atchafalaya carried much of the surplus flood waters of the Red directly to the Gulf, and thus diverted them from the main river. It has been thought that the Atchafalaya was originally the direct outlet for the river, but it is likely that it has only been a large, natural valley drain, and has served as a spillway outlet. The survey and report made by the Interstate Flood Commission for flood control by reservoirs in the Arkansas Basin also included a similar investigation for source stream control in the Red Basin.

The lower basin includes the great plain or embayment below the mouth of the Missouri. Near the head of this basin are two rivers, each of which drains a large area, the Yazoo on the east and the St. Francis on the west. The principal flood districts or basins of this valley are the following:

East of the Mississippi and south of Cairo is a low, swampy region subject to periodic overflow known as the American Bottom. In the southern part of this district is Reelfoot Lake, which is a natural basin having an area of about 1,000 square miles.

South of Memphis on the east side of the basin lies the Yazoo Basin. This great alluvial plain drained by the Yazoo River has an area of about 6,500 square miles. It was originally heavily timbered. The plain has a slope away from the river of about 0.4 foot per mile and from north to south of about 0.6 foot per mile. The basin is protected by levees except for backwater at its southern extremity.

On the west of the Mississippi the northernmost basin is the St. Francis, which extends from Cape Girardeau, Mo., to Helena, Ark. About two-thirds of the entire area of over 6,000 square miles of this basin is low bottom land and subject to overflow except where protected by levees. A large part of this area was flooded in 1927. The basin is nearly level with a slope to the south of nearly three-quarters of a foot to the mile and from east to west of about one-half foot per mile. Crowley's Ridge is a ridge of land extending from Stoddard County, Mo., for a distance of about 150 miles to Helena, Ark., on the main river. This ridge has a width of from 1 to 12 miles and an elevation above the adjacent lowlands of from 100 to 200 feet. Geologists generally agree that in early times the Mississippi River ran west of this ridge, presumably following along the present courses of the Black and White Rivers.

The southern end of Crowley's Ridge separates the St. Francis from the Tensas Basin to the south. The latter has an area of nearly 5,000 square miles and extends as a long, narrow area of lowlands just west of the main river to the so-called Old River outlet of the Red River. This area was largely overflowed in 1927.

West of the Tensas Basin and separated from it by a ridge lies the basin of the Ouachita and Boeuf Rivers extending from Harrisonburg, La., north to the valley of the Arkansas River. This basin has an area of about 1,500 square miles; a large part of which is low, swamp lands, which were overflowed by the flood of 1927.

The great alluvial plain which lies to the south of the Red River is known as the Delta. This area is about 10,000 square miles in extent and was originally low, marsh, or swamp lands cut through by a large number of bayous. The principal drain of this delta plain is the Atchafalaya. In the early part of the last century and before the construction of the levee system in the lower delta country, Bayou Plaquemine left the main river about 20 miles below Baton Rouge and connected with the Atchafalaya through the Grand River. The second larger drain of the Delta was Bayou La Fourche, which left the Mississippi at Donaldsonville and flowed south to the Gulf, between the main river and the Atchafalaya.

The entire central valley basin with an area of nearly 60,000 square miles has a low basin area of 29,500 square miles consisting of alluvial lands covered with river sediment and which, prior to levee protection, was subject to overflow from the periodic floods. The rainfall over this lower Mississippi Basin is generally heavy and increases to about 60 inches per year in the southern section. It is the run-off from this section of the Mississippi watershed that piling up the spring flood waters from the northern basin causes the extreme flood crests of such floods as 1785, 1844, and 1927. In the early half of the Ninteenth century and previous to the construction of the existing levee system, these side basins were subject to overflow during every high-water year and retained large volumes of water in partial storage, which prolonged the length of the flood flow and kept the crest or wave heights low.

V. Low and Flood Water Conditions in the Lower Mississippi Basin

The Mississippi River is essentially a silt-bearing stream. At high-water stages the amount of sediment carried is enormous and comes largely from the Missouri River drainage. The banks of the river are low and have always been subject to overflow by the periodic floods. The channel is generally tortuous and winding and thus establishes special conditions of flow. The bed of the channel is of relatively recent origin, while the banks are continually being cut away, thus changing the course of the river.

The river channel below Cairo has gradually established a low-water slope which is primarily governed by the slope of the Delta floor and is fixed in elevation at the rock shelf near Commerce and at the Gulf of Mexico. The channel width averages from about 2,500 feet to nearly 6,000 feet. The low-water depth varies from 6 feet at the bars to 50 feet at the pools. The Mississippi River Commission endeavors to maintain a navigation channel of 9-foot depth, but natural conditions continually tend to reduce this depth at the bars to 6 feet or less. The range from low to high water is about 40 to 50 feet, and flood velocities run up as high as 15 feet per second. The regimen of the river is largely permanent in so far as its slope, velocity, length, and cross section are in practical adjustment with its discharge and the stability of the material forming the bed and banks.

In the natural state of the river the vegetation on the banks helped to maintain and protect them against erosion. With the coming of the settlements and the clearing of the banks, this natural protection has been removed and rapid erosion and caving has resulted.

The section of the Mississippi River from the Ohio to the Red River has a length of about 770 miles and a low-water elevation of about 270 feet at the mouth of the Ohio, while at the Red River it is only about 3 feet above mean Gulf level. This section of the main river is characterized by great variations in width, depth, and discharge; high rate of erosion of banks; long periods of saturation of levees; shallow depths of river at crossings; and frequent overflows and crevasses under flood conditions. The construction of the levee system up the river has resulted in the gradual augmentation of the flow within the restricted area, and has thus increased the variation of stage and discharge between high and low water and the building up of the crossing bars.

Typical sections of the river below Cairo are the straight reach near New Madrid and the unusually crooked section near Greenville, caused by the current encroaching first on one bank and then on the other, where the current has continually eroded the concave banks and built out points or bars opposite the bends.

These conditions of river change and adjustment on the lower Mississippi are well known.[16] Sand bars are large in extent; islands and tow heads are numerous. In general the water over the sand bars is not less than 5 feet in depth and the greater part of this section of the river has water of sufficient depth for navigation. Low-water conditions that affect navigation are limited to about four months in the fall and early winter, and the river is rarely obstructed by floating ice. The low-water slope averages about 0.35 foot to the mile. There are several large oscillations from low to high water during the course of a year and a range in volume of flow of 1 to 22.

Below the mouth of Red River the Mississippi has a length of about 300 miles and the slope is quite flat. In this section of the river there is an approach to stability, with only one long variation in each year from low water to high water and return, with a variation in volume of flow of from 1 to 10. The development of the levee system has tended to transfer the instability of the upper section of the river, as regards flow conditions, to this lower section. The channel in this lower part of the river becomes more regular, uniform, and efficient as the Head of the Passes is approached. From Baton Rouge to the Passes, a distance of about 225 miles, the water flows in a single channel of a width of about one-half mile and with a depth up to 300 feet. This is the most stable section of the river, with a low-water slope to about sea level and the discharge brought about by the dynamic force of the momentum of the moving mass of water confined in the channel.

The channel of the Mississippi River below the latitude of Old River has a present capacity of about 1,400,000 second-feet, and that of the Atchafalaya River is about 500,000 second-feet.

Except by greatly increasing levee heights the flood-discharge capacity of the Mississippi River past New Orleans can not be increased, at reasonable expense, beyond 1,400,000 second-feet, the amount discharged during the flood of 1927 with a spillway below New Orleans.[17]

The office of the Chief of Engineers reported that the Jadwin plan [18] of flood control was based on a possible maximum flood as follows:

	Second-feet
At Cairo	2, 250, 000
At Arkansas City	2, 850, 000
At Old River	3, 000, 000

[16] Thomas and Watt, Improvement of Rivers, p. 28.
[17] Flood Control in the Mississippi Valley, House Document No. 90, Seventieth Congress, first session.
[18] Report of Mississippi River Commission, Nov. 28, 1927, House Committee Document No. 1, Seventieth Congress, first session.

The estimated flood flow discharges as given by the Mississippi River Commission[19] are—

	Second-feet
At Cairo	2, 250, 000
At Arkansas City	3, 110, 000
At Old River	3, 640, 000

by adding to the Cairo estimated discharge 860,000 second-feet for the Arkansas City, 230,000 second-feet, for the Red River, and 300,000 second-feet for the Central Valley. This condition assumes no retention on the tributaries or in the natural flood-way basins along the lower Mississippi, which has occurred in past floods, and has resulted in a lower estimated flood-discharge figure for Old River than for Arkansas City as in 1927.

For a possible future superflood condition it would seem to be a liberal estimate to assume a maximum over-all discharge at the latitude of Old River, the so-called bottleneck, of 4,000,000 second-feet, assuming no retention by source stream control, floodway basins, or other means.

Hence the preliminary proposed plan for the conservation, utilization, and control of the flood waters of the Mississippi River Basin will be based on the possible future need of providing for a superflood condition of 4,000,000 second-feet at the Old River section.

VI. Methods of Controlling Floods in the Mississippi River Basin

1. HISTORY

The development of methods of controlling the floods of the Mississippi River started with the earliest settlements in the lower basin and has kept pace with the development of civilization.

In 1717, De la Tour, the engineer who laid out the city of New Orleans, started the construction of a dike or levee along the river front for a distance of about 18 miles to protect the city from overflows of the river. This work was completed about 10 years later.

In 1734, an ordinance was passed that required the river front landowners to build levees within that year or suffer forfeiture of their land to the French Crown. Thus this act officially established the policy of the application of levees for flood protection in the Mississippi Valley.

As the country became settled the levees were gradually extended upstream, each landowner building the line along his river front.

By 1812,[20] Stoddard records:

> These banks extend on both sides of the river from the lowest settlements to Point Coupee on one side, and to the neighborhood of Baton Rouge on the other, except where the country remains unoccupied.

By 1828, Humphreys and Abbot indicate that the levees had been extended as far as Red River landing on the west bank and to the high bluffs at Baton Rouge on the east bank of the river. By 1844, the line of levees had been built as far north as Napoleon, Ark., on the west bank, and in disconnected sections along the Yazoo Basin.

[19] Flood Control—Hearings on Flood Control, House of Representatives, Seventieth Congress, first session, 1928, p. 4991.

[20] History of Louisiana, Stoddard.

During a period of nearly a century and a half, private interests and local governments spent large sums of money in leveeing the river to protect the adjacent lands and communities against the floods that occurred periodically. As a natural result a division of interests and jurisdiction developed, and gradually emphasized the need for a central agency to have authority and control over flood protection in the Mississippi Valley. So the Federal Government was turned to for aid early in the nineteenth century.

In 1822, the Corps of Topographical Engineers of the United States Army, upon request, made an investigation and report.[21]

In 1850, Congress enacted the swamp and overflow land act, which gave to the States of the Mississippi Valley all the wet lands then remaining unsold; the proceeds of their sale to be devoted to their reclamation by levees and drains. This was the first congressional appropriation in aid of flood protection. The effect of the resultant draining of the low lands in the northern part of the basin was to increase the flood heights on the lower river. Charles Ellet, jr., in 1850–1852, after an investigation, made a comprehensive report[22] to the Secretary of War. The following is quoted therefrom:

> It is not for one acting for the moment as an officer of the Government to criticize the past or to dictate the future legislation of Congress, yet it may not be inappropriate to say that if the vast bonus granted for the purpose of excluding the water from the swamps above, and sending it down upon the States below, had been accompanied by an adequate appropriation to enable those States below to give vent to that water, or to protect their borders from the deluge which it will bring, the good which was intended by the grant would have been accompanied by less destruction than is now certain, without additional legislation, to follow the donation.
>
> *   *   *   *   *   *   *
>
> The process by which the country above is relieved is that by which the country below is ruined.

In 1861 Humphreys and Abbot filed their monumental report.[23] During the quarter century from the time of this investigation to the organization of the Mississippi River Commission in 1879, the lower valley passed through a trying period of floods, Civil War, and reconstruction.

In 1851, 1858, 1859, 1862, 1865, 1867, and 1874 occurred floods which wrought destruction in the Delta country. In the years 1882, 1883, and 1884 the successive floods caused 712 crevasses in the levee system below Cairo.

Following and largely induced by the unfortunate conditions of the reconstruction days after the Civil War and precipitated by the disastrous flood of 1874 Congress appointed a special commission which made a report in 1875.[24] As a result of this report the Mississippi River Commission was created by act of Congress in 1879 primarily as an aid to the navigation of the river. At that time navigation was a factor in the commerce of the country and of national prosperity, while flood control was and had been considered a matter of local interest.

There were at the time of the 1927 flood about 1,880 miles of main line levees along the Mississippi River, 1,590 miles of this being below

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[21] House Document No. 35, Seventeenth Congress, second session, Bernard and Totten.
[22] Senate Executive Document No. 20, Thirty-second Congress, first session.
[23] Senate Executive Document No. 8, Fortieth Congress, first session. Report on the Mississippi River, 1861.
[24] House Executive Document No. 127, Forty-third Congress, second session.

Cairo. In the construction of these levees, there had been a varying degree of cooperation between the Federal, State, and local agencies. The official reports of the Mississippi River Commission show that from 1882 to December 31, 1926, about $225,000,000 has been expended in the construction of levees, of which amount the Federal Government contributed $68,000,000, or 30 per cent, and State and local organizations about $157,000,000, or 70 per cent.

The work of the commission was at first largely devoted to the matter of river improvement. As time went on, river improvement and flood control became more involved coordinately in the building of levees, and hence the expense was shared by the Federal and local agencies. In later years, flood control plans and measures have received an increasing amount of attention both by Congress and the commission. Prior to 1916, flood control was dealt with in Congress as a rivers and harbors matter. In 1916, the House appointed a separate committee on flood control, and this matter has since been dealt with separately both as to legislation and appropriation.

It is noteworthy that while nearly a quarter of a billion of dollars was spent on levee construction in the 45-year period 1882–1926, the report of the special engineering board of 1874–75, which led to the establishment of the Mississippi River Commission, indicated a cost of less than $46,000,000 for complete control by levees. In 1896, the levee system was only partly completed, and the report of the Chief of Engineers estimated the cost of complete protection by levees as $18,000,000. In 1912, the president of the commission estimated that a further expenditure of $73,000,000 would complete the necessary levee system. In 1924, the Chief of Engineers reported that 90,000,000 cubic yards of embankment would be required to finish the levees. In 1926 the Chief of Engineers stated in his annual report:

> The improvement is providing a safe and adequate channel for navigation and is now in condition to prevent the destructive effect of floods.

Then came the flood of 1927, the investigation of Congress and its subsequent legislation—Jones-Reid bill based on the Jadwin plan—providing for an expenditure of $325,000,000. The essential features of this plan under the authority of which the Army Engineers are now working on the control of floods in the Mississippi Basin are as follows:[25]

> The Army engineer (Jadwin) plan for flood control of the Mississippi River contemplates at this time flood control of the waters of the Mississippi in the alluvial valley only. Outside the alluvial valley control of flood waters is not so important and can wait future developments. The alluvial valley is that portion of the Mississippi Valley below Cape Girardeau, Mo. The principal subdivisions of this valley are the four great basins—the St. Francis Basin, in Missouri and Arkansas; the Yazoo Basin, in Mississippi; the Tensas Basin, in Arkansas and Louisiana; and the Atchafalaya Basin, in Louisiana. The alluvial valley in its original state was all subject to overflow from the Mississippi River. It comprises some 20,000,000 acres of land, of which about 13,000,000 acres are good usable land and the remaining 7,000,000, acres are mostly swamp and timber lands.
>
> From Cape Girardeau south to Cairo, Ill., where the Ohio enters the Mississippi, the Mississippi waters do not constitute a serious problem. The narrow strip of land on the east side of the river is not of sufficient width to warrant the expense involved in its complete protection. On the west side is the upper St. Francis Basin and this is to be given complete protection by raising the levees about 2 feet and enlarging their cross sections.

[25] World Almanac, 1929, p. 160. Specially prepared by Corps of Engineers.

From Birds Point, Mo., opposite Cairo, Ill., to New Madrid, Mo., the channel of the main river is too narrow to carry the volume of water that may flow through this reach, without causing excessive stages. Therefore a new levee is to be built on the west side of the river about 5 miles back, so as to about double the width of the river here for superflood use. This will permit the maximum flood to pass without raising stages above the present levee grades at Cairo, Ill. Around Cairo the existing levees are to be enlarged in cross section. The existing riverside levee from Birds Point to New Madrid, Mo., is to be lowered about 3 feet, so that if a superflood ever occurs water will flow over this levee, breach it, and bring into operation the wider flood channel back to the new levee, 5 miles to the westward. This will permit the lands between the river side levee and the new levee to be used in the same manner they are now used for about 9 out of 10 years on the average.

South of New Madrid to the mouth of the Arkansas River the natural channel of the Mississippi is sufficiently wide to permit the superflood to be confined within it without excessive levee raising. So existing levees in this reach of the river, where they occur, on both sides, are to be raised and strengthened sufficiently to protect against the maximum flood.

South of the Arkansas to the mouth of the Red River, the levees on both sides of the main channel of the Mississippi are to be raised about 3 feet and strengthened except for a section about 35 miles long on the west side of the river just below the mouth of the Arkansas. With this improvement the main channel can carry about 1,950,000 second-feet of water and if the superflood ever occurs, 900,000 second-feet will leave the river just below the mouth of the Arkansas, and flow down the swamp basin on the west side through which flood waters have always passed in every great flood. In order to protect the good lands in the Tensas Basin from this 900,000 second-feet of water, if it ever comes, guide levees are to be constructed on each side of the Boeuf River Basin about 13 miles apart. Thus the flood waters will be confined to the swamp and timber lands of the Boeuf where they have always gone, and the cultivated inhabited sections on each side will be protected against a contingency which may occur on the average about once in 12 years.

South of the Red River the scheme is similar to that just below the Arkansas. At the mouth of the Red all the floodwaters come together again. The main channel of the Mississippi below the Red, if the levees on both sides are strengthened and raised about 3 feet, can carry about 1,500,000 second-feet of water. If a superflood ever occurs there may be 1,500,000 second-feet in addition. Excess water in great floods has always left the main channel near the mouth of the Red and flowed down through the swamps and lakes of the Atchafalaya Basin. The good lands in the Atchafalaya Basin are to be protected against 1,500,000 second-feet of water by guide levees placed on the east and west sides of the swamp lands from 10 to 25 miles in width. It is estimated that flood waters may overtop the levees at the head of the Atchafalaya Basin, on the average about once in 15 years. So such lands as are usable within the limiting guide levees (about 10 per cent of the area), can be used the same as now about 14 out of 15 years.

In order that flood waters passing down the main channel of the Mississippi may pass by the great city of New Orleans without raising the gage there above what is considered safe, viz, 20 feet on the gage, there is to be constructed just above New Orleans, at Bonnet Carre, a controlled spillway capable of relieving the river of 250,000 second-feet. This water will flow through a leveed channel about 5 miles long and 2 miles wide into Lake Pontchartrain. With this amount of water taken out there will be left in the main channel about 1,250,000 second-feet, which can pass New Orleans with the gage below 20 feet.

In addition to the levee work described above, the flood-control plan includes bank revetment work, dredging, and regulation works. Bank revetment is for the purpose of preventing caving of banks and the undermining of levees by this caving. Dredging is done in low-water season to make deeper channels through shallow stretches of the river for navigation.

The estimated costs of the projected work in the various districts is as follows:

Cape Girardeau to Arkansas River:	
Mississippi levees, including levee work around Cairo and certain levees necessary to keep water out of St. Francis Basin	$58, 000, 000
Rights of way flood-way levees	250, 000
Flowage flood way	2, 550, 000

Arkansas to Red River:	
Mississippi levees	$59, 300, 000
South bank Arkansas	5, 000, 000
Rights of way on Arkansas	350, 000
Boeuf Basin levees	10, 000, 000
Rights of way in Boeuf Basin	700, 000
Ring levee and right of way, Arkansas City	350, 000
Total	75, 400, 000
Below Red River:	
South bank Red River	3, 000, 000
South bank Red River rights of way	150, 000
Bayou des Glaize setback rights of way	1, 000, 000
Mississippi levees	18, 700, 000
Atchafalaya River levees, revetment, rights of way	5, 000, 000
East Atchafalaya Basin protection levee	12, 600, 000
West Atchafalaya Basin protection levee	17, 300, 000
Rights of way, protection levees	750, 000
Ring levees and rights of way, Simmesport, Melville, and Morgan City	1, 000, 000
Construction, Bonnet Carre	8, 200, 000
Rights of way, flowage and damages, Bonnet Carre	3, 300, 000
Revetments	80, 000, 000
Contraction works	20, 000, 000
Dredging	10, 000, 000
Mapping	1, 000, 000
Grand total	318, 500, 000

2. PROPOSED METHODS OF FLOOD CONTROL

(*a*) *Soil cultivation.*—Throughout the world and for many centuries some form of soil cultivation has been used to conserve the rainfall as surface and, subsequently, as soil moisture for the benefit of vegetation. The form of surface device to retain the run-off varies with the condition and the purpose, and may be furrows, terraces, or trench reservoirs. Well known are the terraced hillsides of the Philippines and Palestine, with their field crops, grapevines, or groves of olive and coffee trees. But relatively unknown is the recent use of contour plowing on hillsides to conserve the rain water for the apple crop of a farm in western Virginia, and of terraces with back trench for field water storage on a power project in North Carolina.

A recent report [26] of Congress contains the following statements:

> Soil erosion is the most grave problem confronting land usage in this country and least is being done to control it.
>
> Increased run-off is a problem of serious concern over all eroded areas. The serious aspects are manifold. Impaired productivity or actual destruction of the land by sheet erosion and gullying, reduction of soil-stored moisture for summer use of crops, removal of stream-choking silt, and augmented floods.
>
> This indicates a possible saving by practical means of 25 per cent or possibly more of the run-off over a considerable part of an area comprising something like 500,000 square miles in the Mississippi drainage basin.

The United States Department of Agriculture points out the importance of soil conservation as a means of flood control in the following statements: [27]

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[26] Hearings on Agricultural Department Appropriation Bill, 1930, House of Representatives, Seventieth Congress, first session.

[27] Soil Erosion as a National Menace, Circular No. 33, U. S. Department of Agriculture, p. 17, 1928.

Soil conservation, therefore, should be an important adjunct of any long-continued system of flood control.

* * * * * * *

Suspended material to the amount of 428,715,000 tons annually passes out of the mouth of the Mississippi River alone. This is but a part of the solid material that enters the river and its tributaries, since much is left stranded somewhere along the pathway to the sea. * * * So many tons of silt in the river stand, unmistakably, for so many denuded or partly denuded acres of sloping land somewhere upstream, land enabled by its denuded condition to contribute to the stream at a faster rate more of the rain that falls upon it.

That soil cultivation will prevent soil erosion is generally claimed by the leading students of this subject. Undoubtedly there is a need for a national awakening and program of education among landowners and farmers in the important subject of a better scientific handling of land. Terracing and contour cultivation of sloping areas to retain the surface water and check erosion have been used extensively in the Southeastern States and recently adopted in Texas and Oklahoma.

Soil cultivation with a view to the conservation of moisture and the prevention of soil erosion is unquestionably a factor of importance in the development of agriculture, especially in those sections of the Mississippi watershed where there are upland silt soils of the erosive type. It is evident, however, that unless practiced in a universal, controlled, and scientific manner, soil-cultivation methods would have little practicable effect on the control of flood waters of the Mississippi Basin. This condition can only be brought about by an educational campaign extending over a long period of years and can not properly be made a part of a plan for immediate flood control.

(*b*) *Reforestation.*—The effect of forests upon stream flow is a subject which has provoked much discussion during the past two years (1927–1929), especially with relation to flood control in the Mississippi Basin.

The Forest Service of the United States Department of Agriculture has been making extensive studies of the relations of forests to floods and has recently published some reports.[28] The following statements, quoted from these documents, are significant:

Among the factors, such as climate and character of the soil, which affect the storage capacity of a watershed, and therefore regularity of stream flow, the forest plays an important part, especially on impermeable soils. The mean low stages as well as the moderately high stages in the rivers depend upon the extent of forest cover on the watersheds. The forest tends to equalize the flow throughout the year by making the low stages higher and the high stages lower.

Floods which are produced by exceptional meteorological conditions can not be prevented by forests, but without their mitigating influence the floods are more severe and destructive.

The outstanding facts, presented in the report of Associate Forester Sherman, are as follows:

The forests of the Mississippi Valley never covered more than 40 per cent of the total area of the drainage basin.

By necessary human use and by unnecessary abuse and neglect this proportion has been reduced until it is now about 20 per cent, or about 244,000 square miles.

A very small part of this total area of forest land is in a virgin condition, the remainder being largely cut over, with 35,000 square miles so denuded of forest or other valuable growth as to be classified as "waste" or "idle" land.

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[28] Forests and Water in the Light of Scientific Investigation, Raphael Zow. Forests and Floods, Ward Shepard, Circular No. 19, January, 1928. The Protection Forests of the Mississippi River Watershed and Their Part in Flood Prevention, E. A. Sherman, Circular No. 37, August, 1928.

About 115,000 square miles, of which 10,000 square miles are in the idle class, are in farm woodlands, and 120,000 square miles, of which 25,000 are "idle" or "waste," are within the commercial timberland class.

By reason of character of soil, topography, and precipitation, the character and density of forest cover on certain of these lands have a direct relation to run-off or soil erosion or both, and on such areas forest destruction increases torrential run-off and causes serious erosion. Areas with such characteristics were therefore classified as "critical areas."

The regions classified as critical areas on the Mississippi drainage amount to 289,000 square miles, of which, upon the basis of the present tendency toward increase or decrease in the ability to help prevent floods, 64,000 square miles were found to be beneficial, 75,000 neutral, and 150,000 detrimental.

The actual acreage of critical forest land within the regions outlined is about 150,000 square miles, and the approximate distribution by class is, beneficial, 35,000 square miles; neutral, 40,000 square miles; detrimental, 75,000 square miles.

In addition to the critical forest lands, 15,000 square miles of bad land and 17,000 square miles of breaks (although treeless) should also be classified as critical areas because of their great contributions of silt to the Mississippi flood problem. The bad lands appear to be responsible for contributing an annual burden of silt aggregating 144,000,000 tons and the breaks for contributing a somewhat smaller amount.

The loss of soil by erosion from cultivated fields is a serious menace not only to the channel of the Mississippi River, but to the permanency of profitable agriculture in many parts of the valley which has thus far flourished through the virgin fertility of rapidly eroding soils.

Several eminent observers claim that scrub or abandoned cut-over land is equal to, if not better than, forest in reducing run-off. Colonel Potter, former president of the Mississippi River Commission, made the following statement [29] from a study of the reservoirs at the headwaters of the Mississippi, and especially of conditions at Pokegama Lake and Dam:

Of the 3,265 square miles in this watershed, 384 square miles are water surface. The locality is such that evaporation and rainfall are practically equal. So the run-off passed through Pokegama Dam, or stored in the reservoirs, is that from the remaining 2,681 square miles of land surface. I first began this study in 1913, when the record covered 28 years. I divided the time into four 7-year periods. These were long enough to give fair averages; gave equal divisions of time; and represented, to my mind, a good division as to conditions. The run-off percentages were as follows:

	Per foot
1885–1891 (primeval conditions)	20. 2
1892–1898 (deforestation began)	22. 7
1899–1905 (most active deforestation)	34. 2
1906–1912 (partial relapse to scrub)	23. 7

This indicated that deforestation had done its worst, and that relapse to scrub was bringing the run-off back to its primeval rate. I looked for even greater improvement as time advanced.

I have recently obtained the records for the past 11 years, bringing the data down to date. For the full 11 years the rate of run-off has been 23.1 per cent, a drop of 0.6 since 1912. Taking the last seven years for comparison with my original 7-year periods, the run-off is reduced to 19 per cent, or 1.2 per cent below anything recorded. A visit to this area in the summer of 1923 showed a full growth of scrub and increased farming. This is why I maintain that land, cleared of timber and gone back to scrub, as has probably 80 per cent of this area, is equal to, if not greater than, the original forest in reducing run-off. As more of this land goes under cultivation the run-off will be less. This brings me to my early theory that farms are better than forests in reducing run-off.

Undoubtedly this disputed problem of the influence of forests on rainfall and floods can only be understood as a result of extensive

[29] Some Suggested Ways of Controlling the Mississippi Floods, Charles L. Potter, Engineering News-Record, Apr. 2, 1925.

scientific studies based on long-period observations. The burden of evidence as recently presented by the United States Forest Service and other authorities seems to indicate from investigations here and abroad that the forest has a moderating effect, and, while—

necessarily helpless to prevent the occurrence of excessive floods during periods of exceptional rainfall, yet by protecting the soil against erosion by diminishing the proportion of detritus carried by the run-off, and by absorbing at least part of the water that falls upon the ground, it has a mitigating influence even on the highest floods.[30]

It is impossible to estimate the influence of good forest cover on floods in the Mississippi Basin. The evidence presented by Federal Government and other authorities indicates that this influence should be considered. Undoubtedly forest rehabilitation on lands not serviceable for agricultural use should be carried on in a systematic and coordinated manner. Like soil cultivation, this is a matter of education over a long period of time and can not in any way displace but may supplement a comprehensive plan for work for flood control in the Mississippi Basin.

(*c*) *Detention reservoirs on the tributaries.*—The use of storage basins for the retention of the flood waters of rivers dates back to the ancients and their works on the Tigris and Euphrates Rivers in Mesopotamia and on the Nile in Egypt. To-day source stream control by the use of reservoirs is universally and successfully used [31] abroad and is becoming better known and used to a limited extent in this country, as in the case of the Miami conservancy district in Ohio.

The importance of the use of reservoirs for source stream control was recognized by the ancients and was noted by Sir William Willcocks in an address before the National Drainage Congress in these words:

The perfect control of the Euphrates where massive dikes were supplemented by escapes into the deserts, and the imperfect control of the Tigris where double banks without escapes into the deserts failed to provide absolute protection, teach the lesson that protecting dikes unaided by works of control higher up the stream were not of themselves sufficient to insure the lower reaches of the rivers against inundations in years of exceptional floods.

The control and regulation of the flood waters of the Mississippi Basin have been studied and reported on by the earliest students of this region.

About the middle of the nineteenth century, Charles Ellet, jr., made a comprehensive study of the Mississippi Valley and made the following observations on reservoirs: [32]

It will be necessary, in order to assure the protection of the whole Delta from overflow, compatibly with the reclamation of the swamps, to construct new reservoirs in the hilly country, at the sources of the Mississippi and its tributaries, there to hold back a portion of the surplus water and act as substitutes for those reservoirs which are thrown out of use in the lowlands by the innovations of society.

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30 Forests and Water in the Light of Scientific Investigation, Raphael Zow, 1927, p. 67.

31 Report of Pittsburgh Flood Commission, 1911, Appendix No. 5, Method of Flood Relief in Foreign Countries.

32 Physical Geography of the Mississippi Valley, Charles Ellet, jr., Smithsonian Contributions to Knowledge, Vol. II.

In a subsequent report,[33] made to the Secretary of War, Mr. Ellet again emphasizes the value of reservoirs and indicates the national character of the flood-control problems:

It is entirely practicable for a cost that will be fully justified by more than one of the great objects which will be accomplished by the plan, to hold in reservoirs surplus water enough to improve navigation of every navigable stream in the Mississippi Valley, by discharging the excess so retained into the channels when it is needed there; and at the same time, by the same process, to protect the whole Delta and the borders of every river in it, primary or tributary, from overflow. That plan will relieve not merely the country below Red River, but the whole valley of the Mississippi, from the sites of the reservoirs in the distant mountains to the Gulf. It will ultimately reclaim the swamps of the entire Delta and convert the most worthless and least habitable soil into the richest and most productive. It will render every stream that is ever navigable permanently so. It will remove that great difficulty which statesmen now find in deciding on what rivers are worthy of national care by rendering them all national. For surely, whatever helps to protect the whole Delta, in any degree, from overflow, and at the same time improves the navigation of the Ohio and the Mississippi, must be considered as of national importance even though it may incidentally improve the navigation of the Allegheny and Illinois, so far as those streams are used as the conduits for the water.

This subject of reservoirs on the tributaries of the Mississippi River was subsequently studied and reported by a number of Army and civil engineers, including W. Milnor Roberts,[34] Ellwood Morris, C. E.,[35] Maj. William E. Merrill,[36] Lieut. Col. H. M. Chittenden,[37] T. P. Roberts,[38] M. O. Leighton,[39] James A. Seddon,[40] and others. In 1927, a special board of Army engineers, appointed by the Chief of Engineers, made a study and report on The Control of Floods of the Mississippi River by Means of Reservoirs.[41]

The available data on source stream control by reservoirs indicate the following resources in the various sections of the Mississippi Basin:

MISSOURI BASIN

The State Engineer of North Dakota reports [42] on a proposed flood-control and power reservoir on the "big bend" near Fort Clark, N. Dak. He estimates that this reservoir will store the run-off from 40 per cent of the Missouri River drainage basin, and gives the following data as the effect of this proposed improvement upon the flow of the Missouri River, assuming 1923 as a representative year:

	Bismarck	Sioux City	Kansas City
	Per cent	*Per cent*	*Per cent*
Reduction of 1923 flood	80	70	30
Increase of low-water flow	73	55	35

A low-water discharge of 10,000 second-feet can be maintained with a minimum head of 30 feet, yielding 30,000 horsepower at all times. The low-water discharge of the river will be built up in such

[33] The Mississippi and Ohio Rivers, Charles Ellet, jr., 1853.
[34] Journal of the Franklin Institute, 1857-58.
[35] Journal of the Franklin Institute, 1857.
[36] Report of Chief of Engineers, Sept. 1, 1873.
[37] House Document No. 141, Fifty-ninth Congress, second session, 1897.
[38] Proceedings of Engineers' Society of Western Pennsylvania, July 1907.
[39] Report of Inland Waterways Commission, 1908.
[40] Reservoirs and Their Effects on the Floods of the Mississippi System, James A. Seddon, 1898.
[41] House Committee Document No. 2, Seventieth Congress, first session, 1927.
[42] Preliminary Report on Missouri River Dam in North Dakota, Office of State Engineer, N. Dak., 1928.

a way as to make the stream navigable and to prevent the destruction by erosion of 30,000 acres of rich farm soil, which is the annual soil loss occurring between Fort Clark, N. Dak., and Sioux City, Iowa. This regulation will stabilize the river flow so that diversion will be possible for irrigation and a material reduction of the detritus and silt content of the stream result. It is estimated that this storage basin would reduce the flood flow crest at Bismarck by 110,000 second-feet and add 13,000 second-feet to the low-water stages. The estimated storage is 15,000,000 acre-feet and the cost is $47,500,000. The estimated maximum peak or flood flow [43] since 1883 is 500,000 second-feet at Bismarck, N. Dak.; 605,000 second-feet at Sioux City, Iowa; and 790,000 second-feet at Kansas City, Mo. It is assumed that this flood condition would be reduced by 300,000 second-feet by this proposed impounding reservoir.

OHIO

In 1911, a commission [44] made a thorough and comprehensive report on the control of the Ohio River above Pittsburgh, Pa. After a careful survey and study of physical and economic conditions, 17 reservoir sites were selected in the valleys of the Allegheny and Monongahela Rivers above their confluence. The report states that these reservoirs shall constitute the major part of river control for the purpose of flood protection and other economic uses of these streams. The following data summarize the essential features of this storage plan:

Reservoir storage in acre-feet	1, 363, 000
Total construction costs	$21, 670, 200
Reservoir cost per acre-foot storage	$15. 90

Estimated stage reduction at Pittsburgh, from 10 to 12 feet.
Estimated increase of low-water stage at Pittsburgh, 10 feet.

The low-water discharge of the Ohio River at Pittsburgh becomes as low as 1,600 second-feet and seriously affects navigation and uses of the river water for other purposes. The development of the power resources of the Tennessee River and its tributaries is helping to stabilize the flow of the streams of this watershed.

ARKANSAS-WHITE

The Arkansas and Red River Basins have been investigated by an interstate commission representing the interests of Alabama, Louisiana, Mississippi, Arkansas, Texas, Oklahoma, Kansas, New Mexico, and Colorado. Engineers surveyed and reported on the possibilities of source stream control on these two great southwestern tributaries. The engineers' report [45] indicates an impoundage of 14,000,000 acre-feet, at an estimated cost of $126,000,000. This storage would control one-third of the Arkansas River drainage above Fort Smith and presumably reduce the flood conditions in this basin by one-third. It is further estimated that the 1916 and 1927 Mississippi flood crests would have been reduced from 3 to 5 feet below the confluence of

[43] Flood Flow Characteristics, C. S. Jarvis, Transactions, American Society Civil Engineers, vol. 89, 1926.
[44] Report of Flood Commission, Pittsburgh, Pa., 1911.
[45] Report of Interstate Flood Control Commission, and Oklahoma Commission of Drainage, Irrigation and Reclamation. Flood Control, E. E. Blake, Professional Engineer, July, 1927.

the Arkansas, and the average flood crest would be reduced from 2 to 4 feet by this source stream control. The studies of the commission further indicate the possibility of the utilization of the stored waters of this reservoir system for irrigation, the stabilization of the flow of the streams, the regulation of low-flow conditions for navigation, and the reduction of the silt contribution of these rivers to the Mississippi.

As in the case of the streams of the Missouri Basin, the control, conservation, and utilization of the waters of the Arkansas-White watershed for economic purposes will aid materially in the amortization of the investment, as well as contributing directly to the agricultural, industrial, and commercial development of the region. For example, the following is quoted from a report made to the Congress (Flood Committee of the House, 70th Cong., 1st sess.):

It is safe to say that the flood control of the Arkansas River area will not cost to exceed $72,000,000, and by adding 10 per cent to the flood-control cost, sufficient water could be conserved to irrigate 800,000 acres, making the storage cost $9 per acre, and with a cost of $15 per acre for canals and laterals, would make the irrigation cost complete $24. The $15 per acre would be a direct charge to the lands irrigated. The resource to help pay for such control works for irrigation alone, or 800,000 acres at $30 per acre water right, would return $24,000,000, or one-third the cost.

The report of the special board of Army Engineers [46] indicates the opportunity for construction of two large impounding reservoirs on the Arkansas River, one near Little Rock and one between Ozark and White Oak, Ark.

These two reservoirs would give sufficient capacity to control the entire flow of the Arkansas. By the use of the Little Rock Reservoir alone, the extraordinary high flood of 1927 could have been held down to 40,000 cubic feet per second, which would have had a marked effect on the Mississippi flood at Arkansas City and lower points. The resulting reduction in the maximum flow of the Mississippi would have been about 400,000 cubic feet per second, which would have lowered the Arkansas City gage nearly 7 feet. The estimated capacity of the Little Rock Reservoir is 25,300,000 acre-feet, and its cost $163,000,000.

RED

In the Red River Basin the Interstate Commission estimated a probable storage of about 6,000,000 acre-feet at a cost of not to exceed $30,000,000. The retention system is assumed to be able to control one-third of the Red River drainage above Texarkana and flood height on the Mississippi at Old River about 1 foot.

As in the case of the Arkansas Basin, the control and economic use of the waters of the Red River for irrigation and other purposes would be a direct benefit to the region and would materially aid in the amortization of the cost of the project. The commission's report to the Congress states:

The flood control by the reservoirs in Oklahoma will not cost to exceed $30,000,000, and by adding 10 per cent to the flood-control cost sufficient water could be conserved to irrigate 400,000 acres in this area, making the storage cost $7.50 per irrigable acre and, with a cost of $15 per acre for canals and laterals, would make the irrigation cost $22.50 per acre complete. The $15 per acre would be a direct charge to the land irrigated. The resource to help pay for such

[46] Report on the Control of Floods of the Mississippi River by Means of Reservoirs. House Committee Document No. 2, Seventieth Congress, first session.

control works from irrigation alone in 400,000 acres at $30 per acre water right would return $12,000,000, or two-fifths the cost.

SUMMARY

The report [47] on flood and drought control in the Missouri River Basin gives a summary of approximate estimates from available data on proposed source stream control in the basins of the Missouri, Ohio, Red, and Arkansas-White as follows:

River basin	Mean annual acre-foot discharges	Reservoir storage in acre-feet	Estimated costs	Estimate discharge reduction cubic feet per second
Missouri	82,000,000	30,000,000	$300,000,000	350,000
Arkansas-White	46,000,000	14,000,000	126,000,000	400,000 (Arkansas-White and Red)
Red	42,000,000	6,000,000	5,000,000	
Ohio	143,000,000	1,360,000	21,672,100	150,000
Total	313,000,000	51,360,000	452,672,000	900,000

It seems evident that the figure noted above for the estimated cost of the Red River storage system is in error and should be about $30,000,000. The similar figure for the Ohio storage system is also probably low, as this estimate was made in 1910–11. Hence, the total estimated cost as noted in the table should probably be increased to about $500,000,000.

The board of Army engineers, appointed by the Chief of Engineers in 1927, made a very comprehensive report [48] on reservoirs for flood control in the entire Mississippi Basin. A group of 30 selected reservoirs were studied on the basis of three different methods of operation.

Method A is the method of uniform storage over a 60-day period. For method B it was assumed that the maximum future flood would have a peak discharge of 2,250,000 cubic feet per second at Cairo and 2,850,000 cubic feet per second below the mouth of the Arkansas. The duration of the flood and the distribution of flow throughout the flood period were assumed to be similar to that which occurred in 1922. Method C assumed the same peak discharge but took the duration and distribution to be the same as in 1927.

From a study of these three methods it was considered that the 60-day uniform storage schedule of method A gave the most satisfactory results.

Against maximum future floods of either of the types considered this would give a dependable reduction of the maximum discharge amounting to about 200,000 cubic feet per second at Cairo, 600,000 cubic feet per second at Arkansas City, and 500,000 cubic feet per second at Vicksburg. The corresponding reductions in gage height are approximately 3 feet, 10 feet, and 7 feet, respectively.

The estimated total cost of this project is $525,000,000.

The use of reservoirs to control the floods of the Mississippi Basin can be done effectively and efficiently only in watershed groups, considering the utilization and operation of the watersheds of each major tributary independently. Thus the storage basin systems of the Ohio, Missouri, Arkansas-White, and Red River Basins would be studied,

[47] House Committee Document No. 21, Seventieth Congress, first session.
[48] Report on the Control of Floods of the Mississippi River by Means of Reservoirs. House Committee Document No. 2, Seventieth Congress, first session.

designed, built, and operated as separate but coordinated units as regards the control of the waters of each and every basin for flood control, low-water regulation, irrigation, power development, and navigation.

The value of each storage reservoir system and its relation to the other systems of the entire Mississippi Basin are entirely dependent on its proper operation. It is easily conceivable that a group of reservoirs in any one watershed area such as the Arkansas-White, could be so operated as to increase the flood crest at Arkansas City and thus be a serious detriment rather than a benefit with relation to flood conditions on the the Mississippi River.

Hence the vital element in the use of a system of reservoirs is their scientific and effective operation so that they will empty at all times except as they may be temporarily filled while attaining excessive flood waters. These waters will be released as soon as the streams subside in order that the space will be empty and available for the control of the excess run-off of subsequent storms.

The studies [49] of the division of engineering and irrigation of the State of California show that it is practicable to ascertain:

The amount of reservoir space required under the many variant circumstances of time of year, type of season, and degree of desired control—

and to prepare rules that may be used to release the space required for flood control as soon as its need for that purpose has passed. This space may then be filled for conservation. These rules are expressed in the form of graphic diagrams:

which show the amount of reservoir space that, for the circumstance existing on any current day, should be empty in order to assure the degree of flood control desired.

The effective coordinated operation of reservoir detention systems on the tributaries, the Missouri, Ohio, Arkansas-White, and Red Rivers, must be based on a scientific application of these principles:

First. Each reservoir system will be used to reduce the short time and sharp flood peak on its tributary, and the coordinated system to reduce the flood crests on the lower main river.

Long-time (60 to 90 days) storage periods of all the excess flood waters between levees will not have to be used as is generally assumed. The flow of a flood down a river such as the Ohio is accompanied by a series of progressive flood stages. Part of this water fills the river channel and the adjacent bottom lands. If no water enters the river between two selected points, it will be observed, on a rising river, that less water will be flowing out at the lower point than in at the upper point. Also, at any point when the river is falling, there is a less discharge at the same gage height than when rising. Flood waters from the upper Mississippi or Missouri tend to block the mouth of the Ohio and check the flow of this river, creating a ponding effect near Cairo. Furthermore, a flood from the Missouri carries large quantities of sediment and silt which tends to fill up the channel at its bars, and thus reduces the discharge at these points for the same gage heights. Taking these factors into account, it is likely that part of the volume of water at any point on the river for a stated

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[49] The Control of Floods by Reservoirs, by Paul Bailey. Bulletin No. 14, division of engineering and irrigation, department of public works, State of California.

gage height, is due to accumulation from retarded flow below the point on the river. Hence it is necessary:

Second, to prevent the sharp, short-time flood crests by storing the surplus waters of a flood in detention reservoirs located as far down on the main tributaries as is practicable.

The prevailing storms resulting in great floods move across the Mississippi Basin from southwest to northeast. This results in producing flood crests on the lower tributaries of the Ohio several days previous to its own main flood crest as it travels southwesterly down the river. On the Missouri and Arkansas Rivers the side-stream flood crests nearly coincide with that of the main river, so that detention reservoirs on these side streams are necessary to hold back the flood waters until those of the main river have passed.

Studies of the flood-crest conditions during the 1927 flood indicate the amounts of temporary flood-water detention necessary to keep the flood stages on the main river and its tributaries down to ordinary flood-stage levels.[50] J. P. Kemper, civil engineer, an authority on the lower river, shows by graphic charts that at Friars Point on the Mississippi, during the 38 days from March 30 to May 6, 1927, there was a discharge above 54 feet gage reading of 2,500,000 acre-feet. Similarly, and during the same period of time there was a discharge at Clarendon, Ark., of 6,706,000 acre-feet above flood stage of 30 feet on the White River, and of 12,738,000 acre-feet above flood stage of 22 feet at Little Rock on the Arkansas River.

The available preliminary data concerning storage reservoir sites on the tributaries of the Mississippi clearly indicate the practicability of carrying out the plan of providing storage to reduce, or eliminate, by scientific operation of reservoir systems, the sharp, short-time flood crests on the tributaries and the main river.

(d) *Side basin water storage and flood ways.*—The Mississippi River flows southward through the so-called lower valley with a total fall of about 300 feet in a distance of about 550 miles. It has a width of from 20 to 85 miles from Cairo to the Old River where it broadens into the delta plain of a width of from 35 to 100 miles. The valley plain is traversed by long, narrow ridges of higher land which extend along the valley on both sides of the river. The sides of the plain are formed by abrupt slopes which lead to the rolling plateaus, extending back from the river.

The river traverses this plain in a very irregular course; the first stretch along the east side of the valley, and then swerving to the southwest to Arkansas City, then south to the bluffs along the east side of the plain at Vicksburg, and thence southwest along this high land to the Old River, where the river emerges into the open space of the delta country.

The valley floor lies at a lower elevation than the high water of the Mississippi, the lowest land lying back from the banks of the river in the swamps and bayous which follow down along the valleys of the St. Francis, White, Arkansas, Tensas, and Yazoo Rivers. During past ages the periodic overflows of the river (before the construction of the present levee system) have resulted in the building up of the banks of the river in the form of broad dikes about a mile in width

[50] Floods in the Valley of the Mississippi, A National Calamity, J. P. Kemper, civil engineer, National Flood Commission, 1928.

and having an elevation of from 10 to 25 feet above the general level of the plain, which they connect with gentle slopes.

The flood waters as they came down the lower reaches of the main tributaries and the main river first overflowed the banks at low places and at small outlet bayous extending back toward the side swamp lands. As the river rose, the overflows extended for increasing lengths along the banks, and the water gradually accumulated in the natural side basins and formed long, relatively narrow, and shallow lakes. In the case of the greater floods, the water flowed slowly in a broad stream out of the lower end of the natural basin into and perhaps across the main river and into another natural side flood-way basin, then out of the lower end of this basin into the main river again, and so on along and across the valley from Cairo to the "bottle neck," where large quantities of flood waters flowed south through the Atchafalaya Basin to the Gulf of Mexico.

The flow of this natural floodway was much obstructed by tree and brush growth, and débris, and resulted in its slackening in places and the deposition of its sediment over large areas of low swamp lands. These floodways probably covered from 5,000 to 25,000 square miles of the valley plain and contained a volume of waters depending on the height of the floods and their duration. As the flow of the floodway was somewhat less than the current of the main river, it thus served as a great retention basin to hold in check the waters of the main river and to somewhat level and flatten out the general flood wave down the valley. Undoubtedly the flood crests of recent floods, since the building of the levees, have been raised by the restriction of the waters between these lines of artificial banks.

> The water is supplied by nature, but its height is increased by the works of man.[51]
>
> So long as the levees are raised and lengthened above, we must, therefore, expect the country below to be assailed by increasing floods.

Mr. Ellet reports on studies made of the effect of levees on flood heights during the flood of 1851. At Bunch's Bend, near the mouth of the Arkansas River, the flood of 1851 was 2½ inches higher than that of 1850, when it should have been 12 inches lower, taking into consideration the volume of discharge. He stated that this increased flood height of 14½ inches was due to the building of levees in Bolivar and Washington Counties, Miss., in the period between these two floods.

Humphreys and Abbot [52] made the following observations concerning the effect of the swamp lands upon the floods of the Mississippi:

> The following final conclusions respecting these swamp regions in their unleveed condition must therefore be considered established. First, they produced no effect whatever upon the volume of the maximum discharge of the Mississippi, above or below them in great flood years. Second, they did reduce this volume along their fronts, and by an amount which increased from their upper to their lower limits. Third, they retarded both the rising and falling of the river at all points below them. Fourth, they tended to increase the duration of the floods throughout the alluvial region.
>
> It may be added that in their present semireclaimed condition, they do serve as reservoirs, inasmuch as the levees keep the swamps comparatively empty until near the top of the flood, when they break and relieve the river of a part of the excessive volume.

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51 The Mississippi and Ohio Rivers, Charles Ellet, jr., Brambo & Co., Philadelphia, Pa., 1853.
52 Report on the Mississippi River, Humphreys and Abbot, 1861.

The utilization of these natural floodway basins for temporary storage of excess flood waters of the main river and hence the reduction of flood crests has been advocated by several students of the lower river flood conditions. A recent plan [53] for a comprehensive system of flood-storage reservoirs is as follows:

The water-storage floodways along the Mississippi River would be located in the low stream drainage parts of each of the river-side basins, such as the St. Francis, Yazoo, Tensas-Red, and Atchafalaya Basins. They would consist of a series of artificial basins located one after the other, and inclosed at the lower end and sides by levees so located as to place the upper end of each reservoir just below where large tributary side streams entered the basin. The reservoirs would thus serve as catchment basins for floods from these tributaries. The control of floods on these streams, however, could be aided by having smaller storage reservoirs on them at points above the flat basins.

These basin floodway storage reservoirs, some four in number in each of the three upper side basins, would cover about one-fifth of the area of each basin or have combined areas of 1,000 to 1,500 square miles, with water-storage capacities of about 10,000,000 acre-feet in the upper 10 feet of each series. There would be a drop of 20 to 25 feet through a power house from the lower end of one reservoir to the next one just below it, and this drop in water level would be maintained throughout the year by drawing down each storage reservoir an equal distance when storage water was used from them during lower water periods on the Mississippi River.

It is proposed to divert flood waters from the Mississippi River through a gate-controlled spillway into the head of each of these series of reservoirs in amounts up to 300,000 second-feet, starting the water diversion when a rising river in the winter or spring passed its medium water stage to the amount of some 25,000 second-feet at each intake. When a flood stage is reached on the river, this diversion of water could be increased gradually up to 300,000 second-feet at each place, of which amount of water some 200,000 second-feet would pass on through and out of the floodway reservoirs over the spillways between each reservoir, while some 100,000 second-feet would be retained in storage in the reservoir system of each basin. By following out this method of diversion the water in the main river channel would be held down to lower levels at the beginning of a flood and thus provide a greater storage capacity for flood water in that channel, aside from the flood water that passes through the flood ways and that held in storage in the flood-way reservoirs. When the water height of the Mississippi River fell several feet below its allotted crest, the spillway gates could be closed and all the flood passed down the main river channel. This closure should be made on a falling river in order to preserve its channel to its full size below the spillway outlet. The necessity of thus preserving the river channel appears to have been overlooked or considered to be unimportant by the Army engineers in carrying out their plan of operating the proposed flood ways.

The proposed system of stepped-down reservoirs in each of the side basins along the Mississippi River may seem objectionable to

[53] The Mississippi River, A Review and Analysis, H. N. Sulliger, February, 1928.

some on account of locating levees on two sides of part of the basin lands, the length of time the water would stand against these basin levees, and also the danger of one or more of the reservoir dams going out in floods. These valley lands, however, could be protected by spur levees and ample drainage systems outside of each levee line, while great care could be used in the construction of the higher levees and sheet piling used where considered to be necessary. The reservoired flood-way system as proposed would allow a freer and better escape passage for floods than the proposed partly cleared-off water-escape flood ways. Owing to their size, width, and depth, there would not be much of a current through these reservoirs even during great floods, and the use of spillway gates at their lower ends would allow the sudden drawing off of great volumes of water from them if necessary.

(*e*) *Diversion channels.*—The early investigators,[54] Humphreys and Abbot, gave serious consideration to the diversion of the Arkansas and Red Rivers from the main river channel. They refer to the practicability of diverting the flood waters of the Arkansas, and state:

> The floods of the Arkansas are particularly disastrous to the lower Mississippi * * * Keeping the Arkansas floods out of the Mississippi must, therefore, have a peculiarly beneficial effect from Napoleon down to Red River Landing, where the water would, of course, again make its appearance through the Red River Channel.

These authorities indicate that:

> The works necessary to guard against this flood of 1858 would, so far as it is possible to foresee, be sufficient to restrain any probable combination of floods in the two rivers. The union of the greatest floods in both rivers is, of course, possible but so highly improbable as to amount to a practical impossibility.

In 1927, however, maximum flood conditions did occur on these two tributaries practically simultaneously, due to excessive precipitation in the lower central valley. The flood waters from these two streams discharged into the lower reaches of the main river at such a time as to produce the highest recorded flood stages in history.

The further objections of Humphreys and Abbot to the diversion of the Red River through the Atchafalaya Basin would not apply so potently to-day; especially as their estimated capacity of 130,000 cubic feet per second for the Atchafalaya River has been increased to a present estimated flood discharge capacity of 500,000 cubic feet per second.

On November 21, 1913, the Mississippi River Commission [55] reported on an investigation of the "necessity, urgency, and practicability of permanently separating the waters of the Red and Atchafalaya Rivers from those of the Mississippi River." The commission reported:

> That the project is practicable, but not urgent; that it is necessary to insure the reclamation of the Louisiana delta; that it will reduce the expenses of developing lands for agriculture in the interior of the basins, but by adding to the burdens of those localities which are situated on the main river.

In this report the commission estimated the maximum flood discharge of Red River as about 350,000 second-feet, and that under the conditions which existed during the floods of 1912 and 1913, the

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[54] Report on the Mississippi River, Humphreys and Abbot, 1861.
[55] House Document No. 841, Sixty-third Congress, second session, Mar. 19, 1914.

Atchafalaya had a discharge capacity of about 400,000 second-feet and the main river below Red River Landing of 1,600,000 second-feet. A further and interesting statement relating to the separation of the Red and Atchafalaya from the Mississippi is as follows:

If, on the other hand, dredging in Old River should be abandoned, the separation of the Mississippi River from the Red and Atchafalaya, up to medium or even higher stages, would be slowly but surely accomplished by deposits of such sediment, encouraged, if need be, by the use of permeable dikes. Such separation would be so gradual that the main stream would increase its capacity to accommodate the increasing volume, and tend to reduce the levee heights necessitated by an immediate closure with a dam.

As a result of the 1927 flood considerable attention has been given to this subject of diversion channels to relieve the main river below Cairo of the flood waters of the tributaries.

A plan has been advocated by J. P. Kemper, civil engineer, in a report [56] to the National Flood Prevention and River Regulation Commission, as follows:

The plan provides for taking care of 3,000,000 cubic feet of water per second at the mouth of Red River by having 1,600,000 second-feet go down the Mississippi, 600,000 second-feet down the Atchafalaya and 800,000 second-feet into Vermilion Bay, by means of a new outlet.

The plan includes a spillway below Poydras on the east side of the river, for increasing the discharge down the Atchafalaya River, and a new outlet from the lower Tensas Basin south into Vermilion Bay.

The Morgan Engineering Co. has submitted to the Flood Committee of the House of Representatives a report [57] on a proposed diversion channel for carrying Mississippi River flood water through the St. Francis Basin. This plan contemplates the diversion of 300,000 second-feet from the Mississippi River at Cape Girardeau by a floodway situated in the alluvial section of the St. Francis Basin. The floodway would include a dredged canal for 21 miles followed by an enlargement of the natural channel with levees. The outlet from the Mississippi into the floodway would be regulated by a mechanically controlled spillway. Local drainage would be provided for by backwater levees. The estimated cost of this project, including rights of way, is $129,000,000; against which a $50,000,000 credit could be taken for reduction in work outlined by the Army Engineers, and that would otherwise be necessary on the Mississippi River levees and at Cairo. It is further estimated (in accord with the estimates of the Mississippi River Commission) that this diversion will lower the flow line of the probable maximum flood five feet downstream to where the water is again returned to the river. This proposed diversion is claimed to relieve the strain on the levee along the St. Francis Basin front, to reduce the flood menace at Cairo, and to save large expenditures along the main river and possible future flood damages to property in west Tennessee.

The diversion board of the Mississippi River Commission made a report [58] on August 31, 1927, concerning the diversion of water from the Mississippi River below Cape Girardeau, across the upper and

[56] Plan for Flood Control in the Mississippi by Means of Lower Flood Levels through Outlets and Spillways Below the Arkansas River, J. P. Kemper, civil engineer. New Orleans, August 1927.
[57] Flood Control, House Committee Document No. 25, Seventieth Congress, first session. Feb. 4, 1928.
[58] The Control of Floods of the Mississippi River by Means of Diversion Channels. House Committee Document No. 3, Seventieth Congress, first session.

lower St. Francis Basins to the White River, thence through Arkansas and Louisiana, to the Gulf; and the diversion of water from the Arkansas River, or the Mississippi River near the mouth of the Arkansas, by either the same or a parallel course to the Gulf.

The diversion board studied four possible channel routes through the St. Francis Basin and gives estimates on the "ridge route" location for the diversion of 300,000 second-feet, 200,000 second-feet, and 100,000 second-feet. It is noteworthy that this estimate for a diversion of 300,000 second-feet through the St. Francis Basin is $254,000,-000 or practically twice that of the Morgan Engineering Co., for their plan (see statement preceding). To extend this diversion channel to the White River would involve an additional expenditure of $83,600,-000, making a total cost of $337,600,000. As this estimated cost was considerably more than the estimated cost of increased height of levees to afford equal protection, the board reported unfavorably on the diversion plan. It is probable that a further and more detailed study of this proposed diversion channel through the St. Francis and White Basins would indicate the economic practicability of such a plan for diverting and handling the 300,000 second-feet from the Mississippi and local drainage of these basins.

The diversion boards plan for a channel from the Arkansas to the Red River was based on providing a flood way with a capacity of from 600,000 to 750,000 second-feet. The route of the proposed flood way follows the low ground of Boggy Bayou, Bayou Macon, southwest into the Boeuf River, into the Ouachita River below Columbia, and thence into Sicily Island gorge, which discharges into the Black and subsequently into the Red River at their confluence. This investigation showed that such a flood way would cost from $117,000,000 to $135,000,000 for capacities of from 600,000 to 750,000 second-feet, and would reduce levee heights at and below the Arkansas River about 8 feet. The board in its report points out the obvious advantage of security in the use of such a diversion channel. Obviously the same advantage would apply to a similar practical channel above in the St. Francis and White Basins.

A plan [59] for the relief of the lower Delta country west of the main river in southern Louisiana is that of Welman Bradford, who proposes to divert the waters of the Red River from its present channel at Egg Bend and at Natchitoches and carry them through new channels to the Gulf. These channels include a direct canal as an outlet from the Red River, discharging into Calcasieu Bay, with a capacity of 314,400 second-feet, and works (excavation, embankments, locks, and control gates), at an estimated cost of $50,000,000; and a branch outlet canal into Vermilion Bay to carry 498,000 second-feet, and at an estimated cost of $71,000,000.

All of these investigations indicate the importance of utilizing the natural existing drainage channels and of providing a permanent flood-control plan for the lower Mississippi Basin that works with nature and uses her available resources for the welfare of man.

(f) Spillways: The occasional overflowing or breaking out of the levees in the form of crevasses under flood conditions early called attention to the possible need and importance of providing artificial

[59] Suggestions of Plan Flood Relief for Southern Louisiana by the Louisiana Gravity Canal Co. (Inc.), May 10, 1927.

relief for extreme flood flows, which as time has gone on, have become more and more confined by the works of man in the channel of the main river.

Ellet [60] advocated an outlet from the Mississippi into Lake Borgne, at a point about 11 miles below New Orleans, with an opening 5,000 feet wide to give a discharge of 210,000 second-feet. He is unfavorable to an outlet at Bonnet Carre on the grounds that the disposal of flood waters into Lake Pontchartrain would deposit silt to such an extent as to destroy navigation, convert the lake into a swamp and cause the shore to be leveed.

Humphreys and Abbot [61] state that outlets are "only applicable below the Arkansas River." They discuss fully possible outlets at Manchac, Bonnet Carre and Lake Borgne, and advise against their use. The Lake Borgne location is advised as the least objectionable for a trial of this method of flood relief. These observers quote A. D. Wooldridge, State engineer of Louisiana in 1852, to show the disadvantages of opening the Bayou Manchac; the flooding of the parishes of Ascension and Baton Rouge or the great expense of building levees to protect the agricultural lands of this fertile region. The objections to the Bonnet Carre site are the difficulty of maintaining the outlet and the injury to navigation that would result from the gradual silting up of Lake Pontchartrain.

The general policy of the Mississippi River Commission has been unfavorable to spillways. After the major floods, this policy has been expressed publicly by the president of the commission as follows:

> Outlets [62] have been suggested as another means of relief, and the Mississippi River Commission has frequently discussed the inadvisability of outlets and waste weirs as a means of lowering flood heights. * * * Where the river has a depth exceeding 100 feet, as in the vicinity of New Orleans, I am of the opinion we could afford to permit a moderate diminution of river depths if thereby we could obtain a material reduction of levee heights.
>
> Another serious objection to an outlet is the difficulty in regulating the velocity with which the water will flow through it at varying heights of the main stream. If it is so constructed that it will discharge at a greater velocity than the river itself, there is danger of its enlargement to such an extent as to divert the greater part of the flow down it, and transfer the main stream itself into an outlet; and if, on the other hand, it discharges at a lower velocity, it will tend to fill with sediment.

Col. Charles L. Potter [63] stated:

> The commission maintains that the spillway will be a disappointment; that the results will not be those shown by weir formulas or by a hydraulic laboratory; and that it can not justify the expenditure of $5,000,000 to $10,000,000 in a demonstration which it thoroughly believes will be a failure, or so disappointing as to amount to a failure.
>
> If a spillway is to be installed near New Orleans it should be above rather than below the city. * * * New Orleans had better be in the region of the reduced current (below the spillway) rather than in the region of increased current—above the spillway—for the safety of its wharves.

In 1922, as a result of the serious flood conditions of that year, especially on the lower Mississippi, a committee of citizens of New Orleans made a special investigation [64] with the purpose of ascertain-

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[60] Physical Geography of the Mississippi Valley, Charles Ellet, jr., Smithsonian Contributions to Knowledge, Vol. II.

[61] Report on the Mississippi River, Humphreys and Abbot, 1861.

[62] Address by Col. C. M. D. Townsend, at Memphis, Tenn., Sept. 26, 1912.

[63] Some Suggested Ways of Controlling the Mississippi Floods, Charles L. Potter, Engineering News-Record, vol. 94, No. 14.

[64] Report of Engineering Committee to the Safe River Committee of 100 on spillways as a means of lowering the flood levels in the lower Mississippi River, New Orleans, Aug. 15, 1922.

ing a method of protecting the city against future great floods. The subcommittee of engineers recommended a spillway to be located six miles below the barrack and discharging over a direct route of about 5 miles in length into Lake Borgne. This spillway was planned with a width of 6,000 feet, and a discharge capacity of 250,000 second-feet with a river stage of 20 feet on the Carrollton gage. The estimated cost of this flood-protection measure was $4,000,000 to $5,000,000, including construction, right of way, and damages.

The unusual number and extent of the crevasses which occurred during the 1927 flood, and especially the critical flood situation that threatened New Orleans and resulted in the blowing out of an artificial crevasse at Poydras on April 29, has forced the Army Engineers to consider and adopt spillways as a flood-protection measure supplementing levees on the lower Mississippi. A special board of officers appointed by the Chief of Engineers reported on November 12, 1927, on a plan [65] for flood relief in the vicinity of New Orleans. The plan includes a floodway down the Atchafalaya River, a controlled spillway at Bonnet Carre discharging into Lake Pontchartrain, and enlarged levees where necessary. The project is based on flood-control works that would pass a flood of 2,750,000 second-feet, and at an estimated cost of $63,600,000.

The Mississippi River Commission, in its report [66] of November 28, 1927, suggests the use of "safety-valve spillways" at various critical points along the crown of the levee, and be used only when it appeared imminent that a crevasse might occur or a levee be topped. The commission gave the following opinion:

> It is assumed that the levee grade is to be fixed to protect from any probable flood, and afford a chance to fight a possible flood, the safety-valve spillways thus providing means for substituting a minor disaster for a major one.
>
> Everything considered, the commission is of the opinion that while safety-valve spillways, automatic or controlled, may entail objections, they are worthy of further consideration as part of a comprehensive flood-control plan.

The so-called Jadwin plan which was authorized by act of Congress on May 15, 1928, and is now being executed by the Army engineers, provides for a spillway at Bonnet Carre, with the plan of providing a controlled outlet to relieve the main river of 250,000 second-feet of water, with a gage reading of 20 feet at Carrollton. The plan provides a leveed channel about 2 miles wide and 5 miles long into Lake Pontchartrain.

(*g*) *Levees.*—The earthen embankment, dike, or levee is the primary and essential measure that has been used in the Mississippi Basin to control the flow of the waters of the main river and the lower sections of the principal tributaries. The building of levees was done by private enterprise, and the local and State governments concerned until about 50 years ago. Soon after the organization of the Mississippi River Commission in 1879, this Federal body adopted levees as the form of regulative works to guide and control the Mississippi River in its flood flow, and thus provide for and expedite

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[65] Spillways on the lower Mississippi River, House Document No. 95, Seventieth Congress, first session.
[66] House Committee Document No. 1, Seventieth Congress, first session.

the making of a proper channel for navigation. In its report of 1880, the commission states:

In a restricted sense as auxiliary to a plan of channel improvement only, the construction and maintenance of a levee system is not demanded. But in a larger sense, as embracing not only beneficial effects upon the channel, but as a protection against destructive floods, a levee system is essential; and such system also promotes and facilitates commerce, trade, and the postal service.

The original project for the improvement of the Mississippi has been modified and extended by acts of Congress at various times since 1879, so as to include dredging of bars where necessary to maintain a 9-foot channel below Cairo at all times, and the construction of levees for flood protection from Rock Island, Ill., to the Head of the Passes, and up the tributaries as far as they are affected by back water during flood periods. Since June 3, 1896, the permanent work of channel improvement has consisted largely of bank revetment.

Humphreys and Abbot [67] early expressed the view:

The plan of levees, on the contrary, which has always recommended itself by its simplicity and its direct repayment of investments, may be relied upon for protecting all the alluvial bottom lands liable to inundation below Cape Girardeau. The works, it is true, will be extensive and costly and will exact much more unity of action than has thus far been attained.

The use of levees was early advised and adopted subsequently by the Army engineers for the purpose of limiting the high-water width of the river, and by thus concentrating the flood discharge within the channel to cause its deepening and enlargement by scour. There has been a controversy extending over a generation as to whether the levee system has raised the bed of the main river by sediment deposition. The evidence obtainable seems to indicate that as a result of a complex action of scouring, bank erosion, and channel change, the river bed has maintained somewhat of a condition of equilibrium. Flood heights have been raised as a result of the confinement of more of the flood waters, but floods of equal volume are not passing down the river at an appreciably lower gage height than formerly.

As the flood heights have increased due to the increasing confinement of the flood waters, it has become necessary to increase the height and cross-section of the embankments or levees.[68]

There is going on continually in the main river, especially in the section between Cairo and Baton Rouge, a change of channel section and location except where bank protection and fixation have been made by revetment. The increase of flood velocities, produced by raising flood heights, has gradually increased bank caving, bar building, and river elongation. Hence the protection of the banks of the river from caving is necessary to stabilize and maintain the channel for navigation and to keep down flood heights as far as practicable.

The history of the levee system of the Mississippi Basin is replete with the records of failures, breaks in the embankments and crevasses. During the great floods, these crevasses have served as natural spillways to relieve the pressure on weak sections of the levees. These breaks in the Army Engineers' "line of defense" have played such an

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[67] Report on the Mississippi River, Humphreys and Abbot, 1861.

[68] How the Mississippi River is Regulated, by Charles L. Potter, Engineering News-Record, Mar. 26, 1925.

important part in the results of the great floods that the Weather Bureau made the following statement:

During recent years the history of floods in the lower Mississippi Basin and its great tributaries is the history of the loss and damage caused by the breaking of protection levees and the flow of water through the crevasses thus formed.[69]

In Supplement No. 29, Monthly Weather Review, the Weather Bureau lists 52 major crevasses. The public press gave 226 as the total number of crevasses occurring during the 1927 flood, but it is probable that three-fourths of these breaks were minor and of little consequence. The total area of lands overflowed by the flood water of 1927, as obtained and reported by the Weather Bureau, was 18,286,700 acres, or 28,573 square miles. Of this area, 4,417,500 acres of crop lands were overflowed; about 2,600,000 acres in cotton, 1,100,000 acres in corn, 360,000 acres in hay, and about 357,500 acres in other crops. During the floods of 1897, 1903, 1912, 1913, and 1922 there were no losses of human life directly attributable to the flood, but in the flood of 1927, the reports show that 313 people lost their lives as a result of the flood. The estimated property loss was about $300,000,000.

The unprecedented number of crevasses and levee failures in 1927, under the highest flood levels on record, are a cause for pause and consideration of this whole matter of levees. What is the practical, safe limit in height to which they can be built? The Army engineers under the Jadwin plan are proceeding with the raising of the levees 3 feet south of the Arkansas to the mouth of the Red River, on both sides of the main river. Have any studies or tests been made to ascertain the strength or safety of these enlarged earthen embankments under flood conditions with a possible freeboard of 1 foot?

The Mississippi levee is an earthen embankment located on relatively pervious, unstable soil and subject to the disintegrating and weakening effects of moving water, sometimes at a high velocity. Hence, as a protective structure, the levee can not be considered as possessing a high degree of safety or permanency. In the case of floods, great lengths of levees must be patrolled, and at signs of sand boils, bank caving, or other forms or weakening, emergency measures must be used to strengthen, repair, or reinforce the section affected.

The recent failure of the Lafayette Dam in California calls attention to the possible weakness of an earth embankment. This structure had been carried to a height of 120 feet and was about 90 per cent complete, and with 15 feet of water behind it when failure occurred. Had the reservoir been full, it is likely that a devastating flood would have occurred.

As levees will continue to constitute one of the principal elements in any general, permanent plan for flood control in the Mississippi Basin, comprehensive studies and careful investigations should be made of the structural conditions of existing levees and proposed enlargments. Measures should be devised to establish, as soon as practicable, protection and greater permanency and stability of the existing levees, expecially along the main channel of the lower river.

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[69] The Floods of 1927 in the Mississippi Basin, H. C. Frankenfield, Monthly Weather Review, Supplement No. 29, Oct. 18, 1927.

VII. Comprehensive Plan for Flood Control and Water Conservation and Utilization

Working with nature in the practicable utilization of all the available natural resources of the Mississippi Basin is the fundamental principle on which this plan for the control, conservation, and utilization of the flood waters is based. Hence, at the outset, it is necessary to consider all of the elements and phases of the situation from the headwaters near the Canadian boundary to the outlets into the Gulf of Mexico.

The principal objective of the flood-control program is so to conserve and regulate the flood flows as to maintain the lowest practicable flood stages and reduce the crests to a minimum. This can be done by reducing the run-off on the watersheds of the headwaters by developing the widespread cultivation of tillable lands, the prevention of soil [70] erosion on slopes and hillsides by planting, terracing, contour plowing and other similar methods, and the growth of trees, scrub, or other suitable protective covering on waste lands; and by expediting the flow of the high water in the channels of the lower tributaries and main river, so as to keep the flood levels down at all times, and especially during the early part of the regular yearly flood period, January to March.

Sufficient authoritative data have been collected, studied, and published by the Department of Agriculture to justify the establishment of a comprehensive program of research and education by this Federal agency and with sufficient appropriations to determine and introduce in all sections of the basin, the proper, scientific methods of soil culture of the protection of slopes and hillsides by protective planting, reforestation, and other methods for the most effective conservation and utilization of the rainfall. Such a program should be based on further detailed studies in each section of the basin concerned, regarding rainfall and run-off and their relations to soil cultivation, forest cover, and other relevant factors. These studies should be made in cooperation with the water resources branch of the United States Geological Survey and the United States Weather Bureau. There is little if any available data on run-off in the lower Mississippi Basin and the Forest Service, in cooperation with the Weather Bureau, has recently initiated [71] studies of the relation of forest cover to stream flow.

The plan as set forth in this report must of necessity be based on existing available data, which are not sufficiently detailed or comprehensive to justify the presentation of more than a preliminary outlined statement. It is a well-known fact that topographic maps or even adequate elevations are not available for the greater part of the lower basin and continuous, reliable records of stream flow in the basin have not been made. Hence immediate steps should be taken to collect, compile, and make available these fundamental data, which will make it possible to determine, with a reasonable degree of accuracy, the total flow of the river, the seasonal and annual variations of flow, the origin and probable volume and frequency of floods,

[70] Under an appropriation of $160,000 made by the Seventieth Congress, the Department of Agriculture has set up a series of erosion prevention and moisture conservation stations. Twelve of these stations will study soil erosion conditions in the Mississippi Basin.

[71] Forest and Stream Flow Experiment at Wagon Wheel Gap, Colo., Monthly Weather Review, Supplement No. 30, 1928.

and the probability of the synchronization of floods on the tributaries and from the principal tributaries on the lower river. These data should be made available as soon as practicable, under special appropriations, by existing governmental agencies, such as the Mississippi River Commission, Geological Survey, and the Weather Bureau.

The primary factor in this plan of flood control, which provides for the consideration of the entire basin, is an estimate of the amount of flood water to be provided for at the "Bottleneck." Observations indicate a total discharge of 3,500,000 second-feet in the 1927 flood.[72] The history of floods in this country shows that many flood estimates have been exceeded by subsequent floods. The flood-control situation on the Sacramento River is a typical case. In 1881, the maximum flood discharge of this river was estimated at 100,000 second-feet. The so-called Dabney report—Commissioners of Public Works of California for 1905—recommended 250,000 second-feet, and in 1925 the State engineer stated in a report:

> The floods of 1907 and 1909 demonstrated the fact that floods more than twice as large as that for which the Dabney project has been designed should be used as a basis for a flood-control project.

In view of existing data a maximum flood condition with a discharge of 4,000,000 second-feet at the Old River will be assumed.

The essential elements of this plan are:

1. The protection and strengthening of the present levee system to carry with safety a discharge of 1,500,000 second-feet in the main river at the latitude of Old River.

2. The provision of adequate outlet relief below the mouth of the Arkansas River, so as to keep the lower river stages low in preflood periods, especially January to March of each year.

3. The retention of flood waters in systems of scientifically controlled detention reservoirs on the principal tributaries. These storage-basin systems will be so designed and operated to provide space for excess flood waters at such times and in such quantities as to eliminate dangerous flood crests and to keep the flood stages down to predetermined safe levels.

4. The diversion of flood waters of a predetermined amount from the Mississippi at Cape Girardeau and the waters of the White, Arkansas, and Red Rivers, from the main channel of the Mississippi and their discharge west of the lower river through the Atchafalaya Basin into the Gulf of Mexico.

The following is a detailed discussion of these elements:

LEVEES

It is clearly evident that the existing levee system must be maintained and made—as far as practicable—of a permanent nature to carry a maximum discharge of 1,500,000 second-feet in the lower river at Old River. This is in accord with the Jadwin plan, which is now under way and provides for the raising and strengthening of the levees on the lower river, varying from an increase of 3 feet above Old River to zero at Bonnet Carre. The estimated cost of this levee enlargement is $136,000,000.

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[72] Report on Flood and Drought Control in the Missouri River Basin. House Committee Document No. 21, Seventieth Congress, First session. Exhibit No. VI, Jan. 28, 1928.

The Jadwin plan provides for the carrying out of "a general bank-protection scheme" for the stabilization of the channel and at an estimated cost of $80,000,000.

Undoubtedly the enlargement of the levees and the stabilization of the channel should be proceeded with on the basis of a maximum discharge capacity of 1,500,000 second-feet at Angola, and with a 5-foot freeboard all along the lower river from Cairo to the Gulf. A thorough field examination of existing levee sections should be made before proceeding with embankment enlargement to ascertain their physical condition, especially with relation to foundations. Field tests of bank protection are necessary to determine the most efficient method of providing for a stable channel under varying soil and water stage conditions. It is possible that in many localities cut-off walls of sheet piling or other similar structures may be required to prevent undercutting of the wetted slopes at the lower edge of the bank revetment.

OUTLETS

The principal outlet will continue to be the main channel of the Mississippi River. The channel below New Orleans is fairly straight and stable, and will undoubtedly maintain itself.

To provide for excessive flood conditions and to protect the city of New Orleans with its population of nearly one-half million and property valued at about $600,000,000, the Jadwin plan includes a spillway at Bonnet Carre. This structure is being designed to discharge a maximum of 250,000 second-feet through a leveed channel into Lake Pontchartrain, at flood stages above 20 feet on the Carrollton gage. It is assumed from past flood records, that this floodway will operate about once in five years, and for a period of from one to three months. With an assumed maximum discharge of 1,500,000 second-feet in the river channel, this spillway will provide for a reduction of 16⅔ per cent, and allow a maximum discharge of 1,250,000 second-feet past New Orleans.

The Bonnet Carre [73] location was chosen by the Army engineers in preference to one for the floodway at Caernarvon on account of the desirability of discharging excess flood waters above New Orleans and thereby reducing the high flood velocities which would result in serious bank erosion and caving in New Orleans harbor. A study of the silt problem indicates that "the average rate of silting for the entire lake (Pontchartrain) would be one thirty-second of an inch per annum."

Other locations for spillways adjacent to New Orleans on the east bank of the lower river have been studied and reported on by various engineers and commissions since the report of Ellet in 1851. While it is probable that under existing conditions—physical, economic, and engineering—the Bonnet Carre location may be the most feasible; there are so many elements to consider and balance with relation to securing a permanent structure, that a further study should be made, including the Manchao-Maurepas and the Caernarvon sites.

While the Army engineers' estimate for this spillway project is $8,200,000, it is recommended, in view of probable unusual founda-

[73] Flood Control in the Mississippi Valley, House Document No. 90, Seventieth Congress, first session.

tions, scour, and other conditions that must be provided for, that an allotment of $10,000,000 be made for this project.

RESERVOIRS

The efficacy of storage basins or reservoirs for the detention of flood waters has been demonstrated throughout Europe and recently in several sections of this country. Undoubtedly such a method of flood control is very costly, but it is certainly an important factor and economically justified in any plan for a permanent system of river control and regulation works. It is neither logical nor rational to reject an important factor in a plan because the use of more of another and less permanent factor will involve a less initial cost. A true economic study of any problem must include all factors and be based on final cost, comprising initial costs, maintenance and repair expenses, replacements, and losses to life and property from periodic failures. Supposing that a workable system of detention reservoirs had been built in the Ohio, Arkansas-White, and Red Basins after the 1922 flood and had reduced flood stages sufficiently to have prevented most if not all of the major crevasses that occurred in the flood of 1927; the savings in property damages alone would have practically paid for their cost of construction.

The basic data including topographic maps, stream-flow measurements, and actual field studies are not now available for a definite, accurate statement concerning a detention reservoir system for the entire Mississippi Basin. But the recent investigations, made largely as a result of the 1927 flood, furnish sufficient data to indicate the development of a possible practical system.

A comprehensive plan should include flood and low-flow regulation in each of the major tributaries by a system of storage or detention reservoirs and their operation as a group so as to control the flood stages and eliminate dangerously high-flood crests on the Mississippi from Cairo to the Gulf. This would involve the study of each basin system and of the entire group of basin systems as a whole, and the preparation of operation charts that will be used to control the entire system, very much as division and central chief train dispatchers control the operation of a great transportation system.

The principal tributary basins, the floods of which have and are likely in the future to cause major flood conditions, are the Missouri, the Ohio, the Arkansas-White, and the Red.

Generally, a flood control system of reservoirs should be used solely for that purpose, as the requirements of a storage basin for flood control and for power or irrigation are not compatible. But there are notable examples of very large (high head) reservoir sites in the Mississippi Basin such as that on the Mississippi River at Commerce, Mo.; on the Missouri River at Fort Clark, N. Dak.; and on the Arkansas near Little Rock, Ark., that could probably be operated by zoning the reservoirs for their respective uses—such as is planned for the Los Angeles flood control district reservoir.

The Missouri and Upper Mississippi Basins have never (as far as records show) been a major factor in contributing to the serious or maximum flood conditions on the lower river. Occasionally, however, the floods from the Missouri and upper Mississippi synchronize and produce high-flood stages at St. Louis, as in 1922.

High flood stages on the lower Missouri have caused great property losses at Omaha and Kansas City, as in 1903.

A careful field study should be made of the possible 20,000,000 acre-feet of storage on the upper Missouri and of the proposed storage near Commerce on the Mississippi between St. Louis and Cairo. Existing data indicate that the proposed reservoir at Fort Clark, N. Dak.,[74] will reduce flood flows on the lower river by 300,000 second-feet. The highest recorded discharge at Cairo is 1,420,000 second-feet in 1858.[75] The estimated maximum discharge at Cairo in 1927 was 1,800,000 second-feet, and the estimated probable maximum flood is 2,400,000 second-feet.[76] Hence the possible flood reduction at Kansas City, Mo., might be about 38 per cent and in case of synchronization with the upper Mississippi and Ohio at Cairo about 14 per cent. Taking into account the time element of flood crest flow and possible augmentation by simultaneous floods from the principal trubutaries, it is probable that this proposed storage in North Dakota would reduce flood stages at Cairo by 3 feet.

The proposed reservoir near Commerce, Mo., is estimated at a storage capacity of 3,900,000 acre-feet and a cost of $20,000,000.[77] The strategic location of this reservoir—within 25 miles of Cairo—as a control factor in the operation of the reservoir systems of the three great tributary basins north of Cairo, makes its inclusion worthy of serious consideration in spite of its estimated high unit cost, $20 per acre-foot. The preliminary surveys indicate that this reservoir also has considerable power potentialities and is thus a source of revenue.

It is recommended that a further investigation be made to determine the practicability of utilizing these two reservoir sites; the one at Fort Clark, N. Dak., to control the flood waters of the upper section of the Missouri Basin, to regulate the low-flow conditions of the river below Bismarck, N. Dak., for navigation and irrigation purposes, and to supply about 30,000 horsepower at a 30-foot head; and the other at Commerce, Mo., to control flood flow conditions on the river below St. Louis, to develop about 300,000 horsepower, and to regulate the low-water flow during August to December of each year.

It is probable that these two reservoirs could be built at a total cost of about $150,000,000, and reduce the flood stages at Cairo about 5 feet. Their capitalized power value would be about $45,000,000 and their value to navigation about $15,000,000. This would reduce the net cost for flood control to about $90,000,000.

If some combined system for the Mississippi Basin, to the north and west of the mouth of the Ohio River be established, there would be no future need to make provision for the Missouri River June floods in the lower river basin.

The Ohio Basin has been and probably always will be a major contributor to great floods on the lower Mississippi. Hence the control

[74] Preliminary Report on Missouri River Dam in North Dakota, Office of State Engineer, North Dakota, 1928.

[75] Results of Discharge Observations, Mississippi River and its Tributaries and Outlets, 1838–1923, Mississippi River Commission.

[76] Special Report of Mississippi River Commission, Nov. 28, 1927, House Committee Document No. 1. Seventieth Congress, first session.

[77] Report on The Control of Floods of the Mississippi River by Means of Reservoirs, House Committee Document No. 2, Seventieth Congress, first session.

of floods by the reduction of flood stages and the elimination of flood crests on the Ohio River and its tributaries is an important factor in this entire plan.

The report of the Pittsburgh Flood Control Commission considered the use of a detention reservoir system on the Allegheny and Monongahela Rivers to protect the city of Pittsburgh, Pa. Seventeen reservoirs, furnishing a storage of 1,363,000 acre-feet at an estimated cost of $21,670,200, were recommended. It was estimated that by their combined use, the flood-stage reduction at Pittsburgh would be from 10 to 12 feet, and the increase of low-water stage about 10 feet.

The so-called Kelly report of the Army engineers considered 12 reservoir sites in this same watershed above Pittsburgh, giving a total storage capacity of 3,860,600 acre-feet at an estimated cost of $27.55 per acre-foot, as compared with the Pittsburgh Flood Commission's estimate of $15.90 per acre-foot. The Army engineers' report, however, does not include any of these sites in its selected group "of 30 reservoirs of moderate cost." This report, furthermore, does not indicate what effect these 12 reservoirs would have on reducing maximum flood heights at Cairo. It is likely that this stage reduction would be about 2 feet.

The most efficient system of flood retention reservoirs would be a large storage basin above Cincinnati on the Ohio River and a group on the lower sections of the main tributaries between Wheeling and Cincinnati. It is recommended that a careful investigation be made to ascertain the practicability of locating such a system of reservoirs. In the location of such reservoirs it should be the aim to secure sites where the natural water surface at flood has a considerable width and area, and where their total water area would be a relatively small proportion of the area of the protected lands.

Insufficient data are available to suggest any definite plan and estimate for the Ohio River Basin. But it is believed possible to find a group of reservoirs above Cincinnati that would protect the large cities from high-flood stages, regulate low-water conditions for navigation, and reduce flood crests at Cairo by 5 feet, and at a net cost for flood control of about $150,000,000.

Assuming that such a combined reservoir system would lower the maximum flood crests on the Ohio River at Pittsburgh by 11 feet and at Cincinnati by 15 feet, the serious flood of March–April, 1913, would have been controlled and a damage loss of about $150,000,000 averted. Thus practically the net cost of the proposed reservoir system might be saved in the event of another flood condition in the Ohio basin, similar to that of the spring of 1913. It is possible that a more serious flood, with a stage of 9 feet [78] above that of 1913 at Pittsburgh, might occur if the watersheds of all of the rivers above Pittsburgh were to receive as great a rainfall as occurred over Ohio and portions of Indiana in the 1913 flood.

The latest great flood of 1927 demonstrated the destructive influence of floods from the Arkansas-White and Red Rivers when synchronizing with high-flood stages on the lower Mississippi.[79] Studies indicate the value of the possible retention of flood waters

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[78] The Floods of 1913, Bulletin 2, U. S. Weather Bureau, 1913.

[79] Floods in the Valley of the Mississippi, J. P. Kemper, C. E. National Flood Commission, New Orleans, La., 1928.

by reservoirs in reducing or eliminating flood crests on the Arkansas River at Little Rock, Ark., and on the White River at Clarendon, Ark., during the 38 days from April 1 to May 8, inclusive, 1927. Estimates indicate that during this period a storage of about 12,700,000 acre-feet would have eliminated the flood crest above the flood stages of 23 feet on the Arkansas River at Little Rock, Ark., and likewise a retention of 6,700,000 acre-feet during this same period of time would have eliminated the flood crest over the flood stage of 30 feet on the White River at Clarendon, Ark.

The Army engineer reservoir board[80] report refers to a reservoir site on the Arkansas River, 2½ miles northwest of Little Rock, Ark., with a capacity of 25,300,000 acre-feet and an estimated cost of $163,000,000. The report states:

> By the use of the Little Rock Reservoir alone, the extraordinary flood of 1927 could have been held down to 40,000 cubic feet per second, which would have had a marked effect on the Mississippi flood at Arkansas City and lower points. The resulting reduction in the maximum flow of the Mississippi would have been about 400,000 cubic feet per second, which would have lowered the Arkansas City gage nearly 7 feet.

It will be noted that this Little Rock Reservoir would have practically double the capacity required to have stored the flood-crest waters above the flood stage of 23 feet at this point.

The Army engineer report also gives data concerning 13 reservoir sites on the White and its tributaries, affording a possible storage of 13,827,200 acre-feet at an average estimated cost of $7.38 per acre-foot. Five of the largest capacity sites of this group would provide a combined storage of 9,634,000 acre-feet at an estimated cost of $53,296,610. This reservoir system would provide 50 per cent more capacity than would have been required during the flood of 1927 to eliminate the flood crest above the 30-foot flood stage on the White River at Clarendon, Ark.

In the Red River Basin the report of the Interstate Flood Control Commission indicates the possibility of a detention reservoir system that will have a storage capacity of 6,000,000 acre-feet and cost about $30,000,000. The report of the Army engineer board notes two reservoirs in this basin that will have a combined capacity of 6,460,000 acre-feet and an estimated cost of $17,000,000. Assuming that these two reservoirs are well down on the lower section of the Red River, they would be preferable for flood-control purposes at Old River to the group of a larger number of storage basins on the headwaters.

In any review of this Mississippi flood-control problem, considerable research should be done to investigate the practicability of source stream control on the headwaters, especially in the Arkansas-White and Red River Basins, by the check-dam system, which has been used to some extent in the Southwest, and especially in southern California.[81] The beds of the Arkansas River and several of its main tributaries are largely of shifting sand and it is possible that some of the flood-control methods used in the arid Southwest might be applied to these streams to check the flood flows.

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[80] Report on The Control of Floods of the Mississippi River by Means of Reservoirs, House Committee Document No. 2, Seventieth Congress, first session, 1927, p. 24.

[81] Flood Control, The Mississippi River and Its Tributaries, pt. 6, statement of George H. Maxwell, p. 4133.

A résumé of the possible available reservoir sites in the various basins indicates the following:

Basin	Proposed reservoir storage, acre-feet	Estimated cost, gross	Estimated discharge reduction, second-feet	Estimated capitalized value for power, navigation, irrigation, etc.
Missouri	15, 000, 000	$47, 500, 000	300, 000	$1, 000, 000
Upper Mississippi	3, 900, 000	130, 000, 000	60, 000	50, 000, 000
Ohio	10, 000, 000	250, 000, 000	300, 000	100, 000, 000
Arkansas-White	34, 000, 000	200, 000, 000	500, 000	50, 000, 000
Red	6, 460, 000	17, 000, 000	100, 000	5, 000, 000
Total	69, 360, 000	644, 500, 000	1, 260, 000	206, 000, 000
		206, 000, 000		
Total		438, 500, 000		

$438,500,000 is the estimated net cost of a complete storage-reservoir system of the Mississippi Basin. If it is assumed that this entire system would have a net cost of $450,000,000, this would mean an average net unit retention cost of about $6.50 per acre-foot, which is a reasonable figure for a capital expenditure of this permanent nature.

The operation of the reservoir system would reduce a maximum flood at Cairo by about 660,000 second-feet, and this would bring the assumed greatest flood of 2,400,000 second-feet at Cairo down to 1,740,000 second-feet, or slightly less than the estimated highest discharge of 1927 at this place.

Below Arkansas City the operation of the combined reservoir systems of the Arkansas-White Basin would make a still further reduction of 500,000 second-feet, and thus in the case of a flood condition similar to 1927 would leave a surplus of about 320,000 second-feet to be taken care of in the Mississippi or in an auxiliary channel.

Similarly the operation of the proposed reservoir system in the Red River Basin would reduce the maximum flood condition at Old River by 100,000 second-feet, leaving about 150,000 second-feet to run off into the Mississippi channel or through the Atchafalaya or other diversion channel south into the Gulf.

This suggested detention reservoir plan is intended to show the practicability of the use of a scientifically operated system for the control of flood waters in the various main tributary basins and on the lower river. This system would also be of great value in the regulation of low-water flow for navigation and for power development at a few locations such as Fort Clark, N. Dak., Commerce, Mo., and Little Rock, Ark.

An engineering review should investigate the reservoir systems proposed by the interstate flood-control commission in the Arkansas and Red River Basins. It is possible that these systems or sections of them would provide a more feasible and economical method of flood control and general development in these two basins than the larger reservoirs suggested in the plan outlined above. Sufficient data are not availabe to make a comparative study of this matter at this time (June, 1929).

DIVERSION CHANNELS

The experience of the 1927 flood, especially with relation to the overflow of the lowlands of the St. Francis, Tensas, and Atchafalaya Basins, demonstrated the need of auxiliary channels to such an extent that the Army engineer plan included three floodways west of the Mississippi River; the most northerly one in the St. Francis Basin from Birds Point, opposite Cairo, to New Madrid, Mo.; the second one below the mouth of the Arkansas River, in the Boeuf River Basin, and the third and southernmost in the Atchafalaya Basin to the Gulf. This floodway plan involves the periodic flooding of about 135,000 acres of land in southeastern Missouri. This area includes 175 miles of highway, 97 miles of drainage canals, 35 highway bridges, many miles of railway and highway, and property with an estimated value of from $12,000,000 to $15,000,000. In the Atchafalaya Basin the area flooded and propery value would be very much greater.

The combined use of diversion channels with the detention reservoir system, described in the preceding section, will conserve and control the excess waters of a superflood and stabilize the flow of the Mississippi River from Cairo to the Gulf.

The project of diversion channels is to utilize the natural floodways west of the Mississippi River in the form of the sloughs, swamps, marshes, small lakes, and streams which, in a general way, parallel the main river through the St. Francis, Tensas, and Atchafalaya Basins. Thus natural resources will be utilized as far as practicable, and the natural channels enlarged by excavation and levee construction only as may be required to carry the flood flows at various sections.

The investigations made as a result of the 1927 flood have furnished sufficient data to make it possible to outline a diversion channel plan for the lower basin west of the main river.

Beginning with the St. Francis Basin, this plan proposes a diversion of 300,000 second-feet from the Mississippi River at Cape Girardeau, and following through the alluvial section of the basin to Big Lake at the Missouri-Arkansas line, thence southwest to St. Francis Lake, then south generally following the St. Francis River to the gap in Crowleys ridge near Marianna, and thence across to the White River Basin where it will join the White River below St. Charles.

In this diversion plan, it should be noted here that waters diverted from Cape Girardeau must never be returned to the Mississippi River but be taken down through a continuous auxiliary channel, if possible, to the Gulf, as studies have shown: [82]

> It was found that the crest of the Mississippi River flood and that of the waters diverted on date of crest at Cape Girardeau would meet at Helena on the tenth day after the Cape Girardeau crest.

A recent [83] investigation indicates a practical channel through the alluvial section of the St. Francis Basin consisting of a large dredged channel for the first 21 miles, then a flood way between levees, varying in width from 3 miles to 5½ miles below St. Francis Lake. The

[82] Report on the Control of Floods of the Mississippi River by Means of Diversion Channels. House Committee Document No. 3, Seventieth Congress, first session.

[83] Report on Diversion Channel for Mississippi River Flood Water Through St. Francis Basin. House Committee Document No. 25, Seventieth Congress, first session.

spillway at Cape Girardeau will be a mechanically operated structure of a permanent nature, and so operated to release flood waters at stages to be determined by flood stage conditions on the Mississippi River, and in coordination with the operation of the reservoir systems in the Missouri, upper Mississippi and Ohio Basins.

To pass through the gap in Crowleys Ridge will require considerable excavation from Marianna to Barton. The channel will then follow south along the west slope of the ridge and pass between levees into the White River nearly opposite Friar Point on the Mississippi.

From the White River to the Arkansas, the diversion will form a part of the existing delta basin.

The estimated cost of this upper section of the proposed diversion channel—from Cape Girardeau to the Arkansas River—is about $220,000,000, including spillway, excavation, and embankment work, rights of way, railway and highway changes, etc. Should this project be carried out, it would eliminate proposed levee construction and other work—under the Jadwin plan—in southeast Missouri and thus afford a credit of $50,000,000, making a net cost of the diversion of $170,000,000.

In time of a superflood this diversion channel would relieve the Mississippi River below Cairo of 300,000 second-feet and lower the flood stage about 5 feet. Hence in coordination with the operation of the proposed reservoir systems in the Missouri, upper Mississippi and Ohio basins, a maximum flood of 2,400,000 second-feet at Cairo would reduce this discharge to about 1,500,000 second-feet, which the Army Engineer's [84] report states can be safely taken care of in the existing channel of the Mississippi—with some raising and strengthening under the Jadwin plan.

The lower section of the proposed diversion channel will begin at the Arkansas River and follow, in a general way, the course taken by the flood waters, which, prior to 1921, overflowed through Cypress Creek, above the stage of 53 feet, on the Arkansas City gage, and flowed down the valleys of Bayou Boeuf and Bayou Macon, and discharging into the Red River through the Ouachita and Tensas Rivers. These streams thus form a natural diversion channel.

Between the upper and lower diversions sections—adjacent to the mouth of the Arkansas River—the flood waters will flow through an enlarged channel including the Mississippi, and the head of the lower diversion floodway near the mouth of Cypress Creek, will be a spillway of a permanent nature and mechanically controlled to divert a maximum discharge of 700,000 second-feet. Thus the spillway and floodway below would provide for the 300,000 second-feet received from the upper floodway, the 320,000 second-feet of excess flood waters from the Arkansas-White basin and allow for 80,000 second-feet of flood waters from the Tensas Basin, when operated in coordination with the reservoir systems of the Arkansas-White basin.

The estimated cost of this floodway, including spillway, levees, rights-of-way, railway and highway changes, etc., is approximately $130,000,000. As this diversion channel would preclude the necessity of a large part of the proposed levee construction along the Mississippi and in the Boeuf Basin—under the Jadwin plan—there would be

[84] Mississippi River Flood Control. The World Almanac for 1929, p. 160

a saving of about $50,000,000 which could be credited to the diversion channel plan and thus make its estimated net cost approximately $80,000,000.

At the junction of the Red River, at Old River, the excess flood waters from the Red, not retained by the proposed reservoir system, would add about 150,000 second-feet, in case of a superflood, to the discharge from the lower diversion channel at this location. The accumulated discharge to be carried directly south to the Gulf would be about 850,000 second-feet.

As at the mouth of the Arkansas a spillway may be found necessary so as to control and pass part of the excess flood waters discharging in the diversion channel from the Arkansas-White and Red Basins, in case of low flood stage conditions on the main river. It is assumed in this plan that the lower Mississippi will at all times safely and continuously carry a discharge of 1,500,000 second-feet, which will be reduced by the spillway at Bonnet Carre to a discharge of 1,250,000 second-feet past New Orleans.

South of the Bottleneck at Old River, the Atchafalaya River provides a natural watercourse that will carry safely a maximum discharge of 500,000 second-feet. This leaves a surplus of 350,000 second-feet, which may be carried through the Atchafalaya River by creating an enlarged floodway channel, or by diverting this excess into an additional channel, which would follow the low swamp lands to the west of the Atchafalaya Valley and discharge into Vermilion Bay. Considerably more field study of these routes is necessary and should be made a part of the proposed engineering and economic review. One authority [85] recommends the diversion of 750,000 second-feet through a floodway along the Atchafalaya River. The Mississippi River Commission [86] recommends the enlargement of the existing floodway down Atchafalaya River, to carry a discharge of about 900,000 to 1,000,000 second-feet. The estimated cost of this floodway, including rights-of-way, is $52,500,000.

The Spillway Board [87] recommended an Atchafalaya flood way

> to be created by setting back the levees in the upper river so as to afford an overflow channel approximately 7 miles in width; and the protection of the lands around Grand Lake, including Morgan City and Berwick, together with the Teche and Lafourche districts by levees.

The estimated cost of this project is $17,500,000, but not including rights-of-way, direct or indirect damages, railroad or highway changes, drainage, etc. If these elements of expense are included, the total cost would probably be about $50,000,000.

It is recommended that a detailed field and economic study be made to ascertain the most practicable outlet plan in the Atchafalaya Basin below Old River. Either an enlargement of the Atchafalaya River channel to care for a total flood of 850,000 second-feet, or the construction of additional channel to care for 350,000 second-feet, will provide a practicable outlet west of and supplemental to the main channel of the Mississippi River to take care of a superflood discharge into the Gulf. It will probably be sufficient to estimate a cost of $50,000,000 for this project. Should a spillway at Old River

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85 Floods in the Valley of the Mississippi, J. P. Kemper, civil engineer, National Flood Commission 1928.

86 Special Report of the Mississippi River Commission, Senate committeee print, Nov. 28, 1927, p. 60.

87 Spillways on the lower Mississippi River, House Document No. 95, Seventieth Congress, first session, Dec. 10, 1927.

be found practicable and necessary, about $10,000,000 should be added to the above figure.

It is further recommended that a comprehensive study of diversion channels should consider the practicability and economic feasibility of the following:

(*a*) The utilization of the backwater areas at the junction of the St. Francis, Arkansas-White, Red, and Yazoo Rivers with the lower Mississippi River. There is a natural storage condition at these areas that can and should be utilized in coordination with the reservoir systems and the diversion channels.

(*b*) The diversion of the waters of the Tennessee River across the southwestern corner of the State of Tennessee and into the headwaters of the Coldwater or Tallahatchie River, and thence down the Yazoo River to a point near Satartia, Miss., then by a cut-off channel to the Big Black River and along this stream to the Mississippi near St. Joseph, La.

(*c*) The "new river plan" to provide a flood way in the Yazoo Delta beginning with the Coldwater River and constructing a controlled channel with two levees along the lowest and most inexpensive (poorest) lands of the delta.

(*d*) The diversion of the headwaters of the Red River into the Brazos and Trinity Rivers in Texas.

(*e*) The use of permeable dikes and the method [88] of "regulation of rivers without embankments" in those sections of the proposed diversion channels where the soil and flow conditions are suitable.

To summarize the suggested plan for the control, conservation, and utilization of the flood waters of the Mississippi Basin, it is intended to keep the flood stages down on the lower river by new outlets and diversion channels, and to control and regulate the flood flows on the tributaries by coordinated systems of reservoirs. Thus the Mississippi channel from Cairo to the Gulf will at all times have a regulated flow, a safe maximum in flood seasons, and a low-flow minimum for navigation during the drought or low-water periods.

The estimated cost of this coordinated project is as follows:

Levees (raising and strengthening)	[89] $30,000,000
Revetment and levee protection	90,000,000
Outlet (spillway on lower river)	10,000,000
Reservoirs	[90] 438,000,000
Diversion channels	410,000,000
Channel dredging, etc	10,000,000
Contingent expenses (surveys, research, etc.)	12,000,000
Total	1,000,000,000

The execution of such a broad, stupendous project must be carried out over a period of years, probably not less than 10 in length. The entire work should be planned and scheduled in advance, as far as practicable, somewhat along the following procedure:

1. The early raising and strengthening of the levees, and bank revetment and protection.

2. Channel dredging and improvement, and the building of the spillway on lower river.

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[88] Regulation of Rivers Without Embankments, F. A. Lute, Crosby, Lockwood & Son, London, 1924.
[89] Allowing $100,000,000 saving in using diversion channels in the St. Francis and Tensas Basins.
[90] Allowance made for proposed capitalized value of reservoirs for power development, navigation, and irrigation.

3. The construction of the larger and more important detention reservoirs, especially in the Arkansas-White and Red Basins, and the development of the natural backwater-areas at the mouths of the St. Francis, Arkansas-White, Red, and Yazoo Rivers, to keep flood stages on the lower Mississippi down and to retain excessive flood waters on the lower reaches of the principal tributaries in the southwestern part of the Mississippi Basin.

4. The construction of the reservoir systems in the northern basins.

5. The development of the diversion channels, beginning with the southernmost in the Atchafalaya Basin, which could be used as a relief spillway and floodway from Old River south, in case of a maximum flood condition, before the diversion channels are built in the Tensas and St. Francis Basins.

From the inception of this plan, and as a vital element of it, should be carried on the field studies, investigations and research, upon the results of which will be based the execution of the details of design and construction.

The execution and administration of this plan should be carried out under a national flood-control commission, which would be an independent Federal establishment and would be charged with the administration of a national policy concerning flood-control and allied matters.

The nature and scope of a flood-control policy, especially with relation to the Mississippi Basin, has been a subject of discussion in the Halls of Congress and among all classes of peoples concerned for many years. Our leading statesmen, including Clay, Lincoln, Garfield, and Roosevelt, have pointed out in public statements that this is a national problem; and the two great political parties, speaking through their respective platforms during the 1928 national campaign, clearly affirmed this principle.

Any national policy governing flood control should be based on the recognition by the Federal Government of its obligation to maintain interstate commerce, and to protect the lives and property of its citizens when the States fail in this duty. Hence, it would be the duty of the Federal Government to proceed with the repair, strengthening and enlargement of the levee system of the lower Mississippi, and such bank protection and channel improvement required to protect the lives and property and to provide a navigable channel as required by existing laws.

The further carrying out of a national flood-control plan under a national commission should be based on a policy of cooperative action and contribution on the part of the National and State Governments. A national flood-control program should be so established and administered as to be free from political control and mismanagement. It is recommended that the construction and administration of the reservoir diversion channel and spillway project be carried out on a cooperative basis, somewhat similar to the Federal-aid highways program; the Federal and State Governments sharing in the expense and administration of a predetermined program, and plan, which shall be established by act of Congress. Such an act would, of course, require the repeal of some existing Federal legislation, and the adoption by the various State legislatures concerned of flood-control codes that would be in working conformity with the national flood-control policy.

VIII. Navigation

Navigation was the principal interest and concern of the Mississippi River Commission at its inception, as is indicated by its first report in 1880:

The views of the several members, however, are not in entire accord with respect to the degree of importance which should attach to the concentration of flood waters by levees, as a factor in the plan of improvement of low-water navigation, which has received the unanimous preference of the commission.

Furthermore, the commission also recognized the needs and methods of improvement of the river channel, required for navigation, as noted in the following extracts from the preliminary report of 1880:

The bad navigation of the river is produced by the caving and erosion of its banks, and the excessive widths and the bars and shoals resulting directly therefrom.

The plan of improvement must comprise, as its essential features, the contraction of the waterway of the river to a comparatively uniform width, and the protection of caving banks.

The work to be done, therefore, is to scour out and maintain a channel through the shoals and bars existing in those portions of the river where the width is excessive, and to build up new banks and develop new shore lines, so as to establish as far as practicable the requisite conditions of uniform velocity for all stages of the river.

The rivers and harbors bill of 1881 appropriated $1,000,000 for the improvement of the Mississippi River in accordance with the commission's plans. The bill specifically provided that funds should be used in the construction and repair of levees solely as a means of deepening the channel of the river, improving it for navigation, and affording safety and ease to its commerce.

The commission early adopted the policy of building light, permeable dikes to contract the channels, and thus to develop new banks and shore lines. The early experience in the use of this type of regulation works was secured at Plum Point reach, 147 to 186 miles below Cairo, and at the Lake Providence reach, 517 to 550 miles below Cairo. In both places low-water navigation was difficult. The lack of permanence of such works has been due to their insufficient strength and resistance to scour and led the commission in the early nineties to the development of hydraulic dredges of great capacity for the maintenance of the channel. The act of Congress, of June 3, 1896, provided for the maintenance, by dredging, of a channel below Cairo, of not less than 250 feet in width and 9 feet in depth, at all periods of the year except when navigation is closed by ice. Since 1895, a navigable channel has been maintained by dredging, and except for occasional periods of low-water flow, this channel has been available. This annual cost of maintaining this channel has averaged about $600,000.

RIVER TRAFFIC

The development in river traffic in recent years, especially in the use of large barge tows, has demanded a channel width greater than 250 feet. The traffic[91] in crude oil in 1926 was 2,500,000 tons,

[91] Improvement of Navigation in Relation to Flood Control, Stuart C. Godfrey, Proceedings American Society of Civil Engineers, December, 1927.

about the equal of the entire foreign commerce of Boston, Mass., Newport News, Va., or Galveston, Tex.

The following table shows the tonnage handled on the Mississippi and Ohio Rivers since 1920:

Section of river	Annual tonnage		
	1920	1923	1926
Cairo, Ill., to Memphis, Tenn	1, 044, 945	1, 048, 322	1, 660, 188
Memphis, Tenn., to Vicksburg, Miss	925, 763	1, 452, 837	4, 792, 780
Vicksburg, Miss., to New Orleans, La	2, 874, 190	5, 493, 297	11, 074, 488
Ohio River	9, 869, 325	9, 245, 647	[1] 19, 700, 000

[1] Approximate estimate.

The Inland Waterways Corporation, on its Mississippi Warrior line, charging a rate at 80 per cent of the rail rate, carried 1,341,000 tons of freight in 1926. This was an increase of 18 per cent over 1925, and effected a saving of more than $2,000,000 to the shippers. Present (1929) indications are for an increase in the extent and amount of freight transportation on the Ohio and lower Mississippi, especially in the movement of the heavier, slow-moving commodities such as lumber, steel, coal, oil, etc.

The changing conditions in transportation since the "packet" days on the Mississippi are shown by the record of the giant steamer *Sprague*, which on March 21, 1926, finished a 300-mile tow at Baton Rouge with a cargo of petroleum (224,000 barrels of crude oil) contained in 19 steel barges. This consignment would have been the equivalent of 28 full trainloads of 40 tank cars each, or one solid train 9 miles in length.[92]

RECENT DEVELOPMENTS IN RIVER REGULATION

The past experience of the Mississippi River Commission in its endeavor to maintain a channel has demonstrated the principle of so regulating the flow of the river as to have a stable direction of current at all stages. The difficulty in securing this condition is due to the rapid change in the stages of the river during flood-flow conditions. The channel consists of a series of great pools separated by sand bars, varying in extent and location from season to season, and from year to year. These sand bars build up during high water and are the cause of increased stage heights during great floods such as that of 1927. A rapidly rising river tends to fill in its channels at the bars, and a rapidly falling river may cause a shoaling even at medium stages. After the flood of 1927, it became necessary to dredge in places at stages, well above ordinary conditions, to remove these shoals.

The method of Captain Eads of concentrating the channel by jetties and other similar contraction works has worked well at The Passes where the flood-water rise range is relatively low, and the channel is fairly stable. But on the upper reaches of the lower Mississippi, where the flood range is large and rapidly changing and the the channel unstable, these works have not proved successful nor

[92] Improvement of Navigation in Relation to Flood Control, Maj. Stuart C. Godfrey, Proceedings American Society of Civil Engineers, December, 1927.

permanent. Dredging has likewise not proved successful in maintaining a stable channel, as it has been found impossible to insure, with a reasonable number of dredges, a channel of project depth. Those limitations of dredging are well set forth in a report by Capt. O. H. Ernst, April 10, 1903, referring especially to the middle Mississippi:

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 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

Recent special investigations and reports [93] indicate the vital need of stabilizing the banks and bed of the river channel. The later report of the Board of Engineers points out that:

At present, expenditures are being made on bank stabilization at the rate of nearly $4,000,000 per year. There is, in addition, a substantial annual loss due to setting back levees forced by bank caving of about $900,000 per year. This loss will gradually decrease and finally disappear with stabilized banks. There is also an annual loss of revetments due to the present unstable regimen of the river. This is estimated to amount to $150,000 per year

Hence it is evident that the present unstable condition of the river channel requires the following approximate annual expenditure to maintain the channel:

Dredging	$600, 000
Stabilization	4, 000, 000
Setting back levees	900, 000
Revetment losses	150, 000
Total	5, 650, 000

During the year 1927, $3,696,426.11 was spent in revetment work. From 1881 to 1927, inclusive, $61,229,695.20 was spent for the protection of levees. Adding this sum to the $238,000,000 expended for levee construction, there is a total of about $300,000,000 spent for flood control. The amount spent on the river to benefit navigation, during this period, was relatively small.

The report of the Army engineers [94] recommends a comprehensive program for bank and channel stabilization; involving an annual expenditure of $15,000,000 for 10 years. The works intended are "largely standard revetments of proven capacity." The project further contemplates that:

In planning and carrying out such a program, it is essential that the river be considered as a unit, with mutually supporting works, deliberately and progressively carried out over a considerable period of time, and successively adapted to meet changing river conditions. If so performed, the board believes the stabilization of the banks of the Mississippi and the eventual regulation of its channel, to be entirely practicable.

The experience of European countries has clearly shown that fully regulated rivers have reduced the flood heights. Hence the essential factor in the reducing of flood heights and maintaining the channel for

[93] House Document No. 50, Sixty-first Congress, first session. Report on Improvement of Mississippi River for Navigation, House Committee Document No. 6, Seventieth Congress, first session.
[94] House Committee Document No. 6, Seventieth Congress, first session.

low-water flow is the regulation of the regimen of the river. Foreign experience has again shown the value of reservoirs and auxiliary channels as controlling elements in river regulation—both to reduce flood heights and to raise low water stages. Major Godfrey in his recent [95] paper before the American Society of Civil Engineers states:

> The writer has no data relative thereto, in addition to what have been given, except the statement that if all the reservoirs above Cairo thus far studied were built, they would increase the low-water flow below that point by an amount estimated at 150,000 second-feet for a period of six months, which would about double the low-water flow, and greatly diminish the dredging required.

The regulation of the river flow would result in a great improvement in its condition at flood stages for navigation. The reduction in velocity of the current and in the sudden variations in stage would greatly facilitate the safe handling of water-borne transportation, which is difficult and dangerous, under existing conditions, at high flood stage of the river.

The Pittsburgh Flood Commission report (1911), indicated that the use of the 17 reservoirs recommended would have maintained a 5,400-second-foot flow over the 10-day low water period of 1908, or an increase in gage height of from 0.0 foot to 2.3 feet. Similarly, the 13 proposed Allegheny reservoirs, if they had been available or use during the low-water period of August 14 to December 17, 1908, would have maintained a flow of 3.5 times the minimum for 124 days on a half-full basis, or a flow of 5,400 second-feet for 143 days on a reservoir full basis.

The eport of the State engineer of North Dakota on the Fort C ark reservoir states that the late summer and fall flows of the Missouri River would be increased by 13,000 second-feet with the use of the proposed reservoir, and that the resulting increase on low-water flow of the Missouri River would be as follows:

	Per cent increase
Bismarck, N. Dak	75
Sioux City, Iowa	55
Kansas City, Mo	35

The Commerce, Mo., reservoir, if used full in the low-water period, would raise the stage below Cairo three feet for eleven days, or, half-full, would increase the low-water level the same amount for practically one week.

The Arkansas-White reservoir system would have a marked effect on low-water conditions on the lower Mississippi below Arkansas City. If operated full, these reservoirs would raise the low-water stages about eight feet at Arkansas City, about six feet at Vicksburg, and about five feet at Old River.

Thus this comprehensive plan of flood control, based on the regulation of the main tributaries and the lower Mississippi will have a direct effect of great value in maintaining a channel for navigation on these streams. The reduction of flood levels and the raising of low-water stages will contribute toward bank and bed stabilization and considerably reduce the yearly expenditures required for bank protection, revetment, building and repair, and dredging. It is probable that the estimated annual expense of about $5,650,000 can be cut in half at the very least by the carrying out of such a flood control plan.

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[95] Proceedings, American Society of Civil Engineers, December, 1927, p. 2574.

The value of river regulation to navigation through the prosecution of a comprehensive flood control program is impossible to estimate at this time. Should the President's vision of a 9,000-mile consolidated system of inland waterways materialize during the next decade or two, this value would be inestimable.

IX. Power Development

The statement is often made that there is 60,000,000 horsepower of energy going to waste in the Mississippi River every year. Just where and how the authors of this statement obtained this figure is not known. As a matter of fact, under existing conditions on the Mississippi below Cairo, water-power development is impracticable.

Above Cairo there are a few opportunities for power development on the middle Mississippi, notably at Commerce, Mo., where about 300,000 horsepower could be developed in conjunction with the use of the reservoir for flood control.

The total installed water power [96] in the Mississippi Basin was about 1,500,000 in 1926. The estimated potential water-power resources in 1924 were 5,848,500 horsepower, available 90 per cent of the time, and 10,210,000 horsepower available 50 per cent of the time.

The United States Geological Survey [97] in 1909 estimated for the Mississippi Basin a minimum of 6,682,480 horsepower, and a maximum of 8,090,060 horsepower. These figures were based on 80 per cent efficiency and 50 per cent time for the assumed maximum development. The figures for the principal basins are given as follows:

Horsepower

Basin	Minimum	Assumed maximum development
Ohio	1, 993, 590	3, 987, 700
Missouri	3, 372, 490	5, 437, 700
Arkansas	272, 400	719, 000
Red	48, 900	148, 000

The latest report [98] on the Tennessee River and its tributaries gives 360,000 kilowatt of installed water power, and a possible development of 22,600,000,000 kilowatt-hours, requiring a 4,777,800 kilowatt installation at a 50 per cent load factor.

A recent plan [99] suggests the use of a series of floodway basins in the St. Francis, Tensas, and Atchafalaya Basins, arranged in a series of steps and supplied with flood waters over spillway intakes from the Mississippi River. Each reservoir would empty directly into another just below it over a spillway and through a power house. The difference in elevation between reservoir surfaces would be from 15 to 25 feet at low and high stages. The estimated power development under this plan is 750,000 horsepower at low and 1,100,000

[96] Power Capacity and Production in the United States, Water Supply Paper 579, United States Geological Survey, 1928.

[97] Conservation of Water Resources, Water Supply Paper 234, United States Geological Survey, 1909.

[98] Tennessee River and Tributaries, House Document No. 185, Seventieth Congress, first session, Feb. 27, 1928.

[99] The Mississippi River, a Review and Analysis, H. N. Sulliger, February, 1928.

horsepower at high stages. Considerable research would be necessary to overcome some possible difficulties in the carrying out of this plan, especially with relation to the construction of the great spillways and power-house structures required for these basins under existing foundation soil conditions.

In the Missouri Basin, there are a number of attractive opportunities for power development in the upper reaches, especially in the Dakotas. In North Dakota is the Fort Clark site, which has been referred to above in the section on reservoirs. In addition to this project, which contemplates a combined flood control and water-power development, there are a series of sites in South Dakota, where about 236,000 horsepower could be developed at an estimated cost of about $65,300,000.

The Pittsburgh Flood Commission report did not include a detailed study of water-power development in the Ohio River basin above Pittsburgh. The report states:

> The natural conditions on certain streams are favorable, under well-planned combinations, for power development of considerable magnitude.
>
> The effect of the manipulation of these reservoirs, if built, would be to increase the minimum flow. Surplus storage, which is also possible, in many instances, by enlargement of the flood-control reservoirs, would further increase this minimum flow.
>
> In the aggregate many reservoir sites are feasible on the principal tributaries and on the branches, and these, under manipulation directed by State or national authority, could, in combination with the main projects, be made to effectively produce power and assist in the regulation of the navigable parts of the rivers.

On the Tennessee River, there has been a gradual development of its resources to effect a combined control and utilization of its water resources for navigation, power, and flood control. This plan is described by the district engineers in their report.[1] In the report of February 27, 1928, the district engineer states:

> Flood-control reservoirs do not seem to be applicable to the Tennessee River Basin. All reservoir sites at which storage can be economically provided are very much needed for regulating stream flow for power and navigation. * * * The results which may be secured by flood-control reservoirs would be local, whereas storage reservoirs, by regulation of stream flow and power, benefit the whole system.
>
> Studies indicate that satisfactory results in flood control may be secured by the combined use of storage reservoirs and of flood storage and spillway regulation on navigation-power projects.

The relation of power development to flood control on the Mississippi River is somewhat of a complex problem. It is probable that power is and can be but a re atively unimportant factor in this great issue of flood control.

Col. F. W. Scheidenhelm discusses this subject in a recent engineering symposium.[2] The following extracts from his conclusions are pertinent:

> 1. As regards the flood control of a given stream, power developments involving reservoirs on that stream generally have a beneficial effect and in especially fqvorable cases may have important beneficial effect.
>
> 2. On streams which are under complete regulation by storage; that is, where approximate equalization of flow is attained, the requirements of both power development and of flood control on that stream may be met adequately and without conflict.

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[1] House Document No. 463, Sixty-ninth Congress, first session. House Document No. 185, Seventieth Congress, first session.
[2] Proceedings of the American Society Civil Engineers, December 1927, pp. 2610-15.

3. In cases of streams which are under only partial regulation by storage, power developments may have favorable or unfavorable effects from the standpoint of flood control; in the main, however, such effects of power development will tend to be beneficial.

4. As regards the flood control of the Mississippi River, power is likely to be a minor consideration, both as to effects of power reservoirs in reducing Mississippi River floods and as to financial aid toward flood control.

The engineering and economic review of the Mississippi flood situation—proposed in this report—to be made by a national flood commission, should study each tributary basin and the Mississippi Basin as a whole as to flood control, and the influence and relationship thereto of power development, navigation, irrigation, drainage, water supply and stream pollution. Only by a comprehensive understanding and set-up of the complete "picture" can the problem of flood control be truly and finally settled.

X. Economic Conditions

In his message of December 6, 1927, the President said:

It is necessary to look upon this emergency as a national disaster. It has so been treated from its inception.

On April 30, 1927, then Secretary Hoover and General Jadwin issued at Memphis, Tenn., a joint statement from which the following quotation is made:

The disasters accruing from an insufficient flood protection of the valley of the Mississippi are not local in effect, but react on the producers, the consumers, manufacturers, distributors, and investors in all parts of the country.

Subsequently, in his report to the President at Rapid City, S. Dak., on July 21, 1927, Mr. Hoover stated:

There is no question that the Mississippi River can be controlled if a bold and proper engineering plan is developed. It is not possible for the country to contemplate the constant jeopardy which now exists to 1,500,000 of its citizens or the stupendous losses which the lack of adequate control periodically brings about. Furthermore, flood control means the secure development of some 20,000,000 acres of land capable of supporting five to ten millions of Americans. The costs of such work, if spread over 10 years, would be an inconsiderable burden upon the country. It is not incompatible with national economy to prevent $10 of economic loss by the expenditure of $1 of Federal outlay.

And still later, in his speech before the Mississippi Valley Association, at St. Louis, on November 14, 1927, Mr. Hoover said:

The loss of several millions of acres of crops in this flood deprived the American people of just that much goods which they might otherwise have consumed or exported, and again, every worker, and every farmer in our country to some degree was a loser through the decreased buying power of flood sufferers themselves. Every investor in railways and industry in the South lost something.

Thus did our present Chief Executive, after weeks of personal inspection and study of the flood condition of 1927, clearly set forth the economic character and importance of the Mississippi Basin flood problem.

The United States Weather Bureau in its report [3] of the flood of 1927 makes this statement:

It would therefore appear to be not beyond the mark to say that the flood of the spring of 1927 was the greatest economic disaster in the history of the United States.

[3] The Floods of 1927 in the Mississippi Basin. Monthly Weather Review, Supplement No. 29, 1927, p. 36.

The following statement—issued by the Bureau of Agricultural Economics of the United States Department of Agriculture—gives the acreage of crop lands and crops flooded and the livestock losses:

About 4,400,000 acres of crop land was inundated in the lower Mississippi Valley as a result of levee breaks and swollen local streams during the months of May, June, and July, 1927. Cotton was grown on about 2,600,000 acres of this area in 1926; corn on about 1,100,000 acres; hay on about 360,000 acres and other crops combined on about 370,000 acres.

The area of crop land flooded in Arkansas exceeded 1,800,000 acres; in Louisiana over 1,100,000 were inundated; in Mississippi over 800,000; in Missouri over 300,000; in Tennessee nearly 200,000 and in Kentucky about 50,000 acres.

A summary of the acreage of crop land estimated to have been flooded and the acres devoted to principal crops in 1926 is shown below:

Estimated acreage crop land flooded and crops grown in 1926

State	Number of counties or parishes	Crop land flooded, 1927	Acres of flooded area planted last year (1926) in—			
			Cotton	Corn	Hay	Other crops
		Acres				
Arkansas	50	1, 839, 400	1, 111, 900	414, 400	158, 500	150, 700
Louisiana	33	1, 105, 200	578, 700	281, 400	69, 700	175, 400
Do	2	7, 000	0	[2] 1, 500	[2] 1, 000	[2] 4, 500
Total	35	1, 112, 200	578, 700	282, 900	70, 700	179, 900
Mississippi	10	735, 000	550, 000	115, 000	53, 000	17, 000
Do	9	126, 900	96, 400	20, 650	7, 030	2, 820
Total	19	861, 900	646, 400	135, 650	60, 030	19, 820
Missouri	10	319, 000	125, 000	145, 000	35, 000	14, 000
Do	[1] 4	40, 000	[2] 9, 000	[2] 24, 000	[2] 5, 000	[2] 2, 000
Total	10	359, 000	134, 000	169, 000	40, 000	16, 000
Tennessee	6	195, 000	90, 000	75, 000	28, 000	2, 000
Kentucky	4	[2] 50. 000	[2] 15, 000	[2] 25, 000	[2] 7, 000	[2] 3, 000
Total of above	124	4, 417, 500	2, 576, 000	1, 101, 950	364, 230	371, 420

[1] Additional area in 4 of the 10 counties covered as result of back water and run-off.
[2] No survey made. Rough estimate only.

LIVESTOCK LOSSES FROM FLOOD

About 25,000 head of horses and mules were lost as a result of the flood. Cattle losses were about 50,000; swine losses in excess of 150,000; sheep losses about 1,300 and losses of chickens over 1,300,000 head. In the area for which an inquiry was made livestock losses were as follows:

Livestock losses from flood

State	Horses and mules	Cattle	Swine	Sheep	Poultry
	Number	*Number*	*Number*	*Number*	*Number*
Arkansas	9, 250	21, 060	66, 590	310	525, 440
Louisiana	7, 100	19, 630	55, 930	740	487, 830
Mississippi	7, 375	9, 000	22, 690	250	263, 300
Missouri	1, 000	([2])	([3])	([2])	([4])
Tennessee	600	800	2, 900	0	([1])
Kentucky	([1])	([1])	([1])	([1])	([1])
Total of items shown	25, 325	50, 490	148, 110	1, 300	1, 276, 570

[1] No data. [2] Slight. [3] Considerable. [4] Heavy.

The following table [4] gives the estimated loss and damage expressed in value:

[4] Monthly Weather Review, Supplement No. 29, 1927, p. 35.

Loss and damage from flood

District	Territory	Loss and damage					Total
		Miscellaneous	Crops	Livestock and other farm property	Protection work	Suspension of business	
Indianapolis, Ind	Indiana	$128, 150					$128, 150
Nashville, Tenn	Tennessee and Kentucky	218, 000					218, 000
Knoxville, Tenn	Virginia and North Carolina	50, 000	$25, 000				75, 000
Louisville, Ky	Kentucky	7, 000, 000					7, 000, 000
Missouri River, South Dakota to Kansas City, Mo.	South Dakota, Iowa, and Nebraska	201, 500	797, 250				998, 750
Hannibal, Mo	Iowa and Missouri	5, 000				$18, 000	23, 000
St. Louis Mo	Missouri and Illinois	4, 872, 000	[1] 8, 382, 000			839, 000	14, 093, 000
Cairo, Ill	Illinois, Missouri, Tennessee, and Kentucky	2, 054, 692	1, 713, 050	$306, 300	$600, 000	807, 821	5, 481, 863
Memphis, Tenn	Tennessee and Arkansas	6, 734, 450	10. 236, 595	593, 350	218, 508	10, 268, 565	28, 051, 468
Vicksburg, Miss	Mississippi and Louisiana	[2] 14, 500, 000	[2] 50, 000, 000	[2] 15, 000, 000	[2] 15, 000, 000	[2] 10, 000, 000	[2] 104, 500, 000
New Orleans, La	Louisiana and Arkansas	30, 000, 000	22, 000, 000	6, 250, 000	15, 000, 000	28, 000, 000	101, 250, 000
Topeka, Kans	Kansas	418, 500	376, 000	73, 000		102, 500	970, 000
Fort Smith, Ark	Kansas, Oklahoma, and Arkansas	1, 770, 400	3. 532, 000	90. 000		325, 000	5, 717, 400
Little Rock, Ark	Arkansas	8, 386, 000	3, 654, 000	637, 000		1, 259, 000	13, 936, 000
Shreveport, La	Texas, Louisiana, Oklahoma, and Arkansas	560, 000	846, 500	136, 500		132, 000	1, 675, 000
Total		76, 898, 692	101. 562, 395	23, 086, 150	30, 818, 508	51, 751, 886	284, 117, 631

[1] Includes livestock and other movable farm property.
[2] Estimated.

The Weather Bureau further states: [5]

The total of all losses, however obtained, was $284,117,631, but these figures, staggering as they may be, do not cover all the losses that were incurred. It has been the experience of the Weather Bureau that flood losses as reported are at least 25 per cent less than the actual losses. This is considered a fair estimate, as many losses must necessarily be of such a character that they can not be accurately stated. Among these, as stated by the official in charge of the New Orleans river district, are "economic losses resulting from such causes as removal of inhabitants by thousands from their regular occupations and sources of income; disruption of transportation and business; depreciation in values (a very serious item); losses of rents, interest, and accounts; permanent losses of tenants and labor; and other attendant circumstances, which can not be estimated, but which must be thought of in terms of many millions of dollars." Therefore, if 25 per cent are added to the total of $284,117,631, the grand total would be $355,147,039.

Hence in the flood of one season, 1927, the lower Mississippi Basin suffered a loss of about $350,000,000. Similarly, in 1922, a loss of $17,087,790 was incurred. In 1913, the estimated loss was $163,564,793; in 1912, $78,187,670; and in 1903, about $40,000,000. In a period of about a quarter of a century, the loss due to a series of the five major floods has been a total of about $654,000,000. This estimate does not include loss from minor floods and unreported damage and loss, which would probably make a grand total of at least three-quarters of a billion dollars for the 25-year period.

It is estimated that the overflow area in the lower Mississippi Basin is about 29,790 square miles, or 19,065,600 acres. Of this area, 17,456,647 acres are within the 34 levee districts of the alluvial plane, and with approximately 5,000,000 acres of this land under cultivation. It was from this area that the 1927 floods swept 7,879 houses, 17 gins, 118 stores, 2,997 barns, 16,971 outbuildings, and destroyed $1,317,575 worth of farm implements, $3,054,544.50 of foodstuffs, and $47,730,627 household goods.

The overflowed areas lie largely in the Delta States of Arkansas, Mississippi, and Louisiana. These three States have the following areas and population:

State	Land area		Population			
	Square miles	Per cent of United States	1920 Census		Estimated, 1928	Per cent of United States
			White	Negro		
Arkansas	52, 525	1. 76	1, 279, 757	472, 220	1, 944, 000	1. 62
Mississippi	46, 362	1. 56	853, 962	935, 184	1, 790, 618	1. 49
Louisiana	45, 409	1. 53	1, 096, 611	700, 257	1, 950, 000	1. 62

The productive power of these three States is:

[From Blue Book of Southern Progress, 1929]

	Manufactured products, value	Mineral products, value	Agricultural porducts, value	Gross value of all products
Arkansas	$182, 750, 871	$59, 449, 000	$265, 142, 000	$507, 341, 871
Mississippi	196, 640, 742	2, 554, 000	278, 998, 000	478, 192, 742
Louisiana	638, 361, 215	51, 267, 000	205, 288, 000	894, 916, 215
United States	62, 721, 375, 881	5, 520, 000, 000	15, 045, 930, 000	83, 287, 305, 881

[5] Monthly Weather Review, Supplement No. 29, 1927, p. 36.

The Federal tax receipts were as follows:

[From Blue Book of Southern Progress, 1929]

State	1927		1928		Per capita
	Income tax	Total revenue	Income tax	Total revenue	
Arkansas	$5, 053, 440. 00	$5, 258, 927. 00	$4, 223, 761. 00	$4, 332, 022. 00	$2. 23
Mississippi	3, 324, 902. 00	3, 460, 085. 00	2, 678, 803. 00	2. 760, 433. 00	1. 54
Louisiana	15, 396, 335. 00	17, 478, 975. 00	12, 180, 548. 00	14, 214, 434. 00	7. 29
United States	2, 219, 952, 444. 00	2, 865, 683, 130. 00	2, 174, 573, 103. 00	2, 790, 535, 538. 00	23. 18

It will be seen from the above data that these three Delta States pay low Federal taxes, especially as compared with other Southern States, such as North Carolina ($76.69 per capita) and Missouri ($18.48 per capita).

The assessed value of taxable property is as follows:

[From Blue Book of Southern Progress, 1929]

State	1900	1910	1927	1928
Arkansas	$201, 908, 783	$384, 000, 000	$618, 174, 000	$609, 721, 000
Mississippi	215, 765, 947	393, 605, 644	744, 056, 000	775, 634, 000
Louisiana	276, 659, 407	527, 773, 950	1, 724, 954, 000	1, 733, 553, 000
United States	6, 511, 195, 329	13, 033, 636, 877	33, 558, 167, 000	34, 068, 884, 000

The bonded indebtedness of the States as of January 1, 1927, is given by the Census Bureau [6] as $2,625,000 for Arkansas, $16,002,000 for Mississippi, and $51,336,000 for Louisiana.

The debt, by the kinds of districts, in 1922, was as follows:

State	School	Drainage	Levee	Road	All other
Arkansas	$4, 275, 000	$15, 057, 000	$7, 830, 000	$48, 441, 000	$5, 322, 000
Mississippi	3, 754, 000	12, 425, 000	7, 535, 000	41, 411, 000	----------
Louisiana	5, 998, 000	4, 658, 000	10, 551, 000	9, 606, 000	250, 000

The plan proposed in the report is suggested for review and study as providing for permanent future control of the waters of the Mississippi Basin and especially of that section of the lower river basin lying south of Cairo, Ill. This area lies largely in the States of Arkansas, Mississippi, and Louisiana. The above data give the economic status of these States, and show that they are and would be capable and justified in cooperating with the Federal Government in the administration of a national flood control policy under a national flood control commission, in order to build and operate flood-control works for the protection of their delta lands.

Similarly other States in the Mississippi Basin, such as Missouri, Ohio, Illinois, and Iowa, will contribute and cooperate in this national plan and policy on the basis of benefits to be received from the carrying out of the project.

[6] Statistical Abstract of the United States, 1928. Department of Commerce.

Presumably the Federal Government would pay the initial cost of the improvements to the main channel of the lower river, including levee enlargement, bank stabilization, dredging, etc., on the basis of constitutional authority for the expenditure of funds granted by the "commerce clause"; the authority granted to the Congress to regulate commerce between the States, with foreign nations, and with the Indian tribes.

The political and economic history of this country is replete with examples of the ill effects of paternalism and its related issues. In establishing a national flood control policy, the President and the Congress should consider primarily our national economic stability. Such a policy concerning the protection, welfare, and progress of the group of States in the Mississippi Valley must therefore be framed on the following principles:

1. The flood-control problem is national in character and scope, and any plan and its execution must be made on this basis.

2. The prosecution of a plan should be done by the cooperative efforts and financial contributions of the Federal and State Governments.

3. The Congress by legislative enactment should establish a national flood-control policy, to be administered by a national flood-control commission of engineers and economists, appointed by the President, and in cooperation with State flood-control commissions. These latter agencies would be appointed by their respective governors and be responsible for the carrying out of State code provisions in conformity with the uniform national policy.

Much time, space, and speech have been devoted to the classification of this flood-control problem in order to prove that Uncle Sam should or should not pay the bills. It does not seem material as to whether the problem is one of protection, reclamation, or navigation. Undoubtedly it includes all of these matters. The important consideration before this country and its lawmakers is the fact that after 70 years of temporizing the time has come for the adoption of a plan and a national policy that will, in the course of the next decade, result in the development of a rational, comprehensive, permanent system of works for flood control and the efficient conservation and utilization of the waters of the Mississippi Basin.

Does existing legislation and constitutional authority make it possible for the Congress to establish a national flood-control policy and a suitable organization to administer such a national plan in cooperation with the States?

Dr. Arthur E. Morgan[7] has recently suggested the need and importance of a new constitutional amendment that will provide:

> The Federal Government with the powers necessary for the control and administration of our interstate or national waters, with power to apportion costs in proportion to the interests involved.

As Mr. Morgan well states:

> This policy would relieve Congress of a vast amount of political logrolling and of special legislation which now clogs the congressional machinery. It would replace arbitrary and political determination of issues by providing judicial and analytical appraisals. It would replace the pork barrel by equitable distribution

[7]Address at annual dinner American Engineering Council, Washington, D. C., Jan. 14, 1929.

of costs. It would allow any community to initiate and pay for its own improvement without waiting for decades upon Congress.

Section 4 of the act of Congress creating the Mississippi River Commission is as follows:

It shall be the duty of said commission to take into consideration and mature such plan or plans and estimates as will correct, permanently locate, and deepen the channel and protect the banks of the Mississippi River; improve and give safety and ease to the navigation thereof; prevent destructive floods; promote and facilitate commerce; trade and the postal service; and when so prepared and matured, to submit to the Secretary of War a full and detailed report of their proceedings and actions, and of such plans, with estimates of the cost thereof, for the purpose aforesaid, to be by him transmitted to Congress: *Provided*, That the commission shall report in full upon the practicability, feasibility, and probable cost of the various plans known as the jetty system, the levee system, and the outlet system, as well as upon such others as they may deem necessary.

In 1916, flood control, as a subject of legislation by Congress, was placed under a separate legislative standing committee in the House, and was dealt with similar to, but independent of, river and harbor projects.

The act of 1917[8] provided $45,000,000 for work in connection with the Mississippi River. Section 3 of the act states:

That all the provisions of existing law relating to examinations and surveys and to works of improvement of rivers and harbors shall apply, so far as applicable, to examinations and surveys and to works of improvement relating to flood control. And all expenditures of funds hereafter appropriated for works and projects relating to flood control shall be made in accordance with and subject to the law governing the disbursement and expenditure of funds appropriated for the improvement of rivers and harbors.

A later act,[9] in 1923, made available $60,000,000 additional, to be spent at the rate of $10,000,000 a year for a period of six years beginning July 1, 1924.

The Constitution of the United States contains no language expressly granting to Congress authority to legislate for the improvement of the navigability of streams, or for the control of floods. But the Congress has assumed an implied right from the broad grant of power to regulate commerce in the so-called commerce clause. The courts have consistently, and practically without exception, upheld the authority of Congress over navigable streams and coastal waters. The United States Supreme Court has in several cases (Jackson *v.* United States, 230 U. S.; Bedford *v.* United States, 192 U. S. 225; Hughes *v.* United States, 230 U. S. 24–57 L. ed. 1374; and Lynah *v.* United States, 188 U. S. 455, 1913), clearly defined Federal authority with relation to flood-control measures. It should be noted that in the Lynah case (188 U. S. 455, 1913), the court ruled

The rule deducible from these cases is that when the Government appropriates property which it does not claim as its own, it does so under an implied contract that it will pay the value of the property so appropriated. * * *

So the contention that the Government has a paramount right to appropriate this property may be conceded, but the Constitution in the fifth amendment guarantees that when the governmental right of appropriation—this asserted paramount right—is exercised, it shall be attended by compensation.

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[8] Public No. 367, Sixty-fourth Congress, H. R. 1477.

[9] Public No. 528, Sixty-seventh Congress, H. R. 13810.

There seems to be sufficient legislative and judicial background and precedent for Congress to establish by enactment a national flood-control policy, a national flood-control commission to administer this policy in cooperation with the States, and appropriate funds from time to time for the work of the commission and the execution of its plans and operation of its works.

The estimated cost of the comprehensive, permanent type of flood-control plan recommended in this report is $1,000,000,000. A huge sum of money to spend on any project; even one of such an important national character. Is such an expenditure of the fiscal resources of the National and State Governments economically justified?

The aggregate expenditures for flood protection, previous to 1879, are estimated at $125,000,000. Since the establishment of the Mississippi River Commission, it has supervised the expenditure of $91,647,242.47 on levee construction and auxiliary work. Of this amount, some $15,000,000 was contributed by local interests, including the States and levees districts. In addition to the $71,000,000 spent by the Federal Government for levees from 1882 to 1927,[10] State and local organizations have expended or contributed about $167,000,000. Hence, available records indicate an expenditure of some $363,000,000 on flood-control works in the lower Mississippi Basin.

The Jadwin plan contemplates an expenditure of $318,500,000 to enlarge the existing levees, to build a spillway at Bonnet Carre, and to construct emergency flood ways in the St. Francis, Boeuf, and Atchafalaya Basins This estimated cost (to be distributed over a construction period of 10 years) does not include damages for lands and other property which will undoubtedly be flooded during the great flood periods in the future. Various estimates have been made as to the extent of these probable damages, ranging from $500,000,000 to $1,000,000,000. Data are not available to make an accurate estimate. It is interesting to note, however, that the original estimates of the Chief of Engineers do not agree with later developments. For example, he reported [11] to the Flood Control Committee of the House that the proposed flood way near New Madrid (Army engineer plan) would involve 49,920 acres of uncleared (swamp and timber) land, or a total area of 99,840 acres In the recent Congress, Senator Hawes states:

> The area to be designedly flooded in Missouri covers 135,000 acres of land. containing 175 miles of highways, 97 miles of drainage canals, 35 highway bridges. hundreds of miles of tile drains, 2,500 persons and their homes and improvements. many miles of railroads, and schools and churches.
>
> The assessed valuation for State tax purposes of this area is about $5,000,000 for farm lands alone. This does not include the valuation of public improvements, highways, schools, and churches.
>
> In addition, the residents of this area have already taxed themselves in excess of $3,000,000 for ditches and levees to develop this area.
>
> A fair valuation of the property has been variously estimated at between $12,000,000 and $15,000,000, and a large part of the bonded indebtedness is still outstanding.[12]

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[10] House Committee Document No. 1, Seventieth Congress, first session.

[11] Hearings before the Flood Control Committee, House of Representatives, Seventieth Congress, first session, pt. 6, p. 4821

[12] Remarks of Hon. Harry B. Hawes in the Senate of the United States, May 28, 1929.

In the Boeuf and Atchafalaya Basins, the areas and property damages would be very much greater than in southeast Missouri. These data, furnished to the Flood Committee of the House by the Chief of Engineers, give estimated areas of the following:

	Cleared land	Swamp and timber land
	Acres	*Acres*
Boeuf	361, 562	1, 086, 438
Atchafalaya	91, 520	826, 240

Data,[13] similarly supplied by the Mississippi River Flood Control Association, indicate that in the Boeuf flood way are counties and parishes with a total of 5,479,720 acres, of which 1,594,462 acres are under cultivation and have a total farm value of $72,174,270. In the Atchafalaya flood way are parishes having an area of 3,087,300 acres, of which 1,028,124 acres are farm lands having a value of $63,183,067. The livestock value for each of these flood way basin areas is about $6,500,000, and the crops value in 1924 was about $20,000,000.

Assuming that the cost of the proposed flood-control program is one billion dollars, it is believed that this expenditure of funds over a reasonable period of years (from ten to fifteen) would be economically justified. The Mississippi River Commission it its special report [14] to the Congress, November 28, 1927, states:

> The investment of Federal and other funds already made in levees has been returned in the increase in the value of the lands. Without the protection, large areas would have been useless except for growing timber. Prosperous communities now exist throughout the alluvial valley, all owe their existence to the protection furnished by the levee system. Large investments in roads and railroads have been made possible. The development of the alluvial valley as a whole has added and will continue to add much to the wealth of the Nation, and the work of flood control carried on heretofore must be credited with all such gain in national wealth. Greater protection will hold that gain and add to it.

Sufficiently complete and accurate data are not now (June, 1929) available for a full economic study of this flood-control project. But in view of the existing conditions and the benefits that would ensue to the Mississippi Basin and the entire Nation, it is believed that a flood-control project such as recommended in this report would be fully justified from an economic standpoint. One of the leading authorities [15] on flood control estimates that the benefits resulting from a flood-control system consisting of the present levee system, supplemented by dams to hold the river within its natural banks except during years of extreme run-off, when the levees would come into use, would probably reach a value of $1,000,000,000. It is undoubtedly true that a comprehensive economic study, based on accurate data, and taking into account the savings and benefits that would result from the gradual execution of this plan to the protection of property, to navigation, to the stabilization of the river channel,

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[13] Hearings before the Committee on Flood Control, House of Representatives, Seventieth Congress, first session. P. 6, pp. 4814–15.

[14] House Committee Document No. 1, Seventieth Congress, first session.

[15] The Basis of the Case Against Reservoirs for Mississippi Flood Control, Arthur E. Morgan; Proceedings American Society of Civil Engineers, December, 1927.

to the protection and prevention of losses to cities and communities, to power development and other minor factors, would show that in the course of the next quarter century or less a rational, scientific program of flood control would pay for the entire cost of the proposed works and their maintenance and operation.

APPENDIX A

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