SOME PROBLEMS IN FLOOD CONTROL

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INTRODUCTION

Flood problems are as old as civilization. History, tradition, and the remains of prehistoric structures disclose the work of man for flood control. Natural stream channels are developed and continuously modified by erosion and deposition of soil materials. Steep slopes produce velocities of greater eroding and transporting power. Soil materials are disintegrated and reduced to smaller particles by the rubbing and grinding incident to the movement by flowing water. In alluvial valleys, stream channels develop bank-full capacities approximately equal to the average annual flood discharges. Maximum floods exceed the average annual flood by two to ten fold. The channels of streams which have frequent floods and greater annual flows are more stable, other things being equal, than those which have lower annual flows and occasional great floods.

WATER

Water, the universal solvent, occupies a most prominent place in the scheme of nature and in the life and attainments of man. It is found and used as vapor, liquid, and solid and is combined with other elements into innumerable substances in nature or produced in the kitchen, laboratory, or factory.

Water occupies three-fourths of the earth's surface. Water vapor, evolved from the water surfaces, is carried by warm air currents and is precipitated as rain or snow when condensed by mingling with colder air currents.

PRECIPITATION

The distribution of precipitation (rain and snow) on land and sea follows nature's laws, but due to varying conditions of climate, including effects of temperature, air currents, and the topography of the land, precipitation ranges from practically nothing on so-called arid areas to a maximum depth of 25 feet or more annually. The annual range of precipitation in this locality—Peoria, Illinois—is from about 20 inches to more than 60 inches.

The time and amount of precipitation are not within the control of man but by study of the accumulated meteorological records many of the laws, conditions, and forces influencing precipitation have been identified and satisfactorily accounted for, so the time, location, and amount of precipitation may be predicted with some degree of assurance. However, the future occurrence of excessive precipitation can only be anticipated by applying mathematical theory of probabilities based on recorded experiences. The records frequently are too few and their accuracy only approximate. The first problem in flood protection or prevention is *precipitation, its duration, amount, intensity and local distribution and the prevailing temperatures.*

Relation of Rainfall to Run-off

Destructive floods on small streams are produced by excessive rainfall, frequently referred to as cloudbursts, and on larger streams by prolonged rainfall of unusual intensities over large areas. In the temperate zones, snow is frequently melted by warm rains and adds to the spring freshets. In the Mississippi Valley, spring and summer rains follow in cycles of about one week and the great floods follow unusually heavy storms when the ground is frozen or saturated and the channels full from previous rains. Our second problem is therefore the *relation of rainfall to run-off.*

Published Data

Rainfall and stream flow data have been collected and published by the U. S. Weather Bureau and the U. S. Geological Survey for many years. This work is supported by the states and supplemented by cities and other public and private interests. These data as they apply to each stream are used in flood control studies. Estimates of probable flood discharges and frequency are based largely upon the daily flow of the stream, if it has an acceptable record for ten years or more, using mathematical probability curves found to most nearly follow the flood experiences with similar areas having longer records. In some eastern states flood-flow records are available for more than one hundred years. In Europe some records cover three hundred to five hundred years.

For streams with few or no flow records, flood flows are estimated by analogy from data of other watersheds. Rainfall records cover much longer periods than stream flow data. The relation of rainfall to run-off where both are known furnishes a basis for the extension of flood predictions and their application to similar watersheds similarily situated.

Geological and Topographic Formations

The geological formation and topography of a watershed, and the prevailing temperatures are next in importance to rainfall in determining flood flows. Open, sandy, level land will store much water which flows underground and does not contribute to floods. Frozen, heavy, or rocky land will absorb little and the major portion of all rain produces flood flow. Lakes and reservoirs and overflowed valley lands store or detain surface flow. The third problem in flood control studies may readily be the *storage capacities underground, in lakes and reservoirs, and on low level lands,* and their bearing upon the relation of rainfall to run-off.

Erosion and Transportation of Soil Materials

Soil materials, clay, silt, sands and gravel, are eroded from the hillsides, transported by flowing water to the valleys and deposited where the velocities are retarded. These eroded materials are carried along by the streams and deposited in the valleys, thus forming plains or deltas of alluvial soils which are the most fertile agricultural lands. Cultivation exposes the surface to erosion. In rolling and hilly areas terracing is applied to prevent erosion. This method of cultivation also detains the rain on the ground longer than farming on natural slopes and reduces floods from such areas. Erosive velocities are to be avoided as far as practicable in channel improvements for flood relief.

The fourth problem therefore in flood control may refer to the consideration of *methods for prevention of erosion and transportation of soil by surface waters and streams.*

Diversion From Lake Michigan

During the past thirty years an average of about 8,000 cubic feet per second of water has been flowing from Lake Michigan through Chicago River and Chicago Sanitary and Ship Canal into Des Plaines River at Lockport, thence through Illinois and Mississippi rivers to the Gulf. This flow has been practically continuous and frequently when Illinois River and its tributaries are in flood, the flow from the sanitary canal at Lockport has been more than the average. This diversion from Lake Michigan into Illinois River has increased the flood hazard and increases the cost of flood protection works.

The stages of Illinois River have been increased by diversion from Lake Michigan through the Chicago Sanitary and Ship Canal about 5½ feet at low water and about 1½ feet at high water on the Peoria gauge. The high water stages of the Illinois are increased by diversion from Lake Michigan about 1 foot on the Beardstown gauge since the levees were built and from 5/10 to 6/10 of a foot before the levees were built.

Illinois Floods in Relation to Navigation

Illinois River is being improved by the Federal government for a 9-foot navigable depth at low water with an 8-foot gauge height in Peoria. Five dams with navigation locks are located in the upper Illinois and Des Plaines rivers as follows: at Starved Rock above LaSalle; at Marseilles; at Dresden Island, below the junction of the Kankakee and Des Plaines rivers which form the Illinois at Brandon Bridge, below Joliet; and at Lockport, the west end of Chicago Sanitary and Ship Canal. This plan was based upon a flow from Chicago Sanitary and Ship Canal of about 6,500 cubic feet per second through the controlling works at Lockport during low water in Illinois River. It may be necessary to continue to maintain dams and locks in the lower Illinois River to sustain a navigable depth of 9 feet if the diversion is reduced to 1,500 cubic feet per second, as indicated by the decision of the Supreme Court a few months ago. Four dams have been maintained in Illinois River for a navigable depth of 6 or 7 feet and experience has shown that these dams have had no material effect on flood stages. The dams in Illinois River between Lockport and Starved Rock are designed with gates so that the flood stages are not to be increased. The construction and maintenance of dams for navigation in Illinois River therefore are not considered to present any new flood-control problems.

Flood Prevention Agencies

Flood prevention in its early stages was by individual initiative. A landowner, to protect some cultivated area from overflow, constructed small levees. This was followed by other owners acting individually or by mutual agreement and subsequently by organizing taxing districts for constructing and maintaining such work. In the Illinois Valley a number of small private levees were built by individual owners before the State Legislature enacted laws for the organization of levee districts with taxing powers. All levees along Illinois River are now under the levee laws of the State. Other states in the Mississippi Valley have enacted similar laws.

Along Mississippi River and some of the larger tributaries the flood areas extend into two or more states. Portions of 31 states, 40 per cent of the entire area of the United States, drain through Mississippi River, and the Mississippi flood problem has been recognized as national in scope since the United States came into possession of both banks of the river. Numerous reports have been made under authority of Congress, from 1850 to the present time. The Chief of Engineers of the United States Army has recently made a report to the Secretary of War with recommendations for the completion of the flood control work on Mississippi River from Cape Girardeau to the Gulf substantially as authorized by an Act of Congress in 1928 following the disastrous flood of 1927.

The Illinois Legislature, since the flood of 1926-1927, in recognition of the public interest and the public benefit resulting from the protection of the property of its citizens, has appropriated more than $3,000,000 for flood relief and flood protection, a large portion of which applied to the Illinois Valley.

The agencies of flood control are therefore (1) the owners of the land, acting individually or collectively, (2) the district or municipality, (3) the State, and (4) the Federal Government, each contributing its proportionate share as the benefits may appear.

Engineering Methods of Flood Relief

Three general methods are employed for flood relief works, namely,

1. Channel improvement giving greater carrying capacity.
2. Levees for protection from overflow with resulting increased flood heights.
3. Storage in holding reservoirs or in detention basins.

The first two methods, channel improvement and levees, are the most commonly used, but each method produces new problems and frequently may produce new flood hazards. Alluvial valley stream channels are unstable. In streams of steep valleys the bed and banks are being eroded continuously. Some portions of the bank are removed and deposited in an eddy forming bars at down-stream points. In this way the streams tends to lengthen and establish itself on a flatter gradient with a more stable channel. When bends are cut, the velocity is greater, erosion is increased and channel protection is required to maintain a stable channel. The usual effect of stream straightening in this locality is for the channel to widen by erosion and become filled by the coarser sand and gravel so that in a few years it is necessary to re-excavate a portion of the channel to have the water-table in the adjacent valley low enough for agricultural drainage.

Levees remove overflowed land from the floodway, increasing flood heights, first, by reducing the storage area available and making it necessary for the floods to pass through the valley in less time and at greater rate of flow; and second, by reducing the flood cross-section of the stream thus causing the river to rise higher between the levees to overcome both of these restrictions.

Storage, in order to be effective in reducing floods, must be empty when the floods come. On the other hand, conservation of flood waters for municipal and power purposes, for irrigation or for maintaining navigation through the low water periods requires that the storage reservoirs be maintained full because the time and amount of precipitation can not be predetermined. Therefore, flood control through detention and storage reservoirs that are to function for conservation of the water, must be a compromise.

The engineering methods that are to be employed therefore depend upon the economic conditions and will change as population and industrial enterprises in the Illinois Valley increase. It is reasonable to anticipate that within the next two or three decades the industrial development in the Illinois Valley will call for the conservation of the flood waters and will result in helping to solve some of the flood control problems in connection with our water supply developments.

Detention and Storage Reservoirs

Flood prevention by storage has been applied successfully on many streams in Europe. The most striking example in America is the flood detention reservoirs of the Miami Conservancy District in Ohio where the flood water is detained behind dams with outlets restricted to a capacity which the channel below will carry without damage to the adjacent valley lands and property.

Many storage reservoirs have been constructed for municipal and sanitary water supplies, for power development, and for irrigation. The cities located upon the Great Lakes, Chicago, Detroit, Cleveland, Buffalo, etc., obtain their water supplies from the lakes upon which they are located; New York City from storage reservoirs located in the mountainous areas north of the city; Philadelphia by pumping from the Delaware River and filtration; Boston from storage reservoirs on the Merrimac and other streams of the State; St. Louis, New Orleans and many of the other Mississippi River cities by pumping from the river and by filtering; western cities on both sides of the Rocky Mountains by storage reservoirs. Los Angeles now takes its principal supply from a mountain stream 275 miles from the city and will take an additional supply from the new Hoover Dam on the Colorado River more than 300 miles from the city.

Irrigation and Flood Control

Irrigation of the arid and semi-arid lands of the western portion of the United States is made possible by storing the flood waters and feeding it out as needed. All of these storage projects influence the flood stages of the streams upon which they are located.

It does not seem probable that storage of water for irrigation will be a factor in flood control in the Illinois Valley.

Flood Prevention in the Illinois River

Storage Effects

Consideration has been given to the prevention of floods by storage, but to appreciably reduce flood stages in the Illinois Valley, much valuable agricultural land would be taken for flood control reservoirs. Levees for flood protection have therefore received the approval of State authorities and landowners.

The extent of storage areas required in the Illinois Valley may be illustrated by considering the natural storage in one of the major floods between Peoria and LaSalle. The length of the valley from Peoria to LaSalle is about 60 miles and the average width at flood stage is about 1½ miles, an area of about 57,000 acres. The river had been at about a 19-foot stage for more than two weeks and rose 5.45 feet to 24.65-foot stage at Peoria from April 16th to April 24, 1927. On May 15th the flood had receded to a 19-foot stage. During that thirty-day period, 2,500,000 acre-feet of water flowed past Peoria. During the 9 days of rising stage, from April 16th to 24th, the total discharge at Peoria was 778,000 acre-feet and the added storage was 315,000 acre-feet, or a total flood-water inflow of 1,092,000 acre-feet. The added storage was about 28.8 per cent of the total inflow or 40½ per cent of the total outflow for the rising period. At the beginning of this rise on April 15th there was an average depth of overflow in this portion of the Illinois Valley of about 7 feet, and storage of about 500,000 acre-feet making 800,000 acre-feet stored at the crest of the flood. When we consider that the amount of water storage in the Illinois River Valley at this flood period was sufficient to cover 800,000 acres, or an area 60 miles long and 21 miles wide one foot deep, we may visualize the magnitude of the problem of providing storage area sufficient to materially modify flood stages. It is also necessary to have in mind that storage, to be available for reducing flood stages, must be empty when the flood waters come, otherwise it would be of no value. The conservation of water for municipal and industrial purposes in storage reservoirs is useful for flood relief only before the storage capacity is filled. The records show that the great floods have always been produced by heavy rainfall after the underground storage and the lakes, ponds, reservoirs and overflowed areas have been substantially filled.

Levees for Protection of Illinois Valley Lands

The Illinois River Valley from Starved Rock to the Mississippi, a distance of about 230 miles, is from one mile to six miles wide, and averages more than two and one-half miles in width. The total overflowed area, including river channel, is about 400,000 acres, of which about 60,000 acres is above Peoria. From Beardstown to the mouth of Illinois River, a distance of about 90 miles, the overflowed valley is from two and one-half to four miles wide and practically all of this area has been leveed, leaving a floodway from 1,200 feet to 2,500 feet wide.

Between Beardstown and Peoria about 70 per cent of the overflowed area has been leveed. Between Peoria and LaSalle only one small district of 2,600 acres near Hennepin has been leveed. The areas of Illinois Valley reclaimed lands are as follows:

Grafton to Peoria	166,000 acres
Beardstown to Peoria	80,000 acres
Peoria to LaSalle	2,600 acres
Total reclaimed area	248,600 acres

This represents 60 per cent of the total area of overflowed lands in the Illinois Valley between LaSalle and the mouth of Illinois River.

The overflowed lands protected by these levees were all in a fine state of cultivation prior to the floods of 1922 and 1926. The levees have been repaired since those floods and most of this land is again in a good state of tilth.

Destructive Floods

Three or four levees were constructed along Illinois River before 1904 and most of the others were completed before 1922. There have been three destructive floods in the Illinois Valley since the levee-building era began, namely, in 1913 with about half of the present levees constructed a number of the levees failed; in 1922, about half of the levees failed; and in October, 1926, the greatest flood occurred and continued through the spring and early summer of 1927 breaking about half of the levees and flooding approximately half of all the reclaimed lands. The flooding of these districts checked the rise in the river which would have been about 1.7 feet higher at Beardstown if all levees had held.

Illinois River Levees Restored

All but one or two of the Illinois River levee districts, aided by State appropriations, have restored their levees since the 1926-1927 flood. The Mississippi River Commission, in charge of the flood control work on Mississippi River and up the tributaries as far as the backwater of the Mississippi extends, has taken over Illinois River from its mouth to Beardstown. The Mississippi River Commission, with appropriations from the Federal Government, is authorized to pay two-thirds of the cost of building and strengthening levees on the tributaries and has allotted $2,000,000 for the levees on Illinois River below Beardstown.

The Illinois Legislature in 1929 appropriated $1,000,000 for strengthening levees on Illinois River. Several districts below Beardstown are availing themselves of these appropriations to have their levees raised and strengthened. All flood control plans of the Mississippi River Commission are subjected to the approval of the Chief of Engineers of the U. S. War Department. The Commission plans for Illinois River levees conform substantially with the plans in the Illinois River Flood Control Report of 1929. This plan provides for setting levees back where the floodway is too narrow and for raising and enlarging the levees.

Effect of Illinois River Levees on Flood Heights

Flood control studies of Illinois River show estimated flood stages 9 feet higher at Beardstown and 3.0 feet higher at Peoria than the 1844 flood stage which was the highest known flood prior to the building of levees. In 1926 the observed flood stage at Beardstown was 3.86 feet above the 1844 flood. With all existing levees holding, the estimated flood stages will be 5.2 feet higher at Beardstown and 4.9 feet higher at Peoria than the record flood of 1926. At Beardstown a sea wall along the river front and levees back to the high land have been constructed by the State of Illinois.

The effect of the Mississippi River levees on flood stages has been similar and of greater magnitude than on Illinois River. Along the Mississippi several hundred miles of levees from 20 feet to 30 feet high are now required where the banks were overflowed only a few feet deep before any levees were built. Surveys show that the average depth and cross-section of the Mississippi River channel, and therefore its carrying capacity, below bank-full stage is substantially the same as before the levees were built.

The following illustration shows what would happen at Peoria if the river from Peoria to LaSalle, a length of about 60 miles and an average flood width of about 1½ miles, should be reduced to 1,500 feet between levees. The flood, beginning April 16, 1927, with river stage 19.2 feet at Peoria, crested at 24.65 feet on April 24th. The increase in storage computed from the stage heights and valley cross-sections and the total inflow is equal to the outflow at Peoria plus the increase in storage. Under present conditions, with only one levee enclosing about 2,600 acres of bottom land at Hennepin, the remaining overflowed area including river channel is about 58,000 acres. If the channel were reduced by levees or other means to a flood width of 1,500 feet including the river channel, the total area of water surface would be 13,700 acres or about 23½ per cent of the present flood area. The rise in the river for the nine days from the 16th to the 24th of April, inclusive, was 5.45 feet. The total discharge at Peoria for that period was 778,000 acre-feet and the increase in storage was 315,000 acre-feet, or a total inflow of 1,093,000 acre-feet. The storage was 28.8 per cent of the total inflow, or 40½ per cent of the total outflow. During this rise in the river, the storage was almost half of the inflow on the day of maximum inflow and the maximum rise in the river for one day was 1.4 feet. The reduction in storage would have produced a rise at Peoria on the day of maximum inflow of 4 feet, instead of 1.4 feet. The river would have crested two days earlier and 3.75 feet higher at a stage of 28.4 feet. A stage of 28.4 feet would have overflowed all of the industrial area opposite Peoria and would have been about 3 feet deep in the Rock Island Depot at Fulton and Liberty streets.

There would have been a material increase in hydraulic slope from Peoria to LaSalle and the rise above would have been greater than at Peoria due to the combined effect of reducing the flood channel and the overflowed area.

Conclusions

The following conclusions are suggested:

1. That flood relief presents new problems as population increases, as agriculture and industry develop, and with the physical changes produced by natural forces and the works of man.

2. That engineering methods of flood control depend upon economic conditions and will be modified to meet economic changes.

3. That flood flows depend on precipitation, condition of the soil, topography of the watershed, and atmospheric temperature.

4. That diversion through the Chicago Sanitary and Ship Canal increases flood heights in the lower Illinois River from 0.5 foot to 1.5 feet.

5. That the construction of locks and dams for low-water navigation on the Illinois does not increase flood heights.

6. That economic conditions do not now justify development of detention reservoirs for flood control.

7. That storage reservoirs for municipal and industrial purposes are not now a factor in flood control in the Illinois Valley, but may be within two or three decades.

8. That the construction of levees along Illinois River has greatly increased flood heights requiring additional levees for areas naturally above overflow.

9. That the flood protection plans of the Illinois Division of Waterways and of the Mississippi River Commission, by setting back and strengthening the levees along Illinois River, will provide adequate flood protection for the 248,000 acres under levees so long as no new levees are built.

10. That higher levees or detention basins in the tributaries will be required to offset areas hereafter taken from the valley floodway.

REFERENCES.

1. Report of U. S. War Department Engineers on a Fourteen-foot Waterway from Chicago to St. Louis. House Document 263, 59th Congress, First Session, 1905.
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3. "Illinois River Flood Control Report" of the Illinois Division of Waterways, by Jacob A. Harman, 1929.