FLOOD PREDICTIONS FROM STORM PATHS, PREFLOOD RIVER STAGES, PRECIPITATION DATA, AND PEAK RIVER STAGES[1]

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This paper outlines a working method of making flood predictions from storm paths, preflood river stages, precipitation data, and peak river stages. The study is confined to flood predictions for the Lake Lynn Hydro-Electric Plant,[2] but the method can be applied to future run-of-river hydroelectric plants in Cheat Basin. (See fig. 1.) Also it is believed that the method can be used in developing flood prediction systems for other Appalachian drainage systems.

At the Lake Lynn plant there is an occasional heavy flood water wastage which might be reduced by utilizing stored water ahead of the floods and storing water during the floods. Manifestly, such a method of storage manipulation is not feasible without an accurate flood warning system—a system for which any flood warning would be available long enough before the arrival of the flood peak at the Lake Lynn plant to permit the desired plant usage of preflood stored water, of which about 30,000 acre feet, with 18½ feet draw down of the pond, is economically available for use.

A study of past floods indicates that the United States Weather Bureau's accurate system of flood warnings, based on an upstream peak stage method of prediction, will not give enough warning time to be of material benefit in operating run-of-river hydroelectric plants located on short, steep-sloped rivers. This is due to the fact that warnings of the rapidly moving crest stages would not be available much, if any, before the floods reached the point for which the predictions were made. Accordingly, a Cheat River flood prediction system, based on a new method, has been developed which, by virtue of accuracy and warning time, will permit a safer utilization of preflood stored water than has been possible in the past. The new method of flood prediction is based on storm paths, preflood stages for Cheat River, storm precipitation for selected Weather Bureau stations southwest of Cheat Basin, storm precipitation for Cheat Basin, and upstream peak river stages for Cheat River.

In making the flood prediction study, it was necessary, of course, to make a study of past records of floods, storms, and precipitation. For this flood study and future prediction work, it was found that the flood records for Rowlesburg, 40 miles upstream from the Lake Lynn plant, would give the most satisfactory results. Rowlesburg gage readings were started in 1884, but accurate readings at all stages were not available until after a Mott tape gage was installed July 19, 1912, and correctly read starting about October 11, 1912. The record from October 1, 1912, to December 31, 1928, has been utilized in this study.

The time and peak stages of the Rowlesburg flood as well as the preflood stages, prior to November 18, 1923, were obtained from graphs drawn from the regular twice daily gage-height readings, augmented by many special peak readings. An automatic water-stage recorder was installed on November 18, 1923, and data for floods after that date were taken from its record.

The greatest Cheat River discharge that normally can be handled without flood warning and without spillage at the Lake Lynn plant has been taken as the dividing line between floods and nonfloods. This discharge is about 8 second-feet per square mile, or 8,000 second-feet at Rowlesburg and 11,500 second-feet at Lake Lynn.

The study that was necessary, not only in developing the new method but also in working out a Cheat River flood prediction system from the method, involved the consideration of all possible flood factors. Analyses of the immediate Cheat River flood factors indicated that they are as follows: (1) Ground storage capacity, of which river stage is an inverse index; (2) rate of release of water to the river in the form of liquid precipitation or melted snow; (3) basin distribution of the total released water; (4) direction and rate of travel of the rainstorm when present.

It was considered justifiable to disregard items (3) and (4) above, because the basin rainfall distribution and the direction and rate of storm travel are fairly uniform for the storms under consideration.

A measure of the available ground storage capacity prior to a flood was determined from the Rowlesburg preflood stage, i. e., the lower the stage the greater the available ground storage, and the higher the stage the less the available ground storage (up to complete soil saturation). The preflood stage was taken from the Rowlesburg flood hydrographs, which were extended backward far enough to obtain the minimum stage that occurred prior to the flood peak (ordinarily from 12 to 24 hours before, and never more than 72 hours before the occurrence of the flood peak).

The rate of release of water to the river in the form of precipitation was determined from the average 48-hour precipitations recorded at Elkins, Rowlesburg, and Davis, W. Va. The 48-hour average includes the maximum published 24-hour average plus the amount recorded for the previous 24 hours, an arrangement which apparently gives the best definition between floods and nonfloods.

The rate of release of water to the river in the form of melted snow is a difficult quantity to determine. It depends on the amount of snow on the ground, the temperature, and the amount of rainfall. Good judgment is essential to a proper interpretation of these factors.

The precipitation over Cheat Basin is normally the greatest flood factor. It may be the result of local rains and thunderstorms, or it may come from well-defined cyclonic disturbances that pass over or near the basin. Analyses of past basin records indicate that the latter type of storm was the major cause of flood precipitation, and, accordingly, a study of all cyclonic movements since October, 1912, was made.

The origins and paths of storms that caused floods at Rowlesburg in the past were taken from the charts published in the United States MONTHLY WEATHER REVIEW. The storm origins as set forth by Messrs. Bowie and Weightman in Types of Storms of the United States and Their Average Movements (Supplement No. 1, MONTHLY WEATHER REVIEW) were tried for this study, but after careful investigation, new storm origin areas were laid out and named northern, western, Gulf, central, and Atlantic coast. (Fig. 2.) These names apply not only to the origin areas adopted, but also to the storms

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[1] This paper is essentially a condensation of one presented at the twenty-first annual convention of the Pennsylvania Electric Association at Bedford Springs, Pa., Sept. 5-7, 1928. However, an additional year of data has been utilized and the previously used data thoroughly reviewed.

[2] Located in West Virginia, 3½ miles upstream from the mouth of Cheat River. Constructed in 1925 and 1926 by Sanderson and Porter; owned by West Penn Power Co.; and operated by West Virginia Power & Transmission Co., a subsidiary of the West Penn Power Co.

themselves and their paths. (See figs. 3 and 4.) The paths for all flood storms, segregated by months, were traced according to the adopted classification. Figure 3, showing all the March western type of flood storms, illustrates the procedure that was followed, and Table 1 is a summary of the results obtained from this classification.

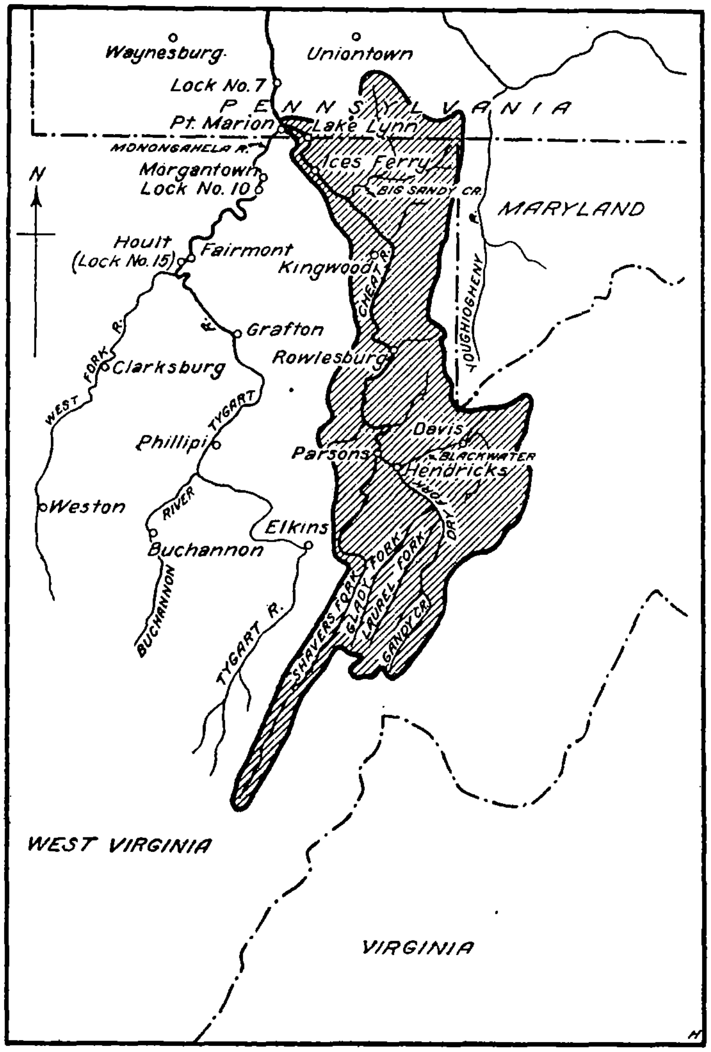

FIGURE 1.—Cheat River watershed

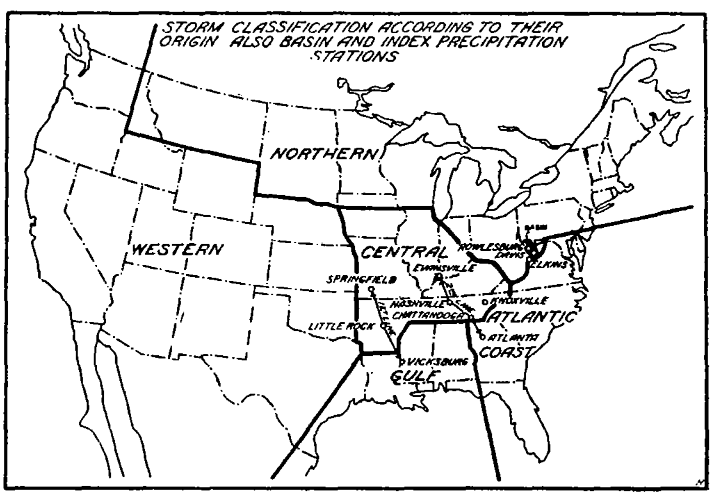

FIGURE 2.—Geographic districts

TABLE 1.—*Flood storms (flows greater than 8,000 second-feet), October 1, 1912–December 31, 1928*

Month	Atlantic coast	Gulf	Central	Western	Northern	No storm	Total
October	1	4	2	7	0	1	15
November	2	3	2	10	0	0	17
December 1–15	0	1	2	7	0	1	11
December 16–31	0	3	0	12	1	1	17
January	2	9	1	21	1	3	37
February	0	5	0	19	3	4	31
March	2	3	3	17	6	4	35
April	2	7	0	7	3	4	23
May	3	1	0	11	5	2	22
June 1–15	0	0	0	3	1	0	4
Total	12	36	10	114	20	20	212
June 16–30	0	0	0	3	0	1	4
July	0	0	1	4	2	2	9
August	0	0	1	2	1	4	8
September	1	0	0	0	2	1	4
Total	1	0	2	9	5	8	25
Total for year	13	36	12	123	25	28	237

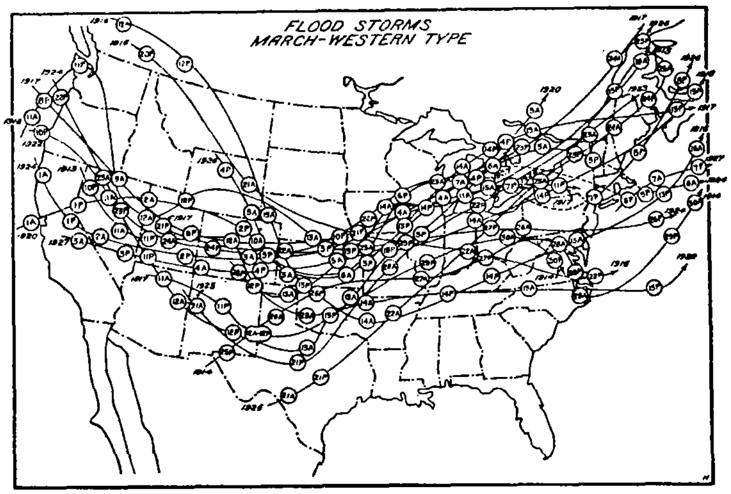

FIGURE 3.—March western type flood storm paths

A thorough investigation of the flood storms indicated that, due to their general poor flood-producing qualities, the northern type storms should be omitted from any

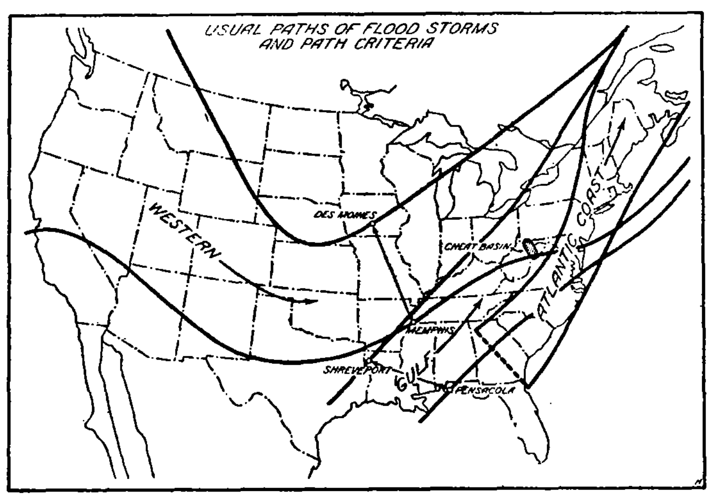

FIGURE 4.—Idealized storm paths

flood prediction plan. The investigation also led to the establishment of the following rules and path criteria for the remaining four types of storms. (Also see fig. 4.)

a. Atlantic coast type storms must originate on land to be considered possible flood makers.

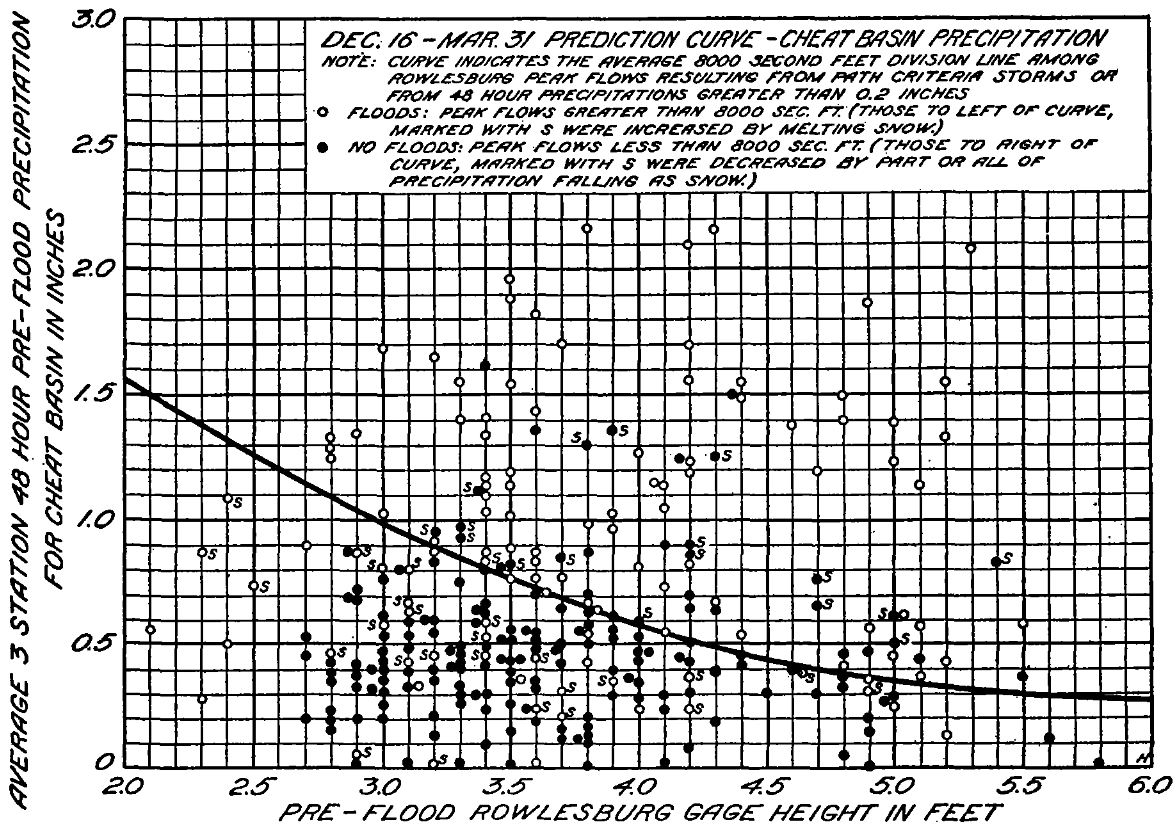

FIGURE 5.—December 16–March 31 prediction curve Cheat Basin precipitation

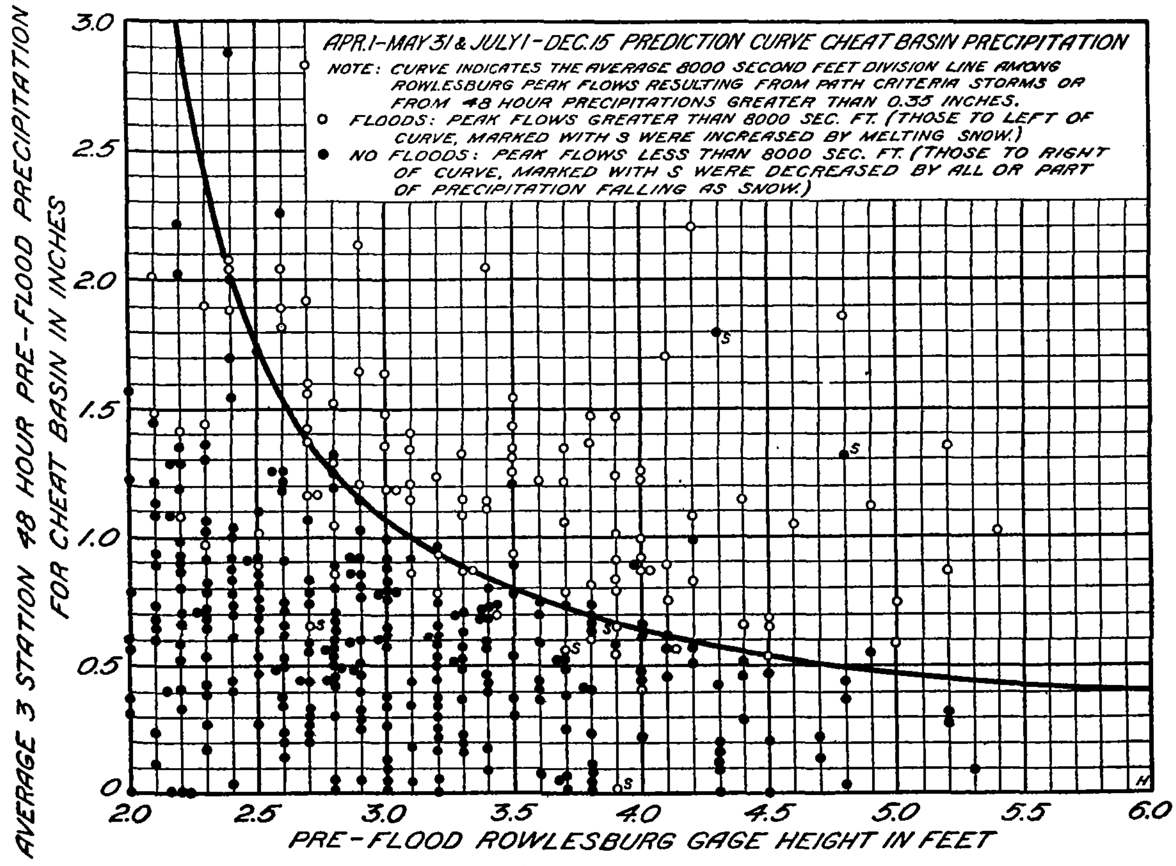

FIGURE 6.—April 1–May 31 and July 1–December 15 prediction curve Cheat Basin precipitation

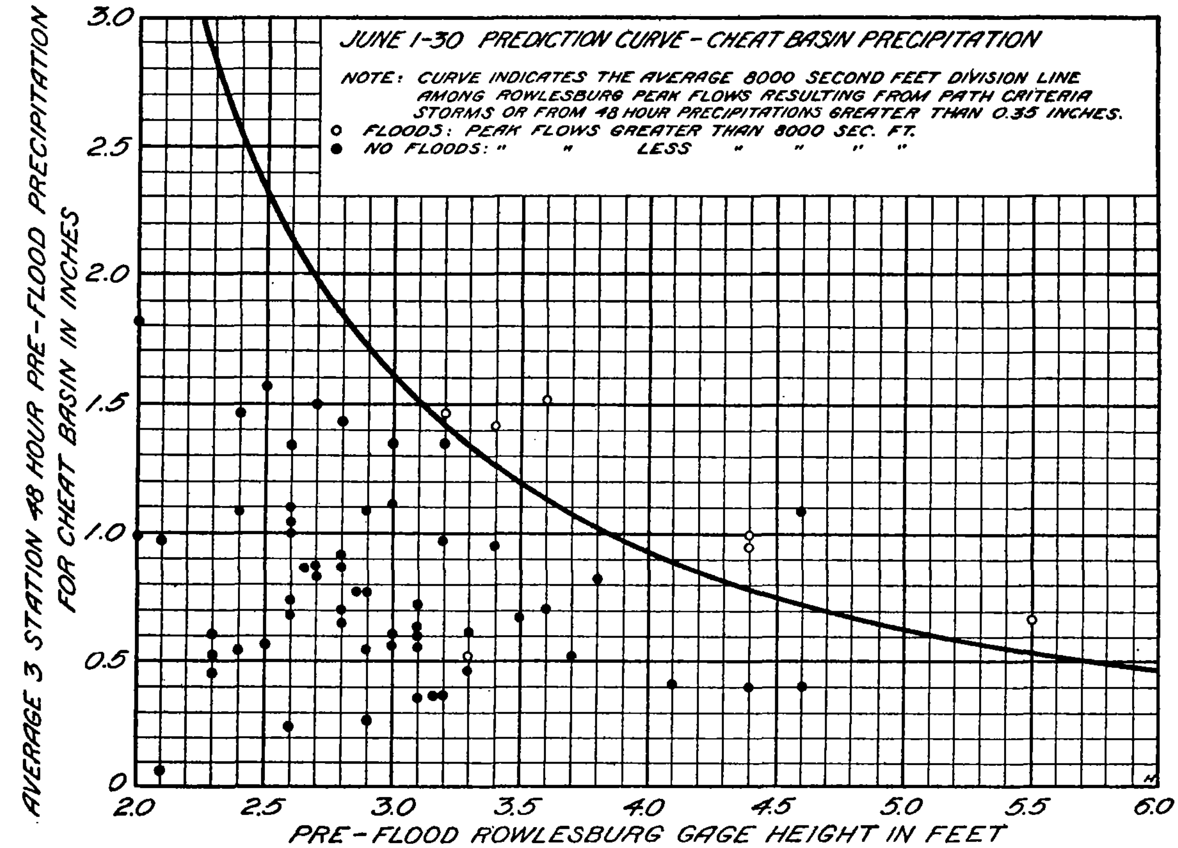

FIGURE 7.—June 1-30 prediction curve Cheat Basin precipitation

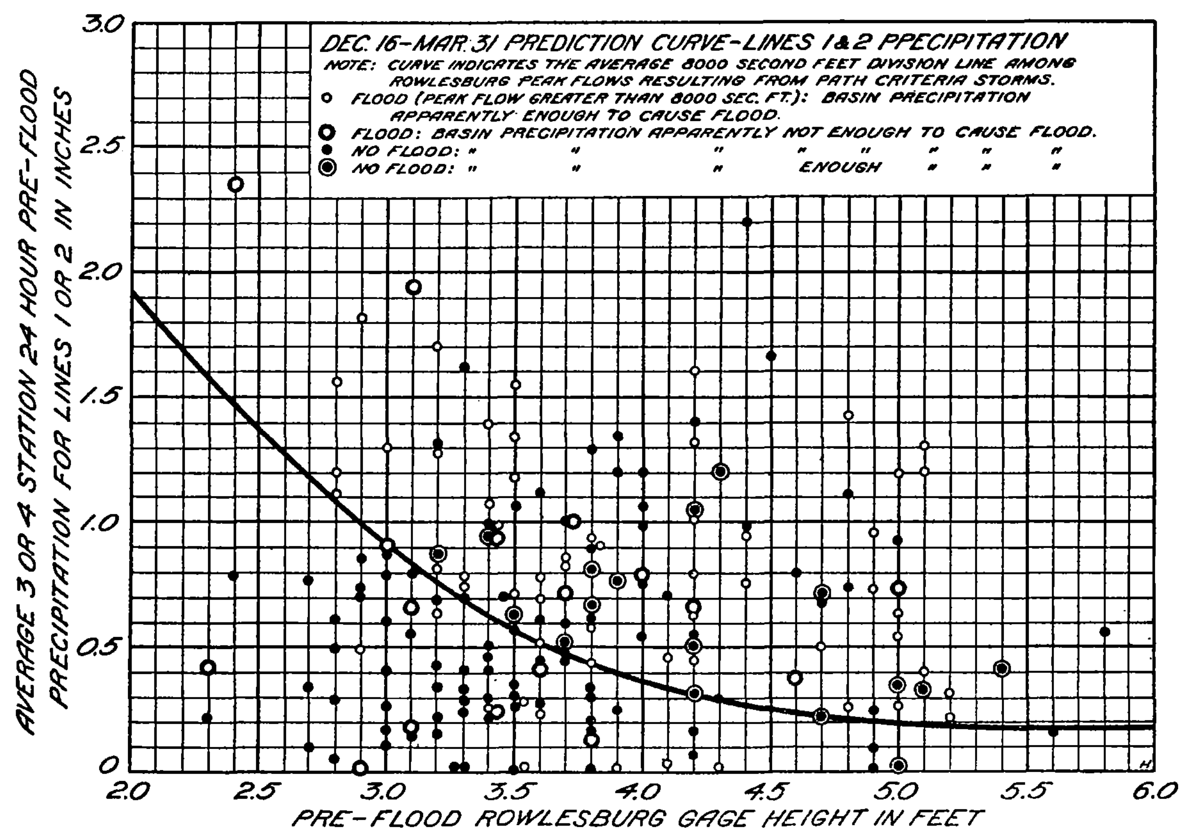

FIGURE 8.—December 16-March 31 prediction curve, lines 1 and 2 precipitation

b. Gulf type storms forming southwest of a line passing through Shreveport, La., and Pensacola, Fla., must pass between those two cities to be considered possible flood makers.

c. All Gulf type storms forming northeast of the Shreveport-Pensacola line are to be considered possible flood makers.

d. All central type storms are to be considered possible flood makers.

e. Western type storms must cross the Mississippi River and pass between Des Moines, Iowa, and Memphis, Tenn., to be considered possible flood makers.

f. No northern type storms are to be considered possible flood makers.

g. Any storm touching the Gulf of Mexico is to be considered a Gulf type, regardless of its origin.

h. No storms of any type, June 16 to September 30, will be considered possible flood makers.

A large number of nonflood storms fulfilled the above set of criteria. (See Table 2.) Therefore the study was carried further, so as to differentiate as far as possible between flood and nonflood storms. It was found that the differentiation could be made most easily by using precipitation data for the same storms at certain Weather Bureau stations southwest of Cheat Basin (hereafter designated southwestern stations). These southwestern stations are located in the general path of the storms and far enough away from the basin to give enough warning time to be of some value in flood predictions.

Accordingly, precipitation data were collected for the following southwestern stations (also see fig. 2):

1. Springfield, Mo.
2. Little Rock, Ark.
3. Vicksburg, Miss.
4. Evansville, Ind.
5. Nashville, Tenn.
6. Chattanooga, Tenn.
7. Atlanta, Ga.
8. Knoxville, Tenn.

Stations 1–3 and 4–7 are on two lines about 350 miles apart. These lines are nearly normal to the paths of all storms except the Atlantic coast type, and have been designated lines 1 and 2, respectively. The maximum 24-hour average precipitation for whichever line gave the maximum was used in the study of flood prediction for the western, Gulf, and central types of storms.

TABLE 2.—*Summary of all storms fulfilling path criteria, October 1, 1912–December 31, 1928*

Month	Atlantic coast	Gulf	Central	Western	Total
October	2	7	6	22	37
November	8	7	4	26	45
December 1–15	0	7	4	15	26
December 16–31	2	7	1	20	30
January	4	19	1	29	53
February	3	12	0	39	54
March	6	13	6	45	70
April	8	12	1	38	59
May	6	7	2	28	43
June 1–15	0	0	1	13	14
Total for period	39	91	26	275	431
Nonflood storms	29	59	16	181	285
Flood storms	10	32	10	94	146
Per cent of storms fulfilling path criteria that caused floods	25.6	35.2	38.4	34.2	33.8

The maximum 24-hour precipitation at station 8, Knoxville, was found to give the best indication as to whether or not a flood would result from any given Atlantic coast storm. Accordingly, the precipitation for that station was so used. The maximum precipitation for the southwestern stations was found to occur generally about a day before the flood reached Rowlesburg. In no case was precipitation considered that fell more than three days prior to the flood peak.

As a result of the analyses and investigations described in the above paragraphs, Cheat River preflood stages and Cheat Basin precipitation were used in preparing three Cheat River flood diagrams, of which the first is applicable December 16 to March 31; the second, April 1 to May 31 and July 1 to December 15; and the third, June 1–30. (See figs. 5, 6, and 7.)

There are a number of exceptions on the basin diagrams. Some floods apparently had too little precipitation, and some nonfloods apparently had too much. In the first case, the flood usually was caused in part by the melting of old snow; in the second case, no floods occurred because all or part of the precipitation fell as snow. Another source of error is the impossibility of obtaining a true average precipitation for any extensive basin from a 3-station average, especially when local thunderstorms occur. It is evident, therefore, in using the foregoing diagrams, that considerable attention should be given to local meteorological conditions, particularly as to the nature of the precipitation and whether show is melting, when present.

Cheat River preflood stages and southwestern precipitation have been used in preparing three Cheat River flood diagrams applicable to storms fulfilling the source and path criteria. The first two are to be used for the western, Gulf, and central storms; the first being applicable December 16 to March 31; and the second April 1 to June 15 and October 1 to December 15. The third diagram is to be used for Atlantic coast storms occurring between October 1 and June 15. (See figs. 9 and 10.)

Many exceptions will be noted on the southwestern station diagrams. Some storms which followed the usual path and gave ample precipitation over lines 1 and 2, or Knoxville, failed to produce Cheat River floods. On the other hand, some storms that apparently lacked precipitation at lines 1 and 2 or Knoxville resulted in Cheat River floods. It is difficult, for all these exceptions, to give explanations that can be used in flood prediction work. However, an abrupt change in the path or speed of the storm after fulfilling the path criteria explains many of them. A summary of all exceptions and explanations is given in Table 3.

Utilizing the diagrams mentioned above in the proper flood-prediction sequence, a Cheat River flood-prediction system has been worked out as follows:

(1) A tentative flood prediction will be made, for the period October 1 to June 15, for all storms fulfilling source and path criteria. About 62 per cent of all floods can be predicted by this means, and about 34 per cent of the storms for which floods are predicted will result in floods.

(2) All flood predictions under item (1) will be confirmed or discredited on the basis of diagrams utilizing Cheat River preflood storm stages, and the average 24-hour precipitation for certain southwestern precipitation stations. About 40 per cent of all floods can be predicted by this means, and about 53 per cent of the storms for which floods are predicted will result in floods.

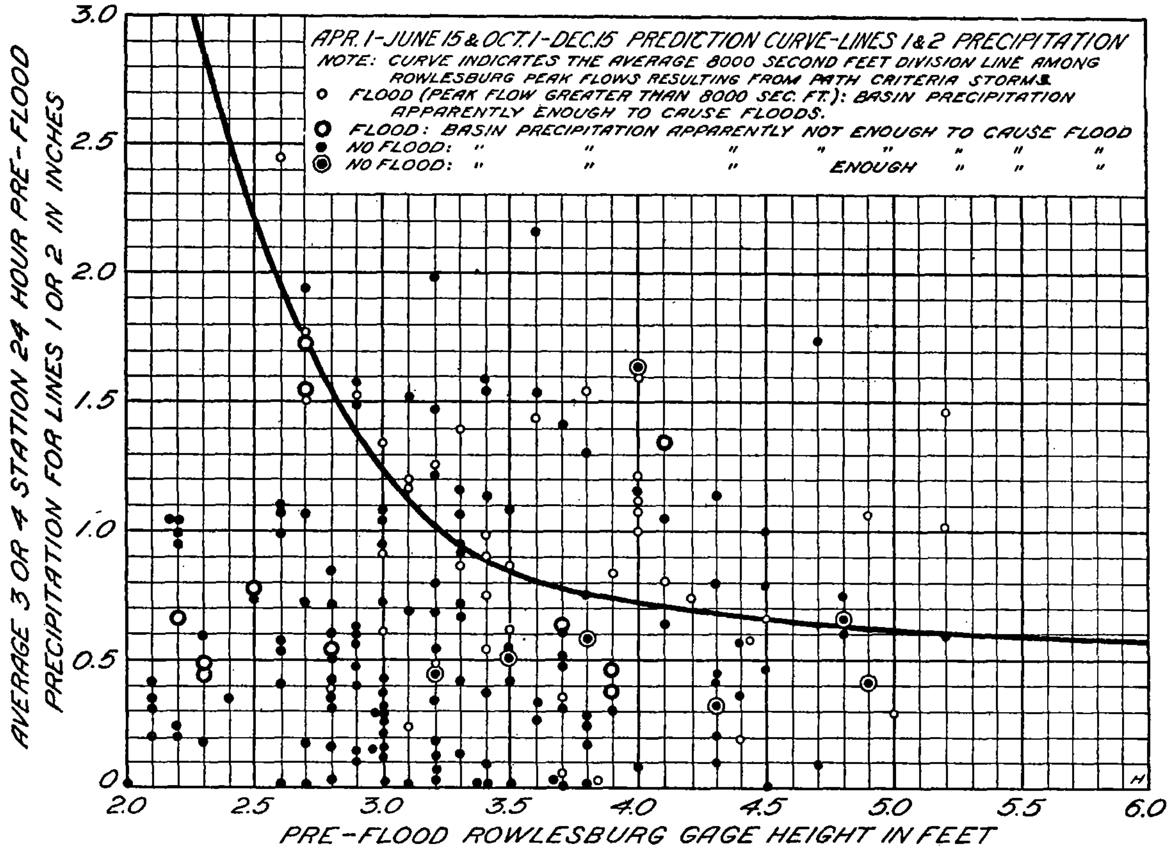

FIGURE 9.—April 1-June 15 and October 1-December 15 prediction curves, lines 1 and 2 precipitation

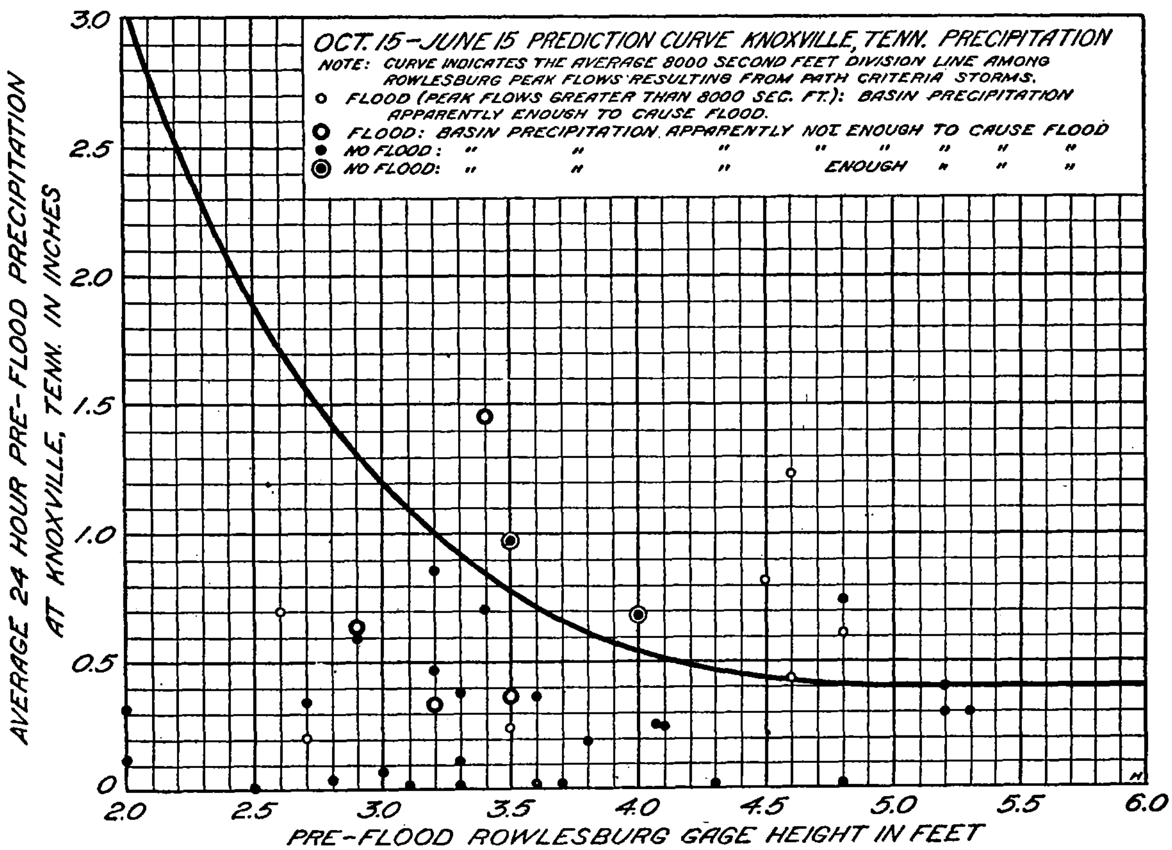

FIGURE 10.—October 15-June 15 prediction curves, Knoxville (Tenn.) precipitation

TABLE 3.—*Summary of exceptions to curves*

BASIN CURVES

•	July 1-Dec. 15, Apr. 1-May 31	Dec. 16-Mar. 31	June 1-30
1. Floods but precipitation over basin below minimum	26	35	1
Number under 1 explained	4	30	0
Net exceptions unexplained	22	5	1
2. No floods but precipitation over basin above minimum	14	33	1
Number under 2 explained	6	28	0
Net exceptions unexplained	8	5	1

CURVES FOR GULF, CENTRAL, AND WESTERN STORMS

	Oct. 1-Dec. 15, Apr. 1-June 15	Dec. 16-Mar. 31
1. Floods, ample precipitation over basin, deficient over lines 1 and 2	17	10
2. Floods, deficient precipitation over basin, ample over lines 1 and 2	1	10
3. Floods, deficient precipitation over basin, deficient over lines 1 and 2	10	8
4. No floods, deficient precipitation over basin, ample over lines 1 and 2	28	34
5. No floods, ample precipitation over basin, deficient over lines 1 and 2	5	1
6. No floods, ample precipitation over basin, ample over lines 1 and 2	2	16

CURVES FOR ATLANTIC COAST STORMS

	Oct. 1-June 15
1. Floods, ample precipitation over basin, deficient over Knoxville, Tenn	3
2. Floods, deficient precipitation over basin, ample over Knoxville, Tenn	1
3. Floods, deficient precipitation over basin, deficient over Knoxville, Tenn	3
4. No floods, deficient precipitation over basin, ample over Knoxville, Tenn	2
5. No floods, ample precipitation over basin, deficient over Knoxville, Tenn	0
6. No floods, ample precipitation over basin, ample over Knoxville, Tenn	2

(3) Flood predictions will be made throughout the entire year, utilizing all available Cheat Basin meteorological data, depending mainly on diagrams that are based on Cheat River preflood stages and Cheat Basin average 48-hour precipitation.

The flood predictions in this item are in no way dependent on storm paths and precipitation at southwestern stations. However, all flood predictions under item (2) will be confirmed or discredited by information made available at this third stage of prediction. About 88 per cent of the predicted floods will occur.

(4) Flood predictions will be made, throughout the entire year on the basis of the increasing and crest stages for Rowlesburg floods. Practically 100 per cent of the Lake Lynn floods can be accurately predicted by this means.

Nearly all of the meteorological data for this flood prediction study were obtained at the Pittsburgh office of the United States Weather Bureau, and the authors desire to express their appreciation to W. S. Brotzman and his assistants for their courtesy and helpfulness in making available the vast amount of data that were needed. Assistance on this paper also has been rendered by a large number of other persons, and the authors hereby gratefully acknowledge such assistance.

NORTHERS OF THE GULF OF TEHUANTEPEC [1]

By WILLIS EDWIN HURD

The Isthmus and Gulf of Tehuantepec occupy a relatively unimportant position geographically, but nevertheless constitute a region that is unique in a meteorological sense. The isthmus, which separates the Gulf of Mexico from the Pacific Ocean, lies near the southeastern extremity of the Mexican Republic, with a least width of about 125 miles, although the distance by way of the Tehuantepec Railway from Puerto, Mexico, on the Atlantic to Salina Cruz on the Pacific side is 188 miles. For some 60 or 70 miles along that part of the Sierra Madre range that traverses the isthmus, the hills and highlands shrink many hundred feet in elevation, being mostly between 1,000 and 2,000 feet high, although at the highest point on the railway track the altitude is as low as 688 feet. There is thus formed a natural pass, or spillway, from one ocean to the other. The isthmus lies almost due south, across the Gulf of Mexico, from the Great Plains of North America, across which sweep unimpeded the continental anticyclones. Frequently in the colder season the air masses reach the Gulf, which thus becomes an atmospheric reservoir, the walls of which are the semi-inclosing continent. When the head of air which presses on down across the Bay of Campeche becomes too great, a part of the surplus overflows across the spillway of the isthmus, and rushes in a torrent down the opposite slopes and across the open gulf to the southward.

The Gulf of Tehuantepec, though comparatively small in area, is nevertheless a great roadstead, facing the Pacific in a direction slightly west of south, its visible boundary comprising approximately the southernmost 300 miles of the Mexican Pacific coast line. It is traversed by the shipping lines between the Panama Canal and various Pacific ports, and therefore the weather conditions which may be experienced here have an important bearing on navigation. Any study of the atmospheric overflows, or northers, of this gulf, therefore, has a practical as well as a scientific application.

The norther as such should not be confused with other northerly gales that sometimes occur over the Gulf of Tehuantepec. During the wet season—June to October—one or more tropical cyclones of moderate to considerable intensity are likely annually to form over, or cross the waters of the gulf from the southeastward. Those that originate locally are less likely to produce severely disturbing weather in this locality than those that come in from the southward and have had a longer time in which to develop. Ordinarily little confusion arises in identifying the type of gale wind that may blow here. But since the mariner, while at the head of the gulf, might experience the northeasterly gales, without much barometric depression, of the northwestern quadrant of a cyclone passing to the southward, he might erroneously identify them as a norther, unless a

[1] The word "Tehuantepec," as applied by the native Indians to the range of hills of that name near the head of the Gulf, signifies the mountains of the man-eating beasts, referring to the dangerous carnivorous animals that once infested the region.—*W. E. H.*