Papers on Flood Problems, University of Chicago, Paper No. 70
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CHAPTER VIII

SEASONALITY

Robert W. Kates[1]

Most hydrologic investigations are prompted by the design needs of engineer- structures. Knowledge of seasonality is a minor factor in the design of channel ›rovements and storage structures. It is important for "run of river" power de- opment and irrigation diversion and for the operation of reservoirs. It also has n suggested that seasonal information could be applied to the definition of "safe" iods for construction in flood hazard areas.[2]

In general, the use of seasonal frequencies of flood events is only widespread he calculation of agricultural crop damages for economic feasibility studies. › government organizations engage in such studies, the Corps of Engineers and Soil Conservation Service, and employ seasonal frequencies marked by wide iation in time units considered significant for the establishment of seasonal dif- ›nces.[3] These range from weekly periods up to four months.

The Corps of Engineers and the Soil Conservation Service both recommend use of frequency plotting methods applied to seasonal data in order to calculate ›onal frequencies. The Corps also provides for the alternative use of this sim- seasonal weighting factor:

$$\emptyset = \frac{nx}{N} \cdot \frac{\bar{q}x}{\bar{Q}}$$

Where $\emptyset$ = weighting factor in the month or season, x, and represents the percentage of the x seasonal damages or benefits to be incorporated in the average annual damages or benefits,

[1]The writer gratefully acknowledges the assistance of the district offices of Jnited States Geological Survey with responsibility for the Ohio Basin and the ›ngton, West Virginia district office of the Corps of Engineers.
Ian Burton, Richard Schneider, and John R. Sheaffer have been constant ›es of stimulation. Joseph Huber and Karl Gudenberg have helped with the il- ations.
The writer is further indebted to Brian J. L. Berry for his supervision of ırect factor analysis.

[2]W. P. Cross and E. E. Webber, Floods in Ohio, Magnitude and Frequency, of Ohio, Department of Natural Resources, Division of Water Bulletin No. 32 mbus: State of Ohio, 1959), pp. 24-28.

[3]U. S., Department of Agriculture, Soil Conservation Service, National Engi- ng Handbook, Section 4, Hydrology Supplement A (Washington: U. S. Depart- of Agriculture, 1957), p. 3.18-1; U. S. Army, Corps of Engineers, "Prelimi- Engineering Manual, Civil Works Construction" (unpublished draft), Part C-1, vi, p. 52.

nx = number of known floods in month or season, x,
N = total number of known flood events,
$\bar{q}$x = average monthly or seasonal flood peak discharge, c.f.s,
$\bar{Q}$ = average peak discharge of all floods in sample.

In addition to feasibility studies, the Tennessee Valley Authority has made available local flood reports which include data on flood occurrence presented graphically as a monthly frequency distribution.[4]

Henry has noted the persistence of major floods in the lower Ohio Valley during the months of January, February, and March.[5] White has discussed three outstanding forms of seasonal occurrence in the United States.[6] Harbeck and Langbein have constructed a map of flood seasonality in the United States based on the highest monthly normal flow for a sample of one hundred and two gages.[7] (See Fig. VIII-1.) Cross and Webber have plotted seasonal frequencies for groups of Ohio stations.[8]

Design of a Study

There are four requirements for a study of the seasonality of flood events in time and space: the development of a measure of seasonality, the definition of a flood event, the delimitation of a study area, and the determination of a time period.

A measure of seasonality.- If, by definition, seasonality is the concentration of flood events, then a measure of seasonality could be a measure of the concentration of events in a stated time unit. Such concentration would range between a maximum concentration of seasonality and a maximum evenness or minimum seasonality. (See Fig. VIII-2 for a graphic example utilizing a monthly time period.) The flood events occurring at a stream gage will fall on a curve lying between the two extremes and such a curve will adequately describe the concentration of such events, at that point, through time.

[4]An example of such a report may be found in: U. S., Congress, Senate Committee on Public Works, A Program for Reducing the National Flood Damage Potential, 86th Cong., 1st Sess., 1959, p. 17.

[5]Alfred J. Henry, The Floods of 1913 in the Rivers of the Ohio and Lower Mississippi Valleys, U. S., Weather Bureau Bulletin Z (Washington: Government Printing Office, 1913), p. 51.

[6]Gilbert F. White, Human Adjustment to Floods, (Chicago: University of Chicago, Department of Geography Research Paper No. 29 1942), pp. 39-40.

[7]G. E. Harbeck, Jr., and W. B. Langbein, Normals and Variations in Runoff 1921-1945, Water Resources Review, Supp. No. 2 (Washington: U. S. Geological Survey, 1949), p. 31.

[8]Cross and Webber, pp. 24-28.

FLOOD SEASONALITY IN THE UNITED STATES

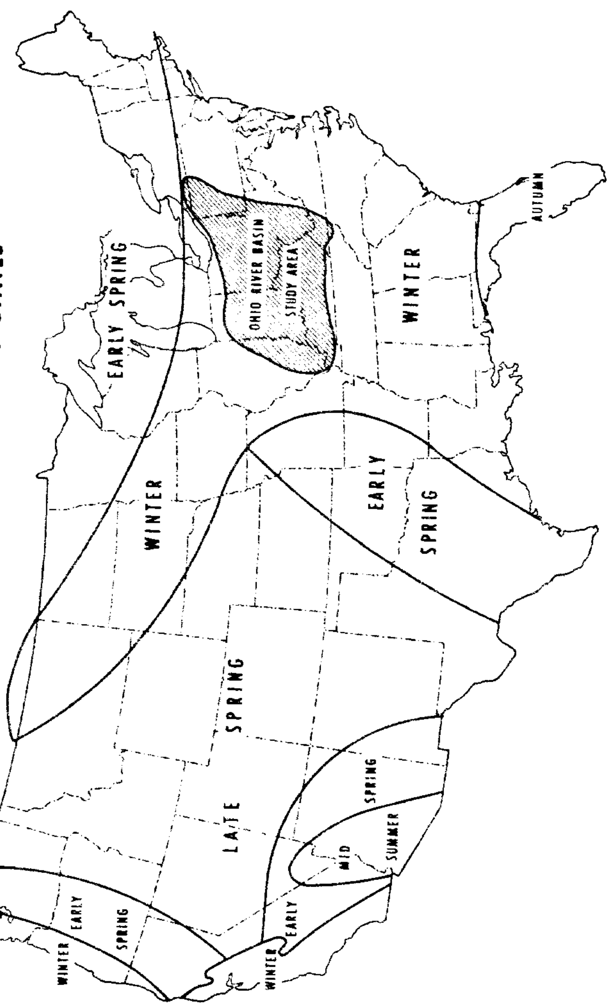

Fig. VIII-1. Flood Seasonality in the United States after Harbeck and Langbein.

A flood event defined.- In this study, as in Chapter VII, a flood event is defined as the period during which a river stage equals or exceeds flood stage, or the stage at which damage begins. It should be noted that this stage is a culturally defined elevation subject to change as the intensity of use of the flood plain varies through time. The Weather Bureau has determined flood stage at many sites.[9] Where flood stage is unavailable, bankfull stage is used.[10]

The choice of a study area.- The area chosen for this study is the basin of the Ohio River excluding the basins of the Cumberland and Tennessee Rivers. Four considerations were involved in this choice: (1) The size of the task of collecting data required the use of an area substantially smaller than the continental United States. (2) The study by Sheaffer of the "flood-to-peak" interval in the Ohio Basin (Chapter VII) provided a well-designed random areal sample of stream gages, stratified by size of drainage area. The sampling procedure results in the selection of one gage for each 3,740 square mile area in the basin. (See Figure VII-5). (3) The stream gages of the Ohio Basin have relatively long continuous records of river stage. (4) The basin is located entirely within the homogenous region of winter seasonality on the Harbeck and Langbein map. (See Figure VIII-1.) Furthermore Henry, as previously cited, had noted the marked seasonality of major floods along the main stem. White describes the upper Ohio as an area in which "a great flood may occur in any month of the year, but in which most floods occur during a fairly well-defined season."[11] These studies suggest the value of investigating an area with highly generalized uniform characteristics to determine what variations in uniformity would be revealed by the record from a denser gage network when analyzed by different techniques.

A sample of time.- A record of a recurring natural phenomenon such as a flood event is but a sample of a large universe of time which began at the last significant period of climatic and geologic change. Therefore, to improve the reliability of inferences based on such a sample, all recorded information on floods at any time was collected for each gage at the outset of the study. The time unit chosen for measuring seasonality was a month.

Data Collection and Organization

For each of the forty-five gages a record or flood series of the maximum

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[9] These may be found along with river stages of flood events in U. S., Weather Bureau, Flood Manual (Washington: U. S. Weather Bureau, 1957); U. S., Weather Bureau, Monthly Weather Review, 1875-1950; U. S., Weather Bureau, Climatological Data, 1950, et seq.

[10] This was only necessary in one case and was based on information supplied by the District Engineer of the Geological Survey.

[11] White, pp. 40-41.

ly occurrence of a flood event was constructed for each month. Published al and state sources were used and where possible data were compared and ed.[12]

Each monthly flood series contained two basic items of information; the ab- number of maximum monthly occurrences during the record,and the magni- f each event recorded in tenths of feet above flood stage. The periods of re- anged from ten to one hundred and two years and items of historical infor- n extended as far back as 1762. Therefore, as a first step in the analysis, the ter of magnitude and length of record was examined briefly.

Length of record.- The records from eight stations were subdivided into -five year periods and these were compared. The basic pattern of flood- distribution through the year is not altered greatly by doubling the period of l, except for those stations with a very low frequency of flooding. (See Fig- II-3.) However, the observations of rare, unseasonable events were in- d by extending the record and can be seen in the longer records.

Magnitude.- For eight stations, the magnitude of events expressed as a ratio maximum flood of record was compared to occurrence of flood events. (See VIII-4.) It was found that, excluding stations of very low frequency of flood- agnitude varies directly with the frequency of all flood events and in general loods occur in the months when many floods of all sizes occur.[13]

t was concluded that seasonality could be identified and compared with data ecords of varying lengths and that the magnitude of events could be ignored. ch station then, the number of maximum monthly events was tabulated, per- es of the total number of events calculated, ranked, and cumulated in prepa- for further analysis.

The Classification of Seasonality

wo approaches were developed to seek out significant patterns of seasonality uld be used as a summary measure or to establish seasonal flood types.

umulative concentration of flood events.- The monthly percentages of flood were ranked, cumulated, and plotted graphically as a series of Lorenz curves.

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[2]In addition to the Weather Bureau publications previously cited, the U. S., cal Survey, Surface Water Supply of the United States (published as Water Papers between 1899 and 1957) were used extensively. An example of a iblication is William D. Mitchell, Floods in Illinois: Magnitude and Fre- (Springfield: State of Illinois, 1954).

[3]The Cross and Webber study previously cited measured magnitude as the the mean annual flood. The probabilities of various events occurring the year were graphed and these tend to confirm this conclusion.

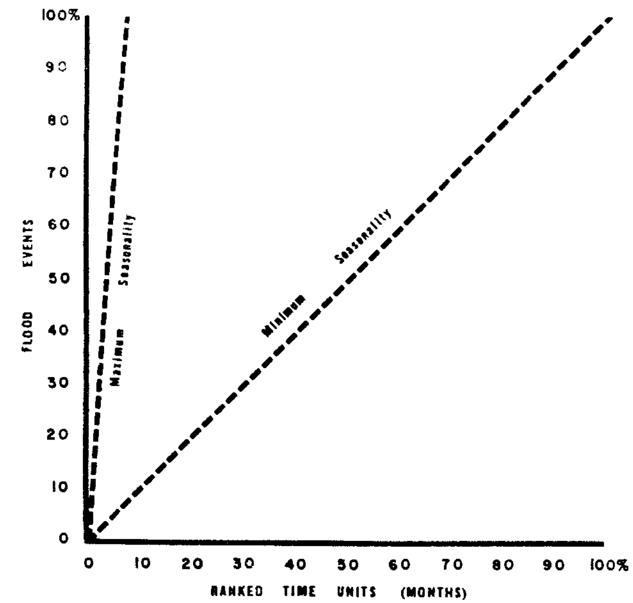


Fig. VIII-2. - Extremes of seasonality

The curves of all stations fall between the extreme of seasonality at Beaver at Beaver Falls, Pennslyvania, and the extreme of evenness at Wabash at Wabash Indiana. A separation of two groups of curves takes place along a line, XY, in Figure VIII-5, identifying flood types of greater and lesser seasonality. When the stations were plotted on a map and the array of ranked months observed, each ma- jor group is seen to fall into two distinct sub-types:

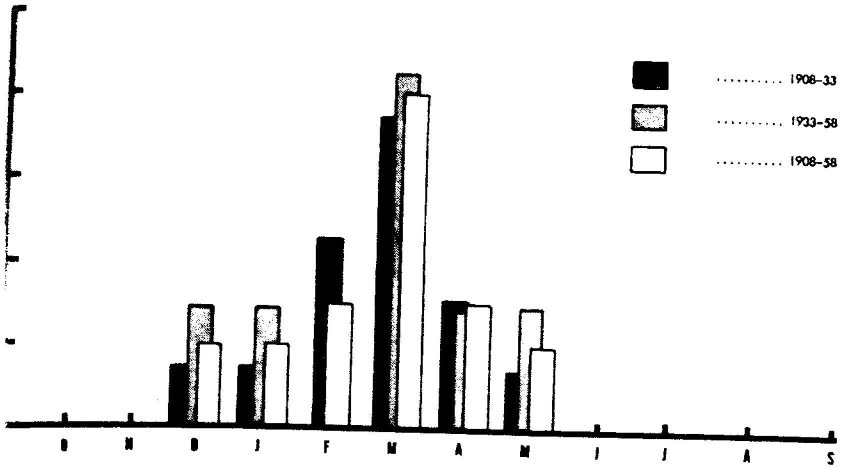
Seasonal Flood Types of Greater Seasonality

Type A.- Late Winter.- Stations of this type are found in the northeastern and north-central portions of the basin and along the main stem of the Ohio River. These stations cumulate in excess of 70 per cent of all flood events during the months of January-February-March-April, with the mode coming in March.

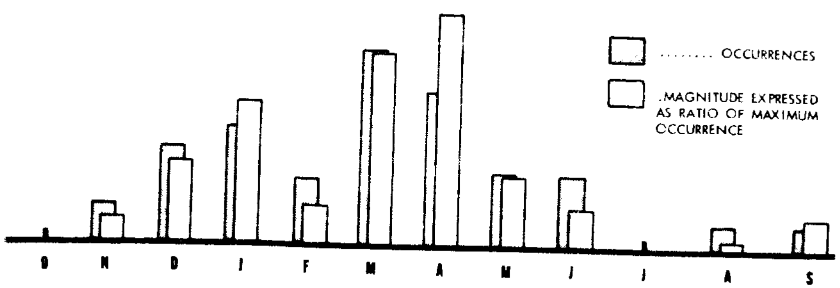
Type B.- Early Winter.- All stations of this type are found in Kentucky, along the southern tributaries of the Ohio River. These stations cumulate in excess of 70 per cent of all flood events in the months of December-January-February-March, with a January-February mode.

Seasonal Flood Types of Lesser Seasonality

Type C.- Winter-Spring.- Stations of this type are found solely in the water-



ig. VIII-3. Monthly percentages of total flood events for different periods
d, Allegheny River at Franklin, Pennsylvania.



. VIII-4. Monthly percentage of total occurrences and magnitude ex-
s ratio of maximum occurrence, Hocking River at Athens, Ohio.

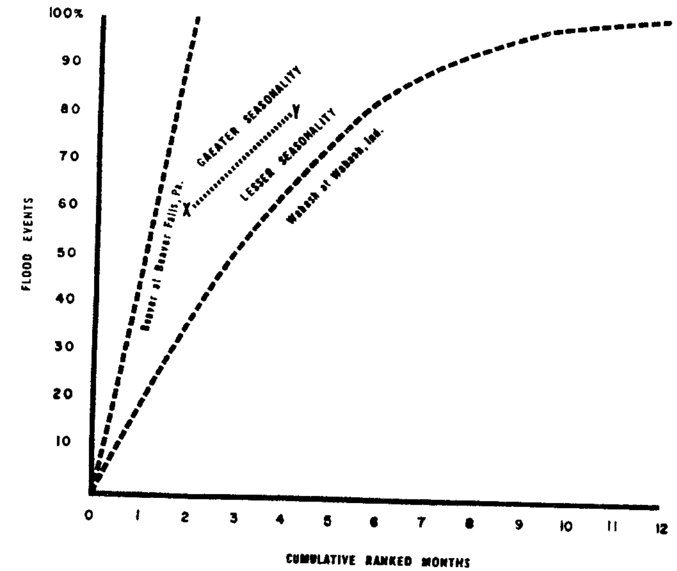


Fig. VIII-5. Extremes of seasonality of sample gages, Ohio Basin

sheds of the Wabash and White Rivers. Floods here are less concentrated and cumulate in excess of 70 per cent in the months of January-February-March-April-May, with a March-April peak.

Type D.- Complex Mountain.- These stations are found in the mountain areas of Virginia and West Virginia and exhibit a complex pattern of flooding marked by a winter peak and relatively large number of events in August, October, and December. (See Figure VIII-6.)

Time-space associations measured by direct factor analysis.- The second approach begins with the calculation of the deviation from the joint probability of a number of events occurring during a month at a given station.[14] The amount of

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[14] These deviations were arranged in a 45 x 12 matrix where each cell contains the deviation for a given station for a given month measured as $n - \frac{n_i n_j}{N}$, where n is the flood experience at that station for the month, n_i the experience at all stations during that month, n_j the events experienced in the station record, and N the total events in the basin of 1,602. The direct factor analysis was conducted under the supervision of Brian J. L. Berry. A detailed mathematical discussion of this analysis is beyond the technical competence of the writer and the reader is referred to Brian J. L. Berry, "Grouping and Regionalizing: An Approach to the Problem Using Multivariate Analysis" (unpublished draft, University of Chicago, 1960).

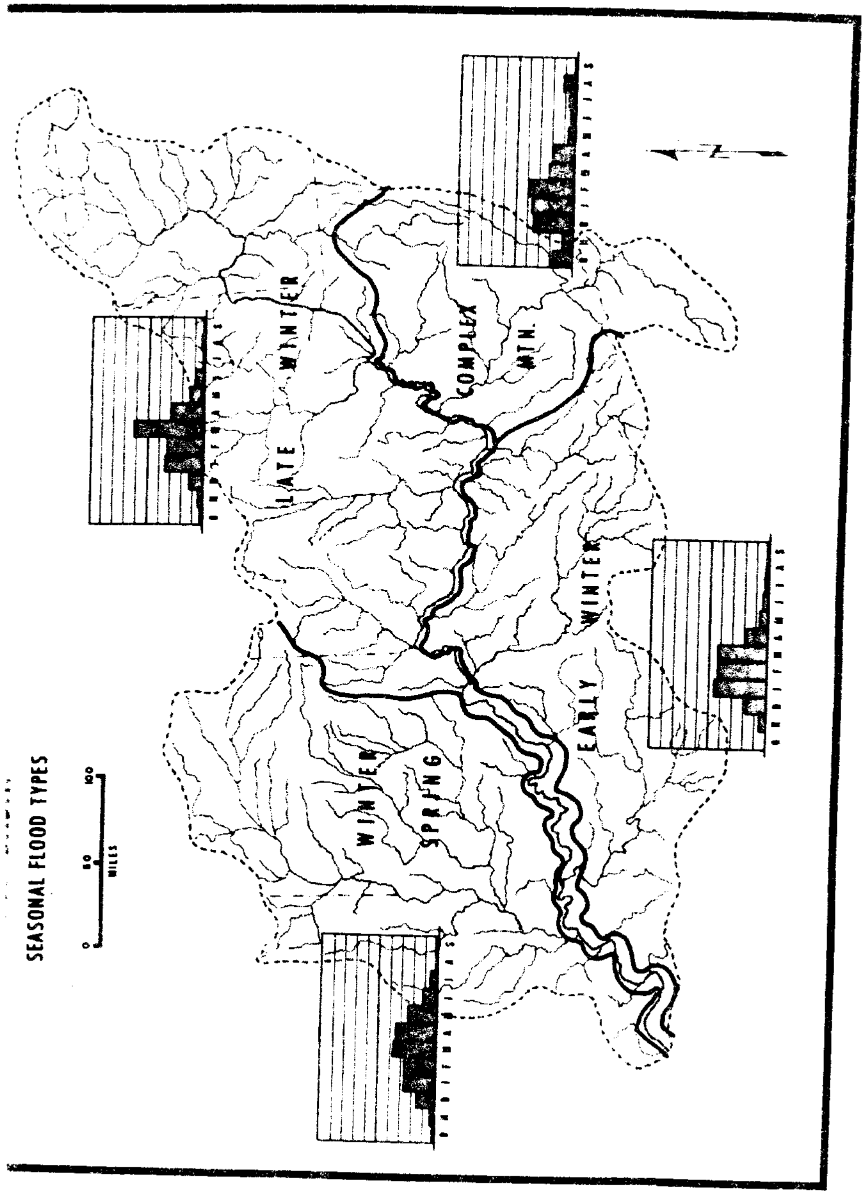

Fig. VIII-6

deviation is the difference between the actual experience of a station and the joint probability. This was calculated by months for each station and the resulting 45 x 12 matrix of deviations was submitted to direct factor analysis on the UNIVAC computer at the Operations Analysis Laboratory of the University of Chicago.

Direct factor analysis attempts to identify the principal components of the matrix of deviations, both for months and for stations. The factor analysis seeks, among the forty-five stations, each of which contributes a different increment to the basin-wide pattern, those highly associated stations, and among months, those months whose collective behavior contributes the largest increments to the pattern. These associations of months (time) and stations (space) are the factors; each accounting for successively smaller increments of the variance within the basin. Each factor associates by a positive or negative quantitative value the months of the water year and the stations in the sample. The higher the values, the greater is the degree of association. Stations and months of like sign vary directly with each other and inversely with those of opposite sign. The following six factors were identified by the analysis (Table VIII-1).

The main Factors (Factors one and two) which account for two-thirds of the variance in the basin, provide a dynamic model of the march of flooding over the basin. In Figure VIII-7, the positive and negative high monthly associations are identified by A-B-C-D. Stations which are associated with these months by values exceeding one are labeled with the appropriate letter. Where there is more than one association the first letter signifies that of greater significance.

Flooding begins in December in the southeast and moves northwest with the seasons along a broad axis roughly parallel to the main stem of the valley. While there is substantial March flooding everywhere in the basin, it reaches its peak along the main stem. April and May find minor flooding in the southern tributaries and very substantial amounts in the Wabash Valley.

Factor three suggests a minor (9.4 per cent) east-west influence in the pattern of the basin. Factors four, five, and six are marked by diverse associations of months and scatter of stations. These reflect random elements in the flood phenomena.

<u>The two approaches--a comparison.</u>- The seasonal flood types developed by the Lorenz curve analysis and the association identified by the factor analysis are in essential agreement. The pattern of regionalization described by the seasonal flood types (see Figure VIII-6) is a generalized static model of the pattern of flooding in time and space. The factor analysis suggests the dynamic aspects of the process underlying the regional patterns; the migration north and west with the seasons, the east-west influence, and the random, localized aspect of flood occurrences. The downstream main stem stations classified as Late Winter are shown also to be highly associated with the Early Winter stations. Complex Mountain stations are

FACTOR ANALYSIS OF OHIO BASIN FLOODING

Factor No.	Per Cent of Sum of Squares Extracted			General Description of Association[a]	
	Per Cent	Cum. Per Cent	Sign	Time--Months	Space-Location of Station
1	38.0	38.0	Positive	May, Apr., June	Wabash Valley and scattered stations
			Negative	Jan., Feb., Mar.	Kentucky and lower main stem
2	28.0	66.0	Positive	Mar., Apr., May	North of Ohio R. and upper main stem
			Negative	Dec., Jan., Feb.	South of Ohio River
3	9.4	75.4	Positive	Mar., Nov., Oct.	Eastern end of basin
			Negative	Feb., Apr.	Western end of basin
4	6.9	82.3	Positive	Dec., Oct. Mar.	Scattered
			Negative	Jan., June, July	Scattered
5	7.2	89.5	Positive	Jan., Apr., June	Scattered
			Negative	May, Feb.	Scattered
6	2.8	92.3	Positive	Jan., May	Scattered
			Negative	June, Feb.	Scattered

[a]This is a generalized description of the highly associated months and stations. Complete data are available upon request.

clearly influenced by the seasonal migration and are highly associated with the Early Winter stations.

The factor analysis forcefully reminds the observer of the complex nature of natural phenomena, a truism often obscured by the needs of map generalization. Factors one and two, which most resemble the seasonal flood types, explain the major variations within the basin, but leave a substantial portion (one-third) to reflect the random quality of localized flood situations.

Factor analysis does not measure the degree of concentration of flood events in time as does the Lorenz curve, but concerns itself primarily with "explaining" the over-all pattern in time and space. The two approaches complement each other, providing a system of checks for a classification and additional insights into the nature of seasonality.

The Seasonal Flood Types of the Ohio Basin--Some Associations

Physiographic.- Thirteen distinct physiographic sections are found in the Ohio Basin. Only the Complex Mountain type suggests a physiographic association, where the mountain topography with small drainage areas and high orographic rainfall contributes to the complexity of the flood pattern.

Factor three, an east-west association identified by the factor analysis, approximates somewhat the lowland-low plateau and mountain-high plateau division of the basin and may be related.

Climatic.- The source of all floods is some form of precipitation, rain or snow. The occurrence of a flood at a point takes on a random character when the complex of land and atmospheric factors is considered. Over large areas, however, seasonal flooding takes place in a manner that strongly suggests a climatic process at work. An investigation of such a process is beyond the scope of this study. However, climatic counterparts to the seasonal patterns of flooding were sought for and obtained.

A Weather Bureau study of intense precipitation over large areas in the eastern United States indicates a seasonal migration of intense precipitation in much the same manner as the seasonal march of flooding over the basin.[15]

In this study intense precipitation was defined by a curve enveloping 99.0 per cent of weekly precipitation totals in excess of one inch for climatological divisions east of the Rocky Mountains. This process identifies the magnitude of unusual precipitation for large areas while eliminating the extremely rare occurrences. A

[15]R. W. Schloemer, "An Empirical Index of Seasonal Variation of Intense Precipitation over Large Areas." Monthly Weather Review, LXXXIII, No. 12 (December, 1955), pp. 302-13.

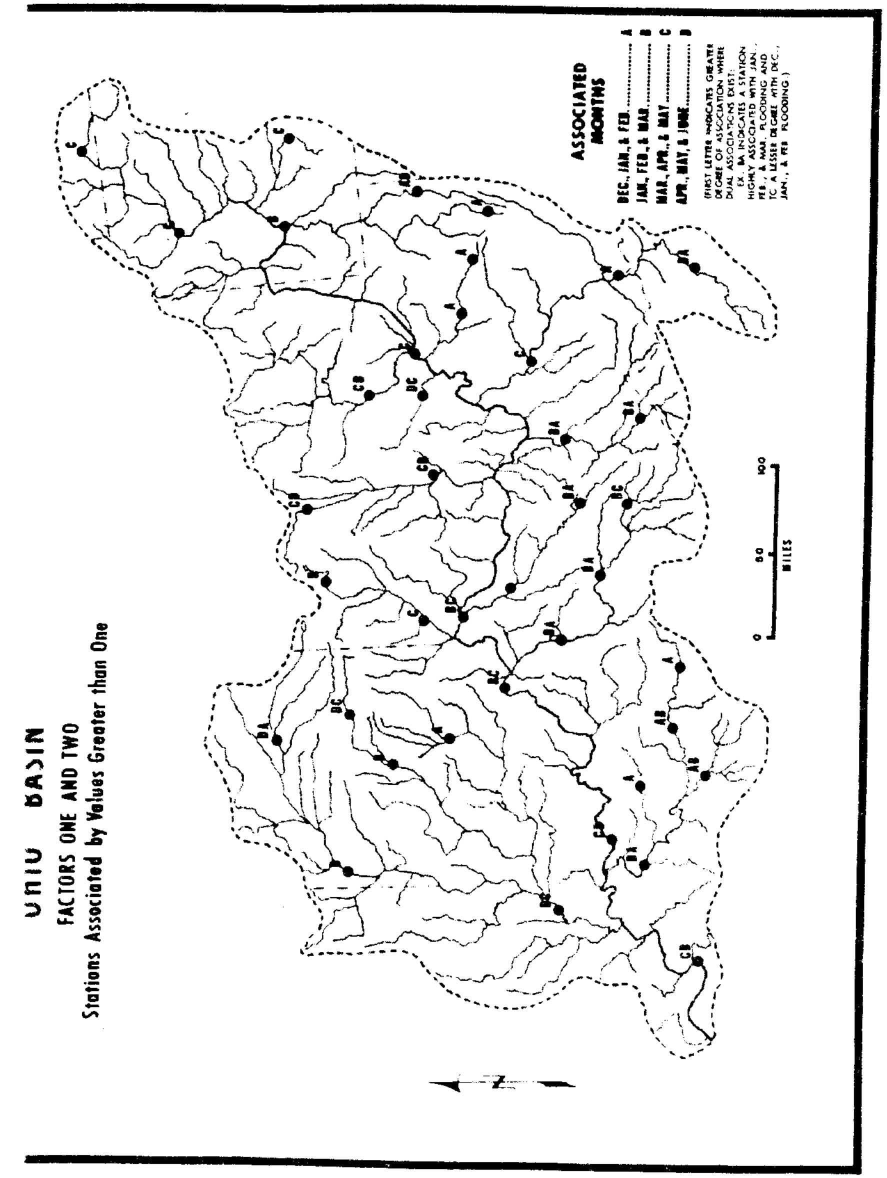

Fig. VIII-7

TABLE VIII-2

PHYSIOGRAPHIC REGIONS AND SEASONAL FLOOD TYPES, OHIO BASIN[a]

Province	Section	Seasonal Flood Type	Number of Stations
Coastal Plain	East Gulf	Late Winter	1
Blue Ridge	Southern	Complex Mountain	1
Valley and Ridge	Tennessee	Complex Mountain	1
Appalachian	Southern New York	Late Winter	2
Plateau	Allegheny Mountain	Late Winter	2
	Kanawha	Late Winter	9
		Complex Mountain	5
		Early Winter	4
	Cumberland Plateau	-	-
	Cumberland Mountain	-	-
Interior Low	Highland Rim	Early Winter	3
Plateaus	Lexington Plain	Early Winter	3
	Possible W. Sec.	Early Winter	2
		Late Winter	1
Central Lowland	Eastern Lake	Winter-Spring	1
	Till Plains	Winter-Spring	5
		Late Winter	1

[a]Based on the map prepared by Nevin M. Fenneman, Physical Divisions of the United States (Washington: U. S. Geological Survey, 1956).

ratio of the magnitude of the intense precipitation for a given period to the magnitude of the maximum 99.0 per cent value was calculated by bi-weekly periods. A series of bi-weekly maps was constructed for the eastern states. Table VIII-3 describes the location of the centers of maximum intense precipitation relevant to the seasonal flood types.

Size of Drainage Area and Frequency of Flooding.- Flood types are compared by size of drainage area and frequency of flooding in Table VIII-4 (page 130). There is a wide range of both drainage area size and frequency of flooding in each type. No clear association between seasonality and drainage area size or frequency emerges.[16]

[16]The smallest drainage area in the sample is relatively large. Cross and Webber in Floods in Ohio, Magnitude and Frequency show that for a sample of 12

TABLE VIII-3

LOCATION OF CENTERS OF MAXIMUM INTENSE PRECIPITATION IN THE OHIO VALLEY BY FLOOD TYPE AND MONTHS

Location	Month	Flood Type
-	October	-
-	November	-
Kentucky	December	Early Winter
Kentucky	January	Early Winter
Southern main stem of the Ohio River	February	Late Winter
Indiana-Ohio	March	Late Winter--Winter-Spring
Indiana-Ohio	April	Late Winter--Winter-Spring
Indiana	May	Winter-Spring
-	June	-
West Virginia-Virginia	July	Complex Mountain
West Virginia	August	Complex Mountain
-	September	-

[a]Centers are defined by 100 per cent isolines.

Source: R. W. Schloemer, "An Empirical Index of Seasonal Variation of ·nse Precipitation over Large Areas," Monthly Weather Review, Vol. LXXXIII, 12 (December, 1955), Figures 6-31.

Flood Plain Occupance

It has long been hypothesized that seasonality has a marked effect on flood ·age. White suggests that, next to frequency, seasonality is one of the more sig- ·ant factors of flood occurrence for human adjustment.[17] Burton further sug- ·s that there might be observable patterns of human adjustment to seasonality, ·icularly agricultural occupance.[18] The impact of seasonal variation in the Ohio

ons with drainage areas smaller than 30 sq. miles a very different pattern of ing is developed than for the larger drainage areas. They attribute this dif- ·ce to the marked effect of local thunderstorms of late spring and early sum- in the smaller drainage areas.

[17]White, p. 40.

[18]Ian Burton, "An Exploratory Investigation of Factors affecting the Agricul- Occupance of Flood Plains in the United States" (Chicago: unpublished draft, , pp. 54-62.

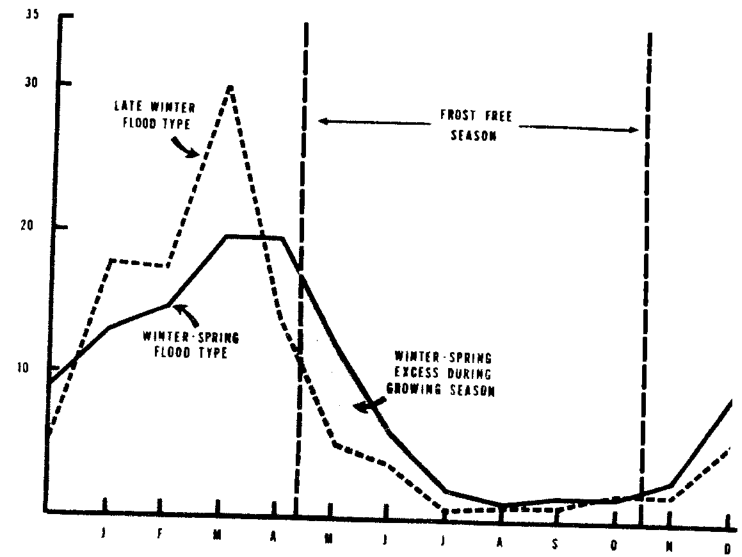

Fig. VIII-8.

Basin of both the seasonal and unseasonal event on agricultural flood plain occupance is examined briefly.

The seasonal event.- Portions of Ohio and Indiana share the same limits on growing season with distinct variation in the seasonality of flooding. (See Figure VIII-8.) This suggests the following inquiry for future research: Does the increased probability of floods during the growing season make farming more hazardous in Indiana than Ohio? Can a measure be designed to test this hazard considering differences in flood plain use intensity, regulation, flood frequency, and other variables? Even if this could be done, would greater damage be revealed in Indiana, or have the farmers in that area adjusted to the later seasonality of flooding with a later schedule of plantings, late varieties of crops, less intense use of the flood plains, and other possible adjustments?

The unseasonal event.- Though the actual form of the response to seasonality in agricultural occupance is unknown, that such a response takes place is certain. The continued occupance of flood plains of frequent but seasonal inundation is ample proof that some adjustment takes place. It then follows that severe damage from floods comes not from the predictable seasonal event but from the rarer unseasonal event or the rare seasonal event of uncommon magnitude.

TABLE VIII-4

FLOOD TYPES, DRAINAGE AREAS, AND FREQUENCY OF FLOODING, OHIO BASIN

Flood Type	Drainage Area (sq. mi.)			Frequency (yrs.)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Early Winter	451	202,700	31,623	27.40	0.72	1.53
Late Winter	742	7,580	2,688	6.57	0.44	1.29
Winter-Spring	401	28,600	7,028	1.23	0.38	0.49
Complex Mountain	272	8,367	2,231	7.43	0.74	1.83

Floods in August in the Ohio Basin are rare. In the entire study only fourteen floods were found. However, nine of these were in the Complex Mountain Type . For example, in August, 1943, the Little Kanawha River flood caused damage cess of $1,300,000, half of which was damage to agricultural crops.[19] Thus, of the significant variations revealed by this study is a region where the rare is less rare and significant flood hazard is increased.

Another impact of the rare unseasonal event is its possible catastrophic effect highly-regulated stream. In general, reservoir operation for multi-purpose use s the established pattern of seasonality of flow. The occurrence of rare un- nal floods catches man ill-prepared in two ways. The flood plain may be used intensely and the protection works are at their lowest effectiveness.

A precise evaluation of the impact of both the seasonal and unseasonal event man occupance over larger areas must be preceded by the definition and meas- ent of seasonality under varying climatic regimes. It is hoped that the tech- s explored in this study might prove useful in such an endeavor, extending them er parts of the United States.

Summary and Conclusions

Seasonality of flood events in the Ohio Basin has been measured in two ways. o methods, cumulative concentration curves of flood events and time-space ations measured by direct factor analysis, are found to produce complemen- esults. In the light of this measurement and classification, previous observa- y Henry, White, and Harbeck and Langbein are found to be accurate, but

[19] Monthly Weather Review, LXXI, No. 8 (August, 1943), 139.

highly generalized representations of seasonality whose lack of precision tends to obscure significant variations within the basin. Instead of a single homogenous region, the spatial distribution of seasonality in the Ohio Basin falls into four distinct types: Early Winter, Late Winter, Winter-Spring, and Complex Montain.

The seasonality of flood events in the Ohio Basin appears to be associated with a seasonal migration of intense precipitation. The study does not indicate associations of seasonality with drainage area, frequency of flooding, or physiography.