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CLIMATOLOGY OF LAKE ERIE STORM SURGES AT BUFFALO AND TOLEDO

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CLIMATOLOGY OF LAKE ERIE STORM SURGES AT BUFFALO AND TOLEDO

N. Arthur Pore, Herman P. Perrotti, and William S. Richardson

ABSTRACT. The Techniques Development Laboratory of the National Weather Service has compiled a climatology of storm surges at each end of Lake Erie. For this study, storm surge is defined as the departure of the lake level from the mean monthly lake level. Thirty-three years of lake level data for Buffalo, N.Y. and Toledo, Ohio have been processed. The occurrences of storm surges greater than two feet, both positive and negative, have been put into classes at half-foot intervals for each month of the year. This information should be useful in determining the probabilities of specific storm surge heights and lake levels in the future.

INTRODUCTION

Extratropical storms frequently cause the water surface of Lake Erie to become distorted with high water in one end of the lake and low water in the other. The abnormal water levels are called storm surges and are defined to be the effect of meteorological disturbances on the lake level. Storm surges can be either positive or negative. Although storm surges can occur on all of the Great Lakes, they are most important on Lake Erie because of its geographic orientation and shallow depth. The most important surges are the positive surges as they result in flooding and extensive damage. When long term low water conditions prevail during some periods, the occurrences of negative storm surges become important. Low water conditions can cause serious navigation problems, especially in the western end of Lake Erie.

The Techniques Development Laboratory has been asked many times about the probability of storms causing high water levels on Lake Erie in the coming months. When asked such questions, we have been able to make crude estimates of the frequencies of storms which would cause storm surges of certain magnitudes by recalling storm frequencies during the past 2 or 3 years. During the past couple of years, this problem has become more acute because of the extremely high mean level of Lake Erie.

To answer such questions more adequately, we have compiled a climatology of storm surge levels at each end of Lake Erie from the lake level data of the Lake Survey Center of the National Ocean Survey.

An earlier investigation was made of the Lake Erie water level frequencies by Irish and Platzman (1962). They considered cases during the 20-year period of 1940-1959 in which the difference in lake level between Buffalo and Toledo ("Buffalo-minus-Toledo set-up") exceeded 6 feet. They found November to be the month having the highest frequency of such cases, with more than 70% of the cases occurring in the three months November, December, and January.

The object of this study is to present the climatological monthly frequencies of storm surges of various heights at the eastern and western ends of Lake Erie.

TYPES OF LAKE LEVEL FLUCTUATIONS

The effects of several types of water level fluctuations on Lake Erie combine to produce the observed lake level. These fluctuations can be classed as long range, seasonal, and meteorologically-generated fluctuations.

Long range fluctuations in the level of Lake Erie are caused mainly by variations in the amount of precipitation in the Great Lakes Basin. Periods of higher than normal precipitation are followed by periods of higher lake level. Such fluctuations are evident in Figure 1, where monthly mean lake levels for Buffalo and Toledo are shown for the period 1940 through 1973. Low water levels are quite evident for some periods such as 1940-1941 and 1962-1965. Compare these with high water periods such as that of 1972-1973. Over a hundred years of record of the Lake Survey Center show the lake levels to vary from above normal to below normal in somewhat of a cyclic manner but cycles of any definite length are not evident. In general, the mean levels tend to remain above normal or below normal for several years at a time.

Another type of water level fluctuation is the seasonal variation that occurs regularly, with high levels during summer and low levels in winter. These seasonal fluctuations are very evident in Figure 1. They are caused by seasonal differences of weather conditions over and near the lake. The average seasonal fluctuations on Lake Erie indicated in Figure 1 are about 1 1/2 feet.

The third type of variation consists of the water level changes caused by storms crossing the Great Lakes area. The most significant are the winter storms which approach the Great Lakes from the central part of the country and cause strong southwest winds over Lake Erie. This results in a storm surge, which is essentially the pile-up of water by the wind. The result of southwest winds is a tilted lake surface--the eastern end of the lake is raised and the western end is lowered.

Occasionally a storm system will pass south of Lake Erie, bringing northeast winds over the lake, When this happens, the reverse water level situation occurs, with the pile-up of water occurring in the western portion of the lake. Such was the case on November 14, 1972 when strong northeast winds caused the level of western Lake Erie to rise. The resulting storm surge of over 4 feet added to the existing level of more than 2 feet in excess of the long term mean caused extensive flooding and damage.

Irish and Platzman (1962) have summarized several factors which affect the seasonal distribution of storm surges on Lake Erie. They include seasonal distribution of storm frequencies, the deeping of storms passing over the Great Lakes area caused by the lake acting as a heat source in winter, the effect of thermal instability in the lower atmosphere on wind stress intensification, and the effect of thermal stability within Lake Erie itself.

Another factor that may be important is the effect of ice cover on Lake Erie. During a normal winter, 95% of the lake becomes ice covered (Rondy, 1971); maximum ice cover normally occurs in late February. Extensive ice cover is believed to have a restraining effect on the generation of storm surges.

A type of water level disturbance infrequently observed on Lake Erie is that generated by barometric pressure jumps that may occur with thunderstorms. If the barometric disturbance travels near the speed of the generated water wave, which is controlled by the water depth, significant water level disturbances can occur.

THE DATA

The lake level data for Buffalo, N.Y. and Toledo, Ohio were obtained from the Lake Survey Center of the National Ocean Survey for the 33-year period from 1940 through 1972, except for four months of missing data for Toledo. Hourly observations were available for Buffalo. Hourly observations were also available for Toledo, except for the period of January 1940 through June 1953 during which two-hourly observations were available.

The determination of storm surge, the effect of the meteorological disturbance, can be made several ways. The method used was simply to subtract the monthly mean water level from the observed water level at the time of the disturbance, except when the disturbance occurred within five days of the beginning or end of a month. When the disturbance occurred in the first five days of the month, the mean was determined by averaging the mean levels of the previous month and the present month. For disturbances occurring during the last five days of the month, the mean levels of the current month and the following month were averaged.

The lake level records were examined for departures of 2 feet or more from the mean. The duration of a storm surge case was defined as that period of time during which the water level differed from the mean by 2 feet or more. The duration of a case can vary from one to many hours. The storm surge value assigned to each case was the maximum recorded. These values were put into classes to the nearest half-foot for climatological compilation.

Detailed graphs of the Buffalo and Toledo storm surges for the greatest positive and negative surges during our period of study are shown in Figures

2 through 5. These storm surges have the following values:

+7.79 ft at Buffalo on Feb. 16, 1967;
+5.29 ft at Toledo on April 27, 1966;
-4.65 ft at Buffalo on March 10, 1964; and
-7.46 ft at Toledo on March 22, 1965.

Figures 2 through 5 show the storm surge graphs for these cases, the available wind observations at Toledo and Buffalo, and a series of surface weather charts for each case.

COMPILATION OF DATA

The storm surges of 2 feet or more at Buffalo and Toledo for the 33-year period are separated into class intervals of a half-foot. These data are presented in a series of graphs and tables (Fig. 6-18, Tables 1-4).

Figure 6 shows the overall distribution of storm surge for all months of the year combined. The upper graph is for Buffalo and the lower for Toledo. High water cases (positive storm surges) are shown on the right sides of the graphs, low water cases (negative storm surges) on the left. Most of the surges at Buffalo are high water cases, resulting from southwest winds of the winter storms passing to the north of the Great Lakes. These storms are also responsible for most of the low water cases at Toledo.

Figures 7 through 18 show the storm surge data for each month of the year in a manner similar to that in Figure 6. Because of the large differences in monthly frequencies, the vertical scales on these graphs vary considerably.

Tables 1 through 4 show the same information in tabular form. Most of the storm surges, since nearly all are caused by extratropical storms, occur in the fall, winter, and early spring months. Tables 1 and 3 show the following in this regard:

a. 94% of surges +2 feet or greater at Buffalo occur from September through April.

b. 91% of surges +2 feet or greater at Toledo occur from September through April.

Information on the frequency of storm surges of various magnitudes is most useful when used in conjunction with the information available on the longer term lake level anomalies. The Lake Survey Center publishes monthly bulletins that show the mean lake levels for recent months, projected mean levels for several future months, and long term monthly averages. By combining information on the frequency of storm surges with the projected mean monthly lake levels, one can obtain the probability of absolute lake levels for several months in the near future.

SUMMARY

Thirty-three years of water level data for Buffalo, N.Y. and Toledo, Ohio have been processed to determine the monthly frequencies of storm surges in both ends of Lake Erie. Water level cases which differed by 2 feet or more from the monthly lake level were classified by height at one-half foot intervals.

These statistical storm surge frequencies, when combined with the projected mean levels for future months, as determined by the Lake Survey Center of the National Ocean Survey, should yield probabilities of specific lake level heights for future months.

ACKNOWLEDGMENTS

Appreciation is expressed to the Lake Survey Center of the National Ocean Survey for the lake level data used in this study. The authors also express appreciation to Mary-Blue Battle for typing the manuscript.

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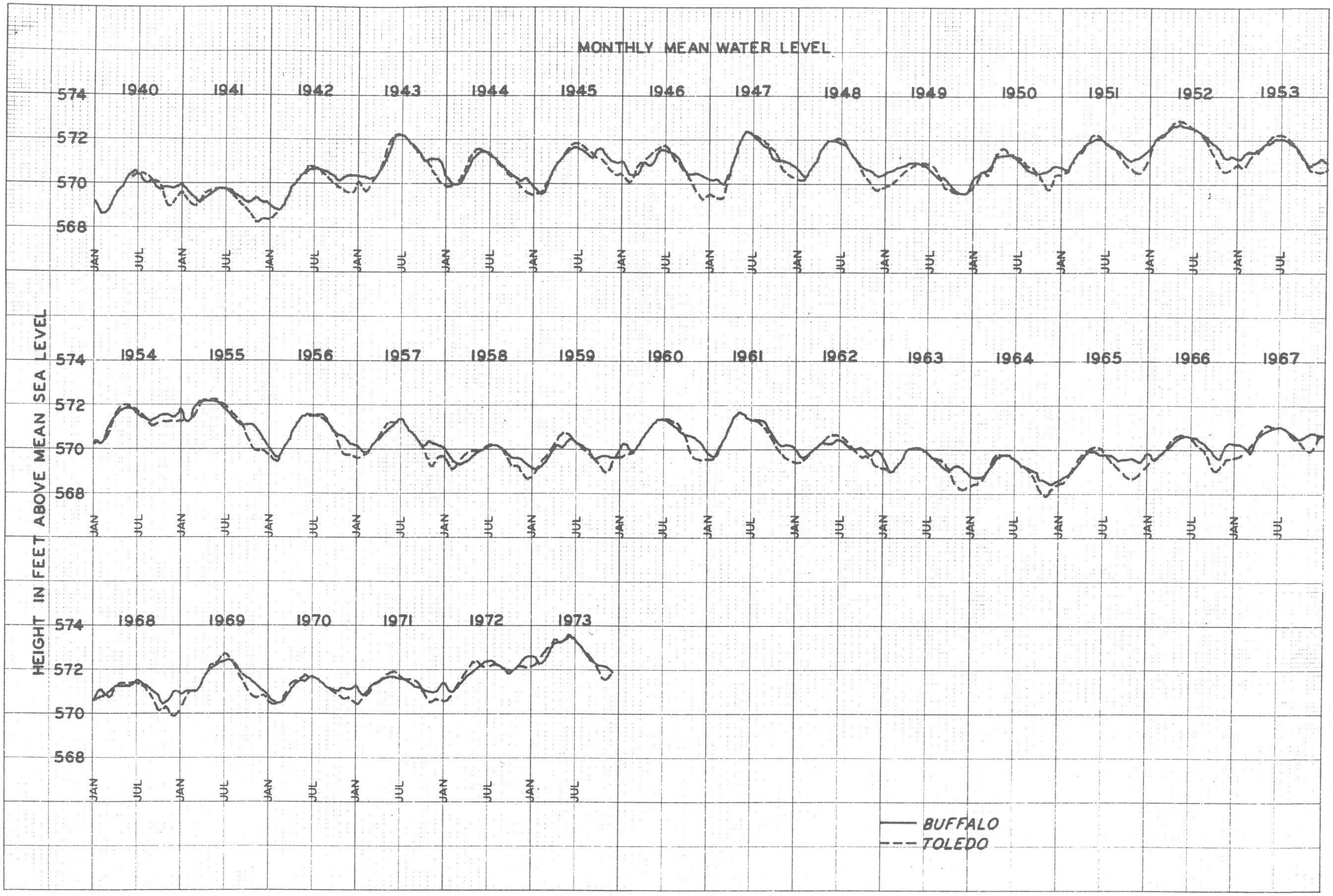

Figure 1.--Monthly mean water levels on Lake Erie at Buffalo, New York and Toledo, Ohio for the period 1940 through 1973.

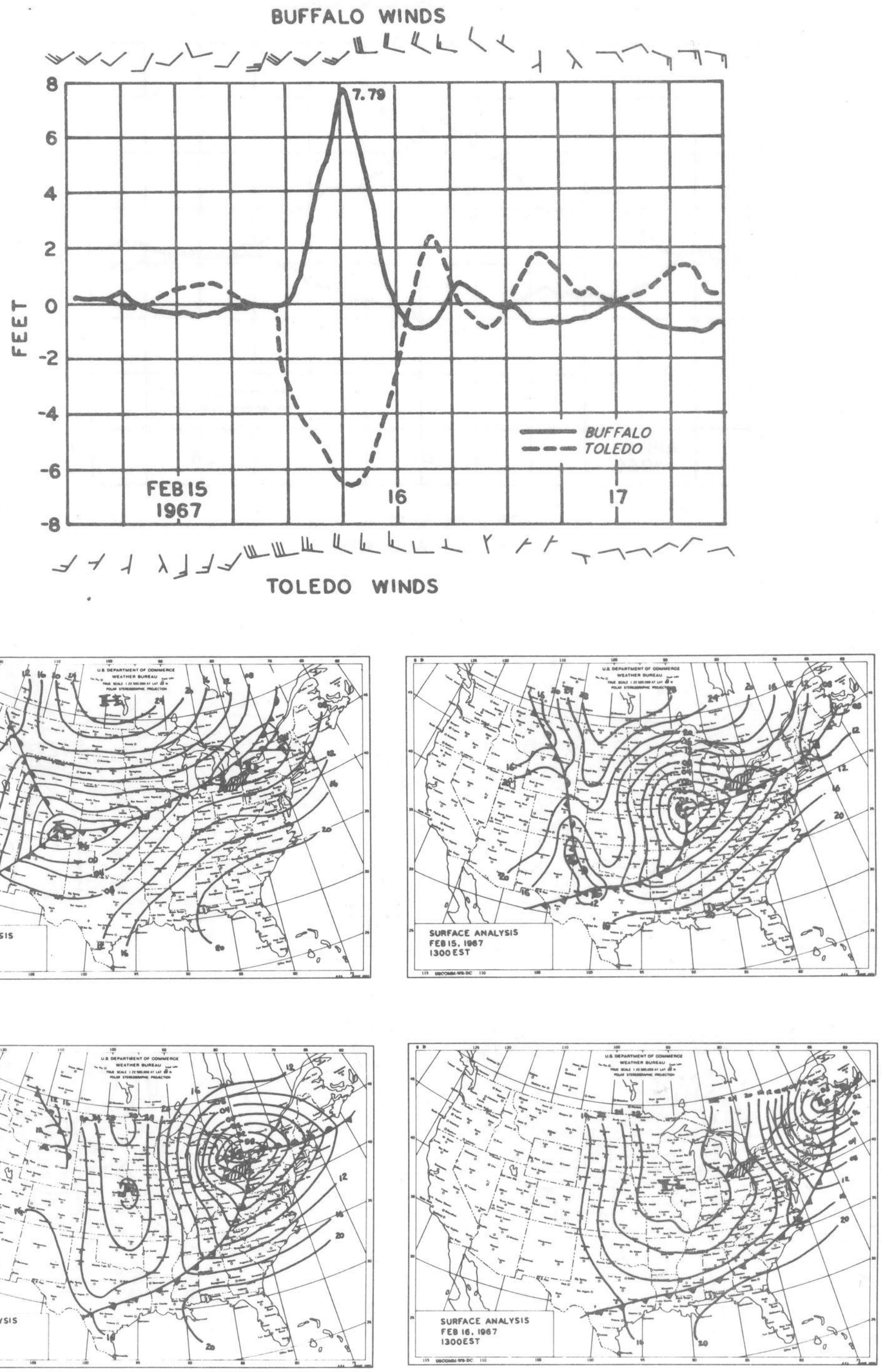

Figure 2.--Storm surge curves and surface weather charts for the highest storm surge (+7.79 feet) at Buffalo for the period 1940 through 1972. The dates are placed at the 1200 EST position on the storm surge graphs.

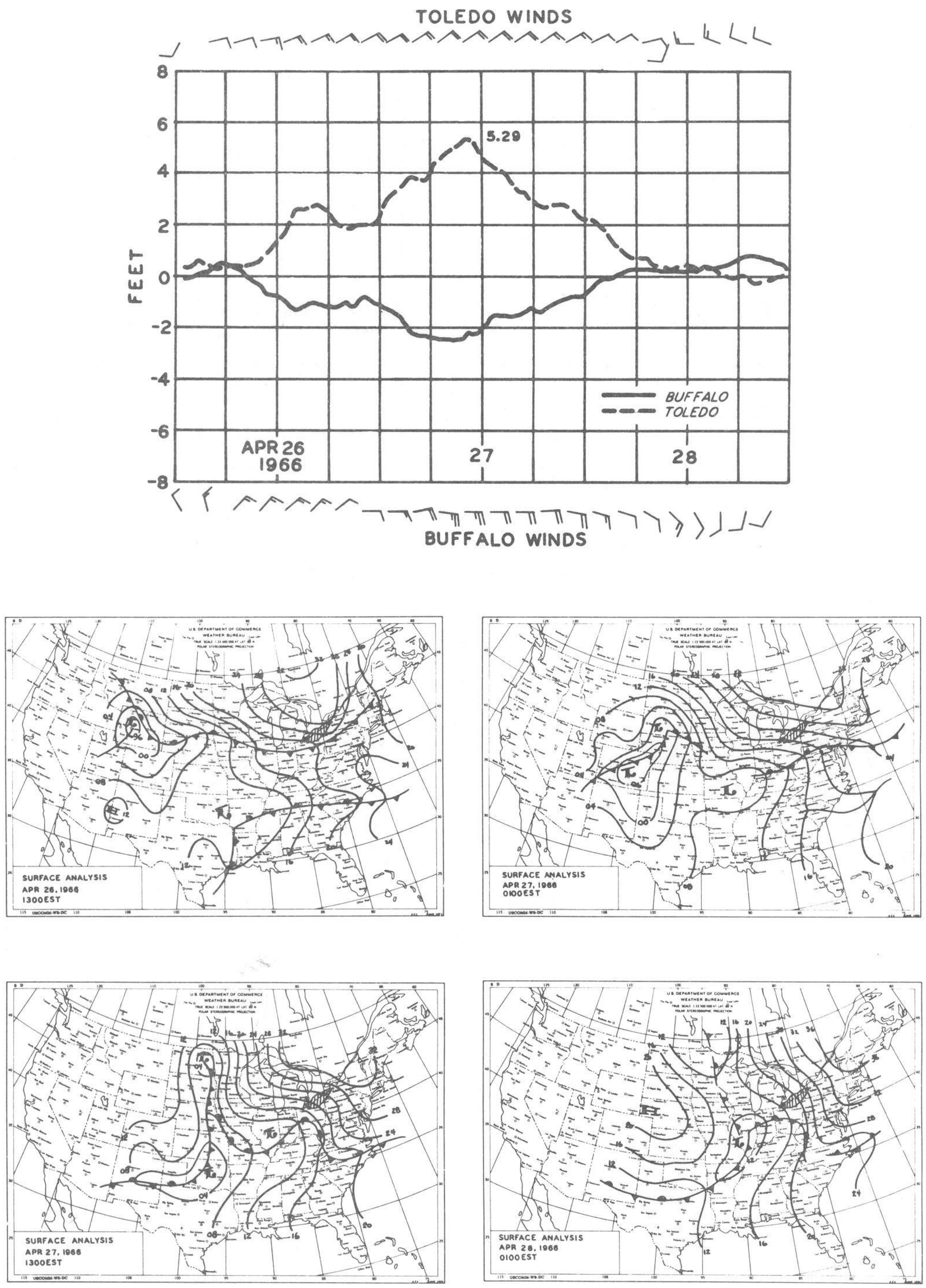

Figure 3.--Storm surge curves and surface weather charts for the highest storm surge (+5.29 feet) at Toledo for the period 1940 through 1972. The dates are placed at the 1200 EST position on the storm surge graphs.

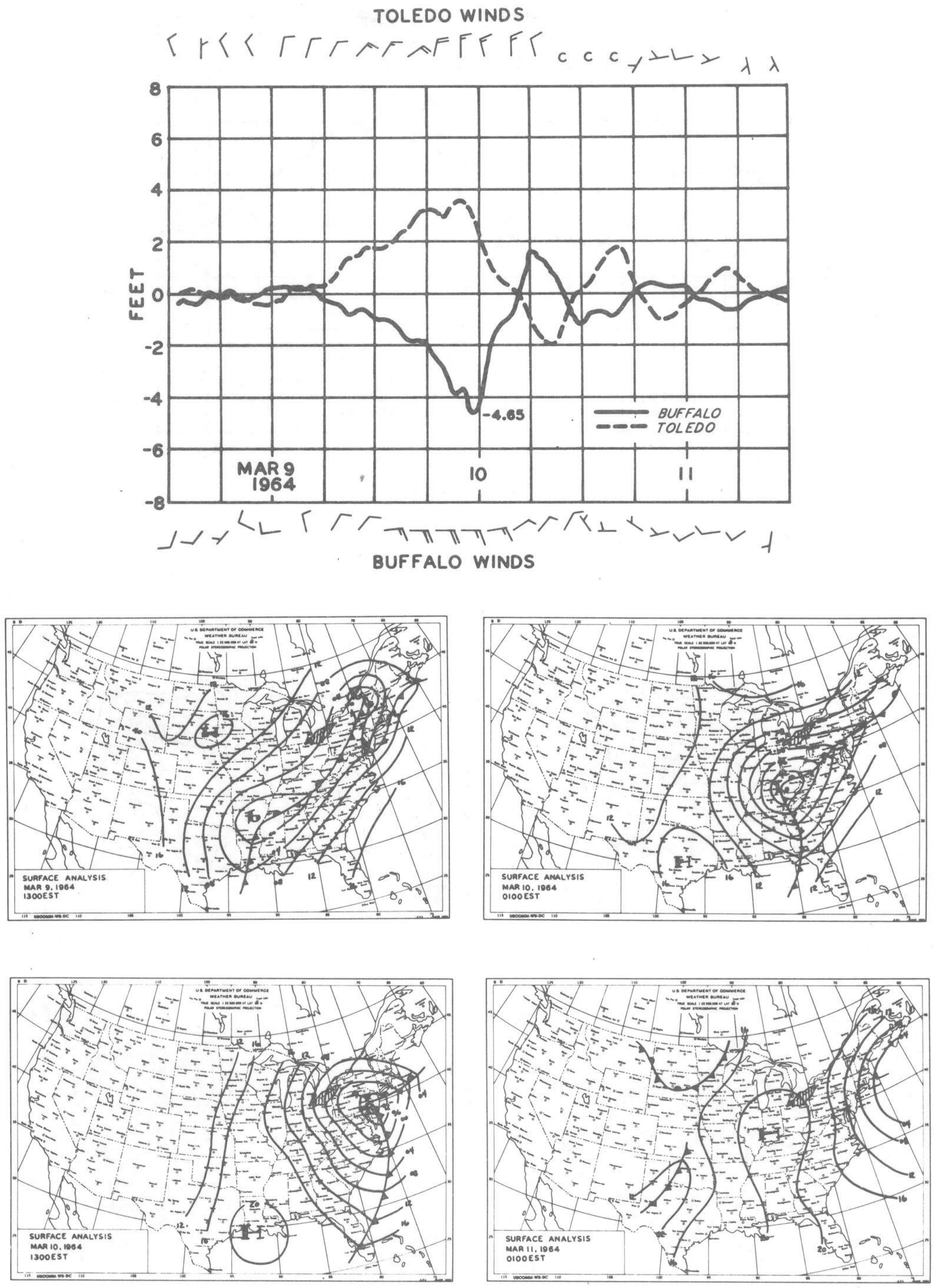

Figure 4.--Storm surge curves and surface weather charts for the lowest storm surge (-4.65 feet) at Buffalo for the period 1940 through 1972. The dates are placed at the 1200 EST position on the storm surge graphs.

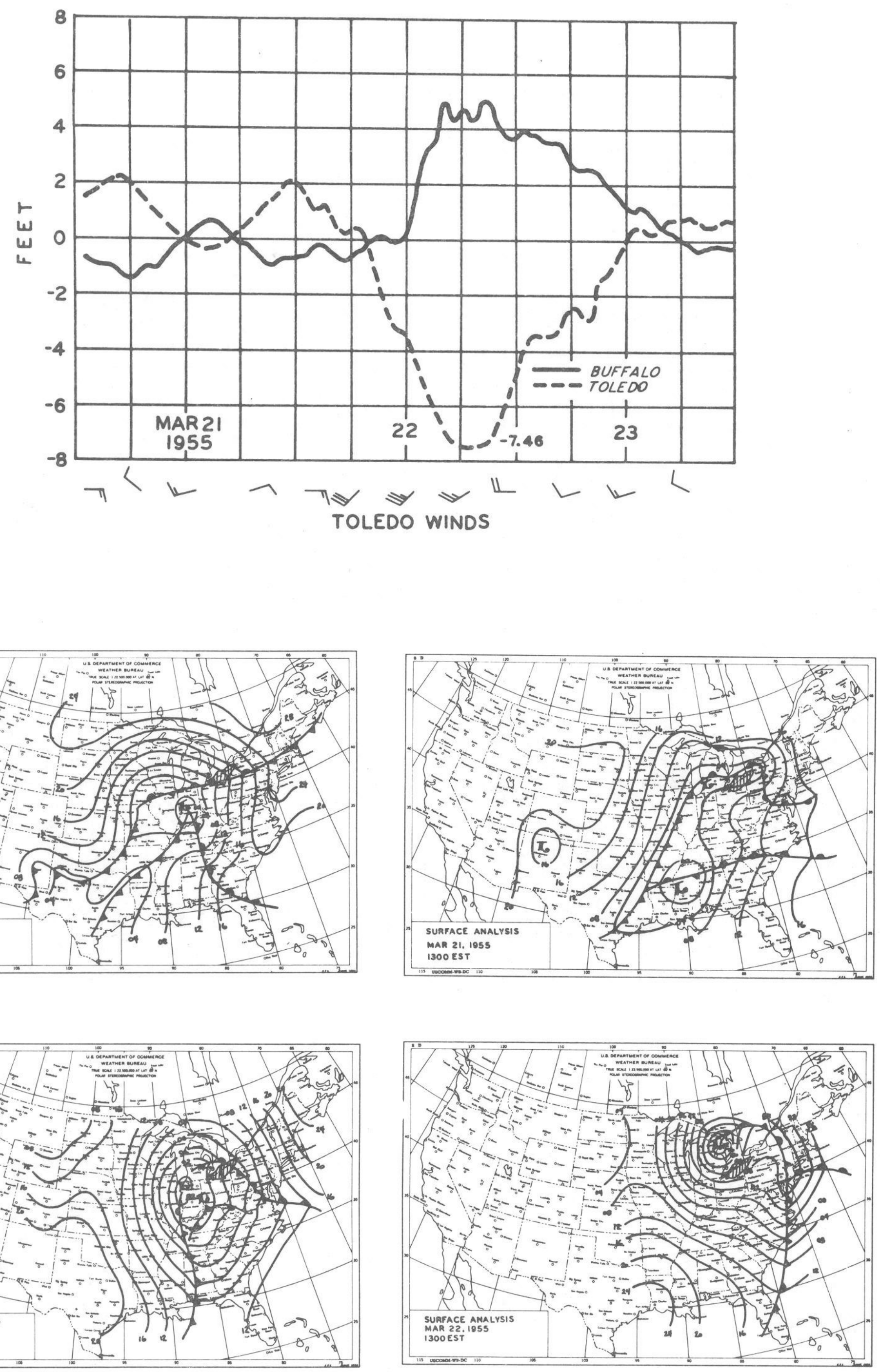

Figure 5.--Storm surge curves and surface weather charts for the lowest storm surge (-7.46 feet) at Toledo for the period 1940 through 1972. The dates are placed at the 1200 EST position on the storm surge graphs.

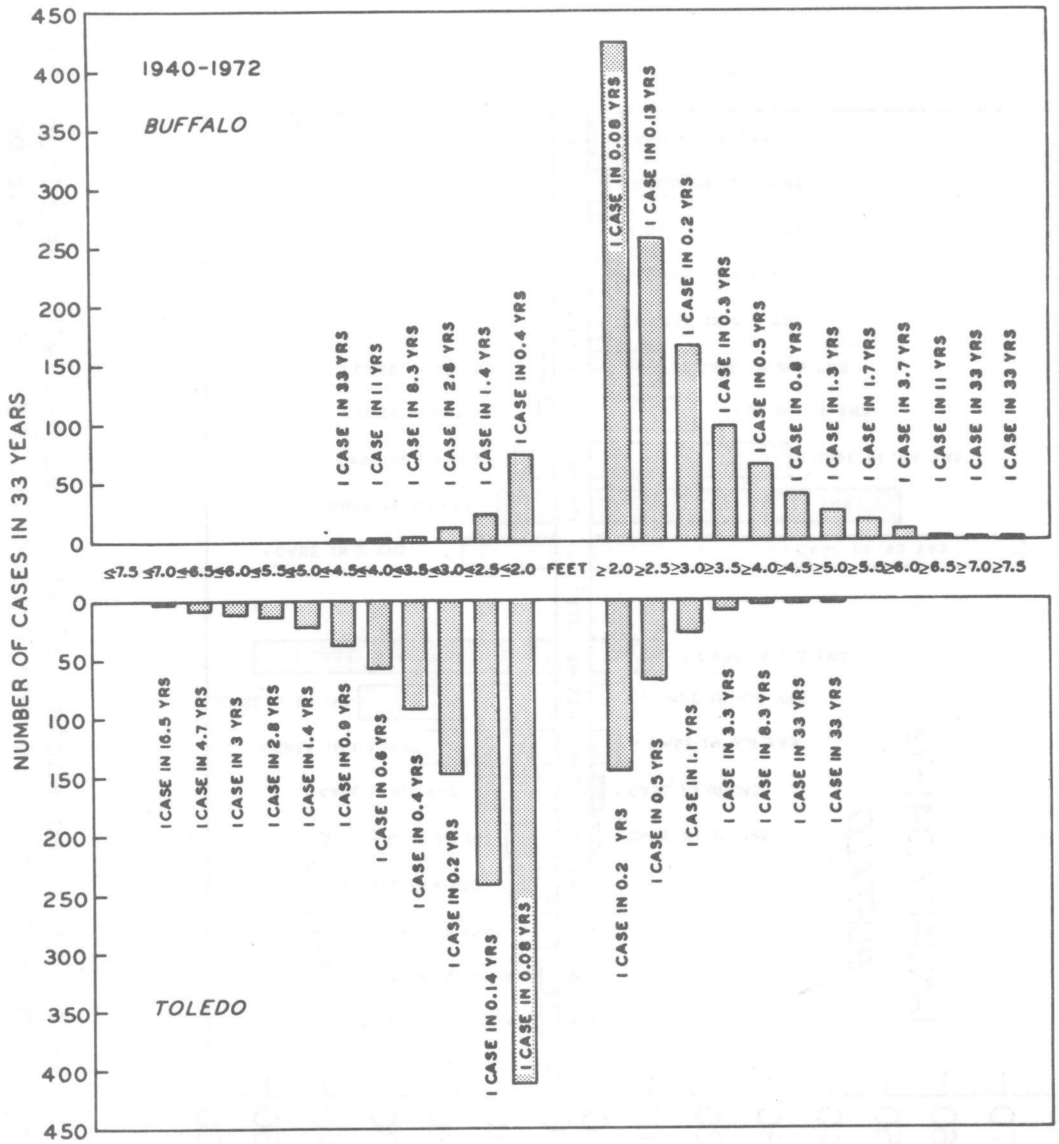

Figure 6.--Frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

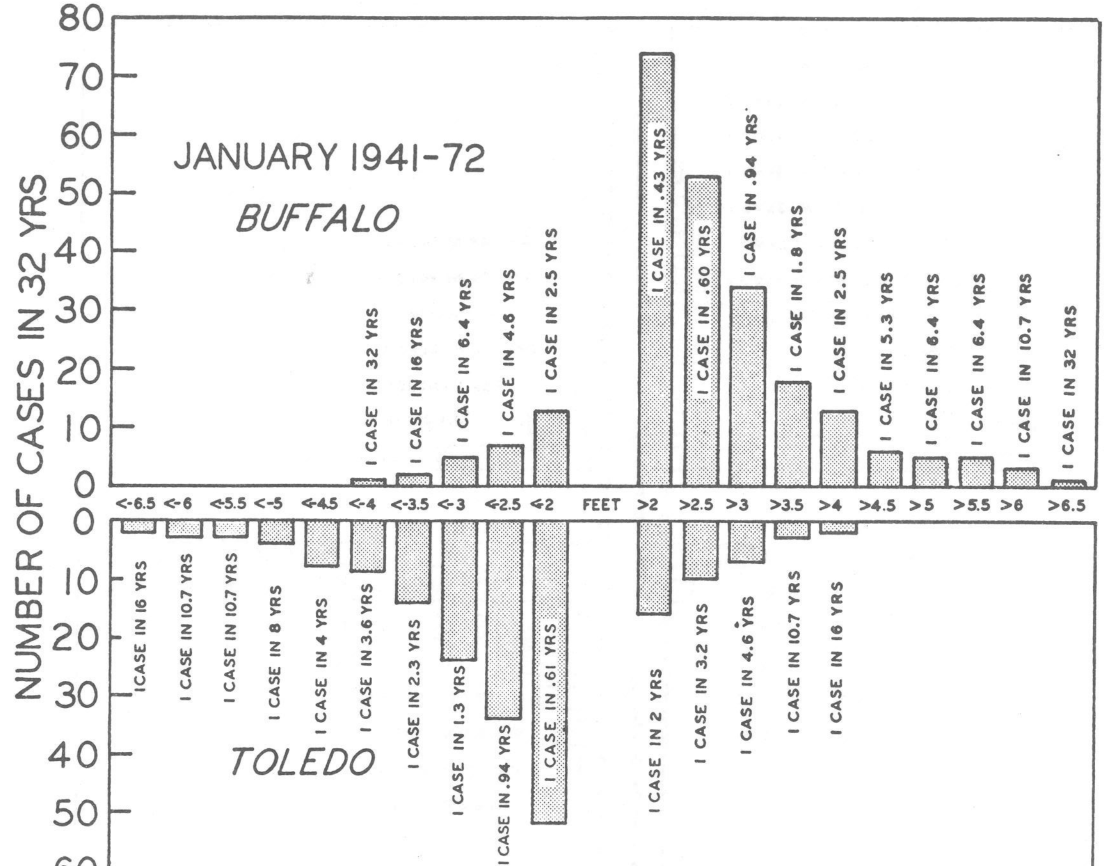

Figure 7.--January frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 32-year period 1941-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

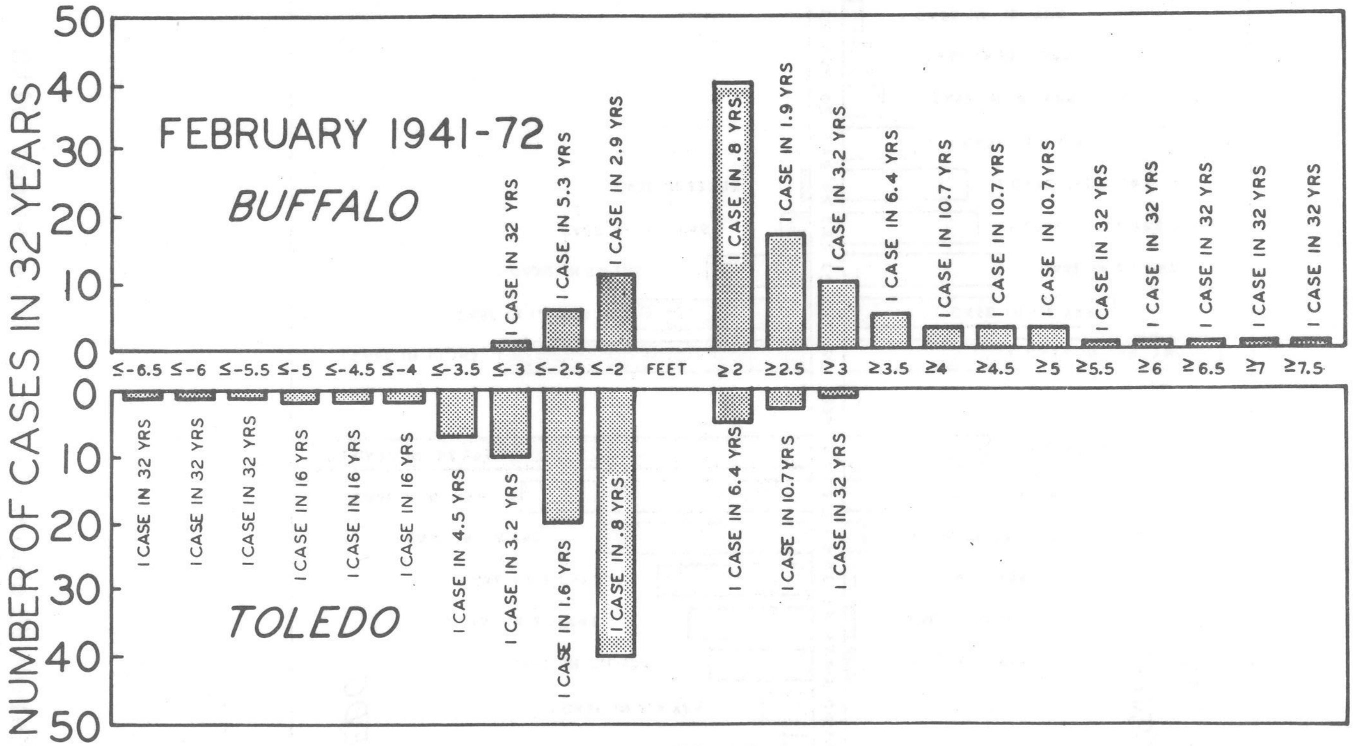

Figure 8.--February frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 32-year period 1941-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

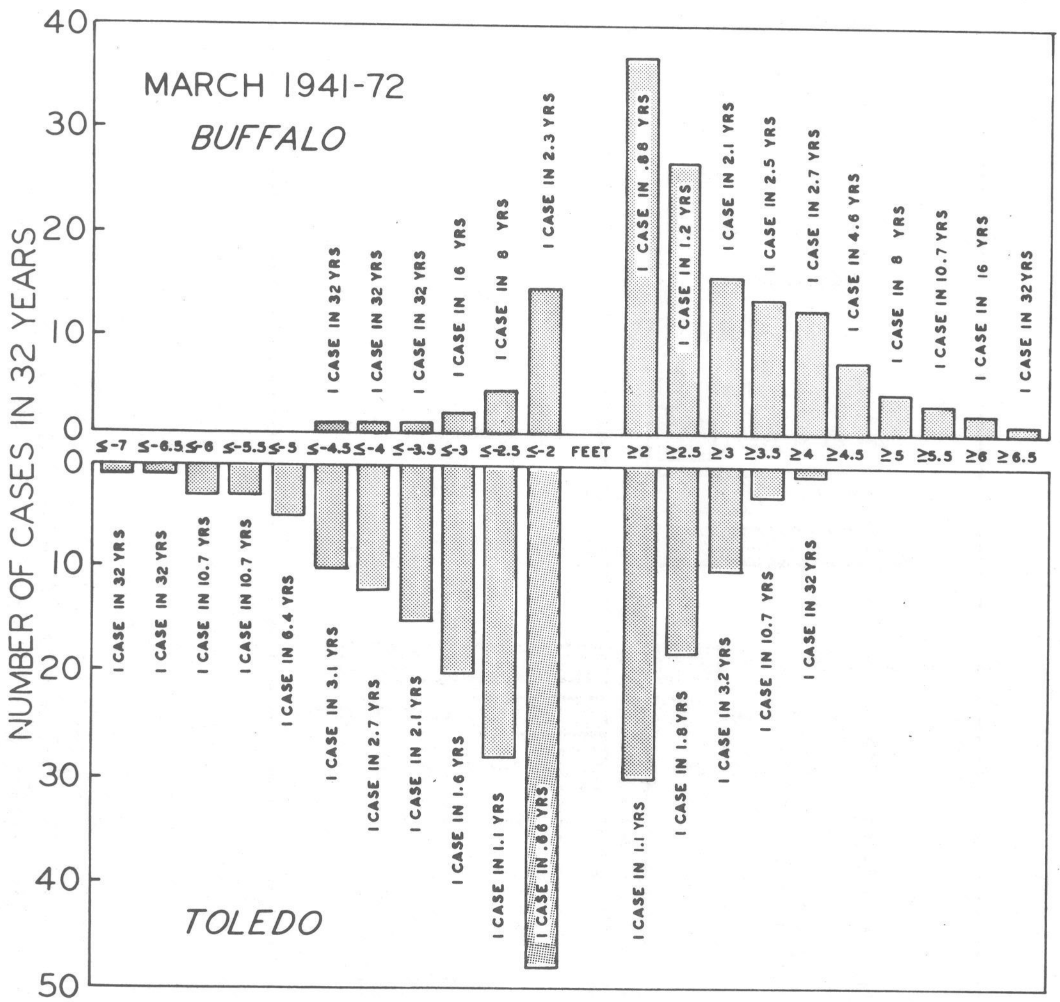

Figure 9.--March frequencies of storm surge with magnitudes of 2 feet or more at Buffalo and Toledo during the 32-year period 1941-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

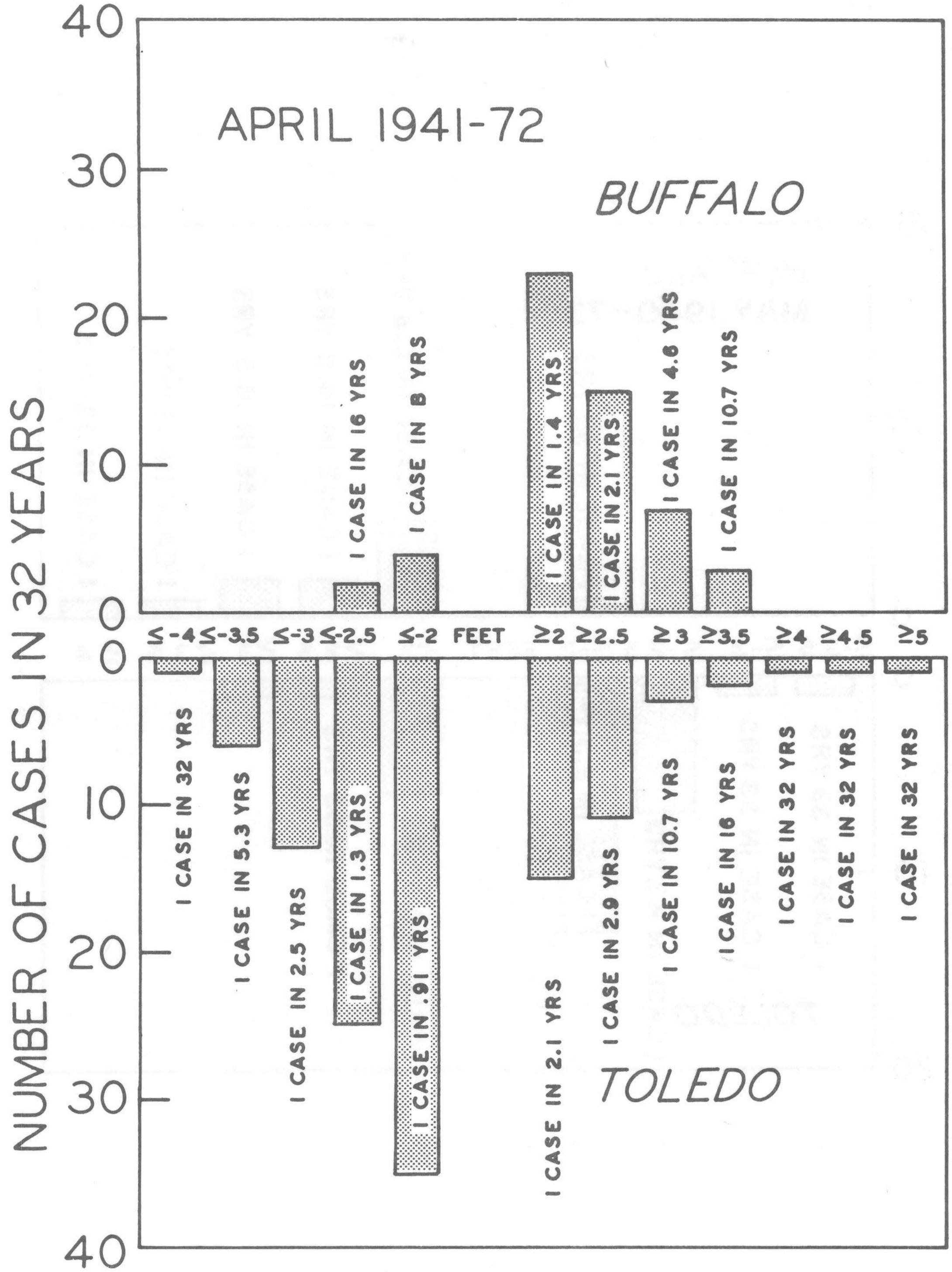

Figure 10.--April frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 32-year period 1941-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

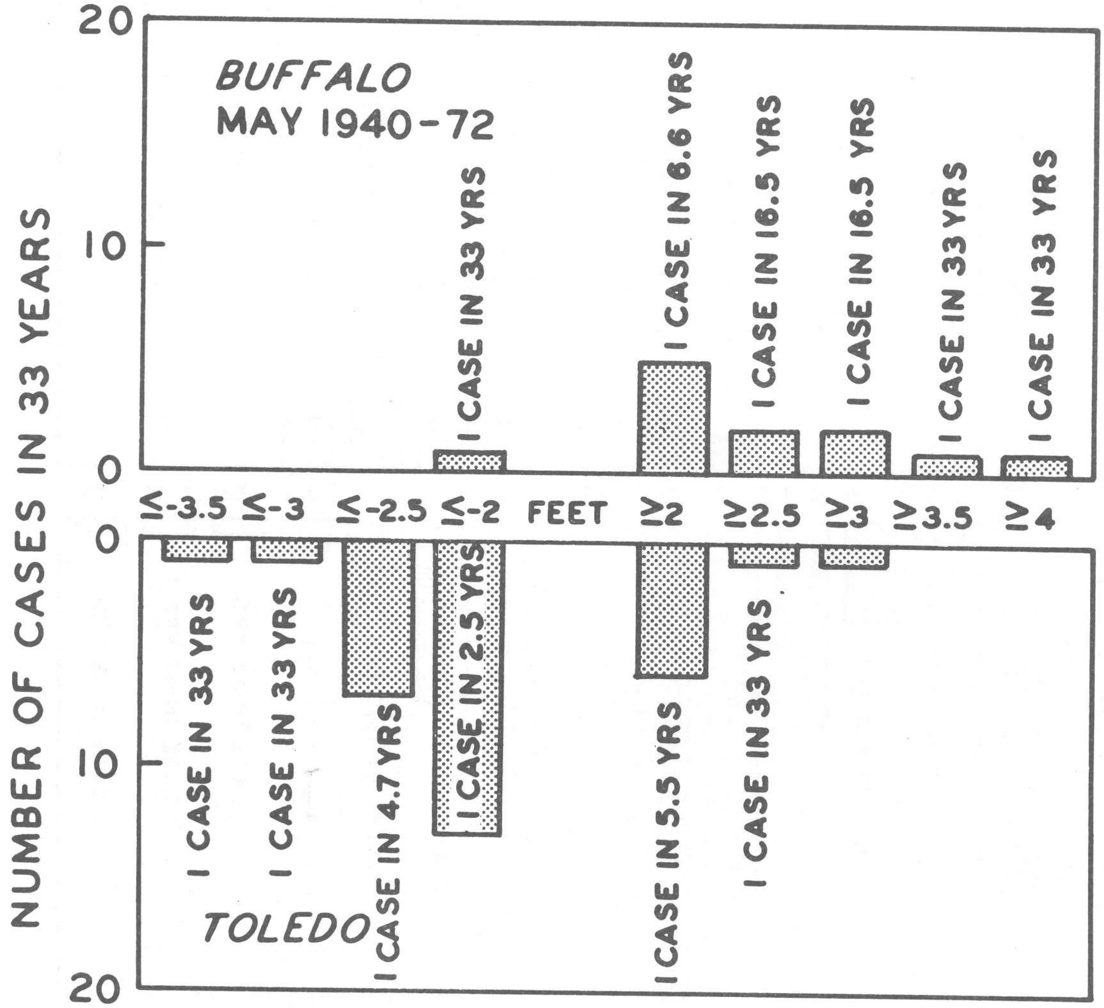

Figure 11.--May frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

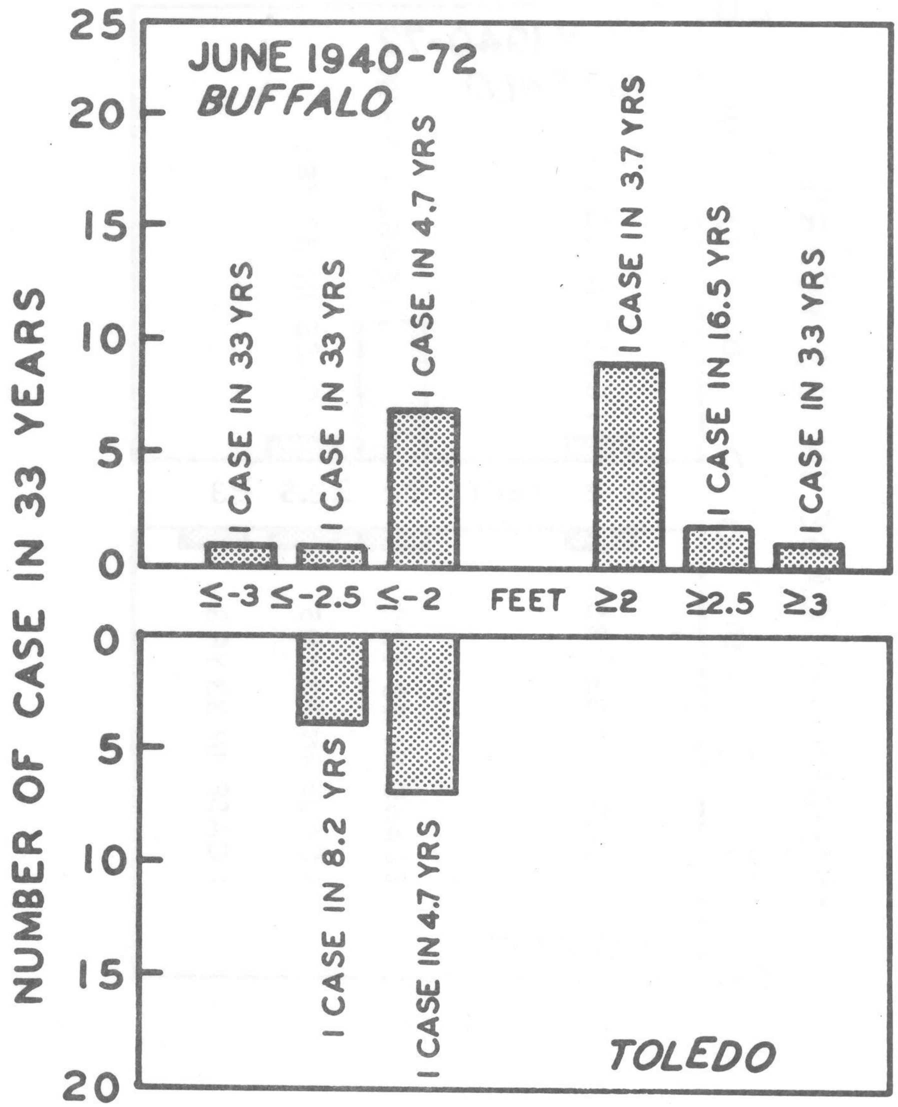

Figure 12.--June frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

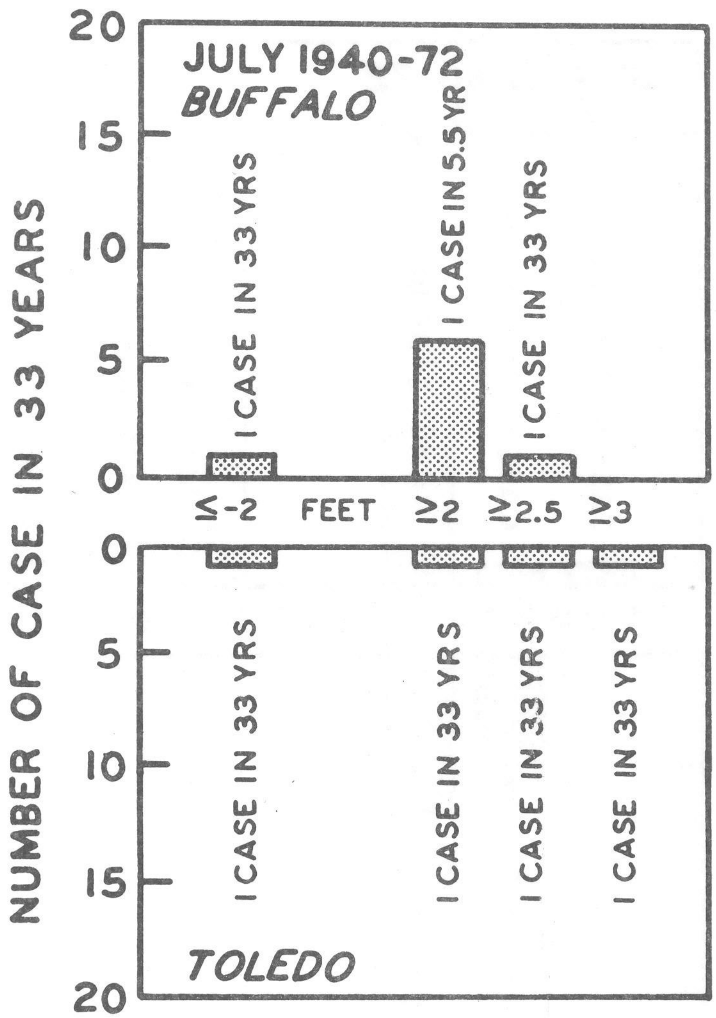

Figure 13.--July frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

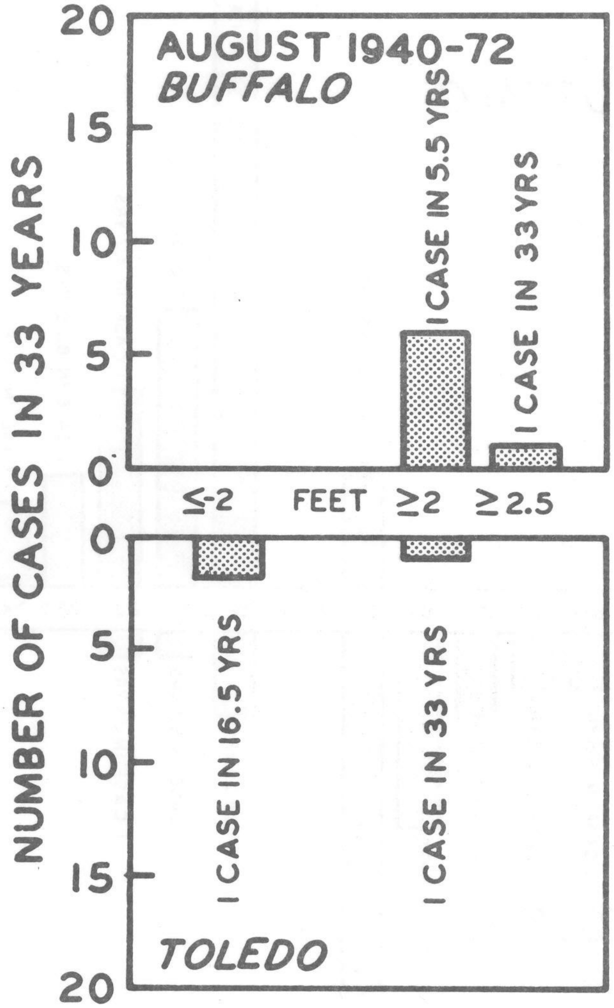

Figure 14.--August frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

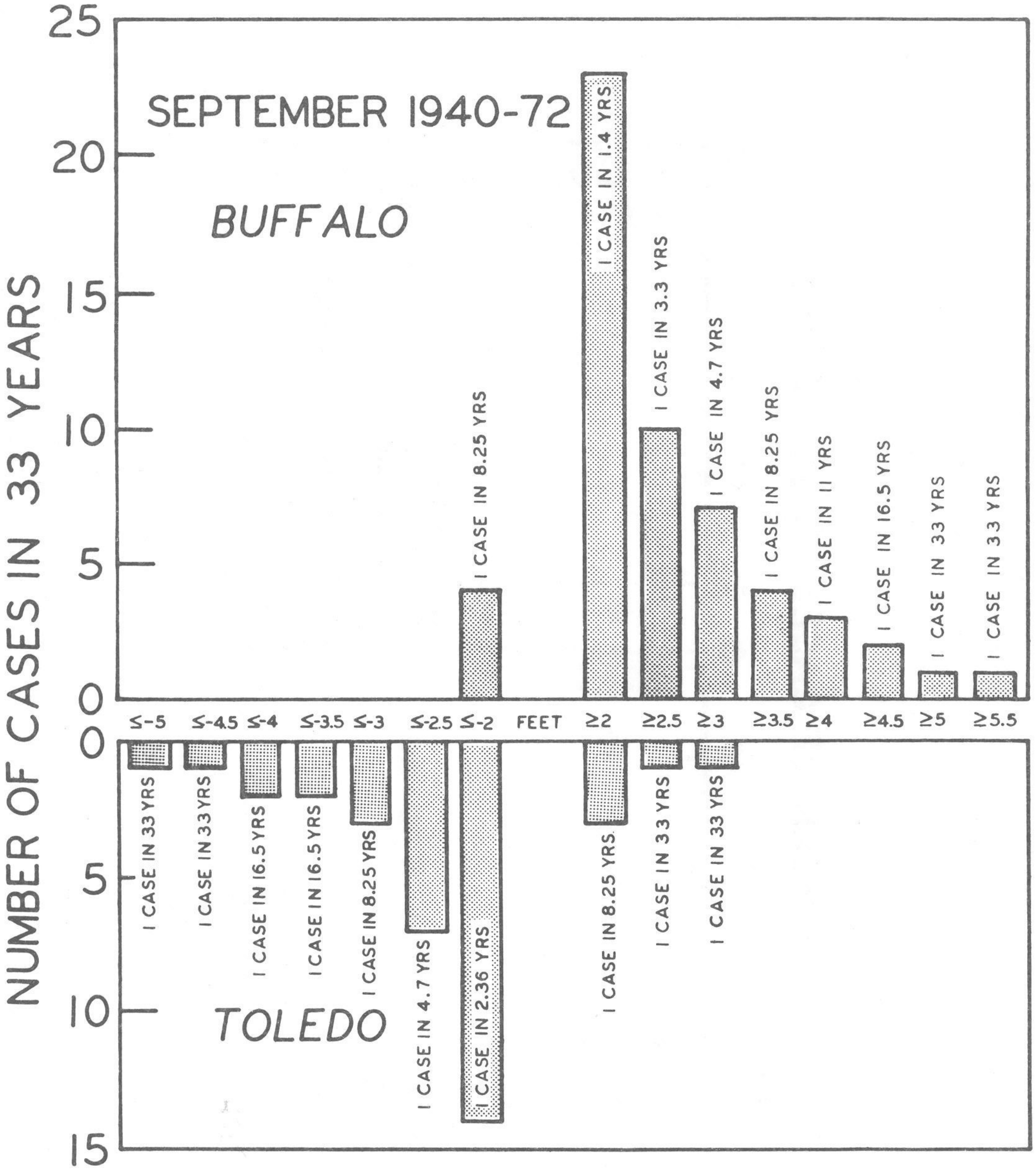

Figure 15.--September frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

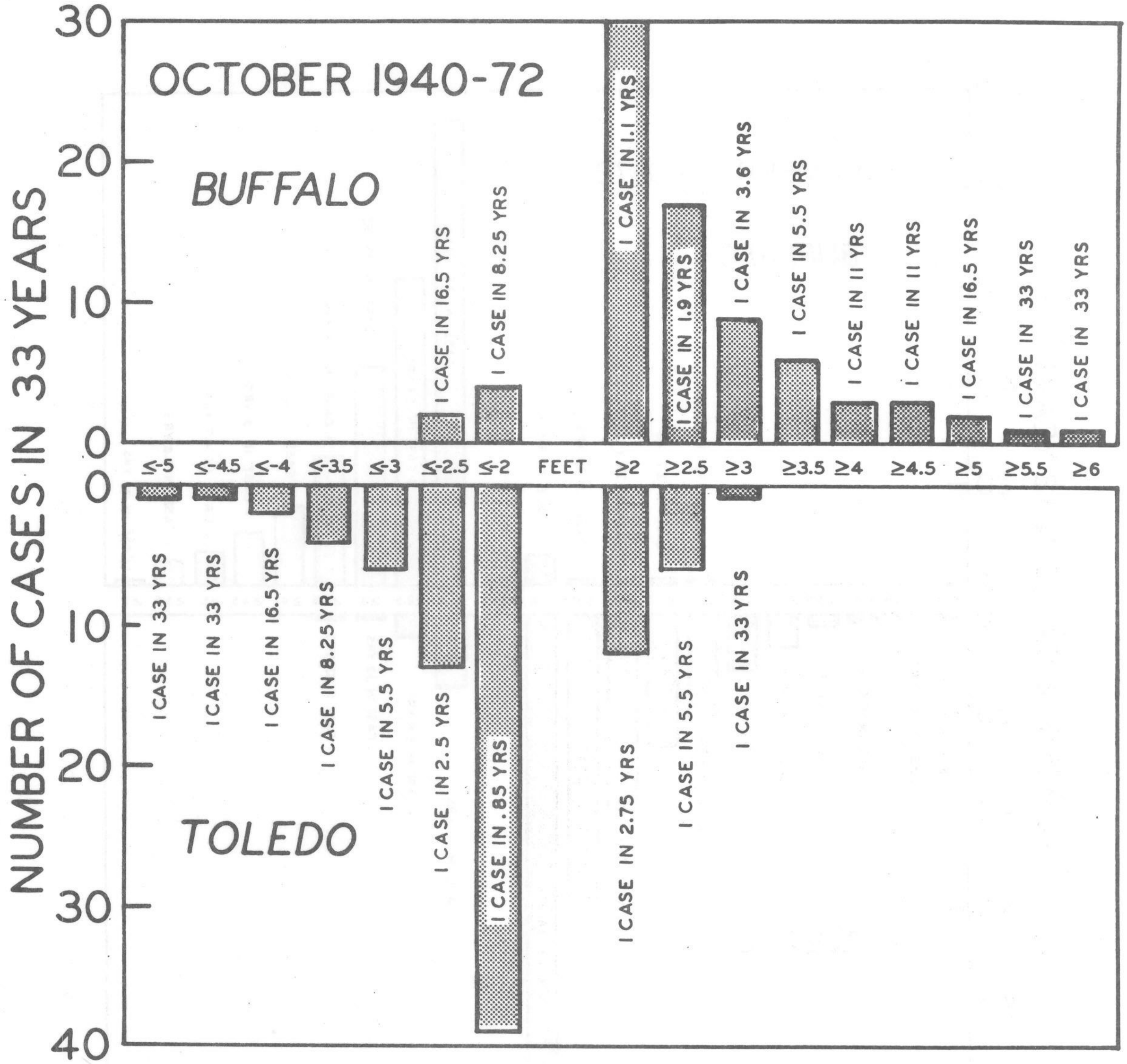

Figure 16.--October frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

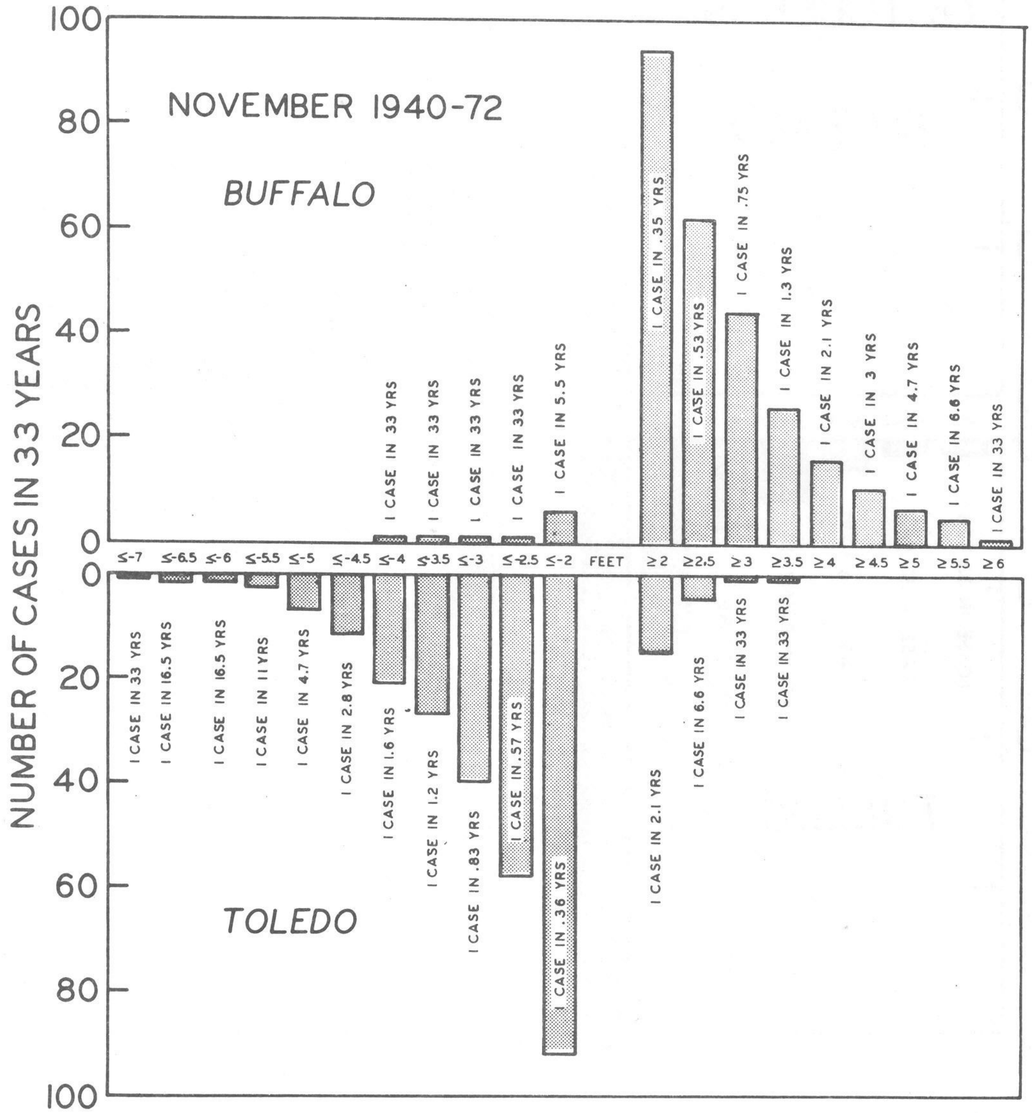

Figure 17.--November frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

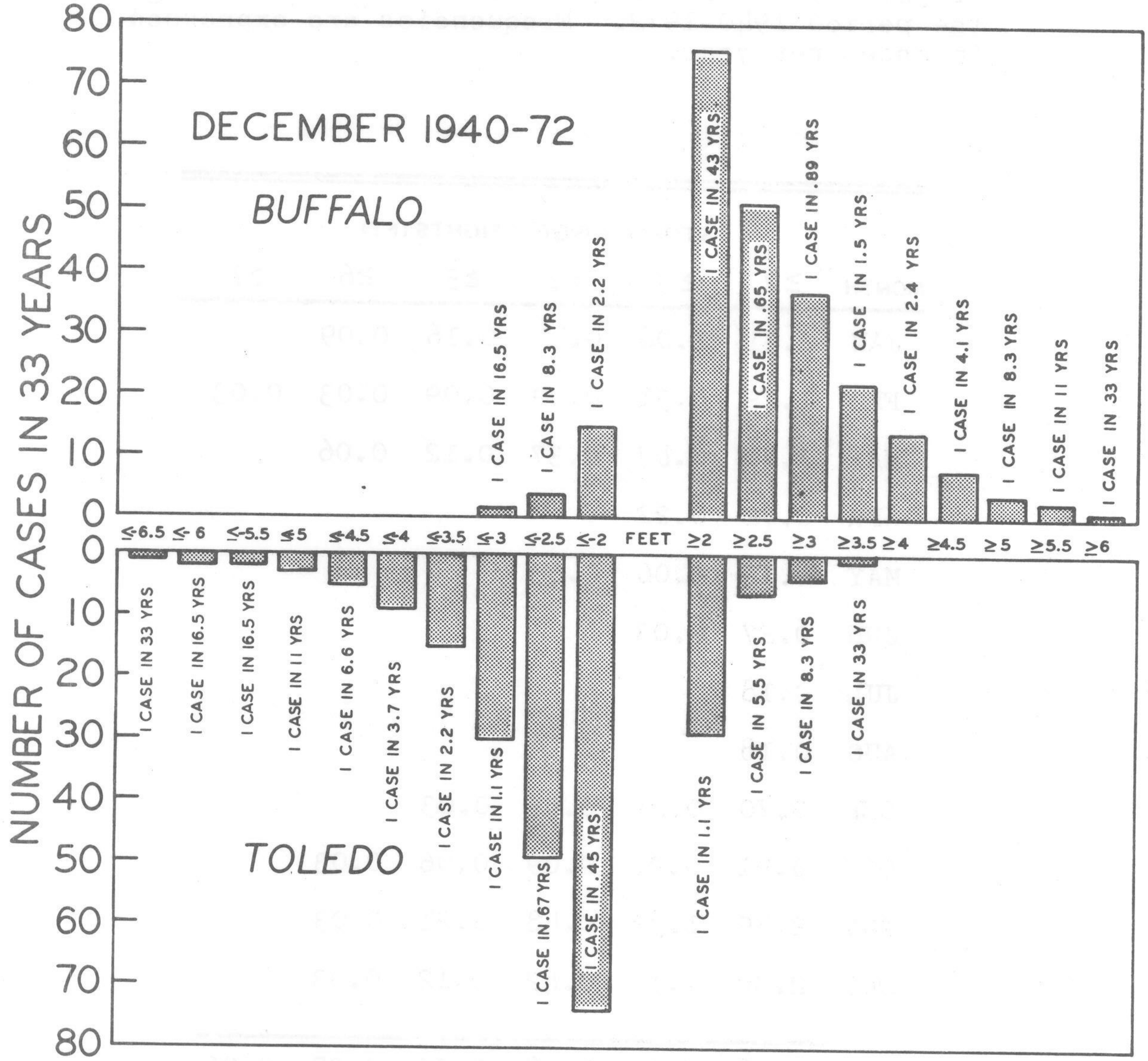

Figure 18.--December frequencies of storm surges with magnitudes of 2 feet or more at Buffalo and Toledo during the 33-year period 1940-1972. High water cases are shown on the right side of the graph, low water cases are shown on the left.

Table 1.--Average monthly and annual frequencies of positive storm surge cases at Buffalo during the period 1940-1972. Frequencies are expressed in cases per year.

MONTH	STORM SURGE HEIGHTS (FT) ≥2	≥3	≥4	≥5	≥6	≥7
JAN	2.31	1.06	0.41	0.16	0.09	
FEB	1.25	0.31	0.09	0.09	0.03	0.03
MAR	1.16	0.47	0.37	0.12	0.06	
APR	0.72	0.22				
MAY	0.15	0.06	0.03			
JUN	0.27	0.03				
JUL	0.18					
AUG	0.18					
SEP	0.70	0.21	0.09	0.03		
OCT	0.91	0.27	0.09	0.06	0.03	
NOV	2.85	1.33	0.48	0.21	0.03	
DEC	2.30	1.12	0.42	0.12	0.03	
ANNUAL	12.98	5.08	1.98	0.79	0.27	0.03

Table 2.--Average monthly and annual frequencies of negative storm surge cases at Buffalo during the period 1940-1972. Frequencies are expressed in cases per year.

	STORM SURGE HEIGHTS (FT)					
MONTH	≤-2	≤-3	≤-4	≤-5	≤-6	≤-7
JAN	0.41	0.16	0.03			
FEB	0.16	0.03				
MAR	0.44	0.06	0.03			
APR	0.12					
MAY	0.03					
JUN	0.21					
JUL	0.03					
AUG	0.03					
SEP	0.12					
OCT	0.12					
NOV	0.18	0.03	0.03			
DEC	0.45	0.06				
ANNUAL	2.30	0.34	0.09			

Table 3.--Average monthly and annual frequencies of positive storm surge cases at Toledo during the period 1940-1972. Frequencies are expressed in cases per year.

	STORM SURGE HEIGHT(FT)					
MONTH	≥2	≥3	≥4	≥5	≥6	≥7
JAN	0.50	0.22	0.06			
FEB	0.34	0.03				
MAR	0.94	0.31	0.03			
APR	0.47	0.09	0.03	0.03		
MAY	0.18	0.03				
JUN	0.21					
JUL	0.03					
AUG						
SEP	0.09	0.03				
OCT	0.36	0.03				
NOV	0.48	0.03				
DEC	0.88	0.12				
ANNUAL	4.48	0.89	0.12	0.03		

Table 4.--Average monthly and yearly frequencies of negative storm surge cases at Toledo during the period 1940-1972. Frequencies are expressed in cases per year.

	STORM SURGE HEIGHT (FT)					
MONTH	≤-2	≤-3	≤-4	≤-5	≤-6	≤-7
JAN	1.62	0.75	0.28	0.09	0.09	
FEB	1.25	0.31	0.06	0.06	0.03	
MAR	1.50	0.62	0.37	0.16	0.09	0.03
APR	1.09	0.41	0.03			
MAY	0.39	0.03				
JUN						
JUL	0.03	0.03				
AUG	0.06					
SEP	0.45	0.09	0.06	0.03		
OCT	1.18	0.18	0.06	0.03		
NOV	2.79	1.21	0.63	0.21	0.06	0.03
DEC	2.24	0.91	0.27	0.09	0.06	
ANNUAL	12.60	4.54	1.76	0.67	0.33	0.06

(Continued from inside front cover)

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