ANALYSIS OF 112 YEARS OF ICE CONDITIONS OBSERVED ON THE OHIO RIVER AT CINCINNATI

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ABSTRACT

Daily ice conditions observed on the Ohio River at Cincinnati for the winters of 1874-75 through 1985-86 were analyzed. The amount of ice on the river, except during particularly cold winters, has decreased since 1900. The decline has been especially significant starting around 1930. Investigation of the severity of each winter, using the number of freezing degree-days as an index, revealed no systematic temperature trends over the 112 years of record.

Associations between number of days with river ice and concurrent accumulated freezing degree-days over 10- or 11-winter increments were investigated. The results showed that between the winters of 1934-35 and 1963-64 considerably more freezing degree-days were required to produce ice, but the trend has reversed slightly since then. This decreasing trend in observed ice has occurred during a period of basin development, as indicated by a sample population, the construction of large locks and dams, and an increase in navigation tonnage on the river. The increase in heated discharge into the river corresponding with basin development and the construction of large locks and dams have probably had the most significant impacts.

I. Introduction

A chronological tabulation of ice conditions observed on the Ohio River at Cincinnati has been compiled by the U.S. Weather Bureau (now National Weather Service, NWS) for the winters of 1874-1875 through 1985-86. The bulk of this information was obtained from a U.S. Army Corps of Engineers (1978) report. It is the longest known continuous record of river ice conditions in the United States. This study is an analysis of that record. First, historical trends in the observed river ice are noted, then the trends in ice conditions versus the winter climate at Cincinnati are compared. The winter climate is described by the total number of freezing degree-days (based on monthly average temperatures) recorded during a winter. The trends in the observed ice are also compared to the general development of the basin, as represented by the population of Cincinnati. Finally, a short discussion of the possible effects of the increase in navigation on the Ohio River is presented.

II. The Observed Ice Record

The ice record compiled by the NWS provides the dates of the following river ice conditions: 1) light floating, 2) heavy floating, 3) frozen over, and 4) ice gorged. The dates when navigation on the river was suspended are also given in the tabulation; however, these events occurred at the same time when frozen over or ice gorged conditions were recorded.

The terms "ice gorged" and "navigation suspended" as given by the Corps of Engineers (1978) are defined as follows:

"The term gorge is used to denote that situation where ice is stopped in current, bridged all the way across the river, and is obstructing streamflow in a damming effect causing head differential."

"The Corps of Engineers ..... will normally close a structure or suspend navigation through a structure only when there exists a bona fide threat to the integrity of that structure ..... the U.S. Coast Guard may close portions of a waterway or place restrictions thereon in terms of types of craft and cargo. Navigation suspended, as used in the NWS summary ..... was used to cover, not only ..... specific agency action, but also the condition in which it was simply not physically possible for boats to move or industry chose not to move."

The chronological list of these various types of river ice coverage and the dates when these conditions were observed as given in the 1978 Corps report will not be reproduced here. Instead, a graph of the time intervals during which any of the four ice types (i.e. omitting navigation suspended) were observed is shown in Figure 1. For example, the upper-left line in Figure 1 shows that during the winter of 1874-1875 at least one of the four listed ice types on the river was observed almost continuously from 7 January to 21 February 1875. The discontinuous lines shown during some years in Figure 1 indicate the sporadic time periods of observed ice during that particular winter.

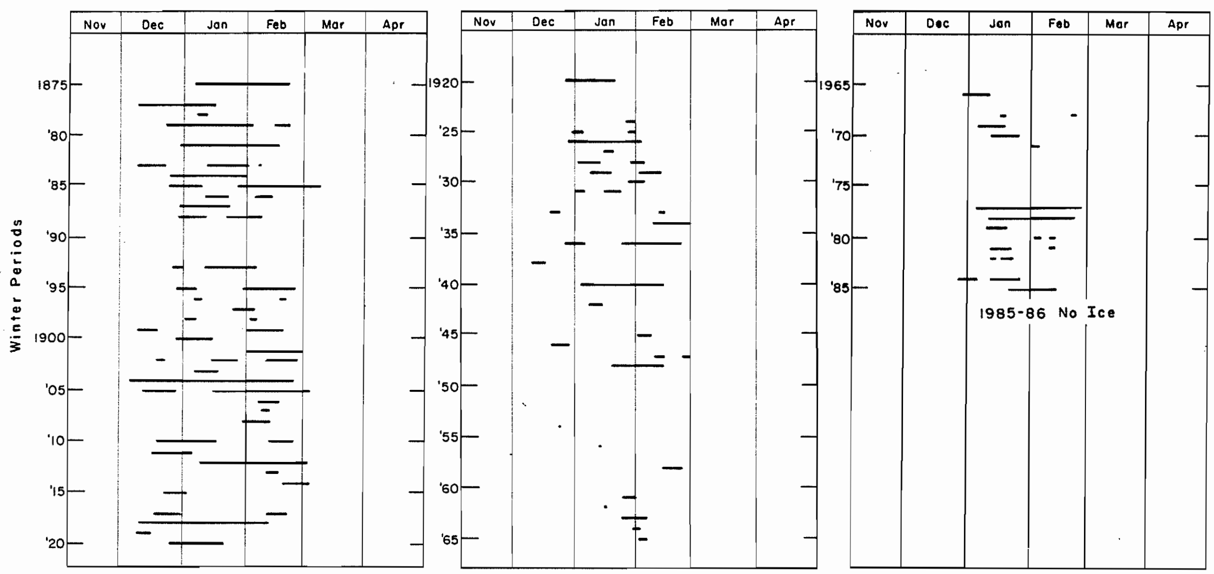

Figure 1. Period of time when ice was observed on the Ohio River at Cincinnati during each winter.

III. Previous Ice Record Summaries

The results of a review of the ice data collected from 1874 through 1964, conducted by the Weather Bureau Office at Cincinnati (U.S. Army Corps of Engineers, 1978) are presented in the following quotations:

"Ice has appeared in the Ohio River at Cincinnati in 62 of the past 90 winters since 1874, 28 winters (31.1%) having been without ice. ... The official minimum atmospheric temperatures (°F) at Cincinnati have averaged as follows: with the occurrence of light ice 13°, heavy ice 9°, frozen 3°.

"Light floating ice has usually been followed in about one day by heavy floating ice; and the river has usually frozen over after about three days of heavy ice. The river has frozen over in only 13 winters in the 90 years of record, always following heavy or gorged ice.

	December Days	%	January Days	%	February Days	%	March Days	%	Total Number of Days
Light ice	76	15	237	48	174	35	10	2	497
Heavy ice	84	17	220	45	186	38	2	0	492
Frozen over	11	10	57	49	48	41	0	0	116
Gorged	58	29	100	51	38	19	1	1	197
Total all kinds*	229	18%	614	47%	446	34%	13	1%	1302

*not including Navigation Suspended

Navigation Suspended	109	19%	279	49%	175	30%	9	2%	572"

The Corps of Engineers 1978 report also included the following statements:

"Impact on navigation ..... begins to become significant when there is heavy running ice or when there is ice from bank to bank as is the case when the river freezes over. Heavy running ice has been experienced in about every other year, on the average, but the river has frozen over (at Cincinnati) on an average of only one year out of every seven years.

"Jamming and gorging most certainly produce a significant impact on navigation. Although some of these situations again were of relatively short duration, they have occurred on an average in one year out of every seven years. ..... However, heavy floating ice also often caused suspension. Navigation during these events came to a halt in just over one out of every three years."

IV. History of Observed River Ice

The period of time when ice was observed on the Ohio River at Cincinnati can be described as dates of occurrences (Fig. 1) or numerically where bar graphs are used to show the total number of days with ice during each winter (Fig. 2). Also shown in Figure 2 is a trace of the average number of days with ice for each consecutive five-season interval (i.e. starting with 1874-75 through 1878-79), and the winters when no ice was observed on the river. Although minor variations in the time of occurrence for the high and low values in the five-season averages were noted when the starting point was shifted two or three seasons forward, the overall trend for the full record was similar. When ten-season averages were used, the high and low values became less distinct.

From Figure 2 we find that the longest periods of ice on the river each winter (i.e. 40 days or more of observed ice per season) occurred during 13 random winters prior to 1940-41, with only two other such events thereafter (i.e. during the very cold winters of 1976-77 and 1977-78). No ice was observed on the river during 17 of the 66 years of record prior to 1940-41 (or 26% of the time), whereas no ice was noted during 20 of the following 46 winter seasons (or 43% of the time).

A gradual decrease of ice on the river from about 1902 to 1975 is shown by the sequential five-year average ice values (i.e. the points joined by the dashed line in Figure 2). Although the trend is rather erratic, the reduction in observed ice during this period is evident. The decrease from about 1921 to 1956 coincides somewhat with the warmer winters recorded during most of these years.

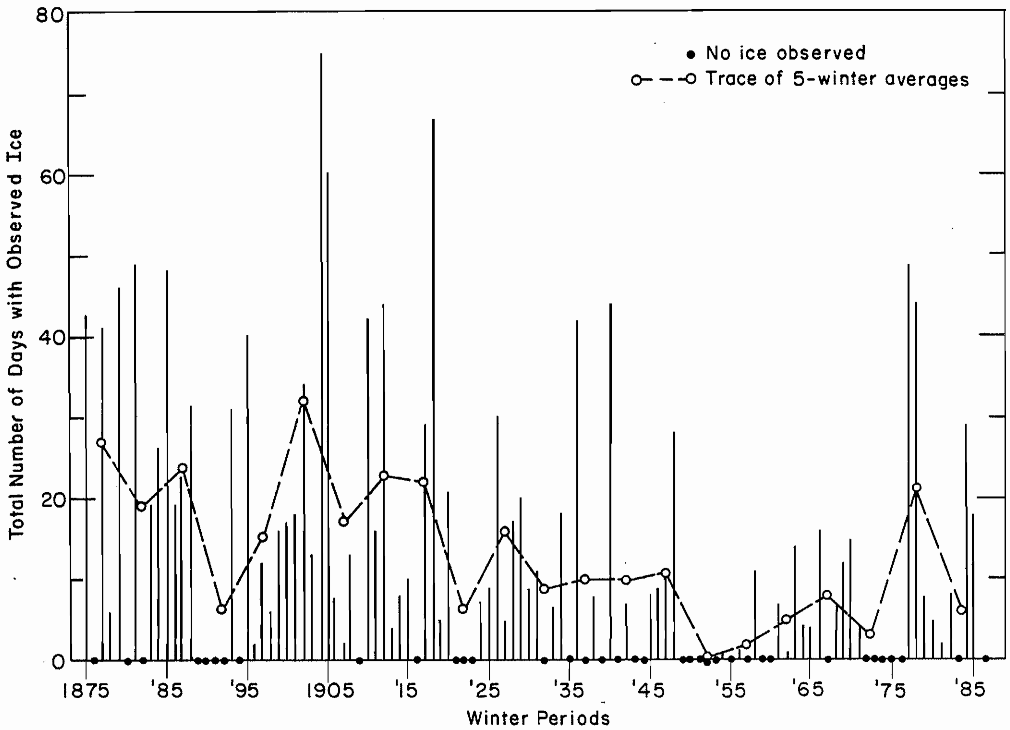

Figure 2. Total number of days when ice was observed on the Ohio River at Cincinnati during each winter (e.g. 1875 = winter of 1874-75).

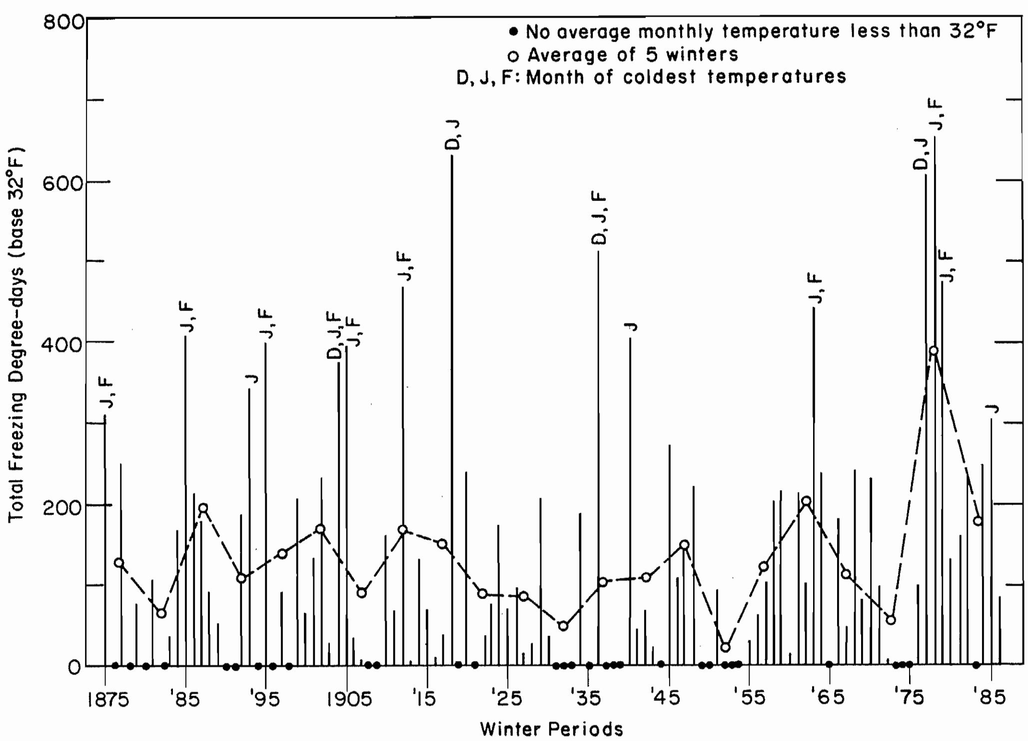

Figure 3. Total seasonal freezing degree-days at Cincinnati during each winter (e.g. 1875 = winter of 1874-75).

V. Freezing Air Temperature History

A combined measure of the duration and magnitude of below-freezing air temperatures occurring during any freezing season is the freezing index, which is simply the accumulated number of freezing degree-days (FDDs) over the winter. The FDD value for any one day equals the difference between the average daily air temperature (in °F) and 32°F (U.S. Army and Air Force, 1966). This index provides a realistic account of the length and/or intensity of the freezing regime for an area. Seasonal FDD totals for each winter at Cincinnati from 1874-1875 through 1985-1986 are shown in Figure 3. These seasonal totals were obtained by using average monthly air temperature records. The records for the following three Cincinnati weather stations were used:

1. For the winters from 1874-75 through 1919-20, "Cincinnati, U.S." at 39°06'N, 84°30'W, elevation 628 feet (Smithsonian Institution, 1927),
2. For 1920-21 through 1963-64, "Cincinnati Abbe Observatory," at 39°09'N, 84°31'W, elevation 761 feet (U.S. Department of Commerce, 1920-1964), and
3. From 1964-65 through 1985-86, "Cincinnati Muni-Lunken Field," at 39°06'N, 84°26'W, elevation 483 feet (U.S. Department of Commerce, 1964-1986).

Differences in climatic regime due to local physical conditions between the weather stations was investigated. The test was conducted by comparing the observed air temperatures for the winter months when the records for the stations overlapped. The results, in which two sets of four consecutive winter periods were used, showed that average temperatures during December, January and February at Cincinnati Abbe Observatory were 2°F colder than those at Cincinnati, U.S., and 1°F colder than those at Cincinnati Muni-Lunken Field. These differences were considered to be insignificant because during the Abbe Observatory period of record (i.e. from 1920-21 through 1963-64) the area actually experienced its warmest winters, and 14 ice-free seasons.

Bar graphs were used to display the seasonal total FDDs for each of the 112 winters at Cincinnati (Fig. 3). Also shown in the figure are: 1) a trace of the average FDDs for each consecutive five-winter interval, 2) the years when no FDDs (i.e. based on average monthly air temperatures) were recorded, and 3) the specific month(s) (D-December, J-January, F-February) when significant freezing temperatures were observed during 15 colder winters (i.e. when the FDDs exceeded 300). The various periods of warmer and colder winters were found to be randomly distributed throughout the entire 112 years of record. Average monthly temperature values greater than or equal to 32°F (i.e. zero FDDs) were recorded during 31 of the 112 winters, as compared to the 15 winters when the total seasonal FDDs exceeded 300. During these 15 winters the greatest accumulated FDDs occurred most often in January.

Over longer consecutive time periods, i.e. the trend shown by the five-winter average increments, the FDDs (dashed line in Fig. 3) revealed colder winters between 1874 and 1920. Then, except for three or four cold winters, this cold period was followed by a warmer trend that lasted until about 1956. Between 1957 and 1986, the area experienced two significant intervals of colder winters. The first interval extended mostly from 1956 to 1970, and the second from 1976 to the most recent winter (i.e. 1985-86). These two colder periods were separated by four consecutive warm winters from 1971-72 to 1974-75. Of special note are the two winters that were extremely cold across most of the eastern half of the United States, including most of the Ohio River region, during 1976-77 and 1977-78 (Kerr, 1985).

Further discussion of the data given in Figure 3, including associations between observed ice on the Ohio River and the seasonal FDDs is given in the sections that follow.

VI. Associations Between Observed Ice and Freezing Air Temperatures

The relationship between the number of days with ice each winter and the concurrent total seasonal FDDs was determined by computing their ratios. For example, during the winter of 1874-1875, ice on the Ohio River at Cincinnati was observed on 43 days, and the total of the FDDs for that winter was 311; 43 divided by 311 results in a ratio of 0.138. Similar ratios were computed for all 112 winters in the study and the values were plotted in bar-graph form (Fig. 4). Included in the diagram are 1) those winters when ice was reported but the total FDDs was zero (indicated as solid squares), 2) three winters when the ratio

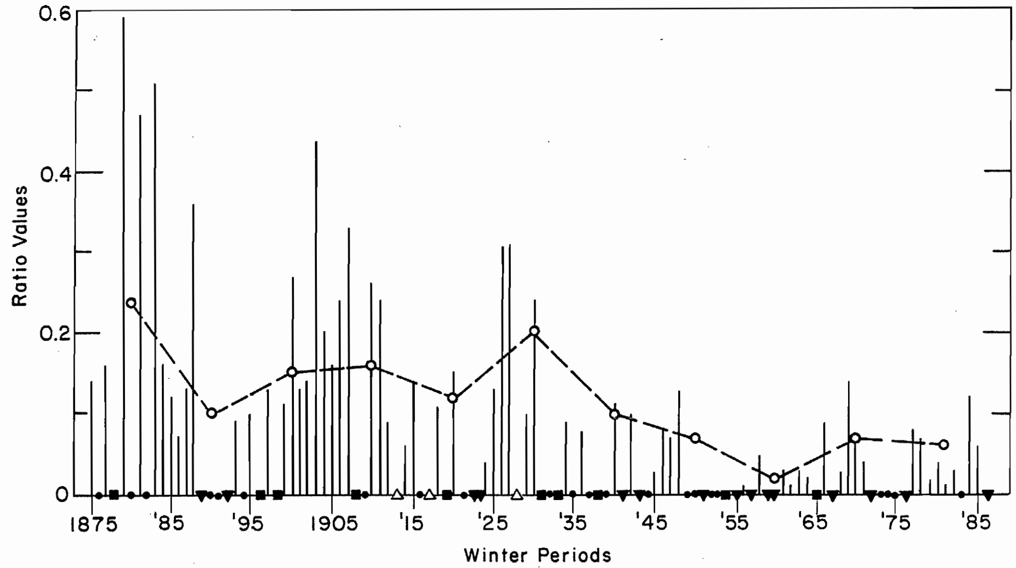

Figure 4. Ratio of total number of days of ice on the Ohio River divided by the total seasonal freezing degree-days for each winter (e.g. 1875 = winter of 1874-75).

Table 1. 10-winter totals of: a) the number of days of observed ice, b) the FDDs during the same decade; and c) the ratio value of a/b for December, January and February from 1874-1875 to 1963-1964, and 11-winter totals from 1964-1965 to 1985-1986.

	December			January			February		
	No. days of ice	Total FDDs	Ratio	No. days of ice	Total FDDs	Ratio	No. days of ice	Total FDDs	Ratio
10-winter increments									
1874-75 to 1883-84	47	279	0.17	137	530	0.26	46	137	0.34
1884-85 to 1893-94	12	108	0.11	93	1080	0.09	47	327	0.14
1894-95 to 1903-04	31	155	0.20	93	459	0.20	110	932	0.12
1904-05 to 1913-14	41	186	0.22	61	502	0.12	94	580	0.16
1914-15 to 1923-24	50	292	0.17	62	751	0.08	27	133	0.20
1924-25 to 1933-34	15	71	0.21	70	258	0.27	40	308	0.13
1934-35 to 1943-44	14	174	0.08	49	636	0.08	38	241	0.16
1944-45 to 1953-54	10	291	0.03	13	403	0.03	33	151	0.22
1954-55 to 1963-64	2	556	<0.01	19	777	0.02	17	294	0.06
11-winter increments									
1964-65 to 1974-75	0	25	0	36	724	0.05	22	153	0.14
1975-76 to 1985-86	6	321	0.02	99	1934	0.05	58	760	0.08

value exceeded 0.6 (indicated as open triangles; due to apparent observational errors, these three ratio values were considered unrepresentative and therefore were not used in the study), 3) those winters with some recorded FDDs but no days with observed ice (indicated as inverted solid triangles), 4) those winters with no observed ice and no FDDs(indicated as solid circles), and 5) a trace of the average ratio values for each consecutive 10-winter interval (i.e. starting with 1874-75 through 1883-84) (indicated as 0--0).

The winter-to-winter ratios shown in Figure 4 reveal considerable variance. Omitting those winters with the solid symbols and open triangles, the ratios range from greater than 0.5 during the early part of the record to < 0.02 during the later part of the record. The dashed line joining the sequential 10-winter average ratios, however, included six consecutive average values of between 0.1 and 0.2 for the winters extending from 1884-85 to 1943-44. A trace of average five-winter ratio values showed an erratic overall trend. The average value for the 33 winters during which ratios were computed in this time period was 0.17, with highest and lowest ratios of 0.46 and 0.04. Of greater significance though is the marked decrease in the value, as well as the increase of the number of years with FDDs but no observed ice (indicated by the inverted solid triangles), that occurred after the winter of 1941-42.

The relationships between FDDs and number of days with ice shown in this study are not intended to be used as a method for forecasting ice. In many instances severe ice conditions and cases of serious flooding can occur during relatively mild winters (i.e. with moderate total seasonal FDDs) when several consecutive days of severe cold weather occurred. Such events are concealed when average monthly air temperature values are used.

Monthly variations in the relationship between FDDs and observed ice was investigated by computing 10-winter average ratios separately for December, January and February (Table 1). During the first six decades from 1874 to 1934 these ratios ranged from 0.08 to 0.34, with averages of 0.18 during December and February, and 0.17 during January. In the subse-

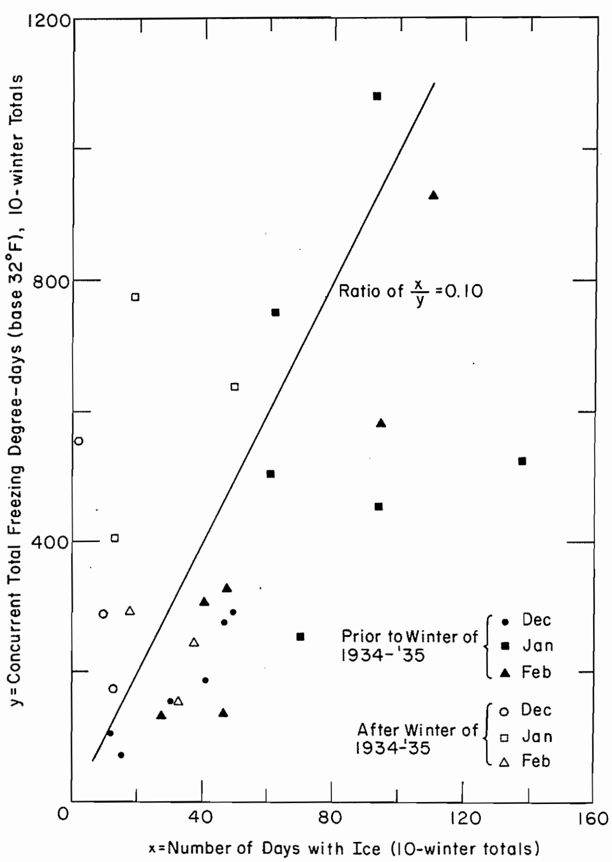

Figure 5. Relationship between total freezing degree-days and number of days with ice (monthly averages of 10-year increments from 1874-75 to 1963-64).

quent three decades, from 1935 to 1964, the ratios during December and January decreased sharply, but the decrease did not occur until the last decade during February. It is possible that the ratios generally remain higher in February because some river ice observed at Cincinnati toward the end of winter may not necessarily be due only to freezing temperatures. The light floating ice, for example, could also be residual floes in transit from colder areas upstream.

The ratios for the 11-winter period 1964-65 to 1974-75 for January and February were 0.05 and 0.14, respectively, and zero for December since no ice was observed on the river during the 11 years in that month. During the 11-winter period of 1975-76 to 1985-86 the ratios for December, January and February, respectively, were 0.02, 0.05 and 0.08. These results indicate that during recent years fewer FDDs are required to produce ice on the river.

A plot of the data sets for the monthly total FDDs versus the number of days with ice for the nine 10-winter intervals given in Table 1 is shown in Figure 5. A line which separates ratios of above and below 0.10 is also given in the diagram. Note that 16 of the 18 points with ratios greater than 0.10 occurred during the first six decades, and seven of the nine points with ratios less than 0.10 occurred during the latter three decades.

VII. Observed Ice and Basin Development

As has been noted in the previous sections, a dramatic decline occurred in the number of days of observed ice relative to the number of recorded freezing degree days at Cincinnati. In this section and the next we will discuss some of the possible reasons for this decline. Unfortunately, it will not be possible to determine the exact cause in the decline of observed ice. The decline can be correlated with several conditions that also occurred during the same period. These conditions are the construction of high-lift locks and dams, the increase of navigation on the river, and the general development of the Ohio River Basin. The first two possible causes will be discussed in the next section. In this section we will briefly discuss the development of the Ohio River Basin.

Development of a watershed can have a large impact on the hydrology of the watershed. Urbanization can lead to increases in runoff and shorten the time to the peak of a runoff

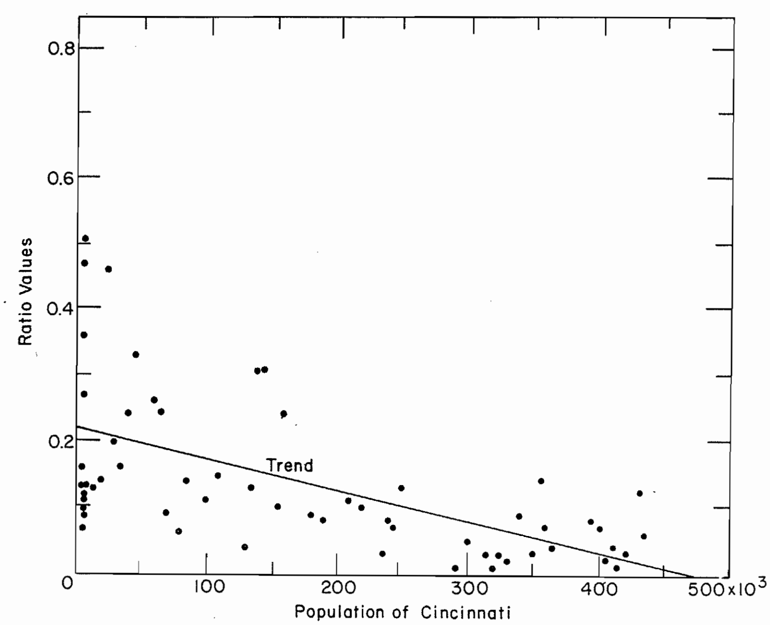

Figure 6. Relationship between ratio values (of observed ice versus freezing degree-days) and population trends at Cincinnati, Ohio, since 1900.

event. Urbanization generally requires the construction of flood control works, channelization, and other physical changes to the stream morphology. Perhaps more important, the development of a watershed implies an increase of heated discharge into the receiving water of the streams and rivers of the watershed. Regulatory control of the quantity and quality of the discharges has been limited or nonexistent until relatively recently. The increase in industrial discharge, power plant cooling water discharge, and sewage discharge that can occur with watershed development will have a large impact on the heat budget of the rivers. This impact would be to reduce the amount of ice formed on the river.

A good index of watershed development is the watershed population. In fact, population can be correlated with several hydrologic parameters (Daly and Peters, 1979). As a representative population of the watershed under study, the census records for Cincinnati, Ohio, was examined. The population of Cincinnati has increased more or less linearly since 1900, from about 4,000 to 400,000. The decrease in the ratio of observed ice to freezing degree days during this period was associated with this general increase in population (Fig. 6). It is not possible to provide direct cause and effect other than what has been suggested above. However, the decrease in the ratio of observed ice relative to the number of freezing degree days has occurred during the period of watershed development, as indicated by a representative population. An inverse relationship can be seen to exist.

VIII. Observed Ice and Navigation

During the period of decline in the number of days of observed ice relative to the number of recorded freezing degree-days, the construction of high-lift locks and dams occurred in the vicinity of Cincinnati and upstream. These dams replaced a far greater number of wicket dams which had a much lower head in general and most likely passed ice much easier than the present high-lift dams. The construction of these newer dams would increase the total volume of water in the river. This would slow the response of the river to changes in the air temperature. This could delay the formation of ice and in many cases reduce the amount of ice produced. However, it is difficult to quantify this effect. Changes in the flow depth and velocity in the immediate vicinity of Cincinnati would have the most affect in the observed ice at Cincinnati. Construction of Dam 37 at Fernbank, Ohio, in 1936 raised the stage to a minimum of eleven feet at Cincinnati. Before this time stages as low as 5 feet had been recorded. Construction of Markland Locks and Dam, completed in 1963, increased the stage to a minimum of 25 feet at Cincinnati (U.S. Army Corps of Engineers, 1978).

Navigation in the Ohio River has increased substantially over the period of record. In 1930, slightly over 20 million tons of freight were shipped over the Ohio River. In 1974, the amount was nearly 140 million tons and was made up largely of coal and coke, with lesser amounts of other commodities such as petroleum, stone, sand, gravel, chemicals, iron and steel (U.S. Army Engineer Institute for Water Resources, 1979). Navigation is carried out during the winter on the Ohio River, except for the few instances when severe ice conditions occurred. Navigation can influence the ice conditions in a navigable waterway such as the Ohio River (Ettema and Huang, 1985). However, it has generally been reported that navigation tends to increase ice production by repeatedly creating open water areas in which new ice can grow (Sandhurst, 1981). Therefore, it is not likely that the increase in navigation itself has caused the decrease in observed ice at Cincinnati.

IX. Conclusions

There has been a decline in the observed ice at Cincinnati, Ohio, on the Ohio River over the period 1902-1985. The number of days of observed ice relative to the number of freezing degree-days has also declined during this period, with the most dramatic decline starting in the 1930s. There has been no systematic change in the severity of winters as indicated by the number of freezing degree-days recorded each winter. It is not possible to positively determine the direct cause of the decline in ice observed at Cincinnati. The decline has corresponded with the basin development, as indicated by the increase in population of Cincinnati, the construction of large locks and dams, and the increase in navigation. Changes to the thermal balance of the Ohio River brought about by an increase in heated discharges due to basin development may be one cause. Changes in the stage and flow regime at Cincinnati through the construction of locks and dams is probably also a significant cause. Further research is required to quantify the effect of this construction on river ice formation.

X. References

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