In cooperation with the
City of Willoughby, Ohio

Trends in Selected Streamflow and Stream-Channel Characteristics for the Chagrin River at Willoughby, Ohio

Water-Resources Investigations Report 02–4017

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By G.F. Koltun and Allison E. Kunze

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Columbus, Ohio
2002

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
Length		
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Monotonic upward trends in annual mean streamflows and annual 7-day low flows were identified statistically for the streamflow-gaging station on the Chagrin River at Willoughby, Ohio. No monotonic trends were identified for the annual peak streamflow series or partial-duration series of peak streamflows augmented with annual peak streamflows that did not exceed a base discharge of 4,000 cubic feet per second.

A plot of cumulative departure of annual precipitation from the long-term mean annual precipitation for the weather-observation station at Hiram, Ohio, indicates a relatively dry period extending from about 1910 to about 1968, followed by a relatively wet period extending from about 1968 to the late 1990s. A plot of cumulative departure of annual mean streamflow from the mean annual streamflow for the Chagrin River at Willoughby, Ohio, closely mimics the shape of the precipitation departure plot, indicating that the annual mean streamflows increased in concert with annual precipitation. These synchronous trends likely explain why upward trends in annual mean streamflows and annual 7-day low flows were observed. A lack of trend in peak streamflows indicates that the intensity and severity of flood-producing storms did not increase appreciably along with the increases in annual precipitation.

An analysis of point-of-zero-flow data indicates that the low-water control of the Chagrin River streamflow-gaging station tended to aggrade over the period 1930–93; however, the magnitude of aggradation is sufficiently small that its effect on stages of moderate to large floods would be negligible.

Stage values associated with reference streamflows of 500 and 5,000 cubic feet per second tended to remain fairly stable during the period from about 1950 to 1970 and then decreased slightly during the period from about 1970 to 1980, suggesting that the flood-carrying capacity of the stream increased somewhat during the latter period. Since a large flood on May 26, 1989, significant changes have occurred in the relation between stage and streamflow. The most recent relation indicates that stage values associated with streamflows of 500 and 5,000 cubic feet per second are about 0.5 foot and 0.1 foot higher, respectively, than the pre-1989 levels.

INTRODUCTION

Changes in land use and increases in imperviousness due to development in some parts of the Chagrin River Basin have raised questions about whether streamflow characteristics of the Chagrin River have changed appreciably over time. Some basin residents suggest that, in recent years, the land-use changes have resulted in an increase in the severity and (or) frequency of flooding in the lower part of the basin. The perceived increase in flooding has been attributed to a variety of causes, including increased stormwater runoff (presumably due to land-use or land-cover changes) and reduction of the channel's flood-carrying capacity due to sedimentation. To answer questions about possible time-based trends in streamflow and stream-channel characteristics, the U.S. Geological Survey (USGS), in cooperation with the City of Willoughby, Ohio, conducted a study to assess trends in these characteristics based on long-term data collected at the USGS streamflow-gaging station on the Chagrin River at Willoughby, Ohio.

Purpose and Scope

This report describes the results of a study to assess time-based trends in instantaneous peak streamflows, annual mean streamflows, and annual 7-day low flows at the USGS streamflow-gaging station on the Chagrin River at Willoughby, Ohio, and to assess trends in stream-channel characteristics in the vicinity of the gaging station. Precipitation data from the weather-observation station in Hiram, Ohio, were analyzed to provide a climatological context with which to interpret the results of the trend analyses. Although there are documented cases in which urbanization resulted in increased peak streamflows and frequencies of flooding (U.S. Environmental Protection Agency, 2001), no attempt is made in this study to establish causal relations between any observed trends and changes in land use, land cover, or population within the Chagrin River Basin. Some trend results presented in this report are site specific; consequently, identified trends (or lack thereof) may not be equally applicable at other locations within the basin.

Description of the Study Area

The Chagrin River drains 264 mi^2 in northeastern Ohio (fig. 1). The river is approximately 48 miles long and flows southwest from the headwaters near Chardon, in Geauga County, to Chagrin Falls, in Cuyahoga County, where it is joined from the south by Aurora Branch (58.2 mi^2). The river then flows north, where it is joined in Willoughby by the East Branch Chagrin River (51.1 mi^2), which flows west from northern Geauga County. Ultimately, the Chagrin River discharges into Lake Erie in Eastlake, Ohio. Approximately 49 river miles of the Chagrin River and its tributaries were designated as a State Scenic River in 1979 (Ohio Department of Natural Resources, 2001).

The basin lies within the Appalachian Plateaus Physiographic Province (Fenneman, 1938). Glacial till, a poorly sorted mixture of clay, silt, sand, and gravel deposited directly by glacial ice, covers most of the area at thicknesses (for all layers) ranging from less than 2 ft on ridges to several hundred feet in buried valleys (Totten, 1988). Most of the glacial materials in northern Ohio were deposited during the Wisconsinan period. Bedrock underlying the basin is composed of sandstones, conglomerates, and shales (Totten, 1988) belonging to the Devonian, Mississippian, and Pennsylvanian systems.

Land cover in the Chagrin River Basin in the early 1990s consisted mostly of forested and herbaceous areas, followed by developed areas and small percentages of wetlands, open water and barren lands (table 1).

Table 1. Land cover in the Chagrin River Basin in the early 1990s

[Source: National Land Cover Data, Ohio (U.S. Geological Survey, 2000)]

Land use	Percentage of basin
Barren	0.4
Open water	1.3
Wetlands	4.5
Developed	14.9
Herbaceous	21.3
Forested	57.6

Population densities tend to be greatest in the extreme northern part of the basin in Lake County and along the western edge of the basin in Cuyahoga County (U.S. Census Bureau, 2001). Population densities are also high in and around Chagrin Falls (U.S. Census Bureau, 2001). Population in the watershed grew by about 15 percent during the period 1970–90 (Andy Vidra, Senior Environmental Planner, Northeast Ohio Areawide Coordinating Agency, oral commun., November 2001). For the same period, the number of housing units in the watershed increased by 38 percent, indicating a trend towards fewer persons per household (Andy Vidra, Senior Environmental Planner, Northeast Ohio Areawide Coordinating Agency, oral commun., November 2001).

Acknowledgments

The authors of this report thank the Chagrin River Watershed Partners and the City of Willoughby, Ohio, for their support of this study. Financial assistance for this study was provided by the Coastal Zone Management Act, administered by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, and the Ohio Coastal Management Program, administered by the Ohio Department of Natural Resources, Division of Real Estate and Land Management.

Figure 1. Chagrin River Basin and location of streamflow-gaging station

STREAMFLOW DATA

On July 9, 1925, the USGS established a nonrecording streamflow-gaging station (station number 04209000) on the Chagrin River at Willoughby, Ohio, approximately 800 ft downstream from where East Branch joins the Chagrin River mainstem. A nonrecording gaging station typically consisted of staff gages[1] that were read by hydrographers or trained observers. The streamflow-gaging station was discontinued on November 30, 1935, and restarted on October 11, 1939. On December 20, 1939, the gaging station was moved downstream to its present location (150 ft below the Willoughby waterworks dam and approximately 5 mi upstream from the mouth) (fig. 1) and equipment was installed to automatically record stage. Stage at the present location is referenced to a datum of 594.57 ft above sea level. Prior to December 20, 1939, the gage datum was approximately 7 ft higher. Gaging-station operation was discontinued again on September 1, 1984. The gaging station was restarted on March 25, 1988 and operated until September 30, 1994, when it was temporarily discontinued. The gaging station was restarted again on October 1, 1995, and operated until September 30, 1999, when determination of streamflow was suspended. The drainage area of the Chagrin River at the gaging station is 246 mi^2.

Daily mean and instantaneous peak streamflows were determined for the periods that streamflow data were collected (through September 30, 1999). Daily mean streamflow data were used to determine annual mean streamflows (the arithmetic mean of the individual daily mean streamflows for each water year[2]), and the annual 7-day-average low flows (the lowest 7-day-average streamflows for each climatic year[3]).

TRENDS IN STREAMFLOW AND STREAM-CHANNEL CHARACTERISTICS

A variety of graphical and statistical techniques were used to assess trends in streamflow and stream-channel characteristics, including time-series plots, boxplots, locally weighted scatterplot smoothing, and Mann-Kendall trend tests.

[1]A staff gage is composed of graduated ruler-like plates that are permanently installed in a stream or other body of water and used to measure the stage (the height of water above a given datum).

[2]A water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends.

[3]A climatic year is the 12-month period from April 1 through March 31 and is designated by the calendar year in which it begins.

Analytical Methods

The nonparametric Mann-Kendall test was used to assess whether selected streamflow and stream-channel characteristics tended to increase or decrease monotonically[4] with time. The test statistic used in the Mann-Kendall test, called tau (τ), is a nonparametric correlation coefficient determined from rank-transformed data; tau ranges from 1 to -1 in magnitude (Helsel and Hirsch, 1992). Because tau is determined from rank-transformed data, it is more resistant to the effects of a small number of unusual values (outliers) than are parametric correlation coefficients (Helsel and Hirsch, 1992). The magnitude of tau generally will be smaller than the magnitude of Pearson's correlation coefficient (r) for linear associations of the same strength. For example, Pearson's correlations of 0.9 or above commonly correspond to tau values of about 0.7 or above. These lower values do not mean that tau is less sensitive than r but simply that a different scale of correlation is being used (Helsel and Hirsch, 1992).

Time-series plots of streamflow data in this report also show a locally weighted scatterplot smoothing (LOWESS) (Cleveland, 1979) curve drawn through the data. Smoothing is an exploratory technique, having no unique equation or significance tests associated with it. LOWESS uses an algorithm that applies weighted least-squares regression methods (where weights decrease with distance from the point of interest) to subsets of the data to construct a point-by-point function that describes the deterministic part of the variation in the data. The smoothness of the LOWESS curve is varied by altering the amount of data considered when determining each point in the function, as controlled by a smoothness factor (f), which can range from 0 to 1. As the magnitude of f is increased, more data are used to determine each point in the LOWESS function, thereby increasing the smoothing effect. A value of 0.6 was assigned for f for all analyses described in this report.

Boxplots are used to visualize distributional characteristics of data. Boxplots provide a visual summary of (1) the center of the data (the median or centerline of the box), (2) the variation or spread (interquartile range or the box height), (3) the skewness (quartile skew or the relative size of the box segments), and (4) the presence or absence of unusual values ("outside" and "far outside" values) (Helsel and Hirsch, 1992).

Peak Streamflows

Peak streamflows can be classified into two categories: annual peaks and partial-duration peaks. An annual peak streamflow is the maximum instantaneous streamflow in a given water year. A partial-duration peak streamflow is an instantaneous peak streamflow that is larger than a

[4]A monotonic function is one that increases without ever decreasing or decreases without ever increasing.

designated base discharge. Partial-duration peak streamflows must result from distinctly separate events so that no more than one peak is recorded for a time period associated with a given runoff event; however, more than one partial-duration peak streamflow can occur in a given water year. Ideally, the base discharge is chosen so that the record contains an average of about three peak-streamflow values per water year (Office of Water Data Coordination, 1977). The base discharge designated for the Chagrin River at Willoughby is 4,000 ft^3/s.

Annual Peak Streamflows

A Mann-Kendall analysis of 67 values of annual peak streamflows observed between water years 1913 and 1999 (table 2, page 6) resulted in a computed tau value of -0.073 (table 3, page 7). The significance of the computed tau value can be assessed by determining the probability of obtaining a value of this magnitude (or one even less likely) assuming that the true tau value is 0 (the null hypothesis; indicating no correlation between time and peak streamflows). That probability, known as a p-value, was determined to be 0.580, indicating that there was a reasonably good chance of obtaining a tau value of -0.073 even if the true value of tau is 0. In this report, the null hypothesis (the hypothesis of no trend) is rejected only when the p-value is 0.05 or smaller. Because the trend is considered statistically significant only when the null hypothesis is rejected, this test result indicates no significant monotonic trend in annual peak streamflows at the Chagrin River streamflow-gaging station.

It is possible for a trend to occur in high-magnitude peak streamflows without a concurrent trend in low- to moderate-magnitude peak streamflows. It also is possible for a trend to occur in low- to moderate-magnitude peak streamflows without a concurrent trend in high-magnitude peak streamflows. To explore those possibilities, separate Mann-Kendall analyses were done on each of two groups of annual peak streamflow data: one group containing annual peak streamflows of low-to-moderate magnitude and the second group containing annual peak streamflows of higher magnitude. The breakpoint between the two groups was arbitrarily set at the 75th percentile of the partial-duration peak streamflow series (7,910 ft^3/s) observed for the Chagrin River at Willoughby.

The results of the Mann-Kendall analyses for both high-magnitude and low- to moderate-magnitude annual peak streamflows indicate no significant trend for either group of peak streamflows for the period 1913–99 (table 3). These results are consistent with the broader regional findings of Lins and Slack (1999), who found no significant trends in annual peak streamflows during the 20th century in nearly a dozen climate-sensitive streams south and east of Lake Erie.

Partial-Duration Peak Streamflows Plus Annual Peak Streamflows Less Than 4,000 ft^3/s

The partial-duration series of peak streamflows combined with annual peak streamflows that did not exceed the base discharge of 4,000 ft^3/s were separated into groups of high- and low- to moderate-magnitude peak streamflows on the basis of the same breakpoint (7,910 ft^3/s) used for the annual peak streamflows. Those data are plotted as a function of time in figure 2 (page 7) with LOWESS curves drawn through each group. The LOWESS curve for the low- to moderate-magnitude peak streamflows has a relatively constant, but small, negative slope, suggesting a slight decrease in low to moderate peak streamflow magnitudes over time. The LOWESS curve for the high peak streamflows is negatively sloped in some sections and positively sloped in others, but it does not, at any point on the curve, vary in magnitude from a value of 10,000 ft^3/s by more than about 4.5 percent. The fact that the LOWESS curve for the “high” peak streamflows has a small positive slope from about the mid-1970s on does not provide conclusive evidence of an ongoing trend, given that the LOWESS curve exhibits other positive- and negative-slope segments associated with earlier time periods.

Boxplots, grouped by month of occurrence, were constructed for the partial-duration series of peak streamflows plus annual peak streamflows that did not exceed the base discharge of 4,000 ft^3/s (fig. 3, page 8). The number of peak streamflows that occurred in each month are shown below each box. The most peaks were recorded in March (51) followed by February (36), January (34), and then April (33), indicating that the frequency of flooding historically has been greatest during late winter and early spring. Of the 10 largest peak streamflows of record, 7 occurred during January–May, indicating that the severity of flooding also tends to be greater during late winter and early spring.

Annual Mean Streamflows

A Mann-Kendall analysis of 65 values of annual mean streamflow measured between water years 1926 and 1999 resulted in a computed tau value of 0.275, with an associated p-value of 0.001, and a median slope of 1.62 ft^3/s per year (table 3). This result indicates a statistically significant upward trend in annual mean streamflow with time and a median rate of increase of 1.62 ft^3/s per year. This result also is consistent with the broader regional findings of Lins and Slack (Harry F. Lins, Hydrologist, U.S. Geological Survey, oral commun., November 2001).

Table 2. Annual peak streamflows and stages for the Chagrin River at Willoughby, Ohio

[ft^3/s, cubic feet per second; –, no data; boldface type in date indicates a gap of one or more water years to next peak-streamflow observation]

Date of peak flow (YYYY-MM-DD)	Peak flow (ft^3/s)	Peak stage (feet above datum)	Date of peak flow (YYYY-MM-DD)	Peak flow (ft^3/s)	Peak stage (feet above datum)
1913-03-23	24,500[a]	10.30[b]	1963-03-17	7,990	10.81
1926-09-24	10,400[a]	6.20[b]	1964-03-05	17,200	15.33
1927-01-22	8,900[a]	5.70[b]	1965-01-24	6,990	10.07
1927-12-14	12,700[a]	6.90[b]	1966-02-10	7,640	10.56
1929-01-19	22,000[a]	9.40[b]	1966-12-07	6,210	9.49
1930-01-12	10,700[a]	6.30[b]	1968-01-30	6,200	9.84
1931-06-26	24,000[a]	9.90[b]	1969-05-19	23,300	16.83
1932-03-22	5,860[a]	4.50[b]	1970-03-04	4,610	8.16
1933-03-14	8,600[a]	5.60[b]	1971-02-20	5,030	8.30
1934-03-03	4,380[a]	3.80[b]	1972-06-23	9,720	11.68
1935-08-03	6,540[a]	4.80[b]	1973-06-04	7,520	10.21
1940-04-20	6,850	9.10[c]	1974-04-04	5,690	8.84
1940-12-29	5,960	8.54	1975-08-31	8,960	11.17
1942-05-16	10,000	11.90	1976-07-11	11,400	12.71
1943-03-17	8,160	10.20	1977-02-24	7,940	10.49[d]
1944-04-11	7,900	10.50	1977-12-14	10,600	12.24
1945-05-18	8,740	11.12	1979-09-14	8,130	10.28
1946-06-01	4,370	7.73	1979-12-25	10,100	11.92
1947-06-02	14,400	13.70	1981-02-19	9,350	11.30
1948-03-22	28,000	17.95	1982-02-01	5,600[e]	–
1949-05-22	5,060	8.29	1983-05-03	5,490	8.16
1950-02-14	9,400	11.60	**1984-05-12**	7,630	9.87
1950-12-03	9,200	11.52	1988-03-25	6,130	8.69
1952-01-26	10,400	12.06	1989-05-26	23,900	17.14
1953-01-18	3,330	6.85	1990-05-16	9,750	11.32
1954-03-25	11,300	12.53	1990-12-30	11,600	12.47
1954-10-15	18,600	15.22	1992-08-28	5,460	8.01
1956-05-13	8,410	11.07	1992-12-31	9,480	11.13
1957-05-20	14,800	14.74	**1994-08-13**	15,200	14.41
1958-08-06	6,900	10.03	1996-01-19	9,500[e]	11.15[f]
1959-01-21	22,000	16.73	1997-02-27	14,900	14.22
1960-03-29	7,080	10.14	1998-01-08	6,970	9.39
1961-04-25	9,560	11.84	1999-01-23	4,480	7.39
1962-02-26	12,200	13.24			

[a]Only annual maximum peak recorded for year.

[b]Gage height at different site and (or) datum than current gage.

[c]Gage datum changed during this year.

[d]Gage height is not the maximum for the year.

[e]Streamflow is an estimate.

[f]Gage height is an estimate.

Table 3. Results of Mann-Kendall tests for trends in streamflow characteristics at the Chagrin River at Willoughby, Ohio

[<, less than; ft^3/s, cubic feet per second; ft^3/s/yr, cubic feet per second per year; NST, no significant trend]

Streamflow characteristic	Minimum-maximum year of record	Number of observations	Kendall's tau	p-value	Median slope of trend (ft^3/s/yr)	Direction of significant[a] trend
Annual peak streamflows	1913–1999	67	-0.073	0.580	-19.20	NST
Annual peak streamflows less than 7,910 ft^3/s	1913–1999	26	-.015	.930	-.83	NST
Annual peak streamflows greater than or equal to 7,910 ft^3/s	1913–1999	41	-.049	.661	-10.18	NST
Annual mean streamflows	1926–1999	65	.275	.001	1.62	Upward
Annual 7-day low flow	1927–1999	62	.423	<.001	.44	Upward

[a]The term "significant" refers to the condition in which the p-value associated with an observed value of a test statistic is less than or equal to 0.05, and, consequently, the hypothesis of no trend is rejected.

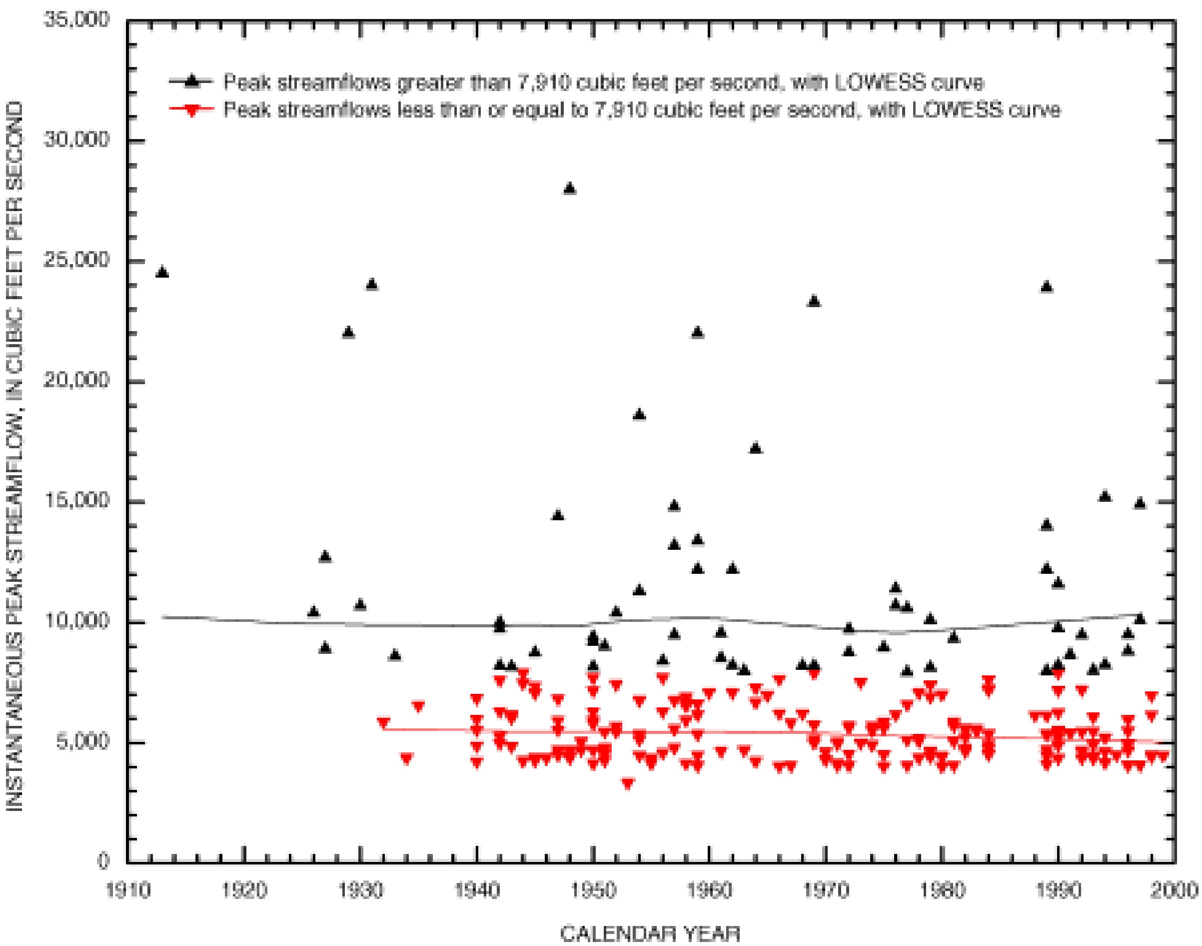

Figure 2. Time-series plots of the partial-duration series of peak streamflows plus annual peak streamflows less than 4,000 ft^3/s for the Chagrin River at Willoughby, Ohio, with LOWESS curves.

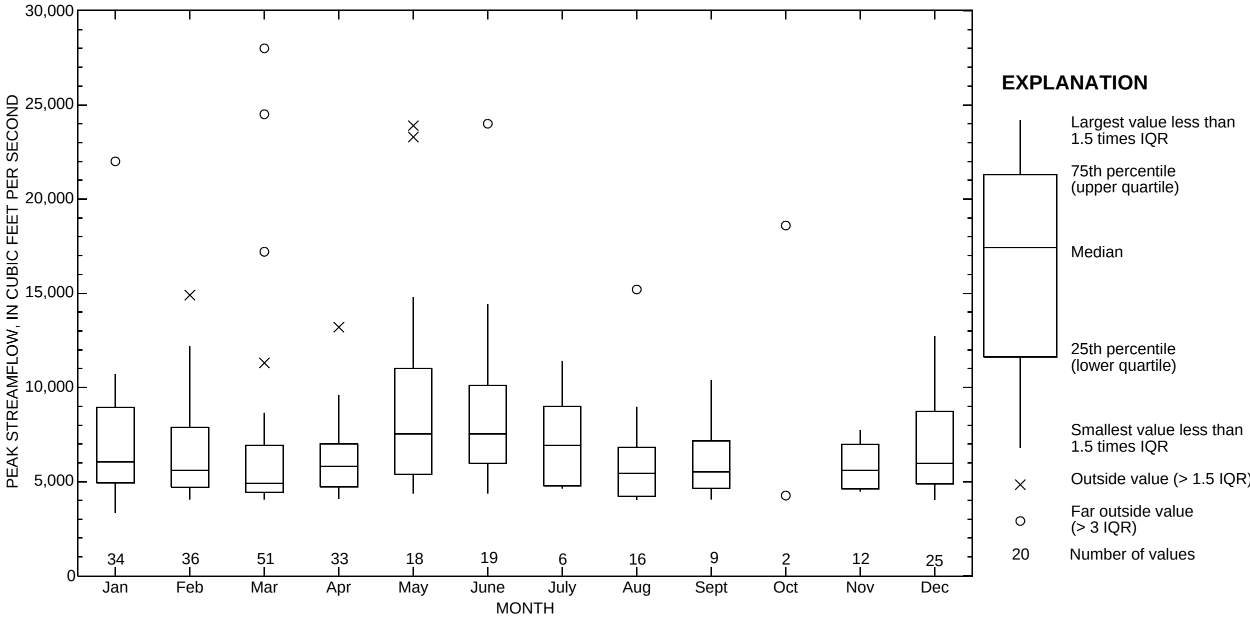

Figure 3. Boxplots of the partial-duration series of peak streamflows, plus annual peak streamflows less than 4,000 ft^3/s, grouped by month (IQR, interquartile range).

In figure 4 (page 9), annual mean streamflows are plotted as a function of water year with a LOWESS curve drawn through the data. The upward trend identified with the Mann-Kendall analysis is also reflected in the LOWESS curve. Of note in figure 4 is the fact that annual mean streamflows less than 300 ft^3/s were common before about 1970; however, annual mean streamflows after 1970, with the exception of 1999, have been greater than 300 ft^3/s.

Annual 7-day Low Flow

A Mann-Kendall analysis of 62 values of annual 7-day low flow measured between climatic years 1927 and 1999 resulted in a computed tau value of 0.423 with a p-value of less than 0.001 and a median trend slope of 0.44 ft^3/s per year (table 3). Interpretation of this result is complicated by the fact that until January 1985, the Lake County Department of Utilities withdrew water from the Chagrin River upstream from the streamflow-gaging station for water-supply purposes. In late January 1985, water withdrawals, which at the time averaged about 3 Mgal/d, ceased[5] (Rick Douglas, Plant Superintendant, Lake County Department of Utilities, oral commun., September 2001). The cessation of water withdrawals should, by itself, result in an increase in streamflow measured at the gaging station. The small magnitude of the increase likely would have little or no effect on observed trends in peak streamflows or annual mean streamflows; however, the effect on observed trends in annual 7-day low flows could be significant. Consequently, although the Mann-Kendall analysis identified a statistically significant upward trend in annual 7-day low flows with time, the causative factors underlying the trend remain unclear.

Lins and Slack (1999) also found statistically significant increases in annual minimum streamflow throughout northern Ohio and western Pennsylvania over the past 40 to 70 years. They attributed those increases to precipitation increases during summer and autumn, because streamflows at gaging stations used in their analysis were not subject to regulation or diversions (Harry F. Lins, Hydrologist, U.S. Geological Survey, oral commun., November 2001).

In figure 5 (page 10), annual 7-day low flows are plotted as a function of climatic year with a LOWESS curve drawn through the data. Although the Mann-Kendall test indicated a statistically significant upward trend in annual 7-day low flows with time, the LOWESS curve shown in figure 5 does not increase monotonically. Instead, the LOWESS curve can be divided into four time periods of relatively constant slope: 1927–45, 1945–60, 1960–75, and 1975–99. The first three time periods exhibit increasingly larger average positive slopes, indicating that the upward trend in annual 7-day low flows preceded the cessation of water withdrawals. The fourth time period has a small negative average slope. The change in slope (from positive to negative) of the LOWESS curve resulted from the fact that the eight highest annual 7-day low flows in the record occurred during the period 1974–82, before water withdrawals were stopped.

[5] Average withdrawal rates before 1985 were less than or equal to 3 Mgal/d.

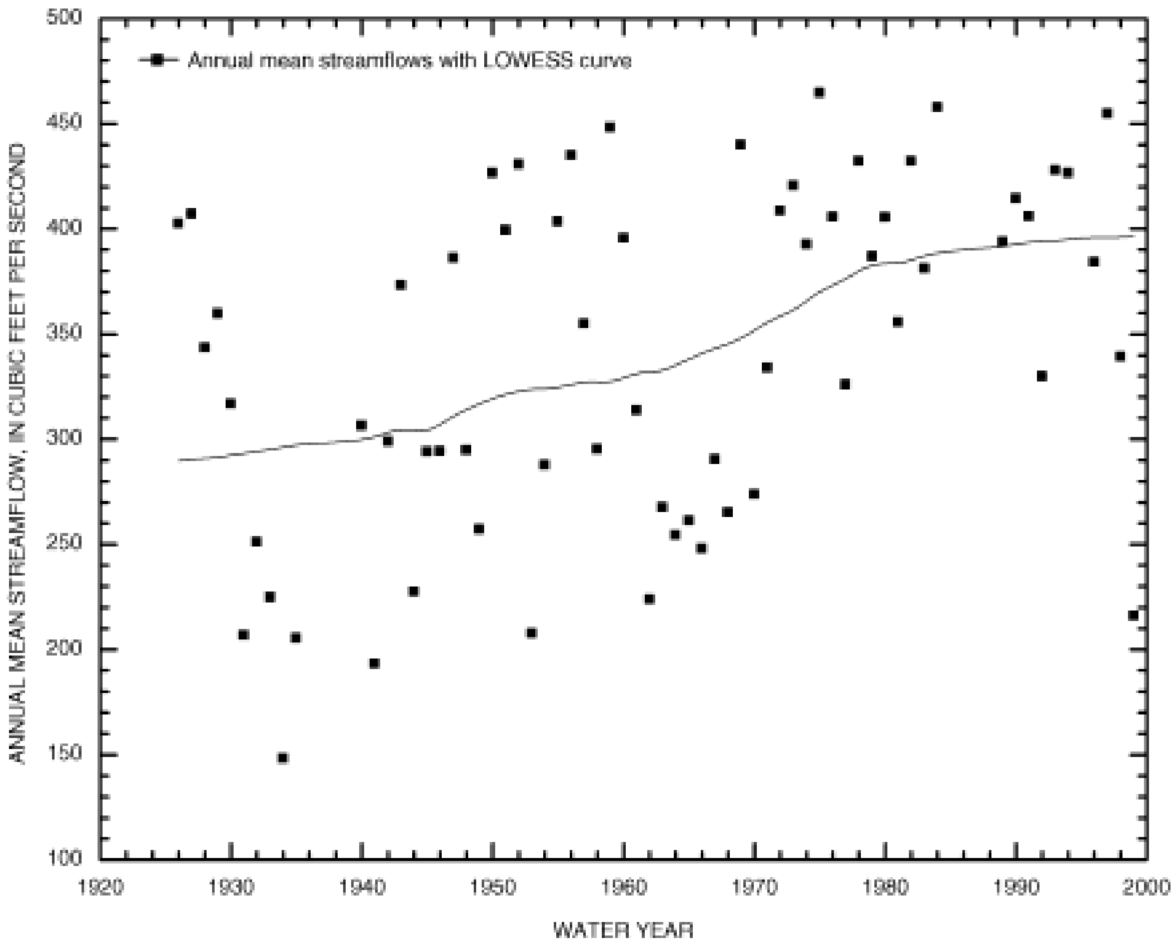

Figure 4. Time-series plot of annual mean streamflows for the Chagrin River at Willoughby, Ohio, with LOWESS curve.

Although the LOWESS curve associated with the period 1975–99 is negatively sloped, annual 7-day low flows for that period were, on average, higher than annual 7-day low flows observed during the period 1927–60.

Annual Precipitation in Relation to Streamflow

Precipitation data for the National Weather Service cooperative weather-observation station at Hiram, Ohio (approximately 30 miles southeast of Willoughby in Portage County, Ohio), were obtained from the Midwestern Regional Climate Center[6] and examined to place observed trends in streamflow and stream-channel characteristics in the context of local climate. Annual precipitation is plotted as a function of climatic year in figure 6 (page 11). A LOWESS curve drawn through the data suggests that annual precipitation in the second half of the 20th century tended to be greater than in the first half of the 20th century. Notably, the three largest climatic-year annual-precipitation values in the record at Hiram occurred in the 1990s.

A plot is shown in figure 7A (page 12) of the cumulative departure of annual precipitation from the long-term mean annual precipitation measured at Hiram for the period 1897–1998. In the absence of trend, a cumulative-departure plot shows a curve that begins at zero, varies randomly above and below the zero departure line, and then ends at zero. The plot in figure 7A is not random, but instead indicates a relatively dry period (increasingly negative cumulative departure) extending from about 1910 to about 1968, followed by a relatively wet period (predominately positive-sloped departure line) extending from about 1968 to the late 1990s.

Not surprisingly, the plot of cumulative departure of annual mean streamflow from the mean annual streamflow for the period including water years 1926–35, 1940–84, 1989–94, and 1996–99[7] (fig. 7B, page 12) closely mimics the shape of the precipitation departure plot. This correspondence indicates that the annual mean streamflows increased

[6]The Midwestern Regional Climate Center is a cooperative program of the Illinois State Water Survey (Illinois Department of Natural Resources) and the National Climatic Data Center (National Oceanic and Atmospheric Administration, U.S. Department of Commerce).

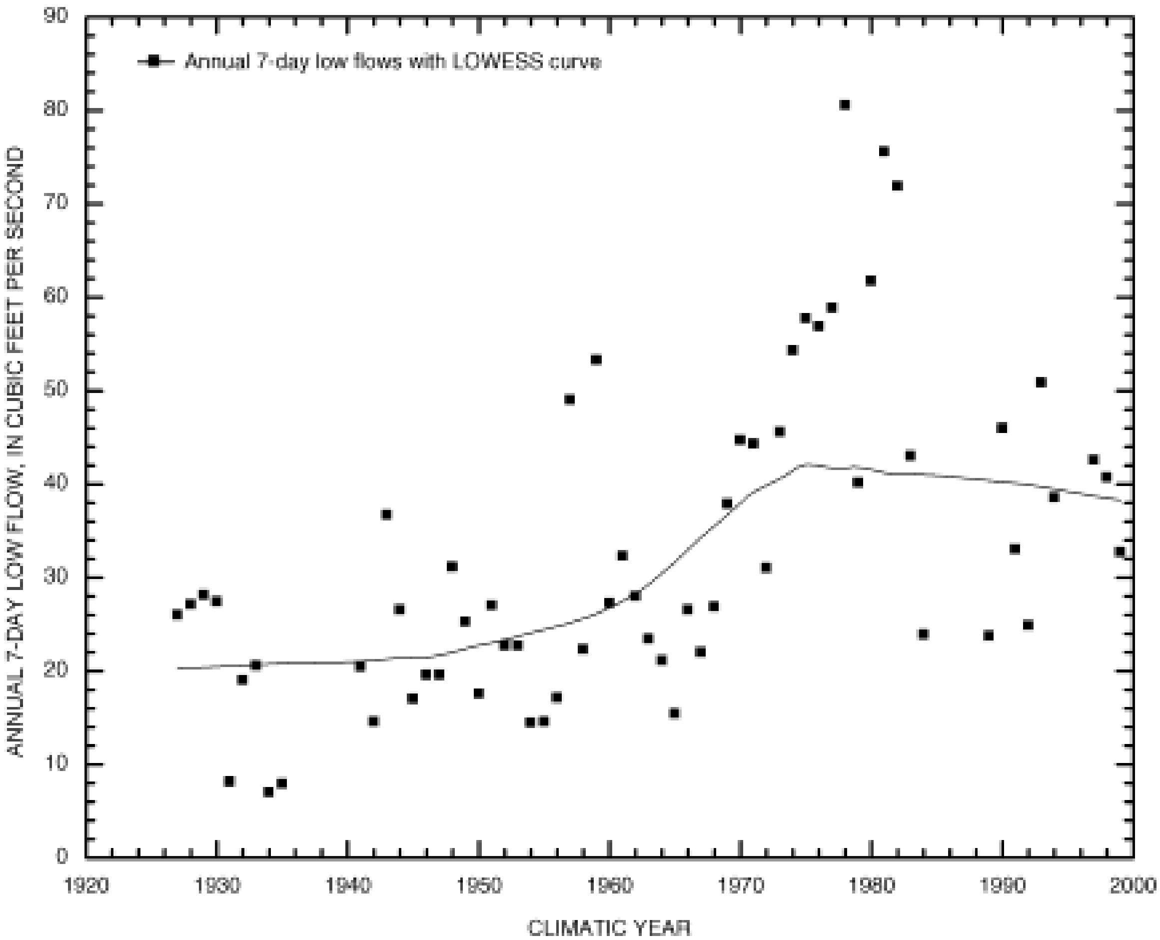

Figure 5. Time-series plot of annual 7-day low flows for the Chagrin River at Willoughby, Ohio, with LOWESS curve.

in concert with annual precipitation, most likely explaining why upward trends in annual mean streamflows and annual 7-day low flows were observed. The absence of any statistically significant trend in peak streamflows indicates that the intensity and severity of flood-producing storms did not increase appreciably along with the increases in annual precipitation.

Stream-Channel Characteristics

Up to this point, analyses have focused on trends in streamflow characteristics and associated climatic factors. Although it is obvious that increases (or decreases) in peak streamflows can affect flood levels, it may be somewhat less obvious that changes in stream-channel characteristics can do the same. For a given set of peak-streamflow characteristics, the frequency and severity of out-of-bank flooding will worsen if the flood-carrying capacity of the stream channel is reduced through an increase in effective channel roughness or a reduction in main-channel area. The effective roughness of a stream is influenced by a number of factors, such as obstructions and vegetation in the channel, the amount of channel meandering, and the amount of longitudinal variation in channel size and shape. No attempt was made to assess trends in channel roughness directly, owing to a lack of available data on all of the underlying factors; however, data were sufficient to assess some trends in stream-channel characteristics.

Two separate analyses were done to assess trends in stream-channel characteristics. The first analysis involved examining time-based trends in streambed altitudes as represented by a measure known as the point-of-zero-flow (PZF). The PZF is measured periodically under low-flow conditions to determine the stage at which water will cease to flow over the low-water control[8] (forming a stagnant pool at the stage-measurement location). Most streamflow-gaging stations operated in Ohio have low-water controls that are composed of natural streambed materials. Natural low-water controls are subject to being aggraded or degraded as a result of

[7]The discontinuous periods of streamflow record were treated as one continuous period when computing the cumulative departures.

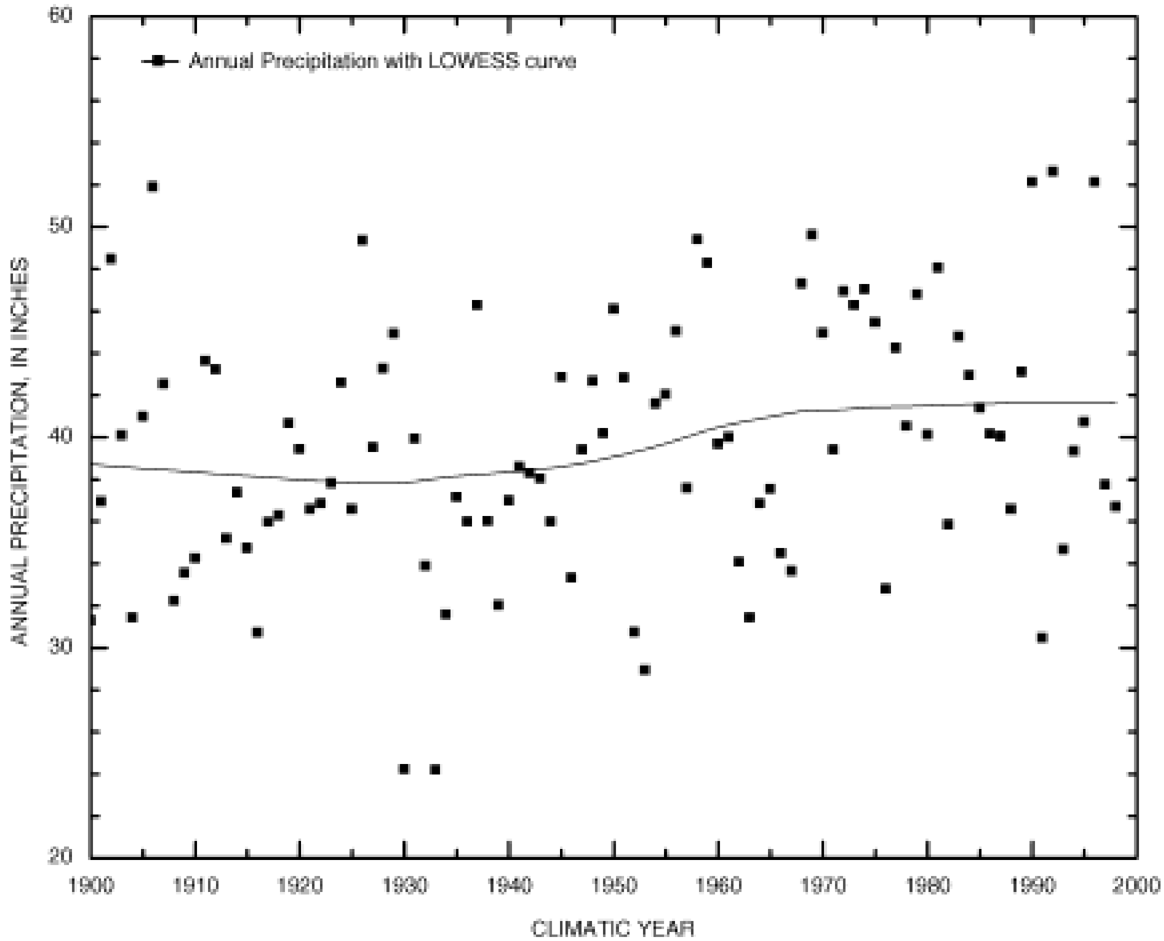

Figure 6. Time-series plot of climatic-year annual precipitation at the National Weather Service cooperative weather-observation station at Hiram, Ohio, with LOWESS curve.

sedimentation or erosion, respectively. For the streamflow-gaging station on the Chagrin River at Willoughby, the minimum altitude of the low-water control is constrained by the presence of a concrete-encased pipeline that crosses the stream approximately 40 ft downstream from the streamflow-gaging station. Whereas a stable artificial control of this type is desirable for the purpose of gaging a stream, it is considerably less desirable for the purpose of assessing trends in streambed altitude.

Although the minimum PZF at the Chagrin River gaging station is constrained by the pipeline, the maximum PZF is not. Natural sediments can (and do) deposit in the channel, burying the concrete-encased pipeline and thereby forming a new low-water control. Consequently, the PZF information remains useful, because it is this latter scenario of channel aggradation that is of interest with respect to increases in the severity and (or) frequency of flooding.

A Mann-Kendall analysis of 32 PZF measurements made between calendar years 1940 and 1993 resulted in a computed tau value of 0.437 with a p-value of less than 0.001. This result indicates that the low-water control at the Chagrin River streamflow-gaging station tended to aggrade over time; however, the magnitude of the change in the PZF is so small that its effect on stages of moderate to large floods would be negligible. To help illustrate the magnitude of the changes in the PZF (fig. 8), the last recorded observation of PZF (1.55 ft in 1993) corresponded to a stage that was only 0.15 ft (1.8 in.) higher than first recorded observation of PZF (1.40 ft in 1940). Eighty percent of the PZF observations over time were within ±0.20 ft of the long-term median PZF of 1.40 ft.

Analyses of the long-term relation between selected streamflow values and stage were done to assess the presence of time-based trends. The general relation between stage and streamflow, called a stage-discharge rating (or rating for short), is determined empirically for each streamflow-gaging station by measuring streamflow over a broad range of stages, plotting values of streamflow as a function of stage on a graph, and drawing a smooth curve through the

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[8] A low-water control is a physical feature of the stream channel that, similar to a dam or a weir, forms the pool under low-water conditions in which the stage-measuring device is located.

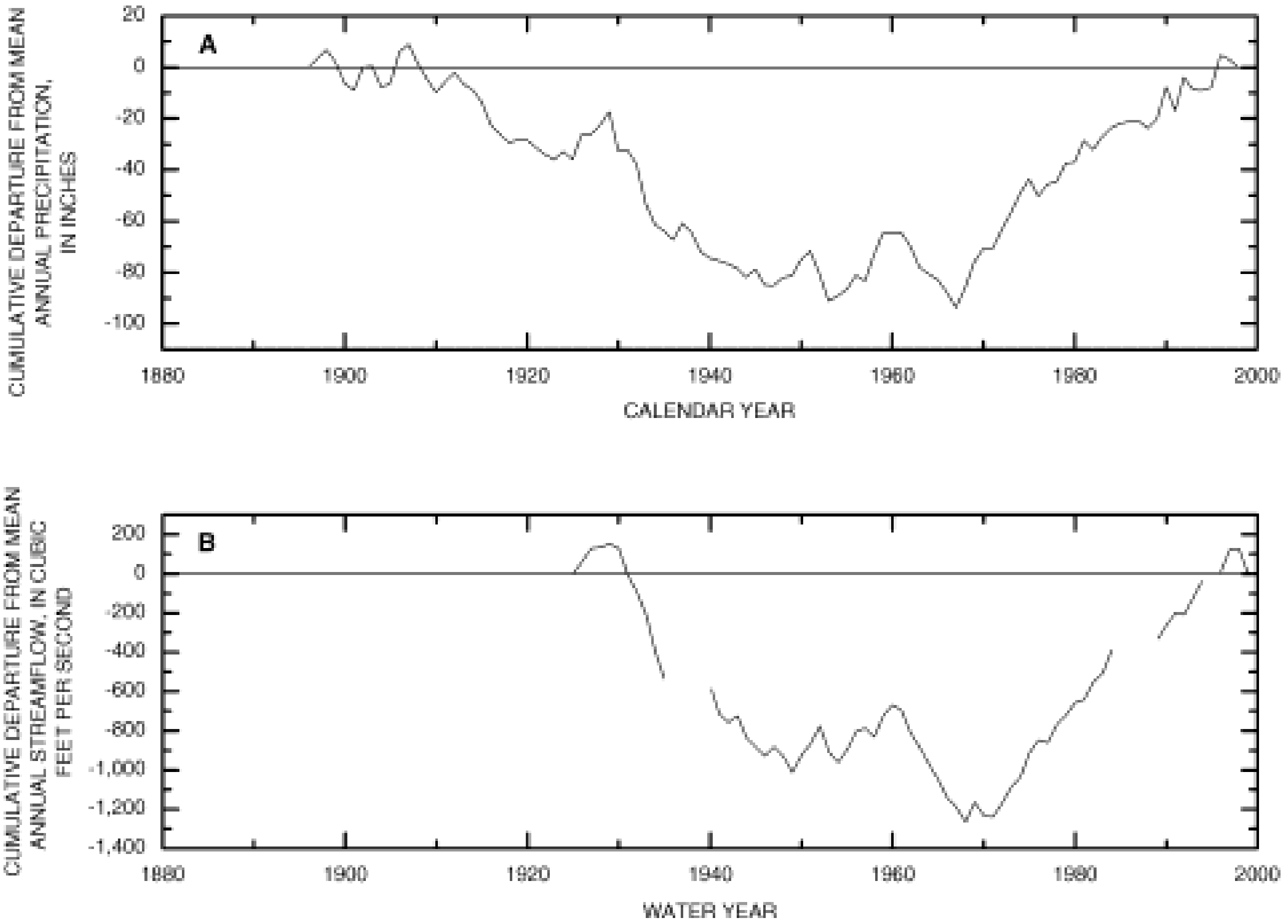

Figure 7. Cumulative-departure plots of (A) annual precipitation from the long-term mean annual precipitation at Hiram, Ohio, and (B) annual mean streamflow from the long-term mean annual streamflow for the Chagrin River at Willoughby, Ohio.

points. As the relation between stage and streamflow changes over time, ratings are revised to reflect those changes.

A total of 45 ratings have been used for the Chagrin River at Willoughby since the gaging station was moved to its present location in 1939. Stages that correspond to reference streamflows of 500 and 5,000 ft^3/s, as defined by those ratings, were plotted against the date that each rating became effective (fig. 8, page 13). Streamflow values of 500 and 5,000 ft^3/s were chosen arbitrarily to represent moderate and higher flows that remain within banks[9]. Changes to the relation between stage and streamflow at these streamflow magnitudes reflect changes to the main-channel characteristics without reflecting any changes that may have occurred to the flood plain.

[9]The National Weather Service identifies flood stage for the Chagrin River at Willoughby as 11 ft (National Weather Service, 2001), which corresponds to a streamflow of about 9,300 ft^3/s.

As shown in figure 8, stage values associated with streamflows of 500 and 5,000 ft^3/s tended to remain fairly stable during the period from about 1950 to 1970 and then decreased slightly during the period from about 1970 to 1980, suggesting that the flood-carrying capacity of the stream increased somewhat during the latter period. A significant change in the rating followed the flood of May 26, 1989. The flood peak was 23,900 ft^3/s making it the largest flood at the gaging station since May 1948. Its recurrence interval is estimated to be between 25 and 50 years (Koltun and Roberts, 1989).

Since the May 1989 flood, the rating for the Chagrin River gaging station has been subject to significant ongoing modification. It is not uncommon for stage-discharge ratings to undergo substantial change for some time after large, channel-altering floods because it takes time for poorly consolidated flood-deposited sediments to be reworked by the stream, for vegetation on streambanks to recover or be reestablished, and for enough streamflow measurements to be made to adequately define the characteristics of the new

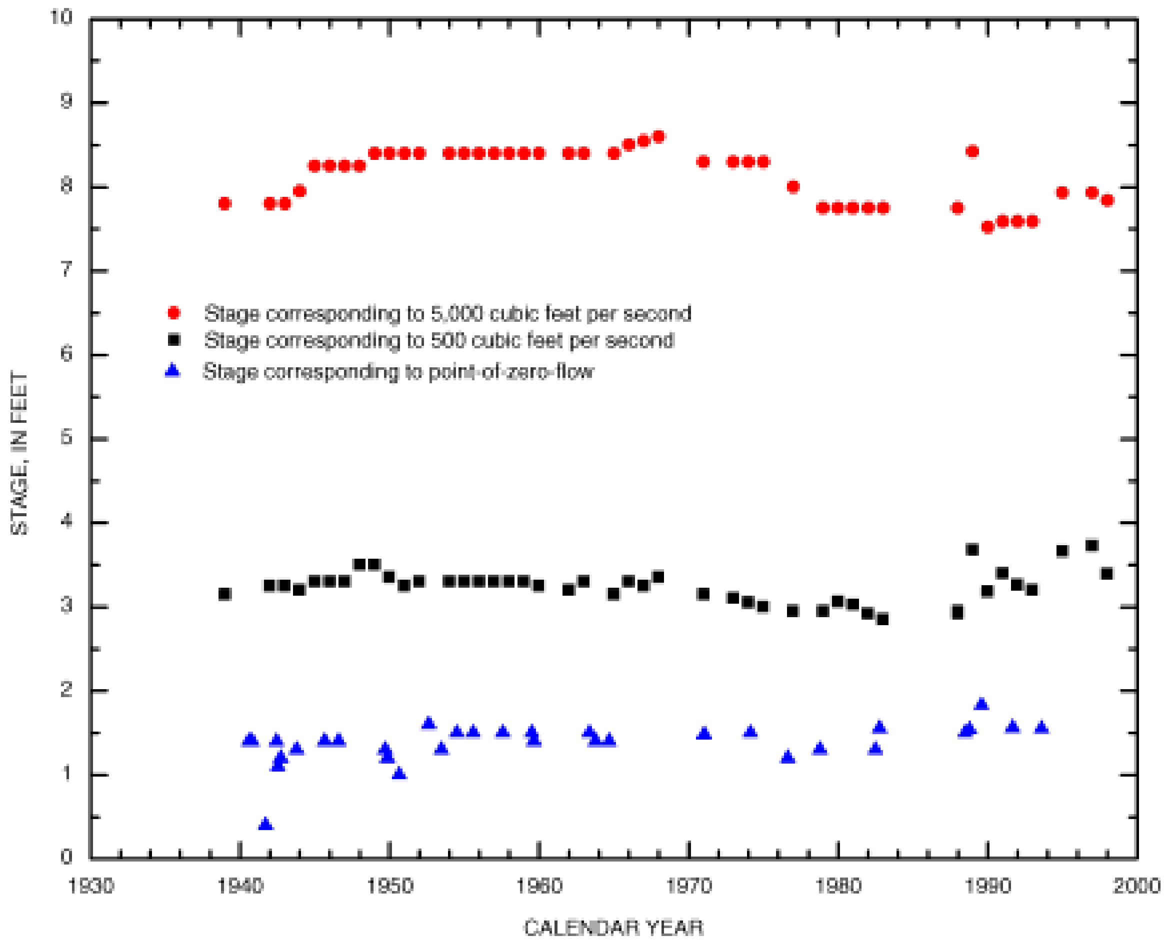

Figure 8. Time-series plots of stage values corresponding to the point-of-zero-flow and reference streamflows of 500 and 5,000 ft^3/s at the Chagrin River at Willoughby, Ohio.

rating. The most recent rating (effective 01/08/1998) indicates that stage values associated with streamflows of 500 and 5,000 ft^3/s are about 0.5 ft and 0.1 ft higher, respectively, than the pre-1989 values.

SUMMARY AND CONCLUSIONS

Trends in streamflow and stream-channel characteristics for the streamflow-gaging station on the Chagrin River at Willoughby, Ohio, were assessed by means of a variety of graphical and statistical techniques. A Mann-Kendall analysis of annual peak streamflows observed between water years 1913 and 1999 indicates no significant monotonic trend. Similar analyses on peak streamflows separated into groups of low- to moderate-magnitude and high-magnitude annual peak streamflows also showed no significant monotonic trends for either group. Boxplots showing distributional characteristics of the partial-duration series of peak streamflows plus annual peak streamflows that did not exceed the base discharge of 4,000 ft^3/s indicate that the frequency and severity of flooding at the streamflow-gaging station historically have tended to be greater during late winter and early spring than at other times of the year.

A Mann-Kendall analysis of annual mean streamflows measured between water years 1926 and 1999 indicated a statistically significant upward trend with time, with a median rate of increase of 1.62 ft^3/s per year. Similarly, a Mann-Kendall analysis of annual 7-day low flows measured between climatic years 1927 and 1999 also indicated a statistically significant upward trend, with a median trend slope of 0.44 ft^3/s per year. Interpretation of the trend results for the annual 7-day low flows is complicated by the cessation of water withdrawals upstream from the gaging station in 1985, which could, by itself, lead to indications of trend; however, the shape of the locally weighted scatterplot smoothing (LOWESS) curve fit to the annual 7-day low-flow data suggests that the upward trend started well in advance of when water withdrawals were stopped. In fact, the eight highest annual 7-day low flows in the record occurred during the period 1974–82, before water withdrawals were stopped. Moreover, the indicated trend is consistent with regional increases in annual minimum streamflow reported by Lins and Slack (1999) at gaging stations not subject to confounding human influences.

Plots of the cumulative departure of annual precipitation from long-term (1897–1998) mean annual precipitation measured at the weather-observation station in Hiram, Ohio, show a relatively dry period extending from about 1910 to about 1968, followed by a relatively wet period extending from about 1968 to the late 1990s. A plot of cumulative departure of annual mean streamflow from the mean annual streamflow for the period including water years 1926–35, 1940–84, 1989–94, and 1996–99, closely mimics the shape of the precipitation departure plot, indicating that the increase in annual mean streamflow was caused largely by the increase in precipitation. The lack of an accompanying significant trend in peak streamflows suggests that the intensity and severity of flood-producing storms did not increase appreciably along with the increases in precipitation.

A Mann-Kendall analysis of point-of-zero-flow (PZF) measurements made between calendar years 1940 and 1993 indicates that the low-water control at the Chagrin River streamflow-gaging station tended to aggrade over time; however, the magnitude of the change in PZF was so small that its effect on stages of moderate to large floods would be negligible.

Stage values associated with reference streamflows of 500 and 5,000 ft^3/s tended to remain fairly stable from about 1950 to 1970 and then decreased slightly from about 1970 to 1980, suggesting that the flood-carrying capacity of the stream increased somewhat during the latter period. Since the large flood of May 26, 1989, the rating for the Chagrin River streamflow-gaging station has been subject to significant ongoing modification. The most recent rating indicates that stage values associated with streamflows of 500 and 5,000 ft^3/s are about 0.5 and 0.1 ft higher, respectively, than the pre-1989 levels.

The analyses summarized above do not support the hypothesis that systematic increases in the frequency and (or) severity of flooding have occurred with time at the Chagrin River streamflow-gaging station. The results do indicate, however, that there have been upward trends in annual mean streamflows and annual 7-day low flows and that those trends have resulted, at least in part, from increases in precipitation since the late 1960s.

Some trend results presented in this report are site-specific and, consequently, identified trends (or lack thereof) may not be equally applicable at other locations within the Chagrin River Basin. For example, trends in stream-channel characteristics can be very site-specific, whereas trends similar to those observed in mean annual streamflow at the Chagrin River streamflow-gaging station are likely to be applicable at points located some distance upstream and downstream of the gaging station. Even if peak streamflow characteristics remain unchanged at a site, local conditions can affect flood levels. For example, flooding at stream sites near Lake Erie can be exacerbated by high lake levels, and the addition or replacement of culverts or bridges can cause localized increases (or decreases) in flood levels depending on their design and construction.

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