ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS FOR WISCONSIN URBAN STREAMS

UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

Prepared in cooperation with the WISCONSIN DEPARTMENT OF TRANSPORTATION, SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION and MILWAUKEE METROPOLITAN SEWERAGE COMMISSION

ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS FOR WISCONSIN URBAN STREAMS

e.

By Duane H. Conger

Water-Resources Investigations Report 86–4005

Prepared by UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

Prepared in cooperation with the WISCONSIN DEPARTMENT OF TRANSPORTATION, SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION, and MILWAUKEE METROPOLITAN SEWERAGE COMMISSION

> Madison, Wisconsin December, 1986

UNITED STATES DEPARTMENT OF THE INTERIOR DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY Dallas L. Peck, *Director*

For additional information write to:

District Chief U.S. Geological Survey 6417 Normandy Lane Madison, Wisconsin 53719 Copies of this report can be purchased from:

Open-File Services Section Western Distribution Branch U.S. Geological Survey Box 25425, Federal Center Lakewood, Colorado 80225 (Telephone: (303) 234-5888)

CONTENTS

P	Page
Abstract	. 1
Introduction	. 1
Purpose and scope	. 1
Acknowledgments	. 1
Flood characteristics	. 4
Data collection	
Rainfall-runoff modeling	. 4
Flood-frequency analysis of gaged streams	. 5
Estimating magnitude and frequency of floods for ungaged streams	
Basin characteristics	
Regression analysis	.14
Flood-frequency equations	.15
Accuracy and limitations	.16
Alternate method for determining impervious area	.16
Application of equations	.17
Summary and conclusions	.18
References cited	.18

ILLUSTRATIONS

Figure	1.	Map showing location of gaging stations	2
-	2.	Graph showing observed and simulated hydrographs at Fisher Creek tributary at Janesville, Wis	14
	3.	Graph showing relation of simulated peak discharges to observed peak discharges for Fisher Creek tributary at Janesville, Wis	

TABLES

			Page
Table	1.	Annual peak stage and discharge data at rainfall-runoff gaging stations	5
	2.	Annual flood-peak discharges for Milwaukee crest-stage gages	
	3.	Flood discharges at selected recurrence intervals for urban gaging stations	
	4.	Drainage-basin characteristics for urban gaging stations	12
	5.	Flood-frequency equations for Wisconsin urban areas	
	6.	Flood-frequency equations for Milwaukee County	
	7.	Total impervious area (percent) within land-use categories	
	8.	Tabulation of total impervious area (/) for gaging station 05430403, Fisher Creek tributary at Janesville, Wis., using the alternative method	

Page

CONVERSION TABLE

The following factors may be used to convert the inch-pound units used in this report to metric (International System) units.

Multiply inch-pound unit	Ву	To obtain metric unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
square mile (mi²)	2.590	square kilometer (km²)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m³/s)
cubic foot per second per square mile [(ft ³ /s)/mi ²]	0.01093	cubic meter per second per square kilometer [(m³/s)/km²]

ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS FOR WISCONSIN URBAN STREAMS

By Duane H. Conger

ABSTRACT

Equations for estimating magnitude and frequency of floods for Wisconsin streams with drainage basins containing various amounts of existing or projected urban development were developed by flood-frequency and multiple-regression analyses.

Multiple-regression techniques were used to develop equations for estimating flood frequencies at ungaged urban sites. The flood-frequency equations are based on data from 32 urban gaging stations, including 19 crest-stage gages and 13 rainfall-runoff gaging stations. Significant characteristics in the equations are drainage area and impervious area. Standard errors of estimate for the regression equations ranged from 32 to 39 percent. Separate equations were developed for Milwaukee County. The U.S. Geological Survey Distributed Routing Rainfall-Runoff Model-Version II was used to extend records by synthesis for the 13 rainfall-runoff urban stations.

INTRODUCTION

Purpose and Scope

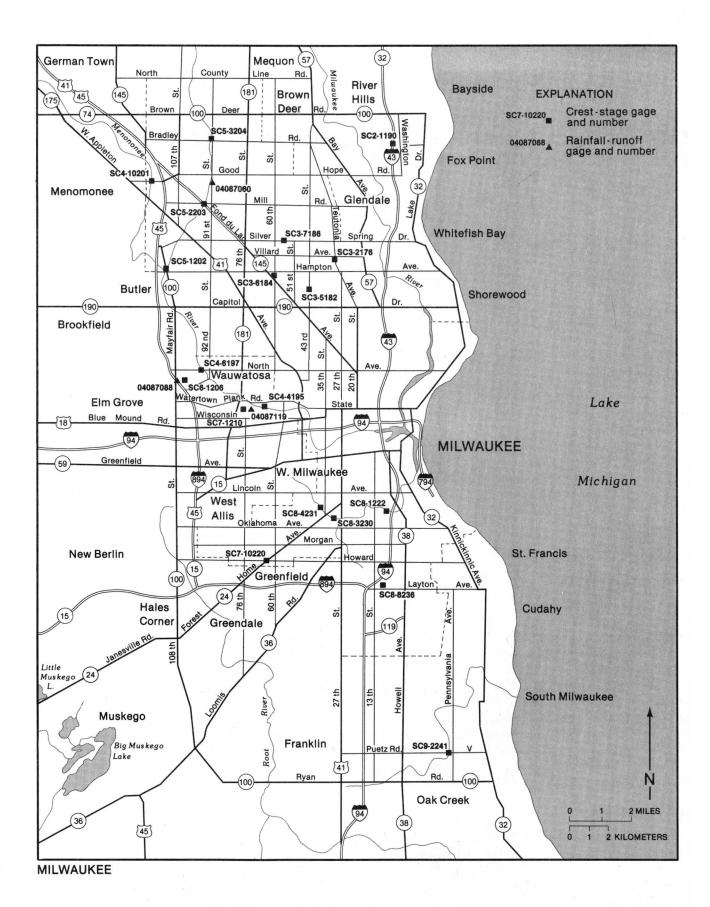
Estimates of flood frequencies and magnitudes are useful for planning and designing culverts, bridges, drainage systems, and for effective flood-plain management. This report provides a method for estimating the frequencies and magnitudes of floods of ungaged urban streams in Wisconsin.

Multiple-regression techniques were used to develop flood-frequency equations by relating flood frequency and magnitude characteristics for 32 sites to basin characteristics, such as drainage area and impervious area (fig. 1). The resulting equations can be used to estimate flood magnitudes of urban streams that lack significant diversion or regulation. The equations apply only to urban streams. Flood discharges for rural Wisconsin streams can be estimated using the techniques described by Conger (1981).

Annual peak data from 19 urban crest-stage gages with at least 12 years of record and annual synthesized long-term peaks from 13 urban rainfall-runoff gaging stations were included in the analysis to develop regional flood-frequency equations for urban areas in Wisconsin. Flood-frequency characteristics were estimated for these sites by the log-Pearson type III method described in the U.S. Water Resources Council Bulletin 17B (1981).

Acknowledgments

This report was prepared by the U.S. Geological Survey in cooperation with the State of Wisconsin, Department of Transportation, Division of Highways; the Southeastern Wisconsin Regional Planning Commission; and the Milwaukee Metropolitan Sewerage District. The crest-stage-gage stations in Milwaukee are maintained by the Milwaukee Metropolitan Sewerage District, and stage-discharge relations were developed by the U.S. Geological Survey. Long-term daily precipitation data and storm rainfall at 5-minute intervals were obtained from the National Oceanic and Atmospheric Administration.





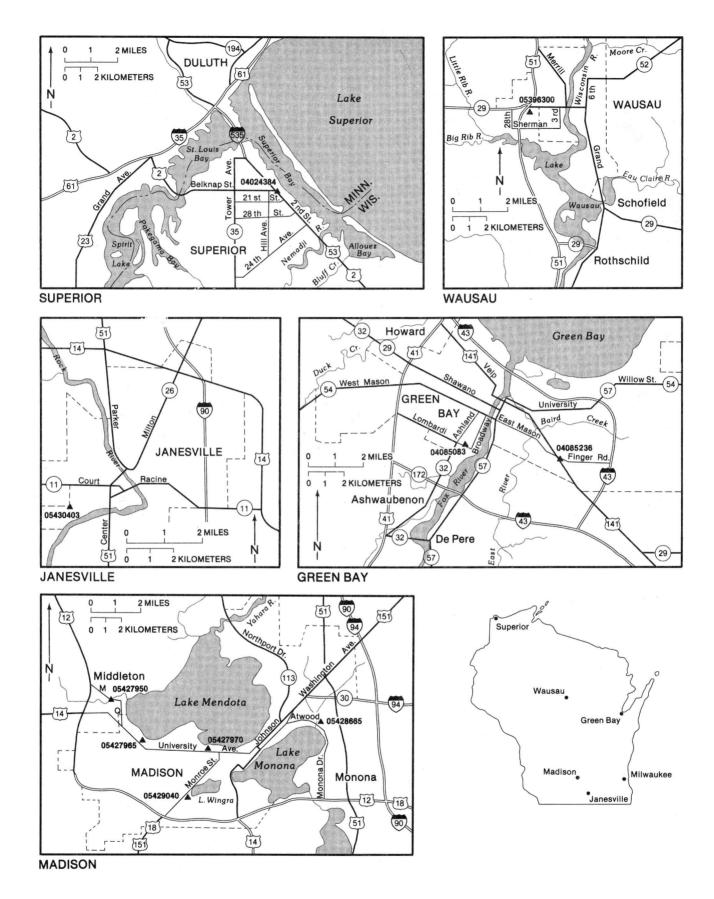


Figure 1. Location of gaging stations-Continued.

FLOOD CHARACTERISTICS

The flood discharges presented in this report are the Q_2 , Q_5 , Q_{10} , Q_{25} , Q_{50} , and Q_{100} . These are discharges at the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. Flood discharges are increased by the impervious area associated with urbanization. The lower flood frequencies usually have a significant increase in flood discharge as urbanization increases but the higher flood frequencies may have only a minor increase in flood discharge for the same situation. For example, when the drainage basin of the North Fork Pheasant Branch at Airport Road changed from a rural to a completely urbanized condition, the magnitude of the 2-year flood increased by 224 percent, whereas the magnitude of the 100-year flood increased by only 30 percent (Krug and Goddard, 1985).

Factors that affect urban flood discharges are conditions of the drainage channel, such as concrete-lined channels, presence and size of storm-sewer pipes, and size of drainage structures, such as culverts and bridges. Streams with concrete channels and connecting storm-sewer pipes can convey water faster than natural channels. These streams have the greatest effect on the lower flood frequencies. Water starts to go into storage when the channels and storm-sewer pipes are full and overflowing during the higher flood frequencies. This diminishes flood peaks because of constrictions created by storm-sewer pipes and culverts.

DATA COLLECTION

Data needed to develop the urban flood-frequency relations for this report were collected at 32 gaged urban sites in Wisconsin. Rainfall and runoff data, for use in a rainfall-runoff model, were obtained at 13 of these sites. The remaining 19 sites are instrumented with crest-stage gages that are maintained by the Milwaukee Metropolitan Sewerage District. The U.S. Geological Survey obtained discharge measurements at these sites and developed stage-discharge relations. Annual peak discharge data for the 32 urban sites are listed in tables 1 and 2.

Additional long-term records were used in the U.S. Geological Survey Distributed Routing Rainfall-Runoff Model – Version II (Alley and Smith, 1982) to extend the records for the 13 rainfall-runoff stations. Long-term daily precipitation data and storm rainfall data at 5-minute intervals were obtained from the National Oceanic and Atmospheric Administration for Madison, Wis.; Milwaukee, Wis.; Green Bay, Wis.; and Minneapolis, Minn. Daily evaporation data were obtained for stations at Arlington University Farm, Marshfield Experimental Farm, and Rainbow Reservoir in Wisconsin.

RAINFALL-RUNOFF MODELING

Long-term records of synthetic flood peaks were generated by the U.S. Geological Survey Distributed Routing Rainfall-Runoff Model – Version II (Alley and Smith, 1982). The model was used to simulate flood-peak data at 13 urban gaging stations where concurrent rainfall and runoff data were collected. Flood hydrographs were generated by the rainfall-runoff model for each station by using daily rainfall, daily evaporation, and unit discharge-rainfall data. The model consists of rainfall-excess components and routing components. The rainfall-excess components are soil-moisture accounting, pervious-area rainfall excess, impervious-area rainfall excess, and parameter optimization. The routing components are channel and overland-flow segments, reservoir segments, and nodal segments. The model has seven parameters – four control soil-moisture accounting and three control infiltration.

The model was calibrated using concurrent values of unit streamflow and unit precipitation, daily precipitation, and daily pan evaporation. The seven parameters are determined by an optimization process. Figure 2 is a plot of observed and simulated hydrographs for Fisher Creek tributary at Janesville and figure 3 is a plot of simulated peak discharges versus observed peak discharges for this site. The standard error of estimate for the plot in figure 3 is 26.5 (ft³/s).

A long-term series of flood peaks were simulated using the final optimized parameters with 67 to 83 years of long-term rainfall and evaporation data. Long-term rainfall and evaporation data used in the synthesis were selected according to the location of the National Weather Service sites relative to the rainfall-runoff stations and a study of past storm patterns.

FLOOD-FREQUENCY ANALYSIS OF GAGED STREAMS

Flood-frequency analyses are used to define the relation of flood-peak magnitude to probability of occurrence or to recurrence interval. Probability of occurrence is the percentage chance that a given flood magnitude will be equaled or exceeded in any one year. Recurrence interval is the reciprocal of the probability of occurrence times 100 and is the average number of years between occurrences. A flood having a probability of occurrence of 2 percent has a recurrence interval of 50 years. Recurrence intervals imply no regularity of occurrence; a 50-year flood may be exceeded in consecutive years or it might not be exceeded in a 50-year period.

Flood-frequency analyses were performed on the synthetic flood-peak data at each of the 13 rainfall-runoff stations and on annual peak data at each of the 19 crest-stage gages that had at least 12 annual flood events. Guidelines in U.S. Water Resources Council Bulletin No. 17B (U.S. Water Resources Council, 1981) were used to develop the flood-frequency relations. Estimates of the discharges for selected recurrence intervals for each station are given in table 3.

Table 1. Annual peak stage and discharge data at rainfall-runoff gaging stations

Station no (Station name Drainage area	Lake Superior tributa	ary at Superior, Wis.	e de la tra
Water year	Date	Gage height	Discharge
		(ft)	(ft ³ /s)
1981	Apr. 23, 1981	3.66	110
1982	July 9, 1982	4.80	298
1984	Sept. 24, 1984	3.67	122
Water year 1979 1980 1981	Date Aug. 9, 1979 Aug. 19, 1980 June 15, 1981	Gage height (ft) 14.75 14.84 13.51	Discharge (ft ³ /s) 152 160 97
1982	July 18, 1982	16.27	324
1983	Aug. 21, 1983	15.18	182
1984	July 11, 1984	15.98	290

Station no. -- 04085136 Station name -- Baird Creek tributary at Green Bay, Wis. Drainage area -- 1.22 mi²

Water year	Date	Gage height (ft)	Discharge (ft ³ /s)
1979	Aug. 9, 1979	13.73	110
1980	Aug. 14, 1980	15.09	203
1981	Aug. 14, 1981	13.51	97
1982	Aug. 3, 1982	18.19	485
1984	Sept. 1, 1984	16.23	410

Table 1. Annual peak stage and discharge data at rainfall-runoff gaging stations—Continued

Station no. -- 04087060 Station name -- Noyes Creek at Milwaukee, Wis. Drainage area -- 2.35 mi² Gage datum -- 710.00 ft above mean sea level Gage height Discharge Water year Date (ft) (ft^3/s) 1975 Aug. 22, 1975 6.06 152 1976 Mar. 4, 1976 6.44 215 June 11, 1977 269 1977 7.00 1978 322 July 2, 1978 7.52 Aug. 20, 1979 1979 320 7.50 Station no. -- 04087088 Station name -- Underwood Creek at Wauwatosa, Wis. Drainage area -- 19.1 mi² Gage datum -- 690.00 ft above mean sea level Discharge Water year Date Gage height (ft^3/s) (ft) 1975 Feb. 24, 1975 4.34 540 1976 Apr. 24, 1976 4.14 388 1977 Aug. 13, 1977 4.16 396 3.97 1978 320, Sept. 30, 1978 4.26 1979 Apr. 11, 1979 434 1980 Aug. 4, 1980 3.94 343 1981 July 13, 1981 5.55 2,100 579 1982 Apr. 3, 1982 4.46 1983 Apr. 2, 1983 4.19 378 1984 June 22, 1984 5.09 812 Station no. -- 04087119 Station name -- Honey Creek at Wauwatosa, Wis. Drainage area -- 10.7 mi² Gage datum -- 630.86 ft above mean sea level . Gage height Discharge Water year Date (ft^3/s) (ft) 1975 Apr. 28, 1975 15.47 810 1976 1,050 Mar. 4, 1976 16.19 1977 July 18, 1977 16.38 1,140 1978 May 13, 1978 15.78 894 1979 Mar. 30, 1979 14.90 815 1980 Sept. 9, 1980 15.84 1,240 1981 Apr. 10, 1981 14.85 846

1982 1983	Date July 30, 1981 June 24, 1982 July 19, 1983 Sept. 24, 1984	Gage height (ft) 5.43 5.72 5.08 5.52	Discharge (ft ³ /s) 117 135 79
1981 1982 1983	June 24, 1982 July 19, 1983	5.72 5.08 5.52	135 79
1982 1983	June 24, 1982 July 19, 1983	5.08 5.52	79
1983	July 19, 1983	5.52	
1983	July 19, 1983		117
1984	Sept. 24, 1984	0.07	117
		8.07	480
Gage datum 868.68 Water year	ft above mean se Date	a level Gage height	Discharge
		(ft)	(ft ³ /s)
1978	July 1, 1978	3.56	483
1979	July 21, 1979	1.65	100
1980	Mar. 16, 1980	2.26	195
1981	Sept. 1, 1981	3.14	370
Station no 05427 Station name Sprin Drainage area 3.50	ng Harbor storm s	ewer at Madison, Wis	

Water year	Date	Gage height (ft)	Discharge (ft ³ /s)
1976	Mar. 4, 1976	3.24	169
1977	July 18, 1977	3.70	572
1978	July 1, 1978	3.58	529
1979	Aug. 9, 1979	2.62	248
1980	Sept. 12, 1980	3.35	450
1981	Aug. 31, 1981	4.04	706
1982	Oct. 17, 1981	2.77	283
1983	Sept. 6, 1983	2.91	318
1984	June 9, 1984	3.90	650

•

Table 1.	Annual peak	stage ar	nd discharge	data at	rainfall-runoff	gaging
	stations-Co		•			

Table 1. Annual peak stage and discharge data at rainfall-runoff gaging stations – Continued

Station no. -- 05427970 Station name -- Willow Creek at Madison, Wis. Drainage area -- 3.12 mi² Gage datum -- 847.90 ft above mean sea level Gage height Discharge Water year Date (ft^3/s) (ft) Aug. 16, 1974 July 3, 1975 Aug. 14, 1976 July 18, 1976 1,600 1974 6.22 1,590 1975 6.21 5.54 766 1976 1,520 1977 1978 June 25, 1978 6.40 1,900 June 28, 1979 624 1979 6.11 1980 June 7, 1980 6.26 685 754 1981 Aug. 31, 1981 6.42 600 1982 6.16 511 1983 5.81 Sept. 6, 1983 Station no. -- 05428665 Station name -- Olbrich Park storm ditch at Madison, Wis. Drainage area -- 2.50 mi² Gage datum -- 860.00 ft above mean sea level Discharge Water year Gage height Date (ft^3/s) (ft) 1976 Mar. 4, 1976 6.67 154 1977 July 18, 1977 7.61 270 1978 June 25, 1978 10.37 480 306 1979 Aug. 5, 1979 7.99 244 Sept. 9, 1980 7.44 1980 ÷ Station no. -- 05429040 Station name -- Manitou Way storm sewer at Madison, Wis. Drainage area -- 0.22 mi^2 Gage datum -- 840.00 ft above mean sea level Gage height Discharge Water year Date (ft) (ft^3/s) Apr. 12, 1971 12.97 . 66 1971 Aug. 26, 1972 62 1972 12.88 Mar. 6, 1973 58 1973 12.79 1974 Oct. 10, 1973 12.76 56 108 1975 July 3, 1975 13.79 1976 June 23, 1976 36 12.20 72 1977 July 18, 1977 13.08

Station no 05430403 Station name Fisher Creek tributary at Janesville, Wis. Drainage area 1.88 mi ²								
Water year	Date	Gage height (ft)	Discharge (ft ³ /s)					
1981	Aug. 14, 1981	7.59	800					
1982	June 25, 1982	6.37	294					
1983	Nov. 1, 1982	6.09	222					
1984	Sept. 24, 1984	6.75	410					

Table 1. Annual peak stage and discharge data at rainfall-runoff gaging stations—Continued

ESTIMATING FLOOD-FREQUENCY CHARACTERISTICS AT UNGAGED SITES

Basin Characteristics

1

Many factors influence the flood discharges that occur in a drainage basin. In this study eight factors or basin characteristics were obtained for each urban gaging station. Multiple-regression techniques were used to relate these drainage-basin characteristics (independent variables) to 2-, 5-, 10-, 25-, 50-, and 100-year flood discharges. The drainage-basin characteristics used in the multiple-regression analysis are listed in table 4 and are defined as follows:

1. Drainage area (*A*), in square miles, is the area contributing to surface runoff into the stream. This area can be planimetered from topographic maps or obtained directly from the Wisconsin drainage-area report (Henrich, 1986). Special attention should be given to determining drainage area for storm-sewer networks that may not drain the same area as the natural drainage patterns. Failure to do this could result in inaccurate drainage-area determinations.

2. Main-channel slope (S), in feet per mile, is the slope of the stream between points that are 10 percent and 85 percent of the distance along the channel from the gaging station to the basin divide (determined from topographic maps).

3. Storage (ST), expressed as a percentage of the drainage area, includes lakes, ponds, and wetlands determined from Geological Survey maps and Soil Conservation Service data. A constant of 1 percent is added to each value of ST used in the regression equation to avoid zero values.

4. Mean annual precipitation (*PREC*), 1951-80 average, in inches, is determined from an isohyetal map furnished by the State Climatologist (written commun., 1984).

5. Precipitation intensity index (/24,2) (2-year, 24-hour rainfall), expressed in inches, is determined from U.S. Weather Bureau Technical Paper 40 (Hershfield, 1961).

6. Soil permeability (*SP*), a measure of the rate at which water can infiltrate soil, expressed in inches per hour, is based on the least permeable soil horizon. The median rate is used for each soil-permeability range. The soil-permeability ranges were obtained from a soils table published by the U.S. Department of Agriculture, Soil Conservation Service (1964). Soil permeability (*SP*) can be obtained by referring to a previous report (Conger, 1981, plate 1).

7. Impervious area (*I*), expressed as a percentage of the drainage area, represents the total impervious area of the basin. The method used to determine impervious area for single-family residential areas is to determine the average impervious area for each dwelling (including the rooftop, driveway, and sidewalks) and also to determine the average street width. The total number of dwellings is then counted and the total length of streets is measured. The total impervious area is calculated by multiplying the number of dwellings by the average impervious area per dwelling, and the total length of streets by the average street width.

8. Undeveloped urban area (UUA), expressed as a percentage of the total drainage area, represents undeveloped urban drainage area.

Station number <u>1</u> /	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
SC2-1190									140	270	295	250	520
SC3-2176	2,200		2,650		3,400	3,100	1,950	1,680	3,220	3,100	2,520	2,920	4,280
SC3-5182						3,750	1,190	1,940	3,740	2,800	2,480	2,740	1,600
SC3-6184	1,055		1,600		2,500	2,900		1,870	3,900	2,300	2,200	1,900	2,760
SC3-7186	375		325		475	400	325	400		130	280		230
SC4-4195								1,600	4,100	3,000	2,850	2,200	5,400
SC4-6197									1,240		1,160	1,100	1,850
SC4-10201									980	1,420	1,120	1,200	2,160
5C5-1202											690	710	1,100
C5-2203									340	380	240	120	500
C5-3204												300	440
C6-1206													1,200
SC7-1210								670	1,070	1,070	1,030	920	1,280
SC7-10220										120			
SC8-1222									2,060	2,310	1,650	1,640	2,350
SC8-3230									1,800	2,200	1,800	1,800	3,670
5C8-4231									1,060	1,100	790	780	1,610
SC8-8236									860	1,090	800	660	630
SC9-2241	1,100								625	310	360	460	800
Station number 1/	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	
SC2-1190	1,040	310	270	540	80	800	380	450	320	1,000	380	710	
SC3-2176	3,920	1,260	1,120	1,760	3,040	2,700	2,320	2,240	3,600	1,300	4,200		
SC3-5182	4,710	2,740	1,200	1,740	2,700	2,700	2,440	2,360	4,000	1,700	3,200	2,880	
SC3-6184	3,900	1,520	1,650	1,920	2,170	2,820	2,620	2,470	3,600	1,920	2,980	3,750	
SC3-7186		130	220	280	175	220		380	200				
SC4-4195	13,100	2,400			2,500	3,700	2,500	2,300	4,800	2,400	5,450	2,300	
SC4-6197	3,680	1,150	2,900	1,030	1,040	2,250	1,430	1,160	2,180	2,900	2,900	1,380	
SC4-10201	2,200	1,410		1,700	1,020	2,100		1,820	1,780	1,480	1,240	1,200	
SC5-1202	1,370	800	1,460	830	390	1,460	1,460	900	810	1,050	940	1,100	
SC5-2203	1,380	440	430	440	320	600	380	340	700	420	520	440	
C5-3204	560	320	260	250	190	240	250	210	240	325		440	
C6-1206	4,880	1,200	1,350	1,110	1,120	830	2,980	880	1,210	675	1,575	1,125	
SC7-1210	1,400	1,050	1,030	1,060	1,050	1,040	760	1,850	1,200	920	1,000	1,040	
C7-10220		260	240	330	390	340	250	370	480	350	1,040	380	
C8-1222	4,500				4,790	2,650	3,370	3,580	4,290	2,360	2,400		
C8-3230	4,230	1,400	1,400	1,350	2,630	2,000	1,500	1,840	2,300	1,400			
C8-4231	1,490	480	500	640	780	520	400	720	840	430	980	470	
											5 A 1		
SC8-8236	1,170	740	980	880	960	900	880	1,120	900	760	740	600	

Table 2. Annual flood peak discharges for Milwaukee crest-stage gages

1/ The first four or five digits of each crest-stage gage station number represent the Milwaukee Metropolitan Sewerage Commission station number and the last three digits of the station number represent the city of Milwaukee station number. Station number SC5-3205 references the Milwaukee Metropolitan station number SC5-3 and the city of Milwaukee station number 205.

4

Table 3. Flood discharges at selected recurrence intervals for urban gaging stations

Number // Image is a subscription of the start of the st								
Baperior, Mar. Solution of the second s		Station name	Q2	Q ₅	Q ₁₀	Q ₂₅	Q ₅₀	Q100
Outeen Bay, Wit. Did Office at Filmsary at Oreen Bay, Wit. Dis of Creek at Filmsake, Wit. Dis of Creek at Minuske, Wit. <thdis at="" creek="" minuskee,="" of="" th="" wit.<=""> Di</thdis>	04024384		138	301	428	598	726	853
Orean Bay, Mis. Orean Bay, Mis. Orean Bay 04007000 Noyee Creek at Muhamban, Mis. 273 473 616 810 982 04007008 Numerosci, Mis. 472 1,036 1,544 2,348 3,060 04087139 Henney Creek at Muhamban, Mis. 940 1,307 1,551 1,860 2,090 04087000 Phasant Funch Lanchary Avenue 104 303 548 759 923 05427900 Phasant Funch Lanchary Avenue 104 303 548 759 923 05427900 Phasant Funch Lanchary Avenue 104 303 568 759 923 05427970 Willow Creek at Madison, Wis. 341 556 700 681 1,032 05428040 Renitou May storn sever at Misaidson, Wis. 341 586 700 833 412 054380403 Picher Creek tributary at Jance Top Fold, Wis. 31 82 102 126 147 054204003 Picher Creek tributary at Jance Top Fold, Wis. 350	04085083		153	202	230	259	278	295
04067088 Underwood Creek at Wauwatosa. 472 1,030 1,546 2.346 3.000 040677110 Diney Creek at Wauwatosa. Wis. 940 1,307 1,551 1.800 2.000 05396300 Wisconsin River tribustry 100 208 280 380 458 05427050 Phesantk Franch at Contury Arenue 194 393 5.64 7.79 923 05427050 Phesantk Franch at Madison. 341 555 700 881 1.012 05427070 Willow Creek at Madison. 341 556 700 881 1.012 05427070 Willow Creek at Madison. 341 556 700 881 1.012 05428040 Madison. Mis. 341 556 700 881 1.012 05429040 Madison. Mis. 216 204 338 383 412 05439040 Pieber Creek tribetary at 216 204 380 4.560 4.980 052-5128	04085236		113	176	223	286	337	389
Wis. Non- Wis. 940 1.307 1.551 1.860 2.000 05395300 Wiscomain River tribuatry 100 206 280 380 458 05427500 Phessant Branch at Contry Avenue 104 303 548 759 923 05427600 Spring Harbor stors sever at Mis. 255 330 744 1.037 1.264 05427601 Willow Creek at Mediaon, Wis. 341 555 700 881 1.032 05427602 Olf-tch Pack store ditch at Madiaon, Wis. 341 555 700 881 1.032 05426040 Manitou May storn sever at Madiaon, Wis. 341 204 338 383 412 05426040 Madiaon, Wis. 214 294 338 383 412 05426040 Madiaon, Wis. 250 3.405 3.900 4.540 4.980 SG2-1180 Incoln Creek at North Foton 2.580 3.465 3.900 4.540 4.980 SG2-1180 Incoln Creek at North Street 3.100	04087060	Noyes Creek at Milwaukee, Wis.	279	473	616	810	962	1,119
S6386300 Wisconsin River tribustry at Wannan, Mis. 100 206 280 380 488 05427080 Phessant Bruch at Century Avenue at Middloon, Wis. 104 303 548 759 923 05427080 Spring Harbor storm sever at Madison, Wis. 341 556 700 851 1.037 1.264 05427070 Willew Creek at Madison, Wis. 341 556 700 851 3.012 05427080 Madison, Wis. 341 556 700 851 3.012 05427090 Willew Creek at Madison, Wis. 341 556 700 851 3.012 05427090 Madison, Wis. 341 556 700 851 3.012 05427090 Madison, Wis. 341 556 760 970 3.130 05427090 Missione River Rorb Phessant Janesville, Wis. 2.500 3.465 3.990 4.560 4.960 0525-5182 bincoln Creek at North Stherean Street at Missikee, Wis. 2.300 3.120 3.560 4.500 <t< td=""><td>04087088</td><td></td><td>472</td><td>1,036</td><td>1,546</td><td>2,348</td><td>3,060</td><td>3,873</td></t<>	04087088		472	1,036	1,546	2,348	3,060	3,873
at Wausen, Mis. 05427060 Phessont Branch at Contury Avenue 194 303 548 759 923 05427060 Spring Harbor store sever at Middleon, Mis. 341 555 530 744 1.037 1.264 05427070 Willow Creek at Madison, Mis. 341 555 700 861 1.012 05427070 Willow Creek at Madison, Mis. 341 555 700 861 1.012 05428040 Maniton Way store sever at Madison, Mis. 341 294 338 383 412 05430403 Flahen Creek tributary at Janesville, Wis. 214 294 338 383 412 052-2170 Indian Creek nar North Phessont Scient Scie	04087119	Honey Creek at Wauwatosa, Wis.	940	1,307	1,551	1,860	2,090	2,320
at Middleton, Wis. D5427065 Spring Harbor storm sever at distorn, Mis. 255 530 744 1,037 1,264 D5427070 Willow Creek at Madison, Mis. 341 556 700 851 3,012 D5427070 Willow Creek at Madison, Mis. 341 556 700 851 3,012 D5428655 Olbrich Park storm ditch at Madison, Mis. 209 361 477 636 764 D5429040 Maniton May storm sewer at Madison, Mis. 51 82 102 128 147 D5430603 Pinch Creek tributary at Janesville, Wis. 214 204 338 383 412 D5430603 Pinch Creek to North Pottspeant Janesville, Wis. 350 590 760 970 1.130 SC2-1190 Inclin Creek at North Shresan Boulevard at Milwakee, Wis. 2.520 3.410 3.980 4.540 4.980 SC3-5182 Lincoln Creek at North Shresan Boulevard at Milwakee, Wis. 2.580 3.120 3.560 1.420 500 500 500 SC4-6197 Mennoanee River at Milwakee, Wis. 3.160 4.970 6.380	05396300		100	206	280	380	458	538
Nadieon, Wis. Nadieon, Wis. S41 S56 TOO B81 1.012 05427970 Willew Creek at Madieon, Wis. S41 S56 TOO B81 1.012 05428065 Olbrich Park storm ditch at 209 361 477 G36 764 05432040 Madieon, Wis. S1 S2 102 128 147 05432040 Pisher Creek tributary at Janeaville, Wis. 214 294 S38 S83 412 054320403 Pisher Creek tributary at Janeaville, Wis. 216 294 S38 S83 412 054320403 Pisher Creek tributary at Janeaville, Wis. S50 760 970 1.130 S62-1190 Indian Creek at North Teutonia 2.560 3.465 3.960 4.560 4.980 S63-5182 Lincoln Creek at North S0th 2.380 3.120 3.560 4.070 4.420 S63-5184 Lincoln Creek at North S1. 2.380 3.120 3.560 1.000 1 S63-6184 Lincoln Cr	05427950		194	393	548	759	923	1,090
05428655 Olbrich Park storm ditch at Madison, Mis. 209 361 477 636 764 05428040 Manitou Way storm sewer at Madison, Mis. 51 82 102 128 147 054280403 Pisher Creek tributary at Janeaville, Mis. 214 294 338 383 412 054320403 Pisher Creek tributary at Janeaville, Mis. 350 590 760 970 1.130 SC2-1190 Indian Creek near North Pleasant Lane at Fox Point, Mis. 2.580 3.465 3.990 4.580 4.980 SC3-5182 Lincoln Creek at North Sherman Boulevard at Milwaukee, Wis. 2.380 3.120 3.680 4.070 4.420 SC3-6184 Lincoln Creek at North Sherman Street at Milwaukee, Wis. 270 370 430 500 550 SC4-6184 Nentsets Street at Maumatoes, Wis. 1.660 2.410 2.640 3.640 4.190 SC4-10201 Menomonee River at Sorth Maumatoes, Wis. 1.660 2.070 2.340 2.530 SC4-10201 Menomonee River at West Maumatoes, Wis. <	05427 9 65		255	530	744	1,037	1,264	1,495
Madison, Mis. D5422040 Manitou Nay storm sever at Madison, Mis. 51 52 102 128 147 D54320403 Pisher Creek tributary at Janswills, Mis. 214 294 338 383 412 D54320403 Pisher Creek tributary at Janswills, Mis. 350 590 760 970 1.130 SC3-2176 Bincoln Creek at North Phessent Boulevard at Milwaukee, Mis. 2.500 3.465 3.990 4.540 4.980 SC3-6184 Lincoln Creek at North Oth 2.380 3.120 3.550 4.070 4.420 SC3-6184 Lincoln Creek at North Oth 2.380 3.120 3.560 10.000 1 SC3-7186 Lincoln Creek at North Oth 2.380 3.120 3.640 4.960 SC4-1950 Menomenee Hiver ast Silver 270 370 430 500 10 SC4-1950 Menomenee River at Good Hope 1.480 1.850 2.070 2.340 2.530 SC4-10201 Menomenee River at West 100 1.260 1.420	05427970	Willow Creek at Madison, Wis.	341	556	700	881	1,012	1,140
Medison, Wis. 05430403 Pisher Creek tributary at Janesville, Wis. 214 294 338 383 412 05430403 Pisher Creek tributary at Janesville, Wis. 350 590 760 970 1,130 SC2-1190 Indian Creek nat North Preutonia 2,560 3,465 3,990 4,560 4,980 SC3-5182 Lincoln Creek at North Sherman 2,520 3,410 3,930 4,540 4,980 SC3-5182 Lincoln Creek at North Oth Boulevard at Milwaukee, Wis. 2,380 3,120 3,560 4,070 4,420 SC3-5184 Lincoln Creek at North Oth Street at Milwaukee, Wis. 270 370 430 500 550 SC4-4195 Menomome River east side of North 68th Street at Waumatosa. 3,180 4,970 6,360 8,380 10.000 1 SC4-1020 Menomome River at Kest North Avenue at Milwaukee, Wis. 1,660 2,410 2,940 3,840 4,190 SC5-1202 Little Menomone River at West Milwaukee, Wis. 1,480 1,650 2,070 2,340 2,530	05428665		209	361	477	636	764	898
Janesville, Wis. SC2-1190 Indian Creek near North Pheasant 350 590 760 970 1,130 SC3-2176 Lincoln Creek at North Feutonia 2,560 3,465 3,990 4,580 4,980 SC3-2176 Lincoln Creek at North Shrman 2,520 3,410 3,980 4,540 4,960 SC3-5182 Lincoln Creek at North Shrman 2,520 3,410 3,980 4,540 4,960 SC3-5182 Lincoln Creek at North Shrman 2,520 3,410 3,980 4,540 4,960 SC3-5182 Lincoln Creek at North Shrman 2,520 3,410 3,980 4,540 4,960 SC3-5182 Lincoln Creek at Misukkee, Wis. 270 370 430 500 550 SC4-1985 Menosonee River at Sold of Misukace, Wis. 1,660 2,410 2,940 3,640 4,190 Avenue at Muwakosa, Wis. 1,480 1,880 2,070 2,340 2,530 SC4-10201 Menosonee River at West 990 1,260 1,420 1,	05429040		51	82	102	1 28	147	165
Lane at Por Point, Wis. SC3-2176 Lincoln Creek at North Testonia 2.560 3.465 3.990 4.580 4.980 SC3-5182 Lincoln Creek at North Shrman Boulevard at Milwaukee, Wis. 2.520 3.410 3.980 4.540 4.980 SC3-5182 Lincoln Creek at North Shrman Boulevard at Milwaukee, Wis. 2.520 3.410 3.980 4.540 4.980 SC3-5184 Lincoln Creek at North Sorth 60th Street at Milwaukee, Wis. 2.70 370 430 500 550 SC4-4195 Menomone River at side of North 68th Street at Wauwatosa, Wis. 3.180 4.870 6.380 8.350 10.000 1 SC4-6197 Menomonee River at West North Avenue at Mauwatosa, Wis. 1.660 2.410 2.940 3.640 4.190 SC5-1202 Little Menomone River at West Nilwaukee, Wis. 1.480 1.850 2.070 2.340 2.530 SC5-2203 Little Menomone River at West Milwaukee, Wis. 990 1.280 1.420 1.610 1.740 SC5-3204 Little Menomone River at West Milwaukee, Wis. 2.90 385 <td>05430403</td> <td></td> <td>214</td> <td>294</td> <td>338</td> <td>383</td> <td>412</td> <td>437</td>	05430403		214	294	338	383	412	437
Avenue at Milwaukee, Mis. Avenue at Milwaukee, Mis. Avenue at Milwaukee, Mis. SC3-5182 Lincoln Creek at North Sherman Boulevard at Milwaukee, Mis. 2,320 3,410 3,930 4,540 4,960 SC3-6184 Lincoln Creek at North Goth Street at Milwaukee, Wis. 2,380 3,120 3,560 4.070 4,420 SC3-7186 Lincoln Creek at West Silver 270 370 430 500 550 SC4-4195 Menomonee River east side of North 68th Street at Wauwatosa, Wis. 3,180 4,970 6,360 8,360 10,000 1 SC4-6197 Menomonee River at Good Hope Nord at Milwaukee, Wis. 1,660 2,410 2,940 3,640 4,190 SC4-10201 Menomonee River at Good Hope Nod at Milwaukee, Wis. 1,480 1,680 2,070 2,340 2,530 SC5-1202 Little Menomonee River at west Mill Road and Old Fond du Lac Avenue at Milwaukee, Wis. 430 610 740 920 1,060 SC5-1202 Little Menomone River at West Mill Road at Milwaukee, Wis. 290 385 445 520 580 SC6-12	SC2-1190		350	590	760	970	1,130	1,290
Boulevard at Milwaukee, Wis. SC3-6184 Lincoln Creek at North 60th 2,380 3,120 3,560 4,070 4,420 SC3-7186 Lincoln Creek at Weis Silver 270 370 430 500 550 SC4-7186 Lincoln Creek at Weis Silver 270 370 430 500 550 SC4-4195 Menomone River east side of Morth 66th Street at Maumatosa, Wis. 3,180 4,970 6,360 8,350 10,000 1 SC4-6197 Menomone River at West North Avenue at Wauwatosa, Wis. 1,660 2,410 2,940 3,640 4,180 SC4-10201 Menomone River at Good Hope Net Maukee, Wis. 1,480 1,680 2,070 2,340 2,530 SC5-1202 Little Menomone River at west side of Highway 100 at Milwaukee, Wis. 990 1,260 1,420 1,610 1,740 SC5-2203 Little Menomone River at West Mill Road and Old Fond du Lac Avenue at Milwaukee, Wis. 290 385 445 520 580 SC6-3204 Little Menomone River at West Or Creek 300 ft west of Parkway anorhwest of 72nd Street at Wauwatosa, Wis. <t< td=""><td>SC3-2176</td><td></td><td>2,560</td><td>3,465</td><td>3,990</td><td>4,580</td><td>4,980</td><td>5,340</td></t<>	SC3-2176		2,560	3,465	3,990	4,580	4,980	5,340
Street at Milwaukee, Wis. SC3-7186 Lincoln Creek at West Silver Street at Milwaukee, Wis. 270 370 430 500 550 SC4-4195 Menomone River assiside of North 63th Street at Wauwatosa, Wis. 3,180 4,970 6,360 8,350 10,000 1 SC4-6197 Menomonee River at West North Wauwatosa, Wis. 1,660 2,410 2,940 3,640 4,180 SC4-10201 Menomonee River at West North Avonue at Milwaukee, Wis. 1,660 1,850 2,070 2,340 2,530 SC4-10201 Menomonee River at West ide of Highway 100 at Milwaukee, Wis. 1,480 1,850 2,070 2,340 2,530 SC5-1202 Little Menomonee River at West ide of Highway 100 at Milwaukee, Wis. 1,260 1,420 1,610 1,740 SC5-2203 Little Menomonee River at West Milwaukee, Wis. 290 385 445 520 580 SC5-3204 Little Menomonee River at West Milwaukee, Wis. 2,900 2,630 3,460 4,160 SC6-1208 Underwood Creek 300 ft west of Parkway northwest of 72nd Street at Wauwatosa, Wis. 1,050	SC3-5182		2,520	3,410	3,930	4,540	4,960	5,350
Street at Milwaukee, Wis. SC4-4195 Mencomone River east side of North 85th Street at Wauwatosa, Wis. 3,180 4,970 6,360 8,350 10,000 1 SC4-6197 Mencomone River at West North Avenue at Mauwatosa, Wis. 1,660 2,410 2,940 3,640 4,190 SC4-6197 Mencomone River at West North Avenue at Mauwatosa, Wis. 1,660 2,410 2,940 3,640 4,190 SC4-6197 Mencomone River at Good Hope Road at Milwaukee, Wis. 1,480 1,850 2,070 2,340 2,530 SC5-1202 Little Mencomone River at west side of Righway 100 at Milwaukee, Wis. 990 1,260 1,420 1,610 1,740 SC5-2203 Little Mencomone River at West Milwaukee, Wis. 290 385 445 520 580 SC5-3204 Little Mencomone River at West Bradley Road at Milwaukee, Wis. 290 3.040 4.180 4.180 SC6-1206 Underwood Creek 300 ft west of cul de sac of West Fisher Parkway northwest of 72nd Street at Mauwatosa, Wis. 1,050 1,270 1,400 1.550 1.670 SC7-10220 Honey Creek at Honey Creek Mise Avenue at Milwaukee, Wis. 335 510 635	SC3-6184		2,380	3,120	3,560	4,070	4,420	4,740
North 88th Street at Wauwatosa, Wis. SC4-6197 Menomonee River at West North Avenue at Wauwatosa, Wis. 1,660 2,410 2,940 3,640 4,190 SC4-10201 Menomonee River at Good Hope Road at Milwaukee, Wis. 1,480 1,850 2,070 2,340 2,530 SC5-1202 Little Menomonee River at west side of Highway 100 at Milwaukee, Wis. 990 1,260 1,420 1,610 1,740 SC5-2203 Little Menomonee River at West Mill Road and Old Yond du Lac Avenue at Milwaukee, Wis. 430 610 740 920 1,060 SC5-3204 Little Menomonee River at West Bradley Road at Milwaukee, Wis. 290 385 445 520 580 SC6-1206 Underwood Creek 300 ft west of Date of West of 1,290 2,040 2,630 3,460 4,160 SC7-1210 Honey Creek at Binher Parkway at Wauwatosa, Wis. 1,050 1,270 1,400 1.550 1.670 SC7-10220 Honey Creek at Money Creek Mis. 335 510 635 800 930 SC8-1222 Kinnickinnic River at South Home Avenue at Milwaukee, Wis. 1,940 <	SC3-7186		270	370	430	500	550	600
Avenue at Wauwatosa, Wis. 1.480 1.850 2.070 2.340 2.530 SC4-10201 Menomonee River at Good Hope Road at Milwaukee, Wis. 1.480 1.850 2.070 2.340 2.530 SC5-1202 Little Menomonee River at west side of Highway 100 at Milwaukee, Wis. 990 1.260 1.420 1.610 1.740 SC5-2203 Little Menomonee River at West Milwaukee, Wis. 430 610 740 920 1.060 SC5-2203 Little Menomonee River at West Milwaukee, Wis. 290 385 445 520 580 SC5-3204 Little Menomonee River at West Bradley Road at Milwaukee, Wis. 290 2.040 2.630 3.460 4.160 SC6-1206 Underwood Creek 300 ft west of cul de sac of West Pisher Parkway at Wauwatosa, Wis. 1.050 1.270 1.400 1.550 1.670 SC7-1210 Honey Creek at Honey Creek Mis. 335 510 635 800 930 SC8-1222 Kinnickinnic River at South Home Avenue at Milwaukee, Wis. 2.760 3.730 4.350 5.120 5.690 SC8-1222 Kinnickinnic River at South 28th Street at Milwaukee, Wis. 1.940 2.6	SC4-4195	North 68th Street at	3,180	4,970	6,360	8,350	10,000	11,800
Road at Milwaukee, Wis. 1.260 1.420 1.610 1.740 SC5-1202 Little Menomonee River at west side of Highway 100 at Mill Road and 01d Yond du Lac Avenue at Milwaukee, Wis. 930 1.260 1.420 1.610 1.740 SC5-2203 Little Menomonee River at West Mill Road and 01d Yond du Lac Avenue at Milwaukee, Wis. 430 610 740 920 1.060 SC5-3204 Little Menomonee River at West Bradley Road at Milwaukee, Wis. 290 385 445 520 580 SC6-1206 Underwood Creek 300 ft west of oul de sae of West Pisher Parkway at Wauwatosa, Wis. 1,290 2.040 2.630 3.460 4.180 SC7-1210 Honey Creek at Honey Creek Street at Mauwatosa, Wis. 1,050 1,270 1,400 1.550 1.670 SC7-10220 Honey Creek at West Forest Home Avenue at Milwaukee, Wis. 335 510 635 800 930 SC8-1222 Kinnickinnic River at South 7th Street at Milwaukee, Wis. 2.760 3.730 4.350 5.120 5.690 SC8-3230 Kinnickinnic River at South 29th Street at Milwaukee, Wis. 735 1.050 1.260 1.540 1.750 SC8-4231 Kinn	SC4-6197		1,660	2,410	2,940	3,640	4,190	4,750
side of Highway 100 at Milk Waukee, Wis. SC5-2203 Little Menomonee River at West 430 610 740 920 1,060 Milk Road and Old Pond du Lac Avenue at Milwaukee, Wis. 290 385 445 520 580 SC5-3204 Little Menomonee River at West 290 385 445 520 580 SC6-1206 Underwood Creek 300 ft west of 1,290 2,040 2,630 3,460 4,180 cul de sac of West Pisher Parkway at Wauwatosa, Wis. 1,050 1,270 1,400 1.550 1.670 SC7-1210 Honey Creek at Honey Creek 1,050 1,270 1,400 1.550 1.670 SC7-10220 Honey Creek at West Forest 335 510 635 800 930 SC8-1222 Kinnickinnic River at South 2,760 3,730 4,350 5,120 5.690 SC8-3230 Kinnickinnic River at South 1,940 2,620 3,090 3,700 4,180 SC8-4231 Kinnickinnic River at Jackson 735 1,050 1,260 1,540 1,750 SC8-62	SC4-10201		1,480	1,850	2,070	2,340	2,530	2,710
Nill Road and Old Fond du Lac Avenue at Milwaukee, Wis. SC5-3204 Little Menomonee River at West 290 385 445 520 580 SC6-1206 Underwood Creek 300 ft west of l.290 2.040 2.630 3.460 4.160 SC6-1206 Underwood Creek 300 ft west of l.290 2.040 2.630 3.460 4.160 SC7-1210 Honey Creek at Honey Creek 1.050 1.270 1.400 1.550 1.670 Parkway at Wauwatosa, Wis. SC7-10220 Honey Creek at Honey Creek 335 510 635 800 930 SC7-10220 Honey Creek at West Forest Honey Creek at Milwaukee, Wis. 2.760 3.730 4.350 5.120 5.690 SC8-1222 Kinnickinnic River at South Street at Milwaukee, Wis. 1.940 2.620 3.090 3.700 4.180 SC8-3230 Kinnickinnic River at Jackson Park Drive at Milwaukee, Wis. 735 1.050 1.260 1.540 1.750 SC8-4231 Kinnickinnic River at South Street at Milwaukee, Wis. 735 1.050 1.260 1.540	SC5-1202	side of Highway 100 at	990	1,260	1,420	1,610	1,740	1,870
Bradley Road at Milwaukee, Wis. SC6-1206 Underwood Creek 300 ft west of oil de sac of West Pisher Parkway at Wauwatosa, Wis. 1,290 2,040 2,630 3,460 4,180 SC7-1210 Honey Creek at Honey Creek 1,050 1,270 1,400 1,550 1,670 Parkway northwest of 72nd Street at Wauwatosa, Wis. 1,050 1,270 1,400 1,550 1,670 SC7-10220 Honey Creek at West Forest Mis. 335 510 635 800 930 SC8-1222 Kinnickinnic River at South 7th Street at Milwaukee, Wis. 2,760 3,730 4,350 5,120 5,690 SC8-3230 Kinnickinnic River at South 1,940 2,620 3,090 3,700 4,180 SC8-4231 Kinnickinnic River at Jackson Park Orive at Milwaukee, Wis. 735 1,050 1,260 1,540 1,750 SC8-8236 Kinnickinnic River at South 6th 855 1,000 1,180 1,240	SC5-2203	Mill Road and Old Fond du Lac	430	610	740	920	1,060	1,210
cul de sac of West Pisher Parkway at Wauwatosa, Wis.SC7-1210Honey Creek at Honey Creek1,0501,2701,4001,5501,670Parkway northwest of 72nd Street at Wauwatosa, Wis.1,0501,2701,4001,5501,670SC7-10220Honey Creek at West Forest Home Avenue at Milwaukee, Wis.335510635800930SC8-1222Kinnickinnic River at South 7th Street at Milwaukee, Wis.2,7603,7304,3505,1205,690SC8-3230Kinnickinnic River at South 29th Street at Milwaukee, Wis.1,9402,6203,0903,7004,180SC8-4231Kinnickinnic River at Jackson Park Drive at Milwaukee, Wis.7351,0501,2601,5401,750SC8-8236Kinnickinnic River at South 6th8551,0001,0801,1801,240	SC5-3204		290	385	445	520	580	635
Parkway northwest of 72nd Street at Wauwatosa, Wis. SC7-10220 Honey Creek at West Forest Home Avenue at Milwaukee, Wis. 335 510 635 800 930 SC8-1222 Rinnickinnic River at South 7th Street at Milwaukee, Wis. 2,760 3,730 4,350 5,120 5,690 SC8-3230 Kinnickinnic River at South 29th Street at Milwaukee, Wis. 1,940 2,620 3,090 3,700 4,180 SC8-4231 Kinnickinnic River at Jackson Park Drive at Milwaukee, Wis. 735 1,050 1,260 1,540 1,750 SC8-6236 Kinnickinnic River at South 6th 855 1,000 1,080 1,180 1,240	5C6-1206	cul de sac of West Fisher	1, 290	2,040	2,630	3,460	4,160	4,920
Home Avenue at Milwaukee, Wis. SC8-J222 Kinnickinnic River at South 2,760 3,730 4,350 5,120 5,690 SC8-J222 Kinnickinnic River at South 2,760 3,730 4,350 5,120 5,690 SC8-J223 Kinnickinnic River at South 1,940 2,620 3,090 3,700 4,180 SC8-4231 Kinnickinnic River at Jackson 735 1,050 1,260 1,540 1,750 Park Drive at Milwaukee, Wis. SC8-8236 Kinnickinnic River at South 6th 855 1,000 1,080 1,180 1,240	SC71210	Parkway northwest of 72nd	1,050	1,270	1,400	1,550	1,670	1,770
7th Street at Milwaukee, Wis. SC8-3230 Kinnickinnic River at South 1,940 2,620 3,090 3,700 4,180 29th Street at Milwaukee, Wis. 29th Street at Milwaukee, Wis. 3000 1,260 1,540 1,750 SC8-4231 Kinnickinnic River at Jackson 735 1,050 1,260 1,540 1,750 SC8-4235 Kinnickinnic River at Milwaukee, Wis. 3000 1,080 1,180 1,240	SC7-10220		335	510	635	800	930	1,060
29th Street at Milwaukee, Wis. 3C8-4231 Kinnickinnic River at Jackson 735 1,050 1,260 1,540 1,750 Park Drive at Milwaukee, Wis. 3C8-8236 Kinnickinnic River at South 6th 855 1,000 1,080 1,180 1,240	SC81222		2,760	3,730	4,350	5,120	5,690	6,240
Park Drive at Milwaukee, Wis. 3C8-8236 Kinnickinnic River at South 6th 855 1,000 1,080 1,180 1,240	SC83230		1,940	2,620	3,090	3,700	4,180	4,660
3C8-8236 Kinnickinnic River at South 6th 855 1,000 1,080 1,180 1,240	SC8-4231	Kinnickinnic River at Jackson	735	1,050	1,260	1,540	1,750	1,960
berdet de Hirkdunee, His.	3C8-8236		855	1,000	1,080	1,180	1,240	τ,300
6C9-224] Oak Creek at East Puetz Road 460 650 780 945 1,070 at Oak Creek, Nis.	SC9-2241		460	650	780	945	1,070	1,200

[Crest-stage gage stations are indicated by numbers prefixed SC]

 $1^{/}$ The first four or five digits of each creat-stage gage station number represent the Milwaukee Metropolitan Sewerage Commission station number and the last three digits of the station number represent the city of Milwaukee station number. Station number SCS 3205 references the Milwaukee Metropolitan station number SCS-3 and the city of Milwaukee station number 205.

ţ

Station number <u>1</u> /	Station name	Drainage area (mi2) A	Slope (ft/mi) S	Storage (percent) ST	Precip- itation (in.) PREC	Precip- itation intensity index (in.) I ₂ 4,2	Soil permea- bility (in/h) SP	Impervious area (percent) I	Undeveloped urban area (percent) UUA
04024384	Lake Superior tributary at Superior, Wis.	4.54	20.30	18.50	29.5	2.6	0.10	15.8	63.2
04085083	Fox River tributary at Green Bay, Wis.	. 47	19.70	.0	28.5	2.4	3.50	90.8	2.13
04085236	Baird Creek tributary at Green Bay, Wis.	1.22	64.50	.0	28.2	2.4	3.50	19.8	23.8
04087060	Noyes Creek at Milwaukee, Wis.	2.35	2.08	.0	29.9	2.6	.40	33.5	23.8
04087088	Underwood Creek at Wauwatosa, Wis.	19.00	18.00	.0	30.9	2.6	.40	30.0	27.0
04087119	Honey Creek at Wauwatosa, Wis.	10.74	13.20	.0	31.0	2.6	.40	36.9	13.9
05396300	Wisconsin River tribuatry at Wausau, Wis.	.92	182.00	.0	31.2	2.6	.05	25.0	47.8
05427950	Pheasant Branch at Century Avenue at Middleton, Wis.	16.68	16.70	.0	31.2	2.8	.80	4.8	72.5
05427965	Spring Harbor storm sewer at Madison, Wis.	3.56	66.80	.0	31.2	2.8	1.00	27.5	34.3
05427970	Willow Creek at Madison, Wis.	3.12	30.20	.0	31.2	2.8	1.00	42.6	11.5
05428665	Olbrich Park storm ditch at Madison, Wis.	2.50	37.40	2.80	31.0	2.8	.60	28.1	32.8
05429040	Manitou Way storm sewer at Madison, Wis.	.22	176.00	.0	31.3	2.8	.80	38.6	4.55
05430403	Fisher Creek tributary at Janesville, Wis.	1.88	53.50	.0	32.6	2.8	1.20	18.7	47.9
SC2-1190	Indian Creek near North Pheasant Lane at Fox Point, Wis.	1.67	4.17	.0	29.5	2.6	.12	31.6	25.1
SC3-2176	Lincoln Creek at North Teutonia Avenue at Milwaukee, Wis.	16.10	12.20	.0	29.8	2.6	.60	44.6	17.1
SC3-5182	Lincoln Creek at North Sherman Boulevard at Milwaukee, Wis.	12.10	12.00	.0	29.8	2.6	.60	41.6	21.8
SC3-6184	Lincoln Creek at North 60th Street at Milwaukee, Wis.	9.54	11.40	.0	29.8	2.6	.60	42.5	20.5

Table 4. Drainage-basin characteristics for urban gaging stations [Crest-stage gage stations are indicated by numbers prefixed SC]

_

Station number <u>1</u> /	Station name	Drainage area (mi2)	Slope (ft/mi)	Storage (percent)	Precip- itation (in.)	Precip- itation intensity index (in.)	Soil permea- bility (in/h)	Impervious area (percent)	Undeveloped urban area (percent)
		A	S	ST	PREC	I _{24,2}	SP	I	UUA
SC3-7186	Lincoln Creek at West Silver Street at Milwaukee, Wis.	4.09	10,00	.0	28.8	2.6	.60	27.2	42.1
SC4-4195	Menomonee River east side of North 68th Street at Wauwatosa, Wis.	124.00	8.72	.75	30.0	2.6	.40	21.0	52.4
SC4-6197	Menomonee River at West North Avenue at Wauwatosa, Wis.	90.90	8.05	.88	30.0	2.6	.40	15.6	63.7
SC4-10201	Menomonee River at Good Hope Road at Milwaukee, Wis.	50.70	8.83	1.56	29.8	2.6	.70	10.4	73.4
SC5-1202	Little Menomonee River at west side of Highway 100 at Milwaukee, Wis.	21.40	10.90	.37	29.9	2.6	.60	14.5	68.7
SC5-2203	Little Menomonee River at West Mill Road and Old Fond du Lac Avenue at Milwaukee, Wis.	18.00	13.00	.44	30.0	2.6	.60	12.2	74.4
SC5-3204	Little Menomonee River at West Bradley Road at Milwaukee, Wis.	13.20	16.10	.61	29.9	2.6	.60	7.3	87.1
SC6-1206	Underwood Creek 300 ft west of cul de sac of West Fisher Parkway at Wauwatosa, Wis.	19.20	18.00	.65	30.5	2.6	.50	27.1	28.0
SC 7-12 10	Honey Creek at Honey Creek Parkway northwest of 72nd Street at Wauwatosa, Wis.	10.70	13.20	.0	30.3	2.6	.50	38.9	13.7
SC7-10220	Honey Creek at West Forest Home Avenue at Milwaukee, Wis.	3.16	6.44	.0	31.0	2.6	.60	33.2	24.4
SC8-1222	Kinnickinnic River at South 7th Street at Milwaukee, Wis.	20.40	23.10	.04	30.6	2.6	1.04	43.7	19.5
SC8-3230	Kinnickinnic River at South 29th Street at Milwaukee, Wis.	16.90	15.10	.04	30 6	2.6	.60	43.0	18.8
SC8-4231	Kinnickinnic River at Jackson Park Drive at Milwaukee, Wis.	4.78	29.40	.02	30.5	2.6	.50	50.0	10.0
SC8-8236	Kinnickinnic River at South 6th Street at Milwaukee, Wis.	5.86	5.78	.0	30.9	2.6	.60	40.5	13.7
SC9-2241	Oak Creek at East Puetz Road at Oak Creek, Wis.	16.20	11.80	.37	31.5	2.6	.70	13.8	65.4

1/ The first four or five digits of each crest-stage gage station number represent the Milwaukee Metropolitan Sewerage Commission station number and the last three digits of the station number represent the city of Milwaukee station number. Station number SC5-3205 references the Milwaukee Metropolitan station number SC5-3 and the city of Milwaukee station number 205.

ສ

Regression Analysis

Multiple-regression analysis was used to estimate the relation between flood discharges for given frequencies (table 3) and drainage-basin characteristics (table 4) for 32 urban sites in Wisconsin. This technique provides a means to transfer flood-peak characteristics from gaged sites to ungaged sites by means of regression or flood-frequency equations. The method is outlined in detail by Thomas and Benson (1970).

The regression equations relate the peak-flow characteristics (dependent variables) $(Q_2, Q_5, \ldots, Q_{100})$ to the most significant basin characteristics (independent variables). The multiple-regression model used to define this relation is expressed by the equation,

$$Q_{T} = aA^{b}B^{c}C^{d}....N^{o}$$

where:

 Q_T = flood magnitude, in cubic feet per second, having a T-year recurrence interval;

a = regression constant defined by regression analysis;

A, B, C, \ldots N = related basin characteristics; and

 b, c, \ldots, o = regression coefficients defined by regression analysis.

Step-forward regression techniques were used to define the flood-frequency equations. The step-forward regression includes all the independent variables that contribute significantly to the dependent variable and excludes those variables that have little additional effect on the dependent variable. Each independent variable is tested for the proportion of the total sum of the squares explained in the dependent variable. The variables included in the derived regression equation are those that are significant at a prescribed confidence level.

Of the eight basin characteristics used in this study, only drainage area and impervious area were significant in the final equations. Standard errors of estimate for the regression equations ranged from 32 to 39 percent.

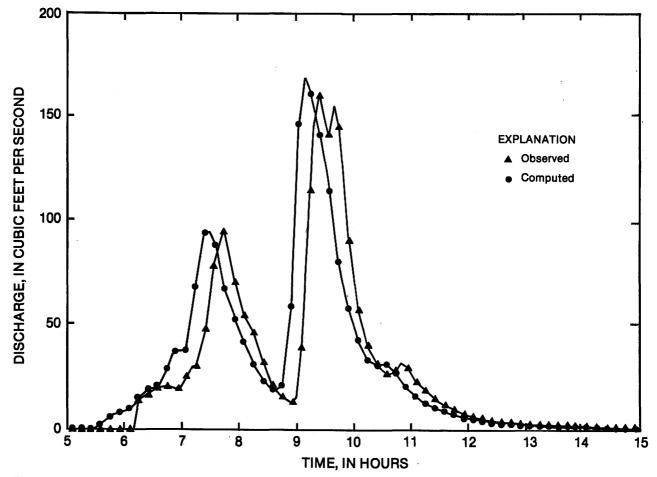


Figure 2. Observed and simulated hydrographs at Fisher Creek tributary at Janesville, Wisconsin.

Flood-Frequency Equations

Table 5. Flood-frequency equations for Wisconsin

Flood-freqency equations are listed in tables t and 6. The equations in table 5 are applicable to urban drainage areas in all parts of Wisconsin without significant regulation or diversion. The equations in table 6 are applicable only to Milwaukee County and are recommended for use in that area.

Table 6.

County

Flood-frequency equations for Milwaukee

urban areas		County	
Equation	Standard error of estimate (percent)	Equation	Standard error of estimate (percent)
$Q_2 = 4.18A^{0.786} / 1.02$	37	$Q_2 = 3.72A^{0.743}I^{1.11}$	39
$Q_5 = 9.97 A^{0.739} / 0.910$	32	$\Omega_5 = 5.73 A^{0.727} / 1.09$	32
$Q_{10} = 14.7 A^{0.723} 0.863$	32	$Q_{10} = 7.05 A^{0.724} / 1.09$	32
$Q_{25} = 21.5 A^{0.712}/0.818$	33	$Q_{25} = 8.72A^{0.725}/1.08$	32
$Q_{50} = 27.0 \ A^{0.707} / 0.792$	35	$Q_{50} = 10.0 \ A^{0.727} / 1.08$	33
$Q_{100} = 32.8 \ A^{0.704}/0.770$	37	$Q_{100} = 11.3 \ A^{0.729} / 1.07$	34

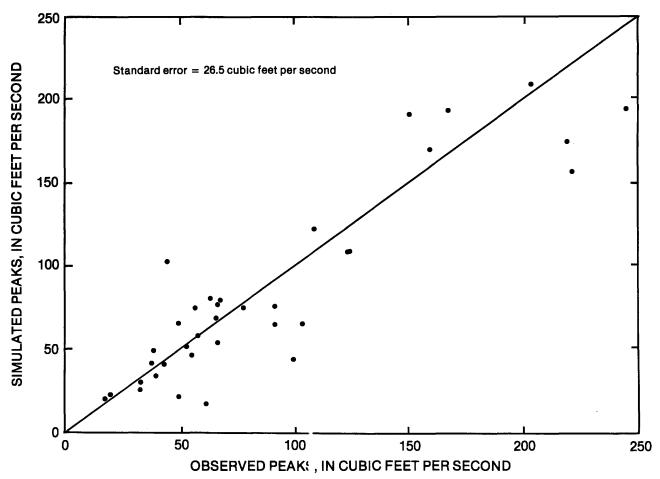


Figure 3. Relation of simulated peak discharges to observed peak discharges for Fisher Creek tributary at Janesville, Wisconsin.

Accuracy and Limitations

The accuracy of the regression equations in tables 5 and 6 is expressed by the standard error of estimate, in percent. The standard error of estimate is a measure of how well the computed flood discharges agree with the observed flood discharges used to derive their regression equations. Approximately two out of three observed values fall within one standard error of estimate of the computed values. The standard error of estimate could be slightly different when modified methods are used for determining the basin characteristics such as percent of impervious area.

The regression equations are applicable for estimating the magnitude of floods for urban streams that lack significant regulation or diversion. Estimated flood discharges by regression equations should be compared to flood discharges determined from gaged basins with similar types of development wherever possible.

Alternative Method for Determining Impervious Area

An alternative method involving population density and using a table of typical impervious areas can be used to expedite the determination of impervious area. The basin can be divided into single-family residential areas, multiple residential areas, industrial areas, commercial areas, park areas, and other areas. Centerlines of streets and lot lines can be used to determine the boundaries. These land-use areas can be measured with a planimeter or digitizer. This information along with typical values (table 7) of impervious area for various land-use categories can be used to determine the total impervious area.

Instead of using table 7 for single-family residential areas the following relation can also be used.

I = 9.41 D + 7.4 (D from 1 to 8)

Where: D is dwellings per acre, and

I is total impervious area expressed as a percentage of the basin drainage area.

The values in table 7 represent average total impervious area for a specific land-use category. These values are based on general field observations, various urban flood-frequency reports, and values used by the Southeastern Wisconsin Regional Planning Commission.

Each urban area needs to be evaluated to ascertain the best procedure for determining impervious area. See the following application of equations for an example of determining percentage of total impervious area.

Land-use category	Typical values of total impervious area (percent)				
	Low	Intermediate	High		
Single-family residential ¹	16	27	45		
Multifamily residential ²	50	60	70		
Commercial ³	80	88	.95		
Industrial⁴	50	75	90		
Public facilities⁵	50	60	75		
Parks and undeveloped land ⁶	0	1	3		

Table 7.	Total impervious area	(percent) within	land-use categories	
----------	-----------------------	------------------	---------------------	--

¹ Single-family residential - Single-family dwellings predominate.

² Multifamily residential-Multiple-family units predominate. These include duplexes, apartment buildings, and condominiums.

³ Commercial – Zones consisting of various types of business.

⁴ Industrial – Manufacturing complexes, railroad yards, and large utilities.

⁵ Public facilities - Schools, hospitals, churches, airports, and other public buildings.

⁶ Parks and undeveloped land – Parks, forests, and open undeveloped land.

Application of Equations

Use of the flood-frequency equations is illustrated by the following problem in which the magnitude of a 100-year flood (Q_{100}) for the urban gaging station 05430403, Fisher Creek tributary at Janesville, Wis., is determined. The applicable equation from table 2 is:

$$Q_{100} = 32.8 A^{0.704} / 0.700$$

1. Determine the size of the contributing drainage area (A) from the best-available topographic map or city map. For this example, the drainage area is 1.88 mi², A = 1.88.

2. Compute the percentage of total impervious area (/) as follows:

(a) Determine the percentage of each land use by using a planimeter or digitizer. For this example, the percentage of single-family residential area is 40 percent, percentage of multifamily residential area is 3 percent, percentage of commercial area is 2 percent, percentage of industrial area is 3 percent, and percentage of public facilities area is 4 percent.

(b) The residential area is uniformly developed regarding lot sizes and development within these lots. Determine (*D*) expressed in dwellings per acre. *D* is 2.5. Using the equation on page 16, l = 9.41 D + 7.4. *l* is equal to 9.41 \times 2.5 + 7.4 = 30.9 percent for 40 percent of the area. "*l* residential" is equal to 0.40 \times 30.9 = 12.4 percent of the total area.

(c) The multifamily area is low level density. Determine the percentage of impervious area from table 7. "I multifamily" is 50 percent for 3 percent of the area. "I multifamily" is equal to $0.03 \times 50 = 1.5$ percent of the total area.

(d) Using table 7 and the same procedure as (c) for the commercial area, industrial area, and public facilities, "/ commercial" is 1.6 percent, "/ industrial" is 1.5 percent, and "/ public facilities" is 2.0 percent of the total area.

(e) Determine the total impervious area l = 12.4 + 1.5 + 1.6 + 1.5 + 2.0 = 19.0 percent. l = 19.0 (table 8). 3. Determine the flood discharge using the selected 100-year flood equation from table 5.

$$\begin{array}{l} Q_{100} = 32.8 A^{0.704} / \ 0.770 \\ Q_{100} = 32.8 (1.88)^{0.704} (19.0)^{0.770} \\ Q_{100} = 32.8 (1.56) (9.65) \\ Q_{100} = 494 \ \mathrm{ft}^3/\mathrm{s} \end{array}$$

Table 8. Tabulation of total impervious area (/) for gaging station 05430403, Fisher Creek tributary at Janesville, Wis., using the alternate modified method

Land use	Percentage of basin area	Percentage of impervious area within land-use area	Percentage of impervious area within the basin area
Single-family residential	40	30.9 (from equation)	12.4
Multifamily residential	3	50 (table 7)	1.5
Commercial	2	80 (table 7)	1.6
Industrial	3	50 (table 7)	1.5
Public facilities	4	50 (table 7)	2.0
	Total impervious area for bas	in (/)	19.0

SUMMARY AND CONCLUSIONS

The flood-frequency equations in this report can be used to provide estimated flood discharges for urban streams in Wisconsin for selected recurrence intervals from 2 to 100 years. The U.S. Geological Survey Distributed Routing Rainfall-Runoff Model-Version II (Alley and Smith, 1982) was used to extend records by synthesis for 13 rainfall-runoff small-stream stations. The model was used to calibrate each rainfall-runoff site by defining seven parameters and then using these parameters and long-term rainfall and evaporation data to generate a long-term series of flood peaks. Log-Pearson type III frequency distribution and guidelines outlined by the U.S. Water Resources Council Bulletin 17B (1981) were used to define the flood-frequency relations.

Observed and synthetic streamflow records were analyzed by multiple regression to define the flood-frequency equations. Significant independent variables in the equations are drainage area and impervious area. Standard errors of estimate for the regression equations range from 32 to 39 percent.

The determination of peaks at crest-stage gages in Milwaukee County are generally based on step-backwater computations. Therefore, the accuracy of the multiple-regression equations may be improved if the discharges assigned to the recorded stages can be verified by current-meter measurements or dye-dilution measurements.

REFERENCES CITED

Alley, W. M., and Smith, P. E., 1982, Distributed routing rainfall-runoff model-version II: U.S. Geological Survey Open-File Report 82-344, 201 p.

Conger, D. H., 1981, Techniques for estimating magnitude and frequency of floods for Wisconsin streams: U.S. Geological Survey Open-File Report 82–1214, 115 p.

Henrich, E. W., 1986, Drainage-area data for Wisconsin streams: U.S. Geological Survey Open-File Report 83-933, 322 p.

Hershfield, D. M., 1961, Rainfall frequency atlas of the United States: U.S. Weather Bureau Technical Paper 40, 115 p.

Krug, W. R., and Goddard, G. L., 1986, Effects of urbanization on streamflow, sediment loads, and channel morphology in Pheasant Branch basin near Middleton, Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 85-4068, 82 p.

Thomas, D. M., and Benson, M. A., 1970, Generalization of streamflow characteristics from drainage-basin characteristics: U.S. Geological Survey Water-Supply Paper 1975, 55 p.

U.S. Department of Agriculture, Soil Conservation Service, 1964, Engineering test data and interpretations for major soils of Wisconsin: Table 11, p. 3-43.

U.S. Water Resources Council, 1981, Guidelines for determining flood flow frequency: Water Resources Council Bulletin No. 17B, 186 p.

.

