Water Resources Investigations Report 86-4005

ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS FOR WISCONSIN URBAN STREAMS

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

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By **Duane H. Conger**

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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	By	To obtain metric unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.590	square kilometer (km^2)
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 (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS FOR WISCONSIN URBAN STREAMS

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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

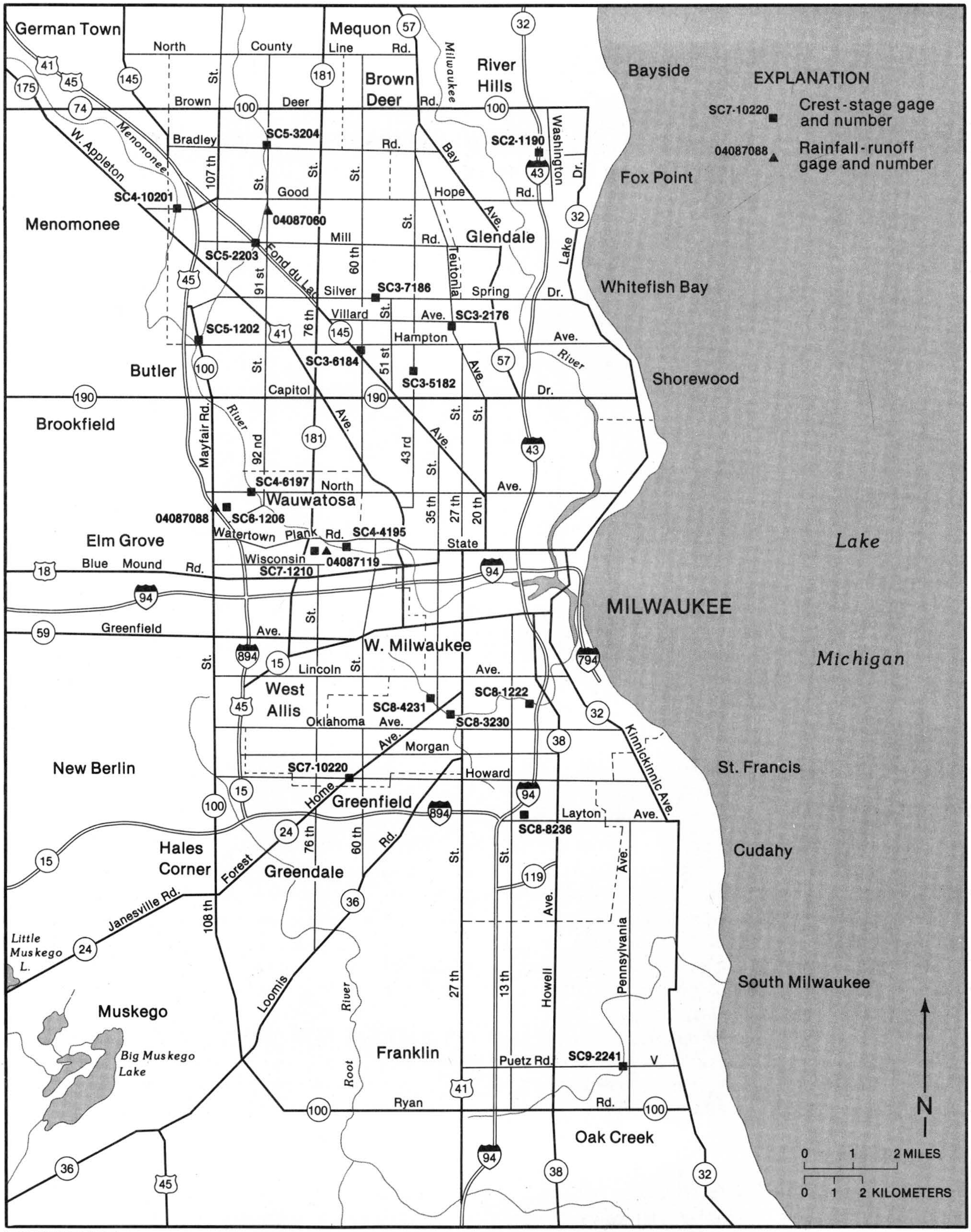
Estimates of flood frequencies and magnitudes are useful for planning and designing culverts, bridges, drainage systems, and for effective flood-plain management. This report provides a method for estimating the frequencies and magnitudes of floods of ungaged urban streams in Wisconsin.

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.



MILWAUKEE

Figure 1. Location of gaging stations.

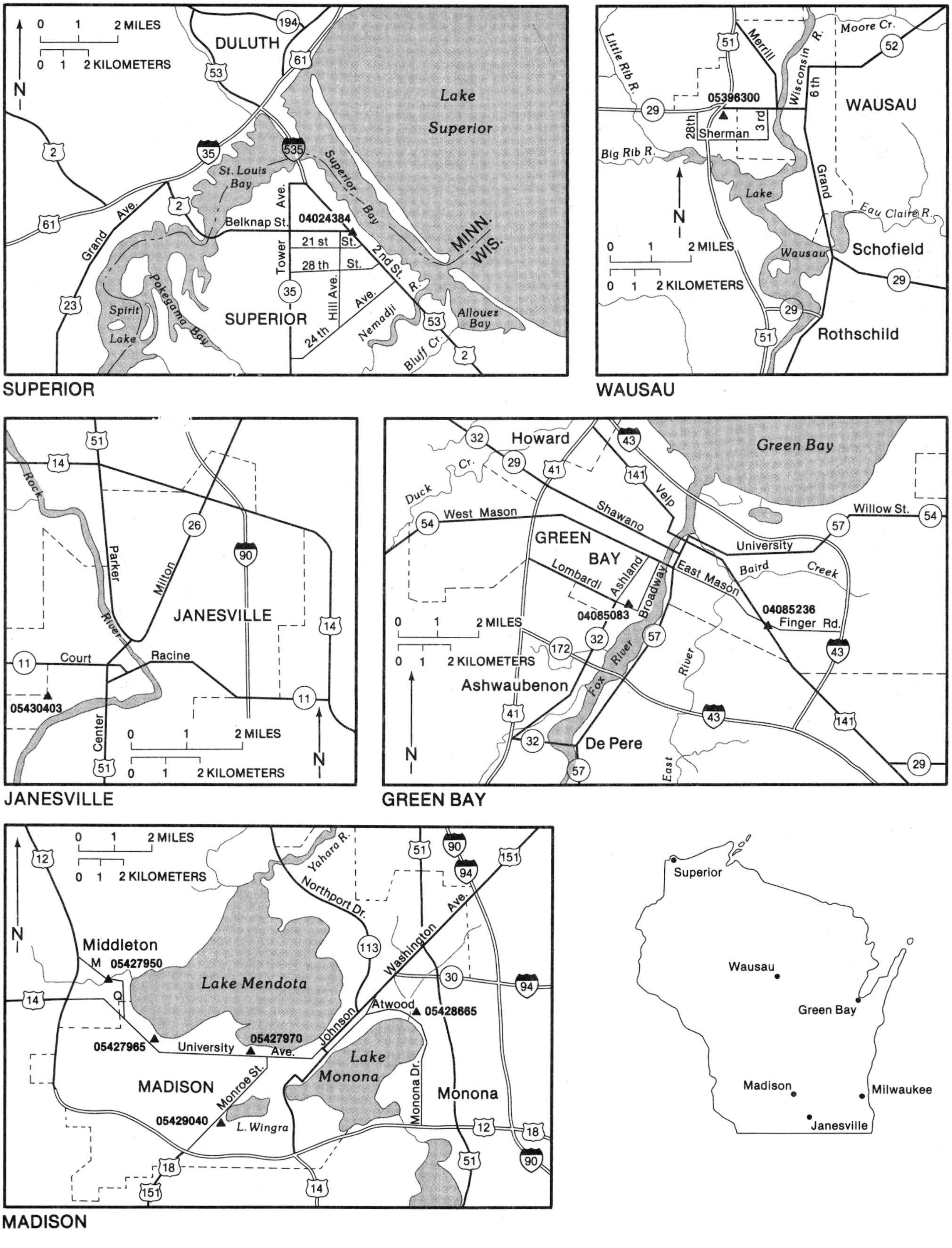


Figure 1. Location of gaging stations—Continued.

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 (ft^3/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. -- 04024384
Station name -- Lake Superior tributary at Superior, Wis.
Drainage area -- 4.54 mi^2

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1981	Apr. 23, 1981	3.66	110
1982	July 9, 1982	4.80	298
1984	Sept. 24, 1984	3.67	122

Station no. -- 04085083
Station name -- Fox River tributary at Green Bay, Wis.
Drainage area -- 0.47 mi^2

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1979	Aug. 9, 1979	14.75	152
1980	Aug. 19, 1980	14.84	160
1981	June 15, 1981	13.51	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 mi^2

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 mi^2
Gage datum -- 710.00 ft above mean sea level

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1975	Aug. 22, 1975	6.06	152
1976	Mar. 4, 1976	6.44	215
1977	June 11, 1977	7.00	269
1978	July 2, 1978	7.52	322
1979	Aug. 20, 1979	7.50	320

Station no. -- 04087088
Station name -- Underwood Creek at Wauwatosa, Wis.
Drainage area -- 19.1 mi^2
Gage datum -- 690.00 ft above mean sea level

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1975	Feb. 24, 1975	4.34	540
1976	Apr. 24, 1976	4.14	388
1977	Aug. 13, 1977	4.16	396
1978	Sept. 30, 1978	3.97	320
1979	Apr. 11, 1979	4.26	434
1980	Aug. 4, 1980	3.94	343
1981	July 13, 1981	5.55	2,100
1982	Apr. 3, 1982	4.46	579
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 mi^2
Gage datum -- 630.86 ft above mean sea level

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1975	Apr. 28, 1975	15.47	810
1976	Mar. 4, 1976	16.19	1,050
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

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

Station no. -- 05396300
Station name -- Wisconsin River tributary at Wausau, Wis.
Drainage area -- 0.92 mi^2

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1980		5.43	117
1981	July 30, 1981	5.72	135
1982	June 24, 1982	5.08	79
1983	July 19, 1983	5.52	117
1984	Sept. 24, 1984	8.07	480

Station no. -- 05427950
Station name -- Pheasant Branch at Century Avenue at Middleton, Wis.
Drainage area -- 16.7 mi^2
Gage datum -- 868.68 ft above mean sea level

Water year	Date	Gage height (ft)	Discharge (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. -- 05427965
Station name -- Spring Harbor storm sewer at Madison, Wis.
Drainage area -- 3.56 mi^2
Gage datum -- 855.30 ft above mean sea level

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 and discharge data at rainfall-runoff gaging stations—Continued

Station no. -- 05427970
Station name -- Willow Creek at Madison, Wis.
Drainage area -- 3.12 mi^2
Gage datum -- 847.90 ft above mean sea level

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1974	Aug. 16, 1974	6.22	1,600
1975	July 3, 1975	6.21	1,590
1976	Aug. 14, 1976	5.54	766
1977	July 18, 1976	6.17	1,520
1978	June 25, 1978	6.40	1,900
1979	June 28, 1979	6.11	624
1980	June 7, 1980	6.26	685
1981	Aug. 31, 1981	6.42	754
1982		6.16	600
1983	Sept. 6, 1983	5.81	511

Station no. -- 05428665
Station name -- Olbrich Park storm ditch at Madison, Wis.
Drainage area -- 2.50 mi^2
Gage datum -- 860.00 ft above mean sea level

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1976	Mar. 4, 1976	6.67	154
1977	July 18, 1977	7.61	270
1978	June 25, 1978	10.37	480
1979	Aug. 5, 1979	7.99	306
1980	Sept. 9, 1980	7.44	244

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

Water year	Date	Gage height (ft)	Discharge (ft^3/s)
1971	Apr. 12, 1971	12.97	66
1972	Aug. 26, 1972	12.88	62
1973	Mar. 6, 1973	12.79	58
1974	Oct. 10, 1973	12.76	56
1975	July 3, 1975	13.79	108
1976	June 23, 1976	12.20	36
1977	July 18, 1977	13.08	72

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

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

ESTIMATING FLOOD-FREQUENCY CHARACTERISTICS AT UNGAGED SITES

Basin Characteristics

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 (*I24,2*) (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.

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

Station number 1/	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
SC5-1202											690	710	1,100
SC5-2203									340	380	240	120	500
SC5-3204												300	440
SC6-1206													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
SC8-4231									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
SC5-3204	560	320	260	250	190	240	250	210	240	325		440
SC6-1206	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
SC7-10220		260	240	330	390	340	250	370	480	350	1,040	380
SC8-1222	4,500				4,790	2,650	3,370	3,580	4,290	2,360	2,400	
SC8-3230	4,230	1,400	1,400	1,350	2,630	2,000	1,500	1,840	2,300	1,400		
SC8-4231	1,490	480	500	640	780	520	400	720	840	430	980	470
SC8-8236	1,170	740	980	880	960	900	880	1,120	900	760	740	600
SC9-2241	560	640	330	680	210	380	460	320	290	430	630	375

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.

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

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

Station number[1/]	Station name	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
04024384	Lake Superior tributary at Superior, Wis.	138	301	428	598	726	853
04085083	Fox River tributary at Green Bay, Wis.	153	202	230	259	278	295
04085236	Baird Creek tributary at Green Bay, Wis.	113	176	223	286	337	389
04087060	Noyes Creek at Milwaukee, Wis.	279	473	616	810	962	1,119
04087088	Underwood Creek at Wauwatosa. Wis.	472	1,036	1,546	2,348	3,060	3,873
04087119	Honey Creek at Wauwatosa, Wis.	940	1,307	1,551	1,860	2,090	2,320
05396300	Wisconsin River tribuatry at Wausau, Wis.	100	206	280	380	458	538
05427950	Pheasant Branch at Century Avenue at Middleton, Wis.	194	393	548	759	923	1,090
05427965	Spring Harbor storm sewer at Madison, Wis.	255	530	744	1,037	1,264	1,495
05427970	Willow Creek at Madison, Wis.	341	556	700	881	1,012	1,140
05428665	Olbrich Park storm ditch at Madison, Wis.	209	361	477	636	764	898
05429040	Manitou Way storm sewer at Madison, Wis.	51	82	102	128	147	165
05430403	Fisher Creek tributary at Janesville, Wis.	214	294	338	383	412	437
SC2-1190	Indian Creek near North Pheasant Lane at Fox Point, Wis.	350	590	760	970	1,130	1,290
SC3-2176	Lincoln Creek at North Teutonia Avenue at Milwaukee, Wis.	2,560	3,465	3,990	4,580	4,980	5,340
SC3-5182	Lincoln Creek at North Sherman Boulevard at Milwaukee, Wis.	2,520	3,410	3,930	4,540	4,960	5,350
SC3-6184	Lincoln Creek at North 60th Street at Milwaukee, Wis.	2,380	3,120	3,560	4,070	4,420	4,740
SC3-7186	Lincoln Creek at West Silver Street at Milwaukee, Wis.	270	370	430	500	550	600
SC4-4195	Menomonee River east side of North 68th Street at Wauwatosa, Wis.	3,180	4,970	6,360	8,350	10,000	11,800
SC4-6197	Menomonee River at West North Avenue at Wauwatosa, Wis.	1,660	2,410	2,940	3,640	4,190	4,750
SC4-10201	Menomonee River at Good Hope Road at Milwaukee, Wis.	1,480	1,850	2,070	2,340	2,530	2,710
SC5-1202	Little Menomonee River at west side of Highway 100 at Milwaukee, Wis.	990	1,260	1,420	1,610	1,740	1,870
SC5-2203	Little Menomonee River at West Mill Road and Old Fond du Lac Avenue at Milwaukee, Wis.	430	610	740	920	1,060	1,210
SC5-3204	Little Menomonee River at West Bradley Road at Milwaukee, Wis.	290	385	445	520	580	635
SC6-1206	Underwood Creek 300 ft west of cul de sac of West Fisher Parkway at Wauwatosa, Wis.	1,290	2,040	2,630	3,460	4,160	4,920
SC7-1210	Honey Creek at Honey Creek Parkway northwest of 72nd Street at Wauwatosa, Wis.	1,050	1,270	1,400	1,550	1,670	1,770
SC7-10220	Honey Creek at West Forest Home Avenue at Milwaukee, Wis.	335	510	635	800	930	1,060
SC8-1222	Kinnickinnic River at South 7th Street at Milwaukee, Wis.	2,760	3,730	4,350	5,120	5,690	6,240
SC8-3230	Kinnickinnic River at South 29th Street at Milwaukee, Wis.	1,940	2,620	3,090	3,700	4,180	4,660
SC8-4231	Kinnickinnic River at Jackson Park Drive at Milwaukee, Wis.	735	1,050	1,260	1,540	1,750	1,960
SC8-8236	Kinnickinnic River at South 6th Street at Milwaukee, Wis.	855	1,000	1,080	1,180	1,240	1,300
SC9-2241	Oak Creek at East Puetz Road at Oak Creek, Wis.	460	650	780	945	1,070	1,200

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.

Table 4. Drainage-basin characteristics for urban gaging stations

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

Station number1/	Station name	Drainage area (mi2) A	Slope (ft/mi) S	Storage (percent) ST	Precipitation (in.) PREC	Precipitation intensity index (in.) $I_{24,2}$	Soil permeability (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

Station number[1]	Station name	Drainage area (mi2) A	Slope (ft/mi) S	Storage (percent) ST	Precip-itation (in.) PREC	Precip-itation intensity index (in.) $I_{24,2}$	Soil permea-bility (in/h) SP	Impervious area (percent) I	Undeveloped urban area (percent) 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
SC7-1210	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.

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. . . . . . Q_{100}) to the most significant basin characteristics (independent variables). The multiple-regression model used to define this relation is expressed by the equation,

$$Q_T = aA^bB^cC^d. \ldots . N^o$$

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.

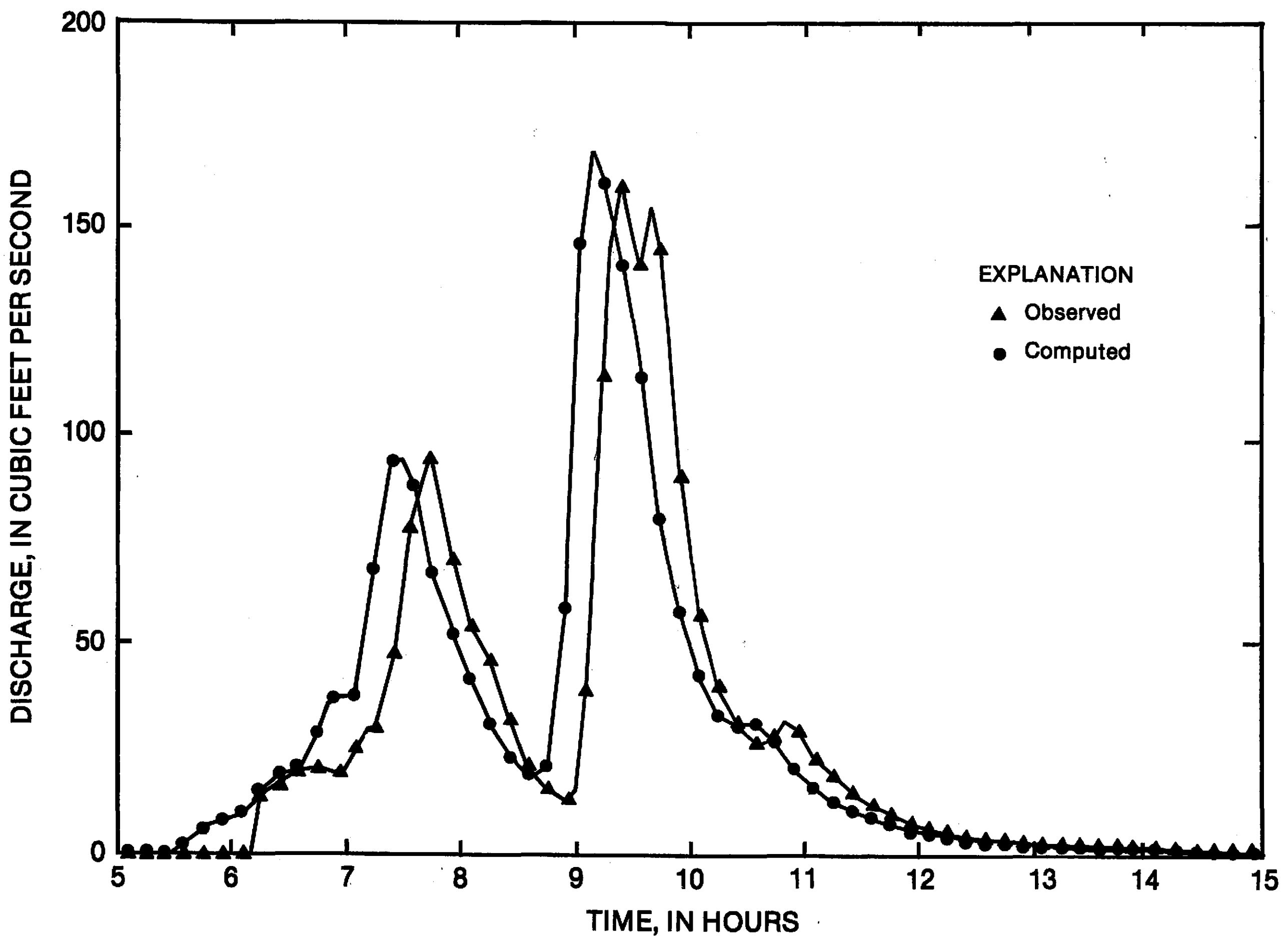


Figure 2. Observed and simulated hydrographs at Fisher Creek tributary at Janesville, Wisconsin.

Flood-Frequency Equations

Flood-freqency equations are listed in tables 5 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 5. Flood-frequency equations for Wisconsin urban areas

Equation	Standard error of estimate (percent)
$Q_2 = 4.18A^{0.786}I^{1.02}$	37
$Q_5 = 9.97A^{0.739}I^{0.910}$	32
$Q_{10} = 14.7\ A^{0.723}I^{0.863}$	32
$Q_{25} = 21.5\ A^{0.712}I^{0.818}$	33
$Q_{50} = 27.0\ A^{0.707}I^{0.792}$	35
$Q_{100} = 32.8\ A^{0.704}I^{0.770}$	37

Table 6. Flood-frequency equations for Milwaukee County

Equation	Standard error of estimate (percent)
$Q_2 = 3.72A^{0.743}I^{1.11}$	39
$Q_5 = 5.73A^{0.727}I^{1.09}$	32
$Q_{10} = 7.05A^{0.724}I^{1.09}$	32
$Q_{25} = 8.72A^{0.725}I^{1.08}$	32
$Q_{50} = 10.0\ A^{0.727}I^{1.08}$	33
$Q_{100} = 11.3\ A^{0.729}I^{1.07}$	34

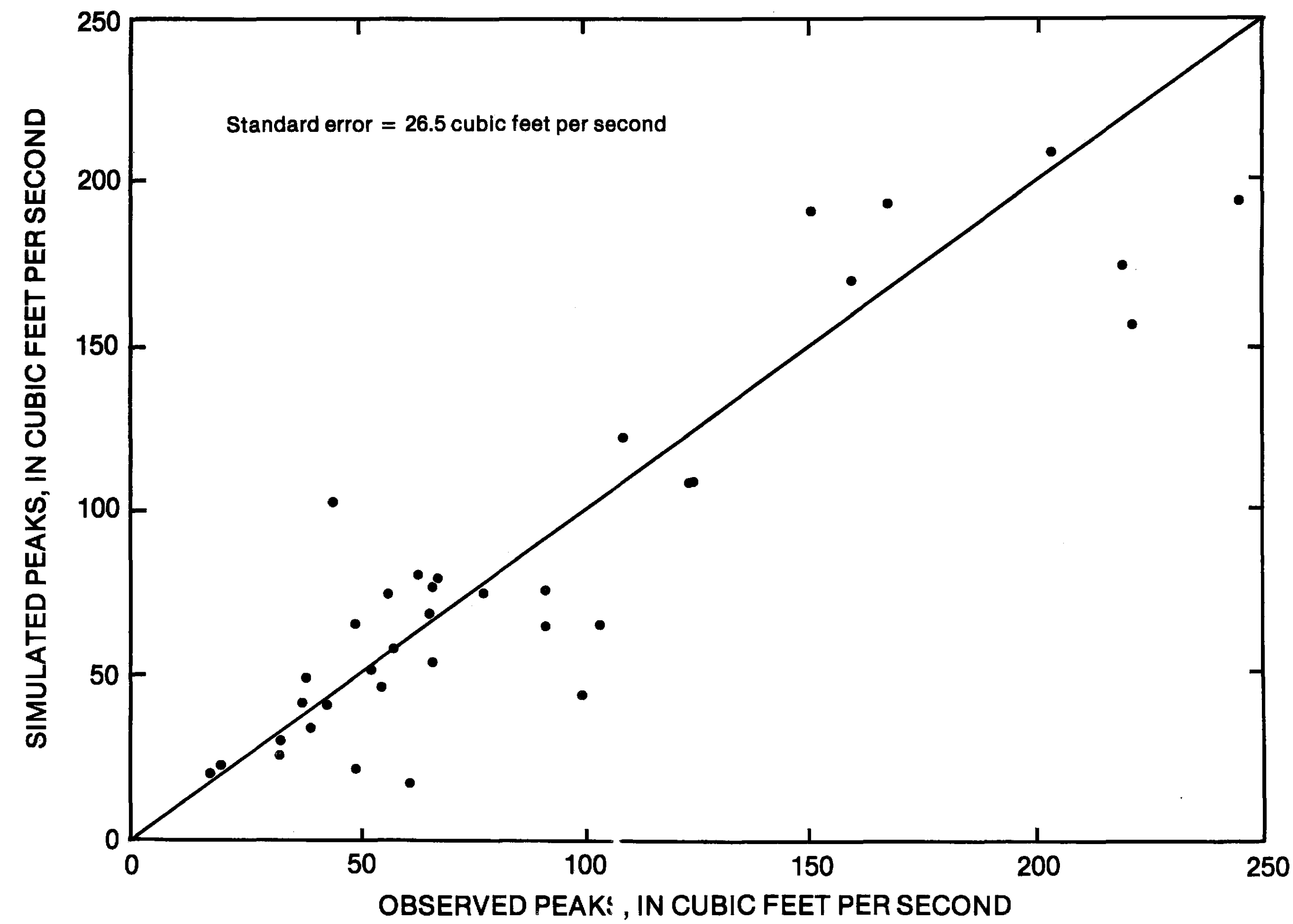


Figure 3. Relation of simulated peak discharges to observed peak discharges for Fisher Creek tributary at Janesville, Wisconsin.

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.

$$I = 9.41\,D + 7.4 \qquad (D \text{ from 1 to 8})$$

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.

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

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
Industrial[4]	50	75	90
Public facilities[5]	50	60	75
Parks and undeveloped land[6]	0	1	3

[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:

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

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 (I) 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, $I = 9.41D + 7.4$. I is equal to $9.41 \times 2.5 + 7.4 = 30.9$ percent for 40 percent of the area. "I 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, "I commercial" is 1.6 percent, "I industrial" is 1.5 percent, and "I public facilities" is 2.0 percent of the total area.

(e) Determine the total impervious area $I = 12.4 + 1.5 + 1.6 + 1.5 + 2.0 = 19.0$ percent. $I = 19.0$ (table 8).

3. Determine the flood discharge using the selected 100-year flood equation from table 5.

$$Q_{100} = 32.8A^{0.704}I^{0.770}$$
$$Q_{100} = 32.8(1.88)^{0.704}(19.0)^{0.770}$$
$$Q_{100} = 32.8(1.56)(9.65)$$
$$Q_{100} = 494 \text{ ft}^3/\text{s}$$

Table 8. Tabulation of total impervious area (I) 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 basin (I)			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.

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