FLOOD MAGNITUDE AND FREQUENCY OF DELAWARE RIVER TRIBUTARY AT THE CULVERT ON NEW JERSEY ROUTE 29, AT LAMBERTVILLE, NEW JERSEY

By Paul Dunne and Robert D. Schopp

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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per mile (ft/mi)	0.189	meter per kilometer
inch per hour (in/hr)	25.4	millimeter per hour
cubic foot per second (ft^3/s)	0.028	cubic meter per second

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ABSTRACT

Six methods were used to estimate the magnitude and frequency of floods at the Delaware River tributary at the culvert on New Jersey Route 29, at Lambertville, New Jersey. Flood magnitude and frequency calculated by the six methods, as well as drainage-basin characteristics, are included in this report. The 100-year-flood estimates range from 228 cubic feet per second to 662 cubic feet per second. Flood magnitude and frequency estimates obtained by using the rational method and the U.S. Soil Conservation Service Technical Release 55 method are reasonable but somewhat greater than the data transferred from the four nearby crest-stage gages.

INTRODUCTION

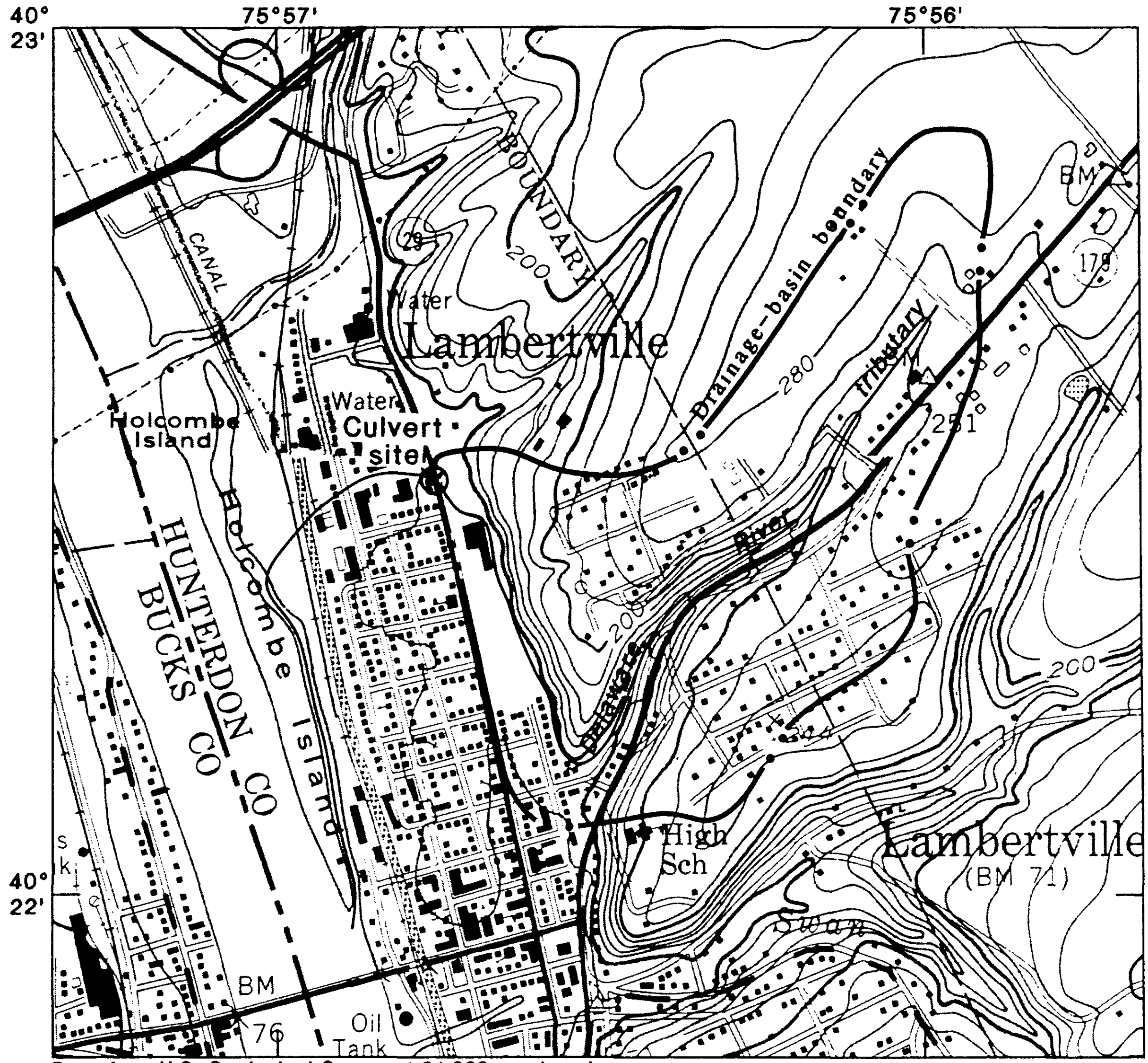
Information on the magnitude and frequency of floods is critical to the planning and design of highway culverts and bridges. Such information is not available for many stream crossings in New Jersey. To fulfill this information need, the U.S. Geological Survey, in cooperation with the New Jersey Department of Transportation, began an analysis of flood data from stream-crossing sites on New Jersey streams. This report presents results of the analysis for the Delaware River tributary at the culvert on New Jersey Route 29, at Lambertville, N.J. The culvert is located 50 ft north of Union No. 1 firehouse (230 North Main Street) on the eastern side of N.J. Route 29 (fig. 1). The drainage area above the site is 0.34 mi^2. A field reconnaissance was performed on April 29, 1993, to verify the locations of the drainage divides and land use. Because the direction of storm-sewer drainage in some parts of the basin is uncertain, the calculated drainage area is approximate.

Janitorial personnel at Lambertville Public School at 200 North Main Street (N.J. Route 29), located 150 ft south of the culvert, were interviewed on April 29, 1993. They reported that the school and N.J. Route 29 near the school were flooded on April 22, 1993. The upstream end of the culvert was blocked with debris and water was observed to be covering the road. Accumulation of a large amount of debris at the N.J. Route 29 and firehouse culvert entrances also was reported. The recurrence interval of this flood is undetermined.

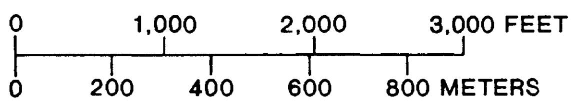
The flood-insurance study for Lambertville (Federal Emergency Management Agency, April 1983) did not include this stream; therefore, flood discharges were not determined previously.

FLOOD MAGNITUDE AND FREQUENCY METHODS

Various flood magnitude and frequency methods were used to determine the flood magnitudes that are likely to be exceeded at this site within a given number of years (recurrence interval). The methods used include the rational method (Chow and others, 1988), New Jersey Department of



Base from U.S. Geological Survey, 1:24,000 quadrangles, Lambertville, 1953; Stockton, 1954



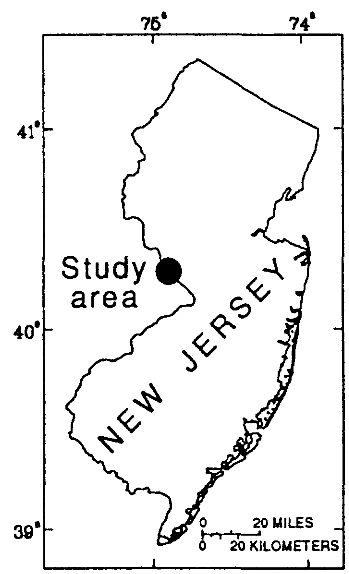


Figure 1.--Delaware River tributary at the culvert on New Jersey Route 29, at Lambertville, New Jersey.

Environmental Protection (NJDEP) Special Report 38 method (Stankowski, 1974), U.S. Geological Survey (USGS) index-flood method (Thomas, 1964), USGS transfer method (N.J. Department of Environmental Protection, 1988), U.S. Soil Conservation Service (SCS) Technical Release 55 (TR-55) method (U.S. Soil Conservation Service, 1986), and the U.S. Army Hydrologic Engineering Center (HEC) Special Projects Memo 480 method (U.S. Army Corps of Engineers, 1977).

Data and computations used in this study can be obtained from the U.S. Geological Survey, 810 Bear Tavern Road, Suite 206, West Trenton, NJ 08628.

Rational Method

The rational method is based on the concept that if a rainfall of a particular intensity begins instantaneously and continues indefinitely across a watershed, the runoff rate will increase until the time of concentration, which is the time when the entire watershed is contributing to the flow at the outlet (Chow and others, 1988). The time of concentration (the time needed for water to travel from the farthest point in the watershed to the outlet) is computed by summing the travel times for consecutive components of a drainage system (U.S. Soil Conservation Service, 1986). Many factors, including channel shape, surface roughness, and slope, affect the time of concentration.

The equation that expresses this method is:

$$Q = CiA ,$$

where Q is the rate of peak discharge at the time of concentration, in cubic feet per second; i is the rainfall intensity, in inches per hour; A is the watershed area, in acres; and C is the runoff coefficient. The runoff coefficient depends on various watershed characteristics, including the composition and condition of the soil, the type and condition of land use, and the percent imperviousness of the watershed. Appropriate runoff-coefficient values based on these watershed characteristics were chosen from a table (N.J. Department of Environmental Protection, 1988). This method is recommended for the calculation of peak discharges in homogeneous drainage areas up to 0.5 mi^2 in size (N.J. Department of Environmental Protection, 1988).

New Jersey Department of Environmental Protection Special Report 38 Method

This method consists of the development and use of a set of regression equations for the 2-, 5-, 10-, 25-, 50-, and 100-year floods based on the watershed characteristics drainage area, basin storage (percent area of lakes and swamps, plus 1.0 percent in order to avoid zero values), and impervious cover (based on population density). This method is recommended for use in drainage areas of 1 to 1,000 mi^2 (Stankowski, 1974).

U.S. Geological Survey Index-Flood Method

Flood estimates are made with this method by using two graphical curves. One curve expresses the relation between the mean annual flood and the size of the drainage basin; the other expresses the ratio between the mean annual flood and floods of other recurrence intervals. The mean annual flood is adjusted on the basis of the percentage of lakes and swamps in the drainage basin. This method is recommended for drainage areas greater than 4 mi^2 and is most accurate for drainage areas of 10 to 200 mi^2 (Thomas, 1964).

U.S. Soil Conservation Service Technical Release 55 Method

For this method, an SCS curve number, which represents the overall soil type, land use, and antecedent soil-moisture conditions, is assigned to the basin. This curve number is used to account for the initial abstraction and infiltration losses. Other required input parameters are the 24-hour rainfall associated with the desired frequency, the drainage-basin area, and the time of concentration (total travel time). The time of concentration for a basin is determined by using a set of equations describing the travel time for the overland- flow or sheet-flow segment, the shallow-concentrated-flow segment, and the open-channel-flow segment. The time of concentration is the sum of the ratios of flow length to flow velocity for each segment. This value depends on the surface type, hydraulic radius, cross-sectional-flow area, wetted perimeter, land slope, channel slope, and Manning's roughness coefficient. This method is recommended for drainage areas of less than 5 mi^2 (U.S. Soil Conservation Service, 1986).

U.S. Army Hydrologic Engineering Center Special Projects Memo 480 Method

This method is based on multiple-regression analysis of the mean and standard deviation of the logarithms of the annual peak flows at 58 long-record streamflow-gaging stations. An adjustment is made by estimating a generalized skew coefficient (U.S. Geological Survey, 1982). This method is recommended for use for drainage areas of 10 to 300 mi^2 (U.S. Geological Survey, 1982).

U.S. Geological Survey Transfer Method

The relation that is used to calculate flood estimates is based on a ratio of drainage areas raised to an exponent:

$$\frac{Q_{PI}}{Q_{PG}} = \left(\frac{A_{PI}}{A_{PG}}\right)^{0.75},$$

where Q_{PI} is the design flood at the point of interest, Q_{PG} is the design flood at the gaged point, A_{PI} is the drainage area at the point of interest, and A_{PG} is the drainage area at the gaged point. An exponent of 0.75 is used (New Jersey Department of Environmental Protection, 1988). This method is recommended for drainage areas that are either less than twice or more than half the drainage area above the gaged point (New Jersey Department of Environmental Protection, 1988).

COMPARISON OF RESULTS

The explanatory variables used in applying the methods described above at the N.J. Route 29 site are listed in table 1. The flood-magnitude and -frequency estimates for the site obtained by using each of the various methods are shown in table 2. The range in the estimates is large; estimates of the 100-year flood discharge at the site range from 228 to 662 ft^3/s.

Flood data from nearby streamflow-gaging or crest-stage gaging stations provide a good indication of the flood magnitude and frequency that can be expected at an ungaged site, particularly if drainage area and other basin characteristics are similar. In this section, the estimates developed by using the various methods are compared with discharge data that have been transferred to the culvert site by using the USGS transfer method.

Table 1.--Explanatory variables for the flood-magnitude and -frequency methods Delaware River tributary, Lambertville, New Jersey

Drainage area: 0.34 square miles
Latitude: 40°22′33″
Longitude: 75°56′44″
Highway: New Jersey Route 29
U.S. Geological Survey 7-1/2-minute Quadrangle(s): Lambertville, Stockton

Variable	Value	Unit
Drainage area	= 0.34	square miles
Main channel slope	= 153.0	feet per mile
Total stream length	= 1.33	miles
Surface storage index	= 1.0	percent
Population density (1990)	= 1,802	persons per square mile
Impervious cover	= 17.0	percent
Forest cover	= 10.0	percent
Regional skew coefficient[1]	= 0.3	
Lake and swamp area	= 0.0	percent
Hydrologic area[2]	= 2	
Flood frequency region[2]	= C	
Rational method runoff coefficient[3]	= 0.65	
Runoff curve number[4]	= 80	
Time of concentration[4]	= 0.47	hours
2-year, 24-hour rainfall[5]	= 3.50	inches
5-year, 24-hour rainfall	= 4.50	inches
10-year, 24-hour rainfall	= 5.20	inches
25-year, 24-hour rainfall	= 5.80	inches
50-year, 24-hour rainfall	= 6.50	inches
100-year, 24-hour rainfall	= 7.30	inches
2-year rainfall intensity[6]	= 2.20	inches per hour
5-year rainfall intensity	= 2.78	inches per hour
10-year rainfall intensity	= 3.18	inches per hour
25-year rainfall intensity	= 3.74	inches per hour
50-year rainfall intensity	= 4.20	inches per hour
100-year rainfall intensity	= 4.64	inches per hour

[1]From U.S. Army Corps of Engineers, 1977
[2]From Thomas, 1964
[3]From New Jersey Department of Environmental Protection, 1988
[4]From U.S. Soil Conservation Service, 1986
[5]All rainfall values from Hershfield, 1961
[6]All rainfall-intensity values from Frederick and others, 1977

Table 2.--Estimates of flood magnitudes for selected frequencies, Delaware River tributary, Lambertville, New Jersey

[Q, flood-magnitude estimates in cubic feet per second along with number indicating the frequency of the recurrence interval, in years; DA, drainage area, in square miles; S, main-channel slope, in feet per mile; St, surface storage index, in percent of drainage area; I, index of manmade impervious cover, in percent of drainage area; YR, years of record; D, distance of station used in USGS transfer method from flood site; NJDEP, New Jersey Department of Environmental Protection ; USGS, U.S. Geological Survey; SCS, U.S. Soil Conservation Service; HEC, U.S. Army Hydrologic Engineering Center; SPM, Special Projects Memo; TR, Technical Release; SR, Special Report; NA, not available; --, not applicable]

Drainage area: 0.34 square miles
Latitude: 40° 22′33″
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Highway: New Jersey Route 29
U.S. Geological Survey 7-1/2-minute quadrangle(s): Lambertville, Stockton

Estimating method	Q2	Q5	Q10	Q25	Q50	Q100	DA	S	St	I	YR	D
Rational method[1]	311	393	449	528	594	656						
NJDEP SR 38	70	106	144	201	243	303	0.34	153.0	1.0	17.0	--	--
USGS index method	56	93	119	157	190	228						
SCS TR-55[1]	210	325	409	480	564	662						
HEC SPM 480	77	154	227	348	465	606						
USGS transfer method												
Station 01397500	70	135	194	289	379	483	2.24	159.0	1.1	3.1	54	10.7
Station 01398045	195	277	333	413	474	541	1.98	30.0	1.0	NA	12	7.1
Station 01400850	82	151	219	340	462	618	1.78	37.8	1.0	5.3	19	6.2
Station 01400930	77	123	159	213	260	313	1.99	66.1	1.0	5.3	31	6.3
Station 01462198						[2]794	.98	NA	NA	NA	NA	NA

[1] This method recommended by NJDEP (1988) for a drainage basin of this size.

[2] Based on an indirect measurement of peak flow. This measurement of 1,550 cubic feet per second was made by USGS personnel at Moore Creek tributary, located approximately 3.5 miles from the Lambertville site, on August 15, 1989 (Bauersfeld and others, 1990). The recurrence interval of this flood, estimated by using method NJDEP SR 38, is greater than 100 years.

In New Jersey, for streams that drain areas smaller than 0.5 mi^2, the rational method is the most commonly used (N.J. Department of Environmental Protection, 1988). The drainage area of the site at N.J. Route 29 falls within this limit. The discharge values estimated by using the rational method are somewhat greater than the values estimated by using the USGS transfer method from data collected at four nearby crest-stage gages (station numbers 01397500, 01398045, 01400850, and 01400930). The discharge values estimated by using the rational method seem reasonable considering that the slopes and impervious areas of the drainage basins gaged by the four nearby crest-stage gages generally are less than those of the drainage basin above the site at N.J. Route 29 (table 2).

The drainage area of the site is outside the recommended ranges for using the NJDEP Special Report 38 method (Stankowski, 1974), the USGS index-flood method (Thomas, 1964), and the HEC Special Project Memo 480 method (U.S. Army Corps of Engineers, 1977). The TR-55 method also yielded an estimate of the 100-year-flood discharge that is reasonable when compared to the discharge-value data transferred from the four crest-stage gages and is within 1 percent of the estimate determined by using the rational method (table 2).

An indirect measurement of peak flow made on Moore Creek tributary, 3.5 mi from the N.J. Route 29 site, tends to confirm the flood-magnitude and -frequency estimates made by using the rational and TR-55 methods, although the exact recurrence interval of this peak discharge is unknown (table 2).

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