# STORM AND FLOOD OF JULY 5, 1989, IN NORTHERN NEW CASTLE COUNTY, DELAWARE

By Gary N. Paulachok, Robert H. Simmons, and Anthony J. Tallman

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## CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| inch per hour (in/hr) | 25.4 | millimeter per hour |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| cubic foot per second per square mile [$(ft^3/s)/mi^2$] | 0.01093 | cubic meter per second per square kilometer |

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

# GLOSSARY

**Crest-stage station.** A stream site where information is collected systematically only on peak stage and discharge.

**Cubic feet per second.** A unit of measurement for water discharge. One cubic foot per second is equal to the discharge of a stream at a rectangular cross section 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot per second. Equivalent to 448.8 gallons per minute.

**Cubic feet per second per square mile.** The average number of cubic feet of water flowing per second from each square mile of area drained, assuming that the runoff is distributed uniformly in time and area.

**Floodmark.** A mark showing the highest level reached by a flood water, sometimes referred to as a "high-water mark."

**Flood stage.** The approximate stage of a stream at which property damage would begin.

**Isohyetal.** A contour line drawn on a map which connects points receiving equal rainfall.

**Peak stage.** The highest value of stage attained during a flood.

**Recurrence interval.** The average number of years between occurrences of an annual peak flood or storm greater than or equal to a specified magnitude. Because of the random nature of flood events, the times between annual peak discharges of a specified magnitude may differ greatly from the average. In any given year, the chance that the annual peak flow will exceed the discharge with a specified recurrence interval is the reciprocal of (or one divided by) the recurrence interval. In any year, for example, there is 1 chance in 100 that the annual peak flow will exceed the flow with a 100-year recurrence interval (the 100-year flood).

**Runoff.** That part of the precipitation that appears in surface-water bodies.

**Stage.** Height of the water surface in a river above a predetermined point that may be on or near the channel floor. Used interchangeably with gage height. In this report, stage is given in feet.

**Station number.** Identification numbers assigned by the U.S. Geological Survey to streamflow-gaging stations in a downstream direction along the main stream. Stations on tributaries are assigned numbers based on the location where they enter the main stream.

**Streamflow-gaging station.** A site on a stream, canal, lake, or reservoir where systematic observations of stage or discharge are made.

# STORM AND FLOOD OF JULY 5, 1989, IN NORTHERN NEW CASTLE COUNTY, DELAWARE

*By* Gary N. Paulachok, Robert H. Simmons, *and* Anthony J. Tallman

## ABSTRACT

On July 5, 1989, intense rainfall from the remnants of Tropical Storm Allison caused severe flooding in northern New Castle County, Delaware. The flooding claimed three lives, and damage was estimated to be $5 million. Flood conditions were aggravated locally by rapid runoff from expansive urban areas.

Rainfall developed from convective uplift in a regional trough of low pressure that extended over northern Delaware. Because upper-level winds were weak, the storm remained virtually stationary and produced substantial amounts of rain. At the New Castle County Airport, 6.63 in. (inches) of rainfall was recorded on July 5, 1989, the greatest 24-hour amount ever measured officially at that location. A total of more than 9 in. of rainfall was reported unofficially at Arden, Delaware, and Carneys Point, New Jersey, during July 4-6, 1989.

Peak discharges at three active, continuous-record streamflow-gaging stations in northern New Castle County exceeded previously recorded maximums. Estimated recurrence intervals for peak flow at these stations exceeded 100 years. Peak streamflow at Shellpot Creek at Wilmington was 8,040 $ft^3/s$ (cubic feet per second) at a stage of 13.76 ft (feet). This discharge was about 30 percent greater than the 100-year flood, exceeding the previous flood of record, recorded in 1971, by 1,190 $ft^3/s$ and1.8 ft in stage. The Christina River at Coochs Bridge peaked at 5,530 $ft^3/s$ at a stage of 13.12 ft. This discharge was about 10 percent greater than the 100-year flood, exceeding the previous flood of record, recorded in 1947, by 1,200 $ft^3/s$ and 0.7 ft in stage. White Clay Creek near Newark peaked at 11,600 $ft^3/s$ at a stage of 16.55 ft. This discharge was about 10 percent greater than the 100-year flood, exceeding the previous flood of record (resulting from Hurricane Agnes, 1972) by 2,500 $ft^3/s$; the 1989 and 1972 stages are not comparable because the flood of 1972 was recorded at a site 0.5 miles upstream and at a datum of 2.6 ft higher than that of the current streamflow station. Peak discharges also exceeded previously recorded maximums at one active crest-stage station and at two discontinued streamflow-gaging stations.

The U.S. Geological Survey conducted comprehensive post-flood surveys to determine peak water-surface elevations that occurred on affected streams and their tributaries during the flood of July 5, 1989. Detailed surveys were performed near bridge crossings to provide additional information on the extent and severity of the flooding and the effects of hydraulic constrictions on floodwaters. Selected data from the surveys are included in this report.

## INTRODUCTION

On July 5, 1989, intense rainfall from the remnants of Tropical Storm Allison caused record-breaking floods in northern New Castle County, Del. The storm also caused floods in adjoining parts of southeastern Pennsylvania, northeastern Maryland, and southwestern New Jersey, and, on a broader scale, from northern Virginia to New York City.

During July 4-6, 1989, more than 9 in. of rain fell in a narrow band from Arden, Del., to Carneys Point, N.J. In Delaware, the maximum storm-total rainfall reported unofficially was 9.52 in. at a nonrecording rain gage at Arden. More than 8 in. of rain was measured or reported in the region encompassing northeastern New Castle County, southeastern Delaware County, Pa., and the vicinity of Penns Grove, N.J.

Record-breaking floods occurred on many streams in northern New Castle County. Flood discharges exceeded previously recorded maximums at three active, continuous-record streamflow-gaging stations, at one active crest-stage station, and at two discontinued streamflow-gaging stations. In Delaware, the flooding claimed three lives, and damage to private property, highways, and bridges was estimated to be $5 million (Office of the County Executive, New Castle County, oral commun., 1992).

This report complements an earlier report (Talley, 1989) on the flood. That report presented basic data to allow for early release of information to the public. This report provides additional, verified data on the flood, including measurements of peak stage at bridge crossings on major streams.

### Purpose and Scope

This report presents a summary of the storm and resultant flood of July 5, 1989, in northern New Castle County, Del. The report provides fundamental information on this extreme hydrologic event and forms a technical basis for planning and management of flood plains and stream corridors in the affected localities.

The report documents the distribution of rainfall at 20 sites and peak stages and discharges for previous floods of record and the flood of July 5, 1989, at 12 streamflow-gaging stations in the study region. The report also documents the time series of flood stage and discharge at seven continuous-record streamflow-gaging stations in the study area, and presents data on peak-flood stage at 67 bridge crossings on five major streams in that area. Data are shown on maps, graphs, and tables, and flood conditions and damage are illustrated by photographs.

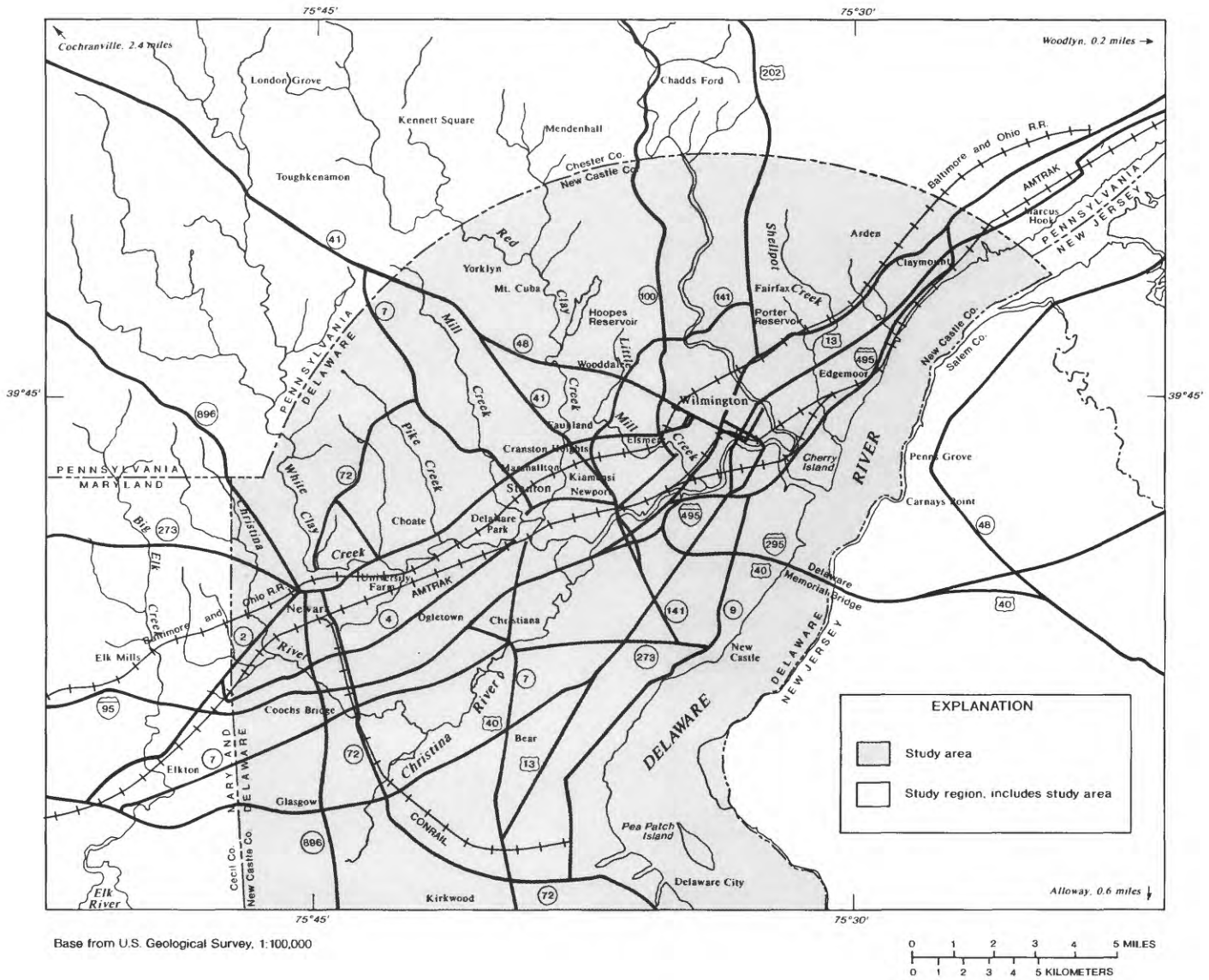
### Location of Study Area

The study area, or area of primary focus in this report, is in northern New Castle County, Del., and occupies about 256 $mi^2$. The area is bounded on the west by the Maryland State line, on the north by the Pennsylvania State line, on the east by the Delaware River, and on the south extending from Delaware City through Kirkwood to the Maryland State line (fig. 1). Wilmington, Stanton, and Newark are the principal municipalities in the study area.

A study region broader in area than the study area was delineated for this report to incorporate supporting meteorologic and hydrologic data for localities in adjacent states. This region occupies about 600 $mi^2$ and is approximately bounded on the southwest by Elkton, Md., on the northwest by Cochranville, Pa., on the northeast by Woodlyn, Pa., and on the southeast by Alloway, N.J. (fig. 1). The study area and study region are situated in the Coastal Plain and Piedmont Physiographic Provinces.

### Acknowledgments

The authors are grateful to the government agencies that provided supporting data on the meteorologic and hydrologic conditions of this flood, and to the private citizens who provided photographs of the flood damage. The U.S. Army Corps of Engineers, Philadelphia District, provided funding for post-flood surveys of peak stage in five major stream basins in northern New Castle County. The Corps of Engineers, along with the Delaware Geological Survey and other State and local agencies, provide continued support for the network of streamflow-gaging stations in Delaware. Franz Schaefer of the U.S. Army Corps of Engineers and William S. Schenck of the Delaware Geological Survey provided fundamental information on benchmarks used for the post-flood surveys. Marian D. Peleski of the National Weather Service furnished real-time



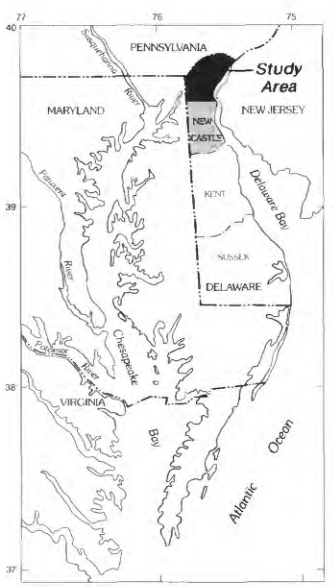




**Figure 1.** Location of study area and study region.

information on storm conditions during July 5, 1989, and provided much of the technical information contained in the Description of Storm section of this report. Denis C. Quinn, a private citizen, provided photographs of flood conditions and property damage in the Shellpot Creek Basin that are used in the report.

## DESCRIPTION OF STORM

On July 5, 1989, the remnants of Tropical Storm Allison caused extensive flooding in northern New Castle County, Del. In late June 1989, the tropical storm moved inland from the Gulf of Mexico and dissipated rapidly over Texas. The moisture associated with the storm persisted over the Southeastern United States, however, through the end of June. By July 4, 1989, the moisture had drifted northward and spread across the mid-Atlantic region.

By early morning of July 5, 1989, the tropical moisture was well established over Delaware. On a larger scale, a weak trough of low pressure formed in the area extending from northern Virginia to New York City. Because upper-level winds were weak, convective uplift remained stationary and localized, and resulted in record rainfall and flooding at several localities in and around northern New Castle County. On July 5, 1989, a record 24-hour rainfall of 6.63 in. was measured officially at the New Castle County Airport.

### Spatial Distribution of Rainfall

Rainfall for the storm period (July 4-6) varied considerably across the study region, and generally increased from west to east. Total amounts of rainfall for the 3-day period rather than daily amounts are presented in this section because of inconsistencies in observation times for recording and nonrecording rain gages (table 1), and the resultant general incomparability of daily amounts.

Total rainfall in the study region ranged from 3.65 in. at Kennett Square, Pa., to 9.52 in. at Arden, Del. (table 1). The greatest amounts, more than 9 in., were concentrated in a narrow band trending from north to south and extending from Arden, Del., to Carneys Point, N.J. (fig. 2). More than 8 in. of rain was measured or reported in a broader area encompassing parts of northeastern New Castle County, southeastern Delaware County, Pa., and adjacent parts of New Jersey (fig. 2). During July 4-6, 1989, average rainfall in the study area, as estimated by isohyetal analysis (Bedient and Huber, 1988, p. 27), was about 6.5 in.

### Temporal Distribution of Rainfall

The rainfall produced by the remnants of Tropical Storm Allison persisted in the study area from July 4 to July 6, 1989. The temporal (chronological) pattern of rainfall was recorded officially by rain gages at the University Farm in Newark and the New Castle County Airport in New Castle (table 1; fig. 2).

By July 4, the moisture associated with the tropical storm moved into the mid-Atlantic region. Localized thunderstorms developed early afternoon on July 4 and produced a reported 2 to 4 in. of rain in the vicinity of Elkton, Md. ( M.D. Peleski, National Weather Service, written commun., 1990). Rainfall varied considerably over the study area, however, as indicated by official measurements of 0.90 in. at the University Farm and 0.24 in. at the New Castle County Airport (table 2; fig. 3).

By 0200 hours on July 5, heavy rain developed over a widespread area of Maryland and Virginia and intensified as it moved northeasterly toward northern Delaware. Rain spread over the study area by 0600 hours and continued at moderate to high intensities through mid-day (fig. 3). From 0600 to 1200 hours, rainfall intensity at the University Farm ranged from 0.10 to 1.20 in/hr and averaged about 0.61 in/hr; rainfall intensity at the New Castle County Airport ranged from 0 to 1.64 in/hr and averaged about 0.90 in/hr. Rainfall intensity was greatest during 1000 to 1100 hours at the University Farm, and during 0700 to 0800 hours at the New Castle County Airport. The rain on July 5 ceased by early afternoon. On July 6, an additional 0.30 in. and 0.26 in. of rainfall was measured at these sites, respectively, resulting in 3-day storm-total amounts of 5.80 in. at the University Farm and 7.13 in. at the New Castle County Airport (table 2; fig. 3).

## Table 1.--*Rainfall data for sites in the study region, July 4-6, 1989*

[° = degrees; ' = minutes; > = greater than; in. = inches; -- = no data; e.d.t. = eastern daylight time; NWS = National Weather Service; Locations shown in figure 2]

| Site no. | Location[1] | Latitude | Longitude | Date | Time of observation (e.d.t.) | Rainfall[2] (in.) | Type of rain gage/ Remarks |
|---|---|---|---|---|---|---|---|
| | | | **New Castle County, Delaware** | | | | |
| 1 | Arden | 39°49' | 75°29' | -- | -- | 9.52 | Nonrecording |
| 2 | Christiana | 39°39' | 75°40' | 7/4/89 | 0700 | 0.00 | Nonrecording |
| | | | | 7/5/89 | 0700 | .66 | |
| | | | | 7/6/89 | 0700 | 6.07 | |
| | | | | | | 6.73 | |
| 3 | Choate | 39°42' | 75°41' | -- | -- | >6 | Nonrecording |
| 4 | Claymont | 39°48' | 75°28' | 7/4/89 | 0800 | 0.00 | Nonrecording |
| | | | | 7/5/89 | 0800 | 4.75 | |
| | | | | 7/6/89 | 0800 | 3.80 | |
| | | | | | | 8.55 | |
| 5 | Glasgow | 39°36' | 75°44' | 7/4/89 | 0800 | 0.00 | Nonrecording |
| | | | | 7/5/89 | 0800 | 3.75 | |
| | | | | 7/6/89 | 0800 | 1.80 | |
| | | | | | | 5.55 | |
| 6 | Mt. Cuba | 39°37' | 75°38' | 7/4/89 | 0800 | 0.00 | Nonrecording |
| | | | | 7/5/89 | 0800 | 3.00 | |
| | | | | 7/6/89 | 0800 | 3.35 | |
| | | | | | | 6.35 | |
| 7 | Newark (University Farm) | 39°40' | 75°44' | 7/4/89 | [3] 2400 | 0.90 | Recording; NWS Station no. 07 6410 01 |
| | | | | 7/5/89 | [3] 2400 | 4.60 | |
| | | | | 7/6/89 | [3] 2400 | .30 | |
| | | | | | | 5.80 | |
| 8 | New Castle (New Castle Co.) Airport) | 39°40' | 75°35' | 7/4/89 | [3] 2400 | 0.24 | Recording; NWS Station no. 07 9595 01 |
| | | | | 7/5/89 | [3] 2400 | 6.63 | |
| | | | | 7/6/89 | [3] 2400 | .26 | |
| | | | | | | 7.13 | |
| 9 | Ogletown | 39°39' | 75°42' | 7/4/89 | -- | 0.60 | Nonrecording |
| | | | | 7/5/89 | -- | 4.85 | |
| | | | | | | 5.45 | |
| 10 | Stanton | 39°42' | 75°38' | 7/4/89 | 0700 | 0.00 | Nonrecording |
| | | | | 7/5/89 | 0700 | .37 | |
| | | | | 7/6/89 | 0700 | 6.43 | |
| | | | | | | 6.80 | |
| 11 | Wilmington (Porter Reservoir) | 39°46' | 75°32' | 7/4/89 | [3] 2400 | 0.24 | Recording; NWS Station no. 07 9605 01 |
| | | | | 7/5/89 | [3] 2400 | 6.15 | |
| | | | | 7/6/89 | [3] 2400 | .36 | |
| | | | | | | 6.75 | |

**Table 1.**--*Rainfall data for sites in the study region, July 4-6, 1989--Continued*

| Site no. | Location[1] | Latitude | Longitude | Date | Time of observation (e.d.t.) | Rainfall[2] (in.) | Type of rain gage/ Remarks |
|---|---|---|---|---|---|---|---|
| | | | **New Castle County, Delaware--Continued** | | | | |
| 12 | Wooddale | 39°45' | 75°38' | 7/4/89 | 0730 | 0.00 | Nonrecording |
| | | | | 7/5/89 | 0730 | .76 | |
| | | | | 7/6/89 | 0730 | 5.56 | |
| | | | | | | 6.32 | |
| 13 | Yorklyn | 39°48' | 75°41' | -- | -- | 5.50 | Nonrecording |
| | | | **Chester County, Pennsylvania** | | | | |
| 14 | Kennett Square | 39°53' | 75°41' | -- | -- | 3.65 | Nonrecording |
| 15 | London Grove | 39°52' | 75°47' | 7/4/89 | -- | 1.10 | Nonrecording |
| | | | | 7/5/89 | | 2.68 | |
| | | | | | | 3.78 | |
| 16 | Mendenhall | 39°49' | 75°38' | 7/4/89 | 0100 | 0.49 | Nonrecording |
| | | | | 7/5/89 | 0715 | .41 | |
| | | | | 7/5/89 | 1200 | 4.48 | |
| | | | | | | 5.38 | |
| 17 | Toughkenamon | 39°49' | 75°44' | 7/4/89 | 0800 | 0.00 | Nonrecording |
| | | | | 7/5/89 | 0800 | 2.60 | |
| | | | | 7/6/89 | 0800 | 2.50 | |
| | | | | | | 5.10 | |
| | | | **Delaware County, Pennsylvania** | | | | |
| 18 | Chadds Ford | 39°52' | 75°37' | 7/4/89 | [3] 0700 | -- | Recording; |
| | | | | 7/5/89 | [3] 0700 | 0.45 | NWS Station no. |
| | | | | 7/6/89 | [3] 0700 | 4.15 | 36 1342 03 |
| | | | | | | 4.60 | |
| 19 | Marcus Hook | 39°49' | 75°25' | 7/4/89 | [3] 2400 | 0.39 | Recording; |
| | | | | 7/5/89 | [3] 2400 | 7.50 | NWS Station no. |
| | | | | 7/6/89 | [3] 2400 | .18 | 36 5390 03 |
| | | | | | | 8.07 | |
| | | | **Salem County, New Jersey** | | | | |
| 20 | Carneys Point | 39°42' | 75°30' | 7/5/89 | -- | 9.22 | Nonrecording |

[1] Location of nearest principal locality.
[2] Daily amounts listed where known. In some cases, only storm totals are known.
[3] Eastern Standard Time.

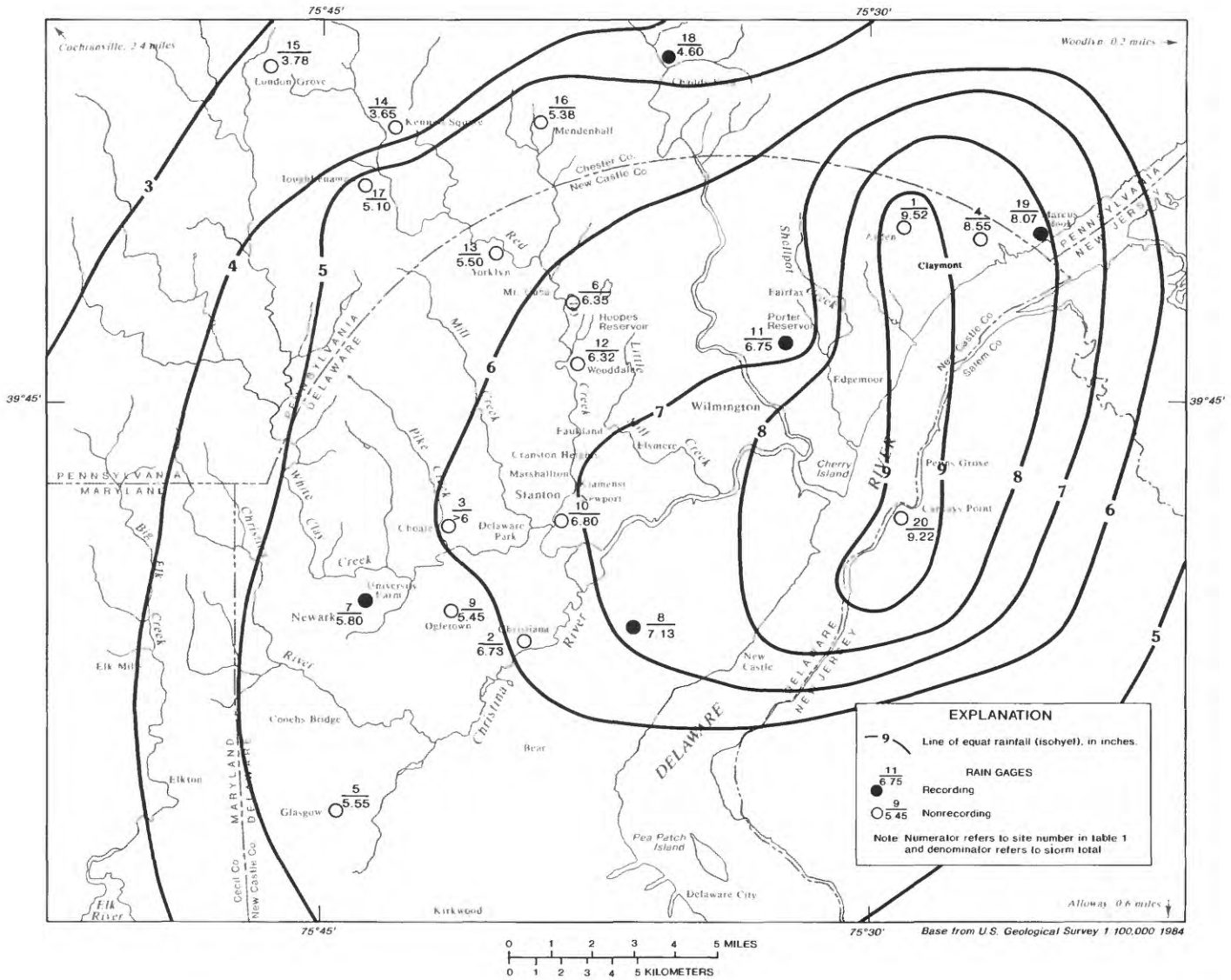



**Figure 2.** Location of rain gages and distribution of rainfall, July 4-6, 1989.

**Table 2.**--*Hourly and cumulative rainfall at the University Farm, Newark, Delaware, and the New Castle County Airport, New Castle, Delaware, July 4-6, 1989*

[Station numbers assigned by National Weather Service; e.s.t. = eastern standard time; Rainfall amounts in inches; Locations shown in figure 2]

| Date | Time (e.s.t.) | University Farm (Station 07641001) | | New Castle County Airport (Station 07959501) | |
|---|---|---|---|---|---|
| | | Hourly | Cumulative | Hourly | Cumulative |
| July 4 ---------- | 0100 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0200 | .00 | .00 | .00 | .00 |
| | 0300 | .00 | .00 | .00 | .00 |
| | 0400 | .00 | .00 | .00 | .00 |
| | 0500 | .00 | .00 | .00 | .00 |
| | 0600 | .00 | .00 | .00 | .00 |
| | 0700 | .00 | .00 | .00 | .00 |
| | 0800 | .00 | .00 | .00 | .00 |
| | 0900 | .00 | .00 | .00 | .00 |
| | 1000 | .00 | .00 | .00 | .00 |
| | 1100 | .00 | .00 | .00 | .00 |
| | 1200 | .00 | .00 | .00 | .00 |
| | 1300 | .00 | .00 | .06 | .06 |
| | 1400 | .20 | .20 | .11 | .17 |
| | 1500 | .50 | .70 | .05 | .22 |
| | 1600 | .10 | .80 | .01 | .23 |
| | 1700 | .00 | .80 | .00 | .23 |
| | 1800 | .00 | .80 | .00 | .23 |
| | 1900 | .00 | .80 | .00 | .23 |
| | 2000 | .00 | .80 | .01 | .24 |
| | 2100 | .00 | .80 | .00 | .24 |
| | 2200 | .10 | .90 | .00 | .24 |
| | 2300 | .00 | .90 | .00 | .24 |
| | 2400 | .00 | .90 | .00 | .24 |
| July 5 ---------- | 0100 | .00 | .90 | .00 | .24 |
| | 0200 | .00 | .90 | .00 | .24 |
| | 0300 | .00 | .90 | .00 | .24 |
| | 0400 | .00 | .90 | .00 | .24 |
| | 0500 | .00 | .90 | .21 | .45 |
| | 0600 | .20 | 1.10 | .95 | 1.40 |
| | 0700 | .80 | 1.90 | 1.64 | 3.04 |
| | 0800 | 1.00 | 2.90 | 1.30 | 4.34 |
| | 0900 | .50 | 3.40 | 1.00 | 5.34 |
| | 1000 | 1.20 | 4.60 | 1.07 | 6.41 |
| | 1100 | .50 | 5.10 | .00 | 6.41 |
| | 1200 | .10 | 5.20 | .42 | 6.83 |
| | 1300 | .20 | 5.40 | .03 | 6.86 |
| | 1400 | .10 | 5.50 | .00 | 6.86 |
| | 1500 | .00 | 5.50 | .00 | 6.86 |
| | 1600 | .00 | 5.50 | .00 | 6.86 |
| | 1700 | .00 | 5.50 | .00 | 6.86 |
| | 1800 | .00 | 5.50 | .00 | 6.86 |
| | 1900 | .00 | 5.50 | .01 | 6.87 |
| | 2000 | .00 | 5.50 | .00 | 6.87 |
| | 2100 | .00 | 5.50 | .00 | 6.87 |
| | 2200 | .00 | 5.50 | .00 | 6.87 |
| | 2300 | .00 | 5.50 | .00 | 6.87 |
| | 2400 | .00 | 5.50 | .00 | 6.87 |

**Table 2.**--*Hourly and cumulative rainfall at the University Farm, Newark, Delaware, and the New Castle County Airport, New Castle, Delaware, July 4-6, 1989--Continued*

| Date | Time (e.s.t.) | University Farm (Station 07641001) | | New Castle County Airport (Station 07959501) | |
|---|---|---|---|---|---|
| | | Hourly | Cumulative | Hourly | Cumulative |
| July 6 ---------- | 0100 | .00 | 5.50 | .00 | 6.87 |
| | 0200 | .00 | 5.50 | .00 | 6.87 |
| | 0300 | .00 | 5.50 | .00 | 6.87 |
| | 0400 | .00 | 5.50 | .00 | 6.87 |
| | 0500 | .00 | 5.50 | .00 | 6.87 |
| | 0600 | .00 | 5.50 | .01 | 6.88 |
| | 0700 | .00 | 5.50 | .03 | 6.91 |
| | 0800 | .10 | 5.60 | .05 | 6.96 |
| | 0900 | .00 | 5.60 | .04 | 7.00 |
| | 1000 | .00 | 5.60 | .04 | 7.04 |
| | 1100 | .10 | 5.70 | .04 | 7.08 |
| | 1200 | .10 | 5.80 | .02 | 7.10 |
| | 1300 | .00 | 5.80 | .01 | 7.11 |
| | 1400 | .00 | 5.80 | .00 | 7.11 |
| | 1500 | .00 | 5.80 | .00 | 7.11 |
| | 1600 | .00 | 5.80 | .00 | 7.11 |
| | 1700 | .00 | 5.80 | .00 | 7.11 |
| | 1800 | .00 | 5.80 | .00 | 7.11 |
| | 1900 | .00 | 5.80 | .02 | 7.13 |
| | 2000 | .00 | 5.80 | .00 | 7.13 |
| | 2100 | .00 | 5.80 | .00 | 7.13 |
| | 2200 | .00 | 5.80 | .00 | 7.13 |
| | 2300 | .00 | 5.80 | .00 | 7.13 |
| | 2400 | .00 | 5.80 | .00 | 7.13 |

## DESCRIPTION OF FLOOD

The intense rainfall from the remnants of Tropical Storm Allison caused severe flooding in northern New Castle County. The flooding claimed three lives and caused extensive damage to public and private property. Flood damage to property, highways, and bridges in the study area totaled about $5 million. Damage was particularly severe in the highly urbanized Shellpot and Little Mill Creek Basins. Floodwaters from Shellpot Creek swept away several vehicles, dislodged large sections of concrete curbing and sidewalk, and damaged public and private property in the Wilmington area. Floodwaters from Little Mill Creek forced evacuation of 600 residents from an apartment complex in Elsmere, and destroyed 39 basement units in the complex. Damage in less urbanized drainage basins also was considerable. The photographs on the cover of this report and in figures 4-9 show flood conditions and property damage in the study area.

### Peak Stage and Discharge at Streamflow-Gaging Stations

Peak stage and discharge on July 5, 1989, was recorded or measured at eight active continuous-record streamflow-gaging stations, one active crest-stage station, and three discontinued recording stations (table 3). The location of these stations is shown in figure 10.

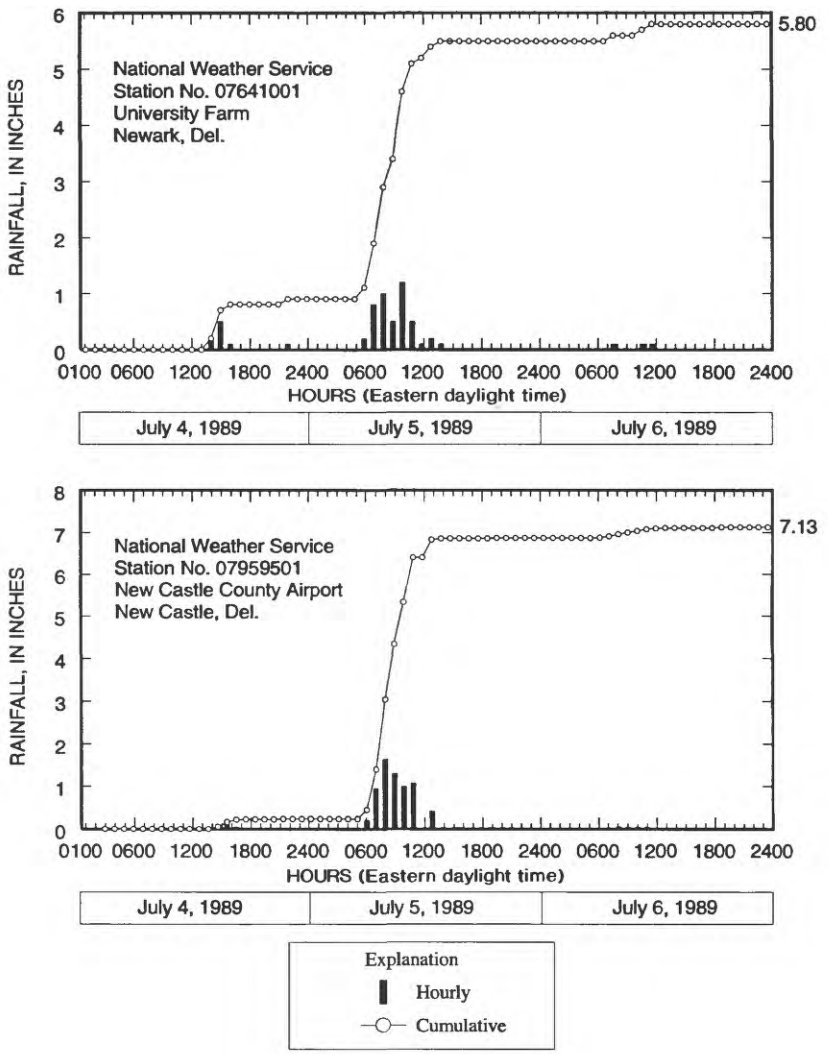



**Figure 3.** Hourly and cumulative rainfall at the University Farm, Newark, Delaware, and the New Castle County Airport, New Castle, Delaware, July 4-6, 1989.

Peak discharge exceeded previously recorded maximums at continuous-record stations on Shellpot Creek, Christina River, and White Clay Creek. Estimated recurrence intervals for peak flow at these stations exceeded 100 years. The recurrence interval for the peak discharge on Shellpot Creek was estimated using the methods presented in Sauer and others (1983). These methods were developed specifically for evaluating the flood-flow characteristics of streams in urban areas in the United States. Recurrence intervals for the other streams were estimated using a log-Pearson Type III analysis; this analysis is commonly used for evaluating the flood-flow characteristics of streams in basins that have not been highly urbanized.

Peak streamflow at Shellpot Creek at Wilmington was 8,040 $ft^3/s$, or about 1,100 $(ft^3/s)/mi^2$, at a stage of 13.76 ft. This discharge was about 30 percent greater than the 100-year flood, and 1,190 $ft^3/s$ more and the stage 1.8 ft higher than the previous flood of record in 1971. The Christina River at Coochs Bridge peaked at 5,530 $ft^3/s$, or 270 $(ft^3/s)/mi^2$, at a stage of 13.12 ft. This discharge was about 10 percent greater than the 100-year flood, and 1,200 $ft^3/s$ more and the stage 0.7 ft higher than the previous flood of record in 1947. White Clay Creek near Newark peaked at 11,600 $ft^3/s$, or 130 $(ft^3/s)/mi^2$, at a stage of 16.55 ft. This discharge was about 10 percent greater than the 100-year flood and 2,500 $ft^3/s$ more than the previous

**Figure 4**. White Clay Creek flooding at Stanton, Delaware, on July 5, 1989. View looking downstream, right bank flood plain.

**Figure 5.** Submergence of concrete-arch bridge along old Route 7 by floodwaters of White Clay Creek at Stanton, Delaware. (Note debris accumulated against bridge.) View looking downstream.

**Figure 6**. Damage to highway bridge and sidewalk from flooding of Shellpot Creek, Wilmington, Delaware. (View looking northeast along Market Street. [Photograph by Denis C. Quinn, private citizen.])

**Figure 7**. Damage to highway and and parking lot caused by flooding of Shellpot Creek, Wilmington, Delaware. (View looking southwest along Market Street. [Photograph by Denis C. Quinn, private citizen.])

**Figure 8.** Floodwaters from Shellpot Creek at Market Street Shopping Center, Wilmington, Delaware. (View looking northeast from left bank. [Photograph by Denis C. Quinn, private citizen.])

**Figure 9**. Floodwaters from White Clay Creek at Stanton, Delaware. (View looking downstream, right bank flood plain.)

## *Table 3.--Peak stages and discharges for previous flood of record and flood of July 5, 1989*

[$mi^2$ = square miles; ft = foot; $ft^3/s$ = cubic foot per second; $(ft^3/s)/mi$ ) = cubic foot per second per square mile; > = greater than; < = less than; -- = no data; Locations shown in figure 10]

| Station no. | Station name and location | Drainage area ($mi^2$) | Period of record (Water years) | Previous flood of record | | | | Flood of July 5, 1989 | | | Recurrence interval (years) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Date | Stage (ft) | Discharge | | Stage (ft) | Discharge | | |
| | | | | | | ($ft^3/s$) | [($ft^3/s$)/$mi^2$)] | | ($ft^3/s$) | [($ft^3/s$)/$mi^2$)] | |
| | | | | **DELAWARE RIVER BASIN** | | | | | | | |
| [1]01477800 | Shellpot Creek at Wilmington, Del. | 7.46 | 1945-89 | 9/13/71 | 11.91 | 6,850 | 918 | 13.76 | 8,040 | 1,080 | >100 |
| [1]01478000 | Christina River at Coochs Bridge, Del. | 20.5 | 1943-89 | 5/01/47 | 12.41 | 4,330 | 211 | 13.12 | 5,530 | 270 | >100 |
| 01478040 | Christina River near Bear, Del. | 40.6 | 1979-82 [1]; 1983-89 [2] | 5/19/88 | 11.57 | 3,480 | 85.5 | 14.34 | 7,500 | 185 | -- |
| [4]01478500 | White Clay Creek above Newark, Del. | 66.7 | 1952-59; 1962-80 | 6/22/72 | 13.77 | 10,200 | 153 | [5]10.4 | 4,910 | 73.6 | >7 |
| [4]01478950 | Pike Creek near Newark, Del. | 6.04 | 1969-75 | 7/28/69 | 9.15 | 2,550 | 422 | [5]11.3 | 5,450 | 902 | 100 |
| [1]01479000 | White Clay Creek near Newark, Del. | 89.1 | 1931-36; 1943-57; 1959-89 | 6/22/72 | [3]17.74 | 9,080 | 102 | 16.55 | 11,600 | 130 | >100 |
| [1]01480000 | Red Clay Creek at Wooddale, Del. | 47.0 | 1943-89 | 7/21/75 | 10.32 | 5,010 | 107 | 8.59 | 3,860 | 82.1 | >10 |
| [1]01480015 | Red Clay Creek near Stanton, Del. | 52.4 | 1988-89 | -- | -- | -- | -- | 19.35 | 5,320 | 102 | -- |
| [4]01480100 | Little Mill Creek at Elsmere, Del. | 6.70 | 1963-80 | 8/10/67 | 8.58 | 3,960 | 591 | [5]8.8 | 4,400 | 657 | 45 |
| [1]01481000 | Brandywine Creek at Chadds Ford, Pa. | 287 | 1911-53; 1962-89 | 6/22/72 | 16.56 | 23,800 | 82.9 | 8.94 | 5,230 | 18.2 | -- |
| [1]01481500 | Brandywine Creek at Wilmington, Del. | 314 | 1946-89 | 6/23/72 | 15.49 | 29,000 | 92.4 | 9.94 | 9,850 | 31.4 | 3 |
| | | | | **ELK RIVER BASIN** | | | | | | | |
| [1]01495000 | Big Elk Creek at Elks Mills, Md. | 52.6 | 1932-89 | 7/05/37 | [5]14.5 | 10,600 | 202 | 8.64 | 5,030 | 95.6 | 5 |

[1] Active continuous-recording gage.
[2] Active crest-stage station.
[3] At previous site 0.5 mi upstream and datum 2.6 ft higher than present datum.
[4] Discontinued recording gage.
[5] From floodmark.

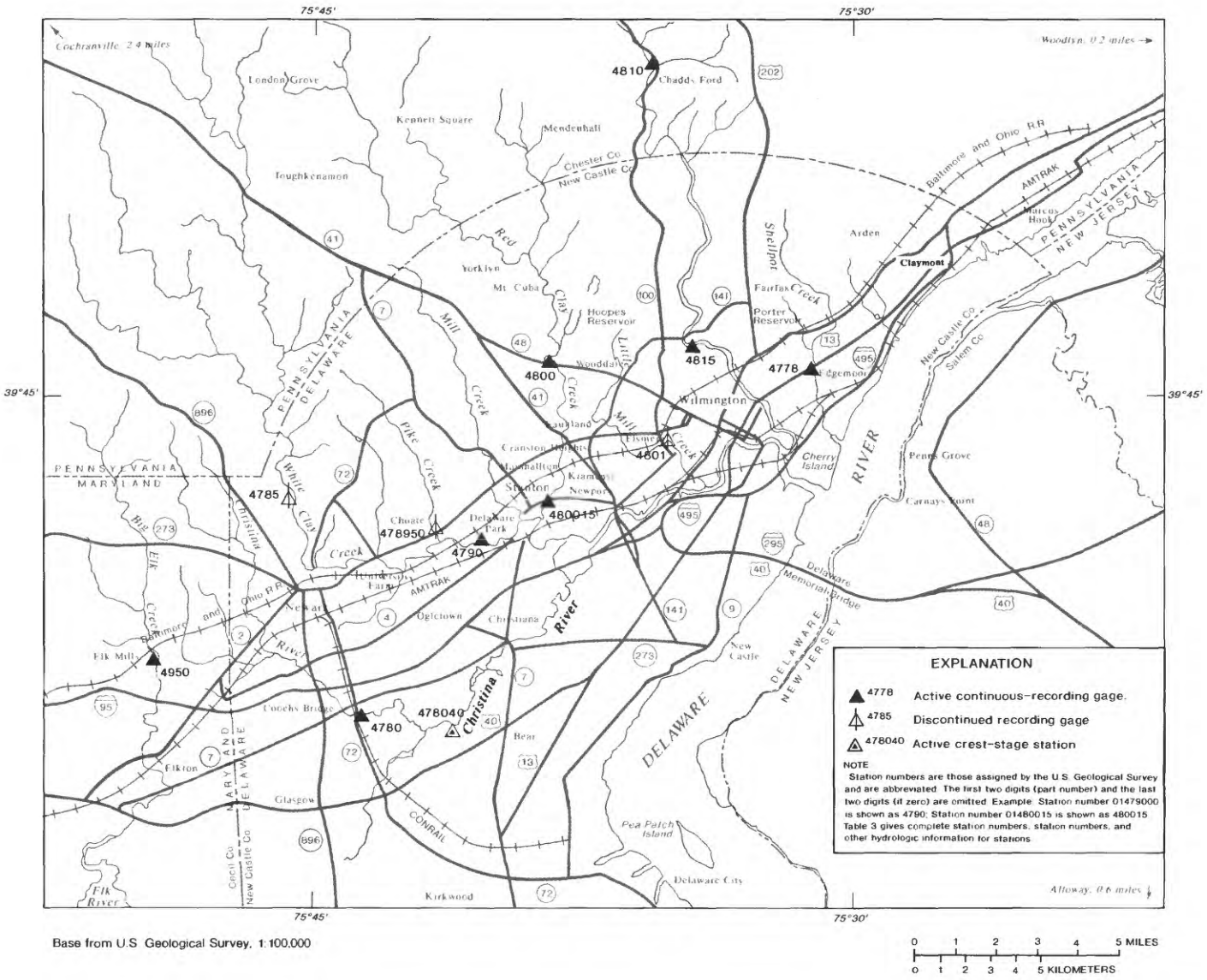



**Figure 10.** Location of stream stage and discharge measuring stations.

flood of record in 1972. The flood of 1972 was observed at a previously operated streamflow-gaging station 0.5 miles upstream from and at datum 2.6 ft higher than the present station.

Peak discharge exceeded the previously recorded maximum at one active crest-stage station. The Christina River near Bear peaked at 7,500 $ft^3/s$, or 185 $(ft^3/s)/mi^2$, at a stage of 14.34 ft. This discharge was about 4,000 $ft^3/s$ more and the stage 2.8 ft higher than the previous flood of record in 1988.

Peak discharge also exceeded previously recorded maximums at two discontinued streamflow-gaging stations. Peak streamflow at Pike Creek near Newark was 5,450 $ft^3/s$, or about 900 $(ft^3/s)/mi^2$, at a stage of about 11.3 ft. This discharge was 2,900 $ft^3/s$ more and the stage about 2.2 ft higher than the previous flood of record in 1969. Little Mill Creek at Elsmere peaked at 4,400 $ft^3/s$, or about 660 $(ft^3/s)/mi^2$, at a stage of about 8.8 ft. This discharge was about 440 $ft^3/s$ more and the stage about 0.2 ft higher than the previous flood of record in 1967.

Selected values of stage and discharge for the period July 4-6, 1989, are presented in tables 4-10 for the active continuous-record streamflow-gaging stations on Shellpot Creek, Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River. All available values of discharge, recorded at a 5-minute frequency at Shellpot Creek at Wilmington and at a 15-minute frequency at the other six continuous-record stations in the study area, were used to prepare the hydrographs presented in figures 11-17. Comparison of the discharge hydrographs shows significant differences in streamflow response to rainfall. These differences are attributable mainly to differences in land use, size, and morphology of the drainage basins.

**Table 4.**--*Selected values of stage and discharge for Station 01477800 Shellpot Creek at Wilmington, Delaware, July 4-6, 1989*

[e.d.t. = eastern daylight time; ft = foot; $ft^3/s$ = cubic foot per second]

| Date | Time (e.d.t.) | Stage (ft) | Discharge ($ft^3/s$) |
|---|---|---|---|
| July 4 | 0600 | 1.53 | 1.2 |
| | 1200 | 1.54 | 1.3 |
| | 1800 | 1.68 | 5.0 |
| | 2400 | 1.70 | 5.8 |
| July 5 | 0600 | 1.62 | 2.9 |
| | 0700 | 2.38 | 78 |
| | 0715 | 2.83 | 210 |
| | 0730 | 3.43 | 481 |
| | 0745 | 4.21 | 925 |
| | 0800 | 5.75 | 1,850 |
| | 0815 | 6.70 | 2,510 |
| | 0830 | 7.46 | 3,130 |
| | 0845 | 9.31 | 4,810 |
| | 0850 | 10.23 | 5,660 |
| | 0855 | 11.10 | 6,270 |
| | 0900 | 11.70 | 6,690 |
| | 0905 | 12.09 | 6,960 |
| | 0910 | 12.36 | 7,130 |
| | 0915 | 12.55 | 7,260 |
| | 0920 | 12.71 | 7,360 |
| | 0925 | 12.88 | 7,470 |
| | 0930 | 13.01 | 7,560 |
| | 0935 | 13.17 | 7,660 |
| | 0940 | 13.34 | 7,770 |
| | 0945 | 13.51 | 7,880 |
| | 0950 | 13.63 | 7,960 |
| | 0955 | 13.71 | 8,010 |
| | 1000 | 13.76 | 8,040 |
| | 1005 | 13.76 | 8,040 |
| | 1010 | 13.72 | 8,020 |
| | 1015 | 13.67 | 7,990 |
| | 1020 | 13.49 | 7,870 |
| | 1025 | 13.36 | 7,780 |
| | 1030 | 13.23 | 7,700 |
| | 1035 | 13.09 | 7,610 |
| | 1040 | 12.99 | 7,540 |
| | 1045 | 12.87 | 7,470 |
| | 1050 | 12.78 | 7,410 |
| | 1055 | 12.67 | 7,340 |
| | 1100 | 12.50 | 7,220 |
| | 1105 | 12.30 | 7,100 |
| | 1110 | 12.14 | 6,990 |
| | 1115 | 11.95 | 6,870 |
| | 1120 | 11.71 | 6,700 |
| | 1125 | 11.44 | 6,500 |
| | 1130 | 11.18 | 6,320 |
| | 1135 | 10.85 | 6,090 |
| | 1140 | 10.53 | 5,870 |
| | 1145 | 10.17 | 5,620 |
| | 1150 | 9.89 | 5,390 |
| | 1155 | 9.57 | 5,060 |
| | 1200 | 9.23 | 4,730 |
| | 1215 | 7.94 | 3,550 |
| | 1230 | 6.31 | 2,220 |
| | 1245 | 5.20 | 1,490 |
| | 1300 | 4.79 | 1,250 |
| | 1315 | 4.30 | 974 |
| | 1330 | 4.25 | 947 |
| | 1345 | 4.21 | 925 |
| | 1400 | 4.31 | 980 |
| | 1415 | 4.22 | 931 |
| | 1430 | 4.05 | 829 |
| | 1500 | 3.62 | 585 |
| | 1530 | 3.29 | 409 |
| | 1600 | 3.08 | 309 |
| | 1700 | 2.84 | 203 |
| | 1800 | 2.70 | 147 |
| | 2000 | 2.47 | 76 |
| | 2200 | 2.34 | 50 |
| | 2400 | 2.23 | 36 |
| July 6 | 0200 | 2.14 | 26 |
| | 0400 | 2.08 | 21 |
| | 0600 | 2.00 | 15 |
| | 1200 | 2.05 | 18 |
| | 1800 | 1.92 | 17 |
| | 2400 | 1.89 | 15 |

## Table 5.--*Selected values of stage and discharge for Station 01481500 Brandywine Creek at Wilmington, Delaware, July 4-6, 1989*

[e.d.t. = eastern daylight time; ft = foot; $ft^3/s$ = cubic foot per second]

| Date | Time (e.d.t.) | Stage (ft) | Discharge ($ft^3/s$) |
|---|---|---|---|
| July 4 | 0600 | 3.16 | 409 |
| | 1200 | 3.18 | 423 |
| | 1800 | 3.21 | 438 |
| | 2000 | 3.28 | 485 |
| | 2200 | 3.37 | 540 |
| | 2400 | 3.48 | 609 |
| July 5 | 0200 | 3.75 | 857 |
| | 0400 | 3.89 | 993 |
| | 0600 | 3.87 | 973 |
| | 0700 | 3.89 | 993 |
| | 0730 | 4.18 | 1,290 |
| | 0800 | 6.07 | 3,200 |
| | 0830 | 8.47 | 6,470 |
| | 0900 | 8.90 | 7,380 |
| | 0930 | 9.22 | 8,100 |
| | 1000 | 9.78 | 9,440 |
| | 1015 | 9.94 | 9,850 |
| | 1030 | 9.91 | 9,770 |
| | 1045 | 9.75 | 9,360 |
| | 1100 | 9.62 | 9,040 |
| | 1115 | 9.47 | 8,680 |
| | 1130 | 9.28 | 8,230 |
| | 1145 | 9.14 | 7,910 |
| | 1200 | 8.98 | 7,560 |
| | 1215 | 8.81 | 7,180 |
| | 1230 | 8.68 | 6,910 |
| | 1245 | 8.53 | 6,600 |
| | 1300 | 8.43 | 6,390 |
| | 1315 | 8.33 | 6,190 |
| | 1330 | 8.25 | 6,040 |
| | 1345 | 8.20 | 5,940 |
| | 1400 | 8.12 | 5,790 |
| | 1415 | 8.08 | 5,710 |
| | 1430 | 8.03 | 5,620 |
| | 1445 | 7.96 | 5,490 |
| | 1500 | 7.92 | 5,420 |
| | 1515 | 7.90 | 5,380 |
| | 1530 | 7.88 | 5,350 |
| | 1545 | 7.85 | 5,300 |
| | 1600 | 7.81 | 5,230 |
| | 1615 | 7.78 | 5,180 |
| | 1630 | 7.75 | 5,130 |
| | 1645 | 7.72 | 5,070 |
| | 1700 | 7.70 | 5,040 |
| | 1730 | 7.72 | 5,070 |
| | 1800 | 7.69 | 5,020 |
| | 1830 | 7.67 | 4,990 |
| | 1900 | 7.69 | 5,020 |
| | 1930 | 7.70 | 5,040 |
| | 2000 | 7.71 | 5,060 |
| | 2030 | 7.72 | 5,070 |
| | 2100 | 7.71 | 5,060 |
| | 2130 | 7.73 | 5,090 |
| | 2200 | 7.74 | 5,110 |
| | 2300 | 7.73 | 5,090 |
| | 2400 | 7.74 | 5,110 |
| July 6 | 0300 | 7.78 | 5,180 |
| | 0600 | 7.07 | 4,190 |
| | 0900 | 5.25 | 2,250 |
| | 1200 | 4.66 | 1,800 |
| | 1500 | 4.42 | 1,550 |
| | 1800 | 4.30 | 1,410 |
| | 2100 | 4.20 | 1,310 |
| | 2400 | 4.14 | 1,250 |

## Table 6.--*Selected values of stage and discharge for Station 01480000 Red Clay Creek at Wooddale, Delaware, July 4-6, 1989*

[e.d.t. = eastern daylight time; ft = foot; $ft^3/s$ = cubic foot per second]

| Date | Time (e.d.t.) | Stage (ft) | Discharge ($ft^3/s$) |
|---|---|---|---|
| July 4 | 0600 | 2.60 | 48 |
| | 1200 | 2.60 | 48 |
| | 1800 | 2.66 | 58 |
| | 2000 | 2.94 | 129 |
| | 2200 | 3.15 | 215 |
| | 2400 | 3.11 | 196 |
| July 5 | 0200 | 2.95 | 131 |
| | 0400 | 2.87 | 108 |
| | 0600 | 2.82 | 93 |
| | 0700 | 2.82 | 93 |
| | 0730 | 2.90 | 118 |
| | 0800 | 3.15 | 210 |
| | 0830 | 3.71 | 530 |
| | 0900 | 3.88 | 638 |
| | 0930 | 4.43 | 970 |
| | 1000 | 5.82 | 1,860 |
| | 1015 | 6.17 | 2,100 |
| | 1030 | 6.31 | 2,200 |
| | 1045 | 6.48 | 2,320 |
| | 1100 | 6.72 | 2,490 |
| | 1115 | 6.94 | 2,660 |
| | 1130 | 7.15 | 2,810 |
| | 1145 | 7.38 | 2,980 |
| | 1200 | 7.56 | 3,110 |
| | 1215 | 7.77 | 3,270 |
| | 1230 | 7.94 | 3,400 |
| | 1245 | 8.10 | 3,520 |
| | 1300 | 8.23 | 3,610 |
| | 1315 | 8.33 | 3,680 |
| | 1330 | 8.42 | 3,740 |
| | 1345 | 8.49 | 3,790 |
| | 1400 | 8.54 | 3,820 |
| | 1415 | 8.57 | 3,840 |
| | 1430 | 8.59 | 3,860 |
| | 1445 | 8.59 | 3,860 |
| | 1500 | 8.58 | 3,850 |
| | 1515 | 8.56 | 3,830 |
| | 1530 | 8.51 | 3,800 |
| | 1545 | 8.49 | 3,790 |
| | 1600 | 8.46 | 3,770 |
| | 1615 | 8.43 | 3,750 |
| | 1630 | 8.37 | 3,700 |
| | 1645 | 8.33 | 3,680 |
| | 1700 | 8.26 | 3,630 |
| | 1730 | 8.12 | 3,530 |
| | 1800 | 7.90 | 3,370 |
| | 1830 | 7.66 | 3,190 |
| | 1900 | 7.41 | 3,000 |
| | 1930 | 7.17 | 2,820 |
| | 2000 | 6.77 | 2,530 |
| | 2030 | 5.80 | 1,850 |
| | 2100 | 4.82 | 1,220 |
| | 2130 | 4.34 | 916 |
| | 2200 | 4.05 | 748 |
| | 2300 | 3.78 | 573 |
| | 2400 | 3.63 | 482 |
| July 6 | 0300 | 3.46 | 379 |
| | 0600 | 3.34 | 312 |
| | 0900 | 3.21 | 241 |
| | 1200 | 3.17 | 225 |
| | 1500 | 3.19 | 230 |
| | 1800 | 3.17 | 225 |
| | 2100 | 3.19 | 230 |
| | 2400 | 3.10 | 191 |

## Table 7.--*Selected values of stage and discharge for Station 01480015 Red Clay Creek near Stanton, Delaware, July 4-6, 1989*

[e.d.t. = eastern daylight time; ft = foot; $ft^3/s$ = cubic foot per second]

| Date | Time (e.d.t.) | Stage (ft) | Discharge ($ft^3/s$) |
|---|---|---|---|
| July 4 | 0600 | 8.57 | 50 |
| | 1200 | 8.58 | 51 |
| | 1800 | 8.65 | 59 |
| | 2000 | 8.69 | 64 |
| | 2200 | 9.30 | 167 |
| | 2400 | 10.25 | 362 |
| July 5 | 0200 | 9.43 | 191 |
| | 0400 | 9.15 | 139 |
| | 0600 | 9.02 | 114 |
| | 0700 | 9.11 | 131 |
| | 0730 | 9.98 | 296 |
| | 0800 | 12.35 | 945 |
| | 0830 | 13.80 | 1,500 |
| | 0900 | 15.30 | 2,270 |
| | 0930 | 16.10 | 2,770 |
| | 1000 | 16.80 | 3,250 |
| | 1015 | 17.00 | 3,400 |
| | 1030 | 17.30 | 3,620 |
| | 1045 | 17.50 | 3,770 |
| | 1100 | 17.78 | 3,990 |
| | 1115 | 17.96 | 4,130 |
| | 1130 | 18.14 | 4,280 |
| | 1145 | 18.32 | 4,420 |
| | 1200 | 18.50 | 4,580 |
| | 1215 | 18.56 | 4,630 |
| | 1230 | 18.62 | 4,680 |
| | 1245 | 18.74 | 4,780 |
| | 1300 | 18.86 | 4,880 |
| | 1315 | 18.96 | 4,970 |
| | 1330 | 19.00 | 5,010 |
| | 1345 | 19.06 | 5,060 |
| | 1400 | 19.13 | 5,120 |
| | 1415 | 19.18 | 5,170 |
| | 1430 | 19.22 | 5,200 |
| | 1445 | 19.35 | 5,320 |
| | 1500 | 19.32 | 5,300 |
| | 1515 | 19.28 | 5,260 |
| | 1530 | 19.32 | 5,300 |
| | 1545 | 19.30 | 5,280 |
| | 1600 | 19.31 | 5,290 |
| | 1615 | 19.34 | 5,310 |
| | 1630 | 19.27 | 5,250 |
| | 1645 | 19.21 | 5,200 |
| | 1700 | 19.17 | 5,160 |
| | 1730 | 19.10 | 5,100 |
| | 1800 | 18.90 | 4,920 |
| | 1830 | 18.70 | 4,750 |
| | 1900 | 17.80 | 4,000 |
| | 1930 | 17.32 | 3,630 |
| | 2000 | 16.85 | 3,290 |
| | 2030 | 16.38 | 2,960 |
| | 2100 | 15.90 | 2,640 |
| | 2130 | 15.42 | 2,350 |
| | 2200 | 14.95 | 2,070 |
| | 2300 | 14.20 | 1,690 |
| | 2400 | 13.30 | 1,280 |
| July 6 | 0300 | 11.33 | 644 |
| | 0600 | 10.24 | 360 |
| | 0900 | 10.01 | 302 |
| | 1200 | 9.94 | 288 |
| | 1500 | 9.89 | 278 |
| | 1800 | 9.88 | 276 |
| | 2100 | 9.90 | 280 |
| | 2400 | 9.76 | 253 |

## Table 8.--*Selected values of stage and discharge for Station 01479000 White Clay Creek near Newark, Delaware, July 4-6, 1989*

[e.d.t. = eastern daylight time; ft = foot; $ft^3/s$ = cubic foot per second]

| Date | Time (e.d.t.) | Stage (ft) | Discharge ($ft^3/s$) |
|---|---|---|---|
| July 4 | 0600 | 5.59 | 78 |
| | 1200 | 5.61 | 84 |
| | 1800 | 6.83 | 295 |
| | 2000 | 7.31 | 417 |
| | 2200 | 7.70 | 534 |
| | 2400 | 7.26 | 407 |
| July 5 | 0200 | 6.92 | 319 |
| | 0400 | 6.64 | 255 |
| | 0600 | 6.46 | 222 |
| | 0700 | 6.98 | 330 |
| | 0730 | 8.46 | 785 |
| | 0800 | 10.86 | 1,580 |
| | 0830 | 13.12 | 2,830 |
| | 0900 | 13.80 | 3,630 |
| | 0930 | 14.46 | 4,700 |
| | 1000 | 14.90 | 5,580 |
| | 1015 | 15.12 | 6,180 |
| | 1030 | 15.36 | 6,990 |
| | 1045 | 15.59 | 7,850 |
| | 1100 | 15.82 | 8,800 |
| | 1115 | 16.16 | 10,200 |
| | 1130 | 16.31 | 10,700 |
| | 1145 | 16.43 | 11,100 |
| | 1200 | 16.48 | 11,300 |
| | 1215 | 16.54 | 11,600 |
| | 1230 | 16.55 | 11,600 |
| | 1245 | 16.53 | 11,500 |
| | 1300 | 16.55 | 11,600 |
| | 1315 | 16.43 | 11,100 |
| | 1330 | 16.37 | 10,900 |
| | 1345 | 16.23 | 10,400 |
| | 1400 | 16.13 | 10,100 |
| | 1415 | 16.02 | 9,670 |
| | 1430 | 15.91 | 9,190 |
| | 1445 | 15.78 | 8,620 |
| | 1500 | 15.67 | 8,170 |
| | 1515 | 15.58 | 7,810 |
| | 1530 | 15.52 | 7,580 |
| | 1545 | 15.41 | 7,170 |
| | 1600 | 15.34 | 6,920 |
| | 1615 | 15.24 | 6,570 |
| | 1630 | 15.18 | 6,370 |
| | 1645 | 15.41 | 6,240 |
| | 1700 | 15.11 | 6,140 |
| | 1730 | 15.08 | 6,050 |
| | 1800 | 15.05 | 5,950 |
| | 1830 | 15.02 | 5,860 |
| | 1900 | 14.96 | 5,710 |
| | 1930 | 14.93 | 5,650 |
| | 2000 | 14.88 | 5,540 |
| | 2030 | 14.80 | 5,370 |
| | 2100 | 14.69 | 5,150 |
| | 2130 | 14.56 | 4,890 |
| | 2200 | 14.35 | 4,500 |
| | 2300 | 13.73 | 3,550 |
| | 2400 | 12.36 | 2,230 |
| July 6 | 0300 | 8.80 | 906 |
| | 0600 | 8.14 | 668 |
| | 0900 | 7.85 | 559 |
| | 1200 | 7.89 | 573 |
| | 1500 | 7.87 | 566 |
| | 1800 | 7.75 | 518 |
| | 2100 | 7.60 | 462 |
| | 2400 | 7.46 | 411 |

## Table 9.--*Selected values of stage and discharge for Station 01478000 Christina River at Coochs Bridge, Delaware, July 4-6, 1989*

[e.d.t. = eastern daylight time; ft = foot; $ft^3/s$ = cubic foot per second]

| Date | Time (e.d.t.) | Stage (ft) | Discharge ($ft^3/s$) |
|---|---|---|---|
| July 4 | 0600 | 3.37 | 23 |
| | 1200 | 3.38 | 24 |
| | 1800 | 8.16 | 476 |
| | 2000 | 7.46 | 363 |
| | 2200 | 5.63 | 168 |
| | 2400 | 4.82 | 105 |
| July 5 | 0200 | 4.38 | 76 |
| | 0400 | 4.12 | 61 |
| | 0600 | 4.01 | 55 |
| | 0700 | 7.42 | 358 |
| | 0730 | 9.86 | 1,020 |
| | 0800 | 10.72 | 1,810 |
| | 0830 | 11.04 | 2,140 |
| | 0900 | 11.20 | 2,310 |
| | 0930 | 11.40 | 2,610 |
| | 1000 | 11.64 | 3,070 |
| | 1015 | 11.85 | 3,480 |
| | 1030 | 11.76 | 3,300 |
| | 1045 | 12.01 | 3,820 |
| | 1100 | 12.19 | 4,230 |
| | 1115 | 12.16 | 4,160 |
| | 1130 | 12.17 | 4,180 |
| | 1145 | 12.34 | 4,430 |
| | 1200 | 12.28 | 4,350 |
| | 1215 | 12.47 | 4,600 |
| | 1230 | 12.46 | 4,590 |
| | 1245 | 12.81 | 5,080 |
| | 1300 | 12.72 | 4,950 |
| | 1315 | 12.94 | 5,260 |
| | 1330 | 12.94 | 5,260 |
| | 1345 | 12.95 | 5,280 |
| | 1400 | 12.98 | 5,320 |
| | 1415 | 13.04 | 5,410 |
| | 1430 | 13.12 | 5,530 |
| | 1445 | 13.05 | 5,430 |
| | 1500 | 12.96 | 5,290 |
| | 1515 | 12.96 | 5,290 |
| | 1530 | 12.89 | 5,190 |
| | 1545 | 12.82 | 5,090 |
| | 1600 | 12.64 | 4,840 |
| | 1615 | 12.51 | 4,660 |
| | 1630 | 12.39 | 4,500 |
| | 1645 | 12.26 | 4,330 |
| | 1700 | 12.16 | 4,160 |
| | 1730 | 11.84 | 3,460 |
| | 1800 | 11.43 | 2,670 |
| | 1830 | 10.98 | 1,930 |
| | 1900 | 10.54 | 1,520 |
| | 1930 | 10.17 | 1,220 |
| | 2000 | 9.79 | 980 |
| | 2030 | 9.31 | 758 |
| | 2100 | 8.82 | 599 |
| | 2130 | 8.34 | 503 |
| | 2200 | 7.99 | 443 |
| | 2300 | 7.51 | 350 |
| | 2400 | 7.19 | 291 |
| July 6 | 0300 | 6.53 | 191 |
| | 0600 | 6.15 | 139 |
| | 0900 | 6.10 | 133 |
| | 1200 | 6.61 | 203 |
| | 1500 | 7.10 | 278 |
| | 1800 | 6.48 | 184 |
| | 2100 | 6.04 | 127 |
| | 2400 | 5.74 | 95 |

## Table 10.--*Selected values of stage and discharge for Station 01478040 Christina River near Bear, Delaware, July 4-6, 1989*

[e.d.t. = eastern daylight time; ft = foot; $ft^3/s$ = cubic foot per second]

| Date | Time (e.d.t.) | Stage (ft) | Discharge ($ft^3/s$) |
|---|---|---|---|
| July 4 | 0600 | 1.31 | 18 |
| | 1200 | 1.31 | 18 |
| | 1800 | 2.18 | 71 |
| | 2000 | 3.87 | 244 |
| | 2200 | 4.57 | 337 |
| | 2400 | 4.88 | 382 |
| July 5 | 0200 | 4.86 | 379 |
| | 0400 | 4.53 | 331 |
| | 0600 | 4.09 | 272 |
| | 0700 | 4.36 | 308 |
| | 0730 | 4.95 | 392 |
| | 0800 | 5.48 | 494 |
| | 0830 | 5.82 | 568 |
| | 0900 | 6.18 | 651 |
| | 0930 | 6.54 | 739 |
| | 1000 | 6.95 | 830 |
| | 1015 | 7.18 | 883 |
| | 1030 | 7.41 | 938 |
| | 1045 | 7.61 | 1,000 |
| | 1100 | 7.81 | 1,090 |
| | 1115 | 8.06 | 1,190 |
| | 1130 | 8.34 | 1,320 |
| | 1145 | 8.67 | 1,480 |
| | 1200 | 9.04 | 1,660 |
| | 1215 | 9.48 | 1,890 |
| | 1230 | 9.94 | 2,180 |
| | 1245 | 10.47 | 2,550 |
| | 1300 | 11.00 | 2,790 |
| | 1315 | 11.44 | 3,350 |
| | 1330 | 11.84 | 3,800 |
| | 1345 | 12.22 | 4,260 |
| | 1400 | 12.56 | 4,680 |
| | 1415 | 12.84 | 5,060 |
| | 1430 | 13.11 | 5,450 |
| | 1445 | 13.35 | 5,820 |
| | 1500 | 13.58 | 6,180 |
| | 1515 | 13.71 | 6,390 |
| | 1530 | 13.87 | 6,660 |
| | 1545 | 13.99 | 6,870 |
| | 1600 | 14.08 | 7,030 |
| | 1615 | 14.17 | 7,190 |
| | 1630 | 14.25 | 7,330 |
| | 1645 | 14.38 | 7,390 |
| | 1700 | 14.33 | 7,480 |
| | 1730 | 14.34 | 7,500 |
| | 1800 | 14.24 | 7,310 |
| | 1830 | 14.11 | 7,080 |
| | 1900 | 13.94 | 6,780 |
| | 1930 | 13.71 | 6,390 |
| | 2000 | 13.44 | 5,960 |
| | 2030 | 13.16 | 5,530 |
| | 2100 | 12.87 | 5,100 |
| | 2130 | 12.56 | 4,680 |
| | 2200 | 12.27 | 4,320 |
| | 2300 | 11.70 | 3,630 |
| | 2400 | 11.14 | 3,080 |
| July 6 | 0300 | 9.44 | 1,870 |
| | 0600 | 7.95 | 1,140 |
| | 0900 | 6.78 | 792 |
| | 1200 | 5.92 | 590 |
| | 1500 | 5.55 | 468 |
| | 1800 | 5.16 | 430 |
| | 2100 | 5.02 | 404 |
| | 2400 | 4.70 | 355 |

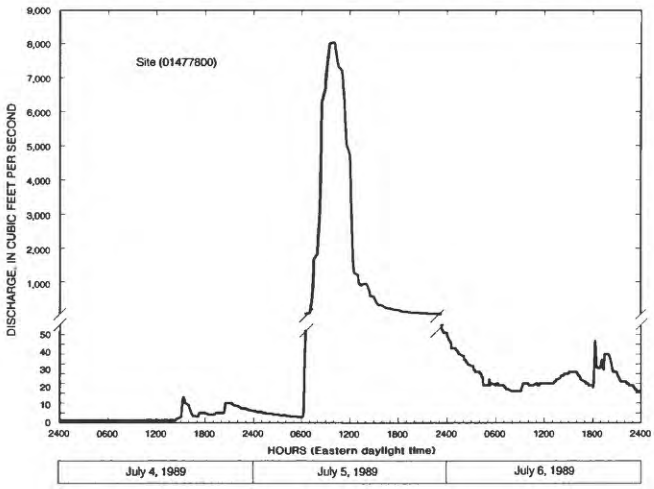



**Figure 11**. Discharge Shellpot Creek at Wilmington, Delaware, July 4-6, 1989.

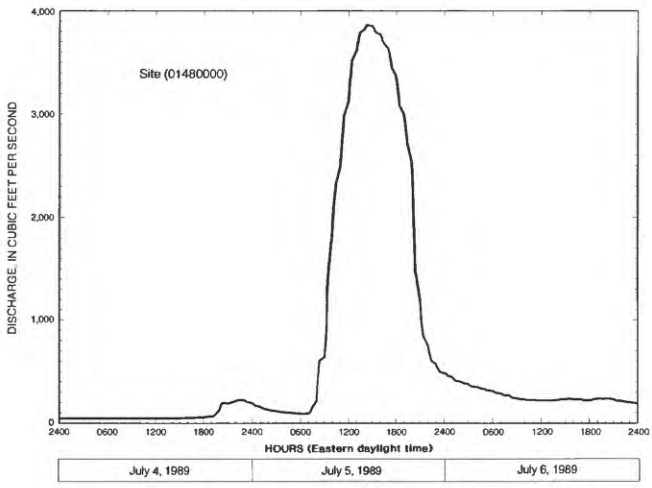



**Figure 13**. Discharge at Red Clay Creek at Woodale, Delaware, July 4-6, 1989.

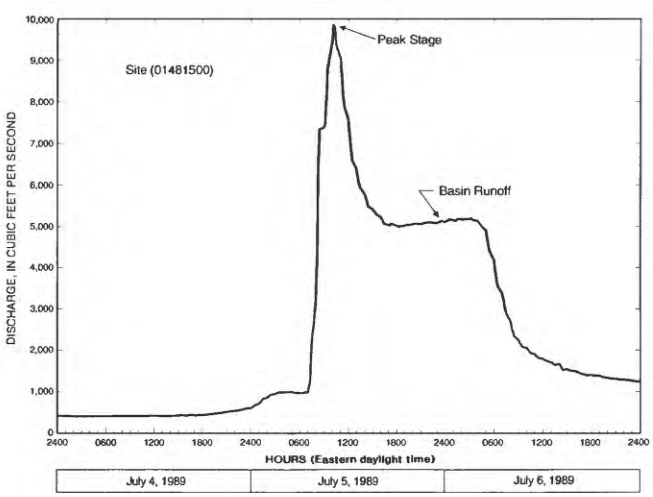



**Figure 12**. Discharge at Brandywine Creek at Wilmington, Delaware, July 4-6, 1989.

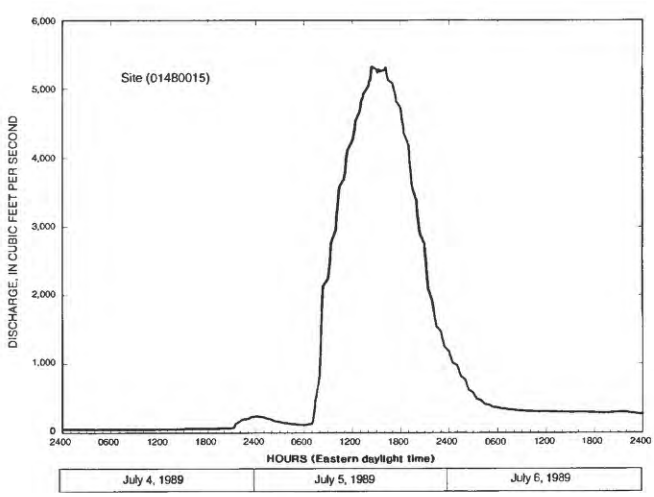



**Figure 14**. Discharge at Red Clay Creek near Stanton, Delaware, July 4-6, 1989.

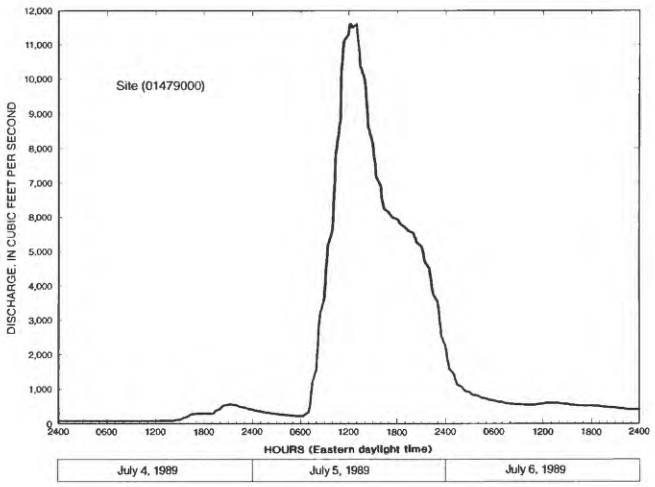



**Figure 15**. Discharge at White Clay Creek near Newark, Delaware, July 4-6, 1989.

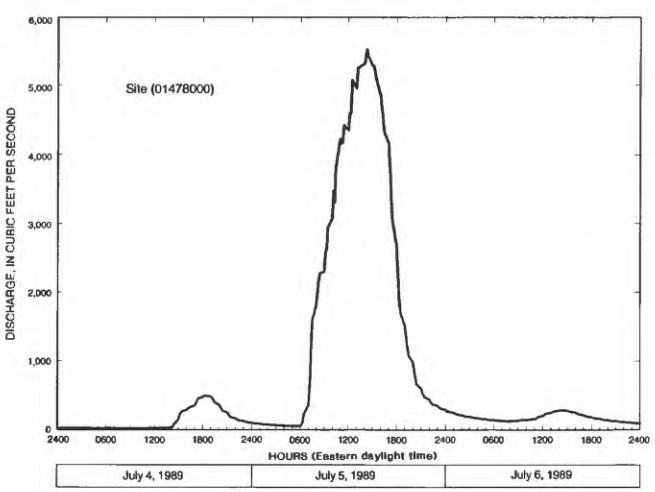



**Figure 16**. Discharge at Christina River at Coochs Bridge, Delaware, July 4-6, 1989.

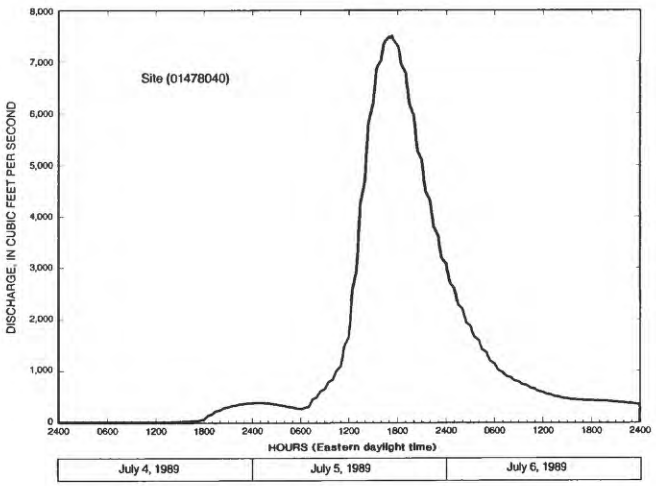



**Figure 17**. Discharge at Christina River near Bear, Delaware, July 4-6, 1989.

## Peak Stage at Selected Sites

The U.S. Geological Survey conducted comprehensive post-flood surveys to determine peak water-surface elevations that occurred on affected streams and their tributaries during the flood of July 5, 1989, and to evaluate the physical and hydraulic characteristics of the stream channels. Detailed surveys were performed near bridge crossings to provide additional information on the extent and severity of flooding and the effects of hydraulic constrictions on floodwaters. Selected data from these surveys are presented in tables 11-15. Locations of the survey sites are shown in figures 18-22.

## Table 11.--*Peak flood stage at selected sites on Shellpot Creek, Delaware, July 5, 1989*

[All sites in Delaware; locations shown in figure 18]

| Site no. | Location | Distance upstream from mouth miles) | Water-surface elevation, in feet (datum is sea level) | |
|---|---|---|---|---|
| | | | Upstream[1] | Downstream[1] |
| 1 | Amtrak railroad bridge at Wilmington | 1.4 | 13.1 | 10.7 |
| 2 | Governor Printz Boulevard (Route 13) highway bridge at Wilmington | 1.6 | 18.6 | 14.2 |
| 3 | Lea Boulevard highway bridge at Wilmington | 1.7 | 20.0 | 18.6 |
| 4 | Colony Boulevard highway bridge at Wilmington | 1.9 | 27.0 | 26.0 |
| 5 | U.S. Geological Survey streamflow-gaging station 01477800 at Wilmington | 2.3 | [2]28.92 | |
| 6 | Market Street highway bridge at Wilmington | 2.5 | 41.7 | 31.6 |
| 7 | Washington Street highway bridge at Wilmington | 3.0 | 74.9 | 67.9 |
| 8 | Shipley Road highway bridge at Wilmington | 3.1 | 85.7 | 77.2 |
| 9 | Carr Road highway bridge near Wilmington | 3.3 | 98.6 | 92.8 |
| 10 | Baltimore and Ohio railroad bridge near Wilmington | 3.9 | 203.2 | 199.3 |
| 11 | Baynard Boulevard highway bridge near Wilmington | 4.3 | 228.9 | 223.5 |
| 12 | Wilson Road highway bridge near Fairfax | 5.0 | 264.2 | 262.5 |
| 13 | Faulk Road (Route 261) highway bridge near Fairfax | 5.4 | 290.4 | 288.4 |
| 14 | Coachman Road highway bridge near Fairfax | 6.0 | 307.2 | 304.7 |

[1] Location of measurement at bridge crossing.
[2] Recorded on water-stage recorder and adjusted to sea-level datum.

## Table 12.--*Peak flood stage at selected sites on Red Clay Creek, Delaware, July 5, 1989*

[All sites in Delaware; locations shown in figure 19; -- = no data]

| Site no. | Location | Distance upstream from mouth (miles) | Water-surface elevation, in feet (datum is sea level) | |
|---|---|---|---|---|
| | | | Upstream[1] | Downstream[1] |
| 1 | Route 4 highway bridge at U.S. Geological Survey streamflow-gaging station 01480015 near Stanton | 0.9 | 20.5 | [2]19.35 |
| 2 | Kiamensi Road highway bridge at Kiamensi | 1.5 | 25.8 | -- |
| 3 | Baltimore and Ohio railroad bridge and dam at Kiamensi | 1.6 | 35.8 | -- |
| 4 | Old Capital Trail highway bridge at Marshallton | 1.8 | 38.3 | 37.7 |
| 5 | Newport Road highway bridge near Cranston Heights | 1.9 | 39.8 | 39.6 |
| 6 | Kirkwood Highway (Route 2) bridge near Cranston Heights | 2.3 | 50.9 | 45.9 |
| 7 | Newport Gap Pike (Route 41) highway bridge near Faulkland | 2.6 | 55.6 | 53.0 |
| 8 | Greenbank Road highway bridge near Faulkland | 2.8 | 56.1 | -- |
| 9 | Baltimore and Ohio railroad bridge near Faulkland | 2.9 | 58.1 | 56.4 |
| 10 | Baltimore and Ohio railroad bridge at Faulkland | 3.4 | 70.3 | 68.2 |
| 11 | Faulkland Road (Route 34) highway bridge at Faulkland | 3.6 | 72.7 | 71.6 |
| 12 | Baltimore and Ohio railroad bridge near Wooddale | 4.3 | [3]86.0 | 85.0 |
| 13 | Route 48 highway bridge at U.S. Geological Survey streamflow-gaging station 01480000 at Wooddale | 4.9 | [3]90.05 | 89.7 |

[1] Location of measurement at bridge crossing.
[2] Recorded on water-stage recorder.
[3] Recorded on water-stage recorder and adjusted to sea-level datum.

## Table 13.--*Peak flood stage at selected sites on White Clay Creek, Delaware, July 5, 1989*

[All sites in Delaware; locations shown in figure 20]

| Site no. | Location | Distance upstream from mouth (miles) | Water-surface elevation, in feet (datum is sea level) | |
|---|---|---|---|---|
| | | | Upstream[1] | Downstream[1] |
| 1 | Amtrak railroad bridge at Stanton | 2.4 | 15.9 | 14.6 |
| 2 | Abandoned Route 4 highway bridge at Stanton | 3.0 | 18.2 | 17.1 |
| 3 | Route 4 highway bridge at Stanton | 3.1 | 18.4 | 18.2 |
| 4 | Dam at Delaware Park near Stanton | 4.1 | 23.5 | [2]23.4 |
| 5 | Bridge on private road at Delaware Park at U.S. Geological Survey streamflow-gaging station 01479000 near Newark | 4.8 | 27.2 | [2]25.55 |
| 6 | Baltimore and Ohio railroad bridge upstream from Delaware Park near Newark | 5.2 | 30.4 | 30.1 |
| 7 | Old Harmony Road highway bridge near Newark | 6.0 | 33.0 | 32.7 |
| 8 | New Harmony Road highway bridge near Newark | 6.1 | 33.6 | 33.0 |
| 9 | Red Mill Road highway bridge near Newark | 7.5 | 41.5 | 40.5 |
| 10 | Kirkwood Highway (Route 2) bridge at Newark | 8.7 | 50.1 | 48.0 |
| 11 | Curtis Mill Road (Route 72) highway bridge at Newark | 10.3 | 68.0 | 67.1 |
| 12 | Dam 1.0 mile north of Newark | 11.2 | 78.7 | 76.4 |
| 13 | U.S. Geological Survey discontinued streamflow-gaging station 01478500 north of Newark | 12.5 | 89.0 | |

[1] Location of measurement at bridge crossing.
[2] Recorded on water-stage recorder and adjusted to sea-level datum.

## Table 14.--*Peak flood stage at selected sites on Christina River, Delaware, July 5, 1989*

[All sites in Delaware; locations shown in figure 21]

| Site no. | Location | Distance upstream from mouth (miles) | Water-surface elevation, in feet (datum is sea level) | |
|---|---|---|---|---|
| | | | Upstream[1] | Downstream[1] |
| 1 | Churchmans Road (Route 58) highway bridge near Christiana (tidal marsh) | 10.1 | 9.7 | 9.1 |
| 2 | Route 7 highway bridge at Christiana | 13.8 | 14.8 | 14.4 |
| 3 | Route 273 highway bridge at Christiana | 14.4 | 16.1 | 15.5 |
| 4 | Smalleys Dam near Christiana | 15.2 | [2]17.1 | 16.7 |
| 5 | Walther Road highway bridge at U.S. Geological Survey streamflow-gaging station 01478040 near Bear | 17.0 | [2]23.36 | 23.3 |
| 6 | Salem Church Road highway bridge near Coochs Bridge | 19.2 | 28.2 | [2]28.1 |
| 7 | Route 72 highway bridge at U.S. Geological Survey streamflow-gaging station 01478000 at Coochs Bridge | 21.7 | 40.8 | [2]38.66 |
| 8 | Conrail railroad bridge at Coochs Bridge | 21.8 | 42.6 | 40.8 |
| 9 | Old Baltimore Pike highway bridge at Coochs Bridge | 22.4 | 45.6 | 43.4 |
| 10 | Dam northwest of Coochs Bridge | 22.9 | 59.2 | 53.9 |
| 11 | I-95 highway bridge near Newark | 23.0 | 61.4 | 59.2 |
| 12 | Route 896 highway bridge near Newark | 23.4 | 66.2 | 64.6 |
| 13 | Welsh Tract Road highway bridge near Newark | 23.6 | 69.7 | 68.2 |
| 14 | West Chestnut Hill Road highway bridge near Newark | 23.9 | 73.8 | 71.2 |
| 15 | Kirkwood Highway (Route 2) bridge at Newark | 26.1 | 100.8 | 98.3 |
| 16 | Barksdale Road highway bridge at Newark | 27.2 | 111.4 | 108.6 |
| 17 | Church Road highway bridge at Newark | 28.1 | 127.2 | 126.3 |
| 18 | Nottingham Road (Route 273) highway bridge near Newark | 28.3 | 130.0 | 128.6 |
| 19 | Wedgewood Road highway bridge near Newark | 29.5 | 158.2 | 157.6 |

[1] Location of measurement at bridge crossing.
[2] Recorded on water-stage recorder and adjusted to sea-level datum.

## Table 15.--*Peak flood stage at selected sites on Little Mill Creek, Delaware, July 5, 1989*

[All sites in Delaware; locations shown in figure 22]

| Site no. | Location | Distance upstream from mouth (miles) | Water-surface elevation, in feet (datum is sea level) | |
|---|---|---|---|---|
| | | | Upstream[1] | Downstream[1] |
| 1 | Amtrak railroad bridge near Elsmere | 0.8 | 13.5 | 9.8 |
| 2 | Maryland Avenue (Route 4) highway bridge at Elsmere | 1.5 | 22.6 | 22.4 |
| 3 | Dupont Road highway bridge at U.S. Geological Survey discontinued streamflow-gaging station 01480100 at Elsmere | 2.2 | 59.7 | 57.4 |
| 4 | Wilmington Avenue (Route 2) highway bridge near Elsmere | 3.7 | 81.2 | 80.8 |
| 5 | Route 141 highway bridge near Elsmere | 4.4 | 91.6 | 88.7 |
| 6 | Faulkland Road (Route 34) highway bridge near Elsmere | 5.2 | 94.2 | 90.9 |
| 7 | Lancaster Pike (Route 48) highway bridge near Wilmington | 6.5 | 145.1 | 139.6 |
| 8 | Barley Mill Road highway bridge near Wooddale | 7.5 | 208.8 | 201.9 |

[1] Location of measurement at bridge crossing.

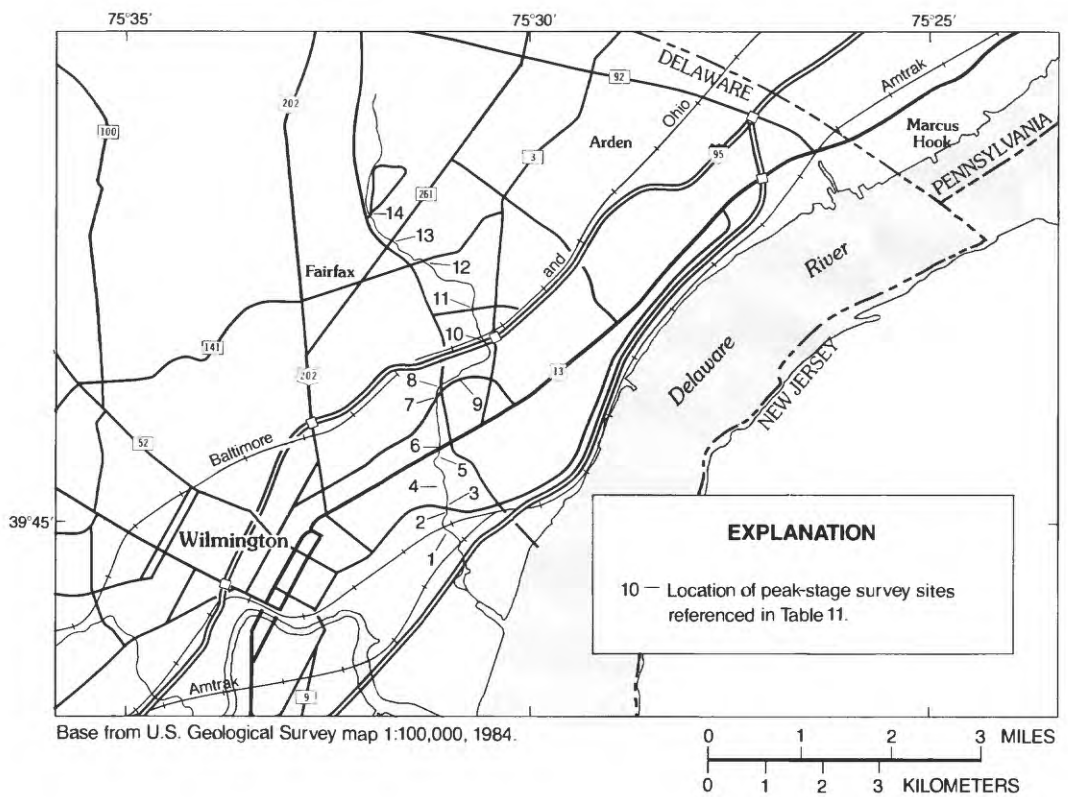



**Figure 18.** Location of peak-stage survey sites on Shellpot Creek in Delaware.

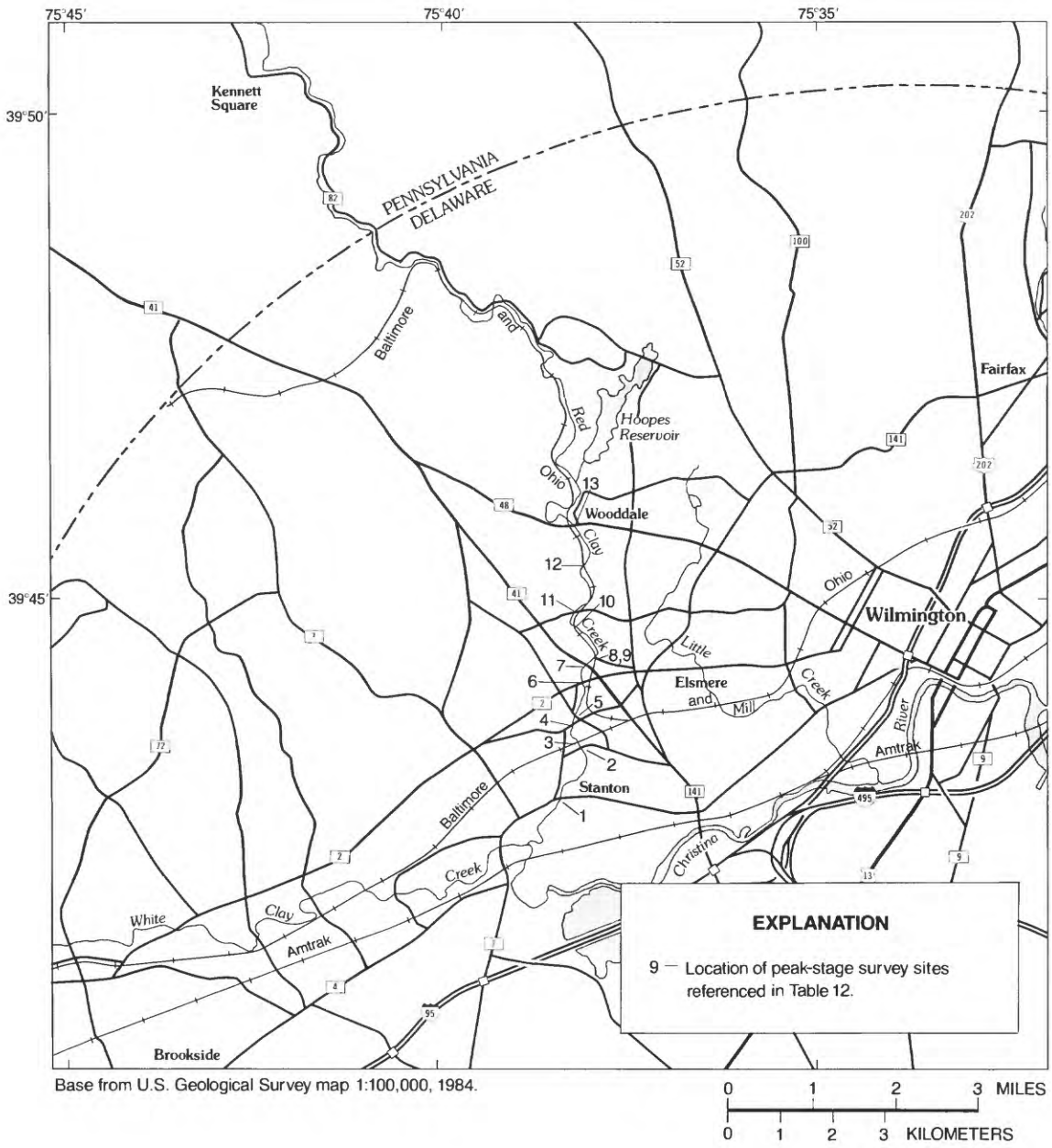



**Figure 19.** Location of peak-stage survey sites on Red Clay Creek in Delaware.

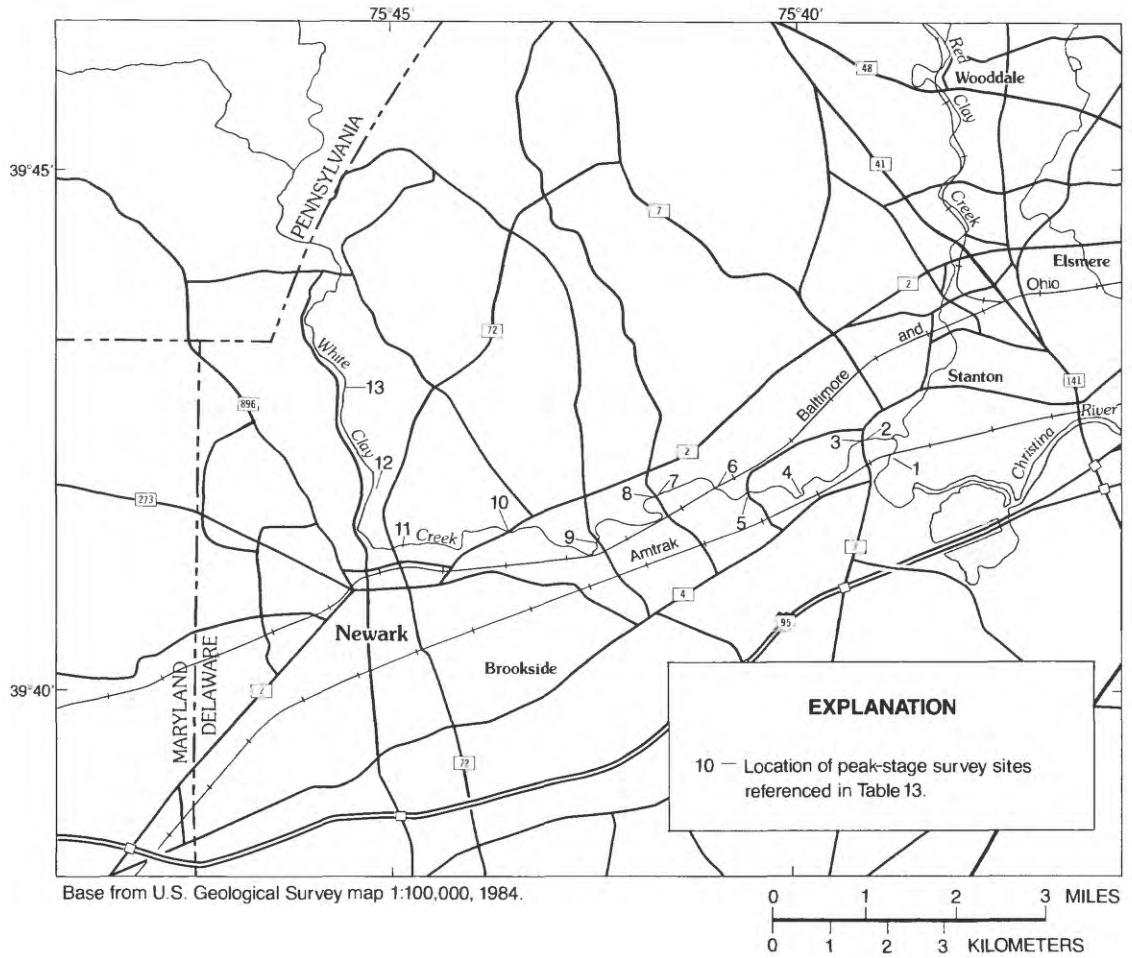



**Figure 20**. Location of peak-stage survey sites on White Clay Creek in Delaware.

## SUMMARY

On July 5, 1989, intense rainfall from the remnants of Tropical Storm Allison caused record-breaking floods in northern New Castle County, Delaware. In Delaware, the flooding claimed three lives and caused an estimated $5 million damage to private property, highways, and bridges. The storm also caused floods in adjoining parts of southeastern Pennsylvania, northeastern Maryland, and southwestern New Jersey, and, on a broader scale, from northern Virginia to New York City.

The amounts of rainfall increased from west to east across the study region. Officially, 6.63 in. of rainfall was recorded on July 5, 1989, at the New Castle County Airport, the greatest 24-hour amount ever measured at that location. Unofficially, a total of 9.52 in. of rainfall was reported during July 4-6, 1989, at Arden, Delaware. In the study area, average rainfall from the storm, as estimated from isohyets, was about 6.5 in.

Peak stage and discharge on July 5, 1989, were recorded or measured at eight active continuous-record streamflow-gaging stations, one active crest-stage station, and three discontinued recording stations.

Peak discharge at continuous-record stations on Shellpot Creek, Christina River, and White Clay Creek exceeded previously recorded maximums. Estimated recurrence intervals for peak flow at these stations exceeded 100 years. Peak streamflow at

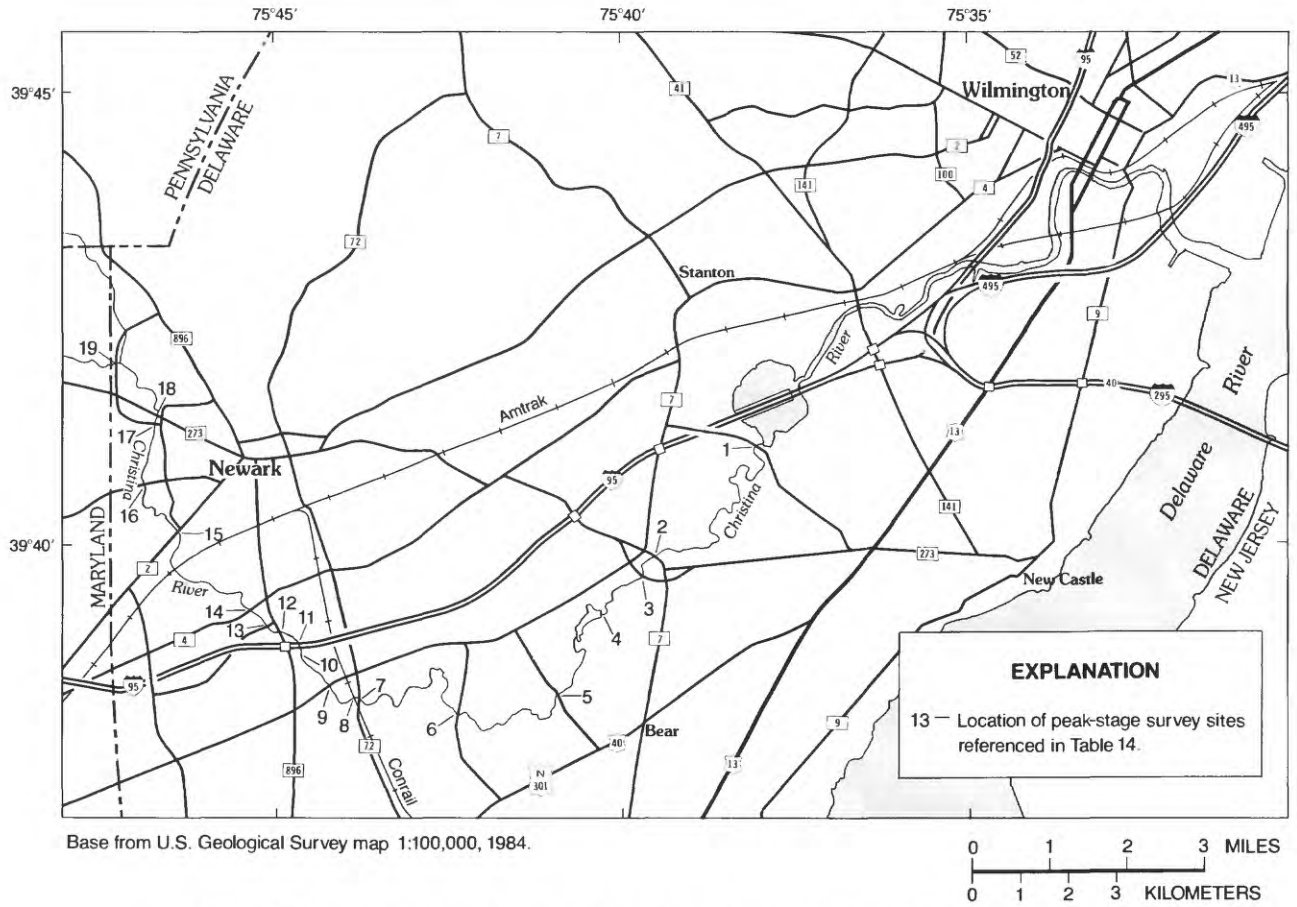



**Figure 21**. Location of peak-stage survey sites on Christina River in Delaware.

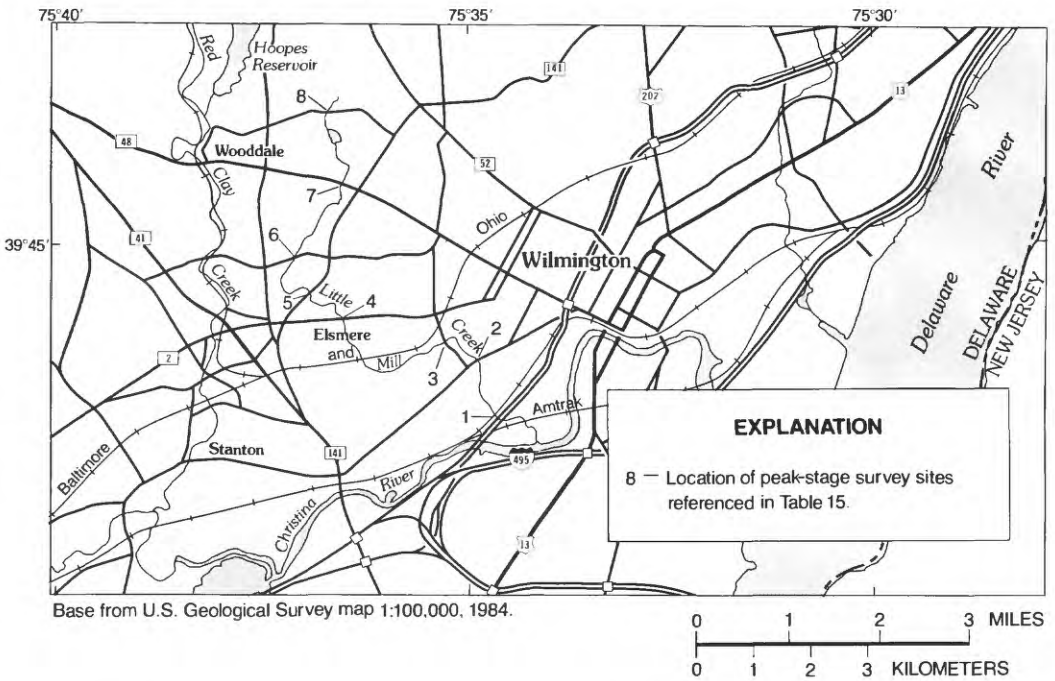



**Figure 22**. Location of peak-stage survey sites on Little Mill Creek in Delaware.

Shellpot Creek at Wilmington was 8,040 $ft^3/s$, or about 1,100 $(ft^3/s)/mi^2$, at a stage of 13.76 ft. This discharge was about 30 percent greater than the 100-year flood, and 1,190 $ft^3/s$ more and the stage 1.8 ft higher than the previous flood of record in 1971. The Christina River at Coochs Bridge peaked at 5,530 $ft^3/s$, or 270 $(ft^3/s)/mi^2$, at a stage of 13.12 ft. This discharge was about 10 percent greater than the 100-year flood, and 1,200 $ft^3/s$ more and the stage 0.7 ft higher than the previous flood of record in 1947. White Clay Creek near Newark peaked at 11,600 $ft^3/s$, or 130 $(ft^3/s)/mi^2$, at a stage of 16.55 ft. This discharge was about 10 percent greater than the 100-year flood and 2,500 $ft^3/s$ more than the previous flood of record in 1972. The flood of 1972 was observed at a previously operated streamflow-gaging station 0.5 miles upstream from and at datum 2.6 ft higher than the present station.

Peak discharge exceeded the previously recorded maximum at one active crest-stage station. The Christina River near Bear peaked at 7,500 $ft^3/s$, or 185 $(ft^3/s)/mi^2$, at a stage of 14.34 ft. This discharge was about 4,000 $ft^3/s$ more and the stage 2.8 ft higher than the previous flood of record in 1988.

Peak discharge also exceeded previously recorded maximums at two discontinued streamflow-gaging stations. Peak streamflow at Pike Creek near Newark was 5,450 $ft^3/s$, or about 900 $(ft^3/s)/mi^2$, at a stage of about 11.3 ft. This discharge was 2,900 $ft^3/s$ more and the stage about 2.2 ft higher than the previous flood of record in 1969. Little Mill Creek at Elsmere peaked at 4,400 $ft^3/s$, or about 660 $(ft^3/s)/mi^2$, at a stage of about 8.8 ft. This discharge was about 440 $ft^3/s$ more and the stage about 0.2 ft higher than the previous flood of record in 1967.

Following the flood, comprehensive field surveys were conducted on affected streams and their tributaries to determine peak water-surface elevations during July 5, 1989, and to evaluate the physical and hydraulic characteristics of the stream channels. Detailed surveys were performed near bridge crossings to provide additional information on the extent and severity of flooding, and the effects of hydraulic constrictions on floodwaters. Data from these surveys and the streamflow-gaging stations provide fundamental information on this extreme hydrologic event and form a technical basis for planning and management of flood plains and stream corridors in the affected localities.

## SELECTED REFERENCES


**Bailey, J.F., Patterson, J.L., and Paulhus, J.L.H., 1975**, Hurricane Agnes rainfall and floods, June-July 1972: U.S. Geological Survey Professional Paper 924, 403 p.

**Bedient, P.B., and Huber, W.C., 1988**, Hydrology and flood plain analysis: Reading, Mass., Addison-Wesley Publishing Co., 650 p.

**Bogart, D.B., 1960**, Floods of August-October 1955, New England to North Carolina: U.S. Geological Survey Water-Supply Paper 1420, 854 p.

**Carpenter, D.H., and Simmons, R.H., 1969**, Floods of August 1967 in Maryland and Delaware: U.S. Geological Survey Open-File Report, 98 p.

**Rostvedt, J.O., 1965**, Summary of floods in the United States during 1960: U.S. Geological Survey Water-Supply Paper 1790-B, 147 p.

**Sauer, V.B., Thomas, W.O., Jr., Stricker, V.A., and Wilson, K.V., 1983**, Flood characteristics of urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2207, 63 p.

**Simmons, R.H., and Carpenter, D.H., 1978**, Technique for estimating magnitude and frequency of floods in Delaware: U.S. Geological Survey Water-Resources Investigations Open-File Report 78-93, 69 p.

**Talley, J.H., 1989**, The storm of July 5, 1989--Hydrologic conditions: Delaware Geological Survey Open-File Report no. 31, 29 p.

**U.S. Geological Survey, 1991**, National water summary 1988-89--Hydrologic events and floods and droughts: U.S. Geological Survey Water-Supply Paper 2375, 591 p.

**U.S. National Oceanic and Atmospheric Administration, 1970-92**, Climatological data annual summaries, Maryland and Delaware: Asheville, N.C., U.S. Department of Commerce, Climatic Data Center (variously paginated).

_____ **1989**, Climatological data, Maryland and Delaware, July 1989: Asheville, N.C., U.S. Department of Commerce, National Climatic Data Center, v. 93, no. 7.

_____ **1989**, Climatological data, Pennsylvania, July 1989: Asheville, N.C., U.S. Department of Commerce, National Climatic Data Center, v. 94, no. 7.

_____ **1989**, Hourly precipitation data, Maryland and Delaware, July 1989: Asheville, N.C., U.S. Department of Commerce, National Climatic Data Center, v. 39, no. 7.

_____ **1989**, Storm data: Asheville, N.C., U.S. Department of Commerce, National Climatic Data Center, v. 31, no. 7.