EFFECTS OF FLOOD CONTROLS PROPOSED FOR WEST BRANCH BRANDYWINE CREEK, CHESTER COUNTY, PENNSYLVANIA

By Ronald A. Sloto

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DONALD P. HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
4th Floor, Federal Building
P.O. Box 1107
Harrisburg, Pennsylvania 17108-1107

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FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC UNITS

For the convenience of readers who prefer metric (International System) units rather than the inch-pound units in this report, the following conversion factors may be used:

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.6093	kilometer (km)
	Area	
square mile (mi^2)	2.59	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233.0	cubic meter (m^3)
	0.001233	cubic hechtometer (hm^3)
	Flow	
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

Twenty-four-hour rainfall, distributed over time according to the U.S. Soil Conservation Service type II rainfall distribution, was used as input to calibrated rainfall-runoff models of three subbasins in the West Branch Brandywine Creek watershed. The effects of four proposed flood controls were evaluated by using these rainfalls to simulate discharge hydrographs with and without the flood controls and comparing the simulated peak discharges.

In the Honey Brook subbasin, 2-, 10-, and 100-year flood-discharge hydrographs were generated for station West Branch Brandywine Creek near Honey Brook to use as the upstream inflow to the Coatesville subbasin model.

In the Coatesville subbasin, 2-, 10-, and 100-year flood-discharge hydrographs were generated for station West Branch Brandywine Creek at Coatesville. For the 2- and 10-year floods, proposed flood controls would reduce the peak discharge from 1 to 8 percent. The combination of all three flood controls proposed for the Coatsville subbasin would reduce the 100-year peak discharge 44 percent.

In the Modena subbasin, 2-, 10-, and 100-year flood-discharge hydrographs were generated for station West Branch Brandywine Creek at Modena. A flood control proposed for Sucker Run, a tributary, would reduce the peak discharge of Sucker Run at State Route 82 by 22, 25, and 27 percent and the peak discharge of West Branch Brandywine Creek at Modena by 10, 6, and less than 1 percent for the 2-, 10-, and 100-year floods, respectively.

For the 2- and 10-year floods, flood control proposed for the Coatesville subbasin would have little effect on the peak discharge of West Branch Brandywine Creek at Modena. For the 100-year flood, the combination of all three flood controls proposed for the Coatesville subbasin would reduce the peak discharge at Modena 25 percent.

When flood control in the Modena subbasin was combined with flood control in the Coatesville subbasin, the 10-percent reduction in the 2-year flood peak of West Branch Brandywine Creek at Modena was due almost entirely to flood control in the Modena subbasin. For the 10-year flood, flood control in the Modena subbasin would reduce the peak discharge 6 percent, and any single flood control in the Coatesville subbasin would provide an additional 1 to 3 percent reduction. Although flood control in the Modena subbasin would have little effect on reducing the 100-year flood peak, it would provide an additional 5 percent reduction in peak discharge, for a total reduction of 30 percent, when combined with the three flood controls in the Coatesville subbasin.

INTRODUCTION

Flooding has always been a problem in the Brandywine Creek watershed. Major floods occurred in 1899, 1920, 1933, 1942, 1955, 1973, and 1979. The August 9, 1942, flood had an estimated peak discharge of 8,600 ft^3/s (cubic feet per second) at station West Branch Brandywine Creek at Coatesville (U.S. Army Corps of Engineers, 1970, p. 33) and caused $1,750,000 damage in 1950 dollars (U.S. Soil Conservation Service, 1952, p. 11). The flood of July 21, 1979, caused $4,500,000 damage in 1979 dollars in the Sucker Run basin.

Various methods of flood control have been proposed. In 1952, the U.S. Soil Conservation Service (U.S.SCS) proposed non-structural flood controls consisting of land treatment measures, channel improvements, and diking (U.S. Soil Conservation Service, 1952, p. 11-12). In 1958, a water-resources study proposed eight reservoir sites on the West Branch Brandywine Creek and its tributaries above Modena for water supply and flood control (Bourguard, Geil, and Associates, 1958, plate 9). In the Watershed Work Plan for the Brandywine developed in 1962, three of these sites were selected for single and multiple purpose flood-prevention structures (Chester County Commissioners and others, 1962, p. 4). The Watershed Work Plan for the Brandywine set in motion the implementation of these flood controls.

Purpose and Scope

This report presents the results of a study to evaluate the effects of flood controls proposed for the West Branch Brandywine Creek basin using U.S.SCS project evaluation rainfalls to generate flood hydrographs. This study used the calibrated rainfall-runoff simulation models developed by Sloto (1982 and 1985). This study was done by the U.S. Geological Survey in cooperation with the Chester County Water Resources Authority.

This report describes the results of digital model simulations of discharge hydrographs with and without flood controls proposed for the West Branch Brandywine Creek basin. Rainfall input to the model and storage-outflow relations of proposed flood controls were provided by the U.S.SCS. The model simulations provide the agencies concerned with the planning and implementation of flood controls with an evaluation of the effect of the proposed flood controls on peak discharge. The results of model simulations were used by the U.S.SCS to evaluate flood-control designs, in cost-benefit analysis, and to aid in preparation of the Environmental Impact Statement required prior to implementation of flood controls.

Description of Project Area

The West Branch Brandywine Creek drains part of western Chester County and a small part of Lancaster County in southeastern Pennsylvania (fig. 1). It is a major tributary to Brandywine Creek, which flows into the Christina River, a tributary to the Delaware River. The project area, 55 mi^2 (square miles), includes the three subbasins shown in figure 2, upstream from the stream-gaging station at Modena (01480617).

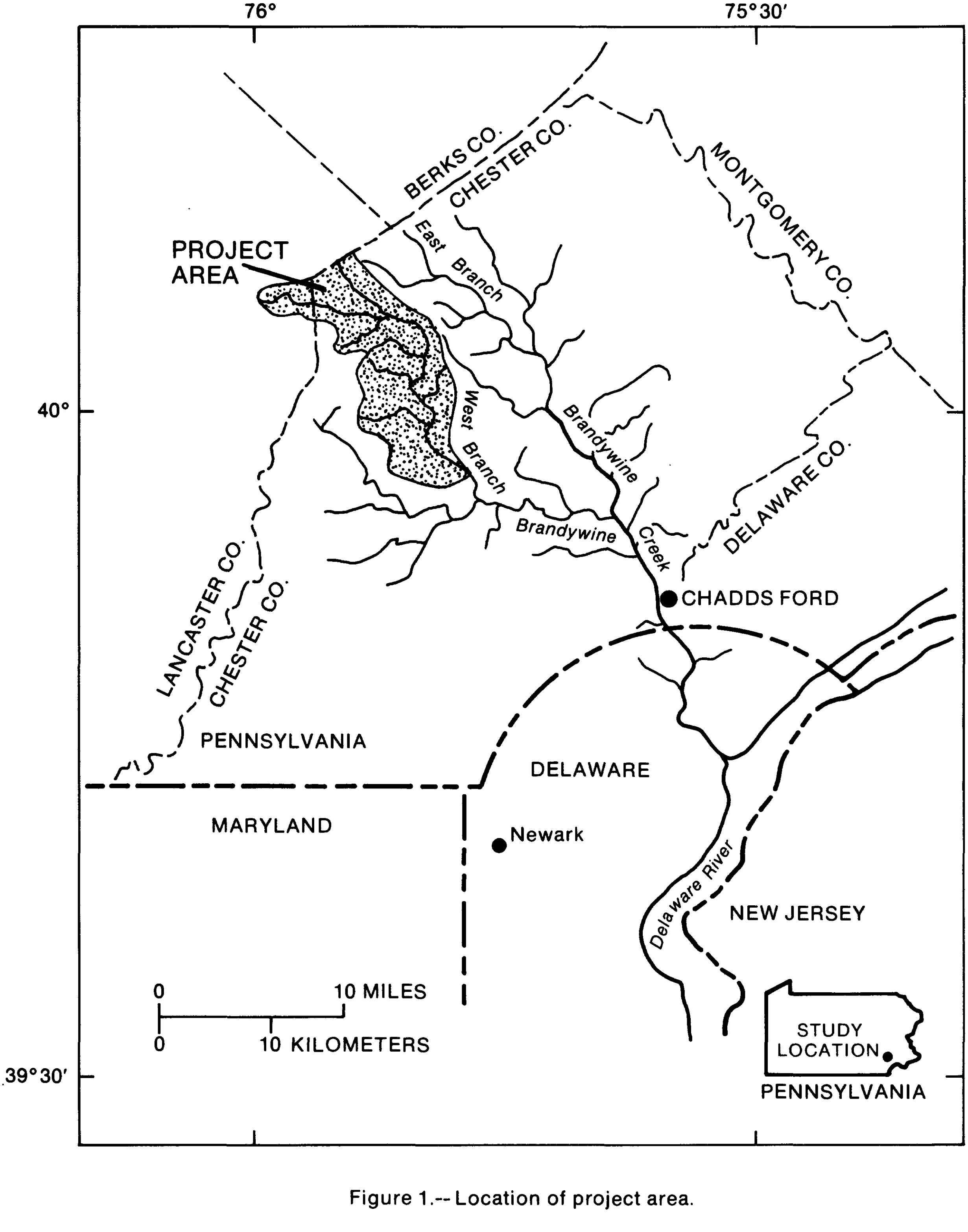

Figure 1.--Location of project area.

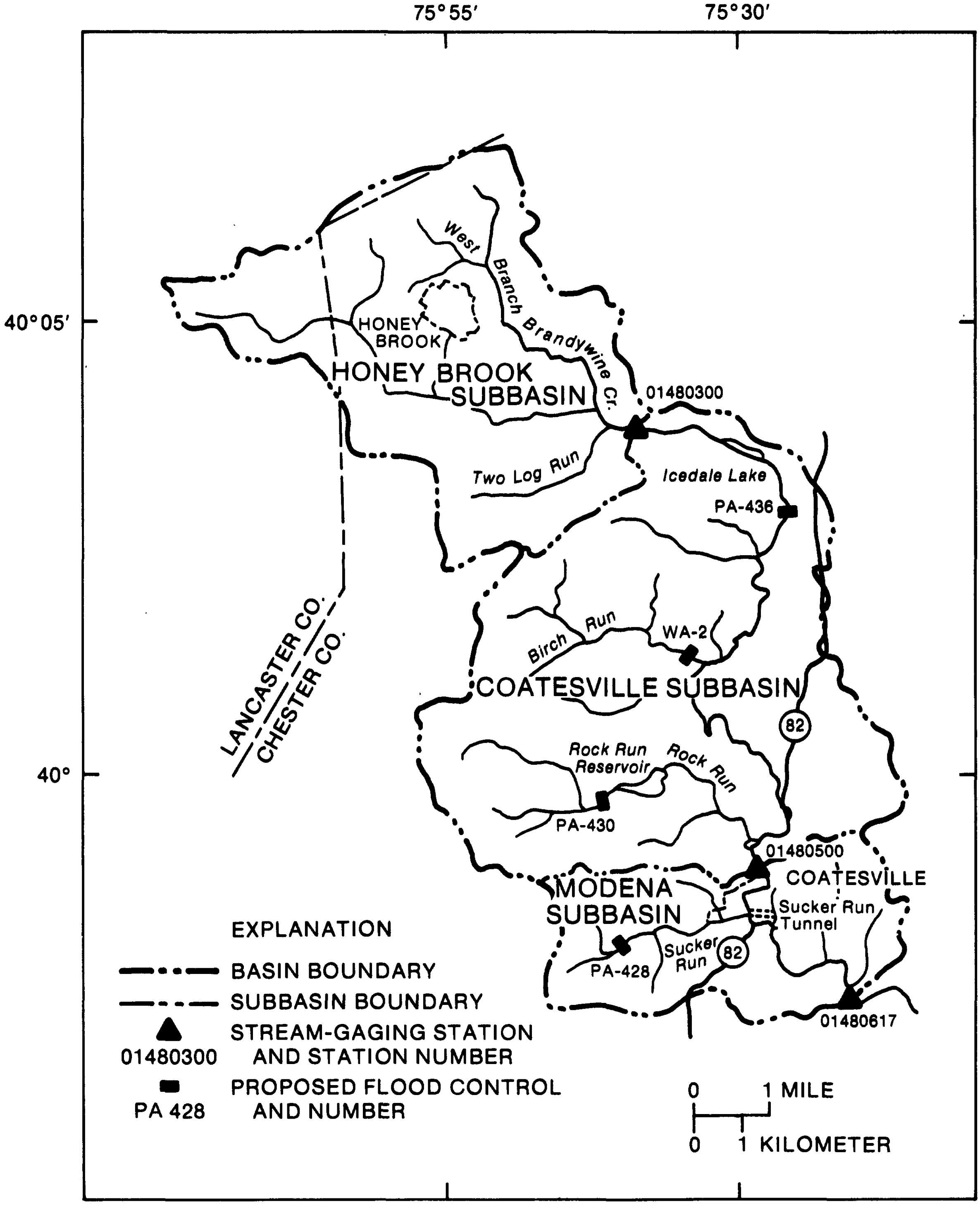

Figure 2.-- Modeled subbasins and locations of stream-gaging stations and proposed flood controls.

Streamflow from the upper subbasin (18.7 mi2) is measured at West Branch Brandywine Creek near Honey Brook (station 01480300). The major tributaries to the West Branch Brandywine Creek in the Honey Brook subbasin are Two Log Run and an unnamed tributary. The slope of the West Branch Brandywine Creek in this subbasin is 28.2 feet per mile. Average discharge for 24 water years of record (1960-84) is 26.5 ft^3/s. The maximum discharge, 8,140 ft^3/s, occurred on June 22, 1972.

Station West Branch Brandywine Creek at Coatesville (01480500) measures streamflow from the upper and middle subbasins (drainage area 45.8 mi^2). The Coatesville subbasin, lying between the Honey Brook and Coatesville stream-gaging stations, has a drainage area of 27.1 mi^2. The major tributaries are Birch Run and Rock Run. The slope of the West Branch Brandywine Creek in this subbasin is 22.9 feet per mile. The average discharge at the Coatesville station for 22 water years of record (1943-51, 1970-84) is 72.8 ft^3/s. The maximum discharge, 8,100 ft^3/s, occurred on June 29, 1973.

Station West Branch Brandywine Creek at Modena (01480617) measures streamflow from all three subbasins (drainage area 55.0 mi^2). The Modena subbasin, lying between the Coatesville and Modena stream gages, has a drainage area of 9.2 mi^2. The main tributary is Sucker Run, which drains 4.8 mi^2. Average discharge at the Modena station for 14 water years of record (1970-84) is 97.3 ft^3/s. The maximum discharge, 9,600 ft^3/s, occurred on June 29, 1973.

The subbasins range from rural to highly urbanized. The Honey Brook subbasin is rural with most of the land being agricultural or woodland. The borough of Honey Brook (1980 population 1,152) is near the center of the subbasin. The Coatesville subbasin is mostly rural, but is changing from rural to suburban. The Modena subbasin is highly urbanized and industrialized in part. Heavy industry is located along the banks of the West Branch Brandywine Creek and Sucker Run. The Modena subbasin includes the city of Coatesville (1980 population 10,687), the borough of South Coatesville (1980 population 1,354), and part of the borough of Modena (1980 population 675).

The topography of the watershed is gently rolling hills, which are underlain by deeply weathered crystalline rock. Altitude ranges from 1,060 ft (feet) at Welsh Mountain on the northern drainage divide to 265 ft at the Modena stream-gaging station.

Approach

Available rainfall-runoff models were used to simulate discharge hydrographs for evaluation of flood-control designs, cost-benefit analysis, and preparation of an Environmental Impact Statement. The model used for the Honey Brook subbasin was an uncalibrated model developed by Sloto (1982). The model used for the Coatesville subbasin was a calibrated model developed by Sloto (1982). The model used for the Modena subbasin was a combination of a calibrated and verified model developed by Sloto (1982) and a model of the Sucker Run subbasin (Sloto, 1985) developed from Sloto (1982).

The Honey Brook subbasin model was calibrated using storms occurring in 1982. The model was used only to generate a hydrograph to input upstream inflow to the Coatesville subbasin model.

The antecedent rainfall condition assumed for all model simulations was the U.S.SCS AMC-II 5-day antecedent rainfall of 1.5 inches for average conditions during the growing season (U.S. Soil Conservation Service, 1972, p. 4.10-4.12). The antecedent rainfall was simulated as 0.3 inches of rainfall for each of the 5 days preceding the simulated storm. A daily pan evaporation rate of 0.2 inches per day was also assumed.

The rainfall input to the model was distributed over time according to the U.S.SCS type II distribution (Kent, 1972). The type II distribution was used to be consistent with other U.S.SCS design evaluations. Rainfall input to the model was provided by the U.S.SCS. Total rainfall volumes were chosen to generate peak discharges close to the 2-, 10-, and 100-year peak discharges at the stream-gaging stations. The 2-, 10-, and 100-year peak discharges at the gaging stations were determined by fitting a frequency curve to a log-Pearson type III frequency distribution of peak flows. The rainfall necessary to generate a selected peak discharge was determined by trial and error. Various rainfall volumes were tried until a peak discharge near the desired discharge was generated by the model.

The models simulated 2-, 10-, and 100-year flood hydrographs. Simulations with and without proposed flood controls were compared to determine the effect of the flood controls on stream discharge.

Acknowledgments

The author thanks Timothy J. Murphy and Stephen T. Abbott of the U.S. Soil Conservation Service, Department of Agriculture, for providing rainfall distributions for input to the model and storage-outflow relations for the proposed flood controls.

RAINFALL-RUNOFF MODEL

The computer program used to simulate storm discharge hydrographs in the West Branch Brandywine Creek basin is version II of the U.S. Geological Survey distributed-routing rainfall-runoff model (Alley and Smith, 1982). Version II of the rainfall-runoff model is an enhanced replacement for version I (Dawdy, Schaake, and Alley, 1978). The major differences include: (1) a choice of three solution techniques for kinematic-wave routing, (2) ability to create segment flow files for use by a water-quality model, (3) use of disk space for measured storm rainfall and runoff data storage to reduce core storage requirements, (4) changes to model output including graphical and statistic comparisons between observed and simulated data, and (5) inclusion of effective impervious area in the parameter optimization algorithm (Alley and Smith, 1982, p. 1-2). The same kinematic-wave solution technique, the explicit finite-difference method, was used by Sloto (1982 and 1984) and for this study. Given the same input data, versions I and II produce an identical discharge hydrograph.

The model is a deterministic, distributed-parameter model that uses many physically-based parameters, the values of which are measured in the field. The model combines rainfall-excess components with kinematic-wave routing. Daily and unit rainfall, and daily pan evaporation are used to compute a simulated discharge hydrograph.

Rainfall-Excess Components

The model components used to compute rainfall-excess are soil-moisture accounting, pervious-area rainfall excess, impervious-area rainfall excess, and parameter optimization. Soil-moisture and infiltration parameters are listed in table 1. The soil-moisture-accounting component measures the effect of antecedent conditions on infiltration. It simulates moisture redistribution in the soil column and evapotranspiration from the soil. Soil moisture is modeled as a two-layered system. During periods between simulated storms, a part of the daily rainfall, determined by coefficient RR, infiltrates into soil-moisture storage (SMS), the upper soil-moisture zone. Evapotranspiration takes place from SMS, or from the lower soil-moisture zone, base-moisture storage (BMS), when SMS = 0. The evapotranspiration rate is determined by multiplying the daily pan evaporation by a pan coefficient, EVC. Moisture from SMS drains into BMS during periods of no rainfall at a rate based on the effective hydraulic conductivity (KSAT). Storage in BMS has a maximum value, BMSN, which is equivalent to field capacity. Field capacity is reached when soil-moisture redistribution approaches equilibrium. When BMSN is exceeded, the excess moisture is assumed to enter the ground-water system.

Table 1.--Description of soil-moisture and infiltration parameters used in the model

Parameter	Units	Description
BMSN	inches	Maximum effective soil-moisture-storage volume at field capacity
EVC	-	Coefficient that converts pan evaporation to potential evapotranspiration
KSAT	inches per hour	Effective saturated hydraulic conductivity
PSP	inches of pressure	Suction at the wetting front for soil moisture at field capacity
RGF	-	Ratio of suction at the wetting front for soil moisture at the wilting point to that at field capacity
RR	-	Proportion of daily rainfall that infiltrates into the soil for the period of simulation excluding unit days

Point-potential infiltration (FR) is computed by a variation of the Green and Ampt (1911) equation. During a simulated storm, moisture is added to SMS based on:

$$FR = KSAT\ (1 + PS/SMS),$$

where FR = point-potential infiltration,
KSAT = the effective saturated-soil hydraulic conductivity, and
PS = average suction head across the wetting front.

PS is varied over the range from wilting point (negligible soil moisture) to field capacity by:

$$PS = PSP\ [(RGF-(RGF-1)\ BMS/BMSN],$$

where PSP = effective value of PS at field capacity, and
RGF = ratio of PS at wilting point to that at field capacity.

Point-potential infiltration is converted to effective infiltration over the basin using a method presented by Crawford and Linsley (1966):

$$QR = \frac{SR^2}{2FR}\ ;\ \text{if } SR \leq FR,$$

$$QR = SR - \frac{FR}{2}\ ;\ \text{if } SR > FR,$$

where QR = the rate of generation of rainfall excess, and
SR = the supply value of rainfall for infiltration.

Two types of impervious surfaces are considered by the model. The first type, effective impervious surfaces, are those impervious areas that are directy connected to the channel drainage system. A roof that drains onto a driveway, street, or paved parking lot that drains to a stream channel is an example of an effective impervious surface. The second type, noneffective impervious surfaces, are those impervious areas that drain to pervious areas. A roof that drains onto a lawn is an example of a noneffective impervious area.

Rain falling on noneffective impervious areas is assumed to run off onto the surrounding pervious area. The model assumes that this occurs instantaneously and that the volume of runoff is uniformly distributed over the pervious area. This volume is added to the rain falling on the pervious areas prior to computation of pervious-area rainfall excess.

The model includes a component to optimize the soil-moisture and infiltration parameters during model calibration. Determination of optimum parameter values is based on the Rosenbrock (1960) optimization technique. This technique adjusts the parameter values to produce the closest match between the observed and simulated runoff volumes for selected storms.

Routing Component

Each subbasin is represented by overland flow, channel, nodal, and reservoir segments, which are described by a set of parameters. Overland flow segments receive uniformly distributed lateral inflow from excess rainfall. Channel segments receive lateral inflow from overland flow segments and upstream inflow from other segments. Two types of nodal segments are used: (1) a junction segment used when more than three segments contribute inflow to the upstream end of a channel segment, and (2) an input-hydrograph point used to input the discharge from an upstream subbasin. Reservoir segments are detention reservoirs that use modified-Puls routing (U.S. Soil Conservation Service, 1972). A user-specified table of storage versus ouflow is used by the model for reservoir routing.

Input data needed to define routing parameters were measured in the field or taken from aerial photographs, topographic quadrangle maps, and 1:2,400 scale topographic maps provided by the Chester County Water Resources Authority. Routing parameters include segment length, slope, roughness, and one or two other special parameters given below. Channel segment length and slope were taken from topographic maps. The roughness parameter, similar to Manning's n, was estimated in the field. Special parameters for bridge openings, channel cross sections, and culvert diameters were measured in the field. Channel segment parameters to describe the Coatesville storm-sewer system were taken from data provided by the City of Coatesville. Overland flow segment length is computed by dividing the area that contributes runoff by the length of stream that drains the contributing area. The contributing areas were planimetered. Stream lengths and overland flow segment slopes were taken from topographic maps. The roughness parameter, an empirical coefficient for overland flow, was estimated from topography. Percentage of impervious, pervious, and effective impervious areas were calculated from field measurements, aerial photographs, and topographic maps.

Excess rainfall is routed for both overland flow and channel segments by applying kinematic wave theory. Because kinematic wave equations are difficult to solve analytically, a numerical solution technique is used. A finite-difference equation, which converges to the differential equation as the step size decreases, is solved. The kinematic wave equation solved for each channel and overland flow segment is:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} + q,$$

where A = area of flow,
Q = rate of flow,
q = rate of lateral inflow,
t = time, and
x = distance along a segment increasing in the downstream direction.

The relation of rate of flow to area is expressed as

$$Q = \alpha A^m$$

where α and m are constants that are determined from the geometry, slope, and roughness of an overland flow plane or channel.

Subbasin Models

The subbasin models are those developed by Sloto (1982 and 1985). The Honey Brook and Coatesville subbasin models are described by Sloto (1982). The Modena subbasin model used in this study is a combination of the Sucker Run basin model described by Sloto (1985) and that part of the Modena subbasin not drained by Sucker Run described by Sloto (1982). For this study, for the Modena subbasin, the value of KSAT was increased from 0.1 to 0.15. Kinematic-wave parameter values for α and m were explicitly specified to describe the Sucker Run tunnel under State Route 82. α was set equal to 0.192 and m was set equal to 1.845 for discharges below 1,050 ft^3/s. For discharges above 1,050 ft^3/s, α was set equal to 2.082 and m set equal to 1.042 (Murphy, T. J., U.S. Soil Conservation Service, written commun., 1983).

Antecedent Conditions

The antecedent rainfall condition assumed for all model simulations was the U.S. Soil Conservation Service AMC-II 5-day antecedent rainfall of 1.5 inches for average conditions during the growing season (U.S. Soil Conservation Service, 1972, p. 4.10-4.12). The antecedent rainfall was simulated as 0.3 inches of rainfall for each of the 5 days preceding the simulated storm. A daily pan evaporation rate of 0.2 inches per day was also assumed.

Rainfall

The rainfall input to the model was distributed over time according to the U.S.SCS type II distribution (Kent, 1972). The distribution is used to distribute the intensity of a given rainfall amount over a 24-hour period. Although distributions other than the type II may yield infiltration and runoff characteristics different from those modelled in this study, the type II distribution was used to be consistent with other U.S.SCS design evaluations.

A 24-hour rainfall, divided into 15-minute increments, was used as rainfall input to the model to simulate an event hydrograph. In the type II distribution, most of the rainfall occurs near the middle of the 24-hour period. In the 1-hour increment from 1130 to 1230, 45 percent of the total rainfall occurs, with 28 percent of the total rainfall occurring in one 15-minute increment.

Total rainfall volumes were chosen to generate peak discharges close to the 2-, 10-, and 100-year peak discharges at the stream-gaging stations. The 2-, 10-, and 100-year peak discharges at the gaging stations were determined by fitting a frequency curve to a log-Pearson type III frequency distribution of peak flows following Water Resources Council (1981) guidelines. The rainfall necessary to generate a selected peak discharge was determined by trial and error. Various rainfall volumes were tried until a peak discharge near the desired discharge was generated by the model. Peak discharges for 2-, 10-, and 100-year floods from the log-Pearson type III frequency distribution and model-generated peak discharges are compared in table 2.

Table 2.--Comparison of simulated peak discharge with peak discharge from a log Pearson type III frequency distribution for selected recurrence intervals

Station	Recurrence interval (years)	Log-Pearson type III frequency distribution discharge (ft^3/s)	Simulated peak discharge (ft^3/s)
Honey Brook 01480300	2	1,130	1,150
	10	3,400	3,630
	100	11,300	11,100
Coatesville 01480500	2	1,800	1,770
	10	5,300	5,380
	100	14,200	14,400
Modena 01480617	2	3,200	2,420
	10	7,800	6,870
	100	16,200	14,900

The log-Pearson type III frequency distribution (table 2) is based on peak flows occurring 1960-81 for Honey Brook, 1942-51 and 1970-81 for Coatesville, and 1970-81 for Modena. The period of record for Honey Brook includes both the dry years of the 1960's and the wet years of the 1970's. The average discharge for long-term station Brandywine Creek at Chadds Ford (1912-53, 1963-81) is 396 ft^3/s; the average for 1963-81 is 418 ft^3/s. The average discharge at Chadds Ford for the period of record of the Coatesville station, 1943-51 and 1970-81 is 446 ft^3/s. The period of record for Modena includes the wet years of the 1970's. The average discharge at Chadds Ford for 1970-81 is 491 ft^3/s, 24 percent higher than the long-term average. Simulated discharges for Modena are not as high as those obtained from the log-Pearson type III frequency distribution, which is based on the wet years of the 1970's and gives higher discharges than if the period of record had more nearly approximated long-term conditions.

SIMULATION OF FLOOD PEAKS IN THE HONEY BROOK SUBBASIN

The Honey Brook subbasin model was not successfully calibrated by Sloto (1982, p. 11) because rainfall data used for calibration were measured by gages outside the subbasin and were not representative of the actual rainfall in the subbasin. However, a discharge hydrograph from the Honey Brook subbasin generated from a type II rainfall distribution was required as upstream inflow to the Coatesville subbasin model.

Two recording raingages were installed in the Honey Brook subbasin subsequent to the study by Sloto (1982) and concurrent rainfall and stream discharge data were collected. Three nonwinter storms having peak discharges of 361, 503, and 1,093 ft^3/s were available for modeling. Although three storms are not enough to calibrate a model, a set of optimized soil moisture and infiltration parameter values were obtained using runoff volumes from these storms. A discharge hydrograph was simulated with poor results. Discharge hydrographs for the same storms were then simulated using soil-moisture and infiltration parameter values for the Honey Brook subbasin from the study by Sloto (1982) and the soil-moisture and infiltration parameter values for the Coatesville subbasin (Sloto, 1982, p. 12). The model simulations using the soil-moisture and infiltration parameter values for the Coatesville subbasin produced the best results (table 3). The soils and underlying geological formations of the Honey Brook and Coatesville subbasins are similar, so the infiltration characteristics of both subbasins are probably similar.

Rainfalls of 2.49, 3.72, and 6.00 inches (fig. 3) were used to simulate 2-, 10-, and 100-year flood-discharge hydrographs, respectively, for West Branch Brandywine Creek near Honey Brook. Simulated peak discharges and runoff volumes are given in table 4.

EFFECT OF FLOOD CONTROLS PROPOSED FOR THE COATESVILLE SUBBASIN

Rainfalls of 2.60, 4.00, and 4.95 inches (fig. 4) were used to generate 2-, 10-, and 100-year flood discharge hydrographs, respectively, for West Branch Brandywine Creek at Coatesville. Simulated peak discharge and runoff volume is given in table 5. The simulated discharge hydrographs from the Honey Brook subbasin (table 4) were used as the upstream inflow to the Coatesville subbasin.

The effects of three flood controls, PA-436, PA-430 and WA-2, proposed for the Coatesville subbasin were evaluated by using the rainfall in table 5 to simulate discharge hydrographs with and without the flood controls, and comparing the simulated peak discharges.

PA-436, to be located on West Branch Brandywine Creek below Icedale Lake, is proposed as a multipurpose flood-control and water-supply reservoir with 6,780 acre-feet of flood-water storage. It would control the drainage of 20.2 mi^2.

WA-2 is to be located on Birch Run 0.3 miles upstream from West Branch Brandywine Creek. It is proposed as a multipurpose flood-control and water-supply reservoir with 776 acre-feet of flood-water storage. It would control the drainage of 4.5 mi^2.

PA-430 is to be located on Rock Run 0.4 miles upstream from Rock Run reservoir. It is proposed as a multipurpose flood-control and water-supply reservoir with 743 acre-feet of flood-water storage. It would control the drainage of 4.4 mi^2.

Proposed flood controls PA-430 and WA-2 are in the same location (fig. 2) as in Sloto (1982, p. 24). The location of PA-436 was moved downstream below Icedale Lake, increasing the controlled drainage area 1.4 mi^2. Storage-outflow relations for PA-436 and PA-430 were revised by the U.S.SCS

Table 3.--Simulated and peak discharge runoff volume for three storms occurring in 1982 in the Honey Brook subbasin

Storm date	Rainfall (inches)	Observed peak discharge (ft^3/s)	Simulated peak discharge (ft^3/s) using soil-moisture and infiltration parameters from: Honey Brook subbasin using storm data	Honey Brook subbasin (Sloto, 1982)	Coatesville subbasin (Sloto, 1982, p. 12)
6/12/82	1.14	361	69	159	13
6/16/82	2.01	1,093	2,230	2,290	1,730
7/27/82	1.73	503	1,970	2,680	654

Storm date	Rainfall (inches)	Observed runoff volume (inches)	Simulated runoff volume (inches) using soil-moisture and infiltration parameters from: Honey Brook subbasin using storm data	Honey Brook subbasin (Sloto, 1982)	Coatesville subbasin (Sloto, 1982, p. 12)
6/12/82	1.14	0.396	0.124	0.215	0.040
6/16/82	2.01	1.115	1.244	1.269	1.064
7/27/82	1.73	.288	.866	1.057	.440

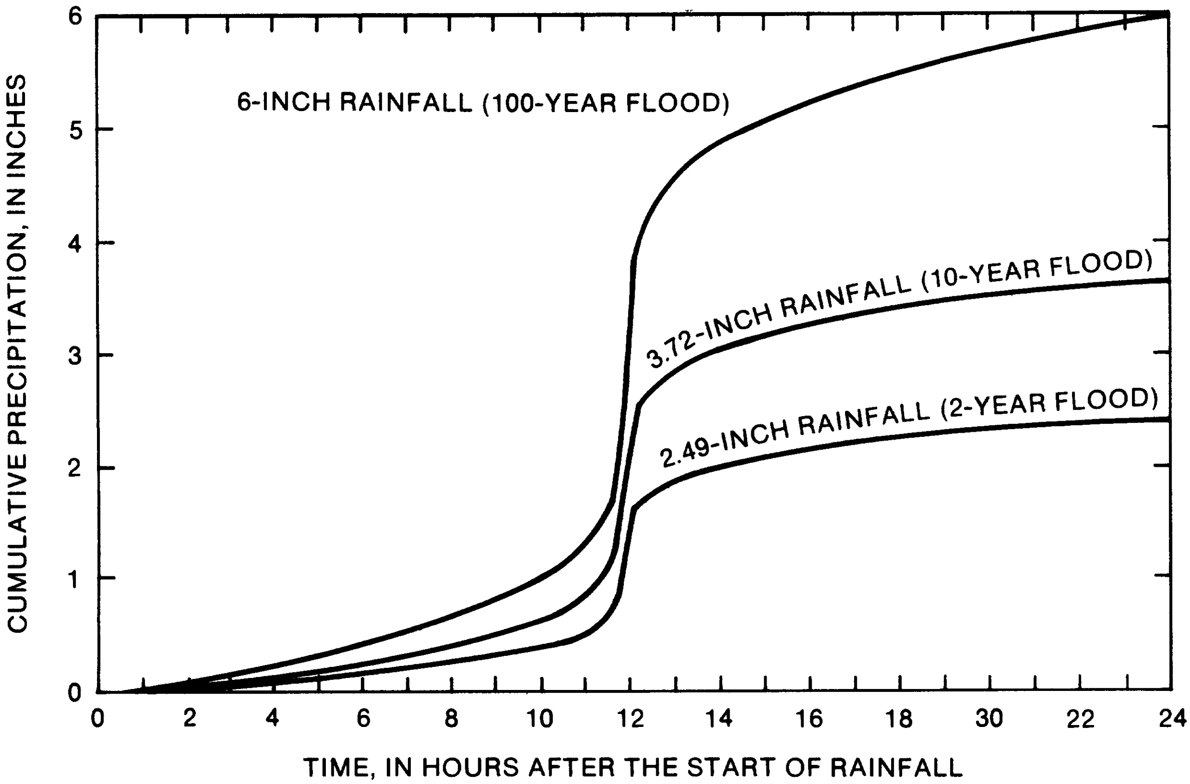

Figure 3.--Cumulative distribution of rainfall used for the Honey Brook subbasin model simulations.

Table 4.--Simulated peak discharge and runoff volume for West Branch Brandywine Creek near Honey Brook

Rainfall (inches)	Flood recurrence interval (years)	Simulated peak discharge (ft^3/s)	Simulated runoff volume (inches)
2.49	2	1,150	0.63
3.72	10	3,630	1.30
6.00	100	11,100	2.71

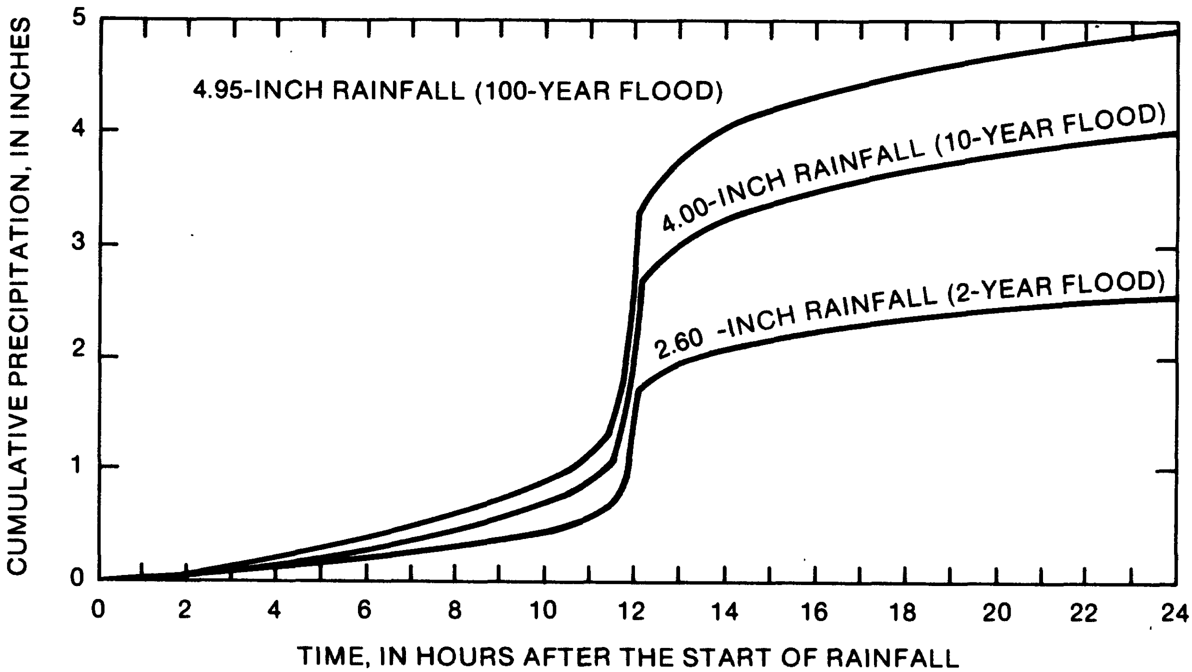

Figure 4.--Cumulative distribution of rainfall used for the Coatesville subbasin model simulations.

Table 5.--Simulated peak discharge and runoff volume for West Branch Brandywine Creek at Coatesville

Rainfall (inches)	Flood recurrence interval (years)	Simulated peak discharge (ft^3/s)	Simulated runoff volume (inches) Coatesville subbasin	Simulated runoff volume (inches) Coatesville and Honey Brook subbasins
2.60	2	1,770	0.71	0.68
4.00	10	5,380	1.49	1.41
4.95	100	14,400	2.09	2.34

(Murphy, T. J., U.S. Soil Conservation Service, written commun., 1983). The storage-outflow relation for WA-2 is the same as in Sloto (1982) and was provided by the U.S.SCS (Kinzer, Barry, U.S. Soil Conservation Service, written commun., 1980). The storage-outflow relations used for model simulations are given in table 6.

Results of model simulations with the proposed flood controls are given in table 7. For both the 2- and 10-year floods, the flood controls would reduce the peak discharge of West Branch Brandywine Creek at Coatesville from 1 to 8 percent.

For the simulated 2-year flood, all three flood controls together would reduce the peak discharge of West Branch Brandywine Creek at Coatesville 8 percent. The combination of WA-2 and either PA-436 or PA-430 would reduce the peak discharge 7 percent. WA-2 alone would reduce the peak discharge 6 percent, while PA-436 would reduce the peak discharge 2 percent and PA-430 would reduce the peak discharge 1 percent.

For the simulated 10-year flood, the combination of all three flood controls was the most effective for reducing peak discharge; they would reduce peak discharge 8 percent. WA-2 was the most effective single flood control; it would reduce peak discharge 6 percent. A combination of WA-2 with either PA-436 or PA-430 was equally effective and would reduce peak discharge 7 percent.

For the simulated 100-year flood, the combination of all three flood controls would reduce peak discharge 44 percent. PA-436 was the single most effective flood control; it would reduce peak discharge 40 percent. PA-436 in combination with WA-2 would reduce peak discharge 43 percent. PA-430, when combined with PA-436, would further reduce peak discharge by less than 1 percent. WA-2 by itself would reduce peak discharge 6 percent and PA-430 by itself would reduce peak discharge 4 percent. WA-2 in combination with PA-430 would reduce peak discharge 11 percent. Figure 5 shows the simulated discharge hydrographs for West Branch Brandywine Creek at Coatesville for the 100-year flood. In the simulation without flood control, the first peak is caused mainly by runoff from the Coatesville subbasin and the second peak is caused by runoff from the Coatesville subbasin combining with upstream inflow from the Honey Brook subbasin. In the simulations with PA-436, runoff from the upstream Honey Brook subbasin is stored, eliminating the second peak. The stored volume of runoff is released slowly over several days, causing a higher flow at a later time below PA-436 than would be observed without flood control. This is shown in figure 6, which is the same set of conditions as shown in figure 5, but simulated for 42 hours after the start of rainfall, and with discharge plotted on a logarithmic scale. For the simulation with PA-436, the discharge of West Branch Brandywine Creek at Coatesville exceeds the discharge that would be observed with no flood control 18 hours after the first peak. For the simulation with all three flood controls, the discharge of West Branch Brandywine Creek at Coatesville exceeds the discharge that would be observed with no flood control 13 hours after the first peak.

The results of these simulations using synthetic rainfalls are different than the results obtained by Sloto (1982, p. 26-28) using historical rainfall data. The difference is because: (1) type II project evaluation rainfall distributions and historical storms have rainfall distributions that are

Table 6.--Storage-outflow relations used for proposed flood controls in the Coatesville subbasin model

PA-436		PA-430		WA-2	
Storage (acre-ft)	Outflow (ft^3/s)	Storage (acre-ft)	Outflow (ft^3/s)	Storage (acre-ft)	Outflow (ft^3/s)
0	0	0	0	0	0
1,442	90	5	16	21	56
2,884	254	10	47	41	86
4,325	467	15	86	51	105
5,767	720	20	132	72	135
6,020	721	59	143	120	157
6,147	722	106	153	258	203
6,400	723	162	162	487	262
6,653	724	238	171	710	309
6,779	725	328	179	940	351
7,777	1,002	439	181	1,170	388
8,777	1,442	559	195	1,260	402
10,574	2,628	701	202	1,270	421
12,771	4,697	724	371	1,310	614
16,764	10,025	748	540	1,360	1,002
21,757	19,536	794	1,222	1,761	3,520
26,750	31,597	844	2,471	2,262	9,220
		961	5,766		
		1,113	11,430		
		1,265	18,470		

Table 7.--Simulated peak discharge for West Branch Brandywine Creek at Coatesville with proposed flood controls

Flood recurrence interval (years)	Simulated peak discharge (ft^3/s)							
	No flood control	PA-436	PA-430	WA-2	PA-436 and PA-430	PA-436 and WA-2	PA-430 and WA-2	PA-436, PA-430 and WA-2
2	1,770	1,740	1,750	1,670	1,720	1,650	1,650	1,620
10	5,380	5,320	5,350	5,080	5,270	5,020	5,030	4,970
100	14,400	8,700	13,800	13,500	8,610	8,210	12,800	8,120

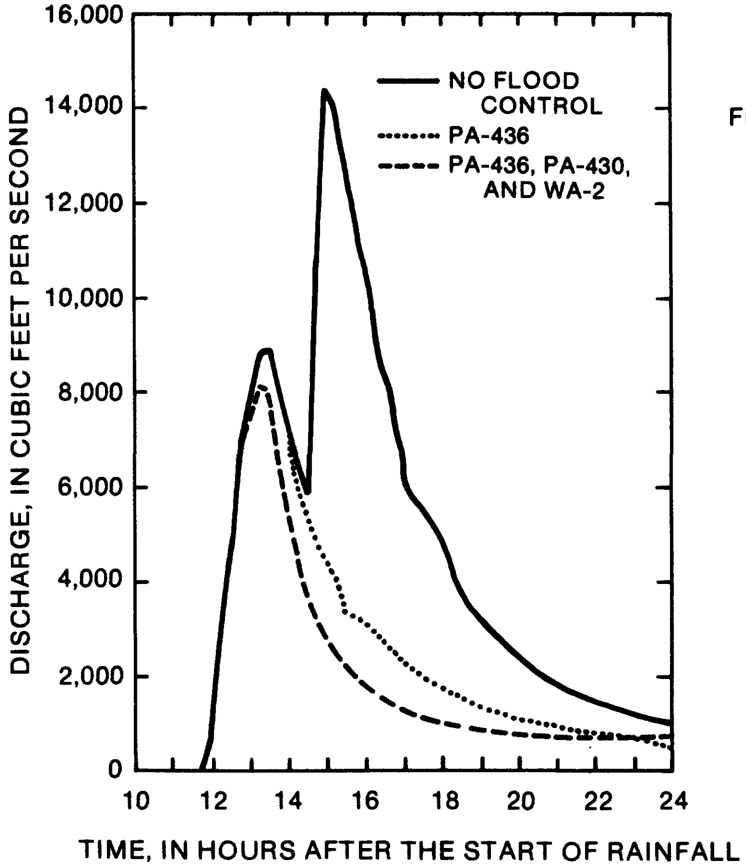

Figure 5.-- Simulated discharge hydrograph of West Branch Brandywine Creek at Coatesville for a 100-year flood with proposed flood controls.

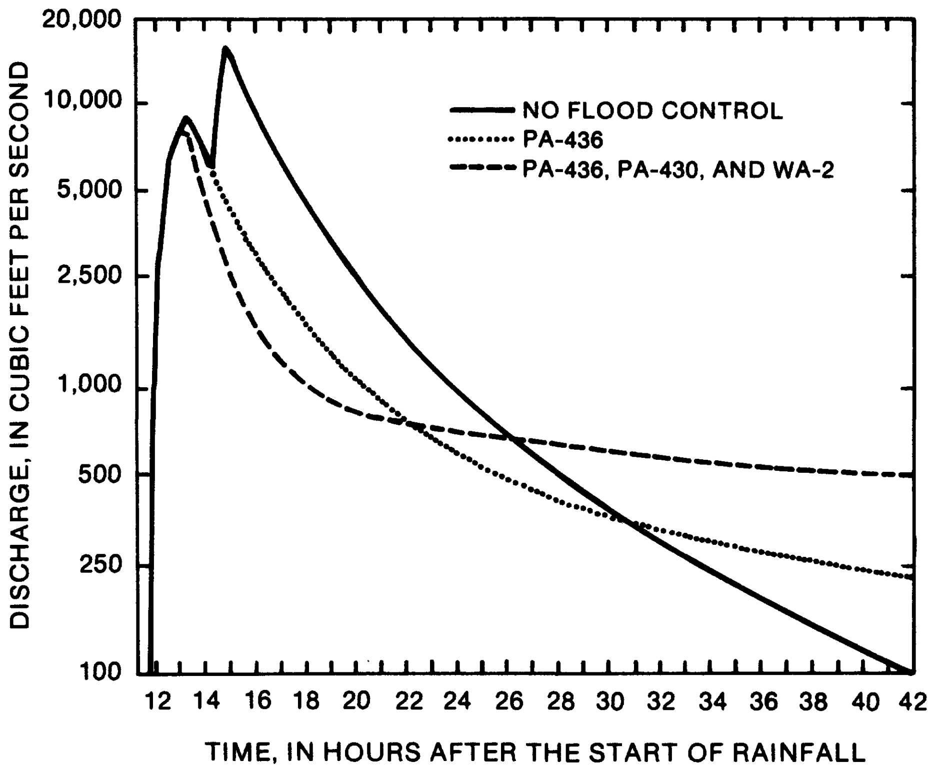

Figure 6.-- Simulated discharge hydrograph of West Branch Brandywine Creek at Coatesville showing the effects of delayed discharge caused by proposed flood controls.

areally and temporally different; (2) the storage-outflow relations of two flood controls are different; and (3) PA-436 was moved downstream to a different location.

EFFECT OF FLOOD CONTROLS PROPOSED FOR THE MODENA SUBBASIN

Rainfalls of 2.82, 3.72, and 4.95-inches (fig. 7) were used to generate 2-, 10-, and 100-year flood discharge hydrographs, respectively, for West Branch Brandywine Creek at Modena. Simulated peak discharge and runoff volume for West Branch Brandywine Creek at Modena and Sucker Run at State Route 82 is given in table 8. The discharge hydrographs simulated for the Coatesville subbasin (table 5) were used as the upstream inflow to the Modena subbasin.

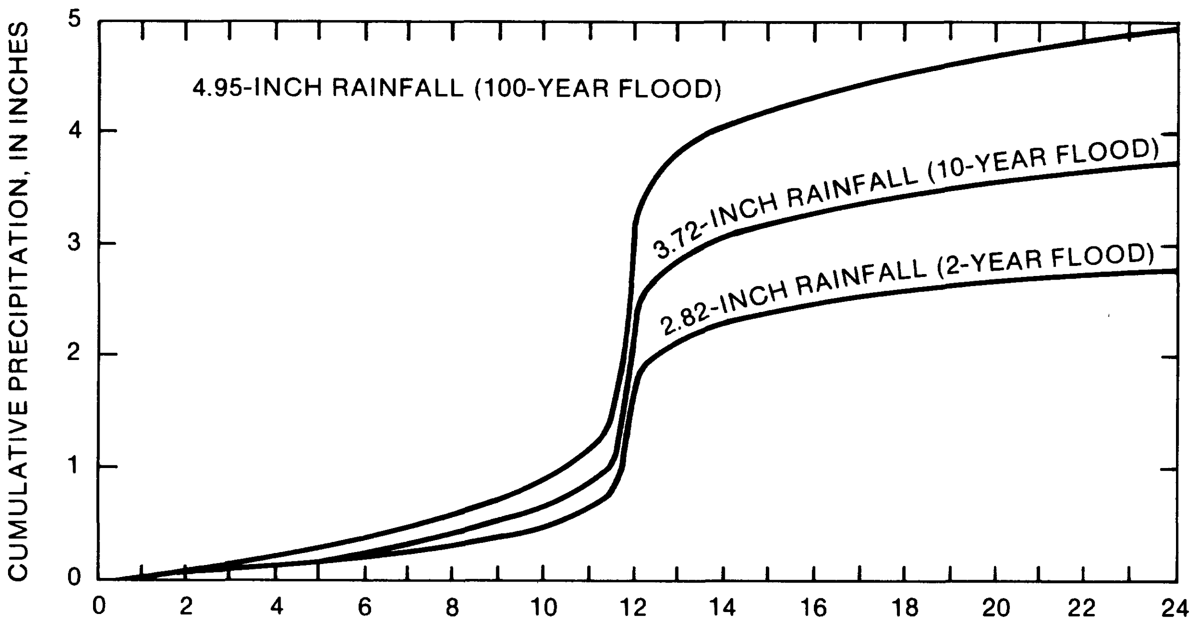

Figure 7.--Cumulative distribution of rainfall used for the Modena subbasin model simulations.

Table 8.--Simulated peak discharge and runoff volume for West Branch Brandywine Creek at Modena and Sucker Run at State Route 82

Rainfall (inches)	Flood recurrence interval (years)	Simulated peak discharge (ft^3/s): West Branch Brandywine Creek at Modena	Simulated peak discharge (ft^3/s): Sucker Run at State Route 82	Simulated runoff volume (inches): Modena subbasin	Simulated runoff volume (inches): West Brance Brandywine Creek basin
2.82	2	2,420	876	0.68	0.68
3.72	10	6,870	2,110	1.15	1.37
4.95	100	4,900	3,860	1.83	2.25

The effect of flood control PA-428, proposed to be built on Sucker Run in the Modena subbasin, on the peak discharge of both Sucker Run at State Route 82 and West Branch Brandywine Creek at Modena was simulated. PA-428 is to be located on Sucker Run, 2.2 miles upstream from West Branch Brandywine Creek. It is proposed as a dry dam with a storage capacity of 254 acre-feet and will control the drainage of 1.3 mi^2. It will cause flood water to be temporarily impounded by restricting outflow. It is in the same location (fig. 2) as in Sloto (1982, p. 24); however, the storage-outflow relation was revised by the U.S.SCS (Murphy, T. J., U.S. Soil Conservation Service, written commun., 1983). The revised storage-outflow relation is given in table 9.

Table 9.--Storage-outflow relation used for proposed flood control PA-428 in the Modena subbasin model

Storage (acre-ft)	Outflow (ft^3/s)
0	0
4.2	1.1
8.3	3.2
12	5.9
59	14
116	19
200	23
213	42
227	76
242	120
259	122
276	123
293	125
316	376
339	769
381	1,836
438	3,483
557	7,729
722	13,806
901	21,245

Simulated peak discharge with PA-428 in the Modena subbasin is given for Sucker Run at State Route 82 and for West Branch Brandywine Creek at Modena for 2-, 10-, and 100-year floods (table 10). The simulations show that PA-428 would reduce the 2-year peak discharge of Sucker Run at State Route 82 by 22 percent, the 10-year peak discharge by 25 percent, and the 100-year peak discharge by 27 percent. PA-428 would reduce the 2-year peak discharge of West Branch Brandywine Creek at Modena by 10 percent, the 10-year peak discharge by 6 percent, and the 100-year peak discharge by less than 1 percent. PA-428 controls 27 percent of the drainage area of Sucker Run at State Route 82, but controls only 2 percent of the West Branch Brandywine Creek basin above the Modena gaging station. The discharge hydrograph at Modena typically shows a double peak (fig. 8). The first peak

Table 10.--Simulated peak discharge for West Branch Brandywine Creek at Modena and Sucker Run at State Route 82 with proposed flood control PA-428 in the Modena subbasin

Flood recurrence interval (years)	Simulated peak discharge (ft^3/s)			
	West Branch Brandywine Creek at Modena		Sucker Run at State Route 82	
	Without flood control	With PA-428	Without flood control	With PA-428
2	2,420	2,180	876	681
10	6,870	6,490	2,110	1,580
100	14,900	14,800	3,860	2,800

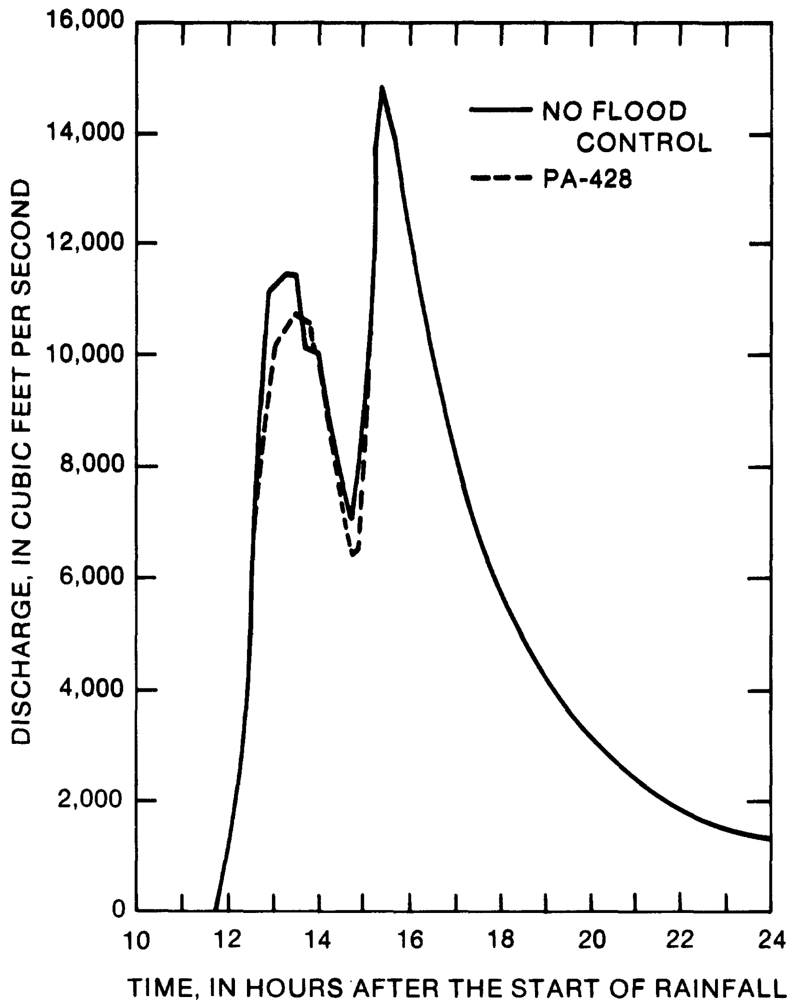

Figure 8.--Simulated discharge hydrograph of West Branch Brandywine Creek at Modena for a 100-year flood with proposed flood control PA-428.

is caused mainly by runoff from the Modena subbasin and the second peak is caused mainly by runoff from the area upstream of the Coatesville gaging station. For more frequent events, the first peak is greater than the second; for less frequent events, the second peak is greater than first. PA-428 reduces the first peak, but has little or no effect on the second peak.

The effect of flood control in the Coatesville subbasin on peak discharge of West Branch Brandywine Creek at Modena was simulated by using the discharge hydrographs generated for the Coatesville station from the simulations with flood control (table 7) as the upstream inflow to the Modena subbasin. Table 11 gives the simulated peak discharge for West Branch Brandywine Creek at Modena with flood control in the Coatesville subbasin and no flood control in the Modena subbasin.

Table 11.--Simulated peak discharge for West Branch Brandywine Creek at Modena with proposed flood controls in the Coatesville subbasin

	Peak discharge of West Branch Brandywine Creek at Modena (ft^3/s)							
Flood recurrence interval (years)	No flood control	With PA-436	With PA-430	With WA-2	With PA-436 and PA-430	With PA-436 and WA-2	With PA-430 and WA-2	With PA-436, PA-430, and WA-2
2	2,420	2,420	2,420	2,400	2,420	2,410	2,410	2,410
10	6,870	6,870	6,870	6,810	6,870	6,820	6,810	6,810
100	14,900	11,400	14,200	14,000	11,400	11,200	13,300	11,200

The simulations showed that for the 2- and 10-year floods, flood control in the Coatesville subbasin would have little effect on reducing the peak discharge of West Branch Brandywine Creek at Modena. Reduction of peak discharge would be less than 1 percent. For the 10-year flood, the discharge hydrograph has two peaks, the first peak being larger than the second peak. The three flood controls in the Coatesville subbasin would reduce the first peak by only 60 ft^3/s because most of the runoff causing this peak comes from the Modena subbasin. The flood controls, however, would reduce the second peak, which is composed mainly of runoff from the area upstream of the Coatesville gaging station, by 1,780 ft^3/s (fig. 9).

For the 100-year flood, as well as for other less frequent events, runoff from the area upstream of the Coatesville gaging station causes the second peak to be higher than the first. Flood controls in the Coatesville subbasin have no effect on the first peak, but reduce the second peak (fig. 10).

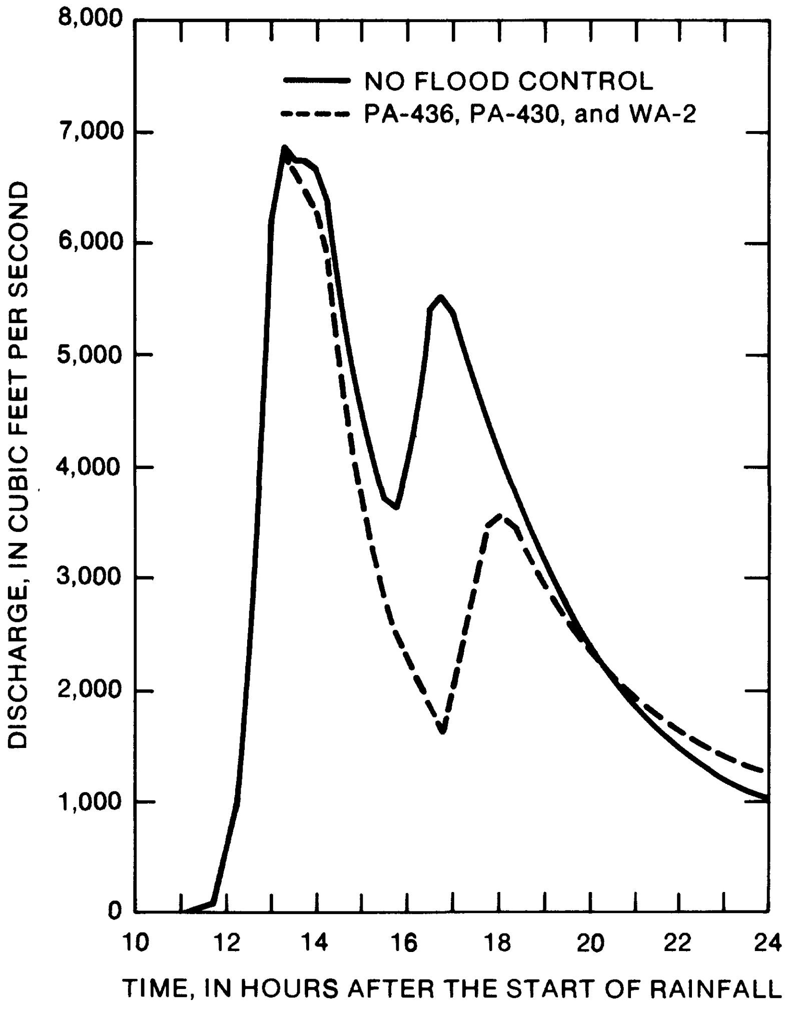

Figure 9.-- Simulated discharge hydrograph of West Branch Brandywine Creek at Modena for a 10-year flood with three proposed flood controls in the Coatesville subbasin.

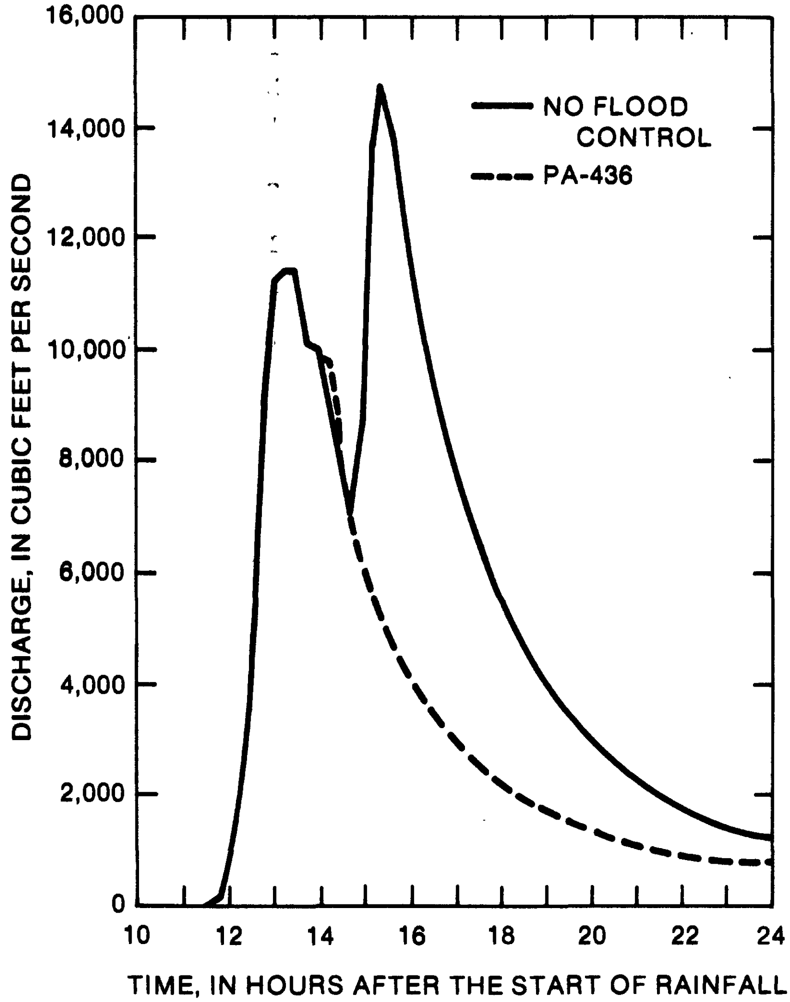

Figure 10.--Simulated discharge hydrograph of West Branch Brandywine Creek at Modena for a 100-year flood with proposed flood control PA-436 in the Coatesville subbasin.

PA-436 would reduce peak discharge 23 percent, WA-2 would reduce peak discharge 6 percent, and PA-430 would reduce peak discharge 5 percent. PA-436 in combination with WA-2 would reduce peak discharge 25 percent, as would the combination of all three flood controls. WA-2 in combination with PA-430 would reduce peak discharge 11 percent. PA-430, when combined with PA-436, or with PA-436 and WA-2, would not provide any additional reduction in peak discharge.

Simulations were made to determine the effect of flood control PA-428 in the Modena subbasin combined with flood control in the Coatesville subbasin on the peak discharge of West Branch Brandywine Creek at Modena (table 12). For the 2-year flood, PA-428, with any combination of flood controls in the Coatesville subbasin would reduce the peak discharge of West Branch Brandywine Creek at Modena 10 percent. This reduction is due almost entirely to PA-428. The combination of PA-436 or PA-430 with PA-428 would not provide any further reduction in peak discharge. The combination of WA-2 with PA-428 would provide less than 1 percent additional reduction in peak discharge.

Table 12.--Simulated peak discharge for West Branch Brandywine Creek at Modena with proposed flood control PA-428 in the Modena subbasin and proposed flood controls in the Coatesville subbasin

Flood recurrence interval (years)	Simulated peak discharge of West Brandywine Creek at Modena (ft^3/s)					
			PA-428 and			
	No flood control	PA-428 only	PA-436	PA-430	WA-2	PA-436, PA-430, and WA-2
2	2,420	2,180	2,180	2,180	2,170	2,170
10	6,870	6,490	6,420	6,430	6,230	6,230
100	14,900	14,800	10,600	14,200	13,900	10,500

For the 10-year flood, all four flood controls together would reduce the peak discharge of West Branch Brandywine Creek at Modena 9 percent. PA-428 itself would reduce peak discharge 6 percent, with any single flood control in the Coatesville subbasin providing an additional 1 to 3 percent reduction. The three flood controls in the Coatesville subbasin, without PA-428 in the Modena subbasin, would reduce the peak discharge of West Branch Brandywine Creek at Modena less than 1 percent.

For the 100-year flood, all four flood controls would reduce the peak discharge of West Branch Brandywine Creek at Modena 30 percent. PA-428 by itself would have little effect on reducing peak discharge. PA-428 would provide no additional reduction in peak discharge when combined with PA-430 (tables 11 and 12). However, PA-428 in combination with PA-436 would provide an additional 5 percent reduction in peak discharge and in combination with WA-2 would provide an additional 1 percent reduction. When PA-428 is combined with all three flood controls in the Coatesville subbasin, it would provide an additional 5 percent reduction in the peak discharge of West Branch Brandywine Creek at Modena.

SUMMARY

Twenty-four hour rainfall, distributed according to the U.S. Soil Conservation Service type II rainfall distribution was used as rainfall input to calibrated rainfall-runoff models of three subbasins in the West Branch Brandywine Creek watershed to simulate 2-, 10-, and 100-year flood discharge hydrographs.

In the Honey Brook subbasin, rainfalls of 2.49, 3.72, and 6.00 inches were used to simulate 2-, 10-, and 100-year flood discharge hydrographs, respectively, for West Branch Brandywine Creek near Honey Brook. These discharge hydrographs were used as the upstream inflow to the Coatesville subbasin model.

In the Coatesville subbasin, rainfalls of 2.60, 4.00, and 4.95 inches were used to generate 2-, 10-, and 100-year flood discharge hydrographs, respectively, for West Branch Brandywine Creek at Coatesville. The effects of three proposed flood controls, PA-436, PA-430, and WA-2, were evaluated by using these rainfalls to simulate discharge hydrographs with and without the flood controls and comparing the simulated peak discharges. For the 2-year flood, the combination of all three flood controls would reduce peak discharge 8 percent. The combination of WA-2 and either PA-436 or PA-430 would reduce peak discharge 7 percent. WA-2 would reduce peak discharge 6 percent, PA-436 would reduce peak discharge 2 percent, and PA-430 would reduce peak discharge 1 percent. For the 10-year flood, the combination of all three flood controls would reduce peak discharge 8 percent. WA-2 was the most effective single flood control; it would reduce peak discharge 6 percent. For the 100-year flood, all three flood controls together would reduce peak discharge 44 percent. PA-436 would reduce peak discharge 40 percent, WA-2 would reduce peak discharge 6 percent, and PA-430 would reduce peak discharge 4 percent. PA-430, when combined with PA-436, would further reduce peak discharge by less than 1 percent. PA-436 in combination with WA-2 would reduce peak discharge 43 percent. WA-2 in combination with PA-430 would reduce peak discharge 11 percent.

In the Modena subbasin, rainfalls of 2.82, 3.72, and 4.95 inches were used to generate 2-, 10-, and 100-year flood discharge hydrographs, respectively, for West Branch Brandywine Creek at Modena. Discharge hydrographs simulated for the Coatesville subbasin were used as the upstream inflow to the Modena subbasin model. Flood control PA-428, proposed to be built on Sucker Run, would reduce the peak discharge of Sucker Run at State Route 82 by 22, 25, and 27 percent for the 2-, 10-, and 100-year floods, respectively. PA-428 would reduce the peak discharge of West Branch Brandywine Creek at Modena by 10, 6, and less than 1 percent for the 2-, 10-, and 100-year floods, respectively.

The effects of flood control in the Coatesville subbasin on the peak discharge of West Branch Brandywine Creek at Modena were simulated. For the 2- and 10-year flood simulations, flood control in the Coatesville basin would have little effect on peak discharge at Modena. For the 100-year flood simulation, the combination of all three flood controls in the Coatesville subbasin would reduce peak discharge at Modena 25 percent, as would the combination of PA-436 and WA-2. PA-430, when combined with PA-436 or with PA-436 and

WA-2, would not provide any additional reduction in peak discharge. PA-436 would reduce peak discharge 23 percent, WA-2 would reduce peak discharge 6 percent, and PA-430 would reduce peak discharge 5 percent.

The effects of PA-428 in the Modena subbasin combined with flood control in the Coatesville subbasin on the peak discharge of West Branch Brandywine Creek at Modena were simulated. For the 2-year flood simulation, the 10 percent reduction in peak discharge would be almost entirely due to PA-428. For the 10-year flood simulation, PA-428 would reduce peak discharge 6 percent and any single flood control in the Coatesville subbasin in combination with PA-428 would provide an additional 1 to 3 percent reduction. PA-428 with all three flood controls in the Coatesville subbasin would reduce peak discharge 9 percent. Although PA-428 itself or in combination with PA-430 would have little effect on reducing the 100-year flood peak, PA-428 in combination with PA-436 would provide an additional 3 percent reduction, and PA-428 in combination with WA-2 would provide an additional 1 percent reduction. When PA-428 is combined with all three flood controls in the Coatesville subbasin, it would provide an additional 5 percent reduction in peak discharge for a total reduction of 30 percent.

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