Prepared in cooperation with the Susquehanna River Basin Commission and Lycoming County

Development of Flood-Inundation Maps for the West Branch Susquehanna River near the Borough of Jersey Shore, Lycoming County, Pennsylvania

Scientific Investigations Report 2010–5057

U.S. Department of the Interior
U.S. Geological Survey

Front cover—Aerial photograph of Jersey Shore, Pa., and Long Island during flooding of September 18, 2004. Photograph taken by the Pennsylvania Civil Air Patrol and used with their permission.

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Conversion Factors and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

List of Acronyms

AHPS	Advanced Hydrologic Prediction Service
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
FIRM	flood-insurance rate map
FIS	flood-insurance studies
GIS	geographical information system
HEC-RAS	Hydrologic Engineering Center River Analysis System
LiDAR	Light Detection and Ranging
NFIP	National Flood Insurance Program
NOAA/NWS	National Oceanic and Atmospheric Administration’s National Weather Service
PaDCNR	Pennsylvania Department of Conservation and Natural Resources
SFFWS	Susquehanna Flood Forecast and Warning System
SRBC	Susquehanna River Basin Commission
USGS	U.S. Geological Survey

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Abstract

Streamflow data, water-surface-elevation profiles derived from a Hydrologic Engineering Center River Analysis System hydraulic model, and geographical information system digital elevation models were used to develop a set of 18 flood-inundation maps for an approximately 5-mile reach of the West Branch Susquehanna River near the Borough of Jersey Shore, Pa. The inundation maps were created by the U.S. Geological Survey in cooperation with the Susquehanna River Basin Commission and Lycoming County as part of an ongoing effort by the National Oceanic and Atmospheric Administration's National Weather Service to focus on continued improvements to the flood forecasting and warning abilities in the Susquehanna River Basin and to modernize flood-forecasting methodologies. The maps, ranging from 23.0 to 40.0 feet in 1-foot increments, correspond to river stage at the U.S. Geological Survey streamgage 01549760 at Jersey Shore. The electronic files used to develop the maps were provided to the National Weather Service for incorporation into their Advanced Hydrologic Prediction Service website. The maps are displayed on this website, which serves as a web-based flood-warning system, and can be used to identify areas of predicted flood inundation associated with forecasted flood-peak stages. During times of flooding or predicted flooding, these maps can be used by emergency managers and the public to take proactive steps to protect life and reduce property damage caused by floods.

Introduction

Floodwaters can present real dangers in the form of loss of life and (or) property. According to the Susquehanna River Basin Commission (SRBC), the Susquehanna River Basin continues to be one of the most flood-prone areas in the country (Susquehanna River Basin Commission, 2009). Since 1889, the West Branch of the Susquehanna River has exceeded the flood stage[1] of 26.0 ft no fewer than nine times (National Oceanic and Atmospheric Administration, National Weather Service, 2009b); the most recent major flood[2] occurred on September 18, 2004, when a gage height of 30.74 ft was recorded at the U.S. Geological Survey (USGS) streamgage 01549760 at Jersey Shore. Areas within and around the Borough of Jersey Shore are designated by the Federal Emergency Management Agency (FEMA) as being within the 1-percent annual chance flood-hazard area. While the development of flood-response and damage-reduction programs in flood-prone communities is instrumental to minimizing the potential impact associated with floods, the effectiveness of such programs can be diminished without adequate forecast lead times.

The SRBC coordinates an interagency committee that maintains and operates the Susquehanna Flood Forecast and Warning System (SFFWS). The purpose of the SFFWS is to provide timely and accurate information to reduce flood damages and prevent loss of life due to flooding within the basin. To assist with the accomplishment of this mission, a subcommittee was established with representation from the National Oceanic and Atmospheric Administration's National Weather Service (NOAA/NWS), SRBC, and USGS to focus on continued improvements to the flood forecasting and warning abilities in the Susquehanna River Basin. An example of a continued improvement is the modernization of NOAA/NWS flood-forecasting methodologies through the implementation of the Advanced Hydrologic Prediction Service (AHPS) in the Susquehanna River Basin. AHPS is the NWS's ongoing effort to modernize NWS hydrologic services that will provide improved river and flood forecasts and water information across America to protect life and property

[1]Flood Stage is defined by the National Oceanic and Atmospheric Administration's National Weather Service as an established gage height for a given location above which a rise in water-surface level begins to create a hazard to lives, property, or commerce.

[2]Major flood is defined by the National Oceanic and Atmospheric Administration's National Weather Service as a general term including extensive inundation and property damage. A major flood is usually characterized by the evacuation of people and livestock and the closure of both primary and secondary roads.

(National Oceanic and Atmospheric Administration, National Weather Service, 2009a).

A priority of the SFFWS interagency committee is the enhancement of AHPS through the development of flood-inundation maps that graphically depict expected areas of inundation relative to stage at specific flood-forecasting locations in the Susquehanna River Basin. A cooperative agreement between Lycoming County, SRBC, and the USGS was enacted to develop flood-inundation maps for the NWS flood-forecast point at Jersey Shore, Pa. Emergency managers and the public will have access on the AHPS website to mapped information of inundated areas in addition to forecasted river stage(s). During times of predicted flooding, these data may be used for evacuation purposes and identification of potential road-closure points.

Study Area Description

The West Branch Susquehanna River Basin is in north-central Pennsylvania (fig. 1). The study area is an approximately 5-mi reach from the confluence of Pine Creek extending downstream past the Borough of Jersey Shore to the confluence of Larrys Creek. The Borough of Jersey Shore is approximately 15 mi southwest of Williamsport, Pa., in southern Lycoming County; the population of the Borough is approximately 4,500 (U.S. Census Bureau, 2009).

The approximate mid-point of the study reach is Long Island, where the West Branch Susquehanna River changes flow direction from a generally easterly direction to a northerly direction with flow splitting into an east and west channel for approximately 1 mi. State Route 44 (SR 44) crosses Long Island, and two bridges span the river. USGS streamgage 01549760, West Branch Susquehanna River at Jersey Shore, Pa., is located on Long Island near the western SR 44 bridge and is a flood-forecasting point for the NWS. The landscape on Long Island consists primarily of agricultural fields with several residential structures; the perimeter of the island is lined with light brush and trees.

Flood-plain areas in the upstream part of the study reach are characterized by steep, forested banks on the southern side of the river; the flood plain on the northern side of the river is low relief with agricultural fields. At the approximate mid-point of the study reach (near Long Island), the flood plains begin to flatten out with the Borough of Jersey Shore situated to the western side of the river; landscape on the eastern side of the river is primarily agricultural fields with sparse residential structures. The flood-plain areas in the downstream part of the study reach are characterized by a sparsely populated residential area with open grassy areas on the immediate left overbank; U.S. Route 220 parallels the river at the base of steep forested banks on the far left flood plain. Agricultural fields dominate the downstream flood plain on the right overbank area of the study reach and include the presence of a local landing airstrip.

Purpose and Scope

This report describes the methods and results of hydrologic and hydraulic analyses and geographic information system (GIS) data-processing techniques used to develop flood-inundation maps for selected water-surface stages at the NWS flood-forecast point on the West Branch Susquehanna River at Jersey Shore, Pa., for incorporation by the NWS into their AHPS website. The USGS, in cooperation with the Susquehanna River Basin Commission and Lycoming County, Pa., developed flood-inundation maps and water-depth maps (or grids) to estimate areas and depths of anticipated flooding at 18 water-surface stages.

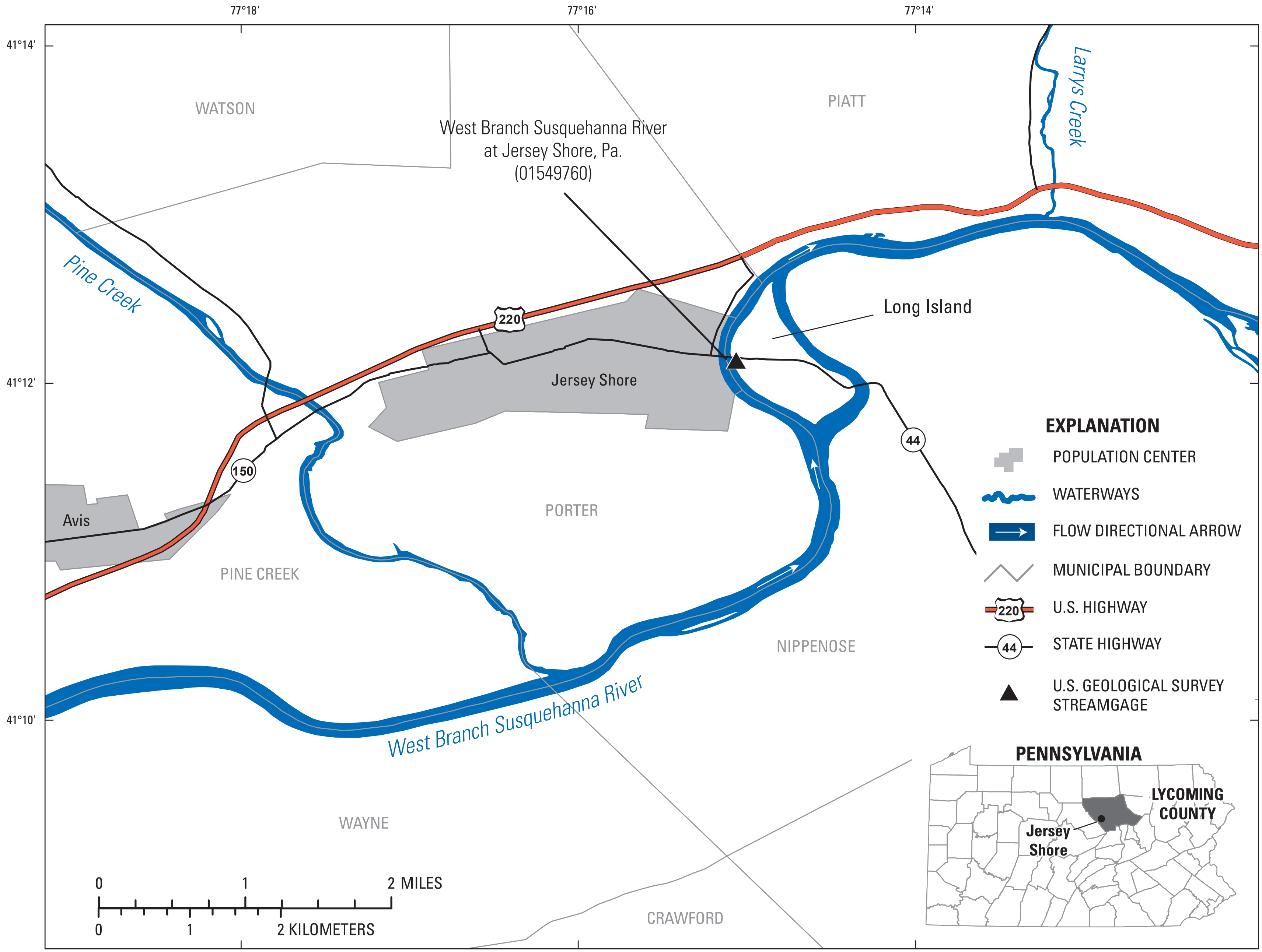
Hydrologic Analysis

The flood-inundation maps prepared for this study range from the action stage of 23.0 ft at 1-ft increments up to a stage of 40.0 ft, which is approximately 2 ft higher than the stage of maximum flow of 38.2 ft observed on June 23, 1972. Therefore, flows were estimated at 18 different gage heights.

A rating table developed for USGS streamgage 01549760 was used to derive flow estimates that are based on stage for use in the hydraulic model (table 1). This streamgage was established as a staff gage in October 1938. Recording equipment was installed in March 2000 for operation as a stage-only gage. On October 1, 2004, it was established as a continuous-record annual peak site. The existing rating table for the Jersey Shore streamgage went up to a gage height of 32.0 ft with a corresponding discharge of 200,000 ft^3/s. The upper end of this rating was initially extended from 32.0 ft to 38.2 ft (with a corresponding discharge of 257,000 ft^3/s), which was the maximum observed stage at this location for the June 1972 flood. This rating extension was based on a discharge-per-square-mile correlation with USGS streamgage 01551500, West Branch Susquehanna River at Williamsport, for the June 1972 flood event. Streamgage 01551500 is downstream from Jersey Shore, shares similar hydrologic basin characteristics as streamgage 01549760, and has been in operation since 1895. The drainage areas of streamgages 01549760 and 01551500 are 5,225 and 5,682 mi^2, respectively. The rating was subsequently extended from 38.2 ft to 40.0 ft (with a corresponding discharge of 273,300 ft^3/s) on the basis of a straight-line extension.

Hydraulic Analysis

The hydraulic-analyses computations were performed using the U.S. Army Corps of Engineer’s Hydrologic Engineering Center River Analysis System (HEC-RAS), version 3.1.1 (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2002). HEC-RAS is a one-dimensional step-backwater model designed for application in flood-insurance studies



Roads, population centers, county and municipal boundaries: Commonwealth of Pennsylvania, 2009
Waterways: U.S. Geological Survey, 2009

Figure 1.—Study area for development of flood-inundation maps for the West Branch Susquehanna River near the Borough of Jersey Shore, Pa.

Table 1. U.S. Geological Survey streamgage 01549760 rating-table stage with corresponding elevations and discharge estimates for the West Branch Susquehanna River at Jersey Shore, Pa.

[Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). The hydraulic analyses computations were performed using the U.S. Army Corps of Engineer's Hydrologic Engineering Center River Analysis System (HEC-RAS), version 3.1.1 (U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2002). ft^3/s, cubic feet per second]

Stage, gage datum (feet)	Discharge (ft^3/s)	HEC-RAS Profile	Elevation, NAVD 88 datum (feet)	HEC-RAS modeled water-surface elevation (feet)	Elevation difference (feet)
23.00	114,700	1	535.53	535.75	0.22
24.00	123,200	2	536.53	536.70	.17
25.00	132,000	3	537.53	537.65	.12
26.00	141,000	4	538.53	538.61	.08
27.00	150,300	5	539.53	539.58	.05
28.00	159,700	6	540.53	540.63	.10
29.00	169,500	7	541.53	541.68	.15
30.00	179,400	8	542.53	542.76	.23
31.00	189,600	9	543.53	543.75	.22
32.00	200,000	10	544.53	544.68	.15
33.00	208,900	11	545.53	545.59	.06
34.00	217,900	12	546.53	546.55	.02
35.00	227,100	13	547.53	547.51	-.02
36.00	236,300	14	548.53	548.49	-.04
37.00	245,600	15	549.53	549.47	-.06
38.00	255,100	16	550.53	550.43	-.10
39.00	264,100	17	551.53	551.38	-.15
40.00	273,300	18	552.53	552.30	-.23

(FIS) and flood-plain management and is accepted by FEMA for use in the National Flood Insurance Program (NFIP).

Hydraulic models from two FISs were obtained and combined into one HEC-RAS hydraulic model for use in this study. The effective FIS for the Borough of Jersey Shore (Federal Emergency Management Agency, 2004) was completed in 1975 by the SRBC and the effective FIS for the Township of Piatt (Federal Emergency Management Agency, 2004) was completed in 1979 by Michael Baker, Jr., Inc., under subcontract to SRBC, each using a HEC-2 hydraulic model (U.S. Army Corps of Engineers, 1984). The data input to each of these models and the associated FIS were reviewed to verify accuracy (e.g., location, spacing, and ground elevations of cross sections). During the review process, it was discovered that a cross section existed in each of the models that was common to both—the farthest upstream cross section in the Township of Piatt FIS was the same as the farthest downstream cross section in the Borough of Jersey Shore FIS. This common cross section was used to effectively join both models together such that the study reach could be evaluated using one model. In 1985, the eastern SR 44 bridge (connecting Long Island to Antes Fort) was replaced. The merged HEC-RAS hydraulic model was updated to reflect the new bridge location and geometry (Pennsylvania Department of Transportation, written commun., 1985).

USGS streamgage 01549760 was used as the calibration point for this model. The 18 rating-table discharges identified in table 1 were incorporated into the HEC-RAS model with their accompanying rating-table stages, which were converted to water-surface elevations. Initially, these water-surface elevations were entered into the model as known starting water-surface elevations at the farthest downstream cross section. Eighteen computed water-surface profiles were subsequently generated for the study reach. On the basis of the slope of these profiles, revised initial water-surface elevations were estimated at the farthest downstream cross section and entered into the hydraulic model. This method provided a means to establish reasonable starting water-surface elevations from which the model subsequently required additional calibration to match the corresponding rating-table stages at the streamgage cross section. For example, at a stage of 28.0 ft (540.53 ft NAVD 88), the corresponding discharge according to the USGS streamgage 01549760 rating table is 159,700 ft^3/s. This discharge was entered into the model and a water-surface profile (fig. 2) was generated throughout the study reach. This water-surface profile subsequently required calibration to correspond with a 28.0 ft stage (540.53 ft

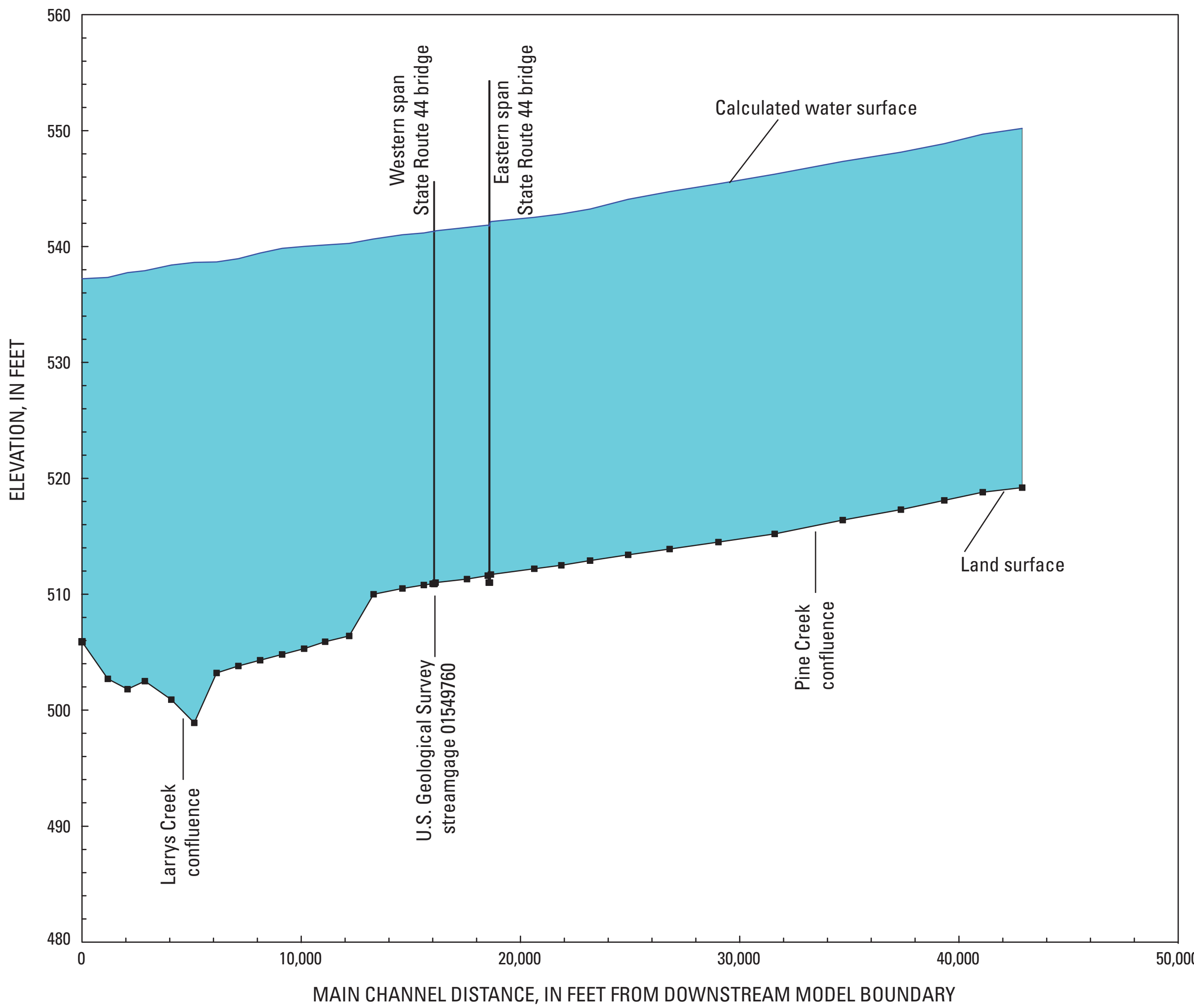


Figure 2.—HEC-RAS water-surface profile for a gage height of 28.0 feet, West Branch Susquehanna River at Jersey Shore, Pa.

NAVD 88) at the modeled location of the streamgage. In this case, model calibration consisted of adjusting the channel and overbank roughness-coefficient values such that the predicted water-surface profiles would best match the stages identified in the rating table. To ensure reasonableness of the roughness-coefficient values, field reconnaissance of the study area was conducted, and orthophotography was examined. This model calibration process was repeated for each of the 18 discharges and their corresponding stages (table 1). Consequently, this was an iterative process because any change to the model (for example, adjustment of roughness coefficients) had the potential to alter any of the water-surface profiles. The resultant 18 water-surface profiles for the study reach (table 1) were within +/- 0.23 ft for each of the 18 corresponding stages at the streamgage location.

Development of Flood-Inundation Maps

The flood-inundation maps were developed using a Light Detection and Ranging (LiDAR) based digital elevation model (DEM) from data collected by the Pennsylvania Department of Conservation and Natural Resources (PaDCNR) and USGS as part of PAMAP, which is a program designed to create a new electronic map of Pennsylvania using high-resolution aerial photography, elevation data collected using LiDAR technology, and existing spatial data from local, state, and federal sources (Pennsylvania Department of Conservation and Natural Resources, 2009). Each PAMAP data set is organized into blocks representing 10,000 ft by 10,000 ft on the ground (Pennsylvania Spatial Data Access, 2009). These blocks do not have gaps or overlapping areas, which allow a seamless mosaic of multiple blocks of data. Six individual DEM blocks were mosaicked together using ArcGIS (Environmental Systems Research Institute, Inc., 2009) software to cover the Jersey Shore model area. The resulting raster data set, or grid, covered approximately 21.5 mi^2 with a horizontal ground resolution of 3.2 ft, for the elevation data. Horizontal accuracy is documented at 5 ft or better and vertical accuracy is 7.3 in. (Pennsylvania Spatial Data Access, 2009).

A study-area polygon, shown on figure 3, was created to assist in the GIS processing for each water-surface-elevation profile. This polygon boundary included the modeled area from Pine Creek downstream to Larrys Creek. The west bank of Pine Creek was used for the upstream limit of the polygon, and the downstream terminus was between 500 and 1,000 ft downstream from the east bank of Larrys Creek. The width of the study-area polygon was determined by digitizing two lines using the ends of cross-section lines that were digitized using FEMA's flood-insurance rate map (FIRM) data as a guide. These lines were then expanded by using a buffer of 500 ft to insure the edge-of-water could be seen at each modeled water-surface profile. The structure of grid-formatted data allowed fast and efficient processing and analyzing of large LiDAR data sets. Bare-earth DEMs generated from LiDAR data are large gridded data sets that do not include data related to man-made objects (Maune, 2007). To represent the impact of flood levels on infrastructure, the DEM was corrected to show the elevations of those areas where bridges and overpasses were located. Cell-elevation values were manually changed using surveyed bridge-deck elevations as references, where possible. In most bridge locations, the bare-earth elevations from roads leading up to the bridges were used and applied to cells across the surface of the bridge.

Each FIRM digitized cross-section line used for the study area was attributed with a HEC-RAS calculated water-surface elevation for each of the 18 profiles (table 1). The flood surfaces were generated using an iterative finite-difference interpolation technique found in the ArcGIS, TopoToRaster tool. This tool is unique because it is the only ArcGIS interpolation routine designed to work intelligently with contour data and combines locally efficient interpolation methods with global surface-continuity routines (Environmental Systems Research Institute, Inc., 2009). Inputs into the tool are as follows: contour data using the digital cross sections attributed with the NAVD 88 elevation, in feet, and boundary data using the study-area polygon. Depth of water grids were generated by subtracting the flood water-surface elevation from the study-area DEM.

Comparison of Flood-Inundation Map to Aerial Photograph

After the HEC-RAS hydraulic model was calibrated to the USGS streamgage 01549760 stage and discharge data and the inundation maps were generated, visual comparison was made between distinguishable inundated or near-inunadated areas (Areas 1 through 4) identified on the inundation map at stage 28.0 ft (fig. 3) and an aerial photograph (fig. 4) of a flood event to judge the relative accuracy of the model. Aerial photography of the September 18, 2004, Hurricane Ivan flood event was taken by the Civil Air Patrol Composite Squadron 401 at various flood-affected communities throughout Lycoming County, including the Borough of Jersey Shore. The peak gage height from the September 18, 2004, event was 30.74 ft recorded at USGS streamgage 01549760. Although a time stamp was not associated with the aerial photograph of the Jersey Shore flooding, it was estimated on the basis of shadows from structures and trees to have been taken in the early afternoon when the corresponding recorded stage was approximately 28 ft.

Areas 1 to 4 (figs. 3 and 4) show similar inundated or near-inundated areas. Area 1 on the eastern side of Long Island near the approach to the SR 44 bridge and the bridge itself were not inundated. Similarly, Area 2 on the western side of Long Island near the approach to the SR 44 truss bridge and the bridge itself are not inundated. Area 3 identifies an agricultural field south of the Borough showing what appears to be a combination of backwater and channelized flow around a topographical high point in the field. Area 4 shows inundated areas within the northern portion of the Borough possibly caused by a combination of small tributaries draining the local area and backwater from a culvert pipe that discharges to the river.

In addition to aerial photograph comparison, a review of flood-inundation maps was performed by County and Borough personnel and residents who indicated that the modeled inundated areas appeared to present reasonable delineations of flooded areas at various stages. These evaluations were based primarily on personal experiences during times of flooding.

Summary

The mission of the Susquehanna Flood Forecast and Warning System in the Susquehanna River Basin is to provide timely and accurate information to reduce damages and prevent loss of life during flood events within the basin. Continued improvements and modernization of National Oceanic and Atmospheric Administration's National Weather Service flood-forecasting methodologies with the implementation of the Advanced Hydrologic Prediction Service can assist with the achievement of this mission. The development of flood-inundation maps that graphically depict areas of expected inundation relative to stage at flood-forecast points can enhance the Advanced Hydrologic Prediction Service. In cooperation with the Susquehanna River Basin Commission and Lycoming County, the U.S. Geological Survey used streamflow data, modeled water-surface-elevation profiles, and GIS digital elevation models to develop a set of 18 flood-inundation maps for an approximately 5-mi reach of the West Branch

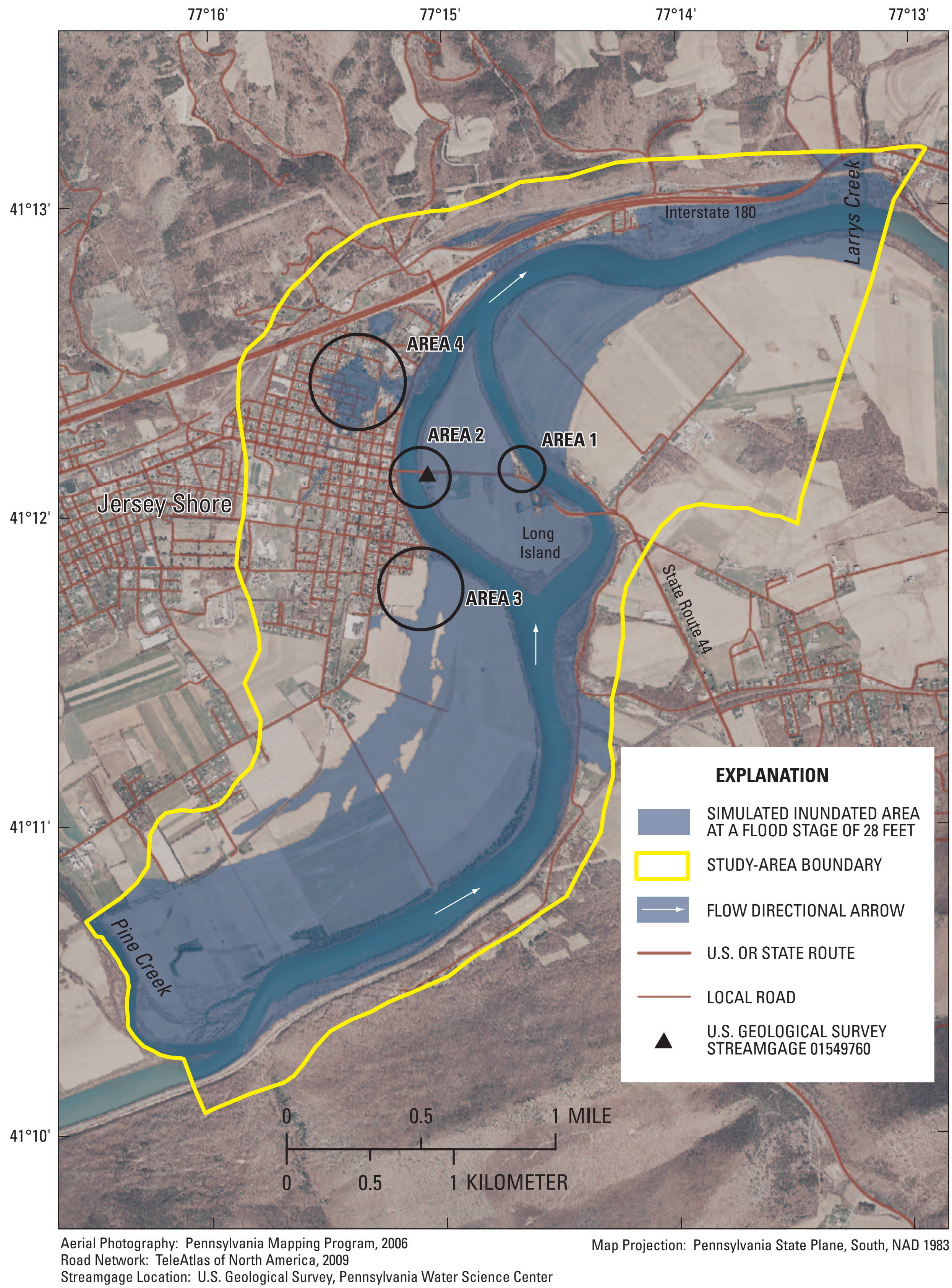


Figure 3.—Simulated areas of inundation at a stage of 28.0 feet for the U.S. Geological Survey streamgage 01549760, West Branch Susquehanna River at Jersey Shore, Pa. (Areas 1 through 4 are inundated and near-inundated areas used for comparison with aerial photograph, figure 4.)

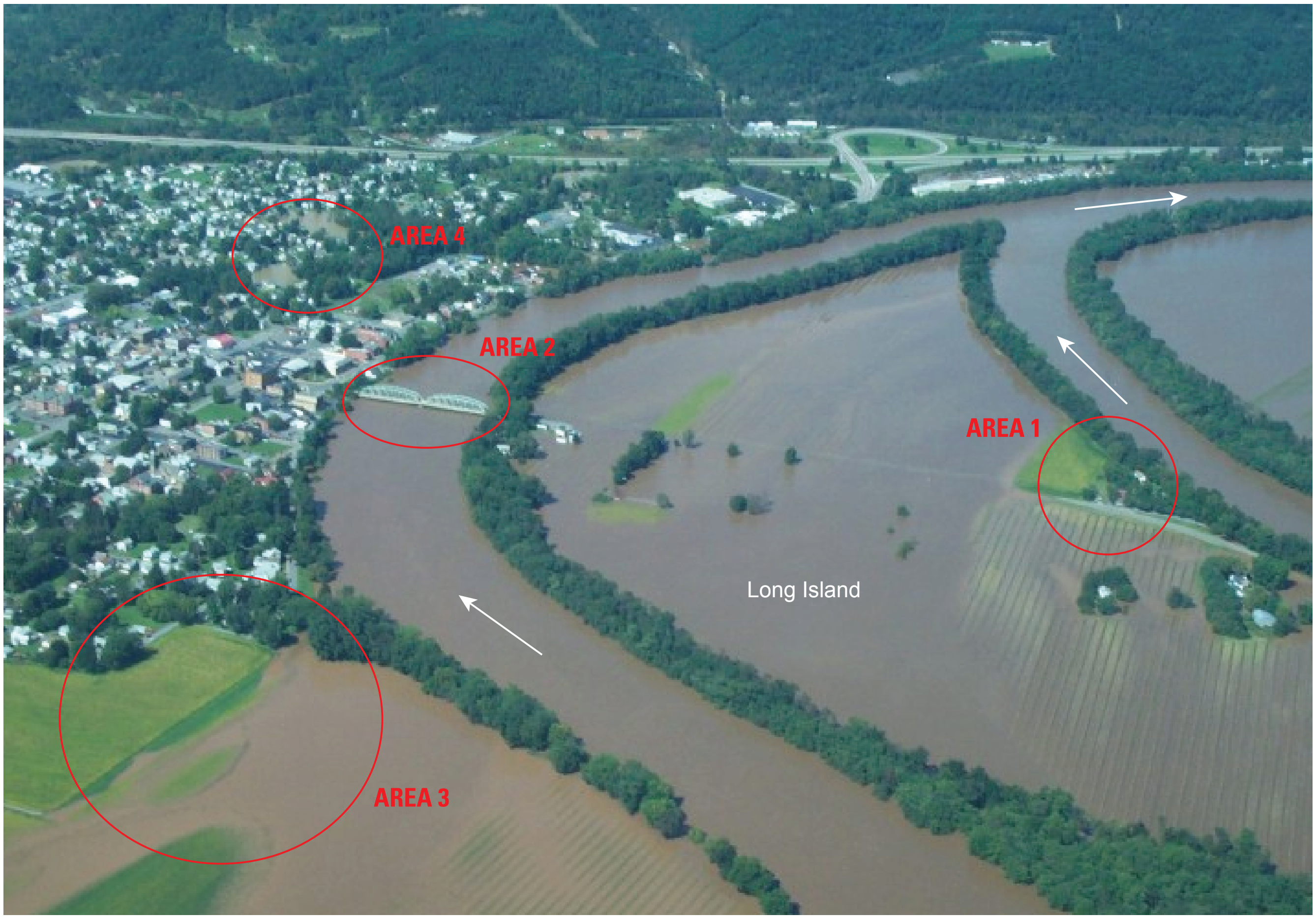


Figure 4.—Aerial photograph of Jersey Shore, Pa., and Long Island during flooding of September 18, 2004. (Photo taken by Pennsylvania Civil Air Patrol and used with their permission.) (Areas 1 through 4 are inundated and near-inundated areas used for comparison with flood-inundation map, figure 3.)

Susquehanna River near the Borough of Jersey Shore, Pa. The surface-water elevations depicted in this set of maps range from a stage of 23.0 ft to a maximum stage of 40.0 ft (approximately 2 ft higher than the stage of maximum observed flow), in 1-ft stage increments. In addition to river stage, emergency managers and the public have access to the mapped information on inundated areas on the Advanced Hydrologic Prediction Service website. During times of predicted flooding, these maps may be used to take proactive steps to protect life and reduce property damage caused by floods.

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