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Flood-Inundation Maps for the West Branch Susquehanna River near the Boroughs of Lewisburg and Milton, Pennsylvania, 2013

Scientific Investigations Report 2014–5094

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

Cover: Photograph taken during the December 2, 2010 flood event looking north on North Front Street in the Borough of Milton, Pennsylvania. (Photograph was taken by Scott A. Hoffman)

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.59	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to either (1) stage, the height above an arbitrary datum established at a streamgage, or (2) elevation, the height above the North American Vertical Datum of 1988 (NAVD 88).

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

Flood-Inundation Maps for the West Branch Susquehanna River near the Boroughs of Lewisburg and Milton, Pennsylvania, 2013

By Mark A. Roland and Scott A. Hoffman

Abstract

Digital flood-inundation maps for an approximate 8-mile reach of the West Branch Susquehanna River from approximately 2 miles downstream from the Borough of Lewisburg, extending upstream to approximately 1 mile upstream from the Borough of Milton, Pennsylvania, were created by the U.S. Geological Survey (USGS) in cooperation with the Susquehanna River Basin Commission (SRBC). The inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science Web site at *http://water.usgs.gov/osw/flood_inundation/*, depict the estimated areal extent and depth of flooding corresponding to selected water levels (stages) at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa. In addition, the information has been provided to the Susquehanna River Basin Commission (SRBC) for incorporation into their Susquehanna Inundation Map Viewer (SIMV) flood warning system (*http://maps.srbc.net/simv/*). The National Weather Service (NWS) forecasted peak-stage information (*http://water.weather.gov/ahps*) for USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., may be used in conjunction with the maps developed in this study to show predicted areas of flood inundation.

In this study, flood profiles were computed for the stream reach by means of a one-dimensional step-backwater model. Calibration of the model was achieved using the most current stage-discharge relations (rating number 11.1) at USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., a documented water-surface profile from the December 2, 2010, flood, and recorded peak stage data. The hydraulic model was then used to determine 26 water-surface profiles for flood stages at 1-foot intervals referenced to the streamgage datum ranging from 14 feet (ft) to 39 ft. Modeled flood stages, as defined by NWS, include Action Stage, 14 ft; Flood Stage, 18 ft; Moderate Flood Stage, 23 ft; and Major Flood Stage, 28 ft. Geographic information system (GIS) technology was then used to combine the simulated water-surface profiles with a digital elevation model (DEM) derived from light detection and ranging (lidar) data to delineate the area flooded at each water level.

The availability of these maps, along with World Wide Web information regarding current stage from USGS streamgages and forecasted stream stages from the NWS, provide emergency management personnel and residents with information that is critical for flood response activities, such as evacuations and road closures, as well as for post-flood recovery efforts.

Introduction

The Boroughs of Lewisburg and Milton, Pennsylvania, are small rural communities with estimated populations of 5,790 and 7,040, respectively (U.S. Bureau of Census, 2010). The boroughs, as well as neighboring communities, have experienced repeated flooding and flood damage, most recently in 1996, 2004, and 2011. According to the Federal Emergency Management Agency (FEMA) National Flood Insurance Program loss statistics (Federal Emergency Management Agency, 2013a), the total amount paid on flood claims since 1978 for the Boroughs of Lewisburg and Milton is in excess of $7 million. Floodplains within the Boroughs of Lewisburg and Milton are moderately developed and contain a mix of residential and commercial structures.

Prior to this study, several products and information sources were available to assist municipal officials when making decisions on how best to alert the public and mitigate flood damages. One source is the FEMA Flood Insurance Studies (FIS) for Union (Federal Emergency Management Agency, 2007) and Northumberland Counties (Federal Emergency Management Agency, 2008). Within the study reach, the West Branch Susquehanna River forms the municipal boundary between Union and Northumberland Counties. The Borough of Lewisburg and neighboring municipalities on the west side of the West Branch Susquehanna River are included in the Union County FEMA FIS document. The Borough of Milton and adjacent municipalities on the east side of the study reach are referenced in the Northumberland County FEMA FIS document. A second source of information are U.S. Geological Survey (USGS) streamgage data available from the West

Branch Susquehanna River at Lewisburg (station 01553500) and West Branch Susquehanna River at West Milton (station 01553240), from which current or historical water levels (stages) can be obtained. A third source is the National Weather Service's (NWS) forecast of peak stage at the USGS streamgages through the Advanced Hydrologic Prediction Service (AHPS) Web site.

Although USGS current stage and NWS forecast stage data are particularly useful for residents in the immediate vicinity of a streamgage, the data are of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream channel. Knowledge of a water level at a streamgage is difficult to translate into depth and areal extent of flooding at points distant from the streamgage. To help guide the general public in taking individual safety precautions and provide local officials with a tool to help manage emergency flood operations and flood-mitigation efforts, digital flood-inundation maps for an approximate 8-mile reach of the West Branch Susquehanna River were developed by the USGS in cooperation with the Susquehanna River Basin Commission (SRBC).

Purpose and Scope

This report describes the development of a library of 26 estimated flood-inundation maps for the West Branch Susquehanna River near Lewisburg and Milton, Pennsylvania, for 2013. Maps were produced for water levels referenced to the stage at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., ranging from NWS defined Action Stage of 14.0 ft to a maximum stage of 39.0 ft. Action stage is the stage at which, when reached by a rising stream, the NWS or a partner needs to take some type of mitigation action in preparation for possible hydrologic activity. The maps and other useful flood information are available on the USGS Flood Inundation Mapping Science Web site and the SRBC Susquehanna Inundation Map Viewer (SIMV) Web site. Internet users can select inundation maps [relative to the nearest 1-foot interval ranging from 14 feet (ft) to 39 ft] that correspond to (1) current stages at the USGS streamgage, (2) the NWS forecasted peak stage, or (3) other desired stream stages.

The scope of the study was limited to the West Branch Susquehanna River beginning at a downstream location approximately 2 miles downstream from the Borough of Lewisburg and proceeding upstream approximately 8 miles to a point approximately 1 mile upstream from the Borough of Milton (fig. 1).

Study Area Description

The West Branch Susquehanna River near the Boroughs of Lewisburg and Milton is located in the central part of Pennsylvania in the Ridge and Valley Physiographic Province. The drainage areas range from approximately 6,824 square miles (mi^2) at the West Branch Susquehanna River at Lewisburg streamgage to approximately 6,679 mi^2 at the West Branch Susquehanna River at West Milton streamgage near the upstream extent of the study reach. The headwaters originate in Clearfield County, Pennsylvania, and the stream flows generally eastward to the City of Williamsport after which the river bends and begins flowing in a southward direction before entering the borough limits of Milton. The basin terrain is moderately hilly to mountainous with most of the land cover classified as forested. In general, the basin is underdeveloped; some small rural communities with residential and commercial buildings are present sporadically throughout the basin.

No major tributaries to the West Branch Susquehanna River join the main stem as it flows through the Boroughs of Milton or Lewisburg. However, smaller tributaries, such as Limestone Run (drainage area 11.6 mi^2), flow into the West Branch Susquehanna River from the left bank in Milton; Buffalo Creek (drainage area 134 mi^2) and Limestone Run (drainage area 8.5 mi^2) join the West Branch Susquehanna River from the right bank near Lewisburg (fig.1). Considering the relative size of drainage areas, the contributing flow from the smaller tributaries has little effect on the West Branch Susquehanna River. The study reach is approximately 8 miles long and has an average top-of-bank channel width of about 1,000 ft. The main channel within the study reach is crossed by two major roads (SR45 in Lewisburg and SR642 in Milton; fig. 1); two railroad crossings span the channel.

Previous Studies

According to the Union County FIS compilation document (Federal Emergency Management Agency, 2007), no previously printed FIS report exists for the Borough of Lewisburg. However, FISs do exist for surrounding communities (the Township of East Buffalo to the south of Lewisburg and the Township of Kelly to the north of Lewisburg) (Federal Emergency Management Agency, 2007). The current FIS for the Borough of Milton, which is contained in the Northumberland County FIS compilation document, was completed by Dewberry, Nealon, and Davis in 1978 (Federal Emergency Management Agency, 2008).

The FIS studies provide information on the 10-, 2-, 1-, and 0.2-percent annual exceedance probability water-surface profiles and associated floodplain maps for the West Branch Susquehanna River in the study reach. Estimates of the peak discharges for the 10-, 2-, 1-, and 0.2-percent annual exceedance probability floods along the West Branch Susquehanna River for the study reach, as shown in table 1, are presented in the FEMA FISs (Federal Emergency Management Agency 2007, 2008). Updated Log-Pearson Type III flood frequency estimates computed using annual peak-flow data (1966–2011) associated with the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., are included in table 1.

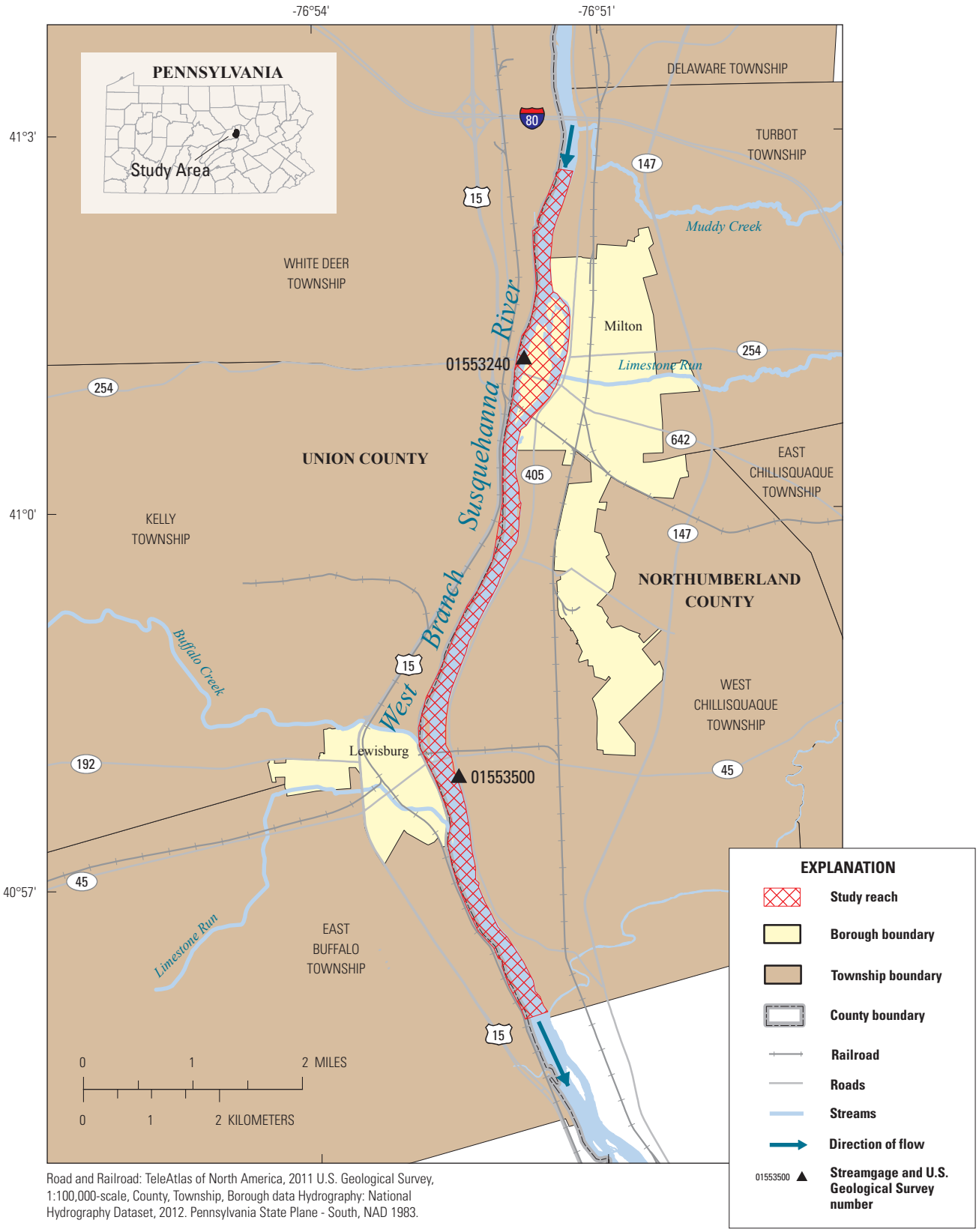

Figure 1. Location of study reach for the West Branch Susquehanna River near the Boroughs of Lewisburg and Milton, Pennsylvania, and location of U.S. Geological Survey streamgages.

Table 1. Estimated 10-, 2-, 1-, and 0.2-percent annual exceedance probability peak discharges and drainage areas for selected locations on the West Branch Susquehanna River from Federal Emergency Management Agency Flood Insurance Study 2007 (Union County) and Flood Insurance Study 2008 (Northumberland County), and Log-Pearson Type III discharge estimates computed using annual peak discharge data for U.S. Geological Survey streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pennsylvania, 1966–2011.

[mi^2, square miles; ft^3/s, cubic feet per second; FIS, Flood Insurance Study]

Location on West Branch Susquehanna River	Drainage area (mi^2)	Discharge estimate (ft^3/s)			
		10-Percent annual chance	2-Percent annual chance	1-Percent annual chance	0.2-Percent annual chance
Northumberland County FIS 2008					
At southern corporate limit of Delaware Township	6,682	180,000	273,000	316,000	495,000
Union County FIS 2007					
At mouth	6,955	185,000	275,000	319,000	500,000
At White Deer Township downstream corporate limits	6,682	180,000	273,000	316,000	495,000
Log-Pearson III discharge estimates computed using annual peak streamgage data 1966–2011[1]					
At streamgage 01553500 in Lewisburg	6,824	170,000	262,000	307,000	432,000

[1]Discharge affected by regulation or diversion.

Creation of Flood-Inundation-Map Library

Methods used in the creation of the flood-inundation maps are generally cited from previously published reports. If techniques varied significantly from previously documented methods owing to local hydrologic conditions or available data, they are described in detail in this report. Tasks specific to development of the maps were (1) evaluation of stage and discharge data at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., and USGS streamgage 01553240, West Branch Susquehanna River at West Milton, Pa. (table 2); (2) collection of high-water-mark data associated with December 2, 2010, flood; (3) collection of topographic data and geometric data (for structures/bridges) throughout the study reach; (4) determination of energy-loss factors (roughness coefficients) in the stream channel and flood plain, and steady-flow data; (5) computation of water-surface profiles using the U.S. Army Corps of Engineer's HEC–RAS computer program (U.S. Army Corps of Engineers, 2010); and (6) production of estimated flood-inundation maps at various river stages using a geographic information system (GIS).

Computation of Water-Surface Profiles

The water-surface profiles used to produce the 26 estimated flood-inundation maps in this study were computed by using HEC–RAS, version 4.1.0 (U.S. Army Corps of Engineers, 2010). HEC–RAS is a one-dimensional step-backwater model used for simulation of water-surface profiles with steady-state (gradually varied) or unsteady-state flow computation options. The HEC–RAS analysis for this study was done by using the steady-state flow computation option with the assumption of unobstructed flow conditions (for example, debris at bridges or backwater from tributaries and (or) confluences).

Hydrologic and Steady-Flow Data

The study area hydrologic network consists of two streamgages (fig. 1; table 2). The USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., was established in 1913 and operated by the Commonwealth of Pennsylvania for flood-warning purposes until 1923. The streamgage was re-established in 1939, and a recorder was installed in 1940. During construction of a new Route 45

Table 2. U.S.Geological Survey streamgage and miscellaneous site information for study basin, West Branch Susquehanna River, Pennsylvania.

[mi^2, square miles; ft, feet; Latitude and longitude are in degrees, minutes, and seconds]

Station name	Station number	Drainage area (mi^2)	Latitude	Longitude	Period of record	Maximum recorded stage and date
West Branch Susquehanna River at Lewisburg	01553500	6,824	40°58'03"	76°52'36"	1913–23, 1941–2013[1]	34.23 ft June 24, 1972
West Branch Susquehanna River at West Milton[2]	01553240	6,679	41°01'07"	76°51'55"	1994–2013	29.25 ft Jan 20, 1996[3]

[1]Discharge affected by regulation or diversion beginning 1966.

[2]West Branch Susquehanna River at West Milton currently operates as a stage-only streamgage.

[3]Because of a datum adjustment applied on March 9, 1999, a peak stage of 27.94 ft recorded on September 19, 2004, has a higher relative water-surface elevation (in reference to National Geodetic Vertical Datum 1929) than the recorded stage of 29.25 ft on January 20, 1996.

bridge during 1987–88, the old streamgage was destroyed, and a new streamgage was built. The USGS streamgage 01553240 West Branch Susquehanna River at West Milton, Pa., was established in 1994 and is currently classified as a stage-only streamgage. Water level (stage) is measured continuously at both sites; however, continuous records of streamflow are computed only at the Lewisburg streamgage. As of 2013, more than 500 discharge measurements have been made at the Lewisburg streamgage, and the current stage-discharge rating is 11.1, which was extended to the 0.2-percent annual exceedance probability (AEP) at a corresponding stage of 39.00 ft for the purposes of this study. The flow distribution was not changed throughout the study reach (that is, discharges at all cross sections within the hydraulic model were assigned the same flow value for a given stage at Lewisburg). The current vertical datum associated with both streamgages is National Geodetic Vertical Datum of 1929 (NGV D29); however, for the purposes of this study all water-surface elevations were converted to North American Vertical Datum of 1988 (NAVD 88) using the National Geodetic Survey online VertCon tool (*http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html*).

Steady-flow data consist of flow regime (subcritical), boundary conditions (known water-surface elevations associated with a streamgage rating-curve and FIS water-surface profile slopes), and peak-discharge information. The steady-flow data for the study reach were obtained from previous studies and field measurements of streamflow at the West Branch Susquehanna River at Lewisburg streamgage. At the streamgage, all computations using discharge values with known stages from actual streamflow measurements or stage-discharge relations were used. The downstream boundary condition was established using the current stage-discharge relation (rating number 11.1) at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., in combination with the slopes of water-surface elevation (WSEL) profiles from the Northumberland and Union County FISs between the location of the streamgage and the furthest downstream modeled cross section (approximately 6 miles). The FIS discharge estimates and corresponding WSEL profile slopes for the 10-, 2-, 1-, and 0.2-percent annual chance flood events between the cross section located near the streamgage and the furthest downstream modeled cross section are listed in table 3.

With the information provided in table 3 in conjunction with the stage-discharge relation (rating number 11.1) at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., WSEL slopes were interpolated and (or) extrapolated on the basis of the hydrology. For example, the associated discharge based on the most recent stage-discharge rating (rating number 11.1) for 26.0 ft is 209,500 ft^3/s. Using the information provided in table 3, a WSEL slope was estimated to be 0.000287 ft/ft. This slope was then used to estimate a starting water-surface elevation at the furthest downstream modeled cross section, which is approximately 6 miles downstream from the streamgage (and approximately 1.5 miles upstream from the confluence of the West Branch and main stem Susquehanna Rivers).

A longitudinal water-surface profile was constructed from high-water marks obtained throughout the study reach for the flood on December 2, 2010, and was used for model calibration. Flood water reached a peak recorded stage at the USGS streamgage 01553240, West Branch Susquehanna River at West Milton, Pa., of 22.76 ft (gage datum), which exceeded the flood category "moderate flood stage" established by NWS at 22 ft. The peak recorded stage at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., was 20.90 ft (gage datum), which was between the flood categories "flood stage" and "moderate flood stage" established by NWS at 18 and 23 ft, respectively. High-water marks (HWMs) were flagged and geo-referenced using hand-held global positioning system (GPS) units along the left and right banks at edge of water on the afternoon of December 2, 2010,

Table 3. Estimated 10-, 2-, 1-, and 0.2-percent annual exceedance probability flood-insurance study discharges and water-surface-elevation profile slopes on the West Branch Susquehanna River between U.S. Geological Survey streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pennsylvania, and furthest downstream modeled cross section.

[ft, feet; ft^3/s, cubic feet per second; AEP, annual exceedance probability; WSEL, water-surface elevation; FIS, Flood Insurance Study]

	10-Percent AEP	2-Percent AEP	1-Percent AEP	0.2-Percent AEP
FIS discharge (ft^3/s)	185,000	275,000	319,000	500,000
WSEL slope (ft/ft)	0.000295	0.000264	0.000215	0.000197

hours before the river crested. Digital pictures were taken during the HWM flagging effort, capturing the HWM in addition to the state of river flooding at various locations throughout the reach. The pictures were useful for comparison purposes once the flood-inundation maps were developed. The HWMs were later surveyed using real-time kinematic global positioning system (RTK-GPS) survey equipment to determine elevations (NAVD 88 datum).

Topographic and Bathymetric Data

The existing FIS HEC-2 hydraulic model for the study reach was obtained from the SRBC, the clearinghouse for FISs performed in the 1970s. Additionally, the digital flood insurance rate maps (DFIRMs) and FISs for Union (Federal Emergency Management Agency, 2007) and Northumberland (Federal Emergency Management Agency, 2008) Counties were uploaded from the FEMA Map Service Center Web site (*http://www.msc.fema.gov*). Electronic files identifying geo-referenced FIS cross sections were included in the data upload and were incorporated into a GIS to evaluate location and orientation of the cross sections within the study reach. The HEC-2 hydraulic model was imported into HEC-RAS and was evaluated using the DFIRM and FIS data to confirm cross-section spacing and associated streambed elevations. Field reconnaissance and surveying were performed to verify the existence of the two railroad bridges within the study reach and the accuracy of the cross-sectional topography included in the HEC-2 model. As-built structural and dimensional bridge drawings were obtained from the Pennsylvania Department of Transportation (PennDOT) for the two vehicular bridges (SR45 and SR642) within the study reach that were replaced in the mid-to-late 1980s (subsequent to the FIS). Information obtained from field surveys and drawings was used to update the structures for inclusion in the hydraulic model.

On the basis of the spacing of cross sections in the FIS model over the entire study reach, it was decided that the overall robustness of the model would benefit from additional cross sections. It was determined that data obtained using two methods—field survey or light detection and ranging (lidar)—could be employed to best accomplish this task. As a check of the relative accuracy of these two potential sources of cross-sectional topography, a randomly selected FIS cross section was cut from the lidar data and field surveyed. A subsequent comparison of the existing FIS model data, lidar-cut data, and field-surveyed data for the selected cross section yielded comparable results. On the basis of this analysis, it was decided to cut cross sections from the lidar data for the entire study reach, not just for supplemental cross sections, and to replace existing cross-section data. This procedure effectively doubled the number of cross sections that was used for the FIS within the study reach. The use of lidar-based topography for the entire study reach had the benefit of being more efficient than field surveying, as well as being geo-referenced, which allowed for the use of Hec-GeoRAS software (U.S. Army Corps of Engineers, 2009) for cutting of the cross sections. HEC–GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS by using a graphical user interface (Whitehead and Ostheimer, 2009).

The lidar data were collected and processed under the PAMAP (2006) Program by the Pennsylvania Department of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey. Digital elevation data for the parts of the cross sections that were above the water surface at the time of the study have an associated vertical accuracy meeting the requirements of the 1998 National Standard for Spatial Data Accuracy (NSSDA) at the 95-percent confidence interval [1.96 x root-mean square error (RMSE)] and a horizontal resolution not to exceed a maximum of 5.0 ft (PAMAP, 2006). A detailed description of the methods used to acquire and process the topographic data can be found in Bales and others (2007). A consideration associated with the utilization of lidar-derived topography is the lack of detailed stream-channel data. To account for this, a trapezoidal channel was added to each of the lidar-cut cross sections incorporating channel-bed elevations obtained from the FIS model (interpolating elevation data where necessary).

Energy Loss Factors

Manning's roughness coefficients ("n" values), contraction/expansion coefficients, and ineffective flow areas within the HEC-RAS hydraulic model were assigned on the basis of existing field conditions and engineering judgment. Previous studies, field observations, and high-resolution aerial photographs were used to select initial (pre-calibration) Manning's n values for energy (friction) loss calculations. The final Manning's n values used ranged from 0.026 to 0.13 for the main channel (with the higher values attributed to the large vegetated islands within the main channel) and 0.04 to 0.20 for the overbank areas (with the higher values assigned to cross sections that extended into communities with residential and commercial structures).

Model Calibration and Performance

The hydraulic model was calibrated to the most current stage-discharge relation (rating number 11.1) at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa.; the water-surface profile from the December 2, 2010, flood event; and the recorded peak gage heights at the Lewisburg and West Milton streamgages from the flood on September 19, 2004 (the largest flood to occur since the establishment of the West Milton streamgage). Historic peak gage heights from major floods prior to the establishment of the West Milton streamgage (1994) also were considered in the calibration efforts but were not weighted as heavily due to the uncertainty associated with the data (location and elevation). The peak discharge associated with the flood occurring on December 2, 2010, at the West Branch Susquehanna River at Lewisburg streamgage was approximately 142,000 ft^3/s (at a corresponding stage of 20.9 ft); however, a discharge value of 138,000 ft^3/s was used for modeling purposes because the flagging occurred several hours prior to the recorded peak stage. Observed water-surface elevations at HEC-RAS modeled cross-sections were determined from the point of intersection of a cross section and the longitudinal water-surface profile associated with the December 2, 2010, flood. The peak discharge associated with the September 19, 2004, flood was 209,000 ft^3/s at recorded peak stages of 25.96 ft at the Lewisburg streamgage and 27.94 ft at the West Milton streamgage. Model calibration was accomplished by adjusting Manning's n values and, in some cases, adjusting the ineffective flow areas associated with a channel cross section until the results of the hydraulic computations generally agreed with the observed discharge and stage values. Differences between observed and modeled water levels for specified flows relating to the current stage-discharge rating (rating number 11.1) at the West Branch Susquehanna River at Lewisburg (station 01553500) were generally less than or equal to 0.5 ft, with an average of -0.12 ft. The highest differences (+/- 0.6 ft) are associated with the 14-, 29-, and 30-ft stages (table 4). The range of differences associated with different stages indicates the model has varying degrees of accuracy throughout the range of modeled flows. Consequently, there is a lower confidence in the accuracy of flood-inundation maps for stages that have comparatively greater differences between modeled and observed water-surface elevations. As suggested by Kelly and Rydlund (2006), evaluation of flood-inundation maps for values of stage both greater and less than the stage of interest is recommended. Differences between observed and modeled water levels for the December 2, 2010, flood profile ranged from -0.4 to +0.3 ft throughout the study reach (table 5). The differences between modeled WSEL and recorded peak gage height for the September 19, 2004, flood at the Lewisburg and West Milton streamgages were -0.2 ft and +0.2 ft, respectively.

Development of Water-Surface Profiles

Profiles were developed for 26 stages at 1-ft intervals from 14 ft to 39 ft, as referenced to the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., which include river stages described in the NWS flood impact statement (for example, Action Stage, 14 ft; Flood Stage, 18 ft; Moderate Flood Stage, 23 ft; Major Flood Stage, 28 ft). Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating number 11.1).

Consistent with the FIS, there are no major tributaries that would require either an increase or decrease in percentage contribution to total flow at locations throughout the study reach. Consequently, discharges remained constant for each profile (table 4) throughout the approximate 8-mile study reach.

Table 4. Calibration of model to observed water-surface elevations associated with the current stage-discharge rating (rating number 11.1) at U.S. Geological Survey streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pennsylvania.

[ft, feet; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic feet per second]

Stage (ft)	Discharge (ft^3/s)	Observed water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Difference between modeled and observed water-surface elevations (ft)
14.0	70,500	441.5	442.1	+0.6
15.0	79,500	442.5	443	+0.5
16.0	89,000	443.5	443.9	+0.4
17.0	99,000	444.5	444.8	+0.3
18.0	109,000	445.5	445.8	+0.3
19.0	120,000	446.5	446.7	+0.2
20.0	132,000	447.5	447.6	+0.1
21.0	144,000	448.5	448.5	0.0
22.0	156,000	449.5	449.5	0.0
23.0	169,000	450.5	450.4	-0.1
24.0	182,000	451.5	451.2	-0.3
25.0	196,000	452.5	452.1	-0.4
26.0	210,000	453.5	453.2	-0.3
27.0	224,000	454.5	454.1	-0.4
28.0	239,000	455.5	455	-0.5
29.0	254,000	456.5	455.9	-0.6
30.0	270,000	457.5	456.9	-0.6
31.0	286,000	458.5	458	-0.5
32.0	303,000	459.5	459.1	-0.4
33.0	320,000	460.5	460.2	-0.3
34.0	330,000	461.5	461.3	-0.2
35.0	356,000	462.5	462.3	-0.2
36.0	374,000	463.5	463.3	-0.2
37.0	393,000	464.5	464.3	-0.2
38.0	412,000	465.5	465.3	-0.2
39.0	432,000	466.5	466.4	-0.1

Table 5. Comparison of observed and modeled water-surface elevations associated with the December 2, 2010, flood on West Branch Susquehanna River near the Boroughs of Lewisburg and Milton, Pennsylvania.

[ft, feet; NAVD 88, North American Vertical Datum of 1988]

HEC-RAS modeled river station (ft)	Observed water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Difference between modeled and observed water-surface elevation (ft)
23,724[1]	444.8	444.7	-0.1
25,406	445.4	445.4	0.0
26,756	445.9	446	+0.1
28,287	446.5	446.6	+0.1
29,706	447	446.9	-0.1
31,128	447.5	447.4	-0.1
32,059	447.8	447.5	-0.3
32,633	448	447.6	-0.4
33,080[2]	448.2	448.1	-0.1
33,140		State Route 45	
33,248	448.2	448.2	0.0
33,354	448.3	448.2	-0.1
33,463	448.3	448.4	+0.1
33,485		Railroad bridge near Lewisburg	
33,965	448.5	448.8	+0.3
34,696	448.7	449	+0.3
36,234	449.2	449.1	-0.1
37,976	449.7	449.8	+0.1
39,479	450.2	450.2	0.0
40,854	450.6	450.7	+0.1
42,342	451.2	451.3	+0.1
43,732	451.8	452	+0.2
45,171	452.4	452.6	+0.2
46,613	453	453	0.0
47,317	453.3	453.1	-0.2
48,157	453.7	453.6	-0.1
49,002	454	454.2	+0.2
49,862	454.4	454.7	+0.3
50,502	454.8	455	+0.2
50,802	454.9	455	+0.1

Table 5. Comparison of observed and modeled water-surface elevations associated with the December 2, 2010, flood on West Branch Susquehanna River near the Boroughs of Lewisburg and Milton, Pennsylvania.—Continued

[ft, feet; NAVD 88, North American Vertical Datum of 1988]

HEC-RAS modeled river station (ft)	Observed water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Difference between modeled and observed water-surface elevation (ft)
50,825		Railroad bridge near Milton	
51,216	455.1	455.3	+0.2
51,612	455.3	455.5	+0.2
52,117	455.5	455.6	+0.1
52,505	455.7	455.8	+0.1
52,560		State Route 642	
52,967[3]	455.8	456.1	+0.3
53,735	456.1	456.4	+0.3
54,731	456.4	456.6	+0.2
55,875	456.8	456.9	+0.1
57,172	457.2	457.1	-0.1
58,267	457.6	457.7	+0.1
59,402[4]	458.1	458.3	+0.2

[1]River station 23,724 corresponds to a location approximately 0.8 miles upstream from the downstream limit of the flood-inundation map study reach.

[2]River station 33,080 corresponds to the approximate location of U.S. Geological Survey (USGS) streamgage 01553500.

[3]River station 52,967 corresponds to the approximate location of USGS streamgage 01553240.

[4]River station 59,402 corresponds to a location approximately 0.6 miles downstream from the upstream limit of the flood-inundation map study reach.

Inundation Mapping

Flood-inundation maps were created for the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., which is a NWS flood-forecast point. The maps encompass an approximate 8-mile reach that extends from approximately 2 miles downstream from the Borough of Lewisburg to approximately 1 mile upstream from the Borough of Milton. The maps were created in a GIS by combining the water-surface profiles and lidar-derived digital elevation model (DEM) data. The GIS processing techniques used to develop the inundation polygons for the flood elevations at stages 14 ft through 39 ft are documented in Roland and Hoffman (2010). The maps show estimated flood-inundated areas overlaid on high-resolution, geo-referenced, aerial photographs of the study area for each of the water-surface profiles that was generated by the hydraulic model.

West Branch Susquehanna River, Pennsylvania, Flood-Inundation Maps on the Internet

The current study documentation is available online at the USGS Publications Warehouse (*http://dx.doi.org/10.3133/sir20145094*). Also, a Flood Inundation Mapping Science Web site has been established at *http://water.usgs.gov/osw/flood_inundation/* to provide a portal so that the general public can obtain USGS flood-inundation study information. That Web portal has a Mapper link to interactive online map libraries that can be downloaded in several commonly used electronic file formats. A screen capture from this Web site depicting inundated areas within the study reach associated with a stage of 39.00 ft at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., streamgage is shown in figure 2. At the map library site, each stream reach displayed contains further links to NWISWeb graphs of the current stage

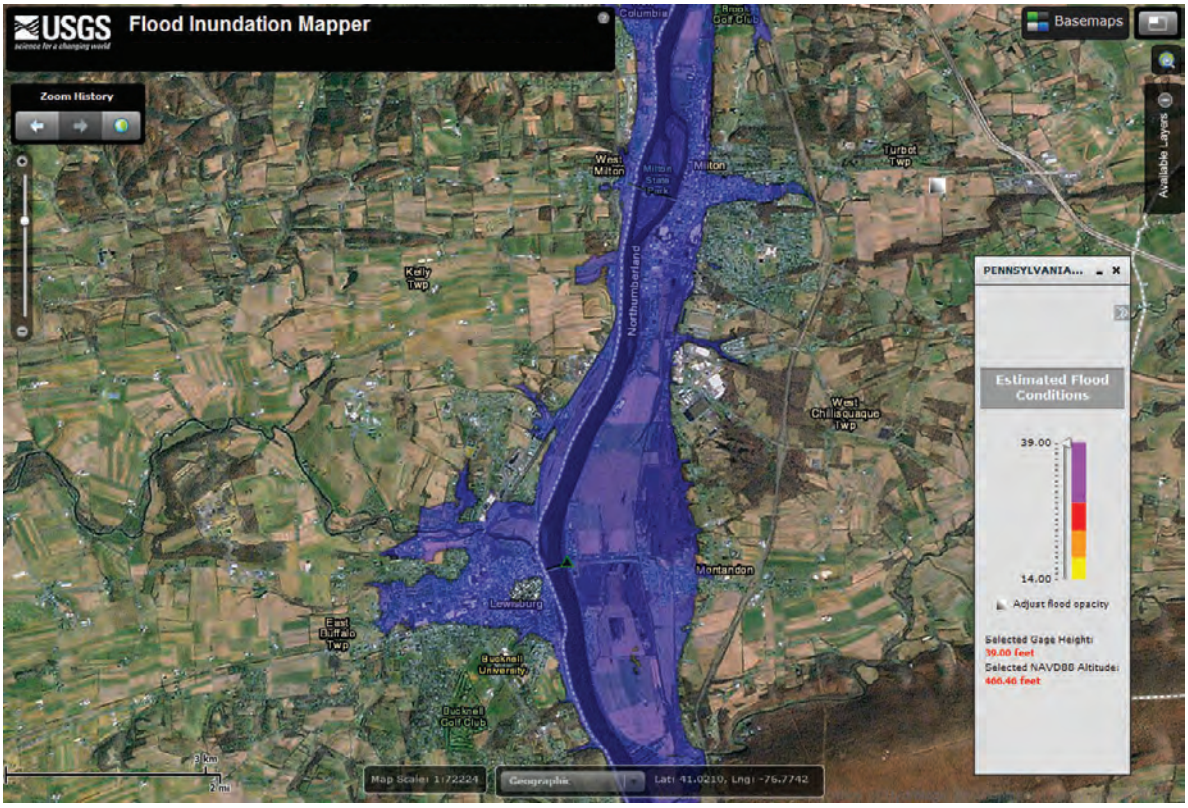

Figure 2. Screen capture from the U.S. Geological Survey Flood Inundation Mapper Web site depicting inundated areas within the study reach associated with a stage of 39.00 feet at the U.S. Geological Survey streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pennsylvania.

and streamflow at USGS streamgages to which the inundation maps are referenced. A link also is provided to the NWS AHPS site (*http://water.weather.gov/ahps/*) so that the user can obtain applicable information on forecasted peak stage. The inundation maps for this study can also be accessed at the SRBC SIMV Web site (*http://maps.srbc.net/simv/*).

Within the USGS map viewer, the flood-inundation maps are displayed in sufficient detail to note the extent of flooding with respect to individual structures so that preparations for flooding and decisions for emergency response can be performed efficiently. Roadways and bridges were closely reviewed and are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. However, buildings that are shaded do not reflect inundation but denote that bare-earth surfaces in the vicinity of the buildings are inundated. When the water depth (as indicated in the Web Mapping Application by holding the cursor over an inundated area) adjacent to the building of interest exceeds that building's height, the structure can be considered fully submerged.

Disclaimer for Flood-Inundation Maps

Inundated areas shown are not meant to be used for navigation, regulatory, permitting, or other legal purposes. The USGS provides these maps "as-is" for a quick reference, emergency planning tool but assumes no legal liability or responsibility resulting from the use of this information.

Uncertainties and Limitations Regarding Use of Flood-Inundation Maps

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, some uncertainty is associated with these maps. The flood boundaries were established on the basis of water stages and streamflows at the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa., streamgage. Measurements of discharge typically are within plus or minus 5 percent of the actual discharge. Water-surface elevations along the stream reaches

were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at the USGS streamgage. As discussed by Kelly and Rydlund (2006), hydraulic models are approximations of actual streamflow, and simulated discharge and stage typically deviate from reality.

The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of September 2012. Unique meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded as a result of unanticipated conditions such as changes in the streambed elevation or roughness, backwater into major tributaries along a main stem river, or backwater from localized debris or ice jams. The accuracy of the inundation extent portrayed on these maps will vary with the accuracy of the DEM used to simulate the land surface. Additional uncertainties and limitations pertinent to this study may be described elsewhere in this report.

The flood-inundation maps are meant to be used in conjunction with NWS river forecasts; however, there are uncertainties inherent in NWS forecast products. The NWS uses mathematical forecast models to predict the quantity and timing of water flowing through selected stream reaches in the United States. Mathematical models are rarely able to predict physical reality with 100 percent certainty. These forecast models (1) establish the amount of runoff generated by precipitation and snowmelt, (2) simulate the movement of floodwater as it proceeds downstream, and (3) predict the flow and stage (and water-surface elevation) for the stream at a given location (AHPS forecast point) throughout the forecast period (every 6 hours and 3 to 5 days out in many locations). For more information on AHPS forecasts, please see *http://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf*.

Taking these potential uncertainties into consideration, Kelly and Rydlund (2006) note that errors and variations in data rarely occur in only one direction; rather, a combination of errors and uncertainties of varying value and sign is more likely to occur. However, to account for these uncertainties, it is recommended to evaluate not only the flood-inundation map for the stage of interest, but also the maps associated with stages of less than and greater than the stage of interest (Kelly and Rydlund, 2006).

Estimation of Potential Losses Due to Flooding

The static flood-inundation maps provide information relative to the depth and areal extent of flooding. These data can be incorporated into a methodology that has been developed by FEMA (2013a) to estimate the potential losses associated with the inundated areas as defined by the maps. This methodology involves the application of Hazus Multi-Hazard (Hazus-MH) software (Federal Emergency Management Agency, 2013b). Government planners, GIS specialists, and emergency managers use Hazus-MH to determine losses and the most beneficial mitigation approaches to take to minimize them (Federal Emergency Management Agency, 2013a).

As presented by Hearn and others (2013), Hazus-MH analyses are categorized according to the spatial resolution of the input data and the equations (loss functions) used in calculating loss and damage extents. A Level 1 estimate of flood loss can be performed using the national databases and analysis parameters included in the Hazus-MH software. A more accurate Level 2 estimate is produced by using more accurate maps of flood extent and (or) replacing the default asset inventories with more detailed local inventories of buildings, essential facilities, and other structures. The most accurate Level 3 estimates include all the improvements of a Level 2 estimate together with expert input from hydrologists or engineers to revise the analysis parameters (Federal Emergency Management Agency, 2013c).

Although Hazus-MH is able to generate reliable assessments of flood risk, its usefulness is limited because it can be run only on a workstation by a trained operator and analyses are not adapted for convenient delivery over the Internet (Hearn and others, 2013). In 2010, the USGS and FEMA began an effort to provide a solution to this problem by integrating Hazus-MH flood risk analyses with the USGS produced flood-inundation maps and making these data available on the Web (Hearn and others, 2013). To this end, a Hazus-MH Level 1 analysis was performed for each of the 26 flood-inundation maps associated with the USGS streamgage 01553500, West Branch Susquehanna River at Lewisburg, Pa. Information relative to the functionality of the Hazus-MH as it relates specifically to the USGS flood-inundation map portal can be accessed online at *http://water.usgs.gov/osw/flood_inundation/toolbox/hazus.html*.

Summary

Flood-inundation maps were developed in cooperation with the Susquehanna River Basin Commission (SRBC) for an approximate 8-mile reach of the West Branch Susquehanna River approximately 2 miles downstream from the Borough of Lewisburg and extending upstream to approximately 1 mile upstream from the Borough of Milton. These maps, in conjunction with the real-time stage data from the U.S. Geological Survey (USGS) streamgage at West Branch Susquehanna River at Lewisburg, Pennsylvania (station 01553500), and National Weather Service flood-stage forecasts, will help to guide the general public in taking individual safety precautions and will provide local officials with a tool to efficiently manage emergency flood operations and flood mitigation efforts.

The maps were developed by using the U.S. Army Corps of Engineers' HEC–RAS and HEC–GeoRAS programs, in addition to geographic information system tools, to compute water-surface profiles and delineate estimated flood-inundation

areas for selected stream stages. The maps show estimated (shaded) flood-inundation areas overlaid on high-resolution, geo-referenced aerial photographs of the study area for stream stages of 14 feet (ft) to 39 ft in 1-ft increments at the West Branch Susquehanna River at Lewisburg streamgage. The maps can be accessed through the USGS Flood Inundation Mapping Science Web site at *http://water.usgs.gov/osw/flood_inundation/*, as well as the SRBC SIMV Web site *http://maps.srbc.net/simv/*. Interactive use of the maps can give users a general indication of depth of water at any point within the shaded areas.

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