Prepared in cooperation with the Muskingum Watershed Conservancy District and the City of Marietta, Ohio

Flood-Inundation Maps and Updated Components for a Flood-Warning System for the City of Marietta, Ohio and Selected Communities along the Lower Muskingum River and Ohio River

Scientific Investigations Report 2014–5195

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

Cover: Looking northwest at Lock and Dam Number 6 and the State Route 266 (Broadway Street) bridge over the Muskingum River at Stockport, Ohio. Photo taken by US Geological Survey, September 2012.

Flood-Inundation Maps and Updated Components for a Flood-Warning System for the City of Marietta, Ohio and Selected Communities along the Lower Muskingum River and Ohio River

By Matthew T. Whitehead and Chad J. Ostheimer

Prepared in cooperation with the Muskingum Watershed Conservancy District and the City of Marietta, Ohio

Scientific Investigations Report 2014–5195

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

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Whitehead, M.T., and Ostheimer, C.J., 2014, Flood-inundation maps and updated components for a flood-warning system for the City of Marietta, Ohio and selected communities along the Lower Muskingum River and Ohio River: U.S. Geological Survey Scientific Investigations Report 2014–5195, 16 p., *http://dx.doi.org/10.3133/sir20145195*.

ISSN 2328-0328 (online)

Contents

Figures

Tables

Conversion Factors, Vertical Datum, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in)	0.0833	foot (ft)
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
kilometer (km)	0.6214	mile (mi)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

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

Flood-Inundation Maps and Updated Components for a Flood-Warning System for the City of Marietta, Ohio and Selected Communities along the Lower Muskingum River and Ohio River

By Matthew T. Whitehead and Chad J. Ostheimer

Abstract

Digital flood-inundation maps for lower reaches of the Muskingum River and a reach of the Ohio River in southeast Ohio were created by the U.S. Geological Survey (USGS), in cooperation with the Muskingum Watershed Conservancy District and the City of Marietta, Ohio. To complete the inundation maps, Ohio River and lower Muskingum River bathymetry was updated and two streamgages, one on the Ohio River upstream of Marietta near Sardis, Ohio, and one on the Muskingum River in Beverly, Ohio, were added as basic components of the flood-warning system. An updated hydraulic model component also led to the new flood-inundation maps. The maps, which can be accessed through the USGS Flood Inundation Mapping Science Web site at *http://water.usgs.gov/osw/flood_inundation/,* depict estimates of the areal extent of flooding corresponding to water levels (stages) at one or more of the following USGS streamgages: Muskingum River at McConnelsville, Ohio (03150000); Muskingum River at Beverly, Ohio (03150500); and Ohio River at Marietta, Ohio (03150700). The maps can be used in conjunction with National Weather Service flood-forecast data to show areas of estimated flood inundation associated with forecasted flood-peak stages.

Flood profiles for selected reaches were prepared by calibrating steady-state step-backwater models to selected streamgage rating curves. The step-backwater models were used to determine water-surface-elevation profiles for up to 12 flood stages at a streamgage with corresponding streamflows ranging from approximately the 10- to 0.2-percent chance annual-exceedance probabilities for each of the 3 streamgages that correspond to the flood-inundation maps. Additional hydraulic modeling was used to account for the effects of backwater from the Ohio River on water levels in the Muskingum River. The computed longitudinal profiles of flood levels were used with a Geographic Information System digital elevation model (derived from light detection and ranging) to delineate flood-inundation areas. Digital maps showing flood-inundation areas overlain on digital orthophotographs were prepared for the selected floods.

Introduction

Marietta, Ohio was established in 1788 at the confluence of the Ohio and Muskingum Rivers and has been affected by flooding from both rivers since its origins. Ohio River flooding in Marietta has been well documented with two of the most severe floods occurring in March 1913 and January 1937, with peak-flood stages[1] recorded at 58.30 and 55.00 feet (ft), respectively (National Weather Service [NWS], 2012). More recently, Marietta experienced significant flooding in September 2004 and January 2005, when peak-flood stages at the U.S. Geological Survey (USGS) streamgage on the Ohio River at Marietta (USGS streamgage number 03150700) reached 44.97 and 43.60 ft, respectively. These floods inundated hundreds of homes and businesses and severely impacted Marietta. The NWS has established flood-severity categories and considers flood stages at, or above, 40 ft at Marietta as “major” (indicating extensive inundation and property damage and characterized by the evacuation of people and livestock and the closure of both primary and secondary roads). Since 1913, 7 Ohio River floods have met or exceeded a stage of 40 ft.

Flood Forecasting and Predicting Peak Flood Stage

The NWS has statutory responsibility for hydrologic forecasts throughout the nation. Peak-stage forecasts are based partly on data from a network of precipitation gages and streamgages. In Ohio, the hydrologic forecasts originate with either the NWS Ohio River Forecast Center (OHRFC) in Wilmington, Ohio or the NWS North Central Forecast Center in Chanhassen, Minnesota. Flood warnings for Ohio are issued to the public by regional NWS offices in Wilmington, Ohio, Cleveland, Ohio, Charleston, West Virginia, Pittsburgh, Pennsylvania, or Syracuse, Indiana. For Marietta and communities

[1] Stage refers to a stream’s height above a reference point. Stage, together with a reference datum, can be used to determine water-surface elevation.

along the lower Muskingum River, the hydrologic forecasts originate with the OHRFC and flood warnings are issued by the Charleston, West Virginia office of the NWS.

The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. These forecast models (1) estimate 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 (Advanced Hydrologic Prediction Service [AHPS] forecast point) throughout the forecast period (every 6 hours and 3 to 5 days in the future for many locations). For more information on AHPS forecasts, please see: *http://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf*.

Flood-prone communities can benefit from advanced predictions of peak flood stage; however, predicted flood stage is an abstract concept that becomes meaningful only when understood in terms of areas that will be inundated by flood waters. By using USGS streamgage data along with hydraulic modeling and digital-elevation data (land surface topography), a library of flood-inundation boundaries can be predetermined for a series of flood stages. The library can be used with NWS predicted flood stages and digital orthophotographs to help visualize expected flood areas well in advance of occurrence of the flood peak. Two Web-based applications that serve predicted flood stages along with a corresponding library of flood boundaries overlain on orthophotographs are available: the AHPS of the NWS at *http://www.nws.noaa.gov/oh/ahps/* and the Flood-Inundation Mapper (FIM) of the USGS at *http://wim.usgs.gov/FIMI/FloodInundationMapper.html*. Inclusion of data pertinent to Marietta and other communities along the lower Muskingum River into FIM and AHPS will help disseminate important and dynamic information to both emergency managers and the public, so they can take preventive measures to minimize flood damages.

Description of the Study Area

The Muskingum River is the largest watershed entirely contained within Ohio and has a contributing drainage area of 8,050 square miles (mi^2; USGS, 2012). The lower Muskingum River, located in Morgan and Washington Counties, drains to the Ohio River through the communities of McConnelsville, Malta, Stockport, Beverly, Waterford, Coal Run, Lowell, Devola, Oak Grove, and Marietta (fig. 1).

Marietta is in Washington County (fig. 1) at the confluence of the Ohio and Muskingum Rivers. The villages of McConnelsville and Malta are in central Morgan County roughly 25 miles (mi) northwest of Marietta, along the Muskingum River. The villages of Stockport, Beverly, Waterford, Coal Run, Lowell, Devola, and Oak Grove are along the Muskingum River between McConnelsville and Marietta. In addition to these communities, many private residences and small commercial properties are within the floodplains of the lower Muskingum River. In 2010, the populations of Morgan and Washington Counties were 15,054 and 61,778, respectively (U.S. Census Bureau, 2012a and 2012b); the population of Marietta was 14,085 (U.S. Census Bureau, 2012c).

Purpose and Scope

Flood-warning systems typically involve many major elements including streamflow and precipitation gage networks, hydrologic and hydraulic modeling, flood-inundation mapping, and various means of disseminating flood-warning information. This report describes a study of components for improving the flood-warning system for selected reaches of Muskingum River and Ohio River in southeast Ohio. The study included the enhancement of the streamgage network, hydraulic modeling, and development of new flood-inundation mapping. A primary goal of this study was to develop tools to provide advanced flood warning for the communities of McConnelsville, Malta, Stockport, Beverly, Waterford, Coal Run, Lowell, Devola, Oak Grove, and Marietta, Ohio.

This report describes (1) the installation of one new streamgage on the Ohio River upstream of Marietta near Sardis, Ohio and (2) one new streamgage on the Muskingum River in Beverly, Ohio, (3) collection of updated bathymetric data for a 75-mi reach of the Ohio River, (4) collection of bathymetric and bridge geometric data for development of a hydraulic model for the Muskingum River, (5) development of flood-inundation boundaries depicting the areal extent of flooding expected to occur for selected stages at selected USGS streamgages based on steady-state[2] model estimates and (6) the flood-inundation boundaries provided to the FIM and NWS for inclusion on their respective Web pages.

[2] Steady-state flow for this report refers to gradually varied steady-state flow in which there may be small variations in flow variables such as area and conveyance with respect to distance but for which all flow variables remain constant with respect to time. Unsteady-state flow refers to gradually varied unsteady-state flow in which there are not only small variations in flow variables with respect to distance but also changes in flow variables with respect to time (Franz and Melching, 1997).

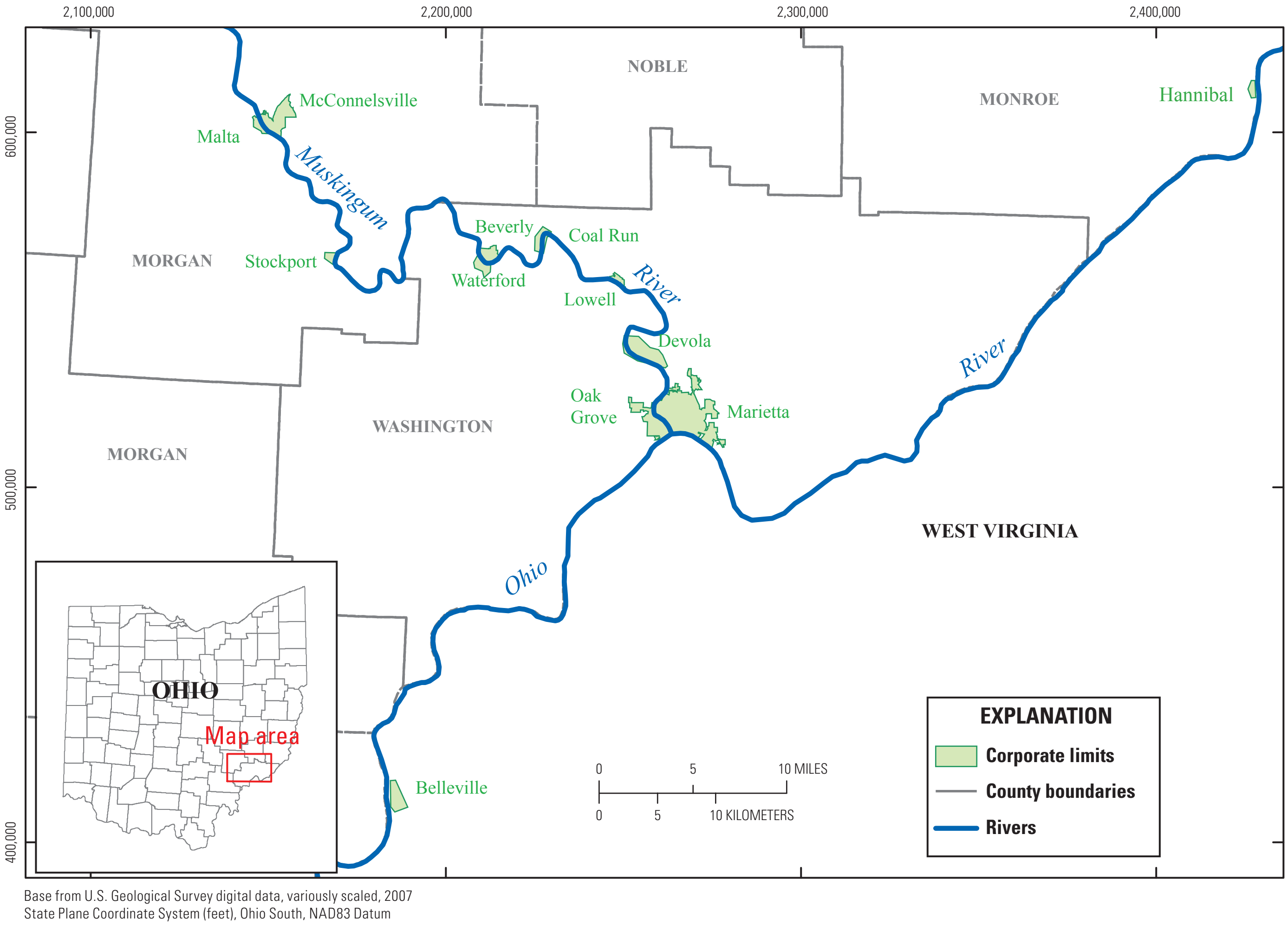


Figure 1. Muskingum and Ohio Rivers and selected communities.

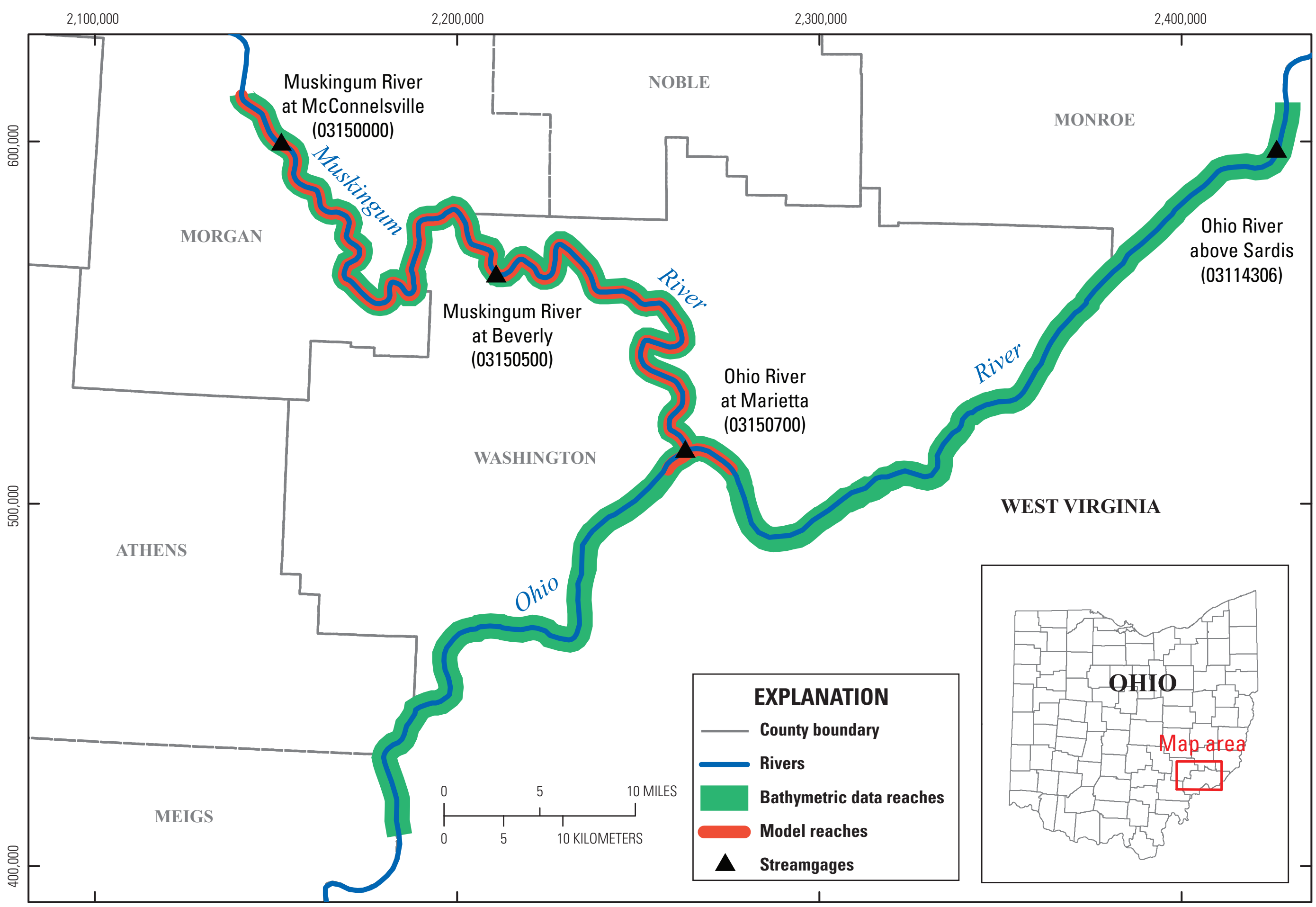
New Streamgages Component

As part of this study, the USGS installed two new streamgages (fig. 2): Ohio River above Sardis (03114306) and Muskingum River at Beverly, Ohio (03150500). The Ohio River above Sardis (03114306) streamgage was installed near the former Lock #15, about 2.7 mi downstream of the Hannibal Lock and Dam (Ohio River mile 126.4). Regular streamflow measurements are now being made at this site to develop an index-velocity rating that relates an index velocity to the mean velocity of the cross section. The USGS will continue to make periodic streamflow measurements to facilitate the computation of continuous streamflow data necessary for accurate flood warnings. Due to the hydraulic characteristics of the Ohio River, especially at lower flows, standard USGS stage-discharge gaging equipment and techniques cannot be used. Therefore, the Sardis site was equipped with an acoustic Doppler current-velocity meter. A stage-area rating and an index-velocity rating are used to compute streamflow at this site.

The USGS Muskingum River at Beverly, Ohio (03150500) streamgage was installed approximately 4 mi downstream from the discontinued streamgage, Muskingum River near Beverly (03150300), which operated from April 1993 to September 1999. It is equipped with a Geostationary Operational Environmental Satellite (GOES) transmitter. Data are transmitted via GOES hourly to facilitate near-real-time monitoring of equipment performance and stage.

Streamflow and stage data from these new streamgages, as well as other USGS streamgages in Ohio, can be accessed by interested parties on the USGS Web-based data portal at *http://waterdata.usgs.gov/oh/nwis/rt* and also are available by email or text alert sent by the USGS WaterAlert program[3] (*http://maps.waterdata.usgs.gov/mapper/wateralert/*). Characteristics of the selected streamgages in the study area are summarized in table 1.

[3] The USGS WaterAlert program is a service that sends e-mail or text messages when certain parameters, as measured by a USGS real-time data collection station, exceed user-definable thresholds.



Base from U.S. Geological Survey digital data, variously scaled, 2007
State Plane Coordinate System (feet), Ohio South, NAD83 Datum

Figure 2. Locations of selected streamgages, and bathymetric and modeling reaches.

Table 1. Summary of characteristics of the selected streamgages in the study area.

[mi², square miles; NWS, National Weather Service; mi², square miles]

Streamgage name	Site number	Drainage area (mi²)	Period of record	NWSforecast point	Comment
Ohio River at Marietta, Ohio	03150700	35,590	2005–present	Yes	
Ohio River above Sardis, Ohio	03114306	26,156	2012–present	No	New site.
Muskingum River at Beverly, Ohio	03150500	7,947	2013–present	Yes[1]	New site.
Muskingum River near Beverly, Ohio	03150300	7,627	1993–99	No	Discontinued.
Muskingum River at McConnelsville, Ohio	03150000	7,422	1921–92 2001–present	Yes	

[1] The NWS plans to forecast peak stage at this location.

River Bathymetry and Structural Geometry Component

An unsteady flow model was developed for the Ohio River through a cooperative effort by the U.S. Army Corps of Engineers (USACE) and the NWS (Debra Lee, USACE Great Lakes and Ohio River Division, and Tom Adams, NWS-Ohio River Forecast Center, verbal communication, 2012). The Ohio River model is currently operational and used on a regular basis by the USACE and NWS. However, the USACE and NWS indicated a need for updated bathymetric data to help improve upon model accuracy.

The USGS collected new bathymetric data (fig. 2) for a 75-mi reach of the Ohio River (from just upstream from the Belleville Lock and Dam upstream to the Hannibal Lock and Dam) and for a 52-mi reach of the lower Muskingum River (from the confluence with the Ohio River to 2 mi upstream from the northern corporate limits of McConnelsville). The bathymetric data were obtained at intervals of approximately every ½ mi on both rivers. For the Ohio River, the bathymetric data were obtained at locations of the cross sections in the hydraulic model obtained from the NWS. Global Positioning System (GPS) surveys were simultaneously conducted to determine water-surface elevations at the time of bathymetric data collection to determine channel bottom elevations.

Bathymetric surveys were made by way of a 19-ft boat with a 2-inch pipe mount that was used to affix the acoustic equipment and software used to collect the bathymetric data. A 210-kilohertz (kHz) Airmar™ transducer and a Navisound™ 210 Reson echo sounder were used for the collection of the depth information. A Trimble™ Differential Global Positioning System (DGPS) was used for horizontal positioning during the survey. The HYPACK™ navigation software package installed on a laptop computer was used to integrate the depths and the DGPS horizontal position data and to display the location of the boat on a georeferenced aerial photo for navigation, and a laser rangefinder computed distance measurements and was used with a compass module, enabling determination of accurate azimuths and delineation of the shoreline.

Raw bathymetric data were processed within HYPACK™ to filter (1) problems related to the echo sounder processing a multiple-return acoustic signal in shallow water, which causes the measured depth to be twice the actual depth; (2) invalid GPS positions; and (3) redundant areas along the banks caused by overlap of data collection at the ends of various cross sections. Analog printouts of the bottom profiles were produced during data collection and used as a quality-assurance measure in bathymetric data processing, because multiple-return errors can be identified in the analog printouts. The data were first reviewed and filtered within HYPACK™ and then were compared to all supporting field notes and analog printouts. The processed bathymetric data (including edge-of-water points) were exported from HYPACK™ into a text file that included geographic coordinates and a corresponding depth.

The bathymetric survey was quality assured by using the echo sounder and a bar-check method. The Navisound™ 210 Reson echo sounder has an accuracy of 0.03 ft at 210 kHz (Reson, Inc., 2005). A built-in bar-check utility enabled depth verification by using a correction for the speed of sound. The USACE suggests performing the bar-check procedure to ensure the adequate calibration of an echo sounder (USACE, 2002b). Bar checks of the echo sounder at multiple depths were conducted by lowering a 2-ft by 4-ft plate to known depths between 5 and 30 ft at 5-ft increments. The echo sounder always reported within plus or minus 0.3 ft of the bar check. The bar-check process was done twice throughout the day, one at the beginning and one at the end, to ensure accurate data collection (Hittle and Ruby, 2008). The survey was completed on calmer days to minimize the effects of wave action on the accuracy of the depth data. The vertical accuracy of the echo sounder was conservatively estimated to be plus or minus 0.5 ft.

Simultaneous to the bathymetric data collection, additional personnel were collecting water surface elevations by using a survey-grade GPS receiver and a real-time network developed by the Ohio Department of Transportation (Ohio Department of Transportation, 2014). Redundant occupations of water-surface elevations and published vertical benchmarks were used to verify GPS elevations and the real-time network accuracy. Data for this effort were collected in the summer of 2012, before USGS Techniques and Methods 11–D1 (Rydlund and Densmore, 2012) was published. The GPS surveys do not meet the specifications for a Real Time Level III survey, as the occupation times were less than the required 180 epochs. A root mean square error analysis of known vertical benchmarks in the study reach indicated an accuracy of the water-surface elevations to be +/- 0.10 ft. The water-surface elevations were used with the bathymetric data to determine channel-bottom elevations.

Hydraulic Structures

Fourteen structures, consisting of 7 road crossings, 1 railroad bridge, and 6 low-head dams, have the potential to affect water-surface elevations during floods along the stream. Bridge-geometry data were obtained from field surveys conducted by personnel from the USGS Ohio Water Science Center. As with the bathymetric data collection, the structure geometries were collected in the summer of 2012, using the same survey-grade GPS and survey techniques. Hydraulic structure surveys and bathymetric data are on file at the USGS office in Columbus, Ohio.

Hydraulic Modeling Component

All hydraulic analyses were done with HEC–RAS version 4.1.0 (USACE, 2010). HEC–RAS is a one-dimensional step-backwater model used to compute water-surface profiles with steady-state or unsteady-state flow computation options. All hydraulic analyses for this report were done with the steady-state flow computation option.

Topographic Data

All topographic data used in this study are referenced vertically to NAVD88 and horizontally to the North American Datum of 1983. Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from light detection and ranging (lidar) data that were collected during March and May of 2007 by Woolpert Inc., Columbus, Ohio. The lidar data have a vertical accuracy of 1.0 ft a 95-percent confidence level for the “open terrain” land-cover category (root mean squared error of 0.5 ft.). By these criteria, the lidar data support production of 2ft contours (Dewberry, 2012); By using HEC–GeoRAS, a set of procedures, tools, and utilities for processing geospatial data in ArcGIS, elevation data were extracted from the DEM for cross sections and subsequently were input to the HEC–RAS model. The grid data from Ohio Geographically Referenced Information Program (Ohio Geographically Referenced Information Program, 2007) was converted into 2-ft contours by USGS personnel.

Hydrologic Data

For the Muskingum River at McConnelsville streamgage (03150000), the stage-discharge relation (rating curve) has undergone only minor revisions over the 83-year history of the gage. For this project, rating number 13 (stages 0.9 ft to 13.8 ft) was the current rating used for calibration of the Muskingum River HEC–RAS model.

For the Muskingum River at Beverly (03150500) location, the rating curve was determined by using the HEC–RAS model developed for the Muskingum River. The rating from the discontinued streamgage Muskingum River near Beverly (03150300) could not be used because the features that control the stage-discharge relation differ between the two sites. As of writing this report (June 2014), 12 streamflow measurements have been made at the Beverly gage (03150500), ranging in stage from 15.39 ft to 26.51ft, and each measurement has agreed with the rating developed with HEC–RAS within the streamflow measurement error.

Revisions to NWS HEC–RAS Model for Ohio River

In-channel data in the HEC–RAS model obtained from the NWS were revised for most of the cross sections within a 75-mi reach of the Ohio River based on USGS bathymetry data. Next, the hydraulic computations for the HEC–RAS model were changed from unsteady flow to steady-state. As a result of this change, a different downstream boundary condition was needed. The downstream boundary condition for the steady-state model was set to be a slope-conveyance (normal-depth) computation with a value of 0.00008 ft/ft estimated from the average streambed slope as determined from field surveys. Lastly, the HEC–RAS model was shortened to include only the area within Marietta (around 4 mi in length). The modeling and mapping study reach of the Ohio River extends from approximately 1.4 mi downstream of the Muskingum River, to 2.6 mi upstream (fig. 2). No other modifications were made to the Ohio River HEC–RAS model obtained from NWS.

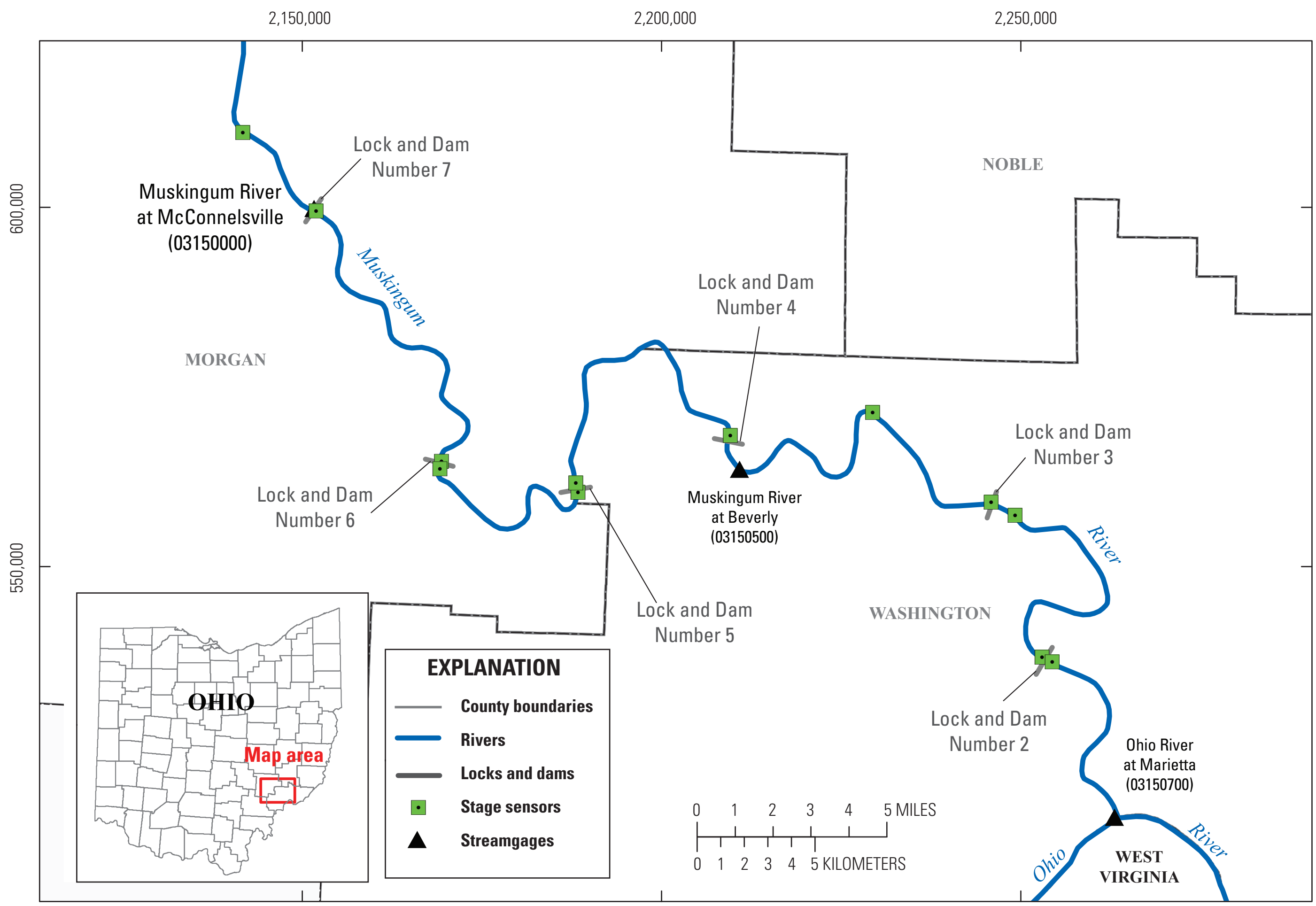
Muskingum River Model Development and Calibration

The Muskingum River HEC–RAS model was constructed as a single reach from the mouth (confluence with Ohio River) upstream to McConnelsville, a reach length of approximately 52 mi. The downstream boundary condition for the Muskingum River HEC–RAS model was also set to be a slope-conveyance (normal-depth) computation with a value of 0.00023 ft/ft estimated from the average streambed slope as determined from the bathymetric data. In-channel data for cross sections where bathymetry data were not collected were approximated by inserting a trapezoidal area. The in-channel areas and bottom elevations were based on the overall shape and average channel-bottom elevation of the bounding bathymetric data.

The model was initially calibrated to the available rating curve for the Muskingum River at McConnelsville (03150000) streamgage and the 13 streamflow measurements made for the Muskingum River at Beverly (03150500) streamgage. For the calibration, Manning's roughness coefficients were adjusted from original field estimates until the results of the hydraulic computations closely agreed with the stage-discharge rating at McConnelsville. Final Manning's roughness coefficients range in value from 0.028 to 0.038 for the main channel and from .046 to 0.150 for the overbanks.

Additional calibration information was obtained by installing stage sensors (pressure transducers) in May 2013 at 12 locations along the modeled reach of the Muskingum River (fig. 3). The stage sensors were located to obtain water-surface elevations (a) just upstream and downstream of each of the locks and dams, (b) in the middle of a reach between lock and dam numbers 3 and 4, and (c) at the upstream modeling limit. Surveys were conducted to establish the vertical datum of each stage sensor relative to the North American Vertical Datum of 1988 (NAVD88). The stage sensor elevations were checked, data were downloaded, and the sensors were cleaned several times during their deployment. The stage sensors were removed in November 2013.

The 12 stage sensor sites plus the two full time streamgages allowed for additional model calibration to measured stage data from several events for numerous locations



Base from U.S. Geological Survey digital data, variously scaled, 2007
State Plane Coordinate System (feet), Ohio South, NAD83 Datum

Figure 3. Locations of locks and dams, streamgages, and stage sensors.

along the 52-mi modeling reach of the Muskingum River. Four flood peaks on June 28, July 11, July 13, and July 24 were recorded during the 6 months of sensor deployment. When the stage sensors were serviced in October 2013, two appeared to be clogged with debris, and it was assumed that the data collected since the previous peak flood event on July 24, 2013, were erroneous (table 2). Discharge values used to calibrate the HEC–RAS model for the four events were obtained directly from the Muskingum River at McConnelsville (03150000) rating curve number 13 and the Muskingum River at Beverly (03150500) rating curve developed for this study. After calibration, the modeled elevations matched the measured elevation data obtained from the sensors (not including the data from the likely clogged sensors) and streamgages on average within 0.14 ft, with a maximum difference of 0.44 ft (table 2).

Hydraulic Model Quality Assurance

As part of the calibration process, model output warnings presented by HEC–RAS were reviewed. The results were assessed for validity, accuracy, and appropriate engineering practices. Some of the areas of concern included: (1) critical water-surface calculations, (2) water-surface elevation differences between adjacent cross-sections, and (3) correct usage of ineffective flow areas. All warnings generated by HEC–RAS were reviewed and judged acceptable. The 1-D HEC–RAS model checklist (USGS, 2014a) was followed to assist in the quality assurance process.

Table 2. Differences in modeled stages and rating curve number 13 for the Muskingum River at McConnelsville (03150000) streamgage.

[ft^3/s, cubic feet per second; ft, feet]

Streamflow from rating number 13 used in HEC–RAS model (ft^3/s)	Stage from rating (ft)	Stage from model (ft)	Difference from rating (ft)
18,650	7.00	6.96	-0.04
24,000	8.00	8.03	0.03
29,300	9.00	9.00	0.00
35,000	10.00	10.00	0.00
41,300	11.00	10.99	-0.01
47,900	12.00	12.00	0.00
54,800	13.00	12.99	-0.01
60,600	13.80	13.77	-0.03

Table 3. HEC–RAS model results compared to stage data collected for four flood events on the Muskingum River.

[All elevation data are shown in feet above the North American Vertical Datum of 1988. Bolded values indicate data that are likely in error due to clogged sensors and are thus assumed incorrect. River mile refers to miles above the mouth of the Muskingum River. Delta refers to the difference in elevation between the model results and the measured data]

		Flood event											
		June 28, 2013			July 11, 2013			July 13, 2013			July 24, 2013		
Stage measurement device	River mile	Model elevation	Measured elevation	Delta	Model elevation	Measured elevation	Delta	Model elevation	Measured elevation	Delta	Model elevation	Measured elevation	Delta
Stage sensor	5.5	590.47	590.34	0.13	596.33	596.11	0.22	591.84	591.96	-0.12	593.83	593.39	0.44
Stage sensor	13.4	601.11	601.24	-0.13	606.26	606.67	-0.41	602.94	603.07	-0.13	606.13	606.13	0.00
Stage sensor	14.1	610.79	610.68	0.11	612.53	612.43	0.10	611.40	611.35	0.05	612.50	612.35	0.15
Stage sensor	18.5	612.30	612.06	0.24	615.64	615.64	0.00	613.46	613.40	0.06	615.59	615.55	0.04
Beverly streamgage	24.1	615.78	615.75	0.03	620.92	620.91	0.01	617.65	617.61	0.04	620.85	620.85	0.00
Stage sensor	25.1	621.49	621.42	0.07	623.37	623.46	-0.09	622.56	622.43	0.13	**623.21**	**623.97**	**-0.76**
Stage sensor	33.7	626.06	625.70	0.36	629.24	629.53	-0.29	628.21	628.01	0.20	**628.77**	**629.81**	**-1.04**
Stage sensor	34.0	631.67	631.73	-0.06	633.02	633.15	-0.13	632.59	632.64	-0.05	632.78	632.91	-0.13
Stage sensor	39.7	635.40	635.28	0.12	638.13	638.22	-0.09	637.31	637.25	0.06	637.67	637.75	-0.08
Stage sensor	40.0	643.74	643.89	-0.15	645.09	645.44	-0.35	644.70	644.91	-0.21	644.87	645.14	-0.27
Stage sensor	49.2	648.74	648.67	0.07	651.77	652.17	-0.40	650.88	651.07	-0.19	651.27	651.54	-0.27
McConnelsville streamgage	49.3	657.19	657.19	0.00	658.98	659.11	-0.13	658.44	658.51	-0.07	658.68	658.78	-0.10
Stage sensor	52.2	658.07	657.77	0.30	660.30	660.36	-0.06	659.64	659.58	0.06	659.93	659.94	-0.01

Muskingum River Mapping Reaches

After calibration, the hydraulic modeling of the Muskingum River focused on two distinct reaches (fig. 4). Mapping Reach 1 extends from the mouth of the Muskingum River upstream through Lock and Dam Number 4 in Beverly and is approximately 26 mi in length. Mapping Reach 2 extends from 2.1 mi downstream from Lock and Dam Number 6 near Stockport upstream to 3.4 mi upstream from Lock and Dam Number 7 in McConnelsville and is approximately 14 mi in length.

For each Mapping Reach, a single discharge value was used (that is, discharge was not varied along the reach). This use of a single discharge was justified due to the small difference in drainage areas between the top and bottom of each reach (table 4). Discharge values from rating number 13 of the Muskingum River at McConnelsville (03150000) streamgage were used for Mapping Reach 2, and discharge values from the rating curve developed for this study for Muskingum River at Beverly (03150500) were used as for Mapping Reach 1.

Determination of Discharges for Water-Surface Profiles

For the Ohio River and Mapping Reach 1of the Muskingum River, streamflows corresponding to the selected even-foot stage values were determined by use of an iterative process wherein the streamflows were varied in the HEC–RAS model until the modeled stages (elevations) equaled the target stages (table 5). Eleven water-surface profiles were generated for the Ohio River, and 12 profiles were generated for Muskingum Mapping Reach 1. The range in discharge values extends from approximately the 10-percent annual exceedance to the 0.2-percent annual exceedance probabilities. For Reach 2 of the Muskingum River, 12 streamflows corresponding to the desired even-foot stage values (table 5) were taken from rating 13 for McConnelsville. These discharge values also extend from approximately the 10-percent annual exceedance to the 0.2-percent annual exceedance probabilities. Stages above 13.0 ft for the Muskingum River at McConnelsville, Ohio (03150000) are outside the range of rating 13.

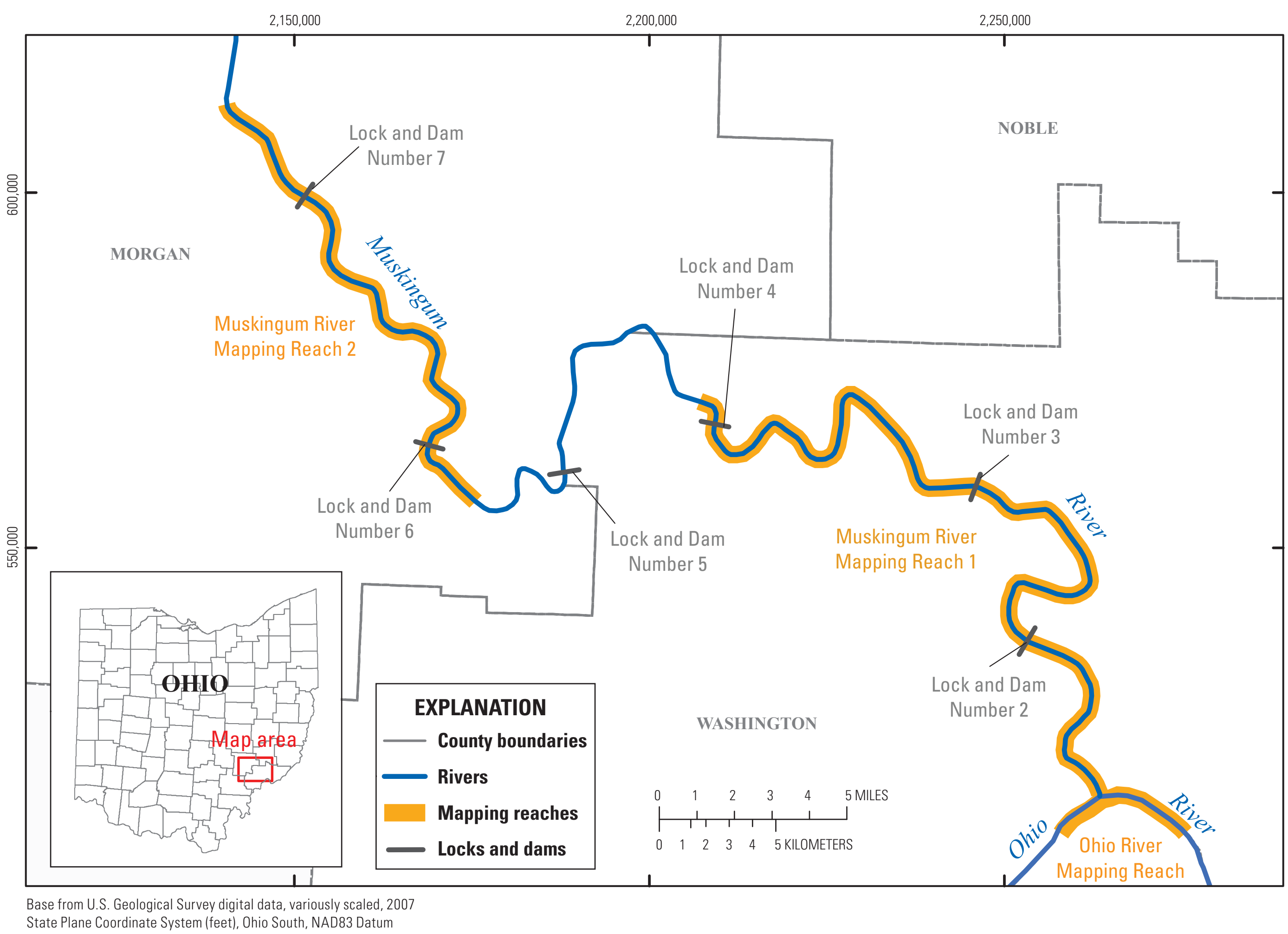


Figure 4. Locations of locks and dams and the mapping reaches for Muskingum River.

Table 4. Approximate mapping reach limits and drainage areas for Reaches 1 and 2 of the Muskingum River.

[River mile refers to miles above the mouth of the Muskingum River. mi, mile; mi², square miles; ft, feet]

Reach number	Reach limit type	Nearby location	River mile	Drainage area (mi²)
Reach 1	Downstream	Mouth of Muskingum River in Marietta	0.0	8,050
	Upstream	0.9 mi upstream from Lock and Dam Number 4 near Beverly	25.9	7,710
Reach 2	Downstream	2.1 mi downstream from Lock and Dam Number 6 near Stockport	39.1	7,460
	Upstream	3.4 mi upstream from Lock and Dam Number 7 in McConnelsville	52.7	7,410

Table 5. Stages and elevations, with corresponding streamflow estimates at selected locations.

[All elevation data are shown in feet above the North American Vertical Datum of 1988. Bolded values indicate values above rating 13 for the Muskingum River at McConnelsville (03150000) streamgage. ft, feet; ft³/s, cubic feet per second]

Ohio River at Marietta (03150700)												
Stage (ft)	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	
Elevation (ft)	600.1	602.1	604.1	606.1	608.1	610.1	612.1	614.1	616.1	618.1	620.1	
Streamflow (in thousand ft³/s)	320	345	375	407	440	476	515	552	590	632	672	
Muskingum River at Beverly (03150500)												
Stage (ft)	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0
Elevation (ft)	618.6	620.6	622.6	624.6	626.6	628.6	630.6	632.6	634.6	636.6	638.6	640.6
Streamflow (in thousand ft³/s)	34.4	42.4	51.1	61.3	72.5	85.2	100	115	131	148	167	186
Muskingum River at McConnelsville (03150000)												
Stage (ft)	9.0	10.0	11.0	12.0	13.0	**14.0**	**15.0**	**16.0**	**17.0**	**18.0**	**19.0**	**20.0**
Elevation (ft)	658.6	659.6	660.6	661.6	662.6	**663.6**	**664.6**	**665.6**	**666.6**	**667.6**	**668.6**	**669.6**
Streamflow (in thousand ft³/s)	29.3	35.0	41.3	47.9	54.8	**62.3**	**70.9**	**79.8**	**88.7**	**96.9**	**104**	**112**

Effects of Backwater from the Ohio River

High stages on the Ohio River can create backwater conditions on the Muskingum River that extend upstream as far as Lock and Dam Number 4 in Beverly (approximately 25 mi). Backwater causes water-surface elevations to increase relative to nonbackwater conditions; however, the amount of increase varies depending on the stage of the Ohio River, the magnitude of streamflow on the Muskingum River, and location. Because of the potential for backwater from the Ohio River, a decision was made to complete additional hydraulic analyses on the Muskingum River Reach 1 to reflect a range of possible Muskingum River streamflows and Ohio River backwater conditions.

Backwater Modeling Solution

To reflect possible backwater conditions from the Ohio River on the Muskingum River, selected Ohio River water levels were used as the downstream boundary condition for the Muskingum River Reach 1 hydraulic model. For the remainder of this report, the original water-surface profiles for the Muskingum River determined using slope conveyance (normal-depth) as the downstream boundary condition will be referred to as modeling scenario A, and profiles determined using selected Ohio River water levels as the downstream boundary condition will be referred to as modeling scenario B. For scenario B, 228 water-surface profiles were determined by using 19 Ohio River water-surface elevations ranging from 584.1 to 620.1 ft (equal to Ohio River stages 18.0 to 54.0 ft) in 2-ft increments in combination with each of the 12 Muskingum River discharges listed in table 5.

Backwater Mapping Solution

Mapping floodplain boundaries corresponding to each of the 228 scenario B profiles was cost prohibitive; however, a method was devised to deliver information on approximate floodplain boundaries on the Muskingum River during backwater conditions. Scenario B profiles for Reach 1 of the Muskingum River were split into 13 geographic areas (fig. 5). Scenario A profiles that most closely matched the Scenario B profiles were determined for each area. Thus, a continuous floodplain boundary made from various segments (geographic areas) of Scenario A could be displayed that approximated each profile from the Scenario B profiles. An example showing a selected Scenario B profile, two selected Scenario A profiles, and the approximated water-surface profile for two mapping area segments is shown in fig. 6.

Backwater Mapping Limitations and Error Analyses

The approximations of backwater-condition floodplain boundaries were limited to the highest mapped stage (stage 48.0) available from Scenario A profiles. As a result, approximated stage 48 floodplain boundaries may underrepresent the expected flooding extents due to backwater conditions from the Ohio River. For the following error analyses, flooding extents exceeding the stage 48.0 floodplain boundaries from Scenario A will be referred to as “48.0+”.

The 48.0+ designation is most prevalent under two situations. The first situation is along the most downstream end of the Muskingum River with extreme stages on the Ohio River. Backwater effects (as expected) are most pronounced at the downstream end of a contributing stream and then dissipate in the upstream direction. For area 1 (fig. 5), the 48.0+ designation is used for all Scenario B profiles above stage 42.0 on the Ohio River. Stage 40 on the Ohio River at Marietta and (by coincidence) stage 40 on the Muskingum River at Beverly is deemed Major Flood stage (NWS, 2012). The second situation is for the upper end of Reach 1 of the Muskingum River with extreme stages on both the Ohio and Muskingum Rivers. In area 13 (fig. 5), the 48.0+ designation is used for only the Scenario B profiles with a stage 48.0 on the Muskingum River and stages 40.0 and above on the Ohio River. The discharge associated with a stage of 48.0 for the Muskingum River at Beverly (table 5) is more than the 0.2-percent chance annual-exceedance probabilities estimate of 185,000 ft^3/sec (USGS, 2012).

The largest differences in water-surface elevations between the approximated water-surface profiles and Scenario B profiles are at the cross sections that bound each of the 13 segmented areas (fig. 5). For Scenario B profiles where the 48.0+ designation occurs, the largest differences range from -12.5 ft in area 1, decreasing to -0.8 ft in area 13. This is not unexpected, as backwater is less pronounced in the upstream direction and the maximum Scenario A profile available for comparison was limited to a stage of 48.0.

For the flooding extents that are not 48.0+ designations, the differences in water-surface elevations between the approximated water-surface profiles and Scenario B profiles ranged from -1.2 to 4.0 ft, with a median value of 0.0 ft; more than 95 percent are within 2 ft. This range is equal to the base mapping contour interval and the mapped-stage interval.

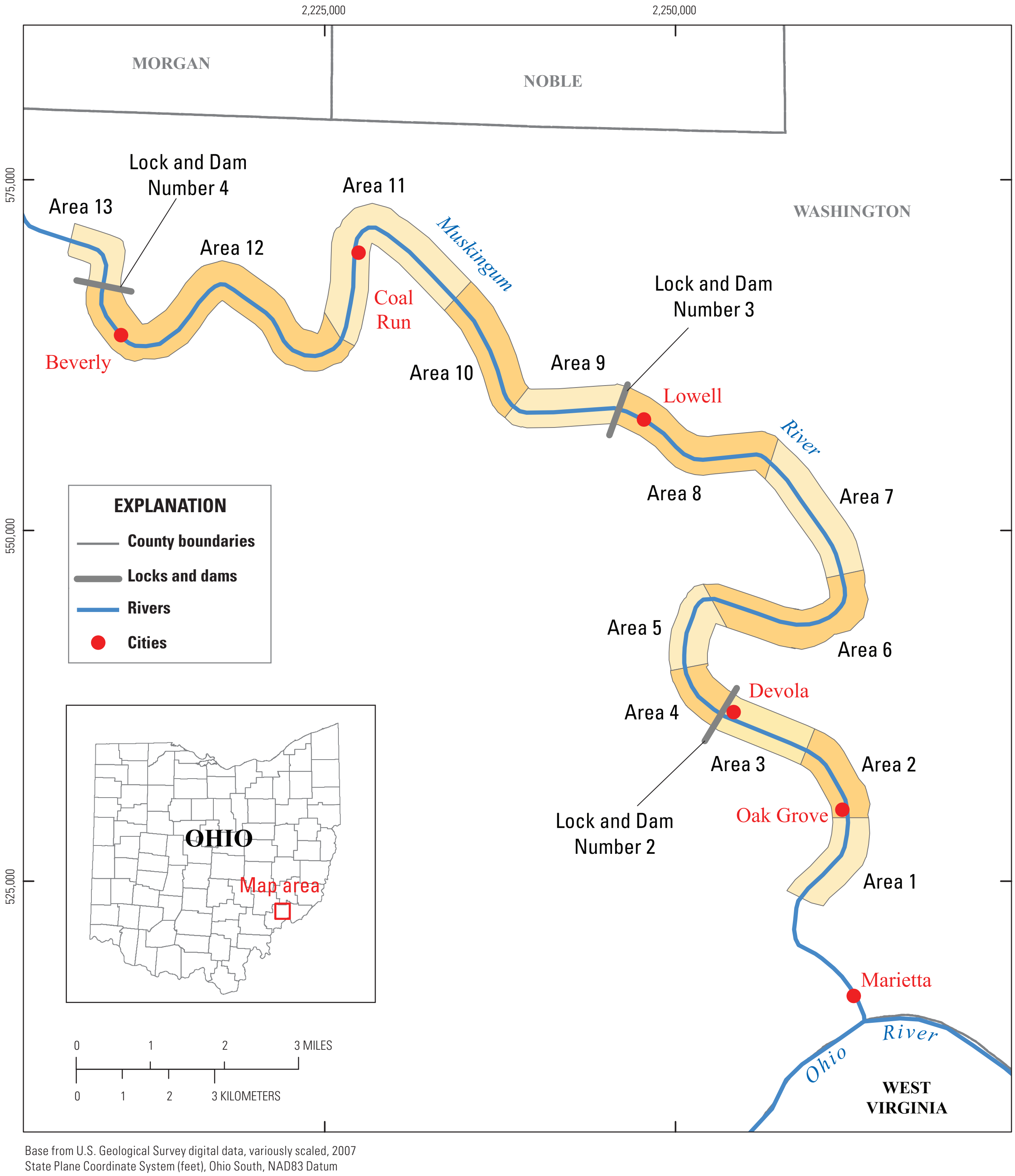


Figure 5. Geographic areas for mapping of the Muskingum River from Beverly to Marietta.

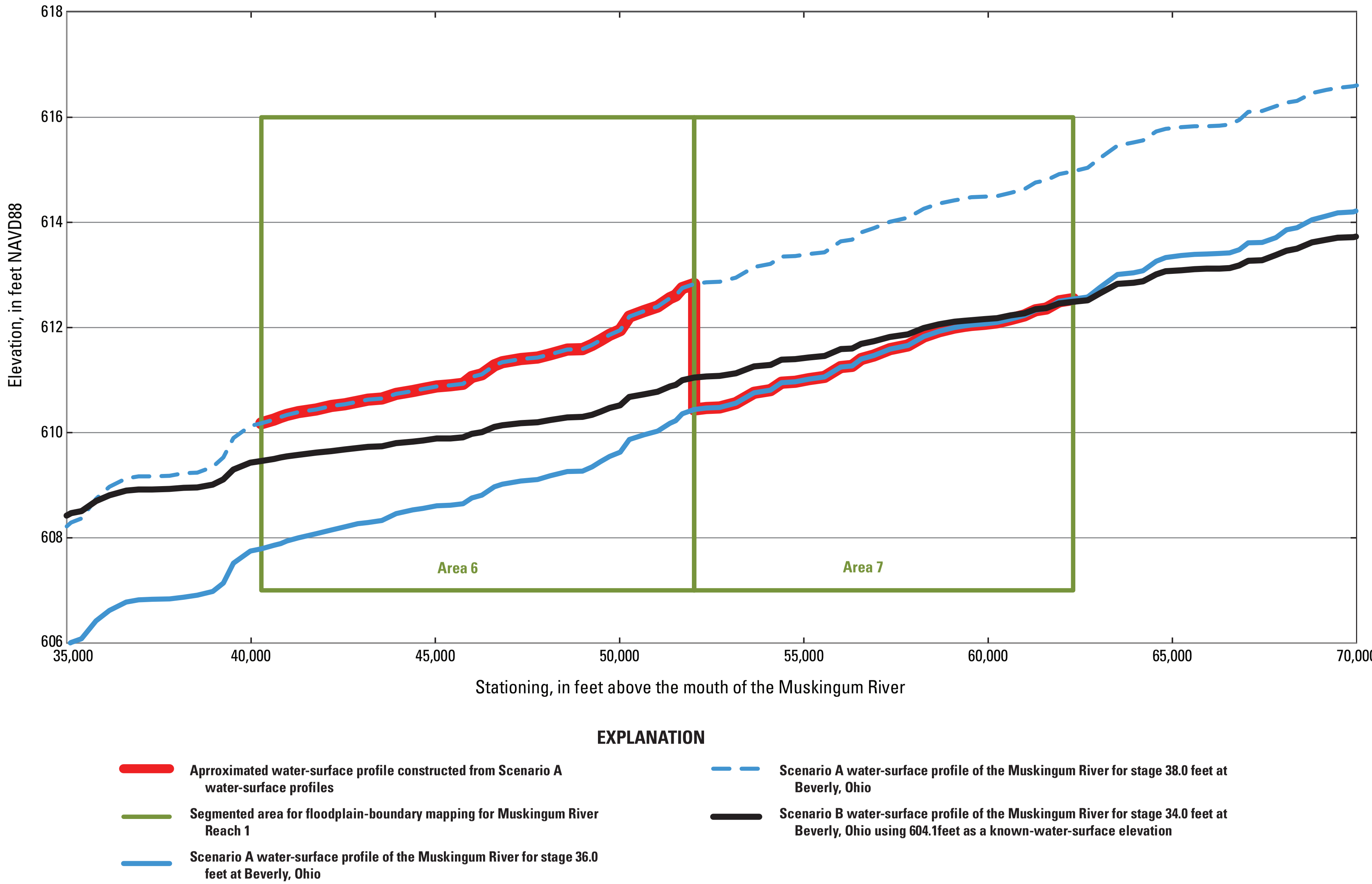


Figure 6. Plot showing two water-surface profiles from Scenario A, one water-surface profile from Scenario B, and the approximated water-surface profile constructed from normal-depth profile segments for two mapping area segments for the Muskingum River.

Flood-Inundation Maps Component

Flood-inundation areas were initially mapped with HEC–GeoRAS software (USACE, 2002a). USGS personnel modified the HEC–GeoRAS results to ensure a logical transition of the flood-inundation boundary between modeled cross sections based on elevation contour data for the land surface (Whitehead and Ostheimer, 2009). Flood-inundation boundaries for the 12 selected profiles at both McConnelsville and Beverly with normal-depth boundary conditions were then overlain onto digital orthophotos from the Ohio Geographically Referenced Information Program (Ohio Geographically Referenced Information Program, 2007).

Flood-Inundation Map Delivery

The current study documentation is available online at the U.S. Geological Survey Publications Warehouse (*http://pubs.usgs.gov/sir/2014/5195*). In addition, a Flood Inundation Mapping Science Web site (USGS, 2014b) has been established to make USGS flood-inundation study information available to the public. That site links to a mapping application that presents map libraries and provides detailed information on flood extents and depths for modeled sites. The mapping application enables the production of customized flood-inundation maps from the map library for the Ohio River near Marietta, Muskingum River at Beverly, and Muskingum River at McConnelsville, Ohio. The estimated flood-inundation maps are displayed in sufficient detail so that preparations for flooding and decisions for emergency response can be performed efficiently. Depending on the flood magnitude, roadways are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. A shaded building should not be interpreted to mean that the structure is completely submerged; rather, shading indicates that bare earth surfaces in the vicinity of the building are inundated. In these instances, the water depth (as indicated in the mapping application by holding the cursor over an inundated area) near the building would be an estimate of the water level inside the structure, unless flood-proofing measures had been implemented.

Disclaimer for Flood-Inundation Maps

The flood-inundation maps should not 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 shown were estimated based on water stages and streamflows at selected USGS streamgages. 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(s). The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of June 2014. 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 due to 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 floodwater extent portrayed on these maps will vary with the accuracy of the digital elevation model used to simulate the land surface. Additional uncertainties and limitations pertinent to this study may be described elsewhere in this report.

If this series of flood-inundation maps will be used with NWS river forecasts, the user should be aware of additional uncertainties that may be inherent or factored into NWS forecast procedures. The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. These forecast models (1) estimate 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 (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.*

Summary

Components of a flood-warning system were updated for selected reaches of the Muskingum and Ohio Rivers in Morgan and Washington Counties, Ohio, by the U.S. Geological Survey (USGS), in cooperation with the Muskingum Watershed Conservancy District and City of Marietta, Ohio. The updates include the addition of two new streamgages to the existing USGS streamgage network and delineation of flood-inundation boundaries that correspond to selected flood stages. The two new streamgages are the Muskingum River at Beverly, Ohio (03150500) and the Ohio River above Sardis, Ohio (03114306). Data from the streamgages could be used by the National Weather Service (NWS) to improve peak-stage predictions for the Ohio and Muskingum Rivers.

Water-surface profiles were estimated by use of steady-state step-backwater models, and corresponding flood-inundation areal boundaries were delineated for up to 12 stages at the following U.S. Geological Survey (USGS) streamgages: Ohio River at Marietta, Ohio (03150700), Muskingum River at Beverly, Ohio (03150500), and Muskingum River at McConnelsville, Ohio (03150000). The flood-inundation boundaries were overlain on digital orthophotos, and the profiles correspond to streamflows ranging from the 10- to 0.2-percent chance annual-exceedance probabilities for each of the 3 streamgages. The effects of backwater from the Ohio River were also modeled, and approximate flood boundaries are shown in segments based upon the normal-depth flood boundaries.

Real-time streamgage information, flood-forecast predictions, and flood-inundation mapping corresponding to flood forecasts can be accessed on Web sites hosted by the USGS and the NWS. It is anticipated that the increased amount and availability of publically accessible streamflow data, along with enhanced flood-prediction capability, will improve the ability of public and emergency-management officials to assess flood conditions, take appropriate steps to protect life and property, and reduce flood damage.

References Cited

Dewberry, 2012, National Enhanced Elevation Assessment: Fairfax, Va., 84 p., accessed July 9, 2013, at *http://www.dewberry.com/files/pdf/NEEA_Final%20Report_Revised%203.29.12.pdf.*

Franz, D.D., Melching, C.S., 1997, Full Equations (FEQ) model for the solution of the full, dynamic equations of motion for one-dimensional unsteady flow in open channels and through control structures: U.S. Geological Survey Water-Resources Investigations Report 96-4240, 258 p.

Hittle, C.D., and Ruby, A.T., III, 2008, Bathymetric surveys of Lake Arthur and Raccoon Lake, Pennsylvania, June 2007: U.S. Geological Survey Data Series 357, p. 3, 4, 9.

National Weather Service, 2012, Advanced Hydrologic Prediction Service, accessed May 29, 2012, at *http://water.weather.gov/ahps2/hydrograph.php?wfo=rlx&gage=mtao1.*

Ohio Department of Transportation, 2014, ODOT's VRS TRK Network, accessed June 25, 2014, at *http://www.dot.state.oh.us/Divisions/Engineering/CaddMapping/Aerial/Pages/VRSRTK.aspx.*

Ohio Geographically Referenced Information Program, 2007, Ohio Statewide Imagery Program, accessed May 29, 2012, at *http://gis3.oit.ohio.gov/geodata/.*

Reson, Inc., 2005, NaviSound 200/400 users guide: Navisound TM 100, 200 & 400 series operator's manual, version 4.01, 177 p.

Rydlund, P.H., Jr., and Densmore, B.K., 2012, Methods of practice and guidelines for using survey-grade global navigation satellite systems (GNSS) to establish vertical datum in the United States Geological Survey: U.S. Geological Survey Techniques and Methods, book 11, chap. D1, 102 p. with appendixes, accessed August 15, 2014, at *http://pubs.usgs.gov/tm/11d1/.*

U.S. Army Corps of Engineers–Hydrologic Engineering Center, 2002a, HEC–GeoRAS, accessed July 29, 2011, at *http://www.hec.usace.army.mil/software/hec-georas/.*

U.S. Army Corps of Engineers, 2002b, Engineering and design—Hydrographic surveying: Washington, D.C., manual no. 1110 2–1003, 510 p.

U.S. Army Corps of Engineers–Hydrologic Engineering Center, 2010, HEC–RAS River Analysis System, user's manual, ver. 4.1 [variously paged].

U.S. Census Bureau, 2012a, State & County QuickFacts, Morgan County, Ohio, Population, 2010, accessed on March 28, 2012, at *http://quickfacts.census.gov/qfd/states/39/39115.html.*

U.S. Census Bureau, 2012b, State & County QuickFacts, Washington County, Ohio, Population, 2010, accessed on March 28, 2012, at *http://quickfacts.census.gov/qfd/states/39/39167.html.*

U.S. Census Bureau, 2012c, State & County QuickFacts, Marietta (city), Ohio, Population, 2010, accessed on March 28, 2012, at *http://quickfacts.census.gov/qfd/states/39/3947628.html.*

U.S. Geological Survey, 2012, Streamstats application, accessed on March 28, 2012, at *http://water.usgs.gov/osw/streamstats/ohio.html.*

U.S. Geological Survey, 2014a, U.S. Geological Survey Flood Inundation Mapping Science, Technical Tools, accessed on March 28, 2014, at *http://water.usgs.gov/osw/flood_inundation/toolbox/librarytools.html.*

U.S. Geological Survey, 2014b, USGS Flood Inundation Mapping Science: U.S. Geological Survey, accessed August 1, 2014, at *http://water.usgs.gov/osw/flood_inundation.*

Whitehead, M.T., and Ostheimer, C.J., 2009, Development of a flood warning system and flood-inundation mapping for the Blanchard River in Findlay, Ohio: U.S. Geological Survey Scientific Investigations Report 2008–5234, 9 p.

Whitehead and Ostheimer—**Flood-Inundation Maps for a Flood-Warning System for Selected Communities along the Lower Muskingum River and Ohio River**— SIR 2014–5195

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20145195