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Prepared in cooperation with the Ohio Department of Transportation; U.S. Department of Transportation, Federal Highway Administration; Muskingum Watershed Conservancy District; U.S. Department of Agriculture, Natural Resources Conservation Service; and the City of Newark and Village of Granville, Ohio

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Scientific Investigations Report 2012–5137

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

Cover photograph: Flooding from the South Fork Licking River, January 21, 1959, looking east along Interstate Route 70 at the State Route 79 interchange. The Ohio Historical Society (reproduced with permission).

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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16. Abstract

Digital flood-inundation maps for selected reaches of South Fork Licking River, Raccoon Creek, North Fork Licking River, and the Licking River in Licking County, Ohio, were created by the U.S. Geological Survey (USGS), in cooperation with the Ohio Department of Transportation; U.S. Department of Transportation, Federal Highway Administration; Muskingum Watershed Conservancy District; U.S. Department of Agriculture, Natural Resources Conservation Service; and the City of Newark and Village of Granville, Ohio. The inundation maps depict estimates of the areal extent of flooding corresponding to water levels (stages) at the following USGS streamgages: South Fork Licking River at Heath, Ohio (03145173); Raccoon Creek below Wilson Street at Newark, Ohio (03145534); North Fork Licking River at East Main Street at Newark, Ohio (03146402); and Licking River near Newark, Ohio (03146500). The maps were provided to the National Weather Service (NWS) for incorporation into a Web-based flood-warning system that can be used in conjunction with NWS flood-forecast data to show areas of predicted flood inundation associated with forecasted flood-peak stages.

As part of the flood-warning streamflow network, the USGS re-installed one streamgage on North Fork Licking River, and added three new streamgages, one each on North Fork Licking River, South Fork Licking River, and Raccoon Creek. Additionally, the USGS upgraded a lake-level gage on Buckeye Lake. Data from the streamgages and lake-level gage can be used by emergency-management personnel, in conjunction with the flood-inundation maps, to help determine a course of action when flooding is imminent.

Flood profiles for selected reaches were prepared by calibrating steady-state step-backwater models to selected, established streamgage rating curves. The step-backwater models then were used to determine water-surface-elevation profiles for up to 10 flood stages at a streamgage with corresponding streamflows ranging from approximately the 50 to 0.2-percent chance annual-exceedance probabilities for each of the 4 streamgages that correspond to the flood-inundation maps. The computed flood profiles were used in combination with digital elevation data to delineate flood-inundation areas. Maps of Licking County showing flood-inundation areas overlain on digital orthophotographs are presented for the selected floods.

The USGS also developed an unsteady-flow model for a reach of South Fork Licking River for use by the NWS to enhance their ability to provide advanced flood warning in the region north of Buckeye Lake, Ohio. The unsteady-flow model was calibrated based on data from four flooding events that occurred from June 2008 to December 2011. Model calibration was approximate due to the fact that there were unmeasured inflows to the river that were not able to be considered during the calibration. Information on unmeasured inflow derived from NWS hydrologic models and additional flood-event data could enable the NWS to further refine the unsteady-flow model.

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Conversion Factors, Vertical Datum, and Abbreviations

Multiply	By	To obtain
	Length	
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).

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

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

ALERT	Automated Local Evaluation in Real Time
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GOES	Geostationary Operational Environmental Satellite
HEC–RAS	Hydrologic Engineering Center–River Analysis System
I–70	Interstate Route 70
NFIP	National Flood Insurance Program
NWS	National Weather Service
ODNR	Ohio Department of Natural Resources
ODOT	Ohio Department of Transportation
OEMA	Ohio Emergency Management Agency
OGRIP	Ohio Geographically Referenced Information Program
OIT	Ohio Office of Information Technology
OSIP	Ohio Statewide Imagery Program
SR–79	State Route 79
USGS	U.S. Geological Survey

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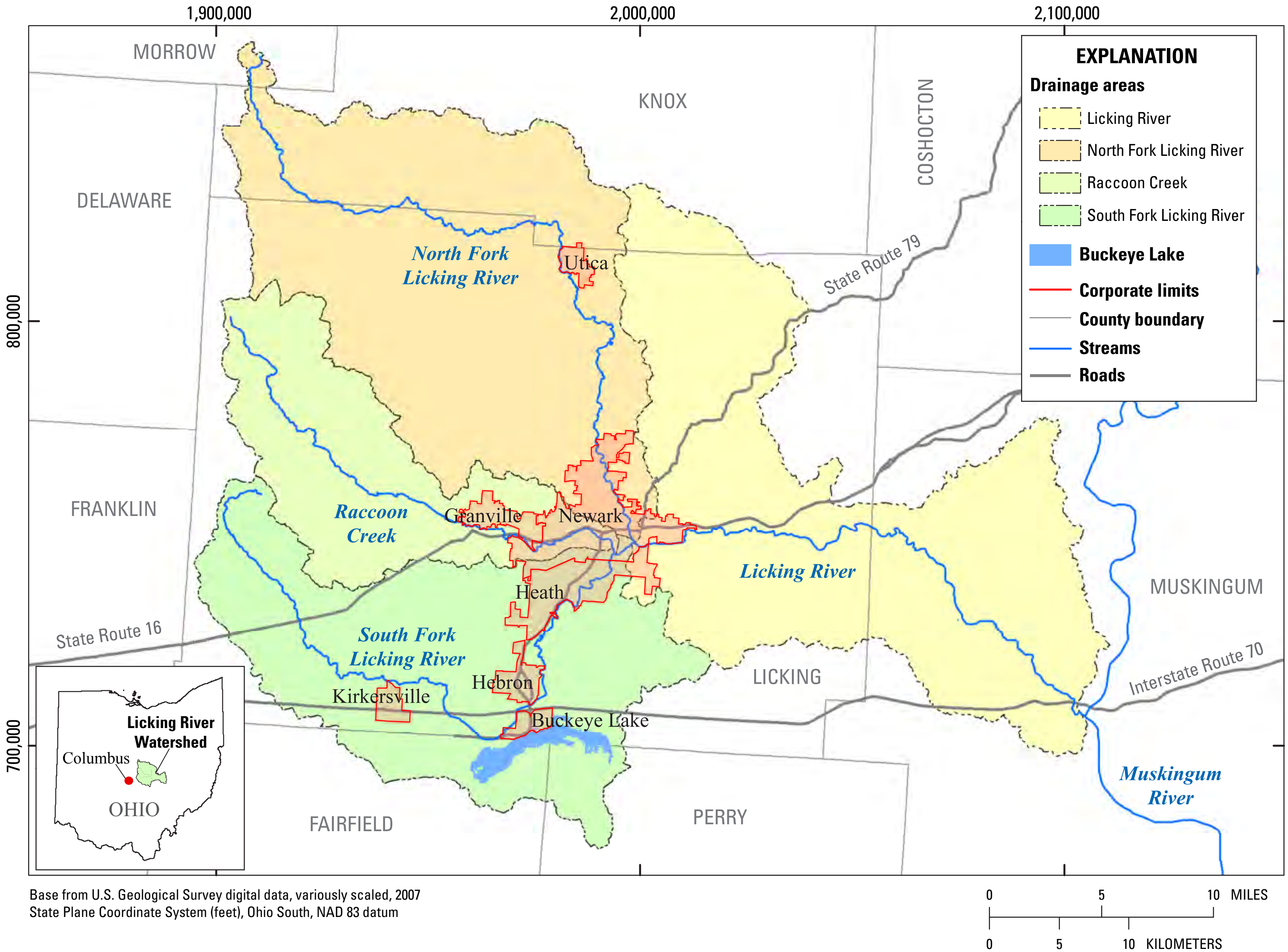
Introduction

Licking County, Ohio, has experienced numerous flood events with the majority of flood damage occurring in the central and south-central areas of the county along four streams: Licking River, North Fork Licking River, South Fork Licking River, and Raccoon Creek. Flooding from these four streams has affected communities including the Village of Granville, City of Newark, City of Heath, Village of Hebron, and Village of Buckeye Lake (fig. 1). Flooding also has resulted in the closure of Interstate Route 70 (I–70) in the vicinity of the Village of Buckeye Lake and the I–70 and State Route 79 (SR–79) interchange. Closure of I–70 has resulted in safety issues (such as the movement of hazardous materials and potential delays to emergency services), loss of commerce, and traffic congestion as commercial truck traffic is detoured onto smaller capacity State routes through nearby communities. Although flood-mitigation planning is ongoing, discussions between the U.S. Geological Survey (USGS) and interested parties[1] have identified the need for a flood-warning system in central and south-central Licking County.

[1] Interested parties included the Ohio Department of Transportation, Village of Granville, Granville Township, Denison University, City of Newark, Licking County, South Licking Watershed Conservancy District, Natural Resources Conservation Service, Muskingum Watershed Conservancy District, Ohio Department of Natural Resources, and the Wilmington National Weather Service forecast office and collocated Ohio River Forecast Center.



Base from U.S. Geological Survey digital data, variously scaled, 2007
State Plane Coordinate System (feet), Ohio South, NAD 83 datum

Figure 1. Licking River and major tributary watersheds and selected corporate boundaries.

Prior to this study, officials from Licking County and Ohio Department of Transportation (ODOT) relied on information from several sources when making decisions on how to best alert the public and mitigate flood damage. One source is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Licking County, Ohio (Federal Emergency Management Agency, 2007). A second source is the forecasts of peak stage from the National Weather Service (NWS). Other sources of information include USGS streamgages South Fork Licking River at Kirkersville (03144816); South Fork Licking River near Hebron (03145000); Raccoon Creek near Granville (03145483); North Fork Licking River at Newark (03146277); North Fork Licking River at Ohio Street, Newark (03146405); and Licking River near Newark (03146500) from which water-level (stage) and in some cases streamflow data can be accessed by use of the Web (fig. 2).

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 forecasts originate with the NWS Ohio River Forecast Center in Wilmington, Ohio, and warnings are issued to the public by regional NWS offices in Wilmington or Cleveland, Ohio.

Although stage information previously could be obtained from USGS streamgages, upgrades and additions to the streamflow network as a result of this study are expected to enhance flood-forecasting capabilities of the NWS for the Licking River, North Fork Licking River, South Fork Licking River, and Raccoon Creek in Licking County (Julia Dian-Reed, National Weather Service, oral commun., July 2010).

Description of the Study Area

Licking County, located in central Ohio approximately 12 miles (mi) (19 kilometers (km)) east of Columbus, Ohio (fig. 1), covers approximately 688 square miles (mi^2) (1,782 square kilometers (km^2)) and contains an estimated population of 158,000 (U.S. Census Bureau, 2009). Licking County straddles the Allegheny Escarpment, with the Till Plains physiographic region to the west and the Glaciated and Unglaciated Allegheny Plateau physiographic region to the east (Ohio Division of Geological Survey, 1998). The relief of Licking County varies with location (rolling to hilly in the eastern portion and nearly flat in the western portion), with altitudes ranging from about 750 to 1,360 feet (ft) (229 to 415 meters (m)). Licking County contains all or most of the headwaters for the Licking River including three major streams: North Fork Licking River, South Fork Licking River, and Raccoon Creek. These streams drain a basin with a predominantly rural headwater area that becomes more developed as it approaches the City of Newark. The streams eventually combine to form the Licking River in the City of Newark. Study-reach limits for the Licking River and its major tributaries are shown in table 1 and figure 2. The Licking River itself discharges to the Muskingum River, which eventually drains to the Ohio River.

Purpose and Scope

Flood-warning systems typically involve major elements including streamflow, lake-level and precipitation networks, hydrologic and hydraulic modeling, flood-inundation mapping, and various means of disseminating the flood-warning information. This study addresses several of those elements including a streamflow and lake-level network, hydraulic modeling, flood-inundation mapping, and Web-based access to the project results. This report describes methods and results of hydrologic and hydraulic analyses of selected streams within Licking County, Ohio, and presents a series of flood-inundation maps developed for selected stages of streamgages located at Licking River near Newark (03146500); North Fork Licking River at East Main Street, Newark (03146402); Raccoon Creek below Wilson Street at Newark (03145534); and South Fork Licking River at Heath (03145173).

Tasks specific to this study and discussed in this report are to (1) re-establish one previously discontinued streamgage, install three new streamgages, and upgrade one lake-level gage; (2) develop flood-inundation maps depicting the areal extent of flooding that may occur along each of the studied reaches within Licking County at selected stages and their corresponding streamgages based on steady-state[2] model estimates; and (3) develop a one-dimensional unsteady-flow model for a reach of the South Fork Licking River for use by the NWS.

Installation of Streamgages and Upgrade of a Lake-level Gage

As part of this study, the USGS re-installed one streamgage on North Fork Licking River; added three new streamgages, one each on the North Fork Licking River, South Fork Licking River, and Raccoon Creek; and upgraded one lake-level gage (fig. 2). The four streamgages installed were South Fork Licking River at Heath (03145173), Raccoon Creek below Wilson Street at Newark (03145534), North Fork Licking River at East Main Street at Newark (03146402), and North Fork Licking River at Utica (03146000) (re-established). The upgraded lake-level gage was Buckeye Lake at Millersport (3954170832314200), located in Fairfield County. A summary of information about the existing and new streamgages and upgraded lake-level gage can be found in table 2.

The North Fork Licking River at Utica (03146000) streamgage was re-established at a site approximately

[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 others, 1997).

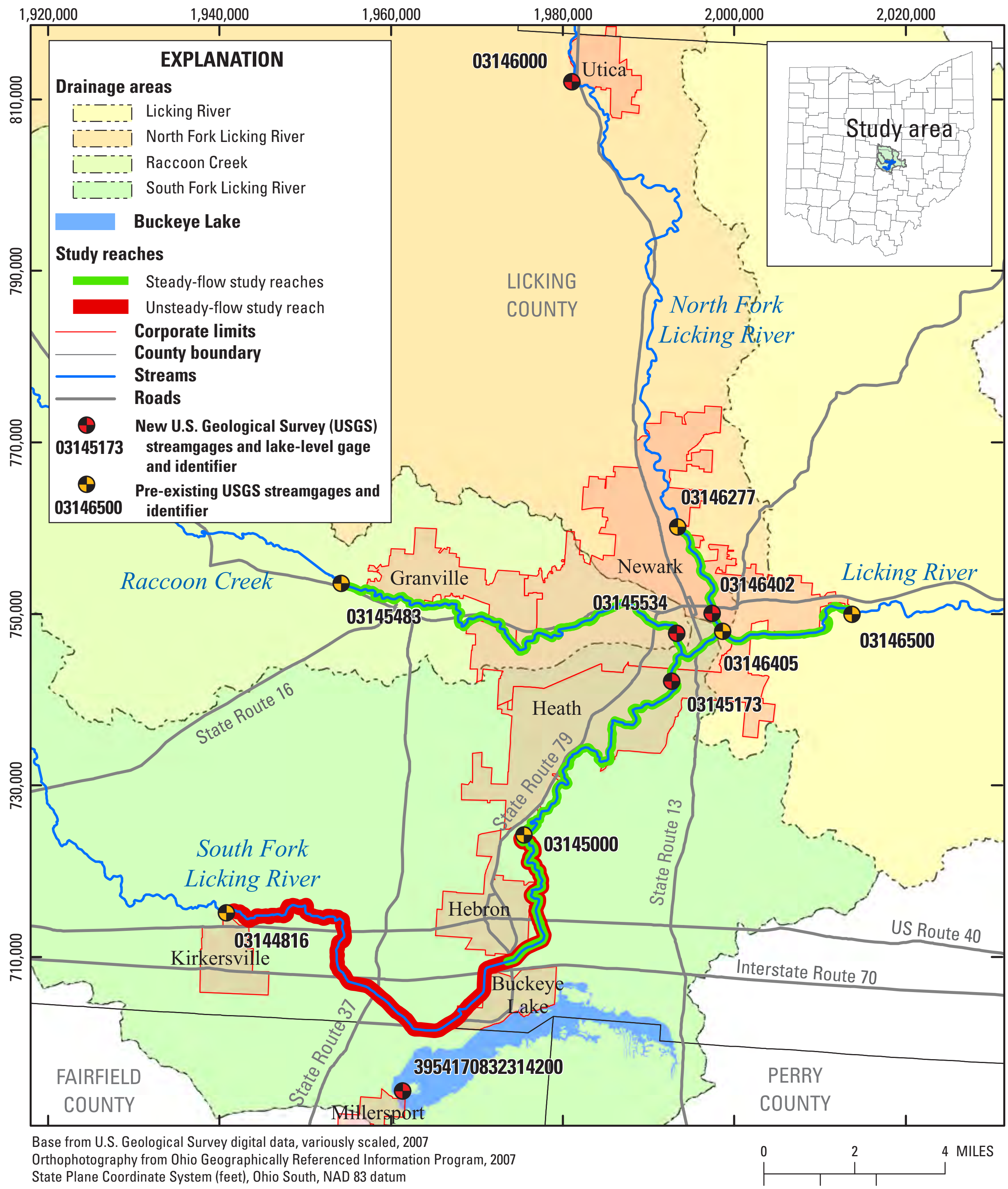


Figure 2. Locations of pre-existing and new U.S. Geological Survey streamgages, lake-level gage, and study reaches in Licking County, Ohio.

Table 1. Study-reach limits for the Licking River and its major tributaries.

[mi, mile; km, kilometer]

Study reach	Downstream limit	Upstream limit(s)	Reach length (mi)	Reach length (km)
Licking River	550 feet (170 meters) downstream from the Licking River near Newark streamgage (03146500)	Confluence of North and South Fork Licking Rivers	3.7	5.9
Licking River (extension into North Fork Licking River)	Confluence of North and South Fork Licking Rivers	North Fork Licking River at East Main Street at Newark streamgage (03146402)	.5	.8
Licking River (extension into Raccoon Creek)	Confluence of South Fork Licking River and Raccoon Creek	Raccoon Creek below Wilson Street at Newark streamgage (03145534)	.5	.8
Licking River (extension into South Fork Licking River)	Confluence of North and South Fork Licking Rivers	South Fork Licking River at Heath streamgage (03145173)	1.8	2.9
North Fork Licking River	North Fork Licking River at East Main Street at Newark	North Fork Licking River at Newark streamgage (03146277)	2.4	3.9
South Fork Licking River	South Fork Licking River at Heath streamgage (03145173)	Interstate Route 70 and State Route 79 interchange	11.3	18.2
Raccoon Creek	Raccoon Creek below Wilson Street at Newark streamgage (03145534)	Raccoon Creek near Granville streamgage (03145483)	10.2	16.4
South Fork Licking River (Buckeye Lake reach)	South Fork Licking River at Hebron streamgage (03145000)	South Fork Licking River at Kirkersville streamgage (03144816)	13.8	22.2

0.25 mi (0.40 km) upstream from its former location using the same site number and a new datum. This streamgage was re-established to provide the NWS with streamflow information in the upper North Fork Licking River Basin, before streamflow arrives at the confluence with the South Fork Licking River. The streamgages on South Fork Licking River at Heath (03145173), Raccoon Creek below Wilson Street at Newark (03145534), and North Fork Licking River at East Main Street at Newark (03146402) were sited as close as possible to the mouths of their respective streams without being subject to any anticipated backwater[3]. The lake-level gage at Buckeye Lake near Millersport (395417082314200) had been previously established and run by the Ohio Department of Natural Resources (ODNR). This gage was upgraded by installing telemetry equipment, which allowed lake-level information to be obtained in near real time.

The upgrade of the lake-level gage and siting of the newly installed streamgages were discussed and coordinated with the NWS and other interested parties with the goal of enhancing the ability of the NWS to predict peak stage for the four studied streams. The drainage areas for the re-established and installed streamgages ranged from 101 to 240 mi^2 (262 to 622 km^2) (table 2).

The four streamgages were equipped with an Automated Local Evaluation in Real Time (ALERT) protocol-based radio-frequency transmitter. The ALERT radio network is operated by the Ohio Emergency Management Agency (OEMA) to facilitate the collection of real-time data pertaining to rainfall and water-level conditions. The NWS uses the ALERT data in the development of flood forecasts, which can result in the issuance of flood watches and warnings. Local officials also can access the ALERT data to independently monitor rainfall amounts and water-level conditions. Additionally, the lake-level gage and the four streamgages were equipped with Geostationary Operational Environmental Satellite (GOES) transmitters. Data are transmitted hourly by use of GOES to facilitate computations of streamflow and near-real-time monitoring of equipment performance and water levels, and to provide back-up data to the ALERT data. Streamflow and stage data from these new streamgages as well as other streamgages can be found at *http://waterdata.usgs.gov/oh/nwis/current/?type=flow*. Precipitation and lake-level data from the new lake-level gage as well as other rain gages can be found at *http://waterdata.usgs.gov/oh/nwis/uv?cb_00045=on&cb_62614=on&format=gif_default&begin_date=2012-03-22&end_date=2012-03-29&site_no=395417082314200*.

[3] Water backed up or retarded in its course as compared with its normal or natural condition of flow.

Rating Selection and Development

For this study, stage-streamflow relations, commonly referred to as rating curves, were available for six pre-existing streamgages (table 2). One of the rating curves was used to determine boundary conditions for the hydraulic analyses: South Fork Licking River near Hebron (03145000), rating curve number 26.0 (unsteady-state modeling). Beginning in 2010, streamflow measurements were made at the one re-established and three new streamgages (table 2) to facilitate the development of rating curves. From September 2010 to June 2012, a total of 73 streamflow measurements were made at the four streamgages. All rating curves were used to evaluate model outputs at their respective locations, with the exceptions of North Fork Licking River at Utica (03146000) (not located within a modeled reach) and North Fork Licking River at Ohio Street, Newark (03146405) (subject to backwater).

Hydraulic Modeling

The hydraulic analyses were done with U.S. Army Corps of Engineer Hydrologic Engineering Center–River Analysis System (HEC–RAS), version 4.1.0 (U.S. Army Corps of Engineers, 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. HEC–RAS is accepted by FEMA for use in the National Flood Insurance Program (NFIP). All hydraulic analyses for this report were done with the steady-state flow computation option, with the exception of South Fork Licking River (Buckeye Lake reach), which was done with the unsteady-state flow computation option.

Previous Study

Prior to this study, a FEMA FIS was published in May 2007 (Federal Emergency Management Agency, 2007). The

Table 2. Summary of streamgage and lake-level gage information in the Licking River Basin, Ohio.

[mi^2, square mile; km^2, square kilometer; NWS, National Weather Service; N/A, not applicable]

Streamgage name	Streamgage number	Drainage area		Period of record	NWS forecast point	Comment
		(mi^2)	(km^2)			
Licking River near Newark	03146500	537	1,391	Oct. 1939–Present	Yes	None
North Fork Licking River at Ohio Street, Newark	03146405	241	624	Oct. 2007 – Present	Yes	None
North Fork Licking River at East Main Street at Newark	03146402	240	240	Nov. 2010 – Present	Yes	New gage
North Fork Licking River at Newark	03146277	227	588	Oct. 2007 – Present	No	None
North Fork Licking River at Utica	03146000	116	300	Oct. 1939 – Oct. 1982 Nov. 2010 – Present	No	Re-established gage
South Fork Licking River at Heath	03145173	181	469	Sept. 2010 – Present	Yes	New gage
South Fork Licking River near Hebron	03145000	133	344	Oct. 1939 – Sept. 1948 July 1968 – Present	Yes	None
South Fork Licking River at Kirkersville	03144816	47.0	122	Oct. 2007 – Present	No	None
Raccoon Creek near Granville	03145483	78.2	203	Oct. 2007 – Present	Yes	None
Raccoon Creek below Wilson Street at Newark	03145534	101	262	Sept. 2010 – Present	Yes	New gage
Buckeye Lake near Millersport	3954170832314200	N/A	N/A	May 1993 – Present	N/A	Installed telemetry equipment

supporting hydraulic modeling for South Fork Licking River and Raccoon Creek were completed in December 2002. The supporting hydraulic modeling for North Fork Licking River and Licking River were completed in October 1997 and sometime in the early 1980’s, respectively. Base maps for the four streams were either digital versions of USGS 7.5-minute series quadrangle maps or mapping developed by Licking County around the year 2000. From 2006 to 2008, the Ohio Geographically Referenced Information Program (OGRIP)—a program of the Ohio Office of Information Technology (OIT)—developed detailed digital mapping and orthographic photography for the State of Ohio as part of the Ohio Statewide Imagery Program (OSIP) (Ohio Geographically Referenced Information Program, 2007). The decision was made to develop new hydraulic models to reflect the best-available topography data and current hydraulic conditions, owing to the availability of these new digital mapping data.

Steady-State Modeling and Calibration

The starting boundary condition for each of the study reaches shown in table 1, with the exception of South Fork Licking River (Buckeye Lake reach), was stage determined from a slope-conveyance calculation. The energy slope was estimated from the average streambed slope as determined from field surveys. Modeling for each stream began downstream of the most downstream gage. Streamflows then were routed upstream to their respective modeled-reach upper limits. For North Fork Licking River, South Fork Licking River, and Raccoon Creek, modeling began at the stream mouth. For Licking River, modeling began approximately 550 feet (170 m) downstream of the Licking River near Newark (03146500) streamgage. In order to account for any potential backwater conditions, streamflows for Licking River then were routed up each of the tributary extensions as shown in table 1. Each model was calibrated to the available rating curves (pre-existing streamgages) or streamflow measurements (new streamgages) for the streamgages associated with each respective study reach (table 1).

To calibrate the model, Manning’s roughness coefficients were adjusted from original field estimates until the results of the hydraulic computations closely agreed with the known flood-streamflow and stage values. Ranges of final Manning’s roughness coefficients are shown in table 3. After calibration, computed water-surface elevations for streamflows corresponding to the range of selected stages matched each rating curve within 0.06 foot (0.02 m). A summary of the differences between the rating curves and model outputs is shown in table 4.

Table 3. Summary of final Manning’s roughness coefficients for the steady-state models.

Study reach	Stream channel		Overbanks	
	Minimum	Maximum	Minimum	Maximum
Licking River	0.035	0.046	0.012	0.100
North Fork Licking River	.034	.046	.030	.200
South Fork Licking River	.039	.062	.012	.200
Raccoon Creek	.032	.048	.012	.100

Table 4. Summary of minimum and maximum differences in water-surface elevation comparing hydraulic-model results to streamgage rating curves.

Streamgage name	Streamgage number	Rating curve number	Hydraulic model output difference from rating curve, in feet (meters)	
			Minimum	Maximum
Licking River near Newark	03146500	47.0	− 0.01 (−0.003)	0.00 (0.000)
North Fork Licking River at Newark	03146277	3.0	−.01 (−.003)	.03 (.009)
South Fork Licking River near Hebron	03145000	26.0	−.01 (−.003)	.01 (.003)
Raccoon Creek near Granville	03145483	3.0	−.06 (−.018)	.02 (0.006)

Determination of Water-Surface Profiles

Water-surface profiles were computed for each steady-state study reach at selected even-foot stages at the objective streamgages for each steady-state study reach. The objective streamgages for this study were Licking River near Newark (03146500), North Fork Licking River at East Main Street at Newark (03146402), Raccoon Creek below Wilson Street at Newark (03145534), and South Fork Licking River at Heath (03145173). Ten water-surface profiles were determined for each stream, with the exception of South Fork Licking River, which had nine profiles. A tenth water-surface profile for South Fork Licking River would have represented an event less than that of a 50-percent chance annual-exceedance probability flood (with almost all water contained in the channel) or an event well in excess of a 0.2-percent chance annual-exceedance probability flood. After each HEC–RAS steady-state model was calibrated, streamflows corresponding to the desired even-foot stage values were determined by use of an iterative process. The process consisted of routing streamflows from the downstream-model limit upstream to their respective objective streamgage until the target even-foot stage values were obtained. The modeled flows for each steady-state study reach range from approximately the 50 to 0.2-percent annual exceedance probabilities. A summary of the modeled stages and corresponding streamflows for each study reach is shown in table 5.

Alternate Flow Scenarios

Main stem and tributary streamflow for profiles at major tributary confluences, upstream from their respective starting streamgages, were computed with the assumption that streamflows are proportional to contributing drainage areas. For this report, this type of flow-distribution scenario is referred to as the “type-A” scenario. This scenario was modeled for each of the stream reaches shown in table 1, with the exception of South Fork Licking River (Buckeye Lake reach).

The percentage of streamflow contributed by South Fork Licking River, Raccoon Creek, and North Fork Licking River to the main stem of the Licking River is variable from storm to storm. Tributary streamflow contributions are affected by antecedent conditions and the areal distribution of rainfall (and possibly snowpack) for a given storm event. As a result, for a given streamflow at the Licking River near Newark (03146500) streamgage, the amount of streamflow in the main stem above a tributary theoretically can vary from zero (if all streamflow at the confluence of the tributary and main stem comes from the tributary) to the approximate streamflow at the streamgage (if no streamflow is contributed by the tributary).

In order to account for the uncertainty in the distribution of flow between the Licking River and its tributaries, an alternate-flow-scenario model was developed for the Licking River study reach (as shown in table 1) for each modeled stage. This alternate flow scenario, referred to as the “type-B” scenario, is based on the initial assumption that each tributary supplies the full main-stem streamflow at its confluence with the main stem. Although this flow-distribution scenario is unlikely, it results in a consistent and conservative estimate of the maximum flooding that likely would occur for a given stage.

The type-B scenario model for each stage was initially developed by assuming that all of the flow in the main stem below the confluence with a tributary was discharged from the tributary. However, maximum tributary inputs were limited to the upper 95-percent confidence limit for their respective 0.2 percent chance annual-exceedance probability floods as estimated from methods described in Koltun and others (2006). This upper limit on streamflow in a tributary was imposed so as to minimize the likelihood of modeling unreasonably large flows in the tributaries. A summary of the type-B scenario modeled stages and corresponding streamflows for each study reach is shown in table 6.

Development of Flood-Inundation Maps

Flood-inundation areal boundaries were initially mapped with HEC–GeoRAS software (U.S. Army Corps of Engineers, 2002). 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. The flood-inundation boundaries then were overlain onto digital orthophotos from OSIP (Ohio Geographically Referenced Information Program, 2007). The resulting estimated flood-inundation boundaries can be found at *http://pubs.er.usgs.gov/*

Table 5. Summary of modeled stages and elevations, and corresponding streamflows.

[ft, foot; m, meter; ft³/s, cubic foot per second; m³/s, cubic meter per second; N/A, not applicable]

Licking River near Newark (03146500)											
Stage	(ft)	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
	(m)	3.35	3.66	3.96	4.27	4.57	4.88	5.18	5.49	5.79	6.10
Elevation	(ft)	789.28	790.28	791.28	792.28	793.28	794.28	795.28	796.28	797.28	798.28
	(m)	240.57	240.88	241.18	241.49	241.79	242.10	242.40	242.71	243.01	243.32
Streamflow	(ft^3/s)	9,180	11,400	13,910	16,690	19,800	23,900	28,330	33,300	38,720	44,600
	(m^3/s)	259	323	394	473	561	677	802	943	1,100	1,260
North Fork Licking River at East Main Street at Newark (03146402)											
Stage	(ft)	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0
	(m)	3.96	4.27	4.57	4.88	5.18	5.49	5.79	6.10	6.40	6.71
Elevation	(ft)	807.69	808.69	809.69	810.69	811.69	812.69	813.69	814.69	815.69	816.69
	(m)	246.18	246.49	246.79	247.10	247.40	247.71	248.01	248.32	248.62	248.93
Streamflow	(ft^3/s)	7,610	8,840	10,200	11,700	13,300	15,100	17,100	19,200	21,400	23,700
	(m^3/s)	216	250	289	331	377	428	484	544	606	671
South Fork Licking River at Heath (03145173)											
Stage	(ft)	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	N/A
	(m)	4.27	4.57	4.88	5.18	5.49	5.79	6.10	6.40	6.71	N/A
Elevation	(ft)	814.0	815.0	816.0	817.0	818.0	819.0	820.0	821.0	822.0	N/A
	(m)	248.1	248.4	248.7	249.0	249.3	249.6	249.9	250.2	250.5	N/A
Streamflow	(ft^3/s)	4,670	5,600	6,590	7,680	8,930	10,500	12,300	14,300	16,220	N/A
	(m^3/s)	132	159	187	217	253	297	348	405	459	N/A
Raccoon Creek below Wilson Street at Newark (03145534)											
Stage	(ft)	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0
	(m)	3.96	4.27	4.57	4.88	5.18	5.49	5.79	6.10	6.40	6.71
Elevation	(ft)	813.0	814.0	815.0	816.0	817.0	818.0	819.0	820.0	821.0	822.0
	(m)	247.8	248.1	248.4	248.7	249.0	249.3	249.6	249.9	250.2	250.5
Streamflow	(ft^3/s)	4,330	5,160	6,080	7,080	8,140	9,250	10,400	11,700	13,000	14,300
	(m^3/s)	123	146	172	201	231	262	295	331	368	405

Table 6. Summary of type-B scenario modeled stages and elevations, and corresponding streamflows for the Licking River study reach.

[ft, foot; m, meter; ft^3/s, cubic foot per second; m^3/s, cubic meter per second; bolded values indicate tributary streamflows that were truncated from the full main-stem flow (station 03146500) at the upper 95-percent confidence limit of the estimated 0.2 percent chance annual-exceedance probability flood magnitude]

Licking River near Newark (03146500)											
Stage	**(ft)**	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
	(m)	3.35	3.66	3.96	4.27	4.57	4.88	51.8	5.49	5.79	6.10
Streamflow	**(ft^3/s)**	9,180	11,400	13,910	16,690	19,800	23,900	28,330	33,300	38,720	44,600
	(m^3/s)	260	323	394	473	561	677	802	943	1,097	1,263
Maximum percentage of the Licking River near Newark (03146500) streamflow supplied by the indicated stream											
North Fork Licking River at the mouth											
Percentage		100	100	10	100	100	100	100	100	**91**	**79**
South Fork Licking River at the mouth											
Percentage		100	100	100	100	100	100	100	100	**86**	**74**
South Fork Licking River above Raccoon Creek											
Percentage		100	100	100	100	100	**93**	**78**	**67**	**57**	**50**
Raccoon Creek at the mouth											
Percentage		100	100	100	100	100	**83**	**70**	**59**	**51**	**44**

Unsteady-State Modeling and Calibration

Flooding conditions in the Buckeye Lake region are complex and best modeled as two- or three-dimensional unsteady-flow processes. The complexities include overbank flow disconnected from the main channel, overbank flow not parallel to the main-channel flow, and uncertainty in the timing of tributary inputs/ lake outflows. While capable of handling multidimensional-flow processes, two- and three-dimensional unsteady-flow modeling is computationally intensive and can result in model-run times approaching the simulated time period. One-dimensional unsteady-flow modeling is more computationally efficient but may not accurately simulate two- or three-dimensional hydraulics. Using a one-dimensional unsteady-flow model can result in model-run times measured in minutes for a simulated period of several days. Since the unsteady-flow model will be used by the NWS to provide advanced flood warning in the Buckeye Lake region, long simulation times are not an option for operational-forecasting purposes. Consequently, the NWS requested the USGS to develop a one-dimensional unsteady-flow model.

For the unsteady-flow modeling effort, the downstream-boundary condition was determined based on the rating curve for the South Fork Licking River near Hebron (03145000) streamgage. Streamflow inputs to the unsteady-flow model were limited to the streamflows determined from stage-streamflow ratings and lake outflows determined from measured lake levels. The model inputs were the South Fork Licking River at Kirkersville (03144816) streamgage and outflows from Buckeye Lake (fig. 3) from the primary spillway (Amil gate) and the emergency spillway (horseshoe weir). Outflows from Buckeye Lake were estimated by using information from the Buckeye Lake near Millersport (3954170832314200) lake-level gage to compute streamflows based on a stage-outflow rating curve obtained from ODNR.

Additional information on flood hydrograph timing and magnitude was obtained by installing stage sensors in October 2011 at five locations along the modeled reach (fig. 3). Surveys were conducted to tie the stage data into a common vertical datum. Locations were selected based upon areas of interest such as upstream and downstream from tributaries and in the area near the I-70 and SR-79 interchange.

While the South Fork Licking River near Hebron (03145000) streamgage (downstream-boundary condition) has 54 years of record, the South Fork Living River at Kirkersville (03144816) streamgage (upstream-flow input site) has only

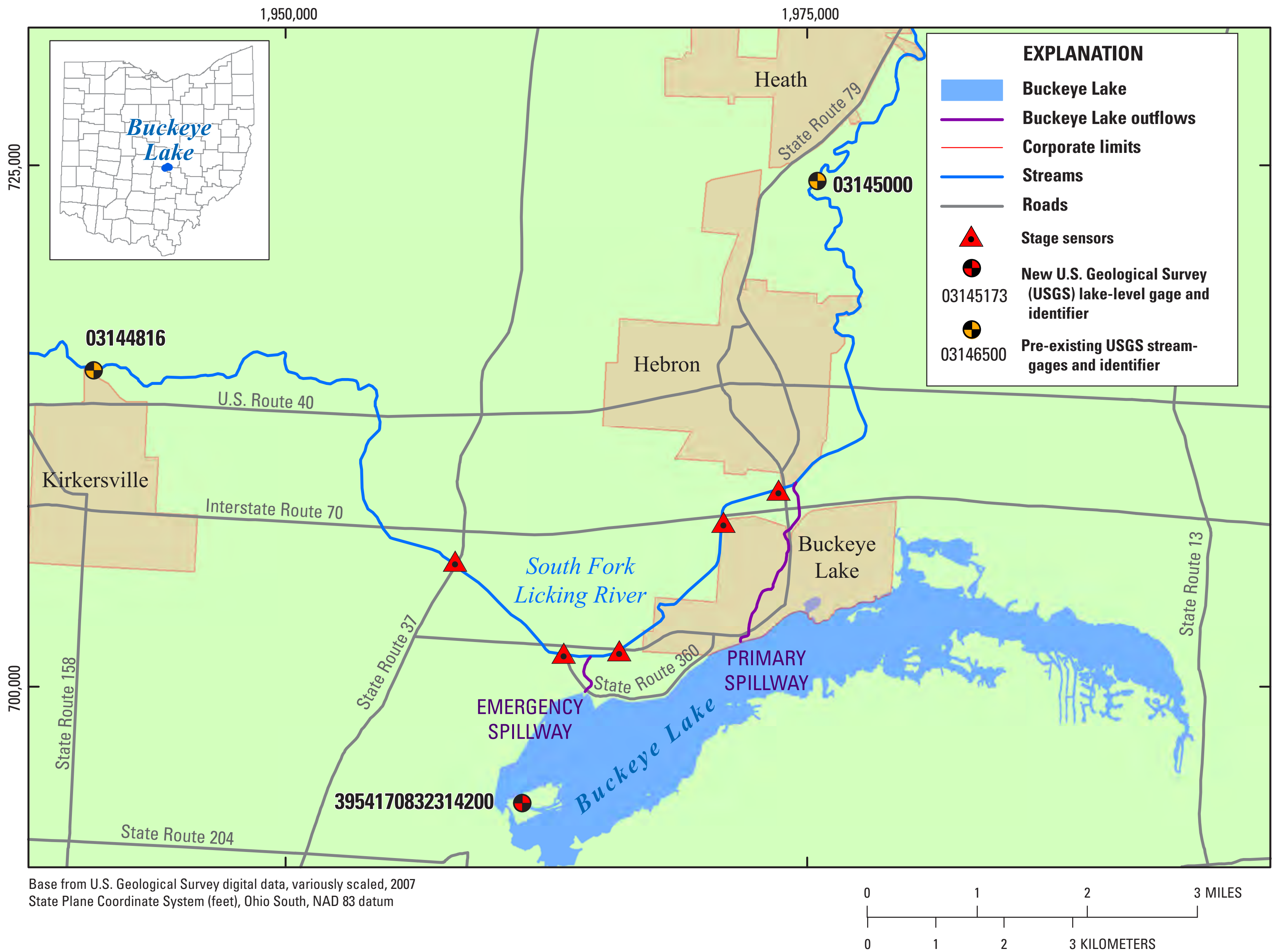


Figure 3. Locations of primary and emergency spillways and stage sensors near Buckeye Lake, Ohio.

4 years of record. Daily lake-level information for Buckeye Lake has been collected since October 16, 1979; however, continuous hourly lake-level information (data of sufficient detail for unsteady-flow modeling) was not collected until May 13, 1993. Calibration of the unsteady-flow model was limited to four well-documented flood events because of these constraints: June 2008, May 2011, October 2011, and December 2011.

For this study, calibration was approximate and focused on the stage sensor located approximately 250 ft (76 m) upstream from I-70 and the South Fork Licking River near Hebron (03145000) streamgage. Only an approximate model calibration was performed due to the fact that all sources of streamflow to the river are not considered in the present model. Of the 133 mi^2 (344.5 km^2) of drainage to the South Fork Licking River near Hebron (03145000) streamgage, total model inputs accounted for only 69 percent. Similar circumstances apply to the stage sensor located just upstream from I-70. The drainage area at this location is 70.7 mi^2 (183.1 km^2), while the model accounted for only 66 percent. No streamflow data were available for the intervening drainage areas.

Approximate calibration was performed by adjusting Manning's roughness coefficients, ineffective flow areas[4], and definition of levees. Levees, in this case, are not FEMA accredited levees but modeling techniques used to prevent flow from moving into areas that are physically separated from the main-channel flow by features such as raised roadways, effectively preventing inundation at levels below the elevation of the separating feature.

It is anticipated that model calibration and refinement will be continued by the NWS. Additional refinement could be achieved by the inclusion of unaccounted for tributary streamflows. Data for tributary streamflows could be estimated by use of a hydrologic model for the South Fork Licking River that the NWS has already developed and may refine as part of its flood-forecasting process.

Summary

A flood-warning network was developed for Licking County, Ohio, by the upgrade of a lake-level gage, the re-establishment and addition of streamgages to the existing network, delineation of flood-inundation boundaries that correspond to selected flood stages, and the development of an unsteady-flow model for use by the National Weather Service (NWS).

The existing streamgage network was enhanced by the re-establishment of one streamgage on North Fork Licking River and the establishment of three new streamgages, one each on Raccoon Creek and the North and South Forks of Licking River. A lake-level gage was upgraded to provide near-real-time data including Web access. Data from the lake-level gage and streamgages could be used by the NWS to improve peak-stage predictions for Raccoon Creek, Licking River, and the North and South Forks of Licking River.

Water-surface profiles were estimated by use of a steady-state step-backwater model, and corresponding flood-inundation areal boundaries were delineated within Licking County for up to 10 stages at the following U.S. Geological Survey (USGS) streamgages: Licking River near Newark, Ohio (03146500), North Fork Licking River at East Main Street at Newark, Ohio (03146402), Raccoon Creek below Wilson Street at Newark, Ohio (03145534), and South Fork Licking River at Heath, Ohio (03145173). The flood-inundation boundaries were overlain on digital orthophotos, and the profiles correspond to streamflows with recurrence intervals ranging from approximately the 50 to 0.2 percent chance annual-exceedance probability floods.

The NWS flood-forecast capability in the Buckeye Lake region was enhanced by the creation of an unsteady-flow model for a reach of the South Fork Licking River. Model calibration, primarily based on four flooding events that occurred from June 2008 to December 2011, was approximate due to the fact that all sources of streamflow to the river were not considered in the present model. Further calibration may be performed by the NWS, as previously unaccounted for streamflow inputs are estimated as part of its flood-forecasting process. Together, the hydrologic and hydraulic models could enable the NWS to provide advanced flood-warning data for the Buckeye Lake region.

Real-time streamgage and lake-level gage 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.

[4] An ineffective-flow area is an area where water is present but is not actively conveyed. Examples include areas such as side channels, pockets of water, and areas upstream and downstream of obstructions such as bridge abutments.

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