Prepared in cooperation with the Northeast Ohio Regional Sewer District Board of Trustees

Flood-Inundation Maps for the Cuyahoga River in and Near Independence, Ohio, 2024

Scientific Investigations Report 2024–5122

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

Cover. Flooding of the Cuyahoga River on Canal Road, facing north towards Interstate 480 in Valley View, Ohio, in 2011. Photograph by The Plain Dealer,

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The content of this report is originally modified from Whitehead and Ostheimer (2009). The data, discussion, and other sections are updated serially as different study areas are investigated with the techniques described in this report (Whitehead, 2011; Whitehead and Ostheimer, 2014, 2015; Whitehead, 2015, 2019; Whitehead and Ostheimer, 2024).

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

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

Datums

Vertical coordinate information is referenced to (1) stage, the height above an arbitrary datum established at a streamgage, and (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).

Abbreviations

AEP	annual exceedance probability
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
HEC–RAS	Hydrologic Engineering Center’s River Analysis System
lidar	light detection and ranging
NWS	National Weather Service
RAS	River Analysis System
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Flood-Inundation Maps for the Cuyahoga River in and Near Independence, Ohio, 2024

By Chad J. Ostheimer and Matthew T. Whitehead

Abstract

Digital flood-inundation maps for a 9.9-mile reach of the Cuyahoga River in and near Independence, Ohio, were created by the U.S. Geological Survey (USGS) in cooperation with the Northeast Ohio Regional Sewer District Board of Trustees. Water-surface profiles were computed for the stream reach by using a one-dimensional steady-state step-backwater model. The model was calibrated to the current (2024) stage-streamflow relation (rating curve 43.0) for the USGS streamgage 04208000, Cuyahoga River at Independence, Ohio. The resulting hydraulic model was then used to compute 13 water-surface profiles for water levels (flood stages) ranging from 14.00 to 26.00 feet. The flood stages range from "action stage" to above "major flood stage" as reported by the National Weather Service. The simulated water-surface profiles were then used in combination with a digital elevation model derived from light detection and ranging data to map the inundated areas associated with each flood profile.

The flood-inundation maps and the supporting hydraulic model produced by this study can be used by emergency managers and local officials to assess flood mitigation strategies and to define flood hazard areas to protect life and property, to coordinate flood response activities such as evacuations and road closures, and to aid postflood recovery efforts.

Introduction

In 2022, the U.S. Geological Survey (USGS), in cooperation with the Northeast Ohio Regional Sewer District Board of Trustees, led a project to produce a library of flood-inundation maps in and near Independence, Ohio. Low-lying areas adjacent to the Cuyahoga River in and near Independence, Ohio are subject to periodic flooding resulting in road closures and damage to homes and businesses. Six flooding events (in 1955, 1989, 1991, 2003, 2004, and 2020) were near the extent of a 10-percent annual exceedance probability (AEP) flood (Federal Emergency Management Agency [FEMA], 2019). The 2003 and 2004 floods resulted in damage in Cuyahoga County costing around $88 million and $23 million, respectively (Brock Metzger, Ohio Emergency Management Agency, written commun., March 4, 2024). Two more flooding events, in 1979 and 2011, were close to the extent of a 2-percent AEP flood (FEMA, 2019), and two floods, in 1959 and 2006, exceeded a 1-percent AEP flood (FEMA, 2019). The 2006 flood resulted in damages in Cuyahoga County exceeding $47 million (Sherwood and others, 2007).

Emergency mangers in and near Independence, Ohio (fig. 1) rely on several information sources to make decisions on how to best alert the public and mitigate flood damages. One source is the FEMA (2019) flood insurance study for Cuyahoga County, Ohio. A second source of information is the data on current and historical water level and streamflow (including annual peak flow) from two USGS streamgages: 04208000, Cuyahoga River at Independence, Ohio and 04208504, Cuyahoga River near Newburgh Heights, Ohio (tables 1 and 2; fig. 1; USGS, 2024a, 2024b), hereafter referred to as the Independence and Newburgh Heights streamgages, respectively. A third source of flood-related information is the National Weather Service (NWS) National Water Prediction Service website, which displays stage height data from the Independence streamgage (the NWS identifies the streamgage with the code "INDO1", fig. 1) and issues forecasts of stages (NWS, 2024). This study provides an additional resource that information emergency managers in and near Independence, Ohio can use to make decisions on how best to alert the public and mitigate flood damages.

Information about the current stage at a USGS streamgage is useful for residents nearby, but it is of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the stream reach. Simply knowing the stage at a streamgage does little to inform nearby residents and officials about the depth and extent of flooding. In addition, flood estimates from stage height increase in uncertainty as the distance from the streamgage increases. One way to address these informational gaps is to produce a library of flood-inundation maps that are referenced to stages at the streamgages. By referring to the appropriate map, emergency responders can better understand the severity of flooding (depth of water and extent), identify roads that are or could soon be flooded, and make plans to notify or evacuate residents that could be in harm's way. In addition, the ability to visualize the potential extent of flooding on a map can motivate residents to take precautions and heed warnings that they previously may have disregarded.

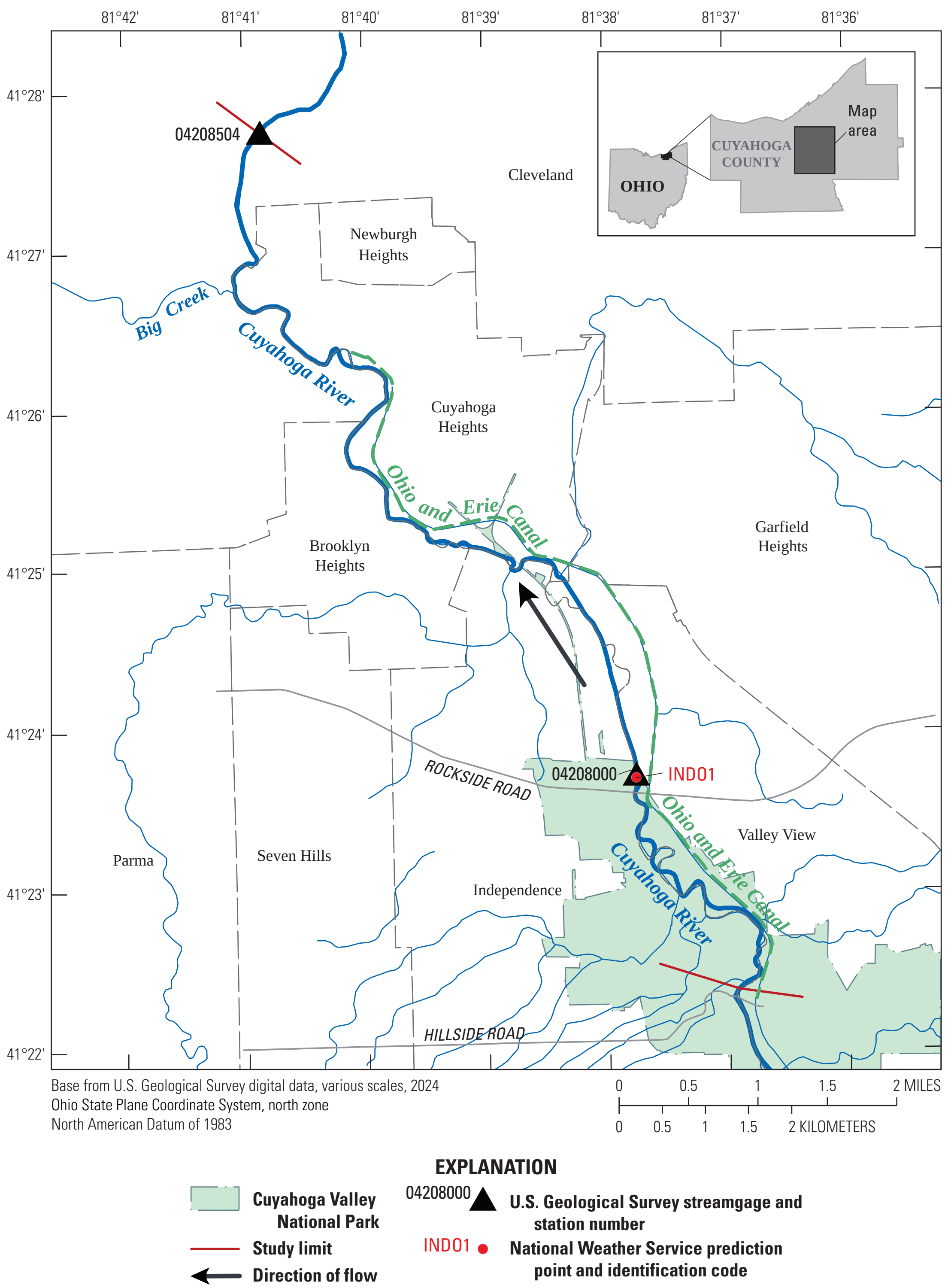

Figure 1. Map showing the study area along the Cuyahoga River and selected tributaries and the locations of the U.S. Geological Survey streamgages 04208000, Cuyahoga River at Independence, Ohio and 04208504, Cuyahoga River at Newburgh Heights, Ohio.

Table 1. Locations and drainage areas of two U.S. Geological Survey streamgages near Independence, Ohio.

[Data from U.S. Geological Survey (2024d). Streamgage locations are shown in figure 1. OH, Ohio]

Streamgage name	Streamgage number	Drainage area (square miles)	Latitude	Longitude
Cuyahoga River at Independence OH	04208000	707	41°23′43″	−81°37′48″
Cuyahoga River near Newburgh Heights OH	04208504	788	41°27′45″	−81°40′52″

Table 2. Maximum stage record at two U.S. Geological Survey streamgages near Independence, Ohio.

[Data from U.S. Geological Survey (2024d). Streamgage locations are shown in figure 1. NAVD 88, North American Vertical Datum of 1988; OH, Ohio]

Streamgage number and name	Streamflow record[1]	Maximum stage			
		Streamgage height (feet)	Maximum stage elevation (feet above NAVD 88)	Streamflow (cubic feet per second)	Date
04208000, Cuyahoga River at Independence OH	Sep. 1921–May 1923, Sep. 1927–Dec. 1935, Mar. 1940–2024	23.29	605.95	25,400	June 23, 2006
04208504, Cuyahoga River near Newburgh Heights OH	1991–2024	77.72	580.13	19,700	March 29, 2020

[1]There are 34 years of data collection at the Cuyahoga River near the Newburgh Heights, Ohio streamgage, but there are only 8 peak flows recorded (U.S. Geological Survey, 2024b).

Study Area

The study reach includes a 9.9-mile (mi) reach of Cuyahoga River and a 6.5-mi reach of the Ohio Canal, also known as the Ohio and Erie Canal, in south-central Cuyahoga County. The area borders the communities of Independence, Valley View, Garfield Heights, Brooklyn Heights, Cuyahoga Heights, Newburgh Heights, and Cleveland, Ohio (fig. 1). The geographic limits of the hydraulic analyses of the Cuyahoga River are the Newburgh Heights streamgage at the downstream end and Hillside Road (which is about 2.4 mi upstream from the Independence streamgage) at the upstream end. During times of flooding, it is possible for streamflow to pass either from the Cuyahoga River to the Ohio Canal or in the reverse direction in various areas of low-lying terrain along the study reach. The contributing drainage areas of the Independence and Newburgh Heights streamgages are 707 and 788 square miles, respectively (table 1). The two streamgages have different periods of record; the Independence streamgage was established in September 1921. The area closest to the Independence streamgage is primarily urban, but about 500 feet (ft) upstream from the streamgage the river flows through the Cuyahoga Valley National Park (50.9 square miles of mostly forested and undeveloped area; National Park Service, 2024). The Newburgh Heights streamgage was established in October 1991. It is surrounded by urban and industrial areas and is subject to backwater from Lake Erie; it was used in some calculations, but it was not useful for establishing a stage-streamflow relation as any particular stage could be associated with multiple streamflows.

Previous Studies

The most recent flood insurance study for Cuyahoga County, Ohio was published in August of 2019 (FEMA, 2019). That study re-delineates the areas prone to large floods corresponding to 10-, 2-, 1-, and 0.2-percent AEP floods from work that originated in 1998. The 2019 flood insurance study detailed flooding analyses for the Cuyahoga River that include, and extend beyond, the upstream and downstream limits of the study reach. Selected AEPs for the Independence and Newburgh Heights streamgage locations are shown in table 3.

Table 3. Peak streamflows for selected annual exceedance probabilities for the U.S. Geological Survey streamgages 04208000, Cuyahoga River near Independence, Ohio and 04208504, Cuyahoga River near Newburgh Heights, Ohio.

[Data from Federal Emergency Management Agency (2019). USGS, U.S. Geological Survey; mi^2, square mile; ft^3/s, cubic foot per second; OH, Ohio]

USGS streamgage number and name	Estimated streamflows (ft^3/s) for indicated annual exceedance probabilities (percent)			
	10	2	1	0.2
04208000, Cuyahoga River at Independence OH	14,300	19,500	21,900	27,800
04208504, Cuyahoga River near Newburgh Heights OH[1]	16,505	22,764	25,625	33,500

[1]This location is referred to in the Federal Emergency Management Agency flood insurance study as “At confluence with Big Creek” (Federal Emergency Management Agency, 2019).

Methods

The current (2024) stage-streamflow relation (number 43.0; USGS, 2024c) at the Independence streamgage was used to input streamflows in the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center’s River Analysis System (HEC–RAS) version 6.3.1 (USACE, 1995). The HEC–RAS software was used to develop 13 water-surface profiles, corresponding to the stages between 14.00 and 26.00 ft in 1-ft increments (table 4).

At the low end of the range, the 14.00-ft stage corresponds approximately to bankfull conditions at the Independence streamgage location; "bankfull" is defined by the NWS (undated) as the “action stage” or “the stage which, when reached by a rising stream, represents the level where the NWS or a partner/user needs to take some type of mitigation action in preparation for possible significant hydrologic activity.” At the upper end of the range, the 26.00-ft stage exceeds the “major flood stage” (21.00 ft) as defined by NWS. The NWS (undated) defines major flooding as “a general term including extensive inundation and property damage. (Usually characterized by the evacuation of people and livestock and the closure of both primary and secondary roads.)”

Standard Procedures for Creating a Flood Map

The USGS has standardized procedures for creating flood-inundation maps for flood-prone communities to ensure that the methods used and products produced are consistent (USGS, 2018). Tasks specific to development of the flood maps were to (1) collect topographic, bathymetric, and geometric data for selected cross sections and structures (such as bridges or culverts) along the study reach, (2) estimate energy-loss factors (roughness coefficients) in the stream channel and floodplain, (3) determine streamflows for each stage to be modeled, (4) compute and calibrate water-surface profiles using HEC–RAS (USACE, 1995, 2024), (5) produce estimated flood-inundation maps for selected stages by using the RAS Mapper (a feature within HEC–RAS; USACE, undated) and a geographic information system, and (6) prepare maps as shapefile polygons that depict the extent of flood inundation and as depth grids that provide the depth of floodwaters for display on a USGS flood inundation mapping application. These methods follow procedures described in Bales and others (2007) and Whitehead and Ostheimer (2009). Techniques that were modified significantly from previously documented methods to accommodate local hydrologic conditions or availability of data are described in detail in this report.

Topographic Data

All the topographic data used in this study are referenced vertically to the North American Vertical Datum of 1988 (NAVD 88) and horizontally to the North American Datum of 1983 (NAD 83). Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from lidar data collected from November 2019 to March 2020 for the Ohio Geographically Referenced Information Program (undated) as part of the USGS 3D Elevation Program (USGS, undated a). The DEM is USGS Quality Level 3 (USGS, undated a) with a cell size of 1.25 ft, a nominal

Table 4. Minimum and maximum target water-surface stages and National Weather Service designated stages for U.S. Geological Survey streamgage 04208000, Cuyahoga River at Independence, Ohio.

[Data from U.S. Geological Survey (2024a) and National Weather Service (2024). All data are shown in feet. OH, Ohio]

Streamgage number and name	Minimum stage included in this report	Maximum stage included in this report	Action stage	Major flood stage
04208000, Cuyahoga River at Independence OH	14.00	26.00	14.00	21.00

pulse spacing of 1.4 m (0.43 ft), and a vertical root mean square error of 20 centimeters (0.60 ft). Lidar is a technology comprised of a global positioning system, an inertial navigation system, and a laser scanner (typically mounted in a small aircraft) that transmits brief pulses of light to the ground surface (USGS, 2024e). Those pulses are reflected, or scattered back, and their travel time is used to calculate the distance between the laser scanner and the ground.

RAS Mapper within HEC–RAS was used to extract distance and elevation data from the DEM for all 211 cross sections (table 5) for use in HEC–RAS. The DEM-derived cross sections were co-located with the field-surveyed cross sections where possible. In those cases, DEM-based elevations were combined with the survey elevations to form composite cross sections. In-channel elevations and dimensions for DEM-derived cross sections that did not have surveyed elevations were estimated by interpolating between the closest field-surveyed cross sections as a function of distance along the hydraulic baseline. The average distance between cross sections (both conventionally surveyed and DEM-derived) was 246 ft.

Bathymetric and Structure Data

Channel cross sections were surveyed to collect elevations and dimensions below the water surface that are not provided by conventional light detection and ranging (lidar). Structures that had the potential to affect water-surface elevations during floods along the streams were also surveyed.

The USGS used a differential global positioning system and differential-leveling (hereafter referred to as conventional) surveys for this study. Differential global positioning system surveys were completed using Level III real-time network surveying techniques (Rydlund and Densmore, 2012) and were used to establish an elevation control network at selected locations along the study reach. Elevations determined using the differential global positioning system at five benchmark locations (table 6) had a root mean square error of 0.10 ft when compared with National Geodetic Survey published elevations (National Oceanic and Atmospheric Administration, undated a).

The USGS used the elevation control network to complete conventional surveys at each structure to obtain its geometry. All conventional surveys were done to third-order accuracy criteria in both horizontal and vertical directions (Federal Geodetic Control Committee, 1984). USGS field crews surveyed a total of four hydraulic structures along the Cuyahoga River from February to May of 2023. Geometric data for an additional 12 structures were obtained from as-built plans from the Cuyahoga County Engineers Office (Cuyahoga County, Ohio, 2024).

Bathymetry data for cross sections were obtained from the U.S. Fish and Wildlife Service that were collected as part of their Cuyahoga River Lake Sturgeon Reintroduction Plan (Fischer and others, undated; Fischer, 2021; Lebson, 2024). The U.S. Fish and Wildlife Service used an acoustic Doppler current profiler equipped with a differential global positioning system receiver to obtain bathymetry at 87 cross-section locations within the study reach during April and May of 2022. In the spring of 2023, the USGS used conventional surveys to obtain data for seven additional cross sections to ensure that no reach length between cross sections was greater than 1 mi. The maximum distance between cross sections was 1,163 ft, with an average distance of 551 ft. In total, field data were collected at 94 cross sections and included 16 structures (table 5).

Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses that result from frictional resistance between the streamflow and the channel. The amount of frictional resistance may be quantified by the Manning's roughness coefficient ("*n*" value). Initial (precalibration) *n* values were selected based on field observations and high-resolution aerial photographs (Esri and others, 2009). As part of the water-surface elevation calibration process, the initial *n* values were adjusted until the differences between computed and observed water-surface elevations at the Independence streamgage were minimized. For the Cuyahoga River, the final *n* values ranged from 0.035 to 0.041 for the main channel and from 0.030 to 0.076 for the overbank (floodplain) areas (table 5). As noted in the "Study Area" section, the floodplains in the Cuyahoga Valley National Park are mostly open grassy fields or forested areas, whereas the floodplains from near the Independence streamgage to the downstream limit are primarily urban. The stream channel throughout the study reach is mainly composed of sand, gravel, and cobble; tall grasses and some light underbrush grow along the channel banks.

Table 5. Survey characteristics and hydraulic parameters used to create the Cuyahoga River hydraulic model.

[Data from Ostheimer and Whitehead (2024)]

Study reach length (miles)	Total number of cross sections	Number of surveyed cross sections	Number of hydraulic structures	Manning's roughness coefficient (*n*)			
				Main channel		Overbanks	
				Lowest value	Highest value	Lowest value	Highest value
9.9	211	94	16	0.035	0.041	0.030	0.076

Table 6. Comparisons of published National Geodetic Survey benchmark coordinates and elevations to those surveyed by the U.S. Geological Survey.

[Data from National Oceanic and Atmospheric Administration (undated a). All data are shown in feet relative to the Ohio State Plane Coordinate System (Ohio North); horizontal datum is the North American Datum of 1983 and vertical datum is the North American Vertical Datum of 1988. NGS, National Geodetic Survey; USGS, U.S. Geological Survey; NA, not applicable]

NGS benchmark name	Permanent identifier[1]	Published by NGS			Surveyed by USGS			Difference of USGS from NGS		
		Northing	Easting	Elevation	Northing	Easting	Elevation	Northing	Easting	Elevation
1075	MB1507	NA	NA	684.03	NA	NA	684.18	NA	NA	0.15
OM 344	MB3191	663,511.68	2,182,812.34	681.13	663,511.57	2,182,812.28	681.00	−0.11	−0.06	−0.13
282	MB1787	NA	NA	672.89	NA	NA	672.80	NA	NA	−0.09
880	MB1793	NA	NA	684.32	NA	NA	684.27	NA	NA	−0.05
275	MB1258	NA	NA	803.83	NA	NA	803.83	NA	NA	0.00

[1]Permanent identifier refers to the designation given to the benchmark by the National Geodetic Survey (National Oceanic and Atmospheric Administration, undated a).

Hydrologic Data

The study reach includes two streamgages (fig. 1; tables 1 and 2). The stage is measured every 15 minutes, transmitted hourly by a satellite radio in the streamgage, and made available on the internet through the USGS National Water Information System (USGS, 2024d). Stage data for the Independence and Newburgh Heights streamgages are referenced to a local datum but can be converted to water-surface elevations referenced to NAVD 88 by adding 582.66 ft and 502.41 ft, respectively (USGS, 2024a, 2024b). Vertical datum surveys for the Independence and Newburgh streamgages were completed in April of 2013 using Level III real-time network surveying techniques (Rydlund and Densmore, 2012) and have a vertical accuracy of 0.09 foot. Continuous records of streamflow (USGS, 2024d) are computed from a stage-streamflow relation (USGS, 2024c) which has been developed for the streamgages, and are also available through the USGS National Water Information System website.

For the profiles up to a stage of 22.00 ft (table 7), the streamflows used in the model simulations were obtained from the current stage-streamflow relation (rating curve 43.0) for the Independence streamgage. For profiles above a stage of 22.00 ft, streamflows were obtained from a theoretical rating curve developed as part of this study (table 7). The theoretical rating curve is based on the same hydraulic model used in this study model whereby streamflows in the model were increased until the resulting water-surface elevation at the Independence streamgage matched the desired targeted stages (stages 23.00 ft, 24.00 ft, 25.00 ft, and 26.00 ft).

There are several small tributaries within the study reach (fig. 1). The largest of the tributaries is Big Creek (more than twice the size of the next biggest tributary in the study area), with a drainage area of 37.6 square miles at the confluence with the Cuyahoga River. These tributary flows need to be factored into the hydrologic model of the Cuyahoga River. To ensure that the Cuyahoga River streamflows were not underestimated and to simplify the adjustment calculation, the target streamflows on the Cuyahoga River downstream from Big Creek were increased (table 7) using a simple ratio of drainage areas at the Newburgh Heights and the Independence streamgages (table 8). The adjusted streamflow in the Cuyahoga River downstream from Big Creek was found by multiplying the Independence streamgage by the drainage area at Newburgh Heights streamgage and dividing by the drainage area at the Independence streamgage. The drainage area of the upstream end of the reach has only a small difference from the drainage area of the downstream end of the reach (1.1 percent and 11.5 percent respectively; table 8).

Table 7. Selected stages and associated streamflows for respective stage-streamflow relations for the U.S. Geological Survey streamgage 04208000, Cuyahoga River at Independence, Ohio.

[Data from U.S. Geological Survey (2024c) and Ostheimer and Whitehead (2024). ft, foot; ft^3/s, cubic foot per second; NAVD 88, North American Vertical Datum of 1988]

Stage[1] (ft)	Elevation (ft, NAVD 88)	Streamflow[2] (ft^3/s)	Drainage-area adjusted streamflow[3] (ft^3/s)
14.00	596.66	7,460	8,320
15.00	597.66	8,190	9,130
16.00	598.66	8,960	9,990
17.00	599.66	9,730	10,800
18.00	600.66	10,600	11,800
19.00	601.66	11,500	12,800
20.00	602.66	12,700	14,200
21.00	603.66	14,000	15,600
22.00	604.66	15,400	17,200
23.00	605.66	20,200	22,500
24.00	606.66	22,900	25,500
25.00	607.66	26,300	29,300
26.00	608.66	30,000	33,400

[1]Flood profiles are 1-foot increments of stage, referenced to the gage datum of the streamgage 04208000, Cuyahoga River at Independence, Ohio.

[2]Streamflows above stage 22.00 are estimates based on a theoretical rating for the streamgage 04208000, Cuyahoga River at Independence, Ohio.

[3]Drainage-area adjusted streamflows include assumed inflow from Big Creek and were estimated by multiplying the streamflows from the Independence streamgage by the ratio of the drainage areas for the Newburgh Heights and Independence streamgages (788 square miles divided by 707 square miles).

Table 8. Drainage areas and percentages for selected locations on the Cuyahoga River.

[Data from U.S. Geological Survey (2024d) and Ostheimer and Whitehead (2024). ft^3/s, cubic foot per second; USGS, U.S. Geological Survey; OH, Ohio]

Location	Cross section[1]	Drainage area (mi^2)	Percentage of drainage area compared to Independence streamgage location
Bottom of the study reach (at USGS streamgage 04208504, Cuyahoga River near Newburgh Heights OH)	0	788	111.5
At USGS streamgage 04208000, Cuyahoga River at Independence OH	38,839	707	100.0
Top of the reach (at the foot bridge upstream from Hillside Road)	51,905	699	98.9

[1]Cross section numbers are referenced (in feet) above the hydraulic baseline used in the hydraulic model. For this study, the hydraulic baseline is approximately 30 feet downstream from the downstream side of the walkway bridge at the USGS streamgage 04208504, Cuyahoga River near Newburgh Heights OH.

Computation of Water-Surface Profiles

The water-surface profiles used to produce the 13 flood-inundation maps in this study were computed by using HEC–RAS version 6.3.1 (USACE, 1995). HEC–RAS is a one- or two-dimensional step-backwater model used to simulate water-surface profiles with steady-state (gradually varied) or unsteady-state flow computation options. The one-dimensional steady-state option was used for this study.

Hydraulic Model

The HEC–RAS analysis for this study was completed using the steady-state flow computation option. Steady-state flow inputs were the flow regime, boundary conditions, and streamflow values that produced water-surface elevations at the streamgage cross section that matched target water-surface elevations. These target elevations coincided with 1-ft increments of stage referenced to the local gage datum for the Independence streamgage. A subcritical (tranquil) flow regime was assumed for the simulations.

The Newburgh Heights streamgage is subject to backwater from Lake Erie. This precludes the establishment or use of a traditional stage-streamflow relation because a particular stage at Newburgh Heights streamgage can be associated with multiple streamflows. Still-water elevations are defined by FEMA (2019) as the surface of the water resulting from astronomical tides, storm surge, and freshwater inputs, but excluding wave setup contribution or the effects of waves. As a result of backwater, the hydraulic model downstream boundary conditions (table 9) for the various profiles were based on information for the 10-percent to 0.2-percent AEP floods (that is, the corresponding water-surface elevations and streamflows) at the Newburgh Heights streamgage as given in the 2019 flood insurance study for Cuyahoga County (fig. 2; FEMA, 2019).

Flood profiles associated with stages of 22.00 to 26.00 ft at the Independence streamgage have corresponding drainage-area adjusted streamflows (table 7; see discussion in “Hydrologic Data”) that are between the 10-percent and 0.2-percent AEP floods at the Newburgh Heights streamgage (tables 3 and 7); therefore, the starting boundary conditions for these five profiles were set to known water-surface elevations

Table 9. Stages and slopes used to create the Cuyahoga River hydraulic model.

[Data from Ostheimer and Whitehead (2024). ft, foot; ft/ft, foot per foot slope]

Stage	Downstream hydraulic model boundary condition
14.00–21.00 ft	Normal-depth slope[1, 2] of 0.000645 ft/ft
22.00 ft	Known water-surface elevation[3] of 580.62 ft
23.00 ft	Known water-surface elevation[3] of 583.08 ft
24.00 ft	Known water-surface elevation[3] of 584.45 ft
25.00 ft	Known water-surface elevation[3] of 585.85 ft
26.00 ft	Known water-surface elevation[3] of 587.36 ft

[1]Normal depth is the depth when the streamflow is uniform, steady, one-dimensional, and is not affected by downstream obstructions. Flow is considered uniform if the energy line, water surface, and channel bottom all are parallel (Chow, 1959).

[2]The normal-depth slope is the slope that resulted in a water-surface elevation for stage 21.00 ft that reproduced the 10-percent annual exceedance probability flood elevation as given in the 2019 flood insurance study for Cuyahoga County (Federal Emergency Management Agency, 2019).

[3]Water-surface elevations for stages 22.00–26.00 ft were based on linear interpolations of information for the 10-percent to 0.2-percent annual exceedance probability floods (water-surface elevations and their corresponding streamflows) as given in the 2019 flood insurance study for Cuyahoga County (Federal Emergency Management Agency, 2019).

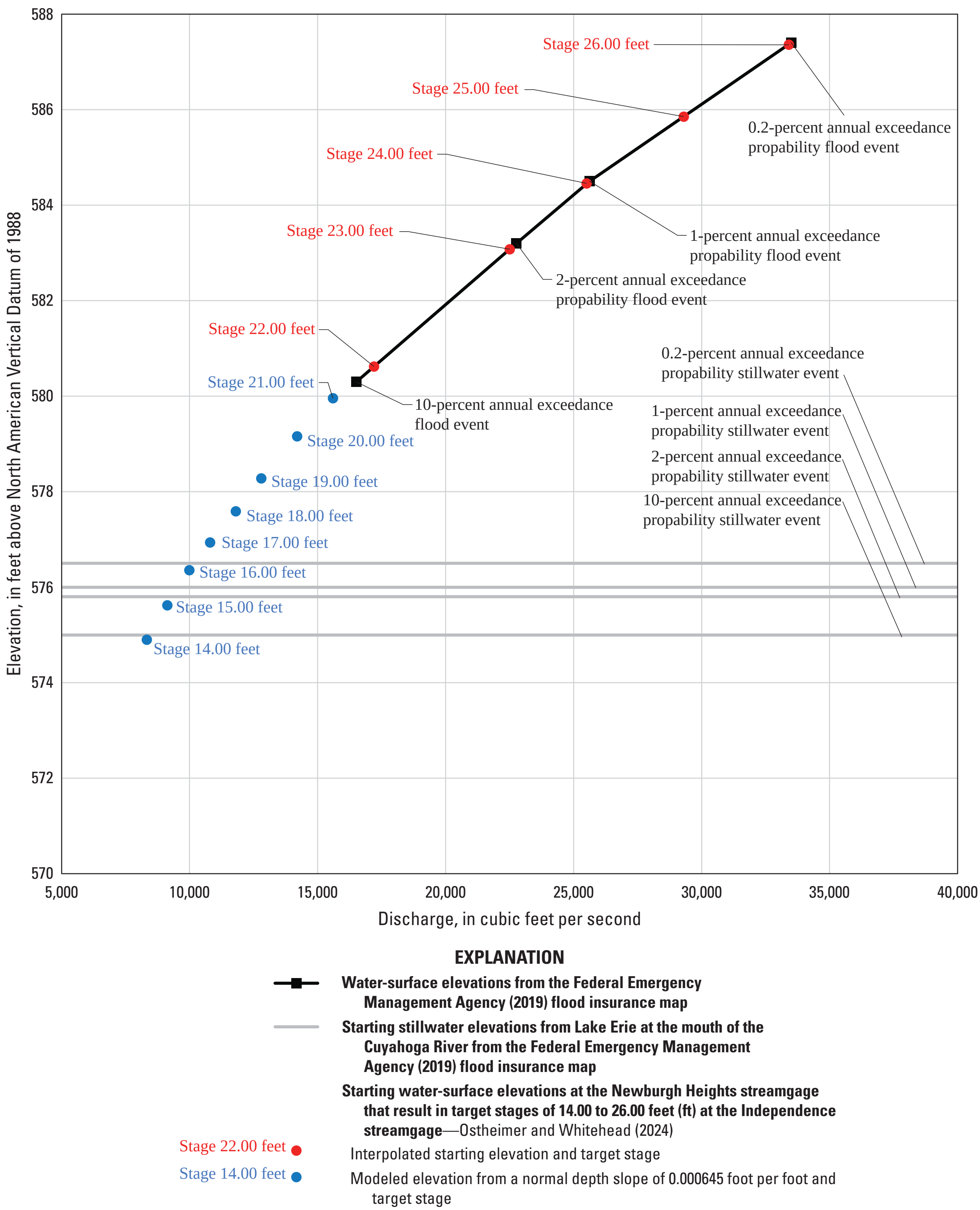

Figure 2. Starting Cuyahoga River water-surface elevations and Lake Erie still-water elevations at U.S. Geological Survey streamgage 04208504, Cuyahoga River at Newburgh Heights, Ohio, that result in target stages at the U.S. Geological Survey streamgage 04208000, Cuyahoga River at Independence, Ohio.

(table 9) based on interpolation between the 10-percent to 0.2-percent AEP water-surface elevations in the 2019 flood insurance study (FEMA, 2019) at the Newburgh Heights streamgage.

Normal depth is defined as the depth when the streamflow is uniform, steady, one-dimensional, and unaffected by downstream obstructions. Streamflow is considered uniform if the energy line, water surface, and channel bottom all are parallel (Chow, 1959). For stages 14.00 to 21.00 ft at the Independence streamgage, the corresponding drainage-area adjusted streamflows are all less than the 10-percent AEP flood (16,505 ft^3/s) at the Newburgh streamgage (tables 3 and 7). To avoid a straight-line extrapolation of the water-surface elevations below the 10-percent AEP flood at the Newburgh Heights streamgage, the starting water-surface elevations for stages 14.00 to 21.00 ft at the Newburgh Heights streamgage were all based upon a single normal-depth slope of 0.000645 ft/ft (fig. 2). This normal-depth slope was found by calibrating the model's starting slope to reproduce the 10-percent AEP flood water-surface elevation (580.30 ft; FEMA, 2019) associated with the corresponding streamflow at the Newburgh Heights streamgage.

The resulting starting water-surface elevations for stages 14.00 to 16.00 ft could be affected by backwater from Lake Erie for a near 10-percent AEP storm surge flood event or a less frequent AEP storm surge flood event (fig. 2). The chances are unknown, but likely small, for a simultaneous Lake Erie storm surge event and a flood event on the Cuyahoga River for stages 14.00 to 16.00 ft. Even with a 0.2 percent AEP storm surge event on Lake Erie, the flooding for stages 16.00 ft and lower are contained within the channel of the Cuyahoga River from the Newburgh Heights streamgage upstream beyond the Independence streamgage.

A comparison of the modeled and target water-surface elevations at the Independence streamgage is given in table 10. As described in the "Hydrologic Data" section, the target water-surface elevations for stages 23.00 to 26.00 ft in the current (2024) stage-streamflow relation (rating number 43.0) are based on the theoretical rating developed from this modeling effort. As a result, the differences in the modeled to target water-surface elevations for stages 23.00 to 26.00 ft were excluded from any root mean square error calculations of the differences between modeled to target water-surface elevations. The root mean square error of the differences between the modeled to target water-surface elevations for stages 14.00 to 22.00 ft is 0.34 ft.

The error between the modeled and target water-surface elevations is larger for the lower water-surface stages. One potential reason for this difference could be the assumption of a constant normal-depth starting water-surface slope for stages of 14.00 to 21.00 ft. The normal depth slope likely varies with streamflow, but due to the variable backwater conditions at the Newburgh Heights streamgage it became very difficult to estimate the slope. All the flooding in stages 17.00 ft and lower have modeled water-surface elevation errors greater than 0.20 ft; almost all of the flooding extent of these stages is contained within the channel of the Cuyahoga River. The only flooding outside the channel for these stages is within the undeveloped Cuyahoga Valley National Park area immediately upstream from Rockside Road.

Table 10. Calibration of model to target water-surface elevations at the U.S. Geological Survey streamgage 04208000, Cuyahoga River at Independence, Ohio.

[Data from Ostheimer and Whitehead (2024). ft, foot; NAVD 88, North American Vertical Datum of 1988]

Stage of water-surface profile (ft)	Water-surface elevation (ft above NAVD 88)		Difference (ft)
	Target	Modeled	
14.00	596.66	597.36	0.70
15.00	597.66	598.20	0.54
16.00	598.66	599.06	0.40
17.00	599.66	599.93	0.27
18.00	600.66	600.85	0.19
19.00	601.66	601.67	0.01
20.00	602.66	602.63	−0.03
21.00	603.66	603.67	0.01
22.00	604.66	604.68	0.02
[1]23.00	605.66	605.66	0.00
[1]24.00	606.66	606.66	0.00
[1]25.00	607.66	607.67	0.01
[1]26.00	608.66	608.67	0.01

[1]Stages above stage 22 are estimates based on a theoretical rating curve for the streamgage 04208000, Cuyahoga River at Independence, Ohio.

Development of Water-Surface Profiles

The calibrated hydraulic model was used to generate water-surface profiles for 13 stages at 1-ft intervals from 14.00 and 26.00 ft as referenced to the local datum of the Independence streamgage. These stages correspond to elevations from 596.66 to 608.66 ft NAVD 88, respectively. Streamflows corresponding to the various stages were obtained from the current stage-streamflow relation for the Independence streamgage.

Development of Flood-Inundation Maps

Flood-inundation maps for the 13 water-surface profiles were created using geographic information system software by combining the water-surface profiles and DEM data. Estimated flood-inundation boundaries and depth grids were developed for each simulated water-surface profile with RAS Mapper—a feature within HEC–RAS (USACE, undated) that allows the preparation of geometric data for import into HEC–RAS and processes simulation results exported from HEC–RAS. Shapefile polygons and depth grids of the inundated areas for each water-surface profile were manually edited using geographic information system software to ensure a hydraulically reasonable transition of the flood boundaries among modeled cross sections.

Any inundated areas that were detached from the main channel were examined to identify subsurface connections with the Cuyahoga River or the Ohio Canal, such as culverts or similar engineering structures under roadways. Where such connections existed, the mapped inundated areas were retained in their respective flood maps; otherwise, the erroneously delineated parts of the flood extent were deleted. The flood-inundation areas were overlain on high-resolution, georeferenced aerial photographs (Esri and others, 2009) of the study area. One example of a profile (stage 26.00 ft) overlain on orthorectified imagery can be seen in figure 3. Bridge surfaces are shown as not inundated up to the lowest flood stage that completely inundates one or both road approaches to the bridge. Estimates of water depths can be determined from the depth-grid data that are included with the maps on an interactive mapping application (USGS, undated b) described in the following section, “Data Dissemination.”

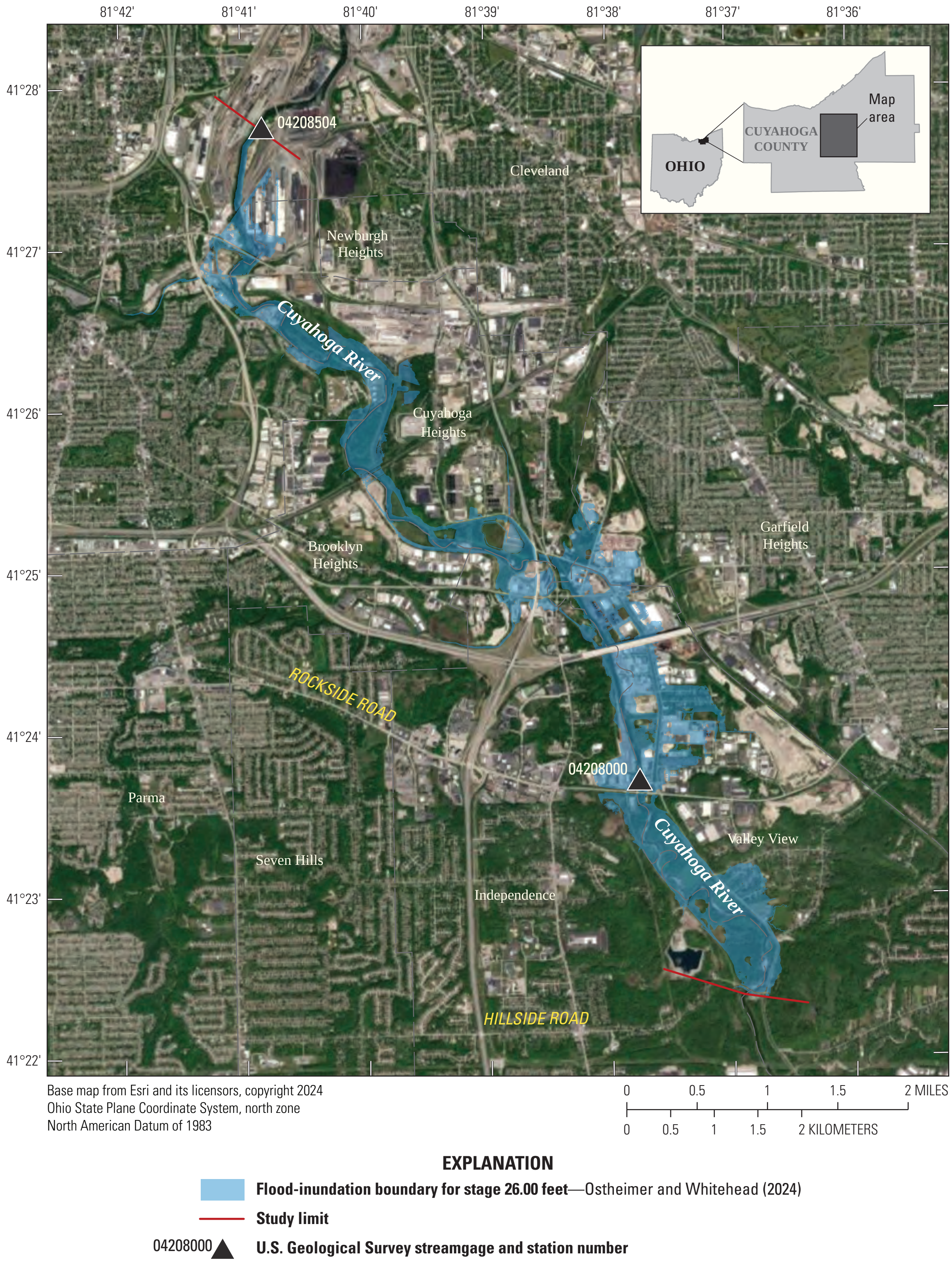

Figure 3. Map showing the floodplain boundary for stage 26.00 ft at the U.S. Geological Survey streamgage 04208000, Cuyahoga River at Independence, Ohio overlain on orthorectified imagery.

Data Dissemination

All data used in the creation of the flood-inundation boundaries are available through a companion USGS data release (Ostheimer and Whitehead, 2024). The data release includes flood inundation polygons and depth grids for each 1-ft increment of stage and the HEC–RAS model containing all input and output files involved with the hydraulic simulation.

The Flood Inundation Mapper website (https://fim.wim.usgs.gov/fim/; USGS, undated b) was established to make USGS flood-inundation study information available to the public. The website links to a mapping application with collections of maps that provide detailed information on flood extents and depths for modeled sites. The website enables the production of customized flood-inundation maps for the Independence streamgage. A link on the Flood Inundation Mapper website connects to the USGS National Water Information System, which presents the current stage and streamflow at the Independence streamgage (USGS, 2024a), to which the inundation maps are referenced. A second link connects to the NWS National Water Prediction Service website (NWS, 2024) so that during periods of high water users can obtain information on forecasted peak stages. The estimated flood-inundation maps have sufficient detail to allow for accurate preparation and decision-making by emergency response teams. Depending on the flood magnitude, roadways are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning. Buildings are shaded where ground surfaces near the building are inundated (this should not be interpreted to mean that the structure is completely submerged). In these instances, the water depth (as indicated in the mapping application by clicking on an inundated area) near the building would be an estimate of the water level inside the structure, if no flood-proofing measures had been implemented.

Uncertainties and Limitations of Flood-Inundation Maps

Although the flood-inundation maps represent the boundaries of floods with a distinct area, some uncertainty is associated with these maps. The flood boundaries shown were estimated on the basis of 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 used streamflows and hydrologic conditions anticipated at the USGS streamgages. The hydraulic model reflects the land-cover and land-use characteristics and any bridge, dam, levee, or other hydraulic structures existing as of October 2023. Unique meteorological factors (such as timing and distribution of precipitation) may cause actual streamflows along the modeled reach to be different from those assumed during a flood, which may lead to deviations from the water-surface elevations and inundation boundaries shown here and in the datasets. Additional areas may be flooded because 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 floodwater extent portrayed on these maps will vary with the accuracy of the DEM used to simulate the land surface.

If this series of flood-inundation maps will be used in conjunction with NWS river forecasts, there may be additional uncertainties. The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States (National Oceanic and Atmospheric Administration, undated b). 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 (National Water Prediction Service forecast point) throughout the forecast period (every 6 hours for the upcoming 3 to 5 days in many locations).

For this study, floodplain boundaries for stages 14.00 to 16.00 ft may be influenced by storm surge events from Lake Erie for a near 10-percent AEP storm surge flood event or more extensive AEP storm surge flood event. The chances for a simultaneous Lake Erie storm surge event and a flood event on the Cuyahoga River are unknown but are likely small. This study shows that even with a 0.2 percent AEP storm surge event on Lake Erie, the flooding for stages 16.00 ft and lower along the study reach is contained within the channel of the Cuyahoga River from the Newburgh Heights streamgage up through the Independence streamgage (Ostheimer and Whitehead, 2024).

Floodplain boundaries for stages above 23.29 ft at the Independence streamgage have greater uncertainty relative to boundaries associated with lower stages because no streamflow measurements at the Independence streamgage have been made above stage 23.29 ft, which is the record flow recorded on June 23, 2003 (USGS, 2024a). The current stage-streamflow relation for the Independence streamgage extends to stage 26.00 ft (USGS, 2024c). While the model is expected to produce reasonable results for the full range of projected streamflows, results for stages above 23.29 ft cannot be verified with stage-streamflow data available as of this writing.

Summary

The U.S. Geological Survey (USGS) developed a series of 13 digital flood-inundation maps in cooperation with the Northeast Ohio Regional Sewer District Board of Trustees for a 9.9-mile reach of the Cuyahoga River in and near

Independence, Ohio, calibrated to the USGS streamgage 04208000, Cuyahoga River at Independence, Ohio. The U.S. Army Corps of Engineers' HEC–RAS and RAS Mapper programs were used to compute water-surface profiles and to delineate estimated flood-inundation areas and depths of flooding for stages 14.00 to 26 ft. The HEC–RAS hydraulic model was calibrated to the current stage-streamflow relation (rating curve 43.0) at the Independence streamgage. The model was used to compute 13 water-surface profiles for flood stages from "action stage" to above "major flood stage," as reported by the National Weather Service. The computed water-surface profiles were then used in combination with a digital elevation model, derived from light detection and ranging (lidar) data, to delineate estimated flood-inundation areas and flood depth grids. The flood maps are available through a mapping application that can be accessed on the USGS Flood Inundation Mapper website (https://fim.wim.usgs.gov/fim/).

Interactive use of the maps on this mapping application can give users a general indication of depth of water at any point in the flood zone. These maps, in conjunction with the real-time stage data from the USGS streamgages and forecasted flood stage data from the National Weather Service National Water Prediction Service, can help emergency planners and the public make more informed decisions about flood risk.

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