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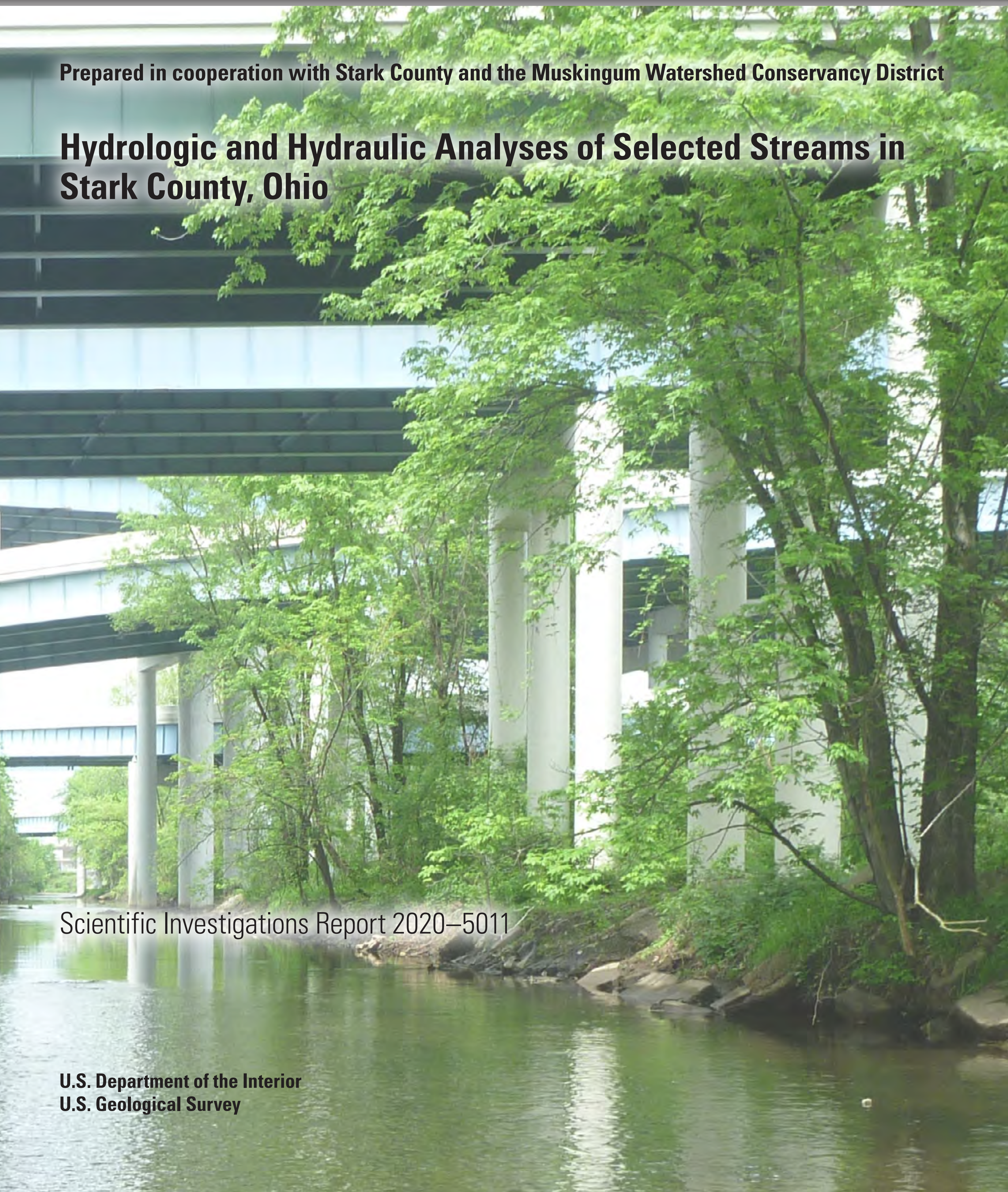

Prepared in cooperation with Stark County and the Muskingum Watershed Conservancy District

Hydrologic and Hydraulic Analyses of Selected Streams in Stark County, Ohio

Scientific Investigations Report 2020–5011

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

Cover. View looking upstream from the U.S. Route 30 and Interstate 77 interchange over West Branch Nimishillen Creek in Canton, Ohio. Photograph by U.S. Geological Survey, May 2018.

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U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2020

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
inch (in)	25.4	millimeter (mm)
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)

Datum

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
FIS	Flood Insurance Study
HEC–GeoRAS	Hydrologic Engineering Center-GeoRiver Analysis System
HEC–RAS	Hydrologic Engineering Center-River Analysis System
lidar	light detection and ranging
NWS	National Weather Service
USGS	U.S. Geological Survey

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Abstract

To update and expand a part of the Federal Emergency Management Agency Flood Insurance Study, the U.S. Geological Survey, the Muskingum Watershed Conservancy District, and the Stark County Commissioners began a cooperative study. The study consisted of hydrologic and hydraulic analyses for selected reaches of 14 streams in Stark County, Ohio: Broad-Monter Creek, Chatham Ditch, East Branch Nimishillen Creek, Fairhope Ditch, Firestone Ditch, Hayden Ditch, Middle Branch Nimishillen Creek, Middle Branch Nimishillen Creek Tributary Number 1, Nimishillen Creek, Reemsnyder Ditch, Sherrick Run, unnamed stream, West Branch Nimishillen Creek, and Zimber Ditch. The study totaled nearly 50 miles of stream reaches.

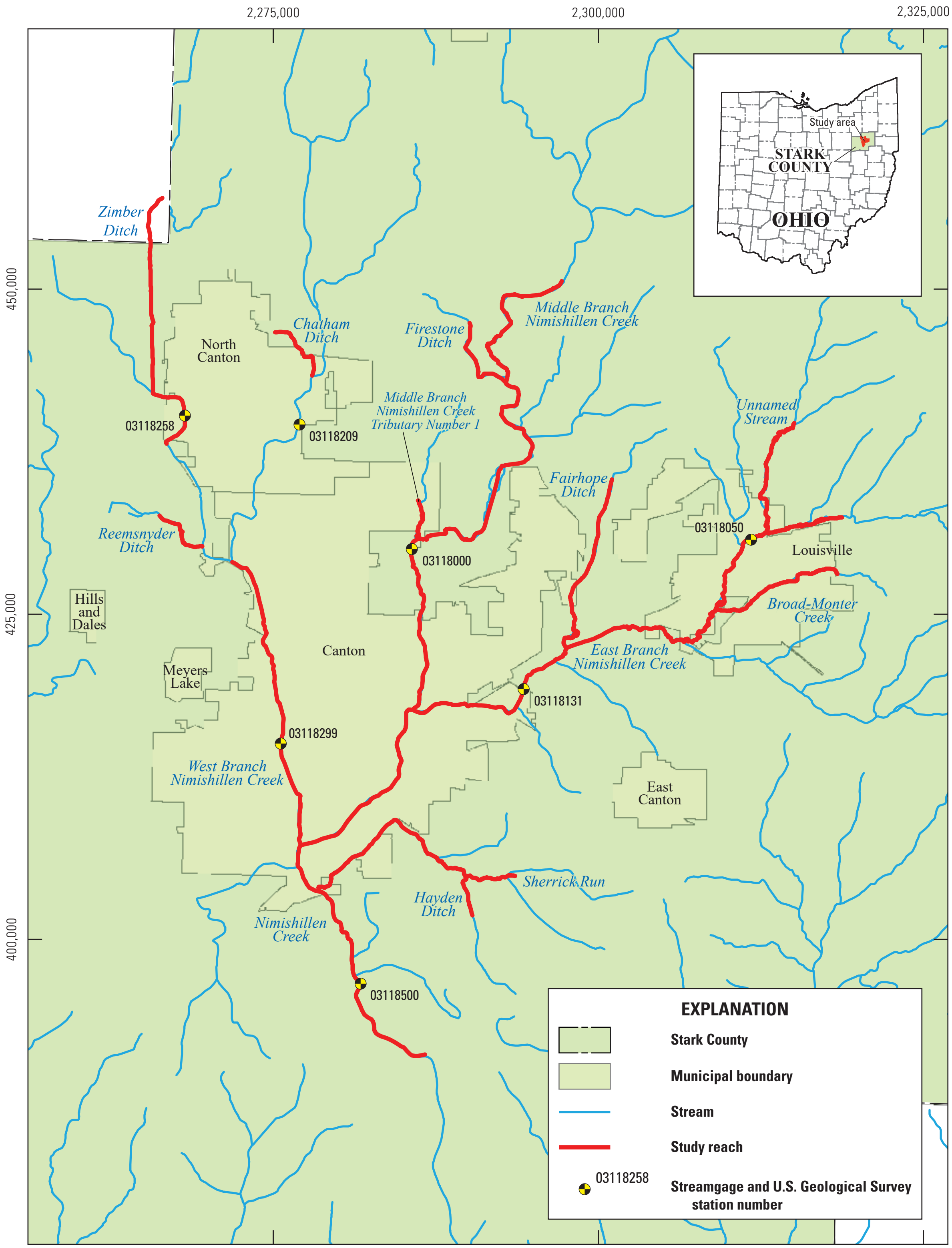
Instantaneous peak streamflows for floods with 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus annual exceedance probabilities were estimated using historical streamflow data from the streamgages Nimishillen Creek at North Industry, Ohio (U.S. Geological Survey station number 03118500), and Middle Branch Nimishillen Creek at Canton, Ohio (U.S. Geological Survey station number 03118000), regional flood regression equations, and streamflow urbanization techniques.

The annual exceedance probability streamflows were then used in a Hydrologic Engineering Center-River Analysis System step-backwater model to determine water-surface profiles, flood-inundation boundaries for the 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus annual exceedance probability floods, and a regulatory floodway along a selected reach of each stream. Model input included DEM-derived cross sections supplemented with field surveys of open channel cross sections and hydraulic structures, field estimates of roughness values, and annual exceedance probability flood estimates from regional regression equations and historical streamflow data. Flood-inundation boundaries were mapped for the 1- and 0.2-percent annual exceedance probability floods and a regulatory floodway for each stream reach.

Introduction

Damaging flooding took place in Stark County, Ohio, along numerous streams in 1913, 1935, 1959, 1969, and 1979. The 1959 flood event in Canton caused more than $5 million (in 1959 dollars) in industrial damage and forced 400 people from their homes (U.S. Geological Survey, 1964). During the July 1969 flood, Massillon, Ohio (not shown on figure 1, about 4 miles west of Canton, fig. 1), received more than 6 inches of rain (U.S. Geological Survey, 1969 and Ohio Historical Society, 1969). In 2003, a peak stage of 14.18 feet (ft) (table 1) was recorded at the Nimishillen Creek at North Industry, Ohio, streamgage (U.S. Geological Survey [USGS] station number 03118500). For reference, major flood stage for the North Industry streamgage as designated by the National Weather Service (NWS) is 13 ft (National Weather Service, 2019).

Before this study, officials and emergency responders relied on several information sources to make decisions on how to best alert the public and mitigate flood damages. One source of information is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Stark County, Ohio, dated February 16, 2012 (Federal Emergency Management Agency, 2012). A second source of information is the USGS National Water Information System (table 1) from which current (U.S. Geological Survey, 2017a, b, c, d, e, f, g) and historical (U.S. Geological Survey, 2017h) stages and streamflows, including annual peak streamflows, can be obtained. A third source of flood-related information is the NWS Advanced Hydrologic Prediction Service, which displays the USGS stage data from the Nimishillen Creek at North Industry, Ohio streamgage (USGS station number 03118500) and provides forecasts of stage for the streamgage (National Weather Service, 2019)



Base from U.S. Geological Survey digital data, variously scaled, 2007
State Plane Coordinate System (feet), Ohio North
North American Datum of 1983

Figure 1. Locations of study reaches and U.S. Geological Survey streamgages in Stark County, Ohio.

Table 1. U.S. Geological Survey gaging information for the Nimishillen Creek drainage area within Stark County, Ohio.

[Site locations are shown in figure 1. USGS, U.S. Geological Survey; ft, foot; NAVD 88, North American Vertical Datum of 1988; °, degree; ′, minute; ″, second; mm, month; dd, day; yyyy, year]

Site name	USGS station number	Drainage area (square mile)	Latitude	Longitude	Period of record	Maximum stage (elevation), date
Middle Branch Nimishillen Creek at Canton, Ohio	03118000	43.1	40°50′29″	81°21′14″	1941–2018	6.78 ft (1,052.90 ft NAVD 88), 03/01/11
East Branch Nimishillen Creek at Louisville, Ohio	03118050	15.0	40°50′33″	81°15′34″	2015–2018	13.62 ft (1,105.37 ft NAVD 88), 06/16/18
East Branch Nimishillen Creek at Trump Ave near Canton, Ohio	03118131	43.0	40°48′43″	81°19′23″	2015–2018	12.99 ft (1,060.39 ft NAVD 88), 01/12/17
West Branch Nimishillen Creek at North Canton, Ohio	03118209	15.8	40°52′05″	81°23′04″	2015–2018	7.27 ft (1,079.24 ft NAVD 88), 01/12/17
Zimber Ditch at North Canton, Ohio	03118258	11.9	40°52′13″	81°24′59″	2015–2018	10.25 ft (1,058.10 ft NAVD 88), 01/12/17
West Branch Nimishillen Creek at Tuscarawas Street at Canton, Ohio	03118299	43.5	40°48′03″	81°23′27″	2015–2018	9.26 ft (1,019.22 ft NAVD 88), 06/18/17
Nimishillen Creek at North Industry, Ohio	03118500	172	40°44′59″	81°22′10″	1921–2018	14.18 ft (994.23 ft NAVD 88), 07/28/03

Purpose and Scope

The purpose of this report is to describe the methods and results of hydrologic and hydraulic analyses for 14 stream reaches totaling 49.7 miles in Stark County, Ohio (fig. 1). The analyses include (1) estimates of flood-peak streamflows corresponding to floods with annual exceedance probabilities (AEPs) of 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus; and (2) determination of water-surface profiles and flood plain boundaries associated with the AEPs and a regulatory floodway. The probability of an occurrence is expressed as a percentage. An AEP is always a fraction of one. So, a 0.2-percent AEP flood has a 20-percent chance of occurring in any given year, and corresponds to a 5-year recurrence-interval flood.

The 1-percent plus flood elevation is defined by FEMA as a flood elevation derived by using streamflows that include the average predictive error for the regression equation streamflow calculation for the Flood Risk project (Federal Emergency Management Agency, 2019a). This error is then added to the 1-percent AEP flood streamflow to calculate the new 1-percent plus streamflow. A “regulatory floodway” means the channel of a river or other watercourse and the adjacent land areas that must be reserved to discharge the base flood without cumulatively increasing the water-surface elevation more than a designated height (Federal Emergency Management Agency, 2019b).

Study Area Description

Stark County is in northeast Ohio (fig. 1) with an estimated population of about 375,300 (U.S. Census Bureau, 2010). The average annual precipitation is between 35 and 39 inches (1931 to 1980) in the county (Ohio Department of Natural Resources, 2019), and approximately 30.6 percent of the area is covered by forest (U.S. Geological Survey, 2014). The streams evaluated in this study are within the Nimishillen Creek drainage area draining mainly to the west and south. Two of the largest streams, East Branch Nimishillen Creek and Middle Branch Nimishillen Creek, join on the east side of Canton to form Nimishillen Creek (fig. 1). Farther downstream, on the southwest side of Canton, the other major stream, West Branch Nimishillen Creek, is tributary to Nimishillen Creek. The upper drainage areas of Nimishillen Creek are predominantly rural in the east and south, with the lower drainage areas quickly becoming urban in the Canton metropolitan area.

Previous Studies

The effective FEMA FIS for Stark County (Federal Emergency Management Agency, 2012) was published on February 16, 2012. The detailed hydrologic and hydraulic analyses in the 2012 FIS that pertain to the 14 stream reaches in this study effort were completed at various times from 1977 to 1993, with the most being completed in 1981. Of the 14 reaches in this study, all but 2 streams (East Branch Nimishillen Creek and West Branch Nimishillen Creek) were remapped in 2011; however, the hydrologic and hydraulic analyses were not updated. Parts of the East and West Branches of Nimishillen Creek had detailed restudies completed by the USGS in 2005 (Federal Emergency Management Agency, 2012).

Study Approach

Tasks specific to development of the flood maps were (1) estimation of peak-flood streamflows using regional regression equations and streamgage data where available, (2) collection of topographic and bathymetric data for selected cross sections and geometric data for structures and bridges along the study reaches, (3) estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain, (4) computation of water-surface profiles (including a regulatory floodway) by using the U.S. Army Corps of Engineers' Hydrologic Engineering Center River Analysis System (HEC–RAS) computer program (U.S. Army Corps of Engineers, 2010), and (5) production of flood-inundation maps at various stream stages by using the U.S. Army Corps of Engineers' Hydrologic Engineering Center GeoRiver Analysis System (HEC–GeoRAS) computer program (U.S. Army Corps of Engineers, 2009) and geographic information systems.

Hydrologic Analyses

Regional regression equations were used to estimate the 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus AEP flood-peak streamflows for selected locations (generally at stream confluences or at easily identifiable points [such as a road crossing] along stream reaches with gradually increasing drainage area) on all stream reaches using the Ohio StreamStats application. The StreamStats application (Koltun and others, 2006) solves regional regression equations that use (1) drainage area, (2) main channel slope (determined by the 10–85 method, SL10–85), and (3) storage (percentage of drainage classified as water and wetlands area) as explanatory variables. The explanatory variables are computed within StreamStats based on geospatial datasets. StreamStats estimates are based on the assumption that the basin is not appreciably regulated and is without significant urbanization (Koltun and others, 2006). The resulting flood-peak streamflow estimates are listed in table 2.

Of the seven USGS streamgages on reaches in the study area (table 1), only two (Nimishillen Creek at North Industry, Ohio [03118500], and Middle Branch Nimishillen Creek at Canton, Ohio [03118000], established in 1921 and 1941, respectively) have been established long enough to provide an adequate length of streamflow data (generally 10 years) to estimate flood-peak streamflows (Interagency Advisory Committee on Water Data, 1982). The streamgages East Branch Nimishillen Creek at Trump Avenue near Canton, Ohio (03118131), and West Branch Nimishillen Creek at Tuscarawas Street at Canton, Ohio (03118299), were established in 2015. Only stage is collected at the three remaining streamgages (streamflow is not computed).

The initial AEP flood-peak streamflows for Nimishillen Creek and Middle Branch Nimishillen Creek were then adjusted using a gage weighting ratio technique (Koltun and others, 2006). For the "1-percent plus" flood, the ratio was assumed to be the same as the 1-percent AEP flood. The gage weighting data used to adjust the initial regression estimates are given in table 3.

The 2012 FIS (Federal Emergency Management Agency, 2012) reported urbanized peak-flood estimates for Broad-Monter Creek. This restudy also employed the use of the same urbanization techniques. The regression estimates for Broad-Monter Creek were urbanized using techniques outlined in Sauer and others (1983). The urbanization data used to adjust the initial regression estimates are given in table 4. Final peak-flood estimates for all streams are given in table 5.

Hydraulic Analyses

The water-surface profiles used to develop the flood-inundation maps for this study were computed using HEC–RAS, version 4.1.0 (U.S. Army Corps of Engineers, 2010). HEC–RAS is a one-dimensional step-backwater model for determining water-surface profiles under steady-state or unsteady flow conditions. All water-surface profiles developed for this report were run within HEC–RAS using the steady-state flow condition. Steady-state flow data consisted of flow regime, boundary conditions, and streamflow estimates. Subcritical flow regime was assumed for all simulations based on hydrologic judgment.

Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses exerted by a channel on flow. These energy losses are quantified by the Manning's roughness coefficient ("*n*" value). The *n* values were selected on the basis of field observations and high-resolution aerial photographs. For the study reaches, the *n* values ranged from 0.030 to 0.050 (sand/cobble to riprap/debris piles) for the main channel and from 0.040 to 0.150 (grass/shrub to heavily wooded) for the overbank areas (table 6).

Table 2. Summary of the explanatory variable values used in the regression equations, the initial 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus annual exceedance probability flood-peak streamflow estimates, and locations for the selected streams in Stark County, Ohio.

[Dark gray shaded values indicate data from the 2012 effective Flood Insurance Study (Federal Emergency Management Agency, 2012); light gray values indicate data calculated for this study effort not included in the 2012 effective Flood Insurance Study; bold values indicate the locations of U.S. Geological Survey streamgages. ft³/s, cubic foot per second; %, percent; °, degree; ′, minute; ″, second; US, upstream; SW, southwest; USGS, U.S. Geological Survey; DS, downstream; NW, northwest]

Location description	Latitude	Longitude	Drainage area (square mile)	Main channel slope[1] (foot per mile)	Storage (water or wetlands area), percent	Annual exceedance probability flood-peak streamflows[2] (ft³/s)					
						10%	4%	2%	1%	0.2%	1% plus[3]
Broad-Monter Creek											
At Broad Street	40°50′05″	81°14′46″	1.09	47.1	1.69	158	200	230	259	324	357
At abandoned railroad	40°49′46″	81°15′32″	1.65	45.4	1.16	227	289	332	375	471	518
At mouth	40°49′39″	81°16′09″	2.20	43.5	0.96	288	365	420	475	597	656
Chatham Ditch											
At mouth	40°52′42″	81°22′47″	1.15	19.6	1.69	139	173	197	220	271	304
East Branch Nimishillen Creek											
At Nickel Plate Street	40°50′42″	81°14′50″	9.29	20.4	0.57	788	985	1,130	1,270	1,570	1,750
US from tributary 2	40°50′37″	81°15′17″	9.40	26.5	0.55	838	1,050	1,200	1,350	1,680	1,850
US from North Chapel Creek	40°50′28″	81°15′42″	15.0	24.9	0.65	1,160	1,450	1,650	1,850	2,300	2,540
US from Broad-Monter Creek	40°49′39″	81°16′10″	19.3	23.4	0.66	1,380	1,720	1,960	2,200	2,720	3,020
US from unnamed tributary	40°49′16″	81°16′42″	21.9	21.2	0.73	1,480	1,830	2,080	2,340	2,880	3,200
At SW Louisville corporate limit	40°49′25″	81°17′21″	32.6	18.7	0.87	1,900	2,350	2,660	2,980	3,660	4,090
At Trump Avenue	40°48′42″	81°19′24″	42.7	12.5	0.96	2,170	2,660	3,010	3,360	4,110	4,640
US from Middle Branch	40°48′26″	81°21′13″	46.5	12.4	1.09	2,270	2,780	3,140	3,510	4,280	4,840
Fairhope Ditch											
At State Route 62	40°50′37″	81°18′07″	1.99	56.0	0.30	310	399	463	527	670	727
At mouth	40°49′11″	81°18′40″	3.90	28.9	0.97	411	516	591	665	829	918
Firestone Ditch											
At mouth	40°52′38″	81°19′37″	2.58	25.6	2.54	253	314	356	398	489	549
Hayden Ditch											
At mouth	40°46′19″	81°20′23″	2.42	24.8	1.56	260	324	370	414	512	571
Middle Branch Nimishillen Creek											
US from Firestone Ditch	40°52′39″	81°19′36″	28.5	3.75	4.54	973	1,140	1,260	1,380	1,610	1,900
At 55th Street	40°51′32″	81°19′38″	37.1	4.45	3.98	1,260	1,490	1,650	1,800	2,130	2,480
At USGS streamgage (03118000)	**40°50′30″**	**81°21′13″**	**43.3**	**4.79**	**4.17**	**1,430**	**1,680**	**1,860**	**2,040**	**2,410**	**2,820**
US from East Branch Nimishillen Creek	40°48′27″	81°21′13″	46.6	5.76	3.97	1,580	1,870	2,080	2,280	2,700	3,150
Middle Branch Nimishillen Creek Tributary Number 1											
At mouth	40°50′36″	81°21′09″	3.25	28.9	1.87	325	406	463	519	641	716

Table 2. Summary of the explanatory variable values used in the regression equations, the initial 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus1 annual exceedance probability flood-peak streamflow estimates, and locations for the selected streams in Stark County, Ohio.—Continued

[Dark gray shaded values indicate data from the 2012 effective Flood Insurance Study (Federal Emergency Management Agency, 2012); light gray values indicate data calculated for this study effort not included in the 2012 effective Flood Insurance Study; bold values indicate the locations of U.S. Geological Survey streamgages. ft^3/s, cubic foot per second; %, percent; °, degree; ′, minute; ″, second; US, upstream; SW, southwest; USGS, U.S. Geological Survey; DS, downstream; NW, northwest]

Location description	Latitude	Longitude	Drainage area (square mile)	Main channel slope[1] (foot per mile)	Storage (water or wetlands area), percent	Annual exceedance probability flood-peak streamflows[2] (ft^3/s)					
						10%	4%	2%	1%	0.2%	1% plus[3]
Nimishillen Creek											
US from West Branch Nimishillen Creek	40°46′45″	81°23′08″	97.9	5.57	2.46	3,020	3,600	4,010	4,410	5,250	6,090
US from Hurford Run	40°46′29″	81°23′11″	145	5.50	2.64	4,020	4,770	5,300	5,830	6,930	8,050
US from Sherrick Run	40°46′10″	81°22′51″	157	5.53	2.57	4,290	5,100	5,670	6,240	7,420	8,610
At USGS streamgage (03118500)	**40°45′00″**	**81°22′12″**	**172**	**6.16**	**2.56**	**4,700**	**5,590**	**6,230**	**6,860**	**8,170**	**9,470**
350 feet DS from CSX railroad	40°44′03″	81°21′10″	175	6.71	2.56	4,840	5,770	6,430	7,090	8,460	9,780
Reemsnyder Ditch											
DS from Whipple Avenue NW	40°50′53″	81°25′19″	3.34	10.6	4.15	237	286	320	353	424	487
At mouth	40°50′33″	81°24′43″	3.69	9.62	4.41	247	298	333	367	439	506
Sherrick Run											
US from Hayden Run	40°46′19″	81°20′23″	4.61	42.7	2.51	435	544	621	697	865	962
US from east tributary (DS from State Route 43)	40°46′33″	81°20′52″	7.21	32.2	2.23	591	735	837	939	1,160	1,300
US from north tributary (US from Warner Road)	40°47′01″	81°21′32″	8.66	23.9	2.46	631	779	883	986	1,210	1,360
At mouth	40°46′10″	81°22′51″	10.4	16.8	2.44	679	832	939	1,050	1,270	1,450
Unnamed stream											
At mouth	40°50′38″	81°15′17″	5.29	31.6	0.82	538	677	777	876	1,090	1,210
West Branch Nimishillen Creek											
US from State Route 62	40°49′45″	81°23′45″	38.6	12.2	2.65	1,710	2,070	2,320	2,570	3,110	3,550
At mouth	40°46′45″	81°23′09″	46.6	10.9	2.99	1,880	2,270	2,550	2,820	3,390	3,890
Zimber Ditch											
At Mount Pleasant Street	40°54′23″	81°25′30″	5.46	36.0	3.51	449	557	632	707	871	976
At Portage Street	40°52′54″	81°25′30″	7.63	23.9	2.76	561	692	783	874	1,070	1,210
At Whipple Avenue	40°52′26″	81°25′19″	10.3	21.8	3.03	680	835	945	1,050	1,280	1,450
At mouth	40°46′45″	81°23′09″	12.3	18.3	2.60	775	950	1,070	1,190	1,460	1,640

[1]The main channel slope is determined by the new channel slope characteristic (SL10–85) (Koltun and others, 2006).

[2]Annual exceedance probability flood-peak streamflows were determined using StreamStats web application for Ohio that solves regional regression equations (Koltun and others, 2006).

[3]The 1-percent plus flood elevation is defined by the Federal Emergency Management Agency (2019a) as a flood elevation derived by using streamflows that include the average predictive error for the regression equation streamflow calculation for the Flood Risk project. This error is then added to the 1-percent annual exceedance probability flood streamflow to calculate the new 1-percent plus streamflow. In this study, the average predictive error for the 1-percent annual exceedance probability flood is 38 percent. Therefore, the 1-percent plus annual exceedance probability flood streamflows were calculated to be 138 percent of the 1-percent annual exceedance probability flood streamflows.

Table 3. Peak-flood streamflow estimates for the 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probability floods are reported in Koltun and others (2006), and weighting ratio is equal to the weighted regression estimate divided by the regression estimate.

[ft^3/s, cubic foot per second; %, percent]

Site name and U.S. Geological Survey station number	Annual exceedance probability flood-peak streamflows (ft^3/s)					Estimate type
	10%	4%	2%	1%	0.2%	
Middle Branch Nimishilen Creek at Canton, Ohio (03118000)	1,170	1,500	1,780	2,080	2,890	Log Pearson Type III
	1,420	1,670	1,850	2,020	2,390	Regression
	1,180	1,510	1,780	2,070	2,840	Weighted
	0.831	0.904	0.962	1.025	1.188	Weighting ratio
Nimishillen Creek at North Industry, Ohio (03118500)	5,260	6,330	7,130	7,930	9,820	Log Pearson Type III
	4,830	5,770	6,430	7,070	8,470	Regression
	5,240	6,300	7,080	7,870	9,720	Weighted
	1.085	1.085	1.092	1.113	1.148	Weighting ratio

Field Surveys

The USGS used the differential global positioning system and differential-leveling surveys (hereafter referred to as conventional surveys) for this study. The differential global positioning system surveys established a control network at pertinent locations along each of the streams studied. Conventional surveys were done to obtain stream and hydraulic-structure geometry. All conventional survey data met third-order accuracy (horizontal and vertical) criteria (Federal Geodetic Control Committee, 1984). Differential global positioning system surveys were completed using USGS real-time network surveying techniques (Rydlund and Densmore, 2012). Elevations determined by using a differential global positioning system at 10 benchmark locations had a root-mean-square error of 0.05 ft compared with National Geodetic Survey published elevations.

The USGS field crews surveyed a total of 640 channel cross sections (table 6) and 154 hydraulic structures. The cross sections were surveyed to provide ground elevations below stream water surfaces that cannot be provided by light detection and ranging (lidar). The structures were surveyed for geometrical data that have the potential to affect water-surface elevations during floods along the streams.

Table 4. Basin development factor estimates (as described in Sauer and others, 1983) used to urbanize the initial peak-flood estimates for Broad-Monter Creek.

Location description	Basin development factor
At Broad Street	6
At abandoned railroad	6
At mouth	3

Topographic and Bathymetric Data

Cross-section elevation data were obtained from a digital elevation model (DEM) that was provided by Stark County, Ohio. The DEM was derived from lidar data collected during March 2004. The lidar data have a horizontal resolution that meets National Map Accuracy Standards and a vertical accuracy of plus or minus 1.0 ft at a 95-percent confidence level for the “open terrain” land-cover category (root-mean-square error of 0.5 ft) (Federal Geographic Data Committee, 1998). By this criterion, the lidar data support production of 2-ft contours (Dewberry, 2012); the final DEM has a vertical accuracy of 1.0 ft.

Using HEC–GeoRAS, elevation data were extracted from the DEM for a total of 1,415 cross sections (table 6) for use in the HEC–RAS models. For all modeled stream reaches, the maximum distance between cross sections (surveyed and geographic information systems derived) was limited to 500 ft and was, on average, 169 ft. DEM-derived cross sections were collocated with the locations of the in-channel field-surveyed cross sections where available. In those cases, in-channel data were directly merged with the DEM data. The bathymetry for the DEM-derived cross sections that did not have surveyed in-channel cross sections was estimated by interpolating between the closest field-surveyed cross sections.

Hydraulic Modeling

The hydraulic baselines for all modeled stream reaches were referenced to feet upstream from their respective mouths (table 6). The downstream boundary conditions for all modeled stream reaches were set to be normal depth and were calculated from field-surveyed streambed slope near their corresponding downstream limits. Normal depth is defined as the depth of uniform flow. Flow is considered uniform if the energy line, water surface, and channel bottom all are parallel

Table 5. Summary of the final 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus annual exceedance probability flood-peak streamflow estimates and locations for the selected streams in Stark County, Ohio.

[Dark gray shaded values indicate data from the 2012 effective Flood Insurance Study; light gray values indicate data calculated for this study effort not included in the 2012 effective Flood Insurance Study (Federal Emergency Management Agency, 2012; bold values indicate the locations of U.S. Geological Survey streamgages. ft^3/s, cubic foot per second; %, percent; US, upstream; SW, southwest; USGS, U.S. Geological Survey; DS, downstream; NW, northwest]

Location description	Annual exceedance probability flood-peak streamflows[1] (ft^3/s)					
	10%	4%	2%	1%	0.2%	1-% plus[2]
Broad-Monter Creek						
At Broad Street	230	279	319	356	434	463
At abandoned railroad	372	449	512	575	702	749
At mouth	470	565	647	728	893	949
Chatham Ditch						
At mouth	139	173	197	220	271	304
East Branch Nimishillen Creek						
At Nickel Plate Street	788	985	1,130	1,270	1,570	1,750
US from tributary 2	838	1,050	1,200	1,350	1,680	1,850
US from North Chapel Creek	1,160	1,450	1,650	1,850	2,300	2,540
US from Broad-Monter Creek	1,380	1,720	1,960	2,200	2,720	3,020
US from unnamed tributary	1,480	1,830	2,080	2,340	2,880	3,200
At SW Louisville corporate limit	1,900	2,350	2,660	2,980	3,660	4,090
At Trump Avenue	2,170	2,660	3,010	3,360	4,110	4,640
US from Middle Branch Nimishillen Creek	2,270	2,780	3,140	3,510	4,280	4,840
Fairhope Ditch						
At State Route 62	310	399	463	527	670	727
At mouth	411	516	591	665	829	918
Firestone Ditch						
At mouth	253	314	356	398	489	549
Hayden Ditch						
At mouth	260	324	370	414	512	571
Middle Branch Nimishillen Creek						
US from Firestone Ditch	921	1,110	1,240	1,390	1,710	1,920
At 55th street	1,110	1,390	1,610	1,830	2,420	2,530
At USGS streamgage (03118000)	**1,190**	**1,520**	**1,790**	**2,090**	**2,860**	**2,880**
US from East Branch Nimishillen Creek	1,350	1,720	2,010	2,330	3,130	3,210
Middle Branch Nimishillen Creek Tributary Number 1						
At mouth	325	406	463	519	641	716
Nimishillen Creek						
US from West Branch Nimishillen Creek	3,060	3,640	4,060	4,480	5,360	6,180
US from Hurford Run	4,250	5,050	5,630	6,280	7,630	8,670
US from Sherrick Run	4,590	5,460	6,100	6,820	8,320	9,420
At USGS streamgage (03118500)	**5,100**	**6,060**	**6,800**	**7,640**	**9,380**	**10,500**
350 feet DS from CSX railroad	5,250	6,260	7,020	7,890	9,710	10,900

Table 5. Summary of the final 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus annual exceedance probability flood-peak streamflow estimates and locations for the selected streams in Stark County, Ohio.—Continued

[Dark gray shaded values indicate data from the 2012 effective Flood Insurance Study; light gray values indicate data calculated for this study effort not included in the 2012 effective Flood Insurance Study (Federal Emergency Management Agency, 2012; bold values indicate the locations of U.S. Geological Survey streamgages. ft^3/s, cubic foot per second; %, percent; US, upstream; SW, southwest; USGS, U.S. Geological Survey; DS, downstream; NW, northwest]

Location description	Annual exceedance probability flood-peak streamflows[1] (ft^3/s)					
	10%	4%	2%	1%	0.2%	1-% plus[2]
Reemsnyder Ditch						
DS from Whipple Avenue NW	237	286	320	353	424	487
At mouth	247	298	333	367	439	506
Sherrick Run						
US from Hayden Run	435	544	621	697	865	962
US from east tributary (DS from SR43)	591	735	837	939	1,160	1,300
US from north tributary (US from Warner Road)	631	779	883	986	1,210	1,360
At mouth	679	832	939	1,050	1,270	1,450
Unnamed stream						
At mouth	538	677	777	876	1,090	1,210
West Branch Nimishillen Creek						
US from State Route 62	1,710	2,070	2,320	2,570	3,110	3,550
At mouth	1,880	2,270	2,550	2,820	3,390	3,890
Zimber Ditch						
At Mount Pleasant Street	449	557	632	707	871	976
At Portage Street	561	692	783	874	1,070	1,210
At Whipple Avenue	680	835	945	1,050	1,280	1,450
At Mouth	775	950	1,070	1,190	1,460	1,640

[1]Annual exceedance probability flood-peak streamflows were determined using StreamStats web application for Ohio that solves regional regression equations (Koltun and others, 2006).

[2]The 1-percent plus flood elevation is defined by the Federal Emergency Management Agency (2019a) as a flood elevation derived by using streamflows that include the average predictive error for the regression equation streamflow calculation for the Flood Risk project. This error is then added to the 1-percent annual exceedance probability flood streamflow to calculate the new 1-percent plus streamflow. In this study, the average predictive error for the 1-percent annual exceedance probability flood is 38 percent. Therefore, the 1-percent plus annual exceedance probability flood streamflows were calculated to be 138 percent of the 1-percent annual exceedance probability flood streamflows.

(Chow, 1959). The HEC–RAS models were used to generate seven water-surface profiles corresponding to the 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus AEP floods, and a regulatory floodway.

As required by FEMA for a FIS, a Technical Support Data Notebook and floodway data tables were prepared and are given in appendix 1 and 2, respectively. Water-surface profiles for each stream were also prepared and are given in appendix 3. The profiles are also in tabular format in an accompanying data release (Ostheimer and Whitehead, 2020). These profiles show computed water-surface elevations as a function of distance from a reference location. Also depicted on the profile plots are the minimum channel elevations at each cross section and the hydraulic structures. All elevations in the profile plots are referenced to the North American Vertical Datum of 1988. The model archive for the hydraulic models used in this study also is included in the accompanying data release (Ostheimer and Whitehead, 2020).

Development of Flood-Inundation Maps

As required by FEMA for a FIS, flood-inundation maps were created in a geographic information system for three water-surface profiles (1- and 0.2-percent AEP floods and a regulatory floodway) by combining flood-profile data with the DEM provided by Stark County (Ostheimer and Whitehead,

Table 6. Selected hydraulic properties used in the hydraulic models.

[DEM, digital elevation model; ft/ft, foot per foot]

Stream name	Baseline reference location[1]	Study reach length (mile)	Number of surveyed cross sections	Number of cross sections derived from DEM	Number of hydraulic structures	Slope used for normal depth[2] calculation (ft/ft)	Manning's roughness coefficient (*n*)			
							Main channel		Overbanks	
							Lowest value	Highest value	Lowest value	Highest value
Broad-Monter Creek	Mouth	2.1	50	99	12	0.0044	0.030	0.050	0.044	0.056
Chatham Ditch	Mouth	1.0	10	35	2	0.0050	0.040	0.042	0.050	0.050
East Branch Nimishillen Creek	Mouth	9.0	89	214	23	0.0021	0.038	0.050	0.040	0.150
Fairhope Ditch	Mouth	2.9	47	86	11	0.0026	0.040	0.042	0.050	0.054
Firestone Ditch	Mouth	1.3	35	52	7	0.0024	0.042	0.042	0.050	0.050
Hayden Ditch	Mouth	0.6	10	21	2	0.0014	0.040	0.040	0.050	0.050
Middle Branch Nimishillen Creek	Mouth	9.5	81	211	20	0.0016	0.038	0.044	0.046	0.056
Middle Branch Nimishillen Creek Tributary Number 1	Mouth	0.7	6	21	1	0.0034	0.042	0.048	0.052	0.068
Nimishillen Creek	Mouth	6.9	93	172	23	0.0015	0.034	0.040	0.046	0.050
Reemsnyder Ditch	Mouth	0.9	11	34	2	0.0063	0.040	0.042	0.060	0.068
Sherrick Run	Mouth	3.9	42	115	10	0.0051	0.040	0.042	0.050	0.050
Unnamed stream	Mouth	2.2	30	81	7	0.0037	0.040	0.044	0.042	0.068
West Branch Nimishillen Creek	Mouth	4.5	94	168	24	0.0016	0.038	0.046	0.040	0.064
Zimber Ditch	Mouth	4.2	42	110	10	0.0012	0.040	0.044	0.050	0.054

[1]Location from which the river stationing is measured upstream, in feet.

[2]Normal depth is the depth of uniform flow. Flow is considered uniform if the energy line, water surface, and channel bottom all are parallel (Chow, 1959).

2020). Initial flood-inundation boundaries were developed for each profile using HEC–GeoRAS software (U.S. Army Corps of Engineers, 2009). HEC–GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS. The hydraulic model was calibrated to 16 flood events. Flood-inundation boundaries and depth grids for the inundated areas were modified in ArcMap (Environmental Systems Research Institute, 2019), as required by FEMA, to ensure hydraulically reasonable transitions of the flood boundaries between modeled cross sections.

Any inundated areas that were disconnected from the main channel were examined to identify artificial connections with the main river, such as through culverts under roadways. Where such connections existed, the mapped inundated areas were retained in their respective flood maps; otherwise, the disconnected inundated areas were deleted. The flood-inundation areas were overlain on high-resolution georeferenced aerial photographs of the study area. The flood-inundation maps are in appendix 4.

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 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 using streamflows and hydrologic conditions anticipated at the USGS streamgage. The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of January 2019. 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 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, 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 (and water-surface elevation) for the stream at a given location (Advanced Hydrologic Prediction Service forecast point) throughout the forecast period (every 6 hours and 3–5 days out in many locations). For more information on Advanced Hydrologic Prediction Service forecasts, please see https://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf. Additional uncertainties and limitations pertinent to this study are described elsewhere in this report.

Summary

The U.S. Geological Survey, in cooperation with the Muskingum Watershed Conservancy District and the Stark County Commissioners, updated and expanded a part of the Federal Emergency Management Agency Flood Insurance Study for Stark County, Ohio. The study consisted of a total of 49.7 miles and 14 stream reaches in the Nimishillen drainage area: Broad-Monter Creek, Chatham Ditch, East Branch Nimishillen Creek, Fairhope Ditch, Firestone Ditch, Hayden Ditch, Middle Branch Nimishillen Creek, Middle Branch Nimishillen Creek Tributary Number 1, Nimishillen Creek, Reemsnyder Ditch, Sherrick Run, unnamed stream, West Branch Nimishillen Creek, and Zimber Ditch. Water-surface profiles were developed for the 10-, 4-, 2-, 1-, and 0.2-percent and 1-percent plus annual exceedance probability floods and a regulatory floodway. Mapping for each stream was developed for the 1- and 0.2-percent annual exceedance probability floods and a regulatory floodway.

The U.S. Army Corps of Engineers' Hydrologic Engineering Center-River Analysis System program was used to compute water-surface profiles and delineate estimated flood-inundation area boundaries. Model input included DEM-derived cross sections supplemented with field surveys of open channel cross sections and hydraulic structures, field estimates of roughness values, and annual exceedance probability flood estimates from regional regression equations and historical streamflow data. The flood-inundation areas were overlain on high-resolution, georeferenced aerial photographs of the study area. The water-surface profiles can help emergency planners and the public make more informed decisions about flood risk.

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Appendixes 1–4

Appendixes 1–4 are available for download at https://doi.org/10.3133/sir20205011. Appendix 1 is the Technical Support Data Notebook. Appendix 2 contains floodway data tables for 14 sites in Stark County, Ohio. Appendix 3 contains graphs of computed water-surface profiles for 14 sites in Stark County, Ohio. Appendix 4 contains flood-inundation maps for 14 sites in Stark County, Ohio.

For more information about this publication, contact:
Director, Ohio-Kentucky-Indiana Water Science Center
U.S. Geological Survey
6460 Busch Boulevard Suite 100
Columbus, OH 43229–1737
614–430–7700

For additional information, visit:
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