

NOTE: This document is intended to be an annotated outline to provide guidance to authors of Flood-Inundation Mapping reports, who choose to publish their work as Scientific Investigation Reports (SIRs) and to present their flood maps solely on the USGS Flood Mapper web site. It is still the author’s choice to publish a Scientific Investigation Map pamphlet with associated PDF flood maps, in which case, the SIM template can be used.

This SIR template follows the layout of the SIM template, but includes additional sections for “Hydraulic Structures” (including levees) and “Estimating Potential Losses Due to Flooding” (i.e., Hazus Analyses), and encourages expansion of information included in such sections, as “Energy-Loss Factors” and “Model Calibration.” Other revisions are in alignment with standard USGS publication protocols, such as moving the “Approach” statements from the Purpose and Scope section to a more appropriate location in the report. Tables have been included in this template (as was done for the SIM template) but can be reproduced in Excel and dealt with as separate files.

Parts of the template are similar to the SIM template in that ***sentences with terms in Blue are generally intended to be used as is, except that the blue terms are to be changed to words, numbers, locations, etc., that are applicable to the subject study area.***

Sections in Red are informational and intended to clarify the type of data that should be included in a given paragraph and to highlight additions or deletions to the paragraph depending on any unique conditions that might exist in a study reach.

This template places more responsibility on the author to thoughtfully pick and choose those parts of the template that can be used as is and those that should be embellished or, in some cases, deleted. As an SIR, this report can contain additional information that the author deems necessary, such as some of the technical information previously included in a Technical Summary Notebook that often accompanied a SIM. Some of this “additional” information is incorporated into this template, but other information is left to the author to decide whether to include here or in a Technical Summary Notebook.

W.F.Coon

New York Water Science Center

March 28, 2014

Prepared in cooperation with *COOPERATING AGENCY(s)*

Flood-Inundation Maps for the *XXX* *River* at *CITY, STATE, YEAR* [from *POINTA* to *POINTB*, *STATE, YEAR*]

By Author, Author, and Author

Scientific Investigations Report XXXX–XXXX

U.S. Department of the Interior

U.S. Geological Survey

U.S. Department of the Interior

RYAN K. ZINKE, Secretary

U.S. Geological Survey

William H. Werkheiser, Acting Director

U.S. Geological Survey, Reston, Virginia: 20xx  
Revised and reprinted: 20xx

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

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

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

Suggested citation:  
Author1, F.N., Author2, Firstname, 20xx, Flood-inundation maps for the XXX River at CITY, STATE, YEAR: U.S. Geological Survey Scientific Investigations Report 20xx-XXXX, xx p.,[https://doi.org/10.3133 /sir/20xxxxxx](https://doi.org/10.3133%20/sir/20xxxxxx)*.*

Any use of trade, firm, or product names is for descriptive purposes only and does not imply   
endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain  
copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be   
secured from the copyright owner.

# Acknowledgments

The author(s) wishes to thank the ***<NAME OF COOPERATOR(S)>***, for funding the operation and maintenance of the gage used for this study. [Mention any agency or representative of an agency that provided assistance in conducting the study. Identify the specific cooperator and his/her/its specific contribution to the successful completion of the study.] Special thanks are given to the National Weather Service for their continued support of the USGS flood-inundation mapping program.

Contents

Acknowledgments iv

Abstract 1

Introduction 2

Purpose and Scope 4

Study Area Description 6

Previous Studies 7

Creation of Flood-Inundation-Map Library 7

Computation of Water-Surface Profiles 8

Hydrologic Data 9

Topographic and Bathymetric Data 10

Hydraulic Structures 12

Energy-Loss Factors 13

Hydraulic Model 14

Development of Water-Surface Profiles 16

Development of Flood-Inundation Maps 17

Flood-Inundation Map Delivery 18

Disclaimer for Flood-Inundation Maps 19

Uncertainties and Limitations Regarding Use of Flood-Inundation Maps 19

Estimating Potential Losses Due to Flooding 20

Summary 21

References Cited 23

Figures

**Figure 1.** Location of study reach for the XXX River at CITY, STATE, and location of U.S. Geological Survey streamgage. 5

**Figure 2.** Observed and simulated water-surface elevations and profiles for the flood(s) of DATE, (and DATE) [and/or the FEMA 1‑percent annual exceedance probability flood] for XXX River at CITY, STATE. 16

**Figure 3.** Flood-inundation map for the XXX River at CITY, STATE, corresponding to a stage of xx.00 feet at the U.S. Geological Survey streamgage (station number xxxxxxxx). 17

Tables

**Table 1.** U.S. Geological Survey streamgage information for XXX River at CITY, STATE. 5

**Table 2.** Peak discharges for selected annual exceedance probabilities for XXX River at CITY, STATE. 7

**Table 3.** Estimated discharges for corresponding stages and water-surface elevations at selected locations, used in the hydraulic model of the XXX River at CITY, STATE . 10

**Table 4.** Calibration of model to target water-surface elevations at U.S. Geological Survey streamgage on XXX River at CITY,STATE, (station number xxxxxxxx). 15

**Table 5.** Calibration of model to water-surface elevations at selected locations along the XXX River for the flood of DATE. 15

Conversion Factors

International System of Units to U.S. customary units

|  |  |  |
| --- | --- | --- |
| Multiply | By | To obtain |
| Length | | |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| Area | | |
| square mile (mi2) | 2.590 | square kilometer (km2) |
| Flow rate | | |
| cubic foot per second (ft3/s) | 0.02832 | cubic meter per second (m3/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). | | |

Flood-Inundation Maps for the *XXX* *River* at *CITY, STATE, YEAR* [from *POINTA* to *POINTB*, *STATE, YEAR*]

By Author, Author, and Author

# Abstract

Digital flood-inundation maps for a ***xx***-mile reach of the ***XXX*** ***River*** from ***POINTA*** to ***POINTB***, ***STATE***, were created by the U.S. Geological Survey (USGS) in cooperation with the ***COOPERATOR***. The flood-inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science web site at [http://water.usgs.gov/osw/flood\_inundation/,](http://water.usgs.gov/osw/flood_inundation/,%20) depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at the USGS streamgage on the ***Station Name*** (station number ***xxxxxxxx***). Near-real-time stages at this streamgage may be obtained on the internet from the USGS National Water Information System at http://waterdata.usgs.gov/ or the National Weather Service (NWS) Advanced Hydrologic Prediction Service at [http:/water.weather.gov/ahps/](http://water.weather.gov/ahps/), which also forecasts flood hydrographs at this site [only include this last phrase if, in fact, the NWS does forecast stages at this site; otherwise delete this phrase].

Flood profiles were computed for the stream reach by means of a one-dimensional step-backwater model. The model was calibrated by using the current stage-discharge relation at the ***<Station Name>*** streamgage ***and***

***- documented high-water marks from the floods of DATE, DATE, and DATE***

***- water-surface profiles from historic floods (give DATEs)***

***- water-surface profiles from the current Federal Emergency Management Agency flood-insurance study, etc.***

The hydraulic model was then used to computer ***xx*** water-surface profiles for flood stages at ***xx***-foot (ft) intervals referenced to the streamgage datum and ranging from xx ft or near bankfull to xx ft,

[Insert an appropriate qualifying phrase for the highest mapped stage]

***- which is approximately the highest recorded water level at the streamgage.***

***- which exceeds the stage that corresponds to the estimated 0.2-percent annual exceedance probability flood (500-year recurrence interval flood)***

***- which exceeds the stage that corresponds to the maximum recorded peak flow***

***- which equals/exceeds the “major flood stage” as defined by the National Weather Service***

The simulated water-surface profiles were then combined with a geographic information system digital elevation model (derived from ***light detection and ranging (lidar)*** data having a ***x.x***-ft vertical accuracy and ***xx***-ft horizontal resolution) to delineate the area flooded at each water level.

The availability of these maps, along with internet information regarding current stage from the USGS streamgage and forecasted high-flow stages from the NWS [delete this last phrase if the NWS does NOT forecast stage at this site], will provide emergency management personnel and residents with information that is critical for flood response activities such as evacuations and road closures, as well as for postflood recovery efforts.

# Introduction

* Provide background information on the community and past/recent flooding (extent of flooding; Federal declarations of disaster; cost of flooding, etc.).

Prior to this study, emergency responders in ***COMMUNITY*** relied on several information sources (all of which are available on the internet) to make decisions on how to best alert the public and mitigate flood damages. One source is the FEMA flood insurance study (FIS) for ***COMMUNITY***, dated ***DATE*** (Federal Emergency Management Agency, ***YEAR***). A second source of information is the USGS streamgage, ***Station Name***, from which current (U.S. Geological Survey, ***YEAR***a) and historical (since ***<first year of record>***; U.S. Geological Survey, ***YEAR***b) water levels and discharges, including annual peak flows, can be obtained. A third source of flood-related information is the National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS), which displays the USGS stage data from the ***CITY*** streamgage and also issues forecasts of stage for the ***Station Name*** (National Weather Service, ***YEARa***). [Include this latter phrase only if the NWS does, in fact, forecast stage at this site; otherwise delete. Alternatively, if appropriate, state “The NWS does not routinely issue forecasts for the STATION NAME, but it does so as needed during times of high-stage flows.”]

[-State justification for creation of flood-inundation maps as follows-]

Although the current stage at a USGS streamgage is particularly useful for residents in the immediate vicinity of a streamgage, it is of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream reach. Knowledge of a water level at a streamgage is difficult to translate into depth and areal extent of flooding at points distant from the streamgage. One way to address these informational gaps is to produce a library of flood-inundation maps that are referenced to the stages recorded at the USGS streamgage. By referring to the appropriate map, emergency responders can discern the severity of flooding (depth of water and areal extent), identify roads that are or will soon be flooded, and make plans for notification or evacuation of residents in harm’s way for some distance upstream and downstream from the streamgage. In addition, the capability to visualize the potential extent of flooding has been shown to motivate residents to take precautions and heed warnings that they previously might have disregarded. In ***20xx-xx***, the USGS, in cooperation with the ***COOPERATOR***, conducted a project to produce a library of flood-inundation maps for the ***XXX*** River at ***CITY, STATE***.

## Purpose and Scope

This report describes the development of a series of estimated flood-inundation maps for the ***XXX*** River at ***CITY, STATE*** and identifies where on the internet the maps can be found and ancillary data (geographic-information-system flood polygons and depth grids) can be downloaded.

-Describe the location of the study reach (xx miles long from POINTA to POINTB [upstream to downstream ends, respectively] (fig. 1).

- The maps were produced for flood levels referenced to the stage recorded at the USGS streamgage on the ***XXX*** River at ***CITY*** (table 1); the gage is ***<where in relation to the study reach?>.***

- The maps cover a range in stage from xx to yy feet (ft), gage datum. [Qualify the stage limits as appropriate to do so.] The xx‑ft stage is approximately bankfull and is defined by the National Weather Service (***YEARb***) as the “action stage” or that stage which, when reached by a rising stream, requires the NWS or a partner to take some type of mitigation action in preparation for possible significant hydrologic activity. The yy‑ft stage

***- is approximately the highest recorded water level at the streamgage.***

***- exceeds the stage that corresponds to the estimated 0.2-percent annual exceedance probability flood (500-year recurrence interval flood)***

***- exceeds the stage that corresponds to the maximum recorded peak flow***

***- exceeds the “major flood stage” as defined by the National Weather Service***

***- is between the water levels associated with the estimated 10- and 2‑percent annual exceedance probability floods (floods with recurrence intervals between 10 and 50 years) and equals the “major flood stage” as defined by the NWS***

1. Location of study reach for the XXX River at CITY, STATE, and location of U.S. Geological Survey streamgage.
2. U.S. Geological Survey streamgage information for XXX River at CITY, STATE.

LAYOUT FOR TABLE 1 when presenting info for one or two stations.

Table 1. U.S. Geological Survey streamgage information for ***XXX*** ***River at CITY***, ***STATE***

[Station location is shown in figure 1. mi2, square miles; ft3/s, cubic feet per second; NAVD 88, North American Vertical Datum of 1988]

|  |  |  |
| --- | --- | --- |
| Station name | ***XXX River at CITY*** |  |
| Station number | ***04189000*** |  |
| Drainage area (mi2) | ***346*** |  |
| Latitude | ***35o 10’10”*** |  |
| Longitude | ***80o10’10”*** |  |
| Period of peak-flow record  (water years1) | ***1955, 1982-2012*** |  |
| Maximum recorded stage, in feet, gage datum (and elevation, in feet above NAVD 88) and date | ***35.50***  ***(1,234.50)***  ***January 25, 1990*** |  |
| Maximum discharge, in ft3/s,  and date | ***25,200***  ***April 1, 1955*** |  |

1Water year is the 12-month period from October 1 of one year through September 30 of the following year and is designated by the calendar year in which it ends.

ALTERNATIVE LAYOUT FOR TABLE 1 when presenting info for more than two stations.

Table 1. Information for U.S. Geological Survey streamgage(s) <and miscellaneous site(s), if applicable>, ***XXX*** ***River at CITY***, ***STATE*** [OR <along study reach, XXX River, CITY, STATE>]

[Station location is shown in figure 1. DA, drainage area; mi2, square miles; ft, feet; ft3/s, cubic feet per second]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Station name | Station number | DA  (mi2) | Latitude | Longitude | Period of peak-flow record | Maximum recorded stage (ft) and date | Maximum discharge (ft3/s) and date |
| ***XXX River at CITY*** | ***04189000*** | ***346*** | ***35o10’10”*** | ***80o10’10”*** | ***Nov. 1981 to Sept. 2012*** | ***35.50,***  ***Jan. 25, 1990*** | ***25,200,***  ***April 1, 2005*** |
| ***XXX River at CITY*** |  |  |  |  |  |  |  |
| ***Miscellaneous site*** |  |  |  |  |  |  |  |

## Study Area Description

Include the following information:

-location of river in the STATE; political entities involved (city, counties, etc.)

- drainage area at the USGS gage

- major tributaries that join the ***XXX*** River within the study reach

- topography (physiographic province(s) or eco-region(s)); land cover and land uses (percentages?) in the study reach; ongoing development and population growth (especially near the river)

- length of study reach; average top-of-bank channel width; average channel slope

- number and type of hydraulic structures in the study reach (for example, “the study reach is traversed by ***xx*** major four-lane highway(s), ***xx*** two-lane county road(s), a railroad, a low-head dam, etc.)

- presence and condition of levees. Are they included in the National Levee Database (USACE, http://nld.usace.army.mil/egis/f?p=471:1:)

## Previous Studies

The current FIS for ***CITY/COUNTY*** (Federal Emergency Management Agency, ***YEAR***) was completed by [***CONSULTANT***/***AGENCY***] in ***YEAR***.

-State whether a new hydraulic model was developed or an earlier model (and associated results) was used for the current FIS. (Some FISs are re-presentations or compilations of earlier FISs; therefore note the date of the hydraulic model that was used to generate the data presented in the current FIS.)

The FIS presents estimates of the peak discharges with 10‑, 2‑, 1‑, and 0.2‑percent annual exceedance probabilities (table 2) and their associated water-surface elevations for the ***XXX*** River at ***CITY***. [Alternatively, you might use/refer to flood frequencies published in a USGS report.]

-Describe any other flood-related studies that pertain to the study reach

1. Peak discharges for selected annual exceedance probabilities for XXX River at CITY, STATE.

[mi2, square miles; ft3/s, cubic feet per second; USGS, U.S. Geological Survey. Data from Federal Emergency Management Agency, ***YEAR***. [or U.S. Geological Survey, ***YEAR***.]]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Location on XXX River | Drainage  area (mi2) | Estimated discharges (ft3/s) for indicated annual exceedance probabilities  (in percent) | | | |
| 10 | 2 | 1 | 0.2 |
| ***Downstream from confluence with TRIB1*** | ***250*** | ***7,000*** | ***16,000*** | ***17,500*** | ***19,000*** |
| ***At USGS streamgage number xxxxxxxx*** | ***280*** | ***9,000*** | ***16,700*** | ***18,000*** | ***19,500*** |
| ***Upstream from County Road XX*** | ***300*** | ***10,000*** | ***17,200*** | ***18,300*** | ***19,800*** |

# Creation of Flood-Inundation-Map Library

The USGS has standardized the procedures for creating flood-inundation maps for flood-prone communities (U.S. Geological Survey, ***YEARc***) so that the process followed and products produced are similar regardless of which USGS office is responsible for the work. Tasks specific to development of the flood maps for ***CITY, STATE*** were [include only those tasks that pertain to the subject study; add tasks that are not cited below] (1) ***installation***/***upgrade***/***reestablishment*** of ***xx*** stream gages on the ***XXX*** ***River*** (table 1) (2) acquisition of the hydraulic model that was used for the most recent FEMA flood insurance study for ***COMMUNITY*** (Federal Emergency Management Agency, ***YEAR***); [if this task is applicable to your study, skip to task 4. If a hydraulic model was developed as part of your study, delete this task and continue with alternate “task 2”] (2) collection of topographic and bathymetric data for selected cross sections and geometric data for structures and bridges along the study reach, (3) estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain and determination of steady-flow data [or use/verification of similar data from previous studies], (4) computation of water-surface profiles using the ***U.S. Army Corps of Engineers’ HEC–RAS computer program (U.S. Army Corps of Engineers, 2010)***, (5) production of estimated flood-inundation maps at various stream stages using the ***U.S. Army Corps of Engineers’ HEC–GeoRAS computer program (U.S. Army Corps of Engineers, 2009)*** and a geographic information system (GIS), and (6) preparation of the maps, both as shapefile polygons that depict the areal extent of flood inundation and as depth grids that provide the depth of floodwaters, for display on a USGS flood‑inundation mapping application and [if applicable] the NWS AHPS web site (National Weather Service, ***YEARa***).

## Computation of Water-Surface Profiles

The water-surface profiles used to produce the ***xx*** flood-inundation maps in this study were computed by using ***HEC–RAS, version 4.1.0 (U.S. Army Corps of Engineers, 2010). [***Alternatively ***“The water-surface profiles used to produce the xx flood-inundation maps in this study were computed with the hydraulic model that was developed for the effective FIS for COMMUNITY (Federal Emergency Management Agency, YEAR). This model, which was developed using HEC–RAS, version x.x (U.S. Army Corps of Engineers, 2010), was created by CONSULTANT/AGENCY in YEAR”*** [NOTE: the year of the hydraulic model may be different from that of the FIS]. ***HEC–RAS*** is a one-dimensional step-backwater model for simulation of water-surface profiles with steady-state (gradually varied) or unsteady-state flow computation options.

### Hydrologic Data

The study reach includes ***xx*** streamgage(s) (fig. 1; table 1.). ***XX*** of the gages were already in operation, ***xx*** gages were upgraded with continuous recorders, and ***xx*** gages were reactivated/established for this project. [Alternatively, “The study reach includes one streamgage (***<sta.no.>***; fig. 1; table 1) that has been in operation since ***MONTH*** ***YEAR***.”] 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 (NWIS; U.S. Geological Survey, ***YEARb***). Stage data from this streamgage are referenced to a local datum but can be converted to water-surface elevations referenced to the NAVD 88 by adding ***xxxx.xx*** ft. Continuous records of streamflow are computed from a stage-discharge relation, which has been developed for the streamgage, and are available through the USGS NWIS web site.

The peak flows used in the model simulations (table 3) were taken from the current stage-discharge relation (number ***xx***, effective ***DATE***) and corresponded with the target stages. [If applicable you should mention if the stages and discharges from a previous FIS were used (cite the source). ALSO if the rating was extended as part of this project, explain how the extension was performed (straight-line extension of log-log plot; used the calibrated HEC–RAS model that was developed for the current study; some other method?).] No major tributaries join the ***XXX*** River within the ***xx***‑mi study reach; therefore, the gage-derived discharges were not adjusted for tributary inflows but were held constant throughout the study reach for a given profile. [Alternatively, ***xx*** minor tributaries—***TRIB1*** and ***TRIB2***—join the ***XXX*** River within the ***xx***‑mi study reach. The streamgage-derived discharges were adjusted, as necessary, to account for tributary inflows (table 3). These adjustments were equal (proportional?) to those applied in the currently effective FIS (Federal Emergency Management Agency, YEAR) [Alternatively, “These adjustments were estimated by applying a drainage-area ratio to the main-channel flows.”]

1. Estimated discharges for corresponding stages and water-surface elevations at selected locations, used in the hydraulic model of the XXX River at CITY, STATE.

[ft, feet; NAVD 88, North American Vertical Datum of 1988; ft3/s, cubic feet per second]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Stage of  water-surface  profile (ft)1 | Water-surface elevation  (ft, NAVD 88) | Estimated discharge at indicated location, in cubic feet per second | | |
| At upstream  end of study  reach | Downstream from confluence with TRIB1 | Downstream from confluence with TRIB2 |
| ***10*** | ***1,357.82*** | ***1,920*** | ***3,010*** |  |
| ***11*** | ***1,358.82*** | ***2,620*** | ***4,120*** |  |
| ***12*** | ***1,359.82*** | ***3,490*** | ***5,480*** |  |
| ***13*** | ***1,360.82*** | ***4,460*** | ***7,010*** |  |
| ***14*** | ***1,361.82*** | ***5,600*** | ***8,800*** |  |

1Water-surface profiles are 1‑foot increments of stage, referenced to the gage datum of the U.S. Geological Survey streamgage, XXX River at CITY, STATE (station number xxxxxxxx)

### Topographic and Bathymetric Data

All topographic data used in this study are referenced vertically to NAVD 88 and horizontally to the North American Datum of 1983. Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from light detection and ranging (lidar) data that were collected during ***MONTH***, ***YEAR***, by ***NAME OF COMPANY***, ***CITY***, ***STATE***. Postprocessing of these data was completed by ***NAME OF COMPANY*** on ***DATE***. The original lidar data have horizontal resolution of ***x.x*** ft (***x.x*** meters) and vertical accuracy of 0.***xx*** ft (***xx*** centimeters) at a 95‑percent confidence level for the “open terrain” land-cover category (root mean squared error of 0.***xx*** ft (***xx*** centimeters)). By these criteria, the lidar data support production of 2‑ft contours (Dewberry, 2012); the final DEM, which was resampled to a ***10***‑ft grid-cell size to decrease the GIS processing time, has a vertical accuracy of plus or minus 1 ft. By using ***HEC–GeoRAS***, a set of procedures, tools, and utilities for processing geospatial data in ArcGIS, elevation data were extracted from the DEM for ***xx*** cross sections and subsequently were input to the ***HEC–RAS*** model. Because lidar data cannot provide ground elevations below a stream’s water surface, channel cross sections were surveyed by USGS field crews during ***20xx***. Cross‑sectional depths were measured ***<how?>*** [by wading or by using hydroacoustic instrumentation at ***xx*** locations. A differential global positioning system (DGPS) with real‑time kinematic (RTK) technology was used to derive horizontal locations and the elevation of the water‑surface at each surveyed cross section. Elevations determined by RTK DGPS at xx benchmark locations were within 0.xx–0.xx ft of the known elevations, an error range that falls within (or exceeds?) the accuracy of the lidar data.]

Where possible, DEM-generated cross sections were made to coincide with the locations of the within-channel field-surveyed cross sections. In these cases, within-channel data were directly merged with the DEM data. For all other cross sections, the within-channel data were estimated by interpolation from the closest field-surveyed cross section.

[Alternatively, In the ArcMap application of ArcGIS (Esri, ***YEAR***), these field data were used in conjunction with a bathymetry mesh tool that was created by Merwade and others (2008) to interpolate below-water ground elevations through the study reach. The density of ground elevations in the mesh was determined by two variables: (1) the number of parallel longitudinal profiles that were evenly spaced across the channel and ran the length of the study reach and (2) the user-specified spacing between cross sections. Ground elevations were either extracted or interpolated from the field data at the intersections of ***xx*** longitudinal profiles and cross sections that were spaced ***xxx*** ft apart. The mesh elevations were subsequently added to the DEM data of the synthetic cross sections before the data were exported to HEC–RAS. Instructions for the bathymetry mesh tool are presented by Merwade (2011).]

[Note: If data from an existing FIS study were used for modeling, you will need to cite the study here and revise this entire section, as is appropriate for your study reach. State whether the cross-sections were spot-checked with surveyed field data].

### Hydraulic Structures

***XX*** structures, consisting of ***xx*** road crossings (County Road ***xx***, U.S. Route ***xx***, and State Route ***xx***), a railroad bridge, and a low-head dam, have the potential to affect water-surface elevations during floods along the stream. Bridge-geometry data were obtained from field surveys conducted by personnel from the USGS ***XXX*** Water Science Center. ***[Otherwise state the source of the bridge data***

***-were obtained from the XXX County Highway Department (xxx, written commun., YEAR]***

***-were obtained from a HEC–2 / HEC–RAS model (cite reference) that was developed and used for the YEAR FIS (Federal Emergency Management Agency, YEAR). ]***

[Note: If data from an existing FIS study were used for modeling, confirm that the bridges in the study reach have not changed since the date of the hydraulic model or completion of the FIS. Otherwise, verify that all bridge data are currently accurate and/or that structures, which were added or modified since the latest FIS, were surveyed or re-surveyed, respectively, as needed for inclusion in the model. State these facts here.]

[If levees exist in the study reach, add a description including location, length, effectiveness to contain floods, whether included in the National Levee Database, etc.. Include the following statement if appropriate: “Because of the uncertainty as to the effectiveness of this levee, it was not simulated as a levee in the ***HEC–RAS*** model; rather, where appropriate to do so, the landward side of the levee was simulated as ineffective flow area up to the elevation of the top of the levee.”]

[If flows through the study reach can be regulated by a dam, describe the dam, its operation, and its effect on flood flows.]

### Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses that result from frictional resistance exerted by a channel on flow. These energy losses are quantified by the Manning’s roughness coefficient (“*n”* value). Initial (precalibration) *n* values were selected on the basis of field observations and high-resolution aerial photographs. [If published tables, photographic –comparison references, or n-value equations also were used to estimate the initial n values, state so and add references.]

[Describe the channel characteristics (bed material, gradient/slope, width, channel and bank vegetation, degree of meandering, etc.) and flood-plain characteristics (vegetation, topographic irregularities, buildings, etc.) that affect the n value and state the initial n value that was selected on the basis of these characteristics.]

[FOR EXAMPLE: Initial (precalibration) Manning’s roughness coefficients (n values) for energy-loss (friction-loss) calculations were estimated by comparison of field photographs with photographs of channels for which n values have been computed and published in references, such as Barnes (1967), Coon (1998), and Hicks and Mason (1991). [Or were estimated from a table of n-values (cite reference) or from an n-value equation (cite reference).] An n value of 0.045 was selected for the wide, low-gradient main channel with sandy bed and tree-lined banks. The flood plains have mixed land uses but are dominated by agriculture. Forested areas cover wide swaths of land on both banks and flood plains adjacent to the river. Densely populated residential areas are east of the XXX River, but these areas are mostly on elevated ground above the left flood plain. A composite n value (0.070) that was presumed to represent the diverse energy-loss factors of these land types was deemed appropriate to use for the initial estimate of the flood plain n value.]

As part of the calibration process, the initial n values were varied by flow and adjusted until the differences between simulated and observed water-surface elevations at the streamgage ***[and elsewhere along the study reach]*** were minimized. The final *n* values ranged from 0.***xxx*** to 0.***xxx*** for the main channel and 0.***xxx*** to 0.***xxx*** for the overbank areas modeled in this analysis. [NOTE: If roughness-coefficient adjustment factors are used in HEC–RAS, then the “final” n values should be computed from the adjustment factors and presented here to reflect that fact. In other words, don’t ignore the effect that the adjustment factors have on the n values.]

### Hydraulic Model

The ***HEC–RAS*** analysis for this study was done by using the steady-state flow computation option. Steady-state flow data consisted of flow regime, boundary conditions, and peak flows that produced water-surface elevations at the streamgage cross section that matched target water-surface elevations. These target elevations coincided with even 1‑ft increments of stage, referenced to the local gage datum. Subcritical (tranquil) flow regime was assumed for the simulations. Normal depth, [or known stage associated with a discharge measurement, or critical depth, or streamgage rating-curve value; whichever method was used to define the boundary condition] based on an estimated average water-surface slope of 0.***xxxx*** from data contained in the FEMA FIS (Federal Emergency Management Agency, YEAR), was used as the reach’s downstream boundary condition. [Describe any changes in “boundary” energy/water-surface slope that were made; for example, to accommodate backwater at the mouth of the study reach from a larger stream.] The peak flows that were used in the model were discussed in the section, “Hydrologic Data.”

The ***HEC–RAS*** model was calibrated to the current stage-discharge relation at the ***XXX*** ***River*** streamgage, and to

***- documented high-water marks from the floods of DATE, DATE, and DATE***

***- water-surface profiles from historic floods (give DATEs)***

***- water-surface profiles from the current Federal Emergency Management Agency flood-insurance study***

***- discrete discharge measurements that were made at miscellaneous sites (table 1) during periods of moderate to high flow***

[If an existing model was used, cite it and summarize the calibration steps from the original report.]

Model calibration was accomplished by adjusting Manning’s *n* values and, in some cases, changing the channel cross section or slope [include this latter phrase ONLY if XS and slope changes were actually made for the study model; otherwise delete] until the results of the hydraulic computations closely agreed with the observed water-surface elevations for given flows. Differences between observed and simulated water-surface elevations for the ***xx*** simulated flows at the USGS streamgage were equal to or less than ***xx*** ft (table 4). [And/or “Differences between surveyed and simulated elevations of high-water marks in the study reach for the flood of ***DATE*** were less than ***xx*** ft (table 5 ).”] [Instead of presenting these latter data in a table, these differences in simulated and observed water-surface profiles could be shown in a figure (fig. 2).] The results demonstrate that the model is capable of simulating accurate water levels over a wide range of flows in the basin.

1. Calibration of model to target water-surface elevations at U.S. Geological Survey streamgage on XXX River at CITY, STATE (station number xxxxxxxx).

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

|  |  |  |  |
| --- | --- | --- | --- |
| Stage of  water-surface  profile (ft) | Target water-surface elevation  (ft, NAVD 88) | Modeled water-surface elevation  (ft, NAVD 88) | Difference in elevation (ft) |
| ***10*** | ***618.74*** | ***618.73*** | ***-0.01*** |
| ***11*** | ***619.74*** | ***619.71*** | ***-0.03*** |
| ***12*** | ***620.74*** | ***620.74*** | ***0.00*** |
| ***13*** | ***621.74*** | ***621.76*** | ***0.02*** |
| ***14*** | ***622.74*** | ***622.74*** | ***0.00*** |

1. Calibration of model to water-surface elevations at selected locations along the XXX River for the flood(s) of DATE (and DATE).

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

|  |  |  |  |
| --- | --- | --- | --- |
| <Cross-section ID (ft)> <River station (miles)>1 | Surveyed water-surface elevation  (ft, NAVD 88) | Modeled water-surface elevation  (ft, NAVD 88) | Difference in elevation (ft) |
| ***810*** | ***618.74*** | ***618.70*** | ***-0.04*** |
| ***1,063*** | ***619.74*** | ***619.79*** | ***0.05*** |
| ***1,225 (at gage)*** | ***620.74*** | ***620.75*** | ***0.01*** |
| ***1,410*** | ***621.74*** | ***621.60*** | ***-0.14*** |
| ***1,568*** | ***622.74*** | ***622.86*** | ***0.12*** |

1Cross-section identification numbers are referenced to the longitudinal baseline used in the hydraulic model [OR River stations are the distances upstream from the river mouth as presented in the flood insurance study (Federal Emergency Management Agency, YEAR]

1. Observed and simulated water-surface elevations and profiles for the flood(s) of DATE, (and DATE) [and/or the FEMA xx‑percent annual exceedance probability flood] for XXX River at CITY, STATE.

### Development of Water-Surface Profiles

The calibrated hydraulic model was used to generate water-surface profiles for a total of ***xx*** stages at ***xx***-ft intervals between ***xx*** ft and ***yy*** ft as referenced to the local datum of the ***Station*** ***Name*** streamgage. These stages correspond to elevations of xxx.xx ft and xxx.xx ft, NAVD 88, respectively. [Discharges corresponding to the various stages were obtained from the current stage-discharge relation for the ***XXX*** ***River*** at ***CITY*** streamgage. Discharges through the study reach were adjusted, as necessary, for tributary inflow(s) as shown in table 3.]

## Development of Flood-Inundation Maps

Flood-inundation maps were created for ***xx*** of the USGS sites, ***xx*** of which have been designated as NWS flood-forecast points (as of ***YEAR***). The maps were created in a GIS by combining the water-surface profiles and digital elevation model data. [Alternatively “Flood-inundation maps were created in a GIS for the ***xx*** water-surface profiles by combining the profiles and digital elevation model data.] The DEM data were derived from the same lidar data described previously in the section “Topographic and Bathymetric Data” and therefore have an estimated vertical accuracy of 2 ft (that is, plus or minus 1 ft). Estimated flood-inundation boundaries for each simulated profile were developed with ***HEC–GeoRAS*** software (U.S. Army Corps of Engineers, 2009), which allows the preparation of geometric data for import into ***HEC–RAS*** and processes simulation results exported from ***HEC–RAS*** (U.S. Army Corps of Engineers, 2010). Shapefile polygons and depth grids of the inundated areas for each profile were modified, as required, in the ArcMap application of ArcGIS (Esri, ***YEAR***) to ensure a hydraulically reasonable transition of the flood boundaries between modeled cross sections.

Any inundated areas that were detached from the main channel were examined to identify subsurface 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 erroneously delineated parts of the flood extent were deleted. The flood-inundation areas are overlaid on high-resolution, georeferenced, aerial photographs of the study area. Bridge surfaces are displayed as inundated regardless of the actual water-surface elevation in relation to the lowest structural chord of the bridge or the bridge deck. [Alternatively, “Bridge surfaces are shown as non‑inundated up to the lowest flood stage that either intersects the lowest structural chord of the bridge or completely inundates one or both approaches to the bridge. In these latter circumstances, the bridge surface is depicted as being inundated.”] Estimates of water depth can be obtained from the depth-grid data that are included with the presentation of the flood maps on an interactive USGS mapping application described in the following section, “Flood-Inundation Map Delivery.” The flood map corresponding to the highest simulated water-surface profile, a stage of ***xx*** ft, is presented in figure 3.

1. Flood-inundation map for the XXX River at CITY, STATE, corresponding to a stage of xx.00 feet at the U.S. Geological Survey streamgage (station number xxxxxxxx).

### Flood-Inundation Map Delivery

The current study documentation is available online at the U.S. Geological Survey Publications Warehouse ([http://pubs.usgs.gov/sir/ **xxxx**](http://pubs.usgs.gov/sir/xxxx)**/xxxx**). Also, a Flood Inundation Mapping Science web site (U.S. Geological Survey, ***YEARc***) has been established to make USGS flood-inundation study information available to the public. That site links to a mapping application that presents map libraries and provides detailed information on flood extents and depths for modeled sites. The mapping application enables the production of customized flood-inundation maps from the map library for ***XXX*** River at ***CITY***, ***STATE***. A link on this web site connects to the USGS National Water Information System (U.S. Geological Survey, ***YEARa***), which presents the current stage and streamflow at the USGS streamgage ***xxxxxxxx*** to which the inundation maps are referenced. A second link connects to the NWS Advanced Hydrologic Prediction Service (AHPS) site (National Weather Service, ***YEARa***) so that the user can obtain applicable information on forecasted peak stage [if applicable to the study site. If the NWS does NOT forecast stage at this site, then delete this reference to forecasted stage]. The estimated flood-inundation maps are displayed in sufficient detail so that preparations for flooding and decisions for emergency response can be performed efficiently. Depending on the flood magnitude, roadways are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. Bridges are shaded—that is, shown as inundated—regardless of the flood magnitude. [Revise this sentence if flooding at bridges is displayed differently.] A shaded building should not be interpreted to mean that the structure is completely submerged; rather that bare earth surfaces in the vicinity of the building are inundated. In these instances, the water depth (as indicated in the mapping application by holding the cursor over an inundated area) near the building would be an estimate of the water level inside the structure, unless flood-proofing measures had been implemented.

[NOTE: If a study reach has levees, separate “levee-area” and “main-channel-area” polygons and depth grids will have to be created so that the levee areas can be properly displayed on the Flood Mapper web site.]

### Disclaimer for Flood-Inundation Maps [NOTE: Authors cannot change the text in this section.]

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 [NOTE: Authors cannot change the text in this section, except as noted below.]

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 stream gages. Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at the USGS streamgage(s). The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of ***MONTH YEAR***. Unique meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded due to unanticipated conditions such as changes in the streambed elevation or roughness, backwater into major tributaries along a main stem river, or backwater from localized debris or ice jams. The accuracy of the floodwater extent portrayed on these maps will vary with the accuracy of the digital elevation model used to simulate the land surface.

If this series of flood-inundation maps will be used in conjunction with National Weather Service (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 (AHPS forecast point) throughout the forecast period (every 6 hours and 3 to 5 days out in many locations). For more information on AHPS forecasts, please see: [http://water.weather.gov/ahps/pcpn\_and\_river\_forecasting.pdf.](http://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf.%20)

[NOTE: additional uncertainties can be added at the end of this section, but the above text cannot be modified.]

[If the study reach includes levees or low-elevation areas on the landward side of high banks, either of which can produce variable flood extents and water depths on the landward side of the levee/high bank, a paragraph should be inserted here to describe this source of uncertainty. Likewise, if flows in the reach are affected by regulation from a dam, you should add a statement that qualifies the uncertainty in flood extent and depths that might be associated with this structure.] Additional uncertainties and limitations pertinent to this study may be described elsewhere in this report.

# Estimating Potential Losses Due to Flooding

The flood-inundation maps provide information relative to the depth and areal extent of flooding. These data can be used in a methodology that has been developed by FEMA (***YEARa***) to estimate the physical, economic, and social effects associated with the inundated areas as defined by the maps. This methodology, named Hazus Multi-Hazard Analysis (Hazus-MH; Federal Emergency Management Agency, ***YEARb***) is used throughout the United States to estimate potential losses from disasters such as earthquakes, floods, and hurricanes and allows for the establishment of a nationwide database of population and infrastructure at risk. Government planners, GIS specialists, and emergency managers can use Hazus-MH to calculate losses from floods and to assess the most beneficial mitigation approaches to minimize these losses.

Although Hazus-MH is able to generate reliable assessments of flood risk, its usefulness is limited because it can be run only on a workstation by a trained operator, and analyses are not adapted for convenient delivery over the internet (Hearn and others, 2013). In 2010, the USGS and FEMA began an effort to provide a solution to this problem by integrating Hazus‑MH flood risk analyses with the USGS produced flood-inundation maps and make these data available on the internet (Hearn, and others, 2013 [and at [***http://water.usgs.gov/osw/flood\_inundation/toolbox/hazus.html***](http://water.usgs.gov/osw/flood_inundation/toolbox/hazus.html).]). To this end, Hazus-MH analyses were performed for the ***xx*** flood-inundation maps associated with the ***XXX*** River at ***CITY***, ***STATE***, and are presented, along with the flood-inundation maps, on the USGS flood mapping application. [Add a description and pertinent info of the Hazus analysis that was performed for the study reach. Background info can be found at Federal Emergency Management Agency (YEARc).]

# Summary

A series of ***xx*** digital flood-inundation maps were developed in cooperation with ***COOPERATOR*** for the ***XXX RIVER*** at ***CITY***, ***STATE***. The maps cover a reach about ***xx*** miles long from ***POINTA*** to ***POINTB***. The maps were developed by using the ***U.S. Army Corps of Engineers’ HEC–RAS and HEC–GeoRAS*** programs to compute water-surface profiles and to delineate estimated flood-inundation areas and depths of flooding for selected stream stages. The ***HEC–RAS*** hydraulic model was calibrated to the current stage-discharge relation at the ***XXX*** ***River*** streamgage, and to ***<what else?>.*** The model was used to compute ***xx*** water-surface profiles for flood stages at ***x***-foot (ft) intervals referenced to the streamgage datum and ranging from ***xx*** ft or near bankfull to ***yy*** ft, which exceeds the stage of the maximum recorded peak flow [or some other appropriate qualifying statement]. The simulated water-surface profiles were then combined with a geographic information system (GIS) digital elevation model derived from light detection and ranging (lidar) data to delineate estimated flood-inundation areas as shapefile polygons and depth grids for each profile. These flood-inundation polygons were overlaid on high-resolution, georeferenced aerial photographs of the study area. The flood maps and depth grids were subsequently used in a Hazus analysis to estimate the potential losses that are likely to result from a flood of a given magnitude. [delete this sentence and the reference to Hazus in the next sentence if a Hazus analysis was not performed] The flood maps and Hazus results are available through a mapping application that can be accessed on the USGS Flood Inundation Mapping Science web site (<http://water.usgs.gov/osw/flood_inundation>*)*.

Interactive use of the maps on this mapping application can give users a general indication of depth of water at any point by using the mouse cursor to click within the shaded areas. These maps, in conjunction with the real-time stage data from the USGS streamgage, ***XXX River*** at ***CITY*** (station number ***xxxxxxxx***), and forecasted flood stage data from the National Weather Service Advanced Hydrologic Prediction Service [delete this latter phrase if it is not applicable to the study reach] will help to guide the general public in taking individual safety precautions and will provide emergency management personnel with a tool to efficiently manage emergency flood operations and postflood recovery efforts.

# References Cited

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

Esri, ***YEAR***, ArcGIS, accessed ***DATE***, at <http://www.esri.com/software/arcgis/.>

Federal Emergency Management Agency, ***YEAR***, Flood Insurance Study, ***XXX*** County, ***STATE***, and incorporated areas: Washington D.C., ***xx*** p., ***xx*** pl.

Federal Emergency Management Agency, ***YEARa***, The Federal Emergency Management Agency’s methodology for estimating potential losses from disasters: Federal Emergency Management Agency, accessed ***DATE***, at <http://www.fema.gov/hazus>.

Federal Emergency Management Agency, ***YEARb***, Hazus Software: Federal Emergency Management Agency, accessed ***DATE***, <http://www.fema.gov/hazus>-software.

Federal Emergency Management Agency, ***YEARc***, HAZUS-Multi Hazard Analysis Levels: Federal Emergency Management Agency, accessed ***DATE***, at [*http://fema.gov/hazus/hazus-multi-hazard-analysis-levels*](http://fema.gov/hazus/hazus-multi-hazard-analysis-levels).

Hearn, P.P., Jr., Longenecker, H.E., Aguinaldo, J.J., and Rahan, A.N., 2013, Delivering integrated HAZUS-MH flood loss analyses and flood inundation maps over the web: Journal of Emergency Management, v. 11, no. 4, p. 293–302.

Merwade, V., 2011, Creating bathymetry mesh from cross sections: Purdue University, School of Civil Engineering, accessed March 15, 2013, at <http://web.ics.purdue.edu/~vmerwade/research/bathymetry_tutorial.pdf>.

Merwade, V., Cook, A., and Coonrod, J., 2008, GIS techniques for creating river terrain models t for hydrodynamic modeling and flood inundation mapping: Environmental Modeling and Software, v. 23, p. 1300–1311.

National Weather Service, ***YEARa***, Advanced Hydrologic Prediction Service, ***XXX*** River at ***CITY***, accessed ***DATE***, at [http://water.weather.gov/ahps2/hydrograph.php?wfo=**XXX**&gage=**XXX**](http://water.weather.gov/ahps2/hydrograph.php?wfo=XXX&gage=XXX). [input the WFO and GAGE IDs from the station’s AHPS webpage.]

National Weather Service, ***YEARb***, National Weather Service Glossary, accessed ***DATE***, at <http://w1.weather.gov/glossary/index.php?word=action+stage>.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2009, HEC–GeoRAS, GIS Tools for Support of HEC–RAS using ArcGIS, User’s Manual, version 4.2, [variously paged].

U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2010, HEC–RAS River Analysis System, Hydraulic Reference Manual, version 4.1, [variously paged].

U.S. Bureau of Census, ***YEAR***, State population datasets—Population, population change and estimated components of population change: ***April 1, 2000 to July 1, 2006*** [replace with actual info used]

U.S. Geological Survey, ***YEARa***, USGS ***<station number> STATION NAME***: U.S. Geological Survey, accessed ***DATE***, at [http://waterdata.usgs.gov/in/nwis/uv?site\_no=**xxxxxxxx**](http://waterdata.usgs.gov/in/nwis/uv?site_no=xxxxxxxx).

U.S. Geological Survey, ***YEARb***, USGS surface-water data for the Nation: U.S. Geological Survey, accessed ***DATE***, at <http://waterdata.usgs.gov/nwis/sw>.

U.S. Geological Survey, ***YEARc***, USGS Flood Inundation Mapping Science: U.S. Geological Survey, accessed ***DATE***, at <http://water.usgs.gov/osw/flood_inundation>.