



Prepared in Cooperation with City of Fort Wayne, Indiana

Flood-Inundation Maps for the St. Marys River at Fort Wayne, Indiana

By Chad D. Menke, Moon H. Kim, and Kathleen K. Fowler

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Conversion Factors

Inch/Pound to SI

| Multiply | By | To obtain |
|--|---------|--|
| Length | | |
| inch (in) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| Area | | |
| square foot (ft ²) | 0.0929 | square meter (m ²) |
| 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) |
| Hydraulic gradient | | |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer (m/km) |

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

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

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Abstract

Digital flood-inundation maps for a 9-mile reach of the St. Marys River that extends from South Anthony Boulevard to Main Street at Fort Wayne, Indiana, were created by the U.S. Geological Survey (USGS) in cooperation with the City of Fort Wayne. The inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science Web site at http://water.usgs.gov/osw/flood_inundation/, depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN. Current conditions at the USGS streamgages in Indiana may be obtained online at <http://waterdata.usgs.gov/in/nwis/current/?type=flow>. In addition, the information has been provided to the National Weather Service (NWS) for incorporation into their Advanced Hydrologic Prediction Service (AHPS) flood warning system (<http://water.weather.gov/ahps/>). The NWS forecasts flood hydrographs at many places that are often collocated at USGS streamgages. That forecasted peak-stage information, also available on the Internet, may be used in conjunction with the maps developed in this study to show predicted areas of flood inundation.

In this study, water-surface profiles were simulated for the stream reach by means of a hydraulic one-dimensional step-backwater model. The model was calibrated using the most current stage-

discharge relation at the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN. The hydraulic model was then used to simulate 11 water-surface profiles for flood stages at 1-ft intervals referenced to the streamgage datum and ranging from bankfull to approximately the highest recorded water level at the streamgage. The simulated water-surface profiles were then combined with a geographic information system digital elevation model (derived from Light Detection and Ranging (LiDAR) data) in order to delineate the area flooded at each water level. A flood inundation map was generated for each water-surface profile stage (11 maps in all) so that for any given flood stage users will be able to view the estimated area of inundation.

The availability of these maps along with current stage from USGS streamgages and forecasted stream stages from the NWS 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 post flood recovery efforts.

Introduction

The City of Fort Wayne, Indiana, is a large urban community with an estimated population of 253,691 in 2010 (U.S. Census Bureau, 2011). Fort Wayne has undergone severe flooding numerous times; most notably in 1913 and 1982. Damage costs adjusted for inflation within Fort Wayne for these floods were reported to be \$4.8 million (Jarosh, 2011), and \$56 million (Lohrmann and Tannehill, 2011), for each year, respectively. The majority of flood damages have occurred along the St. Marys River and several tributaries (including Junk Ditch and Fairfield Ditch), all of which flow through the city (Federal Emergency Management Agency, 2009). Flood plains within Fort Wayne are highly developed and contain a mix of residential and commercial structures.

Prior to this study, Fort Wayne officials have 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 Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Allen County dated August 3, 2009 (FEMA, 2009). A second source of information is the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN, from which current or historical water levels (stage) can be obtained at <http://waterdata.usgs.gov/in/nwis/current/?type=flow>. A third source is the National Weather Service's forecast of peak stage at the USGS streamgages through the AHPS site at <http://water.weather.gov/ahps/>. Although USGS current stage and NWS forecast stage information 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 channel. Also, FEMA and State emergency management mitigation teams or property owners typically lack information related to the depth of water at locations other than near USGS streamgage or NWS flood-forecast points.

Purpose and Scope

The purpose of this report is to describe the development of a series of estimated flood-inundation maps for the St. Marys River near Fort Wayne, Indiana, and to provide maps and other useful flood information on the USGS Flood Inundation Mapping Science Web site at http://water.usgs.gov/osw/flood_inundation/ and the NWS Advanced Hydrologic Prediction Service Web site at <http://water.weather.gov/ahps/>. Internet users can select estimated inundation maps that correspond to (1) current stages at the USGS streamgage, (2) the NWS forecasted peak stage, or (3) other desired stream stages.

The scope of the study was limited to the St. Marys River between USGS streamgage 04182000 St. Marys River near Fort Wayne, IN, at South Anthony Boulevard and USGS streamgage 04182769 St. Marys River at Main St. at Fort Wayne, IN (fig. 1). Tasks specific to development of the maps were (1) collection of topographic data and geometric data (for structures and (or) bridges) throughout the study

reach, (2) determination of energy-loss factors (roughness coefficients) in the stream channel and flood plain, and steady-flow data, (3) computation of water-surface profiles using the U.S. Army Corps of Engineer's HEC-RAS computer program (U.S. Army Corps of Engineers, 2010), (4) production of estimated flood-inundation maps at various stream stages using the U.S. Army Corps of Engineer's HEC-GeoRas computer program (U.S. Army Corps of Engineers, 2009) and a Geographic Information System (GIS), and (5) development of a Web interface that links to USGS real-time streamgage information and (or) NWS forecasted peak stage to facilitate the display of user-selected flood-inundation maps on the Internet.

Figure 1. **Figure 1 .** Location of study reach for the St. Marys River and location of USGS streamgage sites.

Methods used are generally cited from previously published reports (for example, Bales and others, 2007 and Whitehead and Ostheimer, 2009). If techniques varied significantly from previously documented methods due to local hydrologic conditions or available data, they are described in detail in this report. Maps were produced for water levels referenced to the water-surface elevation (stage) at USGS streamgage 04182000 St. Marys River near Fort Wayne, IN, and ranging from approximately bankfull to the approximately maximum observed water level at the streamgage.

Study Area Description

The St. Marys River is in northeastern Indiana in Allen County. The drainage area ranges from 762 mi² at the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN, to 823 mi² at the USGS streamgage 04182769 St. Marys River at Main St. at Fort Wayne, IN. The headwaters originate in western Ohio, and the stream flows generally northward before entering the city limits. There are three major tributaries (Junk Ditch, Snyder Ditch, and Fairfield Ditch) to the St. Marys River that join the main stem as it flows through Fort Wayne. The study reach is approximately 9 miles long, has an

average top-of-bank channel width of about 280 ft and an average channel slope of 1.0 ft/mi. About 3 percent of the basin contiguous to the study reach is classified as urban or developed. The downstream part of the reach has an increased concentration of urban development. The basin is still under development with new houses and commercial businesses. The population of Fort Wayne increased 23.3 percent from 205,727 in 2000 to 253,691 in 2010 (U.S. Census Bureau, 2011). The main channel within the study reach has ten major road crossings that lie within the channel or the adjacent flood plain. Also, there are flood-control levees along the main channel of the study reach.

Previous Studies

The current FIS for Allen County was completed by Christopher B. Burke Engineering in 2006 (FEMA, 2009). That study provided information on the 1.0 and 0.2 percent annual exceedance probability water-surface profiles and associated flood plain maps for the St. Marys River, Fairfield Ditch, Junk Ditch, and Snyder Ditch. Estimates of the peak discharges for the 1.0 percent annual exceedance probability flood was only documented at St. Marys River near Fort Wayne, IN gage location at South Anthony Boulevard (labeled "Just downstream of confluence of Paul Trier Ditch" in FIS) on the study reach with a discharge of 15,700 ft³/s and a drainage area of 762 mi² (FEMA, 2009).

Constructing Water-Surface Profiles

The water-surface profiles used to produce the 11 flood-inundation maps in 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 simulation of water-surface profiles with steady-state (gradually varied) or unsteady-state flow computation options. The HEC–RAS analysis for this study was done using the steady-state flow computation option.

Hydrologic and Steady Flow Data

The study area hydrologic network consists of 2 streamgages (fig. 1; table 1). Both of the gages already existed prior to this study. Water level (stage) is measured continuously at each of the sites and continuous records of streamflow are computed at both sites. All water-surface elevations are referenced to North American Vertical Datum of 1988 (NAVD 88). The gages are equipped with satellite radio transmitters that allow data to be transmitted routinely on the Internet within an hour of collection. USGS streamgage 04182769 St. Marys River at Main St. at Fort Wayne, IN, also is equipped with a recording tipping-bucket rain gage. Flow data can be accessed at <http://waterdata.usgs.gov/in/nwis/current/?type=flow> by selecting the appropriate station number.

Steady-flow data consisted of flow regime, boundary conditions (either known water-surface elevation associated with a discharge measurement, normal depth, or streamgage rating curve value), and peak discharge information. The steady flow data for the study reach were obtained from previous studies and field measurements of streamflow at the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN. At gaged sites, all computations using discharge values with known stages from actual streamflow measurements or stage-discharge relations were used.

Table 1. Table 1. USGS streamgage information for selected sites in Fort Wayne, Indiana.

Topographic/Bathymetric Data

Channel cross sections were developed from USGS field surveys that were conducted in April, May, and June, 2010 ; these cross sections provide detailed channel elevation data below the water surface and were collected using hydroacoustic instrumentation to measure depth and Differential Global Positioning System (DGPS) instrumentation to determine horizontal position. Light Detection and Ranging (LiDAR) data, collected in 2009 for Allen County (David S. Nail, written commun.,

USGS, October 2010), were used to provide digital elevation data for the portions of the cross sections that were above the water surface at the time of the surveys.

Various manmade structures, (bridges, culverts, roadway embankments, and levees) in and along the stream, affect or have the potential to affect water-surface elevations during floods along the stream. To properly account for these features in the model, bridge geometry was imported from a previous HEC-2 model (FEMA, 2009) for seven bridges. All seven bridges were verified as current structures with pictures and elevation checks from digital-elevation model and field observations. The other three bridges at Ferguson Road, Airport Expressway, and Hale Street were not surveyed but most recent bridge plans were acquired from the Allen County surveyor's office and verified (William Reuille, written commun., Allen County Highway Department, June 2011). The geometry data for levees were acquired from the City of Fort Wayne (Kevin S. Holle, written commun., the City of Fort Wayne, February 2011) and the elevation data of the levees were included in the model to properly account for these structures. A detailed description of the methods used to acquire and process the topographic and bathymetric data can be found in Bales and others (2007).

Energy Loss Factors

Field observations and high-resolution aerial photographs were used to select initial (pre-calibration) Manning's roughness coefficients ("*n*" values) for energy (friction) loss calculations. The final Manning's *n* values used ranged from 0.03 to 0.05 for the main channel and 0.05 to 0.08 for the overbank areas modeled in this analysis.

Model Calibration and Performance

The hydraulic model was calibrated to the most current stage-discharge relation at the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN. Historic high-water marks were available

from 1982 or previous events, but all the currently existing levees either had been modified or constructed after that period causing the high-water marks to be invalid calibration input points. The model calibration was accomplished by adjusting Manning's n values and, in some cases, changing the channel cross section until the results of the hydraulic computations closely agreed with the known flood discharge and stage values. Differences between measured and simulated water levels for specified flows were within 0.5 ft (table 2). The results demonstrate that the model is capable of simulating accurate water levels over a wide range of flows in the basin. The calibration was focused around the 0.05 and 0.01 annual exceedance probability flood elevations, where differences in simulated and measured water levels are smaller. Details on techniques used in model development and calibration can be found in Bales and others (2007).

Table 2. Comparison of hydraulic-model output and measured stage at USGS streamgage 04182000 St. Marys River near Fort Wayne, IN.

Development of Water-Surface Profiles

Profiles were developed for a total of 11 stages at 1-ft intervals between 12.0 ft and 22.0 ft as referenced to the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN. Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating no. 32.0) at this same streamgage.

Models on the St. Marys River were calibrated to produce the selected profile elevations at the USGS streamgage 04182000 (table 3). Discharges at the mouth of each tributary flowing in at certain locations on the study reach were determined by calculating cubic feet per second per square mile (CFSM) that corresponded to the measured discharges at the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN. The CFSM is defined as the average number of cubic feet of water per second flowing from each square mile of area drained by a stream, assuming that the runoff is distributed uniformly in time and area.

Discharges on the St. Marys River downstream from the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN were determined by adding the estimated discharges at the mouth of the contributing tributaries to the measured discharges at the streamgage. Drainage areas were calculated using a Web-based GIS application called Streamstats which can be accessed at <http://water.usgs.gov/osw/streamstats/indiana.html>.

Table 3. Discharge in cubic feet per second (cfs) for corresponding gage height estimates at selected locations for the St. Marys River, Ft. Wayne, Indiana, for simulated water-surface profiles. [Numbers in parenthesis reference NAVD88]

Inundation Mapping

Flood-inundation maps were created for USGS streamgage 04182000 St. Marys River near Fort Wayne, IN, which is also a NWS flood-forecast point. The maps were created in a GIS by combining the water-surface profiles and digital elevation model data. The digital elevation model (DEM) data were derived from LiDAR data with 3.3-ft horizontal accuracy and a vertical accuracy of 0.12 ft (David S. Nail, written commun.,USGS, October 2010). The initial resolution of the DEM with 2.5-ft cell size was later re-sampled to 10-ft cell size in order to reduce the GIS processing time. Estimated flood-inundation boundaries for each simulated profile were developed with 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 by using a graphical user interface (Whitehead and Ostheimer, 2009). The interface 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). USGS personnel then modified the HEC–GeoRAS results to ensure a hydraulically reasonable transition of the boundary between modeled cross sections relative to the contour data for the land surface (Whitehead and

Ostheimer, 2009). The maps show estimated flood-inundated areas overlaid on high-resolution, geo-referenced, aerial photographs of the study area for each of the water-surface profiles that were generated by the hydraulic model.

St. Marys River, Indiana Flood-Inundation Maps on the Internet

A USGS Flood Inundation Mapping Science World Wide Web portal has been established by the USGS to provide estimated flood-inundation information to the public (see http://water.usgs.gov/osw/flood_inundation/). The maps and data from this study showing the extent of inundated areas can be downloaded in three electronic file formats from that portal: (1) GIS shapefile format, (2) Keyhole Markup Language (KML) file format, and (3) Portable Document Format (PDF). Users can print out formatted maps quickly or create a customized map using available GIS data layers. In addition, downloadable GIS raster files showing the depth of flooded areas are available at the web portal. All PDF and KML maps show aerial photography beneath the flood layers. Each stream reach displayed on the Web site contains links to NWISWeb graphs of the current stage and stream-flow at USGS streamgage 04182000 St. Marys River near Fort Wayne, IN, to which the inundation maps are referenced. A link also is provided to the NWS Advanced Hydrologic Prediction Service (AHPS) site (<http://water.weather.gov/ahps/>) so that the user can obtain applicable information on forecasted peak stage. The estimated flood-inundation maps are displayed in sufficient detail to note the extent of flooding with respect to individual structures so that preparations for flooding and decisions for emergency response can be performed efficiently.

Disclaimer for Flood-Inundation Maps

Inundated areas shown 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 for Use of Flood-Inundation Maps

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, some uncertainty is associated with these maps. The flood boundaries shown were estimated based on water stages (water-surface elevations) and streamflows at selected USGS streamgages. Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at the USGS streamgage(s). The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of September 2011. Unique meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded due to unanticipated conditions such as: changes in the streambed elevation or roughness, backwater into major tributaries along a main stem river, or backwater from localized debris or ice jams. The accuracy of the floodwater extent portrayed on these maps will vary with the accuracy of the digital elevation model used to simulate the land surface. Additional uncertainties and limitations pertinent to this study are also noted on the map sheets accompanying this report.

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 (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

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Summary

A series of estimated flood-inundation maps were developed in cooperation with the City of Fort Wayne for the St. Marys River in Indiana between Main St. and South Anthony Boulevard. These maps, available at a USGS Web portal, in conjunction with the real-time stage data from the USGS streamgage 04182000 St. Marys near Fort Wayne, IN, and National Weather Service flood-stage forecasts, will help to guide the general public in taking individual safety precautions and will provide city officials with a tool to efficiently manage emergency flood operations and flood mitigation efforts.

The maps were developed 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 for selected stream stages. The maps show estimated flood-inundation areas overlaid on high-resolution,

geo-referenced, aerial photographs of the study area for stream stages between 12.0 ft and 22.0 ft at the USGS streamgage 04182000 St. Marys River near Fort Wayne, IN. The estimated inundation areas are shaded to give a general indication of depth of water at any point.

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