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Method for Estimating Potential Wetland Extent by Utilizing Streamflow Statistics and Flood-Inundation Mapping Techniques: Pilot Study for Land Along the Wabash River Near Terre Haute, Indiana

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U.S. Department of the Interior
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Cover images: Background photograph of a flood plain of the Muscatatuck River in Jackson County, Indiana, 2002, by Gerald (Jerry) L. Roach, U.S. Department of Agriculture, Natural Resources Conservation Service; top left photograph of a great blue heron in a flood plain of the Muscatatuck River, 2008, by Bob J. Steiner, Soil and Water Conservation District, Jennings County, Indiana; center photograph of part of a map of approximate flood extents for the Wabash River near Terre Haute, Indiana (the entire map is figure 3 of this report); lower right photograph of a North American river otter on a beaver lodge by Chris R. Reidy, U.S. Department of Agriculture, Natural Resources Conservation Service.

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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

Abbreviations and Acronyms

7MQ2	Annual highest 7-consecutive-day mean discharge with a 2-year recurrence interval
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GIS	Geographic Information System
HWM	High-water mark
IDNR	Indiana Department of Natural Resources
IWCP	Indiana Wetlands Conservation Plan
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WRP	Wetland Reserve Program
WREP	Wetlands Reserve Enhancement Program

Method for Estimating Potential Wetland Extent by Utilizing Streamflow Statistics and Flood-Inundation Mapping Techniques: Pilot Study for Land Along the Wabash River Near Terre Haute, Indiana

By Moon H. Kim[1], Christian T. Ritz[2], and Donald V. Arvin[1]

Abstract

Potential wetland extents were estimated for a 14-mile reach of the Wabash River near Terre Haute, Indiana. This pilot study was completed by the U.S. Geological Survey in cooperation with the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). The study showed that potential wetland extents can be estimated by analyzing streamflow statistics with the available streamgage data, calculating the approximate water-surface elevation along the river, and generating maps by use of flood-inundation mapping techniques.

Planning successful restorations for Wetland Reserve Program (WRP) easements requires a determination of areas that show evidence of being in a zone prone to sustained or frequent flooding. Zone determinations of this type are used by WRP planners to define the actively inundated area and make decisions on restoration-practice installation. According to WRP planning guidelines, a site needs to show evidence of being in an "inundation zone" that is prone to sustained or frequent flooding for a period of 7 consecutive days at least once every 2 years on average in order to meet the planning criteria for determining a wetland for a restoration in agricultural land. By calculating the annual highest 7-consecutive-day mean discharge with a 2-year recurrence interval (7MQ2) at a streamgage on the basis of available streamflow data, one can determine the water-surface elevation corresponding to the calculated flow that defines the estimated inundation zone along the river.

By using the estimated water-surface elevation ("inundation elevation") along the river, an approximate extent of potential wetland for a restoration in agricultural land can be mapped. As part of the pilot study, a set of maps representing the estimated potential wetland extents was generated in a geographic information system (GIS) application by combining (1) a digital water-surface plane representing the surface of inundation elevation that sloped in the downstream direction of flow and (2) land-surface elevation data. These map products from the pilot study will aid the NRCS and its partners with the onsite inundation-zone verification in agricultural land for a potential restoration and will assist in determining at what elevation to plant hardwood trees for increased survivability on ground above frequently flooded terraces.

Introduction

Wetlands are defined as a transitional environment between water bodies and dry land, and they represent a substantial part of the Nation's natural resources. Over a period of about 200 years, from the 1780s to the 1980s, the total estimated loss of wetlands in the conterminous United States was about 53 percent, from about 221 million acres to about 103 million acres. Indiana lost about 85 percent of its wetlands, from about 5.6 million acres to about 813,000 acres, during the same time period (Dahl, 1990; Indiana Department of Natural Resources, 1996). For many years, wetlands were classified as wastelands that could be made useful by draining and filling for other purposes. In Indiana, the loss of wetlands was mostly due to drainage for agricultural production (Indiana Department of Natural Resources, 1996). To this day, interests in industrial, agricultural, and residential development in Indiana continue to drive the conversion of wetlands by draining, filling, dredging, diking, and damming of the landscape. Remaining wetlands in Indiana are being lost at a rate of about 1 to 3 percent each year, mainly because of drainage for agricultural purposes (U.S. Geological Survey, 1996).

Wetlands serve many ecological and hydrological functions that benefit surrounding ecosystems. One of the best known functions of wetlands is to provide habitat for waterfowl, fish, and other terrestrial and aquatic animals. Wetlands support a wide variety of plant life, and they supply resting

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and feeding places for migrating birds, as well as food, shelter, breeding areas, and nurseries for many animals. By filtering many contaminants out of inflowing water and storing or transforming them, wetlands can prevent or reduce water pollution. Flood control can be achieved near **riparian**[3] wetlands by temporary water storage and gradual release, which together reduce flow velocity and **flood peaks**. Vegetation in riparian wetlands helps to maintain **stream** channels by stabilizing the land surface. In Indiana, wetlands provide considerable value for recreational, educational, and economic activities. Common activities in and surrounding wetlands include birding, hiking, fishing, hunting, swimming, and boating. Economic benefits are provided by wetlands through such activities as fur trapping, lumbering, and tourism (U.S. Geological Survey, 1996).

During the past few decades, as the function of wetlands and their value to society and the environment have become better understood, the interest in conservation of wetlands has increased. In 1996, the Indiana Wetlands Conservation Plan (IWCP) was developed through coordination by the Indiana Department of Natural Resources (IDNR) and funding from the U.S. Environmental Protection Agency. The IWCP is intended as a guide for all wetland conservation efforts in the State and encourages participation from all levels of government, private organizations, and the general public (Indiana Department of Natural Resources, 1996). At the Federal level, several agencies, including the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and National Park Service, participate in many wetland-related activities. These activities include management, regulation, restoration, creation, delineation, and inventory of wetlands.

The Wetland Reserve Program (WRP), created by the 1990 Food, Agriculture, Conservation, and Trade Act, is a voluntary program that provides technical and financial assistance to private landowners to restore, protect, and enhance wetlands in exchange for retiring eligible land from agriculture (U.S. Department of Agriculture, 2012). Since 1994, Indiana has been involved in the WRP, which is administered under the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). To assist with this program, in 2005, funding was awarded for use in Indiana through the Wetlands Reserve Enhancement Program (WREP), a partnership program with the NRCS. The WRP and the WREP operate in Indiana with a high level of partnership involvement. These partnerships are forming between groups and organizations with a great diversity of backgrounds and purposes and have provided technical support, easement acquisition, and restoration work. For example, with the WREP, the Nature Conservancy has partnered with the NRCS to develop the Wabash River Floodplain Corridor for six counties. In Indiana, these programs have three focus areas: the northern one-third of the State, the counties along the Wabash and White Rivers, and the Muscatatuck River Basin. These areas have been identified historically as having the best potential for wetland restoration. Common restoration practices include tree planting, direct seeding, ditch plugs, dikes, tile breaks, water control structures, and **macrotopography** restoration (U.S. Department of Agriculture, 2008b).

Landowners interested in participating in the WRP can contact their local NRCS office. The land may be eligible for participation if it is agricultural land that contains degraded or converted wetlands that have a high probability for successful restoration. If the site is selected for participation, then the NRCS develops a restoration plan and makes an offer to the landowner (U.S. Department of Agriculture, 2012). Existing natural wetlands or adjacent uplands also can be enrolled if they are ecologically important to the restoration of the site.

Under the WRP planning guidelines, before a site in an agricultural land area can be determined to be a wetland and be considered for restoration, several criteria must be satisfied regarding vegetation, soils, and hydrology. Planning successful restorations for WRP easements requires determination of a frequency-duration parameter, which is a key parameter relative to low-lying riparian areas subject to inundation (U.S. Department of Agriculture, 1994, 2007). This parameter is defined as the annual highest 7-consecutive-day mean **discharge** with a 2-year **recurrence interval** (or 50-percent chance annual probability) at a **streamgage**, based on available **streamflow** data. Sites that are in a zone showing evidence of sustained or frequent flooding, as described above, typically support herbaceous hydrophytic vegetation and can be considered for restoration-practice installation (U.S. Department of Agriculture, 2008a). Sites located above such a zone would be deemed suitable for plantings of hardwood seedlings or other similar restorations. In this report, the water-surface elevation that defines the upper limit of this zone hereafter is referred to as the "inundation elevation." The flow that is related to the inundation elevation hereafter is referred to as the "inundation flow." The area that is at or below this inundation elevation hereafter is referred to as the "inundation zone."

Purpose and Scope

The purpose of this report is to describe and document the methods used to estimate the inundation elevation and the inundation zone that meet the planning criteria for vegetative establishment in the river **flood plains** by utilizing streamflow data and statistics available from the USGS streamgage-network database and available flood-inundation mapping techniques. The estimation of inundation elevation and inundation zone can further assist the NRCS and its partners in onsite determination and verification of potential wetlands for restoration in agricultural lands and determination of the zone above the frequently flooded area that would provide increased

[3] Terms defined in the glossary are in **bold** print where first used in the main body of the report.

survivability of planted hardwood trees (U.S. Department of Agriculture, 2008a). For the pilot study, the statistical and mapping analyses were limited to land along the Wabash River near Terre Haute, Indiana (Ind.). The results from the statistical analyses which included data from additional streamgages along the Wabash River were made available for future mapping analyses. These analyses relied on existing sources of information, with no additional field data collection involved.

Description of Study Area

The study area consisted of a reach of the Wabash River about 14 mi in length, along with the contiguous flood plain, near the city of Terre Haute (fig. 1). The upstream extent of the study area was the State Route 63 crossing of the Wabash River (**river mile** (RM) 217.4), and the downstream extent was near the confluence of Honey Creek and the Wabash River (RM 203.5). USGS streamgage 03341500 Wabash River at Terre Haute, Ind., is within the study area (RM 215.0); more than 83 years of streamflow record was available for this streamgage at the time of the study.

The total **drainage area** of the Wabash River at the downstream study extent is about 12,508 mi^2. The average slope of the channel through the study reach is about 0.6 ft/mi; channel widths range from about 300 to 600 ft. The mean annual streamflow at the streamgage (through **water year** 2010) was 11,440 ft^3/s (water year 2010 is the period October 1, 2009, through September 30, 2010). The peak streamflow for the period of record was 189,000 ft^3/s on May 20, 1943. Outside the period of record, the flow reached an estimated 245,000 ft^3/s on March 27, 1913. This study area was chosen because of availability of high-resolution land-surface elevation data, availability of USGS streamgage data, and potential sites for a wetland restoration.

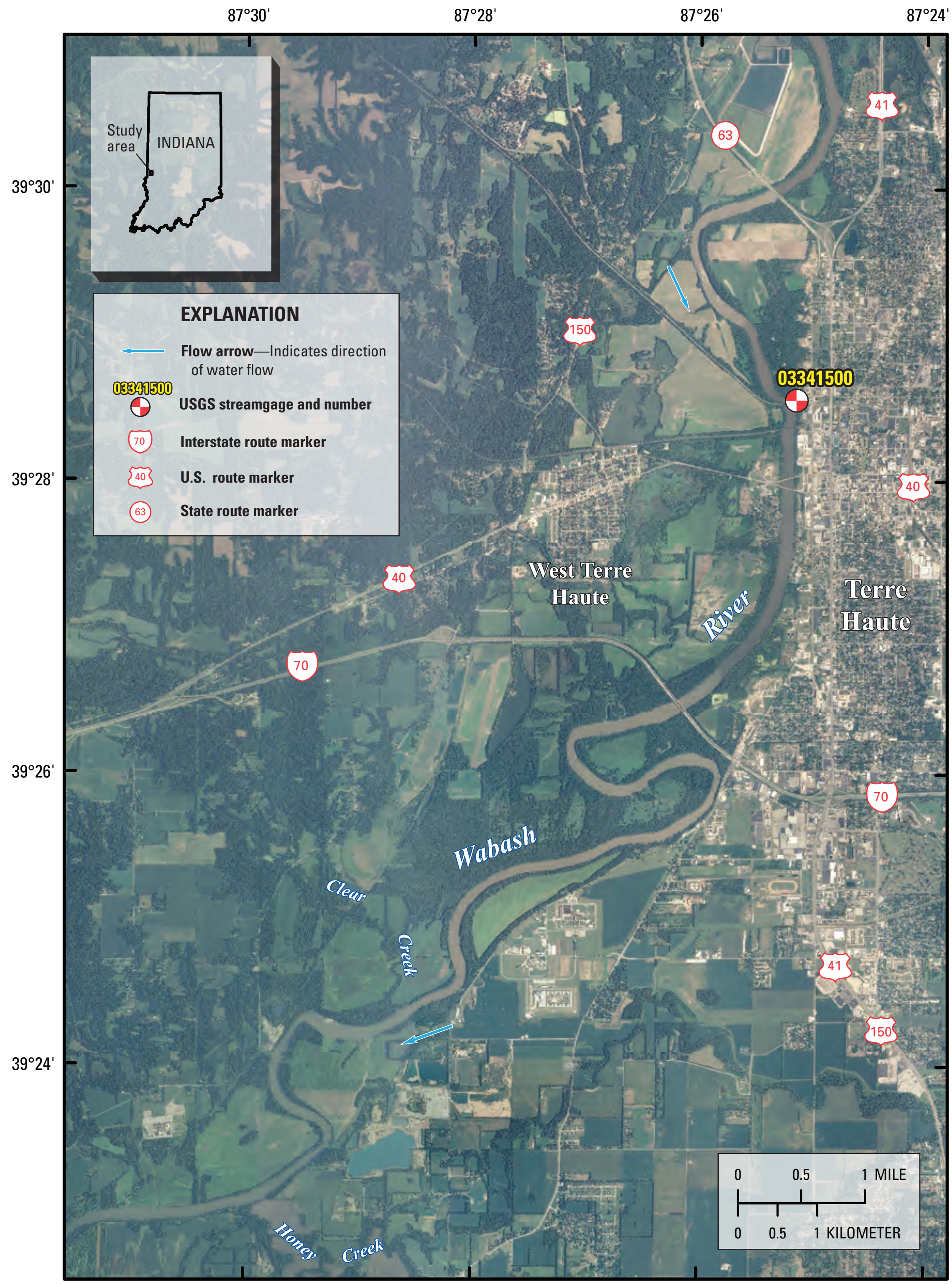
Methods

Whereas the primary focus of this report is on a single selected stream reach, similar methods have been used on numerous stream reaches throughout the State. Through a coordinated effort between the Indiana NRCS and the U.S. Geological Survey (USGS) staff, a procedure was developed for determining streamflow and water-surface elevation along selected stream reaches for the purpose of estimating the inundation elevation and the inundation zone that meet the planning criteria of the WRP. This procedure consists of three phases: (1) compilation of streamflow statistics based on data from the available USGS streamgage-network database, (2) estimation of water-surface elevations based on the streamflow statistics, and (3) mapping of estimated potential wetland extents by use of the estimated water-surface elevations.

Compilation of Streamflow Statistics

The WRP planning guidelines state that in order to meet the planning criteria for determining a wetland for a restoration in agricultural land, a site needs to show evidence of being in a zone prone to sustained or frequent flooding for a period of 7 consecutive days at least once every 2 years on average. The evidence can be obtained through statistical analysis of daily mean discharges stored for USGS streamgages. The statistical value generated by this analysis is the annual highest 7-consecutive-day mean discharge with a 2-year recurrence interval. (A 2-year recurrence interval is sometimes referred to as having a 50-percent probability of occurrence.) This statistical value is referred to in this report as the “**7MQ2**.” The 7MQ2 at a streamgage serves as a determination of the inundation flow at that location. Daily mean discharges for the streamgages used in this study are stored in the USGS National Water Information System (NWIS). On the basis of those daily mean discharges, the set of annual highest 7-consecutive-day mean discharges was calculated for each streamgage. Water year rather than calendar year was used as the annual time period for this flow statistic. By separating annual periods at the time of the year when discharges generally are low, the high-flow periods can be analyzed with a greater degree of continuity.

The set of annual highest 7-consecutive-day mean discharges at each streamgage was used for the frequency analysis. Frequency curves relate the magnitude of a variable to the frequency of occurrence (Riggs, 1968). For this frequency analysis, the 7-consecutive-day mean discharge time-series data were analyzed by using a log-Pearson Type-III distribution, as implemented in the USGS software package SWSTAT (U.S. Geological Survey, 2011). This frequency analysis produced the 7MQ2, which was used as the inundation flow. Resulting data for selected streamgages along the Wabash River in and near Indiana are listed in table 1. In order for the streamflow data to represent current conditions, the dataset included only those years after installation of flood-control reservoirs upstream of the study area (Ruddy and Hitt, 1990). Locations and other information regarding the streamgages can be found at *http://waterdata.usgs.gov/in/nwis/current/?type=flow.*



Orthophotography from Indiana University, Indiana Spatial Data Portal, Vigo County, 2010 NAIP
Universal Transverse Mercator Zone 16 projection
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83)

Figure 1. Location of study area along the Wabash River near Terre Haute, Indiana.

Table 1. Calculated values of inundation flows and corresponding inundation elevations at selected U.S. Geological Survey streamgages along the Wabash River in and near Indiana.

[ft, feet; ft³/s, cubic feet per second; NGVD 29, National Geodetic Vertical Datum of 1929]

USGS streamgage number	USGS streamgage name	Years of record	Period of record* (water year)	Inundation flow (ft³/s)	Corresponding gage height (ft)	Inundation elevation (ft above NGVD 29)
03327500	Wabash River at Peru, Ind.	43	1968–2010	11,000	10.2	628.1
03329000	Wabash River at Logansport, Ind.	43	1968–2010	16,500	9.0	582.3
03335500	Wabash River at Lafayette, Ind.	43	1968–2010	34,300	17.1	521.2
03336000	Wabash River at Covington, Ind.	43	1968–2010	38,110	22.6	496.6
03340500	Wabash River at Montezuma, Ind.	43	1968–2010	55,500	23.6	481.3
03341500	Wabash River at Terre Haute, Ind.	43	1968–2010	56,800	21.3	467.1
03342000	Wabash River at Riverton, Ind.	43	1968–2010	61,700	22.2	436.8
03377500	Wabash River at Mt. Carmel, Ill.	43	1968–2010	137,000	26.6	396.1

* The period of record used in the data analysis represents the water years after the upstream reservoirs for flood control came online along the Wabash River in Indiana.

Estimation of Water-Surface Elevations

Once the inundation flow (the 7MQ2) was calculated for a selected streamgage, the water-surface elevation corresponding to that flow value was established as the inundation elevation at that streamgage location. The water-surface elevation was determined from the **stage**-discharge relation (referred to as the “rating”) at the streamgage, which was developed from periodic measurements of discharge and stage (Rantz and others, 1982). For this study, the most recent rating in effect was used for determining the inundation elevation; negligible benefit was expected from attempting to account for changes in the rating over time.

For sites in low-lying ground adjacent to a stream but not near a streamgage, additional resources were used to estimate the inundation elevation. A primary resource was the IDNR’s historical **flood profiles** (fig. 2), which are available for many of the streams throughout the State and which plot the elevation of surveyed high-water marks against the RM for specific historical floods. The graphs show the water-surface elevation profiles of those documented floods.

If data for a stream are available from both a streamgage and a historical flood profile, then (1) the inundation elevation can be determined at the streamgage location by using data from that streamgage, (2) that elevation can be plotted in context with the elevations of the high-water marks of the historical floods at the streamgage location, and (3) the relation between the inundation elevation and the historical floods can be extended downstream or upstream from the site of interest by extrapolating graphically by RM. This method basically draws an inundation-elevation profile that is approximately parallel to the historical flood-elevation profiles.

For example, the IDNR’s historical flood profiles for the Wabash River include water-surface elevation lines for the floods of March 1913, March 1939, and January 1969. An inundation elevation needed to be estimated for a site adjacent to the Wabash River at RM 203.5. The USGS streamgage 03341500 Wabash River at Terre Haute, Ind., is at RM 215. The inundation flow was determined at RM 215 by calculating the 7MQ2, based on the daily mean discharge data from the streamgage, and the inundation elevation of the water surface was determined by identifying the elevation that corresponds with that discharge value, based on rating established for the streamgage. The inundation elevation at RM 215 was plotted on the historical flood profile to show the relation between that elevation and the elevations of the three documented historical floods. That relation shown at RM 215, where the streamgage is located, was then transferred downstream to RM 203.5, where the site of interest is located.

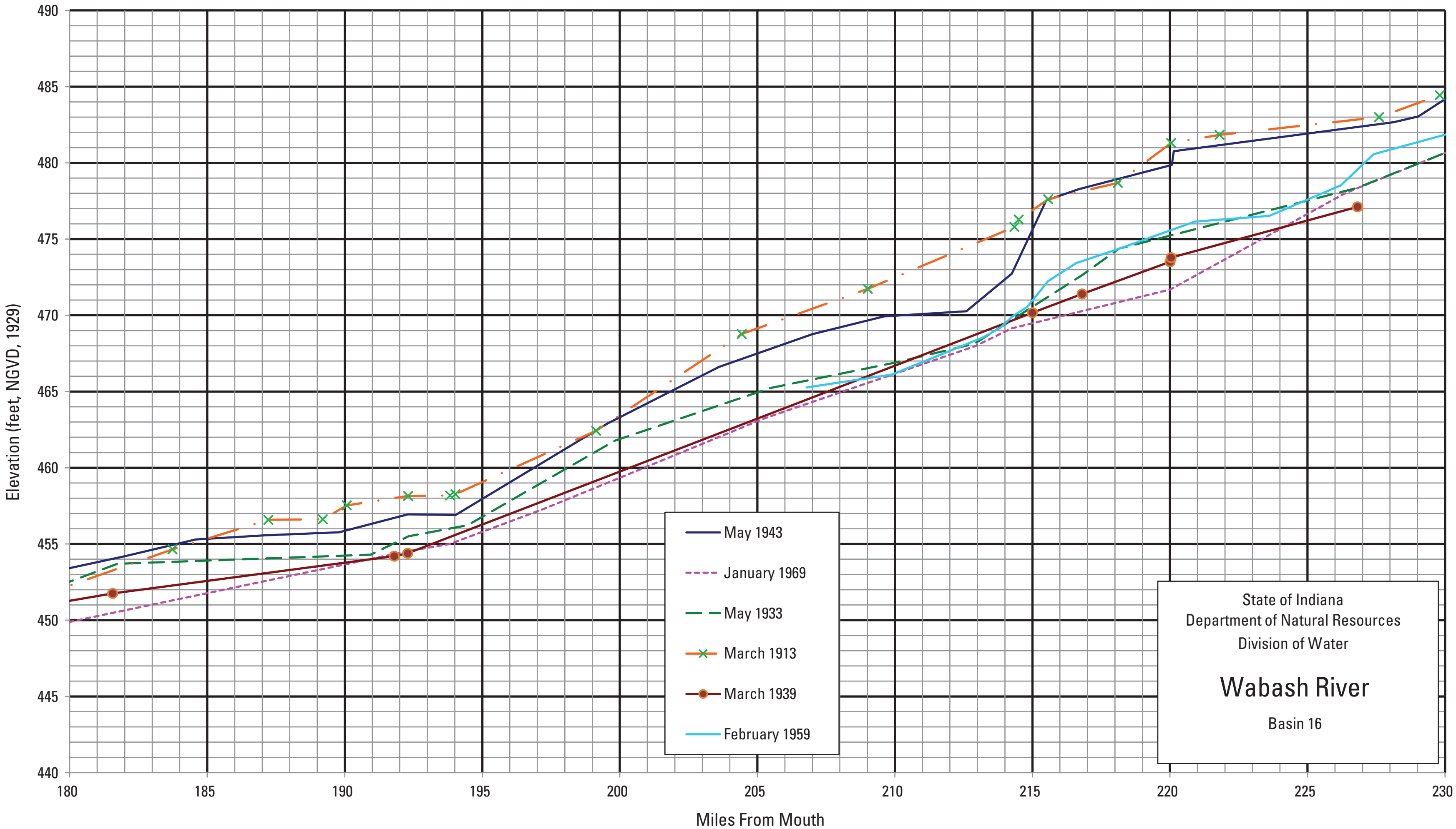


Figure 2. Example of historical flood profile along the Wabash River near Terre Haute, Indiana.

For some WRP sites of interest, a historical flood profile may not be available. If a site is adjacent to a stream and between two streamgages, a linear interpolation method can be used to determine a general range for the inundation elevation. Two basic methods of linear interpolation were used in this study. One method involved assessing the rate of change in elevation per RM between the two streamgages and then applying that rate of change to assign an estimated elevation at the site of interest. This method can be described by using the following equation:

$$y_{site} = \frac{(y_2 - y_1)\times(x_{site} - x_1)}{(x_2 - x_1)} + y_1 \quad (1)$$

where

x_1 is the RM at the downstream streamgage,
x_2 is the RM at the upstream streamgage,
x_{site} is the RM at the site of interest,
y_1 is the inundation elevation at the downstream streamgage,
y_2 is the inundation elevation at the upstream streamgage, and
y_{site} is the resulting inundation elevation at the site of interest.

A second method that employed linear interpolation was particularly useful for estimating the upper range of elevation one might expect at the site of interest. In this second method, the drainage area was used instead of RM. This method can be described by using the following equation:

$$y_{site} = \frac{(y_2 - y_1)\times(d_{site} - d_1)}{(d_2 - d_1)} + y_1 \quad (2)$$

where

d_1 is the drainage area at the downstream streamgage,
d_2 is the drainage area at the upstream streamgage,
d_{site} is the drainage area at the site of interest,
y_1 is the inundation elevation at the downstream streamgage,
y_2 is the inundation elevation at the upstream streamgage, and
y_{site} is the resulting inundation elevation at the site of interest.

Use of a linear interpolation method has limitations as a stand-alone tool. Although such a method can be useful in obtaining a general range for the expected inundation elevation at a site of interest, especially if other supporting data are unavailable, the method does not necessarily reflect the actual hydraulic characteristics of the individual stream segments. Experience has shown that results derived from linear interpolation can differ from those derived by using the historical flood profile method. For this reason, the final results can be improved by making elevation adjustments based on Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) flood maps and profiles. These maps are used in the administration of the National Flood Insurance Program and in the regulation of flood plains in Indiana.

The FIS flood maps and profiles, updated and improved in recent years by cooperative work between FEMA and the IDNR, show the elevation of the 1-percent probability flood (sometimes referred to as the 100-year recurrence interval). These maps are available for many of the major streams throughout Indiana. The elevation of the 1-percent probability flood shown in the FIS flood maps and profiles can be used to calibrate results of the linear interpolation method in a similar way that the historical flood profiles are used.

Another useful source of information for this effort was Indiana StreamStats (*http://water.usgs.gov/osw/streamstats/indiana.html*, accessed October 21, 2011). StreamStats is a national USGS program (*http://streamstats.usgs.gov/index.html*) through which an Indiana statewide Web-based graphical application was developed as a cooperative effort between the USGS and the IDNR. This tool was used to determine the drainage area for selected sites of interest, the boundary delineations for those drainage basins, and flood-frequency discharge determinations for those basins. For the purposes of this study, the products of StreamStats found to be particularly applicable were the basin boundary delineations, the discharge of the 10-percent probability flood (sometimes referred to as the 10-year recurrence interval), and the discharge of the 1-percent probability flood.

Mapping of Wetland Extents

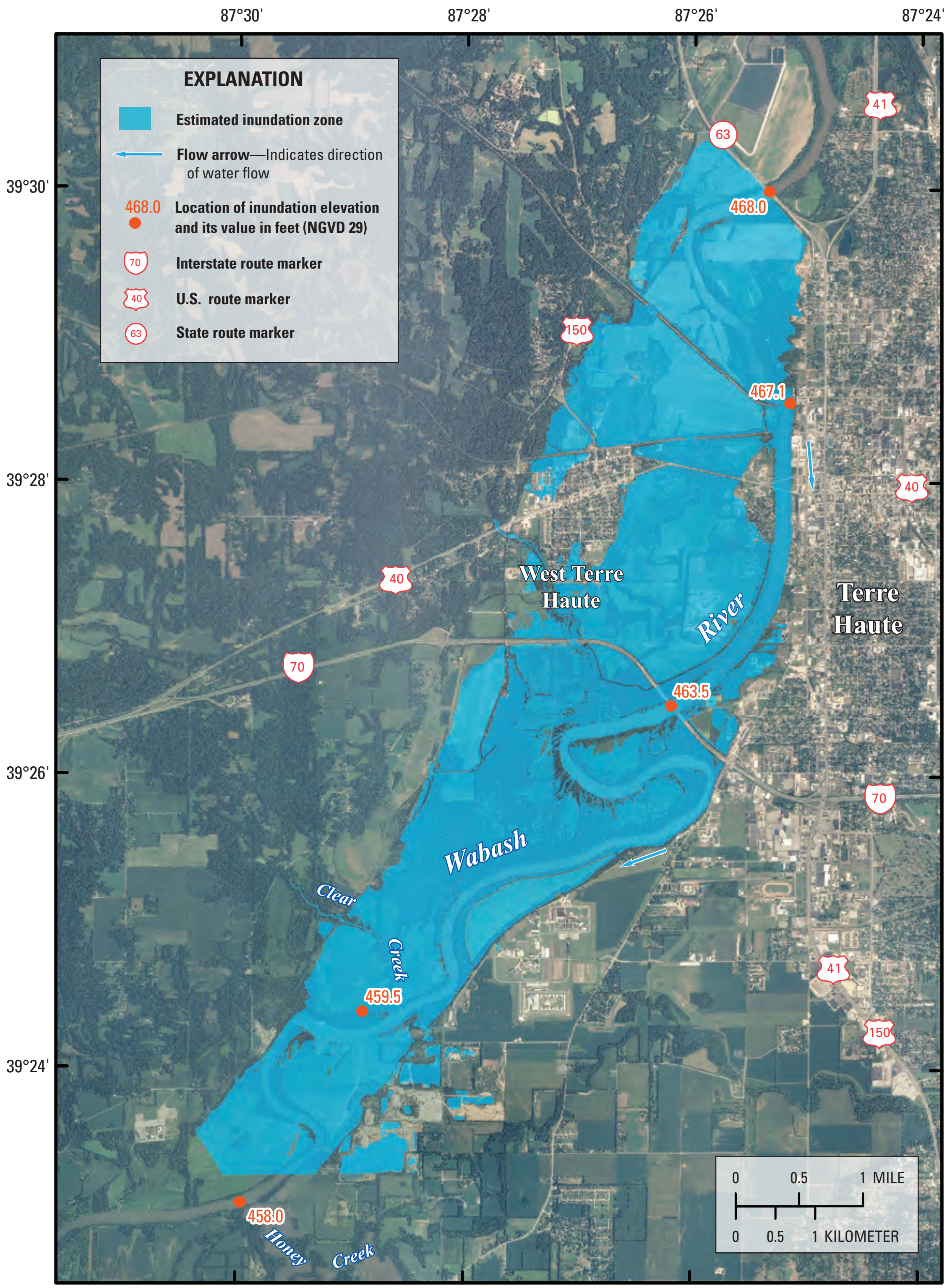
Typically when a wetland map is prepared, combinations of hydrology, vegetation, and soils criteria are applied through aerial-photo interpretation and other sources of information such as satellite imagery, soils data, topographic data, and flood maps. For this study, maps of estimated wetland extents were prepared with the estimated inundation elevation data that meet the planning criteria for the WRP and flood-inundation mapping techniques. In previous studies, flood-inundation mapping techniques were used to develop flood maps by using high-water marks (HWMs) as the water-surface elevation data (Morlock and others, 2008). For this study, the HWMs were replaced by the inundation-elevation data (table 2, fig. 3).

Once the inundation elevations were estimated for the study reach of interest, flood maps were developed in conjunction with digital elevation model (DEM) data. By using a GIS application, a water-surface plane was created to represent the surface of inundation elevation that sloped in the downstream direction of flow. After the surface of inundation elevation was generated, a map representing the inundation zone was created by subtracting the DEM from the surface of inundation-elevation data. The inundation zone maps were produced in a GIS file format that provided estimated wetland extents. This format allows the maps to be overlain upon other maps and aerial photographs; an example is shown in figure 3. A set of estimated inundation-zone maps provided for use by the NRCS is available in appendix 1.

Table 2. Inundation elevations within the study area along the Wabash River near Terre Haute, Indiana.

[ft, feet; NGVD 29, National Geodetic Vertical Datum of 1929]

River mile	Inundation elevation (ft above NGVD 29)	Location description	Latitude (decimal degrees)	Longitude (decimal degrees)
217.4	468.0	Wabash River at State Route 63	39.500	-87.422
215.0	467.1	USGS Streamgage 03341500 Wabash River near Terre Haute, Ind.	39.476	-87.419
212.8	463.5	Wabash River at Interstate 70	39.441	-87.436
206.2	459.5	Wabash River at Clear Creek outlet	39.406	-87.481
203.5	458.0	Wabash River at Honey Creek outlet	39.385	-87.499



Orthophotography from Indiana University, Indiana Spatial Data Portal, Vigo County, 2010 NAIP
Universal Transverse Mercator Zone 16 projection
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83)

Figure 3. Estimated inundation zone within the study area along the Wabash River near Terre Haute, Indiana. The inundation zone and the inundation elevation are based on the inundation flow (annual highest 7-consecutive-day mean discharge with a 2-year recurrence interval).

Utility of the Methods for Future Studies

As a prerequisite for wetland inventory, regulation, management, protection, and restoration, wetland mapping products from the pilot study will aid the NRCS and its partners with the onsite inundation-zone verification for the wetland determination of agricultural land in Indiana through the WRP and WREP. The emphasis of these programs is to protect, restore, and enhance the functions and values of wetland ecosystems in order to attain increased habitat for migratory birds and wetland-dependent wildlife, including threatened and endangered species; increased protection and improvement of water quality; decreased peak streamflows associated with flooding; increased recharge of groundwater; increased protection and enhancement of open space and aesthetic quality; and increased protection of native flora and fauna contributing to the Nation's natural heritage. These programs, in turn, enable eligible landowners to protect, restore, and enhance the original hydrology, native vegetation, and natural topography of eligible lands; restore and protect the functions and values of wetlands in the agricultural landscape; help achieve the national goal of no net loss of wetlands; and improve the general environment of the country.

Data-driven methods, such as those described in this report, for assessing the optimal location for restorations could help more fully realize the benefits of wetlands. For example, by identifying zones of frequent inundation, appropriate plantings can be selected to fit the hydrologic conditions. Certain tree species that cannot tolerate frequent inundation can be planted outside the inundation zone, saving money in lost trees. This project demonstrated that a science- and data-based strategy can be applied to help administer important national programs to restore and protect riparian wetlands. Because data resources used for this project—including DEM data, flood profiles, and a national network of about 8,000 USGS streamgages—are widespread, this project has great transferability potential to other States and regions across the county.

Summary

The U.S. Geological Survey, in cooperation with the U.S. Department of Agriculture, Natural Resources Conservation Service, conducted a pilot study to estimate the potential wetland extents for a 14-mi reach of the Wabash River near Terre Haute, Ind. The pilot study involved three phases: (1) compilation of streamflow statistics based on data from the available USGS streamgage-network database, (2) estimation of water-surface elevations based on the streamflow statistics, and (3) mapping of estimated potential wetland extents by use of the estimated water-surface elevations.

In phase 1, streamflow data were compiled and streamflow statistics were analyzed on the basis of WRP planning criteria and data from USGS streamgages along the Wabash River near Terre Haute, Ind. The WRP planning guidelines state that a site needs to show evidence of being in a zone prone to sustained or frequent flooding for a period of 7 consecutive days at least once every 2 years on average (7MQ2) in order to meet the planning criteria for determining a wetland for a restoration in agricultural land. The inundation flow at a streamgage was determined by calculating the 7MQ2 based on available daily mean discharge data.

In phase 2, once the inundation flow was calculated, the corresponding inundation elevation was determined on the basis of the rating at the streamgage. For selected sites that were not near a streamgage, additional resources such as historical flood profiles and linear interpolation methods were used to estimate the inundation elevation.

In phase 3, a set of maps representing the inundation zone was created by use of a GIS application, inundation-elevation data, DEM data, and flood-inundation mapping techniques. Calculated and estimated inundation-elevation data from phase 2 were used to develop a digital water-surface plane representing the surface of inundation elevation that sloped downward in the direction of flow. By subtracting the DEM data from the inundation-elevation data, GIS data were produced representing the extent of the inundation zone. By combining the GIS data, aerial photographs and other GIS layers, a final set of inundation-zone maps was created.

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Glossary

7MQ2 Annual highest 7-consecutive-day mean discharge with a 2-year recurrence interval.

datum A surface or point relative to which measurements of height and/or horizontal position are reported. A vertical datum is a horizontal surface used as the zero point for measurements of gage height, stage, or elevation; a horizontal datum is a reference for positions given in terms of latitude-longitude, State Plane coordinates, or Universal Transverse Mercator (UTM) coordinates.

discharge In its simplest concept, discharge means outflow; therefore, the use of this term is not restricted as to course or location, and it can be applied to describe the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, a stream, or an ocean (*see also* streamflow).

drainage area The drainage area of a stream at a specified location is that area, measured in a horizontal plane, which is enclosed by a drainage divide.

flood peak The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge. Flood crest has nearly the same meaning, but because it connotes the top of the flood wave, it is properly used only in referring to stage—thus, crest stage, but not crest discharge.

flood plain A strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current. It is called a living flood plain if it is overflowed in times of high water but a fossil flood plain if it is beyond the reach of the highest flood.

flood profile A graph of elevation of the water surface of a river in flood, plotted as ordinate, against distance, measured in the downstream direction, plotted as abscissa.

gage height The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term "stage", although gage height is more appropriate when used with a reading on a gage.

macrotopography Shallow excavation in the flood plain or on terraces, up to 30 inches of depth, providing topographic changes in a flattened and tilled cropland to diversify the landscape, allowing favorable conditions for wetland species of amphibians, birds, and reptiles that thrive within varying hydroperiods having complex wetland vegetation.

recurrence interval (return period) The average interval of time within which the given flood will be equaled or exceeded once.

riparian Pertaining to the banks of a stream.

river mileage The curvilinear distance, in miles, measured upstream from the mouth along the meandering path of a stream channel, and typically used to denote location along a river.

stage The height of a water surface above gage datum; same as gage height.

stream A general term for a body of flowing water. In hydrology the term is generally applied to the water flowing in a natural channel as distinct from a canal.

streamflow The discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course.

streamgage A gaging station where a record of discharge of a stream is obtained. Within the U.S. Geological Survey, this term is used only for those gaging stations where a continuous record of gage-height is obtained.

water year In U.S. Geological Survey reports dealing with surface-water supply, the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ended September 30, 1959, is called water year 1959.

Appendix 1.

Flood-inundation area boundaries are intended to show the approximate extents of floods, with aerial photography and/or digital topographic map used as a base layer. Error sources in these boundaries can include, but are not limited to, digital-elevation-data errors and flood inundation mapping errors. Errors can result in inaccuracies in flood extent; thus, the flood-inundation area boundaries depicted here should be considered estimates.

Maps are in Transverse Mercator projection. Orthophotography is from Indiana University, Indiana Spatial Data Porta*l (http://gis.iu.edu/),* National Agricultural Imagery Program (NAIP), 2010. U.S. Geological Survey Topographic maps are from the National Map *(http://nationalmap.gov/ustopo/index.html).* Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

The inundation zone and inundation elevation are based on the inundation flow (annual highest 7-consecutive-day mean discharge with a 2-year recurrence interval).

Appendix Figures

Separate documents available on Web only, *http://pubs.usgs.gov/sir/2012/5175/*

Figures A1-1–A3-2. Estimated inundation-zone maps for the Wabash River near Terre Haute, Indiana.

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