Wildcat Creek in Howard County
Stream Stability Assessment

Howard County, IN | November 2017

Prepared for:

Howard County Stormwater District

Prepared by:

Christopher B. Burke Engineering, LLC

115 West Washington Street, Suite 1368 South

Indianapolis, Indiana 46204

CBBEL Project No. 15-0132.00000

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Executive Summary

This report documents the results and methodology used by Christopher B. Burke Engineering, LLC (CBBEL) to assess erosion issues in and along Wildcat Creek in Howard County, Indiana. The river stability assessment was conducted by a team consisting of CBBEL staff and Robert C. Barr, a fluvial geomorphologist, in response to concerns that erosion and flooding was increasing along the creek and threatening homes and infrastructure, particularly in and around Kokomo.

The overall purpose of the study is to show how the quality of life for citizens of Howard County may be improved through adopting appropriate flood resilience strategies and by closely managing and preserving the wonderful resource that is Wildcat Creek.

The study was completed in three successive phases:

- The first phase included significant data gathering and site visits.
- The second phase consisted of assimilation and processing of the data to determine major themes of the current morphologic condition of the stream system. Processed data were then used to identify stressors acting on the streambanks and causing flooding.
- The third phase included development of conceptual strategies for reducing or eliminating the stressors.

The key findings of the Wildcat Creek system assessment were as follows:

- The analyses of the available rainfall and streamflow data for the Wildcat Creek Watershed point to an increasing trend in heaviest rainfalls, an increasing trend in observed flood peaks, an increasing trend in the frequency of bankfull discharges, and an increasing trend in flow volumes.
- Although there are several disturbed stream reaches that act as stressors to the Wildcat Creek system, in every case relatively short reaches of the Creek that have retained their functions, or more of their functions than the disturbed reaches, are buffering the effects of disturbed portions of the stream corridor. These remaining undisturbed reaches with attached floodplains are essential and invaluable in maintaining the overall sustainability and health of the Wildcat Creek system.
- The most obvious issue in Howard County that increases flooding risk along Wildcat Creek is the fact that the natural floodplain has been almost completely filled through the Kokomo city limits. This filling occurred over many decades as the city developed, most of it prior to regulatory officials understanding the negative consequences of filling the floodplain. Nonetheless, this has certainly increased flood elevations along the creek, including upstream of, downstream of, and through Kokomo. Continued filling of the remaining floodplain areas will only exacerbate the negative impacts.
- Another issue impacting flooding within Howard County is channel modifications that have been done in the upper watershed (with over 100 square miles of drainage area) in Tipton County. Most of the creek and tributary ditches in this upper watershed have been modified to support agricultural drainage. This well-drained upper watershed results in fast response of the creek. This means that during larger rainfall events, a large pulse of streamflow is sent downstream into

Howard County, or considered another way – as high as 76 percent of the 1% annual event can be generated upstream of Jerome.

Based on the results of the system assessment, the following are the main concerns with regards to stream stability and flooding:

- Future development within the watershed in Howard County, especially along the river corridor impact areas, is expected to increase flooding in low-lying areas and potentially affect the stability of stream.
- Future development within the watershed outside of Howard County in Tipton County, especially along the river corridor impact areas, is expected to increase flooding in low-lying areas and potentially affect the stability of stream within Howard County.
- The current observed trends in increasing rainfall intensities, average daily flows, and peak annual flows, as well as the forecasted intensification of these trends due to a changing climate, is expected to increase flooding in low-lying areas and potentially affect the stability of stream.
- Unless managed properly, the accumulation of large wood and logjams within the Wildcat Creek channel may result in an increase in flood stages and/or stream instability.
- Current new location of stream corridor along the former quarry on the west side of Kokomo threatens the integrity of the gravel pit levee, with grave consequences on stream stability upstream and downstream of this reach expected should the levee fail and the gravel pit be “captured” by the stream.
- Current severe streambank erosion within the highly-modified river corridor reach in Kokomo is expected to further deteriorate the water quality and stream stability in areas immediately west of Kokomo and require costly frequent ongoing maintenance by the City.

The stream assessment results suggest that multiple mitigation strategies will be most effective in improving the stability of the Wildcat Creek system. The stream suffers from issues that are systemic, or watershed scale, as well as several instances of more acute, site-specific problems.

The following are major recommendations from this study:

1. Implement More Stringent Stormwater Standards
2. Institute Riparian Corridor & Use Restrictions
3. Adopt and Implement Flood Resilience Strategies (especially, the strict preservation of the remaining undisturbed river corridors and floodplain areas)
4. Adopt and Implement a Tree and Large Wood Management Program
5. Update & Expand Hydrologic & Hydraulic Models
6. Provide Additional Flood Storage
7. Reroute the Stream along the Former Quarry to its Original Location
8. Address the Severe Streambank Erosion through the Kokomo Reach

Details regarding the study process, findings of this study, and its recommendations are provided in the report.

1.0 Project Overview

1.1 Introduction

This report documents the results and methodology Christopher B. Burke Engineering, LLC (CBBEL) used to characterize channel stability and evaluate flooding risk along the Wildcat Creek corridor. The stream system was assessed to identify the causes of channel instability and flooding, and to aide in developing conceptual solutions. Robert C. Barr, a research scientist specializing in fluvial erosion processes, assisted with this assessment.

Figure 1: Wildcat Creek near 1150 W

1.2 History

With a drainage area (DA) of more than 800 square-miles, Wildcat Creek is a major tributary of the Wabash River. The watershed includes areas in Grant, Madison, Tipton, Howard, Clinton, Carrol and Tippecanoe Counties. The headwaters of Wildcat Creek begin in Tipton County where Mud Creek and Turkey Creek flow northeast across the northern half of the county until their confluence just south of the county line. The two main channels of the headwaters come together just upstream of Jerome, at the confluence of Mud Creek and Wildcat Creek to form the main channel of Wildcat Creek that continues to flow west across the County, through Carroll County, and into Tippecanoe County where it joins the Wabash River. Wildcat Creek's DA increases from 75 mi^2 at the Tipton and Howard County line to 353 mi^2 at the Carroll and Howard County Line. Significantly, at the confluence of Mud Creek and Wildcat Creek upstream of Jerome the DA is 146.0 mi^2. This means that 40 percent of the DA of the Wildcat Creek watershed in Howard County is in the headwaters located outside of the county. Within Howard County, three primary sub-watersheds, Kokomo Creek (DA = 36.6 mi^2), Little Wildcat Creek (DA = 35 mi^2) and Honey Creek (DA = 22.9 mi^2) combine with the main channel west (downstream) of Kokomo. A map of the study area is provided as **Exhibit 1**.

Flooding and isolated areas of channel instability have been issues along Wildcat Creek for many years, most recently during the April 2013 flood of record. Although logjam clearing and stream stabilization projects have been completed over the years, flooding and instability issues have continued, particularly in and around Kokomo.

1.3 Purpose

The overall purpose of the study is to show how the quality of life for citizens of Howard County may be improved by closely managing and preserving the wonderful resource that is Wildcat Creek. To achieve that, this report is intended to serve as the following:

- A conceptual river corridor management strategy
- A guide showing where in the watershed additional flood storage capacity could be created to offset loss of natural flood storage due to previous development
- A guide showing where new development should be allowed and avoided
- A clear communication of what the Wildcat Creek system is doing in terms of flooding and erosion, whether issues are expected to worsen, and the reason for regulations and their enforcement
- A guide for managing trees along the banks and in the creek
- A plan of action for reducing current flooding issues and preventing additional problems

1.4 Process

The study was completed in three successive phases. The first phase included significant data gathering to acquire previous studies, direct observations during site visits, historical aerial photography, streamflow data, rainfall data, soils information, and land use data.

The second phase consisted of assimilation and processing of the data to determine major themes of the current morphologic condition of the stream system. Processed data were then used to identify stressors acting on the streambanks and causing flooding.

The third phase included development of conceptual strategies for reducing or eliminating the stressors.

1.5 Geomorphic Concepts

1.5.1 Stream Stability

Streams are often thought of as static landscape features, unchanging though time; however, this perception is correct for only a small percentage of streams. Most natural streams are constantly changing based on the variable volumes of water and sediment reaching the channel; the channel is ultimately a reflection of the full range of streamflows.

In geomorphic terms, streams are considered ‘stable’ when, over time, the stream transports the runoff and sediment from its watershed without aggrading or degrading, i.e. the channel maintains its dimension, pattern, and profile (Rosgen, 1996).

Underlying the concept of stream stability is a set of processes that contribute to ‘dynamic equilibrium’ (Leopold 1964). Dynamic equilibrium is the process by which a stream’s characteristics change slightly until the erosive potential and erosion resistance of the stream become closer to a balanced state with no excessive erosion or deposition. This process is continual as the inputs of water and sediment are constantly changing due to the climate, weather, human activity, and natural variability. Dynamic equilibrium implies that stream instability and nonequilibrium should be expected following a disturbance, and the process of reaching stability again may take considerable time. Indeed, it is common in some developing areas for streams to experience another disturbance before stability has been achieved, leading to a cycle of disturbance, partial adjustment or recovery, and then another disturbance. Also, significant disturbances may result in a new stable form that is different from its previous form.

Lane's Balance, illustrated in Figure 4, demonstrates how a channel may respond to changes in parameters affecting stream stability. For example, increasing the sediment load will cause the scale to tip toward aggradation, and an increase in stream slope or flow rate (or a combination) would be required to bring the scale back into balance. Conversely, increasing flow rate (as occurs with higher runoff due to development, for example) will cause the scale to tip toward degradation, and an increase in sediment load (typically through streambank erosion) would be needed to achieve balance. A stream can transport sediment and water through the system without degradation or aggradation when sediment load is balanced with flow rate. As the above paragraph states, the "balance" is usually in movement.

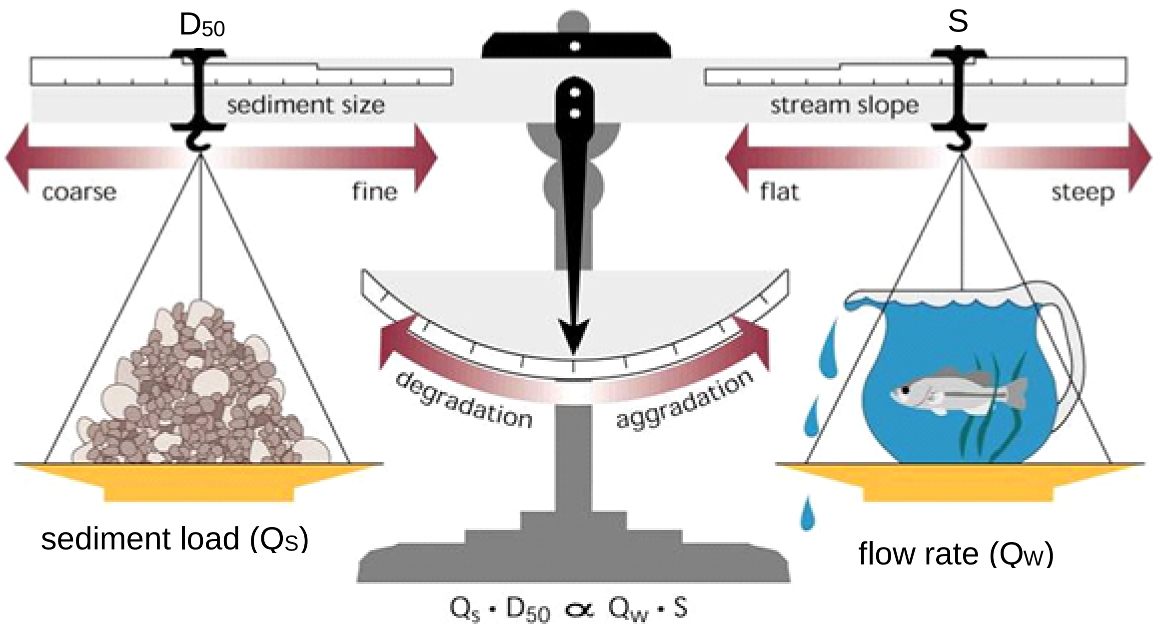


Figure 2: Lane's Balance (after Rosgen, 1996)

1.5.2 Erosion & Sedimentation

Bank erosion and sediment deposition are related. When sediment transport capacity exceeds sediment load, as it can during a flood, or in areas where sediment input has been restricted, erosion of the bed and banks will occur. Similarly, when sediment load is greater than the sediment transport capacity, excess sediment will be deposited in bars. While flow and sediment supply alteration can be found in natural systems, they are particularly common in developed areas. Increased peak flood flows with increased impervious cover are well known, and in urban areas the problems can be further increased as the impervious cover that promotes fast runoff also seals off the local sediment supply; leading to “clear water” discharges that increase erosion in the channel bed and banks. **Figure 3** shows several types of sediment bars that are common in alluvial streams, each caused by different processes occurring in the stream. Alluvial streams and rivers are self-forming. They form their floodplains, and maintain the dimensions, pattern, and profile of the channel. Their depositional features can then be used to better understand how the stream is functioning.

Point Bars: Point bars form in alluvial rivers as the flow passes through meander bends. Water entering a meander flows toward the outside bank where erosion is concentrated and then spirals toward the inside bank. As the water spirals toward the inside of the meander it is slowed by frictional drag imposed by the bed of the channel causing deposition on the inside bank to form a bar. Large point bars in a stream suggest a relatively high sediment load; absent, vegetated, or small point bars suggest a low sediment load.

Lateral Bars: Lateral bars (also referred to as ‘alternate’ or ‘side’ bars) form in relatively straight reaches where sediment load is relatively high. Lateral bars are common in streams that have been straightened causing an imbalance in erosive potential and resistance to erosion. The lateral bars result in increased stream sinuosity (and associated reach length) that helps reduce erosive potential and produce a more balanced state.

Mid-Channel Bars: Mid-channel bars generally form in channels with high sediment loads because of flow divergence around obstructions or due to over-widening of the channel.

Figure 3: Sediment Bar Types

1.5.3 Channel Processes

Over time the dimension, pattern, and profile of channels is adjusted by the interaction of the water and sediment entering the stream and the ability of the channel materials to resist erosion. The progression, or evolution, of the channel toward an equilibrium state is reasonably consistent for all channels and follows a process like that proposed first by Schumm, and later by Simon, as shown in **Figure 4**.

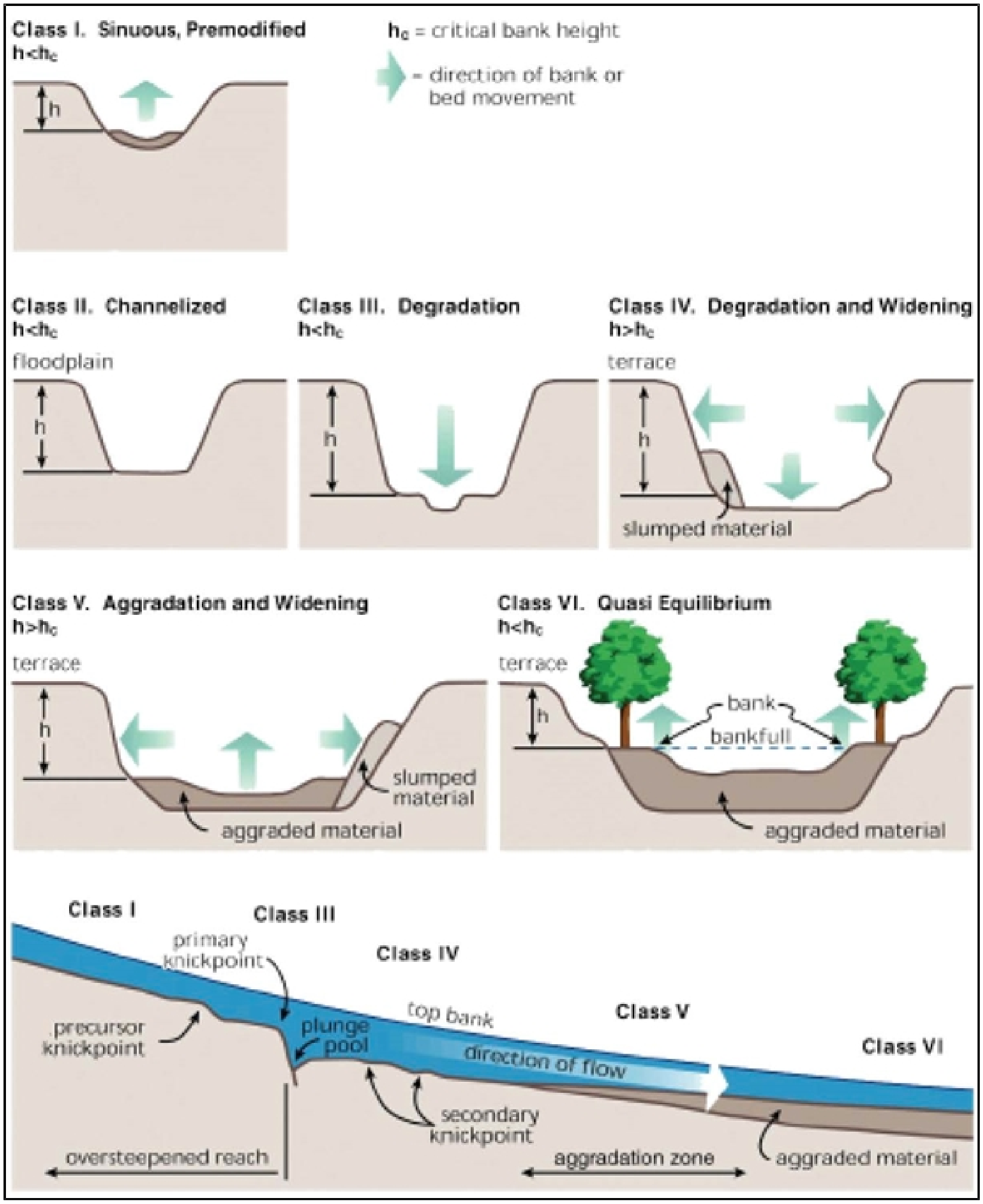


Figure 4: Channel Evolution Model (after Simon, 1989; USACE, 1990)

1.5.4 Large Wood

The presence of fallen trees or limbs in the stream channel, also known as large wood (LW), is common in forested regions, and LW is a vital component of a healthy river system, particularly in sand and gravel bed streams. In addition to providing habitat for fish and other aquatic fauna, LW that is oriented parallel to the bank has been found to play a role in establishment of new floodplain areas. However, excessive amounts of LW can create debris jams and, when oriented perpendicular to the channel, can result in substantial stream instability and erosion.

Wood is important throughout the entire stream corridor. Trees adapted to rooting in the dynamic near-bank area can help stabilize banks, and reduce near bank stress. Trees that have fallen on the floodplain provide habitat and add roughness to the floodplain, helping to reduce velocities, and thereby reduce erosion.

While the benefits of wood in the stream corridor are well documented, the questions of how much wood and where are still being investigated. Most river scientists are promoting a "right tree, right place" strategy to help minimize wood-related debates. The method focuses on looking at the site in question and evaluating the potential benefits or costs of either a living tree, or wood in the stream. The method will often require a site visit to determine impact or strategy, but it removes the problems often associated with a blanket strategy. A common example is "the leaning tree". In the past, some tree management plans would suggest all trees leaning at greater than some angle. Misuse of this method led to lots of trees being cut, and frequently lots of banks being destabilized. If the tree was a silver maple (*Acer saccharinum*), its roots frequently went back into the floodplain, and wrapped the bank. That tree could hold a steep angle for decades, but when it was cut there was nothing left to stabilize the bank. A field inspection might have avoided the loss.

2.0 Data Gathering

Existing and available data and previous studies were supplemented with on-site observations and additional data collected specifically for this study to support a comprehensive understanding of the physical processes at work within the stream system. The following sections detail the sources and use of datasets, previous studies, and the type and extent of additional information gathered.

2.1 Data Sources

Topography

The analysis of Wildcat Creek's corridor and watershed required topographic information for various calculations, and for visual confirmation of floodplain connectivity.

The 2012 IndianaMap Digital Elevation Model (DEM) was used as the source of topographic data for watershed delineation, overbank areas, and in-channel areas some distance away from the stream confluence. The IndianaMap DEM covers the entire watershed and has a 5-foot cell resolution, which is sufficient for producing 1-foot contours.

A topographic map of the Wildcat Creek Watershed is provided as **Exhibit 2**.

Soil and Land Use

Information concerning the properties of the soil and the types and extent of various land uses in the watershed were necessary for the analysis. Soil information was obtained from the National Resource Conservation Service's (NRCS) Soil Survey Geographic Database (SSURGO). Land use information was gathered from the 2011 National Land Cover Dataset (NLCD). Aerial photography from the 2016 USDA National Agricultural Imagery Project (NAIP) was inspected to generally confirm the land uses shown in the NLCD data.

The characterization of channel bed and bank material was completed using visual observation and the Quaternary Map of Indiana (Gray, 1989).

Rainfall

Rainfall data was obtained for several weather stations from the National Climatic Data Center (NCDC) and used to review changes in storm frequency, duration, and intensity over time.

Streamflow

Streamflow information was obtained from the United States Geological Survey's (USGS) online portal. This data was used to review changes in peak annual flow rate, evaluate stream stability and alternatives, and to compare with current regulatory flow rates used by IDNR and FEMA to define flood hazard areas.

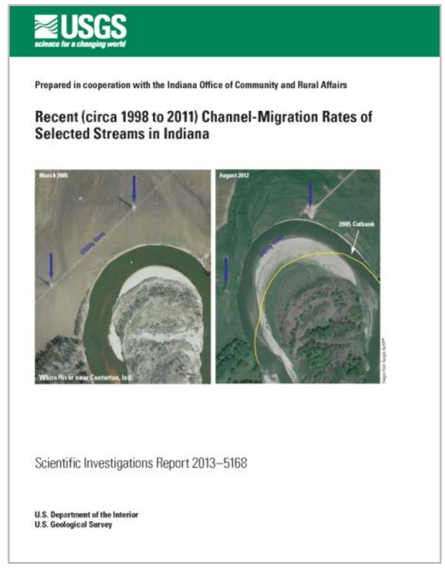
Aerial Photography

The 2016 USDA National Agricultural Imagery Project (NAIP) Orthophotography was the primary source of aerial photography. Historical aerial imagery was collected from Google Earth and the Indiana Historical Society archives.

2.2 Previous Studies

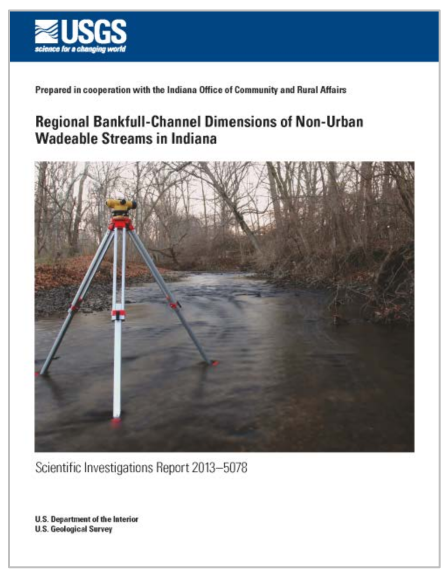
Hydrologic and hydraulic analyses, and a small number of other reports of significance to fluvial stability and flooding considerations were reviewed for the Wildcat Creek watershed.

Recent (circa 1998 to 2011) Channel Migration Rates of Selected Streams in Indiana (USGS, 2013)



A total of 42 stream reaches in Indiana were measured to determine observed lateral migration rates of the streams, or how much a channel's banks shift relative to the surrounding land features. Lateral migration rates can be used as a surrogate for overall stream stability. The analysis completed by the USGS revealed that of the streams considered, Wildcat Creek has the 3rd highest lateral migration rate. The channel moves at a rate of almost 10 feet per year on average, with the maximum migration rate reaching a value of almost 26 feet per year.

Regional Bankfull Channel Dimensions of Non-Urban Wadeable Streams in Indiana (USGS, 2013)



Regionally-based relationships for channel dimensions were developed by analyzing data from streams throughout Indiana. The data was obtained from 81 streams that are non-urban, wadeable, and pristine or naturalized. The regional equations can be used to determine a channels departure from the expected dimensions as well as to aid in channel restoration design processes.

FEMA Flood Insurance Study for Howard County, Indiana and Incorporated Areas (FEMA, 2015)

The Howard County Flood Insurance Study includes detailed modeling and mapping of Wildcat Creek between CR430W and the dam at the Kokomo Water Works Reservoir No. 2. The rest of Wildcat Creek was studied by approximate methods. Although the countywide maps were updated in 2015, the detailed study was completed for the 1981 Flood Insurance Study using the HEC-2 computer model, which is now considered outdated and no longer supported by the USACE, and has not yet been updated.

IDNR Wildcat Creek Coordinated Discharges (IDNR, 2011)

Estimates of peak discharge versus drainage area relationships for various flood frequencies were determined based on USGS gage records have been determined, coordinated with several federal agencies, and published by IDNR in 2011 as a graph. Based on this graph, the 1% annual chance (100-year) estimate of flow at the Kokomo streamflow gage is about 14,000 cfs, which is significantly higher than the 11,000 cfs value used for the current FIS modeling and mapping of Wildcat Creek.

Wildcat Creek through Kokomo, Indiana: Hydrology Report Memo (IDNR, 2014)

An Indiana Department of Natural Resources memo from Joseph Mallory, PE, dated January 22, 2014 done after the 2013 flood found that the reservoir has almost no effect on peak discharges as measured downstream at the Kokomo gage. A comparison of summer and winter pool elevations found that there was not much difference in pool elevation, 812-feet in the summer and 814-feet in the winter, and the surface area of the pool varied only slightly – 451.5 and 461.6 acres respectively. The storage difference when multiplying by the 2-foot elevation difference is only 20.24-acre feet. The calculation using the discharge at Jerome for the April 2013 storm showed that the storage capacity was filled in less than 15 minutes.

Wildcat Creek Through Kokomo, Indiana Hydrology Report (Unknown author and date)

A copy of this 8-page report was available at the County Surveyors Office. The report describes the result of a HEC-HMS hydrologic model that had been calibrated to the April 2013 report. However, the Surveyor's Office did not know who produced the report and a copy of the model was not available at the time of CBBEL study. The report indicated that the April 19, 2013 flood of record in Kokomo resulted from a 10-day, 8.8-inchrainfall event that was comprised of three separate rainfall events, starting on April 10th. During the April 18th through 19th storm, only about 4.5 inches of rainfall occurred over a 16-hour period, which is approximately a 10- to 25-year rainfall event. However, due to prior storms and saturated watershed conditions, the storm produced a 100-year flood event with a peak of 10, 600 cfs at the Kokomo Gage. A CN of 90 was used for this simulation, reflecting the saturated condition of the watershed due to preceding rainfall events over the watershed.

3.0 System Assessment

The system assessment included consideration of findings from previous studies, a site investigation of portions of the watershed and stream, and analysis of other available data. The following paragraphs provide an overview of the system assessment.

3.1 Site Visits

Several areas were visited to observe current conditions and help identify physical processes occurring in the watershed and channel. The focus was primarily on locating signs of morphological change (changes in the channel) such as scoured or failing streambanks, significant upland erosion, and sediment deposition. Channel constraints and limitations (such as encroachment, entrenchment, and restrictive structures) and stream features that affect sediment transport were also documented.

1. **Overall visits to Mud Creek and Wildcat Creek River Corridors**: An initial reconnaissance of the Wildcat Creek corridor was done on March 13, 2017. Greg Lake and Sarah Brichford of the Howard County Storm Water District identified several areas of concern along the main channel of Wildcat Creek, primarily to the east of Kokomo. The Howard County Storm Water District is involved in managing the overall health of streams and waterways in Howard County, and have concerns about wood management, bank erosion, floodplain encroachment, and channel instability along Wildcat Creek.

   The main channels of Mud Creek in Tipton County and Wildcat Creek in Howard County were flown on April 15, 2017 during leaf-off conditions to assess the main channel for signs of stream instability or bank erosion. Areas identified as potentially unstable were then assessed in a series of field visits. Following the April 15 flight, field visits were also made to 8 reference sites, that were selected based on location, interest by the Howard County staff, or geomorphic significance. High flows in Wildcat Creek through early summer limited assessment of lower bank conditions until later in the summer, but proved valuable for assessing the movement of large wood in the channel and potential areas for flood storage.

   On August 12, 2017 stream flow was low enough to assess channel bank stability. Channel conditions were assessed at 23 bridge locations from Sharpsville to the Howard/Carroll County line, the 8 reference sites, and two areas of bank instability. The low flow conditions allowed for observations of large wood in and around the bridge piers, and for bank assessment in areas around the bridge that are prone to instability.

   On August 18, 2917, 6 of the 8 reference sites in Mud Creek and Wildcat Creek were revisited with CBBEL staff to review the sites and to discuss management strategies.

   Selected photos taken during the site visits are contained within the Stream Stability Assessment report in **Appendix 1**.

2. **Large Wood (LW):** LW was observed along Wildcat Creek primarily upstream of the Kokomo reservoir, and downstream of the quarry west of Kokomo. The debris includes fallen trees in the creek and along the channel banks. Some minor logjams have formed in a few locations along the creek, some of which appear to direct flow toward the channel banks.

Figure 5: Large Wood at County Road E 100 N

The data collected show that only 35% of the bridges assessed on Wildcat Creek had Large Wood (LW) associated with them, and the largest accumulation of LW was found on Mud Creek, a headwater tributary. The LW observed was most common in and downstream from disturbance areas. These data suggest that wood management in the Wildcat Creek corridor is not a chronic problem, but an occasional acute problem because of very high stream flow, or a severe storm, like the August 2016 tornadoes.

3. **Rock Quarries:** Over the years, rock quarries have been mined in several locations along Wildcat Creek and there is currently one active quarry located west of Kokomo. Some abandoned quarry areas have been developed into residential neighborhoods. Berms originally built to isolate the gravel pits from the creek have been breached which allowed Wildcat Creek flows to pass through the pits. One such location is upstream of County Road E440W which breached in 2003, shown in **Figure 6**. Other locations along the berms appear to be in imminent danger of failure if not properly assessed and mitigated.

Figure 6: Location of 2003 Berm Failure

3.2 Examination and Analysis of Available Data

3.2.1 Land Use & Urban Development

Current land use in the Wildcat Creek watershed is primarily agricultural with some isolated urban areas. The summary of major land use classifications in the watershed from 1992 to 2011 provided in **Table 1** shows that approximately 10-percent of agricultural land was converted to urban land use over the time period with most of that conversion occurring between 1992 and 2001.

Table 1: Land Use Summary

Watershed Land Use by Year (%)				
Land Use Description	**1992**	**2001**	**2006**	**2011**
Undeveloped	4%	6%	5%	5%
Urban	5%	13%	14%	14%
Agricultural	91%	81%	81%	81%

Figure 7 is a visual of the land use conversions that occurred between 1992 and 2011. Increasing land use intensity has significant implications on the way that the watershed responds to rainfall.

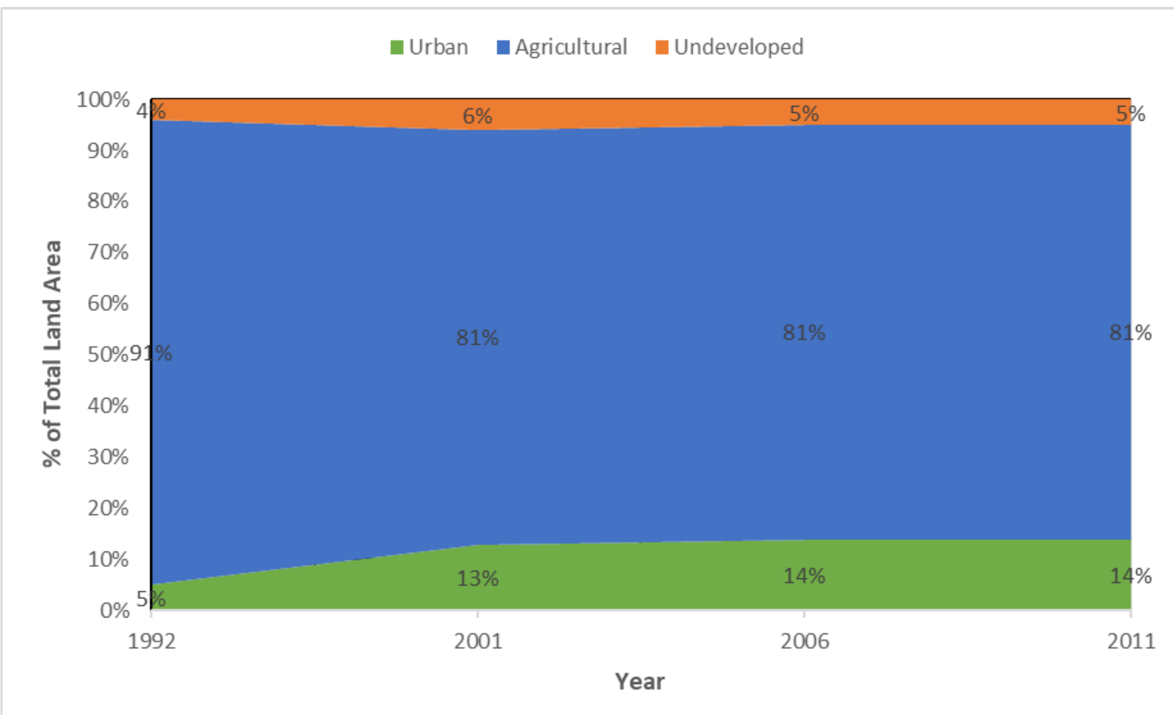


Figure 7: Land Use Summary by Year

3.2.2 Rainfall

The average annual precipitation in Kokomo is approximately 43 inches. The annual precipitation has a steadily increasing trend over the last 30 years of approximately 0.1 inches per year, shown below in **Figure 8**.

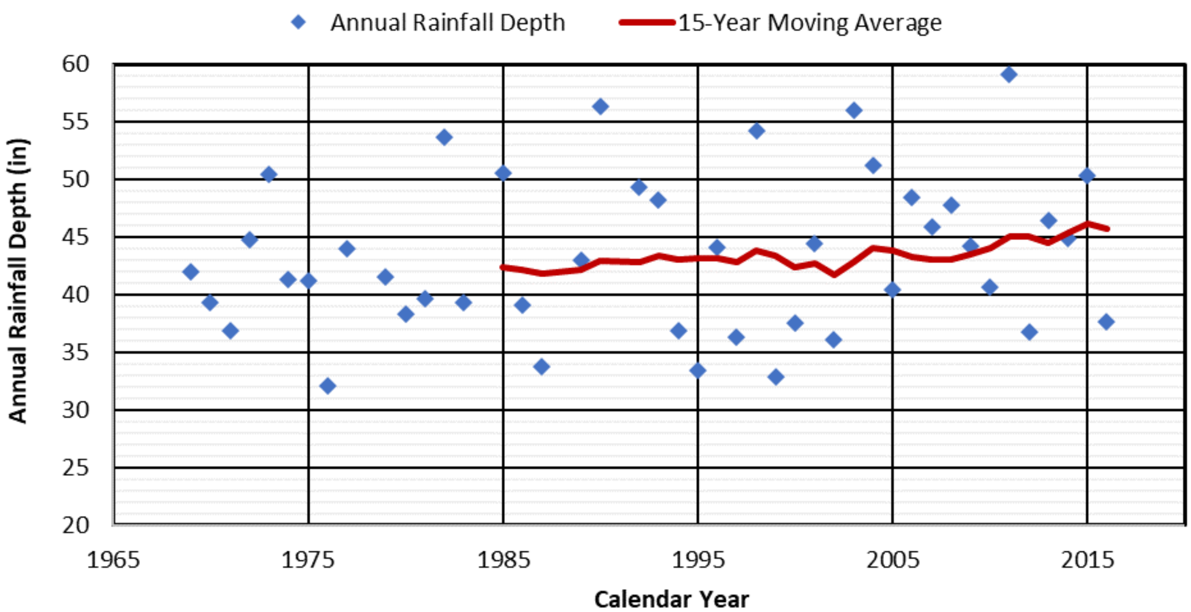


Figure 8: Kokomo, Indiana 3 WSW Annual Rainfall Depth (Data from NCDC)

More relevant to erosion potential than average annual precipitation is frequency of heavy rainfall events. Previous studies of National Weather Service data from 1958 to 2012 show that the Midwest has seen the precipitation during the heaviest 1% of storms increase by 37%, as shown in **Figure 9**.

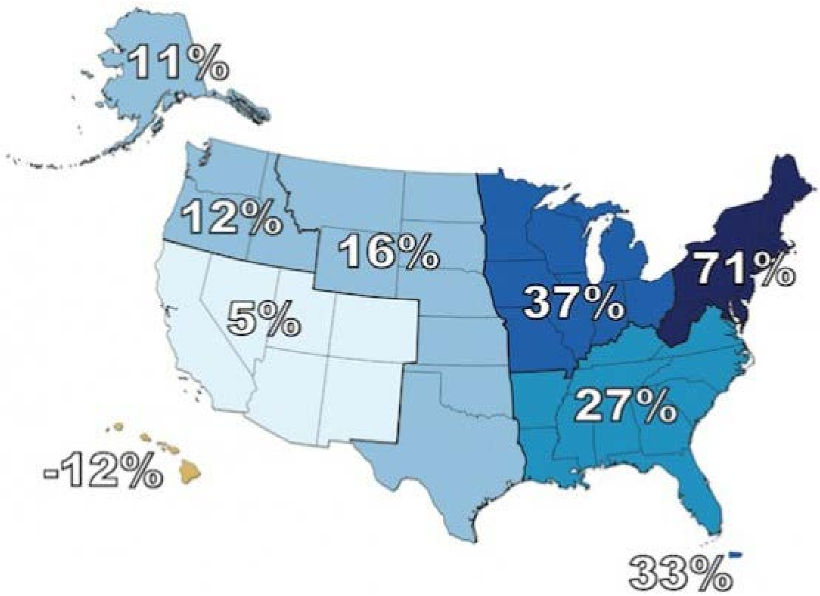


Figure 9: Percent Increase in Rainfall During the Heaviest 1% of Rainfall Events (from the 2014 National Climate Assessment)

Rainfall intensity is the depth of rainfall that occurs over a given duration. The rainfall depth for various durations was analyzed using data from the Burlington, Indiana gage because it was the closest precipitation gage with hourly records. The analysis considered the depth of rainfall to occur in five durations to determine how the intensity for the top 1% of the most severe events has changed over time. **Figure 10** shows the 15-year moving average of the rainfall depth exceeded by 1% of events for each duration. The trendlines show that on the west edge of Howard County, rainfall intensities were on a decreasing trend through about 1980 and have been trending higher since then. The most recent average rainfall intensity is close to the highest historic values.

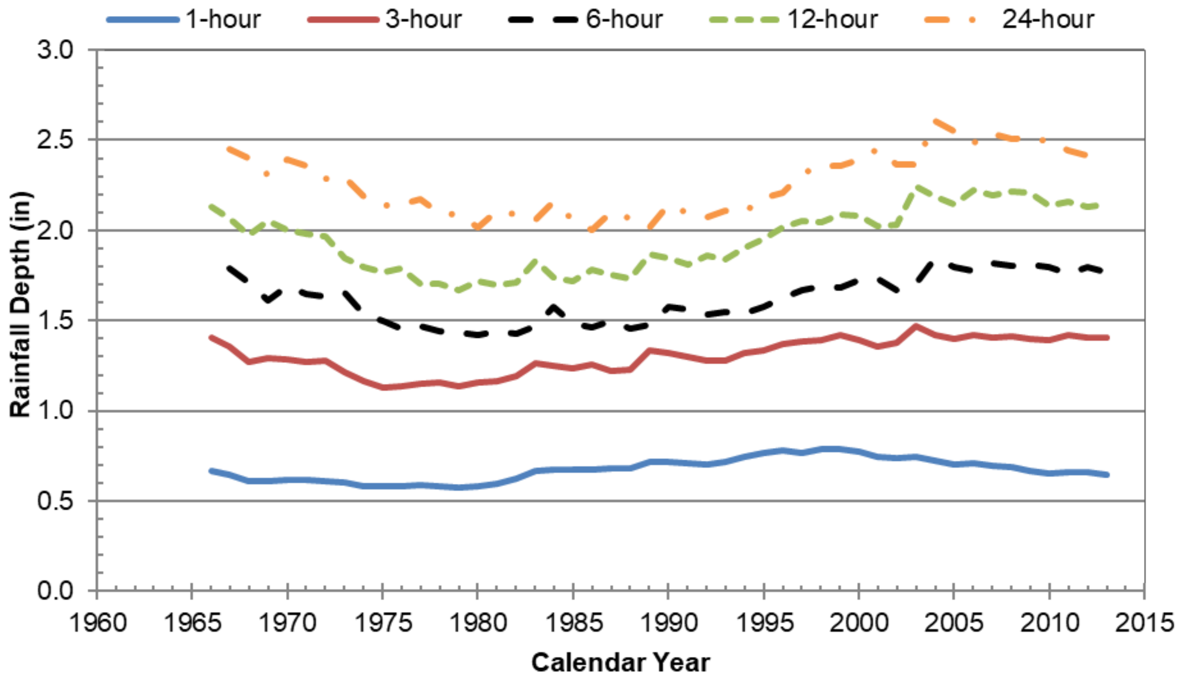


Figure 10: 15-year Moving Average of Rainfall Depth Exceeded by Top 1% of Events by Duration (NCDC Hourly Data for Burlington, IN)

Though the analysis of rain gage data near the Wildcat Creek Watershed did identify a discernable trend in the frequency of heavy rainfall events, analysis of a single gaging station does not necessarily reflect climatic trends of an entire region.

3.2.3 Watershed Hydrology

Watershed response to rainfall is a key factor in fluvial instability and flooding risk along a stream. Watershed response refers to runoff and time required for runoff to accumulate and reach the stream. Urban development and other intensive land use changes typically decrease infiltration which causes an increase in runoff rate and volume resulting in higher, more frequent, and longer lasting peak flows and a much faster response that can lead to flash floods.

The Wildcat Creek streamflow gage at Kokomo, Indiana shows an increasing trend for peak annual flow rate over the past several decades. **Figure 11** shows peak annual flow rates along with a trend line showing average rates over the period of record. The 1975 average peak annual flow of approximately 4,000 cubic-feet per second (cfs) increased to almost 5,200 cfs by 2014, a 30-percent increase over the 39-year period. The increase in average peak annual flow shows a phenomenon that is more readily seen by impacted property owners along Wildcat Creek, larger floods each year.

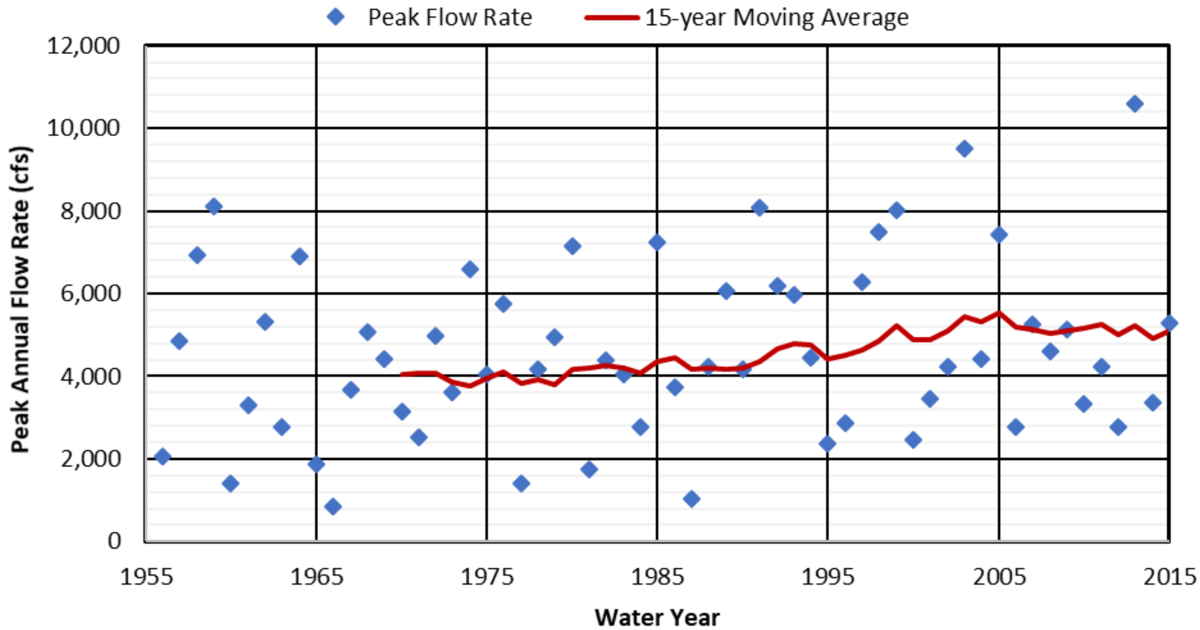


Figure 11: Peak Annual Flow Rate at USGS Gage at Kokomo, IN

Although erosion is normal at any flow rate, and higher flow rates increase erosion, the bankfull discharge (approximately the 1.5-year flow rate) statistically moves the most sediment over time. Erosion in streams is a relatively slow and grinding process that constantly reshapes the channel. Statistical analysis of the Wildcat Creek gage data suggests that the bankfull discharge is approximately 3,400 cfs and is expected occur for a few hours every 18 months. Based on the gage data for Wildcat Creek at Kokomo, the frequency of bankfull discharge has been consistent over the period of record, occurring less frequently than once each year, as shown in **Figure 12**.

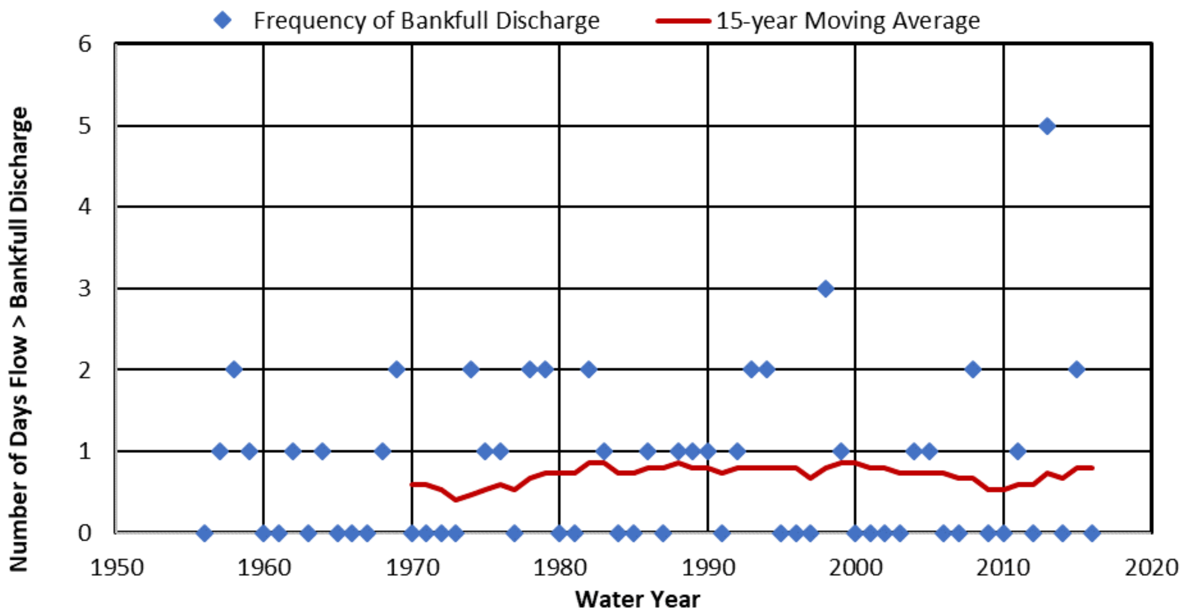


Figure 12: Frequency of Bankfull Discharge at USGS Gage in Kokomo, IN

Although the frequency of bankfull discharge is relatively consistent, the average daily flow rate shows an increasing trend, meaning average runoff volume is increasing. A larger volume of runoff results in flooding from higher flow rates that are sustained over longer periods of time. **Figure 13** shows the average daily flow rate for Wildcat Creek has increased from approximately 200 cfs in 1970 to 300 cfs in 2016; this equates to a 50% increase in flow volume.

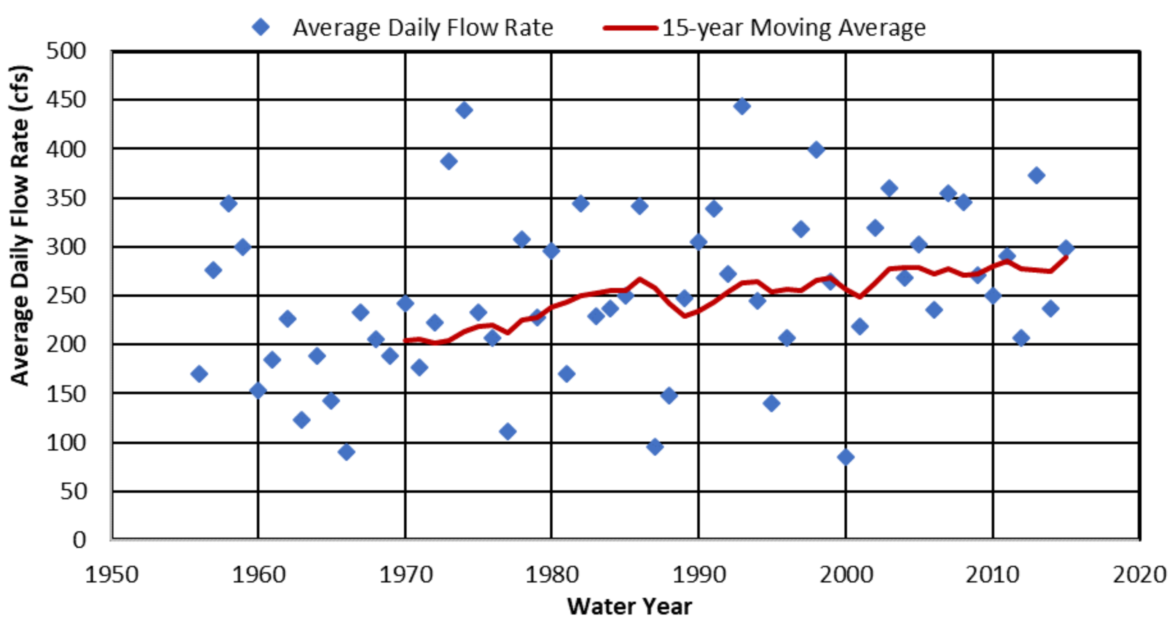


Figure 13: Average Daily Flow Rate at USGS Gage at Kokomo, IN

3.2.4 Comparison of Channel Dimensions to Regional Curves

The apparent bankfull width of the channel was measured at 8 locations using the IndianaMap DEM to determine the channel geometry. Although this method of estimation is less accurate than field measurements, the values (shown in **Table 2**) are accurate enough to show variance from expected bankfull widths calculated using the Indiana "regional curves" which are relationships between drainage area and bankfull channel dimensions. The USGS developed regional curves for Indiana in 2013 by measuring stream channel dimensions in some of the most natural, least disturbed stream reaches. The curves can be invaluable in understanding how modified a stream reach may be.

Table 2: Comparison of Observed Channel Properties with Regional Curves

Measurement Location	Drainage Area (sq. mi.)	Measured Bankfull Width (ft)	Predicted Bankfull Width (ft)
1. Mud Creek at Sharpsville	14.4	35	44
2. Wildcat Creek downstream from Grassy Creek	50.8	57	66
3. Wildcat Creek at Jerome	149	104	94
4. Wildcat Creek near Crooked Creek Ct	183	100	100
5. Wildcat Creek at Apperson Rd	201	110	103
6.Wildcat Creek at Kokomo	241	119	109
7.Wildcat Creek at Malfalfa Rd.	248	116	110
8. Wildcat Creek at CR W 100 N and SR 22	351	132	125

A comparison of the measured bankfull stream widths with predicted stream widths shows that the values are remarkably similar. This indicates that in most sections of the stream the width is "normal". Depth is the most variable of the channel dimensions, so consistent widths can indicate stable channels. The exception for Wildcat Creek is in Kokomo. The stream channels in Kokomo (Apperson Road, Wildcat Creek at Kokomo) are incised, so that while the measured width is close to predicted values, the depths are much greater. For example, the predicted bankfull mean depth at Apperson Road is 3.72 ft. That means that in a stable natural channel at bankfull stage the flow would be moving onto the floodplain. At Apperson Road, the floodplain has been filled and the channel is over twice as deep as predicted. The bankfull depth only partially fills the channel, and much higher discharges are confined to the channel. The increased water depth leads to higher velocities and a cycle of channel degradation that is hard to reverse.

3.2.5 Stream Stability Assessment

A detailed stream stability assessment of Wildcat Creek was performed as part of this study and the results are contained within a report in **Appendix 1**. The following is a summary of a reach by reach assessment from that report. As discussed in the noted report, the project area may be divided into 7 stream reaches based on channel morphology, geomorphic setting, function, and land use (See **Figure 14**). Reach descriptions and results follow.

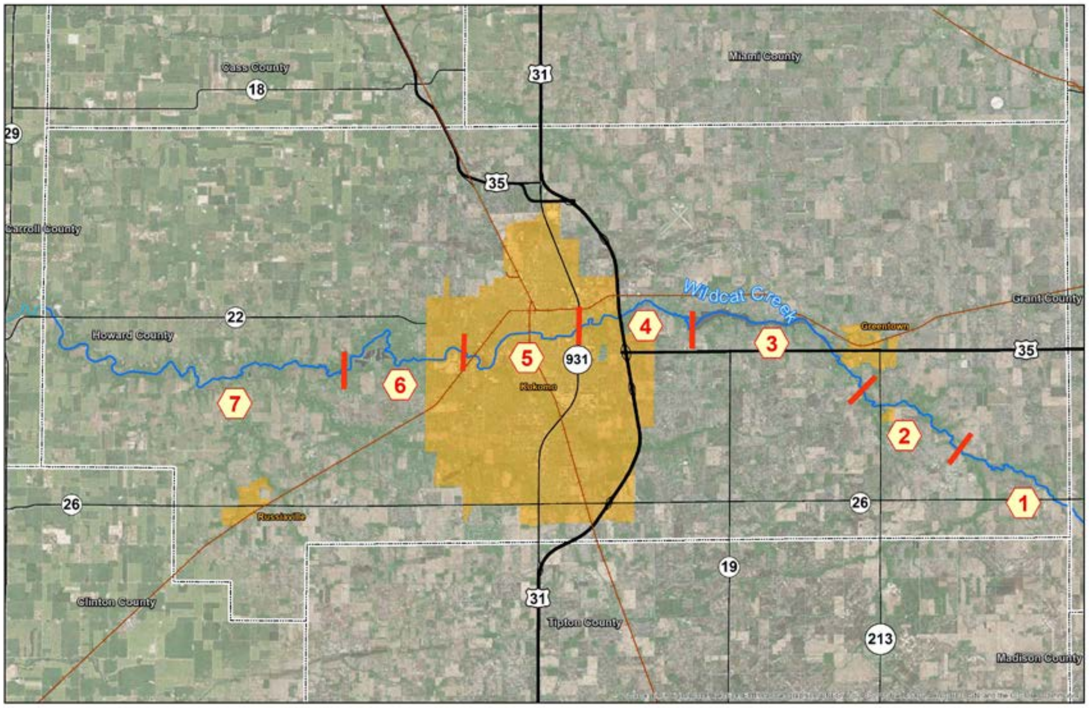


Figure 14: Project Stream Reaches of Wildcat Creek

1. **Agriculturally modified headwaters:** For the purposes of this study, the Wildcat Creek watershed upstream of the confluence of Mud Creek and Wildcat Creek is regarded as the headwaters. The headwaters are dominated by agriculturally-modified streams and constructed drainage channels, and have a drainage area of 149 mi2. The headwaters divide at the confluence into two separate drainage basins, Mud Creek and Middle Fork Wildcat Creek. Mud Creek originates in western Tipton County and flows east for 22 river miles until it turns sharply to the north and into Howard County. While a geomorphic floodplain exists along most of Mud Creek, straightening and clearing of the channel from Sharpsville to Nevada (8 miles) have slightly incised the channel and reduced floodplain connectivity and riparian functions. Upstream of Sharpsville clearing and dredging have eliminated floodplain connectivity for 2.5 miles. The identification of geomorphic floodplains using alluvial soils is a key concept used in geomorphic assessments. County soil surveys, or the Web Soil Survey, show mapped alluvial soils, and can be used to guide to identify floodplains that are still attached, or functioning as floodplains; as well as areas of alluvial soils that are now separated from the main channel by filling, channel incision, or levee-type structures. The primary alluvial soils in the Howard County portion of the Wildcat Creek watershed are Genesee, Shoals, and

Sloan, all of which are classed as silt-loam soils. The soils are part of a drainage sequence where Genesee soil tends to be well drained, Shoals is somewhat poorly drained, and Sloan soils are poorly drained. Because alluvial soils form in alluvium, or material deposited on the floodplain, they tend to be highly variable over short distances, due to changing patterns of deposition.

2. **Wildcat Creek, Jerome to upstream of Greentown:** This reach begins at the confluence of Mud Creek and the Middle Fork Wildcat Creek and flows for 4.75 miles northwest towards Greentown. The reach ends upstream of Greentown where the effects of the reservoir begin to dominate channel processes. The reach is remarkable for its stability given that it begins downstream from the very modified headwaters. It is effectively serving as the buffer, or “shock absorber” for the upstream alteration of the flow regime.
3. **Reservoir Reach (Kokomo Waterworks Reservoir 2):** The reservoir reach is a 5.75-mile section of Wildcat Creek that was drowned out by the formation of the Kokomo Waterworks Reservoir No.2 in 1958. The reservoir is long, narrow, and shallow, the water level was raised 18-feet on average, with some deeper areas around old gravel pits. The reservoirs shape and size reflect its origin as the Wildcat Creek valley. The effect of the reservoir on sediment transport is significant. Reservoirs tend to trap bedload, which is integral to channel-forming processes, and release water on the downstream end that is “hungry” to carry sediment. The sediment-starved water can do more work downstream in the form of erosion.
4. **Wildcat Creek, Reservoir to US 931:** This reach has unstable banks in the upper 2.0 miles. The erosion would be much worse if the stream was not able to access its floodplain. However, the valley is downstream of the reservoir and as the narrow shape of the reservoir indicates, the valley is not wide, the geomorphic floodplain averages 1250-feet through this reach.
5. **Wildcat Creek, Kokomo:** The 4.3-miles of Wildcat Creek in Kokomo, defined here as the stream reach between US 931 on the east side of the city, and S. Dixon Road on the west side, typifies an urban stream. The stream is incised, flat bottomed, lacks instream structure, and its floodplain has been filled throughout the city, leaving a classic “urban canyon”. Downstream from the Apperson Way, and on the west side of the city, there is a 2.0-mile section of Wildcat Creek and Kokomo Creek that were vacuum dredged during the remediation of the Continental Steel facility. EPA documents indicate that from 0.4 to 2.5-feet of contaminated sediment were removed from the stream bed. Extensive remediation of the banks was done as well, which has given the reach a straightened appearance. Downstream from the Continental Steel remediation area, stabilization has also been done on the left bank in an area that was historically a dump site. The area is still used for recycling sorting. Trash and debris is falling out of banks that were “stabilized” with a slag cap. The slag is not heavy enough to be stable on the banks and most of it is ending up being eroded and transported downstream where several central bars have formed.

6. **Mined Reach:** The mined and formerly mined portion of the Wildcat Creek corridor begins at Dixon Road and continues downstream until a point approximately 5.5 miles downstream. In the upper active mined area, quarry operations and levees that were pushed up to keep the quarry from flooding and to store the overburden have removed any floodplain on the left bank, and forced the stream against the high valley wall on the right bank. The result is the most visible erosion in the study area in the form of a large cutbank and sediment bars. While the cutbank is large, the toe of the slope is stable, and there is little lateral movement. What is occurring at the site is more of a slope process, than a stream process. Sediment loss seems low relative to the size of the exposure. While large wood in the channel was reported as a concern by the County, the mined reach was the only area (other than August 2016 tornado-induced large wood in an isolated area in an upper reach of Wildcat Creek) in Howard County where significant large wood was found. However, no channel blockages were seen, and most of the wood was at or near bridge pilings.

   At Malfalfa Road Wildcat Creek flows from the actively-mined area into an area that has been reclaimed. In this area, there are many legacy problems. A new channel was constructed during mining operations to receive the ground water being pumped out of the pit. The constructed channel is narrower and has a steeper grade than Wildcat's natural channel. With mining operations ceased there is no longer any pumping, but the constructed channel has captured most of Wildcat's flow. The original natural channel has very little to no flow at times. During higher flows, it now functions as an overflow channel and fills with large wood and debris as the flow recedes. The constructed channel, which was intended for the pumped discharge, is now carrying most of the flow of Wildcat Creek – right along the toe of the old levee that separated the mine from Wildcat Creeks flood waters. High flows during the 2013 flood breached the levee and flowed in the lake. This type of capture can have catastrophic effects on the stream channel as the stream tries to adjust the grade of the newly captured pit to the upstream channel slope. The stream will erode its bed and banks to try and fill the pit and the instability will continue to move upstream.

   Wildcat Creek and the newly dominant built channel come back together upstream of the CR N 400 S bridge. From the downstream rejoining to the upstream split the main channel is 1.2 miles long, the old pumped channel is 0.6 miles long. The capture reduced stream length by 50%. The bridge will initially catch much of the large wood and debris washed out of the main channel. Downstream from CR N 400 W, Wildcat Creek has been rerouted to the outside of a series of smaller gravel pits. Levee-type structures have been pushed up around these smaller pits just like the larger pit upstream. And just like the large pit, these small pits have the potential for capture as well. What is harder to see, but equally problematic, is that the levees that protect these lakes from flooding exclude the stream from its floodplain. Flow in the channel through these areas is deeper than it normally would be, and faster. The result is once again, a stream with the ability to do more work, or erode more that it might in a more stable system.

7. **Downstream from mined area to County Line:** Immediately downstream from the mined area, the more natural system is adjusting to the effects of the levees and shortened channels in the mined area. The 1.5 river miles immediately downstream from the mined area has the highest sinuosity measured in the study area, which is significantly higher than the rest of the reach. This area acts as a "shock absorber" for the mined area. The upper portion is also characterized by large wood, and the most prominent point bars seen in the study area. Downstream from buffer zone for the mined area, Wildcat Creek flows west for over 10.5 river miles to the County Line near Burlington. This final reach is characterized by wide, well connected floodplains and stable banks.

3.2.6 Review of Floodplain Fill

A river corridor is composed of flow conveyance and flood storage areas in the overbank that act together to move water, sediment, and organic material (most notably LW) through the system. When flow conveyance and flood storage become detached, or when shortcomings in one are not compensated for by the other, flooding can become more severe and devastating. An analysis of the flow conveyance and floodplain storage present in the Wildcat Creek corridor was completed to identify where potential issues might be.

The availability of sufficient flow conveyance and floodplain storage was assessed by examining the Flood Insurance Study (FIS). The FIS profile was reviewed to identify locations where flood elevations increase over a short distance. A copy of

Figure 15: Example of Filled Floodplain Areas

the FIS flood profiles through Kokomo are provided in **Exhibit 3**. As can be seen from the Exhibit, flood profiles jump up considerably through the City's urbanized reach in response to loss of cross sectional area due to floodplain fill, restrictive crossings, and low-head dams. The floodway map was reviewed to identify areas where the floodway is obviously narrow. These indicate locations where most of the flow must pass through a narrow passageway which could be a restrictive bridge or culvert, or areas where the overbank floodplain has been blocked or filled. Floodplain storage was evaluated by comparing the regulatory floodway and floodplain. Areas with little or no adjacent floodplain, or that show development in the floodplain indicate compromised floodplain storage and connectivity. As an example, **Figure 15** shows a portion of Wildcat Creek in downtown Kokomo indicating filled and developed floodplain areas.

An examination of the Wildcat Creek stream reaches through the County shows well-connected floodplain areas along the more natural reaches upstream and downstream of Kokomo. Conversely, through Kokomo, adjacent floodplain areas are either non-existent or development exists within the floodplain, highlighted as vulnerable developed areas. The adjacent developments interfere with the beneficial function of floodplain connectivity and have undoubtedly contributed to increased runoff and flooding along the stream corridor.

Figure 16 is a representative cross section of the creek through Kokomo. It shows the existing channel shape along with an approximation of the natural channel shape and shows the significant volume of overbank floodplain storage that has been filled.

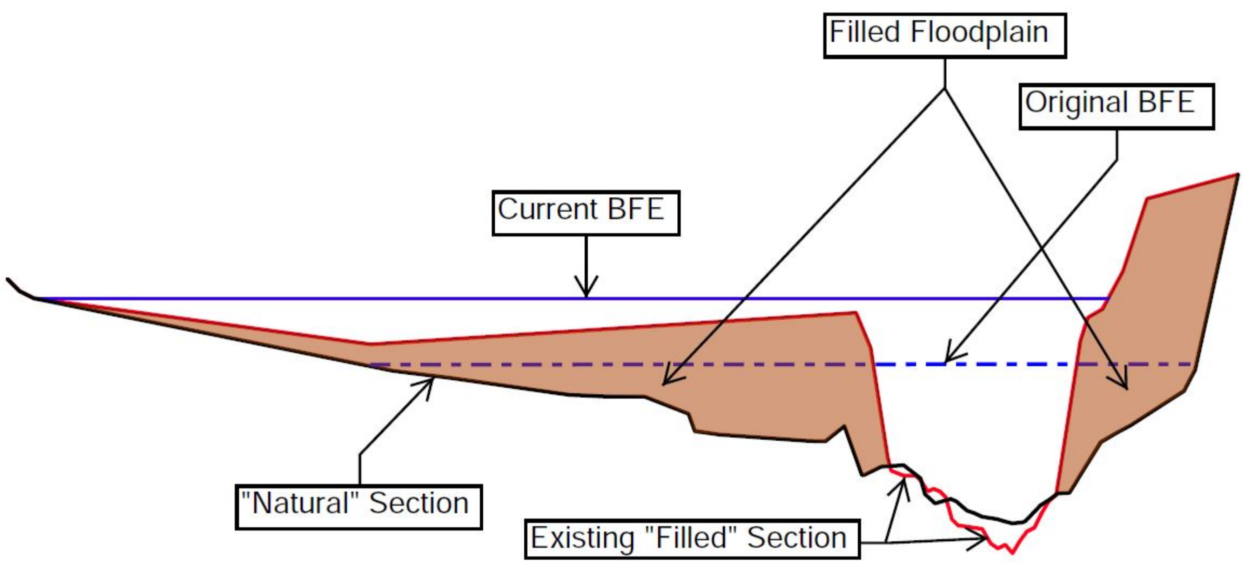


Figure 16: Cross-Section Illustrating Natural Channel Shape and Filled Overbanks in Kokomo

3.2.7 Assessment of Existing Hydrologic and Hydraulic Models

A brief review of the available hydrologic and hydraulic models was completed to help determine what portions of the system could benefit from additional studies or re-analysis.

An investigation of hydrologic modeling for the Wildcat Creek Watershed revealed that a complete, calibrated hydrologic model does not exist.

A cursory review of the hydraulic models in the Indiana Department of Natural Resources (IDNR) model library revealed the following:

- The Howard County Flood Insurance Study includes detailed modeling of Wildcat Creek between CR430W and the dam at the Kokomo Water Works Reservoir No. 2. The rest of Wildcat Creek was studied by approximate methods. The detailed study was completed for the 1981 Flood Insurance Study using the HEC-2 computer model, which is now considered outdated and no longer supported by the USACE.
- Kokomo Creek has a detailed study, and the other main tributaries have approximate studies.
- Major stream reaches with approximate floodplains would benefit from detailed studies before additional development along the creeks is approved.

3.2.8 Review of Current Development Ordinance and Standards

The current Howard County development-related ordinances and standards contained in Chapters 151, 154, and 156 of Title XV (Land Usage) of Howard County Ordinances were reviewed to see if the existing provisions were adequate to compensate new development or redevelopment impacts. While these ordinances contained many good provisions and safeguards, the review revealed several deficiencies. Major deficiencies included lack of control for smaller than post-developed 100-year flows (such as 10-year and 2-year flood peaks), lack of adequate details regarding runoff and detention calculations, lack of detailed standards for design and construction of stormwater control practices and BMPs, lack of compensatory floodplain storage provisions, lack of Channel Protection Volume provisions, and lack of fluvial erosion hazard protection. Lack of adequate, No-Adverse-Impact development standards is expected to lead to an increase in stressors that impact the stability of the stream corridor, resulting in increased exposure to flooding and stream instability.

3.3 Key Findings of System Assessment

The following is a summary of the key findings of the Wildcat Creek system assessment.

3.3.1 An Increasing Trend in Observed Rainfall and Runoff

The analyses of the available rainfall and streamflow data for the Wildcat Creek Watershed point to an increasing trend in heaviest rainfalls, an increasing trend in observed flood peaks, an increasing trend in the frequency of bankfull discharges, and an increasing trend in flow volumes.

3.3.2 The Value of Undisturbed Reaches with Attached Floodplains

As discussed in the Stream Stability Assessment Report in Appendix 1, the recurring theme of this study has been the buffering of the effects of disturbed portions of the stream corridor by reaches that have retained their functions, or more of their functions than the disturbed reaches. There are three distinct areas where this buffering occurs:

1. Headwaters into Jerome-Greentown: 149 mi^2 of highly modified headwaters and up to 90% of the flood discharge recorded at the Kokomo gage flow through 4.75 miles of stream corridor with intact floodplains. The largest area of instability identified in the reach is an eroding cutbank on a meander downstream from the canoe launch at SR213.

2. Reservoir reach into the Dam to US 931 reach: in this reach, 4.3 miles of stream with floodplains buffer the clear water discharge of a 461.6-acre reservoir. The channel in this reach is semi-alluvial in several locations so erosion is increased. The 2.0 miles directly downstream from the reservoir has several sections that are unstable.

3. Kokomo and the Mined area into the stable downstream reach: Approximately 12 miles of Wildcat Creek with intact floodplains begin at the west edge of the mined area. The first 1.5 miles of stream immediately downstream from the mined area has the highest sinuosity measured in the study area.

In each of the three stream sections described above, a relatively short (1.5-2.0 mile) stream reach is absorbing the effect of a much larger area of disturbance. These “shock absorbers” are preserving stream health downstream. The remaining undisturbed reaches of Wildcat Creek with attached floodplains are essential and invaluable in maintaining the overall sustainability and health of this system.

3.3.3 Increase in Flood and Erosion Risks by Floodplain Fill in Kokomo

The most obvious issue in Howard County that increases flooding risk along Wildcat Creek is the fact that the natural floodplain has been almost completely filled through the Kokomo city limits. Although no record was found showing the predevelopment creek shape through Kokomo, it is reasonable to assume the channel shape was like the current creek in the mostly undisturbed reaches upstream and downstream of the city. Comparing a representative channel cross-section from the (mostly filled) Kokomo reach with a natural section indicates that 1,000 or more acre-feet of natural floodplain storage may have been lost due to filling along the creek. This filling occurred over many decades as the city developed, most of it prior to regulatory officials understanding the negative consequences of filling the floodplain. Nonetheless, this has certainly increased flood elevations along the creek, including upstream of, downstream of, and through Kokomo. Continued filling of the remaining floodplain areas will only exacerbate the negative impacts.

3.3.4 The Impact of Upstream Channel Modifications in Tipton County

Another issue impacting flooding is channel modifications that have been done in the upper watershed (with over 100 square miles of drainage area) in Tipton County. Most of the creek and tributary ditches in this upper watershed have been modified to support agricultural drainage. Modifications include channel straightening, removal of most vegetation along the stream banks and overbanks, and installation of field tile networks designed to efficiently and quickly drain adjacent agricultural fields. This well-drained upper watershed results in fast response of the creek. This means that during larger rainfall events, a large pulse of streamflow is sent downstream into Howard County, or considered another way - as high as 76 percent of the 1% annual event can be generated upstream of Jerome. Fortunately, this pulse of flow from upstream areas is slowed somewhat by the natural and meandering creek upstream of the reservoir.

4.0 Conclusions and Recommendations

Based on conversations with the Howard County officials and the results of the system assessment described in Section 3.0, the following are the main concerns with regards to stream stability and flooding.

- Future development within the watershed in Howard County, especially along the river corridor impact areas, is expected to increase flooding in low-lying areas and potentially affect the stability of stream.
- Future development within the watershed outside of Howard County in Tipton County, especially along the river corridor impact areas, is expected to increase flooding in low-lying areas and potentially affect the stability of stream within Howard County.
- The current observed trends in increasing rainfall intensities, average daily flows, and peak annual flows, as well as the forecasted intensification of these trends due to a changing climate, is expected to increase flooding in low-lying areas and potentially affect the stability of stream.
- Unless managed properly, the accumulation of large wood and logjams within the Wildcat Creek channel may result in an increase in flood stages and/or stream instability.
- Current new location of stream corridor along the former quarry on the west side of Kokomo threatens the integrity of the gravel pit levee, with grave consequences on stream stability upstream and downstream of this reach expected should the levee fail and the gravel pit be “captured” by the stream.
- Current severe streambank erosion within the highly-modified river corridor reach in Kokomo is expected to further deteriorate the water quality and stream stability in areas immediately west of Kokomo and require costly frequent ongoing maintenance by the City.

The stream assessment results suggest that multiple mitigation strategies will be most effective in improving the stability of the Wildcat Creek system. The stream suffers from issues that are systemic, or watershed scale, as well as several instances of more acute, site-specific problems.

Mitigation of watershed scale stressors is often accomplished by using “passive measures”. Passive measures include mitigation efforts that involve no channel intrusion and focus on removing the source of instability or flooding risk rather than constructing improvements. The use of soil conservation best management practices (BMPs), improved maintenance practices, and removal of harmful, man-made features are examples of passive measures. Stormwater and floodplain ordinances, adopting flood resilience strategies, and restrictive covenants are also passive measures.

When passive measures are not sufficient to reduce or eliminate a stressor, “active measures” can be used to affect desired changes. “Active measures” involve direct intervention in the channel system and construction of site-specific improvements.

4.1 Passive Mitigation Strategies for Reducing Fluvial and flooding Risk

4.1.1 Implement More Stringent Stormwater Standards

Maintaining current and strict stormwater ordinance and technical standards is critical to protecting the integrity of the stream corridor. To be effective, stormwater regulations must utilize current methods and technology, promote the use of infrastructure designs that mimic the natural / pre-development watershed, protect sensitive / critical environmental areas, and compensate for unavoidable adverse impacts to the stream system.

The analysis of the Wildcat Creek at Kokomo stream gage data shows a clear increasing trend in flow rates despite the current level of stormwater detention requirements within the watershed. A major portion of the drainage area, particularly the urbanized area, lies within Howard County. Though detention has been required, a more consistent and accurate determination of maximum allowable release rates, calculated based on calibrated watershed-wide hydrologic modeling may improve the effectiveness of peak flow control measures. Sub-watershed specific maximum 100-year and 10-year allowable release rates (cfs/acre) required for any new development and re-development within the watershed should be calculated and adopted for various developing drainage basins.

The current requirements also lack the needed control of more frequent, channel forming events and provisions for infiltrating or at least significantly delaying the Channel Protection Volume (the volume of runoff created during the 1-year, 24-hour rainfall event) to prevent further increase in flow rates.

Low Impact Development (LID) and Green Infrastructure (GI) practices should also be promoted and employed to the greatest extent practicable to reduce the amount of stormwater runoff from a developed site. These methods offer a two-fold benefit. The total volume of runoff is reduced due to use of Best Management Practices (BMPs) that allow water to infiltrate into the soil, which results in lower required detention volumes and less runoff delivered to the stream. The second benefit is the flow rate leaving a site is lower than a conventionally designed site and mimics the natural release of stormwater runoff. When implemented well, the pre-development and post-development stormwater runoff metrics are nearly identical, resulting in no changes to the hydrology of the stream.

When large areas in the watershed are planned for development or redevelopment, a holistic approach should be used to design the stormwater infrastructure for the entire development, rather than a site-by-site design. By considering how the infrastructure will function as a whole, the incremental increases in flow rate and flow volume can be more comprehensively addressed. Regional detention may serve as an acceptable method of holistic design. If a site-by-site design concept is more practicable for a given situation, tertiary stormwater infrastructure should be allowed for to act as shock absorbers prior to releasing the flow from the development area.

Environmentally sensitive areas serve a critical role in the stream system. These areas include floodplains, floodways, wetlands, and riparian areas that provide stormwater storage to reduce flow rates, flow conveyance to minimize flood elevations, energy dissipation to reduce erosion, provide habitat for the organisms at the beginning of the food chain, and process natural and manmade pollutants. Development in these areas should be discouraged and prohibited where possible. Where it is not possible or practicable to avoid these areas, compensatory mitigation should occur that will provide the same benefits. It should be noted that a 1:1 ratio for compensatory mitigation (detention/floodplain storage, wetlands, trees, etc.) may not provide the same benefit to the system due to location, quality, and/or maturity. Mitigation ratios should be established to provide equal (or greater) benefit immediately after construction and onward.

Howard County should update the County's Stormwater standards to include the above-noted more restrictive, No-Adverse-Impact requirements when new development is proposed within the County jurisdictional areas. Since a significant portion of the watershed is outside the County, Howard County should also start a multi-county education and outreach effort, and reach out to Tipton County Drainage Board to encourage adoption of similar No Adverse Impact and resilience strategies.

4.1.2 Institute Riparian Corridor & Use Restrictions

Watershed modification, land management, and the properties of the soil material forming the channel bed and banks are the primary source of destabilizing inputs to the system; however, direct human impacts to the channel have also led to decreased stability. The complete removal of trees along the banks, the absence of a riparian buffer, and channel encroachment have negative impacts on the system.

The institution of a protected riparian corridor with use restrictions within the corridor would help to promote more natural stream function, while also decreasing the potential for Fluvial Erosion Hazard (FEH) to threaten human life and property. Meander belt, or refined FEH corridor maps have been developed for the State of Indiana; these maps could serve as a prudent starting point for the extent of the protected riparian corridor as the maps reflect the area where the channel may migrate over time or where disturbance may impact the stability of stream. The refined corridor could be amended in areas where the institution of a protected riparian corridor is not practical due to in-place infrastructure or other complicating factors. The refined corridor map for Wildcat Creek is available through the IDNR portal at:

http://indnr.maps.arcgis.com/apps/webappviewer/index.html?id=43e7b307a0184c7c851b5068941e2e23.

4.1.3 Adopt and Implement Flood Resilience Strategies

With the number of extreme rain events growing each year, it's easy to assume that climate change is the reason behind the increased flooding within our communities. However, there is a cycle at work in our communities contributing to the problem and creating unintentional harm. Like thousands of others across our country, most Indiana communities still allow construction in areas with high risk of flooding or erosion that should be left undeveloped – working to mitigate flood risks in one area while creating new risks in another. Our communities continue to take one step forward in their approach to economic development only to fall three steps back when severe flooding occurs.

The hard truth is that much of the increased flood damage suffered in Indiana's cities and towns (including what is occurring in Howard County) is unnecessary. Hazard planners everywhere have access to flood zone mapping tools to identify and better prepare their response to flood events. Most communities know or should know where they are most vulnerable to flood risks and can precisely predict where flooding will occur. The problem is that this information is not communicated to those making the land use decisions for our cities and towns.

To better communicate the existing flooding and erosion risk areas along Wildcat Creek in Howard County and to help the communities' land use decision makers with area-specific strategies, the following resilience planning areas and area-specific strategies have been developed.

1. *River Corridor Impact Areas*—The river corridor impact area is defined by the floodway or fluvial erosion hazard (FEH) area boundary, whichever is greater. The intent of strategies in this area is to protect land adjacent to the river and minimize streambank erosion. Preserve undeveloped areas in this zone by adopting a "River Corridor Impact Areas" overlay zone and prohibiting any disturbance (fill or excavation) in this zone.

2. *Undeveloped High Flood Hazard/Flood Storage Areas*— These are the remaining high flood hazard areas within the 1% or 0.2% annual chance floodplains. The intent of the strategies in this area is to conserve land and maintain the natural and beneficial function of the floodway fringe. Preserve these areas by adopting a "High Hazard/Flood Storage Areas" overlay zone and limiting the development in these areas to only suitable open space land uses (no buildings), protecting undeveloped land in this zone through incentivizing compatible uses such as parks and trails with help from public land trusts, and requiring compensatory floodplain storage when placement of fill in these areas is unavoidable. Given, as discussed earlier, the additional role the remaining stream reaches with attached floodplain are currently playing in buffering the impacts of upstream disturbed areas, the preservation of the remaining Wildcat Creek attached floodplain areas is of utmost importance.
3. *Vulnerable Developed Areas*—this designation would identify homes, critical facilities, and non-conforming structures that are already present either within the River Corridor Impact Areas or other high flood hazard

areas. These areas have been or are expected to be vulnerable to future flood events. The goals in these areas would be the acquisition of the most vulnerable structures, floodproofing of existing structures (especially critical structures), the development of flood storage areas, and the adoption of a flood response plan.

4. *Safer Areas*—this designation would identify areas where public investments and policies should encourage development. These areas would be land areas with higher elevations and outside of designated floodplain. Steer public policy and investment to support development in “Safer Areas” within the community by revising comprehensive land use plans and capital improvement investments (such as expanding new sewer lines, electricity, and water only in these areas) to incentivize development in safer areas, promoting conservation design/LID/Green infrastructures in these safer areas, and promoting placement of critical facilities only in these safer areas.
5. *Watershed*—this designation would identify the land within the entire watershed. Promote coordination and partnership with various jurisdictions within the entire Wildcat Creek watershed to slow, spread, and infiltrate flood water through encouraging adoption of higher, No-Adverse-Impact development standards, adoption of natural resource overlay zones, and watershed-wide stormwater and flood risk management master plans.

The above resilience planning areas and strategies should be incorporated in the Howard County communities comprehensive land use plans. **Exhibit 4** (14 sheets) shows these resilience planning areas along Wildcat Creek and notes a summary of these strategies on each sheet.

4.1.4 Adopt and Implement a Tree and Large Wood Management Program

Trees are part of a healthy riparian corridor. The right trees growing in the right place can help maintain bank stability. As discussed in Section 1.5.4, the “right tree in the right place” method, while it can require effort, is good at reducing problems. One of the reasons that Wildcat Creek in Howard County has remained resilient, is the extensive wooded buffer found along most of the channel. That forest corridor helps protect the stream, but it can also be seen as a source of LW and logjams within the Wildcat Creek channel, and fears that the LW may result in an increase in flood stages and/or stream instability. The reality is different.

As indicated in Section 3.1 of this report, the data collected show that only 35% of the bridges assessed on Wildcat Creek had Large Wood (LW) associated with them, and the largest accumulation of LW was found on Mud Creek, a headwater tributary. The LW observed was most common in and downstream from disturbance areas. These data suggest that wood management in the Wildcat Creek corridor is not a chronic problem, but an occasional acute problem as a result of very high stream flow, or a severe storm, like the August 2016 tornadoes. Since the LW issues don’t appear to be systemic, a maintenance program is indicated.

To help Howard County better understand and manage the existing trees within the corridor and the LW within the Wildcat Creek channel, a guide has been developed and included in **Appendix 2** of this report.

Developing an understanding of when LW is a problem and when it should be removed will be an important aspect of the ongoing management of the Wildcat Creek corridor. Similarly, in more disturbed areas, like Kokomo, recognizing and removing invasive trees, and understanding what vegetation will help bank stability will be important. To help with these issues, links to the Indiana Drainage Handbook, and the Vermont River Management Handbook (Shiff and others, 2014), and a copy of a recent Indiana Silver Jackets Fact Sheet on LW management is included in the reference section of the report contained in Appendix 2.

Adopt a tree management strategy like that discussed in Appendix 2 and its references to balance the beneficial function of large wood in the stream and the threat of logjam formation and/or significant stream channel blockage.

4.1.5 Update & Expand Hydrologic & Hydraulic Models

The review of the regulatory models in the Wildcat Creek Watershed revealed that the determination of flow rates during flooding events is based on studies that were completed more than 30 years ago. The widespread urbanization that occurred after 1992 was not reflected in those analyses and may have a significant impact of the understanding of flooding risk in the nearby communities. The hydrologic information used in the regulatory models should be updated using the results from a new hydrologic analysis of the watershed.

A detailed, calibrated hydrologic model can help determine the impacts of various changes in the watershed and would allow what-if scenarios useful for master planning. Developing such a comprehensive model allows for analysis of flood detention opportunities and effectiveness of creating additional floodplain storage, determination of accurate watershed-specific maximum allowable release rates for new developments, flood forecasting, flood damage reduction, flood regulation, and system operation.

It is recommended that the County initiate the development of a comprehensive hydrologic model and coordinate with the IDNR to perform detailed hydraulic analysis along the entire length of Wildcat Creek and its tributaries.

4.2 Reach-Specific Mitigation of Fluvial and Flooding Risk

While implementation of passive measures identified in Section 4.1 is expected to prevent an increase in future flooding and streambank erosion risks, there is also a need to address some of the most pressing existing and expected future risks along the Wildcat Creek corridor through active mitigation measures. Several reach-specific mitigation measures were identified along Wildcat Creek to help improving the stream stability and reduce flooding potentials along Wildcat Creek corridor.

4.2.1 Provide Additional Flood Storage

The current observed trends in increasing rainfall intensities, average daily flows, and peak annual flows, as well as the forecasted intensification of these trends due to a changing climate, is expected to negatively affect the flooding in low-lying areas and the stability of stream.

Floodplain storage can be provided by excavating the overbanks along a creek to mimic natural floodplain connectivity. This would be an effective and likely preferred option for restoring floodplain storage along a previously filled channel, such as the reach of Wildcat Creek through Kokomo. However, due to intensive development along the Kokomo reach, this would not be a viable option.

Another alternative would be increasing overbank storage along other reaches of the creek. However, the Wildcat Creek floodplain areas are forested with good connectivity to the channel throughout most of Howard County upstream and downstream of Kokomo. This mostly natural condition provides tremendous flood reduction and streambank stability benefits that should be protected. Since floodplain connectivity is very good along the creek upstream and downstream of Kokomo, the benefit of widening the channel overbanks in these areas would not outweigh the negative impacts of removal of well-established forested areas. Therefore, flood storage should be added outside the river corridor but connected hydraulically to the river, in specific areas that would maximize the benefit of additional overbank storage, while minimizing negative impacts on the river corridors.

Based on these observations, the most appropriate course of action for Howard County is to consider developing off-line regional flood storage areas along Wildcat Creek upstream of Kokomo Reservoir to offset the expected increase in peak flow associated with large flood events (such as 50- and 100-year events) and perhaps improve the existing conditions of flooding through Kokomo. Such off-line flood storage areas could be sized in a manner to also serve as a flood storage compensation “bank” for potential future unavoidable fill in floodplain in lieu of on-site compensatory measures. Due to the expected activation and utilization of such proposed flood storage space only during very large, rare events, the excavated storage cell is expected to be dry most of the time and may be used as open space recreational uses such as a park or athletic fields. Several potential locations for such regional floodplain storage areas are shown in Exhibit 4 (Sheets 9, 11, and 14), with a typical schematic layout of such off-line storage provided in **Figure 17**.

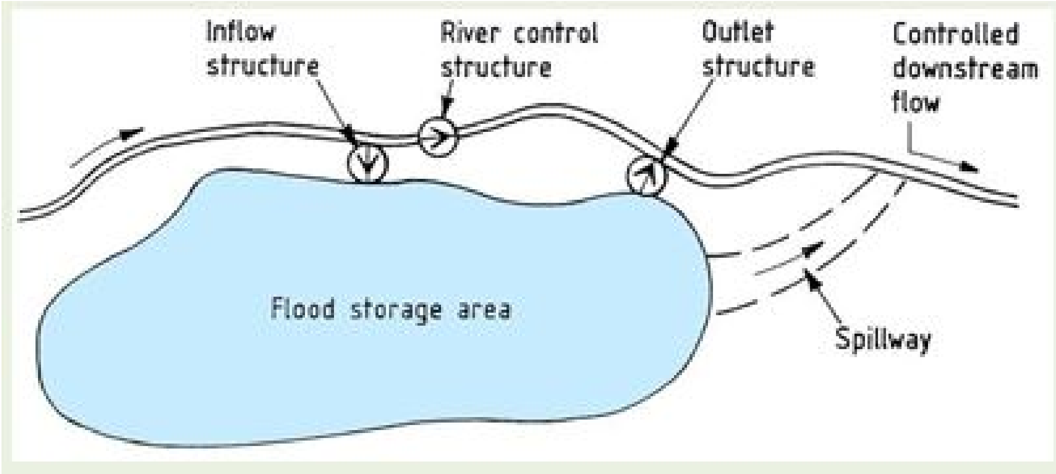


Figure 17: Typical Layout of an Offline Storage Area

Also, since over 50% of the watershed drainage area contributing to Wildcat Creek at the Kokomo gaging station is located outside of Howard County, mainly in Tipton County, potential for creating flood storage areas within Tipton County rural areas should be explored. One potential approach could be to coordinate with Tipton County Drainage Board and work with the landowners in select areas to allow storage of floodwaters on their agricultural fields in very rare (50-100-year) events in exchange for paying flood damages or obtaining flood easements when that occurs. A typical set up for creating such temporary flood storage would include an inline control structure, a wide impoundment berm with non-steep side slops (to allow passage of farm equipment), and an overflow spillway channel. A typical layout of an online temporary flood storage is provided in **Figure 18**.

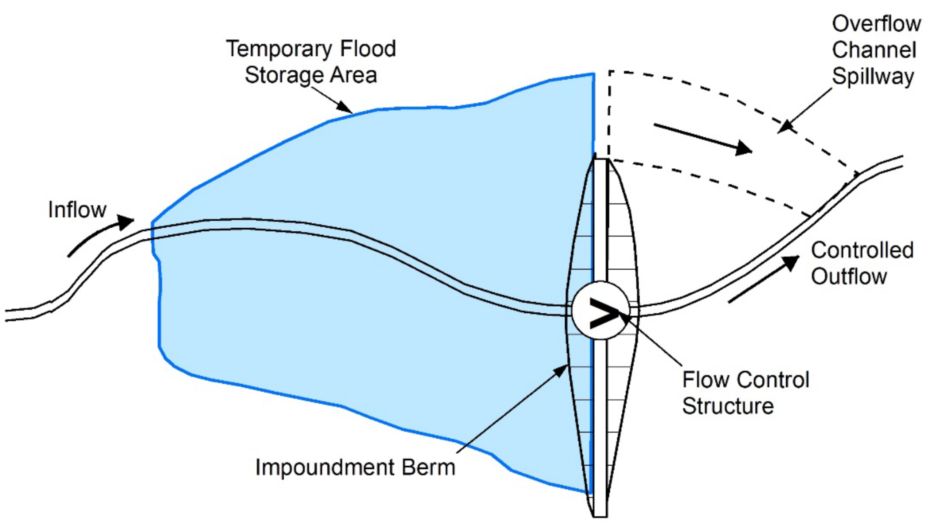


Figure 18: Typical Layout of an Online Temporary Flood Storage Area

observations suggest that this reach is still adjusting to upstream dredging. This combination of issues demonstrates the need for a systemwide plan to improve Wildcat Creek through Kokomo.

Urban stream restoration is difficult. The common deeply incised channels need to be mitigated, and solutions are limited, but the value of a functional and aesthetically pleasing stream corridor is worth the effort. Communities around the state, and around the country are rediscovering their waterways, and finding that they are an asset. Starting just downstream of Howard County, Wildcat Creek is one of the three officially designated ‘Natural, Scenic, and Recreational Rivers’ in Indiana, and a remarkable resource in Howard County – it is worth the effort!

5.0 References

Chow, V. T. (1959). Open-Channel Hydraulics. Caldwell: The Blackburn Press.

Indiana Department of Natural Resources (2014) Wildcat Creek through Kokomo,Indiana: Hydrology Report 8 pp., no pagination.

Leopold, L.B., Wolman, M.G., and Miller, J.P. (1964) Fluvial Processes in Geomorphology. Freeman, 522 p.

National Oceanic and Atmospheric Administration (NOAA). National Climatic Data Center (NCDC). *Daily rainfall data at Kokomo, Indiana and Hourly Rainfall Data for Burlington, Indiana*. Available http://gis.ncdc.noaa.gov/map/viewer/.

Robinson, B.A., 2013, Recent (circa 1998 to 2011) channel-migration rates of selected streams in Indiana: U.S. Geological Survey, Scientific Investigations Report 2013–5168, 14 p. plus 1 app., http://pubs.usgs.gov/sir/2013/5168/.

Robinson, B.A., 2013, Regional bankfull-channel dimensions of non-urban wadeable streams in Indiana: U.S. Geological Survey, Scientific Investigations Report 2013-5078, 33 p.

Rosgen, D, L. (1996) Applied River Morphology. Wildland Hydrology, variously paged.

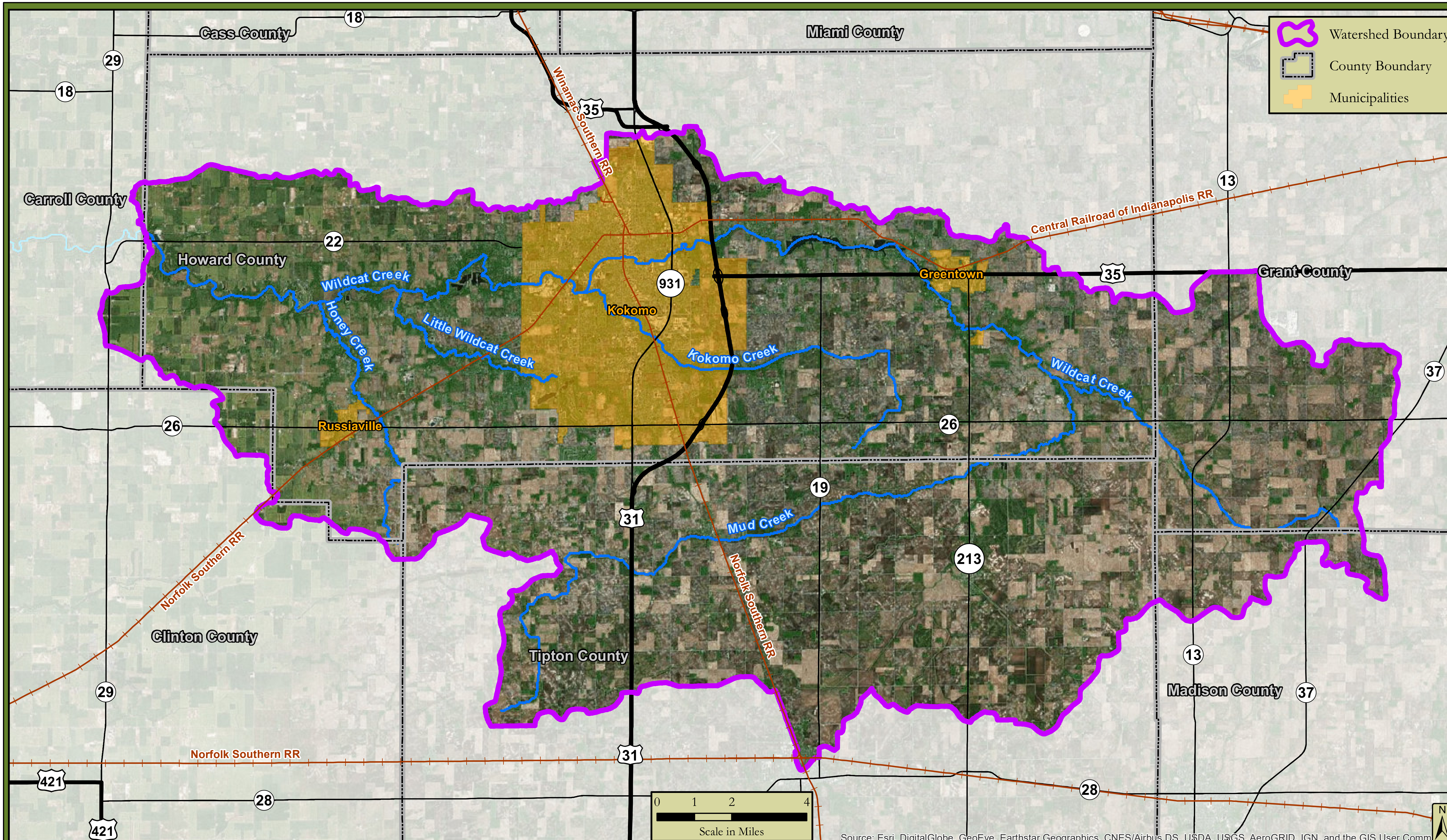
Rosgen,D.L., (1997) A Geomorphological Approach To Restoration Of Incised Rivers. Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, 1997 S.S.Y. Wang, E.J. Langendoen and F.D. Shields, Jr. (eds.)

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database.

United States Department of Agriculture. Natural Resources Conservation Service. Urban Hydrology for Small Watersheds (Technical Release 55). June 1986.

United States Geological Survey. Stream Gage Data for Wildcat Creek at Jerome, Indiana and Wildcat Creek at Kokomo, Indiana. Available http://maps.waterdata.usgs.gov/mapper.

Exhibits



Sources of Data:

1. National Hyrdography Dataset, 2016
2. USGS Streamstats (https://water.usgs.gov/osw/streamstats/indiana.html)
3. US Census Bureau TIGER Files, 2016

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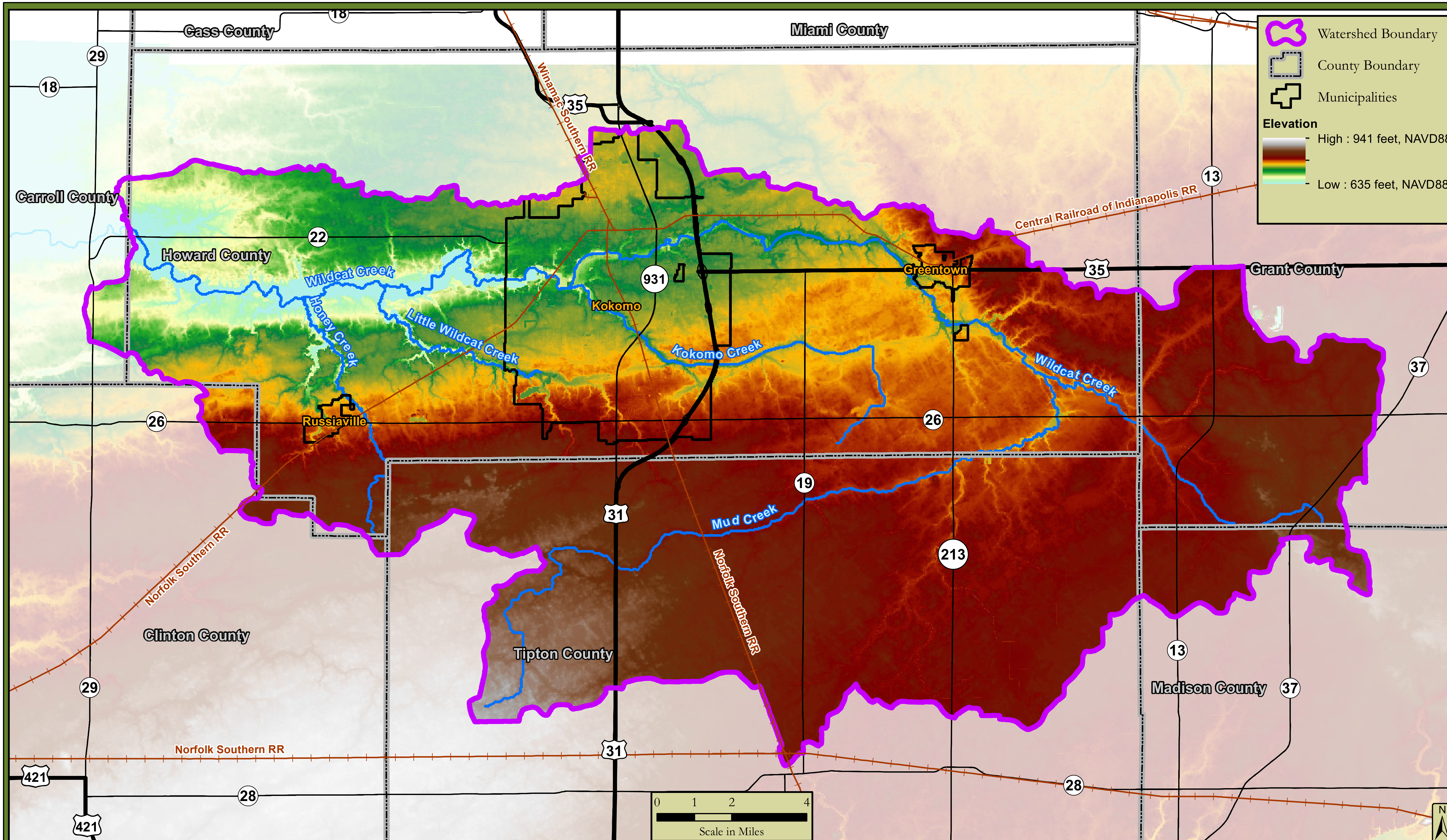
PROJECT:	PROJECT NO.	APPROX. SCALE
Wildcat Creek Stream Stability Assessment	15-0132	as shown
TITLE: Study Area		DATE: 08/2017
		EXHIBIT 1



Sources of Data:

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3. US Census Bureau TIGER Files, 2016
4. IndianaMap Statewide Orthophotography and Elevation Project, 2011-2013

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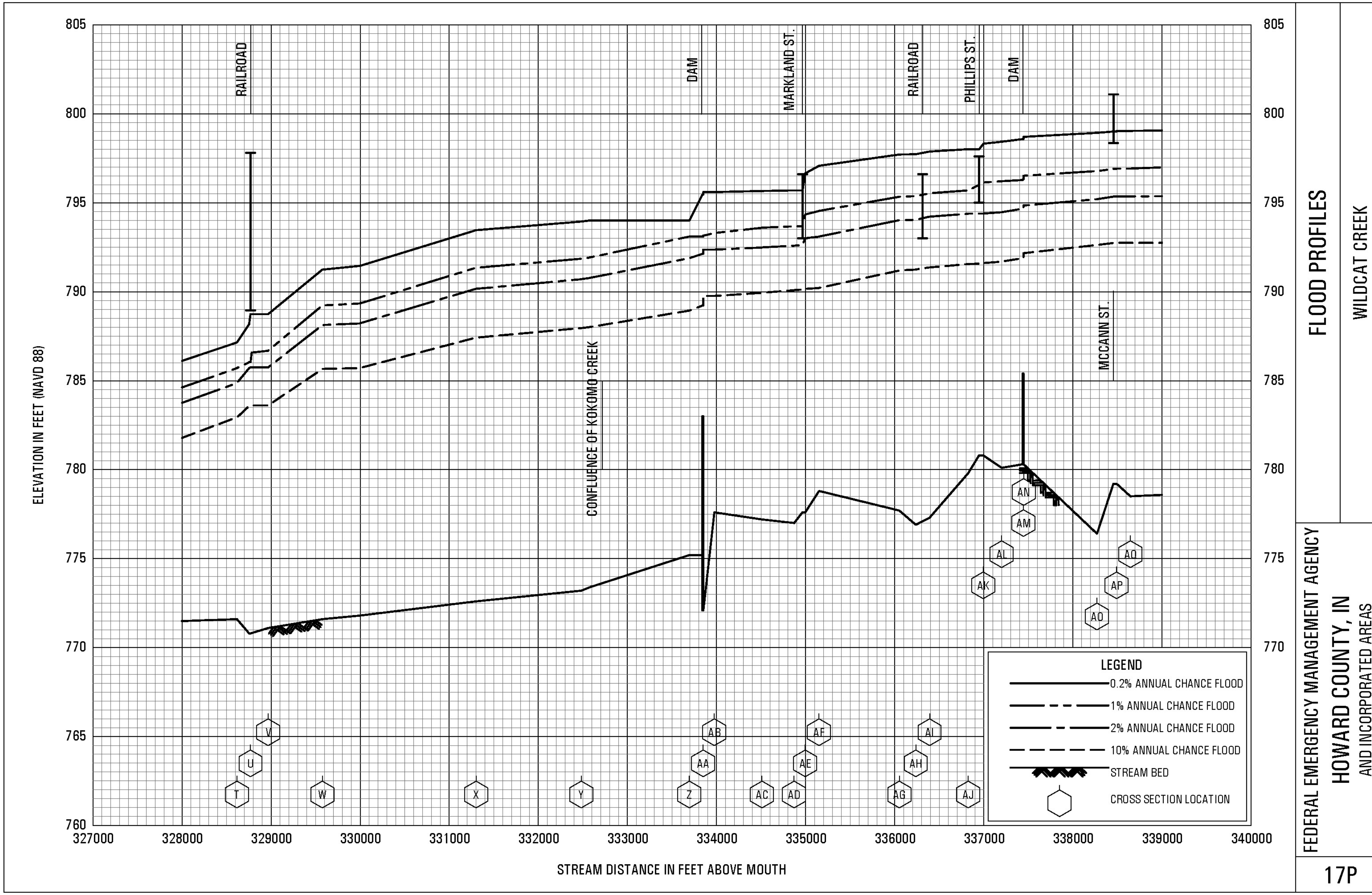
PROJECT:	PROJECT NO.	APPROX. SCALE
Wildcat Creek Stream Stability Assessment	15-0132	as shown
TITLE: Topographic Map		DATE: 08/2017
		EXHIBIT 2



Source of Data:

1. FEMA FIS Profiles, Howard County (02-04-2015)

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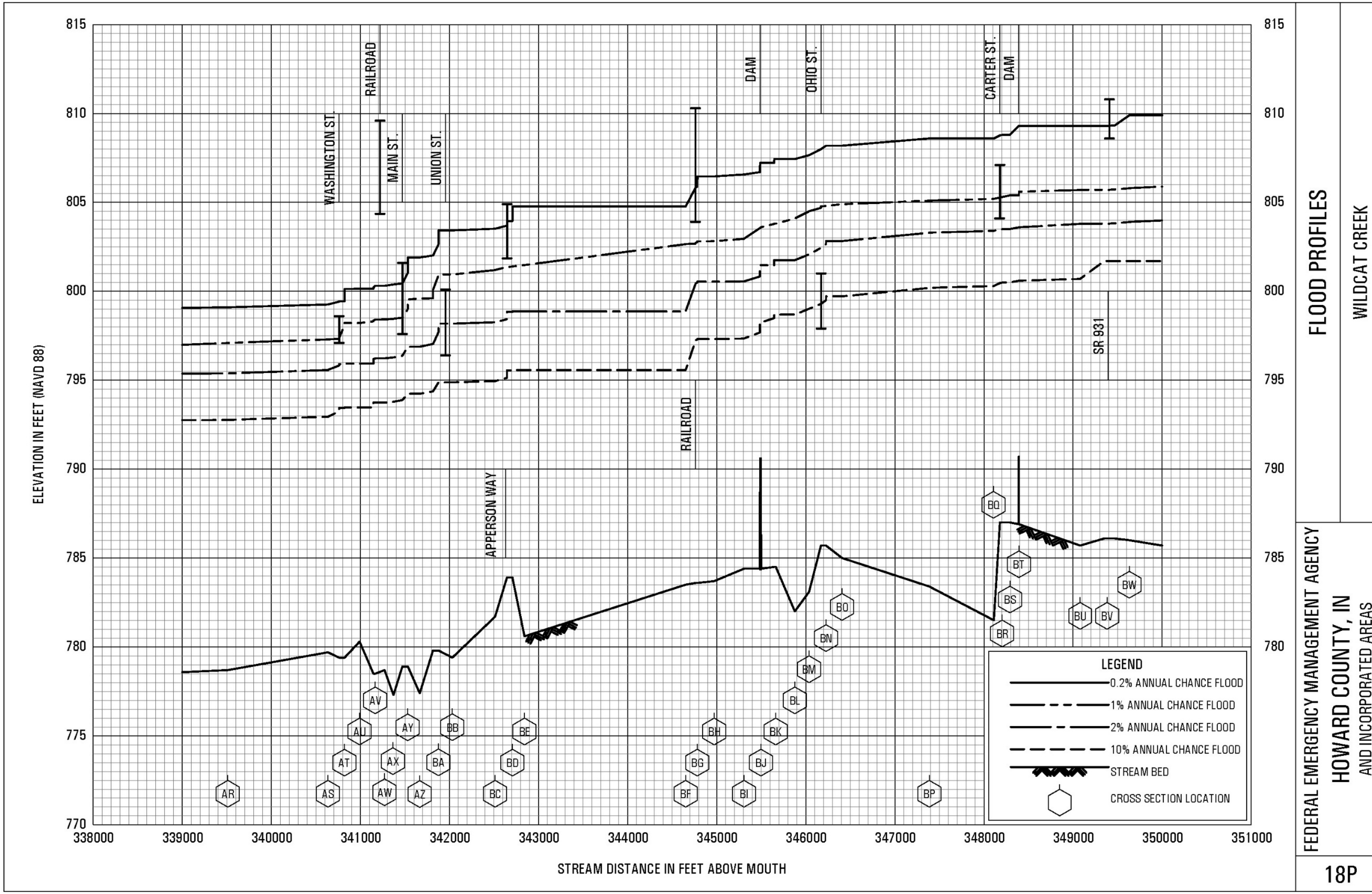
PROJECT:	PROJECT NO.	APPROX. SCALE
Wildcat Creek Stream Stability Assessment	15-0132	as shown
TITLE: FIS Flood Profiles through Kokomo Sheet 1 of 2		DATE: 08/2017
		EXHIBIT 3



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PROJECT: Wildcat Creek Stream Stability Assessment	PROJECT NO. 15-0132	APPROX. SCALE n/a
TITLE: FIS Flood Profiles through Kokomo Sheet 2 of 2		DATE: 08/2017
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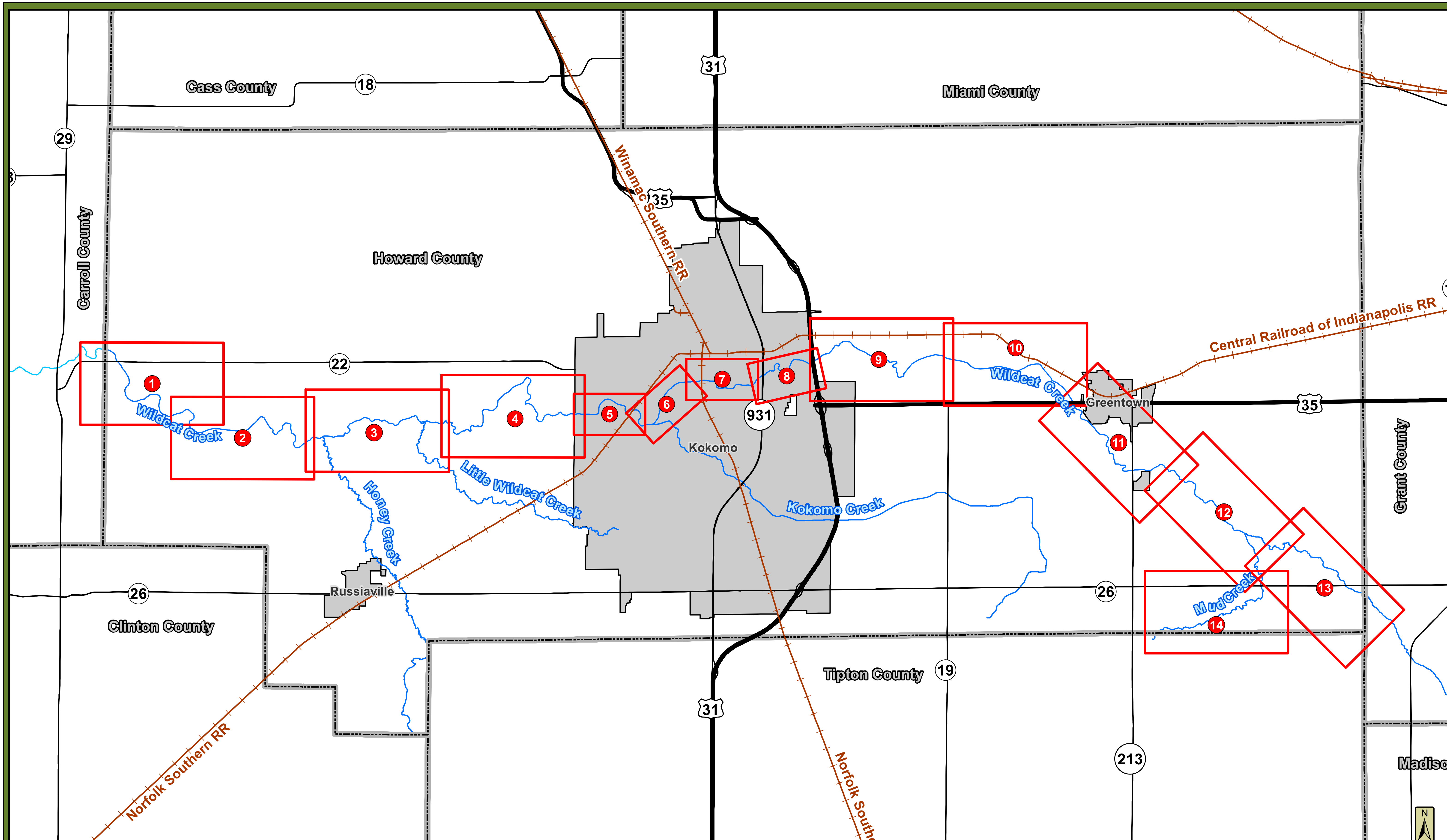

Exhibit 4 Sheet Locations
County Boundary
Municipal Boundary

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PROJECT: Wildcat Creek Stream Stability Assessment

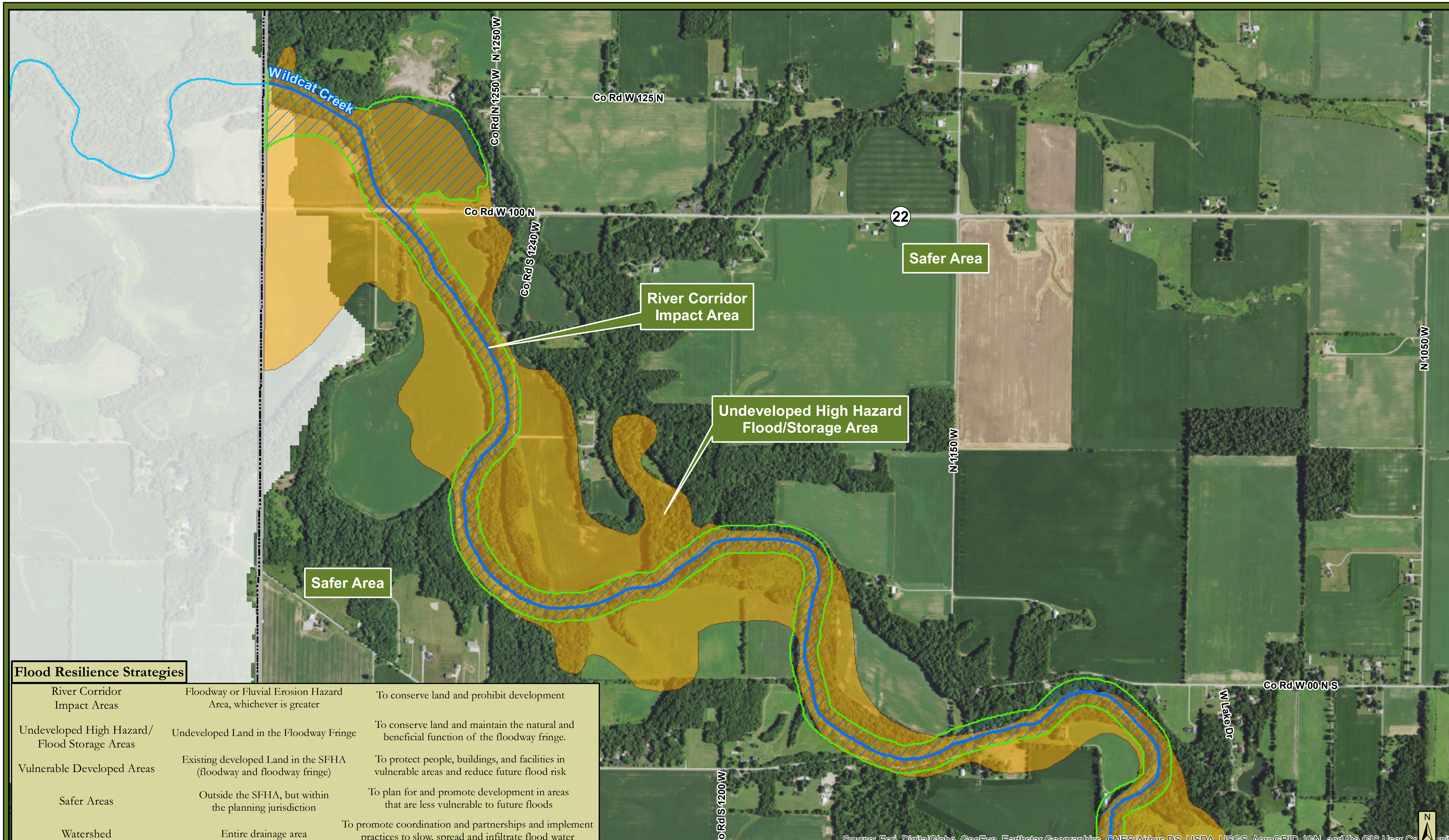
PROJECT NO. 15-0132

APPROX. SCALE 1 " = 10,000 '

DATE: 08/2017

TITLE: Flood Resilience Planning Areas Index Sheet

EXHIBIT 4



Flood Resilience Strategies

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Undeveloped High Hazard/ Flood Storage Areas	Undeveloped Land in the Floodway Fringe	To conserve land and maintain the natural and beneficial function of the floodway fringe.
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1. Orthoimagery from National Agricultural Imagery Project, USDA, 2016
2. Street Centerlines, Political Boundaries from US Bureau of the Census, 2016
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PROJECT: Wildcat Creek Stream Stability Assessment

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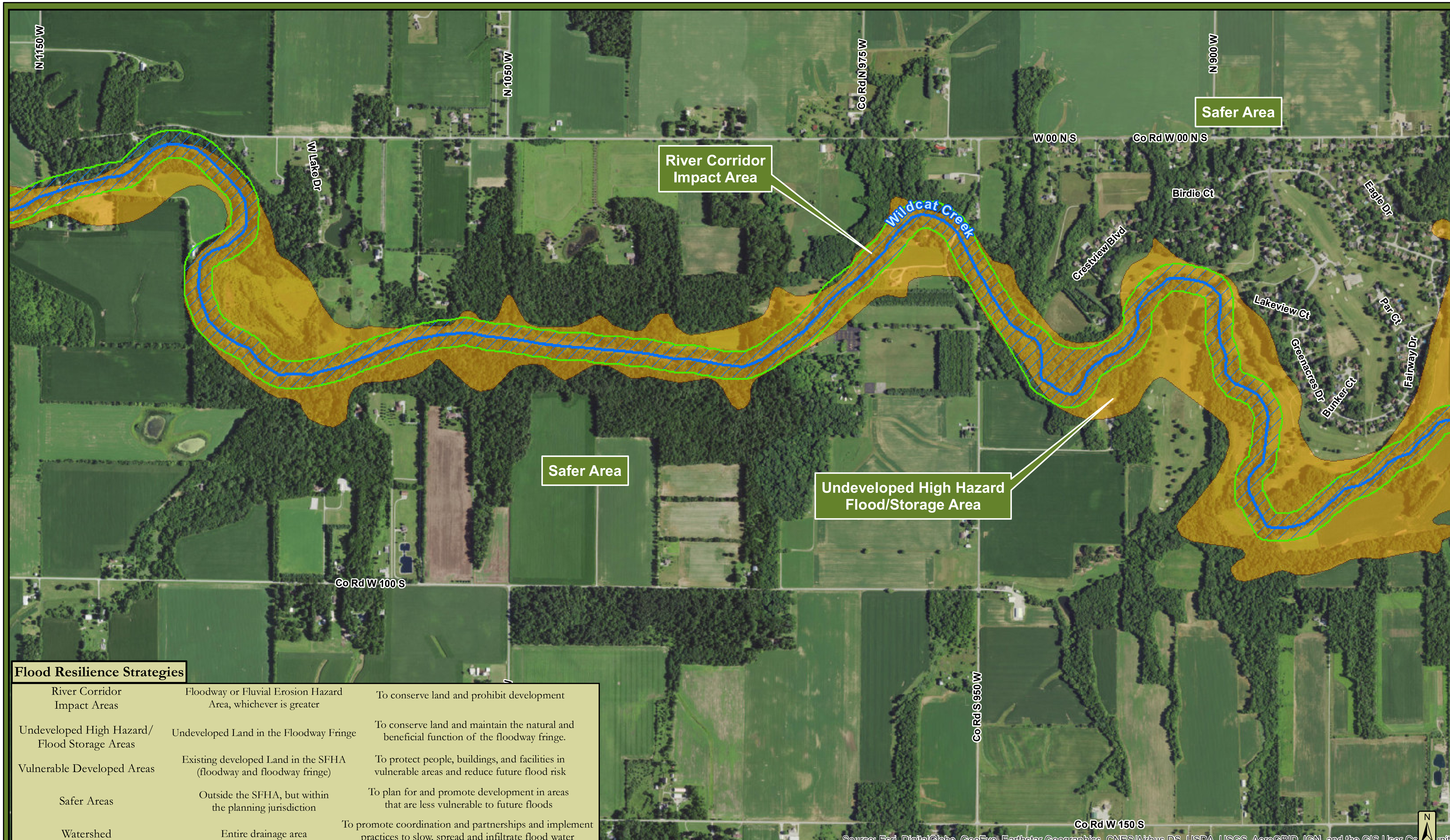
APPROX. SCALE 1 " = 1,000 '

DATE: 08/2017

TITLE: Flood Resilience Planning Areas
Sheet 1 of 14

EXHIBIT 4



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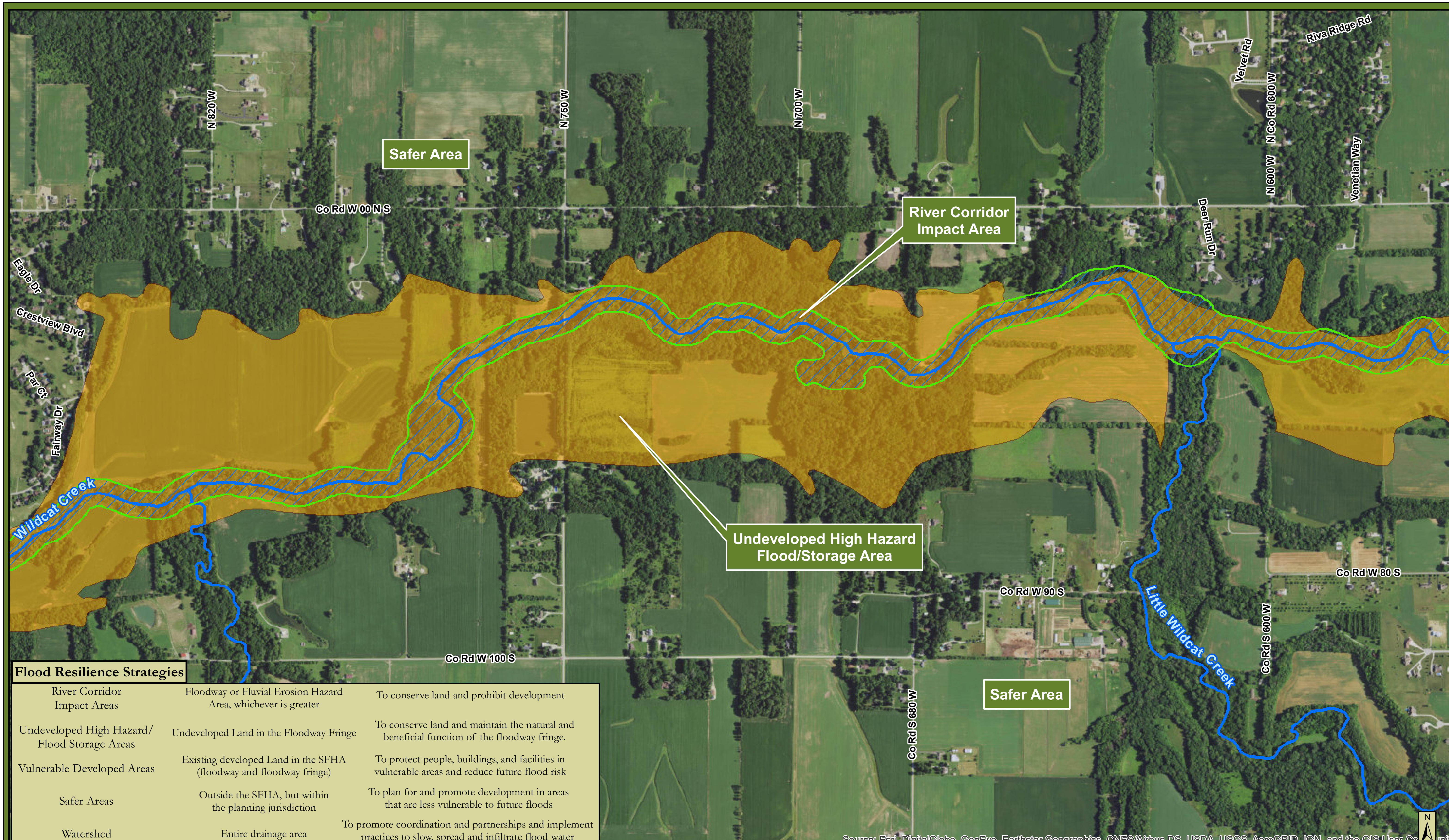

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TITLE: Flood Resilience Planning Areas
Sheet 3 of 14

EXHIBIT 4

Flood Resilience Strategies

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APPROX. SCALE 1 " = 1,000 '

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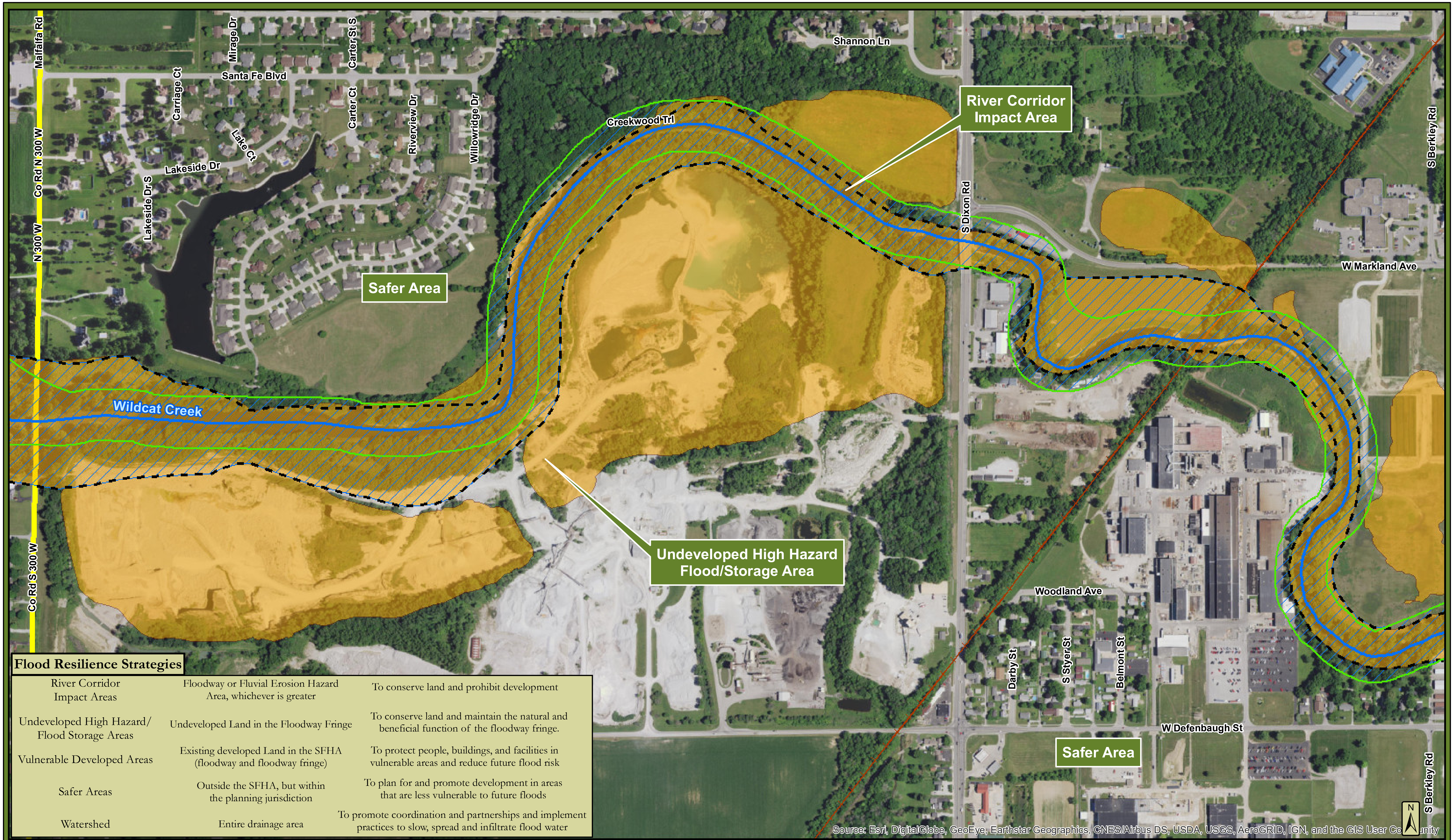
TITLE: Flood Resilience Planning Areas
Sheet 4 of 14

EXHIBIT 4



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PROJECT: Wildcat Creek Stream Stability Assessment	PROJECT NO. 15-0132	APPROX. SCALE 1 " = 500 '
TITLE: Flood Resilience Planning Areas Sheet 5 of 14		DATE: 08/2017
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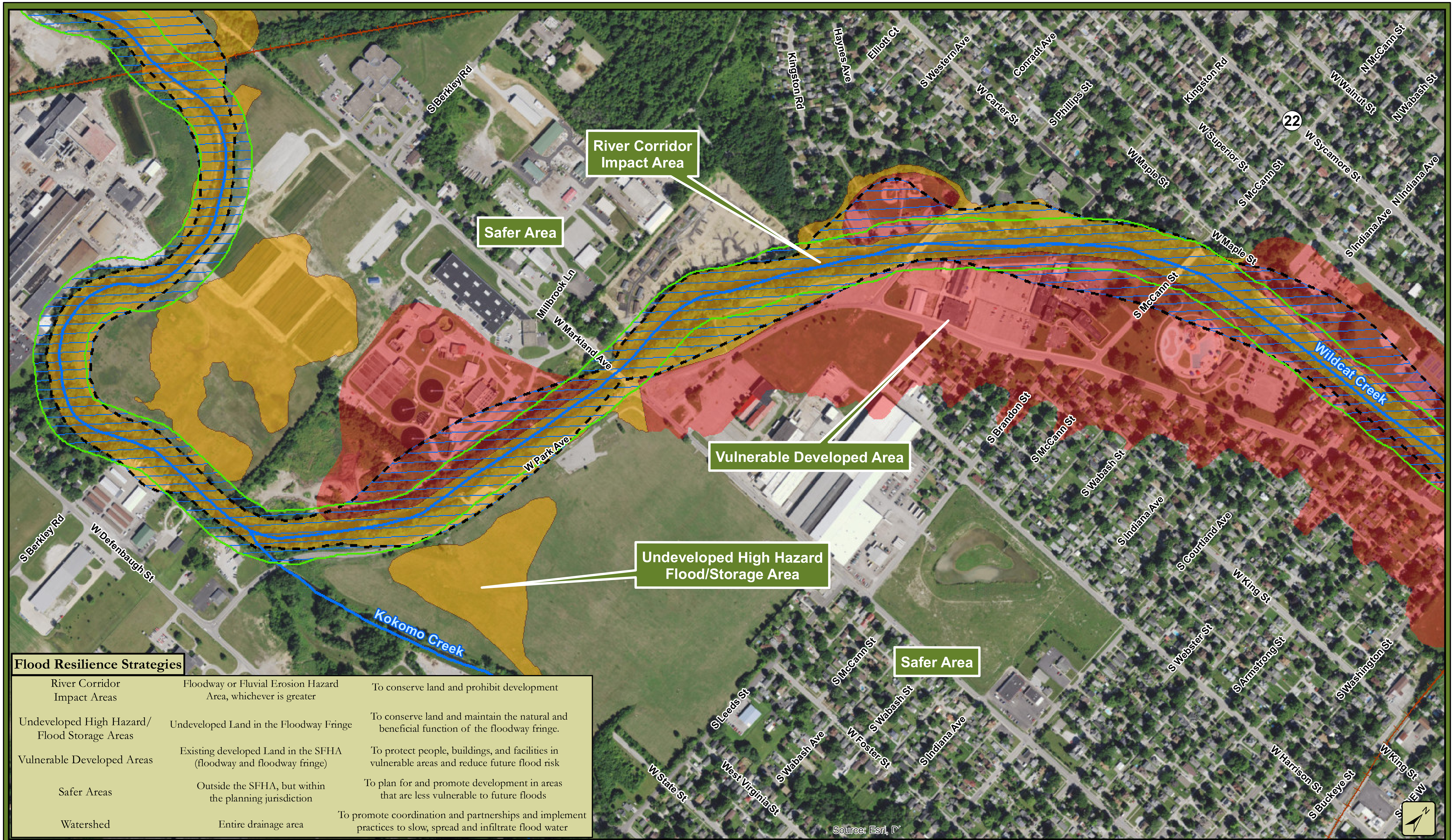

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Wildcat Creek Stream Stability Assessment	15-0132	1 " = 500 '
TITLE: Flood Resilience Planning Areas Sheet 6 of 14		DATE: 08/2017
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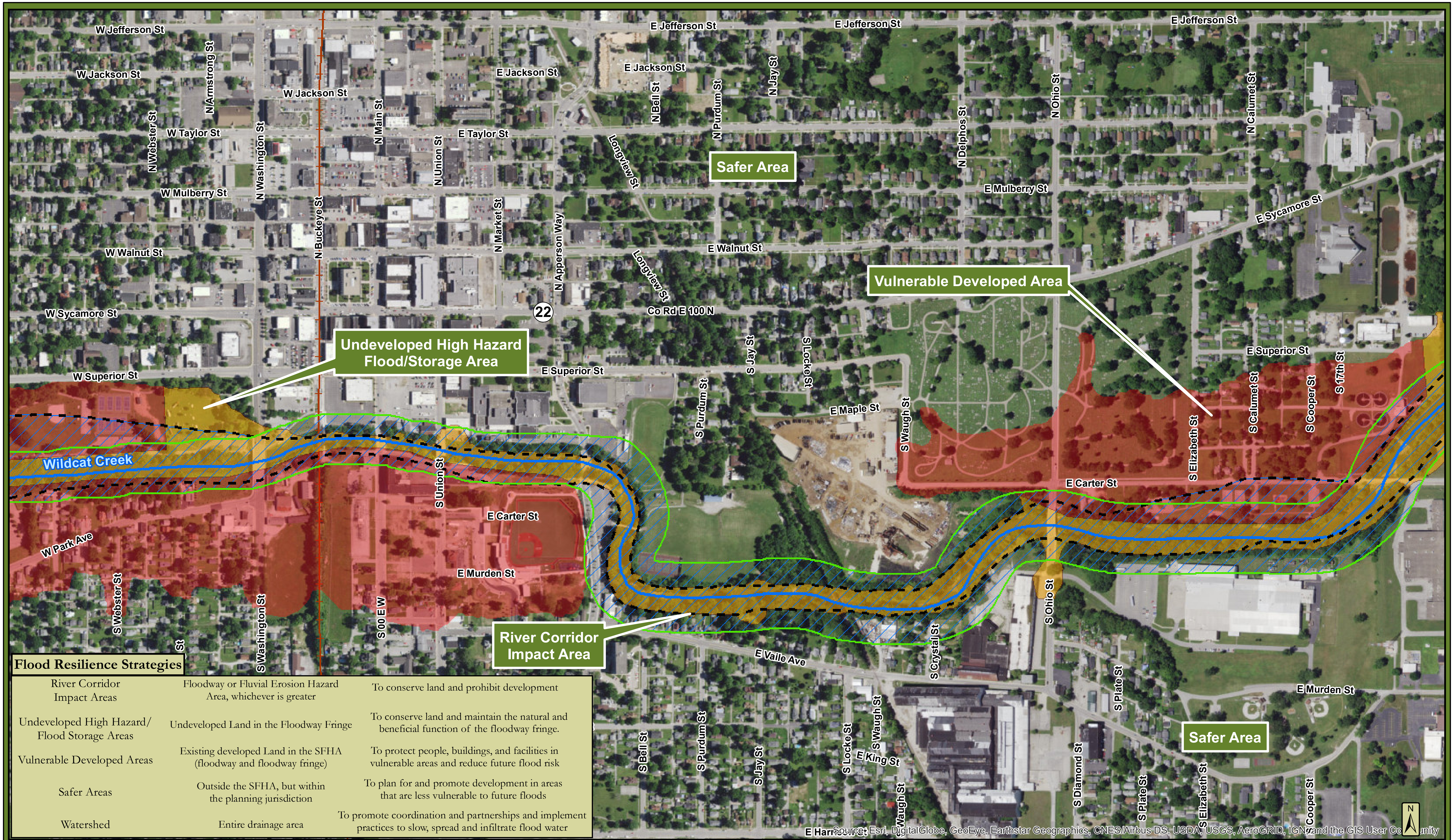

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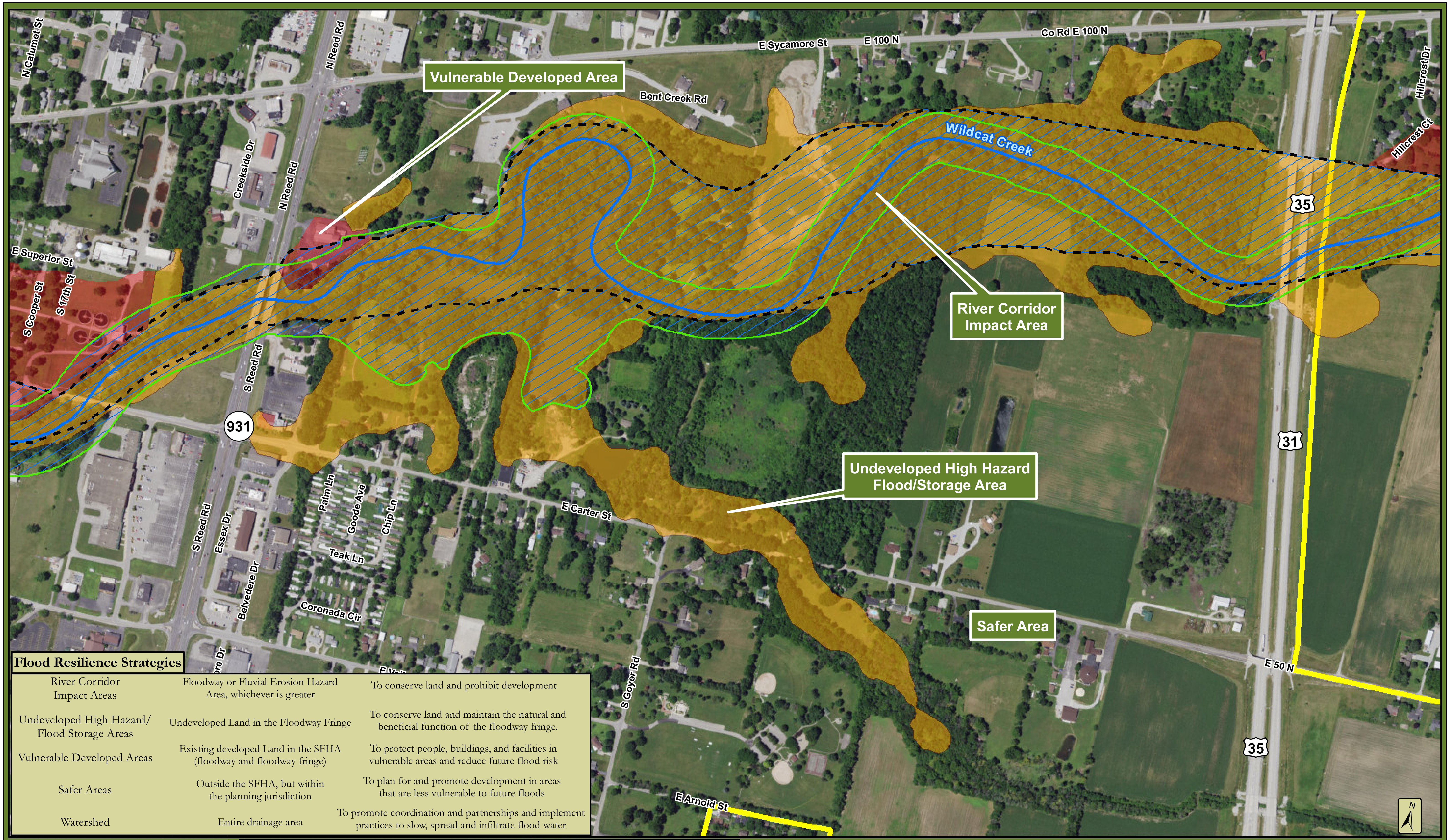
APPROX. SCALE 1 " = 500 '
DATE: 08/2017
TITLE: Flood Resilience Planning Areas
Sheet 7 of 14
EXHIBIT 4



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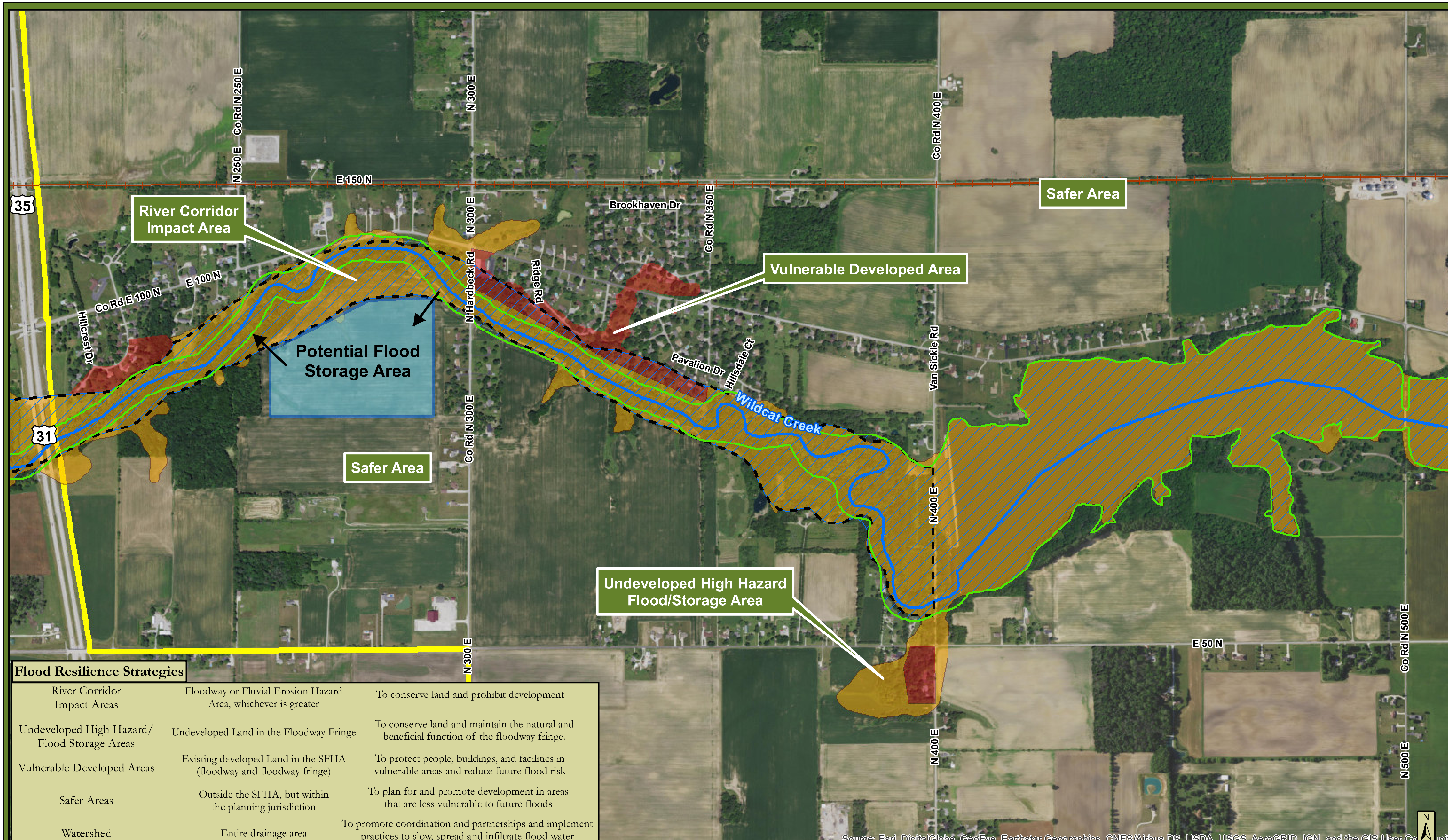
APPROX. SCALE 1 " = 500 '
DATE: 08/2017
TITLE: Flood Resilience Planning Areas
Sheet 8 of 14
EXHIBIT 4



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DATE: 08/2017

TITLE: Flood Resilience Planning Areas
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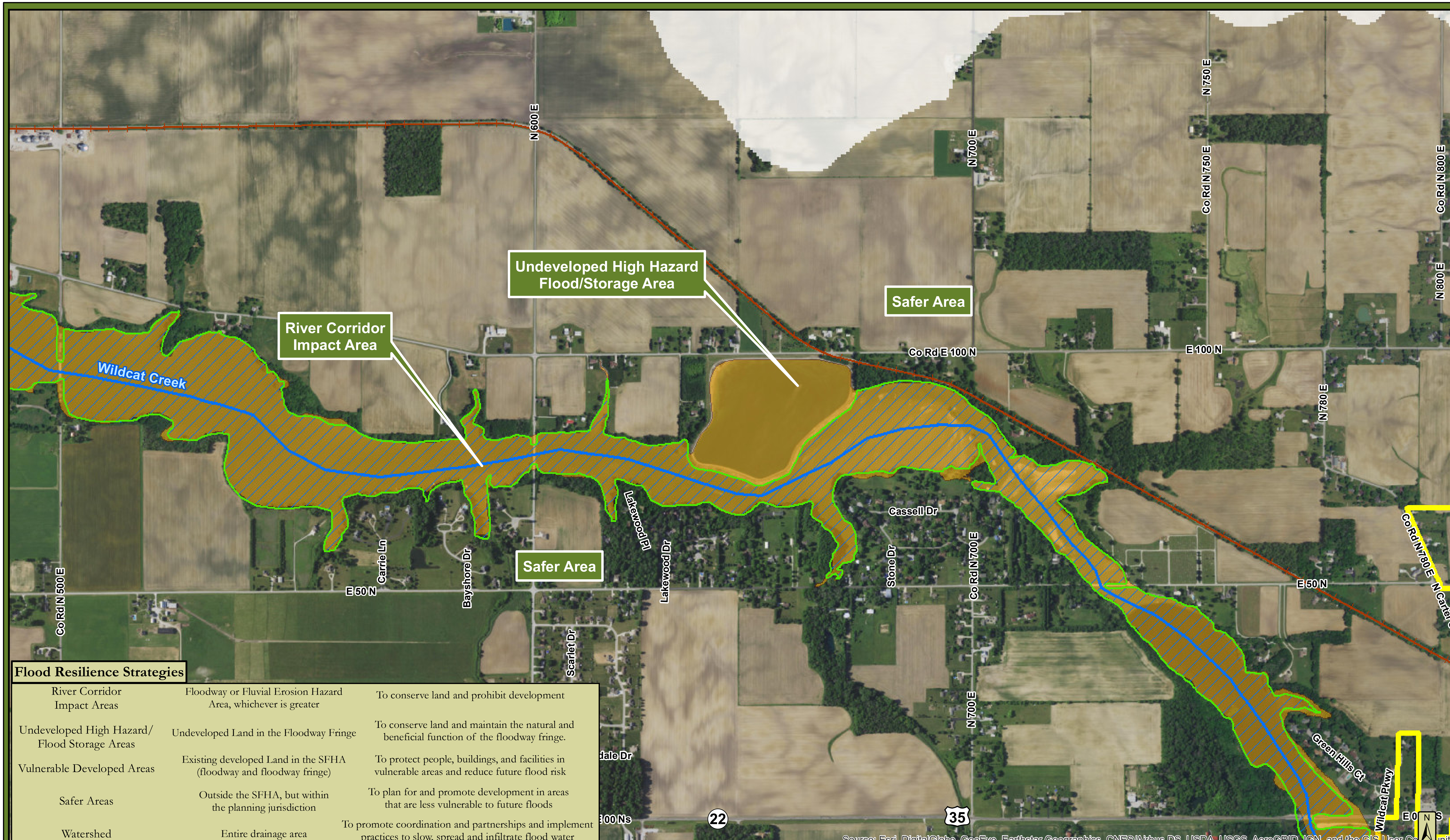
EXHIBIT 4



Flood Resilience Strategies

River Corridor Impact Areas	Floodway or Fluvial Erosion Hazard Area, whichever is greater	To conserve land and prohibit development
Undeveloped High Hazard/ Flood Storage Areas	Undeveloped Land in the Floodway Fringe	To conserve land and maintain the natural and beneficial function of the floodway fringe.
Vulnerable Developed Areas	Existing developed Land in the SFHA (floodway and floodway fringe)	To protect people, buildings, and facilities in vulnerable areas and reduce future flood risk
Safer Areas	Outside the SFHA, but within the planning jurisdiction	To plan for and promote development in areas that are less vulnerable to future floods
Watershed	Entire drainage area	To promote coordination and partnerships and implement practices to slow, spread and infiltrate flood water

1. Orthoimagery from National Agricultural Imagery Project, USDA, 2016
2. Street Centerlines, Political Boundaries from US Bureau of the Census, 2016
3. Floodway from FEMA DFIRM, Effective Date - 2015-02-04
4. Stream Centerlines from National Hydrography Dataset, Local Resolution, 2016

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Floodway
Fluvial Erosion Hazard Area
County Boundary
Municipal Boundary

Christopher B. Burke Engineering, LLC
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115 West Washington Street
Indianapolis, Indiana 46204
(t) 317.266.8000 (f) 317.632.3306

PROJECT: Wildcat Creek Stream Stability Assessment

PROJECT NO. 15-0132

APPROX. SCALE 1 " = 1,000 '

DATE: 08/2017

TITLE: Flood Resilience Planning Areas
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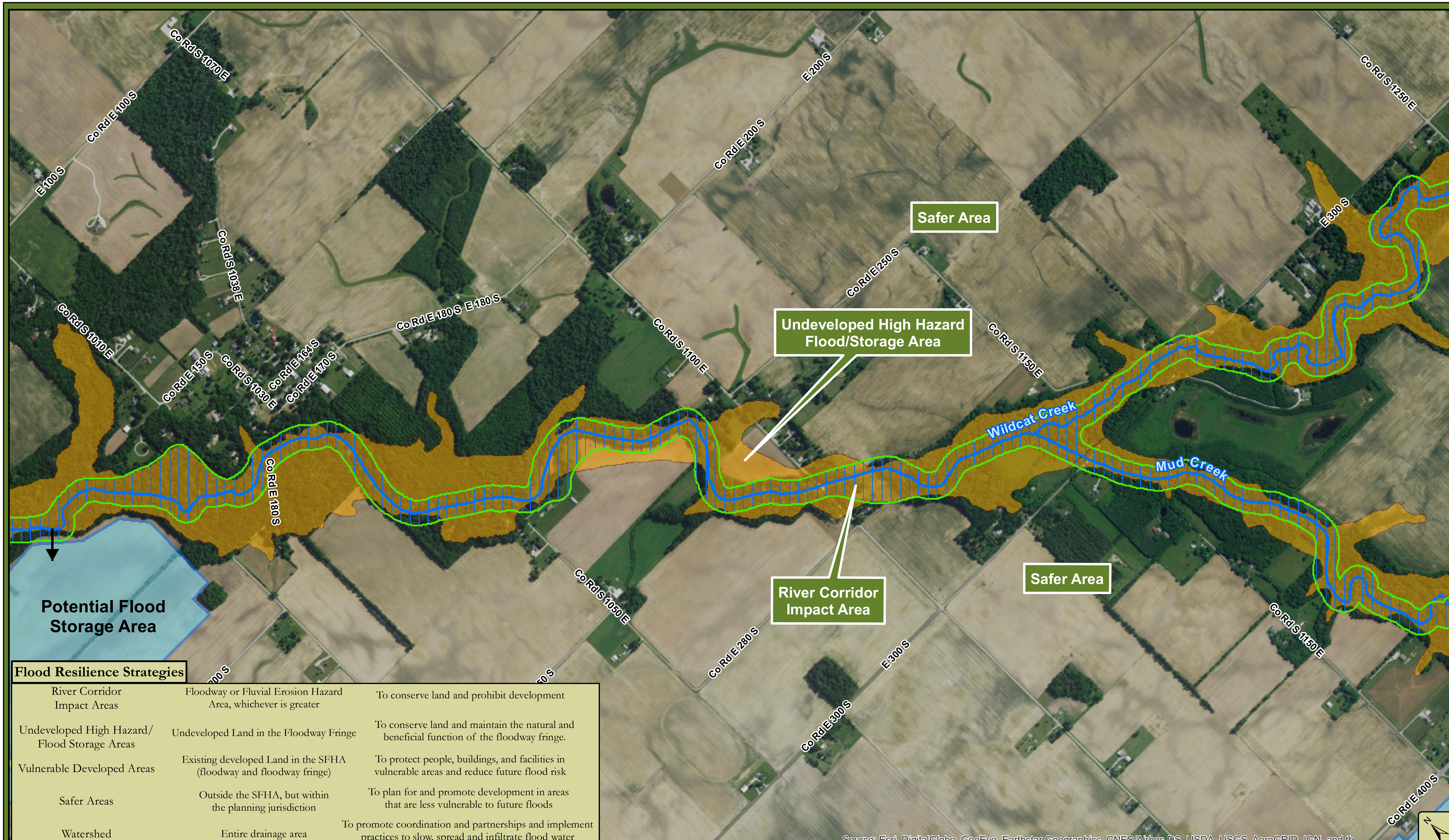

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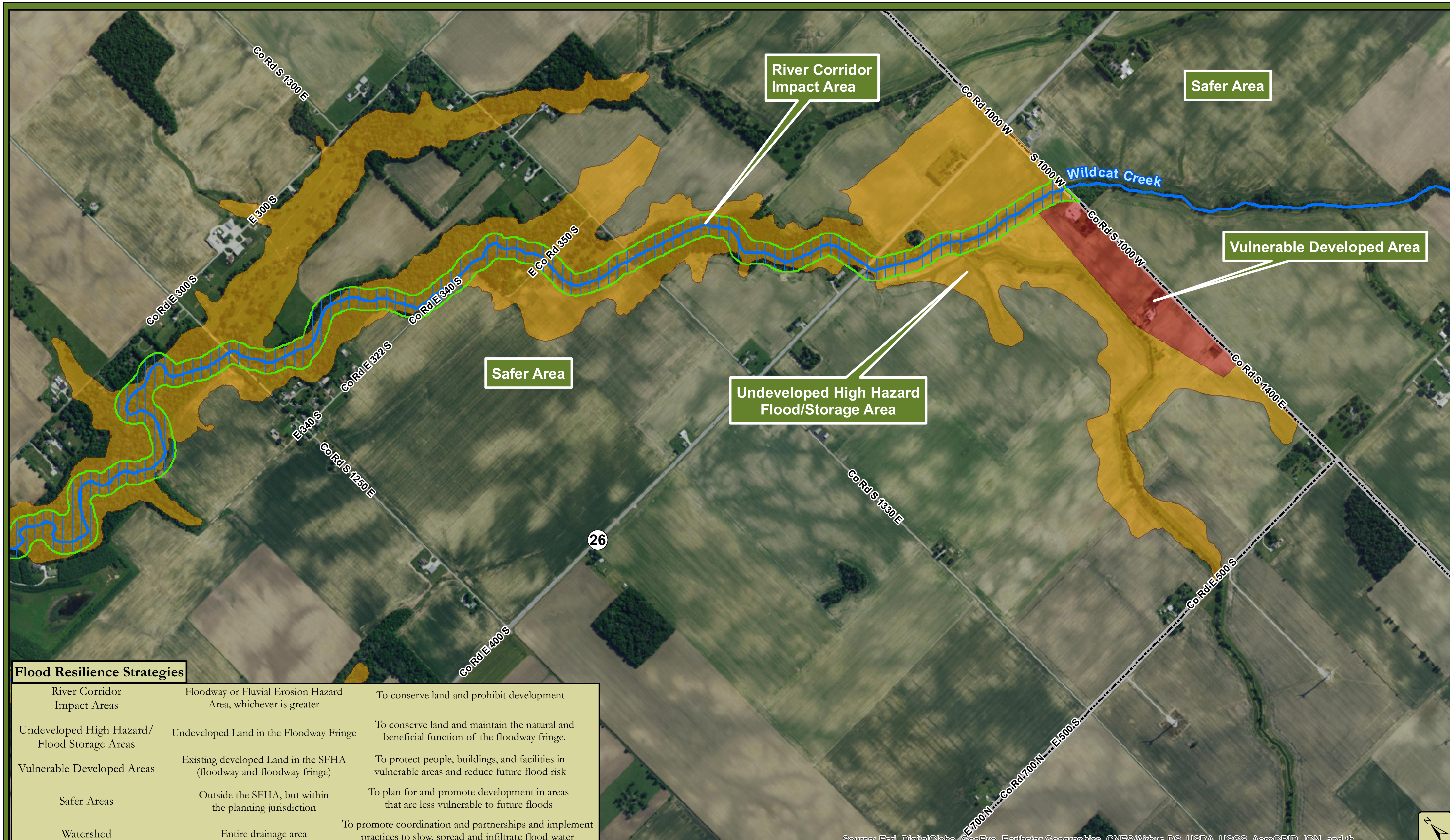

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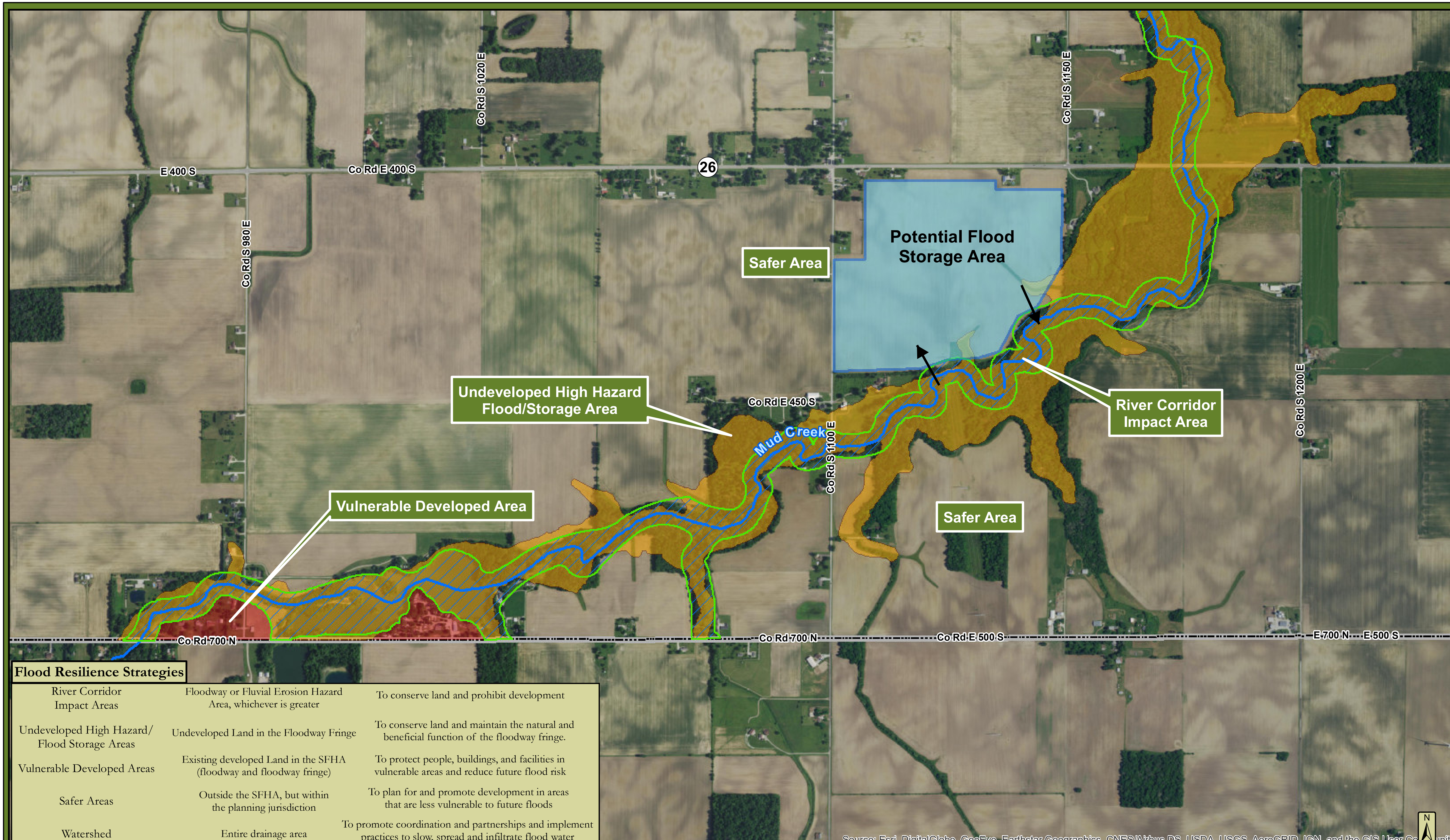

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EXHIBIT 4

Appendix 1 – Geomorphic Assessment of Wildcat Creek

Assessment of Stream Channel Stability for a portion of Wildcat Creek, Howard County, Indiana

Robert C. Barr
Hydrology and Fluvial Geomorphology
5515 N Illinois Street
Indianapolis, IN 4608

Prepared for: Christopher B. Burke Engineering, LLC
September 2017

Wildcat Creek near CR1150 W

CBBEL Project 19. R150132.00000

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1.0 PROJECT DESCRIPTION

Conduct a stream assessment for Wildcat Creek in Howard County and evaluate erosion, sediment sources, large wood in the channel, and flood-water storage areas to reduce downstream flooding. The assessment also includes a preliminary reconnaissance of the Wildcat Creek headwaters in Grant, Montgomery, and Tipton Counties.

2.0 STUDY AREA

This report focuses on the main channel and riparian zone of Wildcat Creek from Jerome in the southeast corner of Howard County to the Carroll County line. The overall stream length for the primary study reach is 42.05 miles. The study also included a reconnaissance of the upper headwaters of Wildcat Creek which begin in Madison, Grant, and Tipton Counties. The two main channels of the headwaters come together just upstream of Jerome, at the confluence of Mud Creek (22.63 miles) and Wildcat Creek (9.9 miles) in Howard County, to form the main channel of Wildcat Creek. Upstream of Kokomo approximately 5 miles of Wildcat Creek were drowned out by the formation of Kokomo waterworks reservoir No.2, upstream of Kokomo. The study area drainage basin consists of the upper 352 mi^2 of the Wildcat Creek watershed (Figures 1, 2, and 3).

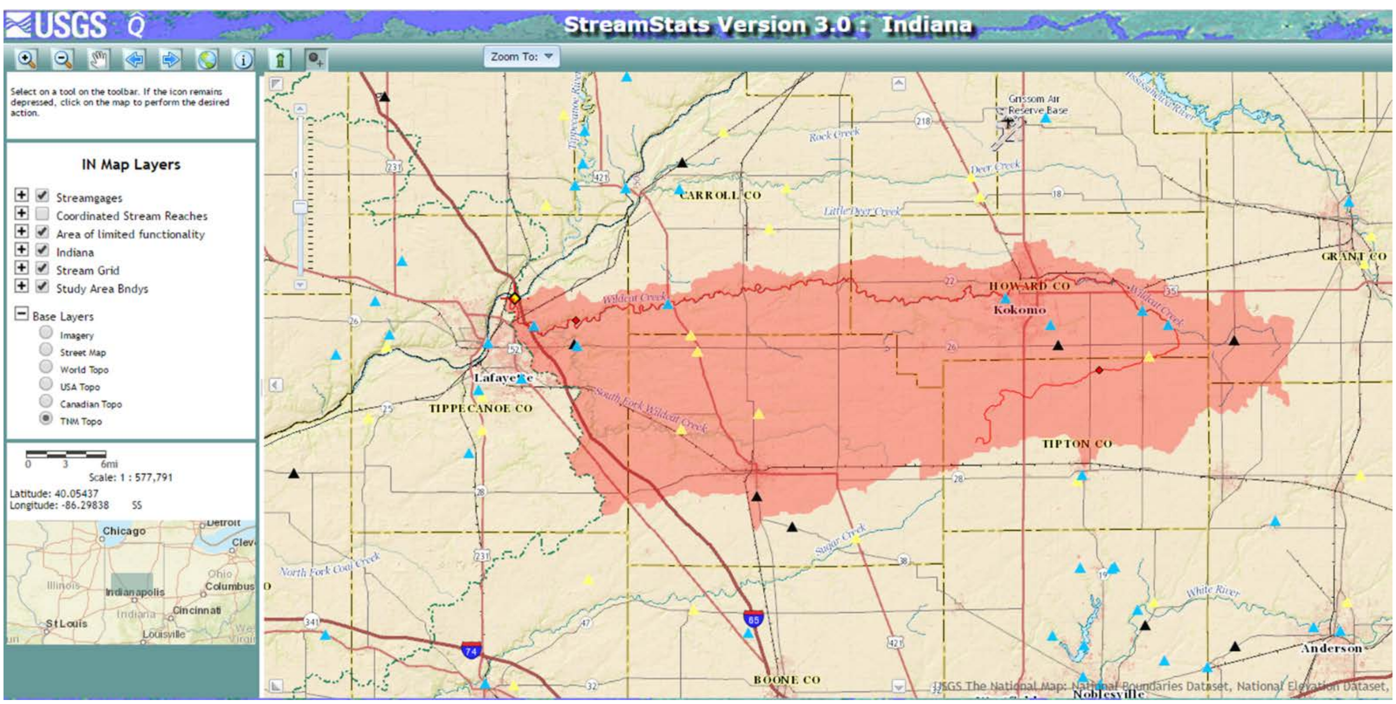

Figure 1: Wildcat Creek watershed (Drainage Area = 804 mi^2) (USGS StreamStats)

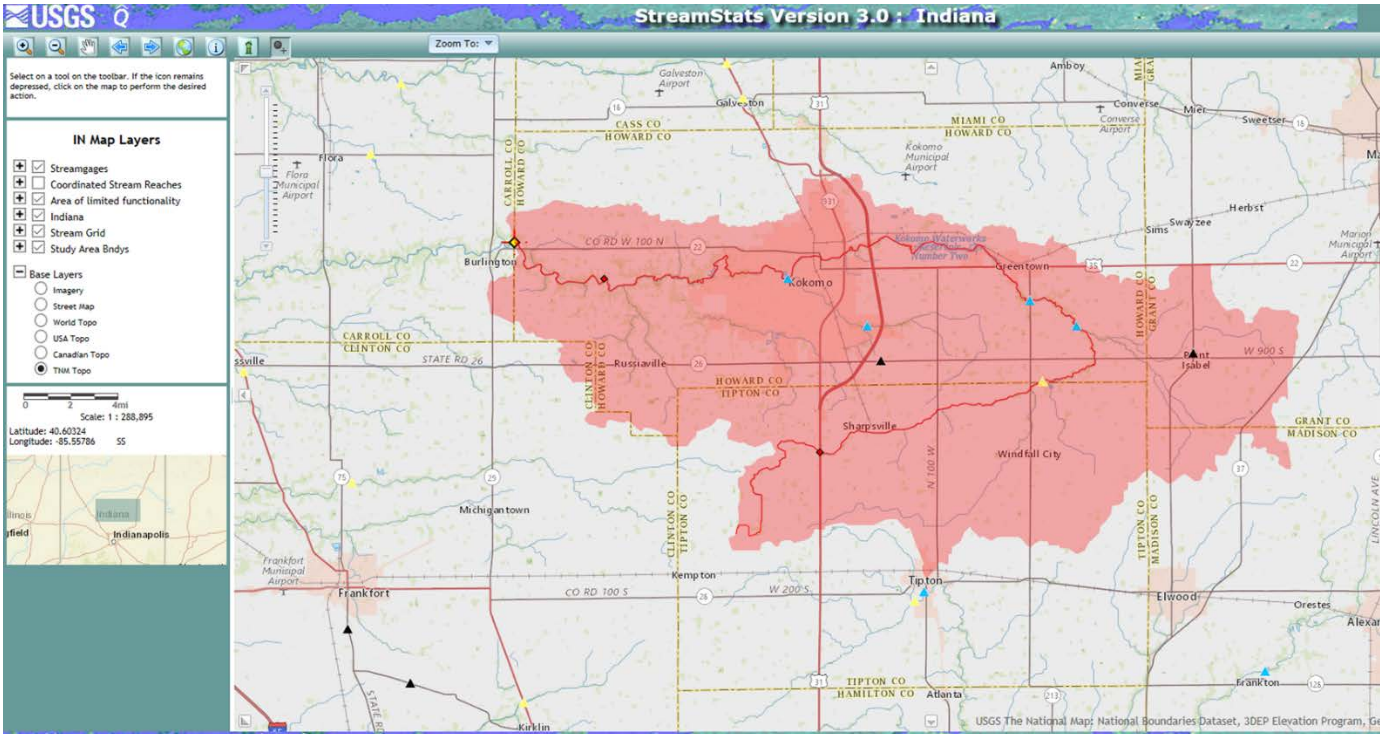

Figure 2: Wildcat Creek at Carroll County – Howard County line (Drainage area = 353 mi^2)

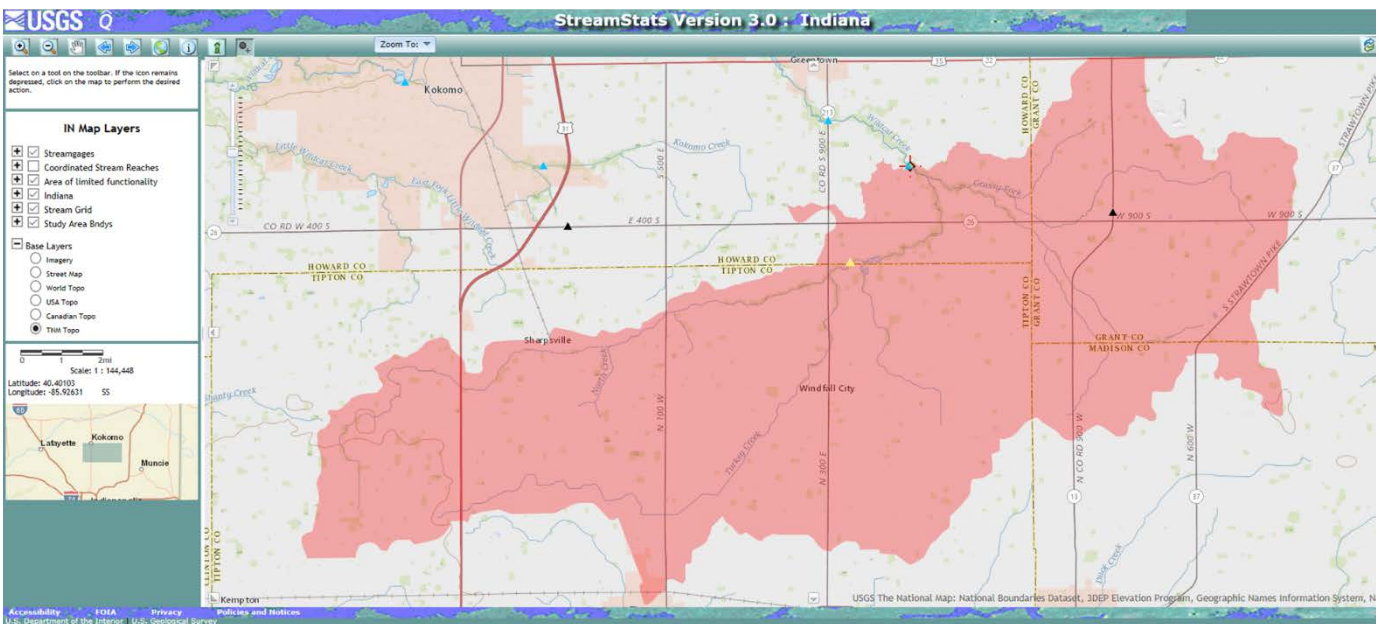

Figure 3: Wildcat Creek at Jerome (Drainage area = 149.07 mi^2) (USGS StreamStats)

The Wildcat Creek drainage basin, except for a small portion on the east side of Howard County flows from east to west across the Tipton Till Plain. On the east side of Howard County, a small (3.5 rm) section of Wildcat Creek flows from the southeast towards the northwest. Geologically the area is significant because it marks where Wildcat Creek captured Mud Creek as the glacial ice retreated. For this study, it is also the area where the highly modified headwaters come together and flow towards the dammed Wildcat Creek valley on the east side of Kokomo (Figure 4).

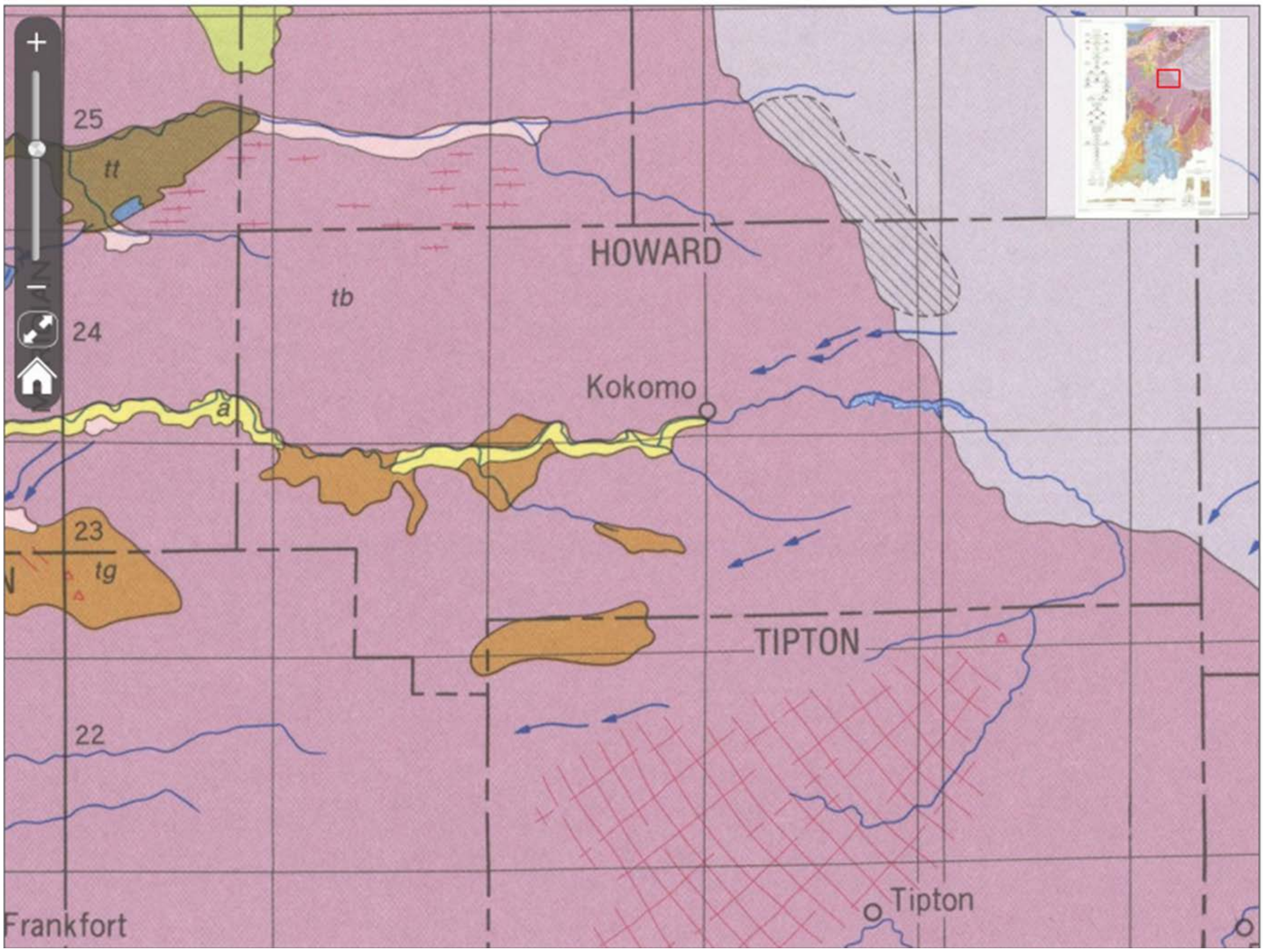

Figure 4: Detail from: Quaternary geologic map of Indiana (Gray, 1989)

Figure 4 shows that alluvial deposits associated with Wildcat Creek become significant enough to be mapped at a state-wide scale near Kokomo. Alluvial soils and therefore a geomorphic floodplain extend on a smaller scale past Sharpsville in Tipton County (Figure 5), and just past the confluence of Wildcat Creek and Grassy Creek. The geomorphic floodplains also correspond with a change in geology. The floodplains in Wildcat Creek occur in areas underlain by outwash deposits.

Tipton County, Indiana (IN159)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
DeA	Del Rey, sandy substratum-Crosby silt loams, 0 to 2 percent slopes	382.0	39.3%
Pn	Patton silty clay loam, 0 to 2 percent slopes	388.2	40.0%
Ps	Pella, sandy substratum-Drummer, till substratum, silty clay loams	9.3	1.0%
SaC2	Sisson-Strawn complex, 6 to 12 percent slopes, eroded	5.1	0.5%
Sh	Sloan silt loam, sandy substratum, occasionally flooded	119.3	12.3%
TuB2	Tuscola, till substratum-Strawn complex, 1 to 6 percent slopes, eroded	44.1	4.5%
WkB	Williamstown silt loam, 1 to 4 percent slopes	23.3	2.4%
Totals for Area of Interest		971.3	100.0%

Figure 5: Detail from Web Soil Survey for a portion of Tipton County near Sharpsville, IN. The bright green line indicates the average width (600-feet) of the Shoals silt-loam alluvium (Sh). That soil is developed on floodplains.

3.0 Methods

An initial reconnaissance of the Wildcat Creek corridor was done on March 13, 2017. Greg Lake and Sarah Brichford of the Howard County Storm Water District identified several areas of concern along the main channel of Wildcat Creek, primarily to the east of Kokomo. The Howard County Storm Water District is involved in managing the overall health of streams and waterways in Howard County, and have concerns about wood management, bank erosion, floodplain encroachment, and channel instability along Wildcat Creek.

The main channel of Wildcat Creek was flown on April 15, 2017 during leaf-off conditions to assess the main channel for signs of stream instability or bank erosion. Areas identified as potentially unstable were then assessed in a series of field visits. Following the April 15 flight, field visits were also made to 8 reference sites, that were selected based on location, interest by the Howard County staff, or geomorphic significance. High flows in Wildcat Creek through early summer limited assessment of lower bank conditions until later in the summer, but proved valuable for assessing the movement of large wood in the channel and potential areas for flood storage.

On August 12, 2017 stream flow was low enough to assess channel bank stability. Channel conditions were assessed at 23 bridge locations from Sharpsville to the Howard/Carroll County line, the 8 reference sites, and two areas of bank instability. The low flow conditions allowed for observations of large wood in and around the bridge piers, and for bank assessment in areas around the bridge that are prone to instability.

On August 18, 2917, 6 of the 8 reference sites were revisited with CBBEL staff to review the sites and to discuss management strategies.

Geomorphic floodplains were determined using Web Soil Survey to map and measure alluvial soils. Floodplain connectivity was determined using a combination of field visits, Google Earth, and USGS topographic maps.

A literature review was ongoing throughout the project.

4.0 RESULTS

The project area divides into 7 stream reaches based on channel morphology, geomorphic setting, function, and land use. Reach descriptions and results follow.

4.1 Agriculturally modified headwaters

For the purposes of this study we have defined the Wildcat Creek watershed upstream of the confluence of Mud Creek and Wildcat Creek as the headwaters (Figure 6). The headwaters are dominated by agriculturally-modified streams and constructed drainage channels, and have a drainage area of 149 mi^2. The headwaters divide at the confluence into two separate drainage basins, Mud Creek and Middle Fork Wildcat Creek.

Mud Creek originates in western Tipton County and flows east for 22 rm until it turns sharply to the north and into Howard County. Mud Creek has a geomorphic floodplain, defined by alluvial soils, from west of Sharpsville to its confluence with Wildcat Creek (Figure 5). The upper 8 rm of Mud Creek, upstream of US 31, doesn’t have an alluvial floodplain (stream stage II on Figure 10). While a geomorphic floodplain exists along most of Mud Creek, straightening and clearing of the channel from Sharpsville to Nevada (8 miles) have slightly incised the channel and reduced floodplain connectivity and riparian functions. Upstream of Sharpsville clearing and dredging have eliminated floodplain connectivity for 2.5 miles (Figures 6 and 10).

The Middle Fork Wildcat Creek begins in Madison County and flows northwest for 6 miles through Grant County to its confluence with Mud Creek. Middle Fork Wildcat Creek merges with Grassy Fork about 0.5 miles below the Mud Creek confluence (Figures 8 and 9). By stream length (11.5 rm) Grassy Creek is the dominate stream, but the stream becomes part of the Middle Fork at the confluence with the Middle Fork Wildcat. Both the Middle Fork Wildcat and Grassy Creek are highly modified for most of their stream length.

Measured and predicted channel dimensions and physical characteristics for reference locations in the study are in Table 1. Potential acreage and functional status of floodplains associated with the main channel of Wildcat Creek in Howard County, and its primary tributaries is in Table 2.

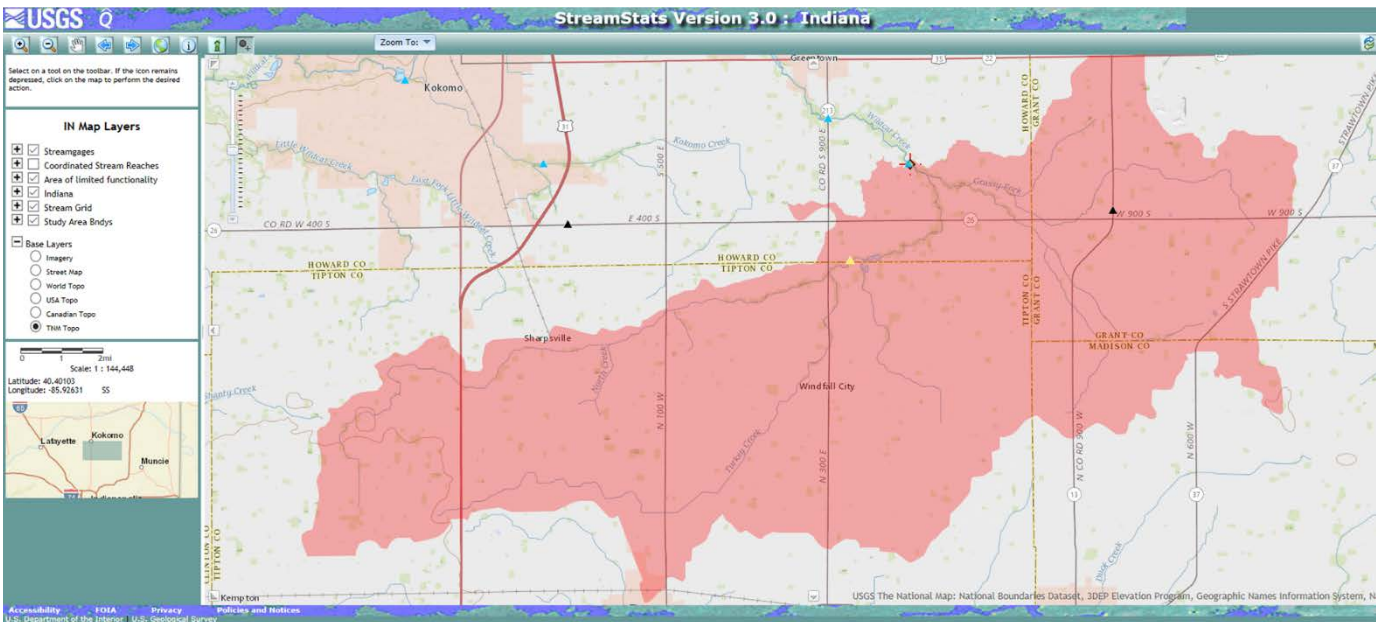

Figure 6: Wildcat Creek, upstream of Jerome, Indiana (DA=149 mi^2) (USGS StreamStats)

Figure 7: Agriculturally-modified section of Mud Creek upstream from Sharpsville, Tipton County, Indiana. Stream channel evolution stage II (Figure 10)

Figure 8: Mud Creek near confluence with Middle Fork Wildcat Creek, upstream of Jerome. Note change in riparian vegetation and stream type.

Figure 9: Middle Fork Wildcat Creek at confluence with Mud Creek, upstream of Jerome. Note riparian vegetation and stream type.

Table 1: Measured and predicted channel dimensions and physical characteristics for reference locations in the study area

Location	DA (mi^2)	W_{bkf} (ft) P	W_{bkf} (ft) M	d_{bkf} (ft)	A_{bkf} (ft^2)	S (10-85) ft/mi	W_{fpa} (ft)	Channel Evolution Stage (Figure 10)	Channel Type	K (SL/VL)	Valley Type
1. Mud Creek at Sharpsville	14.4	43.5	35.0	2.45	106	4.41	700	III	F4	1.0	U-AL-FD
2. Wildcat Creek downstream from Grassy Creek	50.8	65.8	57	2.99	195	3.83	700	III	B4c	1.16	C-GL-TP
3. Wildcat Creek at Jerome	149	93.5	104	3.55	329	3.59	700	I	C4	1.21	C-GL-TP
4. Wildcat Creek near Crooked Creek Ct	183	100	100	3.66	365	2.67	1,250	I	C4	1.41	C-GL-TP
5. Wildcat Creek at Apperson Rd	201	103	110	3.72	381	2.9	C	IV	F4	1.08	n/a
6.Wildcat Creek at Kokomo	241	109	119	3.83	417	2.87	C	IV	F4	1.18	n/a
7.Wildcat Creek at Malfalfa Rd.	248	110	116	3.85	423	2.48	1400	V	B4c	1.12	C-GL-TP
8. Wildcat Creek at CR W 100 N and SR 22	351	125	132	3.21	500	3.21	1600	I	C4	1.54	C-GL-TP

Abbreviations:

DA	Drainage Area
W_{bkf} (P)	Predicted Bankfull Width
W_{bkf} (M)	Measured Bankfull Width
d_{bkf}	Predicted Bankfull Depth
A_{bkf}	Predicted Bankfull Cross Sectional Area
S	Longitudinal Bed Slope
W_{fpa}	Predicted Flood Prone Area Width
C	Contained in the Channel

Table 2: Potential acreage and functional status of floodplains associated with the main channel of Wildcat Creek in Howard County, and its primary tributaries

Stream	Steam Reach	RM	Average floodplain width (ft)	Total Reach floodplain (acres)	Functional Status
Mud Creek	Upstream from Sharpsville	2.5	500	152	Lost – disconnected
Mud Creek	Sharpsville to Nevada	8.0	600	582	Impaired - connected at higher flows
Mud Creek	Nevada to confluence	6.0	400	291	Impaired – multiple levees
Middle Fork Wildcat Creek	Grassy Creek confluence to confluence with Mud Creek	3.0	500	182	Intact
Wildcat Creek	Wildcat Creek near Jerome to upstream of Greentown	4.75	750 (430-1530)	432	Intact
Wildcat Creek	Reservoir	4.9	1000 (750 upstream – 1250 downstream)	581	lost – inline impoundment of stream[1]
Wildcat Creek	Reservoir dam to 931	4.3	1250	652	Intact
Wildcat Creek	Kokomo (US 931- S Dixon Road)	4.3	1600 1221-1849)	834	lost – channel incised, floodplains filled
Wildcat Creek	active mined reach Dixon Rd to Malfalfa Rd	1.3	1400 (1200-1583)	220	Lost
Wildcat Creek	formerly mined reach, Malfalfa Rd to 40.4699, -86.2237	4.2	1400 (1200- 1583)	713	impaired – multiple levees
Wildcat Creek	Downstream to County Line	12.0	1600 (1093-2266)	2327	Intact

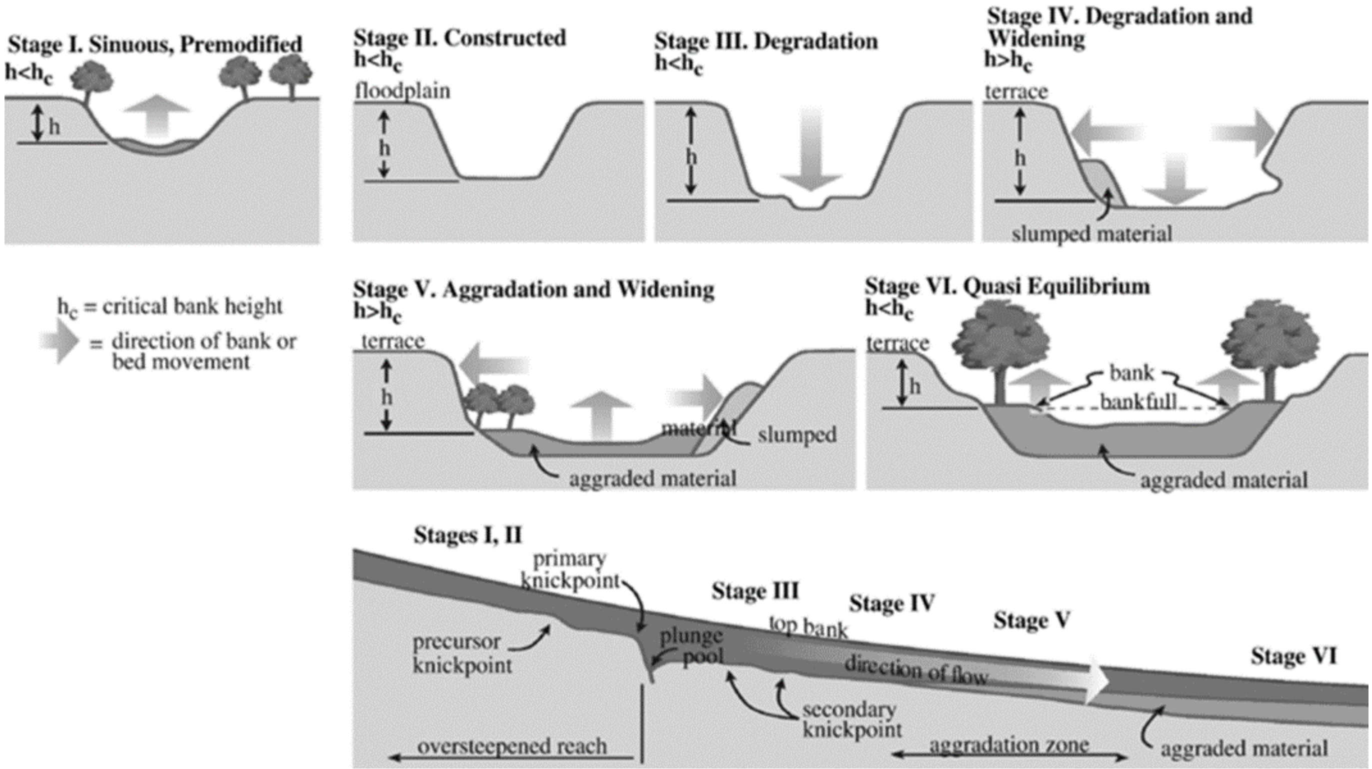

Figure 10: Schumm's Channel Evolution Model Stages (Schumm, from Simon and Rinaldi (2006)

4.2 Wildcat Creek, Jerome to upstream of Greentown

This reach begins at the confluence of Mud Creek and the Middle Fork Wildcat Creek and flows for 4.75 miles northwest towards Greentown. The reach ends upstream of Greentown where the effects of the reservoir begin to dominate channel processes. The reach is remarkable for its stability given that it begins downstream from the very modified headwaters (Figures 11 and 12, and Tables 1 and 2). It is effectively serving as the buffer, or "shock absorber" for the upstream alteration of the flow regime. The USGS gage near Jerome (03333450) is ideally positioned to monitor discharge in the headwaters of Wildcat Creek. A graph of peak annual discharge shows a doubling in the annual peak discharge since the 1960s, with most of the change occurring rapidly after the 1990s (Figure 13). The gage also shows an increase in the occurrence of the bankfull discharge that begins in the early 1990s (Figure 13). The increase in frequency of the bankfull discharge is associated with a change in runoff, and is often used as an indicator of urbanization or agricultural modification. Without a functioning floodplain, the increase in frequency of the bankfull stage results in channel incision and widening, and a loss of stream functions. This reach does have an eroding cutbank on a meander downstream from the canoe launch at SR213, that has been identified as a concern by the County. The cutbank is approximately 385 feet long and has a height of 14 feet. Air photo analysis from 2003 through 2016 shows gradual movement of the meander downstream. The observed erosion is minimal considering the increase in runoff upstream.

Measured and predicted channel dimensions and physical characteristics for reference locations in the study area are in Table 1. Potential acreage and functional status of floodplains associated with the main channel of Wildcat Creek in Howard County, and its primary tributaries is in Table 2.

Figure 11: Wildcat Creek at Jerome Bridge, looking upstream. Note the well-connected riparian forest.

Figure 12: Wildcat Creek at Jerome Bridge. Looking downstream

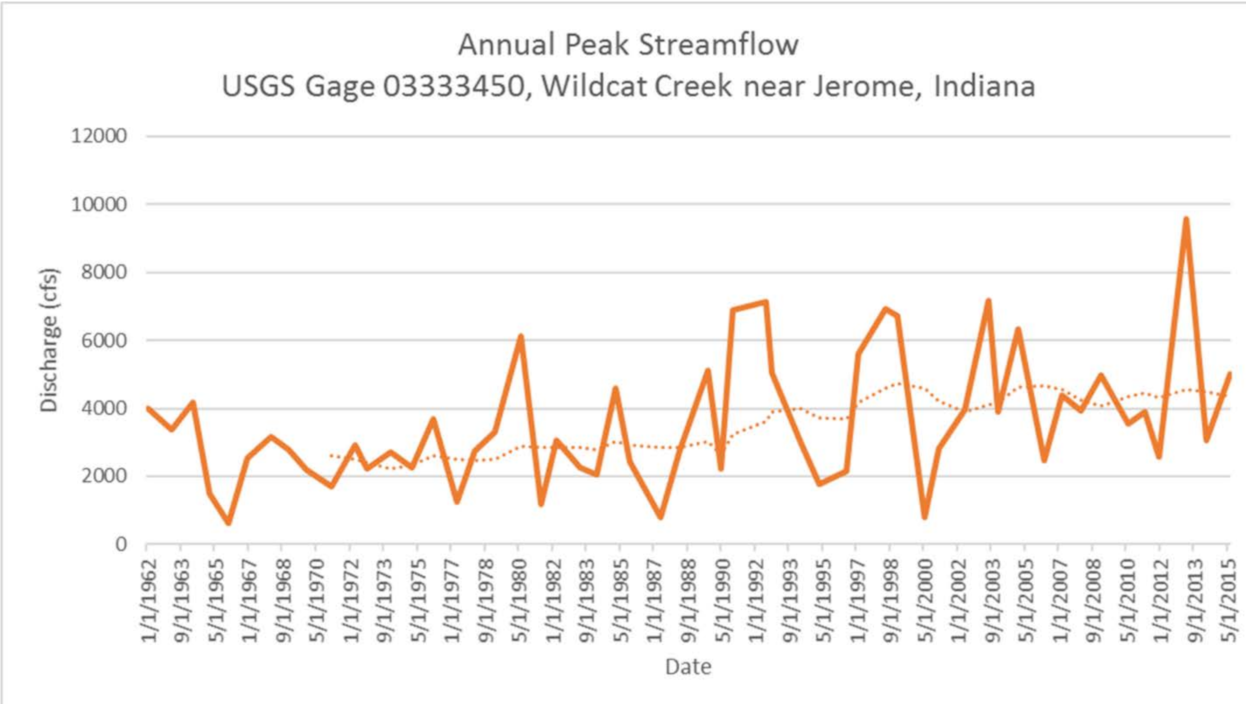

Figure 13: Annual peak discharge for the period of record. USGS gage 03333450, Wildcat Creek near Jerome, Indiana.

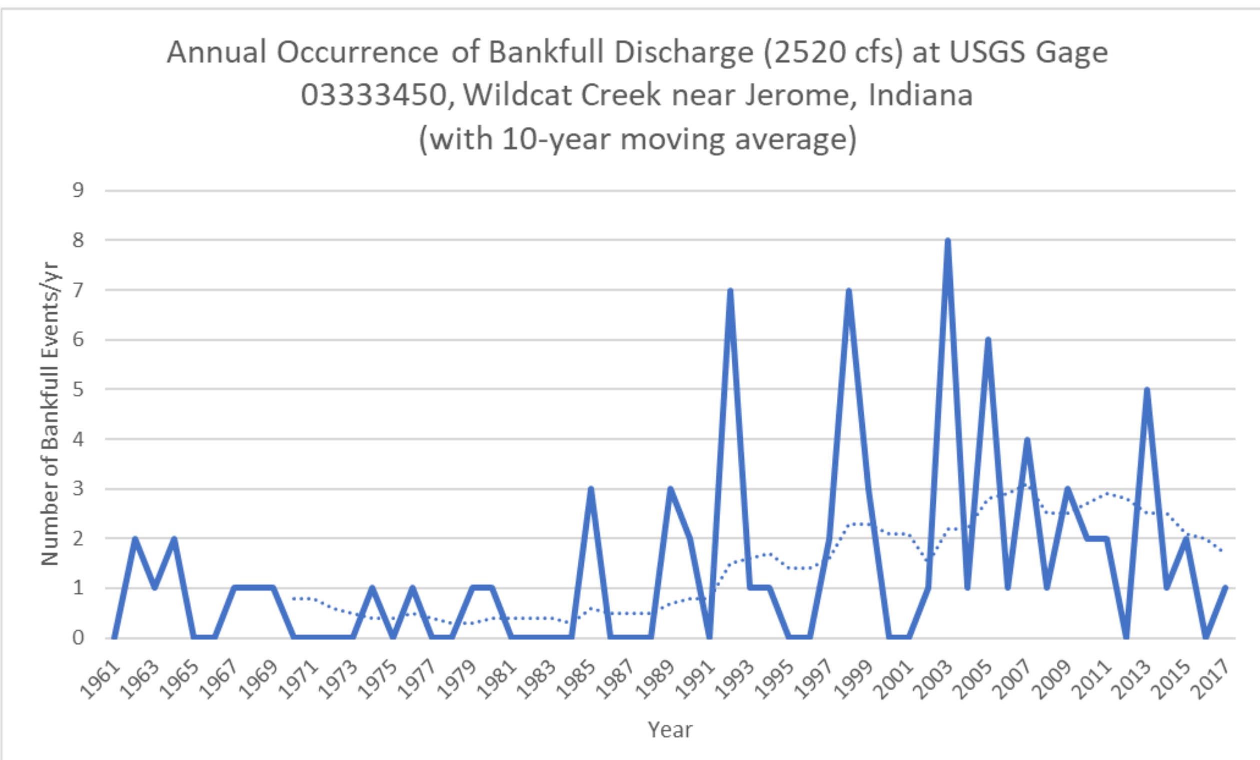

Figure 14: Annual Occurrence of Bankfull Discharge at USGS Gage 03333450, Wildcat Creek near Jerome, Indiana.

4.3 Reservoir Reach (Kokomo Waterworks Reservoir 2)

The reservoir reach is a 5.75-mile section of Wildcat Creek that was drowned out by the formation of the Kokomo Waterworks Reservoir No.2 in 1958. The reservoir is long, narrow, and shallow, the water level was raised 18-feet on average, with some deeper areas around old gravel pits (Edgell, 2008). The reservoirs shape and size reflect its origin as the Wildcat Creek valley.

The effect of the reservoir, and most reservoirs, on sediment transport is significant. Reservoirs tend to trap bedload, which is integral to channel-forming processes, and release water on the downstream end that is “hungry”. The sediment-starved water can do more work downstream in the form of erosion. Note in Table 1 that the sinuosity is higher downstream of the reservoir than in any other reach upstream of Kokomo. That increase in sinuosity corresponds to an increase in bank erosion. Bank erosion is common for over 2.0 miles downstream of the dam. It is very pronounced immediately downstream from the dam. Figure 16 shows a meander trace from April 2017 on an air photo from March 2005. There is over 30-foot of lateral migration on parts of the meander, or on average - 2.5 ft/yr.

The reservoir also affects the movement of large wood. Most wood can’t make it past the two sharp bends in the channel downstream from the SR 213 erosion site. Those that do make it through those bends need to make it past the series of side bars and in-channel bars that have formed upstream of the SR 35 bridge at Greentown, and then through the channel under the bridge (Figure 15). Not many seen to make through, almost no large wood was seen in the stream immediately downstream of the reservoir. The lack of wood, and the channel roughness associated with wood, has probably increased the downstream erosion.

The reservoir was created for water supply. An Indiana Department of Natural Resources report done after the 2013 flood found that the reservoir has almost no effect on peak discharges as measured downstream at the Kokomo gage (Mallory, 2014). A comparison of summer and winter pool elevations found that there was not much difference in pool elevation, 812-feet in the summer and 814-feet in the winter, and the surface area of the pool varied only slightly – 451.5 and 461.6 acres respectively (Edgell, 2008). The storage difference when multiplying by the 2-foot elevation difference is only 20.24-acre feet. Edgell calculated using the discharge at Jerome for the April 2013 storm the storage capacity was filled in less than 15 minutes. Currently the reservoir is managed for a year-round pool of 814-feet.

Potential acreage and functional status of floodplains associated with the main channel of Wildcat Creek in Howard County, and its primary tributaries is in Table 2.

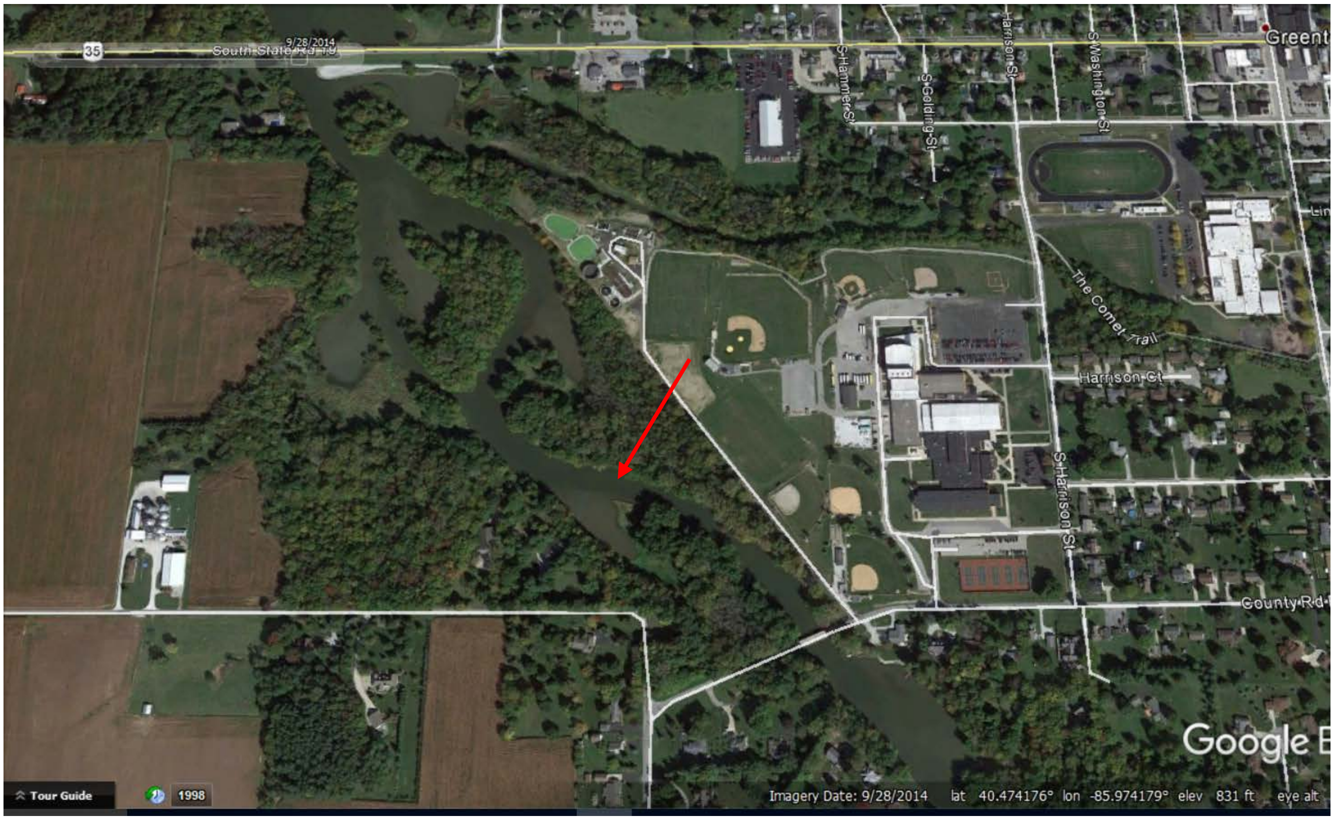

Figure 15: Kokomo Waterworks Reservoir #2 at Greentown, Indiana. Note sediment plumes around the in-channel bars and islands.

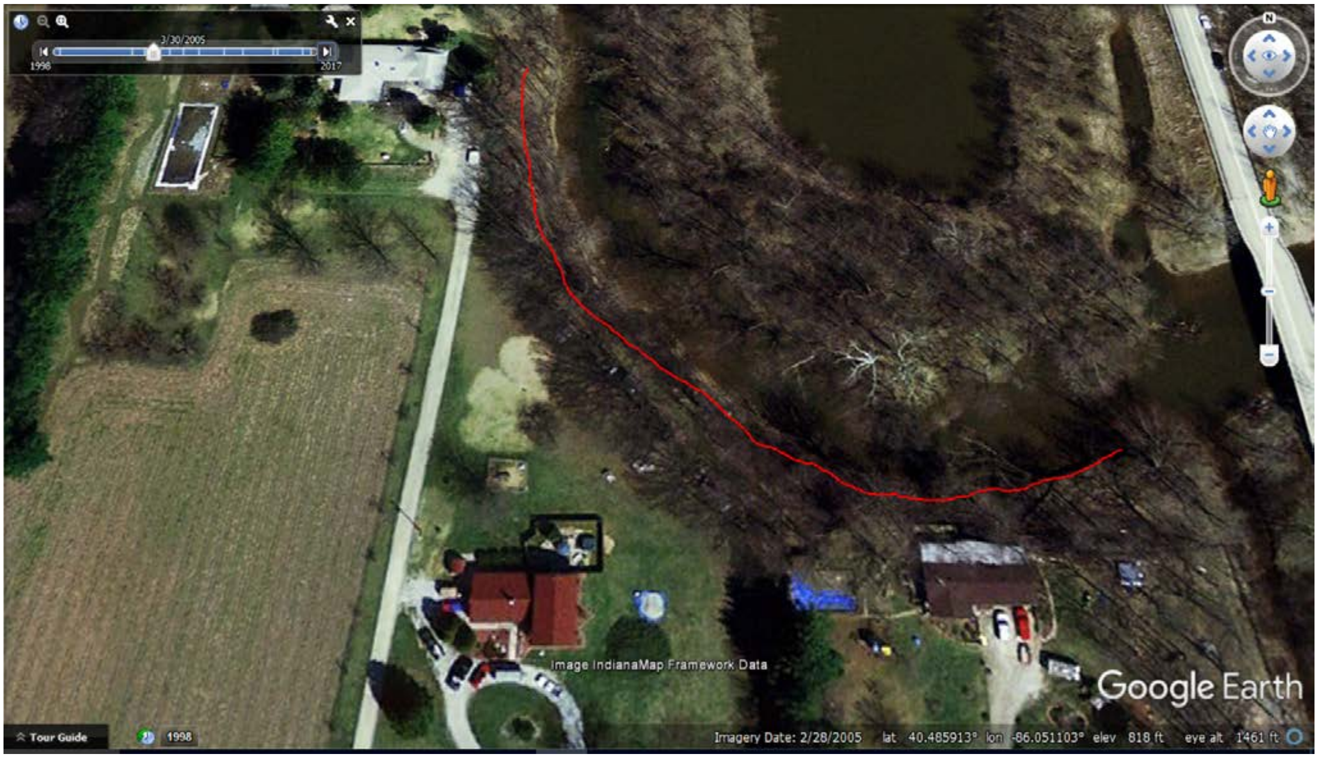

Figure 16: Erosion trace on meander downstream from the reservoir. The line trace shows the present position of the meander and is from April 2017. The air photo is from March 2005.

4.4 Wildcat Creek, Reservoir to US 931

As noted in the preceding section, this reach has unstable banks in the upper 2.0 miles (Figure 16, Figure 18). The erosion would be much worse if the stream was not able to access its floodplain. However, the valley is downstream of the reservoir and as the narrow shape of the reservoir indicates, the valley is not wide, the geomorphic floodplain averages 1250-feet through this reach (Table 2). Figure 17 shows a valley cross-section downstream from the reservoir. This reach also has a semi-alluvial characteristic in that the floodplain shifts from the north to the south side of the channel at a point near the crest of the large meander seen to the left of the cross-section in Figure 16. A detail of the site is seen in Figure 18. Semi-alluvial stream reaches have a floodplain on one side of the stream, the opposing non-alluvial bank is generally a steep escarpment or valley wall. Velocity, and shear stress increase on the non-alluvial side of the channel and increased erosion is common in non-cohesive bank materials.

Measured and predicted channel dimensions and physical characteristics for reference locations in the study area are found in Table 1. Potential acreage and functional status of floodplains associated with the main channel of Wildcat Creek in Howard County, and its primary tributaries is in Table 2.

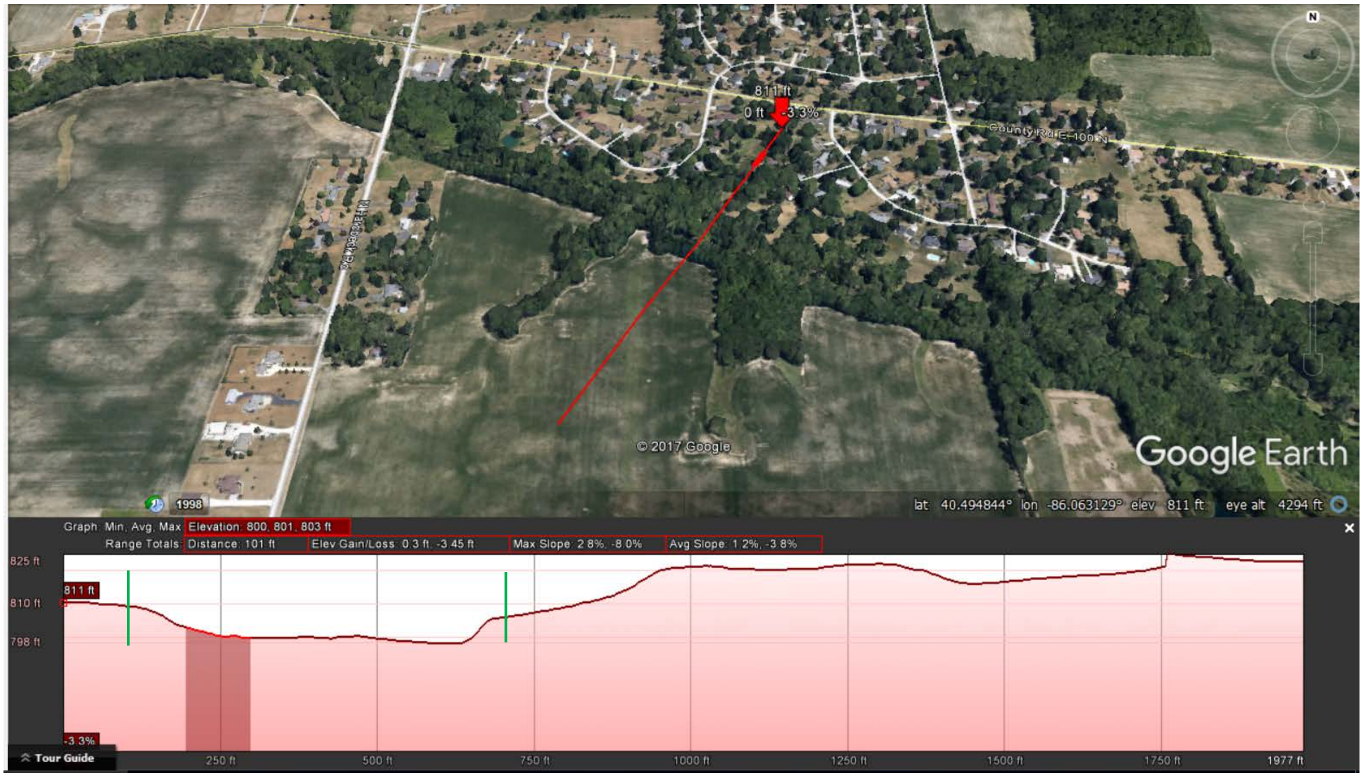

Figure 17: Cross-section of geomorphic floodplain downstream from reservoir. Fluvial plain is between the green lines. Active channel is on the right side of the fluvial plain.

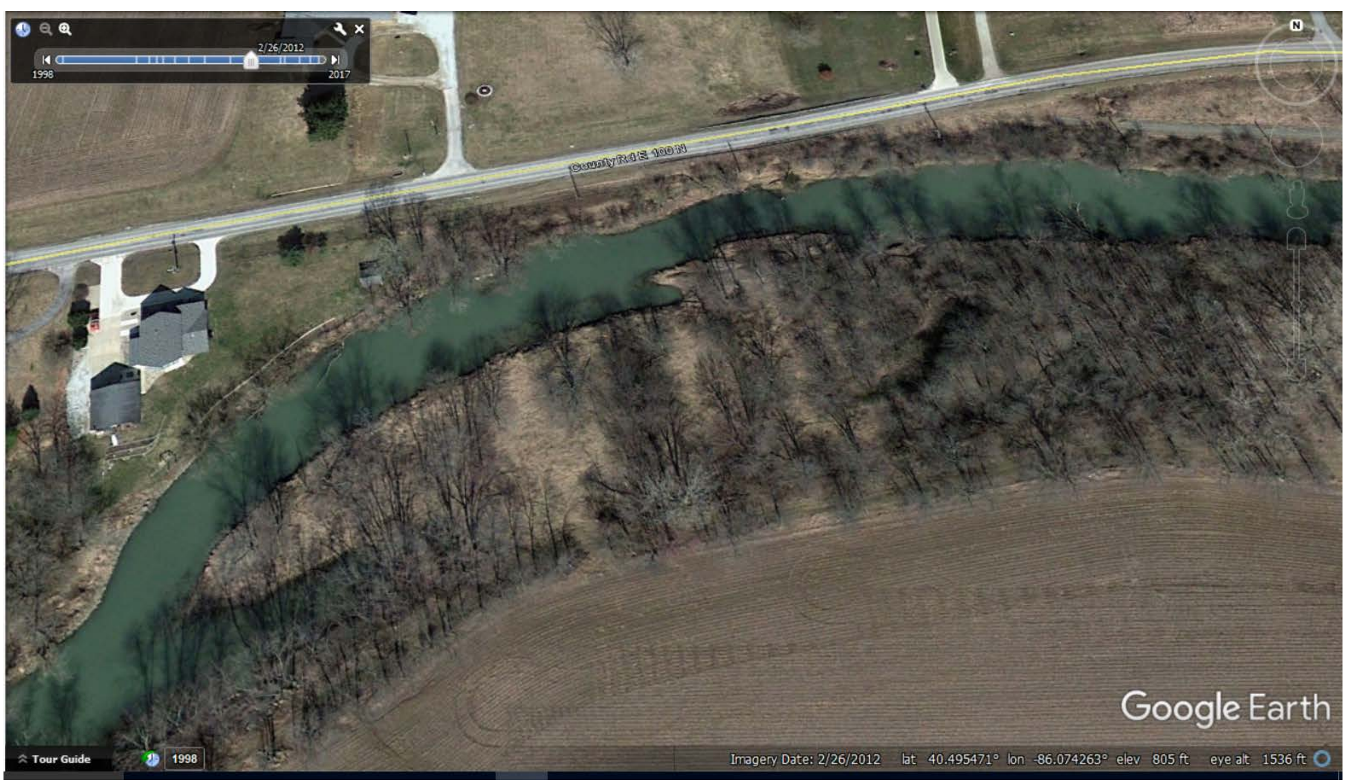

Figure 18: Erosion near CR E 100 N, east of N Hardbeck Road.

4.5 Wildcat Creek, Kokomo

The 4.3-miles of Wildcat Creek in Kokomo, defined here as the stream reach between US 931 on the east side of the city, and S. Dixon Road on the west side, typifies an urban stream. The stream is incised, flat bottomed, lacks instream structure, and its floodplain has been filled throughout the city, leaving a classic “urban canyon”. Figure 19 shows a cross-section downstream from Apperson Way. Note on the north side of the channel the elevation is at 806- feet, if this stream floods it must go to the south. Even on the south side of the channel the top of bank is at 795-feet. Predicted mean bankfull channel depth at this site is 3.72-feet, which with a channel bed elevation of 782-feet, would put the floodplain at an elevation of 786-feet. These data suggest almost 9.0-feet of combined floodplain filling and channel incision in this portion of the central city. Incision is also suggested by the lower channel bed elevation that is shown on the USGS topographic map just downstream of US 931 (Figure 20). Through most of the city Wildcat Creek is an F4c stream according to Rosgen’s classification, incised and unstable. The stream evolution stage is either a IV or V, depending on location. Figures 21 and 22 show Wildcat Creek at Apperson Way. In this area, the stream is in transition from a channel evolution Stage IV to a Stage V (Figure 10).

Measured and predicted channel dimensions and physical characteristics for reference locations in the study area are found in Table 1. Potential acreage and functional status of floodplains associated with the main channel of Wildcat Creek in Howard County, and its primary tributaries is in Table 2.

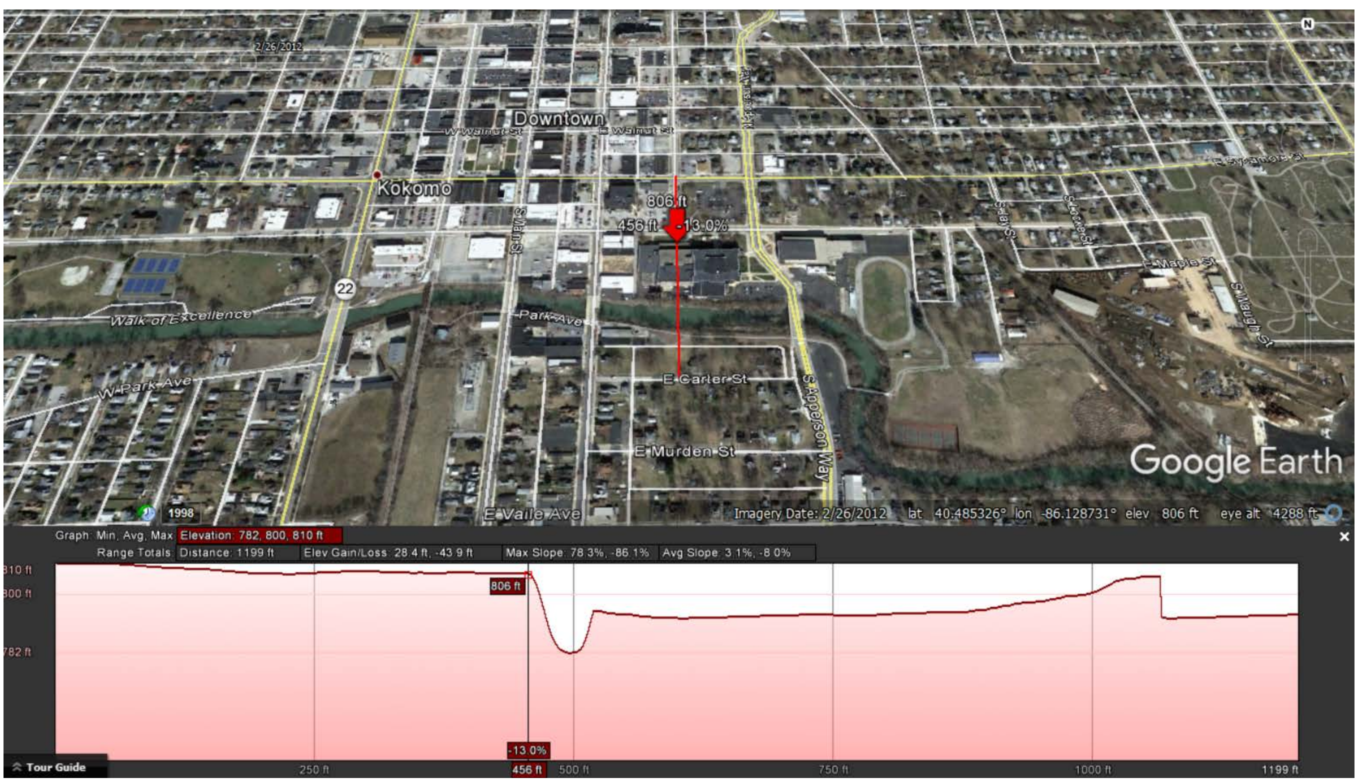

Figure 19: Channel cross-section near Apperson Way (Google Earth)

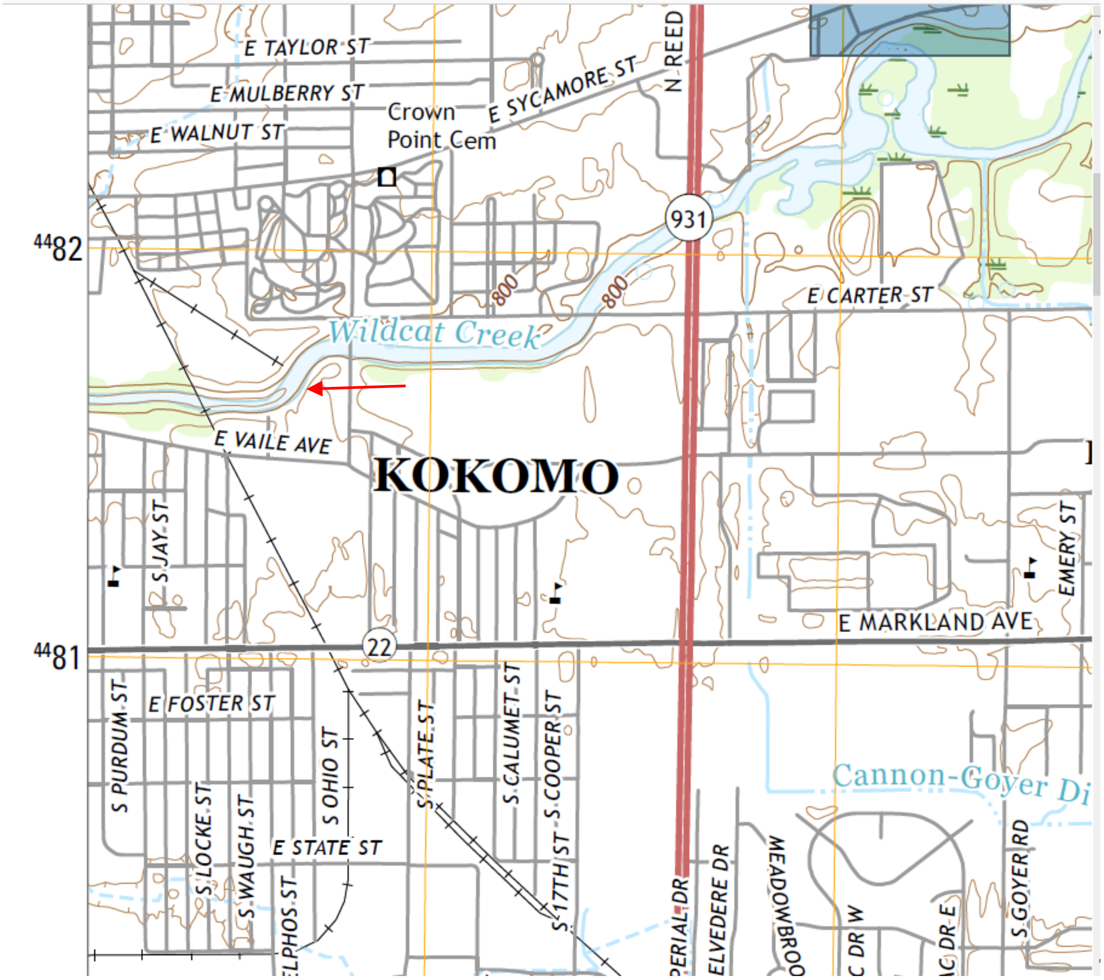

Figure 20: Detail from USGS 1:24,000 Series Topographic Map, Kokomo East, 2016. The contour interval is 10-feet. Note the new contour line downstream from US 931 (red arrow).

Figure 21: Wildcat Creek at Apperson Way, looking upstream. Note CSO outfall on right bank, and developing point bar.

Figure 22: Wildcat Creek at Apperson Way, looking downstream. Note in-channel bar with mature tree.

Downstream from the Apperson site, and on the west side of the city, there is a 2.0-mile section of Wildcat Creek and Kokomo Creek that were vacuum dredged during the remediation of the Continental Steel facility (USEPA, 2008; Figures 23,24,25,26). EPA documents (USEPA, 2010) indicate that from 0.4 to 2.5-feet of contaminated sediment were removed from the stream bed. Extensive remediation of the banks was done as well, which has given the reach a straightened appearance.

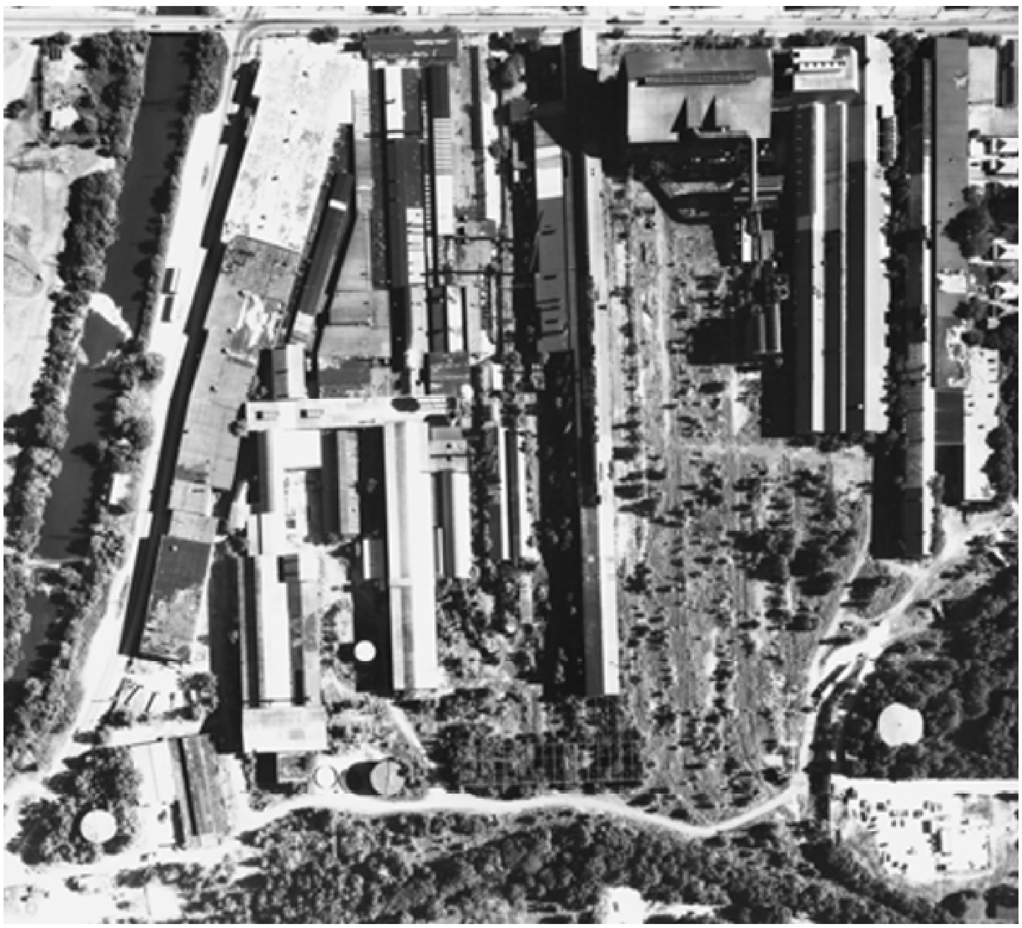

Figure 23: Continental Steel Facility, Kokomo, IN, Pre-demolition photo, Main Plant Area, 1998.

Wildcat Creek is visible on the left side of the image.

(USEPA)

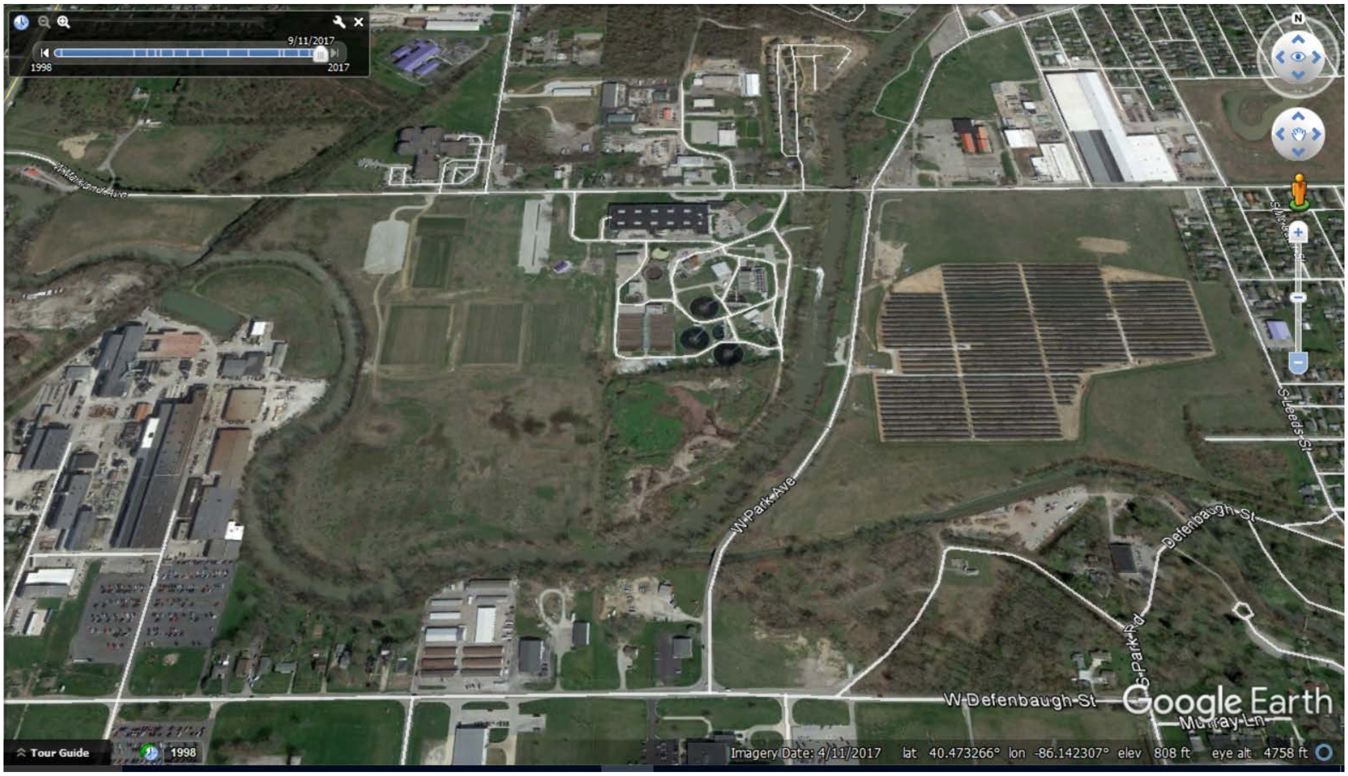

Figure 24: Site of the former Continental Steel Facility, Kokomo, IN. 2017. Note Kokomo Creek in the foreground of the lower right side of the image. Flow direction in Wildcat Creek is from the top of the image.

Figure 25: Wildcat Creek at Markland Avenue, looking upstream. Note straightened form, uniform width, and lack of bed features.

Figure 26: Wildcat Creek at Markland Avenue, looking downstream at the reach that was vacuum-dredged.

Downstream from the Continental Steel remediation area, stabilization has also been done on the left bank in an area that was historically a dump site. The area is still used for recycling sorting. Trash and debris is falling out of banks that were "stabilized" with a slag cap (Figure 27). The slag is not heavy enough to be stable on the banks and most of it is ending up being eroded and transported downstream where several central bars have formed. Presumably to reduce the bank erosion, a large cross-vane appears to have been constructed in the channel (Figure 28).

Figure 27: Wildcat Creek upstream of Dixon Road. Note debris falling out of left bank.

Figure 28: Wildcat Creek upstream from Dixon Road. Note what appears to be a cross-vane in the bottom center of the image (red arrow), and the line of limestone blocks armoring the right bank.

4.6 Mined Reach

The mined and formerly mined portion of the Wildcat Creek corridor begins at Dixon Road and continues downstream until a point near the coordinates, 40.4699, -86.2237, or approximately 5.5 miles downstream. The reaches are grouped together for this report because of the similarity in the mining impacts. The coordinates correspond to a point in the stream where disturbance from mining activities, or post-mining reclamation no longer dominates stream processes. The extent of alteration is this section of the stream corridor can be seen in Figure 29. Quarry operations and levees that were pushed up to keep the quarry from flooding and to store the overburden have removed any floodplain on the left bank, and forced the stream against the high valley wall on the right bank. The result is the most visible erosion in the study area. Figures 30 and 31 show the extent of the cutbank. While the cutbank is large, the toe of the slope is stable, and there is little lateral movement. What is occurring at the site is more of a slope process, than a stream process. Sediment loss seems low relative to the size of the exposure.

While large wood in the channel was reported as a concern by the County, the mined reach was the first area in Howard County where significant large wood was found. However, no channel blockages were seen, and most of the wood was at or near bridge pilings.

Measured and predicted channel dimensions and physical characteristics for reference locations in the study area are found in Table 1. Potential acreage and functional status of floodplains associated with the main channel of Wildcat Creek in Howard County, and its primary tributaries is in Table 2.

Figure 29: Mined and post-mining portion of the Wildcat Creek corridor. Currently operating Martin-Marietta quarry is visible on the right side of the image.

Figure 30: Large cutbank on right bank of Wildcat Creek across from Martin-Marietta quarry. The exposure is approximately 1300-feet long, and over 40 feet high.

Figure 31: View of large cutbank from the top of the right bank. Note the wood oriented against the bank. This alignment helps to protect the toe of the slope and build a floodplain bench at the bottom of the slope.

At Malfalfa Road Wildcat Creek flows from the actively-mined area into an area that has been reclaimed. In this area, there are many legacy problems. In Figure 32, the red arrow points to a location where Wildcat Creek splits. The channel to the left was constructed during mining operations to receive the ground water being pumped out of the pit. The constructed channel is narrower and has a steeper grade than Wildcat's natural channel. With mining operations ceased there is no longer any pumping, but the constructed channel has captured most of Wildcat's flow. The natural channel to the right has very little to no flow at times. During higher flows, it now functions as an overflow channel and fills with large wood and debris as the flow recedes. The constructed channel, which was intended for the pumped discharge, is now carrying most of the flow of Wildcat Creek – right along the toe of the old levee that separated the mine from Wildcat Creeks flood waters (Figure 33). High flows during the 2013 flood breached the levee and flowed in the lake. This type of capture can have catastrophic effects on the stream channel as the stream tries to adjust the grade of the newly captured pit to the upstream channel slope. The stream will erode its bed and banks to try and fill the pit and the instability will continue to move upstream (Kondolf,1997).

Wildcat Creek and the newly dominant built channel come back together upstream of the CR N 400 S bridge. From the downstream rejoining to the upstream split the main channel is 1.2 miles long, the old pumped channel is 0.6 miles long. The capture reduced stream length by 50%. The bridge will initially catch much of the large wood and debris washed out of the main channel (Figures 34 and 35).

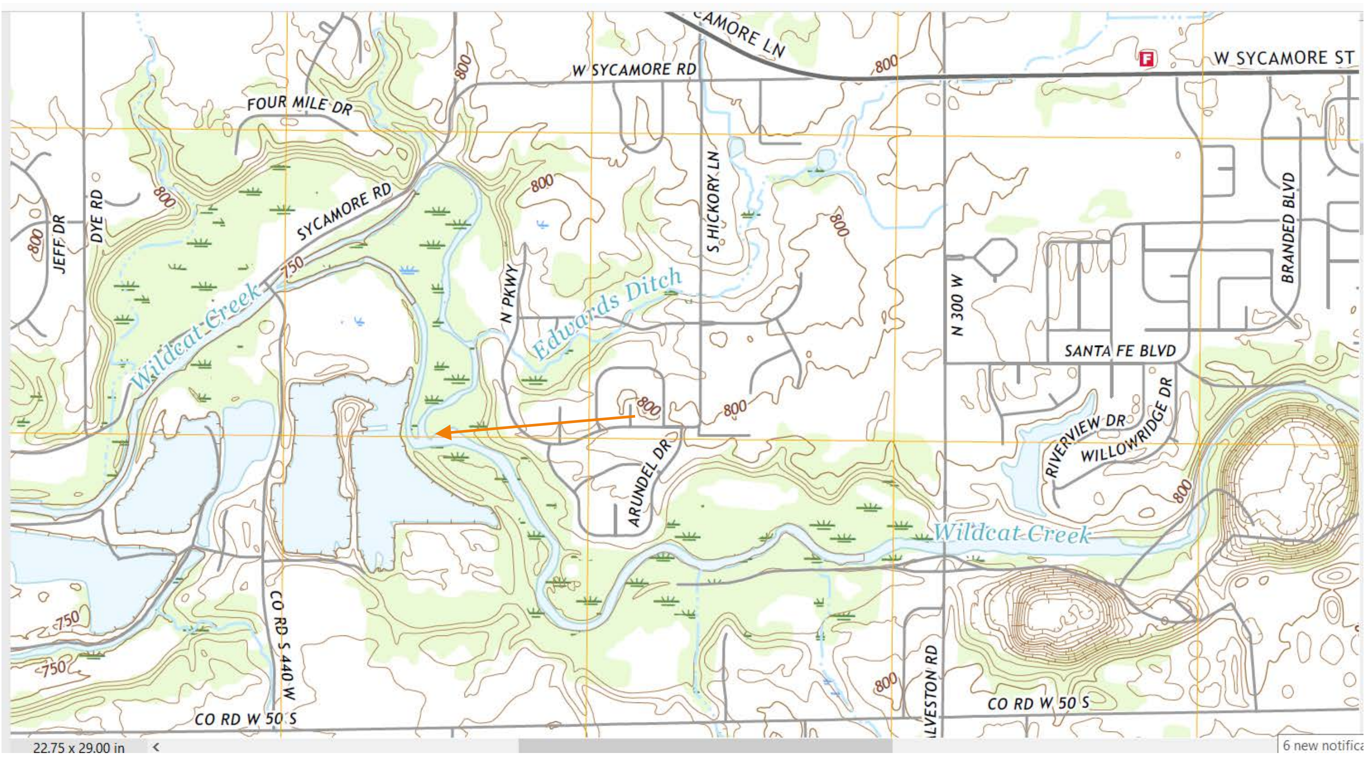

Figure 32: Detail from the USGS 1:24,000 Series Topographic Map, Kokomo West, 2016. The contour interval is 10-feet.

Figure 33: Looking northeast across the lake at the “new” channel (red arrow). Note proximity to levee.

Figure 34: Wildcat Creek at CR N 400 W. The old main channel is on the left, the dry bed is visible upstream. The constructed channel is on the right, it now carries most of the flow.

Figure 35: Wildcat Creek at CR N 400 W, large wood and debris washed out of the main channel and lodged against the bridge. This picture was taken in August following the wettest Spring and early Summer in 135 years (NWS). Howard County officials reported no wood had been cleared from the bridges this summer.

Downstream from CR N 400 W, Wildcat Creek has been rerouted to the outside of a series of smaller gravel pits (Figure 36). Levee-type structures have been pushed up around these smaller pits just like the larger pit upstream. And just like the large pit, these small pits have the potential for capture as well. What is harder to see, but equally problematic, is that the levees that protect these lakes from flooding exclude the stream from its floodplain. Flow in the channel through these areas is deeper than it normally would be, and faster. The result is once again, a stream with the ability to do more work, or erode more that it might in a more stable system.

Figure 36: Wildcat Creek in the "post-mining area". The blue line shows the original position of Wildcat Creek. The new channel positions are indicated by the red arrows.

4.7 Downstream from mined area near (40.4699, -86.2237) to County Line

Immediately downstream from the mined area, the more natural system is adjusting to the effects of the levees and shortened channels in the mined area. The 1.5 rm immediately downstream from the mined area has the highest sinuosity measured in the study area (k=1.72), and significantly higher than the rest of the reach (k=1.54). The upper portion is also characterized by large wood, and the most prominent point bars seen in the study area (Figure 38).

Measured and predicted channel dimensions and physical characteristics for reference locations in the study area are found in Table 1. Potential acreage and functional status of floodplains associated with the main channel of Wildcat Creek in Howard County, and its primary tributaries is in Table 2.

Figure 37: Looking upstream west-southwest. Note large wood in channel (red circle). This location is 0.6 miles downstream from the mined area. The channel is not completely obstructed, and the wood is not closely packed. Image was taken in Spring 2017.

Downstream from buffer zone for the mined area, Wildcat Creek flows west for over 10.5 rm to the County Line near Burlington. This final reach is characterized by wide, well connected floodplains and stable banks. A familiar challenge appears right at the county line. On the north side of SR 22, Wildcat Creek flows right next a large borrow pit

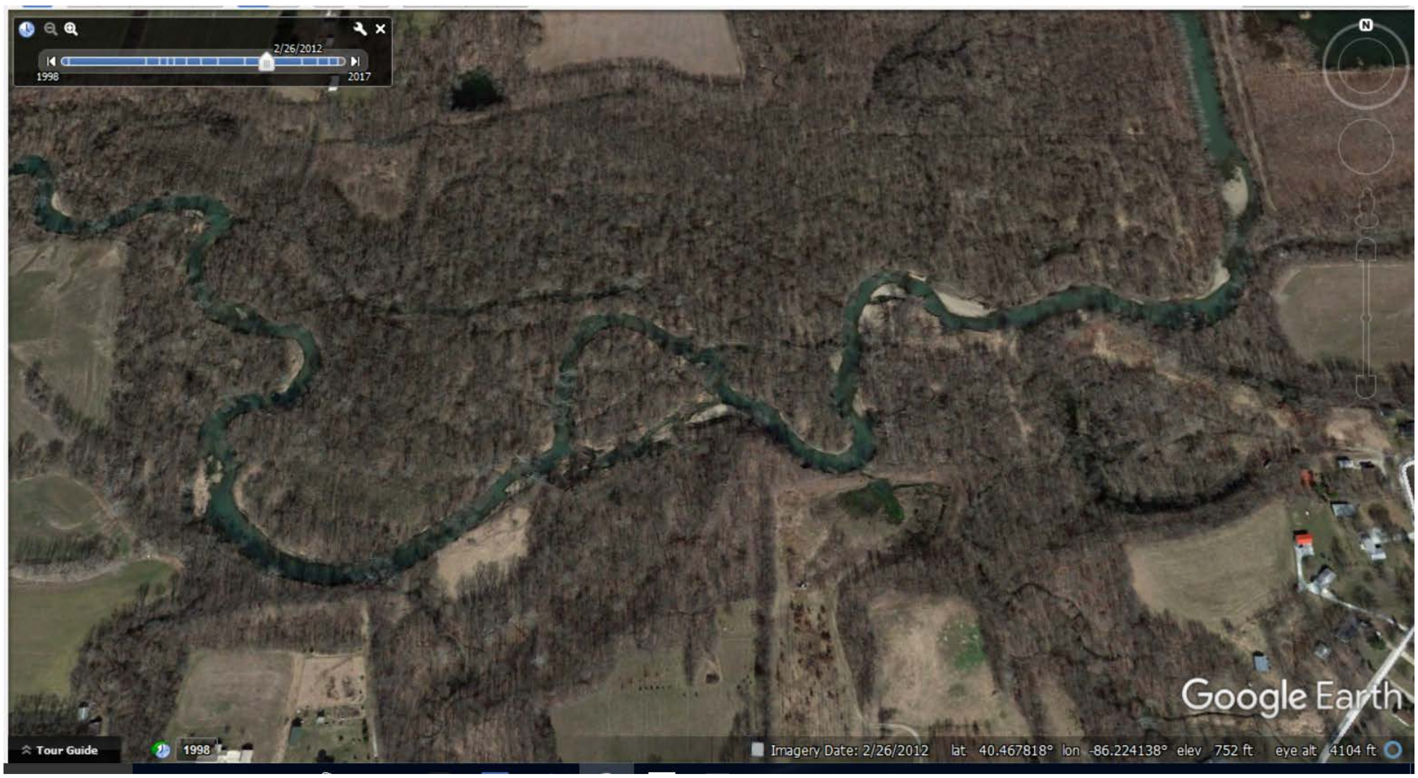

Figure 38: Mined area on the right side of the image, ending at the confluence of the straight channel, and the small remnant of Wildcat Creek that is flowing in from the right. Note the irregular meanders, prominent point bars, and old meander scrolls.

Figure 39: Wildcat Creek at CR S 750 N, looking downstream

Figure 40: Wildcat Creek at CR S 750 N, looking upstream. Note terrace on right bank, stable transition to floodplain on the left bank. Mature riparian forest is present throughout most of this reach.

Figure 41: Wildcat Creek at SR 22, looking downstream. The large in-channel bar is caused by the bridge over SR 22. There is a borrow pit on the other side of the trees on the right side of the image.

Figure 42: Wildcat Creek at SR 22, looking downstream. Borrow pit is visible through the tree gap. Note the position of the trees at the water line. In this uncohesive material the tree roots are holding the bank together.

Figure 43: Wildcat Creek at CR S 750 N, looking downstream

5.0 DISCUSSION

The recurring theme of this study has been the buffering of the effects of disturbed portions of the stream corridor by reaches that have retained their functions, or more of their functions than the disturbed reaches. There are three distinct areas where this buffering occurs:

1. Headwaters into Jerome -Greentown: 149 mi^2 of highly modified headwaters and up to 90% of the flood discharge recorded at the Kokomo gage flow through 4.75 miles of stream corridor with intact floodplains. The largest area of instability identified in the reach is an eroding cutbank on a meander downstream from the canoe launch at SR213.

2. Reservoir reach into the Dam to US 931 reach: in this reach, 4.3 miles of stream with floodplains buffer the clear water discharge of a 461.6-acre reservoir. The channel in this reach is semi-alluvial in several locations so erosion is increased. The 2.0 miles directly downstream from the reservoir has several sections that are unstable.

3. Kokomo and the Mined area into the stable downstream reach: Approximately 12 miles of Wildcat Creek with intact floodplains begin at the west edge of the mined area. The first 1.5 miles of stream immediately downstream from the mined area has the highest sinuosity measured in the study area (k=1.72), and significantly higher than the rest of the reach (k=1.54). The upper portion is also characterized by large wood, and the most prominent point bars seen in the study area (Figure 38).

In each of the three stream sections described above, a relatively short (1.5-2.0 mile) stream reach is absorbing the effect of a much larger area of disturbance. These “shock absorbers” are preserving stream health downstream. The lesson is one that is demonstrated by the functional pyramid developed by Harmon and others to assess stream system functions and health. The bottom of the pyramid “Hydrology” focuses on the watershed delivery of water to the channel. In the headwaters of Wildcat Creek we know from gage analysis that the delivery of water to the channel has been increased. Runoff has been increased and infiltration decreased by the agricultural modifications. The second level of the pyramid is Hydraulics, or the transport of water through the channel. The key metric for assessing the hydraulic function in a stream system is look at floodplain connectivity. With floodplain connectivity we can offset some loss of function in the hydrology, and without floodplain connectivity we quickly lose geomorphic function. Which is why we don’t find pools and riffles in the Kokomo reach of Wildcat Creek, but we can recover those stream functions with just a few stream miles of functional corridor.

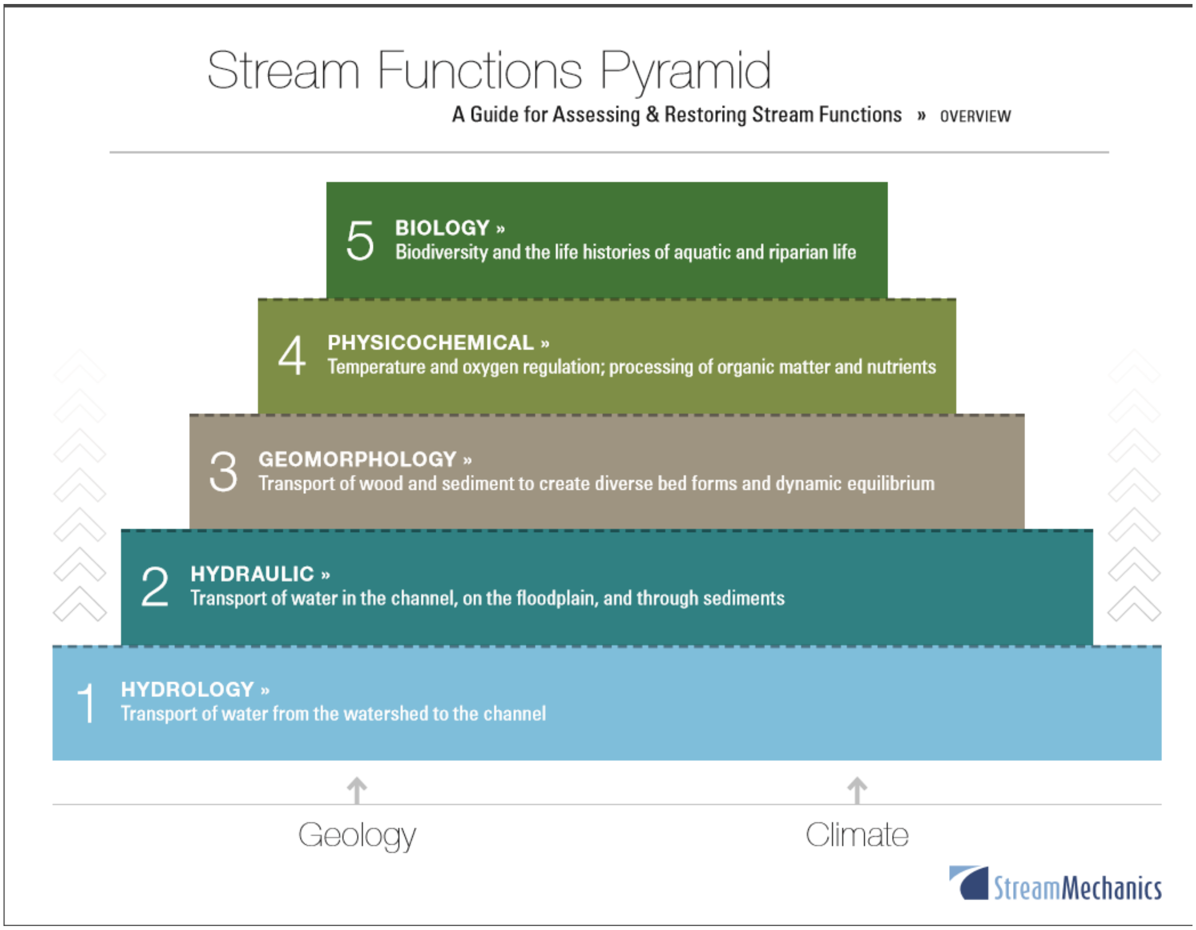

Figure 44: Stream Functions Pyramid (Harmon and others, 2012)

6.0 Areas of Concern and recommendations

The headwaters of Wildcat Creek above Jerome contribute a significant portion of the flow coming into Kokomo. In the July 2003 flood, 75% of the discharge recorded at the Kokomo gage originated at the Jerome gage, and in the April 2013 event, 90% of the discharge was present at the Jerome gage (Mallory,2014). Working with Grant, Madison, and Tipton Counties to increase upstream storage should be a first step in flood reduction.

The erosion downstream from the dam is a result of the clear water discharge from the reservoir and the geology of the valley. The erosion immediately downstream from the dam can be reduced, and should be addressed

The urban corridor of Wildcat Creek through Kokomo needs a consistent treatment. The disturbances are so great, and so many, that a “patch as you go” restoration will not succeed.

The channelized reach downstream from Markland Avenue has a morphology that will tend to make it unstable. Given the history of the section a meandering stream reach isn’t going to be acceptable. A stable “B” type channel should be considered.

The mined and post-mined section of the Wildcat’s corridor has several areas of concern. The constructed channel breached the levee wall in 2003, and will do so again. The capture of the main channel by the constructed channel has shortened stream length and increased flow velocity, exacerbating already unstable banks downstream.

As noted in the discussion, the floodplains that remain are buffering the system. Total floodplain acreage in the study area as determined by alluvial soil is 7,082 acres. Of that number 3,593 acres are intact and functioning - approximately 50%. The number changes for area of Kokomo and upstream. There the total floodplain acreage was 4,755 acres, of that 1,266 acres considered intact and functioning, or approximately 26% (Table 3 and 4). Priority must be put on reconnecting headwater streams to their floodplains.

Table 3: Total study area floodplain acreage and functional status

Total	56.1 rm	7,082 acres
Intact	24.0 rm	3,593 acres
Impaired	18.2 rm	1,586 acres
Lost	13.8 rm	1,903 acres

Table 4: Study reach floodplain acreage and functional status – Kokomo area and upstream

Total	44.1 rm	4,755 acres
Intact	12.0 rm	1,266 acres
Impaired	18.2 rm	1,586 acres
Lost	13.8 rm	1,903 acres

Finally, large wood was listed as a concern in this study area. This investigation doesn't find evidence of excessive wood in the stream, but areas with large amounts of wood in the channel are often indicators of channel instability and incision. Those areas have been identified and should be monitored regularly.

7.0 References

Edgell, R.A. (2008) Kokomo Reservoir, Howard County, 2008 Fish Management Report. Fisheries Section, Indiana Department of Natural Resources, Division of Fish and Wildlife

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012. A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC EPA 843-K-12-006.

Kondolf, G.M. (1997) Hungry Water: Effect of Dams and Gravel Mining on River Channels. Environmental Management Vol. 21, No. 4, pp. 533-551.

Mallory, J. (2014) Indiana Department of Natural Resources Memorandum on the Effect of the Kokomo Reservoirs on the April 2013 Flood.

Stunkard, D. (1986) From Indians to reservoirs: history of a tough old stream. Kokomo Magazine 11(1):6-8. (as cited in Edgell,2008)

U. S. Environmental Protection Agency (2016) Green Remediation at Continental Steel Superfund Site - It Just Made Cents.
https://www3.epa.gov/region5/waste/cars/remediation/whitepaper_11dpatlikins.pdf

Web Soil Survey (no date) https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Appendix 2 – Management of Large Wood in Wildcat Creek

Managing Large Wood in the Wildcat Creek Stream Corridor, Howard County, Indiana

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September 2017

Wildcat Creek at Malfalfa Road

CBBEL Project 19. R150132.00000

Introduction

This report documents a survey of large wood in the Wildcat Creek corridor. Large wood, or “large woody debris” as it was frequently termed in the past, is a persistant theme of discussion and controversy in river management. In the Wildcat Creek corridor there have been frequent complaints and questions about wood in the stream (Gerber,2016; Smith, 2010; Wildcat Paddle Club,2016). However, large wood (LW) is a natural component of river and stream systems in forested regions. In natural areas avulsion, or movement, of the stream around a log jam is part of the processes that lead to channel complexity, and the direct removal of instream wood in a managed stream can have significant negative effects on channel stabiltity (Wohl, 2014).

The term “large woody debris” is falling out of general use because the “debris” portion of the term has a negative connotation, and instream large wood has a number of important functions. For example, instream wood often has a role in floodplain formation, as instream wood forms an in-channel bar that becomes an incipeient floodplain (Simon and others, 2016). In managed rivers, one large question becomes, “how much wood is enough?”.

Management challenges with LW occur in river systems that don’t have adequate corridors. Work by Williams on low- gradient alluvial (streams that form their floodplains) rivers around the world demonstrated that stable alluvial rivers have a meander belt width (MBW) that ranges from 4 to 10 times the bankfull width of the river, but most commonly the MBW is near 7. The meander belt width then becomes key to identifying potential erosion zones, because that width helps to define where a mobile, low-gradient river may move (City of Austin,2013, Robinson,2013). The Indiana Fluvial Hazard Mitigation Program uses a meander belt of 8x bankful width for mobile streams in Indiana. The meander belt defines the zone in which the river needs to move to adjust to changes in flow, sediment, or – an influx of wood. A storm can result in a large number of trees falling into a channel – particularly in areas where the banks are unstable already. Tornados and hurricaines can shed thousands of trees in a river. Rivers are complex systems, an action, like a tree fall, will involve a response, and an adjustment. A tree falls into the river, and flow is diverted towards the opposite bank. As the flow moves toward the bank in a stable system with floodplain connection the flow can simply role up on the floodplain. In a incised, or unstable stream the flow can hit an exposed bank, increasing erosion, and often undermining the bank. As the bank is undercut more trees fall into the channel in different locations, and the process continues. If the stream has room to move and adjust, the process may simply result in a short term increase in sediment downstream. If the stream doesn’t have the MBW room to move, and is forced to erode into someones property, or towards a road or other infrastructure, the natural adjustment process becomes a management issue. Over 75% of the floodplain connections along Wildcat Creek upstream of Kokomo are either lost or impaired (Barr,2017). While that number is high, it is not unusual in developed areas. Over 75% of Vermont’s assessed rivers (950 miles) are considered unstable due to lack of floodplain access (Kline,2006). If 75-percent of a stream’s floodplains are not functioning – mangement will be a continuing effort.

We further compound wood mangement by frequently crossing rivers. Each bridge can effectively become a “stringer”, something across the channel that catches everything that floats downstream. With bridges, even LW that wasn’t causing a problem in the natural channel, can become a problem around the bridge piers. That potentially occuring problem also becomes a good way to assess the amount of wood moving in a stream system, and to identify potential source areas. The Spring and early summer of 2017 were the wettest in 135 years in central Indiana (NWS), and August was very dry. On May 1st, the USGS gage at Jerome recorded a discharge of 2520 cfs. The predicted bankfull discharge at the Jerome gage is 2547 cfs, (Figure 1).

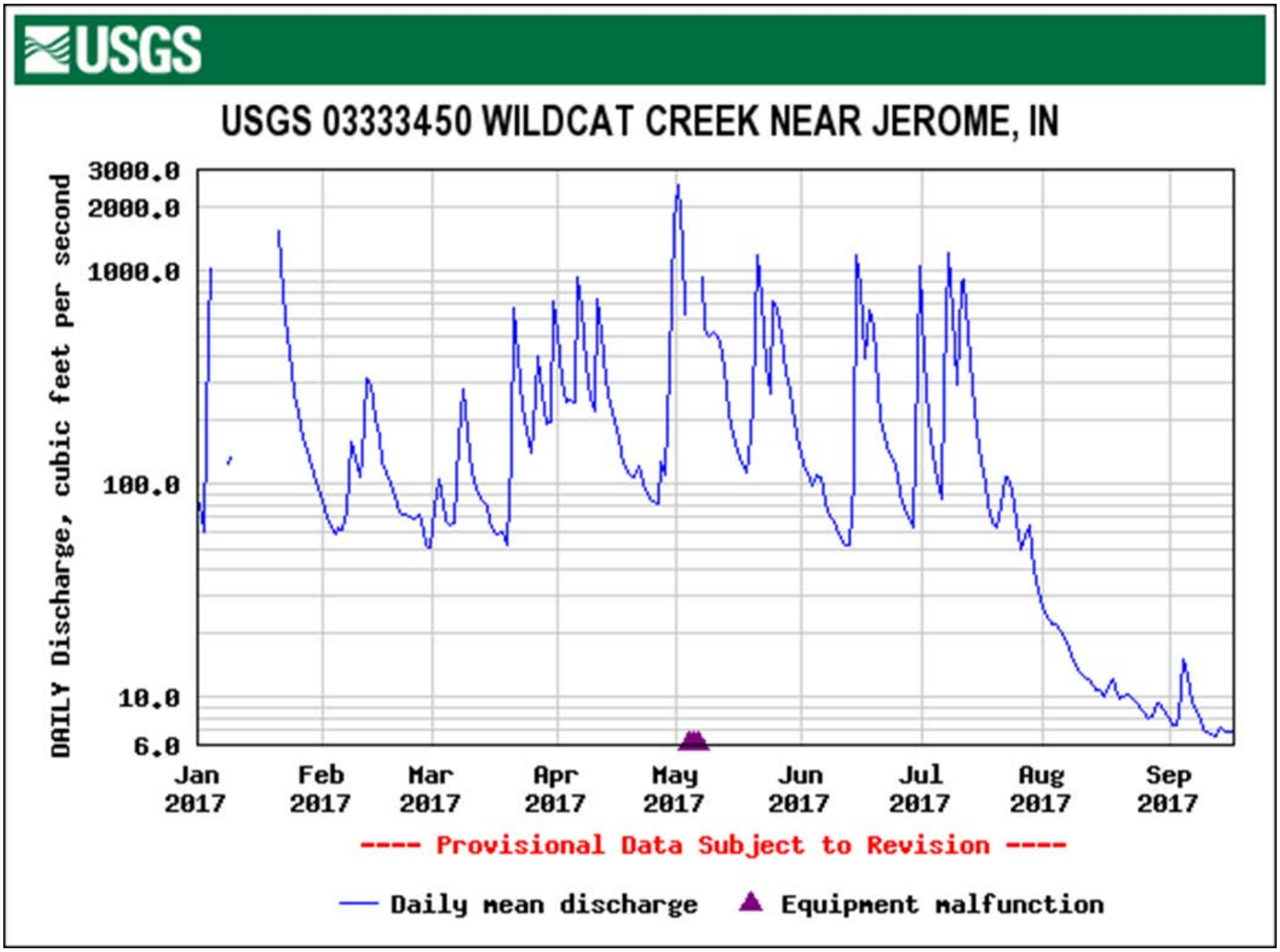

Figure 1: Daily discharge from Jan 1 – Sep 15, 2017 at USGS gage 03333450, Wildcat Creek near Jerome, Indiana.

Methods

To assess the in-stream wood moving in and towards Wildcat Creek in Howard County, bridges were surveyed from the headwaters of Mud Creek to Wildcat Creek at the Carroll County line. Over 65-miles, and 23 bridges.

Results

Wood was observed at 8 of the 23 bridge sites. No bridges were signifcantly blocked (Figures 2-12).

Figure 2: Mud Creek, just upstream of the confluence with Middle Fork Wildcat Creek. This is the first location where LW was found at a bridge. August, 2017

Figure 3: Wildcat Creek at Ohio Street, Kokomo August, 2017

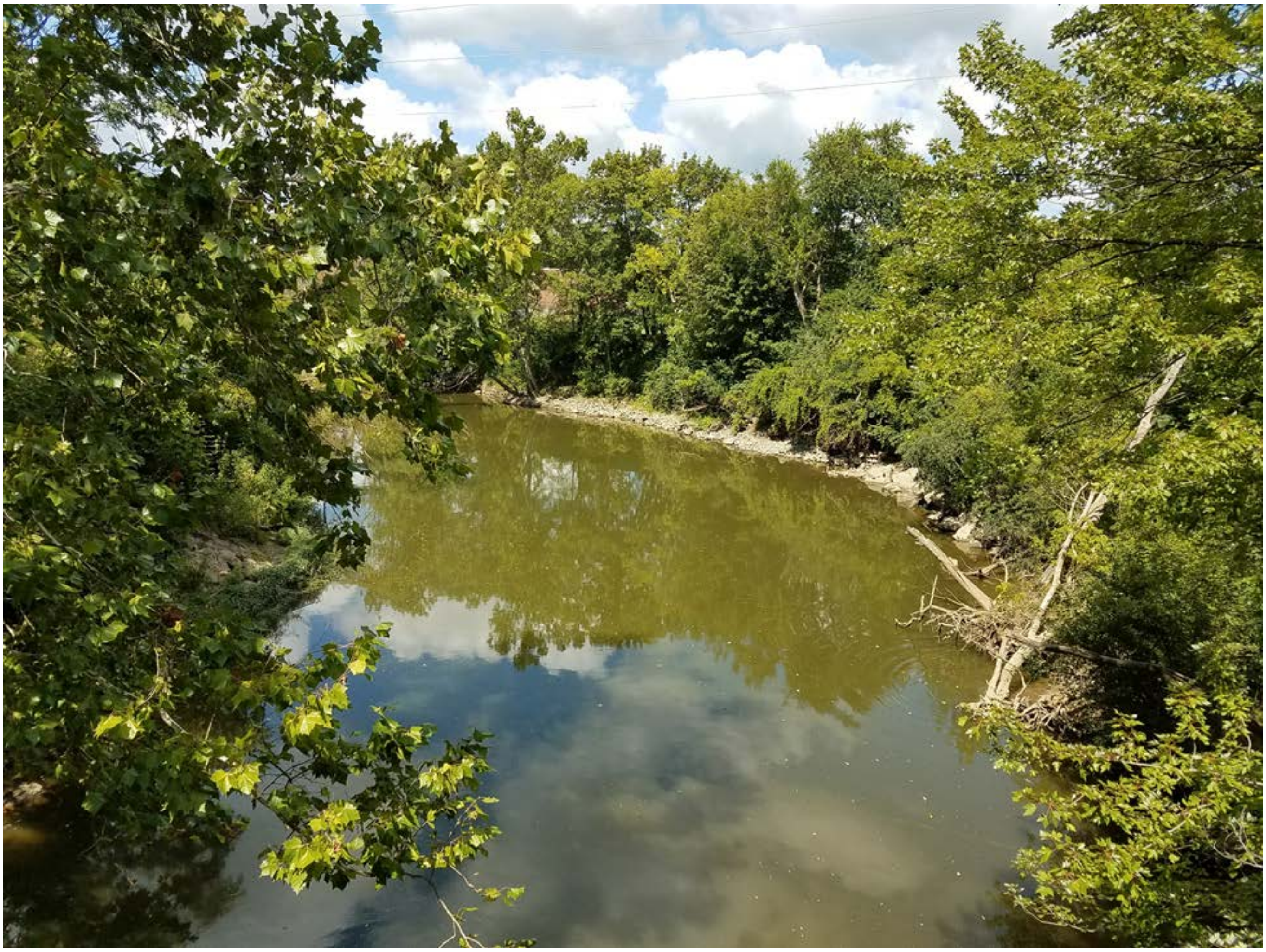

Figure 4: Wildcat Creek at Pedestrian Bridge upstream from Apperson Street, Kokomo Right bank, looking downstream. Wood is oriented along right bank. August, 2017

Figure 5: Wildcat Creek at Apperson Street, Kokomo   Right bank looking uptream. Note stable banks, dominant woody vegetation are native riparian tree species. On the left side of the image a tree growing on the right side of an in-channel bar is visible.   August, 2017

Figure 6: Wildcat Creek at Malfalfa Road. Looking downstream. Wood on left bank is reducing velocity and promoting deposition on the floodplain. Wood on the floodplain is an important aspect of floodplain diversity. August, 2017

Figure 7: Wildcat Creek at Malfalfa Road. Looking upstream. Quarry drainage channel is visible in the upper right. Wood on left bank is reducing velocity and promoting deposition on the floodplain. August, 2017

Figure 8: Wildcat Creek at County Road 400W. At the confluence of the main channel and the drainage bypass channel at the old quarry. The main flow is now moving through the constructed bypass channel. Low flows on the main channel cause wood to accumulate and get pushed out by flood waters. August, 2017.

Figure 9: Wildcat Creek at County Road 750. Left Bank, downstream. One tree is lodged in one cell of the bridge. No flow obstruction. Ausgust, 2017.

Figure 10: Wildcat Creek at County Road 750. Right bank, downstream. August, 2017.

Figure 11: Wildcat Creek at County Road 1150 W. Looking upstream. August, 2017

Figure 12: Wildcat Creek at SR 22, near CountyLine. August, 2017

Discussion

The data collected show that only 35% of the bridges assessed on Wildcat Creek had LW associated with them, and the largest accumulation of LW was found on Mud Creek, a headwater tributary. The LW observed was most common in and downstream from disturbance areas. These data suggest that wood management in the Wildcat Creek corridor is not a chronic problem, but an occassional acute problem as a result of very high stream flow, or a severe storm, like the August 2016 tornadoes. Since the LW issues don't appear to be systemic, a maintenance program is indicated. Developing an understanding of when LW is a problem and when it should be removed will be an important aspect of the ongoing management of the Wildcat Creek corridor. Similarly in more disturbed areas, like Kokomo, recognizing and removing invasive trees, and understanding what vegetation will help bank stability will be important. To help with these issues, links to the Indiana Drainage Handbook, and the Vermont River Mangement Handbook (Shiff and others, 2014) are in the following reference section, and a copy of a recent Indiana Silver Jackets Fact Sheet on LW management is in Appendix A.

References

Barr, R.C. (2017) Assessment of Stream Channel Stability for a portion of Wildcat Creek, Howard County, Indiana. Unpublished Report, 53 p.

City of Austin Watershed Protection Department (2013) City of Austin Drainage Criteria Mannual, Appendix E: Criteria for Establishing an Erosion Hazard Zone

Gerber, C. (2016) Up a creek: Lack of funding leaves William Meehan stuck with logjams left by tornado. Kokomo Tribune, Nov 21, 2016. http://www.kokomotribune.com/news/up-a-creek-lack-of-funding-leaves-william-meehan-stuck/article_85e9cb8c-add9-11e6-8899-97d879b187e9.html

Indiana Drainage Handbook (1999) https://www.in.gov/dnr/water/4893.htm

Kline, M. (2006) Alternatives for River Corridor Management. http://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_managementAlternatives.pdf

Robinson, B.A. (2013) Regional Bankfull-Channel Dimensions of Non-Urban Wadeable Streams in Indiana. Scientific Investigations Report 2013-5078. U.S. Geological Survey

Schiff, R., E. Fitzgerald, J. MacBroom, M. Kline, and S. Jaquith, 2014. Vermont Standard River Management Principles and Practices (Vermont SRMPP): Guidance for Managing Vermont's Rivers Based on Channel and Floodplain Function. Prepared by Milone & MacBroom, Inc. and Fitzgerald Environmental Associates, LLC for and in collaboration with Vermont Rivers Program, Montpelier, Vermont. http://dec.vermont.gov/sites/dec/files/documents/wsmd-rv-standard-river-management-principles-practices-2015-06-12.pdf

Simon, A., Castro, J., and Rinaldi, M. (2016) Channel form and adjustment: characterization, measurement, interpretation and analysis. IN: Tools in Fluvial Geomorphology, Edition: Second Edition, John Wiley & Sons, Ltd, Editors: G.M.Kondolf, H.Piégay, pp.237-259

Smith, S. (2010) Logjam causing flooding along Wildcat Creek. Kokomo Tribune, June 25,2010. http://www.kokomotribune.com/news/local_news/logjam-causing-flooding-along-wildcat-creek/article_9d655d08-5505-5c5c-896c-d1f1ed33902f.htm

Wildcat Paddle Club (2016) “Let us know where they are…” https://www.meetup.com/de-DE/wildcat/messages/boards/thread/49523092

Williams, G.F.(1986) River Meanders and Channel Size. Journal of Hydrology, 88 (1986) 147-164, Elsevier Science Publisher

Wohl,E. (2104) Rivers in the Landscape. Wiley Blackwell, 318 p.

APPENDIX A

Indiana Silver Jackets Fact Sheet on Large Wood Management

Wood Management in Indiana Rivers and Streams

Best Practices and Methods

White Lick Creek near Brownsburg, Indiana

Wood is a natural component of Indiana rivers and streams and plays an important role in maintaining healthy streams by increasing bank stability, habitat formation, and even reducing flow velocities. But how much wood should be in the river is a continuing question, and a question that will have different answers depending on the river - and the nature of the wood. A severe storm, or a tornado, can uproot hundreds of trees that may disrupt stream flow for years after the event. Or trees that might naturally float downstream can lodge under bridge, and put additional stress on the structure. In cases like this "wood management" may be necessary. Fortunately there is guidance on when management is necessary, and on what type of activities might require a permit. Based on Indiana Code IC-14-28-1-22(b)(6), most logjams along Indiana rivers and streams may be removed without a permit if certain conditions are met (see details at http://www.in.gov/dnr/water/files/wa-Logjam_Removal_Guide.pdf). The Indiana Drainage Handbook provides information on log jam removal using hand tools or heavy machinery. That document is available at https://www.in.gov/dnr/water/4893.htm. One method that is increasingly popular is the "clean and clear method" (Figure 1), in this method collected trash and debris is removed, the center of a log jam is cut away to allow better flow, and logs embedded in the stream banks and bed are left in place.

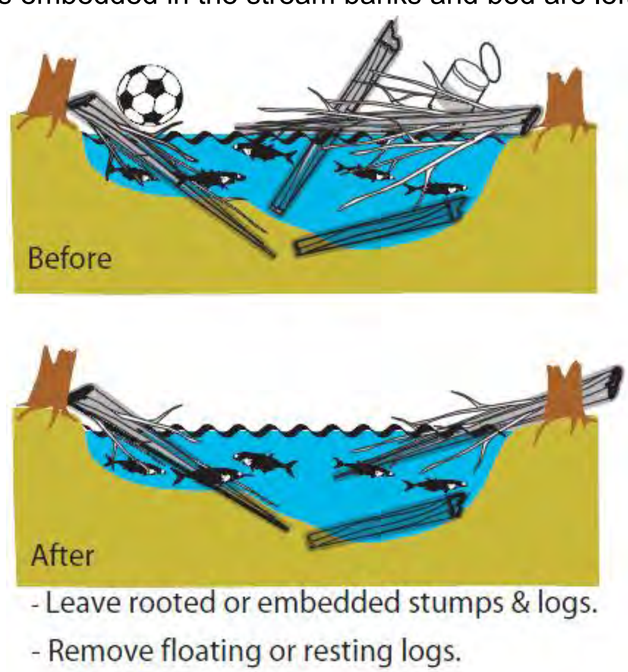

Figure 1: Clean and Clear Method

Another preferred wood maintenance method is to mimic a naturally occurring tree orientation and to move logs that are completely across a channel to a position against the bank. That position will both reduce erosion and provide shelter to fish (Figure 2).

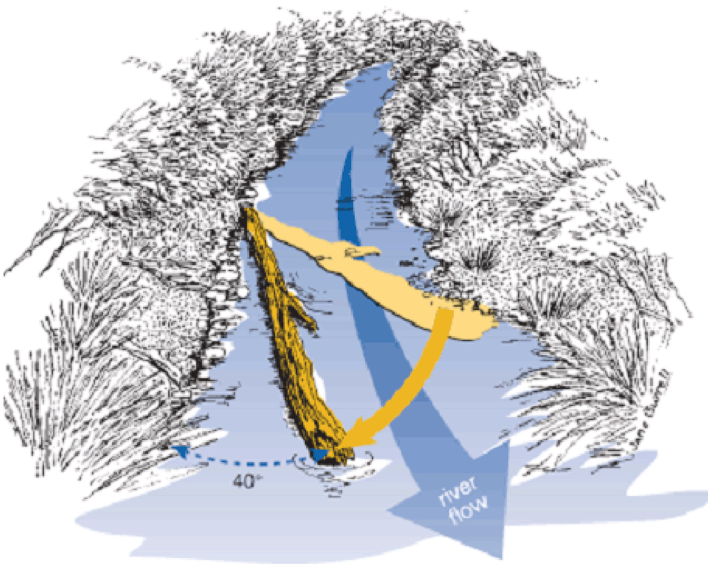

Figure 2: Clearing an obstructed channel

Natural example, Wildcat Creek, Howard County, Indiana

The chart provided in Figure 3 may be used to help determine how or when a log jam needs to be removed (Figure 3).

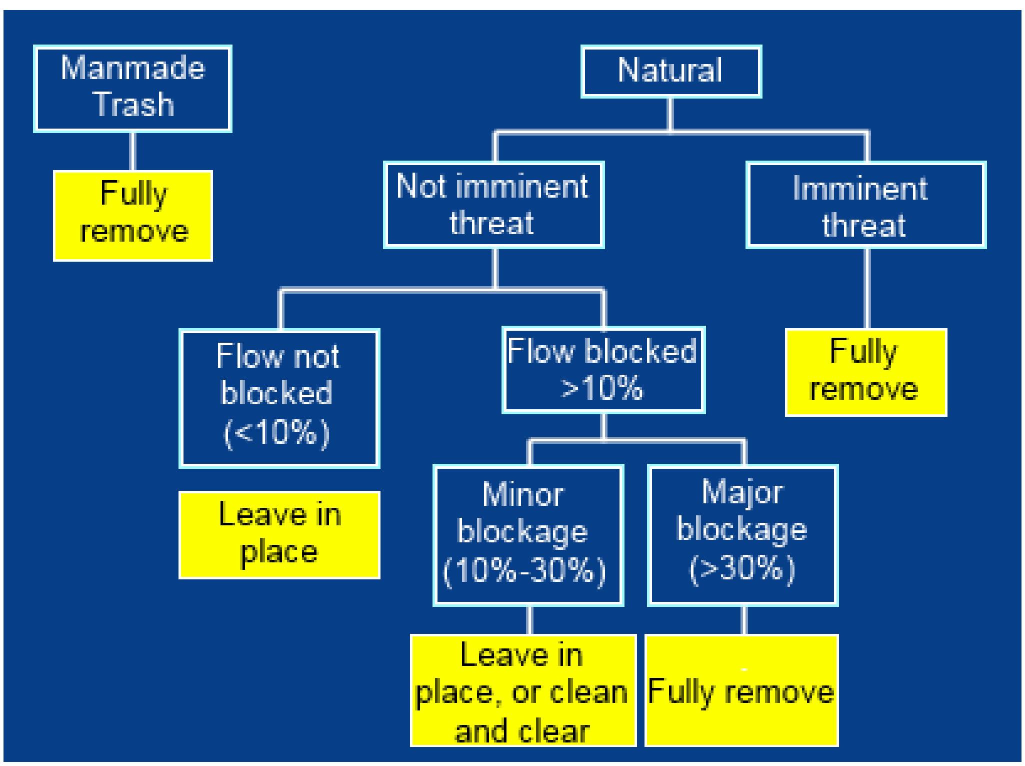

Figure 3: Wood Material Management Flowchart (MDEQ)

In addition to working with existing wood in streams, we also need to think about management of the entire stream corridor. Many times, a large number of trees falling into the channel is an indicator of an even larger problem with channel stability. In those cases we need to find the cause of the instability to properly address the problem.

This guidance document was developed for Indiana Silver Jackets by Robert Barr (IUPUI - CEES) and Siavash Beik (CBBEL) based in part on a similar guide developed by the Michigan Department of Environmental Quality. September 2017