FINAL
FUNCTIONAL ASSESSMENT OF THE MIDDLE UPPER WABASH RIVER

OCTOBER 2020

Prepared for:

Upper Wabash River Basin Commission
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Burke Project No. 19.R200009.00000

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EXECUTIVE SUMMARY

This report documents the results and methodology used by Christopher B. Burke Engineering, LLC (Burke) to identify problem areas along the Wabash River in Wells and Huntington Counties and to develop conceptual mitigation solutions. Robert Barr, a fluvial geomorphologist, assisted Burke in this effort.

The study reach was approximately 17.0 miles and extended from Co Rd S 450 E near Bluffton, Indiana to the Wabash River confluence with Rock Creek near Markle, IN. The Wabash River has a drainage area of approximately 600 square miles at the downstream end of the study reach, approximately 90 of which drain to the reach of the river being analyzed in this report.

A functional assessment of Upper Wabash River was completed by Burke and Robert Barr to identify sites of current or potential future erosion, risk to human life, or other stream health impediments, to locate problem areas that are in the greatest need of intervention, and to aid in the development of conceptual mitigation solutions. The assessment included review of previous studies and analysis of available data for the contributing watershed upstream of Bluffton, IN. The functional assessment determined the following regarding the stability of the Middle Upper Wabash River:

1. **The reach from Bluffton to Markle is generally stable.** The Middle Reach of the Upper Wabash River has fewer urgent problem areas than the Upper Reach. This is due, in part, to very few roads being adjacent to the river, particularly downstream of Bluffton.
2. **Presence of a wooded riparian corridor:** Nearly all of the Middle Reach is bordered on at least one side by a forested riparian zone, though it is quite narrow in some places. The dense root systems of these trees lend support to the silty soils present throughout much of the riparian corridor.
3. **Weak silt loam soils forming the upper bank:** Saturation of the bank may cause the soils to become too heavy to support the weight of the soil above.
4. **Increased flow rates and more frequent bankfull discharges:** Higher peak flow rates and more frequent bankfull discharges have resulted in more frequent saturation of the soils, which can lead to instability in silty deposits.
5. **Rolling topography:** Areas of local instability or apparent lack of floodplain access downstream of Bluffton appear to be more a function of topography than channel processes.

The results of the assessments by Burke and Bob Barr suggest that mitigation projects should be undertaken at two of the seven problem areas identified, with one area requiring two projects. All problem areas are in or near the City of Bluffton in Wells County. The recommended mitigation improvements include channel modifications to improve tributary connectivity to the Wabash River, increase bank stability, and reduce sediment load to the main stem of the River. It is recommended that the additional problem areas not addressed with conceptual project designs in this report be monitored for worsening conditions in the future. It is also recommended that the condition of any implemented improvements at the project areas should be monitored on an annual basis, and/or after significant flooding events to confirm that the measures are performing as expected. A summary of the location, length, and cost of the recommended improvement projects are provided in the table below.

Problem Area	Priority Ranking	Construction Cost	Cost of Engineering	Total Cost
John's Creek, Lower Reach	1	$75,800	$37,000	$112,800
John's Creek, Upper Reach	2	$52,000	$37,000	$89,000
Bill's Creek	3	$21,700	$27,000	$48,700

1.0 PROJECT OVERVIEW

1.1 INTRODUCTION AND PROJECT PURPOSE

This report documents the results and methodology used by Christopher B. Burke Engineering, LLC (Burke) to complete a functional assessment of the Upper Wabash River from Co Rd S 450 E near Bluffton, Indiana to the Wabash River confluence with Rock Creek near Markle, IN. Robert Barr, a fluvial geomorphologist, assisted Burke in this effort. The functional assessment was commissioned by the Upper Wabash River Basin Commission (UWRBC) to identify the stressors leading to channel instability and to identify the fluvial erosion hazards along the study reach.

1.2 STUDY AREA

The study area consists of the Upper Wabash River from Bluffton, Indiana to Markle, Indiana. The drainage area of the Upper Wabash River at its confluence with Rock Creek near Markle is nearly 600 square miles (mi^2). The drainage area for the reach analyzed in the current study is nearly 90 mi^2 and corresponds roughly to the USGS ten-digit hydrologic unit code (HUC) 0512010108. The length of the study reach is 17.0 miles (Barr, 2020). A map of the study area is shown in **Exhibit 1**.

Figure 1: Typical View along River Road in Bluffton

2.0 OBSERVED CONDITIONS

Existing data and previous studies, where available, were used as supporting information for the assessment. Additional data and observations were collected to provide a more comprehensive understanding of the physical processes at work near the sites and within the river system. The following sections detail the origin and use of existing datasets and applicable previous studies, as well as the type and extent of additional information gathered.

2.1 DATA SOURCES

Historic Aerial Photography
Aerial photography of the Upper Wabash River Watershed was obtained from multiple sources. The primary source of aerial photography information was the 2018 IndianaMap Orthophotography. Historical aerial imagery was collected from Google Earth, with local imagery provided by the Wells County Surveyor as needed.

Land Use Information
Information concerning the types and extent of land use practices in the area were necessary for a portion of the analysis. Land use information was gathered from historical and recent National Land Cover Datasets (NLCD). Aerial photography from the 2018 IndianaMap Framework Dataset was inspected to generally confirm the land uses shown in the NLCD data. A map of land use change is provided in Exhibit 2.

Topographic Data
The analysis of the Upper Wabash River corridor through the study area required detailed topographic information for various calculations. The 2016 IndianaMap Digital Elevation Model (DEM) was used as the source of topographic data for floodplain connectivity considerations. The IndianaMap DEM covers the entire Upper Wabash River Watershed and has a 2.5-foot cell resolution, which is sufficient for producing 1-foot contours.

Streamflow Data
Streamflow information was obtained from the United States Geological Survey's (USGS) online portal to provide an extensive record of the hydrology for the Wabash River. The streamflow information was used to determine long-term trends in flow rates and the frequency of significant storm events.

Surficial Geology and Soils Information
Geologic composition and deposition information was obtained from the Quaternary Map of Indiana (Gray, 1989). A map showing the distributions of the various glacial deposits in the Upper Wabash River watershed is shown in Exhibit 3.

Soils information was obtained from the United States Department of Agriculture (USDA) Soil Survey Geographic Database (SSURGO) to provide the properties of the soils along the Upper Wabash River corridor. The characterization of channel bed and bank material at the project sites were completed using visual observations.

2.2 PREVIOUS STUDIES AND ANALYSES

The review of previous studies in the Upper Wabash River Watershed was limited to hydrologic and hydraulic analyses, as well as a small number of other reports of significance to fluvial stability and flooding considerations.

Previous Studies

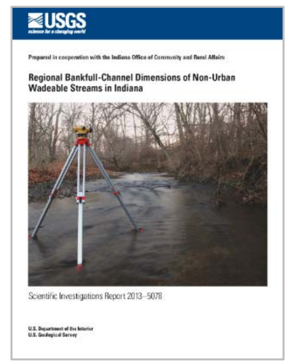
Applicable references included the following reports published by the United States Geologic Survey, the Federal Emergency Management Agency (FEMA), and Burke.

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

A total of 42 streams 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, Upper Wabash River has the 18^{h} highest lateral migration rate. The channel moves at a rate of less than 1 foot per year on average.

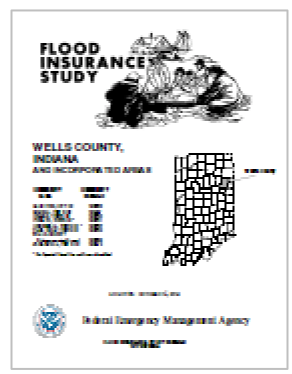
Regional Bankfull Channel Dimensions of Non-Urban Wadeable Streams in Indiana (USGS, 2013b)

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.



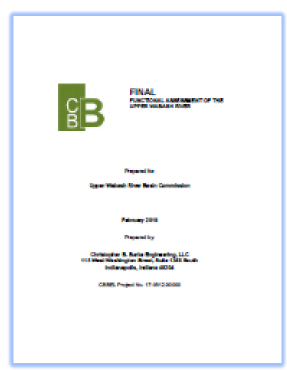
Flood Insurance Study – Wells County, Indiana and Incorporated Areas (FEMA, 2014)

The most recent FIS report for Wells County details flood elevations along the Wabash River and selected tributaries for the 10-, 50-, 100-, and 500-year return period events. Longitudinal profiles of the water surface elevations for the respective events can be found within the report. An interactive map of the 100- and 500-year floodplains can be accessed through the Indiana Department of Natural Resources' (IDNR) Flood Information Portal (INFIP), which can be found at following link: https://dnrmaps.dnr.in.gov/appsphp/fdms/.



Functional Assessment of the Upper Wabash River (Burke, 2019)

Burke completed a detailed assessment of the Upper Wabash River from the Ohio-Indiana state line to the City of Bluffton in Wells County, IN. The effects of land use, surficial geology, and hydrologic trends on stream function and stability were described. Several stream stability issues were identified and conceptual solutions were provided.



Available Models

Hydrologic and hydraulic models exist for the study reach. However, based on observations made during this assessment and the findings provided in Chapter 3 and Chapter 4 of this report, discussion of the models does not provide significant additional insight for the current study.

3.0 FUNCTIONAL CHANNEL ASSESSMENT

3.1 INITIAL BACKGROUND ANALYSIS

An initial background analysis was completed to develop a baseline understanding of the river system prior to completing site visits and visual observation of the river corridor. The initial background analysis included evaluation of the physical basin characteristics, surficial geology and soils, the extent and composition of the riparian corridor, and the hydrologic characteristics of the contributing watershed. The majority of this information was taken from the 2020 Functional Assessment report by Robert Barr, which is included in Appendix 1

3.1.1 Basin Physical Characteristics

The Upper Wabash River has a drainage area of approximately 600 mi^2 at the confluence with Rock Creek near Markle, IN, with nearly 260 mi^2 of that area residing in the State of Ohio. The total drainage area is difficult to accurately measure due to the uncertainty of the contribution of Grand Lake in Ohio. The Upper Wabash River flows from southeast to northwest through the northeast portion of the State of Indiana. The watershed of the current study reach is approximately 90 mi^2 and includes the cities of Bluffton and Markle as well as smaller towns including Murray, Uniondale, and Kingsland. The predominant land use for the watershed is agricultural.

3.1.2 Surficial Geology and Soils

Surficial geology is important when considering the potential for erosion and stream stability issues. The Upper Wabash River is in the Tipton Till Plain and is composed of silty clay and clayey till materials. The surficial geology deposition type in the study area is dominated by recent alluvium, fine-textured lacustrine deposits, and Wisconsin outwash (Barr, 2020). Till refers to material that has been deposited by glaciers and is typically very hard and difficult to erode. Alluvium refers to material that has been deposited by moving water at some time in the past. The fact that the river has transported the sediment previously makes it likely that the material is still able to be moved by water, especially since the alluvial deposits are generally friable, or poorly consolidated.

The capacity of a soil to resist erosion is primarily dependent on three major factors. The first two factors are soil grain size and cohesion and often determine the importance of vegetation, the third factor. Fine-grained, low cohesion or cohesionless soils such as sands and silts have a low tolerance for erosive forces and require vegetation to remain stable over long periods of time. Clayey soils are cohesive and are much more resistant to erosion than sands and silts. Higher percentages of clay in a soil type can dramatically increase the resistance to erosion. The soils along Upper Wabash River in the study area are predominantly silty loams or clay loams (Barr, 2020). Silty loams composed of sand, silt, and a smaller amount of clay, plus organic material. They are generally friable, poorly consolidated, and easily eroded. Clay loam soils are composed of a nearly equal amount of clay, sand, and silt. They are cohesive and not easily eroded.

3.1.3 Wooded Riparian Buffer Assessment

The existence of vegetation is often the most critical factor for the capacity of a soil to resist erosion. Vegetation reinforces the soil structure and serves as a buffer to reduce stress on the soil surface. Most of the study reach was bordered by a forested corridor, though the width of the buffer is quite narrow in places. The presence of a buffer can allow for small, natural adjustments of the stream necessary to maintain stability without impairing adjacent land uses.

3.1.4 Hydrology

The response of the watershed to rainfall is a key factor in the amount of fluvial instability and flooding risk potential posed by a stream. The amount of runoff generated, and the time required for the flow to accumulate and reach the stream affect the erosive potential of the channel and determine how much flow must pass through the most restrictive sections of the channel which may or may not result in significant flooding. Increased drainage efficiency in agricultural areas and other intensive land uses frequently increase runoff and decrease infiltration. These changes often result in higher and more frequent peak flows, as well as a larger volume of runoff.

Details concerning the watershed upstream of Bluffton, Indiana are included previous reports by Burke (2019) and Bob Barr (2018). The Wabash River watershed from Bluffton to Markle is primarily agricultural in nature (roughly 83%), with most of the remaining land area devoted to comparable amounts of urban (8.0%) and forested (7.3%) land cover. The land use characteristics of the watershed have remained largely unchanged over the past 20 years, according to NLCD datasets. The land use change within the Middle Upper Wabash River Watershed from Bluffton to Markle is shown in Figure 2. A map showing the spatial distribution of the land use changes is shown in **Exhibit 2.**

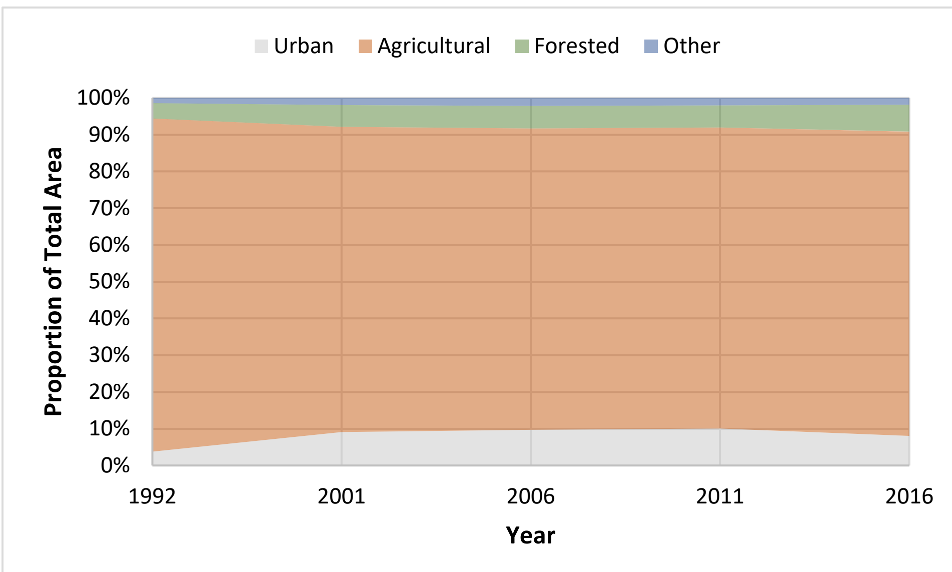


Figure 2: Land Use Characteristics in the Middle Upper Wabash River Watershed

3.2 STREAM GAGE AND PRECIPITATION ANALYSIS

An analysis of available hydrologic data was completed to determine the characteristics and trends in the watershed's response to rainfall. Two gages were analyzed: the Wabash River streamflow gage at Bluffton, IN (USGS Gage 03322985/03323000) and the gage at Linn Grove, IN (Gage 03322900). Although the Linn Grove gage is located upstream of the study reach, it was included due to the short duration and intermittent nature of the daily flow data from the Bluffton gage. The Linn Grove data show an upward trend for peak annual flow rates from 4,700 cubic feet per second (cfs) to 7,200 cfs (Burke, 2019). The increase in peak annual flow shows that large events that can cause significant channel erosion and adjustment are occurring more often.

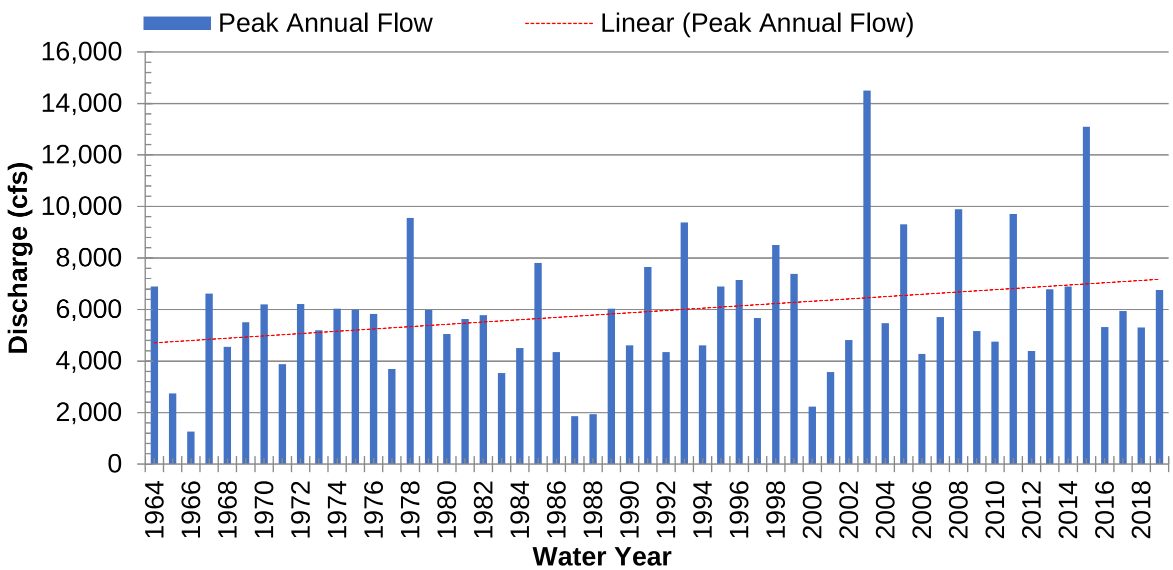


Figure 3: Peak Annual Flow Rate at USGS Gage in Linn Grove, IN

It is important to remember that erosion typically occurs in streams at all flow rates, it is simply a matter of how much erosion occurs. High flow rates obviously lead to high erosion rates; however, it is typically the bankfull flow rate that statistically moves the most sediment over time. This fact highlights the true nature of erosion in streams, a relatively slow and grinding process that is constantly reshaping the channel. For a healthy stream, the bankfull flow rate will occur for a few hours, roughly every 18 months. A statistical analysis of the Linn Grove gage data suggests that the bankfull flow rate is approximately 4,770 cfs, and the average number of days at bankfull has doubled in the last 18 years (Burke, 2019).

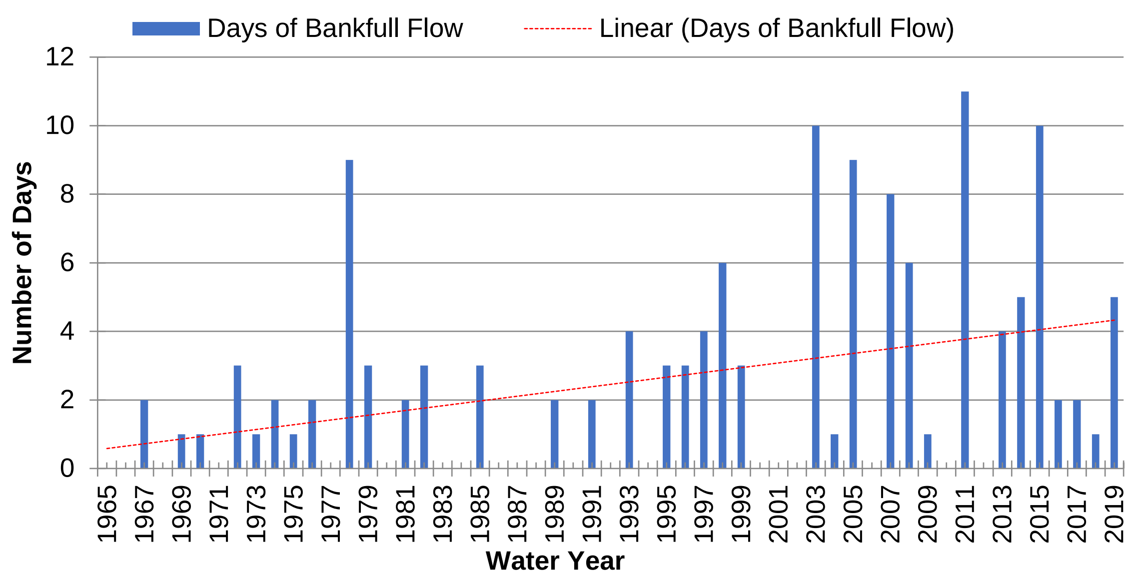


Figure 4: Frequency of Bankfull Discharge at USGS Gage in Linn Grove, IN

The data from the Bluffton gage show similar trends. Figure 5 shows the annual peak flow measured for that gage. There are two very large events (1904, 1912) early in the period of record that heavily influence the overall trend in peak flow values. If those data points are included, the trend is essentially flat, with a 1.5% increase from 1904 to the present (red dotted line). If those points are replaced with the average value for the period of record, the trend becomes much more pronounced, showing a 30% increase in annual peak flow (black dotted line).

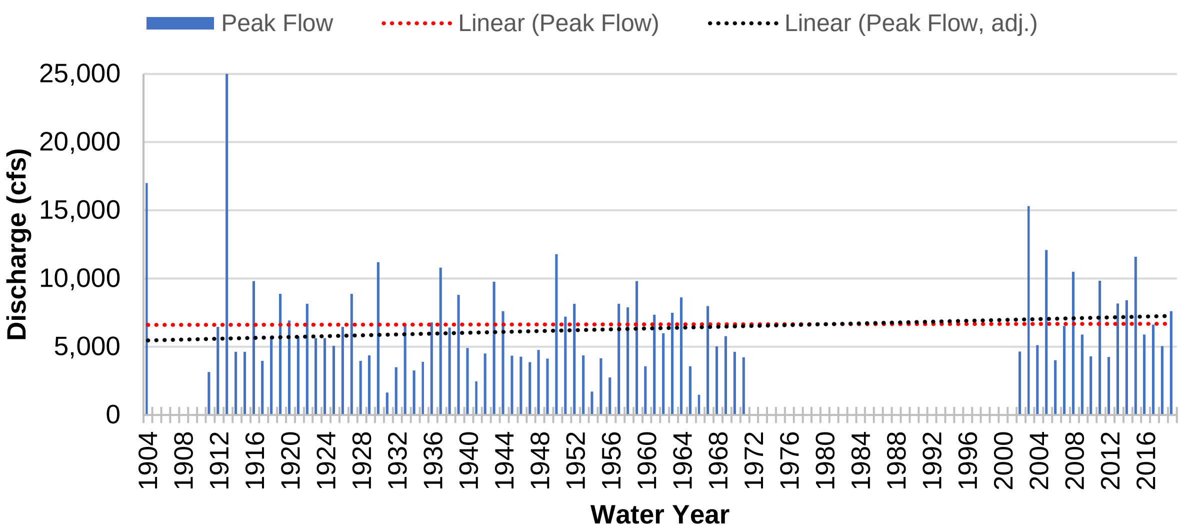


Figure 5: Peak Annual Flow Rate at USGS Gage in Bluffton, IN

The period of available daily flow data for the Bluffton gage extends only from 2001-2008 and 2015-present (Figure 6). Between 2008 and 2015, the gage was moved downstream approximately 1.5 miles, from the White Bridge just upstream of Bluffton to its current location at Main Street. Analysis of the peak flow values at this gage indicates that the bankfull discharge is approximately 4,810 cfs. The short period of record and large gap in data make it difficult to draw meaningful conclusions about the trend in bankfull flow at this location. However, the data are reasonably similar to the Linn Grove gage data over the period of record in terms of average number of days and the pattern of high and low years. This supports the hypothesis that behavior at the Linn Grove gage is a realistic proxy for the Bluffton gage, which is approximately 10 miles downstream.

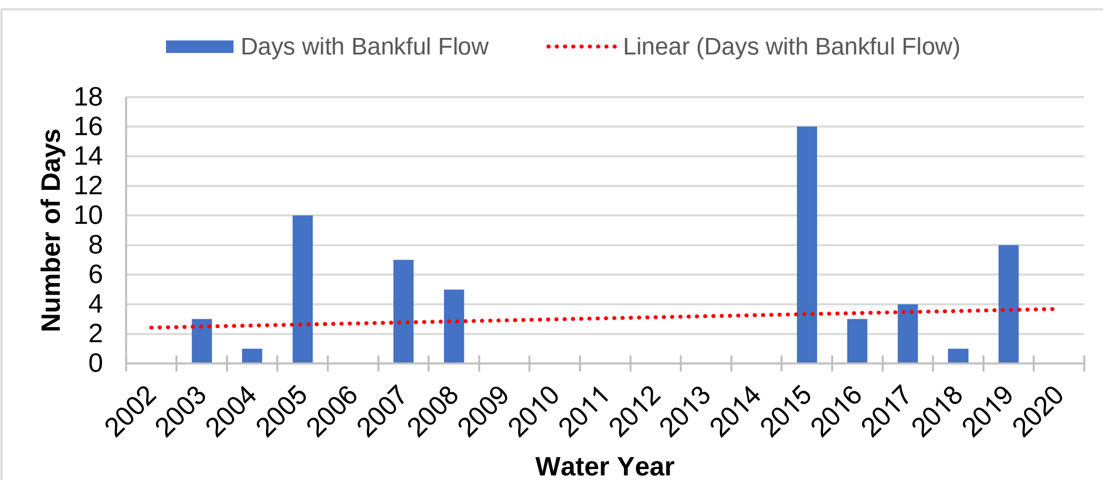


Figure 6: Frequency of Bankfull Discharge at USGS Gage in Bluffton, IN

The average annual precipitation in northeast Indiana is approximately 36 inches. The annual precipitation has an increasing trend over the last 120 years (Climate at a Glance, NOAA), increasing by approximately 4 inches over that period. A more pronounced trend in has been observed since 1960, as shown in Figure 7.

More relevant with regards to flooding and erosion potential than annual average precipitation is the frequency of heavy rainfall events. Previous studies of National Weather Service data from 1958 to 2016 has shown that Indiana as a whole has seen the days of extreme precipitation events increasing from 1 to 3 days since 1900 (IN CCIA, 2018), as shown in Figure 8.

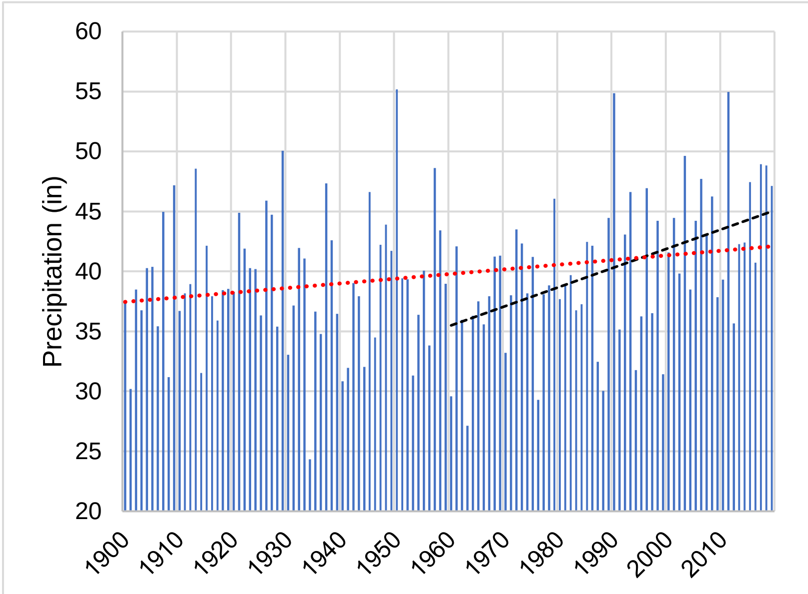


Figure 7: Annual Rainfall Depth, Northeast Indiana
(Climate at a Glance, NOAA)

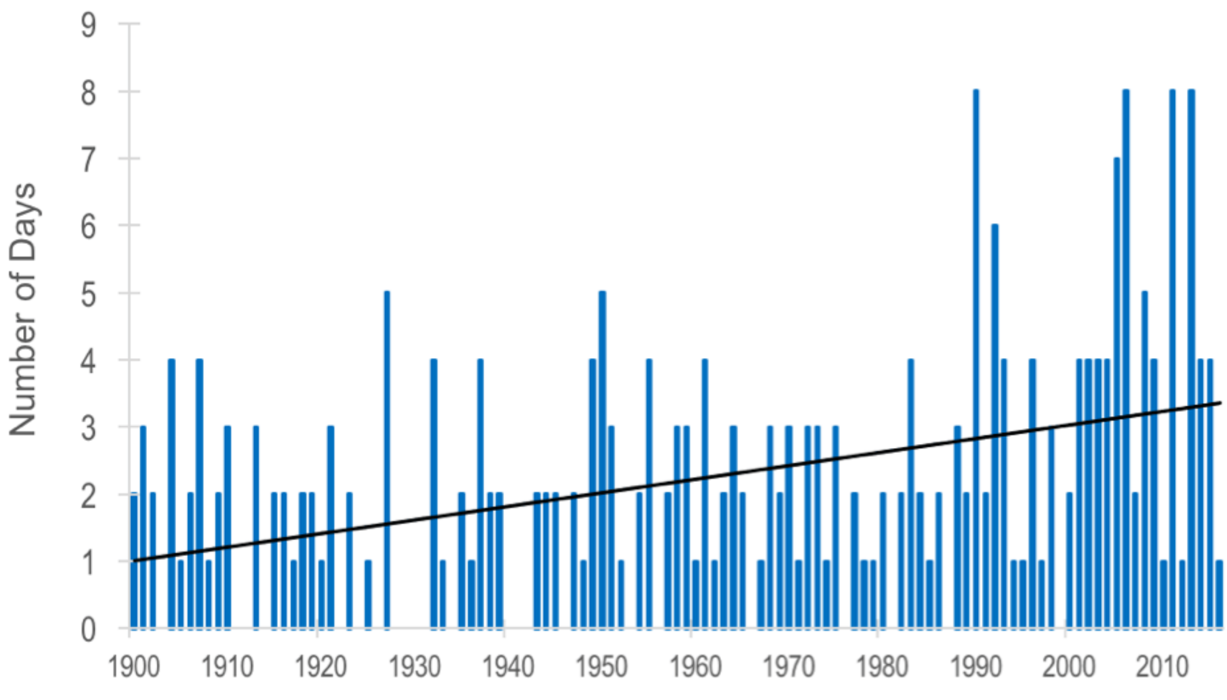


Figure 8: Change in Very Heavy Precipitation
(IN CCIA, 2018)

3.3 CURRENT GEOMORPHIC CHANNEL CHARACTERISTICS

The study reach was divided into two sections based on their channel morphology and history of modification (Barr, 2020). The Upstream Reach, or Bluffton Reach, is from the White Bridge on S County Rd. 450 E to N. Oak Street Ext. shown in Figure 9. This reach is approximately 3.3 river miles and has a bed slope of approximately 2.9 ft/mi. Signs of historical straightening through the City precluded natural sinuosity from being calculated.

Figure 9: Upstream Reach
(S CR 450 E to N. Oak Street Ext. in Bluffton, IN)

The Downstream Reach (Figure 10) extends west from Bluffton to the Wells-Huntington County Line near Markle shown in Figure 10. This reach has a comparable but slightly lesser bed slope of 2.52 ft/mi. Although it is more sinuous than the upstream reach, this reach has a sinuosity value of only 1.2 (with 1.0 denoting a straight line). The sinuosity of the channel typically indicates lateral channel migration; however, the lateral migration rate of the Upper Wabash River is less than 1 foot (USGS, 2013). The lateral stability of the river is due to the clayey till that forms the channel bed and the lower bank. (Barr, 2018).

Figure 10: Downstream Reach
(Bluffton to Markle, IN)

Using the Rosgen stream classification system, the Upstream Reach (Bluffton) was classified as an F4 channel and the downstream reach was classified as a B4c channel. An F4 channel is an entrenched, moderately sinuous channel with low elevational relief. A B4c channel is a moderately entrenched, moderately sinuous channel with low elevational relief.

The study reach of the Wabash River is generally a very stable river. The main channel has eroded into the silt and clay till, which is a very resistant boundary condition (Barr, 2020) that has contributed to a stable toe-of-slope for the channel banks and low lateral migration rates.

3.4 PROBLEM AREA IDENTIFICATION

3.4.1 INITIAL PROBLEM AREA IDENTIFICATION AND VERIFICATION

Several locations were identified as areas of concern by members of the UWRBC during a conference call in March 2020. UWRBC members also cited concerns about large wood and the potential for logjams.

The noted areas of concern, and other areas, were assessed during a series of field visits by Burke and/or Bob Barr from June to September 2020. The River and areas of concern were assessed by a combination of boating and wading in the River, observations at road crossings, and walking on foot along the River and its tributaries.

A total of seven problem areas were identified during the functional assessment. The evaluation, identification, and confirmation of problem areas was completed using the full spectrum of available data. Because all identified problem areas are not the same "type" of problem, there is no single index that can be used to rank them objectively. Rather, a combination of factors including current or potential future erosion risk, risk to human life, or other stream health impediments.

3.4.2 LIST OF PROBLEM AREAS

Seven sites were identified as problem areas, as shown in **Exhibit 4**. All of the sites are in the City of Bluffton in Wells County. The problem areas are listed roughly from upstream to downstream in Table 1.

Table 1: List of Problem Areas

Location	Description
Bill's Creek (Markley Ditch)	Channel obstructions near mouth, including riprap and poured concrete, inhibit movement of water, sediment, and biota
Greenway Trail	Trail-side holes and adjacent streambank erosion were noted near storm sewer outlets
River Road	Pipelines across bed of channel should be monitored for instability and risk to recreators
John's Creek	Channel is incised and highly unstable for ≈1500 ft near confluence with Wabash River
Wayne Street	Vegetation maintenance around utility lines along the right bank appear to have resulted in large areas of bank erosion
Wells Co. Chamber of Commerce and Economic Development Building	Left bank should be monitored for potential future instability at upstream and downstream ends of current bank stabilization extents
N. Oak Street Ext.	Retaining wall is showing signs of wear and possible erosion near downstream end

3.4.3 RANKING OF PROBLEM AREAS

Each of the problem areas were examined to determine their rank of most critical to least critical based on perceived risk level given the anticipated detrimental impact if the area was compromised. Table 2 provides a ranking of the problem areas and the reason for the ranking.

Table 2: Ranking of Problem Areas

Problem Area	Rank	Basis for Assigned Rank
John's Creek[1]	1	Highest potential for sediment contribution to Wabash River; on City property
Bill's Creek (Markley Ditch)[1]	2	Impairment of tributary stream quality and aquatic organism dispersal; risk of pedestrian injury
N. Oak Street Ext.	3	Risk to human life if wall fails; lack of feasible conceptual solutions
Greenway Trail	4	Risk of injury to cyclists and pedestrians
Wells Co. Chamber of Commerce and Economic Development Building	5	Potential for future instability along sharp meander bend
River Road	6	Risk of channel bed instability; risk of injury to kayakers
Wayne Street	7	Current and potential future bank instability and erosion potential

[1]Conceptual solutions detailed in Chapter 4

4.0 CONCEPTUAL SOLUTIONS

The instabilities and issues present at each of the top three ranked problem areas are clarified in the following paragraphs to provide a context for the proposed solutions for each location. The conceptual solutions shown in Exhibits 5 through 7 and discussed in the paragraphs below are specific to the needs of the individual locations. Without a detailed and site-specific consideration of consequences, the installation of bank stabilization measures can result in increased erosion and instability downstream of the project. It must be noted that the conceptual solutions described below and in Exhibits 5 through 7, though based on field observations and measurements, are not construction-ready plans and a more thorough technical evaluation of the sites may indicate that deviations from the solutions provided here may be necessary.

4.1 PROBLEM AREA AT BILL'S CREEK

The problem area located at the mouth of Bill's Creek (sometimes labeled Markley Ditch on maps) is primarily the result of a large amount of riprap that his fallen into the channel beneath the River Road and Greenway Trail crossings, as shown in Figure 11. For Bill's Creek, this has resulted in a small number of almost check dam-like piles that create small pools in the Creek and restrict hydraulic and biotic interaction between the River and the Creek during low-flow conditions. Either through natural transport by the Creek during storm events or human intervention, riprap has become strung out into the Wabash River channel, which can lead to increased bank erosion on the downstream side of the protrusion.

The popularity of the Greenway Trail and the ease of access to the stream from the Trail at this location lead to a large number of children playing on and near the riprap on a regular basis. This could lead to increased risk of child injury and degradation of stream quality through piling of rocks or wearing down exposed portions of the bank.

To increase the connectivity between the River and Bill's Creek, it is recommended that the riprap be removed from the mouth of the Creek and a more consistent bed slope be maintained as the Creek goes under the road and trail crossings into the River. The removal of large rocks will also reduce the risk of children falling or injuring themselves or others.

Figure 11: Obstruction of Bill's Creek and Wabash River by Riprap

The proposed improvements consist of removing the riprap that has fallen into the channel and re-grading the channel bed as it passes under the Greenway Trail crossing and meets the Wabash River. This will remove the obstruction of water and sediment transfer between Bill's Creek and the Wabash River. It will also increase biological connectivity that is currently hindered by the riprap in a similar manner. The length of the channel reshaping will be approximately 35 feet. A schematic layout of the potential improvements is provided in **Exhibit 5**.

The cost of designing, permitting, and constructing these improvements is expected to be approximately $48,700. A detailed breakdown of the anticipated project cost is provided in Appendix 2.

4.2 PROBLEM AREA AT JOHN'S CREEK (LOWER REACH)

The lower reach of John's Creek from the gravel crossing to the riparian corridor of the Wabash River is characterized by vertical banks and in-channel sediment buildup. An additional consideration for this reach is the vulnerability of a power line that runs tangent the channel near the downstream end of the reach, as shown in Figure 12. It is possible that the spraying of vegetation under the power lines has contributed to the instability of the meander, though it does appear that reasonably dense vegetation is still present.

Figure 12: Mid-channel Bar (top) and Power Line in Meander Bend (bottom)

There are signs of bank instability along John's Creek within the wooded riparian corridor of the River, but stabilization projects are not being recommended at those locations due to the presence of numerous large trees adjacent to the Creek.

The proposed improvements consist of regrading the slopes on the outsides of meander bends to a more stable 3H:1V slope and treating the regraded slopes with coir fabric and live willow stakes. In addition, soil will be removed from the inside banks of the meanders down to the expected bankfull elevation to increase floodplain connectivity and further reduce stress on the outside bends. The regraded inside banks and other disturbed areas will be reseeded with a native prairie seed mix. A Newbury riffle will be installed to stabilize the channel bed and improve habitat for benthic organisms at the transition into the wooded riparian corridor at the downstream end of the reach. Excavated material may be used to build up the berms surrounding the lime ponds in the area as needed. A schematic layout of the conceptual improvements is provided in **Exhibit 6**.

The cost of designing, permitting, and constructing these improvements is expected to be approximately $112,800. A detailed breakdown of the anticipated project cost is provided in Appendix 2.

4.3 PROBLEM AREA AT JOHN'S CREEK (UPPER REACH)

Much of the length of John's Creek that is on City property near the Water Filtration Plant is characterized by near-vertical, failing banks due to high rates of erosion. Due to the length of the problem area, it has been split roughly in half at the existing gravel access road that passes through the channel between lime ponds. Both reaches are experiencing particularly high bank instability on the outside of meander bends, as shown in Figure 13. The bank erosion and widening of the channel have caused sediment to build up to the point where vegetation has become established on mid-channel bars. These bars are able to persist through normal, low-flow conditions and possibly contribute to higher water levels and greater bank stress during high-flow events.

Figure 13: Channel Instability and Bank Failure on John's Creek

Failed, over-steepened, and undermined banks are unstable due to an inability to support the weight of the soil forming the bank. Where banks suffer from this type of geotechnical instability, a simple and cost-effective means of correcting the issue is to reduce the slope to a more stable angle, typically in the range of 3-feet horizontal to 1-foot vertical (3H:1V), or flatter.

The proposed improvements consist of regrading the slope on along much of the right bank including the outside of the meander bend upstream of the existing gravel crossing to a more stable 3H:1V slope and treating the regraded slope with coir fabric and live willow stakes. The existing gravel crossing will be replaced with a Newbury riffle to maintain grade upstream of that location and redirect flow towards the center of the channel downstream. The inside meander bend at the upstream end of the reach will be excavated down to the expected bankfull depth to relieve stress on the opposite bank near a private garage. Disturbed areas will be reseeded with a native prairie seed mix. Excavated material may be used to build up the berms surrounding the lime ponds in the area as needed. A schematic layout of the potential improvements is provided in **Exhibit 7**.

The cost of designing, permitting, and constructing these improvements is expected to be approximately $89,000. A detailed breakdown of the anticipated project cost is provided in Appendix 2.

4.4 IMPROVEMENT COST SUMMARY

A summary of the cost estimate for the improvements at each of the problem areas is included in Table 3. The cost estimates are arranged based on the ranking of the problems from most to least critical.

Table 3: Summary of Cost for Each Problem Area

Address	Rank	Cost of Construction	Cost of Engineering	Total Cost
John's Creek, Lower Reach	1	$75,800	$37,000	$112,800
John's Creek, Upper Reach	2	$52,000	$37,000	$89,000
Bill's Creek	3	$21,700	$27,000	$48,700

4.5 LIMITATIONS FOR CONCEPTUAL STRATEGIES

The proposed conceptual strategies make several key assumptions that may greatly affect the details and cost of the improvements.

Environmental Permitting and Mitigation

It is anticipated that stabilizing the streambank at the proposed locations will require the acquisition of the following environmental permits, at a minimum:

- IDNR Construction in a Floodway
- IDEM Section 401 Water Quality Certification

- USACE Section 404 Dredge & Fill Permit
- IDEM Rule 5 Permit

4.6 ALTERNATIVE MITIGATION STRATEGY CONSIDERATIONS

The effect of foregoing implementation of any improvements was also evaluated from a theoretical standpoint. The 'Do Nothing' alternative is generally expected to result in the following:

1. No up-front costs associated with making improvements would be incurred.
2. No reduction in sediment contribution to the stream would be realized.
3. The habitat quality of the Wabash River, John's Creek, and Bill's Creek would not be improved.

4.7 PROBLEM AREAS NOT ADDRESSED WITH CONCEPTUAL SOLUTIONS

The following issues were identified as problem areas but are not addressed with conceptual design solutions in this report due to either lesser risk or lack of feasible solutions.

N. Oak Street Ext.

There is an approximately 350-foot-long retaining wall along the N. Oak Street Ext. The wall is approximately 12 feet tall, 18 inches thick, and appears to be several decades old. Although there is a guard rail along the road at this location, the distance from the guard rail to the top of the wall is less than five feet in some locations. While the potential risk to human life in the event of a wall failure is high, it is impossible to determine when such a failure might occur. The cost to substantively improve the condition of the wall, which might require replacement to achieve, could total close to $1 million. A more feasible long-term solution to the problem might be to purchase the small number of properties adjacent to the road and prevent future residence on the property after the current owners have left. Much of the property along the River in this area is within in the FEMA Special Flood Hazard Area, and thus federal grants may be available to assist in the purchase of the property. However, in some cases, the houses themselves are on high ground above the base flood elevation, which may disqualify them from purchase assistance.

Figure 14: Proximity of Wall to Road and Signs of Wear

Greenway Trail

There are several areas along the Greenway Trail adjacent to the Wabash River where old pipes have collapsed or broken. These failures have caused small sinkholes to form near the paved pedestrian trail. Continued erosion may compromise the path in some locations. Pedestrians who run off-trail or cyclists who leave the pavement to avoid others are potentially at risk of injury because of these holes and depressions. Although no specific remediation plans for this issue are provided here, it is recommended that these areas be identified, monitored, and addressed as needed to maintain the integrity of the trail and safety of its users. There are also locations where the bank adjacent to the Trail is "scalloped" out behind riparian trees or localized riprap applications. These should be monitored for progression towards the paved path.

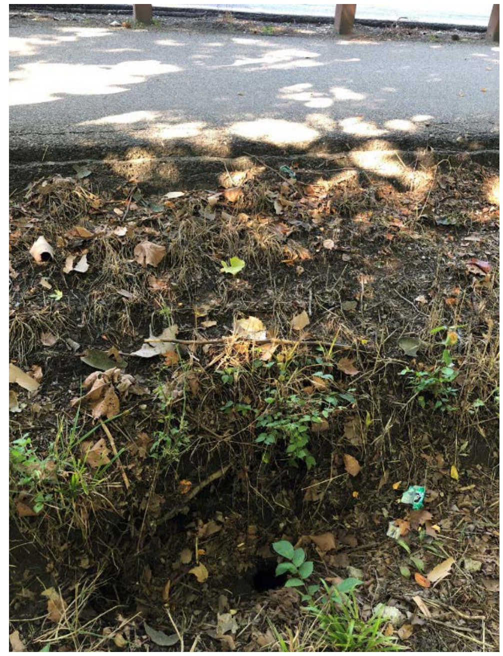


Figure 15: Hole near Greenway Trail

Wells County Chamber of Commerce and Economic Development Building

The south bank of the Wabash River has been modified and vegetated in the past 20 years to stabilize the slope following the construction of the new building and sidewalk. The location of this project on a relatively high bank and at the start of a meander bend in the River put the bank just downstream of the stabilized portion at increased risk of instability. Localized bank stabilization measures, particularly in stream bends, often concentrate erosive potential at their downstream ends as the bank transitions back to its natural composition. The heavily wooded nature of the downstream bank may serve to naturally mitigate the risk at this location. Continued monitoring of the condition of that high bank is recommended.

River Road (Pipeline Crossings)

There are four high pressure gas pipelines that pass under River Road and across the channel bed of the Wabash River. The crossings appear to have been capped with rock or other hard materials that tend to focus flow to the middle of the channel (notice the localized sediment and vegetation accumulation on either side). This could lead to scour or other bed instabilities. Depending on flow conditions, these artificial "riffles" may also pose a hazard for kayakers or other recreators within the channel. If it becomes necessary, the pipelines may be relocated or channel bed mitigation such as Newbury riffles may be implemented.

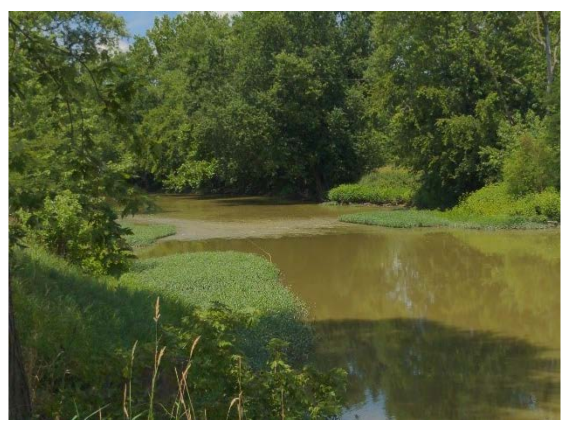


Figure 16: Pipe Crossing across River Channel

Wayne Street (Power Lines)

The clearing of vegetation around power lines has caused bank instability within an otherwise relatively stable, vegetated corridor on the right bank of the River across from the end of Main Street. This phenomenon is quite common, particularly on tall banks or banks made of coarse material that rely on roots to provide structural stability. If possible, it is recommended that utility easements be relocated outside of the wooded riverine corridor or shorter vegetation be maintained in lieu of trees where needed.

Figure 17: Bank Failure near Power Line Clearing

4.8 LARGE WOOD

Due to the degree to which the Middle Upper Wabash River is bordered by a forested riparian corridor, the periodic presence of large wood in the channel is inevitable. Several potential logjam locations were investigated by field observation when possible, while relying heavily on historical aerial photography to estimate the prevalence of debris collection over time. In the City of Bluffton, the Main Street bridge and the Norfolk Southern RR crossing appear to be the primary locations of woody debris buildup. The Wabash Central RR crossing and the abandoned crossing between the Norfolk Southern rail and the N. Oak Street Ext. seem to collect debris less frequently. In general, logjams do not appear to be a chronic issue within the city, but the need for periodic logjam clearing may be expected, as with most large, heavily forested rivers.

Downstream from Bluffton, the primary collection point for woody debris in the Middle Upper Wabash River is at the Town of Murray, at the end of N County Rd 100 E. A sharp westward bend in the River combined with an in-channel island near the abandoned roadway near State Road 116 creates prime conditions for large wood deposition. Based on historical aerial imagery, it appears that the debris primarily collects in the side channel to the right of the island, but at times the debris may also obstruct flow and watercraft passage through the main channel. As with the locations described in Bluffton, no specific preventative maintenance or wood management programs are prescribed, but the location should be monitored and addressed as appropriate.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the functional assessment described in Chapter 3 suggest that the issues at the identified problem areas can be corrected using site specific stabilization measures provided in Chapter 4. While the improvements are expected to remedy the issues at these specific locations, the improvements are not expected to meaningfully alter the stability of other areas along the river. The following paragraphs outline the improvements that are recommended for implementation based on the findings of the functional assessment and the practicability of the proposed improvements. Additional recommendations to promote the stability and sustainability of the river, as well as additional study needs for future stewardship of the river corridor are provided.

5.1 RECOMMENDED CHANNEL IMPROVEMENTS

1. **Implement Proposed Improvements to John's Creek**

   The improvements to John's Creek (Lower and Upper Reaches) are the highest priority areas due to the potential to greatly reduce the amount of sediment entering the Wabash River and the advantage of the project sites being located on City property. Stabilizing the banks and adding riffles will also improve habitat quality within the mitigation area and in the wooded riparian zone between the mitigation reach and the Wabash River.

2. **Implement Proposed Improvements to Bill's Creek**

   The improvements at the mouth of Bill's Creek are given a lower priority because of the overall lesser impact on the health of the Wabash River. However, the project is still expected to provide hydraulic and biotic benefits to Bill's Creek and the River. The high amount of pedestrian traffic in and near the project site increases the safety benefits of removing the riprap from the area and may provide increased visibility of ongoing efforts to improve stream quality along the Upper Wabash River.

5.2 RECOMMENDED PASSIVE MANAGEMENT PRACTICES

As discussed in Chapter 3, the observed (and projected) peak discharge increasing trends have and will continue to act as a watershed stressor, exacerbating the potential for slope failures along the Wabash River. While the scope of this study did not include an examination of all the reasons for the observed and forecasted increases, based on experience with similar areas in Northern Indiana, the major factors contributing to peak discharge increases along the stream are the impacts of climate change in frequency, intensity, and depth of precipitation, increase in runoff peaks and volumes resulting from urban development and agricultural drainage practices, and encroachment and loss of floodplain storage within the river corridor. The following passive management practices should be promoted and implemented to help reduce the impacts of watershed stressors.

5.2.1 SOIL HEALTH PRACTICES

In agricultural areas, the health of the soil has been found to have a noticeable impact on runoff amounts. More organic material in the soil equates to an increase in soil moisture potential, or the ability of the soil to store water. Essentially, organic material in the soil is the agricultural equivalent of bioinfiltration/rain gardens in the urban setting. There are also substantial benefits for agriculture in terms of decreased energy overhead and increased drought tolerance. The set of practices that the NRCS terms "soil health" appear to be the future of sustained agriculture and have the potential to change water management in agricultural regions of the United States.

Current farming practices focus on tillage and clearing the land for "the crop". Soil health practices instead focus on continuing the crop and continuing to improve the soil. An example of a cover crop for improving soil health is shown in Figure 18. Soil health is a work in progress, with experiments across the country attempting to document the benefits of a soil health system. Farmers in Indiana are reporting increased drought tolerance and an increase of as much as 27,000 gallons of water per acre with a 1% increase in soil organic matter; this is approximately equal to storing 1-inch of runoff. That number will certainly vary with soil texture, antecedent conditions, and a number of other factors but the significance is that soil moisture storage can be increased – significantly.

Figure 18: Cover Crop Growing in Harvested Corn Field

In a watershed like the Upper Wabash River with limited natural storage, increasing the infiltration and runoff storage potential of the soil is one of the most effective ways to reduce runoff. To highlight the potential magnitude of the benefit that could be afforded by improved soil health, the total flow volume of the Upper Wabash River at the Bluffton gage was 660,000 ac-ft in 2018. If the cultivated portions of the watershed (~450 mi^2) were to increase the organic content of the soil by 1%, an additional 24,000 ac-ft of runoff could be stored in the soil. This would have reduced the volume of flow through the Upper Wabash River by approximately 3.6%.

5.2.2 ORDINANCE AND STANDARDS REVISIONS

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 Upper Wabash River at Linn Grove stream gage data shows a clear increasing trend in flow rates despite the current level of stormwater detention requirements within the watershed. Although detention has been required in both Wells and Huntington Counties, 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.

Wells and Huntington Counties should update their Stormwater standards to include the above-noted more restrictive, No-Adverse-Impact requirements when new development is proposed within the County jurisdictional areas.

5.2.3 INCREASED BUFFER WIDTH

The buffer on the riparian corridor should be increased to reduce the detrimental impact of natural stream adjustments and to prevent incompatible land uses along the stream. While the removal of tillable land and reduced utility in urban areas has a cost, there is an economic benefit to increasing the buffer width for landowners adjacent to eroding areas. Planting crops along a bank that later fails and takes the young crop with it, caring for a lawn that sloughs into the channel, or constantly attempting to repair or stabilize the bank are all expenses that are potentially unnecessary in the end. Individual landowners typically only have a problem with erosion along a stream if they have something too close to the channel and are at risk of losing their investment. If the buffer width is adequate, the problem with the erosion (even if the erosion continues) is typically eliminated.

5.3 NEXT STEPS

The following list provides the actions that should be taken after review of the functional assessment report:

1. Meet with Burke to discuss the findings and recommendations of this report.
2. Determine which project(s) are to be implemented and seek sufficient project funding. Begin detailed design after funds have been allocated.
3. Continue to seek agreements with landowners and funding opportunities to facilitate property buyouts along the N. Oak Street Ext.

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EXHIBITS

APPENDIX 1: GEOMORPHIC ASSESSMENT REPORT

APPENDIX 2: COST ESTIMATES