DANDY TRAIL SITE
FEH MITIGATION ALONG EAGLE CREEK

Prepared for:

Indiana University and the Indiana Office of Community and Rural Affairs (OCRA) in Support of the Development of the Indiana Fluvial Erosion Hazard Mitigation Manual, an Indiana Silver Jackets Initiative

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Table of Contents

List of Tables and Figures

List of Exhibits

List of Appendices

EXECUTIVE SUMMARY

This report documents the results and methodology used by Christopher B. Burke Engineering, LLC (CBBEL) to characterize an existing fluvial erosion hazard (FEH) at a site on the waterside toe of Levee 12(c), along Eagle Creek downstream of Dandy Trail in Indianapolis, Indiana. This study and preparation of this document was conducted in support of the development of the Indiana Fluvial Erosion Hazard Mitigation Manual, which was an initiative of the Indiana Silver Jackets, made possible through a grant from the Indiana Office of Community and Rural Affairs (OCRA). A FEH mitigation study approach was used to identify the stressors leading to channel instability issues to aide in the development of conceptual mitigation solutions.

Eagle Creek is a tributary to the West Fork White River; the watershed extends into Boone, Hamilton, Hendricks, and Marion Counties and includes portions of Brownsburg, Carmel, Indianapolis, Lebanon, Westfield, Whitestown, and Zionsville. Approximately 162 square miles of the 210.6 square mile total drainage area contributes to Eagle Creek Reservoir.

A system assessment of Eagle Creek was completed by CBBEL to identify the root causes of the erosion that occurs near the toe of Eagle Creek Levee 12 [EC-12(c)], approximately 1.1 miles downstream of the Eagle Creek Dam. The system assessment included review of previous studies and analysis of available data that was focused primarily on EC-12(c). The system assessment determined that two major factors are most responsible for the current erosion and bank failure issues.

1. **Artificial hydrology and sediment barrier caused by Eagle Creek Dam:** Dam controlled artificial hydrology subjects the channel to prolonged erosive flows that would naturally tend to destabilize a channel. The presence of the dam also creates a severe discontinuity in sediment transport.
2. **Channel incision and inadequate floodplain connectivity:** Confinement of the flow in the channel and the lost floodplain connectivity results in significant erosion risk.

The results of the FEH mitigation study suggest that the issues that led to the instability are likely to persist and that a site-specific improvement should be made to stabilize the levee, since the levee serves as critical infrastructure to Indianapolis. The recommended improvements include: reinforcing the toe of the bank, adjusting the upper portion of the bank to provide a stable slope, and protecting the upper slope with erosion control blanket. These improvements are expected to cost approximately $374,000 to implement. Once the improvements have been constructed, the condition of the reconstructed bank at the FEH site should be monitored on an annual basis, and/or after significant flooding events.

CHAPTER 1 PROJECT OVERVIEW

1.1 INTRODUCTION

This report documents the results and methodology used by Christopher B. Burke Engineering, LLC (CBBEL) to identify the need and ability to mitigate an existing fluvial erosion hazard (FEH) along the waterside toe of Levee 12(c) along Eagle Creek just downstream of Dandy Trail in Indianapolis, Indiana. This study and preparation of this document was conducted in support of the development of the Indiana Fluvial Erosion Hazard Mitigation Manual. The development of the Manual was an initiative of the Indiana Silver Jackets, made possible through a grant from the Indiana Office of Community and Rural Affairs (OCRA). A system-based approach was used to identify the stressors leading to channel instability issues to aide in the development of conceptual mitigation solutions.

1.2 PROJECT HISTORY

Figure 1: Stream Bank Along Eagle Creek Levee

Eagle Creek is a tributary to the West Fork White River, with a drainage area of 210.6 square-miles (mi^2). Eagle Creek begins in Hamilton County, and flows south through Boone and Marion Counties to its confluence with the West Fork White River on the west side of Indianapolis, Indiana. The watershed includes several significant upstream tributaries such as Little Eagle Creek (Hamilton County), Mounts Run, Fishback Creek, Little Eagle Creek (Marion County), and School Branch. In addition to Hamilton, Boone, and Marion Counties, the Eagle Creek Watershed also extends west into Hendricks County. Portions of Westfield, Carmel, Zionsville, Whitestown, Lebanon, Brownsburg, and Indianapolis are included in the watershed. Approximately 162 mi^2 of the total drainage area contributes to Eagle Creek Reservoir.

The portion of Eagle Creek and the tributary streams upstream of Eagle Creek reservoir flow through largely agricultural areas. The river corridor transitions to an urban setting near the Hamilton-Marion County border. Downstream of Eagle Creek Reservoir, much of Eagle Creek is leveed.

A map of the study area is shown in **Exhibit 1**.

1.3 PROJECT PURPOSE

Figure 2: Failed Streambank above Revetment at FEH Site

The purpose of the study is to determine the most appropriate repair methods for an existing slope failure and a means of reducing the risk of future damage to the existing levee in Indianapolis, Indiana due to erosion in Eagle Creek. A better understanding of Eagle Creek is required to determine the current characteristics of the channel and watershed, to identify the root causes of the channel instability, and to determine what, if any, mitigation strategies are warranted, applicable, and able to be implemented without detrimental impact to adjacent stream reaches.

1.4 ANALYSIS PROCESS

The project was completed in several successive phases. Phase I of the project included a significant data gathering effort. The information acquired during the data collection phase included local testimony collected during an initial stakeholders meeting, previous studies, observations from site visits, historical aerial photography, streamflow data, rainfall data, soils information, and land use data.

The second phase of the project consisted of the assimilation and processing of the data collected during Phase I to determine the major themes of the current morphologic condition of the river system affecting the site. The processed data were then used to identify the watershed- and local-scale stressors acting on the river system.

Phase III involved the development of conceptual solutions for the stressors identified in Phase II of the project. An implementation sequence of the recommended strategies was also developed during this portion of the work.

CHAPTER 2 DATA GATHERING

Existing data and previous studies, where available, were used as supporting information for the FEH mitigation study. Additional data and observations were collected to provide a more comprehensive understanding of the physical processes at work 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 SOURCES OF DATA

Topography Data

The analysis of the Eagle Creek corridor and watershed required detailed topographic information for various calculations. The 2011 IndianaMap Digital Elevation Model (DEM) was used as the source of topographic data for bankfull width approximation, floodplain connectivity considerations, and as the terrain source for a two-dimensional hydraulic model. The IndianaMap DEM covers the entire Eagle Creek Watershed with a 5-foot cell resolution, which is sufficient for producing 1-foot contours. A limited site survey was completed by SJCA on September 6, 2018 to provide more accurate topographic data of the FEH site, support the determination of the channel classification, and confirm the accuracy of the 2011 DEM. A topographic map of the Eagle Creek Watershed is provided in **Exhibit 2**.

Streamflow Data

Streamflow information served as a critical component to the hydrologic analysis completed as a part of this study. All streamflow information was obtained from the United States Geological Survey's (USGS) online portal.

Aerial Photography

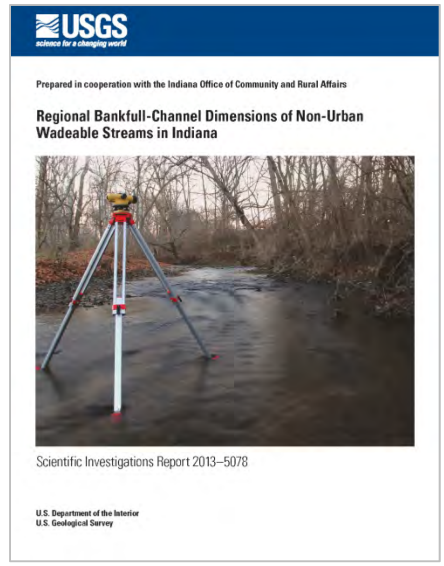
Aerial photography of the Eagle Creek Watershed was obtained from multiple sources. The primary source of aerial photography information was the 2011 IndianaMap Orthophotography.

2.2 PREVIOUS STUDIES

The review of previous studies in the Eagle Creek 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.

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.


USGS
science for a changing world

Prepared in cooperation with the Indiana Office of Community and Rural Affairs

Regional Bankfull-Channel Dimensions of Non-Urban Wadeable Streams in Indiana

Scientific Investigations Report 2013–5078

U.S. Department of the Interior
U.S. Geological Survey


GEOTECHNICAL INVESTIGATION

CITY OF INDIANAPOLIS
PAL LEVEE ACCREDITATION PROJECT
LEVEE EC-12(c)
INDIANAPOLIS, INDIANA
CTL PROJECT NO.: 09050035IND

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Geotechnical Investigation, City of Indianapolis PAL Levee Accreditation Project, Levee EC-12(c) (CTL Engineering, 2011)

A geotechnical analysis of Eagle Creek Levee 12(c) was completed by CTL Engineering in 2011 in support of levee accreditation efforts, in addition to providing design recommendations for repairing a portion of the levee. The repaired levee segment is coincident with the FEH of interest. The analysis included consideration of slope stability at three locations. The soil profiles at the three locations varied, with the slope stability analysis determining that two of the slopes were stable and the final location was unstable during several of the conditions considered.

CHAPTER 3 FEH MITIGATION STUDY

The FEH mitigation study included consideration of the findings of previous studies, an extensive site investigation, and the contributing watershed area to the main stem of Eagle Creek. The FEH mitigation study was broken into three major categories of observations and analysis, including site assessment, watershed-scale assessment, and reach-scale assessment. The following paragraphs provide an overview of each component of the FEH mitigation study.

3.1 IDENTIFICATION OF ASSESSMENT REACH

The preliminary identification of an assessment reach is necessary to determine the extent of the stream that will be evaluated during the site assessment, to establish the portion of the overall watershed that should be considered during the watershed-scale assessment, and to provide an initial estimate of the extent of the reach-scale assessment.

A prudent assessment reach is centered on the FEH location and extends a minimum of 12 bankfull widths in the upstream and downstream direction. The anticipated bankfull width of Eagle Creek at the location of the FEH was determined by applying the contributing drainage area at that point in the stream (164 mi^2) to the regional bankfull equations for the Central Till Plain in Indiana. An approximate bankfull width of 96 feet was determined. The preliminary assessment reach identified for the FEH site is shown in Figure 3.

Figure 3: Preliminary Assessment Reach

3.2 SITE ASSESSMENT

A site visit was conducted on September 6, 2018 to observe the river corridor along the preliminary assessment reach to determine the characteristics of the channel and to help identify the physical processes occurring in the channel. The site observations focused on measuring key dimensions of the channel and locating signs of morphological change, or changes in the channel, such as scoured and/or failed streambanks, significant upland erosion, and sediment deposition. A significant amount of riprap armoring was noted along the lower portion of the streambank.

Observations and representative measurements were made to allow for the assessment reach to be classified and to provide information that can be evaluated to determine if the channel should be expected to be relatively stable or unstable. Photographs taken during the site assessment are provided in Appendix 1.

Downstream of the dam, Eagle Creek is a B4c stream according to Rosgen Classification of Natural Rivers based on the field measurements. A B4c stream is a moderately entrenched stream with moderate sinuosity, gentle slope, and gravel streambed. A copy of the field measurements and stream classification form is provided in Appendix 2.

3.3 WATERSHED-SCALE ASSESSMENT

Typically, an evaluation of the contributing watershed would be necessary to determine if there are systemic issues contributing to the instability noted at the FEH site. The fact that the FEH site exists downstream of Eagle Creek Dam indicates that systemic issues exist, as the dam disrupts the natural conveyance of flow and sediment. Rather than seeking to determine the potential causes of observed changes at the site, the watershed assessment was used to quickly evaluate the severity of the systemic issues caused by the dam and to identify the infrastructure at risk from the anticipated fluvial instability.

3.3.1 Artificial Hydrology and Sediment Barrier caused by Eagle Creek Dam

Eagle Creek Dam effectively controls the hydrology for the assessment reach. The dam operates based on standard procedures that contain a limited number of possible outflow ‘settings’. These discrete ‘settings’ do not allow the downstream channel to experience the continuous, natural, rainfall-driven inputs from the watershed. The downstream channel is subjected to abrupt changes in flow; the flows do not meaningfully increase or decrease, but rather create elongated flow ‘stair-steps’. This artificial hydrology subjects the channel to prolonged erosive flows that would naturally tend to destabilize a channel.

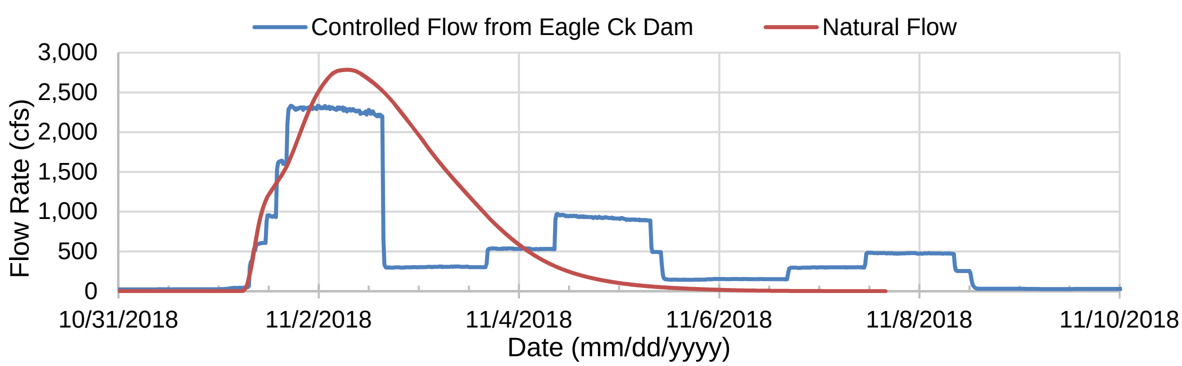

Figure 4: Controlled vs. Natural Flow

The presence of the dam also creates a severe discontinuity in sediment transport. All but the finest of the sediment that is suspended in the water column of Eagle Creek Reservoir settles to the bottom of the waterbody. This creates a tremendous imbalance in the sediment capacity and sediment supplied to the reach immediately downstream of the dam and leaves the sediment capacity to be harvested from the channel bed and banks to reestablish the balance. This is often referred to as the stream being 'hungry', as the bed and banks are rapidly eaten away in unarmored channels.

Figure 5: Eagle Creek Dam

3.3.2 Comparison of Channel Dimensions to Regional Curves

The artificial flow regime caused by the dam is expected to result in significant departure from the anticipated channel dimensions using the bankfull regional curves. The apparent bankfull width of the channel was determined at 30 locations along Eagle Creek to understand the magnitude of the departure. The measurements were made using the IndianaMap DEM to determine the channel geometry. The method used is expected to produce slightly wider bankfull widths than would likely be observed if field measurements were taken; despite this inherent exaggeration, the values shown in Table 1 indicate that the bankfull channel is much narrower than the prediction using regional curves at every location. This is not unexpected since much of the channel has been leveed and flowrates are controlled by Eagle Creek Dam, preventing the channel from developing a form similar to the natural streams used to create the regional curves. A map of the measurement locations is provided in Appendix 3.

Table 1: Comparison of Observed Channel Properties with Regional Curves

Distance Downstream from Eagle Ck Dam (mi)	Drainage Area (sq. mi.)	Approximate Bankfull Width* (ft)	Predicted Bankfull Width** (ft)	Departure from Expected Bankfull Width (ft [%])
0.3	162.0	50	96	-46 ft [-48%]
0.9	164.0	35	96	-61 ft [-64%]
2.0	166.0	75	97	-22 ft [-23%]
3.1	170.0	30	98	-68 ft [-69%]
3.9	173.0	75	98	-23 ft [-24%]
4.9	174.0	65	98	-33 ft [-34%]
6.0	175.0	70	99	-29 ft [-29%]
6.7	177.0	35	99	-64 ft [-65%]
8.1	208.0	40	104	-64 ft [-62%]
8.9	209.0	50	104	-54 ft [-52%]
10.0	210.0	45	105	-60 ft [-57%]
10.9	210.0	35	105	-70 ft [-67%]

3.3.3 Identification of At-Risk Infrastructure

The fluvial erosion hazard corridor along Eagle Creek near the FEH site was used to establish the at-risk area where infrastructure would need to be evaluated. Each location within the assessment reach where significant infrastructure was located within the corridor was examined to determine the perceived risk level given the anticipated detrimental impact if the infrastructure was compromised. The risk level was determined according to the criteria in Table 2. Table 3 provides a summary of the at-risk infrastructure identified during the assessment, including the risk level and contributing factors; Figure 6 provides a map of the locations of the at-risk infrastructure.

Table 2: Risk Level Criteria

Risk Level	Stability Level	Impact to Public if Infrastructure is Compromised
High	Unstable	Minor Disruption → Severe risk to public health or loss of critical infrastructure
	Recently Stable / Transitional	Moderate Disruption → Severe risk to public health or loss of critical infrastructure
	Stable	Severe risk to public health or loss of critical infrastructure
Moderate	Unstable	Minor Disruption → Significant disturbance to daily commute/activities
	Recently Stable / Transitional	Moderate Disruption → Significant disturbance to daily commute/activities
	Stable	Significant disturbance to daily commute/activities
Low	Unstable	No disruption → Minor disruption to localized areas
	Recently Stable / Transitional	No disruption → Minor disruption to localized areas
	Stable	Minor disruption to localized areas

Table 3: Identification of Fluvial Erosion Hazards

Location	FEH Description	Impact of Compromised Infrastructure	Risk Level
EC-1	Levee	Severe risk to loss of critical infrastructure	High
EC-2	Powerline	Potential disruption of power	Low*
EC-3	Powerline	Potential disruption of power	Low*
EC-4	Road (Island Club Drive)	Minor disruption to localized area	Low
EC-5	Structure	Potential loss of life and homes	High
EC-6	Structure	Potential loss of life and homes	High
EC-7	Structure	Potential loss of life and homes	High
EC-8	Structure	Potential loss of life and homes	High
EC-9	Structure	Potential loss of life and homes	High
EC-10	Structure	Potential loss of life and homes	High

* The risk level would typically be classified as Moderate; however, since the powerline structure is on the levee, a critical piece of infrastructure, it is unlikely that the slope will be allowed to fail to the degree that it would impact the powerlines.

Figure 6: Locations of At-Risk Infrastructure

3.4 REACH-SCALE ASSESSMENT

A more detailed evaluation of the assessment reach was completed to quantify the parameters needed to develop conceptual active management solutions. The analyses were also used to further improve the understanding of the local system. The following paragraphs summarize the additional analyses completed for the reach-scale assessment.

3.4.1 Refined Assessment Reach

The preliminary assessment reach extent was evaluated to determine if the detailed analyses should cover the entirety of the reach or if analysis and evaluation efforts could be limited to a smaller area. The full extent of the preliminary reach was determined to be necessary as a result of the overflow path in the right overbank area. Some of the analyses completed considered areas beyond the refined assessment reach but did so only to reduce the influence of assumptions and selected boundary conditions for the hydraulic model.

3.4.2 Hydraulic Analysis

A two-dimensional hydraulic model was developed for the refined assessment reach to determine the speed and direction of flow in the channel near the levee. The design of alluvial channels requires the determination of the channel forming discharge; however, Eagle Creek does not function as an alluvial stream. The portion of Eagle Creek in the assessment reach functions as a threshold channel due to the manipulation of flow and removal of sediment load caused by Eagle Creek Dam, as well as the addition of significant amounts of riprap armoring in the downstream channel.

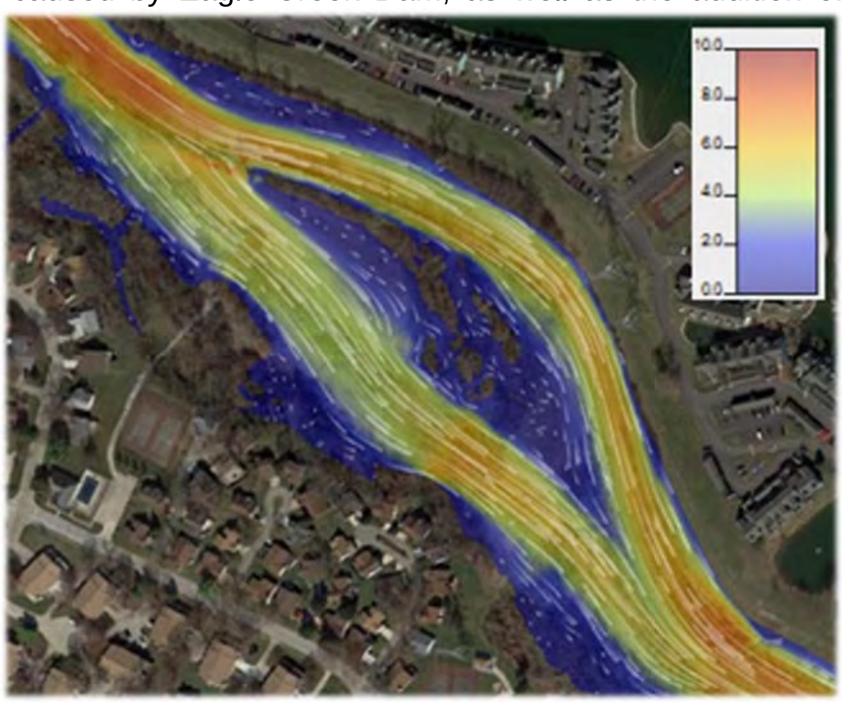

Figure 7: Overflow Path near FEH Site

The hydraulic model was configured to consider flows that ranged from baseflow conditions up to the 100-year flow event to determine what improvements may be necessary to reestablish the adequacy of the channel armoring, which is necessary to maintain the shape and stability of the threshold channel. Additional information concerning the hydraulic model is provided in Appendix 4.

The results from the hydraulic model indicate that the maximum flow velocity in the refined assessment reach ranges from 5 to 9 feet per second (ft/s) for the flows considered. During events larger than the 1.5-year, the hydraulic model indicates that the flow leaves the channel just upstream of the site of interest. The velocities through the overflow path range from 4 to 7 ft/s for events up to the 100-year flow. Flow moving as swiftly as the flow in both locations is capable of causing bank scour and preventing the establishment of vegetation. Bank scour and a lack of vegetation can initiate bank instability.

It should be noted that the maximum velocity in the main channel does not occur during the most extreme event. The highest velocity occurs in the channel just prior to when the overflow path is activated. This provides a clear example of the benefit that a floodplain can provide in terms of energy dissipation. Unfortunately, the floodplain at this location in Eagle Creek is not attached to the channel at an appropriate depth, which allows erosive flows to occur prior to the energy-dissipating activation of the overflow path.

3.4.3 Scour Evaluation

The results of the hydraulic model were used to compute general scour and bend scour at the FEH site. The general scour calculations were completed using the Blodgett and Pemberton and Lara methods. The results of the analyses show that scour depths near the FEH site are expected to range from 2 to 9 feet for general scour. Long-term channel degradation is not accounted for in the above-mentioned scour depths. Scour calculations are provided in Appendix 4.

3.4.4 Slope Stability Analysis

The 2011 CTL Geotechnical Investigation included a slope stability analysis of three locations along Levee EC-12(c). The soil profiles for each location varied; however, the calculated factors of safety are well-correlated with the slope of the bank. The results of the analysis suggest that slopes 2.5 feet horizontal to 1 foot vertical (2.5H:1V) or flatter are acceptably stable and slopes that are 1.2H:1V or steeper are unstable. The low factor of safety (0.882) for the 1.2H:1V slope suggests that slopes slightly flatter than 1.2H:1V are also unstable. It should be noted that the unstable location from the CTL analysis corresponds to the FEH of interest.

An analysis of the land slope within the refined assessment reach was evaluated to determine the location and extent of banks that have either failed or should be considered unstable. Slopes of 2.5H:1V and flatter were considered stable, slopes between 2.5H:1V and 1.7H:1V were considered marginally stable, and slopes steeper than 1.7H:1V were considered unstable. **Exhibit 3** provides a map of the estimated slope stability proximate to the channel. A significant portion of the channel banks within the project reach are expected to be marginally stable; approximately 500 feet of the channel bank at the FEH location has either failed or is expected to be unstable.

3.5 KEY FINDINGS OF FEH MITIGATION STUDY

The most significant factors affecting the stability of the channel through the assessment reach identified during the FEH mitigation study are described in the following paragraphs. All of the stressors identified have interplay with at least one of the other stressors, creating a compounding effect that reduces the overall stability of the river.

Eagle Creek Dam & Threshold Channel Conditions

As discussed in Section 3.3.1, Eagle Creek Dam prevents the natural delivery of flow and sediment to the assessment reach. The operation of the dam results in elevated, elongated, and 'clear water' flows that result in the stream being unstable without armoring.

Much of the channel has been armored with riprap. The areas where the riprap appears to be of inadequate size or depth have eroded, and in many cases become unstable.

Channel Incision & Inadequate Floodplain Connectivity

The human-imposed narrowness of the main channel confines the flow, preventing meaningful floodplain storage at or above a bankfull event. In healthy streams, the channel is well-connected to a substantial floodplain that helps to store excess flow and sediment, as well as to reduce the overall erosive energy in the flow.

CHAPTER 4 STAKEHOLDER INPUT AND MITIGATION OBJECTIVES

The identification of the overall mitigation objectives is critical to the development of mitigation strategies and the success of the project. Establishing a clear decision-making process, evaluating the impairments to be addressed, and considering the potential improvements using a merit-based system is imperative to a prudent design. It is also important to identify what will constitute 'project success'. These factors should be considered by appropriate stakeholders.

4.1 DECISION MAKING PROCESS

The decision to proceed with a design of mitigation features will ultimately lie with the City of Indianapolis. The conceptual improvements identified later in Chapters 5 and 6 were determined by the designer using the objectives noted below with consideration of the impairments to be mitigated and the likelihood of mitigation success.

4.2 MITIGATION OBJECTIVES

Conversations with City officials revealed concern over the long-term viability of the levee adjacent to Eagle Creek due to observations of streambank erosion. The following objectives were implied:

1. Prevent the stream from compromising the toe of the levee and minimize the long-term FEH risk
2. Low maintenance need for improvements
3. Cost efficient construction

4.2.1 Impairments to be Mitigated

The FEH site has several impairments that must be considered to meet the mitigation objectives. The impairments are both local instabilities and systemic issues affecting the channel downstream of the dam. The following issues must be addressed by the design:

1. High flow velocities and scour through the assessment reach
2. Bank instability at the site, largely attributable to over-steepened slopes
3. Prolonged erosive flow rates due to increased runoff volume and artificial hydrology

4.2.2 Functional Lift

The relatively small extent of the FEH of interest and the limited scope of the objectives for the project reduce the potential for providing function lift to the stream reach.

The severe systemic issues imposed by Eagle Creek Reservoir and Dam cannot be alleviated without removal of the facility and the reestablishment of a natural river corridor, both of which are impracticable. Without significant naturalization, localized FEH mitigation measures should not be expected to provide significant functional lift to the overall stream.

4.3 PRIORITIZED MITIGATION OBJECTIVES & PERFORMANCE METRICS

The mitigation objectives identified in Section 4.2 were provided in the order of priority that was understood from conversations with the City of Indianapolis. The specific mitigation objectives have been expanded in the list below and are accompanied by designer-specified performance objectives intended to achieve the stated objectives:

1. **Prevent the stream from compromising the toe of the levee and minimize the long-term FEH risk:**

   This mitigation objective will require active management strategies to effectively stop erosion in the vicinity of the at-risk levee. Prudent performance metrics for the improvements near the area of interest include:

   A. Flow velocity during the 100-year event must be below the acceptable performance threshold of the surface cover/protection to prevent erosion during all but the most extreme of flow events.
   B. Flow vectors during the full range of flow events should be well aligned with the surface contouring inundated by and adjacent to the flow.
   C. Protect against long-term degradation.
   D. Mitigation measures implemented in and adjacent to the stream should consider the potential for the peak annual flow rate to continue to rise for the engineering life-span of the project, although expected at a lower rate of increase compared with an unregulated flow stream.

2. **Low maintenance need for improvements**

   Low maintenance requirements hinge on the types of improvements designed and the types of materials selected. Maintenance need is heavily dependent on uncontrolled variables (e.g. severity and frequency of flooding, debris strikes, etc). As a result, performance metrics are limited to anticipated outcomes rather than results of detailed analyses:

   A. Maintenance activities should be required no more frequently than once, annually.
   B. Material selections should have a long (20+ year) life-span to reduce or prevent the need to replace components of the project.

3. **Cost efficient construction**

   Minimizing the project implementation cost requires evaluation of materials and active management stabilization methods used. Though the overall cost of the improvements cannot be accurately predicted or determined prior to the selection of active management treatments, generalized goals can be established:

   A. A high project cost is anticipated due to the presence of the levee.
   B. The complexity of the design should be minimized to reduce installation costs and materials should be locally available and cost efficient.

CHAPTER 5 PASSIVE MANAGEMENT CONSIDERATIONS

Passive management strategies are most effective for addressing systemic issues that are watershed-based, or site-specific issues for a location that does not have a large contributing drainage area. That would seem to suggest that the use of passive management strategies is ideal for the mitigation of the FEH of interest; however, the majority of the systemic issues arise from the presence of Eagle Creek Dam. Furthermore, the benefit of watershed-scale measures will likely be dampened downstream of the Eagle Creek Reservoir. As a result, passive measures are not considered a viable solution for the FEH site.

CHAPTER 6 ACTIVE RIVER MANAGEMENT ANALYSIS

Active river management includes modifications to the stream corridor that directly combat or eliminate the instabilities that are present. Various types of active management strategies can be combined to create robust improvements to specific portions of the channel or the entire channel through a given reach. Active river management methods must address both vertical and lateral instability to be effective.

6.1 VERTICAL STABILITY CONSIDERATIONS

Improvements to the FEH mitigation site will need to address two potential sources of vertical instability: scour along the toe of the bank during significant flow events and the potential for long-term degradation or head-cutting caused by the imbalance in sediment supply and capacity.

Figure 8: Toe Protection Measures

Toe protection measures are typically necessary for FEH mitigation sites that have vertical or horizontal stability issues due to the fact that a bank is not likely to remain stable if the toe is eroded; this is particularly true for the FEH site due to the slope stability issues already present. Toe protection usually comes in the form of large stone, concrete, or wooden revetment that is designed to be immobile, even during high flow events; sheet piling is sometimes used when the site is particularly confined. An example of riprap toe protection is shown in Figure 8. There is currently toe protection material in place at the site; however, the size, extent, and location may not be ideal.

Grade control structures and/or bed armoring are often used to prevent the process of channel degradation, or the gradual lowering of the channel invert elevation due to erosion downstream propagating upstream. Grade control structures can be made of large, immobile stone, concrete, or sheet piling and span the width of the channel to stop the upstream migration of a headcut.

6.2 LATERAL STABILITY CONSIDERATIONS

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.

Natural, healthy streams in Indiana typically meander and gradually move back and forth across their floodplain. In certain situations, such as this one, allowing the movement of the stream can endanger critical infrastructure. Utilizing an armoring system on the channel banks can help to prevent the natural erosion processes that allow the channel to move or change its shape in meaningful ways. Channel armoring is accomplished by installing a system that can withstand the flow velocity in the channel with negligible loss of bank and bed material over time; riprap, turf reinforcement mats, soil cement, etc. are examples of common armoring systems.

Figure 9: Armored Channel in Indianapolis, IN

6.3 PROPOSED MITIGATION MEASURES

The type of mitigation techniques used to improve the stability of a stream is dependent on the type of instability present in the channel. The reach of Eagle Creek exhibits various forms of instability, including bank scour, potential vertical instability, and minor lateral migration. The proposed mitigation techniques and the portions of the stream to which the strategies are applicable are discussed below.

6.3.1 Evaluation of and Selection of Improvement Alternatives

There are different treatment methods available to address the different types of instability presented at the mitigation site. For vertical instability, treatments that provide toe protection are the most applicable. These treatments include toe wood, interlocking concrete jacks, and gabion baskets. For lateral instability, treatments that provide channel armoring are the most applicable. These treatments include gabion baskets, soil lifts with live stakes, and erosion control blanket systems. Each of the three types of toe protection were considered in conjunction with soil lifts, live stakes, and erosion control blankets.

A triple bottom line comparison was completed for the three channel improvement alternatives to evaluate the economic costs, social benefits, and environmental benefits. A summary of the triple bottom line comparison is provided in Table 4. The complete triple bottom line decision matrix is included in Appendix 5.

Table 4: Triple Bottom Line Comparison of Improvement Alternatives

Improvement Alternative	Economic Score	Social Score	Environmental Score	Total Score
Toe Wood	2.8	2.0	2.7	**7.5**
Interlocking Concrete Jacks	2.5	2.0	3.1	**7.6**
Gabion Wall	2.3	2.0	3.4	**7.7**

Toe wood had the highest economic score because it was the least expensive and has moderate lifecycle cost in this application. Gabion baskets were the most expensive and have a moderate lifecycle cost. The interlocking concrete jacks have a low to moderate lifecycle cost but have a higher installation cost than toe wood.

All three treatment methods have the same potential social benefits score as they all provide a relatively similar level of service. The benefit of maintaining the integrity of the levee extends to a large number of properties and as a result provides a moderate to high level of benefit to public safety. However, none of the treatment methods are capable of improving flooding or drainage issues due to the extreme confinement of the channel. The project will also afford no meaningful improvement to quality of life.

The differentiating factor in the environmental scores relates to the permitability of the treatment methods, particularly with regard to meeting requirements for a certified levee. Toe wood is typically a very high performing treatment method with regard to environmental benefit; however, the permitability of toe wood as a part of a certified levee is doubtful. Adequately consolidating clayey material around the structure will likely be impossible and the infill materials will allow for a preferential seepage path to develop. These concerns caused toe wood to have the lowest environmental score. All the protection types provided a robust level of protection but did little to restore or protect the floodplain function of the stream because the limitations of the project resulting from the upstream dam and confined stream. The certainty in the quality of material consolidation and ease of installation is highest for gabion baskets, which resulted in the highest score due to the ease of permitability.

6.3.2 Description of Improvements

The proposed improvements include the use of riprap to reinforce the toe of the levee and reducing the over-steepened section of the streambank. Erosion control blankets will be used to prevent erosion above the riprap toe protection.

A schematic layout of the potential improvements is provided in **Exhibit 4**. As can be seen in the exhibit, significant impacts to the stream are required to install the treatments. It is anticipated that armoring the streambank would 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

The recommended bank armoring detail, or any other stabilization method, should not be used indiscriminately along the channel to ‘fix’ the banks. The installation of bank armoring can result in increased erosion and instability downstream of the project that impacts adjacent properties. Strategic integration of the improvements into the stream corridor is paramount to project success.

The cost of designing, permitting, and constructing these improvements is expected to be approximately $374,000. A detailed breakdown of the anticipated project cost is provided in Appendix 5.

6.3.3 Anticipated Performance

The improvements are expected the stabilize the streambank through the FEH site. Reinforcing the toe of the bank, adjusting the bank to provide a stable slope, and protecting the levee with erosion control blanket should provide sufficient resistance to erosion and prevent further instability. An evaluation of the mitigation objectives using the previously identified performance metrics is as follows:

1. **Prevent the stream from compromising the toe of the levee and minimize the long-term FEH risk:**

   The anticipated maximum flow velocity is 9 ft/s in the channel and 7 ft/s in the overflow path. Class 1 riprap will be necessary to adequately armor the toe given the high channel velocity. Most erosion control blanket systems have a performance threshold of up to 9 ft/s in an unvegetated state. This performance metric is met, as both erosion prevention systems have adequate erosion resistance during the 100-year event.

   The adjustment of the slope of the left channel bank helps to improve the direction of the flow vectors to be more well-aligned with the bank during the full range of flow events.

   The FEH site is protected against long-term degradation by installing the toe protection measures to an adequate depth to resist scour.

2. **Low maintenance need for improvements**

   Utilizing various forms of riprap protection at and below the ordinary high-water mark will minimize the need for maintenance at the toe of the slope. The use of gabion baskets does require monitoring and maintenance when the baskets begin to break down due to debris strikes or corrosion.

   The use of mitigation measures that are only vegetative on the upper portion of the slope reduces the difficulty of the required maintenance activities; in fact, the grass species used in conjunction with the erosion control blankets can be selected such that they do not need to be mowed to maintain a vigorous stand.

   The use of non-degradable erosion control blankets and vegetation as reinforcement reduce the likelihood that the system would need to be augmented or replaced.

3. **Cost efficient construction**

   The overall project cost for the improvements is anticipated to be approximately $262,000. The total length of stabilized streambank is 265 feet, resulting in a unit cost of $600 per foot. The cost per foot is slightly inflated by the additional grading area not included in the length of stabilized streambank.

   The proposed methods are common construction methods, cost efficient given the presence of the levee, and the materials are locally available.

CHAPTER 7 RECOMMENDATIONS

The results of the stream assessment described in Section 3.0 and the key factors influencing the stability of Eagle Creek described in Section 3.5 suggest that the issues are likely to persist and cannot be solved by correcting a problem in a specific location. However, the levee serves as critical infrastructure to Indianapolis, and should therefore be protected against damage from fluvial erosion. Monitoring the channel conditions at the FEH site will be a critical component to maintaining the integrity of the FEH mitigation along the levee.

7.1 MONITORING

Once the improvements have been constructed, the condition of the reconstructed bank at the FEH site should be monitored on an annual basis, and/or after significant flooding events. If the improvements are damaged or the embankment is threatened by stream migration, remedial action should be completed as soon as possible.

7.2 IMPROVEMENT IMPLEMENTATION

Armoring approximately 265 feet of the bank at the FEH site is expected to prevent the erosion of the streambank from compromising the integrity of the levee. Reinforcing the toe of the bank, adjusting the upper portion of the bank to provide a stable slope, and protecting the upper slope with erosion control blanket should provide sufficient resistance to erosion to prevent further instability. **Exhibit 4** shows a typical section of the recommended method of bank armoring. Additional methods and treatments that are applicable for bank armoring exist; however, the recommended method was selected based on limiting the risk of failure while being sensitive to overall project cost.

7.3 NEXT STEPS

The following steps are recommended to reduce the fluvial erosion hazard risk along Eagle Creek at EC-12(c):

1. Meet with CBBEL to discuss the findings and recommendations of this report.
2. Move forward with the detailed design and permitting of the proposed FEH mitigation measures for EC-12(c).
3. Establish a monitoring plan that records the location and condition of the streambank and other significant changes to the channel at the identified fluvial erosion hazard location and any additional FEH locations that may become a concern in the future.

CHAPTER 8 REFERENCES

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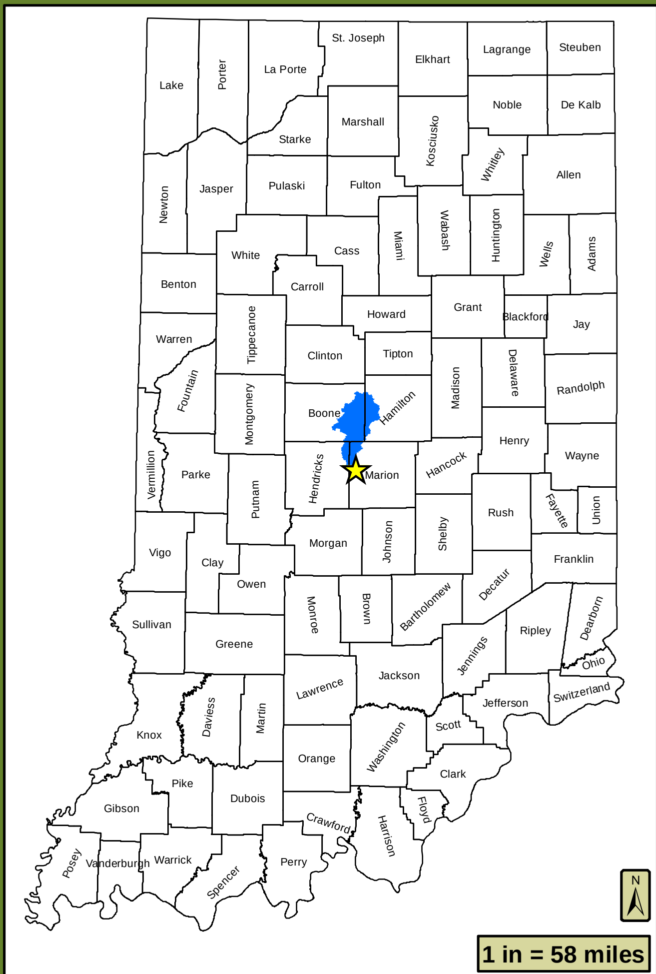
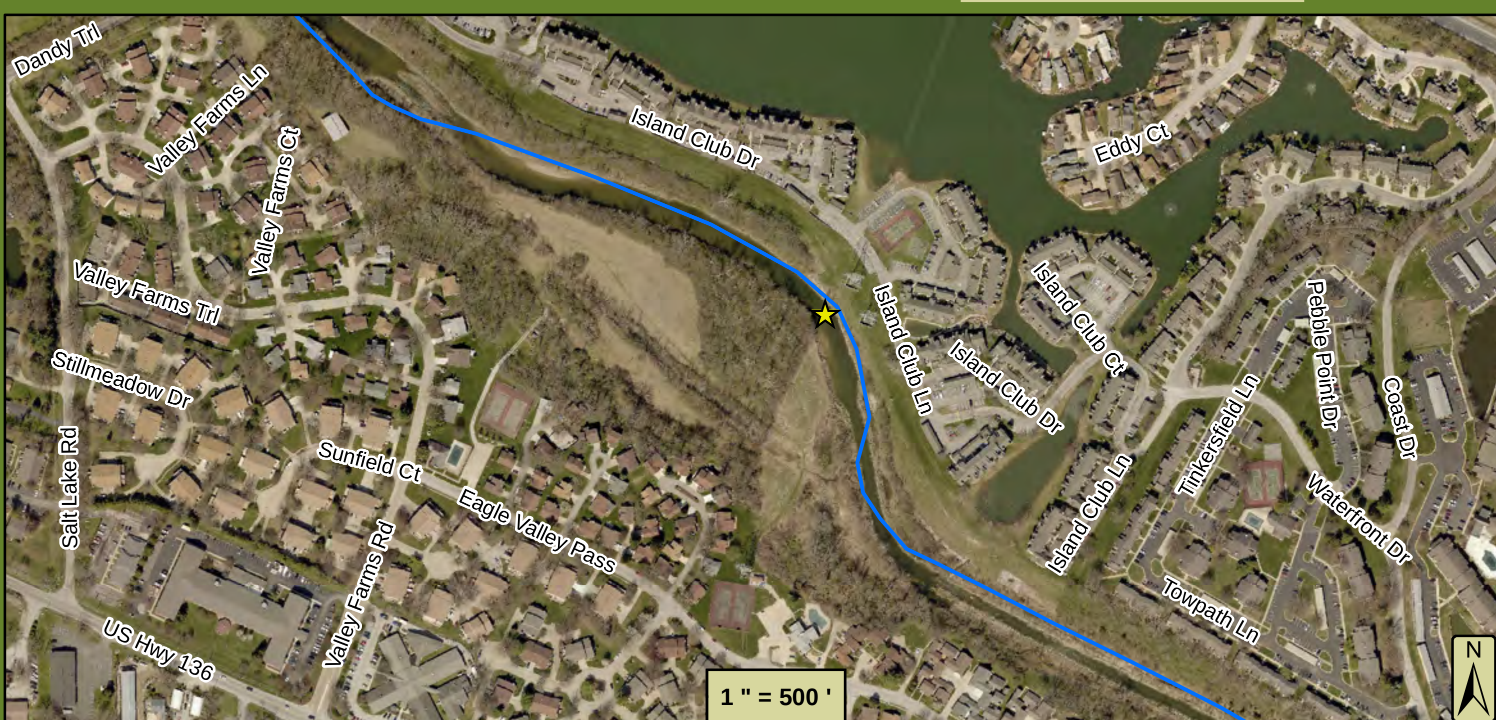
United States Geological Survey. Stream Gage Data for Station 03353500 Eagle Creek at Indianapolis, IN. Available http://maps.waterdata.usgs.gov/mapper. Accessed October 15, 2018.

Exhibits



STATE MAP

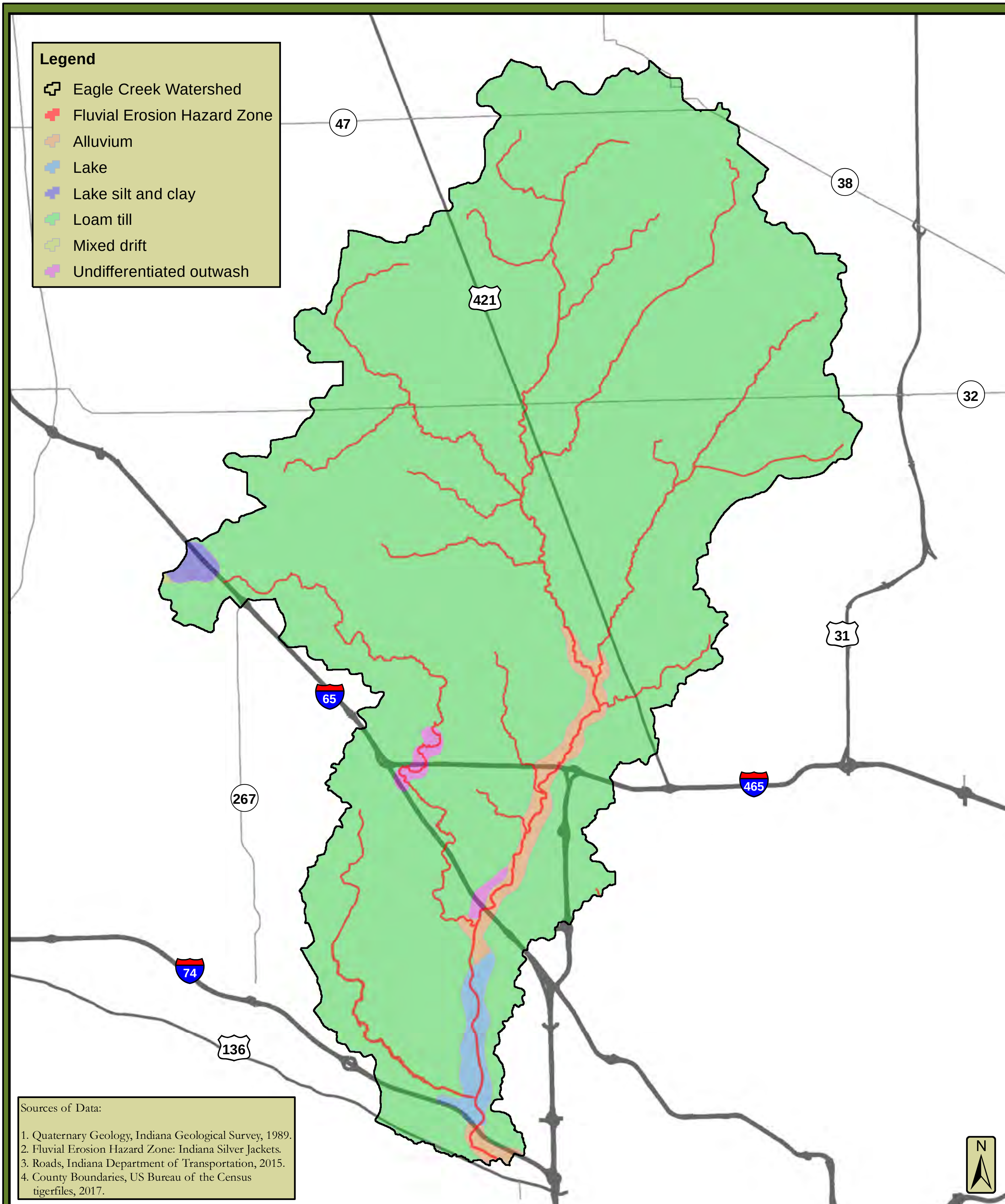
VICINITY MAP



STUDY AREA MAP

Christopher B. Burke Engineering, LLC PNC Center, Suite 1368 South 115 West Washington Street Indianapolis, Indiana 46204 (t) 317.266.8000 (f) 317.632.3306	PROJECT: Eagle Creek FEH Mitigation Assessment	PROJECT NO. 14-0014	APPROX. SCALE As Shown
	TITLE: Study Area Map		DATE: 10/2018
			EXHIBIT 1

Christopher B. Burke Engineering, LLC PNC Center, Suite 1368 South 115 West Washington Street Indianapolis, Indiana 46204 (t) 317.266.8000 (f) 317.632.3306	PROJECT: Eagle Creek FEH Mitigation Assessment	PROJECT NO. 14-0014	APPROX. SCALE 1"=300'
	TITLE: Topographic Map of Eagle Creek Watershed		DATE: 10/2018
			EXHIBIT 2



Sources of Data:

1. Quaternary Geology, Indiana Geological Survey, 1989.
2. Fluvial Erosion Hazard Zone: Indiana Silver Jackets.
3. Roads, Indiana Department of Transportation, 2015.
4. County Boundaries, US Bureau of the Census tigerfiles, 2017.

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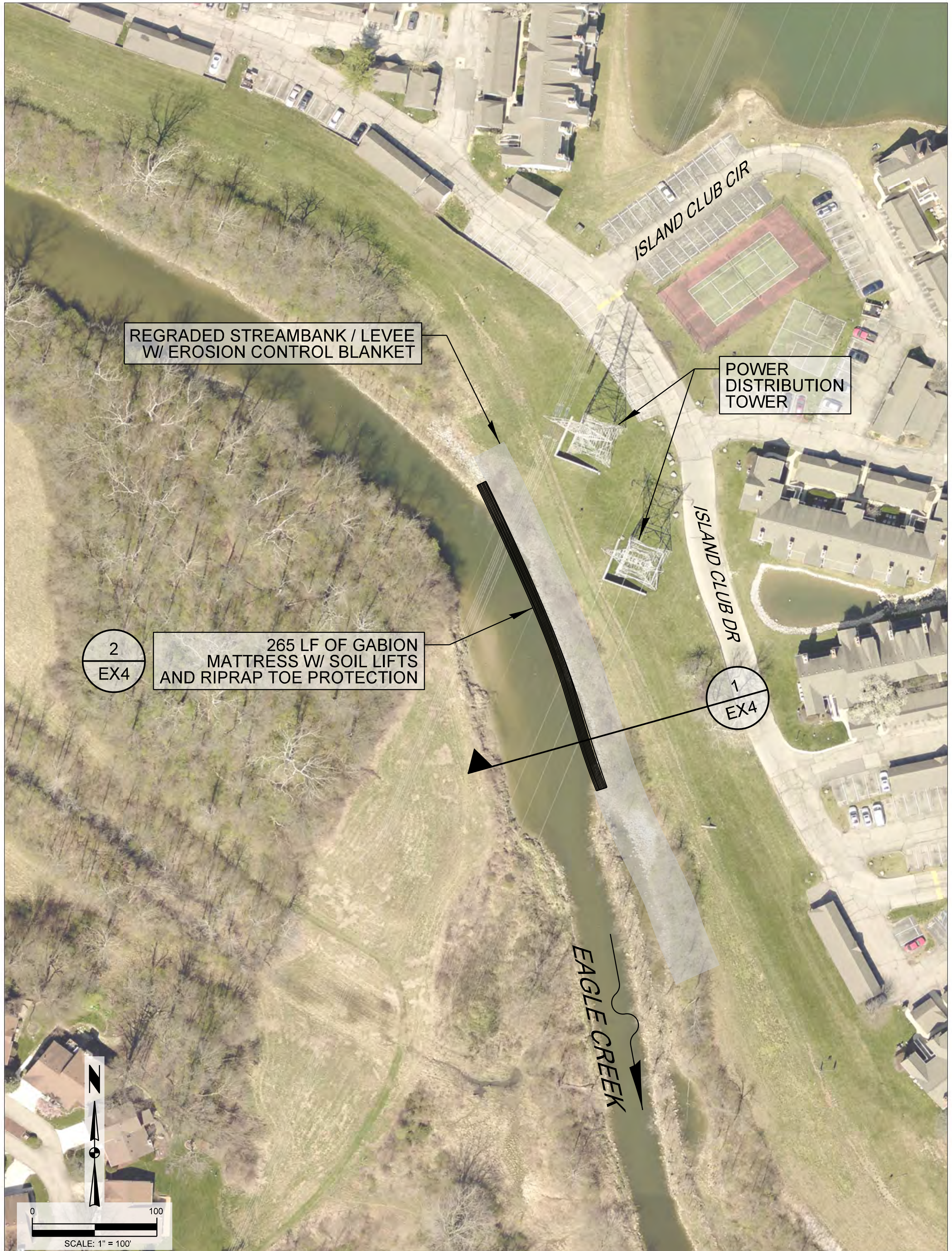
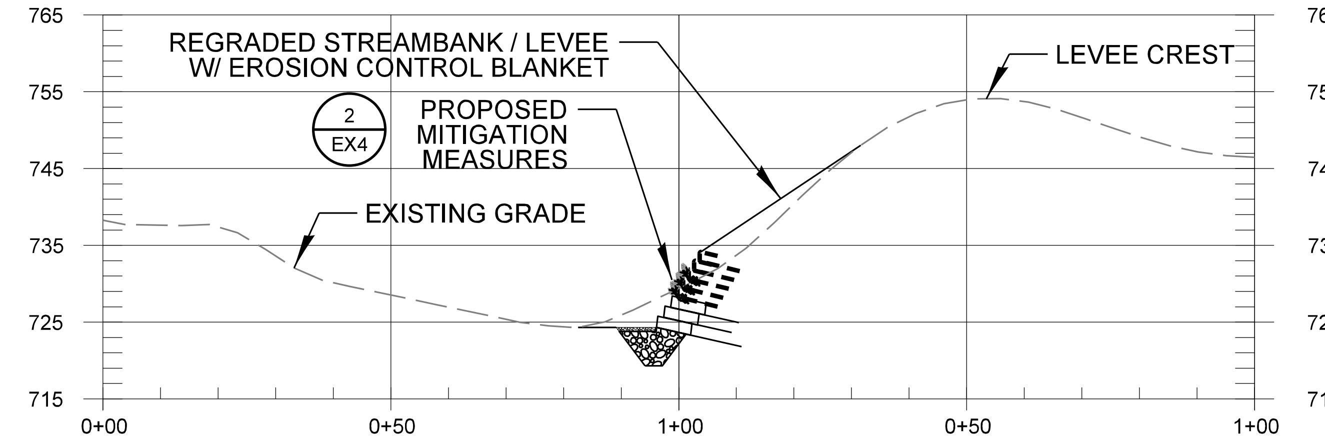
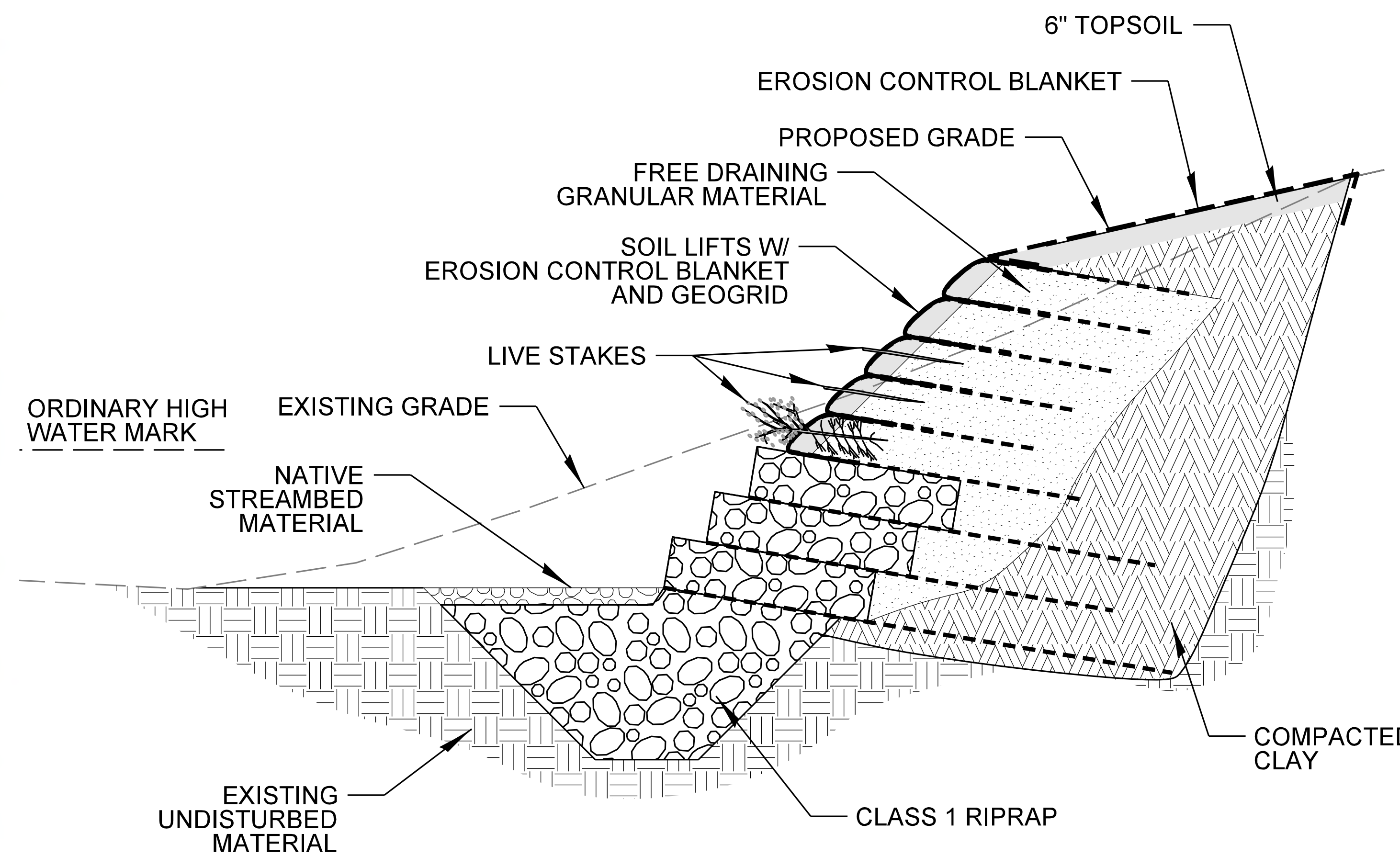
PROJECT: Eagle Creek FEH Mitigation Assessment	PROJECT NO. 14-0014	APPROX. SCALE 1"=14,000'	
TITLE: Quaternary Geology		DATE: 10/2018	EXHIBIT 3

Christopher B. Burke Engineering, LLC PNC Center, Suite 1368 South 115 West Washington Street Indianapolis, Indiana 46204 (t) 317.266.8000 (f) 317.632.3306	PROJECT: **Eagle Creek FEH Mitigation Assessment**	PROJECT NO. **14-0014**	APPROX. SCALE **1"=300'**
	TITLE: **Map of Unstable Slopes**		DATE: **10/2018**
			EXHIBIT **4**





1 TYPICAL CROSS-SECTION
NOT TO SCALE



2 TYPICAL MITIGATION DETAIL
NOT TO SCALE

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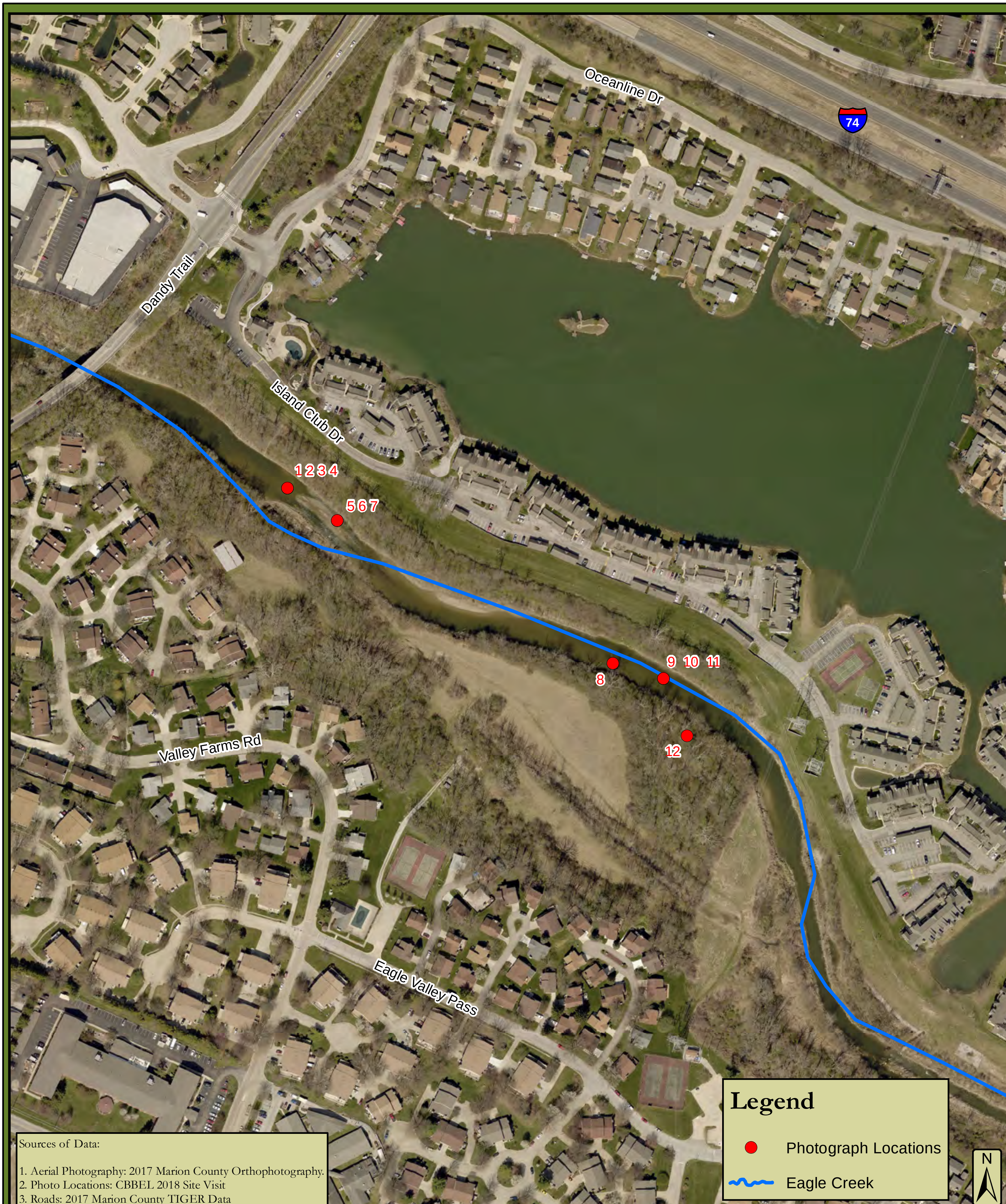
PNC Center, Suite 1368 South
115 West Washington Street
Indianapolis, Indiana 46204
(317) 266-8000 FAX: (317) 632-3306

CERTIFIED: PRELIMINARY NOT FOR CONSTRUCTION

TITLE:	LEVEE EC-12(c) IMPROVEMENTS
PROJECT:	EAGLE CREEK FEH MITIGATION ASSESSMENT
PROJECT NO.	19.R140014.00000
SHEET	1 OF 1
DRAWING NO.	EX5

Appendix 1: Site Observation Photographs



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PROJECT: Eagle Creek FEH Mitigation Assessment		PROJECT NO. 14-0014	APPROX. SCALE 1"=300'
			DATE: 10/2018
TITLE: Photo Location Map			EXHIBIT A1.1

Photo 1: Downstream of Dandy Trail (west bank)

Photo 2: Downstream of Dandy Trail (east bank)

Photo 3: Downstream of Dandy Trail, looking downstream

Photo 4: Downstream of Dandy Trail, looking upstream

Photo 5: Exposed erosion control blanket and riprap (east bank)

Photo 6: Riprap along east bank

Photo 7: Exposed erosion control blanket (east bank)

Photo 8: Eroded west bank

Photo 9: Upstream of site (west bank)

Photo 10: Looking downstream towards site

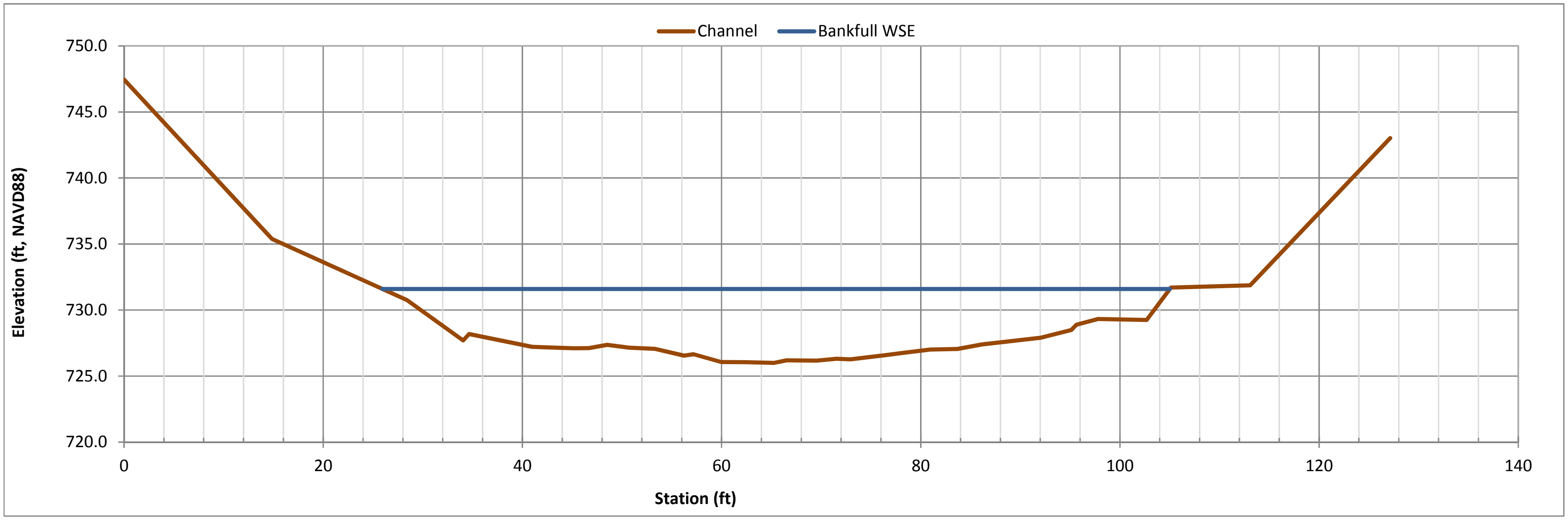
Photo 11: Upstream of site, looking upstream

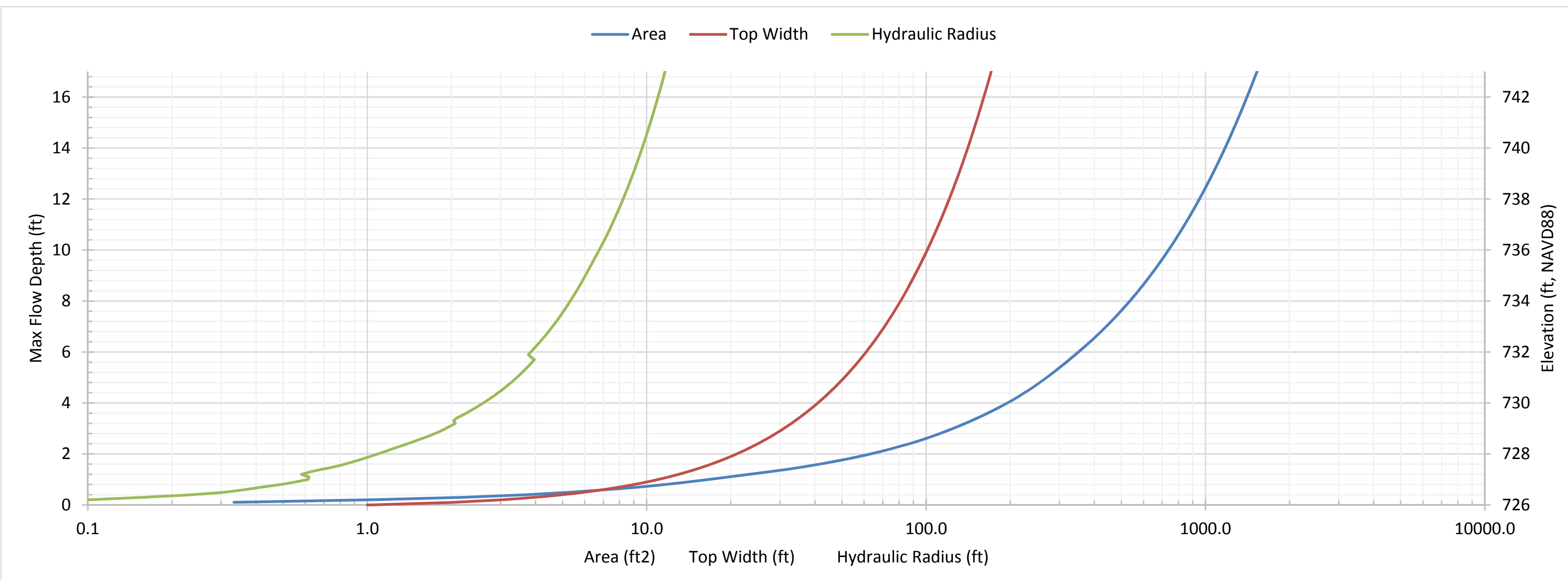
Photo 12: Looking downstream towards site

Appendix 2: Site Assessment Data & Calculations

Bankfull Cross Section Plot

Bankfull Channel Cross-section Properties





Stream Classification Sheet

Worksheet 2-3. Field form for Level II stream classification (Rosgen, 1996; Rosgen and Silvey, 2005).

Stream:	**Eagle Creek**				
Basin:	**Eagle Creek**	Drainage Area:	**104,960** acres	**164**	mi^2
Location:	**Indianapolis, IN**				
Twp.&Rge:		Sec.&Qtr.:			
Cross-Section Monuments (Lat./Long.):				Date:	**8/2018**
Observers:	**BJM, JDF, HLF, JLE**			Valley Type:	**U-GL-TP**

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**79.1**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**4.02**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**317.7**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**19.7**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**5.6**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**107**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**1.4**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**26.7**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.000532**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.04**	

Stream Type **B4c** (See **Figure 2-14**)

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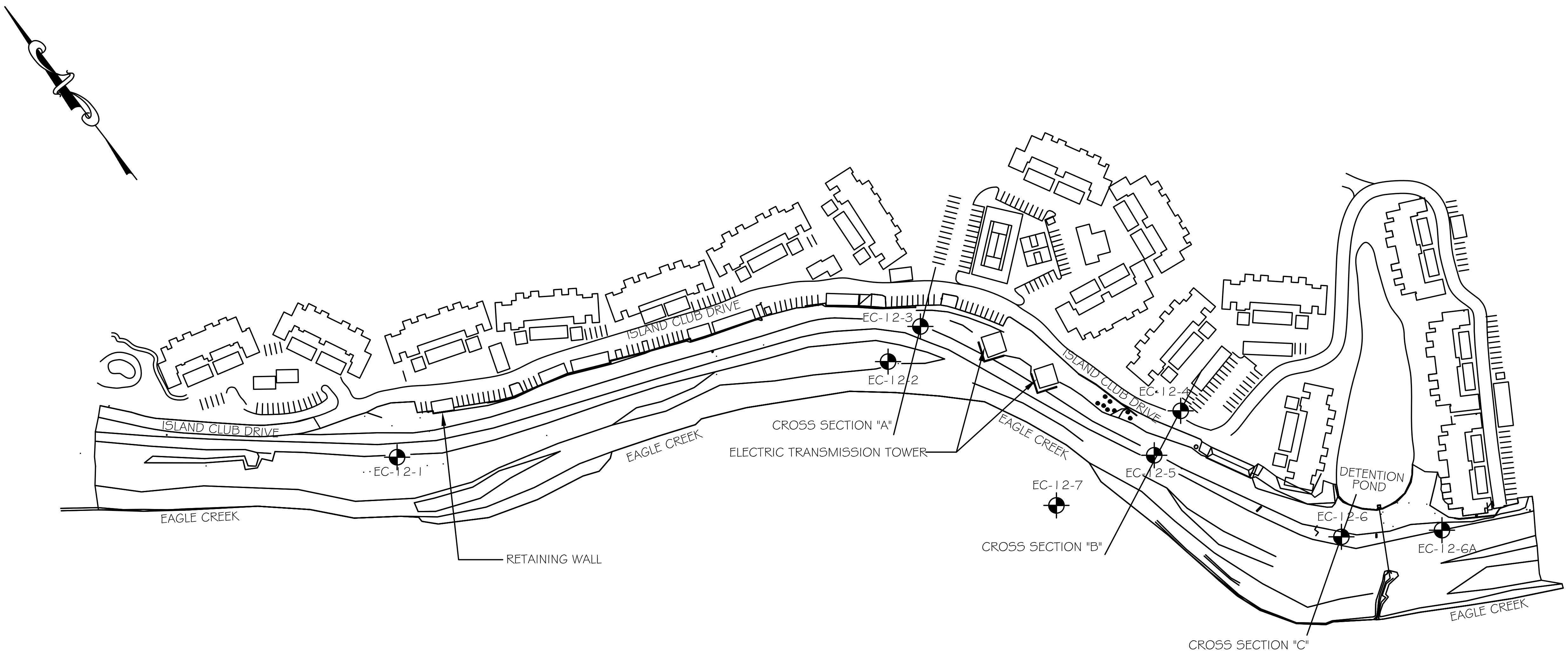
Geotechnical Investigation

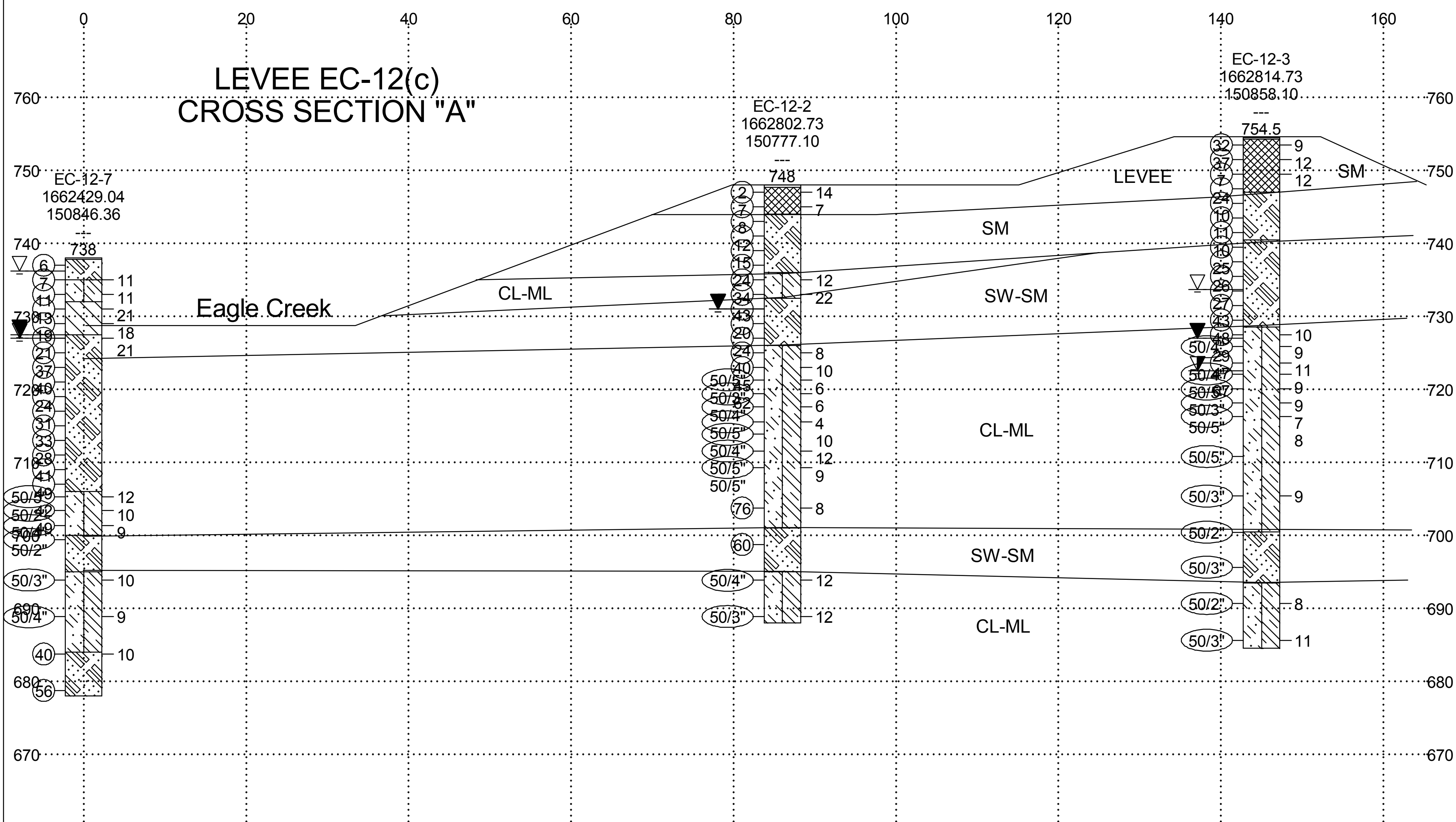


NOTE:

EC-12-1
BORING LOCATION

CTL ENGINEERING INC. CONSULTING ENGINEERS TESTING * INSPECTION LABORATORY SERVICES			
BORING LOCATION PLAN			
DATE 06-01-11	CHRISTOPHER B. BURKE ENGINEERING, INC. INDIANAPOLIS PAL LEVEE ACCREDITATION PROJ. LEVEE EC-12(c) INDIANAPOLIS, IN		
SCALE AS SHOWN			
DRAWN BY C.L.	REVIEWED BY K.R.	PAGE 1 OF 2	PROJECT NO. 09050035IND

LEVEE EC-12(c) CROSS SECTION "A"



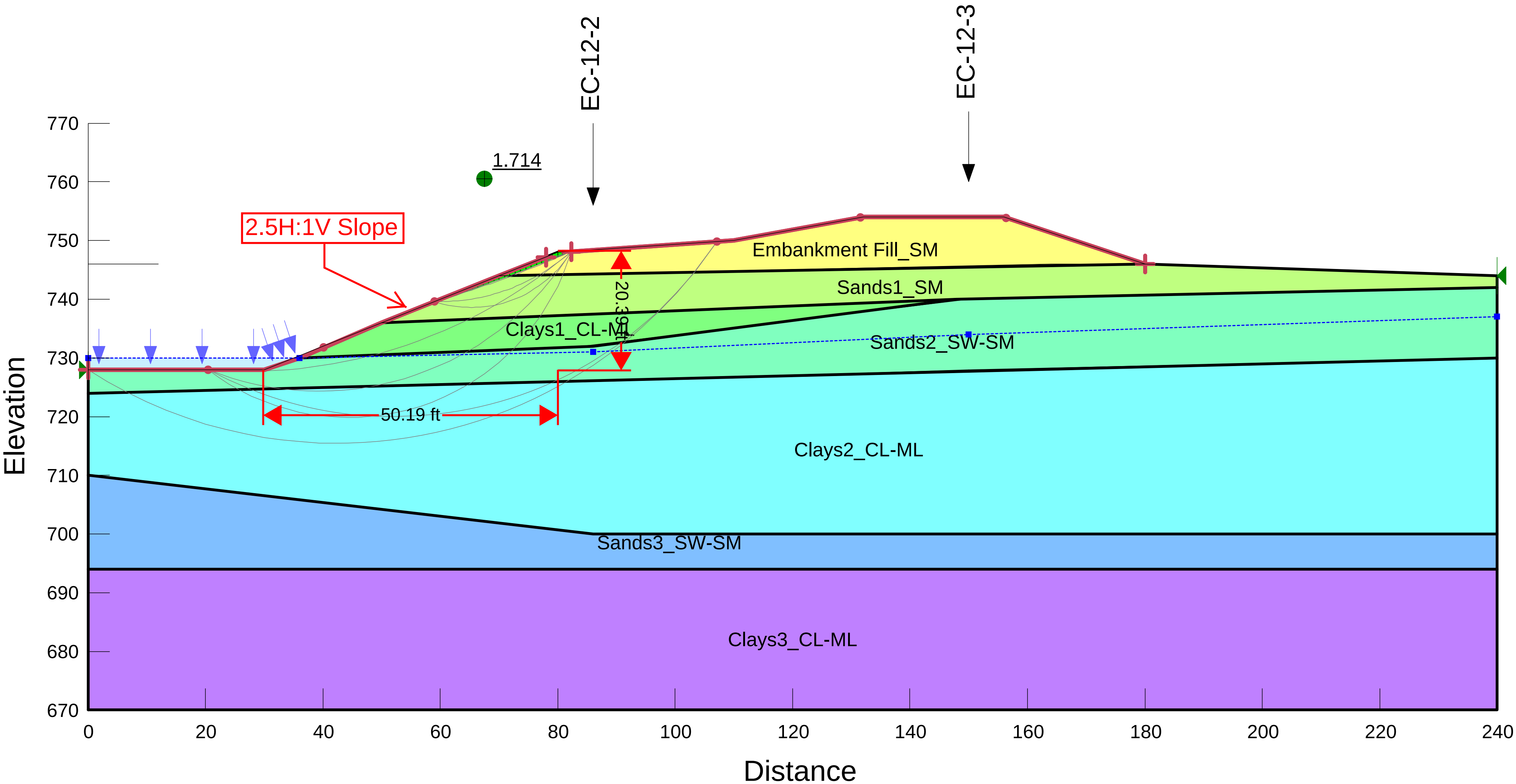
LEGEND

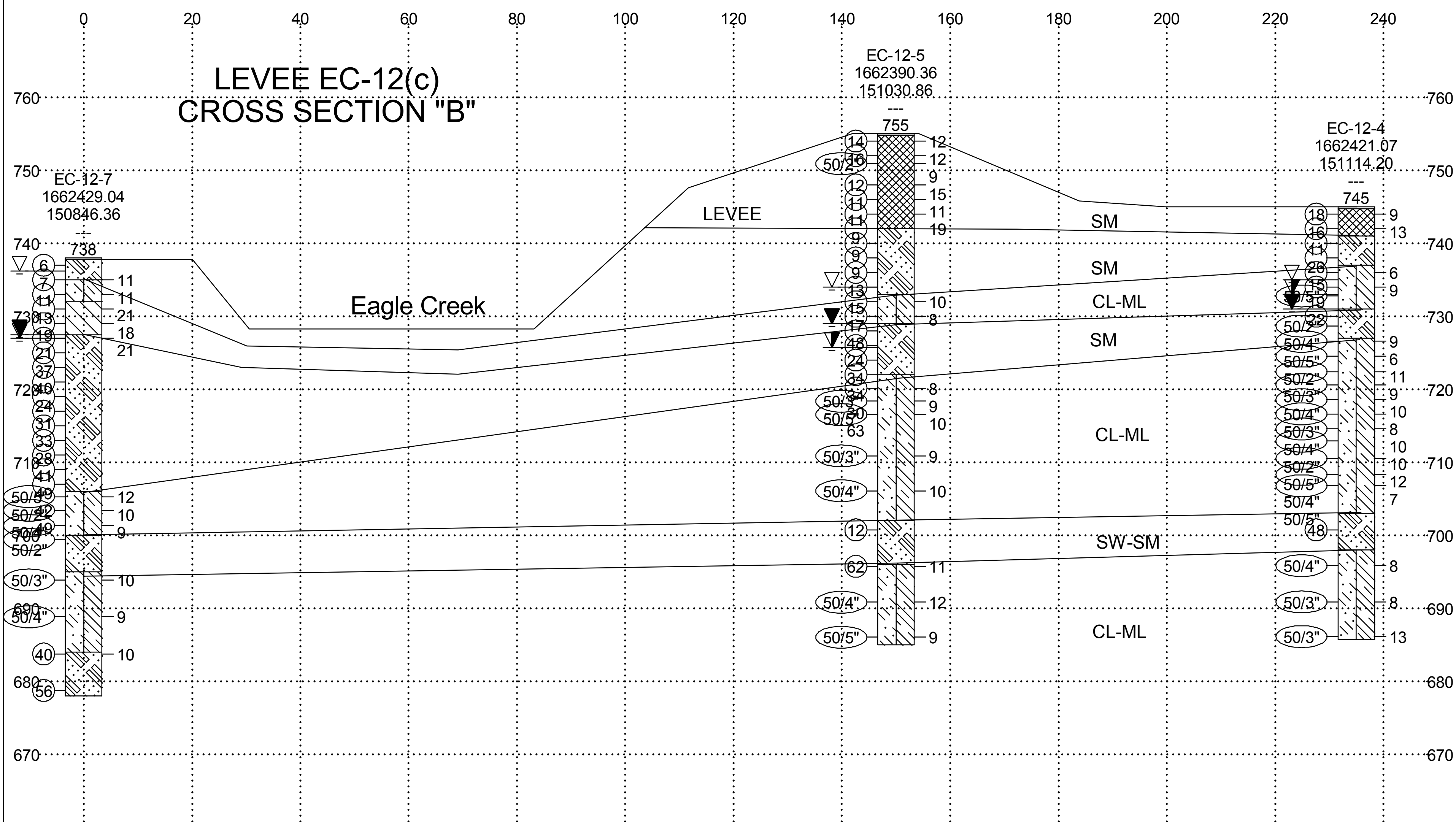
TOPSOIL	CLAY	SILTSTONE	GROUND WATER DURING DRILLING	W MOISTURE CONTENT IN PERCENT (w)
BITUMINOUS CONCRETE	SILT	SANDSTONE	GROUND WATER AT COMPLETION OF DRILLING	(N) STANDARD PENETRATION IN BLOWS PER FOOT (N)
PORTLAND CEMENT CONCRETE	SAND	LIMESTONE	GROUND WATER AT "N" HOURS AFTER COMPLETION	
CRUSHED AGGREGATE GRAVEL/COBBLES	BOULDERS	COAL		
FILL	SAND/GRAVEL	SHALE		
PEAT	WEATHERED SHALE	CLAYSHALE		

SOIL PROFILE

Scale As Shown	Christopher B. Burke Engineering, LTD City of Indianapolis PAL Indianapolis, Indiana
Date 12/10/10	
Drawn By CG	
Reviewed By	Project No. 09050035IND
	Page 1 of 1

Indianapolis PAL Levee Accrediation Project
Levee: EC-12
Cross Section: A
Case: End of Construction
Water Side Analysis - Effective Stress





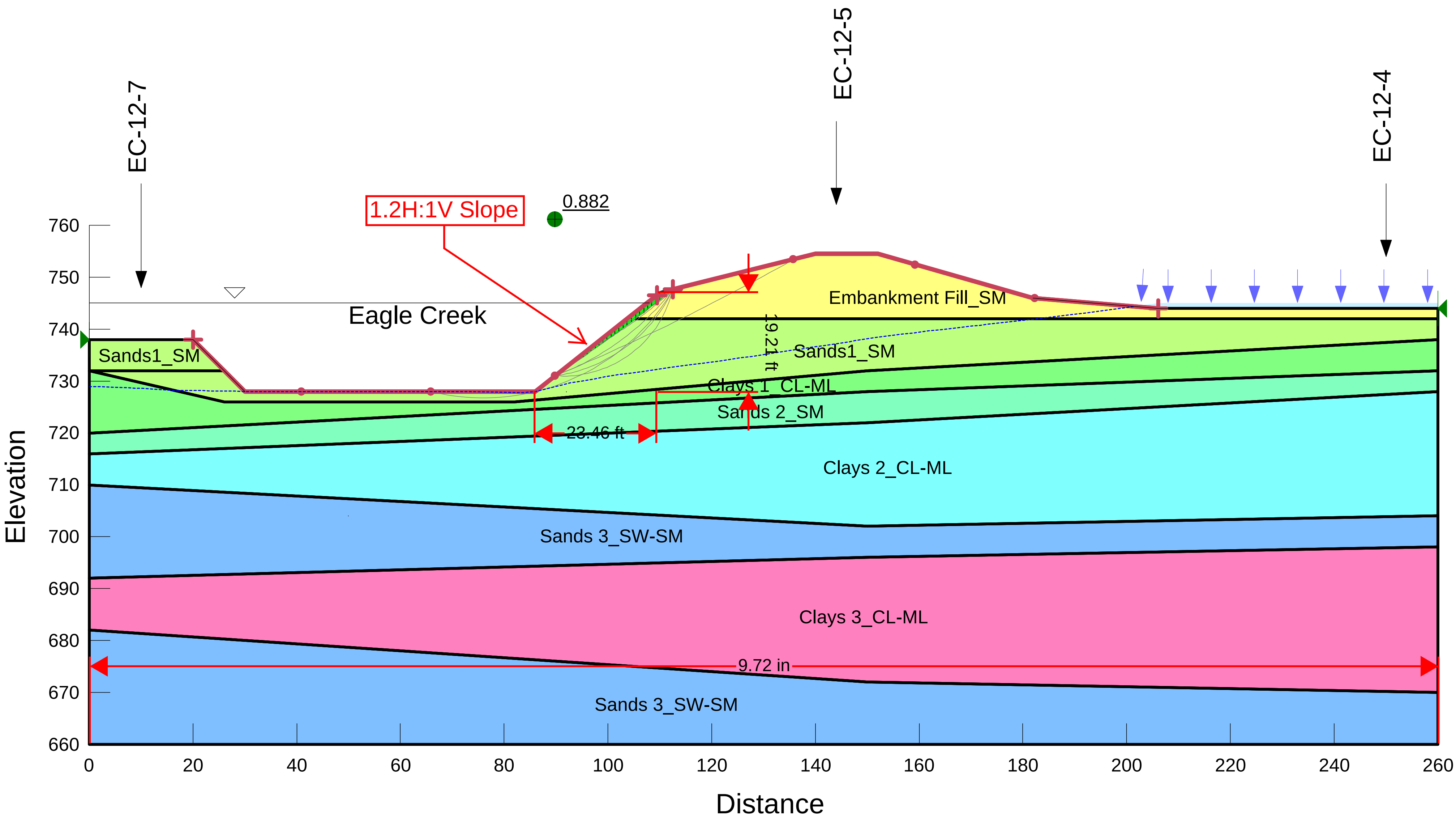
LEGEND

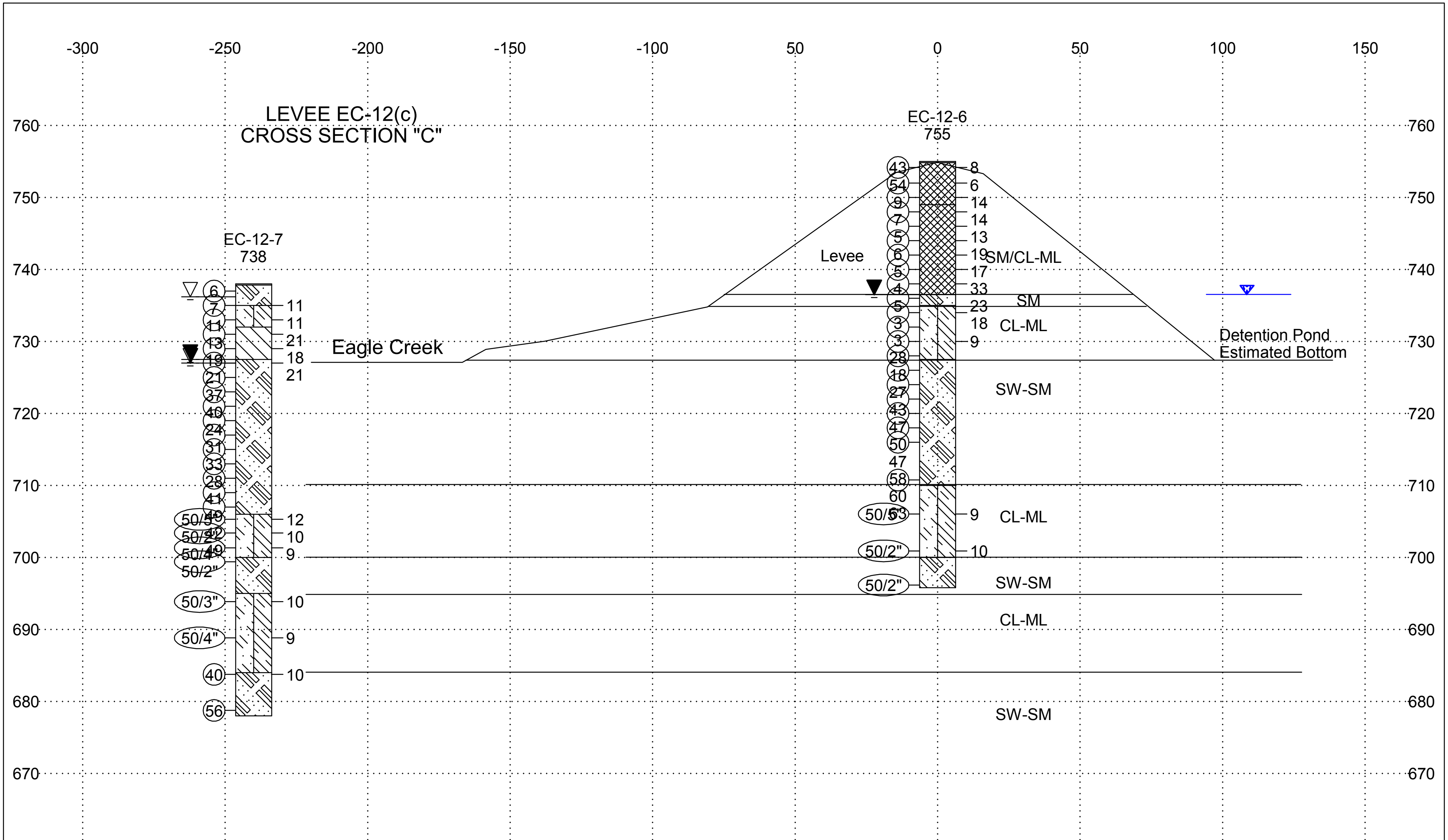
TOPSOIL
BITUMINOUS CONCRETE
PORTLAND CEMENT CONCRETE
CRUSHED AGGREGATE GRAVEL/COBBLES
FILL
PEAT
CLAY
SILT
SAND
BOULDERS
SAND/GRAVEL
WEATHERED SHALE
SILTSTONE
SANDSTONE
LIMESTONE
COAL
SHALE
CLAYSHALE
GROUND WATER DURING DRILLING
GROUND WATER AT COMPLETION OF DRILLING
GROUND WATER AT "N" HOURS AFTER COMPLETION
W MOISTURE CONTENT IN PERCENT (w)
(N) STANDARD PENETRATION IN BLOWS PER FOOT (N)

SOIL PROFILE

Scale As Shown	Christopher B. Burke Engineering, LTD City of Indianapolis PAL Indianapolis, Indiana
Date 12/10/10	
Drawn By CG	
Reviewed By	Project No. 09050035IND
	Page 1 of 1

Indianapolis PAL Levee Accrediation Project
Levee: EC-12
Cross Section: B
Case: Rapid Drawdown
Water Side Analysis





LEGEND

- TOPSOIL
- BITUMINOUS CONCRETE
- PORTLAND CEMENT CONCRETE
- CRUSHED AGGREGATE GRAVEL/COBBLES
- FILL
- PEAT
- CLAY
- SILT
- SAND
- BOULDERS
- SAND/GRAVEL
- Fat Clay - CH
- Lean Clay - CL
- SANDSTONE
- LIMESTONE
- COAL
- SHALE
- CLAYSHALE
- GROUND WATER DURING DRILLING
- GROUND WATER AT COMPLETION OF DRILLING
- GROUND WATER AT "N" HOURS AFTER COMPLETION
- W MOISTURE CONTENT IN PERCENT (w)
- (N) STANDARD PENETRATION IN BLOWS PER FOOT (N)

SOIL PROFILE

Scale As Shown	Christopher B. Burke Engineering, LTD City of Indianapolis PAL Indianapolis, Indiana
Date 5/27/11	
Drawn By CG	
Reviewed By	Project No. 09050035IND
	Page 1 of 1

ASTM_PROFILE 09050035IND.GPJ CTL.GDT 5/27/11

Indianapolis PAL Levee Accrediation Project
Levee: EC-12
Cross Section: C
Case: End of Construction - Total Stress

Water Side Analysis

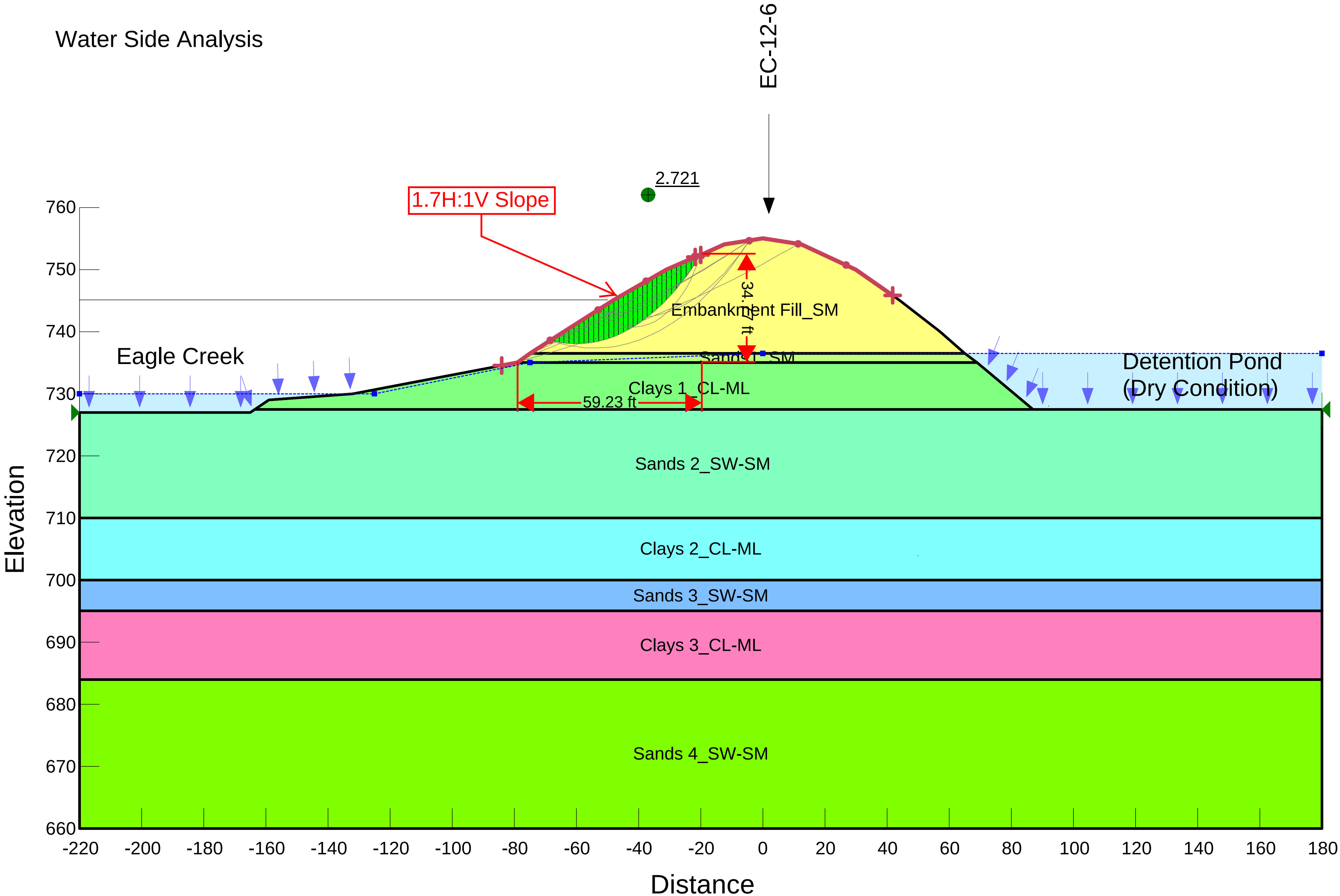


Table 3 – Summary of Factor of Safety for Slope Stability

Parameter	Factor of Safety for Slope Stability							
	Existing Condition		Steady Seepage		Rapid Drawdown		Earthquake	
Side of Levee	Water	Dry	Water	Dry	Water	Dry	Water	Dry
Cross Section "A"	1.7	3.9	1.62	3.0	1.6	---	1.1	2.2
Cross Section "B"	**< 1.0**	---	**0.8**	2.8	**0.8**	3.1	not performed	
Cross Section "C"	**2.4**	1.9	**2.6**	1.8	**2.6**	1.9	1.9	1.4
Minimum Allowed*	1.3		1.4		1.0 to 1.2		1.0	

* *Refer to EM 1110-2-1913, Table 6-1b*

Various permanent methods of repair are available for consideration, including gabion walls, sheet piling with and/or without tiebacks, and riprap. As a temporary solution, the erosion along the east back of Eagle Creek was repaired with a limited amount of riprap due to construction restraints.

The temporary erosion repair using riprap along the river bank was analyzed. By analyzing the levee at the location of Cross Section B after the application of riprap, results of the stability analysis indicate that the entire levee system is stable. However, the levee system does not meet the minimum factor of safety requirements as shown in Table 4 below.

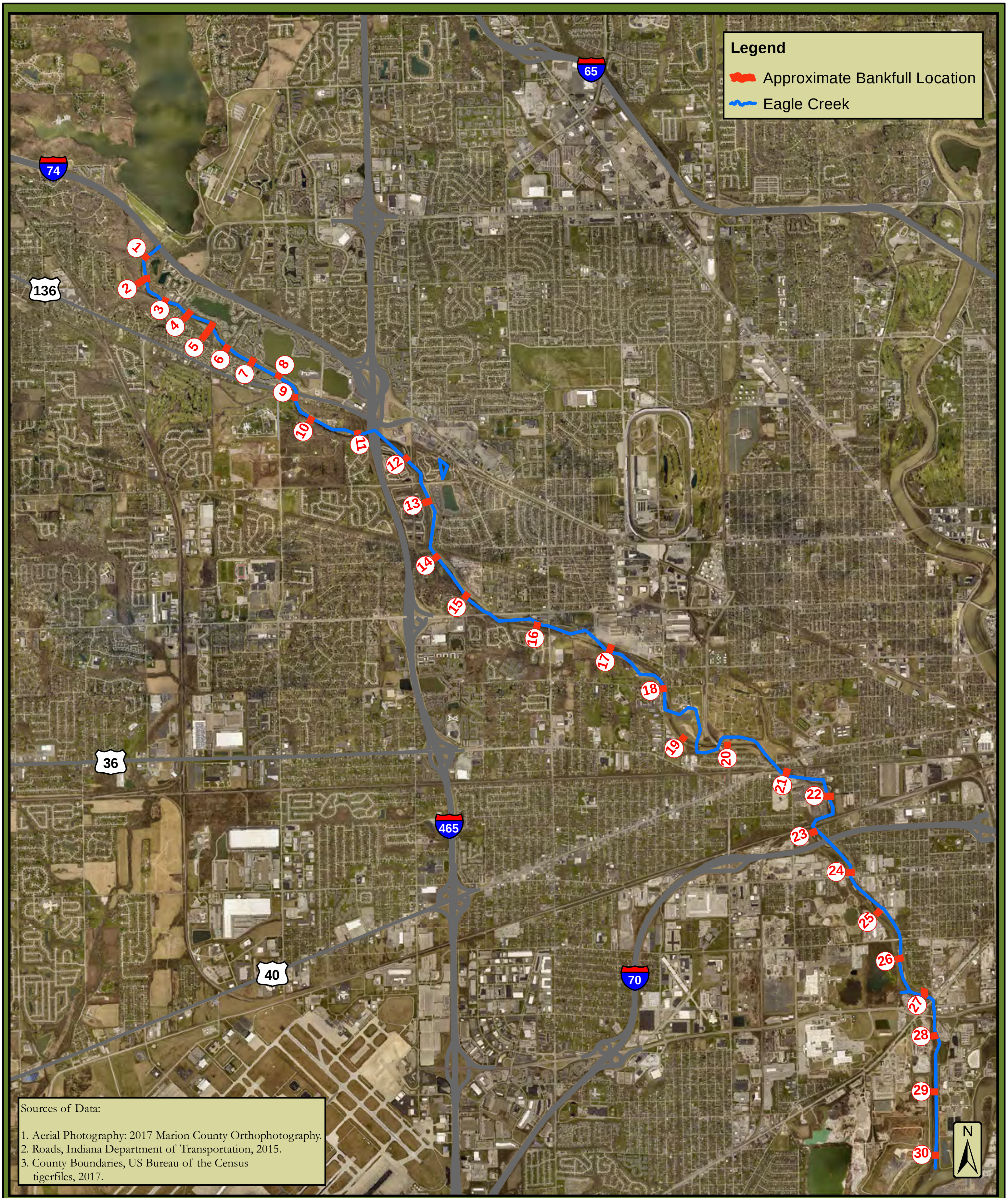
Table 4 – Summary of Factor of Safety for Slope Stability (Using Riprap)

Parameter	Factor of Safety for Slope Stability **Using Riprap**							
	Existing Condition		Steady Seepage		Rapid Drawdown		Earthquake	
Side of Levee	Water	Dry	Water	Dry	Water	Dry	Water	Dry
Cross Section "B"	**1.0**	3.1	**1.1**	2.8	**1.0**	3.3	0.8	2.0
Minimum Allowed*	1.3		1.4		1.0 to 1.2		1.0	

* *Refer to EM 1110-2-1913, Table 6-1b*

Appendix 3: Watershed-scale Assessment Data & Calculations

Approximate Bankfull Location Map and Bankfull Dimension Comparison



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PROJECT: Eagle Creek FEH Mitigation Assessment	PROJECT NO. 14-0014	APPROX. SCALE 1"=5,000'
TITLE: Approximate Bankfull Location Map		DATE: 10/2018
		EXHIBIT A3.2

Measurement Location	Miles from Mouth (mi)	Approximate Distance DS from Dam (mi)	Drainage Area (sq. mi.)	Approximate Bankfull Width* (ft)	Predicted Bankfull Width** (ft)	Predicted Bankfull Depth** (ft)	Predicted Bankfull Area** (ft^2)	Departure from Expected Bankfull Width (ft [%])	Description of Stream at Measurement Location
1	10.818	0.3	162.0	50	96	3.6	343	-46 ft [-48%]	Alluvium
2	10.64	0.5	163.0	80	96	3.6	344	-16 ft [-17%]	Alluvium
3	10.386	0.7	164.0	40	96	3.6	345	-56 ft [-59%]	Alluvium
4	10.181	0.9	164.0	35	96	3.6	345	-61 ft [-64%]	Alluvium
5	9.981	1.1	165.0	40	97	3.6	346	-57 ft [-59%]	Alluvium
6	9.754	1.3	165.0	80	97	3.6	346	-17 ft [-17%]	Alluvium
7	9.535	1.6	165.0	25	97	3.6	346	-72 ft [-74%]	Alluvium
8	9.305	1.8	166.0	45	97	3.6	347	-52 ft [-54%]	Alluvium
9	9.073	2.0	166.0	75	97	3.6	347	-22 ft [-23%]	Alluvium
10	8.853	2.2	169.0	55	97	3.6	350	-42 ft [-44%]	Alluvium
11	8.482	2.6	169.0	45	97	3.6	350	-52 ft [-54%]	Alluvium
12	8.03	3.1	170.0	30	98	3.6	351	-68 ft [-69%]	Alluvium
13	7.648	3.5	170.0	45	98	3.6	351	-53 ft [-54%]	Alluvium
14	7.214	3.9	173.0	75	98	3.6	354	-23 ft [-24%]	Alluvium
15	6.839	4.3	174.0	40	98	3.6	355	-58 ft [-59%]	Alluvium
16	6.235	4.9	174.0	65	98	3.6	355	-33 ft [-34%]	Alluvium
17	5.651	5.4	175.0	40	99	3.6	356	-59 ft [-59%]	Alluvium
18	5.128	6.0	175.0	70	99	3.6	356	-29 ft [-29%]	Alluvium
19	4.708	6.4	177.0	20	99	3.6	358	-79 ft [-80%]	Alluvium
20	4.356	6.7	177.0	35	99	3.6	358	-64 ft [-65%]	Alluvium
21	3.819	7.3	177.0	35	99	3.6	358	-64 ft [-65%]	Alluvium
22	3.409	7.7	205.0	50	104	3.7	385	-54 ft [-52%]	Alluvium
23	3.025	8.1	208.0	40	104	3.7	388	-64 ft [-62%]	Alluvium
24	2.578	8.5	209.0	145	104	3.7	388	41 ft [39%]	Alluvium
25	2.195	8.9	209.0	50	104	3.7	388	-54 ft [-52%]	Alluvium
26	1.792	9.3	209.0	130	104	3.7	388	26 ft [25%]	Alluvium
27	1.43	9.7	210.0	45	105	3.7	389	-60 ft [-57%]	Alluvium
28	1.081	10.0	210.0	45	105	3.7	389	-60 ft [-57%]	Alluvium
29	0.654	10.4	210.0	65	105	3.7	389	-40 ft [-38%]	Alluvium
30	0.174	10.9	210.0	35	105	3.7	389	-70 ft [-67%]	Alluvium

* Approximate bankfull width measured from cross-sections of the IndianaMap DEM. The channel width was measured at an elevation that was the predicted bankfull depth above the invert of the cross-section. This method is expected to produce bankfull widths that will be slightly higher than those that would be measured in the field (if bankfull indicators could be reasonably identified).

** Predicted bankfull width and depth determined using the Central Till Plain Region regression equations published by the USGS in Regional Bankfull-Channel Dimensions of Non-Urban Wadeable Streams in Indiana.

Appendix 4: Reach-scale Assessment Data & Calculations

Stream Gage Analysis

```
1
  Program PeakFq           U. S. GEOLOGICAL SURVEY             Seq.002.000
  Version 7.2        Annual peak flow frequency analysis      Run Date / Time
  3/28/2018                                                    07/02/2018 13:46

                        --- PROCESSING OPTIONS ---

                     Plot option         = Graphics device
                     Basin char output   = None
                     Print option        = Yes
                     Debug print         = No
                     Input peaks listing = Long
                     Input peaks format  = WATSTORE peak file

                     Input files used:
                        peaks (ascii)  - C:\Users\hfinfrock\Desktop
\PEAK_CLERMONT.TXT
                        specifications - C:\Users\hfinfrock\Desktop\PKFQWPSF.TMP
                     Output file(s):
                        main - C:\Users\hfinfrock\Desktop\PEAK_CLERMONT.PRT


  ***  User responsible for assessment and interpretation of the following
analysis  ***

1


  Program PeakFq           U. S. GEOLOGICAL SURVEY             Seq.001.001
  Version 7.2        Annual peak flow frequency analysis      Run Date / Time
  3/28/2018                                                    07/02/2018 13:46

                Station - 03353460  EAGLE CREEK AT CLERMONT, IN


                     TABLE 1 - INPUT DATA SUMMARY

                Number of peaks in record           =       11
                Peaks not used in analysis          =        0
                Gaged peaks in analysis             =       11
                Historic peaks in analysis          =        0
                Beginning Year                      =     2007
                Ending Year                         =     2017
                Historical Period Length            =       11
                Skew option                         =   WEIGHTED
                Regional skew                       =   -0.200
                     Standard error                 =    0.550
                     Mean Square error              =    0.303
                Gage base discharge                 =      0.0
                User supplied high outlier threshold =   --
                User supplied PILF (LO) criterion    =   --
                Plotting position parameter         =     0.00
                Type of analysis                      BULL.17B
                PILF (LO) Test Method                     MGBT
                Perceptible Ranges              =   Not Applicable
```

Interval Data = Not Applicable

TABLE 2 - DIAGNOSTIC MESSAGE AND PILF RESULTS

WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE. 0.0
EMA003I-LOW OUTLIERS WERE DETECTED USING MULTIPLE GRUBBS-BECK TEST 1
5750.0
THE FOLLOWING PEAKS (WITH CORRESPONDING P-VALUES) WERE DROPPED:
3680.0 (0.0751)
WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE. 13196.8
**WCF164W-HISTORIC PERIOD IGNORED. 11.0
**WCF233W-EXPECTED PROB OUT OF RANGE AT TAB PROB. 0.00000 0.00010
WCF002J-CALCS COMPLETED. RETURN CODE = 2

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
GAGED PEAKS	0.236	0.350	150.000	11

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.002
Version 7.2 Annual peak flow frequency analysis Run Date / Time
3/28/2018 07/02/2018 13:46

Station - 03353460 EAGLE CREEK AT CLERMONT, IN

TABLE 3 - ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	3.8500	0.1328	-0.257
BULL.17B ESTIMATE	0.0	0.9091	3.8675	0.1005	0.261

BULL.17B ESTIMATE OF MSE OF AT-SITE SKEW 0.7764

TABLE 4 - ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE
PROBABILITIES

ANNUAL <-- FOR BULLETIN 17B ESTIMATES -->
EXCEEDANCE BULL.17B SYSTEMATICLOG VARIANCE CONFIDENCE INTERVALS

PROBABILITY	ESTIMATE	RECORD	OF EST.	5% LOWER	95% UPPER
0.9950		2992.	--	--	--
0.9900		3282.	--	--	--
0.9500		4190.	--	--	--
0.9000	5519.	4748.	----	4431.0	6280.0
0.8000	6053.	5498.	----	5055.0	6813.0
0.6667	6619.	6274.	----	5706.0	7424.0
0.5000	7297.	7173.	----	6439.0	8243.0
0.4292	7606.	7570.	----	6751.0	8654.0
0.2000	8924.	9186.	----	7931.0	10660.0
0.1000	9971.	10380.	----	8748.0	12490.0
0.0400	11270.	11760.	----	9681.0	15000.0
0.0200	12240.	12710.	----	10330.0	16980.0
0.0100	13190.	13610.	----	10960.0	19060.0
0.0050	14150.	14460.	----	11570.0	21240.0
0.0020	15440.	15530.	----	12360.0	24300.0

1

Station - 03353460 EAGLE CREEK AT CLERMONT, IN

TABLE 5 - INPUT DATA LISTING

WATER YEAR	PEAK VALUE	PEAKFQ CODES	REMARKS
2007	5750.0	K	
2008	7410.0	K	
2009	7680.0	K	
2010	5920.0	K	
2011	7980.0	K	
2012	3680.0	K	
2013	13000.0	K	
2014	7030.0	K	
2015	7000.0	K	
2016	7120.0	K	
2017	8640.0	K	

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization

```
          H        7    Historic peak

          -  Minus-flagged discharge -- Not used in computation
                -8888.0 -- No discharge value given
          -  Minus-flagged water year -- Historic peak used in computation
```

1

```
  Program PeakFq            U. S. GEOLOGICAL SURVEY             Seq.001.004
  Version 7.2          Annual peak flow frequency analysis      Run Date / Time
  3/28/2018                                                      07/02/2018 13:46

                Station - 03353460  EAGLE CREEK AT CLERMONT, IN
```

TABLE 6 - EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	B17B ESTIMATE
2013	13000.0	0.0833	0.0833
2017	8640.0	0.1667	0.1667
2011	7980.0	0.2500	0.2500
2009	7680.0	0.3333	0.3333
2008	7410.0	0.4167	0.4167
2016	7120.0	0.5000	0.5000
2014	7030.0	0.5833	0.5833
2015	7000.0	0.6667	0.6667
2010	5920.0	0.7500	0.7500
2007	5750.0	0.8333	0.8333
2012	3680.0	0.9167	0.9167

1

```
 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      11

Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  03353460       USGS EAGLE CREEK AT CLERMONT, IN


 For the station below, the following records were ignored:
```

FINISHED PROCESSING STATION:

```
1
  Program PeakFq            U. S. GEOLOGICAL SURVEY             Seq.002.000
  Version 7.2         Annual peak flow frequency analysis      Run Date / Time
  3/28/2018                                                      07/02/2018 15:19

                         --- PROCESSING OPTIONS ---

                      Plot option         = Graphics device
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  - C:\Users\hfinfrock\Desktop
\PEAK_SPEEDWAY.TXT
                         specifications - C:\Users\hfinfrock\Desktop\PKFQWPSF.TMP
                      Output file(s):
                         main - C:\Users\hfinfrock\Desktop\PEAK_SPEEDWAY.PRT


  ***  User responsible for assessment and interpretation of the following
analysis  ***

1


  Program PeakFq            U. S. GEOLOGICAL SURVEY             Seq.001.001
  Version 7.2         Annual peak flow frequency analysis      Run Date / Time
  3/28/2018                                                      07/02/2018 15:19

              Station - 03353500  EAGLE CREEK AT INDIANAPOLIS, IN


                     TABLE 1 - INPUT DATA SUMMARY

                Number of peaks in record            =       81
                Peaks not used in analysis           =        1
                Gaged peaks in analysis              =       79
                Historic peaks in analysis           =        1
                Beginning Year                       =     1913
                Ending Year                          =     2017
                Historical Period Length             =      105
                Skew option                          =   WEIGHTED
                Regional skew                        =   -0.200
                     Standard error                  =    0.550
                     Mean Square error               =    0.303
                Gage base discharge                  =      0.0
                User supplied high outlier threshold =   --
                User supplied PILF (LO) criterion    =   --
                Plotting position parameter          =     0.00
                Type of analysis                       BULL.17B
                PILF (LO) Test Method                      MGBT
                Perceptible Ranges               =   Not Applicable
```

```
              Interval Data                   =   Not Applicable



    TABLE 2 - DIAGNOSTIC MESSAGE AND PILF RESULTS


  **WCF109W-PEAKS WITH MINUS-FLAGGED DISCHARGES WERE BYPASSED.       1
  **WCF113W-NUMBER OF SYSTEMATIC PEAKS HAS BEEN REDUCED TO NSYS =   79
    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                  0.0
    EMA003I-LOW OUTLIERS WERE DETECTED USING MULTIPLE GRUBBS-BECK TEST       7
2250.0
      THE FOLLOWING PEAKS (WITH CORRESPONDING P-VALUES) WERE DROPPED:
          1100.0    (0.2674)
          1240.0    (0.0834)
          1470.0    (0.0676)
          1680.0    (0.0678)
          1700.0    (0.0155)
          1860.0    (0.0128)
          1870.0    (0.0021)
    WCF156I-17B HI-OUTLIER TEST SUPERSEDED BY MIN HIST PK   24907.4
    WCF165I-HIGH OUTLIERS AND HISTORIC PEAKS ABOVE HHBASE.  1  1    19000.0
    WCF002J-CALCS COMPLETED.  RETURN CODE =  2


                           Kendall's Tau Parameters

                                            MEDIAN   No. of
                           TAU    P-VALUE    SLOPE   PEAKS
                   ------------------------------------------
    GAGED PEAKS      0.101      0.191     21.053    79


1


  Program PeakFq           U. S. GEOLOGICAL SURVEY           Seq.001.002
  Version 7.2         Annual peak flow frequency analysis      Run Date / Time
  3/28/2018                                                   07/02/2018 15:19

                  Station - 03353500  EAGLE CREEK AT INDIANAPOLIS, IN


     TABLE 3 - ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

                            FLOOD BASE                LOGARITHMIC
                      ----------------------  -------------------------------
                                 EXCEEDANCE                STANDARD
                       DISCHARGE PROBABILITY     MEAN     DEVIATION     SKEW
                      -------------------------------------------------------
 SYSTEMATIC RECORD        0.0      1.0000     3.7375      0.2649     -0.414
 BULL.17B ESTIMATE        0.0      0.9120     3.7661      0.2227      0.096

 BULL.17B ESTIMATE OF MSE OF AT-SITE SKEW     0.0579
```

TABLE 4 - ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	LOG VARIANCE OF EST.	<-- FOR BULLETIN 17B ESTIMATES --> CONFIDENCE INTERVALS 5% LOWER	95% UPPER
0.9950		897.2	--	--	--
0.9900		1102.	--	--	--
0.9500		1875.	--	--	--
0.9000	3042.	2446.	----	2642.0	3423.0
0.8000	3782.	3323.	----	3356.0	4199.0
0.6667	4649.	4356.	----	4188.0	5120.0
0.5000	5789.	5698.	----	5259.0	6369.0
0.4292	6345.	6339.	----	5770.0	6997.0
0.2000	8963.	9205.	----	8077.0	10100.0
0.1000	11320.	11560.	----	10050.0	13050.0
0.0400	14560.	14500.	----	12670.0	17290.0
0.0200	17170.	16640.	----	14720.0	20820.0
0.0100	19950.	18720.	----	16850.0	24660.0
0.0050	22900.	20750.	----	19080.0	28840.0
0.0020	27110.	23370.	----	22190.0	34950.0

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.003
Version 7.2 Annual peak flow frequency analysis Run Date / Time
3/28/2018 07/02/2018 15:19

Station - 03353500 EAGLE CREEK AT INDIANAPOLIS, IN

TABLE 5 - INPUT DATA LISTING

WATER YEAR	PEAK VALUE	PEAKFQ CODES	REMARKS
-1913	19000.0	H	
1938	-8888.0		
1939	6610.0		
1940	1860.0		
1941	1470.0		
1942	4120.0		
1943	9660.0		
1944	6610.0		
1945	4230.0		
1946	3860.0		
1947	3370.0		
1948	9550.0		
1949	7250.0		
1950	8670.0		
1951	3950.0		
1952	5520.0		

1953	4920.0	
1954	2250.0	
1955	2650.0	
1956	9920.0	
1957	28800.0	
1958	8560.0	
1959	6290.0	
1960	1870.0	
1961	7110.0	
1962	9550.0	
1963	8840.0	
1964	14700.0	
1965	5230.0	
1966	1100.0	
1967	4910.0	
1968	5380.0	
1969	1700.0	
1970	6150.0	K
1971	3460.0	K
1972	3740.0	K
1973	4400.0	K
1974	6670.0	K
1975	4900.0	K
1976	7700.0	K
1977	2350.0	K
1978	10500.0	K
1979	6800.0	K
1980	2800.0	K
1981	5200.0	K
1982	4640.0	K
1983	4170.0	K
1984	6220.0	K
1985	9110.0	K
1986	11000.0	K
1987	3340.0	K
1988	6350.0	K
1989	9760.0	K
1990	9840.0	K
1991	13400.0	K
1992	4450.0	K
1993	6250.0	K
1994	8700.0	K
1995	4020.0	K
1996	4770.0	K
1997	7490.0	K
1998	5580.0	K
1999	7650.0	K
2000	1240.0	K
2001	1680.0	K
2002	9560.0	K
2003	15900.0	K
2004	3970.0	K
2005	6960.0	K
2006	2590.0	K
2007	4940.0	K

2008	7270.0	K
2009	6920.0	K
2010	4100.0	K
2011	7820.0	K
2012	3320.0	K
2013	14600.0	K
2014	7190.0	K
2015	7070.0	K
2016	6910.0	K
2017	8560.0	K

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.004
Version 7.2 Annual peak flow frequency analysis Run Date / Time
3/28/2018 07/02/2018 15:19

Station - 03353500 EAGLE CREEK AT INDIANAPOLIS, IN

TABLE 6 - EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	B17B ESTIMATE
1957	28800.0	0.0125	0.0094
-1913	19000.0	--	0.0189
2003	15900.0	0.0250	0.0298
1964	14700.0	0.0375	0.0423
2013	14600.0	0.0500	0.0547
1991	13400.0	0.0625	0.0672
1986	11000.0	0.0750	0.0796
1978	10500.0	0.0875	0.0921
1956	9920.0	0.1000	0.1046
1990	9840.0	0.1125	0.1170
1989	9760.0	0.1250	0.1295

1943	9660.0	0.1375	0.1419
2002	9560.0	0.1500	0.1544
1948	9550.0	0.1625	0.1668
1962	9550.0	0.1750	0.1793
1985	9110.0	0.1875	0.1918
1963	8840.0	0.2000	0.2042
1994	8700.0	0.2125	0.2167
1950	8670.0	0.2250	0.2291
1958	8560.0	0.2375	0.2416
2017	8560.0	0.2500	0.2541
2011	7820.0	0.2625	0.2665
1976	7700.0	0.2750	0.2790
1999	7650.0	0.2875	0.2914
1997	7490.0	0.3000	0.3039
2008	7270.0	0.3125	0.3163
1949	7250.0	0.3250	0.3288
2014	7190.0	0.3375	0.3413
1961	7110.0	0.3500	0.3537
2015	7070.0	0.3625	0.3662
2005	6960.0	0.3750	0.3786
2009	6920.0	0.3875	0.3911
2016	6910.0	0.4000	0.4035
1979	6800.0	0.4125	0.4160
1974	6670.0	0.4250	0.4285
1939	6610.0	0.4375	0.4409
1944	6610.0	0.4500	0.4534
1988	6350.0	0.4625	0.4658
1959	6290.0	0.4750	0.4783
1993	6250.0	0.4875	0.4907
1984	6220.0	0.5000	0.5032
1970	6150.0	0.5125	0.5157
1998	5580.0	0.5250	0.5281
1952	5520.0	0.5375	0.5406
1968	5380.0	0.5500	0.5530
1965	5230.0	0.5625	0.5655
1981	5200.0	0.5750	0.5780
2007	4940.0	0.5875	0.5904
1953	4920.0	0.6000	0.6029
1967	4910.0	0.6125	0.6153
1975	4900.0	0.6250	0.6278
1996	4770.0	0.6375	0.6402
1982	4640.0	0.6500	0.6527
1992	4450.0	0.6625	0.6652
1973	4400.0	0.6750	0.6776
1945	4230.0	0.6875	0.6901
1983	4170.0	0.7000	0.7025
1942	4120.0	0.7125	0.7150
2010	4100.0	0.7250	0.7274
1995	4020.0	0.7375	0.7399
2004	3970.0	0.7500	0.7524
1951	3950.0	0.7625	0.7648
1946	3860.0	0.7750	0.7773
1972	3740.0	0.7875	0.7897
1971	3460.0	0.8000	0.8022
1947	3370.0	0.8125	0.8146

```
    1987     3340.0     0.8250      0.8271
    2012     3320.0     0.8375      0.8396
    1980     2800.0     0.8500      0.8520
    1955     2650.0     0.8625      0.8645
    2006     2590.0     0.8750      0.8769
    1977     2350.0     0.8875      0.8894
    1954     2250.0     0.9000      0.9019
    1960     1870.0     0.9125      0.9143
    1940     1860.0     0.9250      0.9268
    1969     1700.0     0.9375      0.9392
    2001     1680.0     0.9500      0.9517
    1941     1470.0     0.9625      0.9641
    2000     1240.0     0.9750      0.9766
    1966     1100.0     0.9875      0.9891
    1938    -8888.0       --          --
1



 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      81


Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  03353500       USGS EAGLE CREEK AT INDIANAPOLIS,


 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:
```

Bankfull Discharge Calculations

Worksheet 5-2. Computations of velocity and bankfull discharge using various methods (Rosgen and Silvey, 2005).

Bankfull VELOCITY / DISCHARGE Estimates

Site	**Eagle Creek**			Location	**Indianapolis, IN**
Date	**8/2018**	Stream Type	**B4c**	Valley Type	**U-GL-TP**
Observers	**BJM, JDF, HLF, JLE**			HUC	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-section AREA	**317.7**	A_{bkf} (SqFt)	Bankfull Mean DEPTH	**4.02**	D_{bkf} (Ft)
Bankfull WIDTH	**79.1**	W_{bkf} (Ft)	Wetted PERIMETER	**81.70**	W_{Pbkf} (Ft)
D84 @ Riffle	**51.1**	Dia. (mm)	D84 mm / 304.8 =	**0.17**	D84 (Ft)
Bankfull SLOPE	**0.00053**	S (Ft / Ft)	Hydraulic RADIUS A_{bkf} / W_{Pbkf}	**3.89**	R (Ft)
Gravitational Acceleration	**32.2**	g (Ft /Sec^2)	Relative Roughness R (ft) / D84 (ft)	**23.195**	
Drainage AREA	**164.0**	DA (SqMi)	Shear Velocity $u^* = \sqrt{gRS}$	**0.2581**	u* (Ft / Sec)

ESTIMATION METHODS	Bankfull		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\,2.83 + 5.66\text{Log}\{R / D84\}\,]u^*$	**2.7**	Ft / Sec	**866**	CFS
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness. (Figs. 5-6, 5-7) $u = 1.4895 {*} R^{2/3} {*} S^{1/2}/n$ n = 0.030	**5.8**	Ft / Sec	**1834**	CFS
2. Roughness Coefficient: $u = 1.4895 {*} R^{2/3} {*} S^{1/2}/n$ b) Manning's 'n' from Jarrett (USGS): $n = 0.39S^{.38}R^{-.16}$ n = **Note:** This equation is for applications involving **steep, step-pool, high boundary roughness, cobble-boulder-dominated stream systems**; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3.		Ft / Sec		CFS
2. Roughness Coefficient: $u = 1.4895 {*} R^{2/3} {*} S^{1/2}/n$ c) Manning's 'n' from Stream Type n = 0.037	**4.7**	Ft / Sec	**1487**	CFS
3. Other Methods, ie. Hydraulic Geometry (Hey, Darcy-Weisbach, Chezy C, etc.)		Ft / Sec		CFS
3. Other Methods, ie. Hydraulic Geometry (Hey, Darcy-Weisbach, Chezy C, etc.)		Ft / Sec		CFS
4. Continuity Equations: a) USGS Gage: u = Q / A Return Period for Bankfull Discharge (Yr.) Q = 1.5	**20.8**	Ft / Sec	**6619**	CFS
4. Continuity Equations: b) Regional Curves u = Q / A		Ft / Sec		CFS

Options for using the D84 term in the **relative roughness relation** (R/D84), when using estimation method 1.

Option 1. For **sand-bed** channels: measure the **"protrusion height"** (h_{sd}) of sand dunes above channel bed elevations. Substitute an average sand dune protrusion height (h_{sd} in feet) for the D84 term in estimation method 1.

Option 2. For **boulder-dominated** channels: measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an average boulder protrusion height (h_{bo} in feet) for the D84 term in estimation method 1.

Option 3. For **bedrock-dominated** channels: measure several **"protrusion heights"** (h_{br}) of rock separations/steps/joints/ uplifted surfaces above channel bed elevations. Substitute an average bedrock protrusion height (h_{br} in feet) for the D84 term in estimation method 1.

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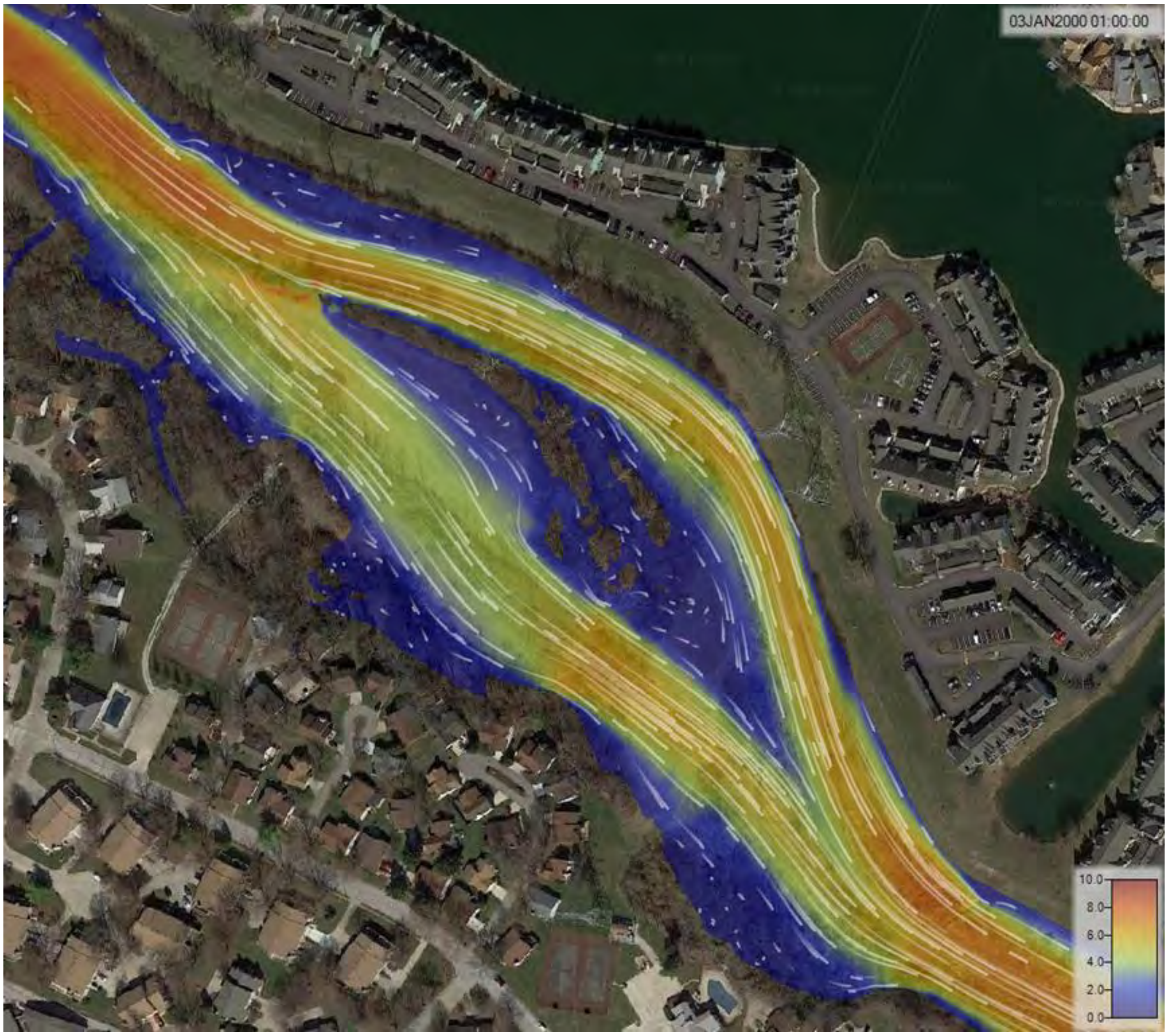
Flow Velocity Grids

Bankfull Velocity Grid with flowlines



100-Year Velocity Grid with flowlines

Scour Calculations

<u>Scour Calculations for Eagle Creek</u>

Date:	10/23/2018
Project No.:	14-0014

General Scour:

Blodgett Method:

$z_t\,(\text{mean}) = KD^{-0.115}$ $\qquad$ $D = D_{50}$

$z_t\,(\text{max}) = KD^{-0.115}$

where:

z_t (mean) = best fit curve, ft

z_t (max) = enveloping curve, ft

D_{50} = median size of bed material, ft

K = 1.42 for z_t mean

K = 6.5 for z_t max

D_{50} (from site visit) = 26.713 mm = 0.088 ft

z_t (mean) = 1.88 ft

z_t (max) = 8.60 ft

Pemberton and Lara Method (Using Blench and Lacey Constants)

$z_t = KQ^aW^bD^c$

$Q = Q_d$

$W = W_f$

$D = D_{50}$

where:

z_t = maximum scour depth, ft

K = coefficient (see table below)

Q_d = design discharge, ft^3/s

W_f = flow width at design discharge, ft
D_{50} = median size of bed material, mm
a, b, c = exponents (see table below)

Q_d = 9,400 cfs
W_f = 189 ft
D_{50} = 26.713 mm

Condition	Lacey				Blench			
	K	a	b	c	K	a	b	c
Moderate bend	0.195	1/3	0	- 1/6	0.530	2/3	- 2/3	-0.1092
Severe bend	0.292	1/3	0	- 1/6	0.530	2/3	- 2/3	-0.1092

Moderate bend, Lacey:

z_t = 2.38 ft

Severe bend, Lacey:

z_t = 3.56 ft

Moderate bend, Blench:

z_t = 5.01 ft

Severe bend, Blench:

z_t = 5.01 ft

Appendix 5: Triple Bottom Line and Cost Estimate Calculations

Alternative Name, Treatment Type, or Other Project Metric	Cummulative Score (15)	ECONOMIC				SOCIAL					ENVIRONMENTAL					
		Capital Cost	**Lifecycle O&M Cost**	**Shared Funding**	Score (5)	**Widespread Benefit (# of properties)**	**Reduce Flooding Drainage Problems**	**Benefit to Public Health & Safety**	**Benefit to Quality of Life**	Score (5)	**Level of Protection for Threatened Features**	**Impact to Adjacent Stream Reaches**	**Restore/ Protect Floodplain Function**	**Improve/ Protect Stream Habitat**	**Permittability**	Score (5)
	Weighting Factor=	*0.45*	*0.20*	*0.35*	*1.00*	*0.25*	*0.25*	*0.25*	*0.25*	*1.00*	*0.40*	*0.10*	*0.10*	*0.10*	*0.30*	*1.00*
	0=	*> $1000/ft*	*very high*	*none*		*0*	*none*	*none*	*none*		*added risk*	*significant (-)*	*no change*	*no change*	*not permittable*	
	1=	*>$750/ft <$1000/ft*	*high*	*100% Owner*		*1-10*	*limited*	*limited*	*limited*		*no change*	*minor (-)*	*limited*	*limited*	*very difficult*	
	2=	*>$500/ft <$750/ft*	*mod-high*	*75% Owner*		*11-30*	*limited-mod*	*limited-mod*	*limited-mod*		*minimal*	*no change*	*limited-mod*	*limited-mod*	*difficult*	
	3=	*>$250/ft <$500/ft*	*moderate*	*50% Owner*		*31-100*	*moderate*	*moderate*	*moderate*		*moderate*	*minor (+)*	*moderate*	*moderate*	*moderate*	
	4=	*>$100/ft <$250/ft*	*low-mod*	*75% Other*		*101-300*	*mod-high*	*mod-high*	*mod-high*		*high*	*moderate (+)*	*mod-high*	*mod-high*	*low*	
	5=	*<$100/ft*	*low*	*100% Other*		*300+*	*high*	*high*	*high*		*robust*	*significant (+)*	*high*	*high*	*encouraged practice*	
Toe Wood	**7.5**	4	3	1	2.8	4	0	4	0	2.0	5	3	0	1	1	2.7
Interlocking Concrete Jacks	**7.6**	3	4	1	2.5	4	0	4	0	2.0	5	2	0	0	3	3.1
Gabion Wall	**7.7**	3	3	1	2.3	4	0	4	0	2.0	5	2	0	0	4	3.4

Opinion of Probably Cost for Eagle Creek FEH Mitigation Project

Levee EC-12(c) Improvements

Line	Description	Estimated Quantities	Units	Unit Price	Estimated Cost (Rounded)
1	**Demolition**				
2	Strip & Stockpile Topsoil	200	CY	$ 7	$ 1,000
3	Selective Tree Clearing, Grubbing, & Hauling	0.4	AC	$ 15,000	$ 6,000
4			Estimated Demolition Cost		$ 7,000
5	**Channel Improvements**				
6	Mass Excavation	300	CY	$ 7	$ 2,000
7	Purchase and Haul Clay Fill Material	1,000	CY	$ 10	$ 10,000
8	Place & Compact Fill Material	1,300	CY	$ 7	$ 10,000
9	Install Riprap Toe	480	TN	$ 45	$ 22,000
10	Install Gabion Mattress	270	CY	$ 250	$ 68,000
11	Install Soil Lifts	1,320	SF	$ 19	$ 26,000
12	Install Live Willow Stakes	1,320	EA	$ 3	$ 4,000
13	Topsoil Placement	1,600	SY	$ 2	$ 4,000
14	Finish Grading	1,800	SY	$ 1	$ 2,000
15	Seeding	1,800	SY	$ 2	$ 4,000
16	Install Erosion Control Blankets	1,600	SY	$ 3	$ 5,000
17		Estimated Channel Improvements Cost			$ 157,000
18	**Miscellaneous**				
19	Dewatering	1	LS	$ 2,000	$ 2,000
20	Erosion and Sediment Control	1	LS	$ 2,000	$ 2,000
21	Construction Surveying	1	LS	$ 2,000	$ 2,000
22	Construction Mobilization/Demobilization	1	LS	$ 10,000	$ 10,000
23	Project Administration & Unforeseen Additional Costs (50%)	1	LS	$ 82,000	$ 82,000
24			Estimated Miscellaneous Cost		$ 98,000
25					
26			**Total Construction Cost**		**$ 262,000**
27					
28	**Professional Services**				
29	Topographic Site Survey	1	LS	$ 6,000	$ 6,000
30	Geotechnical Engineering Investigation	1	LS	$ 6,000	$ 6,000
31	Engineering Design	1	LS	$ 79,000	$ 79,000
32	Construction Observation	1	LS	$ 21,000	$ 21,000
33		Estimated Professional Services Cost			$ 112,000
34					
35		**Estimated Total Cost for Project**			**$ 374,000**

Notes and Assumptions

1. All costs are estimates based on the engineer's knowledge of common construction methods and materials. Christopher B. Burke Engineering does not guarantee that the actual bid price will not vary from the costs used with this estimate.
2. All costs are in 2018 dollars.
3. Estimated costs have been rounded.
4. This estimate does not include unforeseen costs increases that may result from shortages in fuel and materials as a result of a natural or man-made disaster.
5. Costs have been estimated without the benefit of survey data, utility coordination, or design. This estimate is intended for planning level consideration, and should only be used for such purposes.
6. This estimate does not include easement, right-of-way, or land acquisition costs that may be necessary to construct the proposed alternative.
7. This estimate does not include the cost of environmental mitigation, which may be necessary as a result of project impacts