Assessing the Effects of the Removal of a Low Head Dam on a Portion of the East Fork White River at Columbus, Indiana

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Acknowledgements

The Project Team would like to thank the City of Columbus, and The Columbus Redevelopment Commission for providing us the opportunity to be part of the remarkable revisioning of the Columbus Riverfront, and the East Fork White River at Columbus. We appreciate your support.

Cover photograph: Jeff Frey, U.S.Geological Survey

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Section 1: Introduction and Background

The City of Columbus is investigating removing an obsolete low-head dam located on the East Fork White River approximately 3000-ft downstream from the confluence of the Flatrock River and the Driftwood River, and immediately downstream from the 3rd Street Bridge. The confluence of the Flatrock and the Driftwood Rivers forms the East Fork White River (EFWR), which from its beginning, is a large river by Indiana standards, with a drainage area (DA) of 1705 mi^2 (Figure 1). The EFWR has a long history of flooding and the upstream portion of the river is ranked the 4th most laterally active, or meandering, river in the state. With its flood and channel migration history, the effects of any dam removal on river form and function needs to be thoroughly investigated. A background geomorphic assessment will also be a key component of exploring the river's recreational and aesthetic potential once the dam is removed.

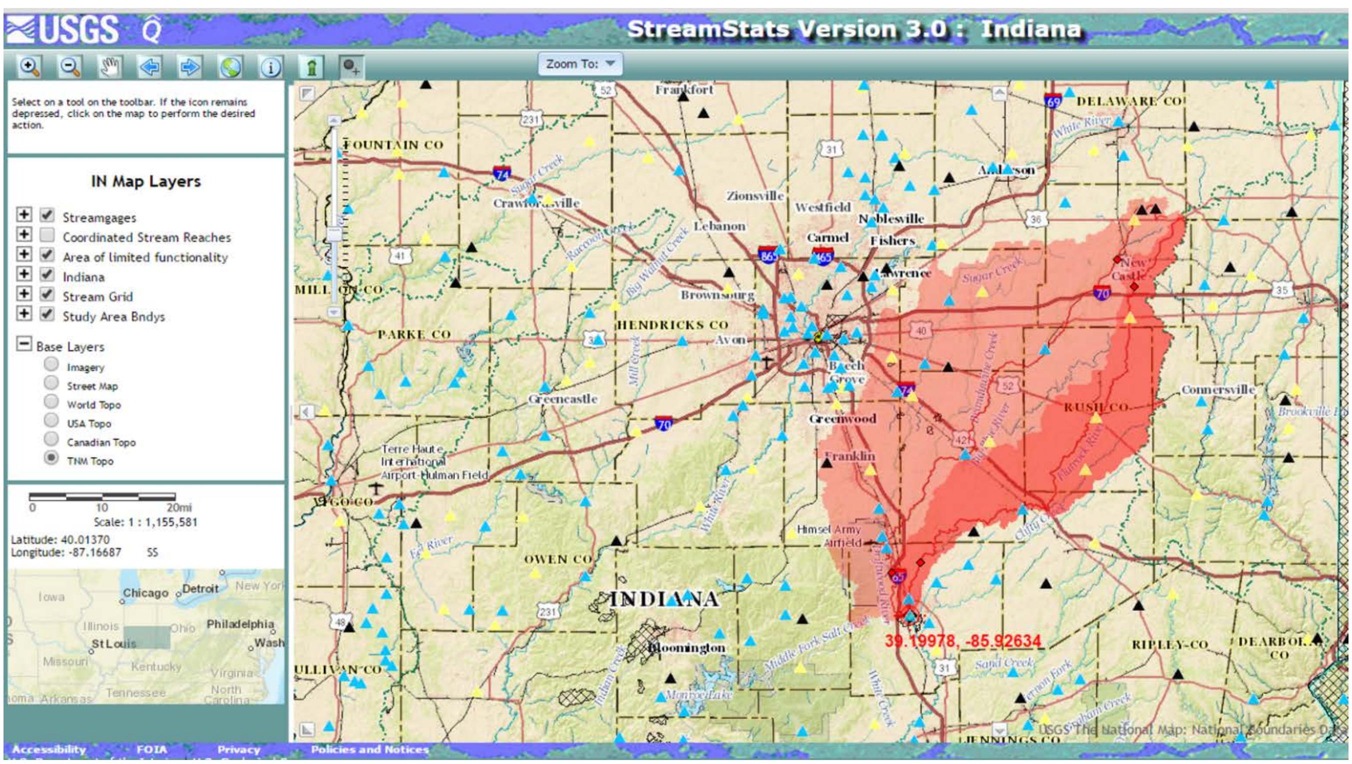

Figure 1: Location of the East Fork White River watershed above Columbus, Indiana. (USGS)

Removing the EFWR Dam at Columbus will be a significant step in the removal of obsolete dams in the State of Indiana. The Indiana Silver Jackets (ISJ), a multiagency hazard and mitigation response team, has made the removal of obsolescent low head dams in Indiana a priority because of their threat to public safety, exacerbation of flood and erosion risk, and overall negative impact on stream ecosystems. As interest in dam removal grows across the State the ISJ wants to ensure that when dams are removed some standard investigations are conducted to maximize the potential for a successful dam removal.

The noted geomorphically-related standard invesigations that can also be viewed as a major component of a more comprehensive “due deligence” investigation before a low-head dam is removed should include 4 major subjects as follows:

- Bathymetric Mapping
- Core Sediment Sampling and Analysis
- Hydraulic Analysis
- Stream Geomorphic Assessment

This report, prepared by ISJ team members, summarizes the results of an analysis that focused on the above 4 subjects as they relate to the proposed removal of East Fork White River Columbus low-head dam.

Study Area

Most site specific geomorphic investigations focus on a reach that is approximately 20 times the bankfull width of the river at the specific area of interest. The predicted bankfull width of the EFWR just below the dam at Columbus, IN is 228- feet (39.1991, -85.926), indicated the need for a study reach of approximately 4,500-feet. River specific considerations for the EFWR suggest that the study reach should be from the confluence of the Driftwood and Flatrock Rivers to the confluence of Haw Creek, approximately 2-river miles (Figure 2). For this investigation, the detailed geomorphic analysis focused on the standard study area of 4,500-ft., while the hydraulic modeling included the East Fork White River from the confluence of the Flatrock and the Driftwood to Haw Creek. To support future design considerations, a preliminary geomorphic assessment was also conducted from the confluence of the Driftwood and Flatrock Rivers upstream to the low head dam located on the Flatrock River near Newson Avenue, approximately 1 river mile. For clarity, the term “project area” will be used to designate the section of the EFWR between the East (3rd Avenue) and West (2nd Avenue) bound bridges of SR 46, while “study area” will refer to the larger study reach.

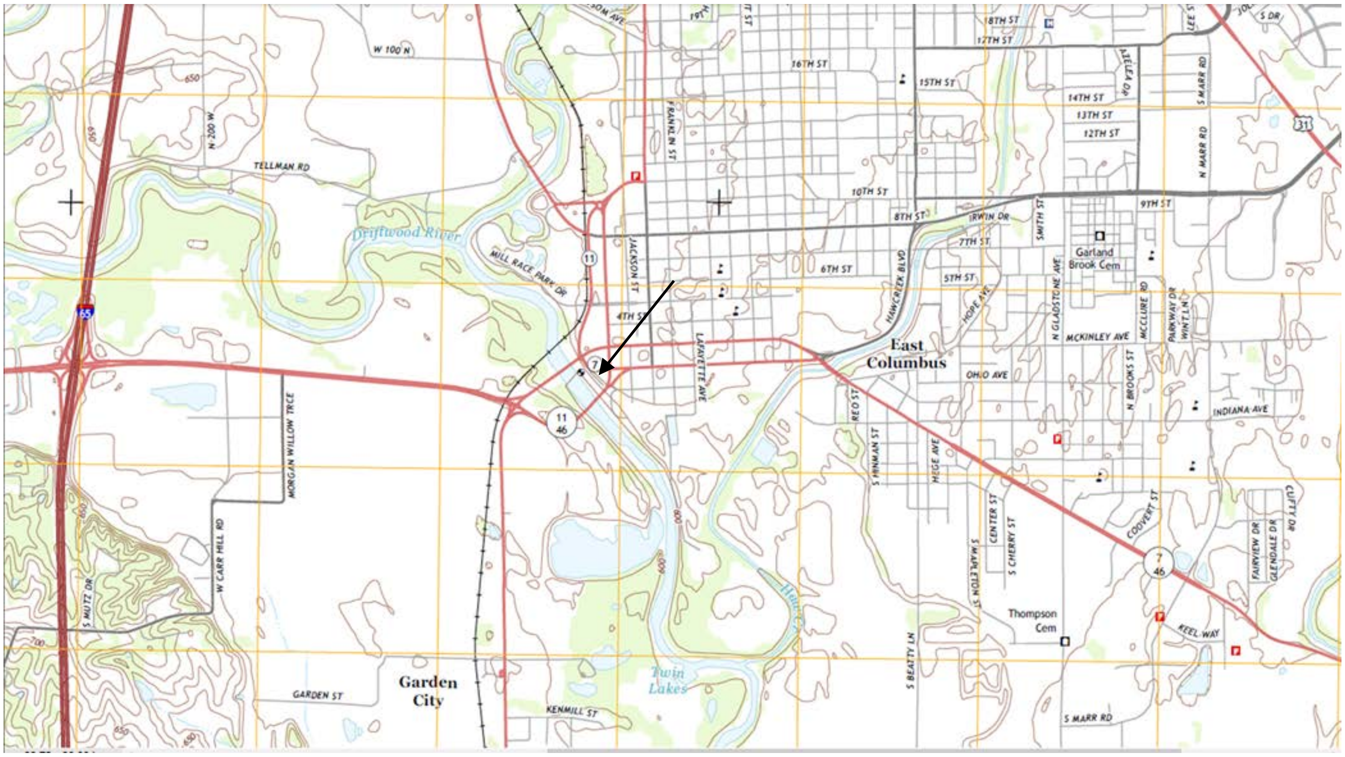

Figure 2: Study area. The project area is indicated by the black arrow. Detail from Columbus Quadrangle, 7.5-minute series, USGS. 2016

Section 2: Bathymetric Mapping

The purpose of a bathymetric mapping as it relates to removal of a low-head dam is to provide an understanding of river processes and information about sediment transport. The data is most useful when combined with at-a-station reference cross-sections.

For this project, the U.S. Geological Survey collected data in March and April of 2017. A Teledyne RDI RiverRay and RiverPro Acoustic Doppler Current Profiler (ADCP) was used to collect geo-referenced river depths at various locations along the East Fork White River at Columbus, IN. Bathymetry was collected on March 30 and 31, 2017 and April 13, 2017. Depth data was collected perpendicular to the East Fork White River, on average, every 200 feet from the confluence of Driftwood and Flatrock River to downstream of Haw Creek. Additional bathymetry data was collected upstream and downstream of the low-head dam in Columbus on April 13, 2017. The ADCPs were equipped with a Differential Global Positioning System (DGPS) device to collect Latitude and Longitude coordinates for every point of data. During the bathymetry data collection, water surface elevation Real-Time Kinematic Global Positioning System (RTK GPS) shots were taken to compute an elevation of the bed surface at each point collected by the ADCP back in the office. The RTK GPS equipment was a Trimble R8 and the Indiana Department of Transportation's Continuously Operating Reference Station network was used to provide real-time elevation values.

The field collected data was Latitude and Longitude in degrees World Geodetic System 1984 (WGS84), river depth in feet, and water surface elevation in feet North American Vertical Datum of 1988 (NAVD88).

In the office, Latitude, Longitude, and river depth values were exported for each ensemble (ADCP data point) using WinRiverII version 2.18. The exported comma-separated text files were imported into Microsoft Excel. Finally, river depth values were subtracted from the water surface elevations to calculate streambed elevation. The final csv file contains columns of Latitude and Longitude in degrees WGS84, and Elevation in feet NAVD88. Each row of data is an ensemble from the ADCP.

These data allowed us to produce 55 cross-sections through the study area. The 7003 data points used for those cross-sections also allowed us to produce a bathymetric surface that illustrates the current sediment distribution in the channel and will allow for comparison of sediment distribution after dam removal. It is important to note that the sediment distribution depicted is dynamic. The maps and cross-sections depict the channel at one point and time. Some features are more permanent, such as the location of pools and riffles, but even those features can shift in a large event. The value of the bathymetry is that it can be used even as a river adjusts to compare how sediment moves and organizes through the pools and riffles. For this project, the bathymetry provides a view of how the river is functioning before the dam comes out.

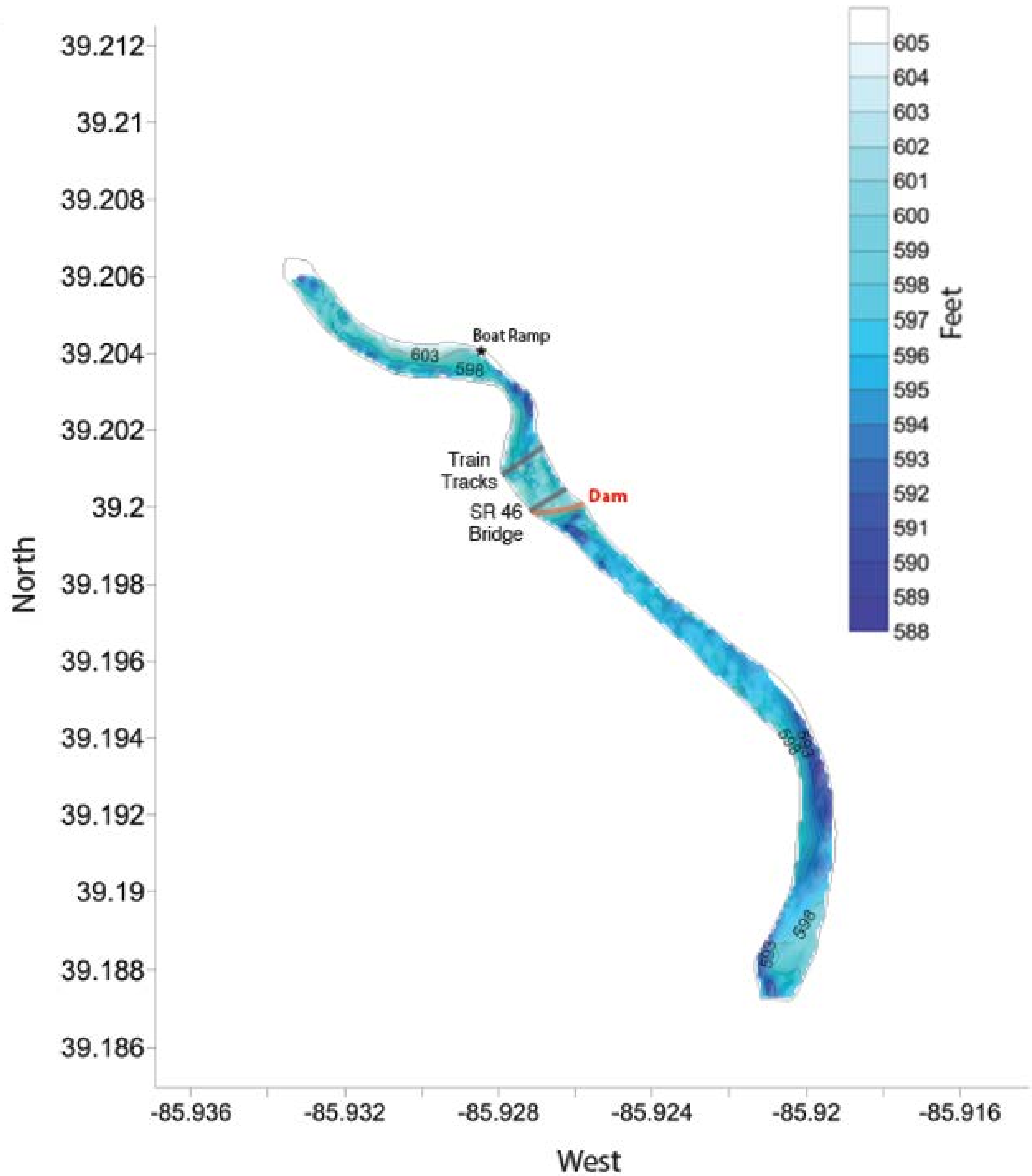

Figure 3: Bathymetric Map of the Study Area, East Fork White River at Columbus, IN. On this general map of the study area the dark blue of the pools stands out, as well as the scour near the right bank in front of the dam. The pools, together with the point bars indicate that sediment is being transported through the system. The light blue in between the bridges shows the sediment behind the dam. Figure 4 is a detail of this larger view.

understanding river processes and providing information about sediment transport understanding river processes and providing information about sediment transport

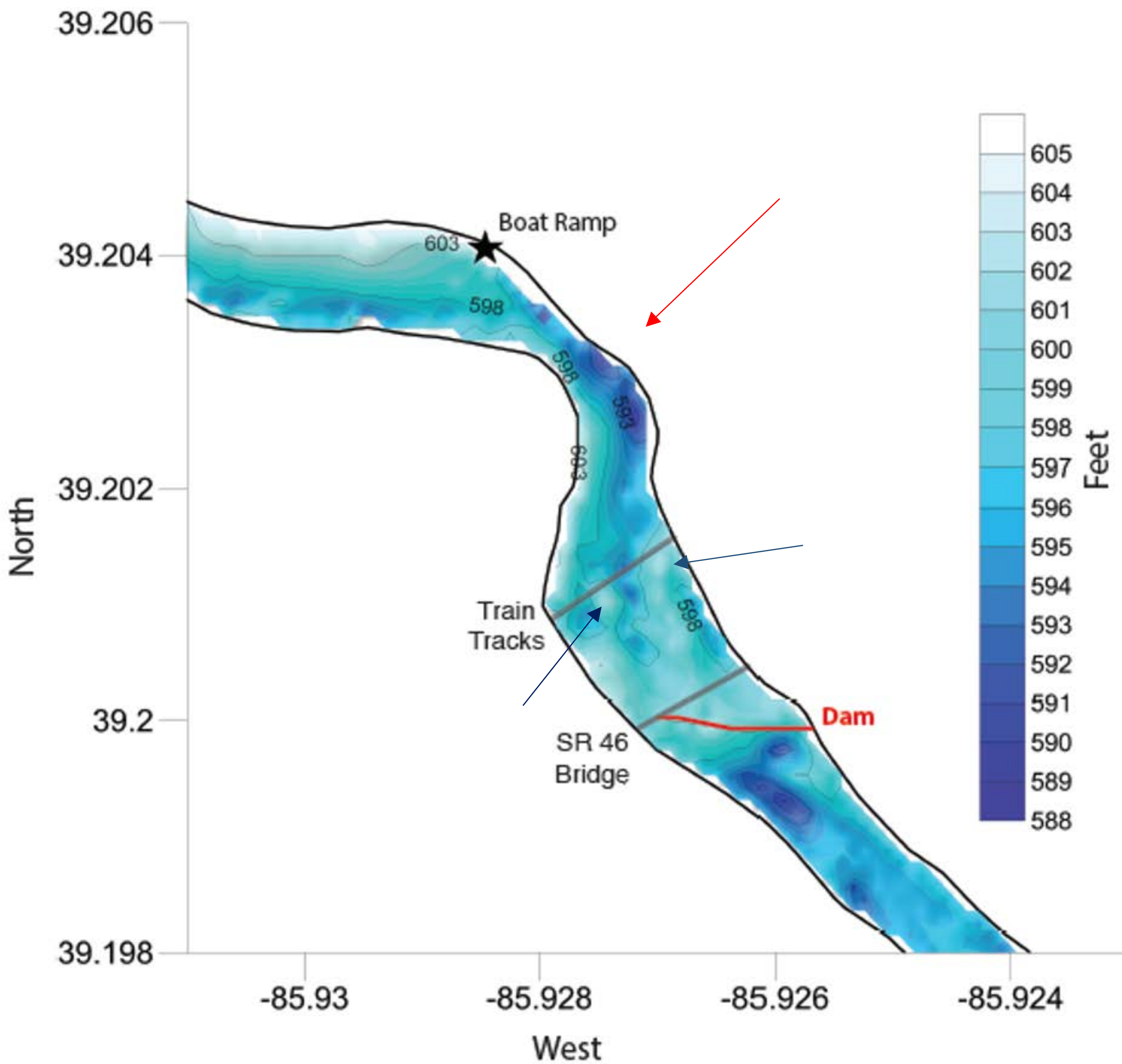

Figure 4: Bathymetric Map of portion of the Study Area, East Fork White River at Columbus, IN. This detail from the larger bathymetric map shows more clearly the sediment transport through the project area. Note the deep pools moving from the right bank to the left bank. The transverse flow from left bank pool above the railroad bridge (red arrow) is interrupted at the bridge and focused into the center of the channel, this is in part due to the remains of a rubble access road (see blue arrows) placed in front of the railroad bridge. The rubble road is acting as a barrier to flow and sediment transport.

The bathymetric data can also be used to evaluate sediment storage behind the dam, by creating a longitudinal profile of the study area. Figure 5 shows a longitudinal profile for the study area. Note that there are two distinct wedges of sediment upstream from the dam. The first occurs near the confluence of the Flatrock and Driftwood Rivers at Mill Race Park and the second occurs at the railroad bridge. The upstream wedge is sediment in transport, as the sediment flows in from upstream it slows in response to the change in channel bed slope created by the dam, and very important to note – the rubble dam in front of the railroad bridge. Both of the these sediment wedges show the classic dune form with the backslope tailing upstream, the crest, and then the slip face on the downstream end. The difference in the two wedges is significant. The wedge at the railroad bridge is truncated at the crest by the rubble dam, indicating that the rubble dam is acting as a grade control – just like the dam. It is also important to note that the sediment wedge behind the railroad rubble dam is similar in size to the sediment load behind the dam. The dashed line indicating channel bed surface with the dam removed also shows that as the dam is removed the rubble dam will become the new grade control, or "dam". Figure 5 also shows that there is not a a significant amount of sediment upstream of the dam, and a large portion of the upstream sediment in storage will go to filling in the plunge pool below the dam.

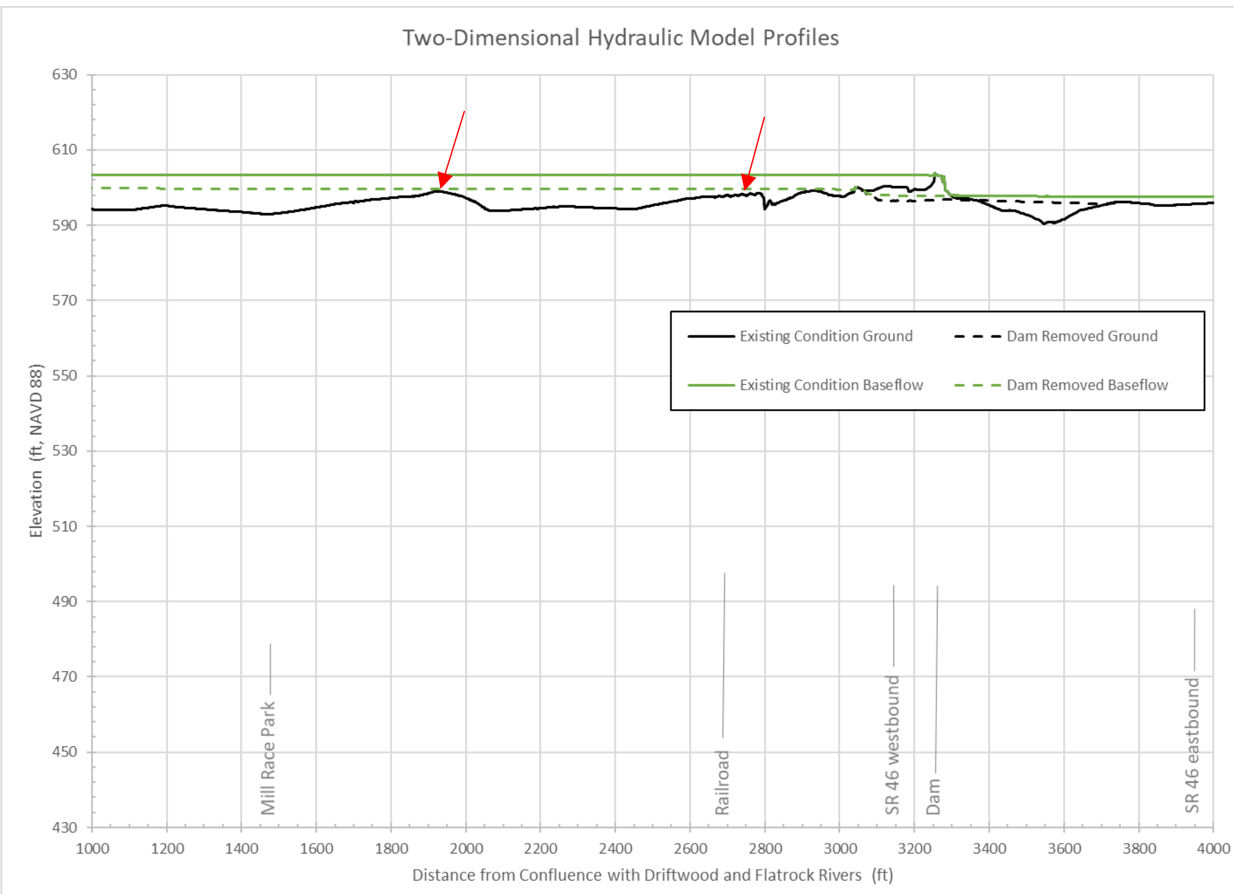

Figure 5: Channel-bed surface for existing conditions, and with the dam removed. East Fork White River at Columbus, Indiana. Red arrows indicated existing sediment wedges upstream of dam.

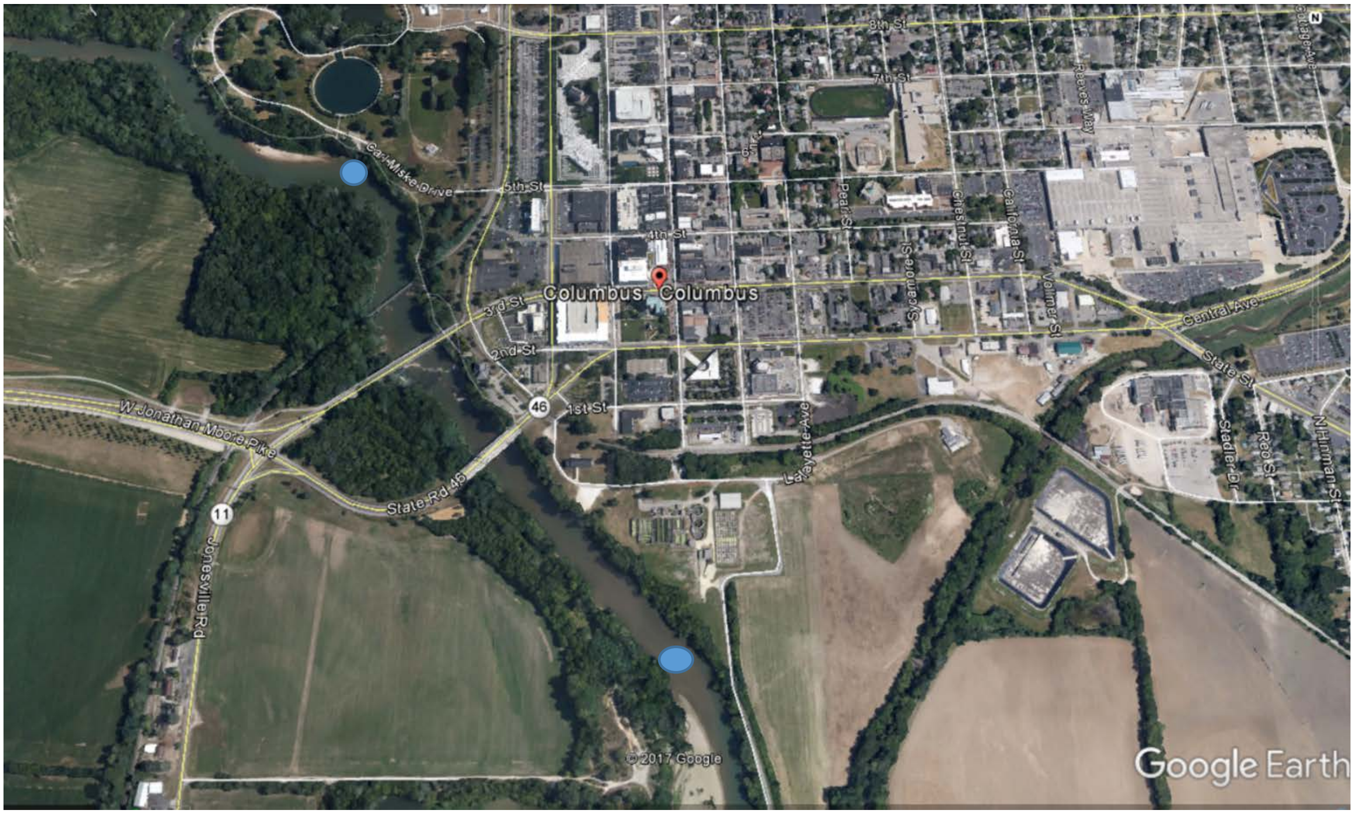

Figure 6: Sediment transport in the study area. Field observations and measurements indicate that the sediment wedge behind the dam extends upstream (1,830-ft) to the first pools located upstream (upper blue dot). The bed and water elevations are graded from the confluence downstream to the lower blue dot (2,500-ft), indicating that there is effective sediment transport above and below the dam, and the system should be expected to quickly grade to the existing reach slope of .001 (Figure 5).

Section 3: Sediment Sampling and Analysis

The primary purpose of sediment sampling and analysis as it relates to removal of a low-head dam is to understand the nature of the sediment behind the dam, and to determine the potential for hazardous materials to be bound to fine-grained sediments (silts and clays) or organic matter.

To understand the type of sediment through the study area, and investigate the possibility of contaminants in the sediment behind the dam, sediment was sampled in 8 locations behind the dam, and an integrated sample was taken at the downstream point bar (Figure 8). Point bar sampling is done to evaluate the full range of sediment in transport. Sampling locations behind the dam are shown in Figure 7. The goal was to core the sediment, but the bed material was primarily washed sand and gravel with few traces of organic material that might hold containments. Samples were collected using an Ekman bottom grab sampler. Two samples, GS-5 and GS-8, had enough organic material in the sample to be split for chemical analysis. The bar sample was taken at the large point bar in the downstream portion of the study area to capture the full range of sediment moving through the project area (see figures 7,8, and 9). Physical sediment characteristics are in Table 1.

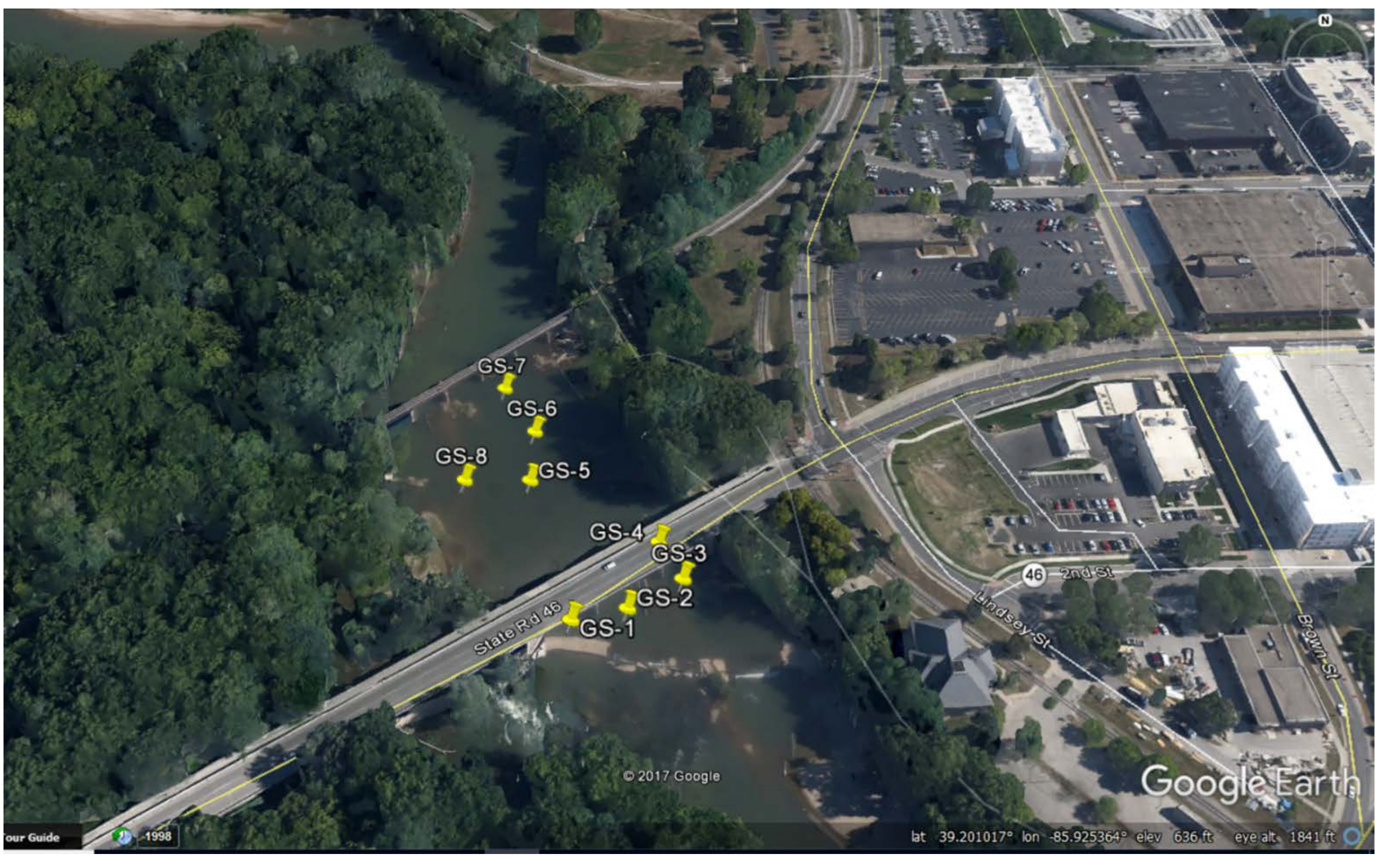

Figure 7: Sediment sampling locations upstream of the dam (Image: Google Earth, 2016)

Figure 8: Point bar sampling location, note breach on right bank and sediment transport into the old sand and gravel pit. The scale can be confusing. The recently deposited bright sand has a surface area of 152,000 ft^2 , and an average thickness of 5.0-ft. The volume of sand in this bar is approximately 28,148 cubic yards. See Figures 9 and 10 for scale.

Figure 9: Downstream point bar. The long axis, parallel to the river, is 1230-ft, and the midline axis, perpendicular to the river is 200-ft. For comparison, the EFWR at Columbus has a predicted bankfull width of 228-ft.

Figure 10: Sediment deposition into the gravel pit. Broxton Bird for scale. Note that in the interior lake side of the point bar, sediment height is > 6.0-ft, and there is little established vegetation. The deposition is recent.

Table 1: Physical Characteristics of sediment samples

Sample Number	Description	D_{50} (mm)	D_{84} (mm)
GS-1	Clean sand and gravel, no organics	5.45	8.32
GS-2	Sand with organics	5.21	7.35
GS-3	Clean gravel, no organics, little sand	5.86	8.35
GS-4	Small cobble, trace mud on one clast	16.0	30.27
GS-5	Sand with organics, split for geochem	5.46	8.39
GS-6	Clean cobble, limited retrieval, suggest coarse bed	45.0 (D_{100}) one sample	45.0 (D_{100}) one sample
GS-7	Clean gravel, angular and rounded, no organics	5.5	9.33
GS-8	Medium – coarse sand, few oragnics	< 2.0	< 2.0
Bar Sample	Clean cobble, gravel, and sand	8.97 (largest cobble on bar 128.0 mm)	15.97
Integrated GS	The integrated GS is a composite of all GS sites	4.6	7.92

The presence of the large military training center at Camp Atterbury, upstream on the Driftwood River indicated that samples with organics should be analyzed for the presence of heavy metals. The two samples with organics present (GS-5 and GS-8), were analyzed using X-ray fluorescence (XRF) to check for particulate lead (Pb), zinc (Zn), or copper (Cu). Only normal background levels of the metals were detected.

Section 4: Hydraulic Analysis

The primary purpose of a hydraulic analysis as it relates to removal a low-head dam is to simulate and compare the pre- versus post-dam removal water surface profiles for a range of flow conditions to better understand the potential impacts of the low-head dam removal. This analysis will also provide valuable information on expected changes in the flow velocity vectors and sheer stress both in the upstream and downstream reaches, which can be used during the geomorphic stream assessment as well as during the future dam-removal design phases.

Christopher B. Burke Engineering, LLC (CBBEL) performed a hydraulic analysis of the East Fork White River near Columbus, Indiana to evaluate the impact of removing the low-head dam. This analysis included two-dimensional hydraulic modeling, calibrated to available gage information.

Two-Dimensional Model Geometry

A two-dimensional model was selected for this analysis because of the complex flowpaths around the low-head dam near westbound SR 46 and an overland flowpath from Driftwood River to East Fork White River that is activated during large flooding events. In lower, more frequent events, the two-dimensional model more accurately depicts the flow in the vicinity of the dam due to the angle of the dam and its relationship to the westbound SR 46 bridge, which cannot be properly modeled with a one-dimensional model. In larger, less frequent events, the two-dimensional model better represents the flow from the Driftwood River, over SR 46 and SR 11, which bypasses the riverfront area.

The full model developed by CBBEL begins approximately 3,700 feet downstream of the confluence with Haw Creek and extends upstream along the Driftwood River to immediately downstream of I-65 and along the Flatrock River to immediately downstream of the railroad between Indianapolis Road and Newsom Avenue. However, the area of interest to this report is along the East Fork White River between approximately 2,000 feet downstream of the eastbound SR 46 bridge and extending upstream to the confluence with Driftwood and Flatrock Rivers.

Two geometric conditions were modeled, the existing condition with the low-head dam and a post-dam-removal condition. There are several sources of existing condition geometric data included in the model. The main source of the two-dimensional geometry surface is the 2011 Bartholomew County Digital Elevation Model (DEM). The channel was updated with data from bathymetric surveys completed by USGS, as dscussed in Section 2, and a supplemental bathymetric survey performed to fill a few data gaps which were necessary for the 2D hydraulic analysis. Channel data was estimated upstream of the confluence with Flatrock and Driftwood Rivers and downstream of the confluence with Haw Creek, as bathymetry was not collected in these areas. Bridge piers were added to the surface by estimating their widths from 2016 aerial photography. The low-head dam data was also collected during the supplemental bathymetric survey. In the post-dam-removal condition, the existing condition geometry was modified to remove the dam and smooth the thalweg to estimate the anticipated movement of sediment behind the dam once it is removed.

Flow Conditions

To evaluate the impacts of the dam removal in various flow conditions, three flow conditions were considered to represent a very large event, a bankfull event, and a low flow event, respectively. The peak flow for the 1% annual chance (100-Year) event was obtained from the Flood Insurance Studies (FIS) for each stream. The bankfull discharge was estimated by adjusting the flow along each stream until the channel was filled. The baseflow discharge was estimated from the gages on Flatrock and East Fork White Rivers. The flow rates used along the East Fork White River are shown in Table 2.

Table 2: Flow Rates used in Event Simulations

Event Description	Flow Rate (cfs)
1% annual chance (100-Year)	79,300
Bankfull	6,200
Baseflow	400

Water Surface Comparisons

The two-dimensial model was then formulated and ran to simulate the impact of the dam removal for the three flow conditions analyzed. Table 3 shows a comparison of water surface elevations at key locations in the 1% annual chance event. The difference in water surface elevations are very small; the maximum difference of 0.06 feet between existing and proposed conditions is located at the dam.

The comparison of water surface elevations for the bankfull flow and baseflow conditions at various locations are summarized in Table 4 and Table 5 , respectively.

Table 3: 1% Annual Chance Water Surface Elevations

Location	Existing Condition (ft, NAVD)	Post-Dam-Removal Condition (ft, NAVD)
At dam	619.42	619.43
Upstream of westbound SR 46	619.59	619.55
At Mill Race Park	620.54	620.51

Table 4: Bankfull Water Surface Elevations

Location	Existing Condition (ft, NAVD)	Post-Dam-Removal Condition (ft, NAVD)
At dam	604.93	604.57
Upstream of westbound SR 46	605.17	604.62
At Mill Race Park	605.62	605.21

Table 5: Baseflow Water Surface Elevations

Location	Existing Condition (ft, NAVD)	Post-Dam-Removal Condition (ft, NAVD)
At dam	603.28	597.80
Upstream of westbound SR 46	603.29	597.96
At Mill Race Park	603.30	599.58

Surface water profiles showing the above comparisons graphically are depicted in Figure 11.

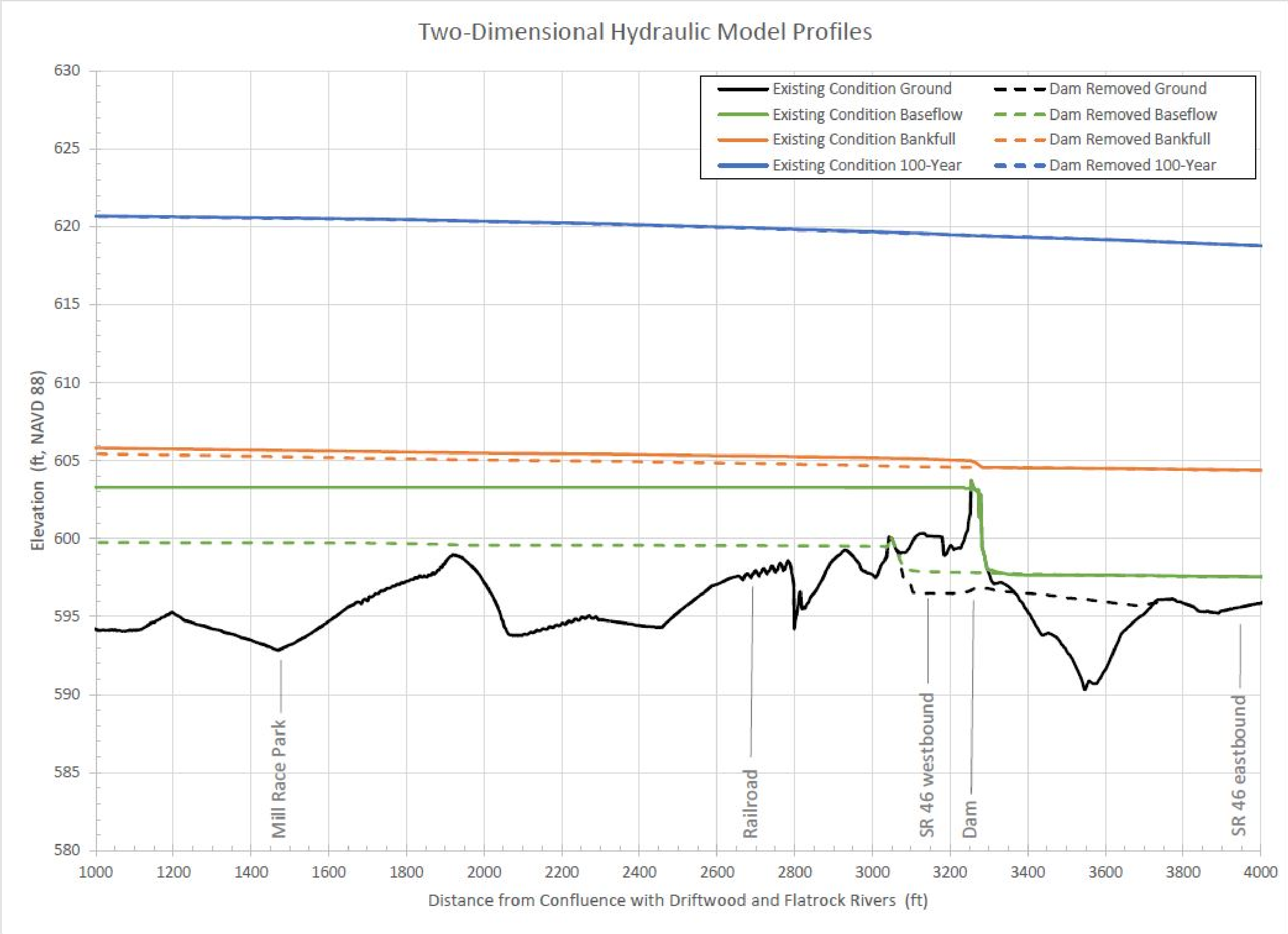

Figure 11: With and Without Dam Water Surface Profile Comparisons

If the dam is removed and no grade control structures are constructed to maintain current water levels, modification of the intake structure near Mill Race Park is likely necessary due to the lowered water surface elevation. The water surface is approximately 50 feet narrower on the north bank, as shown in Figure 12.

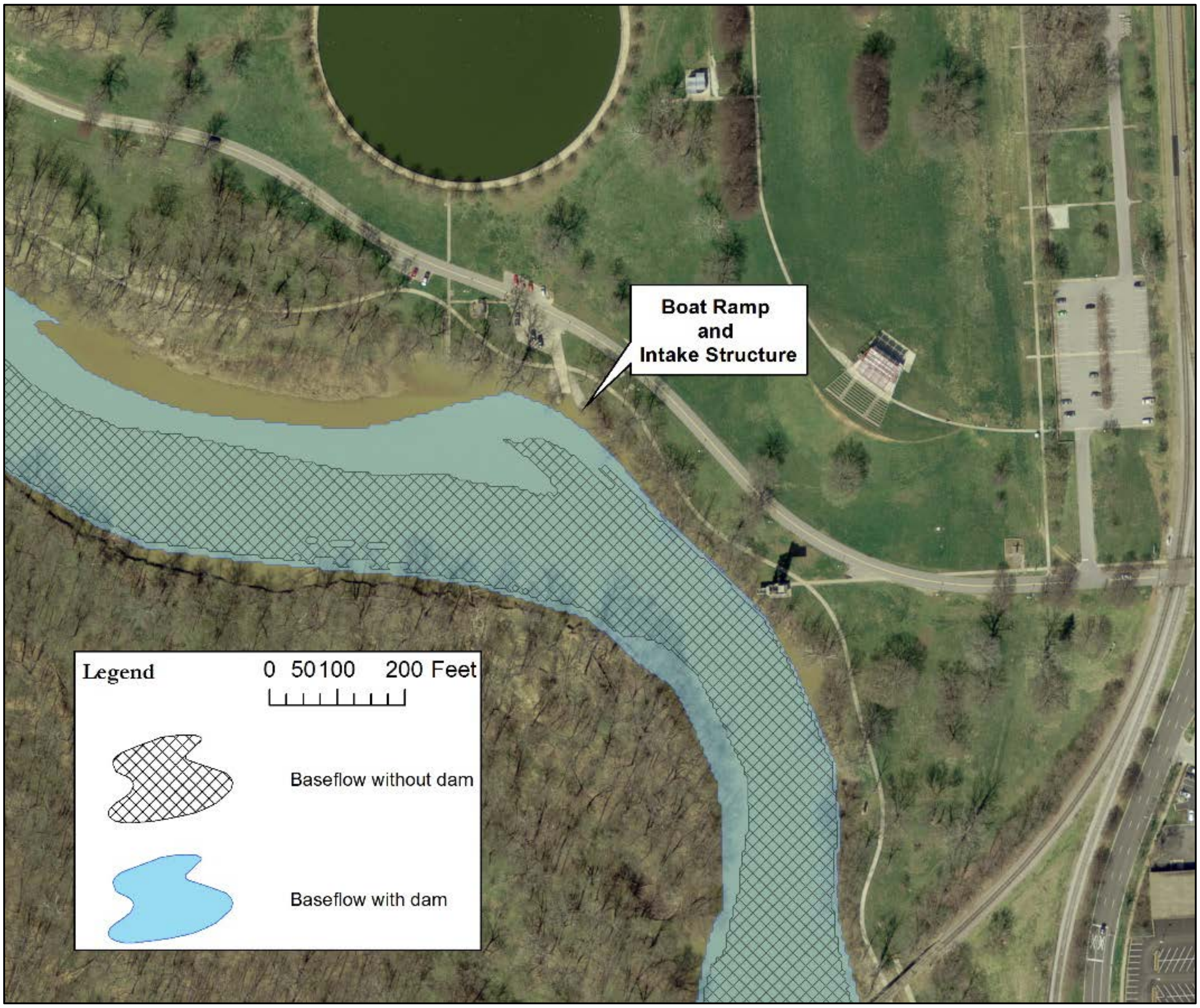

Figure 12: Baseflow Water Surface Inundation Comparison

Section 5: Geomorphic Stream Assessment

The primary purpose of a geomorphic stream assessment as it relates to removal of a low-head dam is to understand how much the low-head dam has effected the river, and what the potential effects of dam removal may be. To assess the change, existing conditions are documented and compared with a reference site, or with reference data collected at other location. These data will then indicate how the river needs to adjust to recover its predicted channel dimensions, pattern, and profile.

Existing Conditions

An initial assessment of the EFWR begins with a comparison of measured channel dimensions with channel dimensions predicted by the Regional Bankfull-Channel Dimensions of Non-Urban Wadeable Streams in Indiana, hereafter “regional curves” (Robinson, 2013). The Indiana regional curves were developed by measuring bankfull channel dimensions on stable streams throughout Indiana, and they have proven to be a useful tool for understanding Indiana streams. However, some background information is needed to understand the significance of the bankfull stage, or elevation. Figure 13 illustrates the bankfull channel and other features of a low-gradient stream with an attached floodplain.

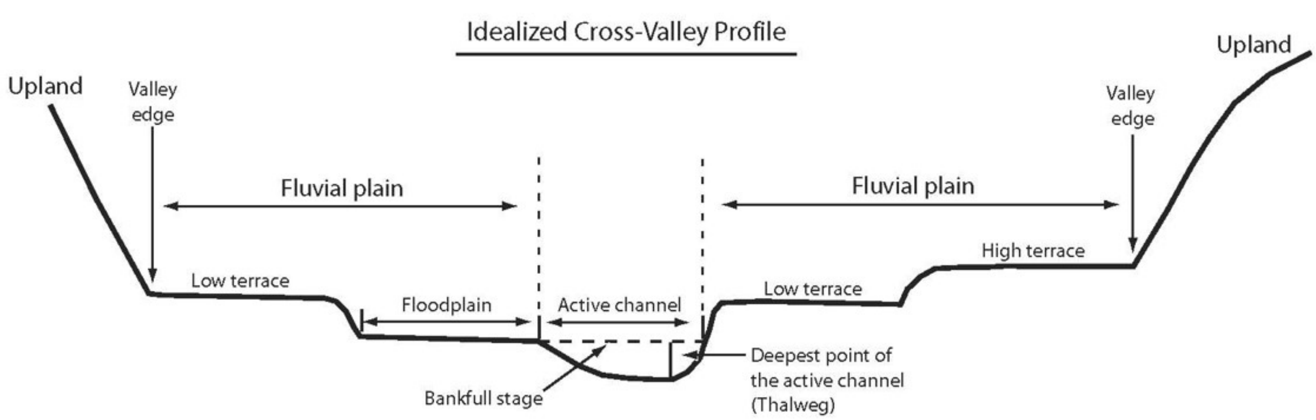

Figure 13: Idealized Cross-Valley Profile (B. A. Robinson, USGS, 2012)

Note in Figure 13, that the bankfull stage, or elevation, is the point where water in the active channel flows out onto the floodplain. The bankfull stage is reached about every 1.5 years in the humid eastern portion of the United States, and it is a channel-forming and maintaining flow (Knighton, 1998). In Figure 14, the bankfull floodplain connection only exists in the left-hand side of the illustration. On the right-hand side, there is a low terrace that is higher than the floodplain. The terraces represent floodplains that were formed when the main channel of the river was at a higher elevation. Terraces can still flood, but not with the frequency of the current, or active, floodplain. Flood levels will need to rise on the current floodplain until water level reaches the elevation of the low terrace for that surface to flood. Compare the relationship of the floodplain with the low and high terraces in Figure 13, with the image of the project area shown in Figure 14. The image is taken looking downstream at east-bound lanes of SR 46 and the Robert N. Stewart Bridge, and was taken from the directly underneath the west-bound lanes of 2nd Avenue (SR 46). The low head dam that was the motivation for this study, is in the foreground of the image and the Pumphouse can be seen on the left bank of the EFWR. By convention river locations are described looking downstream in the direction of flow.

Figure 14: The project area as seen from under the west-bound lanes of 3rd Avenue Bridge. Stream flow is toward the Robert N. Stewart Bridge (red).

The left bank in the primary study area has been filled, raised, and armored, in the upstream portion of the project area (Figure 15). The difference is elevation is striking. There is a stable bankfull attachment to the floodplain on the right bank, and for a wide range of flows the right bank offers the only storage for flood waters (Figure 16). The setting is like the situation shown in Figure 13, but at the project area an even wider range of flows are pushed to the right bank. Figure 17 illustrates the lack of flood storage on the left bank side of the study area, the natural floodplain is all along the right bank, although floodplain access has been restricted by road bridges and non-levee embankments (NLE). Figure 17 also shows the effect of the low-head dam on channel width and depth.

Figure 15: Armored left bank in the project area. Note elevation of stage gage.

Figure 16: Looking to the west at the right bank in the project area. Note the stable and smooth transition to the very restricted bankfull floodplain, and the large sediment wedge directly downstream of the dam. Flow is being directed towards the right bank by the breakdown and lowering of several sections of the dam.

Figure 17: LiDAR image of the East Fork White River at Columbus, IN 2011/2012 Indiana LiDAR, S. Letsinger, IGS

In Figure 17, stream flow is towards the bottom of the image, which means that the "left" bank of the river is on the right side of the image. The image is a false color depiction of topography and elevation, with reddish brown being the highest, and the darkest blue being the lowest elevation. The two sections of the SR 46 bridge are on the left side of the image and the old railroad bridge is seen just about them. The left bank is high and steep, as discussed earlier stream flow is being pushed to the right. Above the railroad bridge the broad floodplain formed at the confluence is easily seen, and it makes the constriction at the bridges even more obvious. The natural opening of the floodplain on the left bank downstream from the project area is also visible, although floodplain access has been lost by building non-levee embankments (NLE) structures along the bank and by filling on the floodplain. Floodplain access is also restricted on the downstream right bank by NLE structures (Figure 17). These structures are common throughout the Midwest and were often constructed to decrease the frequency of flooding on the floodplain to allow for more opportunities to plant the fields, or extract sand and gravel. What they have also done is increase the potential for bank erosion by containing higher flows and thereby increasing stress on the banks. In the project area, the modifications of channel width and depth by a combination of damming and filling are significant even at relatively minor flood levels, as can be seen in Figure 18. Immediately above the Haw Creek confluence, the geomorphic floodplain as defined by alluvial soil, is over 1-mile wide (WebSoil Survey), whereas there is less than 1000-feet of potential floodplain available in the project area. Figure 18 also shows that the EFWR will use its floodplain where it can.

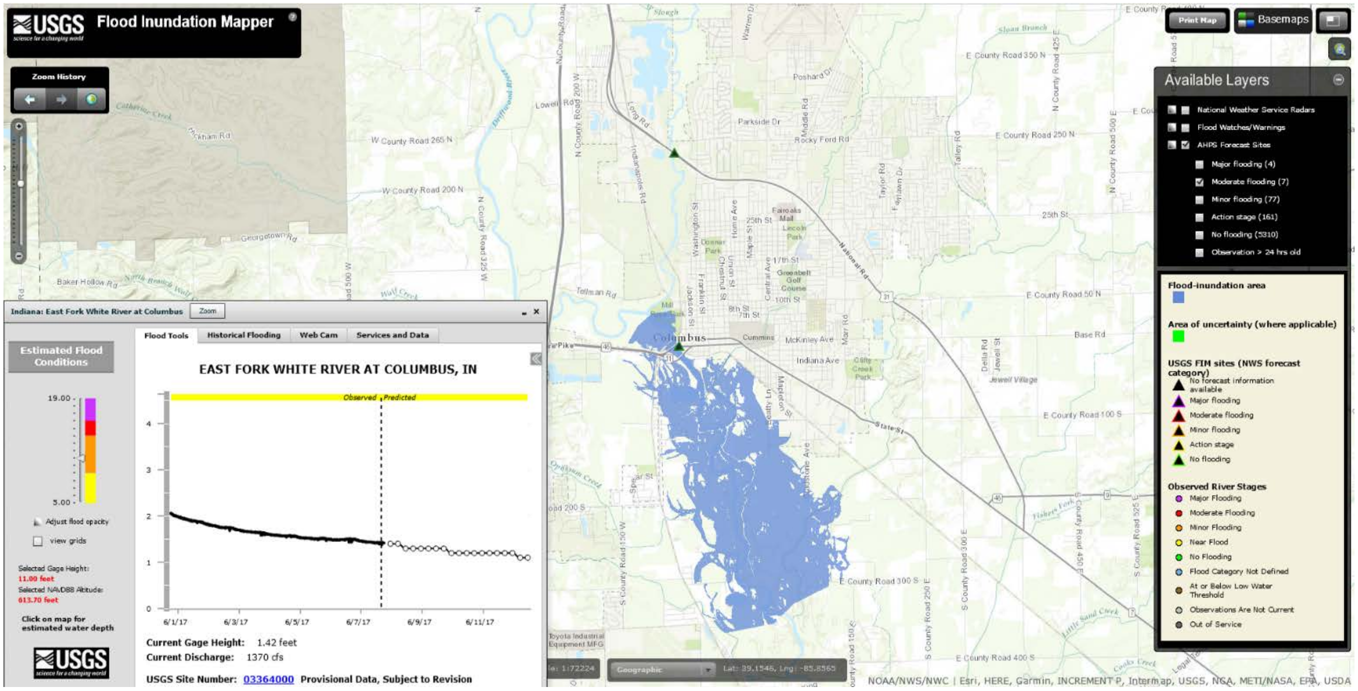

Figure 18: Depiction of minor stage (11-feet) flooding, East Fork White River at Columbus, Indiana. Note the long white non-inundated section of channel in the project area, located to the left of the green triangle. The green triangle marks the location of USGS gage 03364000 East Fork White River at Columbus, IN. The stream gage is located on the left bank by the dam.

As discussed in the description of the study area in the Introduction Section, the EFWR just below the dam should have a bankfull width of 228 feet, and an average bankfull depth of 7.42 feet. Cross-sections through the study area show wide variability. Figure 19 shows the locations of four cross-sections that were selected to show the variability in channel width, depth and cross-sectional area in the study area. The cross-sections also allow for consideration of bank material, or boundary conditions in the channel. The descriptions and images of boundary conditions at a station, will then be used to describe channel bank conditions thoughout the study area. Please note that these cross-sections are shown at an arbitrary site specific datum, and are not linked to the site survey.

Figure 19: Location of representative cross sections, East Fork White River at Columbus, Indiana (Image: Google Earth, 2016).

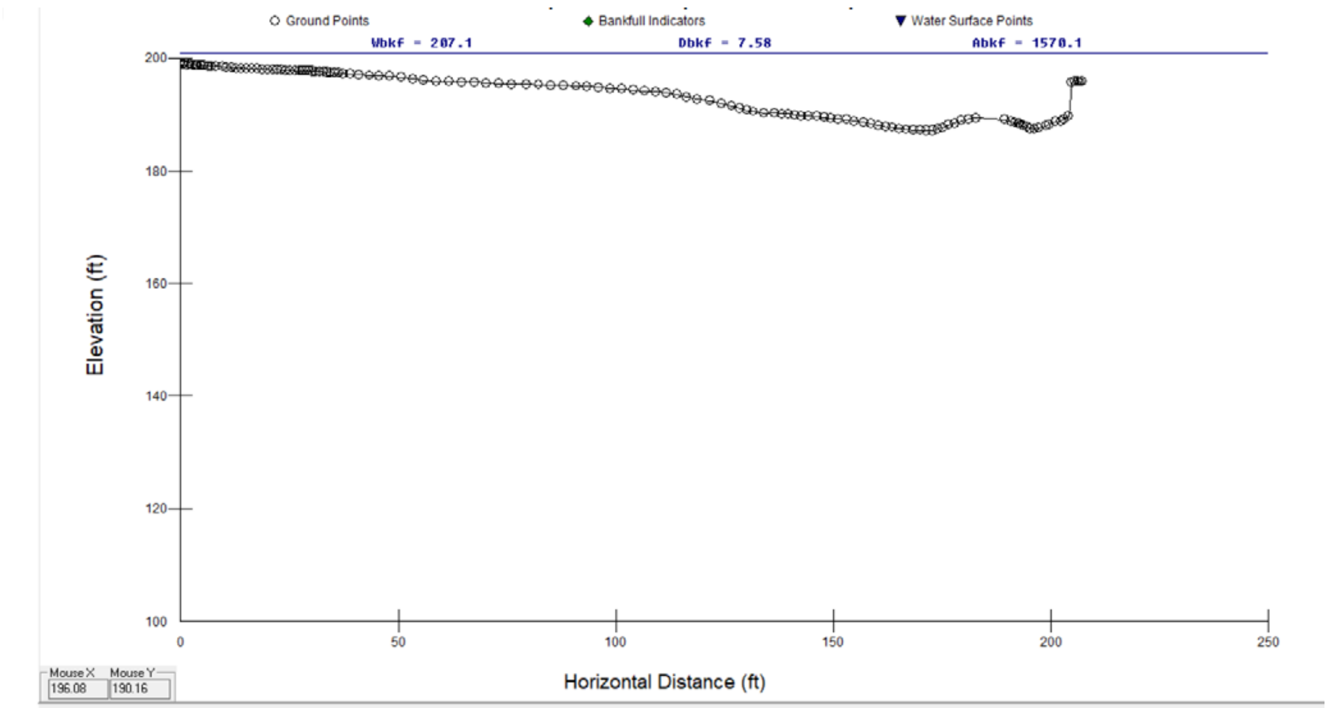

Figure 20: Cross-section EF 8, is located upstream of the boat ramp at Mill Race Park. Cross-section EF 8 is a textbook example of a low gradient alluvial stream cross-section, it shows the slope of the point bar on the left bank and the pool on the right bank (Rosgen, C4 stream type). A Rosgen C-type stream is described as a low gradient, meandering river, with point bar and riffle/pool morphology, and alluvial channels with broad well-defined floodplains. The "4" in the C4 deslignation indicates a gravel bed. The cross-section shown above is from the left bank point bar over to the pool along the right bank (see Figure 19). The Indiana regional curves predict that the bankfull width at this location would be 228-ft (measured is 207.1-ft), bankfull mean depth is predicted to be 7.42-ft (measured depth is 7.58-ft), and the predicted cross-sectional area is 1660-ft^2 (measured is 1570-ft^2). Maximum bankfull pool depth is predicted to be 10.5-ft, and the measured maximum pool depth is 13.7-ft. Those channel dimensions indicate a stable channel near Mill Race Park. Stream banks in that section of the river are variable. The banks on the left side of the channel near cross-section EF 8 are much higher than the right bank, with the top of bank being over 9-ft above the water surface. Mean depth when this cross-section was measured was 4.8-ft. Mean bankfull depth is 7.58-ft at this site. Banks on the right side have a top of bank that is usually less than 3-ft above the water surface that is inundated at bankfull stage, but the left bank has exposed sand above the bankfull stage, making the left bank very unstable (Figure 22).

Reference Measurements for cross-section EF 8:

Entrenchment Ratio (W_{fpa}/W_{bkf}) = 2.41 (ref = 2.2)

W/D ratio = 27.3 (ref = >12)

Sinuosity (=SL/VL) (= k) = 1.3 (ref = >1.2)

Figure 21: Stable right bank above project area near cross-section EF8. Soil on the right bank in this area is primarily Shoals silt loam (Figure 23). Typical for a floodplain, the soil is flat, with 0 to 2 percent slopes. The soils are frequently flooded for a brief duration. Note older stable trees along the channel, and the wide floodplain.

Figure 22: Stonelick soil (SuoAH) on the left bank upstream of the project area (Figure 23). Stonelick is a fine sandy loam, that is developed on floodplains with 0 to 2 percent slopes. Note that the slope angle refers to the surface soil on the floodplain, not the bank angle. Stonelick soils are typically frequently flooded for brief duration. Note the lack of vegetation on the bank.

Figure 23: Soil associations upstream of the project area. Note that the soils on the left bank moving downstream are primarily SuoAH (Stonelick), and then RtxAH (Rossburg silt loam).

Soils on the right bank moving downstream are SuoAH, SidAH, and SuoAH, and then a small area of GccAH0

SuoAH (Stonelick fine sandy loam) 0 to 2 percent slopes, frequently flooded, brief duration

SidAH (Shoals silt loam), 0 to 2 percent slopes, frequently flooded, brief duration

GccAH (Genesee loam), 0 to 2 percent slopes, frequently flooded, brief duration

RtxAH (Rossburg silt loam), 0 to 2 percent slopes, frequently flooded, brief duration

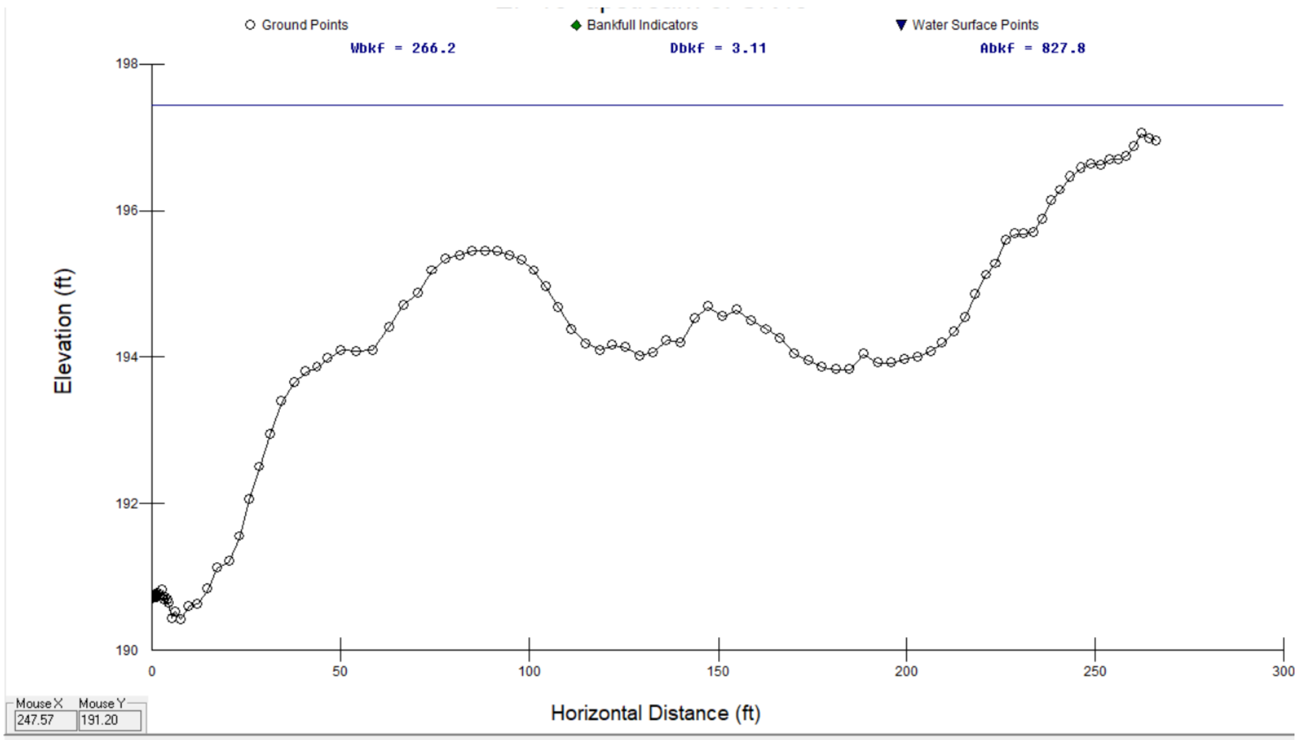

Figure 24: Cross-section EF 16, upstream of SR 46 and the railroad tracks. The thalweg (deepest portion of the channel), flows along the left bank in this section before transverse flow starts to shift flow across the channel towards the right bank. The railroad bridge interrupts the flow path and moves the flow into the center of the channel. Note the significant loss of cross-sectional area as sediment builds up behind the dam. The upstream cross-section had a bankfull cross-sectional area (Abkf) of 1578 ft^2 , whereas this cross-section has a Abkf of 827.8 ft^2, a reduction of 48%.

Reference Measurements for cross-section EF 16:

Entrenchment Ratio (W_{fpa}/W_{bkf}) = 2.0 (ref = 2.2)

W/D ratio = 85.5 (ref = >12)

Sinuosity (=SL/VL) (= k) = 1.3 (ref = >1.2)

Figure 25: Above the railroad bridge looking northeast towards the park (near cross-section EF16). Note the high banks on the left bank (park side). Another image of the left bank follows in Figure 26.

Figure 26: Left bank above railroad bridge. The USGS topographic map of this area shows the top of left bank with an elevation of 620 ft., 10-ft higher than the right bank. Much of the left bank in the Park is geomorphically a high terrace. At the bankfull stage there is still significant (>3-ft) bank above the bankfull flow elevation. The bankfull flow will erode the bare bank and weaken the overlying bank resulting in continued bank failure. Note the concrete piled along the bank, and the lack of vegetation in between the trees.

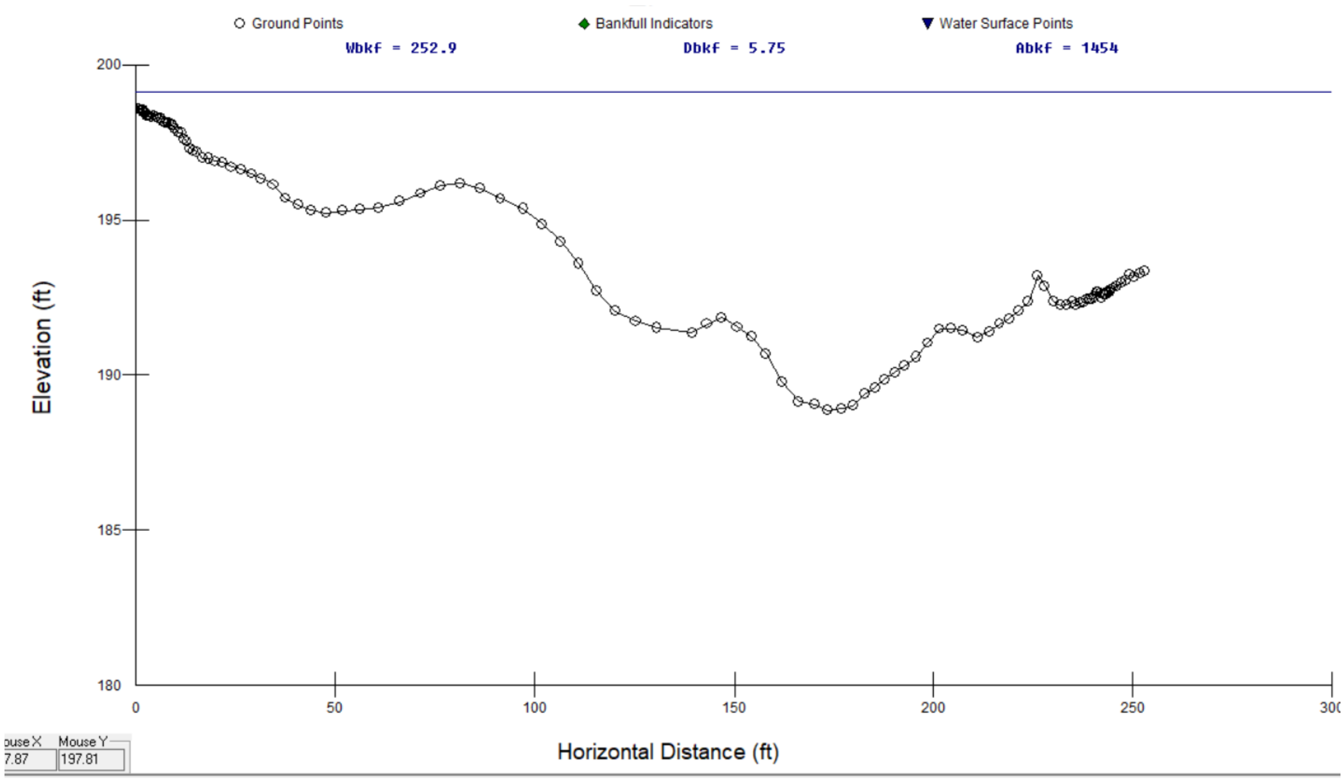

Figure 27: Cross-section EF 17, downstream of dam, in project area, maximum channel depth is 10.6-ft, as predicted. Partial dam failures have focused flow to the right bank coming into the dam. As flow comes over the dam on the right bank it has scoured a small area immediately to the right, and downstream of the dam. Flow converges downstream of that point and moves the thalweg towards the center of the channel. The bankfull area for this cross section is 1598 ft^2. Note that the Abkf has increased to predicted size downstream of the dam.

Reference Measurements for cross-section EF 17:

Entrenchment Ratio (W_{fpa}/W_{bkf}) = 1.32 (ref = 2.2)

W/D ratio = 43.9 (ref = >12)

Sinuosity (=SL/VL) (= k) = 1.1 (ref = >1.2)

Figure 28: Upstream project area near EF17. Note scour zone on far bank, flow convergence, and significant deposition along left bank (foreground).

Figure 29: Left bank in the project area near EF17. Note escarpment wall and sediment deposition.

Figure 30: Left bank in project area near EF17, downstream from the escarpment at the transition down to the Genessee silt loam high terrace. Erosion is isolated, and appears to be influenced by the concrete storm water wing wall position in the bankfull stage flow path. Upper surface is 21-ft above the water surface, and the lower tread surface is 8.5-ft above the water surface.

Figure 31: Left bank of the project area near EF17. Transition from escarpment to terrace.

Figure 32: Looking southwest downstream from the left bank towards the right bank (near EF17. Note the smooth transition onto the very restricted right bank floodplain, and the center channel flow convergence.

Figure 33: Soil associations in the project area. Note that the left bank in the upper portion of the area is dominated by an escarpment. Downstream from the escarpment there is the start of a Genesee loam (GccAH) terrace.

The right bank is composed of sandy Udorthents (Uaz). More complete soil descriptions follow.

GccAH (Genesee loam), 0 to 2 percent slopes, frequently flooded, brief duration

Uaz (Udorthents, sandy) Frequency of flooding: None, Frequency of ponding: None. In the Bartholomew Soil Survey, the Uaz soil areas are described as: “Generally, this map unit consists of areas of mixed sandy soil materials. These areas are old sand and gravel pits, areas from which fill materials have been borrowed, or areas of the fill material itself (Wigginton and Marshall, 2004).

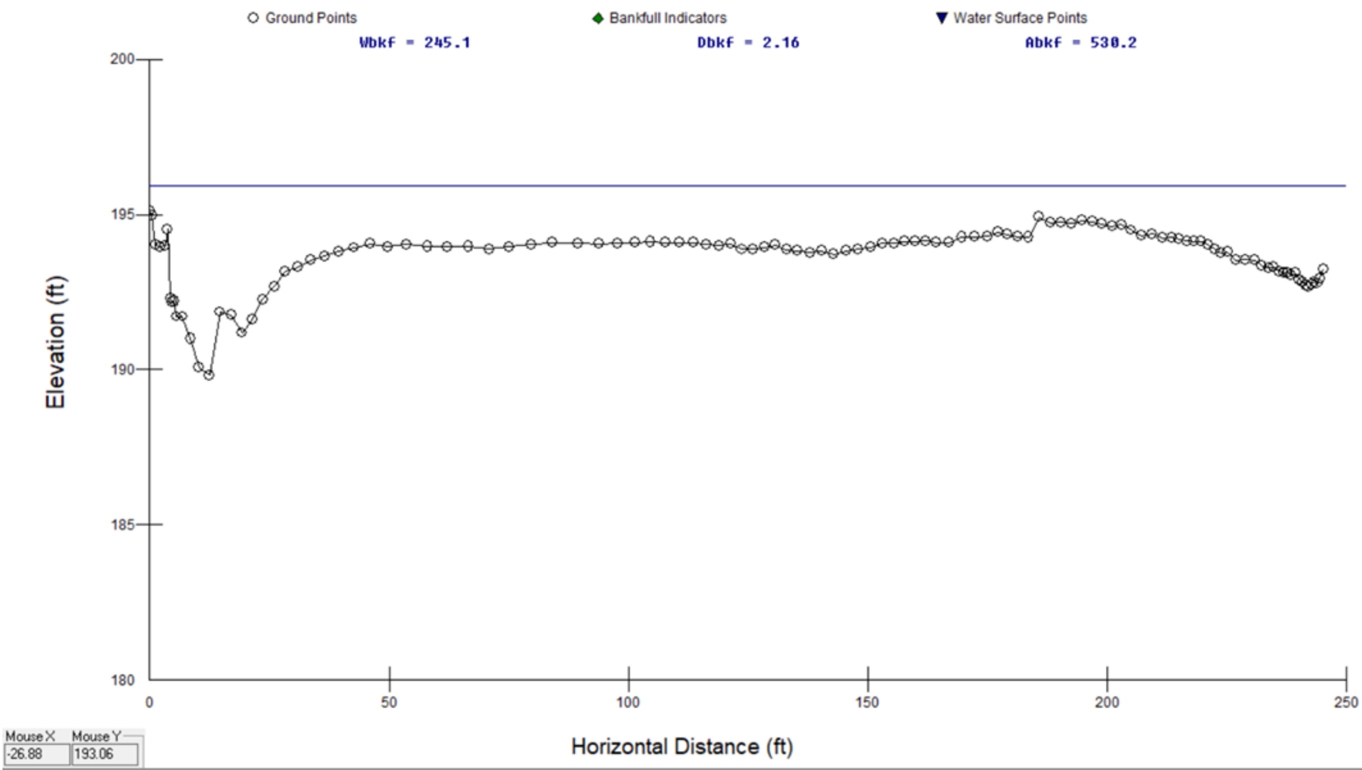

Figure 34: Cross-section EF 24, downstream from project area. The downstream cross-section shows the deep pool along the left bank, and a very aggraded bed leading to reduced cross-sectional capacity. Note that the Abkf at EF24 is 530 ft^2, or 33% of what it was upstream at EF17. This appears to be related to stream flow being routed into an old gravel pit on the right bank and a resultant loss of stream power in the main channel – particularly during low flows. That secondary flow path into the gravel pit on the right bank is also causing a deeper channel to develop along the right bank. Note the deepening channel at about 240 feet from left bank. The sediment observed downstream indicates that at higher flows the EFWR will push the sediment downstream.

Reference Measurements for cross-section 24:

Entrenchment Ratio (W_{fpa}/W_{bkf}) = 4.0 (ref = 2.2)

W/D ratio = 113 (ref = >12)

Sinuosity (=SL/VL) (= k) = 1.3 (ref = >1.2)

Figure 35: Point bar in the downstream portion of the study area, near EF24. Note smooth transition of the point bar onto the adjacent floodplain and the rock placed along the toe of the outside of the meander bend on the opposite side (left bank).

Figure 36: Soil associations in the downstream portion of the study area. Note the left bank is primarily a Genessee silt loam floodplain, with a small area of Uaz, or sandy Udorthent in the middle portion, and Stonelick (SuoAH) fine sandy loam downstream. The right bank is initially sandy Udorthent that changes to Stonelick fine sandy loam downstream. The former sand and gravel pit can be seen on the left side of the image. While the point bar with a deep pool is normal alluvial channel geometry, note that the point bar breaks into the old sand and gravel pit at stages, or river water surface elevations, less than the bankfull stage This is concerning because it may send a wave of channel-bed instability upstream, and increase downstream meandering.

SuoAH (Stonelick fine sandy loam) 0 to 2 percent slopes, frequently flooded, brief duration

Uaz (Udorthents, sandy) Frequency of flooding: None, Frequency of ponding: None. In the Bartholomew Soil Survey, the Uaz soil areas are described as: "Generally, this map unit consists of areas of mixed sandy soil materials. These areas are old sand and gravel pits, areas from which fill materials have been borrowed, or areas of the fill material itself (Wigginton and Marshall, 2004).

The aggraded cross-section shown in EF24 indicates that at the time of the field assessment stream flow had not been adequate to move the sediment downstream. However, sediment transport tends to be episodic. Table 1, noted in Section 3, Sediment Sampling and Analysis Section of this report, shows that the EFWR at Columbus has a sediment load that is primarily sand and small gravel. The bankfull discharge will move the D84 size fraction in a low gradient alluvial river like the EFWR, indicating that the bed and point bars of the EFWR at Columbus are mobile during a bankfull discharge. This is significant when the bankfull discharge has a return interval (RI) of 1.5 years. It is even more significant when the return interval increases, and the bed become mobile more frequently. This is the case for the EFWR at Columbus. Table 6 shows that for the period of record 1975-2016, the RI for the bankfull discharge (19,986 cfs) has become more frequent since 2002, and is now more of an annual event (Table 6). Coupled with the increased frequency of the bankfull discharge is an increase in annual peak discharge (Figure 37). This combined effect of increased frequency of the bankfull discharge, and the increase in annual peak discharge is that the bed of the EFWR has become increasing mobile in the study area. The bathymetric maps and field observations show that sediment transport is disrupted by the dam, but sediment is still moving through the system. Sediment transport is considered in terms of both competence, the size of sediment that can be entrained, and capacity, or the total sediment load. The point bars visible in Figure 38 indicate that the EFWR at Columbus is transporting sediment. The data all suggest that the EFWR can transport the sediment currently stored behind the dam on downstream, and that if stream flow after dam removal is normal, the EFWR will adjust quickly. One challenge noted in Figure 5, is that the rubble dam at the railroad bridge is also acting as a grade control, and the river will not be able to adjust sediment transport with that structure in place.

Table 6: Annual peak discharge, East Fork White River at Columbus, Indiana. U.S.G.S. gage 0336000. Yellow indicates year when the bankfull stage was not reached. Note that the dates are by water year (Oct 1- Sept 30).

Date		Discharge (cfs)	Date		Discharge (cfs)
2/25/1975		32500	4/9/2000		12400
1/27/1976		13100	10/6/2000		13800
4/3/1977		11300	5/15/2002		34400
3/16/1978		24500	9/4/2003		12200
3/5/1979		26500	1/6/2004		37900
11/29/1979		14100	1/7/2005		57300
5/29/1981		19300	3/14/2006		25200
2/1/1982		28600	1/16/2007		25900
5/4/1983		21500	6/8/2008		68100
4/24/1984		17300	8/6/2009		23700
2/25/1985		23500	6/24/2010		20800
11/29/1985		21300	4/21/2011		37400
10/7/1986		14900	12/7/2011		15800
2/3/1988		16700	1/15/2013		23700
5/27/1989		22300	12/23/2013		51400
5/18/1990		25800	7/14/2015		21200
1/1/1991		48400			
4/20/1992		13800			
3/6/1993		13300			
11/16/1993		46400			
5/20/1995		22100			
4/30/1996		39700			
6/2/1997		37100			
6/16/1998		31600			
1/24/1999		32100			

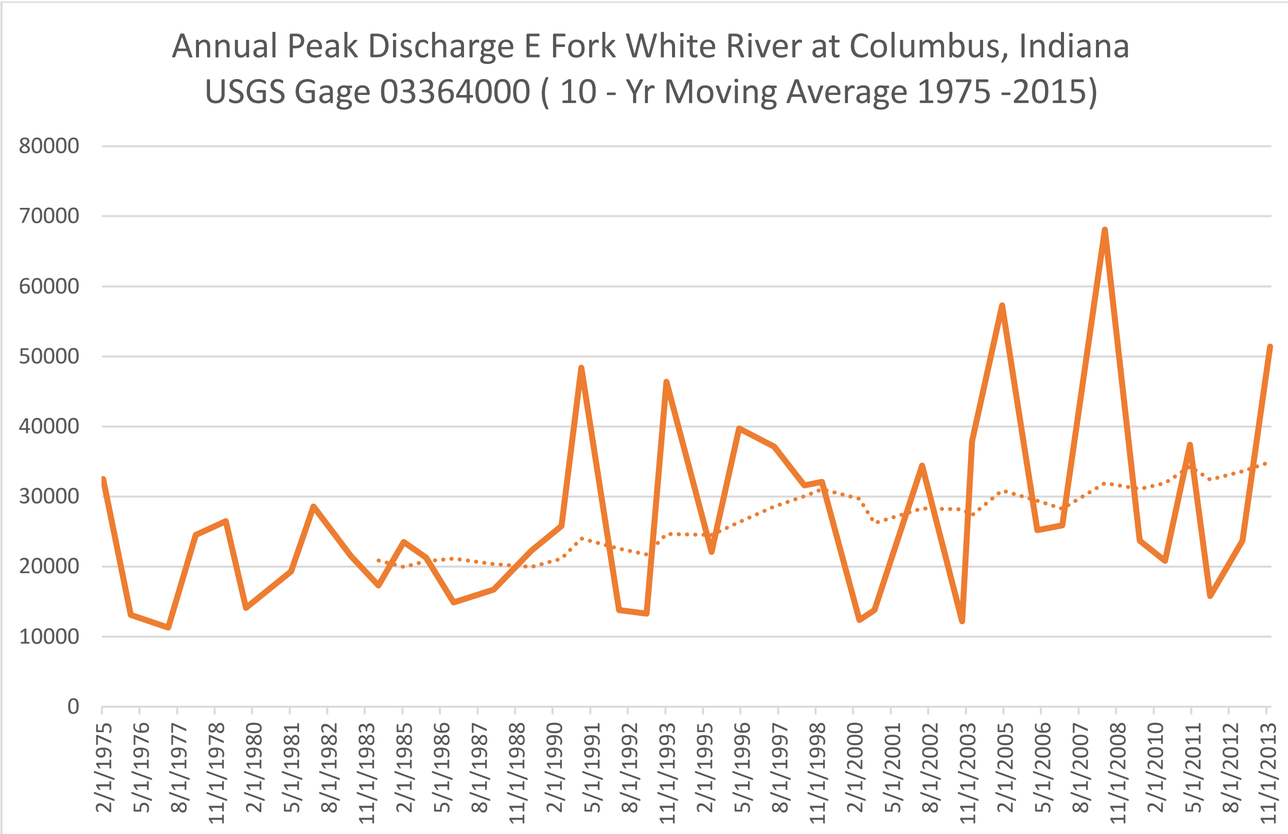

Figure 37: Annual peak discharge, East Fork White River at Columbus, Indiana. U.S.G.S. Gage 0336000. Note the dashed moving average shift in the 1990s.

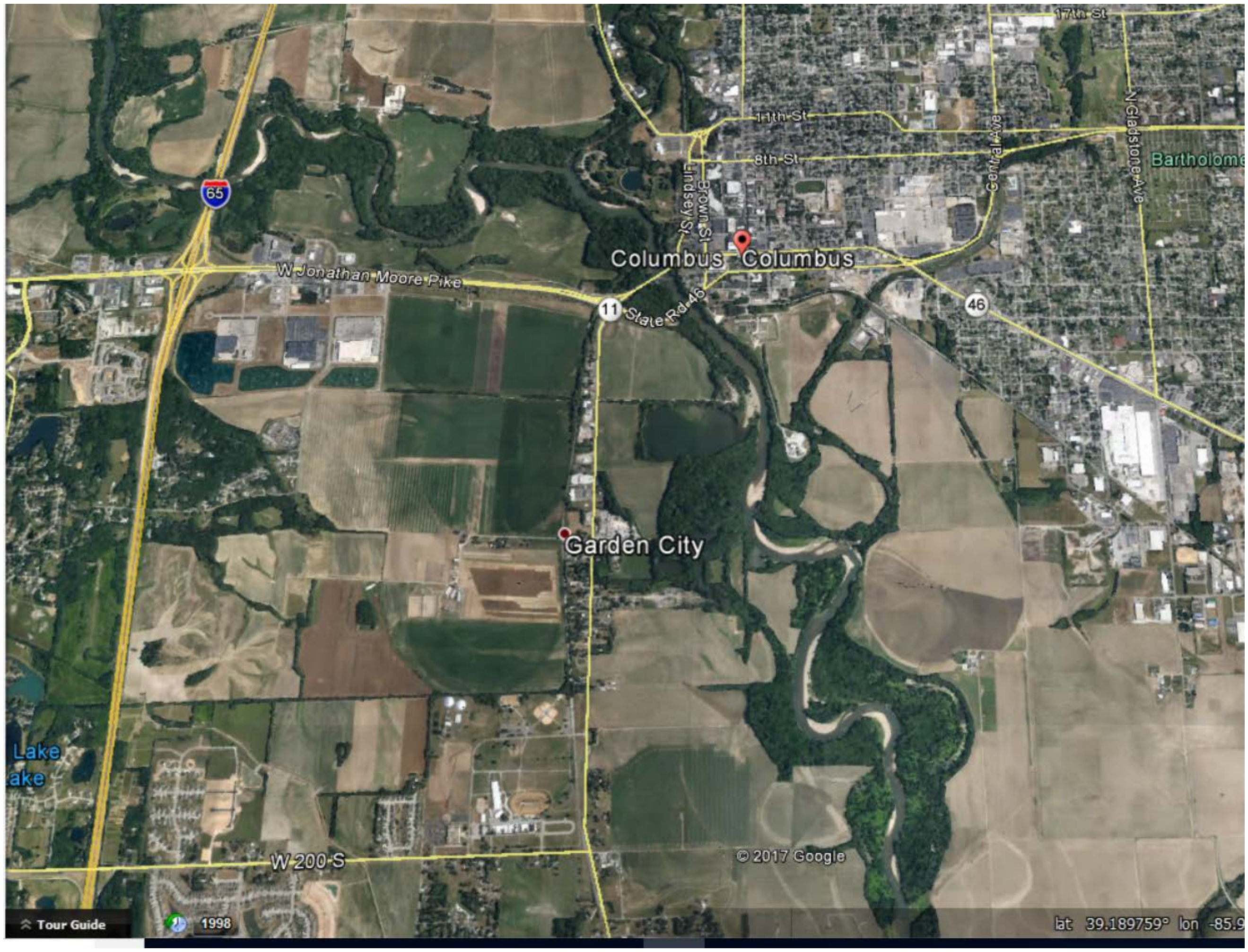

Figure 38: Bright sand bars from the Driftwood River in the upper left of the image continuing down through the main channel of the ERWR in the right center of the image, indicate sediment transport through the project area. The absence of extensive side bars or mid-channel bars indicates that transport is relatively stable, but the long straight portion of the study area without bars indicates localized disruption.

Section 5: Summary and Conclusions

The bathymetric mapping clearly showed the distribution of sediment through the project area. It provides a view of the functioning sediment transport upstream of the dam when the mapping was done and indicates where there are issues downstream. For example, the rubble in front of the railroad bridge appears to be focusing flow towards the right bank, but with the dam in place it is difficult to determine whether the rubble, or the broken dam on the right bank is the larger problem. The longitudinal profile in Figure 5 also shows that the rubble in front of the railroad bridge is acting as a grade control, and is holding back as much sediment as the dam. As the dam comes out it will be important to monitor the development of the channel, if the rubble is not removed at the railroad bridge a plunge pool similar to what is now in front of the dam can be expected to develop.

The bathymetric survey also indicates the channel changes downstream as flow is diverted into the old gravel pit on the right bank. As above, it will be important to monitor this changing area. It may need to be addressed to avoid impacts upstream and downstream.

The sediment sampling indicates clean sand and gravel behind the dam, with no trace of particulate copper, lead, or zinc. Three strong indicators of human-sourced contamination.

The sediment sampling also showed the sediment size above and below the dam was the same, suggesting that the river is currently moving sediment through the channel, albeit in a very disrupted fashion.

The hydraulic analyses demonstrates that the impact of dam removal on water surface elevation is negligible during major flood events. The impact of the dam remooal on water surface elevations during the bankfull event is very limited (a maximum reduction of about 5 inches from Mill Race Park vantage point). During very low (baseflow) river conditions, the water surface elevation near Mill Race Park is expected to be about 3.7 feet lower than what is experienced in existing conditions, likely necessitating modification of the intake structure near Mill Race Park to allow pumping water into the park lake during low flow conditions in the River if no grade control structures are constructed to maintain current water levels.

The geomorphic assessment showed a river that has been significantly affected by both the low-head dam, and now by the breakdown of the low-head dam. Channel dimensions, pattern, and profile, have all been changed from what would be predicted, and further change seems to be occurring as a result of the frequency and magnitude of high discharges. The good news is that there seems to be enough stability in the upstream and downstream portions of the study area for the river to recover. Because there are multiple drivers for the instability seen near the study area it will be important to monitor the developing channel changes.

From a geomorphic perspective, dam removal will generate an adjustment of the bed as the river grades to a stable slope through the study area. With the effectiveness of current sediment transport and the relatively low height of the dam, adjustment should occur quickly. The recent trend of an annual occurrence of the bankfull stage suggest that adjustment should take place within a year. When the dam is removed the scour pools downstream of the dam and near the right bank will fill quickly. The $D_{50,}$ or median grain size of the sediment behind the dam (4.6 mm) suggests that it will be moved rapidly. The one challenge, noted earlier, is that the rubble dam at the railroad bridge may simply replace the lowhead dam as grade control and should be carefully monitored.

Final Comments

A strong caution is given to consider the effect of the rubble in front of the railroad bridge on sediment transport. Field observations suggest that the rubble structure is acting as a grade control and altering sediment transport. The only deep portion of the channel is found in a break in the rubble (Figure 4).

The constrained boundary conditions in the study area suggest that it will be difficult for the river to alter in planform in that area. The combination of armoring, filling, and non-levee embankments have been put into place to keep the river where it is.   Without altering some of those features, the straightened planform of the river in the study area will remain.

Inside its confined corridor, the river will attempt to establish the meandering pattern that it needs for sediment transport, and the probable outcome will be areas of bank instability. In a normally functioning low gradient alluvial river, pool and riffle spacing is variable, but averages between 5-7 times the bankfull width. In the EFWR, pools could be expected to occur every 1,400-ft or so. That spacing is found above and below the study area, but in the study area there are no clearly defined pools for over 2,700-ft (Figure 6). The lack of a pool in the reach is part of the reason for the aggraded cross-section shown in Figure 34, transport capacity has been lost in that area at lower flows resulting in temporary aggradation.

Sediment transport is also being affected by the old sand and gravel pit shown in Figure 36. The breach on the right bank is diverting stream flow and sediment into the pit at fairly low discharges. That routing of flow and sediment out of the main channel will result is continued channel adjustments both upstream and downstream. Further analysis is recommended to help determine the most appropriate methods for minimizing this hazard.

A final factor to consider when thinking about the effects of removing the dam, is the continuing increase in the frequency of bankfull discharge events and increased peak discharges. A naturally functioning river is remarkably resilent to a wide range of flows. Human modification of channel and floodplain width, changes in channel depth, and even needed infrastructure like bridges, make it harder for a river to adjust to changing conditions. Removing the dam can only help the EFWR as it continues to adjust. One thing that was clear during this investigation was that the Driftwood, Flatrock, and East Fork White River are all showing signs of systemic change and adjustments. The banks on all three rivers are unstable in some areas, particularly in reaches without accessible floodplains. This indicates that the floodplains are functioning as “shock absorbers” to the increasing peak discharges, and highlights the need to preserve remaining floodplains

References

Knighton, D. (1998) Fluvial Forms &Processes: A New Perspective. Arnold Publishers.

Leopold, L.B. (1994) A View of the River. Harvard University Press

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

U.S. Geological Survey Flood Inundation Mapper, http://wimcloud.usgs.gov/apps/FIM/FloodInundationMapper.html#

WebSoil Survey (no date) https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Wigginton, M. and Marshall, D. (2004) Soil Survey of Bartholomew County, Indiana. United States Department of Agriculture, Natural Resources Conservation Service. https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/indiana/IN005/0/Bartholomew_IN.pdf