Stream Stability Analysis Report

Eastern Corridor Multi-modal Projects
Segment II/III - Priority Part B Work
Little Miami River Geomorphic Assessment

Stantec Consulting Services Inc.
One Team. Infinite Solutions
11687 Lebanon Rd.
Cincinnati OH 45241-2012
Tel: (513) 842-8200 • Fax: (513) 842-8250
www.stantec.com

Prepared for:
Entran
Cincinnati, Ohio

December 18, 2009

Stantec Consulting Services Inc.
11687 Lebanon Rd.
Cincinnati OH 45241-2012
Tel: (513) 842-8200
Fax: (513) 842-8250

December 18, 2009 rpt_002_174438122

Ms. Deborah Osborne
ENTRAN
1848 Summit Road
Cincinnati, Ohio 45237

Re: Stream Stability Analysis Report
Eastern Corridor Multi-modal Projects
Segment II/III - Priority Part B Work
Little Miami River Geomorphic Assessment

Dear Ms. Osborne

As requested, Stantec Consulting Services Inc. has completed the river stability analysis for the site referenced above. Enclosed you will find the final copy of the River Stability Analysis Report for the Eastern Corridor Multi-modal Projects along Little Miami River. Data collected, analysis of the data, as well as conclusions from the data are presented in the report.

Stantec appreciates the opportunity to provide these services. If you have any questions, or if we may be of further assistance, please call.

Sincerely,

STANTEC CONSULTING SERVICES INC.

Scott Peyton, PE
Project Manager

/cdm

Stream Stability Analysis Report

Eastern Corridor Multi-modal Projects
Segment II/III - Priority Part B Work
Little Miami River Geomorphic Assessment

Prepared for:
Entran
Cincinnati, Ohio

December 18, 2009

Stream Stability Analysis Report

Eastern Corridor Multi-modal Projects
Segment II/III - Priority Part B Work
Little Miami River Geomorphic Assessment

Table of Contents

Section **Page No.**

Table of Contents
(Continued)

List of Tables

List of Figures

Table of Contents
(Continued)
List of Appendixes

Appendix

Executive Summary

Stantec Consulting Services Inc. (Stantec) completed a geomorphic assessment of a 2.5 mile segment (River Mile 4.5 to 7.0) of the Little Miami River as part of planning for Segment II/III of the Eastern Corridor Projects including four reaches (potential clear-span bridge crossing locations). The assessment was conducted in two phases; Phase I included the collection and analyses of existing, historical and field data as well as classification and characterization of the physical stability of the river, insight into the dominant processes influencing channel morphology, and development of a baseline trend analysis for Phase II of the study. Phase II included characterization of the river flows during the study period, collection and analyses of data for comparison to Phase I, and results interpretation and recommendation development for an optimal clear-span bridge location.

The Little Miami River is a C4c- river type according to the Rosgen classification system of natural streams (Rosgen, 1996). The river has irregular, tortuous and confined meander patterns with a high meander width ratio (MWR). It is slightly entrenched with a moderate degree of channel incision. The channel has a flat slope (0.00058 feet/feet) with riffle, run, pool, and glide bed features. Bankfull channel dimensions include mean width of 336 feet and a mean depth of 8.3 feet. Substrate analysis produced a reach median bed material, or D_{50}, of 10 mm. The reach also exhibits several side channels and numerous bar formations which may be indicators of instability in the overall river reach.

Of the four reaches, Reach 1 (Alternative C) exhibits the most favorable geomorphic stability characteristics for a clear-span bridge crossing. Reach 1 had the lowest overall bank erosion rate of the four river reaches. Historical aerial photography indicates this reach has had little channel movement in the past 100 years. In Reach 1, to construct a bridge upstream of the slough that does not have a pier within the ordinary high water marks of Little Miami River, the recommended clear span distance is approximately 350 feet. In order to construct a bridge (upstream of the slough) with piers that stay out of the expected meander pattern of Little Miami River, the recommended clear span distance is approximately 415 feet.

Stantec's recommendation for the second most preferable clear-span bridge crossing location is at the Reach 3 / Reach 4 boundary (Alternative F1/F2), upstream of the Clear Creek – Little Miami River confluence. This crossing location appears to be far enough downstream of the Horseshoe Bend for the potential effects of the potential avulsion or down-valley migration associated with the Horseshoe Bend to be minimized. At this location, to construct a bridge that does not have a pier within the ordinary high water marks of Little Miami River, the recommended clear span distance is approximately 320 feet. In order to construct a bridge with piers that stay out of the expected meander pattern of Little Miami River, the recommended clear span distance is approximately 970 feet.

Stream Stability Analysis Report

Eastern Corridor Multi-modal Projects
Segment II/III - Priority Part B Work
Little Miami River Geomorphic Assessment

1. Introduction

The Eastern Corridor Multi-modal Projects (ECMP) is a large-scale effort designed to increase transportation capacity between Hamilton and Clermont Counties through both the enhancement and creation of new routes as well as new modes of transportation. Segment II/III of the ECMP, which is the focus of this study, extends from US 50 near Fairfax in Hamilton County to the Eastgate area of Clermont County. One proposed means of increasing transportation capacity is through the relocation of State Road (SR) 32 coupled with a new parallel rail transit and a multi-modal clear-span crossing of the Little Miami River.

In an effort to provide recommendations for consideration in the Conceptual Alternatives Study (CAS) regarding the suitability of proposed crossing locations along the Little Miami River, a geomorphic assessment was undertaken to develop a more complete understanding of past, present and future channel conditions. As the Eastern Corridor Tier 1 work performed by ENTRAN documented historical meanders and the potential for their migration within the Horseshoe Bend area, this geomorphic study (Phases I and II) builds upon those efforts by evaluating channel stability characteristics within a targeted 2.5 mile section of the Little Miami River (RM 4.5 to 7.0) at Horseshoe Bend. During Phase I, reaches within the 2.5 mile study area that exhibited geomorphic stability were identified. Initial identification was based on qualitative analysis of soils, channel and valley geomorphology, riparian vegetation, and streambank erosion. For Phase II, qualitative assessments made during Phase I were validated, and conclusions regarding channel stability were made. This report documents methodologies, results, conclusions and recommendations for both Phases I and II.

1.1. Scope of Work

Using methodologies and techniques presented in Rosgen (1996; 2006) and Harrelson et al. (1994), Stantec Consulting Services Inc. (Stantec) conducted a geomorphic assessment of the 2.5 mile study section. The assessment involved a detailed evaluation of components such as bed and bank stability, erosional and depositional features/patterns, utility impacts, and floodplain accessibility. Additionally, features related to habitat stability such as facet (riffle, run, pool, and glide) structures, major lateral river inflows, island complexes, and riparian vegetation integrity were evaluated. Note that the habitat evaluation was performed only to compliment the physical stability analysis, and as such, is NOT intended to fulfill permitting, restoration, or environmental impact study requirements.

The geomorphic assessment was conducted in two phases (Phases I and II); results of both phases are presented in this report. Phase I included the collection of historical and existing data as well as field data representing recent conditions; analyses of these data; and identification of preferred reaches based on geomorphic stability characteristics for a clear-span bridge. Examples of historical and existing data include aerial images and U.S. Geological Survey gage data while examples of field data include surveys of cross-sections, longitudinal profiles, and bank profiles; bed material sampling; scour chain measurements; and photo-documentation. Phase I data served as a baseline to which Phase II data were compared. Phase II work included recollecting data at the same points from Phase I, as well as collecting data from upstream gages and monitoring and surveying large flow events throughout the year.

1.2. Background Information

1.2.1. Location and Watershed Characteristics

The Little Miami River (HUC 05090202), which originates in Clark County, drains a watershed of 1,755 mi^2 before joining the Ohio River at Cincinnati in Hamilton County (Schiefer, 2002). At the study site, the drainage area of the Little Miami River is approximately 1,730 square miles (USGS Stream Stats, 2008). The Little Miami River watershed stretches across five physiographic regions and 11 counties within the Till Plains of Ohio. The Segment II/III study area lies in the Illinoian Till Plain in close proximity to the Outer Bluegrass Region. The Illinoian Till Plain is characterized by rolling ground moraines of older till generally lacking kames and eskers with many buried valleys. Modern valleys alternate between broad floodplains and bedrock gorges with overall moderately low relief. The soils are leached several feet and surficial material typically consists of silt-loam, high-lime Illinoian-age till with a loess cap overlying Ordovician- and Silurian-age carbonate rocks and calcareous shales (ODGS, 1998). The physiographic characteristics of this portion of the watershed match the description for a Valley Type VIII (Rosgen, 1996). A Valley Type VIII denotes a fluvial landform with multiple terraces spread across broad valleys with gentle down-valley slopes. Soils form over alluvium from riverine and lacustrine deposition, which is responsible for the majority of valley landforms and high sediment supply. Slightly entrenched, meandering channels with riffle/pool bedforms are commonly found in this valley type.

Average annual precipitation for the watershed ranges from 38 to 43 inches, with higher levels of precipitation occurring in the southern portions. Average snowfall ranges from 20 to 30 inches per year. Approximately one-third of the precipitation within the watershed becomes surface runoff attesting to the high amounts of impervious surfaces present. Average annual air temperature is 54º F (USGS, 1997).

The Segment II/III study area (5.25 mi^2) includes the communities of Newtown and Shademore, portions of Anderson Township, and the south edges of the communities of Fairfax and Mariemont. The study area is a mix of land uses and disturbances, including residential, commercial and industrial development in Newtown; wooded stream corridors and agricultural lands along the Little Miami River to the west and north of Newtown; and wooded uplands with developing residential areas to the south of Newtown and along existing SR 32 to Eastgate. Segment II/III contains a number of recreational and natural areas including a public golf course, ball/soccer fields, other parkland/greenspace, and the privately owned Horseshoe Bend preserve. The riparian buffer adjacent to the Little Miami River has been reduced in width, thinned of underbrush, or cleared in several areas, leading to bank instability and erosion. Gravel mining and industrial development in the Ancor area to the east of Newtown is on-going; landfills along US 50 to the west of the Little Miami River and along existing SR 32 just east of Newtown are presently active. Landfill operations, specifically dumped rock placement on the western river bank, are contributing to river instability. The Segment II/III area is also sensitive for cultural historic and archaeology resources, especially along the Little Miami River floodplain as well as areas within and surrounding Newtown.

1.2.2. River Designation

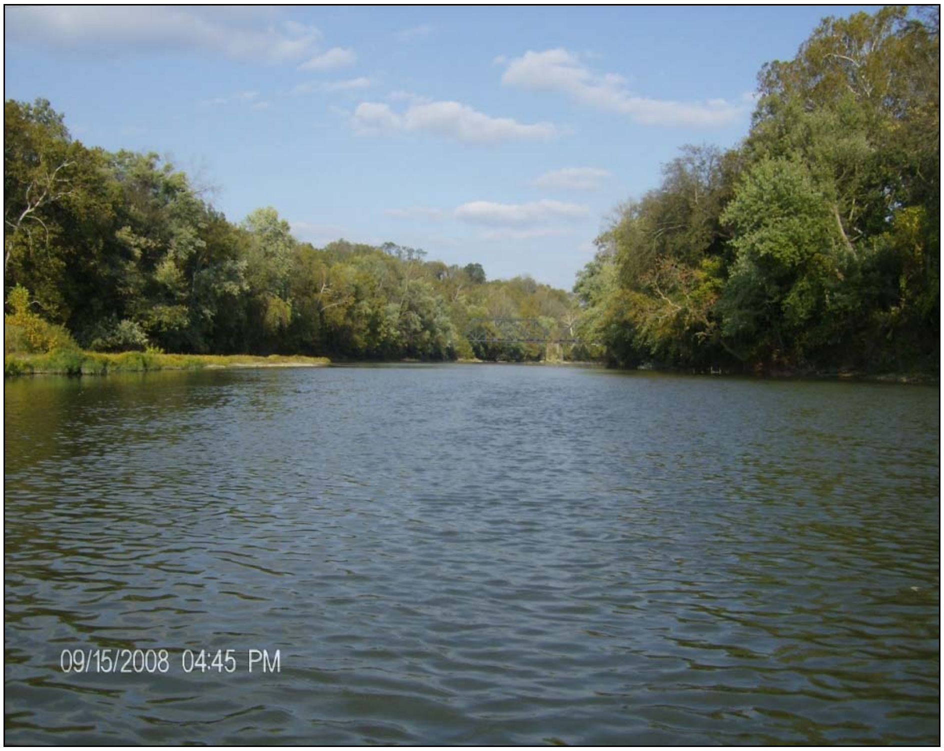
In 1968, the Little Miami River was the first river to be designated a State Scenic River by the State of Ohio; portions were chosen for national designation that same year with more added in 1973. It was the first of three rivers in Ohio to receive both State and National Wild and Scenic Rivers designations. The National Wild and Scenic Rivers Act established the goal of "preserving certain rivers with outstanding natural, cultural, and recreational values in a free-flowing condition for the enjoyment of present and future generations." (WSRA, 1968)

2. Phase I – Geomorphic Assessment of the Little Miami River

The study section was divided into four geomorphically distinct reaches based on bank conditions, channel and floodplain morphology, and tributary and distributary impact to better assess existing conditions and describe influential channel characteristics. Note that while a tributary is a stream that flows to a main channel, a distributary is one that flows away from the main channel.

Reach 1 begins approximately 1,800 feet upstream of the existing railroad bridge and extends to approximately 3,100 feet downstream of the railroad bridge, at which point Reach 2 begins. Reach 2 extends approximately 3,800 ft downstream through the Horseshoe Bend to the point at which the landfill road starts to parallel the river. Reach 3 continues from this point to approximately 1,700 ft downstream to about the location of the slough entrance at the Clear Creek confluence. Lastly, Reach 4 extends to the end of the study area, which is approximately 4,000 feet downstream of the Clear Creek slough inlet. Figure 1 illustrates reach representations and detailed Site Drawing A-1 presented in Appendix A identifies reach locations.

Stantec installed 12 permanent cross-sections, 18 permanent bank study sites, and nine scour chains throughout the study section during Phase I in the fall of 2008. Permanent cross-sections were immediately surveyed. Locations of all monitoring sites were recorded in Ohio State Plane South Coordinates. Modified Wolman pebble counts (Rosgen, 1996) were performed at each surveyed cross-section. Bulk sediment samples were collected at representative depositional features. Detailed Site Drawing A-1 presented in Appendix A shows the monitoring sites along with the type(s) of data collected at each site.



a. View East/upstream through Reach 1

b. View West/downstream through Reach 1

c. View East/upstream through Reach 2

d. View West/downstream through Reaches 2 and 3

e. View North/upstream through Reach 3

f. View South/downstream through Reach 3

g. View North/upstream through Reach 4

h. View South/downstream through Reach 4

Figure 1. Photographic Representation of Reaches

2.1. Little Miami River Description

2.1.1. Level I Assessment: Geomorphic Characterization

Broad-level evaluations of channel dimension, pattern, and profile provide delineative criteria for using the Rosgen system of stream classification (Rosgen, 1996). The study section of the Little Miami River exhibits a meandering, single-channel river pattern in plan view with moderate to high sinuosity. Overall, the channel is wide, shallow and is slightly entrenched with access to a broad, gently sloping, alluvial floodplain. The channel slope is well below the delineative criteria of 2 percent. Congruent with the low channel slope, riffle/pool bed features dominate the study section. These characteristics are indicative of a C-type channel (Level I) with low channel slope (c-). Refer to Appendix B for a graphic detailing the Rosgen system of stream classification.

2.1.2. Level II Assessment: Morphological Description

To attain a greater degree of insight into channel characteristics and evolution patterns, a Level II assessment is performed whereby detailed field-based geomorphic data is collected. This field data includes channel cross-sectional dimensions and profiles, of which surveys are based upon the elevation associated with the channel-forming or bankfull discharge. Dunne and Leopold (1978) define bankfull stage as the elevation that "corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work results in the average morphological characteristics of channels." For non-incised channels, bankfull stage is the incipient point of flooding (i.e. the elevation on the bank where waters begin to exit the banks and spread out onto the active floodplain). When channel incision is present, bankfull flows experience some degree of confinement meaning that their access to the active floodplain is limited. Leopold (1994) defines the active floodplain as the land adjacent to the channel that is presently undergoing construction. When channel incision occurs such that the former floodplain can no longer be accessed, it is considered abandoned (i.e. terrace).

A number of bankfull indicators, largely in the form of flat depositional, sandy surfaces or benches, are present within the study section on the Little Miami River. Field surveys were based upon these indicators and compared to regional curves developed by the USGS (Sherwood and Huitger, 2005).

Field data were collected and analyzed throughout September and October 2008. Select morphological characteristics describing the Little Miami River study section are presented in Table 1.

Table 1. Morphological Channel Characteristics

Dimension and Sediment	
Entrenchment Ratio (ER)	12.8
Width/Depth Ratio (W/D)	40.4
D_{50} (mm) – Reach Median	10.0
Longitudinal Profile	
Bankfall Surface Slope (ft/ft)	0.00056
Planform	
Sinuosity (K)	1.36

Additional classification data are provided on Worksheet 5-3 in Appendix B.

2.1.3. Level III River Stability Prediction – River Stability Indices

Riparian Vegetation

For each reach and for each bank (left and right), the characteristics of the riparian zone varied. Note that left and right bank designations are with respect to a downstream view.

Reach 1 Along the left bank, the woody riparian vegetation has a width of approximately 150 ft and consists of a mixture of mature, deciduous overstory of mostly silver maple (*Acer saccharinum*), eastern cottonwood (*Populus deltoides*), and sycamore trees (*Platanus occidentalis*) (Figure 1a,b). The understory within that riparian zone has a dense population of honeysuckle bushes; various grasses and forbs are less dense. Beyond the woody riparian vegetation, fields of open grass, soybean, corn and sod extend thousands of feet from the channel.

On the right bank, the width of the woody riparian vegetation is approximately 300 feet. Downstream of the railroad bridge, open grass fields with scattered trees extend 400 to 1,200 ft from the river bank before ending near a railroad yard and industrial land use area. A portion of the riparian zone has developed on depositional material, which is primarily located at a lower elevation, while the remainder of the wooded riparian vegetation is at the top of the bank. The depositional area and top of bank are separated by a slough/distributary, beginning approximately 1,100 ft downstream from the railroad bridge and reconnecting to the main channel at Horseshoe Bend. The wooded area on top of the bank has a similar composition of over- and understory as the left bank. The younger/lower riparian zone located on the depositional material extends the entire length of the slough/distributary. The younger/lower riparian zone has a well established population of mixed, deciduous trees (Figure 2) which are evident in historical aerial photographs dating back to 1938.

Figure 2. Typical Vegetation of Lower Riparian Zone in Reach 1

Reach 2 The woody riparian vegetation along the left bank of Reach 2 has a similar composition to that of Reach 1. This zone maintains a width of approximately 150 ft for another 600 ft downstream from the end of Reach 1. Beyond the 600 ft on the left bank of Reach 2, the riparian zone is approximately 500 ft wide. The canopy trees have been selectively cleared and the understory thinned (Figure 3). Remaining understory vegetation is primarily giant ragweed with a low percentage of grass cover. The giant ragweed has a shallow rooting depth as well as low root density. The composition of this zone continues downstream to the confluence of the Little Miami River and Clear Creek in Reach 4, but it varies in width. A number of large cottonwood trees along the left bank of Reach 2 have recently fallen into the river due to bank erosion.

The right bank of Reach 2, upstream of the slough/distributary confluence with the river, is similar in density and composition to the lower riparian zone located on the depositional area of Reach 1 (Figure 4). It ranges in width from approximately 500 to 900 ft. The right bank of Reach 2 is a depositional zone at the inside of a meander bend (i.e. point bar). The vegetation community is a good indicator of this fluvial process as the woody vegetation community close to the river bank consists of younger willow species.

Downstream of the confluence of the Little Miami River and the slough/distributary at Horseshoe Bend, the composition of vegetation along the right bank changes significantly. The floodplain area is comprised almost entirely of giant ragweed with minimal grass ground cover. This vegetation community is approximately 200 ft wide at the confluence and increases to 600 ft in width at the apex of the bend ending abruptly at a stand of trees that line a ditch. A corn field exists along the right bank to the end of the reach. Some willows populate portions of the bank between low flow water levels and the top of bank.

Figure 3. **Typical Vegetation on Left Bank, Upstream of Horseshoe Bend**

Figure 4. **Typical Island Vegetation in Reach 2**

Reach 3 The left bank woody riparian vegetation is dominated by mature willows close to the river and mature silver maple, eastern cottonwood, and sycamores along adjacent terraces (Figure 5). The average width is over 500 ft, bordered by thousands of feet of various grass and sod fields.

The right riparian zone through Reaches 3 and 4 consists of a narrow band of trees bordered by broad fields. Willows cover much of the bank. Atop the banks, mature sycamores dominate the 50 ft wide woody riparian zone. Beyond the woody vegetation zone, flat fields of various grasses, forbs, and bare earth extend from 200 to 1,200 feet from the river.

Figure 5. Riparian Vegetation through Reach 3

Reach 4 The left bank riparian zone narrows significantly (Figure 6), with the lower half having little to no woody vegetation in the riparian buffer. A short segment at the end of the reach has a 200 ft wide stand of trees atop the bank. Only a few trees are growing below the top of bank. Several large trees have fallen into the river due to bank erosion. Sycamores are common in this segment. Beyond the tree line, flat sod fields extend thousands of feet.

Figure 6. Thinning Riparian Vegetation on Left Bank of Reach 4

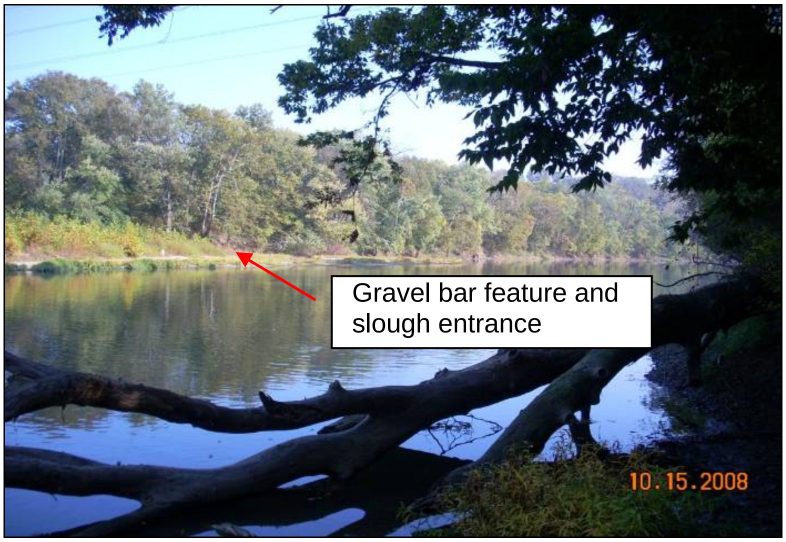
Flow Regime

The Little Miami River is a perennial stream with seasonal flow variations resulting from storm runoff. Refer to Worksheet 5-7 in Appendix F. Urban development in the immediate area as well as throughout the watershed has played a role in altering the local flow regime. Large impoundments located upstream of the study area have significantly altered the Little Miami River's flow regime over the past 35 years. Caesar Creek was dammed to create Caesar Creek Lake in 1973, and East Fork Little Miami River was dammed in 1977 to create Harsha Lake. Aerial photographs indicate marked flow and deposition pattern changes at these times; reduced flood flows likely changed the magnitude, duration, and frequency of bankfull discharge. This flow regime shift likely led to aggradation at the end of the island through Reaches 1 and 2 and around Horseshoe Bend, facilitated the formation of sloughs/distributaries here, and allowed growth of woody vegetation along the right bank entering Horseshoe Bend. A smaller impoundment was placed on Cowan Creek, a tributary to Todd's Fork in the eastern part of the watershed, in 1950.

Depositional Patterns, Tributaries and Distributaries

The study reach has many depositional features including point bars, mid-channel bars, side bars, and diagonal bars with some of these features extending to a length as much as three times the channel width. Sediment sampling data collected at select depositional features is located in Appendix C and sampling locations are presented in Detailed Site Drawing A-1 in Appendix A. An illustrative list of observed depositional patterns observed throughout the study area is presented as Worksheet 5-10 of Appendix F.

Reach 1 During low flow conditions, the slough/distributary is not accessed by the river; it holds long, stagnant pools of water with occasional gravel side bars. The slough is visible in the aerial photography from 1932. A predominately gravel bar feature exists at the entrance to the slough/distributary (Figure 7). The bar feature transitions into a large island between the slough and the river. This bar feature has been formed over the years through deposition and consists of a sandier composition along the island banks and on its floodplain as compared to the gravel section running along the main channel. The end of the slough historically has been dynamic. In 1932, the channels joined at the right-hand bend before Horseshoe Bend. Since then, the main channel has pushed southward pulling away from the old alignment while the slough remained farther north. The island between the slough and the main channel has grown from 1,500 ft in width in 1932 to over 4,000 ft in 2008.



a. Gravel bar on right bank near slough/distributary

b. View West/downstream in slough/distributary

Figure 7. Reach 1 Deposition Patterns and Distributaries

Reach 2   The riffle section (R2_XS1) in this reach has a very high width to depth (W/D) ratio of 124. This high W/D ratio caused a reduction in stream power, hence causing sediment to fall out in this reach by a process known as deposition. The deposition and instability was apparent by 1) an observed gravel island and 2) active deposition in the middle of the bankfull channel before Horseshoe Bend. The low flow channel and thalweg in that specific section of the study reach are in a state of flux. A submerged transverse bar connects the head of the island to a gravel bar feature along the right bank, visible only during lower flows. A long, wide, shallow riffle is present along the left low-flow path. The right side loops around the island and is near half the width of the left and slightly deeper than the left low-flow path. As the right alignment loops around the island, it abruptly bends left along a large side bar to rejoin the left alignment before continuing along the left side heading into the bend. The island is not discernible in 2004 aerial photography, although depositional processes are evident in this area. In 1990, one channel followed along the existing right alignment in a northwest direction. The channel appears to have widened and now flows in a more westerly direction with visible deposition in the island area in 2004. By 2005, the island and dual low flow alignments had become established with the majority of flow remaining in the left alignment. Flow to the right alignment has increased each year since and has pushed the alignment further downstream.

Currently, Horseshoe Bend has a large point bar on the inside of the meander bend, stretching approximately 1,500 ft in river length. The bar is composed predominantly of gravel, near the low flow water surface, with an increasing sand component up the point-bar slope to the bankfull elevation, where the particle distribution is almost entirely sand. A mid-channel, gravel bar began forming on the upstream side of the bend near the point of curvature in 2005. By 2007, the bar had moved outward further into the bend. In 2008, the bar grew larger and connected to the point bar by a thin strip of gravel near the upper third of the point bar. This depositional pattern is not evident in the 2007 aerial photography.

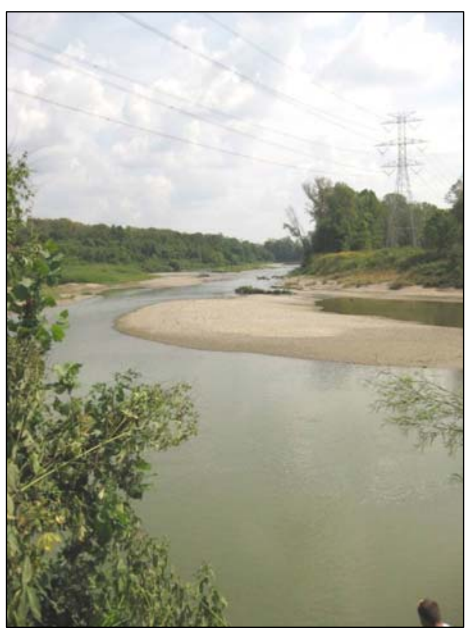


Figure 8.   East/Upstream View from the Outer Bank of Horseshoe Bend

Coinciding with the point and mid-channel bar developments, a large sand bar has formed on the right bank, downstream of the riffle, at the entrance to the bend. The bar consists mostly of gravel near the low-flow channel and on the upstream third of the bar. The downstream/lower third and back of the bar is mostly sand.

Significant pattern changes and depositional feature changes in Reach 2 are visible in the 1950 aerial. At this time, flows at the entrance to the bend began shifting south and widening the active channel. This change created mid-channel bars near the confluence of the Little Miami River with the unnamed tributary and slough/distributary. By 1968, the island was nearly 1,500 ft in length with transverse, high-flow channels. The island continued to build with the majority of flow shifting to the southern channel in the 1970's. By 1981, the northern channel was abandoned and vegetated between the river and the slough/distributary. The point bar at the Horseshoe Bend has consistently been a prominent feature extending into the active channel and has progressively moved downstream, which is often referred to as down-valley migration. The point bar and essentially Little Miami River in this location is expected to continue to shift (migrate) downstream. The progression may be viewed in Appendix D.

Reach 3 Two side bars exist in Reach 3. As the point bar at Horseshoe Bend has moved southward and westward, the channel downstream has begun to move eastward, creating a gradual right-turn bend with a corresponding depositional feature on the lower end. The deposition began forming in the mid-1960's and resembled a side bar. The bar has since grown and is displaying characteristics of a point bar (Figure 1e). In 2008, the bar extended downstream approximately three bankfull widths. The bar is composed mostly of gravel with the percentage of sand increasing with distance from the center of the channel to back and from up- to downstream. A small gravel bar is also present opposite of the primary bar just described. This gravel is likely a portion of a historic river bed that has been exposed due to adjacent bank erosion and not deposition from the river.

Figure 9. South/Downstream View from Gravel Bar in Reach 4

Reach 4 A submerged, transverse gravel bar connects the end of the large bar in Reach 3 to the head of the next side bar on the opposite bank in Reach 4. The thalweg switches from the left third of the channel to the right third at this transition. The side bar on the left bank (Figure 9) is predominantly composed of gravel, and it is adjacent to the island between the slough and Little Miami River. The slough receives inflows from Clear Creek and connects to the Little Miami River on the downstream end. This sidebar is low and is frequently submerged.

The point bar on the right bank has been relatively stable in its present form for approximately 40 years. It appears to be slowly extending and lengthening downstream, pushing the thalweg further to the left third of the channel. The point bar growth coupled with the narrow riparian buffer that lacks sufficient woody vegetation is likely causing high rates of bank erosion along Study Banks (SB) 1, 2 and 3 (See Section 2.2 and Appendix E). The bar sediment size is mostly gravel and sand, fining in the downstream direction.

Meander Patterns

The Little Miami River has irregular meander patterns, a tortuous meander at the Horseshoe Bend, and truncated meanders artificially confined by land use, rip-rap placement, and infrastructure. Historical mapping and aerial photographs show signs of unconfined and confined meander scrolls. (See Worksheet 5-9 of Appendix F). The river has shown little meander movement in the last 30 years with the exception of Reach 2, where significant changes have occurred in the recent past. Overall, river meander patterns from the last 140 years indicate dynamic conditions in the lower two-thirds of the study reach. The historical footprint of the river in the study area is approximately 450 acres. River lengths through the study area have differed by approximately 5,000 feet. According to historical data, maximum lengths occurred in the mid to late 1800's. The length dropped by approximately 3,000 feet by the turn of the century and another 1,000 ft by the middle of the 20th century. These reductions in length most likely contributed to river bed down-cutting (i.e. degradation). Since then, the river has gained approximately 1,500 ft. River stations have varied laterally as much as 3,500 feet.

Figure 10. Rubble Armoring of Right Bank Below Horseshoe Bend

A major realignment (channelization) of the river was constructed downstream of the study reach at Lunken Airport in the 1940's. A 0.75 mi straight channel replaced a 1.5 mile meander in the river. Aerial photos show little change in alignments in the study reach during the 1930's, but in the 1950's meanders begin to lengthen and move, particularly in Reach 4. The lateral movement and gain in length of Little Miami River in the study reach was likely caused by the straightening (loss of length) downstream.

Two measurements that give insight into lateral stability of a stream are belt width and radius of curvature. Belt width is the distance between the outside of consecutive meander bends, measured perpendicular to the down valley axis and radius of curvature is the distance measured from the center of the stream to the intersection of two lines drawn perpendicular to the stream from the bounding inflection points of the bend. Belt widths have ranged from 1,300 to 5,000 feet, with the largest widths having occurred between bends in Reaches 2-4, and radii of curvatures have ranged from 375 (the existing Horseshoe Bend) to over 2,000 feet. Currently, the belt width through the study reach is approximately 4,000 feet with radii of curvature measured to be approximately 375, 740, 860, 1,030, and 2,130 feet. Meander movement through the study reach has been limited by the armoring of portions of the right bank in Reaches 2, 3, and 4. A 1,500 ft segment of right bank immediately downstream of Horseshoe Bend has been armored with concrete rubble (Figure 10). This has stunted meander migration of and compressed the radius of curvature of the Horseshoe Bend. Aerial photography shows bank erosion upstream of the armored portion in Reach 2 and erosion of SBs 9, 10, and 11. Approximate erosion rates ranged from 6.3 to 12.8 ft/yr during the period from 1981 to 2004. These erosion patterns coupled with the existing depositional patterns indicate a down valley migration. From 2004 to present, erosion rates have slowed due to constraints of the meander geometry at Horseshoe Bend imposed by the armored right bank. The river may experience an avulsion, which is a rapid shift in channel pattern, in the short term if the down valley migration continues to be impeded by bank armoring. With the occurrence of an avulsion, the river length will decrease and in turn increase the slope of the river. A steeper slope may cause significant downcutting of the streambed and rapid, large-scale changes in channel shape and pattern immediately downstream.

Side channel sloughs exist in each reach. Reach 1 has a slough/distributary in the right floodplain. This slough/distributary will likely not become the active river channel again due to the existing railroad bridge abutment located upstream. Based on aerial photography, the slough/distributary has not moved laterally for decades. However the slough/distributary length has nearly doubled over the past 70 years and now extends into Reach 2. The slough/distributary receives flows from an unnamed tributary. This slough/distributary flows through a historic river alignment, or meander scroll, before joining the Little Miami River at the Horseshoe Bend.

Historical aerial photographs show various other sloughs which have developed and faded through the study area in past years. The slough at the Clear Creek confluence, within Reach 4, appears to be a result of past channel migration westward. Historical aerial photography shows that this slough is now less frequently accessed by the Little Miami River and is presently filling with sediment and becoming more vegetated; field observations confirm this trend (Figure 11).

Figure 11. View North/Upstream toward Entrance to Clear Creek Slough

Debris and Channel Blockages

Debris and channel blockages are moderate to infrequent throughout the reach. Human influences are evident throughout the reach. Parts of automobiles and watercraft can be seen frequently in the bed, with most objects being floatable and small relative to the channel size (Figure 12a). Refer to Worksheet 5-11 of Appendix F. Several active beaver lodges (Figure 12b) were observed along the river banks, but they likely have little to no influence on the channel processes as they are essentially a part of the bank and do not extend into the channel. In each reach, large, fallen trees are seen frequently along the banks (Figure 12c) and infrequently within the middle one-third of the channel. In general, these fallen trees often cause scour or some bank erosion, but have not had significant impacts to flow patterns. Two tree trunks extending from the outer bank in the Horseshoe Bend (Figure 12d) are affecting flow, as evidenced by local scour of the bank toe.

a. Partial Boat Hull

b. Beaver activity

c. Fallen Trees along Left Bank in Reach 2

d. Buried Trees extending from Bank

Figure 12. Typical Debris and Channel Blockages throughout Study Area

Degree of Channel Incision

The degree of channel incision can often give insight to the sediment supply of the river because an incised river is subject to higher shear stresses on a more frequent occurance. Bank erosion as well as sediment added to the system through bank erosion is proportional to shear stress. Degree of channel incision is determined using the Bank-Height Ratio (BHR), which is determined by the lowest bank height divided by the maximum bankfull depth. The study reach has a BHR of 1.34, a moderately incised channel (Rosgen, 2006).

Degree of Channel Confinement

Channel confinement is determined from the Meander Width Ratio (MWR), which is calculated as belt width divided by the bankfull width. The MWR for the study reach is 11.9, which is high on the range of MWR for a C stream type, indicative of little to no lateral channel confinement.

2.2. Streambank Erosion Analysis

Throughout the study area, eighteen bank sites were chosen for monitoring and assessment based on representative reach characteristics and locations of the proposed clear span bridge crossing locations. On each bank, monuments were installed per Harrleson et al. (1994), and measurements and assessments were performed using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model (Rosgen, 2006) to characterize bank stability. In Phase I, banks were rated using the Bank Erodibility Hazard Index (BEHI) and Near Bank Stress (NBS) evaluations. The BEHI procedure is designed to aide in the prediction of potential erosion levels based on a number of variables including bank height, rooting depth, rooting density, surface protection, bank angle, bank stratification, and soil composition. The NBS procedure evaluates the potential for increased shear stresses in the near bank region. Bank profiles were surveyed during Phases I and II of the study per procedures outlined in Rosgen (2006). At least one control monument was installed at the toe of each bank and two, 6-foot steel pins were inserted in-line with the bank profile and flush to the surface to provide a visual assessment. During Phase I of the study, predictive assessments of erosion rates were made using BEHI and NBS evaluations and erosion rate curves from North Carolina and Colorado. These curves provided a range of values that could be expected based upon the bank assessments in the study area. For Phase II, the predicted rates of erosion were validated.

Reach 1 Banks in Reach 1 are generally steep with frequent mature trees (Figure 1a) producing high rooting depths and moderate rooting densities. SBs 12, 13a, 14, 16, and 17 all exhibited low erosion potential while SBs 13b and 15 exhibited moderate erosion potential. NBS values for Reach 1 were all low with the exception of SB 13a, which was moderate.

Reach 2 SBs 8, 9, 10, and 11 have bare soil faces with low rooting depths and densities coupled with low percentages of surface protection. Frequent bank stratification was observed on many of the banks in Reach 2. These banks have mostly high erosion potential. SB 7 has very high NBS but low erosion potential due to concrete rubble armoring (Figure 10). SB 8 (Figure 13), located on the outer bank of Horseshoe Bend, exhibited very high erosion potential due to low rooting depths and densities, along with poor surface protection and extreme NBS.

Figure 13. Study Bank 8 on the Outside of Horseshoe Bend

Reach 3 The banks in Reach 3 have a high percentage of sand (Figure 14) as well as material stratification. Bank height, rooting depth and rooting density vary throughout the reach. The thalweg of the river is located on the left one-third of the channel, causing the near bank stress on the left banks to be moderate to high. SB 5 had several mature trees nearby with greater than 50 percent of their rootwads hanging over the bank, indicating past erosion along this reach. Overall, this reach exhibits high erosion potential.

Figure 14. High Sand Content in Left Banks of Reach 3

Reach 4 Erosion potential in Reach 4 varies from moderate to extreme. The upper portion of this reach has banks of high sand content with stratification and low rooting depth, while the lower portion has high banks with extremely steep slopes, low root densities and depths, and minimal vegetative coverage and protection. Some banks are stratified with gravel, sand and silt/clay. SB 3, in Reach 4, is located near the exit of the Clear Creek slough, which creates additional impacts due to inundation and flows from multiple directions. SB 2 has a notable absence of riparian buffer. Large slope failures of various mechanisms were observed at SBs 1 and 2 in both phases of the study as shown in Figure 15.

Figure 15. Bank Failure Near Study Bank 2

Overall, bank erosion potential increases in the downstream direction. Further details of bank assessment scoring and measured erosion rates are located and discussed in Section 3.4.

3. Phase II – River Stability Analysis

Throughout 2009, Stantec revisited reaches and collected data from the same field locations as those established for the Phase I study which occurred during the fall of 2008. Additional data were collected from stream gages upstream of the study area as well as other nearby gages to validate analyses of the study reach data. For clarity, reach and sample location nomenclature were established during Phase I data collection and maintained throughout Phase II collection and analysis. The following sections present the analyses and findings of Phase II based on the data collected and compared in both Phase I and II of the study.

3.1. Flow Characterization

3.1.1. General Flow Comparison

Flow characteristics of the 2009 water year were examined for comparison to typical conditions of the Little Miami River for normalization purposes. The study section experienced several significant flow events during 2009 with ten events recording peaks greater than 5,000 cfs. However, the mean annual discharge for 2009 was lower than the majority of mean annual discharges since 1975, indicating a drier than normal water year for the study period. Table 2 provides examples of large events that occurred between Phase I and II data collection events.

Table 2. Significant Flow Events During 2009 Water Year

Date	Flow (cfs)
December 24, 2008	8,000
February 8, 2009	9,830
June 26, 2009	17,950
July 31, 2009	11,460
August 4, 2009	19,080

3.1.2. Bankfull Flow

To estimate bankfull flow during Phase I, a prediction method was used to calculate an estimate of bankfull mean velocity. The bankfull mean velocity was then used to obtain the bankfull flow via the continuity equation. Cross-section R4_XS1, which is representative of the overall study section, in addition to particle size data from the pebble count at this location, was used to compute the mean bankfull velocity.

$$u = (1.4865)(R^{2/3})(S^{1/2}) / n$$

Where: u = velocity
R = Hydraulic Radius
S = Hydraulic Slope
n = Manning's "n"

Bankfull velocity was estimated to be 6.0 ft/s, and the bankfull discharge was estimated to be 17,300 cfs (See Worksheet 5-2 of Appendix F). This flow value was validated during a site visit on June 26, 2009; the water stage matched the bankfull indicator at the Horseshoe Bend.

During Phase II analysis, USGS stream gage station data were used in conjunction with morphological field data at the gage station sites to verify the bankfull flow for the study reach. Two U.S. Geological Survey stream gages were used for flow analysis purposes; one gage was on East Fork of Little Miami River (032547500) and the other was on Little Miami River near Milford (03245500), upstream of the confluence with East Fork (See Appendix A – 2 for Gage Site Location Map). The summary sheets for the USGS gage station analysis are Worksheets 5-1 of Appendix F. The gage data, when viewed as a combined flood frequency curve for the study reach, provided validation that the bankfull discharge of the study reach is approximately 17,300 cfs, which corresponds to about a 1.2 year return period for the river. Review of Table 2 above revealed that the study reach received two flow events during the period between Phase I and II that were equal to or greater than bankfull flow.

3.2. Watershed Influences

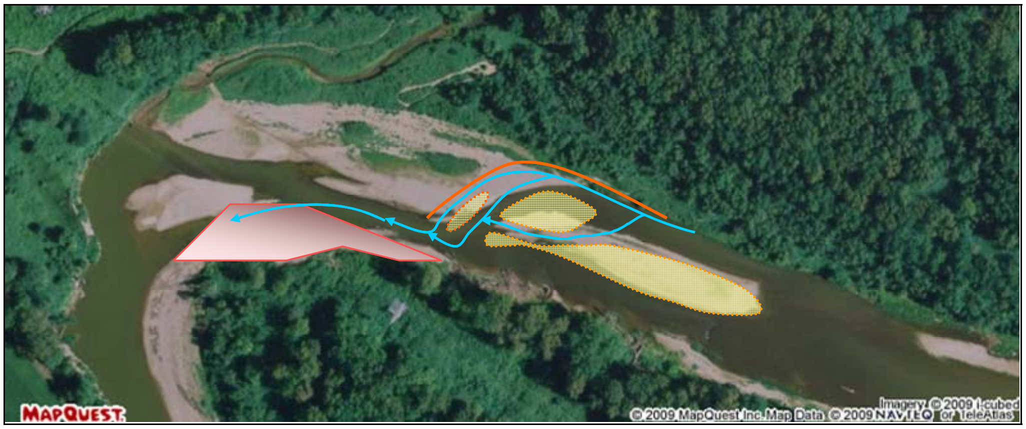
No major changes were observed in the adjacent areas of the watershed surrounding the study reach. Floodplain land use as well as the riparian width and composition essentially remained unchanged during both phases of the study. One exception was the presence of new fallen trees within the bankfull channel during Phase II, while other fallen trees noted within the channel during Phase I were absent. The two large, submerged logs extending from the outer bank of Horseshoe Bend were still present, although bank erosion has further exposed the logs. Overall, the level of debris observed in the channel was similar between study phases, most of which consisted of small floatable material. See Worksheets 5-11 and 5-15 in Appendix F for a qualitative description of influences and characteristics.

3.3. Channel Data Analyses and Results

Within this section, each Reach is discussed with note of specific characteristics and surveyed features influencing channel morphology. Refer to the Detailed Site Map in Appendix A for a view of sample and survey locations in each Reach.

Reach 1 Very little morphological change was observed in Reach 1. During the study period, flood-flow monitoring frequently revealed flow through the slough of Reach 1, indicating its hydraulic connectivity at flows less than bankfull. Although very active, no changes in depositional or flow patterns were observed in conjunction with the slough during the study. Comparisons of cross section surveys during Phase I and Phase II for Reach 1 indicate no change in deposition or scour features (Appendix B). Similarly, scour chains installed in cross sections R1_XS2 and R1_XS3 showed no change in bed elevation (Appendix F). Bulk material samples (Bulk Sample 1, Appendix C) taken from a depositional feature at the first riffle upstream from the study reach show a coarsening of material over the study period, while the general distributions of sand and gravel remained similar. Particle sizes from the bulk sample taken at the side bar (Bulk Sample 2) near the slough entrance indicated no significant difference between study phases. Pebble counts indicated slightly smaller bed surface materials. Sediment data is located in Appendix C.

Reach 2 Several changes occurred in Reach 2. Cross section R2_XS1, located in the riffle and through the head of the gravel island above Horseshoe Bend, indicates slight deposition of the left alignment and slight scour of the right alignment. Scour chains reevaluated in Phase II indicated the same results. Scour chain results may be viewed in Appendix F. Further analysis of the reach profile revealed no overall aggradation or degradation of the river profile at the riffle. Pebble counts collected through the section were very similar between study phases, with only a very slight shift to coarser material in 2009. During the study period, significant depositional processes have been observed at the downstream end of the riffle/island complex. Additional mid-channel bar features were created in the northern/downstream path of the river. These features formed as a result of the river eroding away and cutting through the right bank and lower end of the existing gravel island and then depositing the material downstream (Figure 16). Depositional features/patterns were observed during the study period and documented on Worksheet 5-10 in Appendix F. The new channel configuration directs flow towards the left bank and inside of the point bar at Horseshoe Bend. This flow pattern increases local near-bank stress and susceptibility to erosion, which corresponds with field observations of erosion along the inside of Horseshoe Bend and data from cross section R2_XS2.



a. Reach 2 depositional changes.

b. Upstream view toward riffle/island complex.

c. Eroded section of gravel island.

Figure 16. Reach 2 Depositional Changes

Cross section R2_XS2 shows considerable scour on the inside of Horseshoe Bend with some deposition in the pool on the outside of the bend. The deposition may be due in part to bank material falling into the river. Analysis of bar material on the upstream third of the point bar (just above R2_XS2) shows a shift in size distribution, while the D_{50} remained essentially the same around 26 mm (Bulk Sample 3). Downstream of the bend, bar sediment samples (Bulk Sample 4) indicate particles became more coarse, which concurs with the continued scour/erosion of the point bar seen in cross section R2_XS3. Erosion at this section is aggravated by the tight radius as well as the armoring of the right bank. The rigid armoring transfers the river's forces, generated by the tight bend, immediately downward to the bed, causing deep scour pools at the toe of the outer bank. The toe of the outside bank continues to erode and mass failures of the bank occurs in immediate locations where the armoring is absent. Field observation also noted considerable erosion of the downstream one-third of the point bar, which is immediately downstream of R2_XS3.

All of the above mentioned data regarding Reach 2 as well as the historical maps of the study reach reveal that Reach 2 of the river has been in a state of lateral instability for decades.

Reach 3 Reach 3 exhibited minor changes in channel form and composition. Cross section R3_XS1, located immediately upstream of the gravel bar on the right bank in Reach 3, shows deposition on the right side of the channel. This material is likely that which was removed from the point bar upstream in Reach 2. Cross section R3_XS2 through the gravel bar shows relatively no change at all. Pebble counts collected in this section suggest that the bed material is becoming coarser. This is confirmed by analyses of bulk samples taken in both phases from the gravel bar near this section (Bulk Sample 5). The next section downstream, R3_XS3, shows considerable deposition on the right one-third of the channel along the diagonal bar which connects the gravel bars in Reach 3 and 4. Pebble counts at this section indicate a notable shift to finer material. The scour chain located on the left one-third of R3_XS3 showed no change in bed elevation, while the chain on the right was buried by more than 0.5 foot, further validating the deposition. Deposition in the right one-third of the channel on both the upstream and downstream ends of the bar signifies a lengthening of the bar and may foreshadow a shift to a point bar feature.

Reach 4 The upper portion of Reach 4 showed little change throughout the study period. Evidence of flow through the Clear Creek slough was apparent, but no significant changes were noted within the slough or at its entrance and exit. Some local scouring of the bed was noted at cross section R4_XS1 as well as on the profile in that location, in part due to scour affects from a large log partially embedded in the channel bottom. The log is oriented at a slight angle with the direction of flow, having its lower end closer to the left bank. This configuration facilitates scour at the downstream base of the log. The local scour in the middle of the channel is primarily a result of the log, but some sour was also noted on the left, or upstream, side of the log. The local river invert and overall river grade were maintained through a bed feature immediately downstream of the partially embedded log. The scour chain on river left was exposed 0.35 feet. The river right scour chain showed no change in bed elevation. Pebble counts at the riffle adjacent to the Clear Creek slough indicate an overall shift to coarser surface material through the riffle; however, bulk samples taken at the side bar (Bulk Sample 7) and pavement/subpavement samples taken from the river bed (Bulk Sample 6) show a shift to finer subsurface material.

The lower portion of Reach 4 does not exhibit notable changes in channel form. Cross section R4_XS2 is located through the upper third of the point bar as the river turns right and leaves the study area. This section shows some minor deposition along the outer edge of the point bar. Bulk samples taken at the middle (Bulk Sample 8) and lower (Bulk Sample 9) longitudinal thirds of the same point bar indicate a significant shift to coarser material.

3.4. Streambank Erosion Analysis

Each SB was revisited in Phase II of the study. Detailed bank profile surveys were conducted, along with measurements of bank pins. Average lateral erosion rates were calculated for each bank, in feet per year, by dividing the eroded area by the height of the bank. A reach-wide map of all the banks and measured erosion rates is presented as Drawing E-1 in addition to illustrations of each bank with detailed data forms in Appendix E.

Reach 1 Little change was observed on Reach 1 banks. Bank pins generally remained flush with the surface or were slightly buried. Maximum exposure was 0.25 feet, and only two pins exceeded 0.2 feet of exposure. The greater average lateral erosion rates were located at SBs 16 and 17, which are within the downstream zone of influence of the railroad bridge.

Reach 2 Erosion at SBs 11, 10, and 9 increased with proximity to Horseshoe Bend, ranging from 0.12 to 0.15 ft/yr, respectively. SB 8, which is on the outside bank of Horseshoe Bend, exhibited very high erosion potential according to the BEHI and NBS evaluations of Phase I. Data from Phase II shows that the lower portion of SB 8 experienced several feet of lateral erosion (See Figure 17), while the upper portion remained relatively unchanged. The average erosion rate for this bank was 1.34 feet. This erosion was observed frequently along the bank. As described in Section 3.2, the submerged logs extending from the bank were notably more exposed during Phase II data collection. Large bank slumps were also noted just downstream of SB 8, below the sewer outfall. This portion of bank is located in a small "pocket" on the outside of the bend, making it susceptible to eddy scour. It is also in the path of the modified flow line which comes across the inner portion of the bend, as illustrated in Figure 16a.

Figure 17. Erosion at Study Bank 8

Reach 3 Analysis of SBs 5 and 6 on the left bank of Reach 3 validated predictive assessments. These banks produced average lateral erosion rates of approximately 0.5 ft/yr, with local exposure exceeding 0.75 feet (See Appendix E). The extremely high sand content of SB 6 will most likely lead to continued erosion along this bank.

Reach 4 Reach 4 had the highest erosion rates with a minimum average lateral erosion rate of 0.5 ft/yr (SB 4) and a maximum of 2.26 ft/yr (SB 1). SBs 1, 2 and 3 each had a bank pin exposed greater than 1.5 feet (Figure 18), with the upper pin at SB 1 exposed 3.2 feet.

Figure 18. Study Bank 2 Upper Bankpin Exposure

Table 3 contains BEHI/NBS ratings and measured erosion rates for each SB. Phase I of the study involved an erosion prediction using BEHI/NBS ratings as shown on the table below. In Phase II of the study, actual erosion rates were measured for the year and recorded and are also shown in the table. The prediction methods were based upon curves developed in North Carolina and Colorado. While the curves were not expected to predict the actual values, the two curves were expected to provide a range that the Little Miami River site would fall within as well as provide a close average for specific areas. After collection of the Phase II data and viewing the results, the curves provided validation and confidence in quality of the actual measured values. Detailed descriptions and a map of all banks are located in Appendix E.

Table 3. Bank Erodibility Factors

Study Bank	BEHI	NBS	Average Lateral Erosion Rate (ft/yr) Prediction from data in: Colorado	N. Carolina	Measured
Reach 1					
17	Moderate	Low	0.24	0.04	0.18
16	Moderate	Low	0.25	0.04	0.20
15	High	Low	0.38	0.14	0.07
14	Moderate	Low	0.25	0.04	0.01
13b	High	Low	0.34	0.14	0.07
13a	Moderate	Moderate	0.27	0.05	0.00
12	Low	Low	0.07	0.00	0.00
Weighted Average					**0.06**

Table 3. Bank Erodibility Factors

Study Bank	BEHI	NBS	Average Lateral Erosion Rate (ft/yr)		
			Prediction from data in:		Measured
			Colorado	N. Carolina	
Reach 2					
11	High	Moderate	0.42	0.18	0.12
10	High	Low	0.31	0.12	0.13
9	High	Low	0.27	0.11	0.15
8	Very High	Extreme	1.32	1.30	1.32
7	Low	Very High	0.00	0.00	0.00
Weighted Average					**0.20**
Reach 3					
6	High	High	0.61	0.20	0.50
5	High	Moderate	0.46	0.20	0.48
Weighted Average					**0.49**
Reach 4					
4	High	Low	0.37	0.14	0.53
3	High	Low	0.37	0.14	1.12
2	Extreme	Low	0.81	2.10	1.34
1	Very High	Moderate	0.50	0.80	2.26
Weighted Average					**1.29**

As predicted by ratings from Phase I bank erosion analysis, erosion rates increased with distance downstream.

4. Summary and Conclusions

Geomorphic study of the Little Miami River is a part of planning for Segment II/III of the Eastern Corridor Projects. Geomorphic assessment of a 2.5 mile section of the river, including four reaches (potential clear-span bridge crossing locations) was completed by Stantec. Phase I of the geomorphic study included the collection and analyses of existing, historical and field data as well as classification and characterization of the physical stability of the river, insight into the dominant processes influencing channel morphology, and development of a baseline trend analysis for Phase II of the study. Phase II included characterization of the river flows during the study period, collection and analyses of data for comparison to Phase I, and results interpretation and recommendation development for an optimal clear-span bridge location along this specific reach of the Little Miami River.

4.1. Characterization

Dimension, pattern and profile data indicated the Little Miami River is a C4c- river type according to the Rosgen classification system of natural streams (Rosgen, 1996). The river has irregular, tortuous and confined meander patterns with a high MWR. It is slightly entrenched with a moderate degree of channel incision. The channel has a flat slope

(0.00058 feet/feet) with riffle, run, pool, and glide bed features. Bankfull channel dimensions include mean width and depth of 336 and 8.3 feet, respectively. Substrate analysis produced a reach median bed material, or D_{50}, of 10 mm.

The various sloughs throughout the study reach, very low river slope, split flow patterns through several riffles, high width to depth ratios and numerous mid-channel bars provide evidence of a potential future channel evolution from a C4 to a D4 stream type. The current conditions of Little Miami River in the study reach, specifically in the lower reaches, tend toward instability as a high width to depth C stream type. The river system may become more unstable before it begins to return to a more stable state. However, with the current watershed constraints and conditions, stream type C4c- with proper plan form and riparian vegetation can be an appropriate and sustainable stream type over the design life of the proposed bridge.

4.2. Broad Level Stability Factors

Historical aerial photography analysis shows significant meander movement and depositional processes in Reaches 2, 3, and 4 over the past 140 years. Recent geomorphic activity in the past 30 years shows significant channel and depositional pattern shifts in Reach 2. The Horseshoe Bend shows characteristics of active deposition, erosion on the outer banks and down valley channel migration.

Measured erosion rates show increasing erosion on banks from upstream to downstream. From the Horseshoe Bend to the bend in Reach 4, banks exhibit high, very high and extreme bank erosion potential with measured values of bank erosion rates averaging 0.9 feet of bank per year.

Past reach length reductions, lateral meander and channel confinement, and changes to the watershed hydrology often contribute to river instability. The construction of the Caesar Creek and East Fork Dams altered the hydrology and sediment supply of Little Miami River by lowering the peak flows of the river system and likely reducing the sediment supply. A reduced sediment supply from upstream coupled with likely, low sediment in urban runoff would cause a system to begin to erode the banks and/or bed. If the energy in the river system at certain flows was not met by the existing sediment supply, the river would act upon its boundaries to dissipate that energy and essentially gain more sediment supply, contributing to river instability.

A reduction in river length, caused by human channel maintenance, channelization, or a natural river avulsion, at the turn of the 20th century likely led to increased channel shear stresses, bed and bank erosion, degradation, and channel incision. Channel incision often results in a lower water table next to the river, limiting vegetation density and variability, which is evident in portions of each reach of the study area. Lateral confinement which truncates meanders, can also lead to higher shear stresses, higher bank instability and erosion as well as increased sediment supply.

Caesar Creek and East Fork Dams construction caused a shift in bankfull discharge magnitude, duration, and frequency. This shift in the hydrology coupled with low sediment supply, reductions in reach length and increased lateral confinement likely caused some degree of degradation and a great degree of lateral erosion/migration. Field surveys and observations, in the riffle upstream of the Horseshoe Bend, in the past year showed changes in scour and depositional patterns; however, an overall raising or lowering of the river profile was not observed. As mentioned above, the dams likely reduced downstream sediment loadings, which resulted in accelerated bank erosion and lateral movement.

Little Miami River has maintained C river type characteristics for a long period of time as seen in the historical aerial photography. However, the various changes mentioned and overall instability is causing the river to exhibit some characteristics of an unstable river type in a Valley Type VIII. Currently, Little Miami River has a very high width-to-depth ratio and a very low slope for a C stream type. The river system may become more unstable before it begins to return to a more stable form.

4.3. Reach Specific Stability

The following sections provide detailed assessments of observed processes and data analyses on each reach within the study area.

Reach 1 Historic mapping and aerial photography show virtually no change in pattern through Reach 1 for over 100 years. Cross-section geometry, sediment data, and bank analyses provided no significant indication of change through the reach. The continual growth and maturity of trees and other vegetation along the reach has reinforced the banks, aiding in the lateral stability of Reach 1. The relative proximity of the reach to the valley wall, the construction of the railroad running parallel to the river, and the installation of the railroad bridge abutments at the top of the reach have aided in keeping the alignment in place in the past and should continue to facilitate lateral stability in the future. No indication of lateral or vertical movement was observed during the study. However, the current channel incision and terraces that are present throughout the reach indicate that the bed has most likely lowered in the past. Further incision has likely been slowed by the presence of the slough/distributary and low-profile island. These features increase the width and decrease the average depth of high flows, preventing higher shear stresses within the main channel that could cause adverse effects. Based on historical aerial photographs and the low measured rates of bank and bed erosion, it is anticipated that the Reach 1 alignment will remain stable for the expected life of the clear span bridge, provided any channel movement in Reach 2 is not drastic enough to substantially affect Reach 1.

Reach 2 Reach 2 has a history of lateral migration and avulsion, and is the most active of the four reaches (within the overall study reach) with regard to lateral movement in recent years. Since 1959, the entrance to Horseshoe Bend has migrated downstream by approximately 500 feet. However, downstream of the bend at cross section R3_XS1, the banks have moved less than half that distance. From 1990 to present, the entrance to the bend has migrated 275 feet while the exit has moved less than 50 feet. The most recent bend configuration began around 1980, closely following the construction of the Harsha Dam on the East Fork. From 1981 to 2000 the bend extended outward roughly 200 feet, which equals around 10 feet/year. The armoring on the downstream banks of the bend prevented any further migration outward or downstream; however, the river alignment above the bend continued to move downstream, reducing the radius of the bend. These are all indicators of a significant channel movement and potentially a future avulsion. Since 2004, banks in the Horseshoe Bend area have not experienced significant movement. Data and observations presented in Section 3, however, indicate that these processes are still causing change along the river. The outside of the bend continues to erode as evidenced by the loss of over 2 feet of bank at the toe, and the active reconfiguration of the flow around the gravel island upstream. It appears to be removing the point bar at the inside of the bend, exposing even more length of bank around the outside of the bend. Depositional activity remains significant as indicated by the changes in the gravel bars in the bend and upstream of the bend. In the past, significant depositional activity has signified rapid channel movement. Reach 2 is expected to have significant channel movement or possibly an avulsion within the design life of the clear span bridge, which is estimated to be 80 years. Possible avulsion paths are illustrated in Figure 19.

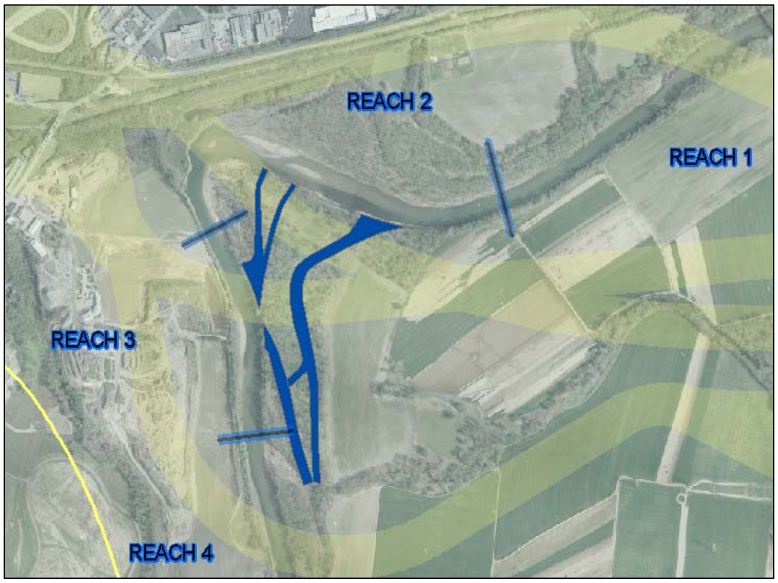


Figure 19. Possible Avulsion Locations Originating in Reach 2

Reach 3 Minimal pattern adjustment has been observed in Reach 3. This is due to the armored banks at the upper portion of the reach and retardation of movement in Reach 2, as well as sections of adjacent, low floodplains that allow the dispersion of flood flows and energy dissipation. Floodplain configuration within the landfill has facilitated storage of large amounts of water.

On the other hand, some indications of pattern adjustment were observed during the study. Deposition on the upstream and downstream ends of the existing gravel bar as well as erosion on the opposing left bank may signify the formation of a more prominent bend and point bar at this location. SBs 5 and 6 in this reach continue to possess the same high erosion potential which produced average lateral erosion rates of 0.5 ft/yr. While Reach 3 has remained stable for a significant time, it is completely dependent upon Reach 2. When Reach 2 finally compensates for its current instability, it will have a major affect on the pattern and stability of Reach 3.

Reach 4 Reach 4 has remained in the same general form for the last 40 years, but has migrated in location. The bend was originally located where the current Clear Creek slough is now located. This bend and the bend downstream from it have gradually migrated downstream to their current positions in the past 40 years. SBs 1 and 2, located on the downstream outer banks of the bend, produced the highest erosion throughout the entire study area. This demonstrates that the bend is still actively migrating downstream. Channel movement through Reach 4 would likely be more rapid if the channel had free movement upstream in Reach 2. It is expected that the bend in Reach 4 will continue to migrate, particularly when Reach 2 makes a significant change.

5. Recommendations

5.1. Bridge Placement and Spans

Of the four reaches, Reach 1 exhibits the most favorable geomorphic stability characteristics for a clear-span bridge crossing. Reach 1 had the lowest overall erosion rate of the four river reaches. Historical aerial photography indicates this reach has had little channel movement in the past 100 years. The armored right bank upstream of the railroad bridge has constricted channel movement upstream of the bridge while the bridge, its abutments, and piers appear to have limited channel movement downstream. The age and relative stability of the railroad bridge also points to a desirable clear-span crossing location. A crossing in Reach 1 would likely require the shortest clear span distance of the four alternatives. In Reach 1, to construct a bridge upstream of the slough that does not have a pier within the ordinary high water marks of Little Miami River, the recommended clear span distance is approximately 350 feet. In order to construct a bridge (upstream of the slough) with piers that stay out of the expected meander pattern of Little Miami River, the recommended clear span distance is approximately 415 feet. While Reach 1 has the most preferable geomorphic characteristics for a clear-span bridge crossing, the potential exists for the erosion rates and dynamic changes in the Horseshoe Bend area to impact the upstream alignment if the channel bed degrades due to an advancing headcut associated with the potential river avulsion.

Reach 2 crossing exhibits the least favorable geomorphic characteristics for a clear-span bridge crossing. Reach 2 has experienced the most channel movement in the past and the Horseshoe Bend is in the process of progressing through a down valley migration. The upstream left river banks and the outside of the Horseshoe Bend experienced significant erosion. These banks continue to exhibit high BEHI ratings, and the NBS ratings at Horseshoe Bend continue to be extreme due to a continuously shrinking radius of curvature to width ratio. Significant changes in deposition and scour are occurring upstream of the bend and at the point bar, which further exhibits instability.

It is anticipated that the Horseshoe Bend will experience a river avulsion or significant down-valley migration during the design life of the clear span bridge. Erosion rates are closely tied to the frequency and magnitude of flood events on the Little Miami River, which adds uncertainty to the complex analyses in determining river avulsion time frames. Of the four reaches, Reach 2 is the most unstable. A clear-span bridge crossing is not recommended for placement in Reach 2.

Reaches 3 and 4 have shown less channel migration than Reach 2 in the recent past, but both have seen historical meander movement; Reach 4 has historically moved more than Reach 3. Reach 3 shows channel stability based on historical aerial photography. However, because the Horseshoe Bend is likely to migrate down valley, or worse, experience an avulsion, Reach 3 is a less preferable location for a clear-span bridge crossing than Reach 1. Lower flooding zones on both sides of the river and Clear Creek would require a longer bridge span through Reaches 3 and 4.

Stantec's recommendation for the second most preferable clear-span bridge crossing alternative location is near the border between Reaches 3 and 4, upstream of the Clear Creek – Little Miami River confluence. This crossing location appears to be far enough downstream of the Horseshoe Bend for the possible effects of the potential avulsion or down-valley migration to be minimized. This crossing location should also be far enough upstream of the unstable and eroding meander bend associated with SBs 1 and 2. However, siting a potential clear span bridge crossing at this location does have design implications as the span and potential roadway embankment would need to be long enough to accommodate Clear Creek, its slough, and low-lying floodplains at the landfill. At this location, to construct a bridge that does not have a pier within the ordinary high water marks of the existing Little Miami River, the recommended clear span distance is approximately 320 feet. In order to construct a bridge with piers that stay out of the expected meander pattern of Little Miami River as well as any potential avulsion locations, the recommended clear span distance is approximately 970 feet.

Potential Restoration Opportunities

Stantec identified restoration opportunities along the Little Miami River during field reconnaissance visits throughout the study.

Riparian Corridor Enhancement and Bank Stabilization

Several sections of the riparian corridor along the river could be enhanced. The left river bank upstream of the Horseshoe Bend (SBs 9, 10, and 11) and the left river bank in Reach 4 (SBs 1 and 2) would benefit most from riparian reforestation and bank stabilization. The stabilization of SBs 9, 10, and 11 will not prevent the avulsion, but should be done in conjunction with channel realignment. The stabilization of SBs 1 and 2 could enhance the overall stability of Reach 4.

Sewer Outfall Repair

The sewer outfall on the right bank just downstream of the Horseshoe Bend needs repair. The gabion baskets are failing, and the concrete outfall channel is degraded. The gabion baskets and concrete channel should be removed and the outfall should be relocated. If left unattended the outfall could be significantly damaged.

Clear Creek

Clear Creek joins the Little Miami River in Reach 4 and is a degraded stream. Long segments of the stream have been channelized in conjunction with adjacent agricultural land uses. The stream is over-widened and entrenched. Stantec also observed significant and excessive algae blooms in Clear Creek, possibly from fertilizer application practices in the adjacent agricultural land use. Clear Creek would benefit from a Priority 1 or 2, full scale stream restoration. This restoration would benefit not only the stability of Clear Creek, but also the slough in Reach 4.

6. References

D.L. Rosgen, 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.

D.L. Rosgen, 2006. *Watershed Assessment of River Stability and Sediment Supply (WARSSS)*. Wildland Hydrology, Fort Collins, CO.

Dunne, T., and L.B. Leopold, 1978. *Water in Environmental Planning*. W.H. Freeman and Company, San Francisco, CA.

Harrelson, Cheryl.C.; Rawlins, C.L.; Potyondy, John P. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. Gen. Tech. Rep. RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.

Harstine, L.J., 1991. *Hydrologic Atlas for Ohio*. Ohio Department of Natural Resources, Division of Water, Water Inventory Report No. 28.

Leopold, Luna B., 1994. *A View of the River*. Harvard University Press, 290p.

Mapquest, Aerial of Horseshoe Bend, Retrieved November 18, 2009, from http://www.mapquest.com/mq/6-_WXJNvoPATr2BJqA.

Ohio Division of Geological Survey, 1998, Physiographic regions of Ohio: Ohio Department of Natural Resources, Division of Geological Survey, page-size map with text, 2 p.,scale 1:2,100,00

Schiefer, M.C. 2002. Basin Descriptions and Flow Characteristics of Ohio Streams, Ohio Department of Natural Resources – Division of Water, Bulletin 47. Columbus, Ohio.

Sherwood, James M., and Huitger, C.A., 2005. Bankfull Characteristics of Ohio Streams and Their Relation to Peak Streamflows: U.S. Geological Survey Scientific Investigations Report 2005-5153, 38 p.

The Wild and Scenic Rivers Act (16 U.S.C. 1271-1287), Public Law 90-542, Passed October 2, 1968. Available at: http://www.rivers.gov/publications/act/complete-act.pdf.

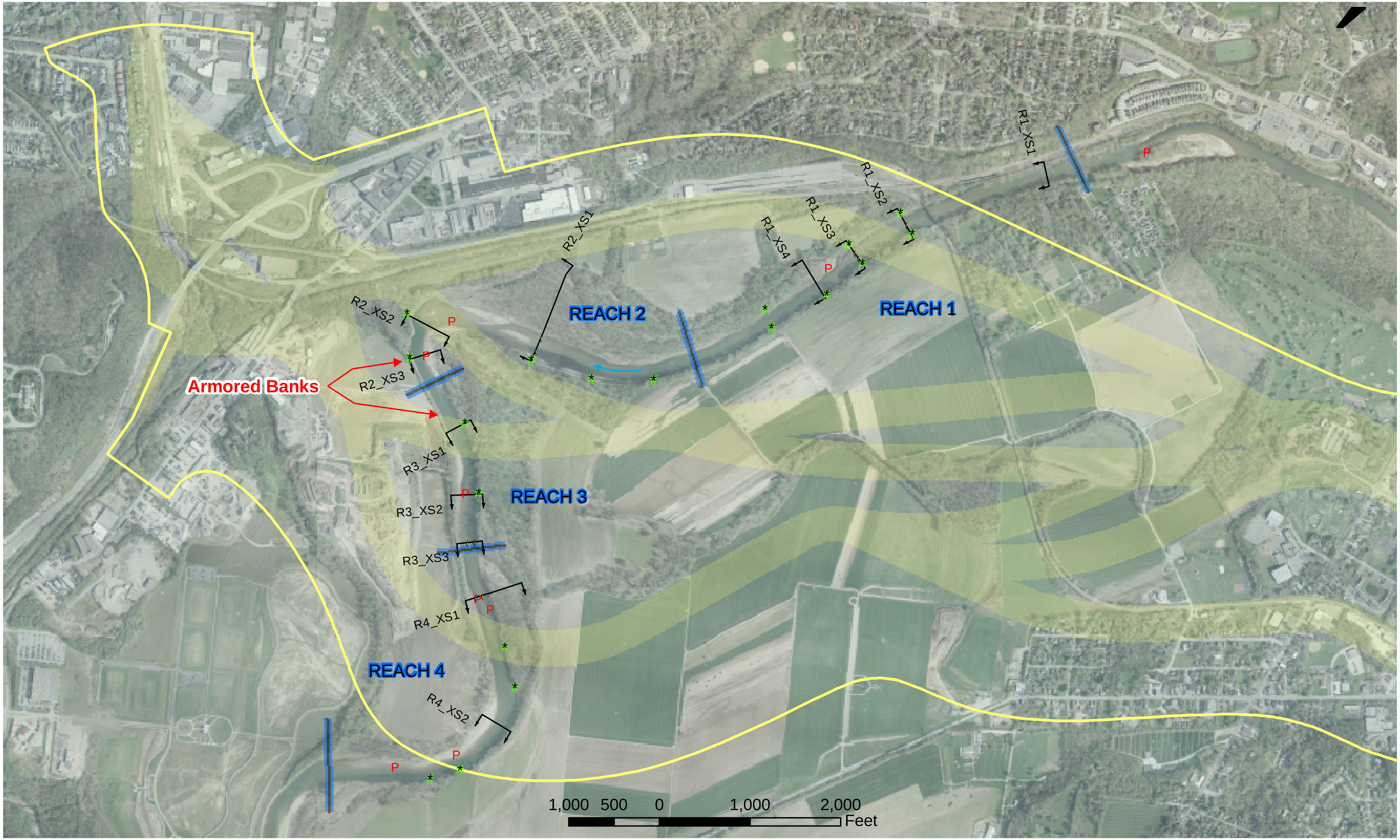
USGS StreamStats. Available at: http://water.usgs.gov/osw/streamstats/ohio.html. As described in: Ries, K.G., Guthrie, J.D., Rea, A.H., Steeves, P.A., and D.W. Stewart, 2008. *StreamStats*: A Water Resources Web Application. U.S. Geological Survey Fact Sheet 2008-3067.

USGS, 1997. National Water Quality Assessment Program: Great and Little Miami River Basins. Fact Sheet (FS-117-97), August 1997.

Appendix A

Detailed Location Maps

- Detailed Site Drawing A-1
- Gage Site Locations Map A-2



Legend

Study Area | Segment II/III Alternatives | Scour Chains | Study Banks | Sieve Analyses | Cross Sections

STANTEC CONSULTING SERVICES INC.
11687 Lebanon Rd.
Cincinnati, Ohio
45241-2012
513-842-8200

Stantec

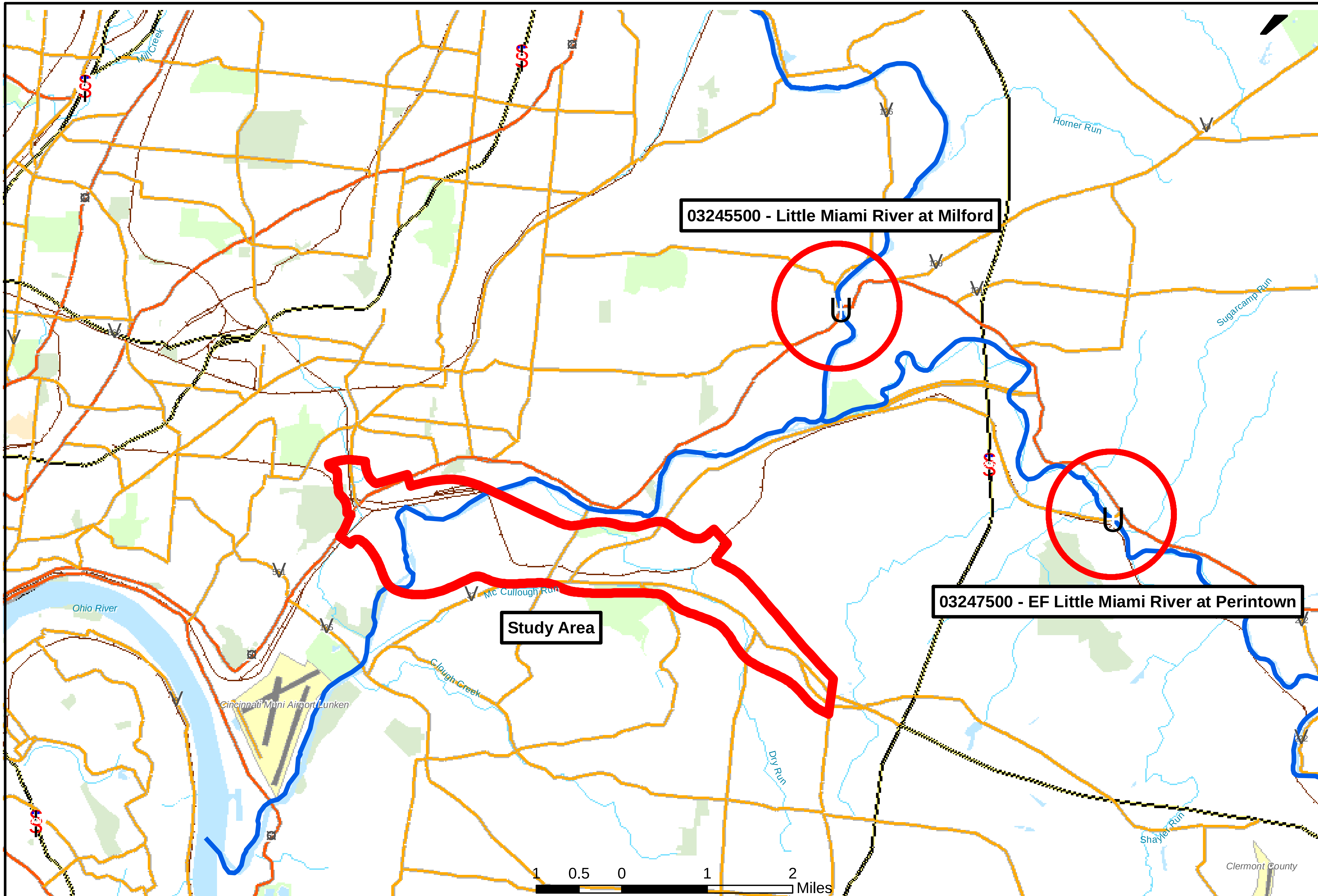
Appendix A - Detailed Site Drawing

Entran
Little Miami River Riparian Crossings Analyses
Eastern Corridor Priority Part B - Segment II/III
Hamilton and Clermont Counties Ohio

PROJECT NO.	174438122
DATE	November, 2009
DRAWN BY	TJT
CHECKED BY	WHL
CHECKED BY	SDP
SCALE	1" = 1000'
REVISED	
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

SHEET

A - 1



STANTEC
CONSULTING
SERVICES INC.
11687 Lebanon Rd.
Cincinnati, Ohio
45241-2012
513-842-8200

Stantec

Appendix A - Gage Station Locations

Entran
Little Miami River Riparian Crossings Analyses
Eastern Corridor Priority Part B - Segment II/III
Hamilton and Clermont Counties Ohio

PROJECT NO.	174438122
DATE	November, 2009
DRAWN BY	TJT
CHECKED BY	WHL
CHECKED BY	SDP
SCALE	1" = 1 mi
REVISED	
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

SHEET

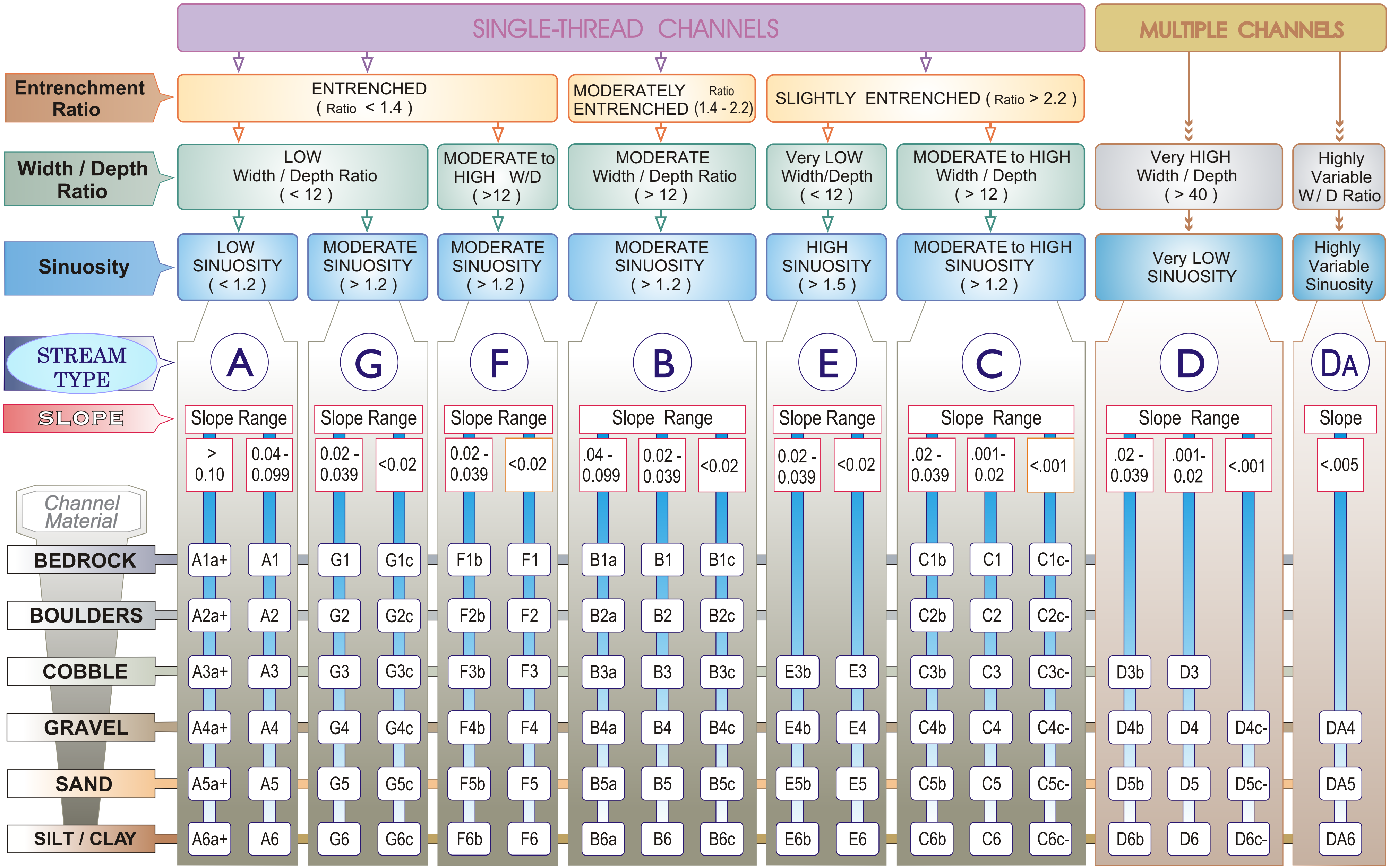
A - 2

Appendix B

Morphological Data

- Classification Form
- Longitudinal Profile
- Cross Sections

The Key to the Rosgen Classification of Natural Rivers



KEY to the *ROSGEN* CLASSIFICATION of NATURAL RIVERS. As a function of the "*continuum of physical variables*" within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

Wildland Hydrology 1481 Stevens Lake Road Pagosa Springs, CO 81147 (970) 731-6100 e-mail: wildlandhydrology@pagosa.net

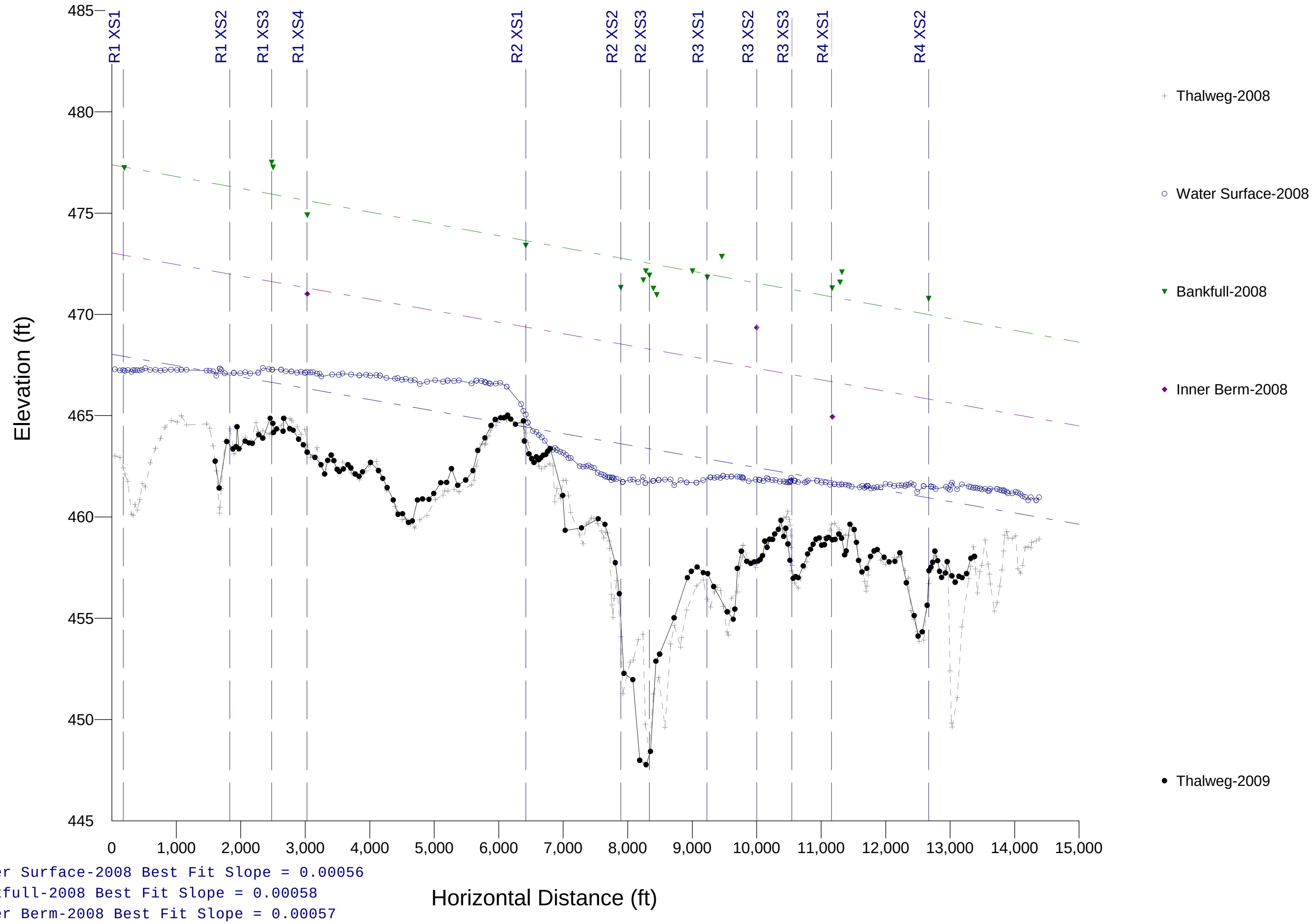
Worksheet 5-3. Field form for Level II stream classification (Rosgen, 1996; Rosgen and Silvey, 2005).

Stream:	**Little Miami River**				
Basin:	**Little Miami River**	Drainage Area:	**1,107,200** acres	**1730**	mi^2
Location:	**RM 4.5 - 7.0, EC Segment II/III**			Date:	**Fall 08**
Observers:	**SDP, TJT**			Valley Type:	**VIII**

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**336**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**8.3**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**2785.4**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**40.4**	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.	**11.6**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or ($2 \times d_{mbkf}$) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**4300**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**12.8**	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.	**10**	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.	**0.00058**	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).	**1.36**	

Stream Type **C 4c-** (See **Figure 2-14**)

Little Miami River Segment II/III - Longitudinal Profile

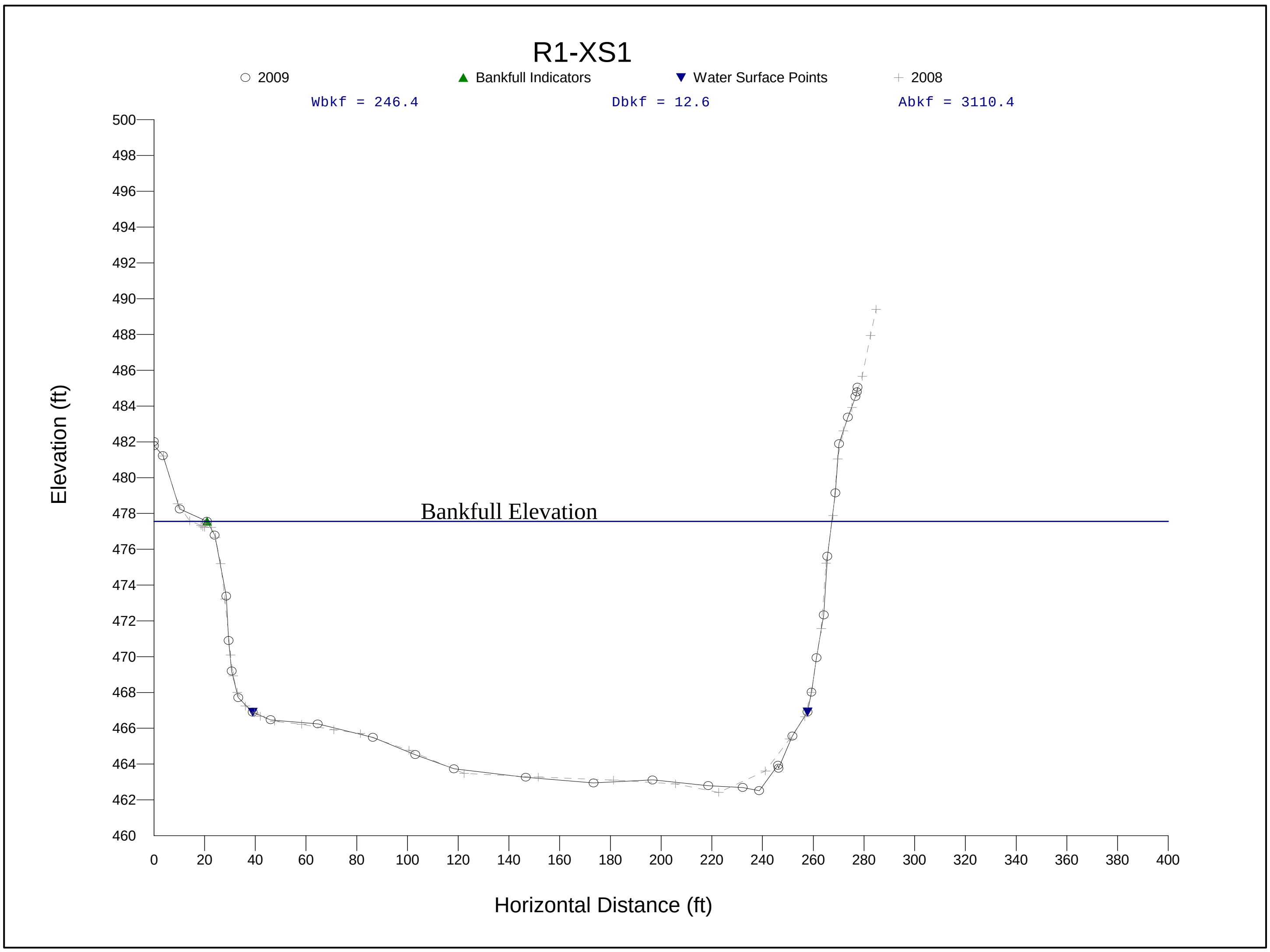


Water Surface-2008 Best Fit Slope = 0.00056
Bankfull-2008 Best Fit Slope = 0.00058
Inner Berm-2008 Best Fit Slope = 0.00057

RIVERMORPH CROSS SECTION SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R1-XS1
Survey Dates: 10/16/2008 & 9/10/2009

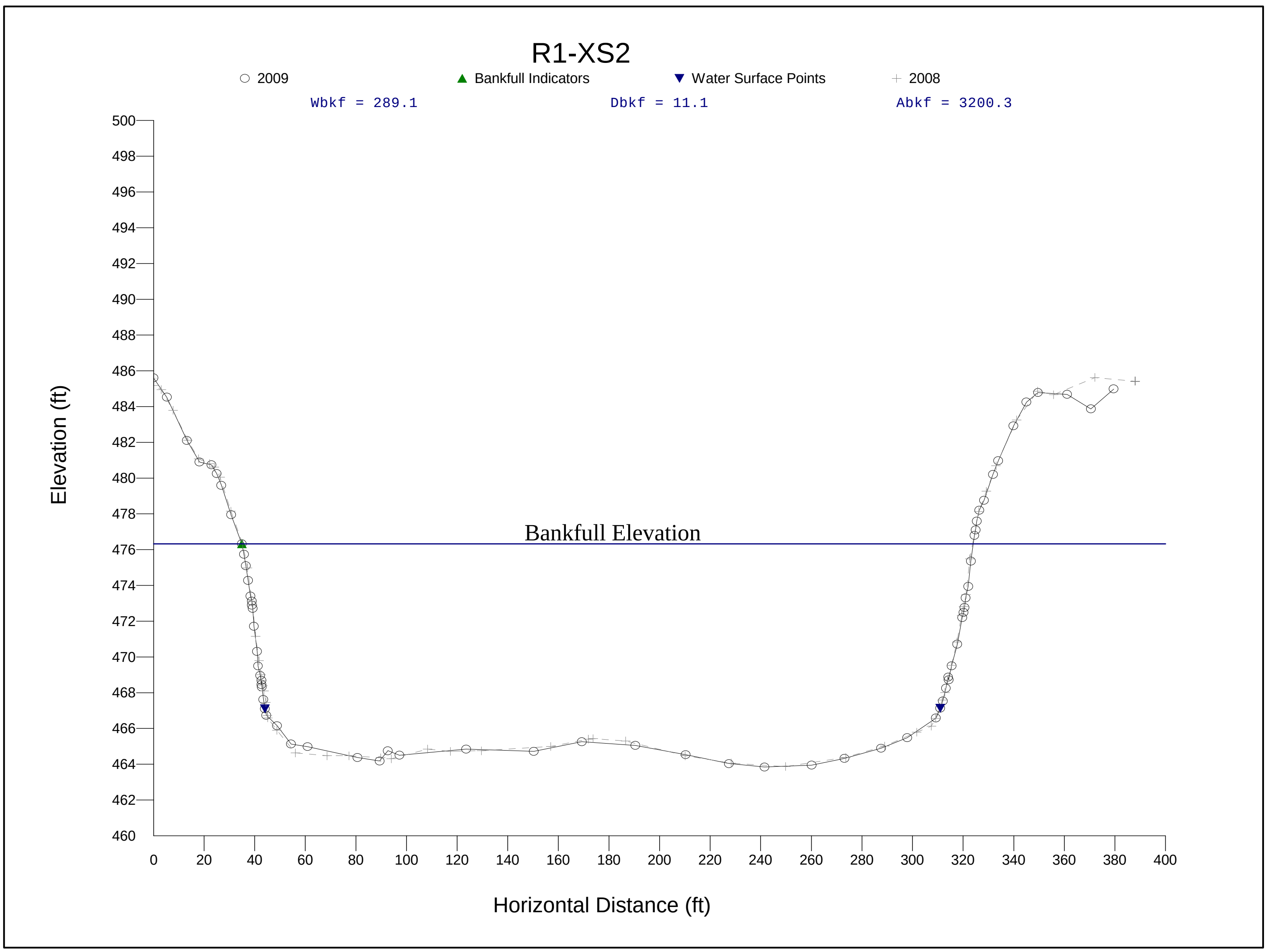
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	492.5	492.6
Bankfull Elevation (ft)	477.5	477.6
Floodprone Width (ft)	5,000	5,000
Bankfull Width (ft)	250.8	246.4
Entrenchment Ratio	19.9	20.3
Mean Depth (ft)	12.3	12.6
Maximum Depth (ft)	15.0	15.1
Width/Depth Ratio	20.5	19.5
Bankfull Area (sq ft)	3,074	3,110
Wetted Perimeter (ft)	260.2	256.4
Hydraulic Radius (ft)	11.8	12.1
Begin BKF Station	16.5	21.0
End BKF Station	267.3	267.3



RIVERMORPH CROSS SECTION SUMMARY

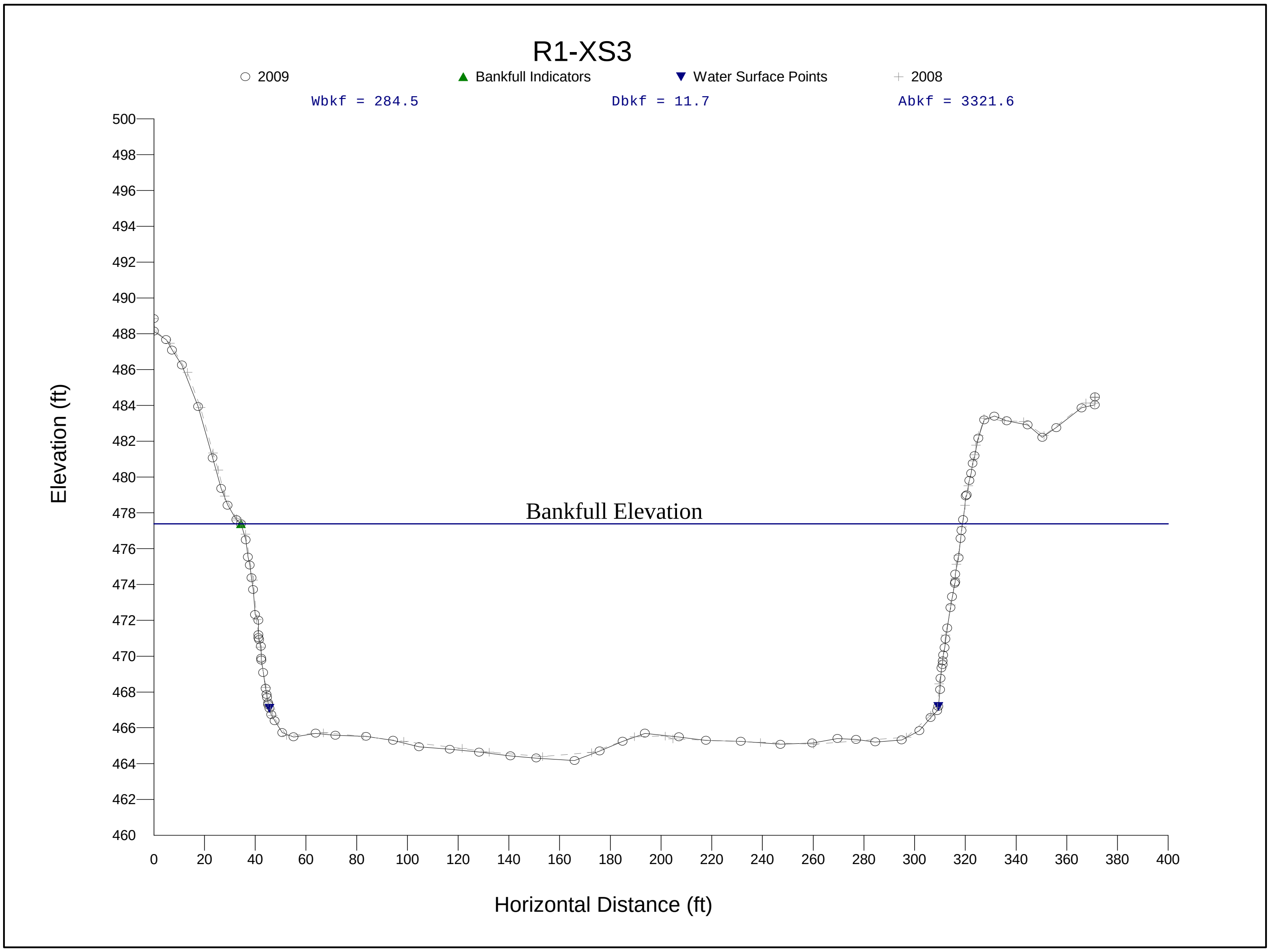
River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R1-XS2
Survey Dates: 10/16/2008 & 9/9/2009

Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	488.7	488.8
Bankfull Elevation (ft)	476.3	476.3
Floodprone Width (ft)	5,000	5,000
Bankfull Width (ft)	288.4	289.1
Entrenchment Ratio	17.3	17.3
Mean Depth (ft)	11.0	11.1
Maximum Depth (ft)	12.4	12.5
Width/Depth Ratio	26.2	26.1
Bankfull Area (sq ft)	3,182	3,200
Wetted Perimeter (ft)	296.1	297.4
Hydraulic Radius (ft)	10.8	10.8
Begin BKF Station	35.3	34.9
End BKF Station	323.7	324.0



RIVERMORPH CROSS SECTION SUMMARY
River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R1-XS3
Survey Dates: 10/16/2008 & 9/9/2009

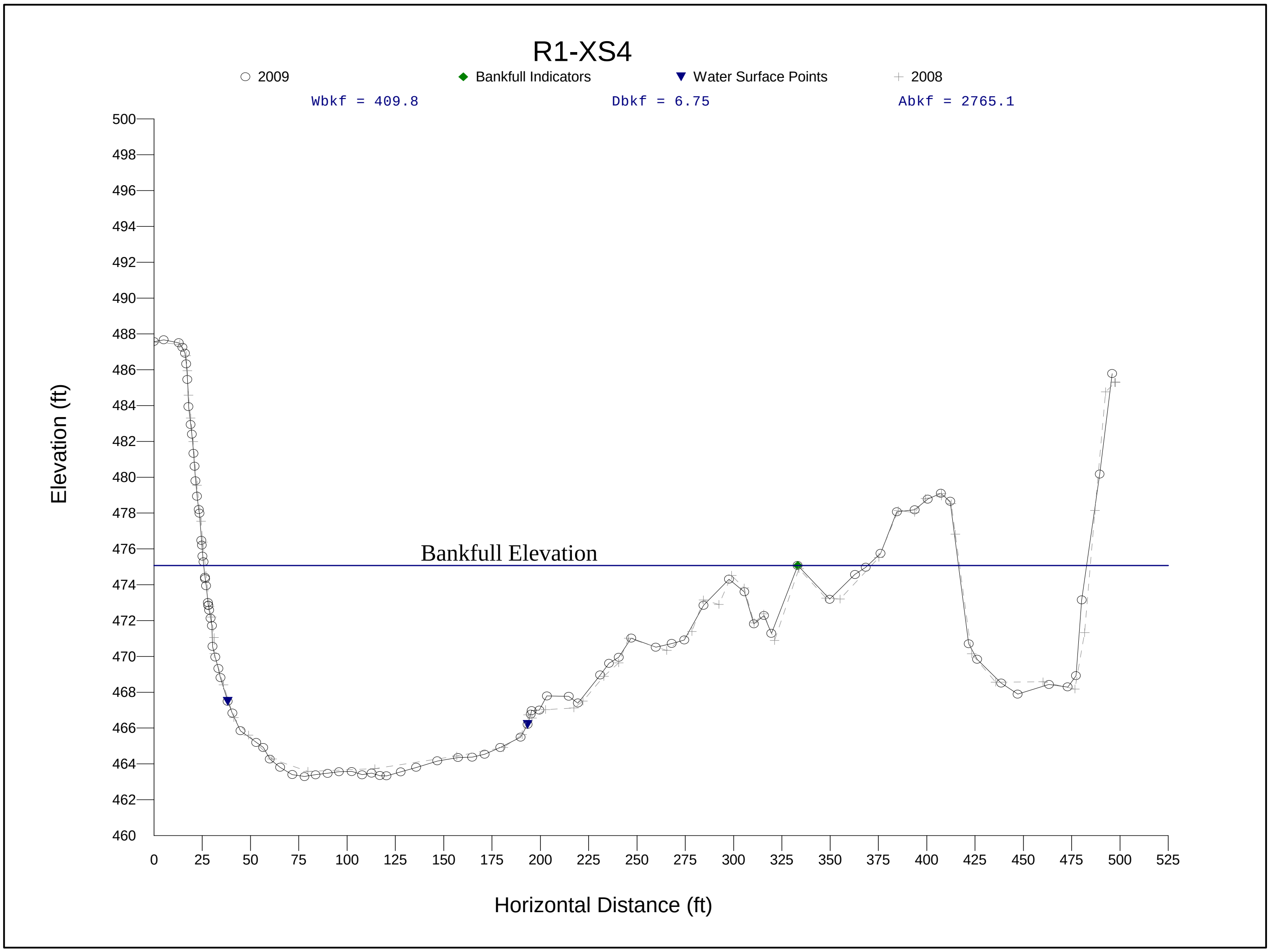
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	490.6	490.6
Bankfull Elevation (ft)	477.5	477.4
Floodprone Width (ft)	1,000	1,000
Bankfull Width (ft)	285.4	284.5
Entrenchment Ratio	3.5	3.5
Mean Depth (ft)	11.7	11.7
Maximum Depth (ft)	13.1	13.2
Width/Depth Ratio	24.4	24.4
Bankfull Area (sq ft)	3,336	3,322
Wetted Perimeter (ft)	294.7	294.6
Hydraulic Radius (ft)	11.3	11.3
Begin BKF Station	33.6	34.4
End BKF Station	318.9	318.9



RIVERMORPH CROSS SECTION SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R1-XS4
Survey Dates: 10/16/2008 9/10/2009

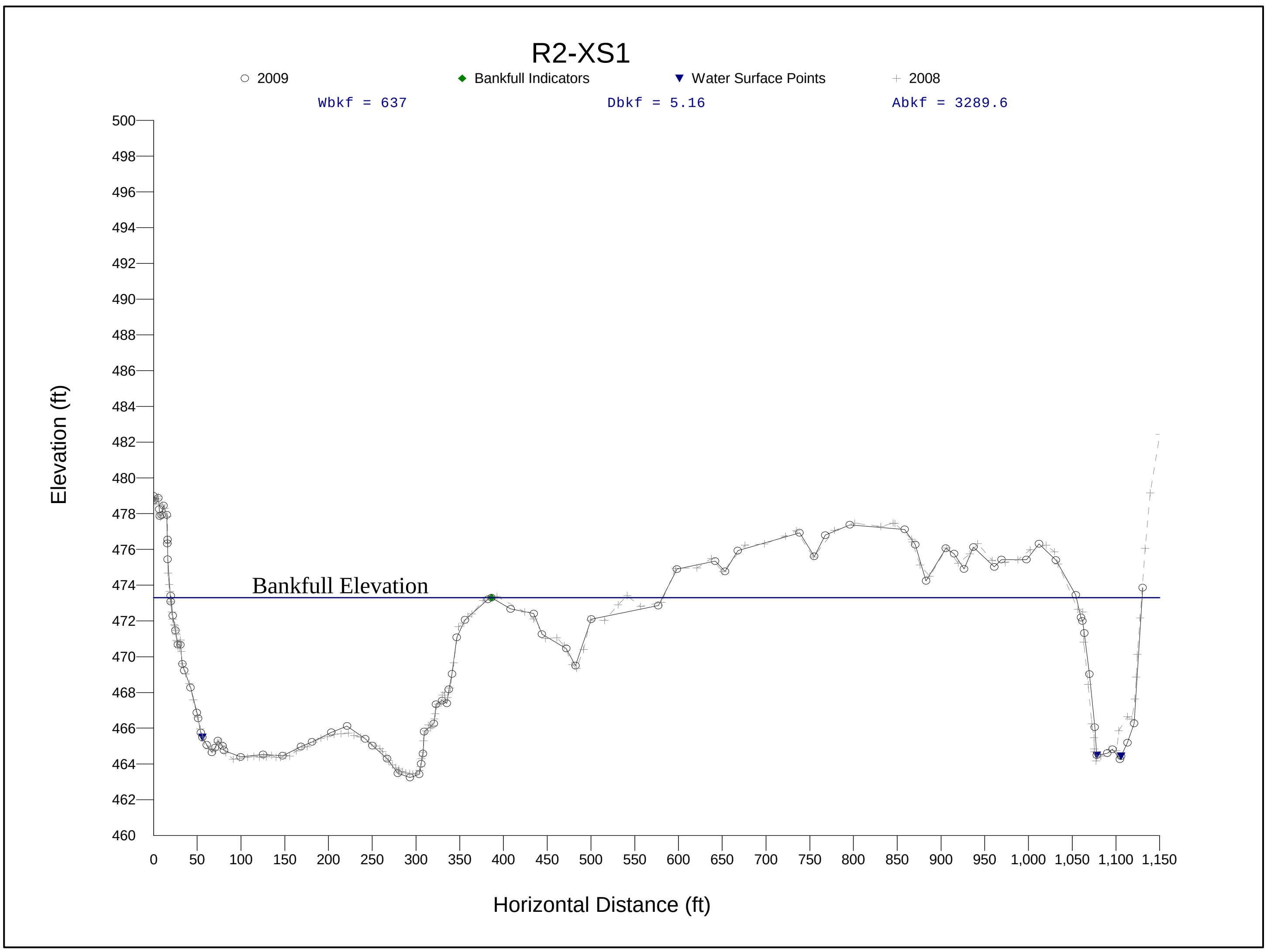
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	486.2	486.9
Bankfull Elevation (ft)	474.9	475.1
Floodprone Width (ft)	2,000	2,000
Bankfull Width (ft)	410.2	409.8
Entrenchment Ratio	4.9	4.9
Mean Depth (ft)	6.6	6.8
Maximum Depth (ft)	11.3	11.8
Width/Depth Ratio	62.3	60.7
Bankfull Area (sq ft)	2,703	2,765
Wetted Perimeter (ft)	420.1	419.6
Hydraulic Radius (ft)	6.4	6.6
Begin BKF Station	26.8	25.9
End BKF Station	484.5	482.8



RIVERMORPH CROSS SECTION SUMMARY

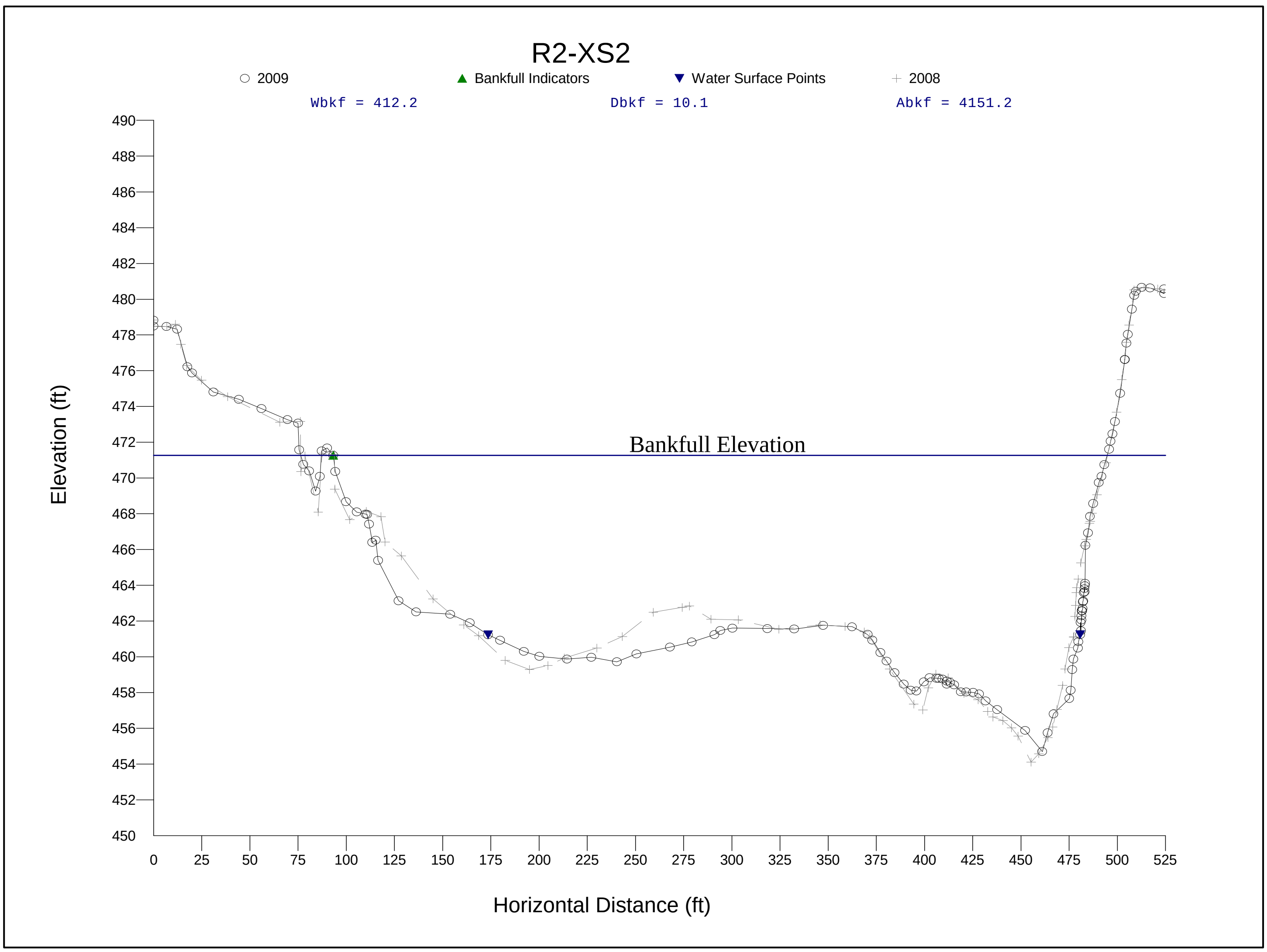
River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R2-XS1
Survey Dates: 10/15/2008 & 9/10/2009

Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	483.3	483.4
Bankfull Elevation (ft)	473.4	473.3
Floodprone Width (ft)	1,600	1,600
Bankfull Width (ft)	641.3	637.0
Entrenchment Ratio	2.5	2.5
Mean Depth (ft)	5.2	5.2
Maximum Depth (ft)	9.9	10.1
Width/Depth Ratio	124.0	123.4
Bankfull Area (sq ft)	3,317	3,290
Wetted Perimeter (ft)	650.3	644.8
Hydraulic Radius (ft)	5.1	5.1
Begin BKF Station	19.3	19.3
End BKF Station	1,129	1,130



RIVERMORPH CROSS SECTION SUMMARY
River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R2-XS2
Survey Dates: 10/15/2008 & 9/15/2009

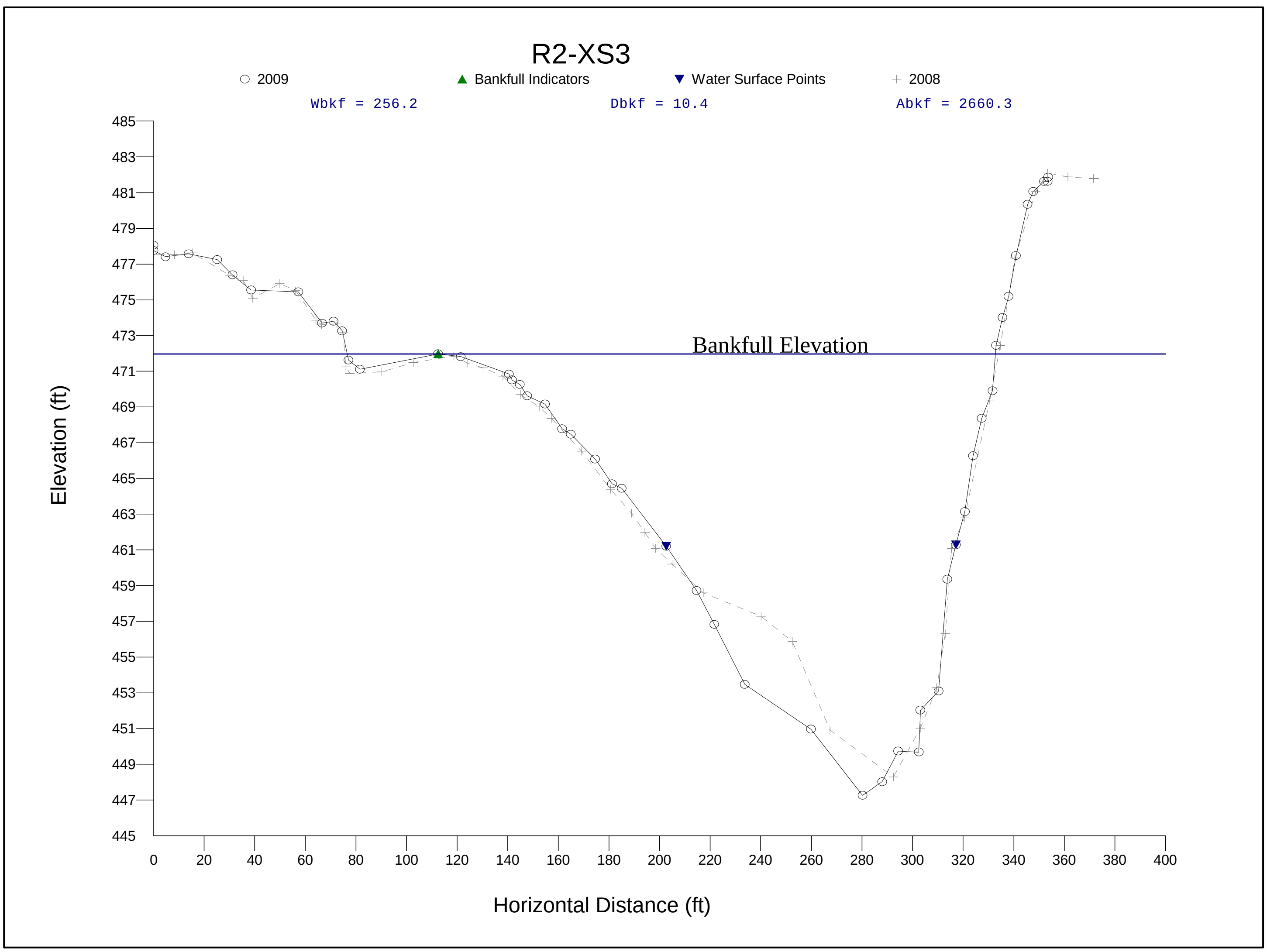
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	488.5	487.8
Bankfull Elevation (ft)	471.3	471.3
Floodprone Width (ft)	2,000	2,000
Bankfull Width (ft)	416.8	412.2
Entrenchment Ratio	4.8	4.9
Mean Depth (ft)	9.7	10.1
Maximum Depth (ft)	17.2	16.6
Width/Depth Ratio	43.0	40.9
Bankfull Area (sq ft)	4,037	4,151
Wetted Perimeter (ft)	428.9	423.8
Hydraulic Radius (ft)	9.4	9.8
Begin BKF Station	76.4	76.4
End BKF Station	495.0	494.8



RIVERMORPH CROSS SECTION SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R2-XS3
Survey Dates: 10/15/2008 & 9/15/2009

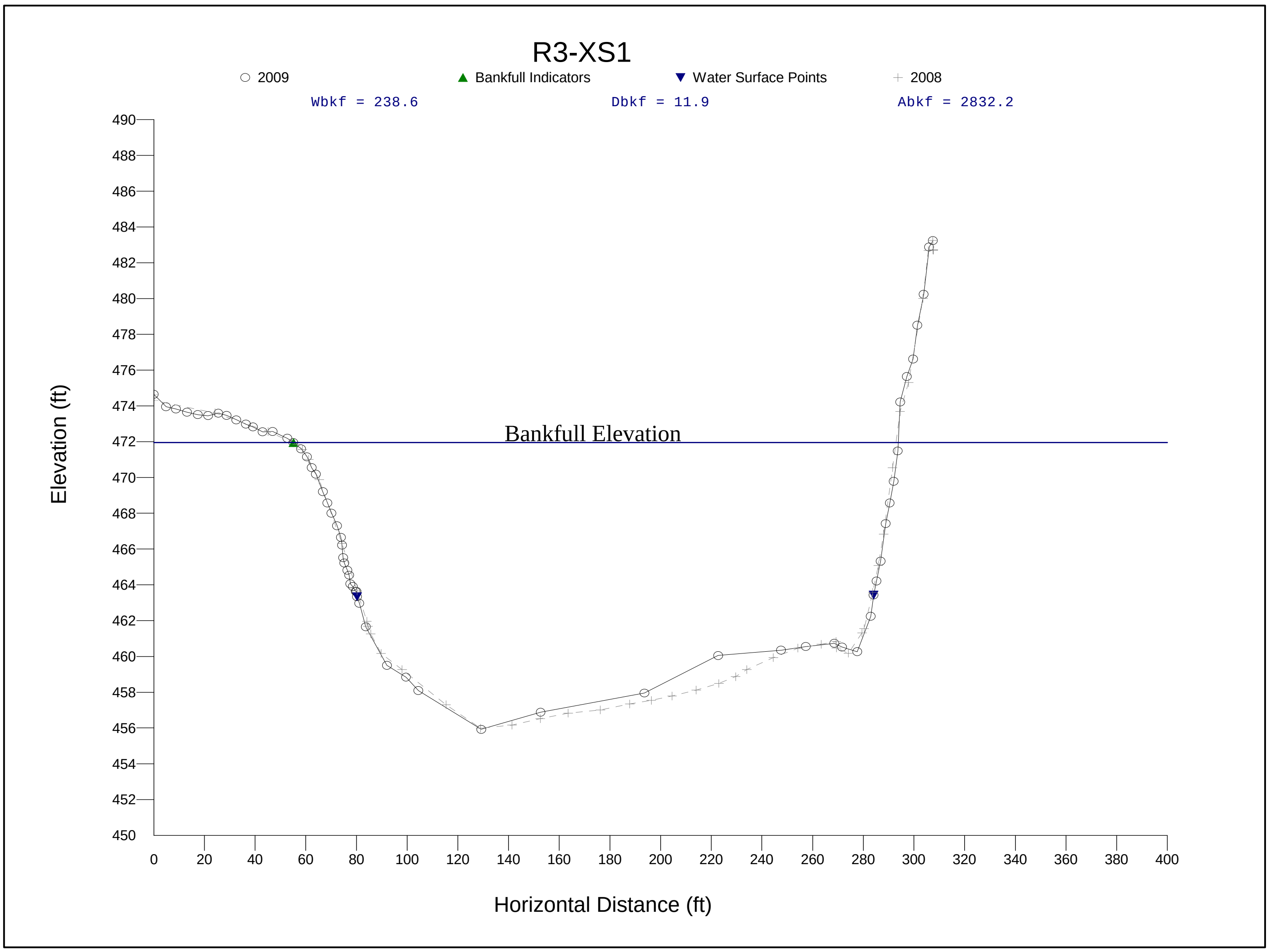
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	495.4	496.7
Bankfull Elevation (ft)	471.8	472.0
Floodprone Width (ft)	2,000	2,000
Bankfull Width (ft)	258.2	256.2
Entrenchment Ratio	7.8	7.8
Mean Depth (ft)	9.7	10.4
Maximum Depth (ft)	23.6	24.7
Width/Depth Ratio	26.7	24.7
Bankfull Area (sq ft)	2,496	2,660
Wetted Perimeter (ft)	268.5	268.8
Hydraulic Radius (ft)	9.3	9.9
Begin BKF Station	75.7	76.5
End BKF Station	333.9	332.8



RIVERMORPH CROSS SECTION SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R3-XS1
Survey Dates: 10/15/2008 9/30/2009

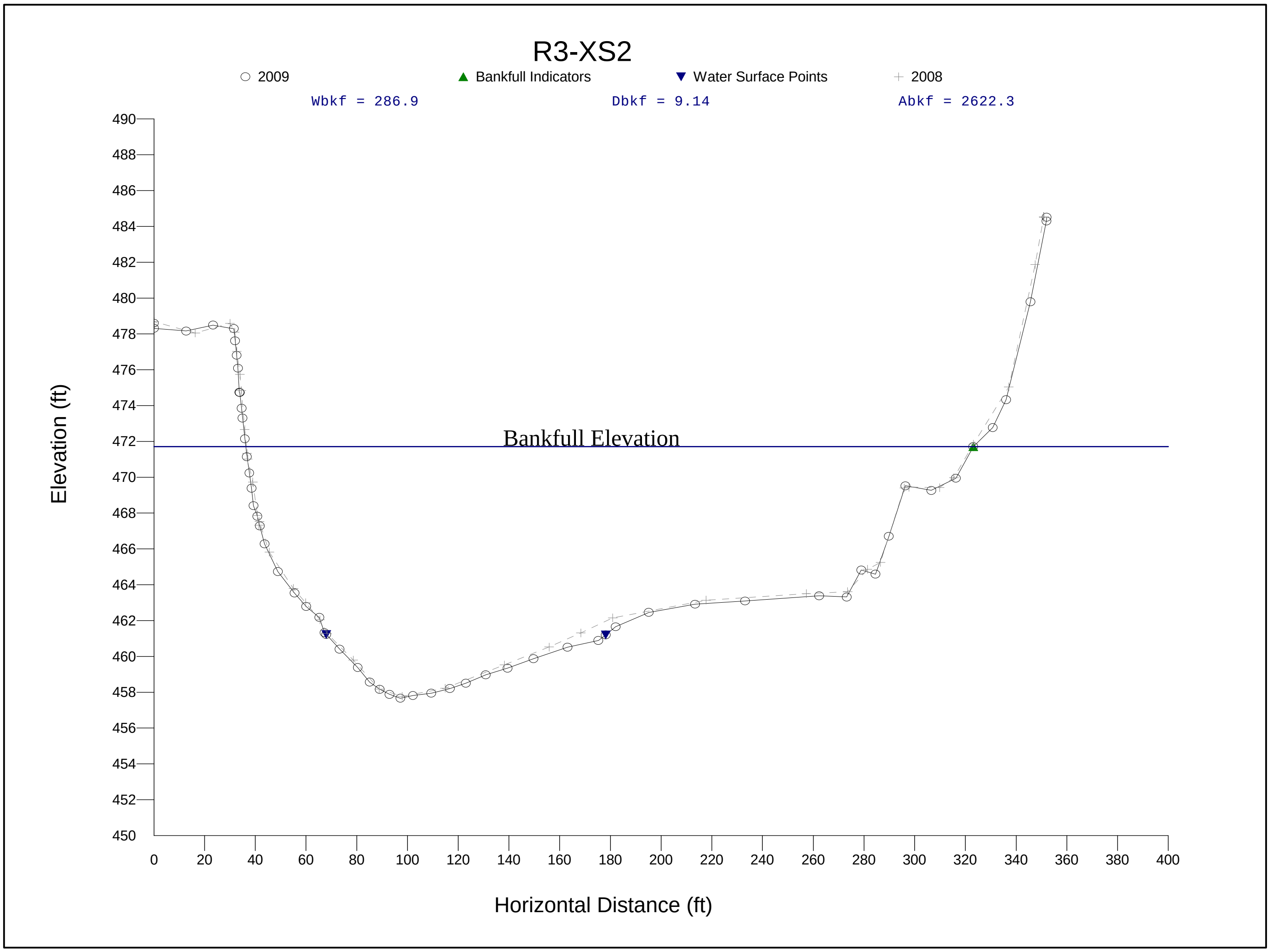
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	487.7	488.0
Bankfull Elevation (ft)	471.8	472.0
Floodprone Width (ft)	2,000	2,000
Bankfull Width (ft)	236.2	238.6
Entrenchment Ratio	8.5	8.4
Mean Depth (ft)	12.1	11.9
Maximum Depth (ft)	15.9	16.0
Width/Depth Ratio	19.5	20.1
Bankfull Area (sq ft)	2,857	2,832
Wetted Perimeter (ft)	242.9	245.8
Hydraulic Radius (ft)	11.8	11.5
Begin BKF Station	56.6	55.2
End BKF Station	292.8	293.8



RIVERMORPH CROSS SECTION SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R3-XS2
Survey Dates: 10/15/2008 & 9/16/2009

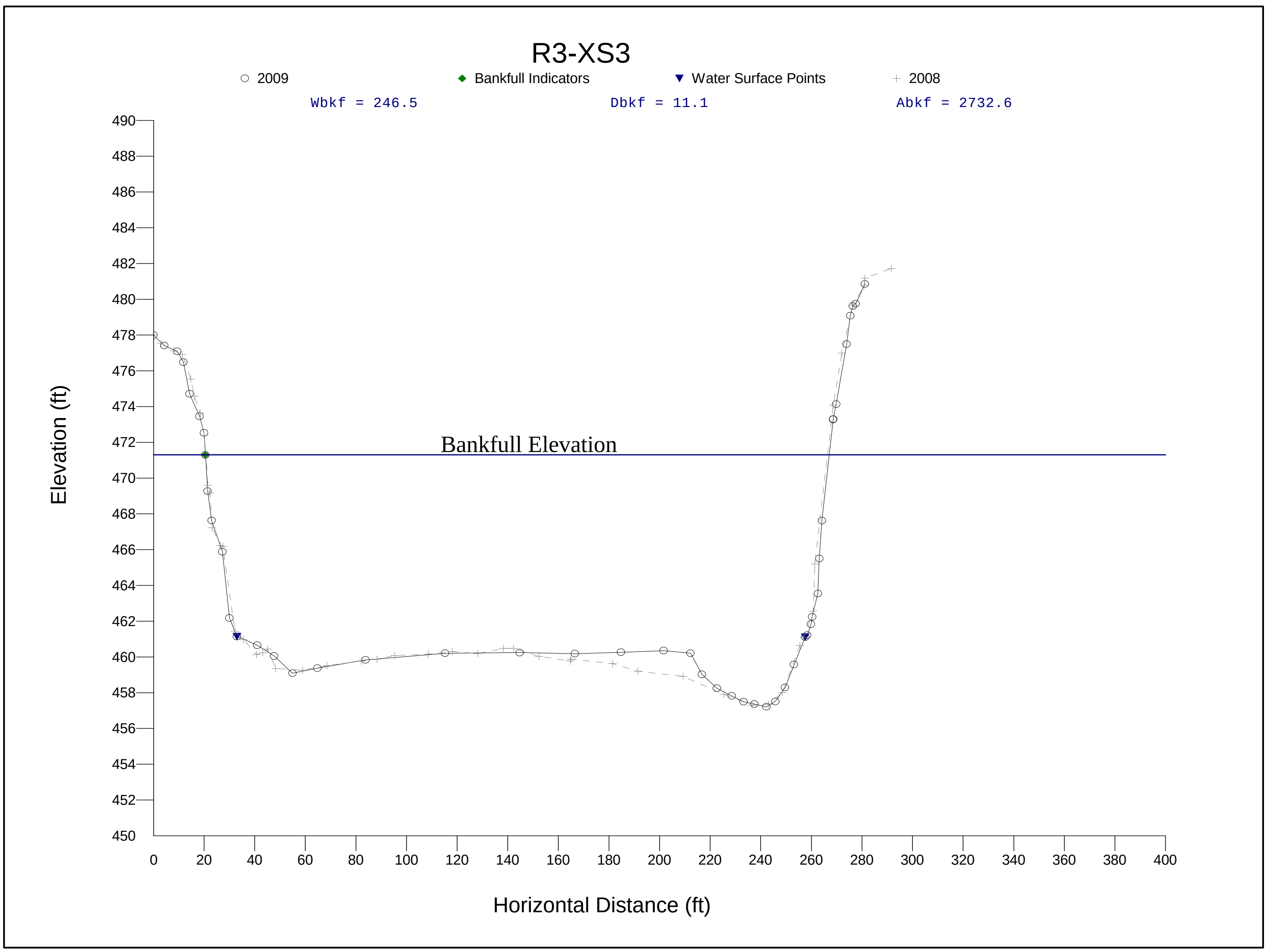
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	485.9	485.7
Bankfull Elevation (ft)	471.9	471.7
Floodprone Width (ft)	2,000	2,000
Bankfull Width (ft)	286.8	286.9
Entrenchment Ratio	7.0	7.0
Mean Depth (ft)	9.1	9.1
Maximum Depth (ft)	14.1	14.0
Width/Depth Ratio	31.6	31.4
Bankfull Area (sq ft)	2,607	2,622
Wetted Perimeter (ft)	291.1	291.2
Hydraulic Radius (ft)	9.0	9.0
Begin BKF Station	36.4	36.3
End BKF Station	323.2	323.1



RIVERMORPH CROSS SECTION SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R3-XS3
Survey Dates: 10/14/2008 & 9/16/2009

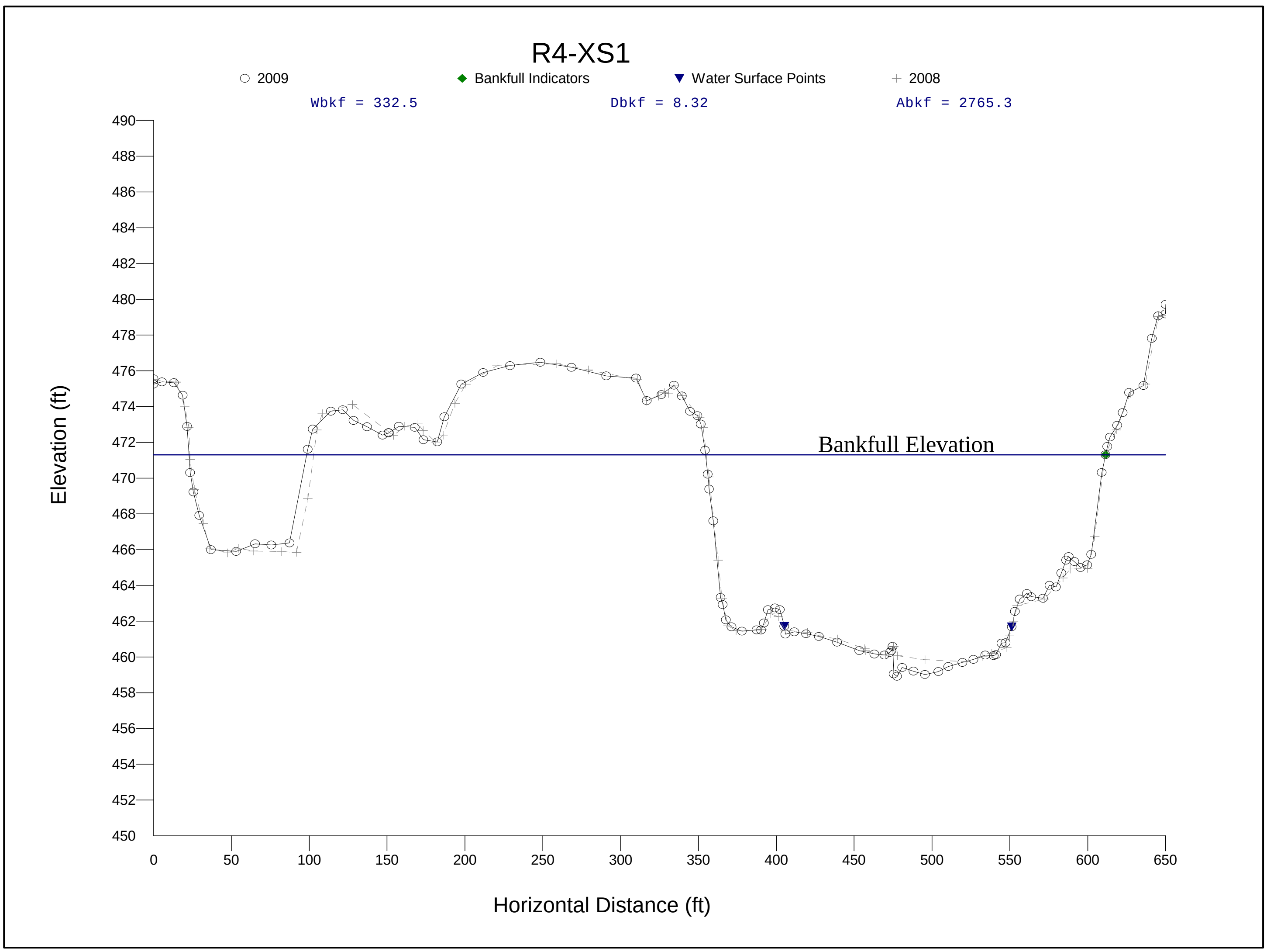
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	485.3	485.4
Bankfull Elevation (ft)	471.3	471.3
Floodprone Width (ft)	4,100	4,100
Bankfull Width (ft)	245.5	246.6
Entrenchment Ratio	16.7	16.6
Mean Depth (ft)	11.3	11.1
Maximum Depth (ft)	14.0	14.1
Width/Depth Ratio	21.8	22.3
Bankfull Area (sq ft)	2,768	2,733
Wetted Perimeter (ft)	256.4	257.1
Hydraulic Radius (ft)	10.8	10.6
Begin BKF Station	20.9	20.5
End BKF Station	266.4	267.1



RIVERMORPH CROSS SECTION SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R4-XS1
Survey Dates: 10/14/2008 & 9/11/2009

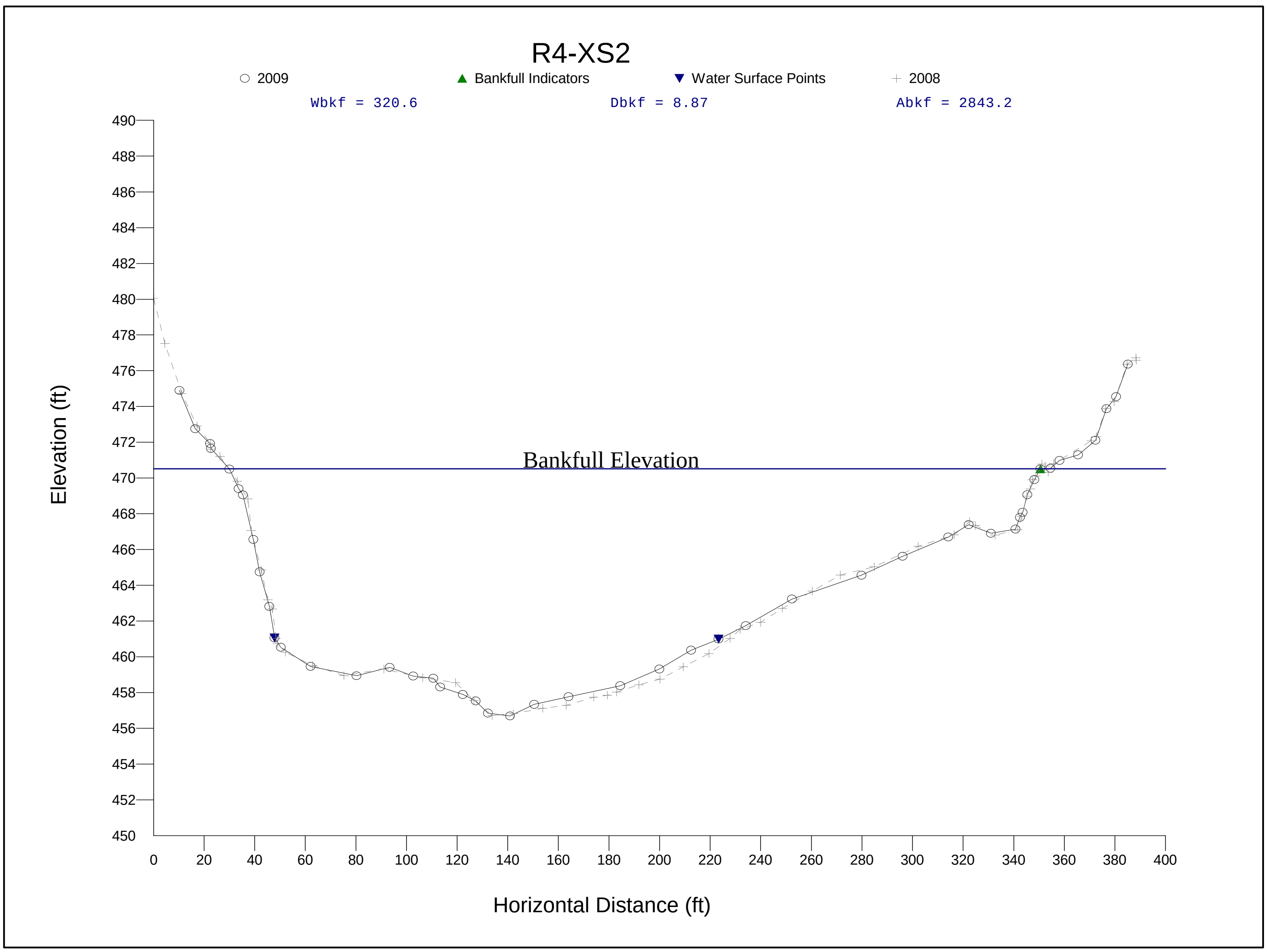
Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	482.9	483.7
Bankfull Elevation (ft)	471.3	471.3
Floodprone Width (ft)	4,300	4,300
Bankfull Width (ft)	335.6	332.5
Entrenchment Ratio	12.8	12.9
Mean Depth (ft)	8.3	8.3
Maximum Depth (ft)	11.6	12.4
Width/Depth Ratio	40.4	40.0
Bankfull Area (sq ft)	2,785	2,765
Wetted Perimeter (ft)	343.7	341.9
Hydraulic Radius (ft)	8.1	8.1
Begin BKF Station	23.4	22.8
End BKF Station	611.2	611.5



RIVERMORPH CROSS SECTION SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Cross Section: R4-XS2
Survey Dates: 10/14/2008 & 9/16/2009

Cross Sectional Geometry	2008 Channel	2009 Channel
Floodprone Elevation (ft)	484.8	484.3
Bankfull Elevation (ft)	470.8	470.5
Floodprone Width (ft)	2,000	2,000
Bankfull Width (ft)	327.3	320.6
Entrenchment Ratio	6.1	6.2
Mean Depth (ft)	9.0	8.9
Maximum Depth (ft)	14.1	13.8
Width/Depth Ratio	36.3	36.1
Bankfull Area (sq ft)	2,952	2,843
Wetted Perimeter (ft)	331.9	324.4
Hydraulic Radius (ft)	8.9	8.8
Begin BKF Station	28.4	30.0
End BKF Station	355.7	350.6



Appendix C

Sediment Data

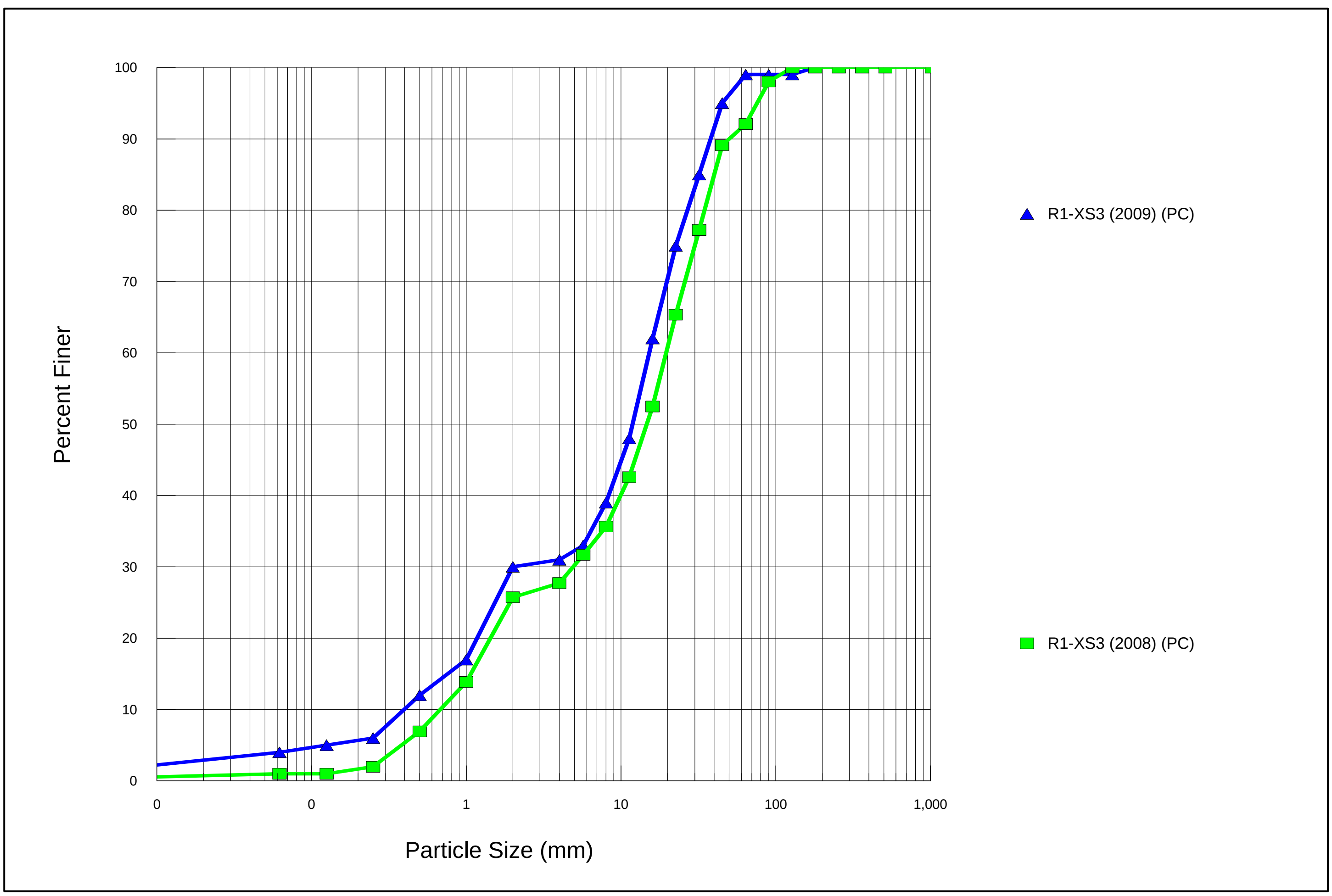
- Pebble Counts
- Bulk Sample – Point Bar Samples

RIVERMORPH PARTICLE SUMMARY

River Name:	Little Miami River
Reach Name:	RM 4.5 to RM 7.0
Sample Name:	R1-XS3
Survey Dates:	11/20/2008 & 9/24/2009

Size (mm)	2008 TOT #	2009 TOT #
0 - 0.062	1	4
0.062 - 0.125	0	1
0.125 - 0.25	1	1
0.25 - 0.50	5	6
0.50 - 1.0	7	5
1.0 - 2.0	12	13
2.0 - 4.0	2	1
4.0 - 5.7	4	2
5.7 - 8.0	4	6
8.0 - 11.3	7	9
11.3 - 16.0	10	14
16.0 - 22.6	13	13
22.6 - 32.0	12	10
32 - 45	12	10
45 - 64	3	4
64 - 90	6	0
90 - 128	2	0
128 - 180	0	1
TOTAL	101	100

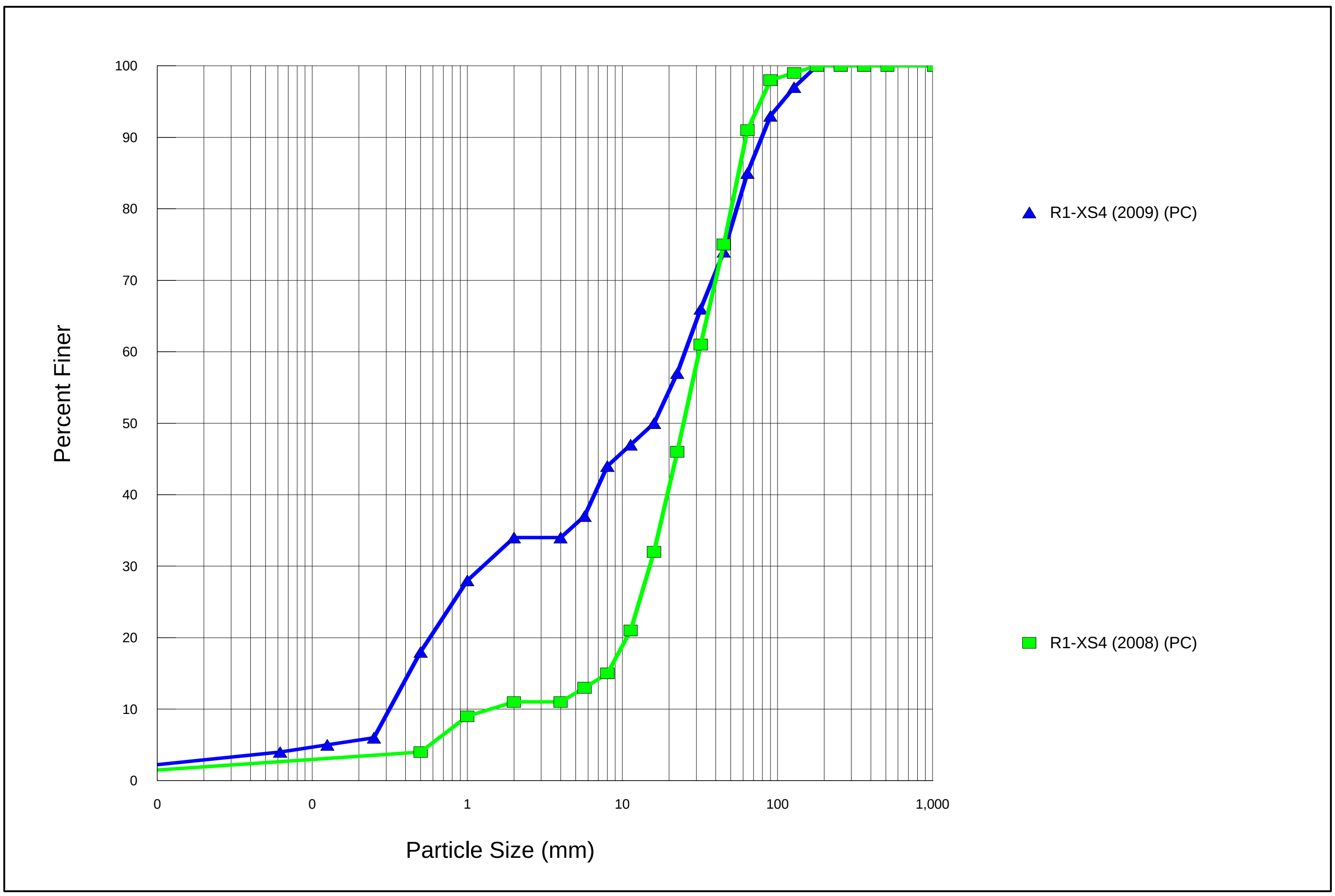
	2008	2009
D16 (mm)	3.0	0.9
D35 (mm)	7.6	6.5
D50 (mm)	14.8	12.0
D84 (mm)	39.4	31.1
D95 (mm)	76.8	45.0
D100 (mm)	128.0	180.0
Silt/Clay (%)	1.0	4.0
Sand (%)	24.8	26.0
Gravel (%)	66.3	69.0
Cobble (%)	7.9	1.0
Boulder (%)	0	0
Bedrock (%)	0	0



RIVERMORPH PARTICLE SUMMARY
River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: R1-XS4
Survey Dates: 11/20/2008 & 9/24/2009

Size (mm)	2008 TOT #	2009 TOT #
0 - 0.062	0	4
0.062 - 0.125	0	1
0.125 - 0.25	0	1
0.25 - 0.50	4	12
0.50 - 1.0	5	10
1.0 - 2.0	2	6
2.0 - 4.0	0	0
4.0 - 5.7	2	3
5.7 - 8.0	2	7
8.0 - 11.3	6	3
11.3 - 16.0	11	3
16.0 - 22.6	14	7
22.6 - 32.0	15	9
32 - 45	14	8
45 - 64	16	11
64 - 90	7	8
90 - 128	1	4
128 - 180	1	3
TOTAL	100	100

	2008	2009
D16 (mm)	8.6	0.5
D35 (mm)	17.4	4.6
D50 (mm)	25.1	16.0
D84 (mm)	55.7	62.3
D95 (mm)	78.9	109.0
D100 (mm)	180.0	180.0
Silt/Clay (%)	0	4.0
Sand (%)	11.0	30.0
Gravel (%)	80.0	51.0
Cobble (%)	9.0	15.0
Boulder (%)	0	0
Bedrock (%)	0	0

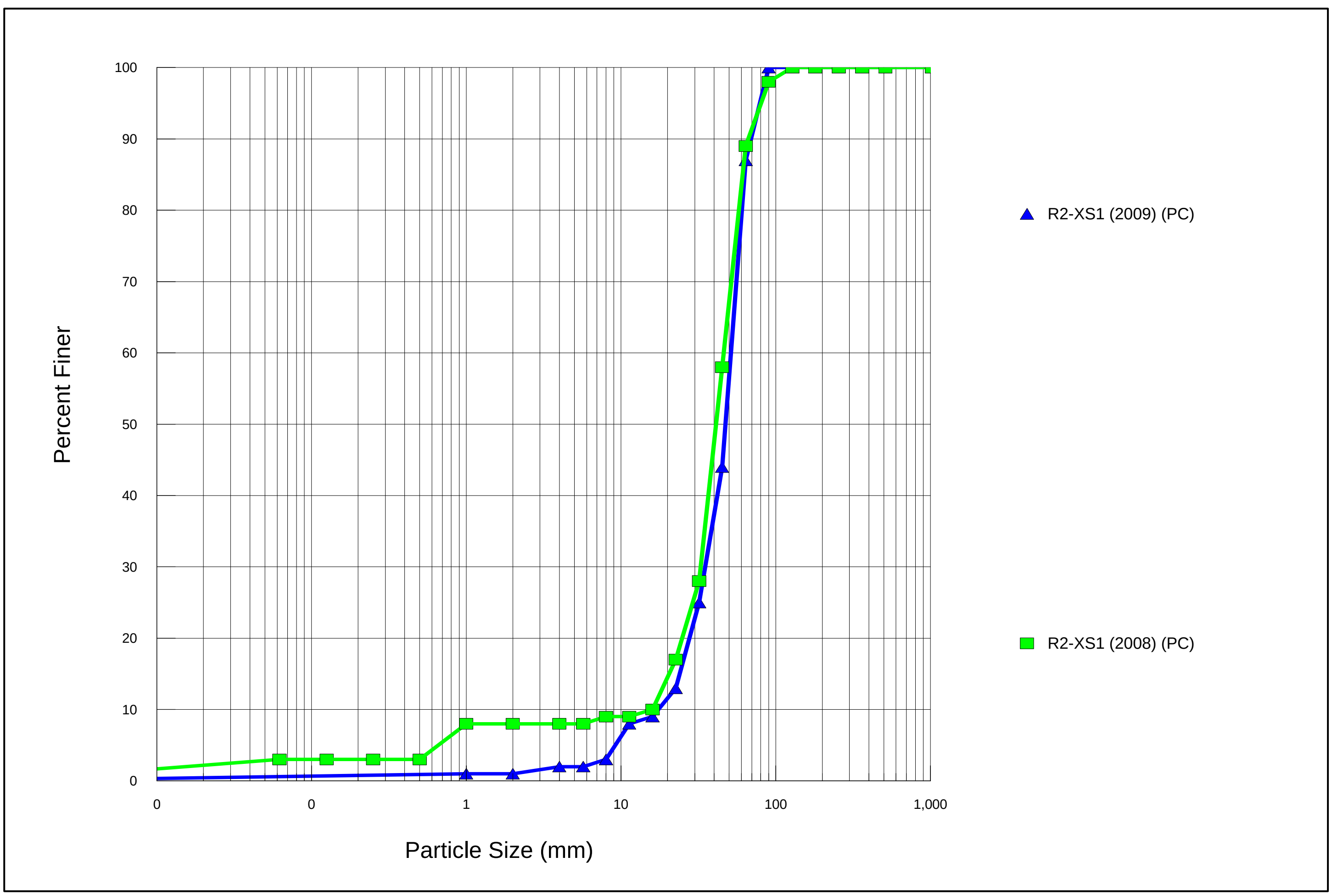


RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: R2-XS1
Survey Dates: 11/20/2008 & 9/17/2009

Size (mm)	2008 TOT #	2009 TOT #
0 - 0.062	3	0
0.062 - 0.125	0	0
0.125 - 0.25	0	0
0.25 - 0.50	0	0
0.50 - 1.0	5	1
1.0 - 2.0	0	0
2.0 - 4.0	0	1
4.0 - 5.7	0	0
5.7 - 8.0	1	1
8.0 - 11.3	0	5
11.3 - 16.0	1	1
16.0 - 22.6	7	4
22.6 - 32.0	11	12
32 - 45	30	19
45 - 64	31	43
64 - 90	9	13
90 - 128	2	0
128 - 180	0	0
TOTAL	100	100

	2008	2009
D16 (mm)	21.7	25.0
D35 (mm)	35.0	38.8
D50 (mm)	41.5	47.7
D84 (mm)	60.9	62.7
D95 (mm)	81.3	80.0
D100 (mm)	128.0	90.0
Silt/Clay (%)	3.0	0
Sand (%)	5.0	1.0
Gravel (%)	81.0	86.0
Cobble (%)	11.0	13.0
Boulder (%)	0	0
Bedrock (%)	0	0

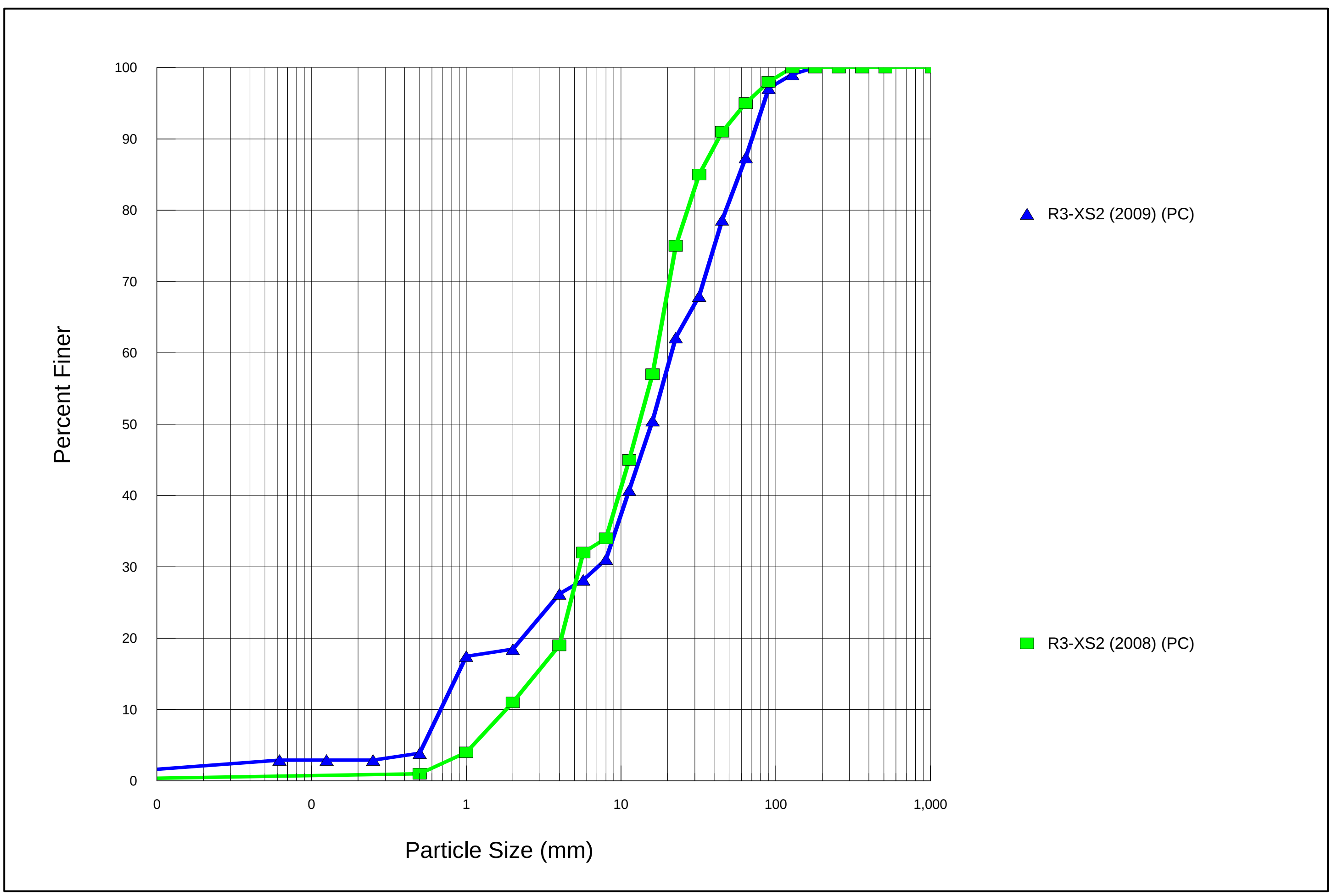


RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: R3-XS2
Survey Dates: 11/20/2008 & 9/17/2009

Size (mm)	2008 TOT #	2009 TOT #
0 - 0.062	0	3
0.062 - 0.125	0	0
0.125 - 0.25	0	0
0.25 - 0.50	1	1
0.50 - 1.0	3	14
1.0 - 2.0	7	1
2.0 - 4.0	8	8
4.0 - 5.7	13	2
5.7 - 8.0	2	3
8.0 - 11.3	11	10
11.3 - 16.0	12	10
16.0 - 22.6	18	12
22.6 - 32.0	10	6
32 - 45	6	11
45 - 64	4	9
64 - 90	3	10
90 - 128	2	2
128 - 180	0	1
TOTAL	100	103

	2008	2009
D16 (mm)	3.3	1.0
D35 (mm)	8.3	9.3
D50 (mm)	13.3	15.8
D84 (mm)	31.1	56.7
D95 (mm)	64.0	84.4
D100 (mm)	128.0	180.0
Silt/Clay (%)	0	2.9
Sand (%)	11.0	15.5
Gravel (%)	84.0	68.9
Cobble (%)	5.0	12.6
Boulder (%)	0	0
Bedrock (%)	0	0

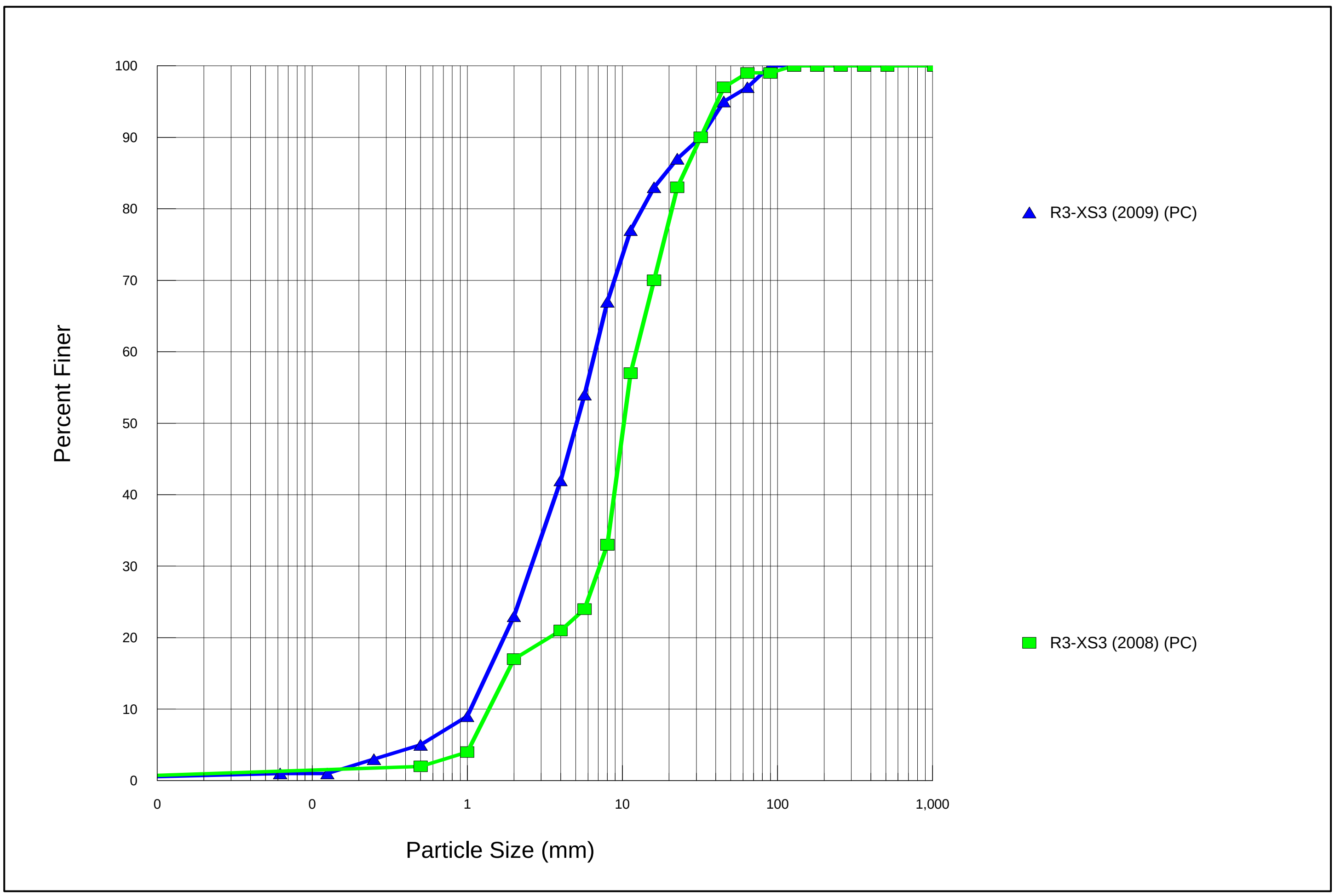


RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: R3-XS3
Survey Dates: 11/20/2008 & 9/17/2009

Size (mm)	2008 TOT #	2009 TOT #
0 - 0.062	0	1
0.062 - 0.125	0	0
0.125 - 0.25	0	2
0.25 - 0.50	2	2
0.50 - 1.0	2	4
1.0 - 2.0	13	14
2.0 - 4.0	4	19
4.0 - 5.7	3	12
5.7 - 8.0	9	13
8.0 - 11.3	24	10
11.3 - 16.0	13	6
16.0 - 22.6	13	4
22.6 - 32.0	7	3
32 - 45	7	5
45 - 64	2	2
64 - 90	0	3
90 - 128	1	0
128 - 180	0	0
TOTAL	100	100

	2008	2009
D16 (mm)	1.9	1.5
D35 (mm)	8.3	3.3
D50 (mm)	10.3	5.1
D84 (mm)	23.9	17.7
D95 (mm)	41.3	45.0
D100 (mm)	128.0	90.0
Silt/Clay (%)	0	1.0
Sand (%)	17.0	22.0
Gravel (%)	82.0	74.0
Cobble (%)	1.0	3.0
Boulder (%)	0	0
Bedrock (%)	0	0

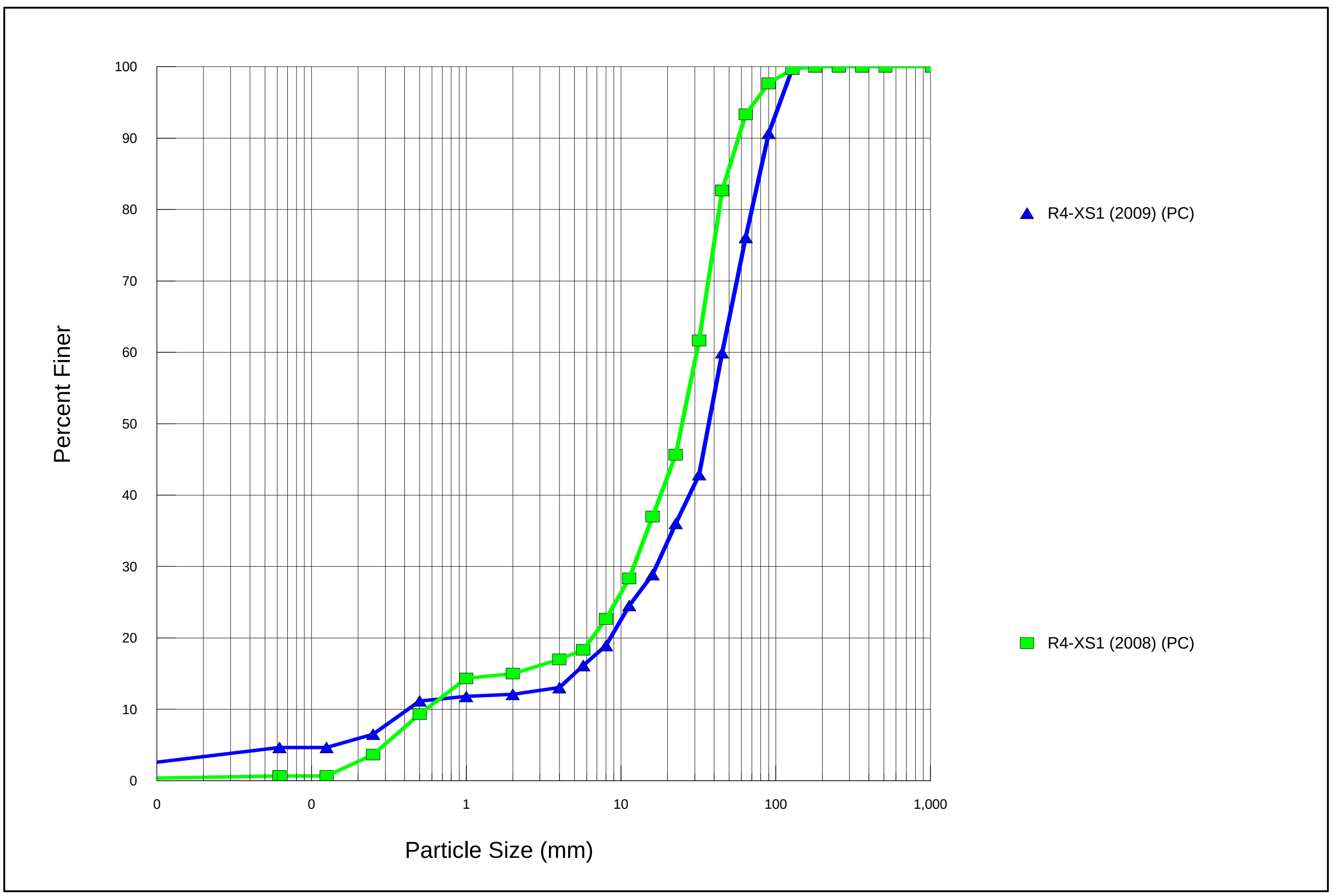


RIVERMORPH PARTICLE SUMMARY

River Name:	Little Miami River
Reach Name:	RM 4.5 to RM 7.0
Sample Name:	R4-XS1
Survey Dates:	11/20/2008 & 9/17/2009

Size (mm)	2008 TOT #	2009 TOT #
0 - 0.062	2	15
0.062 - 0.125	0	0
0.125 - 0.25	9	6
0.25 - 0.50	17	15
0.50 - 1.0	15	2
1.0 - 2.0	2	1
2.0 - 4.0	6	3
4.0 - 5.7	4	10
5.7 - 8.0	13	9
8.0 - 11.3	17	18
11.3 - 16.0	26	14
16.0 - 22.6	26	23
22.6 - 32.0	48	22
32 - 45	63	55
45 - 64	32	52
64 - 90	13	47
90 - 128	6	29
128 - 180	1	1
TOTAL	300	322

	2008	2009
D16 (mm)	3.0	5.6
D35 (mm)	14.9	21.7
D50 (mm)	25.1	37.4
D84 (mm)	47.4	78.1
D95 (mm)	74.0	108.2
D100 (mm)	180.0	180.0
Silt/Clay (%)	0.7	4.7
Sand (%)	14.3	7.5
Gravel (%)	78.3	64.0
Cobble (%)	6.7	23.9
Boulder (%)	0	0
Bedrock (%)	0	0



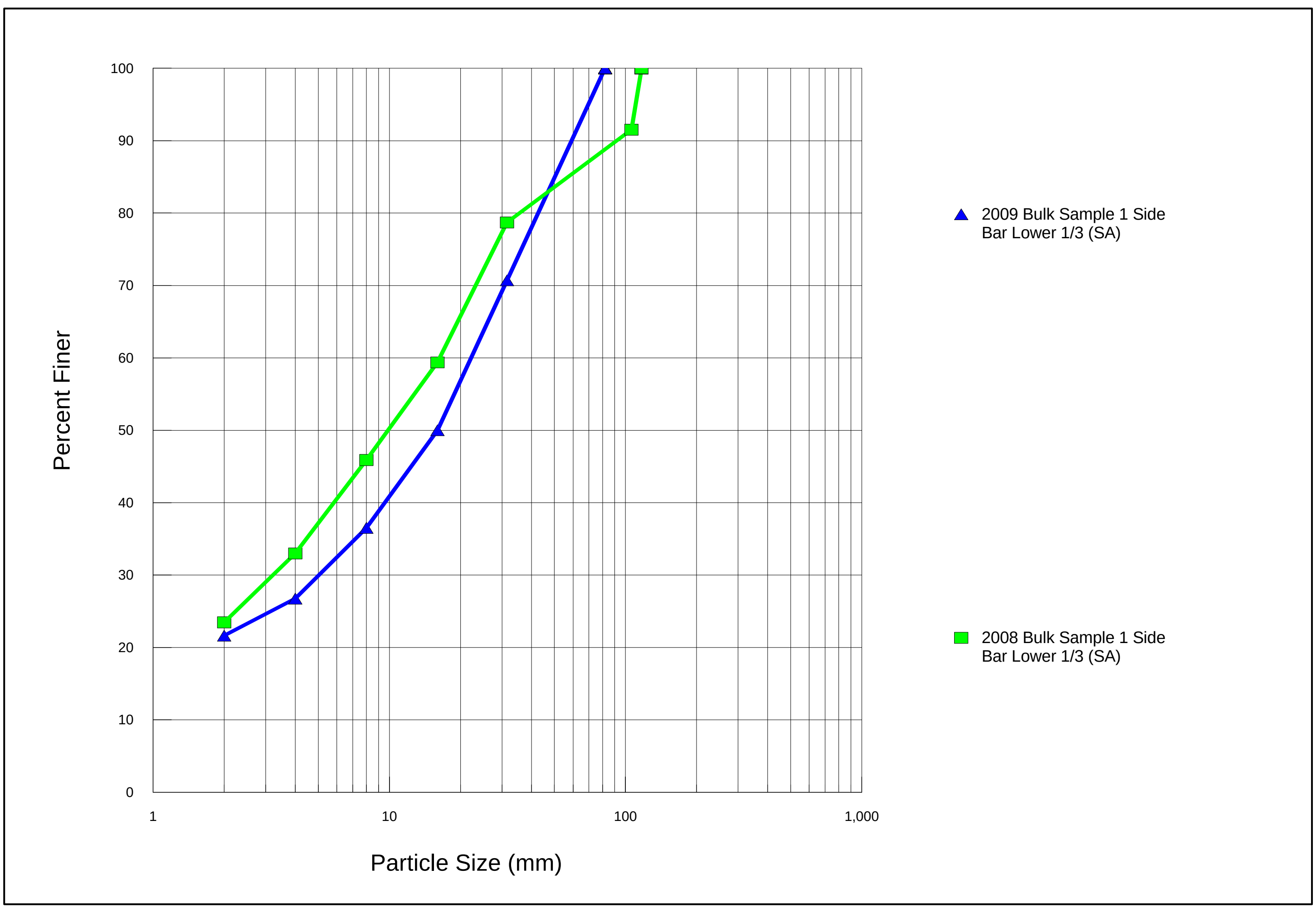
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 1: Side Bar Lower 1/3
Survey Dates: 11/14/2008 & 9/2/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
106	567	----
31.5	3855	5613
16	5812	5046
8	4054	3289
4	3884	2381
2	2863	1247
PAN	7059	5273
TOTAL	30079	24380

	2008	2009
D16 (mm)	0	0
D35 (mm)	4.6	7.4
D50 (mm)	10.4	16.0
D84 (mm)	62.3	54.4
D95 (mm)	110.5	73.4
D100 (mm)	117.0	82.0
Silt/Clay (%)	0	0
Sand (%)	23.5	21.6
Gravel (%)	62.7	70.8
Cobble (%)	13.8	7.6
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008 Size(mm)	2008 Weight	2009 Size(mm)	2009 Weight
Particle 1	117	1928	82	1304
Particle 2	40	57	70	227



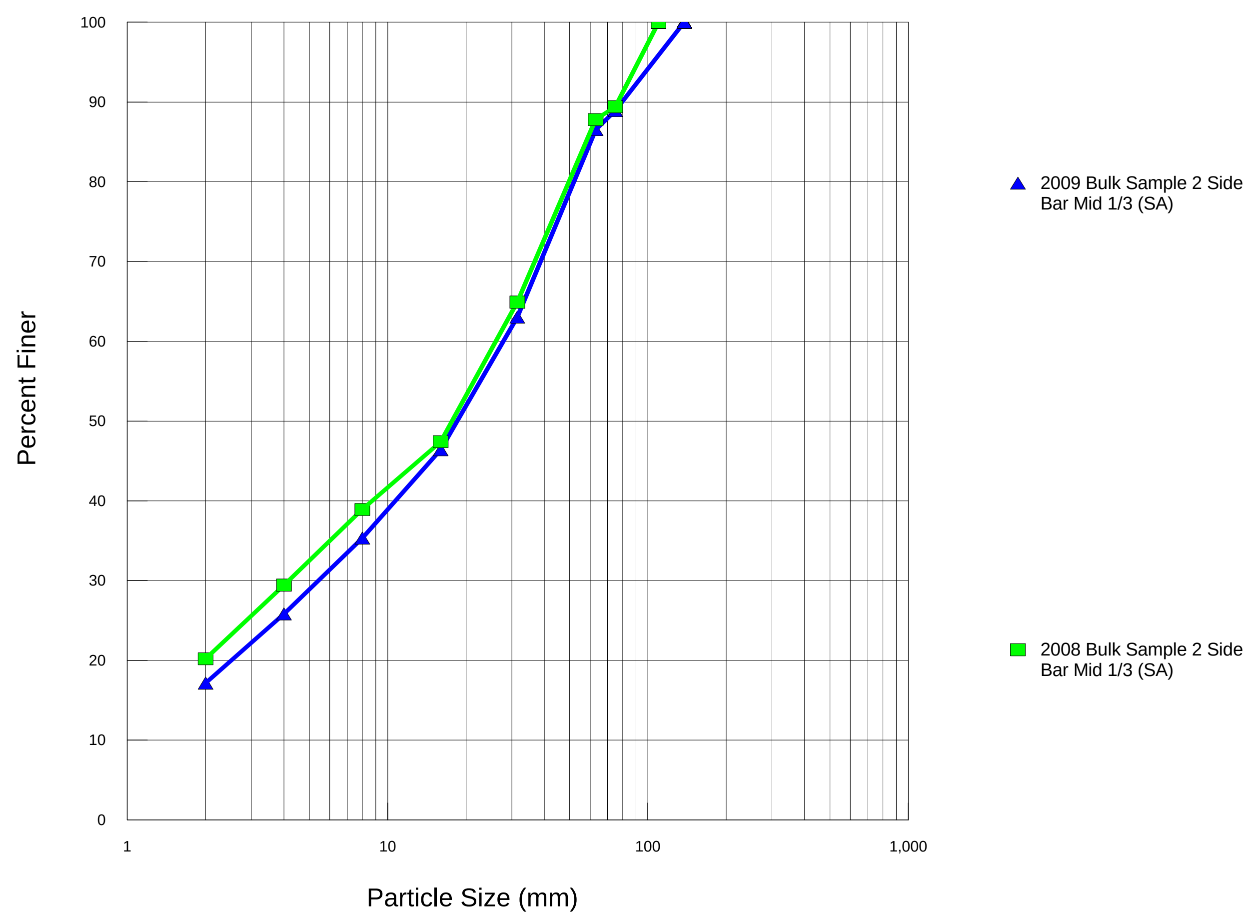
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 2: Side Bar Mid 1/3
Survey Dates: 11/11/2008 & 9/2/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
75	652	539
63	369	907
31.5	5273	8902
16	4026	6294
8	1956	4196
4	2183	3600
2	2126	3289
PAN	4649	6492
TOTAL	23021	37876

	2008	2009
D16 (mm)	0	0
D35 (mm)	6.4	7.9
D50 (mm)	18.3	19.4
D84 (mm)	57.8	59.6
D95 (mm)	93.5	109.6
D100 (mm)	110.0	138.0
Silt/Clay (%)	0	0
Sand (%)	20.2	17.1
Gravel (%)	67.8	69.6
Cobble (%)	12.1	13.3
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008 Size(mm)	2008 Weight	2009 Size(mm)	2009 Weight
Particle 1	110	1418	138	2920
Particle 2	85	369	71	737



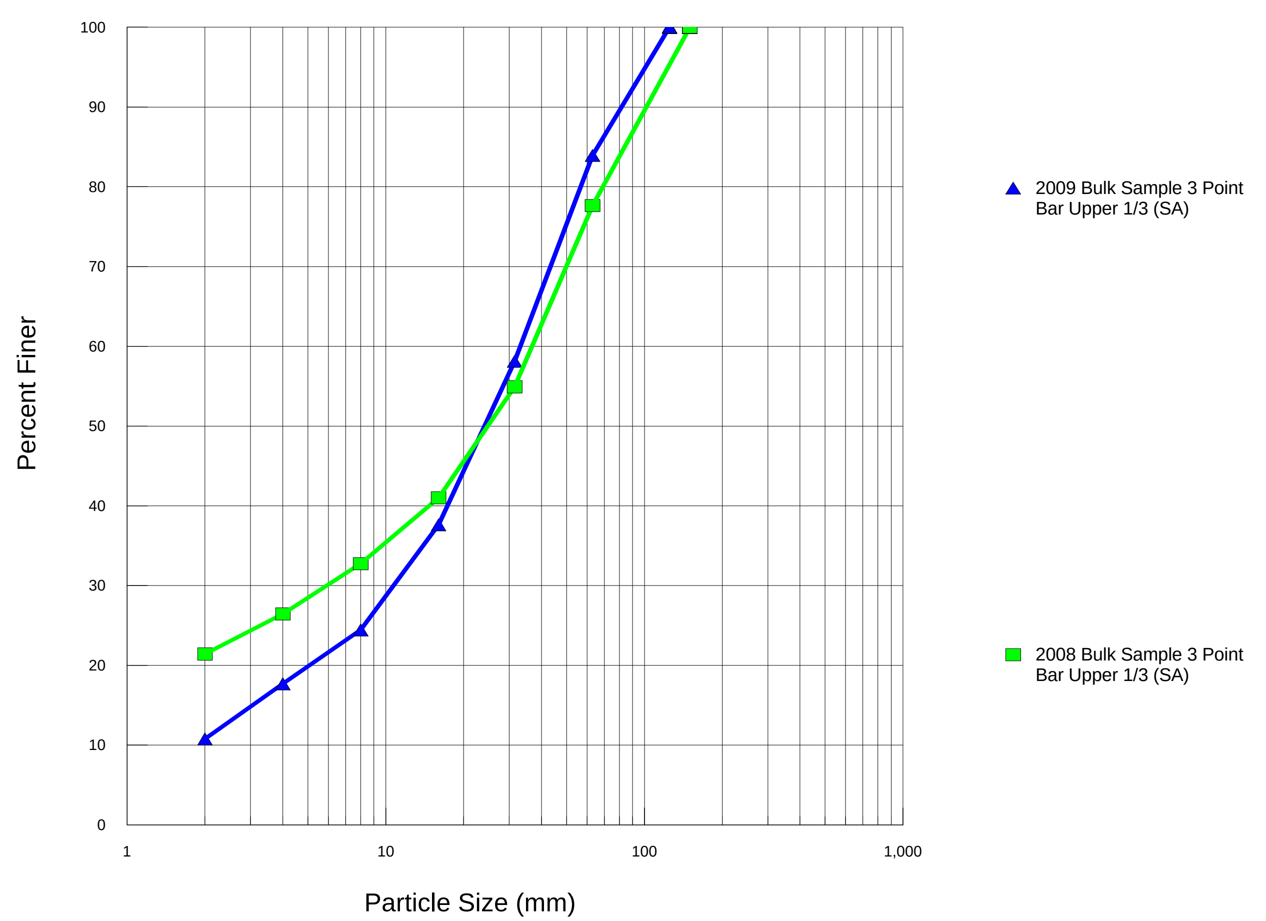
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 3: Point Bar Upper 1/3
Survey Dates: 11/11/2008 & 9/2/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
63	369	1049
31.5	6946	9100
16	4252	7229
8	2523	4649
4	1928	2381
2	1531	2438
PAN	6549	3799
TOTAL	30562	35266

	2008	2009
D16 (mm)	0	4
D35 (mm)	10.2	14.4
D50 (mm)	26.0	25.4
D84 (mm)	87.7	63.3
D95 (mm)	130.5	105.7
D100 (mm)	150.0	125.0
Silt/Clay (%)	0	0
Sand (%)	21.4	10.8
Gravel (%)	56.6	73.5
Cobble (%)	22.0	15.7
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008 Size(mm)	2008 Weight	2009 Size(mm)	2009 Weight
Particle 1	150	6237	125	4167
Particle 2	77	227	49	454



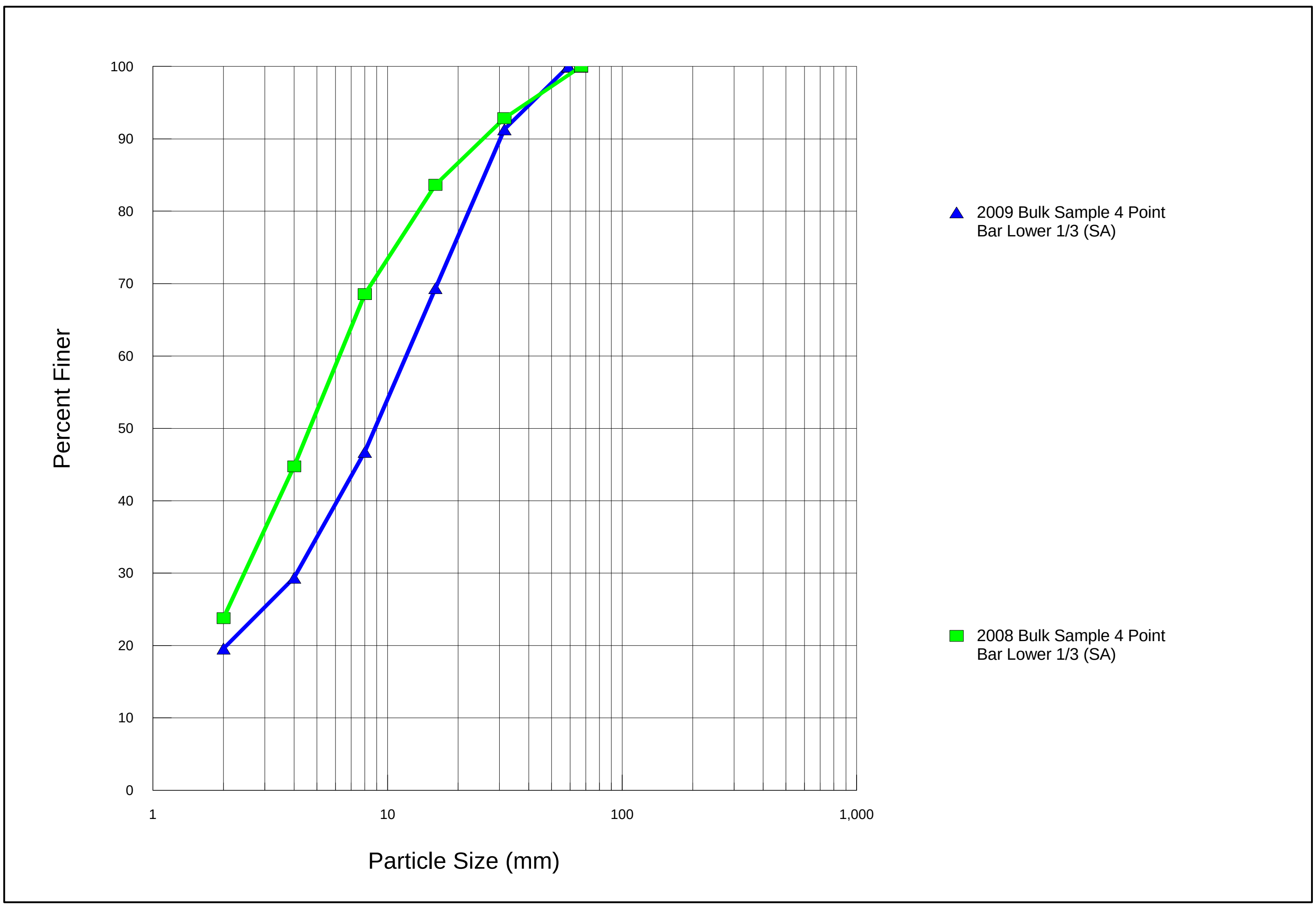
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 4: Point Bar Lower 1/3
Survey Dates: 11/11/2008 & 9/3/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
31.5	283	397
16	1021	2863
8	1673	2948
4	2637	2268
2	2325	1276
PAN	2637	2552
TOTAL	11086	13041

	2008	2009
D16 (mm)	0	0
D35 (mm)	3.1	5.3
D50 (mm)	4.9	9.2
D84 (mm)	16.6	26.3
D95 (mm)	42.2	43.2
D100 (mm)	67.0	59.0
Silt/Clay (%)	0	0
Sand (%)	23.8	19.6
Gravel (%)	75.8	80.4
Cobble (%)	0.4	0.0
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008		2009	
	Size(mm)	Weight	Size(mm)	Weight
Particle 1	67	482	59	652
Particle 2	40	28.3	48	85



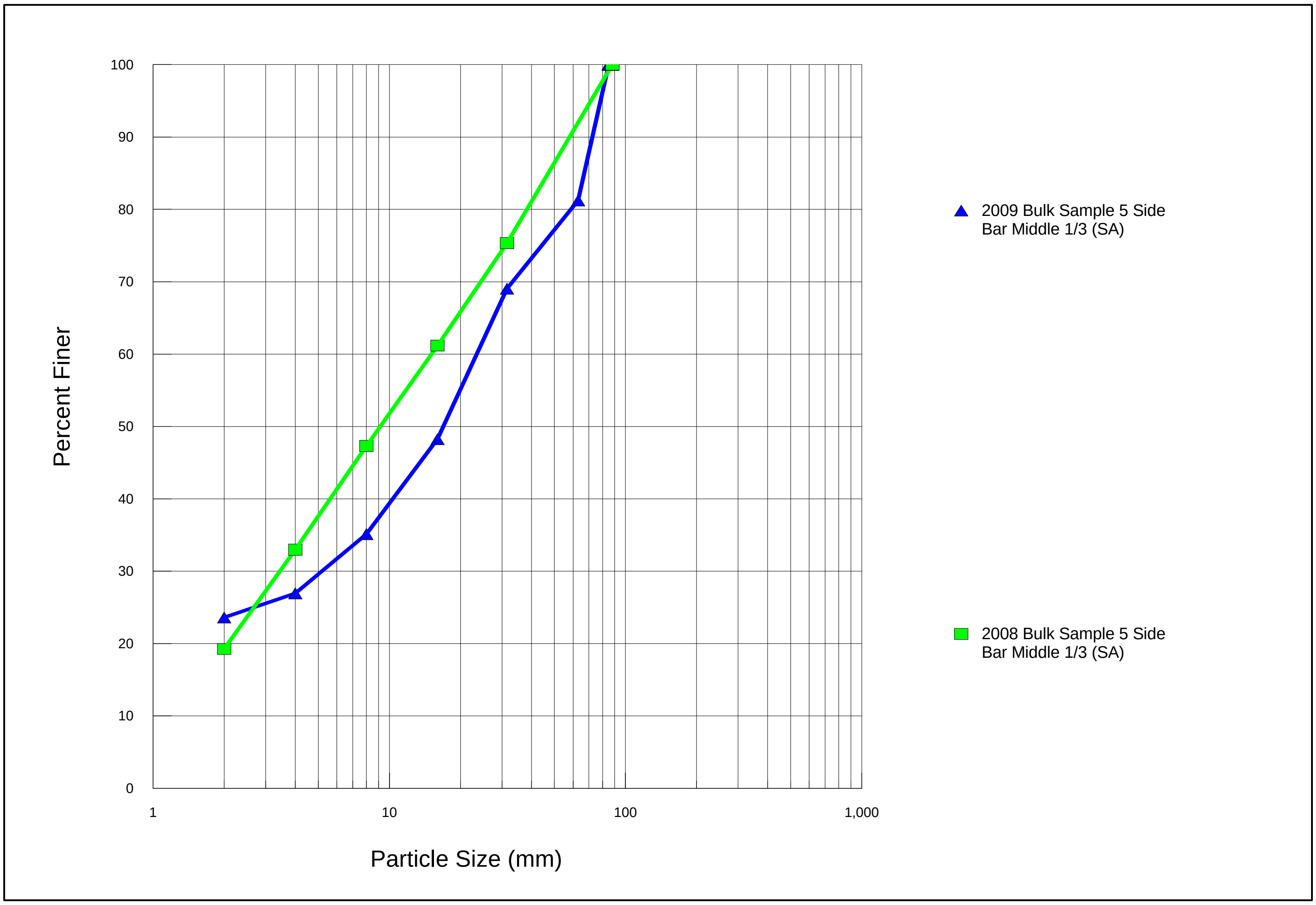
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 5: Side Bar Mid 1/3
Survey Dates: 11/10/2008 & 9/3/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
63	----	567
31.5	2495	2580
16	2608	4394
8	2551	2778
4	2637	1729
2	2523	709
PAN	3544	4990
TOTAL	18399	21149

	2008	2009
D16 (mm)	0	0
D35 (mm)	4.6	7.9
D50 (mm)	9.6	17.3
D84 (mm)	51.3	66.2
D95 (mm)	76.5	79.1
D100 (mm)	88.0	85.0
Silt/Clay (%)	0	0
Sand (%)	19.3	23.6
Gravel (%)	73.1	58.6
Cobble (%)	7.6	17.8
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008 Size(mm)	2008 Weight	2009 Size(mm)	2009 Weight
Particle 1	88	1616	85	2778
Particle 2	64	425	80	624



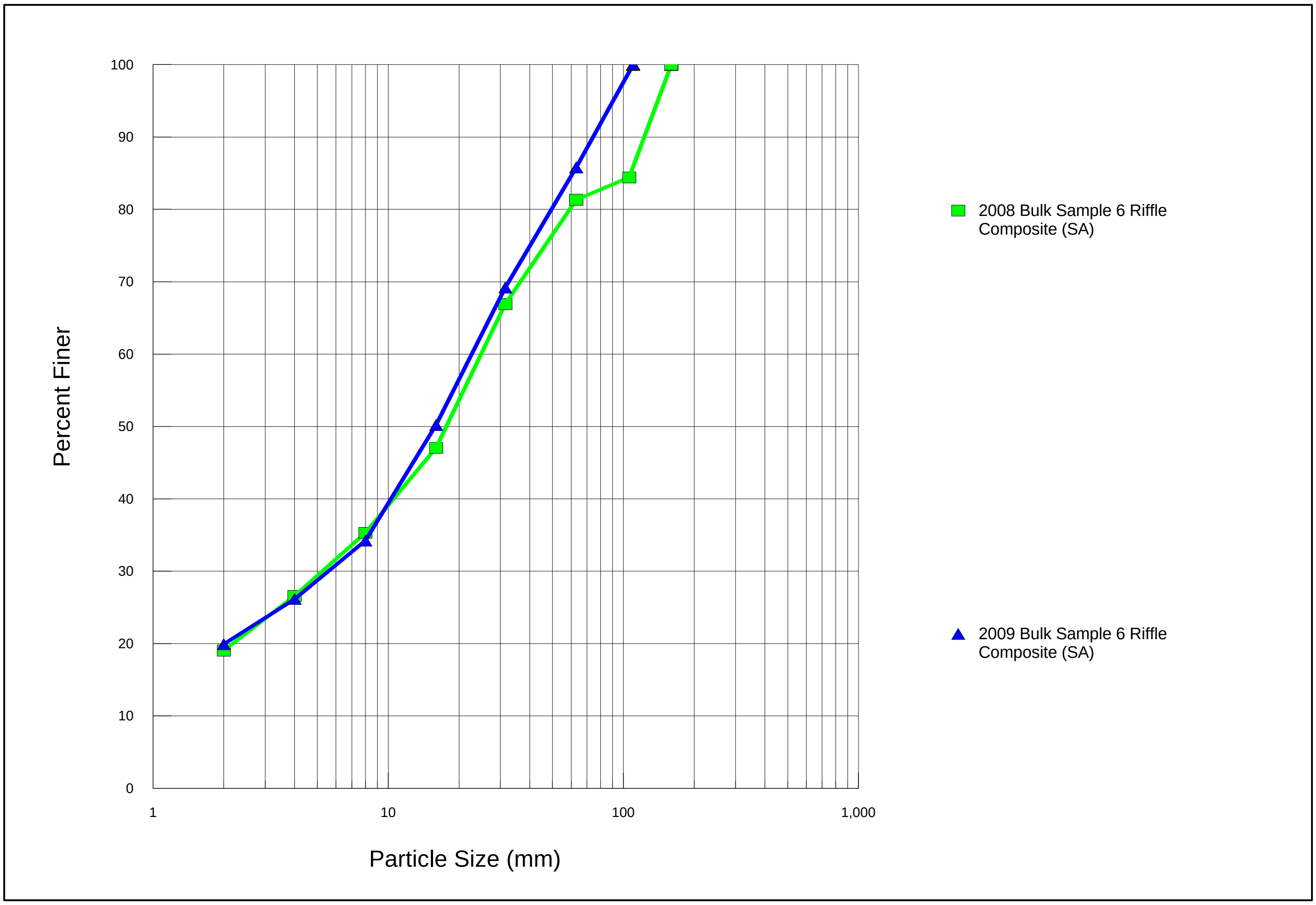
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 6: Riffle Composite
Survey Dates: 11/11/2008 & 9/3/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
106	794	----
63	1021	397
31.5	4763	4536
16	6577	5188
8	3884	4366
4	2892	2211
2	2495	1701
PAN	6294	5443
TOTAL	33085	27329

	2008	2009
D16 (mm)	0	0
D35 (mm)	7.9	8.4
D50 (mm)	18.3	15.9
D84 (mm)	100.3	59.6
D95 (mm)	142.7	93.5
D100 (mm)	160.0	110.0
Silt/Clay (%)	0	0
Sand (%)	19.0	19.9
Gravel (%)	62.4	66.3
Cobble (%)	18.6	13.8
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008		2009	
	Size(mm)	Weight	Size(mm)	Weight
Particle 1	160	3600	110	2977
Particle 2	85	765	78	510



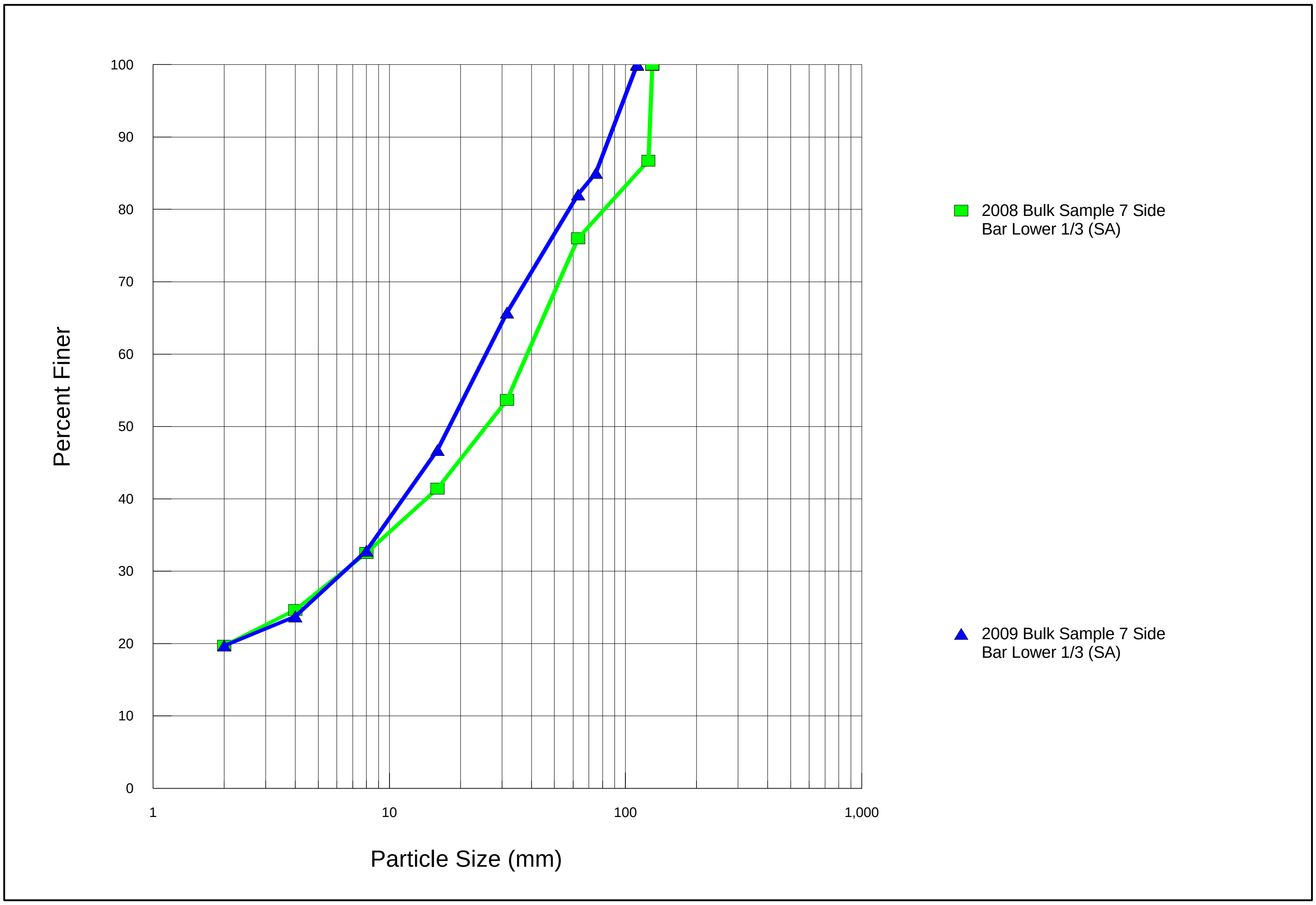
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 7: Side Bar Lower 1/3
Survey Dates: 11/10/2008 & 9/3/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
125	1304	----
75	----	1049
63	3827	822
31.5	7966	4479
16	4366	5216
8	3175	3827
4	2807	2495
2	1758	1106
PAN	7031	5415
TOTAL	35665	27471

	2008	2009
D16 (mm)	0	0
D35 (mm)	10.2	9.3
D50 (mm)	26.9	18.7
D84 (mm)	109.3	70.9
D95 (mm)	128.1	99.6
D100 (mm)	130.0	112.0
Silt/Clay (%)	0	0
Sand (%)	19.7	19.7
Gravel (%)	56.5	62.6
Cobble (%)	23.8	17.7
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008 Size(mm)	2008 Weight	2009 Size(mm)	2009 Weight
Particle 1	130	3289	112	2369
Particle 2	70	142	76	369



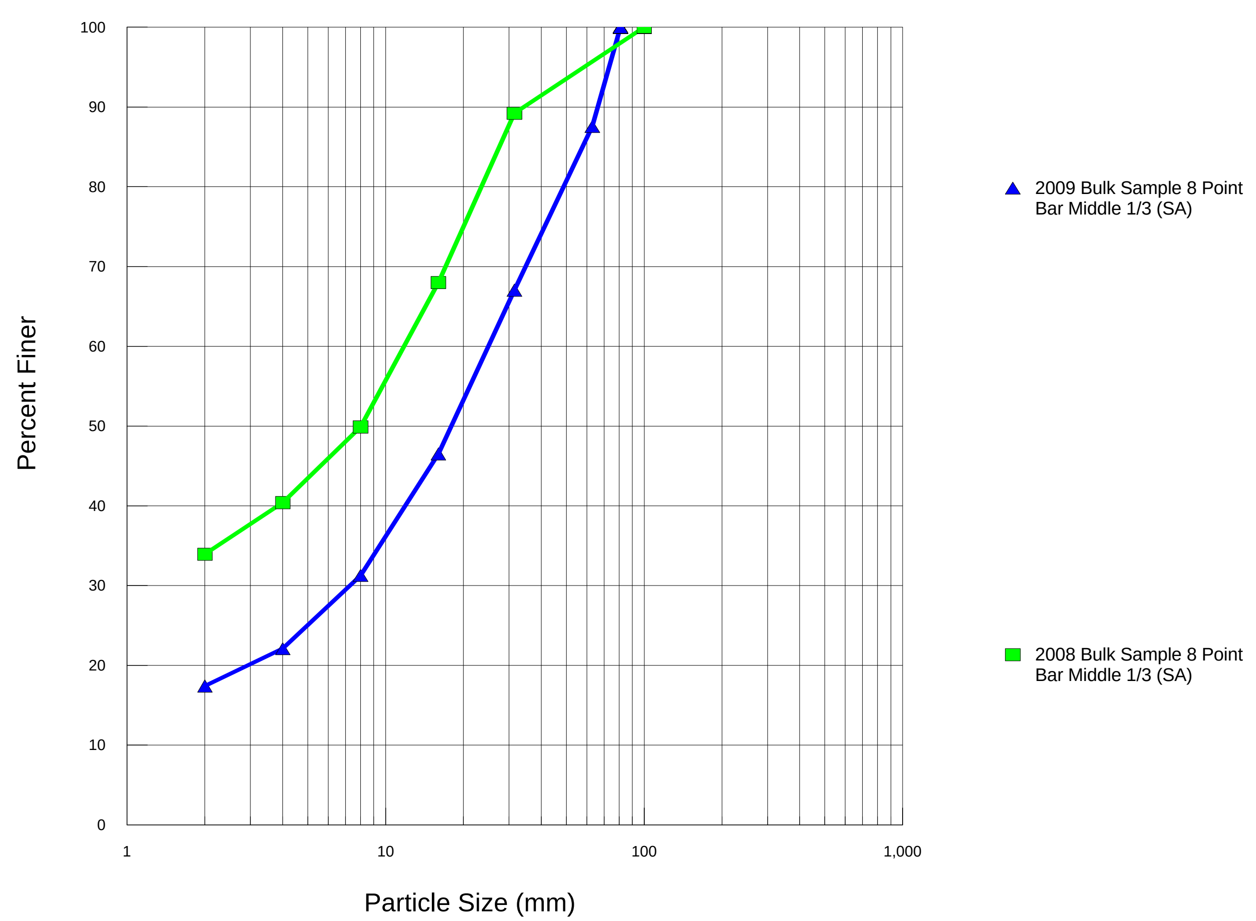
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 8: Point Bar Middle 1/3
Survey Dates: 11/10/2008 & 9/4/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
63	----	340
31.5	1871	3742
16	5018	3742
8	4281	2778
4	2240	1673
2	1531	851
PAN	8023	3175
TOTAL	23644	18229

	2008	2009
D16 (mm)	0	0
D35 (mm)	2.3	10.0
D50 (mm)	8.1	18.6
D84 (mm)	27.7	57.5
D95 (mm)	68.3	73.8
D100 (mm)	100.0	81.0
Silt/Clay (%)	0	0
Sand (%)	33.9	17.4
Gravel (%)	61.9	70.9
Cobble (%)	4.2	11.7
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008 Size(mm)	2008 Weight	2009 Size(mm)	2009 Weight
Particle 1	100	198	81	1701
Particle 2	60	482	74	227



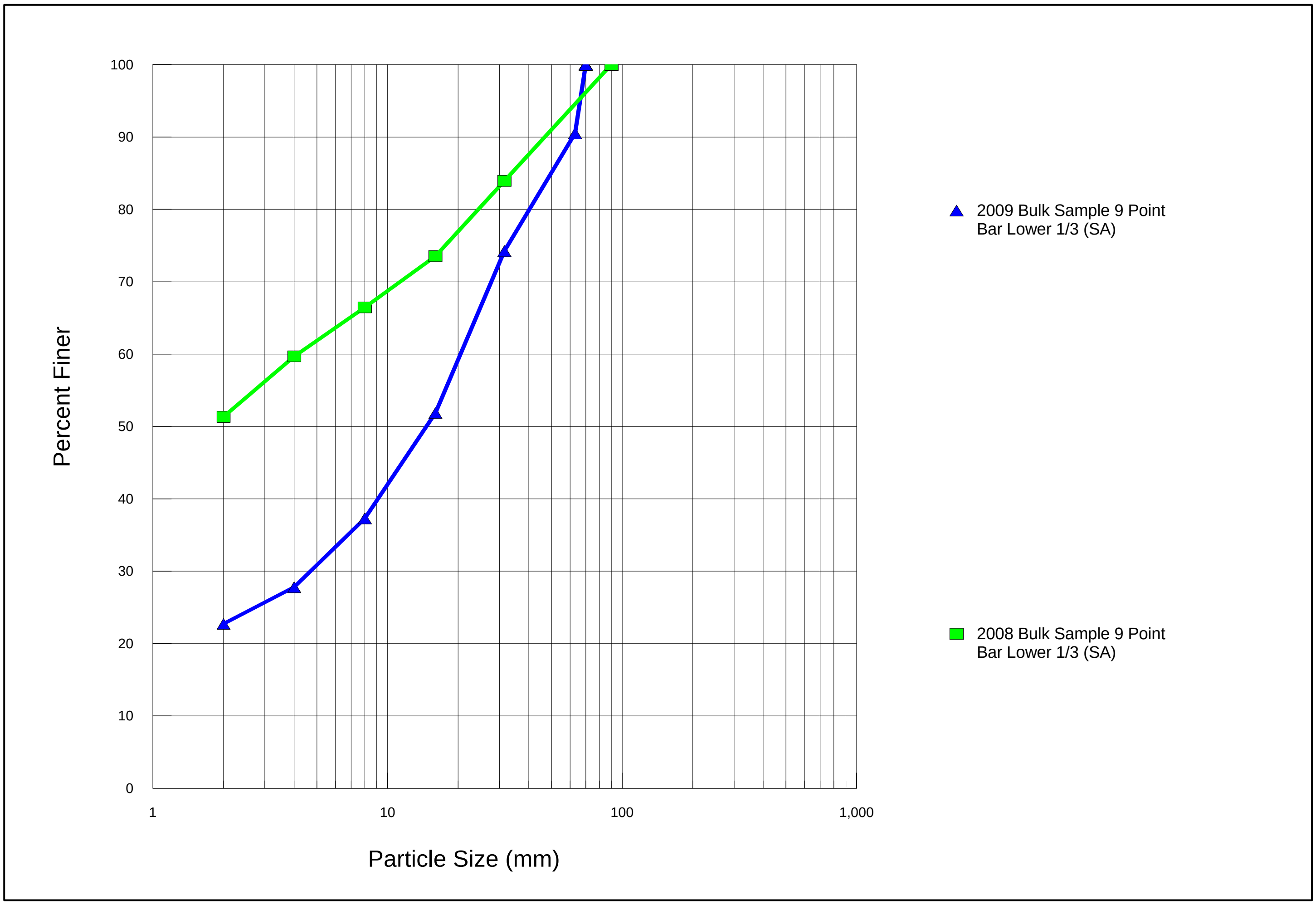
RIVERMORPH PARTICLE SUMMARY

River Name: Little Miami River
Reach Name: RM 4.5 to RM 7.0
Sample Name: Bulk Sample 9: Point Bar Middle 1/3
Survey Dates: 11/10/2008 & 9/4/2009

SIEVE (mm)	2008 NET WT	2009 NET WT
63	----	567
31.5	1673	2722
16	1871	3742
8	1276	2438
4	1219	1588
2	1503	851
PAN	9242	3799
TOTAL	18003	16728

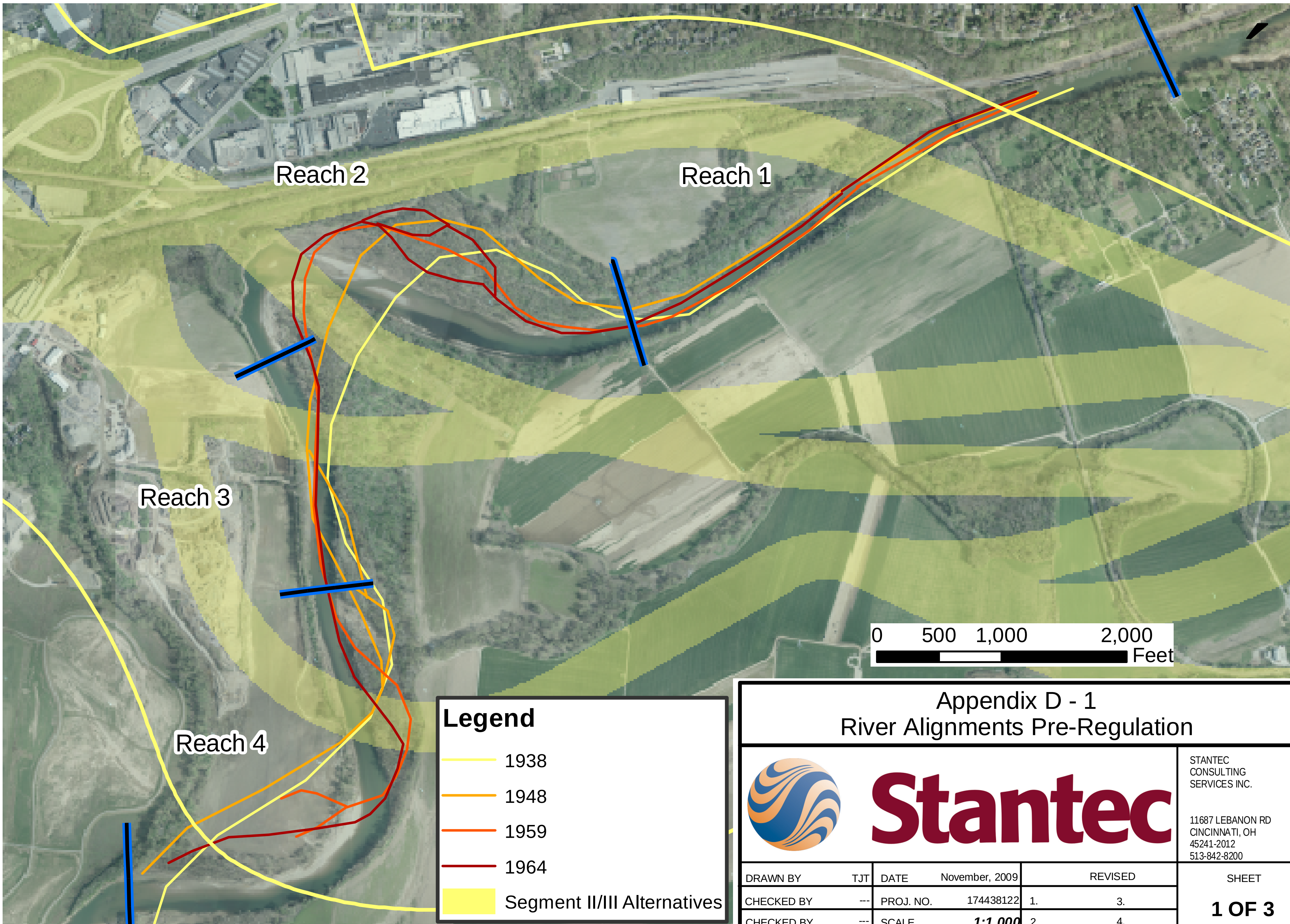
	2008	2009
D16 (mm)	0	0
D35 (mm)	0	7.0
D50 (mm)	0	15.0
D84 (mm)	31.7	50.4
D95 (mm)	71.8	66.3
D100 (mm)	90.0	70.0
Silt/Clay (%)	0	0
Sand (%)	51.3	22.7
Gravel (%)	43.5	69.2
Cobble (%)	5.2	8.1
Boulder (%)	0	0
Bedrock (%)	0	0

Largest Surface Particles	2008 Size(mm)	2008 Weight	2009 Size(mm)	2009 Weight
Particle 1	90	794	70	624
Particle 2	79	425	45	397



Appendix D

Historical Mapping



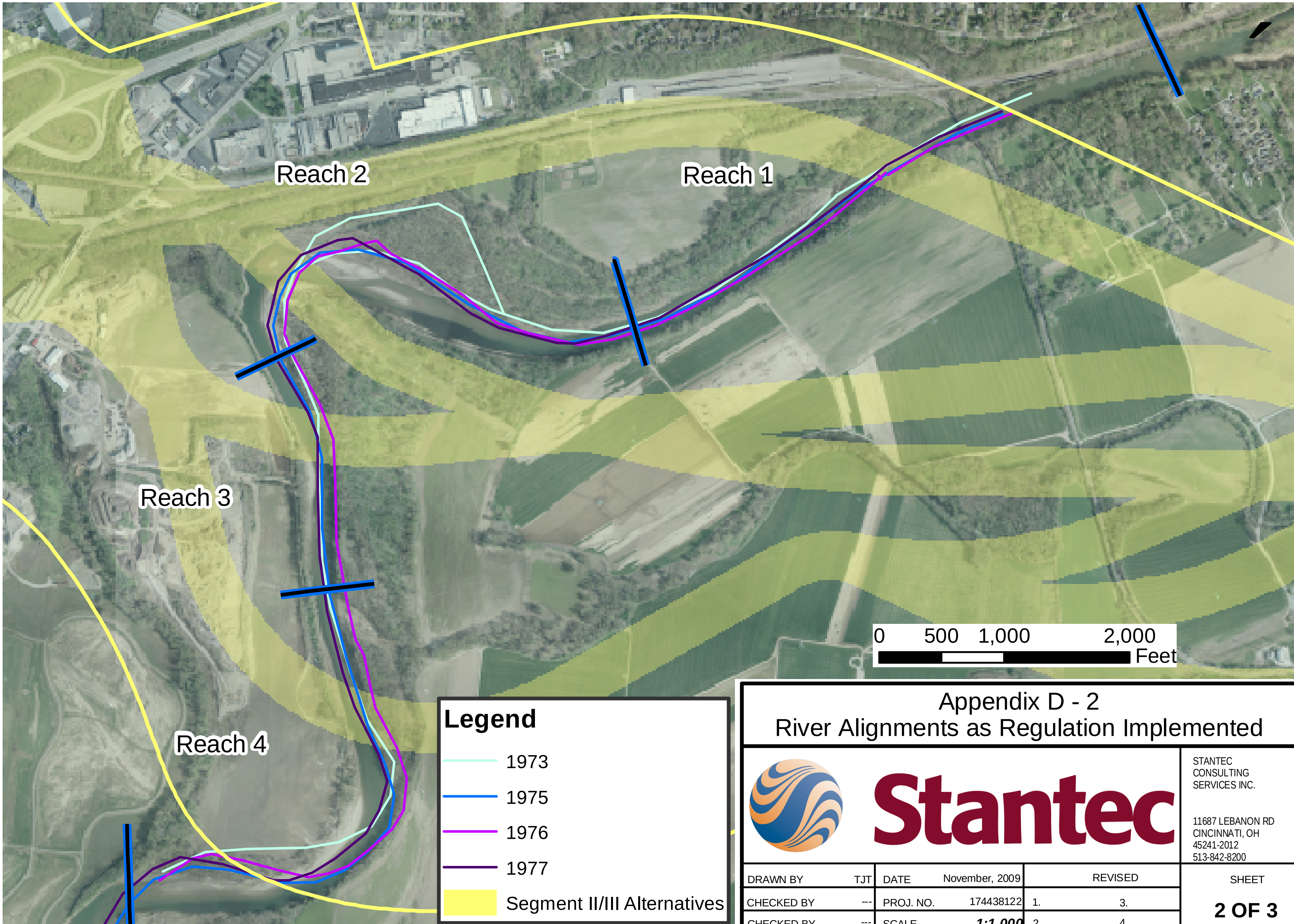
Appendix D - 1
River Alignments Pre-Regulation

Stantec

STANTEC CONSULTING SERVICES INC.

11687 LEBANON RD
CINCINNATI, OH
45241-2012
513-842-8200

DRAWN BY	TJT	DATE	November, 2009	REVISED		SHEET
CHECKED BY	---	PROJ. NO.	174438122	1.	3.	1 OF 3
CHECKED BY	---	SCALE	1:1,000	2.	4.	

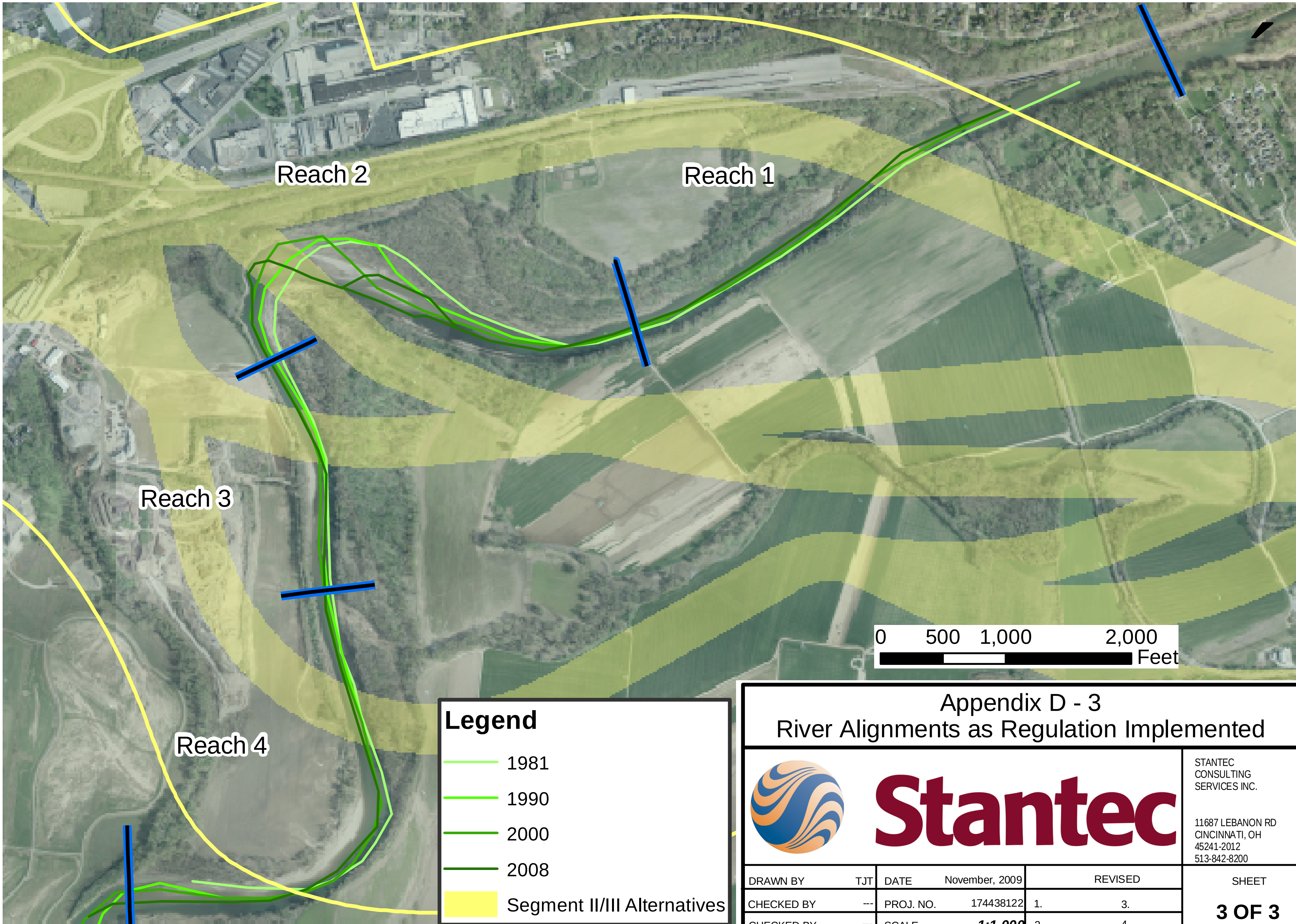


Appendix D - 2
River Alignments as Regulation Implemented

Stantec

STANTEC CONSULTING SERVICES INC.
11687 LEBANON RD
CINCINNATI, OH
45241-2012
513-842-8200

DRAWN BY	TJT	DATE	November, 2009	REVISED		SHEET
CHECKED BY	---	PROJ. NO.	174438122	1.	3.	2 OF 3
CHECKED BY	---	SCALE	*1:1,000*	2.	4.	



Appendix D - 3
River Alignments as Regulation Implemented

Stantec

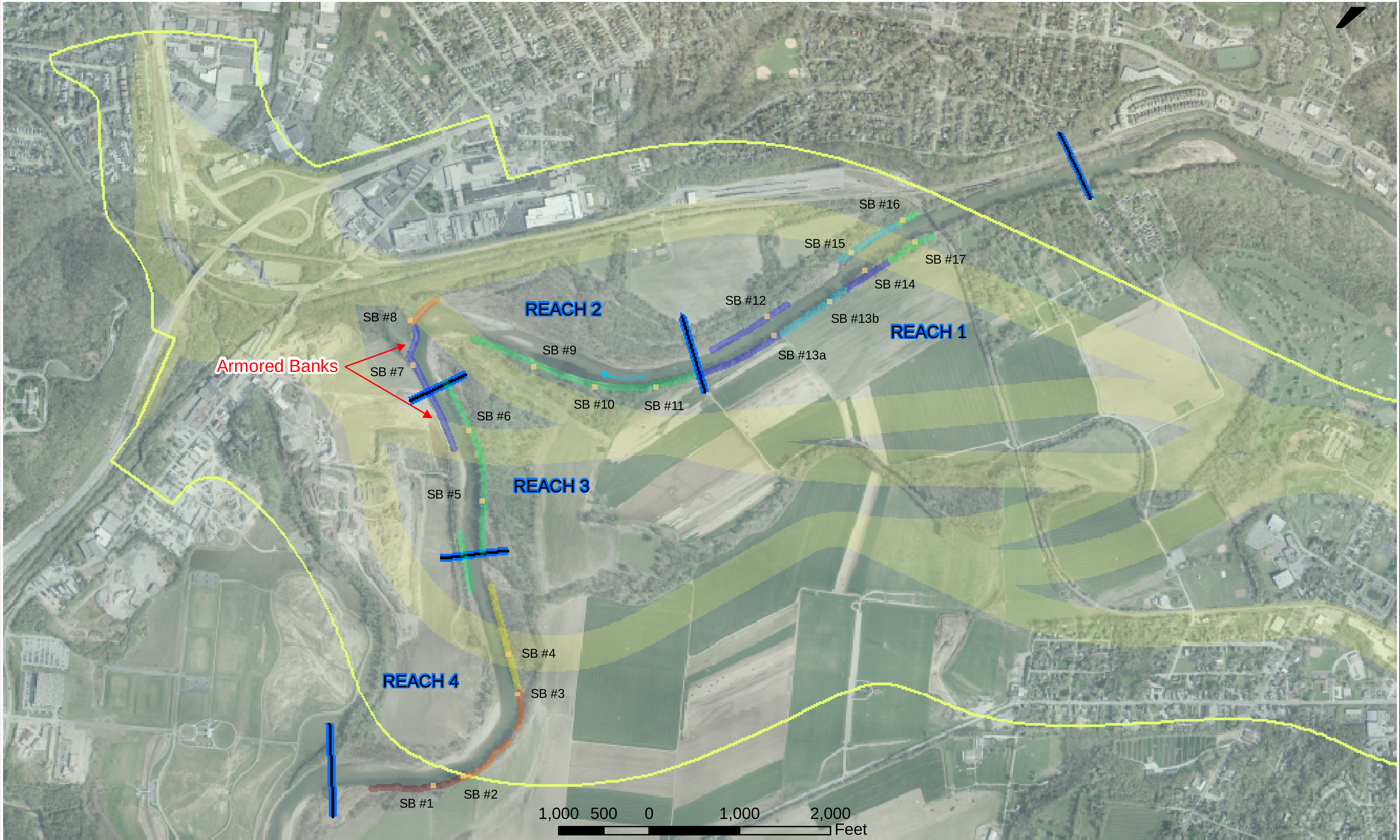
STANTEC CONSULTING SERVICES INC.
11687 LEBANON RD
CINCINNATI, OH
45241-2012
513-842-8200

DRAWN BY	TJT	DATE	November, 2009	REVISED		SHEET
CHECKED BY	---	PROJ. NO.	174438122	1.	3.	3 OF 3
CHECKED BY	---	SCALE	*1:1,000*	2.	4.	

Appendix E

Bank Analyses

- Bank Erodibility Drawing E-1
- Study Banks



Legend

Study Area	Segment II/III Alternatives	Study Banks	Measured Erosion Rates (ft/yr)

0.00 - 0.01	0.01 - 0.10	0.10 - 0.50	0.50 - 1.00	1.00 - 2.00	2.00 - 3.00

STANTEC
CONSULTING
SERVICES INC.
11687 Lebanon Rd.
Cincinnati, Ohio
45241-2012
513-842-8200

Stantec

Appendix E - Bank Erodibility Drawing

Entran
Little Miami River Riparian Crossings Analyses
Eastern Corridor Priority Part B - Segment II/III
Hamilton and Clermont Counties Ohio

PROJECT NO	174438122
DATE	November, 2009
DRAWN BY	TJT
CHECKED BY	WHL
CHECKED BY	SDP
SCALE	1" = 1000'
REVISED	
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

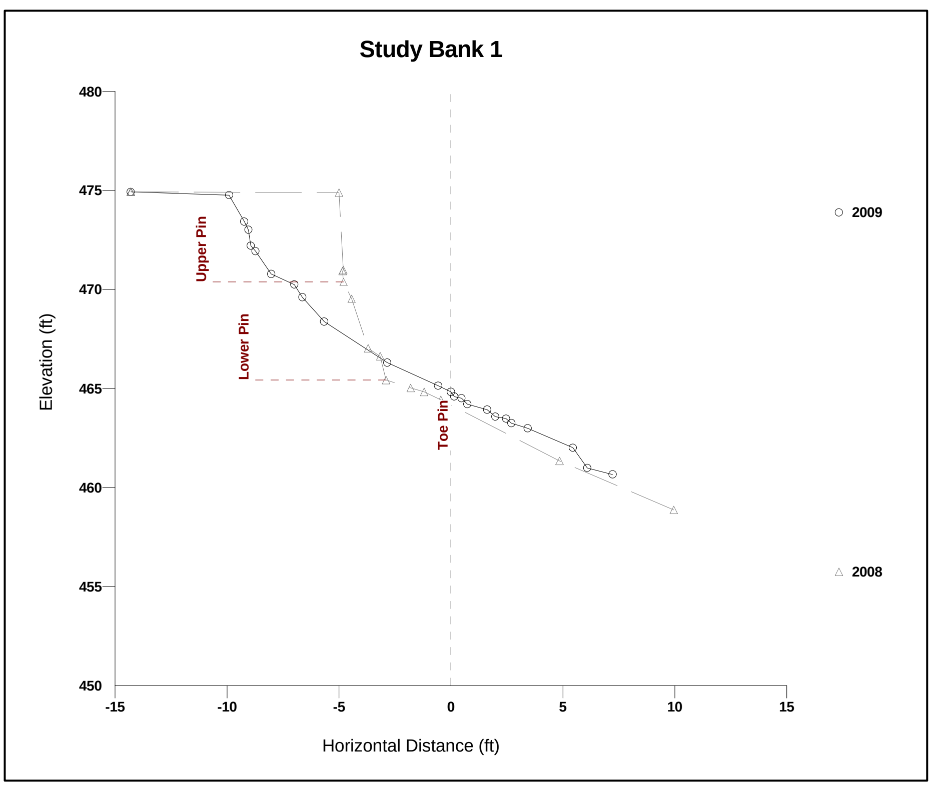
SHEET

E - 1

Study Bank 1

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 1** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

						BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)						
Study Bank Height (ft) =	13.9 (A)	Bankfull Height (ft) =	8.06 (B)	(A) / (B) =	1.7246 (C)	6.57
Root Depth / Study Bank Height (E)						
Root Depth (ft) =	5 (D)	Study Bank Height (ft) =	13.9 (A)	(D) / (A) =	0.35971 (E)	5.3
Weighted Root Density (G)						
		Root Density as % =	1 (F)	(F) x (E) =	0.35971 (G)	10
Bank Angle (H)						
				Bank Angle as *Degrees* =	79.3 (H)	5.7
Surface Protection (I)						
				Surface Protection as % =	5 (I)	10

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: 1

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 2

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score	
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Adjective Rating	High
						Total Score	40.7

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 1** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})...	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})............................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient...	Level IV	Validation

Level I

(1)	Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
	Extensive deposition (continuous, cross-channel)... ....NBS = Extreme
	Chute cutoffs, down-valley meander migration, converging flow.......................................NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress
Moderate

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**14.6**	**8.3**	**1.76**	**Moderate**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting values to a Near-Bank Stress (NBS) rating

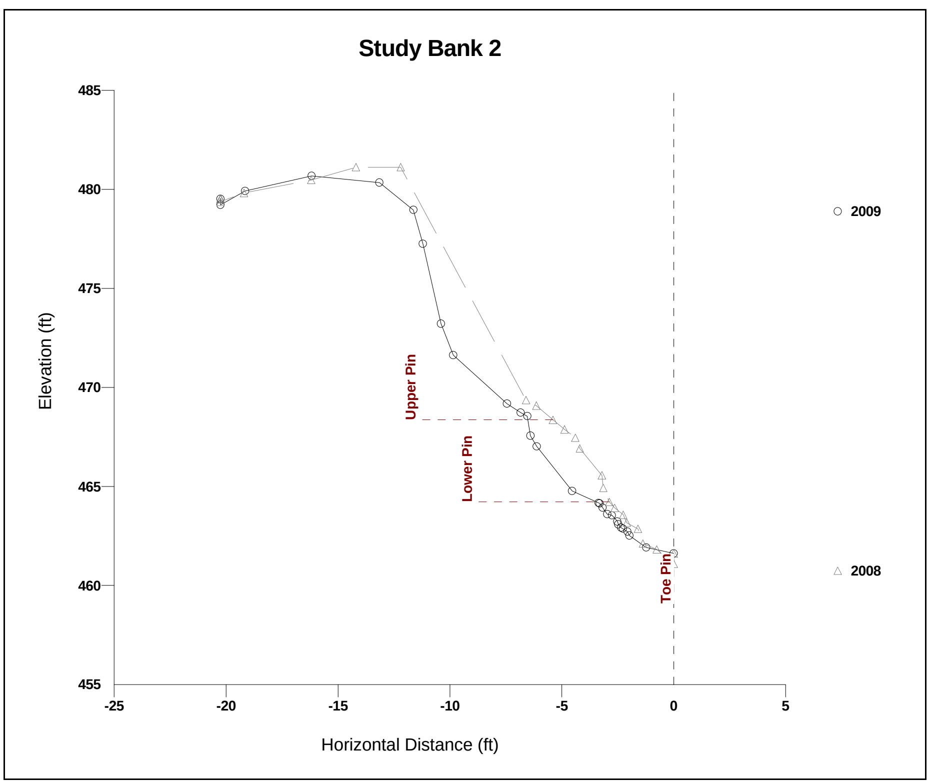
Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Moderate**

Study Bank 2

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River**	Location: **RM 4.5 - 7.0**
Station: **Study Bank 2**	Observers: **SDP, TJT**
Date: **12/10/08** Stream Type: **C 4c-**	Valley Type: **VIII**

					BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 19.48 (A)	Bankfull Height (ft) = 8.08 (B)	(A) / (B) =	2.41089 (C)	8.44
Root Depth / Study Bank Height (E)	Root Depth (ft) = 0.5 (D)	Study Bank Height (ft) = 19.48 (A)	(D) / (A) =	0.02567 (E)	10
Weighted Root Density (G)		Root Density as % = 10 (F)	(F) x (E) =	0.25667 (G)	10
Bank Angle (H)			Bank Angle as *Degrees* =	61.5 (H)	4.05
Surface Protection (I)			Surface Protection as % =	1 (I)	10
Bank Material Adjustment					5
Stratification Adjustment					4

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Extreme** 51.5

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River**	Location: **RM 4.5 - 7.0**	
Station: **Study Bank 2**	Stream Type: **C 4c-**	Valley Type: **VIII**
Observers: **SDP, TJT**		Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)................................	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous................................NBS = High / Very High
- Extensive deposition (continuous, cross-channel)...NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow....................................NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	Ratio R_c / W_{bkf}	Near-Bank Stress (NBS)
	863	**335.6**	**2.57**	**Low**

(3)	Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)

(4)	Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Low

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	11.2	**8.3**	**1.35**	**Low**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

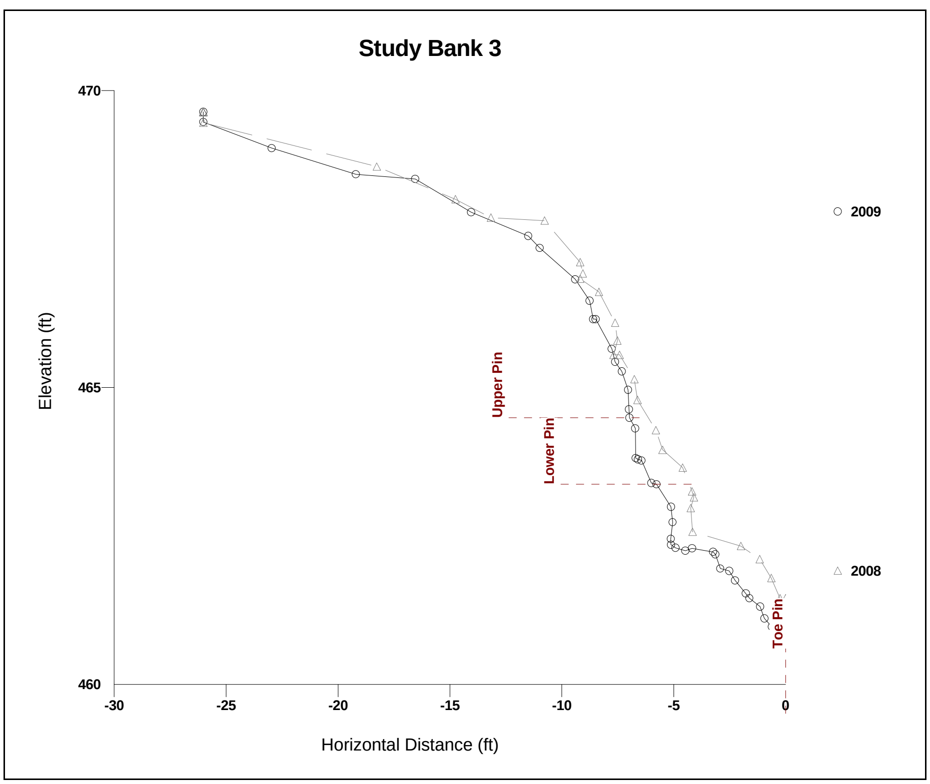
Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Low**

Study Bank 3

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River**		Location: **RM 4.5 - 7.0**	
Station: **Study Bank 3**		Observers: **SDP, TJT**	
Date: **12/10/08**	Stream Type: **C 4c-**	Valley Type: **VIII**	

Variable	Input 1	Value	Input 2	Value	Formula	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) =	7.96 (A)	Bankfull Height (ft) =	8.85 (B)	(A) / (B) =	0.89944 (C)	0.1
Root Depth / Study Bank Height (E)	Root Depth (ft) =	1 (D)	Study Bank Height (ft) =	7.96 (A)	(D) / (A) =	0.12563 (E)	8.11
Weighted Root Density (G)			Root Density as % =	20 (F)	(F) x (E) =	2.51256 (G)	10
Bank Angle (H)					Bank Angle as *Degrees* =	28.4 (H)	2.36
Surface Protection (I)					Surface Protection as % =	50 (I)	4.32

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: 10

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**High** / **34.9**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 3** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})...	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf}).....................	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})............................	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
Extensive deposition (continuous, cross-channel).. ....NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow.......................................NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Low

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
12.27	**8.3**	**1.48**	**Low**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

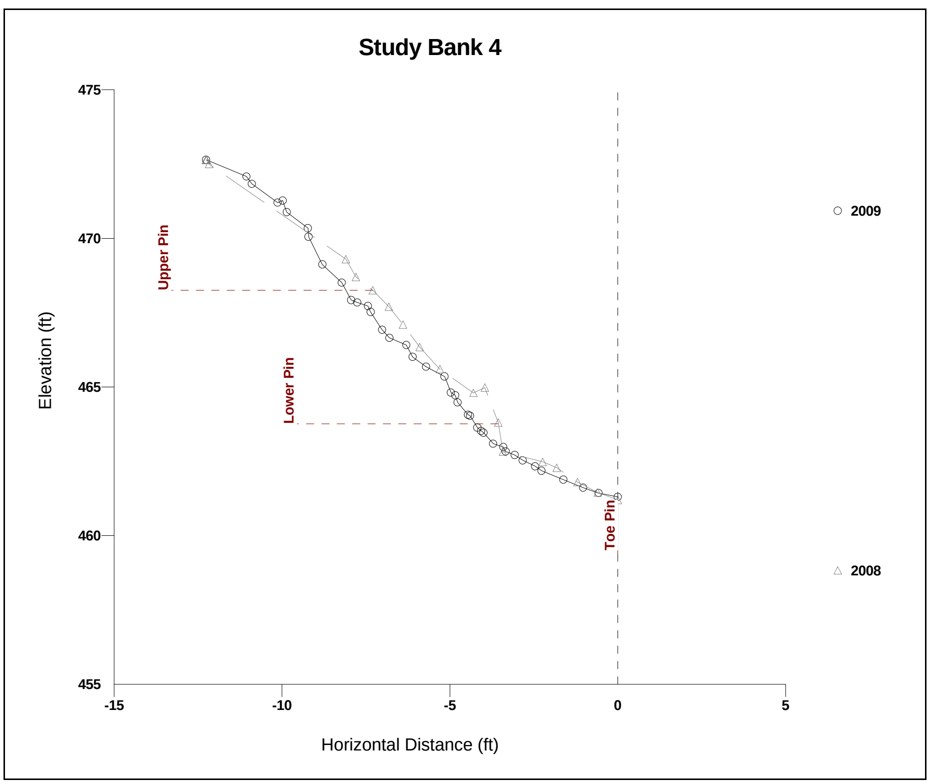
Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **Low**

Study Bank 4

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 4** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	11.5 (A)	Bankfull Height (ft) =	9.4 (B)	(A) / (B) =	1.2234 (C)	BEHI Score (Fig. 5-19): 4.13

Root Depth / Study Bank Height (E)

Root Depth (ft) =	8.5 (D)	Study Bank Height (ft) =	11.5 (A)	(D) / (A) =	0.7391 (E)	2.73

Weighted Root Density (G)

Root Density as % =	10% (F)	(F) x (E) =	7.3913 (G)	8.73

Bank Angle (H)

Bank Angle as *Degrees* =	48 (H)	3.32

Surface Protection (I)

Surface Protection as % =	30% (I)	5.9

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 6

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	High / 30.8

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 4** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I — **(1)**

Transverse and/or central bars-short and/or discontinuous.............................NBS = High / Very High
Extensive deposition (continuous, cross-channel).......................................NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow...............................NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Low

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	12.1	**8.3**	**1.46**	**Low**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

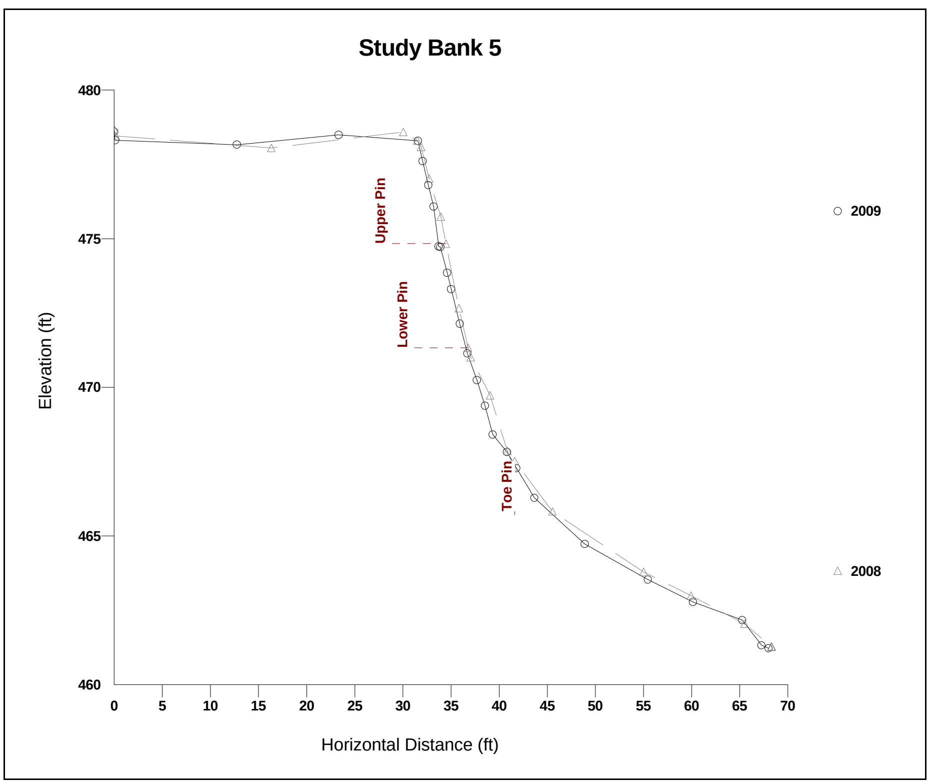
Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Low**

Study Bank 5

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 5** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

Variable	Input 1		Input 2		Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) =	10.78 (A)	Bankfull Height (ft) =	4.03 (B)	(A) / (B) =	2.6749 (C)	8.81
Root Depth / Study Bank Height (E)	Root Depth (ft) =	9.28 (D)	Study Bank Height (ft) =	10.78 (A)	(D) / (A) =	0.8609 (E)	2.15
Weighted Root Density (G)			Root Density as % =	10 (F)	(F) x (E) =	8.6085 (G)	8.6
Bank Angle (H)					Bank Angle as *Degrees* =	43 (H)	3.07
Surface Protection (I)					Surface Protection as % =	20 (I)	7.22

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: **2**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: **5**

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**High** / **36.9**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 5** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S).......................................	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
Extensive deposition (continuous, cross-channel).. ....NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow......................................NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Moderate

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	14.08	**8.3**	**1.7**	**Moderate**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

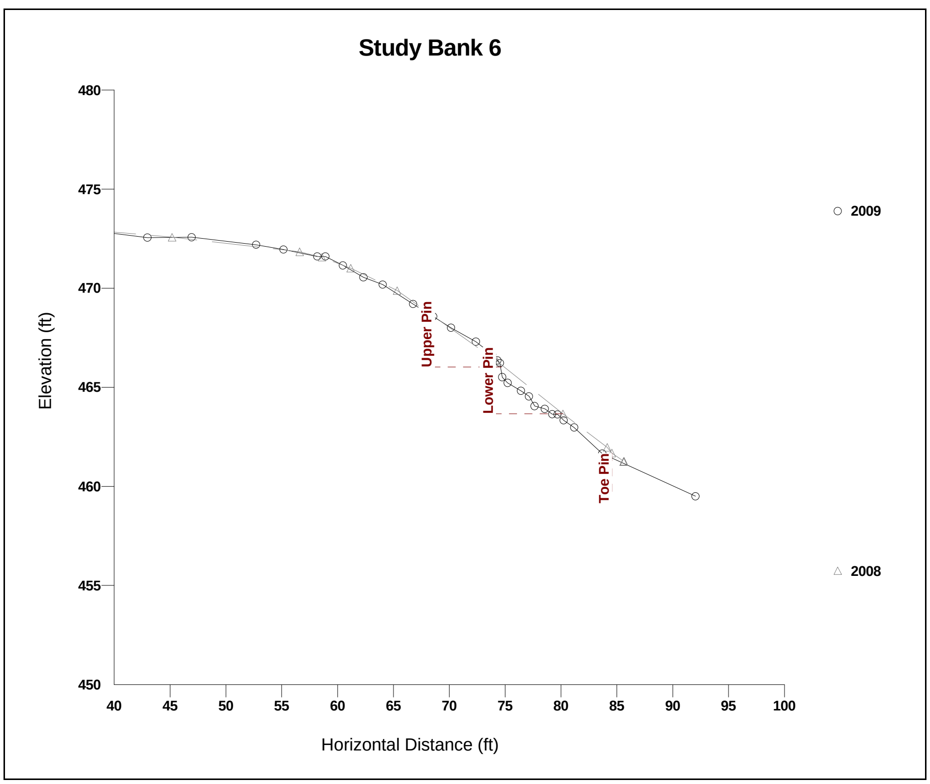
Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Moderate**

Study Bank 6

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 6** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

Variable	Inputs	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 10.2 (A); Bankfull Height (ft) = 10.2 (B); (A) / (B) =	1 (C)	1
Root Depth / Study Bank Height (E)	Root Depth (ft) = 0.5 (D); Study Bank Height (ft) = 10.2 (A); (D) / (A) =	0.04902 (E)	9
Weighted Root Density (G)	Root Density as % = 20 (F); (F) x (E) =	0.98039 (G)	10
Bank Angle (H)	Bank Angle as *Degrees* =	23 (H)	2.1
Surface Protection (I)	Surface Protection as % =	80 (I)	1.9

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: 10

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and **Total Score**: **High** 34.0

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River**	Location: **Rm 4.5 - 7.0**	
Station: **Study Bank 6**	Stream Type: **C 4c-**	Valley Type: **VIII**
Observers: **SDP, TJT**		Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S).......................................	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})...........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)	Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
	Extensive deposition (continuous, cross-channel).. ....NBS = Extreme
	Chute cutoffs, down-valley meander migration, converging flow.......................................NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
High

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)				
	15.85	**8.3**	**1.91**	**High**				
(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

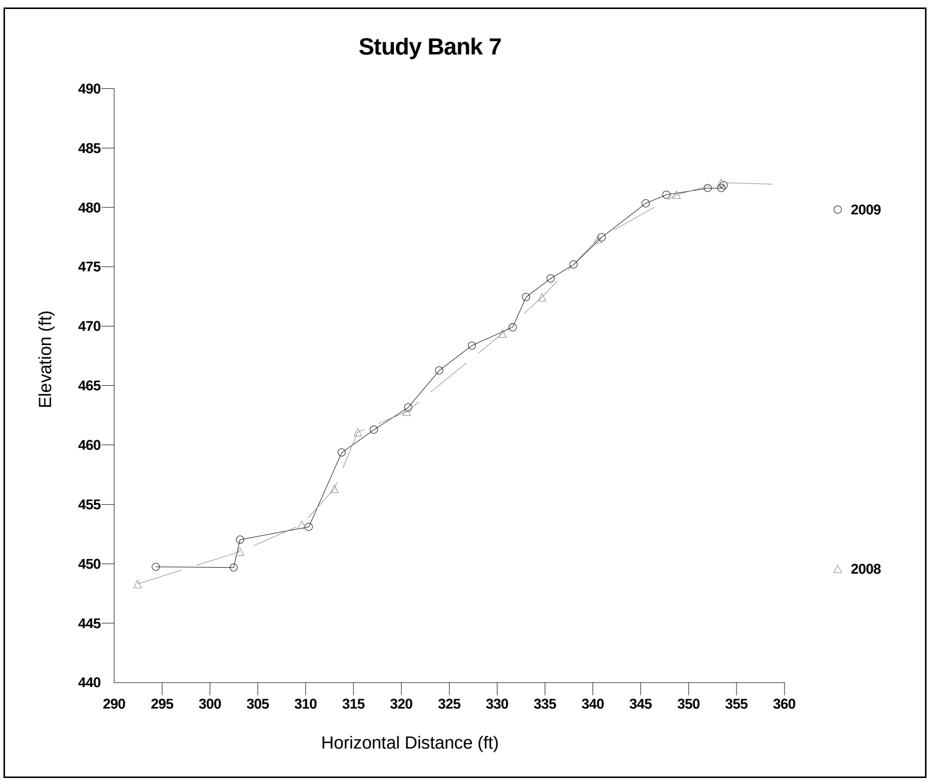
Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**High**

Study Bank 7

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream:	**Little Miami River**	Location:	**Rm 4.5 - 7.0**
Station:	**Study Bank 7**	Observers:	**SDP, TJT**
Date:	**12/10/08**	Stream Type: **C 4c-**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	33.8 (A)	Bankfull Height (ft) =	23.6 (B)	(A) / (B) =	1.4322 (C)	**5.46**

Root Depth / Study Bank Height (E)

Root Depth (ft) =	6 (D)	Study Bank Height (ft) =	33.8 (A)	(D) / (A) =	0.17751 (E)	**7.49**

Weighted Root Density (G)

Root Density as % =	20 (F)	(F) x (E) =	3.5503 (G)	**10**

Bank Angle (H)

Bank Angle as *Degrees* =	29 (H)	**2.39**

Surface Protection (I)

Surface Protection as % =	90 (I)	**1.45**

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: **-10**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: **0**

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and **Total Score**: **Low** / **16.8**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River**	Location: **Rm 4.5 - 7.0**	
Station: **Study Bank 7**	Stream Type: **C 4c-**	Valley Type: **VIII**
Observers: **SDP, TJT**		Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)	Transverse and/or central bars-short and/or discontinuous......................NBS = High / Very High
	Extensive deposition (continuous, cross-channel)......................NBS = Extreme
	Chute cutoffs, down-valley meander migration, converging flow......................NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress
Very High

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**23.55**	**8.3**	**2.84**	**Very High**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting values to a Near-Bank Stress (NBS) rating

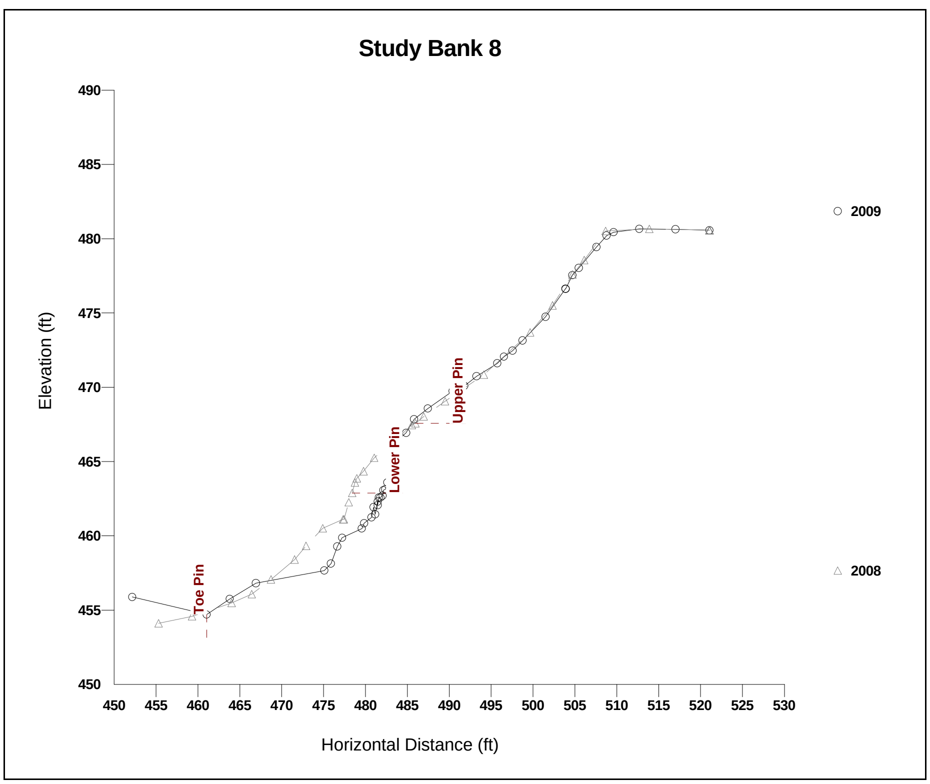
Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Very High**

Study Bank 8

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 8** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	26.41 **(A)**	**Bankfull Height** (ft) =	19.06 **(B)**	(**A**) / (**B**) =	1.38562 **(C)**	**5.2**

Root Depth / Study Bank Height (E)

Root Depth (ft) =	1 **(D)**	**Study Bank Height** (ft) =	26.41 **(A)**	(**D**) / (**A**) =	0.03786 **(E)**	**10**

Weighted Root Density (G)

Root Density as **%** =	10 **(F)**	(**F**) x (**E**) =	0.37864 **(G)**	**10**

Bank Angle (H)

Bank Angle as *Degrees* =	30 **(H)**	**2.44**

Surface Protection (I)

Surface Protection as **%** =	30 **(I)**	**5.9**

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: **0**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: **10**

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Very High** / **43.5**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River**	Location: **RM 4.5 - 7.0**	
Station: **Study Bank 8**	Stream Type: **C 4c-**	Valley Type: **VIII**
Observers: **SDP, TJT**		Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})...	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})...	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})............................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient...	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous..NBS = High / Very High
Extensive deposition (continuous, cross-channel)..NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow...NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
375	**335.6**	**1.12**	**Extreme**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Extreme

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
19.06	**8.3**	**2.3**	**Moderate**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

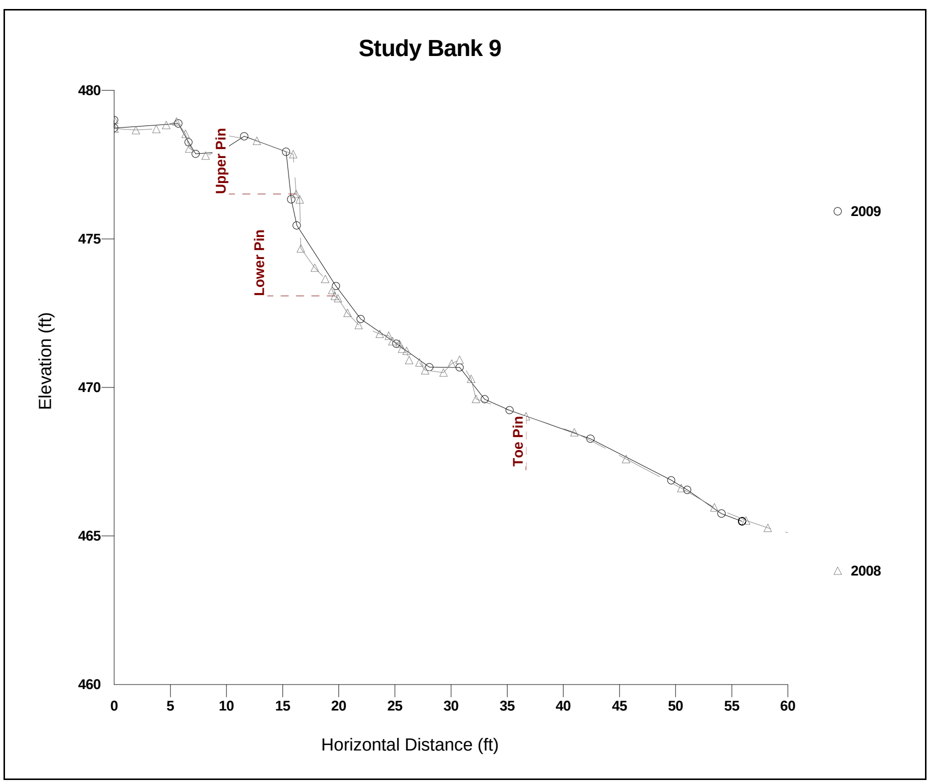
Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Extreme**

Study Bank 9

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 9** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

Variable	Inputs	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 8.55 (A); Bankfull Height (ft) = 4.64 (B)	(A) / (B) =	1.8427 (C)	7.14
Root Depth / Study Bank Height (E)	Root Depth (ft) = 3 (D); Study Bank Height (ft) = 8.55 (A)	(D) / (A) =	0.3509 (E)	5.4
Weighted Root Density (G)	Root Density as % = 7 (F)	(F) x (E) =	2.4561 (G)	10
Bank Angle (H)	Bank Angle as *Degrees* =		35 (H)	2.68
Surface Protection (I)	Surface Protection as % =		25% (I)	6.54

Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 5

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and **Total Score**: **High** / **36.8**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 9** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})...........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
Extensive deposition (continuous, cross-channel).. ....NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow..NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress
Low

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**9.14**	**8.3**	**1.1**	**Low**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting values to a Near-Bank Stress (NBS) rating

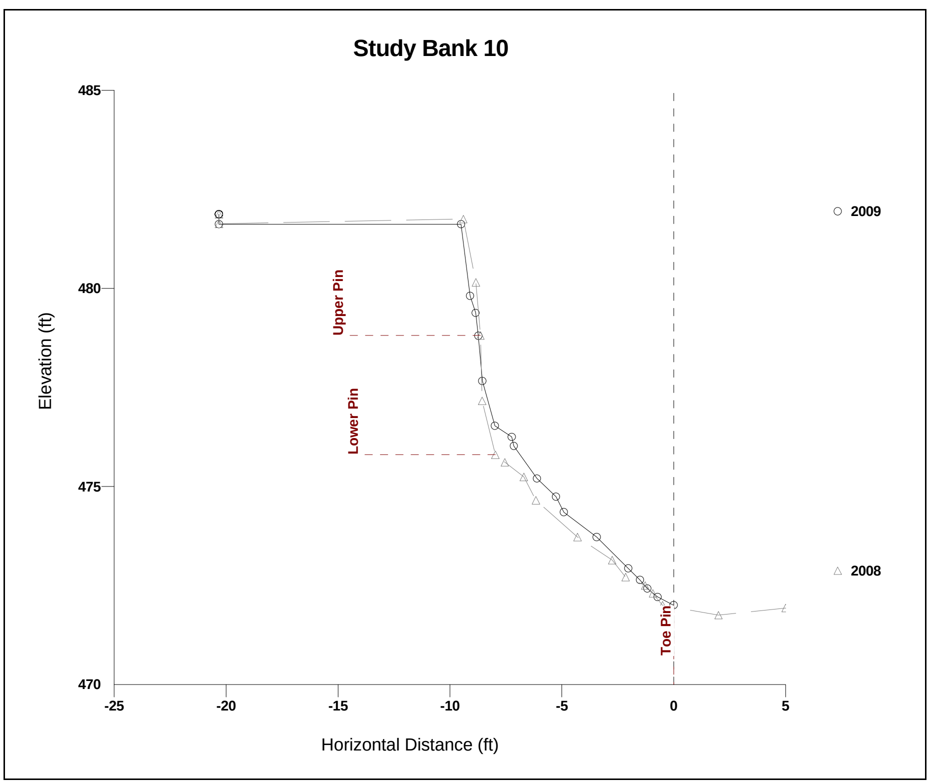
Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Low**

Study Bank 10

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River**		Location: **RM 4.5 - 7.0**	
Station: **Study Bank 10**		Observers: **SDP, TJT**	
Date: **12/10/08**	Stream Type: **C 4c-**	Valley Type: **VIII**	

Variable	Input 1		Input 2		Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) =	9.75 (A)	**Bankfull Height** (ft) =	2 (B)	(A) / (B) =	4.875 (C)	10
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	3 (D)	**Study Bank Height** (ft) =	9.75 (A)	(D) / (A) =	0.3077 (E)	5.8
Weighted Root Density (G)			**Root Density** as % =	5 (F)	(F) x (E) =	1.5385 (G)	10
Bank Angle (H)					**Bank Angle** as *Degrees* =	39 (H)	2.88
Surface Protection (I)					**Surface Protection** as % =	15 (I)	7.9

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	High / 36.6

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River**	Location: **RM 4.5 - 7.0**
Station: **Study Bank 10**	Stream Type: **C 4c-** / Valley Type: **VIII**
Observers: **SDP, TJT**	Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

Method	Level	Prediction
(1) Channel pattern, transverse bar or split channel/central bar creating NBS……….	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})………………….	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)…………………….	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})…………………………….	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})…………………	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})…………………….	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient…………………………….	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous…………………………NBS = High / Very High
- Extensive deposition (continuous, cross-channel)…………………………NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow…………………………NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress
Low

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**10.39**	**8.3**	**1.25**	**Low**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting values to a Near-Bank Stress (NBS) rating

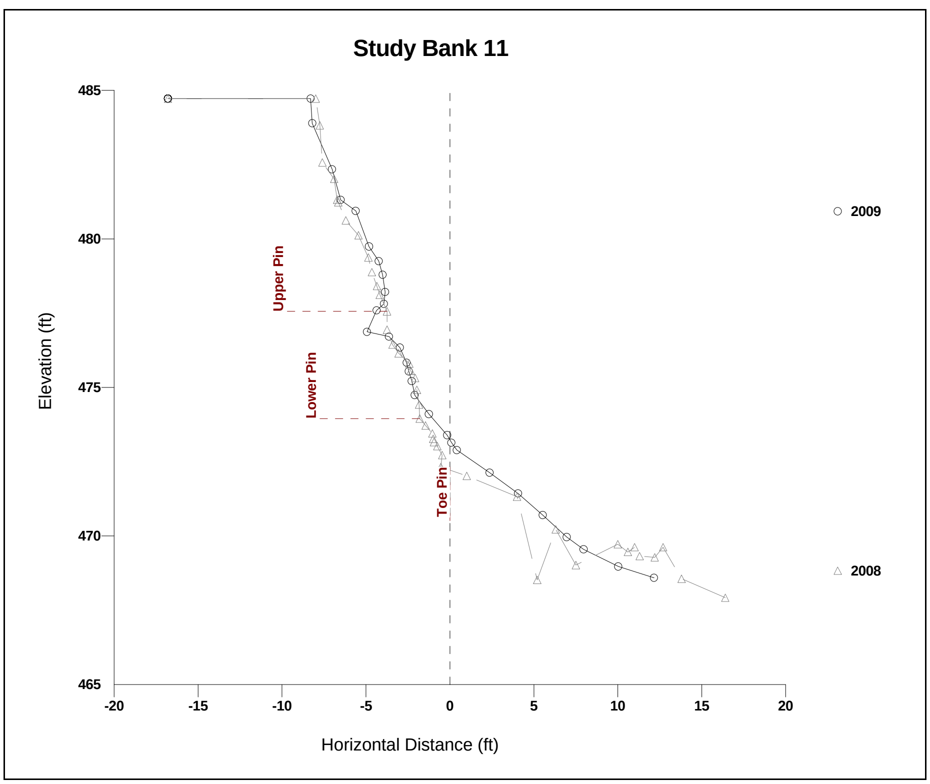
Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Low**

Study Bank 11

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 11** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	12.4 **(A)**	**Bankfull Height** (ft) =	2.08 **(B)**	(**A**) / (**B**) =	5.96154 **(C)**	**10**

Root Depth / Study Bank Height (E)

Root Depth (ft) =	8 **(D)**	**Study Bank Height** (ft) =	12.4 **(A)**	(**D**) / (**A**) =	0.64516 **(E)**	**3.17**

Weighted Root Density (G)

Root Density as **%** =	5 **(F)**	(**F**) x (**E**) =	3.2258 **(G)**	**10**

Bank Angle (H)

Bank Angle as *Degrees* =	58 **(H)**	**3.8**

Surface Protection (I)

Surface Protection as **%** =	30 **(I)**	**5.9**

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment — **2**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage — **5**

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**High** / **39.9**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 11** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})......................................	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)......................................	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})......................................	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient......................................	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous.......................NBS = High / Very High
Extensive deposition (continuous, cross-channel)...............................NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow......................NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Moderate

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
13.32	**8.3**	**1.6**	**Moderate**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

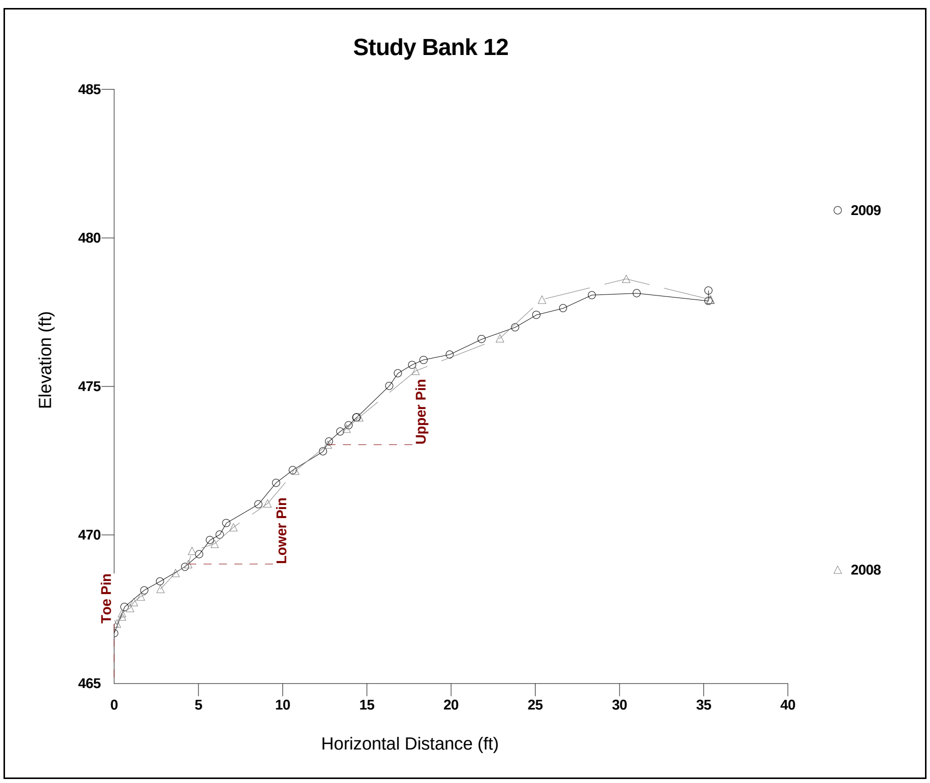
Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Moderate**

Study Bank 12

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream:	**Little Miami River**	Location:	**RM 4.5 - 7.0**
Station:	**Study Bank 12**	Observers:	**SDP, TJT**
Date:	**12/10/08**	Stream Type: **C 4c-**	Valley Type: **VIII**

Study Bank Height / Bankfull Height (C)

						BEHI Score (Fig. 5-19)
Study Bank Height (ft) =	8.23 (A)	**Bankfull Height** (ft) =	8.08 (B)	(A) / (B) =	1.0186 (C)	1.18

Root Depth / Study Bank Height (E)

Root Depth (ft) =	8 (D)	**Study Bank Height** (ft) =	8.23 (A)	(D) / (A) =	0.9721 (E)	1.27

Weighted Root Density (G)

Root Density as % =	30 (F)	(F) x (E) =	29.162 (G)	5.98

Bank Angle (H)

Bank Angle as *Degrees* =	25.5 (H)	2.22

Surface Protection (I)

Surface Protection as % =	45 (I)	4.71

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Low 15.4

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 12** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf}).....................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf}).........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
- Extensive deposition (continuous, cross-channel).. ....NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow..NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Low

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	12	**8.3**	**1.45**	**Low**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

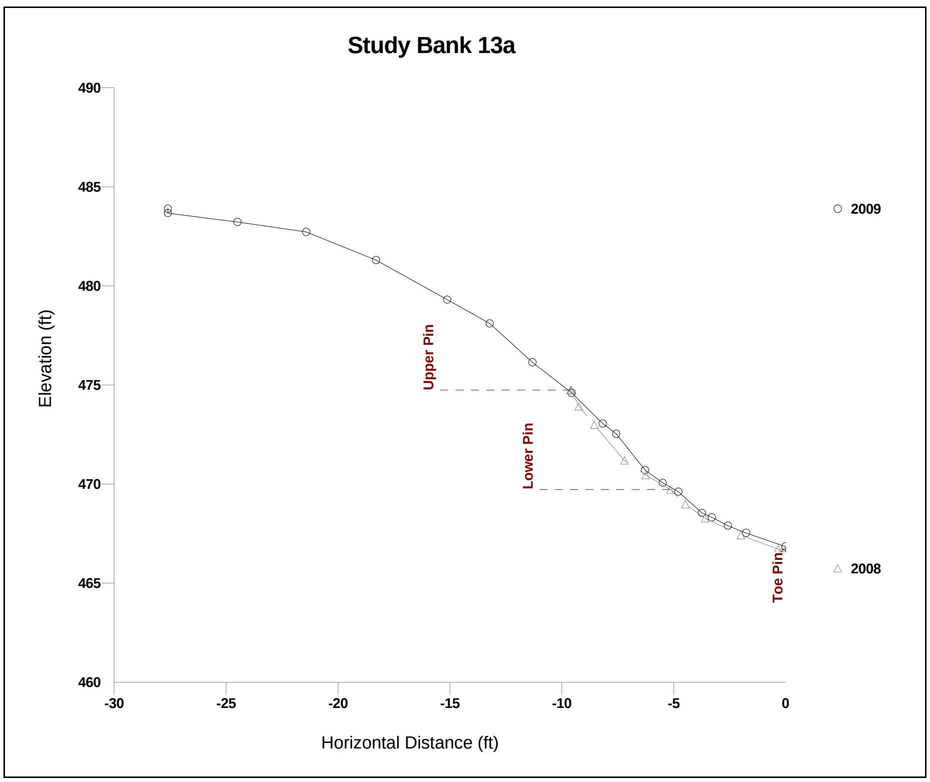
Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Low**

Study Bank 13a

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream:	**Little Miami River**	Location:	**RM 4.5 - 7.0**
Station:	**Study Bank 13a**	Observers:	**SDP, TJT**
Date:	**12/10/08**	Stream Type: **C 4c-**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	17.1 (A)	**Bankfull Height** (ft) =	8.56 (B)	(A) / (B) =	1.9977 (C)	7.9

Root Depth / Study Bank Height (E)

Root Depth (ft) =	17 (D)	**Study Bank Height** (ft) =	17.1 (A)	(D) / (A) =	0.9942 (E)	1.09

Weighted Root Density (G)

Root Density as % =	25 (F)	(F) x (E) =	24.854 (G)	6.56

Bank Angle (H)

Bank Angle as *Degrees* =	34 (H)	2.63

Surface Protection (I)

Surface Protection as % =	25 (I)	6.54

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	**Adjective Rating** and **Total Score**
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Moderate** 24.7

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 13a** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})...	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)...	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})...........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous..NBS = High / Very High
- Extensive deposition (continuous, cross-channel)...NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow..NBS = Extreme

Level II

Method	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

Method	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

Method	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress
Moderate

Level III

Method	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**12.9**	**8.3**	**1.55**	**Moderate**

Method	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

Method	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting values to a Near-Bank Stress (NBS) rating

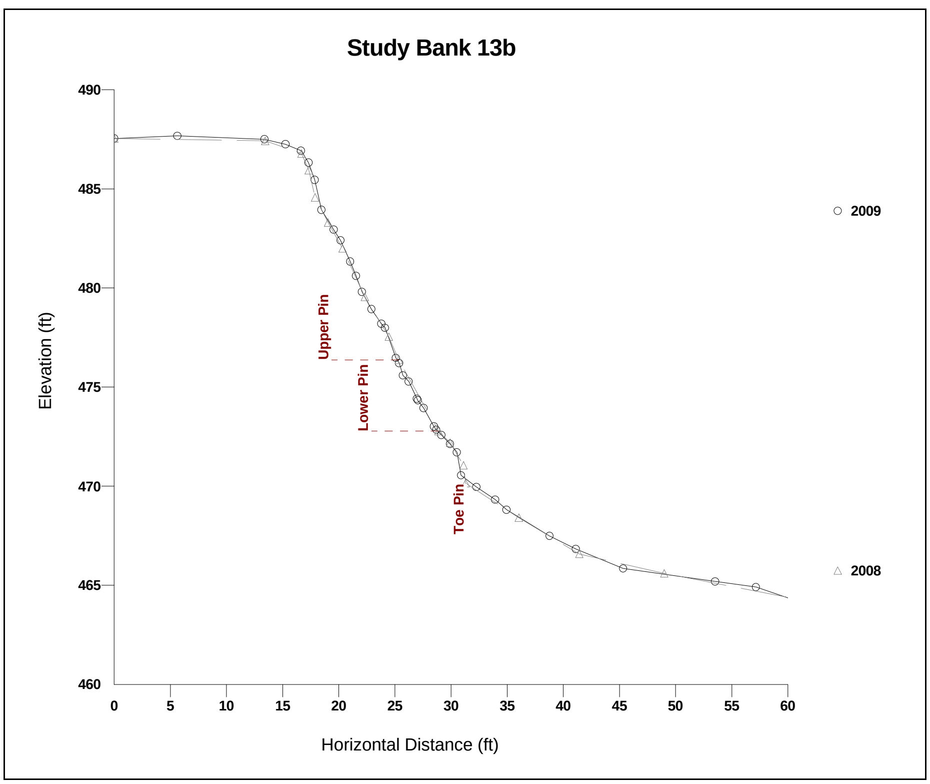
Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Moderate**

Study Bank 13b

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream:	**Little Miami River**	Location:	**RM 4.5 - 7.0**
Station:	**Study Bank 13b**	Observers:	**SDP, TJT**
Date:	**12/10/08**	Stream Type: **C 4c-**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	16.5 (A)	Bankfull Height (ft) =	5.5 (B)	(A) / (B) =	3 (C)	10

Root Depth / Study Bank Height (E)

Root Depth (ft) =	16 (D)	Study Bank Height (ft) =	16.5 (A)	(D) / (A) =	0.9697 (E)	1.27

Weighted Root Density (G)

Root Density as % =	20 (F)	(F) x (E) =	19.394 (G)	7.3

Bank Angle (H)

Bank Angle as *Degrees* =	48 (H)	3.32

Surface Protection (I)

Surface Protection as % =	25 (I)	6.54

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment	0
Stratification Adjustment Add 5–10 points, depending on position of unstable layers in relation to bankfull stage	5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**High** / **33.4**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 13b** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})...	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)..	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})....................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})............................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient...	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
- Extensive deposition (continuous, cross-channel)...................................... ....NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow.......................................NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Low

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
11.3	**8.3**	**1.36**	**Low**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

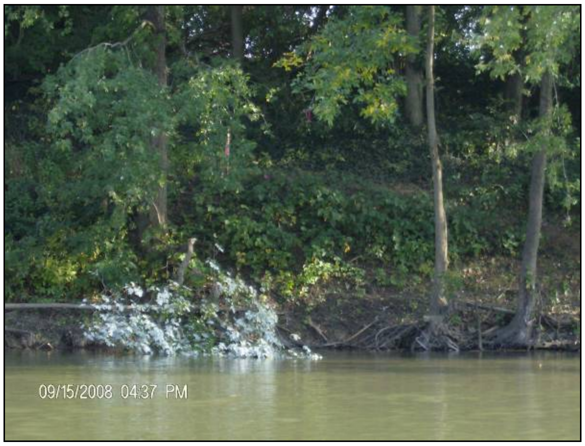
Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

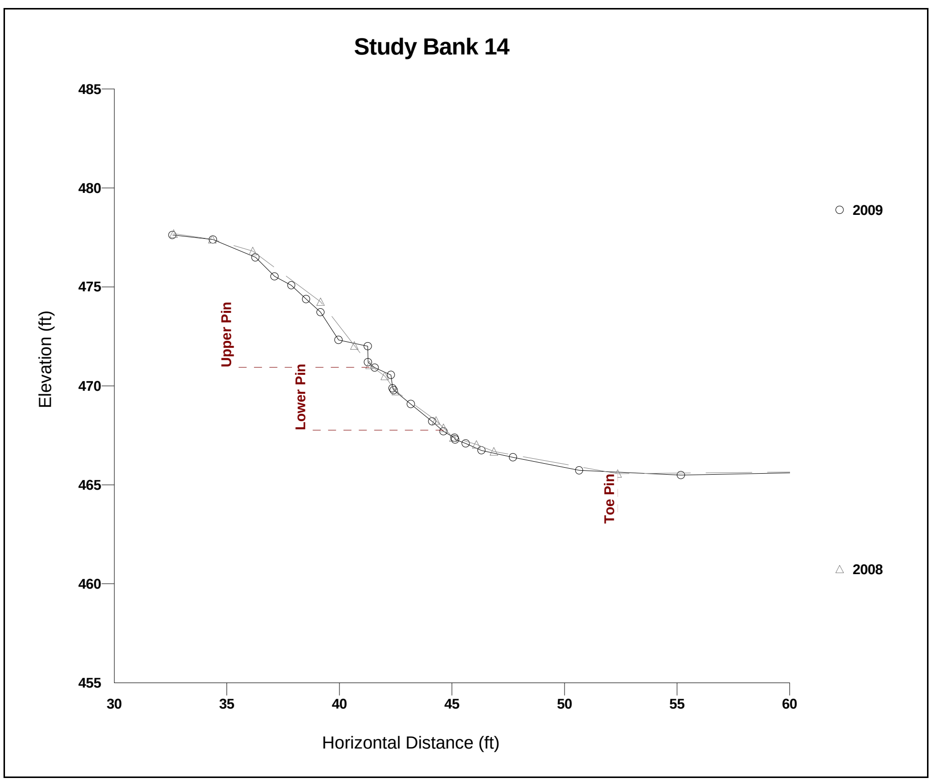
Overall Near-Bank Stress (NBS) rating	**Low**

Study Bank 14



2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 14** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	11.7 **(A)**	**Bankfull Height** (ft) =	10.26 **(B)**	(A) / (B) =	1.1404 **(C)**	**2.71**

Root Depth / Study Bank Height (E)

Root Depth (ft) =	10 **(D)**	**Study Bank Height** (ft) =	10.81 **(A)**	(D) / (A) =	0.9402 **(E)**	**1.54**

Weighted Root Density (G)

Root Density as % =	30 **(F)**	(F) x (E) =	28.205 **(G)**	**6.11**

Bank Angle (H)

Bank Angle as *Degrees* =	40.5 **(H)**	**2.95**

Surface Protection (I)

Surface Protection as % =	20 **(I)**	**7.22**

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: **0**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: **0**

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and **Total Score**: **Moderate** **20.5**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 14** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)................................	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
- Extensive deposition (continuous, cross-channel).. ....NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow..NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Low

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	12.2	**8.3**	**1.47**	**Low**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

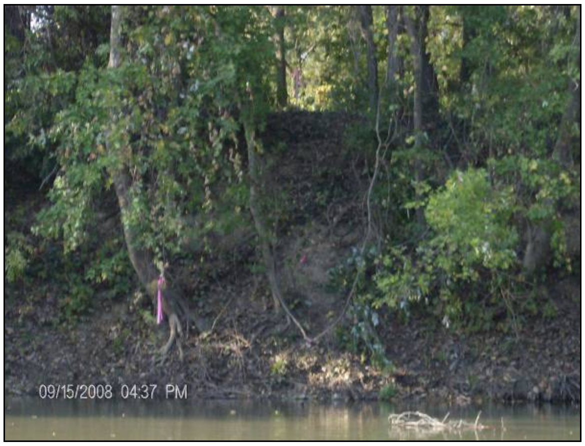
(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)

Converting values to a Near-Bank Stress (NBS) rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

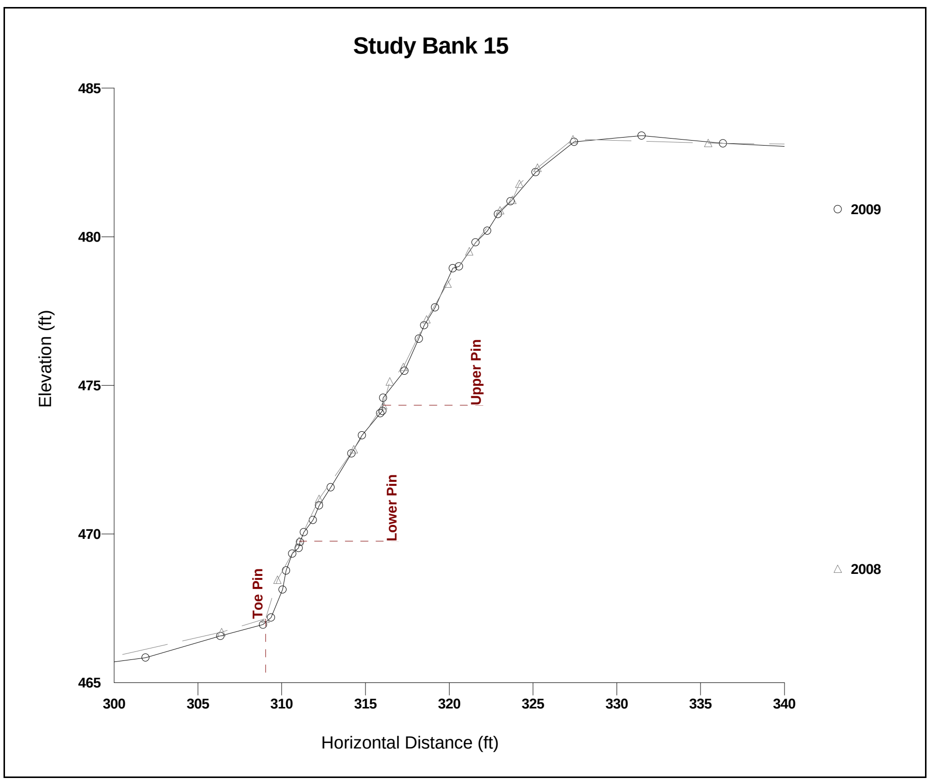
Overall Near-Bank Stress (NBS) rating	**Moderate**

Study Bank 15



2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 15** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

Variable	Input 1	Input 2	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 16.13 (A)	Bankfull Height (ft) = 8.8 (B)	(A) / (B) =	1.833 (C)	7.09
Root Depth / Study Bank Height (E)	Root Depth (ft) = 14 (D)	Study Bank Height (ft) = 16.13 (A)	(D) / (A) =	0.8679 (E)	2.1
Weighted Root Density (G)	Root Density as % = 25 (F)		(F) x (E) =	21.699 (G)	6.99
Bank Angle (H)	Bank Angle as *Degrees* =			42 (H)	3.02
Surface Protection (I)	Surface Protection as % =			30 (I)	5.9

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**High** 30.1

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River**	Location: **RM 4.5 - 7.0**	
Station: **Study Bank 15**	Stream Type: **C 4c-**	Valley Type: **VIII**
Observers: **SDP, TJT**		Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})........	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)........	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})........	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})........	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})........	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient........	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous........NBS = High / Very High
- Extensive deposition (continuous, cross-channel)........NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow........NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress
Low

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**12.42**	**8.3**	**1.5**	**Low**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting values to a Near-Bank Stress (NBS) rating

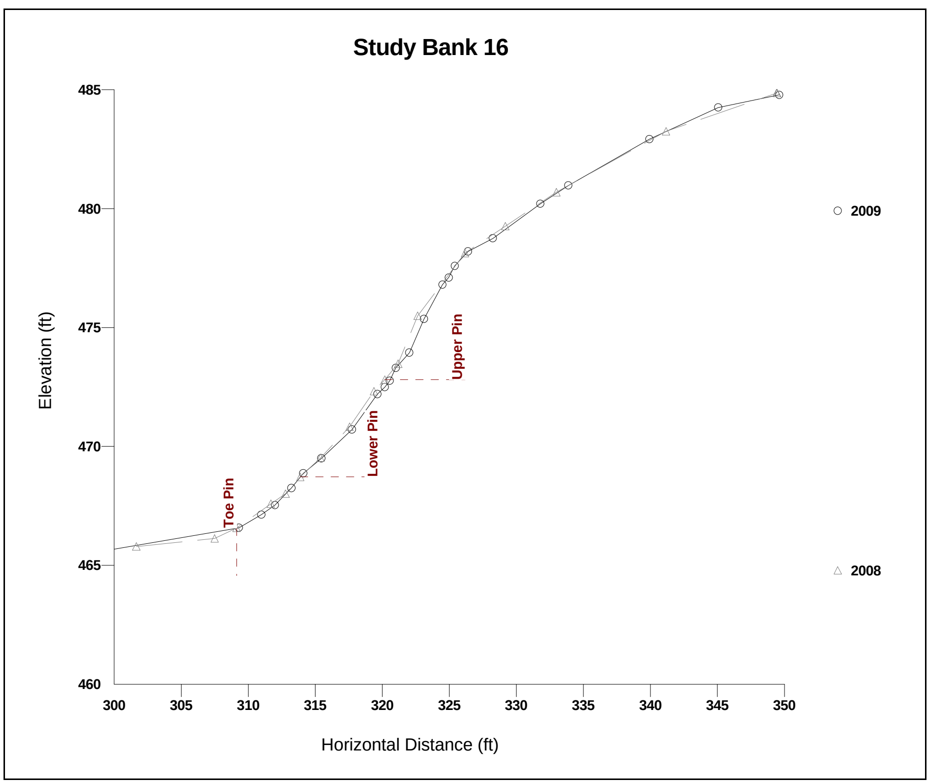
Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Low**

Study Bank 16

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 16** Observers: **SDP, TJT**

Date: **12/10/08** Stream Type: **C 4c-** Valley Type: **VIII**

Variable	Input 1		Input 2		Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) =	**18.73 (A)**	**Bankfull Height** (ft) =	**9.7 (B)**	(A) / (B) =	**1.9309 (C)**	**7.57**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	**13 (D)**	**Study Bank Height** (ft) =	**18.73 (A)**	(D) / (A) =	**0.69407 (E)**	**2.97**
Weighted Root Density (G)			**Root Density** as % =	**5 (F)**	(F) x (E) =	**3.47037 (G)**	**10**
Bank Angle (H)					**Bank Angle** as *Degrees* =	**32 (H)**	**2.54**
Surface Protection (I)					**Surface Protection** as % =	**20 (I)**	**7.22**

Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: **0**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: **0**

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**High** / **30.3**

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 16** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})......................................	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S).....................................	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})....................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})............................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient..	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
- Extensive deposition (continuous, cross-channel)....................................... ....NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow...NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress
Low

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**12.43**	**8.3**	**1.5**	**Low**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting values to a Near-Bank Stress (NBS) rating

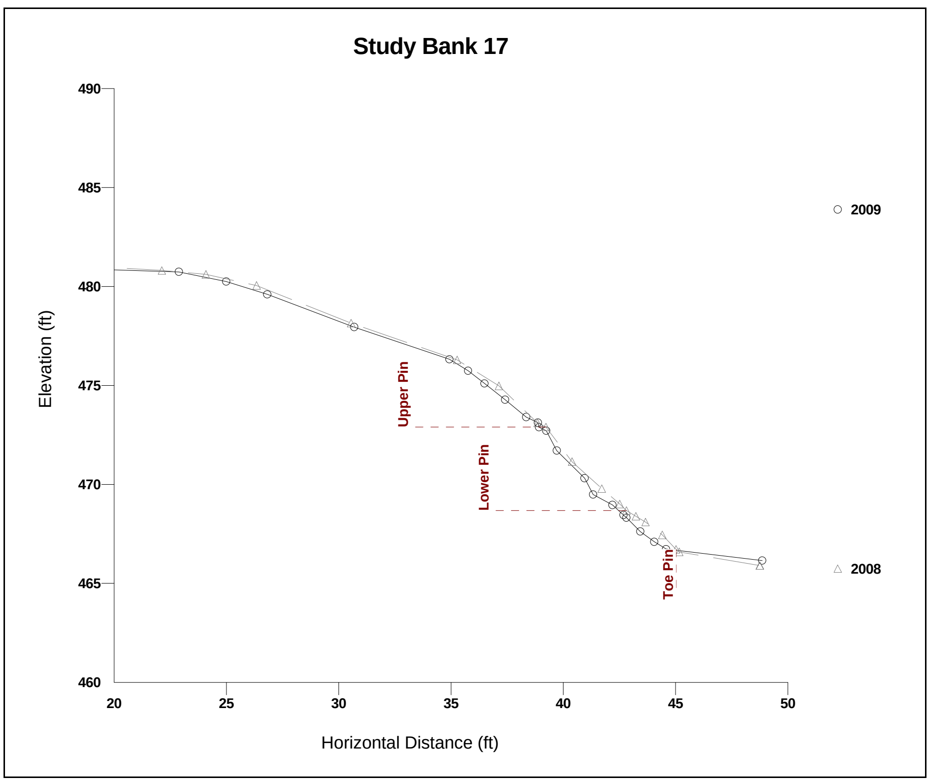
Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Low**

Study Bank 17

2008

2009



Worksheet 5-8. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-19** with BEHI variables to determine BEHI score.

Stream:	**Little Miami River**	Location:	**RM 4.0 - 7.0**
Station:	**Study Bank 17**	Observers:	**SDP, TJT**
Date:	**12/10/08**	Stream Type: **C 4c-**	Valley Type: **VIII**

Variable	Input 1	Value	Input 2	Value	Formula	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) =	14.02 (A)	**Bankfull Height** (ft) =	9.71 (B)	(A) / (B) =	1.44387 (C)	5.52
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	14 (D)	**Study Bank Height** (ft) =	14.02 (A)	(D) / (A) =	0.99857 (E)	1
Weighted Root Density (G)			**Root Density** as % =	25 (F)	(F) x (E) =	24.964 (G)	6.55
Bank Angle (H)					**Bank Angle** as *Degrees* =	45 (H)	3.17
Surface Protection (I)					**Surface Protection** as % =	25 (I)	6.54

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Moderate** 22.8

Worksheet 5-9. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Little Miami River** Location: **RM 4.5 - 7.0**

Station: **Study Bank 17** Stream Type: **C 4c-** Valley Type: **VIII**

Observers: **SDP, TJT** Date: **12/10/08**

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS..........	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})..	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S).......................................	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})..	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})......................	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})...........................	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient...	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous............ ....NBS = High / Very High
- Extensive deposition (continuous, cross-channel)...................................... ....NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow....................................NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress
Low

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**12**	**8.3**	**1.45**	**Low**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting values to a Near-Bank Stress (NBS) rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating: Low

Appendix F

River Stability Forms

- USGS Gage Stations
- Bankfull Velocity/ Discharge Estimates
- Flow Regime
- Meander Patterns
- Depositional Patterns
- Channel Blockages
- Pfankuch
- Competence
- Scour Chain Data

Worksheet 5-1. Sample form to record gage station and field data from *The Reference Reach Field Book* (Rosgen and Silvey, 2007).

Summary….*USGS GAGE STATION* Data/Records for
STREAM CHANNEL CLASSIFICATION

Station NAME:	**Little Miami River at Milford, OH**			Station Number:	**03245500**	
LOCATION:	**Milford, OH**					
Period of RECORD:		yrs		Mean Annual DISCHARGE:	**1459**	cfs
Drainage AREA:	**769920** acres	**1203**	mi^2	Drainage Area Mn ELEV:		ft
Reference REACH SLOPE:		ft/ft		Valley Type:	**VIII**	
Stream Type:				HUC:		

"BANKFULL" CHARACTERISTICS

Determined from FIELD MEASUREMENT			Determined from GAGE DATA Analysis		
Bankfull WIDTH (W_{bkf})	**327.7**	ft	Bankfull WIDTH (W_{bkf})	**223.8**	ft
Bankfull Mean DEPTH (d_{bkf})	**5.73**	ft	Bankfull MEAN DEPTH (d_{bkf})	**11.6**	ft
Bankfull Xsec AREA (A_{bkf})	**1879.20**	ft^2	Bankfull Xsec AREA (A_{bkf})	**2603**	ft^2
Wetted PERIMETER (W_p)	**330.98**	ft	Wetted PERIMETER (W_p)	**247**	ft
Bankfull STAGE (Gage Ht)	**12.20**	ft	Bankfull STAGE (Gage Ht)		ft
Est. Mean VELOCITY (u)	**5.4**	ft/sec	Mean VELOCITY (u)		ft/sec
Est. Bkf. DISCHARGE (Q_{bkf})	**10100.0**	cfs	Bankfull DISCHARGE (Q_{bkf})		cfs

Bankfull DISCHARGE associated with **"field-determined"** Bankfull STAGE (From Gage Height reading at Staff Plate and tabular Stage-Discharge curve data)	**13198.0**	cfs
Recurrence Interval (Log-Pearson) associated with **"field-determined"** Bankfull Discharge	**1.05**	yrs

From the *Annual Peak Flow Frequency Analysis* data for the Gage Station, determine:

1.5 Year **R.I.** Discharge……… =	**23750**	cfs	**10** Year **R.I.** Discharge……... =	**45000**	cfs
2.0 Year **R.I.** Discharge……….=	**28450**	cfs	**25** Year **R.I.** Discharge………=	**51740**	cfs
5.0 Year **R.I.** Discharge……….=	**38950**	cfs	**50** Year **R.I.** Discharge……... =	**56200**	cfs

MEANDER GEOMETRY

Meander Length (L_m)		ft	Radius of Curvature (R_C)		ft
Belt Width (W_{blt})		ft	Meander Width Ratio (W_{blt}/W_{bkf})		ft/ft

HYDRAULIC GEOMETRY

Based on *USGS Discharge Summary Notes* data (Form 9-207) and regression analyses of measured discharge (**Q**) with the hydraulic parameters of Width (**W**), Area (**A**), Mean Depth (**d**) & Mean Velocity (**u**), determine the *intercept coefficient* (**a**) and the *slope exponent* (**b**) values for a power function of the form **$Y = aX^b$**, when **Y** is one of the selected hydraulic parameters and **X** is a given discharge value (**Q**).

	Width (**W**)	Depth (**d**)	Area (**A**)	Velocity (**u**)
Intercept Coefficient: (**a**)				
Slope Exponent: (**b**)				

Hydraulic Radius: $R = A / W_p$		ft	**Manning's "n"** at Bankfull Stage		Coeff.

$$"n" = 1.4865\,[(\text{Area})(\text{Hydraulic Radius}^{2/3})(\text{Slope}^{1/2})] / Q_{bkf}$$

Worksheet 5-1. Sample form to record gage station and field data from *The Reference Reach Field Book* (Rosgen and Silvey, 2007).

Summary….*USGS GAGE STATION* Data/Records for
STREAM CHANNEL CLASSIFICATION

Station NAME:	East Fork Little Miami River at Perintown, (		Station Number:	03247500	
LOCATION:	Perintown, OH				
Period of RECORD:	31	yrs	Mean Annual DISCHARGE:	630	cfs
Drainage AREA:	304640 acres	476 mi^2	Drainage Area Mn ELEV:		ft
Reference REACH SLOPE:		ft/ft	Valley Type:		
Stream Type:	F4		HUC:	_ _	

"BANKFULL" CHARACTERISTICS

Determined from FIELD MEASUREMENT			Determined from GAGE DATA Analysis		
Bankfull WIDTH (W_{bkf})	173.6	ft	Bankfull WIDTH (W_{bkf})	152.5	ft
Bankfull Mean DEPTH (d_{bkf})	6.23	ft	Bankfull MEAN DEPTH (d_{bkf})	8.47	ft
Bankfull Xsec AREA (A_{bkf})	1080.76	ft^2	Bankfull Xsec AREA (A_{bkf})	1292	ft^2
Wetted PERIMETER (W_p)	177.19	ft	Wetted PERIMETER (W_p)	169.40	ft
Bankfull STAGE (Gage Ht)	8.06	ft	Bankfull STAGE (Gage Ht)		ft
Est. Mean VELOCITY (u)	4.0	ft/sec	Mean VELOCITY (u)		ft/sec
Est. Bkf. DISCHARGE (Q_{bkf})	4357.0	cfs	Bankfull DISCHARGE (Q_{bkf})		cfs

Bankfull DISCHARGE associated with **"field-determined"** Bankfull STAGE (From Gage Height reading at Staff Plate and tabular Stage-Discharge curve data)	5050.0	cfs
Recurrence Interval (Log-Pearson) associated with **"field-determined"** Bankfull Discharge	1.00	yrs

From the *Annual Peak Flow Frequency Analysis* data for the Gage Station, determine:

1.5 Year **R.I.** Discharge……… =	10110	cfs	**10** Year **R.I.** Discharge……... =	19490	cfs
2.0 Year **R.I.** Discharge……….=	11910	cfs	**25** Year **R.I.** Discharge………=	23390	cfs
5.0 Year **R.I.** Discharge……….=	16450	cfs	**50** Year **R.I.** Discharge……... =	26300	cfs

MEANDER GEOMETRY

Meander Length (L_m)		ft	Radius of Curvature (R_C)		ft
Belt Width (W_{blt})		ft	Meander Width Ratio (W_{blt}/W_{bkf})		ft/ft

HYDRAULIC GEOMETRY

Based on *USGS Discharge Summary Notes* data (Form 9-207) and regression analyses of measured discharge (**Q**) with the hydraulic parameters of Width (**W**), Area (**A**), Mean Depth (**d**) & Mean Velocity (**u**), determine the *intercept coefficient* (**a**) and the *slope exponent* (**b**) values for a power function of the form **$Y = aX^b$**, when **Y** is one of the selected hydraulic parameters and **X** is a given discharge value (**Q**).

	Width (**W**)	Depth (**d**)	Area (**A**)	Velocity (**u**)
Intercept Coefficient: (**a**)				
Slope Exponent: (**b**)				

Hydraulic Radius: $R = A / W_p$		ft	**Manning's "n"** at Bankfull Stage		Coeff.

"**n**" = 1.4865 **[**(**A**rea) (Hydraulic **R**adius $^{2/3}$) (**S**lope $^{1/2}$)**] / Q_{bkf}**

Worksheet 5-2. Computations of velocity and bankfull discharge using various methods (Rosgen and Silvey, 2007).

Bankfull VELOCITY / DISCHARGE Estimates

Site	Little Miami River		Location	R4-XS1	
Date	Fall 2008	Stream Type	C4c-	Valley Type	VIII
Observers	TJT, MAS		HUC	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ – _ _ _ _ _ _	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-sectional AREA	2885.3	A_{bkf} (ft^2)	Bankfull Mean DEPTH	8.57	D_{bkf} (ft)
Bankfull WIDTH	336.6	W_{bkf} (ft)	Wetted PERIMETER ~ $2 * d_{bkf} + W_{bkf}$	353.74	W_p (ft)
D_{84} @ Riffle	59.6	Dia. (mm)	D_{84} mm / 304.8 =	0.20	D_{84} (ft)
Bankfull SLOPE	0.00058	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	8.2	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R (ft) / D_{84} (ft)	41.70	
Drainage AREA	1730.0	DA (mi^2)	Shear Velocity $u^* = \sqrt{gRS}$	0.39	u* (ft / sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 \text{Log}\{R / D_{84}\}]u^*$	4.7	ft / sec	13514	cfs
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness (Figs. 5-7, 5-8) $u = 1.4865 * R^{2/3} * S^{1/2} / n$; n = 0.024	6.0	ft / sec	17312	cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$; b) Manning's 'n' from Jarrett (USGS): $n = 0.39 S^{.38} R^{-.16}$; n = Note: This equation is for applications involving **steep, step-pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3.		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$; c) Manning's 'n' from Stream Type; n = 0.019	7.6	ft / sec	22028	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.): Dacry-Weisbach; Hey	4.9	ft / sec	14019	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves u = Q / A; Return Period for Bankfull Discharge Q = ___ Yr.		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A		ft / sec		cfs

Options for using the D_{84} term in the relative roughness relation (R/D_{84}), 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 ft) for the D_{84} term in est. method 1.
Option 2.	For **boulder-dominated** channels: Measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an ave. boulder protrusion height (h_{bo} in ft) for the D_{84} term in est. 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 D_{84} term in estimation method 1.

Worksheet 5-7. Flow regime variables that influence channel characteristics, sediment regime and biological interpretations.

Flow Regime

Stream: **Little Miami River**	Location: **RM 4.5 - 7.0, EC Segment II/III**							
Observers: **SP, WL, TT**	Date: **Fall 08,09**							
List ALL COMBINATIONS that APPLY.............☞	**P2**	**P7**						

General Category

E	Ephemeral stream channels: Flows only in response to precipitation
S	Subterranean stream channel: Flows parallel to and near the surface for various seasons - a sub-surface flow that follows the stream bed.
I	Intermittent stream channel: Surface water flows discontinuously along its length. Often associated with sporadic and/or seasonal flows and also with Karst (limestone) geology where losing/gaining reaches create flows that disappear then reappear farther downstream.
P	Perennial stream channels: Surface water persists yearlong.

Specific Category

1	Seasonal variation in streamflow dominated primarily by snowmelt runoff.
2	Seasonal variation in streamflow dominated primarily by stormflow runoff.
3	Uniform stage and associated streamflow due to spring-fed condition, backwater, etc.
4	Streamflow regulated by glacial melt.
5	Ice flows/ice torrents from ice dam breaches.
6	Alternating flow/backwater due to tidal influence.
7	Regulated streamflow due to diversions, dam release, dewatering, etc.
8	Altered due to development, such as urban streams, cut-over watersheds or vegetation conversions (forested to grassland) that change flow response to precipitation events.
9	Rain-on-snow generated runoff.

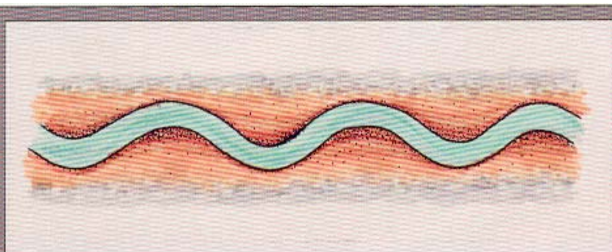
Worksheet 5-9. Meander pattern relations used for interpretations for river stability (modified from Galay *et al* ., 1973; Rosgen, 1996).

Meander Patterns

Stream:	**Little Miami River**	Reach:	**RM 4.5 - 7.0, EC Segment II/III**
Observers:	**SP, WL, TT**	Date:	**Fall 08,09**

List ALL CATEGORIES that APPLY ☞	**M2**	**M3**	**M4**	**M5**	

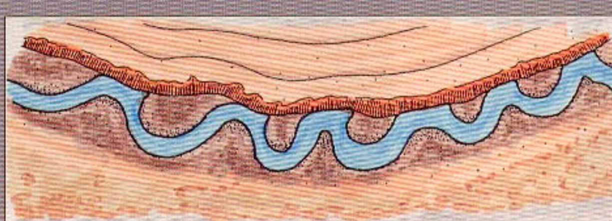
Various Meander Pattern variables modified from Galay et al. (1973)



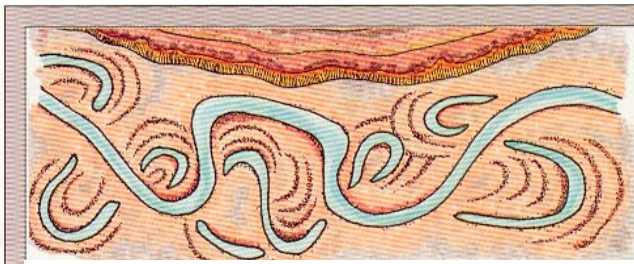
M1 REGULAR MEANDERS

M2 TORTUOUS MEANDERS

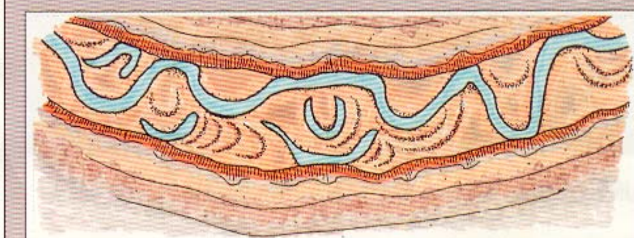
M3 IRREGULAR MEANDERS



M4 TRUNCATED MEANDERS



M5 UNCONFINED MEANDER SCROLLS



M6 CONFINED MEANDER SCROLLS

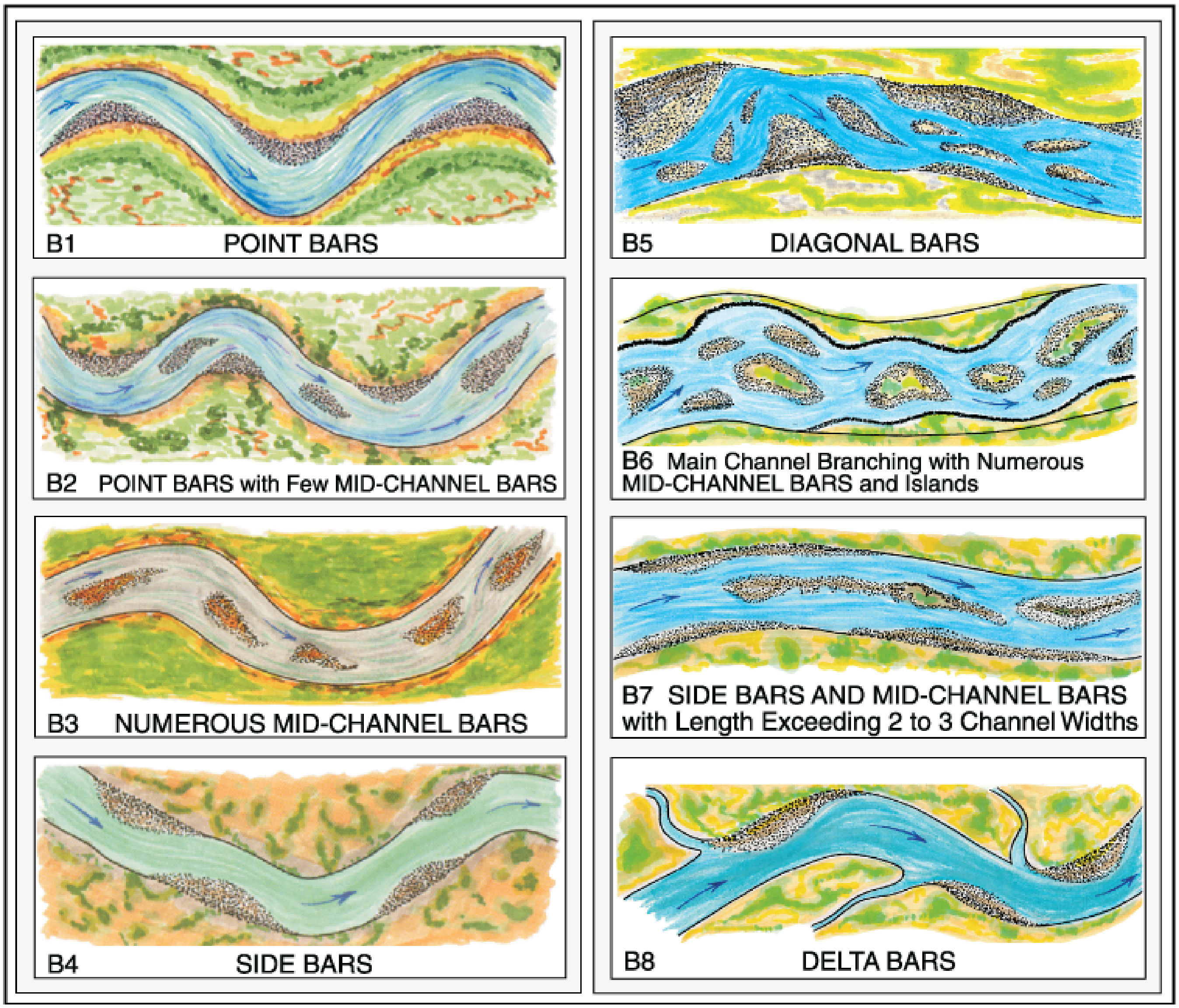
M7 DISTORTED MEANDER LOOPS

M8 IRREGULAR MEANDERS with oxbows and oxbow cutoffs

Worksheet 5-10. Depositional patterns used for stabiilty assessment interpretations (modified from Galay *et al* ., 1973; Rosgen, 1996).

Depositional Patterns						
Stream: **Little Miami River**			Reach: **RM 4.5 - 7.0, EC Segment II/III**			
Observers: **SP, WL, TT**			Date: **Fall 08,09**			
List ALL CATEGORIES that APPLY ☞	**B1**	**B4**	**B6**			

Various Depositional Features modified from Galay et al. (1973)



Worksheet 5-11. Various categories of in-channel debris, dams and channel blockages used to evaluate channel stability (adapted from Rosgen, 1996).

Channel Blockages			
Stream: **Little Miami River**		Location: **RM 4.5 - 7.0, EC Segment II/III**	
Observers: **SP, WL, TT**		Date: **Fall 08,09**	
Description/Extent		**Materials that upon placement into the active channel or flood-prone area may cause adjustments in channel dimensions or conditions due to influences on the existing flow regime.**	**Check (✓) all that apply**
D1	None	Minor amounts of small, floatable material.	☑
D2	Infrequent	Debris consists of small, easily moved, floatable material, e.g., leaves, needles, small limbs and twigs.	☑
D3	Moderate	Increasing frequency of small- to medium-sized material, such as large limbs, branches and small logs, that when accumulated, affect 10% or less of the active channel cross-section area.	☑
D4	Numerous	Significant build-up of medium- to large-sized materials, e.g., large limbs, branches, small logs or portions of trees that may occupy 10–30% of the active channel cross-section area.	☐
D5	Extensive	Debris "dams" of predominantly larger materials, e.g., branches, logs and trees, occupying 30–50% of the active channel cross-section area, often extending across the width of the active channel.	☐
D6	Dominating	Large, somewhat continuous debris "dams," extensive in nature and occupying over 50% of the active channel cross-section area. Such accumulations may divert water into the flood-prone areas and form fish migration barriers, even when flows are at less tha	☐
D7	Beaver dams: Few	An infrequent number of dams spaced such that normal streamflow and expected channel conditions exist in the reaches between dams.	☐
D8	Beaver dams: Frequent	Frequency of dams is such that backwater conditions exist for channel reaches between structures where streamflow velocities are reduced and channel dimensions or conditions are influenced.	☐
D9	Beaver dams: Abandoned	Numerous abandoned dams, many of which have filled with sediment and/or breached, initiating a series of channel adjustments, such as bank erosion, lateral migration, avulsion, aggradation and degradation.	☐
D10	Human influences	Structures, facilities or materials related to land uses or development located within the flood-prone area, such as diversions or low-head dams, controlled by-pass channels, velocity control structures and various transportation encroachments that have an influence on the existing flow regime, such that significant channel adjustments occur.	☑

Worksheet 5-15. Pfankuch (1975) channel stability rating procedure, as modified by Rosgen (1996, 2001b).

Stream: Little Miami River **Location:** RM 4.5 - 7.0 **Valley Type:** VIII **Observers:** TT **Date:** Fall 2009

Location	Key	Category	Excellent Description	Rating	Good Description	Rating	Fair Description	Rating	Poor Description	Rating
Upper Banks	1	Landform slope	Bank slope gradient <30%.	2	Bank slope gradient 30–40%.	4	Bank slope gradient 40–60%.	6	Bank slope gradient > 60%.	8
	2	Mass erosion	No evidence of past or future mass erosion.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly yearlong.	9	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	12
	3	Debris jam potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	6	Moderate to heavy amounts, predominantly larger sizes.	8
	4	Vegetative bank protection	> 90% plant density. Vigor and variety suggest a deep, dense soil-binding root mass.	3	70–90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50–70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species and less vigor indicating poor, discontinuous and shallow root mass.	12
Lower Banks	5	Channel capacity	Bank heights sufficient to contain the bankfull stage. Width/depth ratio departure from reference width/depth ratio = 1.0. Bank-Height Ratio (BHR) = 1.0.	1	Bankfull stage is contained within banks. Width/depth ratio departure from reference width/depth ratio = 1.0–1.2. Bank-Height Ratio (BHR) = 1.0–1.1.	2	Bankfull stage is not contained. Width/depth ratio departure from reference width/depth ratio = 1.2–1.4. Bank-Height Ratio (BHR) = 1.1–1.3.	3	Bankfull stage is not contained; over-bank flows are common with flows less than bankfull. Width/depth ratio departure from reference width/depth ratio > 1.4. Bank-Height Ratio (BHR) > 1.3.	4
	6	Bank rock content	> 65% with large angular boulders. 12"+ common.	2	40–65%. Mostly boulders and small cobbles 6–12".	4	20–40%. Most in the 3–6" diameter class.	6	<20% rock fragments of gravel sizes, 1–3" or less.	8
	7	Obstructions to flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed.	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12–24" high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9	Deposition	Little or no enlargement of channel or point bars.	4	Some new bar increase, mostly from coarse gravel.	8	Moderate depostion of new gravel and coarse sand on old and some new bars.	12	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges. Surfaces smooth and flat.	2	Corners and edges well rounded in 2 dimensions.	3	Well rounded in all dimensions, surfaces smooth.	4
	11	Brightness	Surfaces dull, dark or stained. Generally not bright.	1	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, i.e., 35–65% mixture range.	3	Predominantly bright, > 65%, exposed or scoured surfaces.	4
	12	Consolidation of particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	4	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
	13	Bottom size distribution	No size change evident. Stable material 80–100%.	4	Distribution shift light. Stable material 50–80%.	8	Moderate change in sizes. Stable materials 20–50%.	12	Marked distribution change. Stable materials 0–20%.	16
	14	Scouring and deposition	<5% of bottom affected by scour or deposition.	6	5–30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30–50% affected. Deposits and scour at obstructions, constrictions and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
	15	Aquatic vegetation	Abundant growth moss-like, dark green perennial. In swift water too.	1	Common. Algae forms in low velocity and pool areas. Moss here too.	2	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perennial types scarce or absent. Yellow-green, short-term bloom may be present.	4
			Excellent Total =	0	Good Total =	14	Fair Total =	78	Poor Total =	20

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. Unstable	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+

Stream Type	DA3	DA4	DA5	DA6	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	G1	G2	G3	G4	G5	G6
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
Fair (Mod. Unstable	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

Grand Total =	112
Existing Stream Type =	C4
*Potential Stream Type =	C4
Modified Channel Stability Rating =	Poor

*Rating is adjusted to potential stream type, not existing.

Worksheet 5-22. Sediment competence calculation form to assess bed stability.

Stream:	**Little Miami River**	Stream Type:	**C4c-**
Location:	**RM 4.5 - 7.0**	Valley Type:	**VIII**
Observers:	**SDP, TJT**	Date:	**10/2008**

Enter Required Information for Existing Condition

25	D_{50}	Riffle bed material D_{50} (mm)			
8	$\hat{D}_{50}$	Bar sample D_{50} (mm)			
0.33	D_{max}	Largest particle from bar sample (ft)	**100**	**(mm)**	304.8 mm/ft
0.00058	S	Existing bankfull water surface slope (ft/ft)			
8.3	d	Existing bankfull mean depth (ft)			
1.65	$\gamma_s - 1$	Immersed specific gravity of sediment			

Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress

3.13	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1:	$\tau^* = 0.0834\ (D_{50}/\hat{D}_{50})^{-0.872}$
4	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2:	$\tau^* = 0.0384\ (D_{max}/D_{50})^{-0.887}$
0.0142	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:	**1**

Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample

5.2	d	Required bankfull mean depth (ft)	$d = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(use D_{max} in ft)

Check: ☐ Stable ☐ Aggrading ☑ Degrading

Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample

0.00037	S	Required bankfull water surface slope (ft/ft)	$S = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)

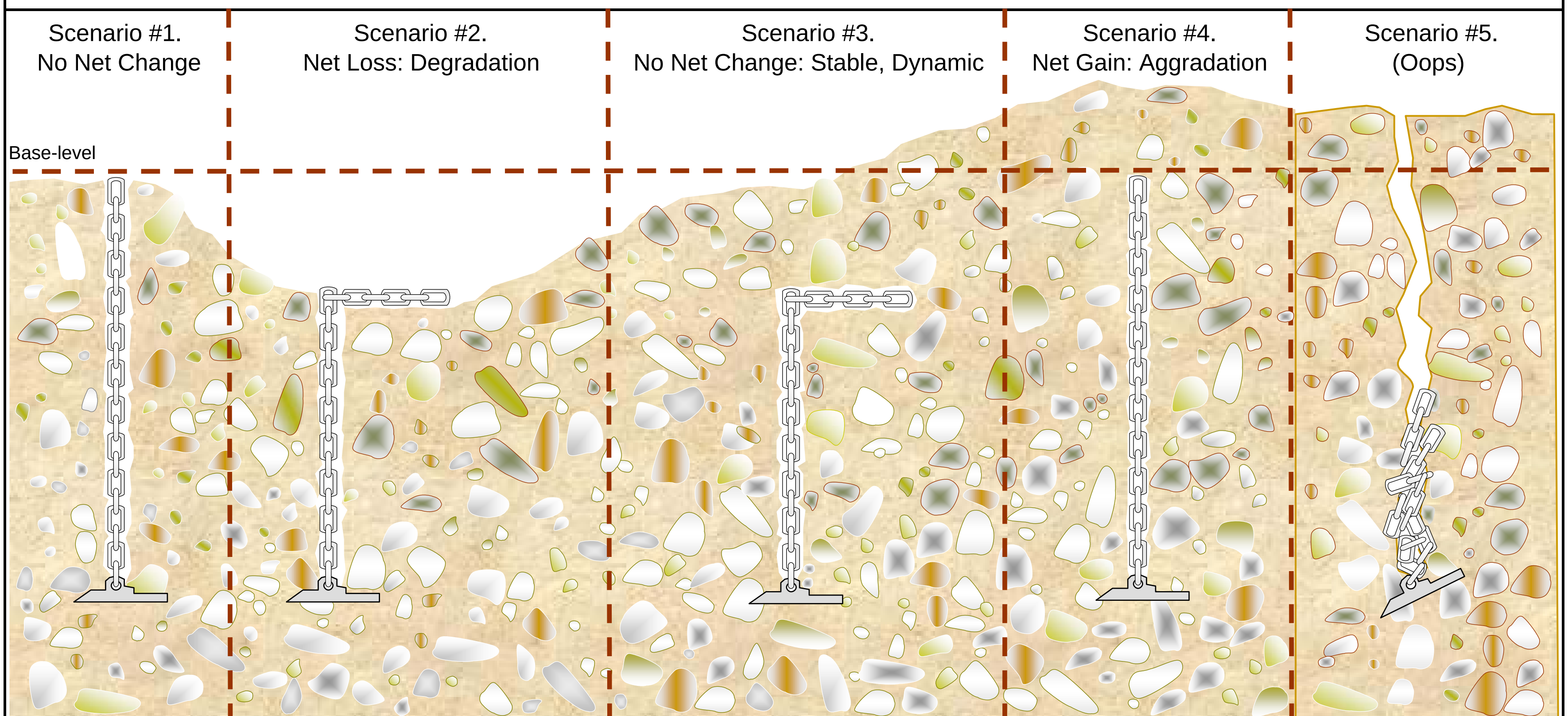
Check: ☐ Stable ☐ Aggrading ☑ Degrading

Sediment Competence Using Dimensional Shear Stress

0.300	Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope	
60	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 5-49)**	
0.32	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 5-49)**	
8.8	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = existing slope	$d = \dfrac{\tau}{\gamma S}$
0.00062	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = existing depth	$S = \dfrac{\tau}{\gamma d}$

Worksheet 6-4. Field form to document scour chain results and corresponding bed-elevation changes.

Stream:		**Little Miami River**					Location: **R1-XS2**				
Observers:		**WL, TT, OR**				Stream Type: **C4c-**		Valley Type: **VIII**		Date: **Fall 08,09**	
		Installation Data (1st Year - 2008)				**Recovery Data (2nd Year - 2009)**					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1	**173.6**	**465.43**	**170**	**132**	**1**	**-**	**465.43**	**0**	**185**	**150**
Riffle	Chain #2										
Glide	Chain #3										
Glide	Chain #4										



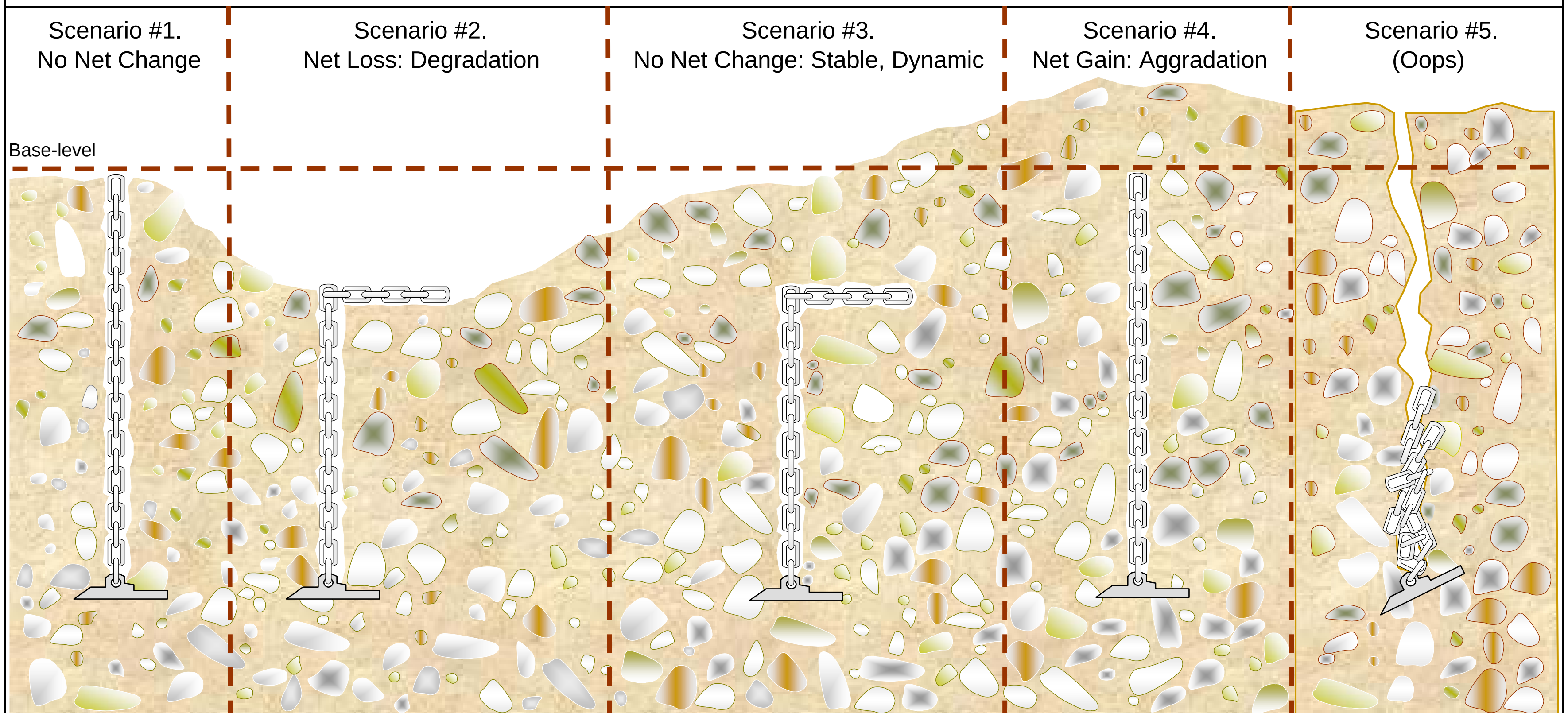
[a] Scenario 2 or 3. Scenario 2: Enter length of chain exposed. Scenario 3: Enter length of chain exposed then subsequently buried.

[b] Scenario 3 or 4. Scenario 3: Enter elevation of bed at same station @ 2nd year. Scenario 4: Enter depth of material over chain.

[c] Scenario 3: Subtract 1st and 2nd year elevations to calculate net change in bed.

Worksheet 6-4. Field form to document scour chain results and corresponding bed-elevation changes.

Stream:	Little Miami River					Location: R1-XS3					
Observers:	WL, TT, OR			Stream Type: C4c-		Valley Type: VIII			Date: Fall 08,09		
		Installation Data (1st Year - 2008)				Recovery Data (2nd Year - 2009)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1	132	464.64			1	-	464.64	0	62	52
Riffle	Chain #2	205	465.38			1	-	465.38	0	75	70
Glide	Chain #3										
Glide	Chain #4										



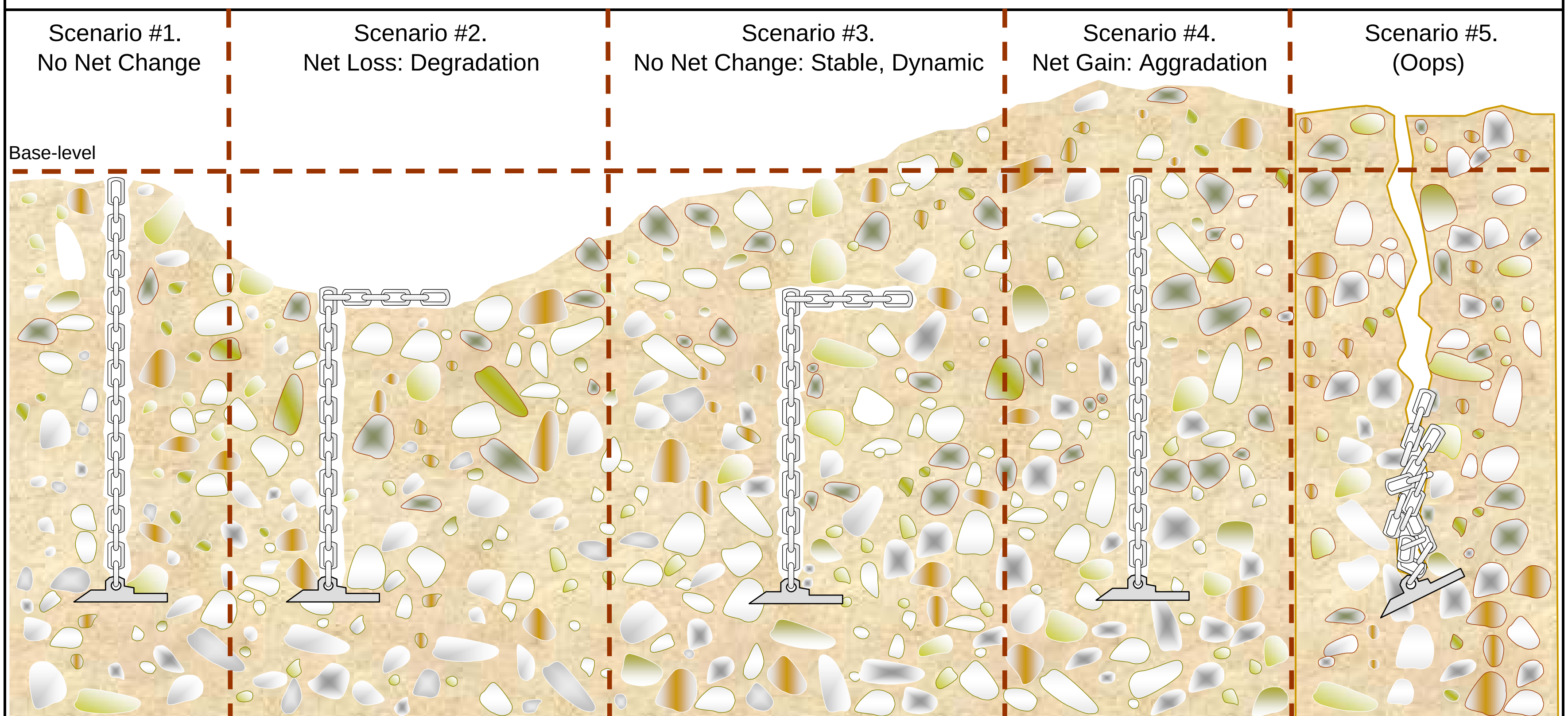
[a] Scenario 2 or 3. Scenario 2: Enter length of chain exposed. Scenario 3: Enter length of chain exposed then subsequently buried.

[b] Scenario 3 or 4. Scenario 3: Enter elevation of bed at same station @ 2nd year. Scenario 4: Enter depth of material over chain.

[c] Scenario 3: Subtract 1st and 2nd year elevations to calculate net change in bed.

Worksheet 6-4. Field form to document scour chain results and corresponding bed-elevation changes.

Stream:	Little Miami River					Location: R2-XS1					
Observers:	WL, TT, OR					Stream Type: C4c-		Valley Type: VIII		Date: Fall 08,09	
		Installation Data (1st Year - 2008)				**Recovery Data (2nd Year - 2009)**					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1	**129**	**464.39**	**60**	**60**	**4**	**-**	**464.49**	**+ 0.1**	**99**	**69**
Riffle	Chain #2	**280**	**463.72**	**76**	**64**	**2**	**0.1**	**463.62**	**- ≤ 0.1**	**85**	**85**
Glide	Chain #3										
Glide	Chain #4										



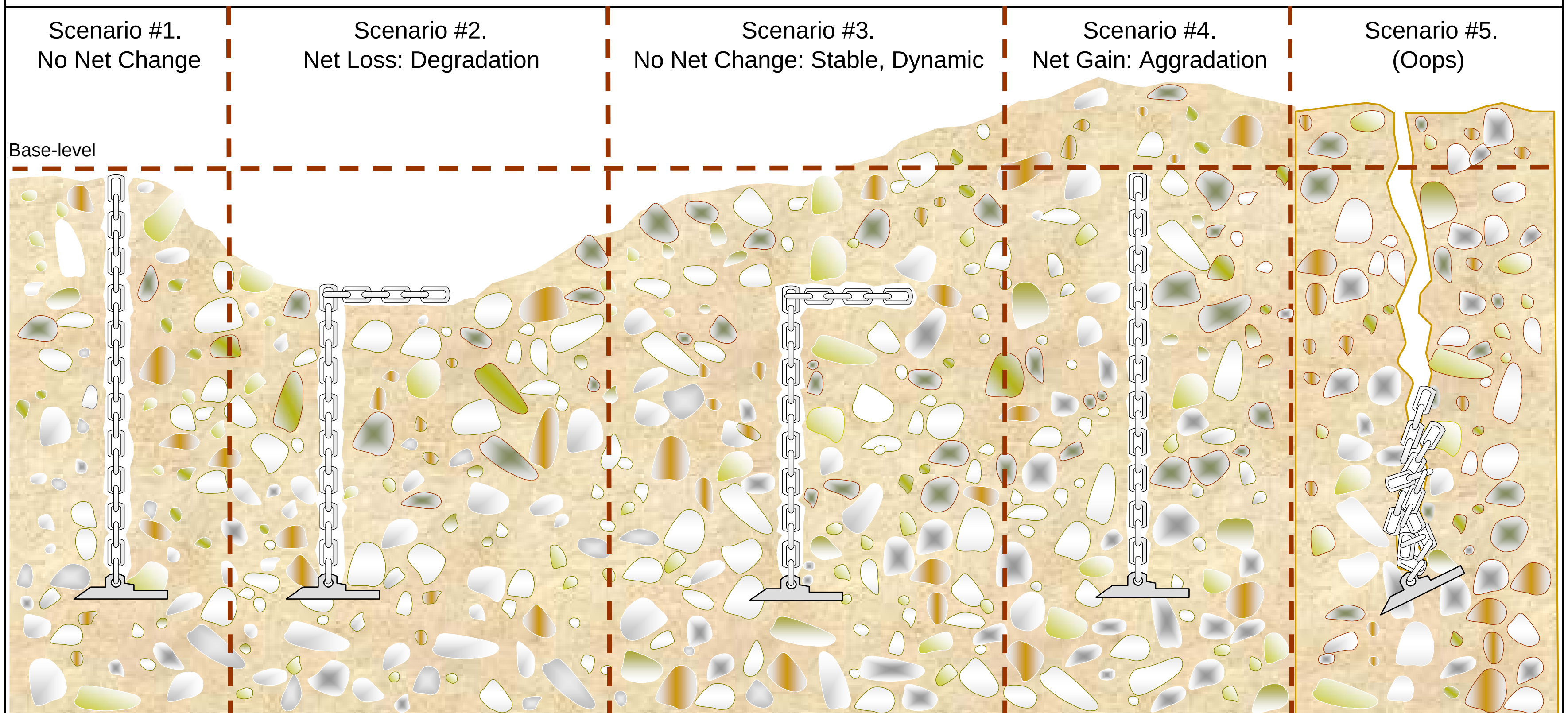
[a] Scenario 2 or 3. Scenario 2: Enter length of chain exposed. Scenario 3: Enter length of chain exposed then subsequently buried.

[b] Scenario 3 or 4. Scenario 3: Enter elevation of bed at same station @ 2nd year. Scenario 4: Enter depth of material over chain.

[c] Scenario 3: Subtract 1st and 2nd year elevations to calculate net change in bed.

Worksheet 6-4. Field form to document scour chain results and corresponding bed-elevation changes.

Stream:		Little Miami River				Location: R3-XS3					
Observers:		WL, TT, OR			Stream Type: C4c-		Valley Type: VIII			Date: Fall 2009	
		Installation Data (1st Year)				Recovery Data (2nd Year)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1	88	459.87	79	78	1	-	459.87	0	90	75
Riffle	Chain #2	165	459.77	60	30	4	-	460.44	+ 0.67	21	20
Glide	Chain #3										
Glide	Chain #4										



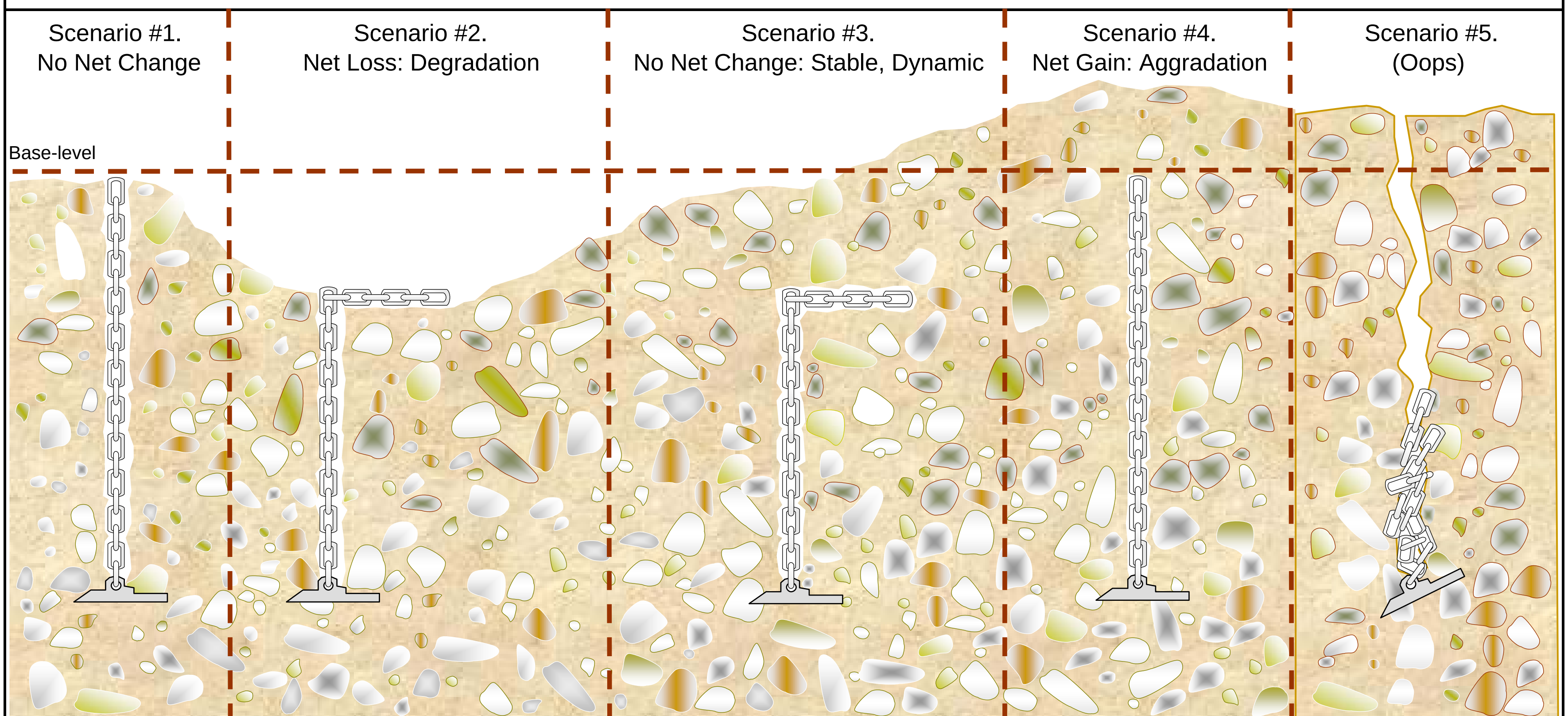
[a] Scenario 2 or 3. Scenario 2: Enter length of chain exposed. Scenario 3: Enter length of chain exposed then subsequently buried.

[b] Scenario 3 or 4. Scenario 3: Enter elevation of bed at same station @ 2nd year. Scenario 4: Enter depth of material over chain.

[c] Scenario 3: Subtract 1st and 2nd year elevations to calculate net change in bed.

Worksheet 6-4. Field form to document scour chain results and corresponding bed-elevation changes.

Stream:		Little Miami River					Location:	R4-XS1			
Observers:		WL, TT, OR			Stream Type:	C4c-	Valley Type:	VIII		Date:	Fall 08,09
		Installation Data (1st Year - 2008)				Recovery Data (2nd Year - 2009)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1	123	460.35	65	54	2	0.35	460	- 0.35	118	75
Riffle	Chain #2	198.5	460.01	80	65	1	-	460.01	0	117	110
Glide	Chain #3										
Glide	Chain #4										



[a] Scenario 2 or 3. Scenario 2: Enter length of chain exposed. Scenario 3: Enter length of chain exposed then subsequently buried.
[b] Scenario 3 or 4. Scenario 3: Enter elevation of bed at same station @ 2nd year. Scenario 4: Enter depth of material over chain.
[c] Scenario 3: Subtract 1st and 2nd year elevations to calculate net change in bed.