Final Report

Kansas River Basin
Regional Sediment Management
Section 204 Stream and River Channel Assessment

Summary Report

Prepared for

U.S. Army Corps of Engineers
Kansas City District
700 Federal Building
Kansas City, Missouri 64106-2896

Kansas Water Office
901 S. Kansas Avenue
Topeka, Kansas 66612-1249

Prepared by

Gulf South Research Corporation
8081 GSRI Avenue
Baton Rouge, Louisiana 70820

August 2011

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Task Order No. 006

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EXECUTIVE SUMMARY

The United States (U.S.) Army Corps of Engineers (USACE), Kansas City District contracted Gulf South Research Corporation (GRSC) to conduct morphological assessments at stream channels and riparian areas within the Kansas River Basin to identify future sediment control opportunities. Juracek and Ziegler (2007) found that the majority of sediment being deposited in Federal reservoirs in northeast Kansas originates from upstream channel-bank erosion processes. This report summarizes research conducted from four previous investigations focusing on stream bed and bank sediment erosion on stream reaches above three major Federal water supply reservoirs in the Kansas River Basin, which include Perry Lake, Tuttle Creek Lake, and Clinton Lake. The objective of the investigations was to determine the amount of instream erosion occurring in selected reaches upstream of the water supply reservoirs and recommend Best Management Practices (BMPs) to stabilize the streambanks that indicated evidence of severe erosion. Detailed fluvial geomorphology survey data were collected at 20 locations: 10 locations were selected above Perry Lake, five above Tuttle Creek Lake, and four above Clinton Lake. One survey was performed above a smaller reservoir: Atchison Lake Reservoir on East Branch Mill Creek. Of the 20 sites surveyed, stream and bank stabilization BMPs were recommended at 10 of the survey sites.

Streambanks in the Tuttle Creek Lake Watershed exhibited the highest erosion rates of the 20 sites surveyed. The Little Blue River site had the highest weighted erosion rate of 4.90 tons per foot per year (tons/foot/year). The two Big Blue River sites showed high weighted erosion rates of 1.74 and 4.30 tons/foot/year. The Delaware River, located in the Perry Lake Watershed, displayed high weighted erosion rates that ranged from 1.77 to 2.11 tons/foot/year in the lower reaches of the river. Conceptual plans to implement BMPs were considered for all of the stream reaches, and the BMP-modified stream scenarios were recalculated in RIVERMorph using the Rosgen Bank Assessment for Non-point Consequences of Sediment (BANCS) model feature to predict changes in erosion loss. Results from the Rosgen BANCS model indicated that the bank types with already low erosion potential did not show a significant erosion reduction with the implementation of BMPs; however, the highly erodible bank types showed a significant reduction in bank erosion. Those survey sites that did not show a significant reduction with the implementation of BMPs were not presented in the results section. Table ES-1 summarizes the rate of erosion, recommended BMPs, and the erosion reduction potential at each of the survey sites.

Table ES-1. Summary of Bank Erosion Results Upstream of Three Major Federal Reservoirs and Two Smaller Reservoirs

Reservoir Watershed	Survey Site and Stream Segment	Stream Sediment Erosion (tons/foot/year)[1]	BMP Percent Reduction Bank Erosion	Recommended Stream Stabilization BMPs
Perry Lake	1a: Tributary to Banner Creek	0.09	Negligible	None Recommended
Perry Lake	2a: Tributary to Mission Creek	0.42	Negligible	None Recommended
Perry Lake	3a: Clear Creek	0.89	93%	Bank Shaping, Riparian Plantings, LPSTP[2], and Rock Vanes
Perry Lake	4a: Delaware River at Kickapoo Nation	0.31	88%	Bank Shaping, Riparian Plantings, LPSTP[2] and Rock Vanes
Perry Lake	5a: Delaware River at Arrington	0.67	93%	Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes
Perry Lake	6a: Banner Creek	0.45	Negligible	None Recommended
Perry Lake	7a: Tributary to Clear Creek	0.26	Negligible	None Recommended
Perry Lake	8a: Delaware River at USGS Muscotah Gauge	1.77	91%	Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes
Perry Lake	9a: Delaware River at Highway 254 Bridge	1.18	93%	Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes
Perry Lake	10a: Delaware River at Muddy Creek Confluence	2.11	88%	Bank Shaping, Riparian Plantings, LPSTP, Rock Vanes and Rock Chutes
Tuttle Creek	1b: Little Blue River	4.90	95%	Bank Shaping, Riparian Plantings, Rock Chutes, LPSTP, and Bendway Weirs
Tuttle Creek	2b: Black Vermillion River	0.27	Negligible	None Recommended
Tuttle Creek	3b: Big Blue River at Alcove Springs	4.30	87%	Riparian and Bank Shaping, Rock Chutes, and Bendway Weirs
Tuttle Creek	4b: Big Blue River near Oketo	1.74	91%	Riparian and Bank Shaping, Rock Chutes, and Bendway Weirs
Centralia Lake	5b: Tributary to Centralia Lake	0.05	Negligible	None Recommended
Clinton Lake	1c: Lynn Creek	0.41	93%[3]	Riparian and Bank Shaping, Rock Vanes, and LPSTP
Clinton Lake	2c: Rock Creek	0.25	Negligible	None Recommended
Clinton Lake	3c: Wakarusa River at Glick Road	0.22	Negligible	None Recommended
Clinton Lake	4c: Wakarusa River at Ratner Road	0.22	Negligible	None Recommended
Lake Wabaunsee	1d: Tributary to East Branch Mill Creek	0.03	Negligible	None Recommended

[1] Erosion results are area-weighted averages for the different bank types of the surveyed stream reach.
[2] Longitudinal peaked stone toe protection (LPSTP).
[3] The percent reduction is only for one stream segment at the Lynn Creek survey site (Bank Type 5).
[4] Negligible means the BANCS modeling did not indicate that BMPs reduced the rate of erosion at the stream reach.

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Appendix A. Bank Erodibility Hazard Index (BEHO) Summary

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ACRONYMS AND ABBREVIATIONS

BANCS	Bank Assessment for Non-point Consequences of Sediment
BEHI	Bank Erodibility Hazard Index
BHR	Bank Height Ratio
BMP	Best Management Practice
Csf	Cubic Feet per Second
EQIP	Environmental Quality Improvement Program
d_{nb}	Near-bank Maximum Depth
d_{bkf}	Mean Bankfull Depth
DRG	Digital Raster Graphs
EQIP	Environmental Quality Improvement Program
GIS	Geographic Information System
GPS	Global Positioning System
GRSC	Gulf South Research Corporation
HUC	Hydrologic Unit Code
KDHE	Kansas Department of Health and Environment
KWO	Kansas Water Office
LPSTP	Longitudinal Peaked Stone Toe Protection
MWR	Meander Width Ratio
NBS	Near-bank Stress
NRCS	Natural Resources Conservation Service
SWIMS	Surface Waters Information Management System
TWI	The Watershed Institute, Inc.
U.S.	United States
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WARSS	Watershed Assessment of River Stability and Sediment Supply

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SECTION 1.0
INTRODUCTION

1.0 INTRODUCTION

The United States (U.S.) Army Corps of Engineers (USACE), Kansas City District contracted Gulf South Research Corporation (GRSC) to conduct stream channel morphologic and riparian assessments identifying future sediment control opportunities within the Kansas River Basin. The project has been executed under Section 204 of the Water Resources Development Act of 1992, as amended by Section 2037 of the Water Resources Development Act of 2007. The Section 204 program provides for Federal cooperation and participation in the preparation of state and regional sediment management plans. The study provides information on sediment management and contributes to planning efforts underway by the Kansas Water Office (KWO) and other state agencies for long-term reservoir sustainability.

Reservoirs are an important source of water in Kansas. They provide potable water to the local population, destinations for recreational activities, and habitat to aquatic life. Kansas's reservoirs supply the municipal and industrial water for more than two-thirds of the state's population. By their nature, reservoirs act as settling basins; they gradually fill with sediment, which reduces their capacity to store water to meet water supply needs. Bed and bank erosion from streams and rivers that flow into the reservoirs has accelerated sediment deposition in the reservoirs, which affects water quality and reservoir water-storage capacity (Hargrove 2008).

Stream bed and bank erosion is a natural phenomenon; however, human activities such as agriculture and channel modification, accelerate this process. Many of the reservoirs in Kansas were built with a projected lifespan of 150 to 200 years; current projections indicate the life span of these reservoirs could be reduced by 50 to 100 years, due to an accelerated rate of sedimentation from upstream sources (Hargrove 2008). The sediment originates from two main sources: stormwater overland flow from adjacent land uses such as agriculture and instream sources such as stream and river bed and bank erosion. Streams and rivers are dynamic systems that adjust to environmental changes imposed upon them. The systems adjust in an effort to maintain a steady state, or dynamic equilibrium, between the driving mechanisms of flow and sediment transport and the resisting forces of bed and bank stability and resistance to flow (Soar et al., 2001).

Streambank erosion is influenced by the erodibility potential and hydraulic/gravitational forces. Processes of streambank erosion include surface erosion, mass failure, fluvial entrainment, freeze-thaw, dry ravel, ice scour, liquefaction/collapse, positive poor pressure, both saturated and unsaturated failures, and soil piping (Rosgen 2001). These processes can be increased in incised channels, such as many of the streams and channels in northeast Kansas. Incised channels are vertically contained streams that have abandoned previous floodplains due to a lowering of stream bed. Incised channels above in northeast Kansas were mainly created by channel straightening. Incised streams or channels can also be created by floodplain encroachment, loss of floodplain access, urban development, major floods, change in sediment regime, and riparian vegetation conversion (Rosgen 1996).

This report summarizes research conducted in four previous sediment erosion investigations in three watersheds upstream of major Federal water supply reservoirs, including Perry Lake (USACE 2008; USACE 2010a), Tuttle Creek Lake (USACE 2010b), and Clinton Lake (USACE 2011). Fluvial geomorphology survey data were collected at 20 locations in the Kansas River Basin: 10 locations were selected above Perry Lake, five above Tuttle Creek Lake, and four above Clinton Lake. One survey was performed above a smaller water supply reservoir, Lake Wabaunsee on East Branch Mill Creek. The survey locations were selected based on aerial photograph interpretation and input from the KWO and USACE. The location of the three major Federal reservoirs and their watershed boundaries are presented in Figure 1-1.

This summary report contributes to the sediment planning efforts underway by the KWO and other state agencies for long-term reservoir sustainability. The objectives of this project were to:

- Summarize research from four previous investigation reports in the Kansas River Basin.
- Update the erosion results from the first and second report in the Perry Lake Watershed by modifying input parameters in the Rosgen RIVERMorph model and rerunning erosion analysis.
- Update the first report from the Perry Lake Watershed by assessing the impact of stream stabilization best management practices (BMPs) scenarios on rates of erosion at survey sites.
- Update the first report from the Perry Lake Watershed by estimating the cost of implementing stream stabilization BMPs at survey sites.
- Present comprehensive stream erosion information needed to identify future streambank stabilization measures, conceptual designs and cost estimates for stream stabilization projects in northeast Kansas.

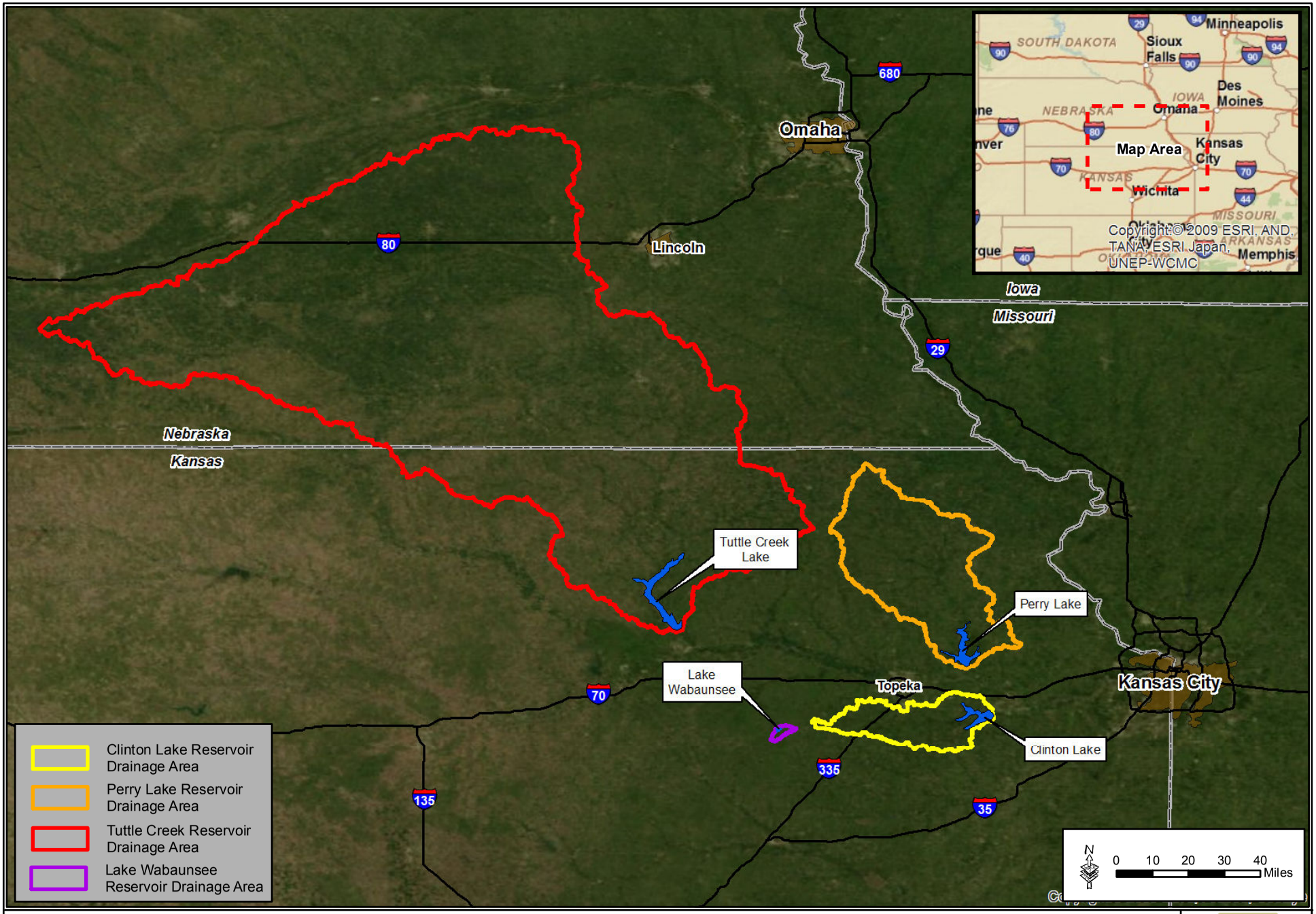

Figure 1-1: Clinton Lake, Tuttle Creek Lake, and Perry Lake Watershed Location Map

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SECTION 2.0
STUDY AREA

2.0 STUDY AREA

All of the watersheds discussed in this report are located within the Kansas River Basin. They include Perry Lake Watershed, Tuttle Creek Watershed, and Clinton Lake Watershed. One survey was performed above Lake Wabaunsee.

2.1 Perry Lake Watershed

The Perry Lake Watershed is located in northeastern Kansas and encompasses 1,117 square miles (sq. mi.). The Delaware River flows into Perry Lake near Lawrence, Kansas, and eventually into the Kansas River. Releases from the reservoir are used to maintain streamflow in the Kansas River during low flow periods, contributing 10 percent of the mean flow. The Kansas River is used as the primary water source to meet many of the municipal drinking water supply needs for communities along the Kansas River (Barns and Kalita 2002). The Delaware River is not meeting designated criteria for primary and secondary recreational uses due to high levels of bacteria (Kansas Department of Health and Environment [KDHE 2008a]).

The historic bluestem prairie, formerly characteristic of the region, has been converted to row crop agriculture throughout the Perry Lake Watershed. Most of the land use in the watershed consists of grassland for grazing livestock (50 percent of the area) or cropland (43 percent of the area), and the remaining 7 percent consists of woodland and residential areas (KDHE 2008b). The existing wooded riparian corridor still resembles the historic lowland cottonwood vegetation described in Kuchler (1974).

Ten surveys were conducted on the Delaware River and its tributaries upstream of Perry Lake. The survey sites along the Delaware River were selected with help from the Delaware River Watershed Restoration and Protection Strategy (WRAPS), KWO, and USACE. Figure 2-1 presents the location of the 10 survey sites in the Perry Lake Watershed. The rivers and streams throughout the Perry Lake Watershed have been channelized extensively as indicated by the relic channel patterns displayed in historical aerial photographs. Figure 2-2 compares a possible historical path of the Delaware River to the current channelized condition. In the past, the Delaware River had a much more sinuous pattern, which mimicked the pattern of several Delaware River tributaries near Muscotah, Kansas. The natural tendency for the Delaware

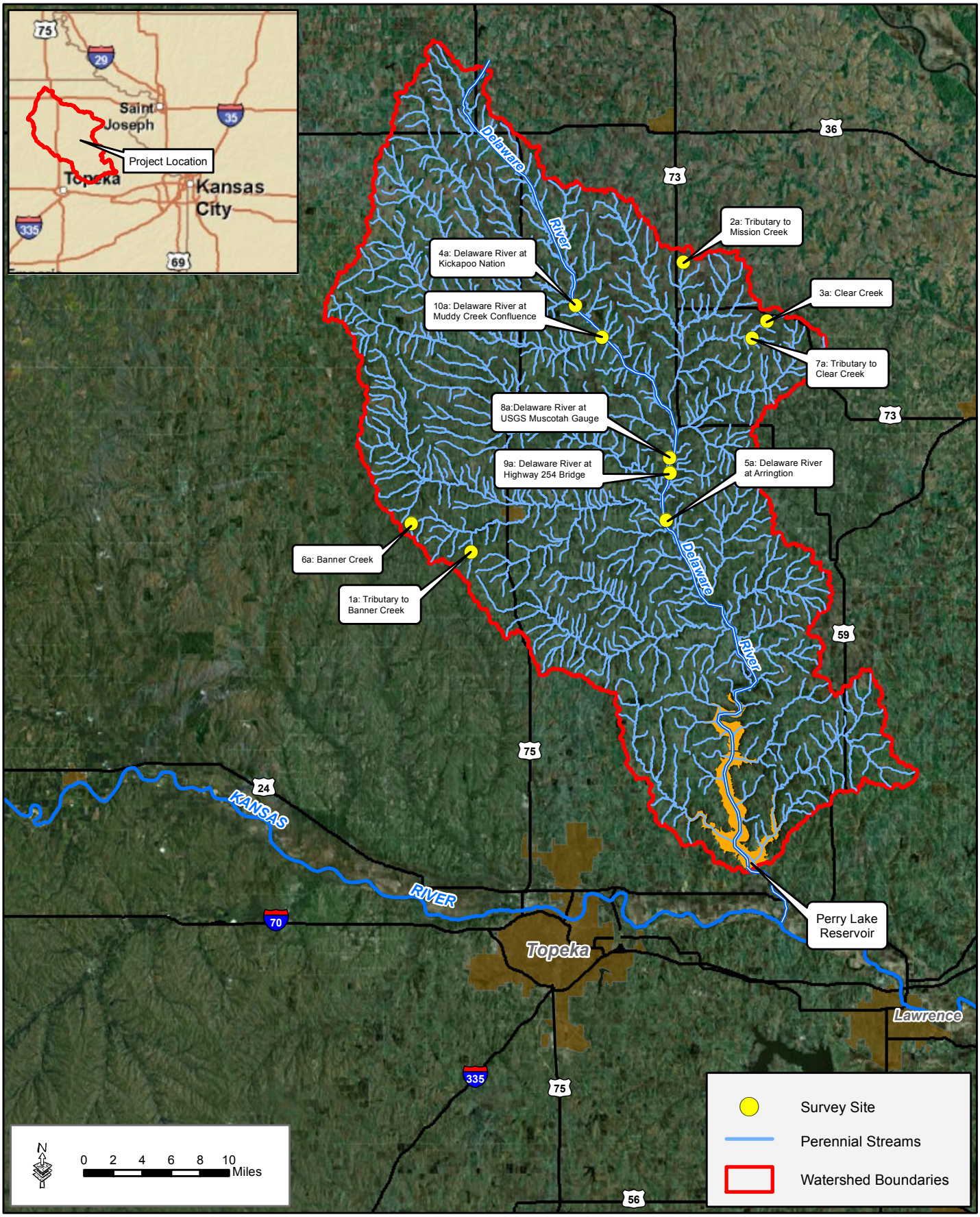


Figure 2-1: Perry Lake / Delaware River Watershed and Survey Sites

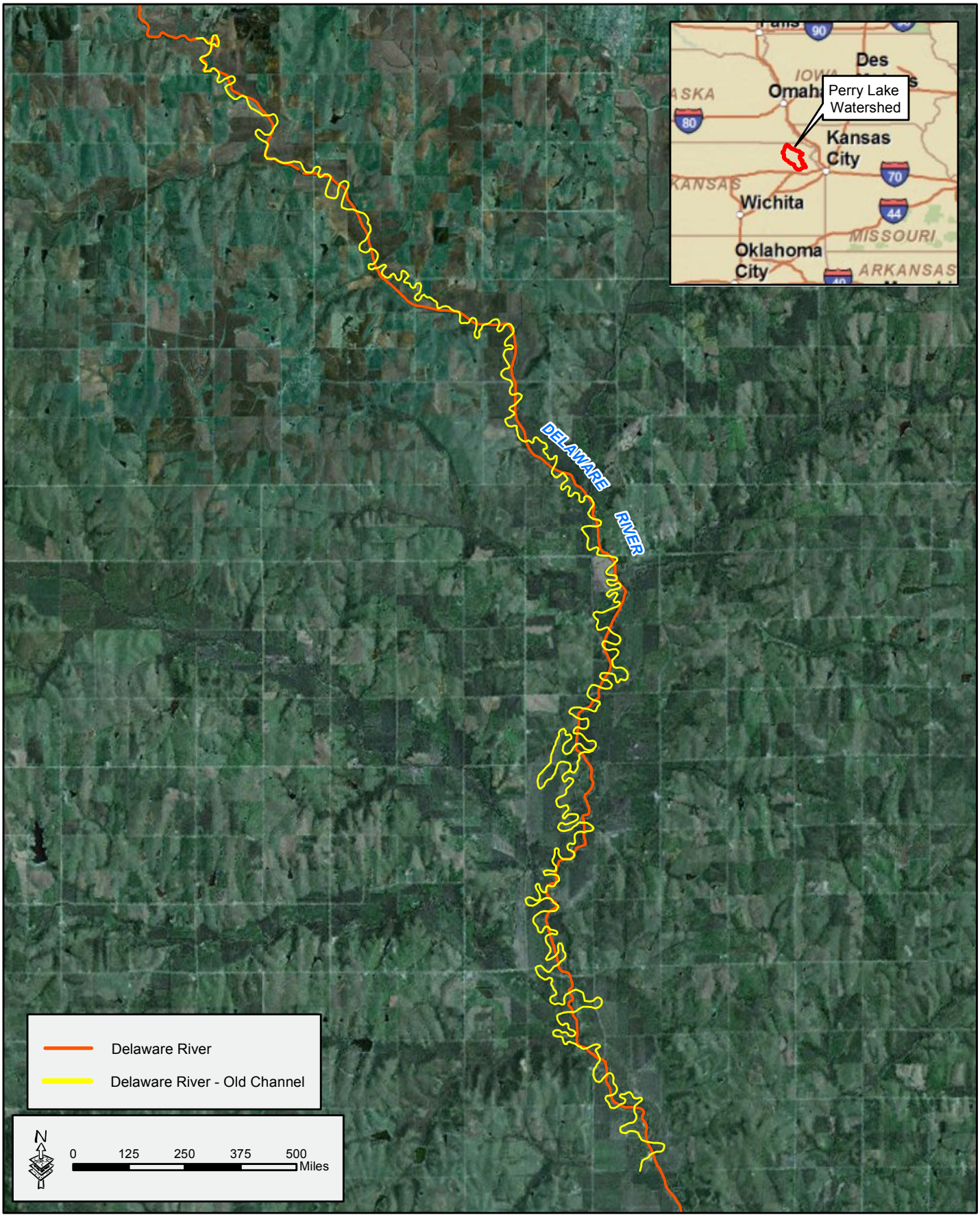


Figure 2-2: Channelization of Delaware River

River is to reestablish a sinuous river course. Table 2-1 presents the survey dates and names of the survey locations.

Table 2-1. Location and Dates of Complete Fluvial Geomorphology Surveys

Site Number	Fluvial Geomorphology Survey	Location – Section – Township Range	Survey Date(s)
1a	Tributary to Banner Creek	SE ¼ S24-T7S-R14E	28 April 2008
2a	Tributary to Mission Creek	NW ¼ S16-T4S-R17E	29 April 2008
3a	Clear Creek – Atchison County Lake	SW ¼ S33-T4S-R18E	30 April 2008
4a	Delaware River – Kickapoo Nation	SE ¼ S30-NE ¼ S31-T4S-R16E	7 July to 8 July 2008
5a	Delaware River - Arrington	NE ¼ Sec 8, T 7 S, R 17 E	10 July to 11 July 2008
6a	Banner Creek Reservoir	SE ¼ S8-T7S-R14E	29 May 2009
7a	Tributary to Clear Creek	NW ¼ S8-T5S-R18E	19 June to 23 June 2009
8a	Delaware River at USGS Muscotah Gauge	NW ¼ S21-T6S-R17E NE ¼ S20-T6S-R17E	31 August to 1 September 2009
9a	Delaware River at Highway 254 Bridge	NW ¼ S28-T6S-R17E NE ¼ S29-T6S-R17E	2 August 2009
10a	Delaware River at Muddy Creek Confluence	SE ¼ S4-T5S-R16E NE ¼ S9-T5S-R16E	11 August to 14 August 2009

Source: GSRC

2.2 Tuttle Creek Lake Watershed

Tuttle Creek Lake is located in Riley and Pottawatomie counties on the Big Blue River, just upstream from the City of Manhattan, Kansas. Tuttle Creek Reservoir was constructed and is operated by the USACE, Kansas City District, as a multipurpose lake project. The Tuttle Creek Lake Watershed is approximately 9,628 sq. mi., and drains parts of southeast Nebraska and northeast Kansas.

Approximately 75 percent of the watershed is located in Nebraska. In 2000, the lake had a surface area of about 12,620 acres and a water-storage capacity of about 280,000 acre-feet. Land use in the Tuttle Creek Lake Watershed is mostly agricultural with cropland accounting for about 66 percent of the watershed. Grassland and pasture account for about 29 percent of the watershed. Woodland and urban land use cover about 3 and 1 percent of the watershed, respectively (Juracek and Mau 2002).

The dam that forms the Tuttle Creek Lake Reservoir is located on the Big Blue River, 12.3 miles above its confluence with the Kansas River. The water quality of Tuttle Creek Lake is moderately good. Tuttle Creek Lake is currently listed as being "impaired" (not meeting designated uses) due to its exceeding four water quality standards: eutrophication, sedimentation, atrazine, and alachlor. The surface water flow in the Tuttle Creek Lake Watershed is dominated by three main streams: the Big Blue River, the Little Blue River, and the Black Vermillion River. The Big Blue River and Little Blue River are shared by Kansas and Nebraska; the Black Vermillion River lies wholly within Kansas.

The Big Blue River contributes the most flow to Tuttle Creek Lake, followed by the Little Blue River and the Black Vermillion River. Five survey sites were selected in the Tuttle Creek Lake Watershed: one on the Little Blue River, Black Vermillion River, and a tributary to Centralia Lake, and two survey sites on the Big Blue River. The three rivers mentioned above have been extensively channelized, causing severe channel degradation and subsequent streambank instability. The location names and dates of the surveys are provided in Table 2-2. The Tuttle Creek Lake Watershed and the locations of the five survey sites are presented in Figure 2-3.

Table 2-2. Location and Dates of Complete Fluvial Geomorphology Surveys

Site Number	Name of Watershed	Location (Section-Township-Range)	Survey Date(s)
1b	Little Blue River	SW ¼ S14-T4S-R6E	6 October to 7 October 2009
2b	Black Vermillion River	SW ¼ S14-T4S-R9E NW ¼ S23-T4S-R9E	19 October to 21 October 2009
3b	Big Blue River at Alcove Springs	S31-T3S-R7E	9 November to 10 November 2009
4b	Big Blue River near Oketo	SE ¼ S27-T1S-R7E N ½ S34-T1S-R7E	11 November to 12 November 2009
5b	Centralia Lake	SW¼ S25-T4S-R11E	28 May 2009

Source: GSRC

2.3 Clinton Lake Watershed

Clinton Lake is located in the east-central portion of Kansas, 8 miles west of Lawrence. It is mainly an impoundment on the Wakarusa River, although Deer Creek and Rock Creek are also major water features that contribute flow directly to the reservoir. The reservoir was created for the purposes of flood protection and is also the primary drinking water source for almost all residents of Douglas County, Kansas.

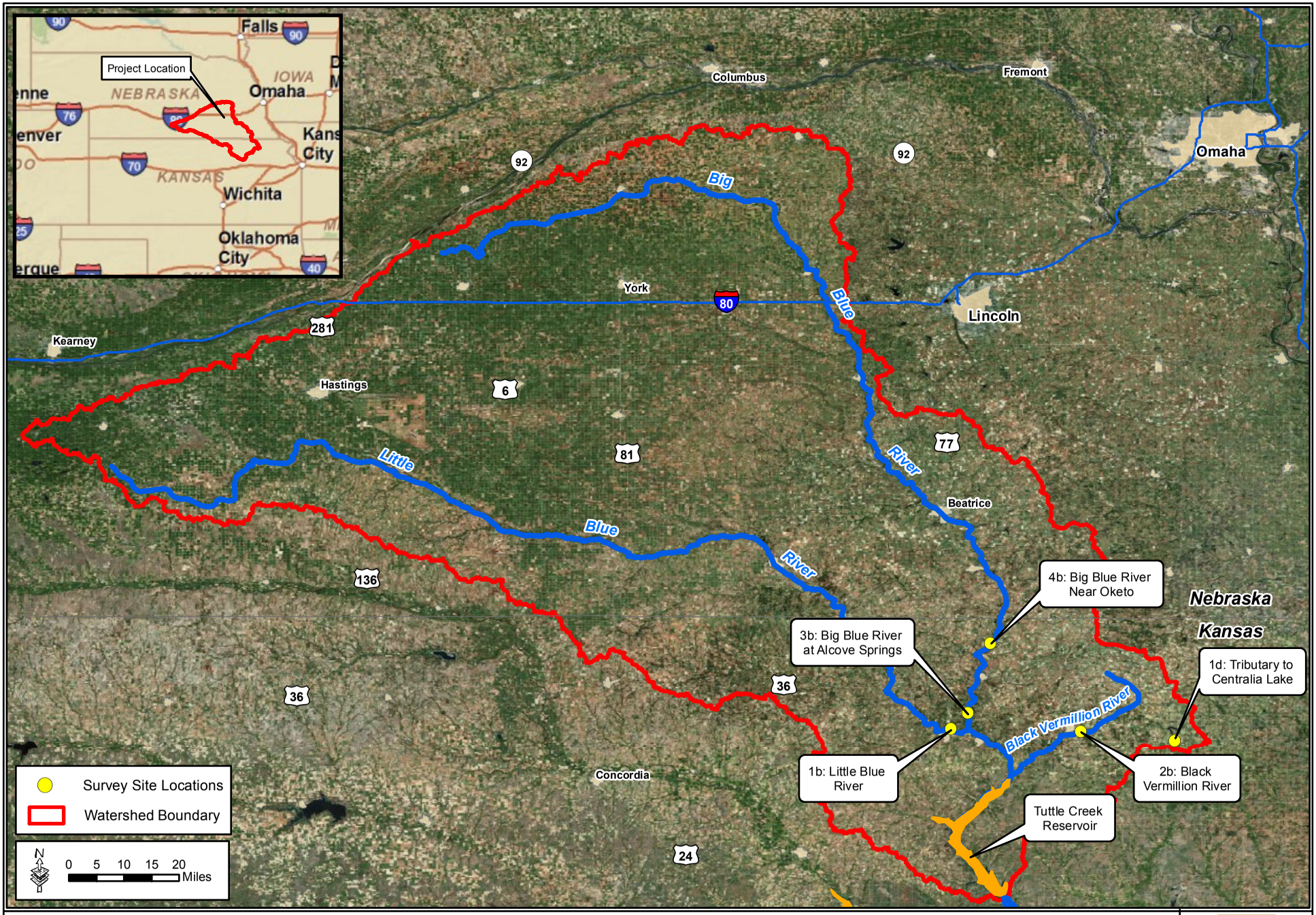


Figure 2-3: Tuttle Creek Lake Watershed and Five Survey Sites

The Clinton Lake Watershed encompasses nearly 368 sq. mi. of land extending west from the dam to the Flint Hills of western Shawnee and northwestern Osage counties. Most of the watershed lies within the Osage Cuestas division of the Osage Plains in the Central Lowland Province. Historically, the watershed was dominated by tall-grass prairie; conversion to agricultural uses has resulted in increased amounts of sediment and nutrients leaving the land and entering the aquatic system. Land use in the watershed is predominantly agricultural, with 56 percent of the land in pasture land and 27 percent cultivated cropland. Forest/woodland occupies approximately 15 percent of the total area of the watershed. About 2 percent of the watershed is in residential or commercial uses (Wang et al. 2000).

Clinton Lake is currently listed as being impaired due to eutrophication. Upstream, the Wakarusa River exceeds three water quality standards: fecal coliform, ammonia, and biological indicators (KDHE 2010). Four survey sites were analyzed in the Clinton Lake Watershed: one on Lynn Creek, a tributary to the Wakarusa River; one on Rock Creek, a tributary to Clinton Lake; and two survey sites on the Wakarusa River. The location names and dates of the surveys are provided in Table 2-3. The Clinton Lake Watershed and the locations of the four survey sites are presented in Figure 2-4.

Table 2-3. Location and Dates of Complete Fluvial Geomorphology Surveys

Site Number	Name of Watershed	Location (Section-Township-Range)	Survey Date(s)
1c	Lynn Creek	NE ¼ S24-T13S-R16E	28 September to 29 September 2010
2c	Rock Creek	NE ¼ S13-T14S-R17E SE ¼ S12-T14S-R17E	29 September to 30 September 2010
3c	Wakarusa River at Glick Road	NE ¼ S29-T13S-R14E	22 September to 23 September 2010
4c	Wakarusa River at Ratner Road	NW ¼ S30-T13S-R17E	21 September to 22 September 2010

Source: GSRC

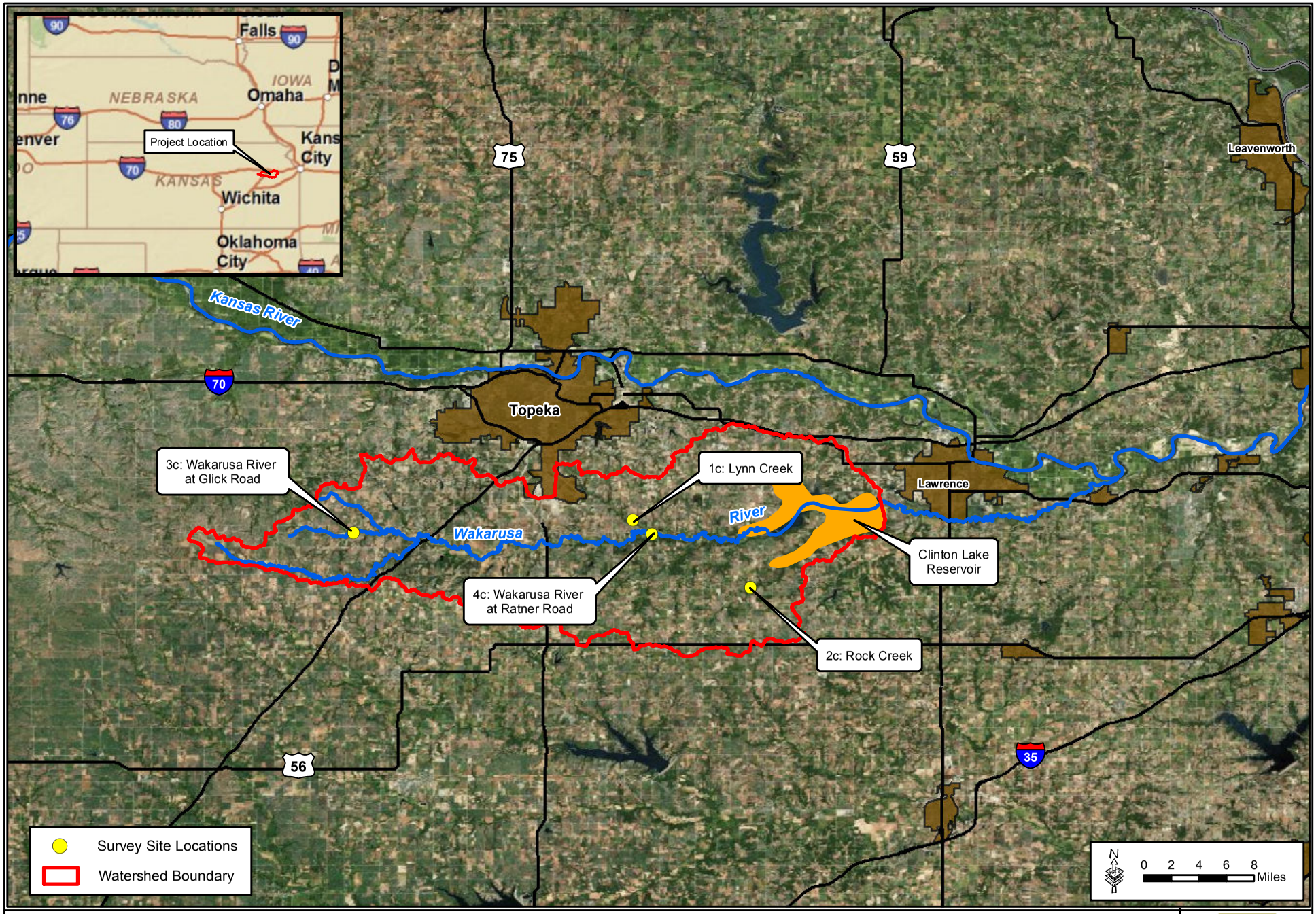


Figure 2-4: Clinton Lake Reservoir Basin and Four Survey Sites

2.4 Lake Wabuansee Watershed

The tributary to East Branch Mill Creek is a small stream with a 229 cubic feet per second bankfull discharge and 2.82 sq. mi. drainage area in the Lake Wabaunsee Watershed. The survey site on this stream had gently sloping banks which were well-vegetated; and bedrock and large boulders line the bank toe, providing very low erosion potential (Photograph 2-1). The location of Lake Wabuansee and watershed is presented in Figure 2-5. The site was surveyed on 23 May 2008 and located at NW¼ S9-T14S-R11E (location-section-township-range).

Photograph 2-1. Tributary to East Branch Mill Creek in Lake Wabaunsee Watershed.

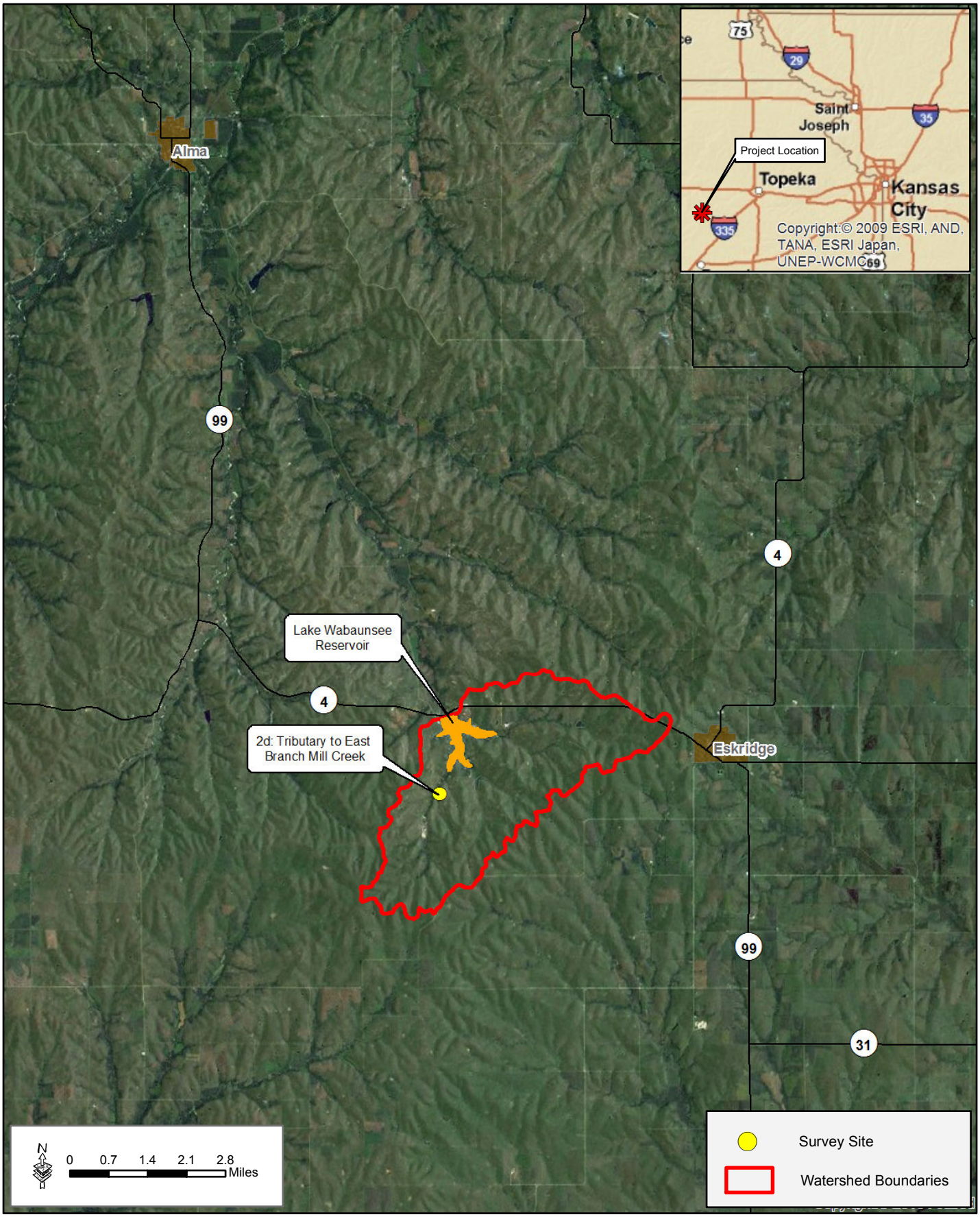


Figure 2-5: Lake Wabaunsee Watershed and Survey Site

SECTION 3.0
METHODOLOGY

3.0 METHODOLOGY

This report summarizes research conducted in four previous investigations on stream bed and bank sediment erosion in the Kansas River Basin. As the research progressed, some coefficients in modeling analysis were updated due to the availability of new information. This section discusses the methods that were revised and used to update the models and rerun the survey data from the first and second Perry Lake Watershed investigations (USACE 2008; USACE 2010). In addition, the first Perry Lake Watershed investigation (USACE 2008) did not calculate the costs associated with the implementation of stream stabilization BMPs or the rate at which erosion would be reduced if the BMPs were installed. This was performed in the subsequent reports, so the results from the first investigation were updated herein. The data for the following six sites within the Perry Lake Watershed were reanalyzed and revised: Tributary to Banner Creek, Tributary to Mission Creek, Clear Creek, Tributary to East Branch Mill Creek, Delaware River at Kickapoo Nation, and Delaware River at Arrington.

3.1 Site Selection for Analysis

From previous investigations, it was noted that survey sites with already low erosion potential did not show a significant erosion reduction with the implementation of BMPs. Therefore, stream and bank stabilization BMPs were recommended at 10 of the 20 survey sites. Table 3-1 presents the survey sites that were not carried forward for further analysis.

Table 3-1. Survey Sites Not Carried Forward in the Summary Report

Federal Reservoir Watershed	Survey Site and Stream Segment	Sediment Erosion (tons/foot/year)
Perry Lake	1a: Tributary to Banner Creek	0.09
Perry Lake	2a: Tributary to Mission Creek	0.42
Perry Lake	6a: Banner Creek	0.45
Perry Lake	7a: Tributary to Clear Creek	0.26
Tuttle Creek	2b: Black Vermillion River	0.27
Centralia Lake	5b: Tributary to Centralia Lake	0.05
Clinton Lake	2c: Rock Creek	0.25
Clinton Lake	3c: Wakarusa River at Glick Road	0.22
Clinton Lake	4c: Wakarusa River at Ratner Road	0.22
Lake Wabaunsee	1d: Tributary to East Branch Mill Creek	0.03

Source: GSRC.

3.2 Survey Site Bank Types and Hot-Spots

Each of the survey sites were segregated into bank types. Bank types change when the geomorphology of the streambank changes within the survey reach. When a change in streambank geomorphology was observed, it was marked sequentially (e.g. Bank Type 1, 2, 3) from upstream to downstream. If a previously noted geomorphology appears in a survey reach, it is referenced as the bank type it resembles upstream. For instance, Bank Type 1 may appear at the beginning and end of a survey.

Erosion rates varied from bank type to bank type within the survey reach. At several survey sites, such as those presented in Table 3-1, erosion rates were low throughout the survey reach. At other survey sites, one or possibly two bank types were unstable and highly erodible. BMP recommendations were made for only the highly erodible bank types within the survey reach. Often, the unstable section of a stream reach composed only 10 to 30 percent of the survey site. The highly erodible bank types are described as “hot-spots” in Section 4 and were carried forward for analysis, to evaluate the effectiveness of BMPs on erosion reduction.

3.3 Bank Erodibility Hazard Index (BEHI)

The BEHI method is discussed because BEHI input parameters from the last two investigations were adjusted with updated information. Therefore, the BEHI data from first and second Perry Lake Watershed investigations (USACE 2008; USACE 2010) were rerun in the RIVERMorph model. The BEHI variables were modified using changes suggested by Sass (2011). Sass (2011) combined the vegetation components (rooting depth ratio and weighted root density percent) into one category (Woody Vegetation Present) since they relate to similar processes. Sass (2011) found that BEHI vegetation scores were consistent for streams in the Black Vermillion Watershed. A BEHI vegetation score of 2.5 was applied if woody vegetation was present, and 8.5 was applied if woody vegetation was absent. The modification strengthened the BEHI Near Bank Stress (NBS) curves for moderate and high BEHI-rated sites. The RIVERMorph data were then exported into a RIVERMorph worksheet and new rates of erosion for survey bank types were determined. Appendix A presents the field measurements used to calculate BEHI scores.

3.4 Evaluating BMP Effectiveness Using BANCS

The Bank Assessment for Non-point source Consequences of Sediment (BANCS) model was used to estimate the erosion rates of the recommended BMP scenarios. The BANCS model is a feature in the Rosgen RIVERMorph BEHI assessment. To predict erosion loss reductions associated with implementing streambank stabilization BMPs, the BANCS model was utilized to determine percent reduction estimates of annual streambank erosion following BMP implementation. Rosgen (1996 and 2006) found a statistically valid correlation between NBS ratings and bank erosion rates stratified by BEHI ratings. Rosgen (1996 and 2006) used erosion monitoring data from Colorado streams found in sedimentary and/or metamorphic geology and from Yellowstone National Park streams found in alpine glaciations and volcanic areas to develop two sets of relationships. It should be noted that the BANCS model is only statistically valid for predicting bank erosion rates in Colorado and Yellowstone National Park streams, as these relationships have not been validated for Kansas alluvial streams. The application of this method for Kansas streams was chosen only to provide a framework to demonstrate the reduction in erosion based on BMP implementation. To date, streambank erosion rates have not been validated for Kansas streams.

To use the BANCS model, BEHI and NBS ratings must be calculated from a selected stream reach. Once the rating values are entered into RIVERMorph, the software allows the user to select a streambank erosion rate relationship (Colorado or Yellowstone). A predicted erosion reduction is calculated from the BANCS estimated erosion rate and the measured height and length of the selected streambank.

For this exercise, the BANCS model was used only to predict the percent reduction in erosion loss when comparing current conditions and BMP implementation scenarios. The percent reduction was then applied to erosion loss data interpreted from aerial photographs. The methods described above were applied to the survey data collected from the first Perry Lake Watershed investigation (USACE 2008) to estimate the potential reduction in erosion, if any, resulting from the implementation of BMPs at the 10 survey sites.

3.5 Streambank Stabilization BMPs

A number of stream bed and bank BMPs were considered to address channel instability observed during field investigations. The BMPs considered for the various survey reaches were

rock bendway weirs, rock vanes, rock chutes, longitudinal peaked stone toe protection (LPSTP), shaping the banks to a 3-foot horizontal to 1-foot vertical (3:1) slope, and restoring the riparian corridor with native trees, shrubs, and grasses.

The BMP implementation scenarios were divided into two periods; years 1 through 3 and years 4 through 10. These scenarios represent two typical periods of vegetation establishment (i.e., young plants versus mature plants). The BEHI parameters were changed to include bank angle, rooting depth, root density percentage, and surface protection. The BEHI modeling scenarios included:

- Current conditions.
- BMP implementation years 1 through 3.
- BMP implementation years 4 through 10.

In addition, the NBS was adjusted to the low rating, as defined by Rosgen (2006), to reflect the installation of bendway weirs or rock vanes, which will help reduce water velocities in the near-bank region.

3.6 BMP Recommendations for Stream Reaches

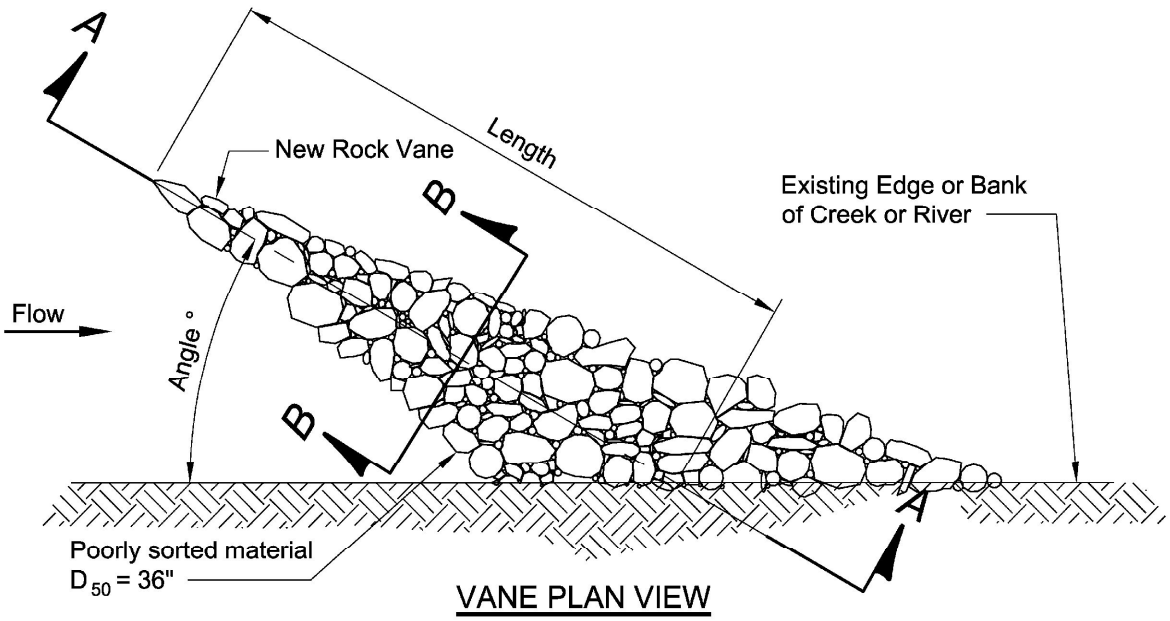
The field surveys indicated that the bank types that were experiencing the greatest erosion rates were banks along outside meander bends with narrow or non-existent riparian corridors. The banks of these reaches have steep slopes and little surface protection, and will continue to move laterally unless effective BMPs are implemented. The following sections describe the recommended stream stabilization BMPs suitable for unstable streambanks.

3.6.1 Rock Vanes

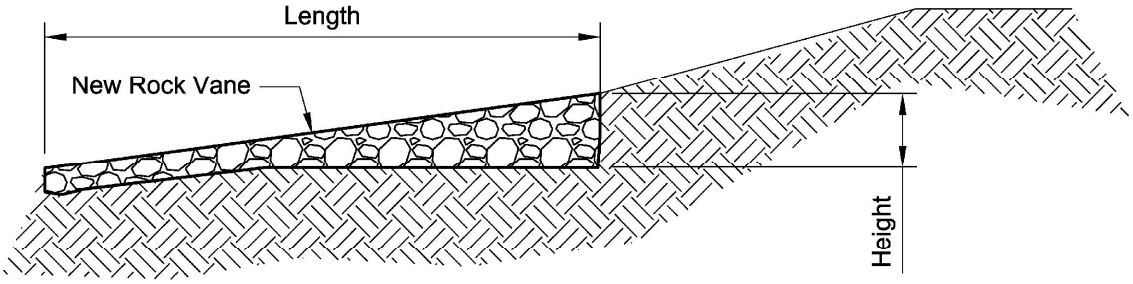
Rock vanes, recommended to address the problem of accelerated streambank erosion, are structures designed to reduce water velocities and redirect flow away from the near-bank region (Figure 3-1). They are most effectively used for channels with low width/depth ratios.

3.6.2 Rock Chutes

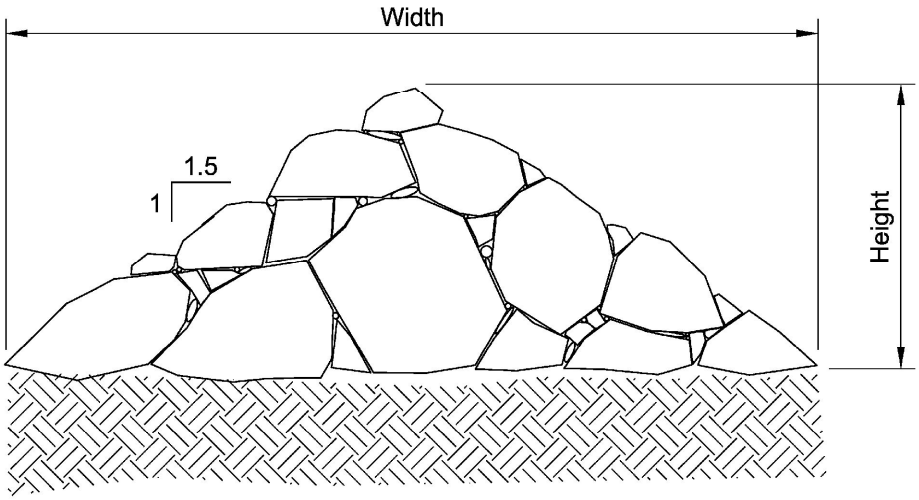
Rock chutes (Figure 3-2) are recommended to stabilize active streambank gully erosion, which was observed at four survey sites: one on the Little Blue River, one on the Delaware River, and two on the Big Blue River. Rock chutes require streambank shaping and the placement of



VANE PLAN VIEW

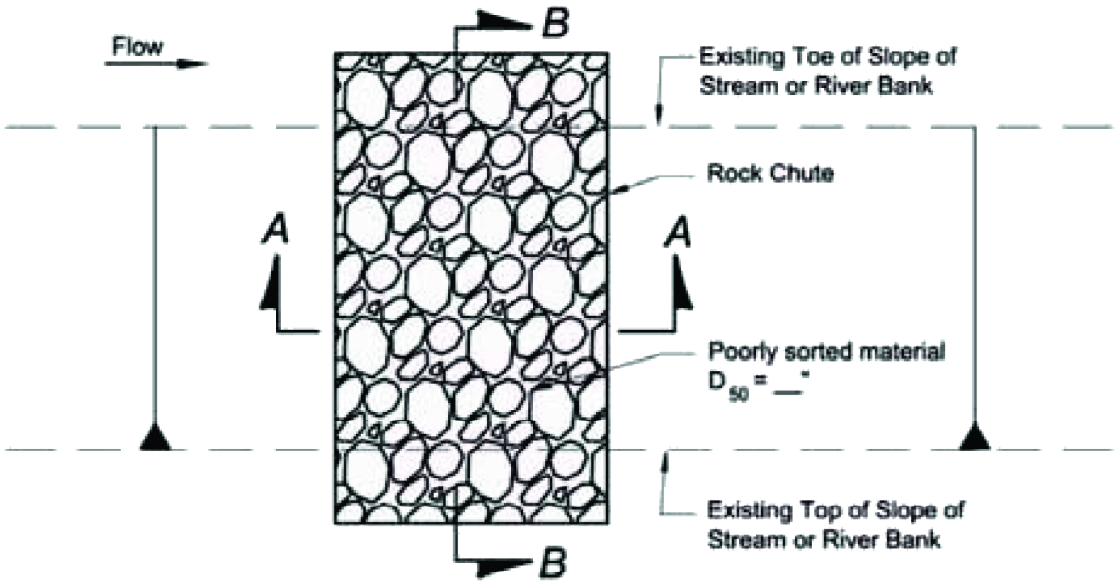


VANE CROSS SECTION A-A

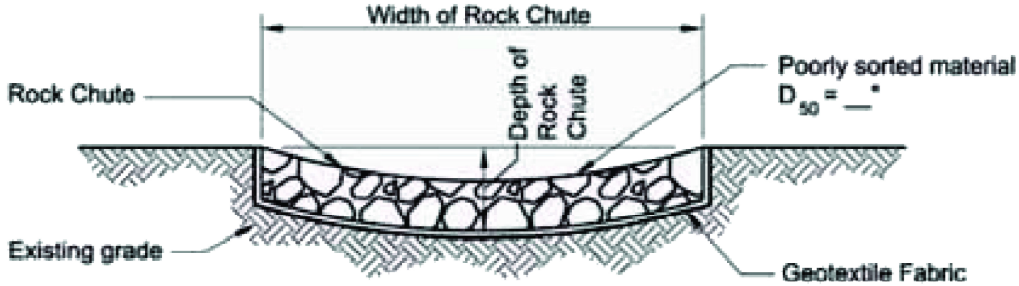


VANE CROSS SECTION B-B

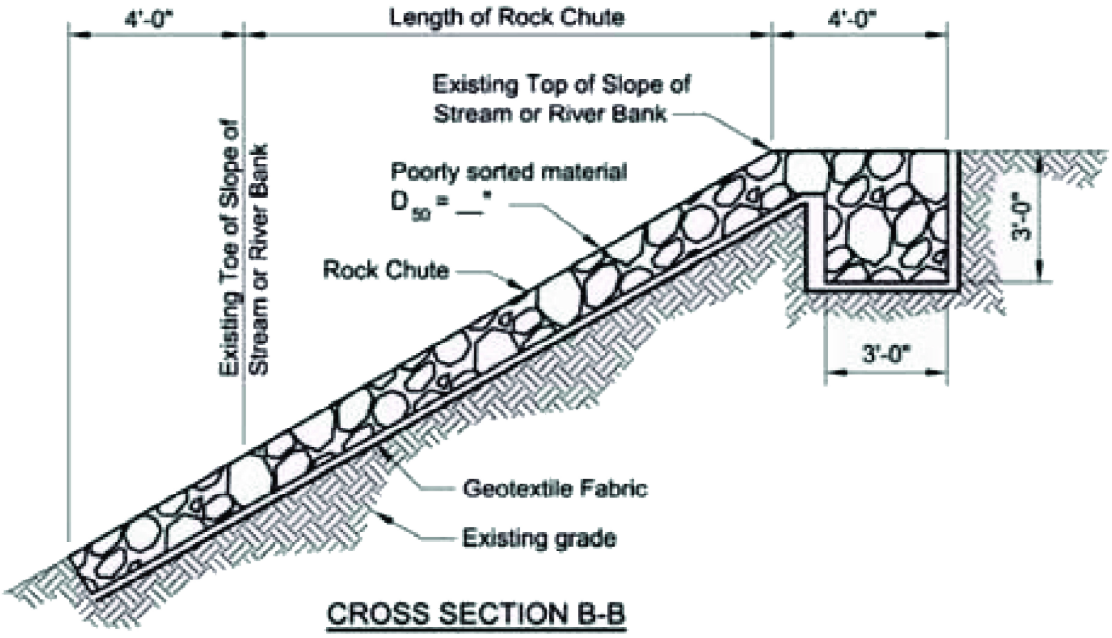
Figure 3-1: Details of Rock Vanes



ROCK CHUTE PLAN VIEW



CROSS SECTION A-A



CROSS SECTION B-B

Figure 3-2: Details of Rock Chutes

graded rock over a geotextile fabric. Gully water is directed over the rock chutes, dissipating the energy of the gully flow and helping to reduce erosion on the streambank.

3.6.3 Bendway Weirs

Bendway weirs (Figure 3-3) are rock structures designed to reduce water velocities and redirect flow away from the near-bank region. The weir should be high and long enough to intercept a large percentage of flow at the river cross-section where the weir is located. Bendway weirs are typically built in sets (4 to 14 weirs per bend) and they have shown to be an effective stabilization structure for channels with moderate to high width/depth ratios to address accelerated steambank erosion.

3.6.4 Longitudinal Peaked Stone Toe Protection

LPSTPs have proven to increase stability on stream reaches experiencing high near-bank stress. LPSTPs are a continuous stone dike placed longitudinally at, or slightly streamward of, the toe of the eroding bank (Figure 3-4). The LPSTP does not necessarily follow the toe exactly, but can be placed to form a "smoothed" alignment through the bend. Smoothed alignment may not be desirable from an environmental or energy dissipation perspective. The amount of stone used depends on depth of scour at the toe, estimated stream forces (impinging flow) on the bank, and flood durations and stages. The LPSTPs provide continuous bank toe reinforcement.

3.6.5 Bank Shaping

Bank shaping, such as constructing a bankfull bench, is recommended to increase streambank stability by dissipating energy during high flow events. Bank shaping is usually employed at outside river bends where the slope of the bank is so great that it is difficult for vegetation to grow (Figure 3-5). Photograph 3-1 illustrates a river bend with a highly erodible bank that is unable to support vegetation. This bank would require excavation to reduce the bank angle and create a gentle slope (3:1) that would support indigenous

Photograph 3-1. Highly Erodible Bank on Big Blue River with Steep Slope and No Vegetation.

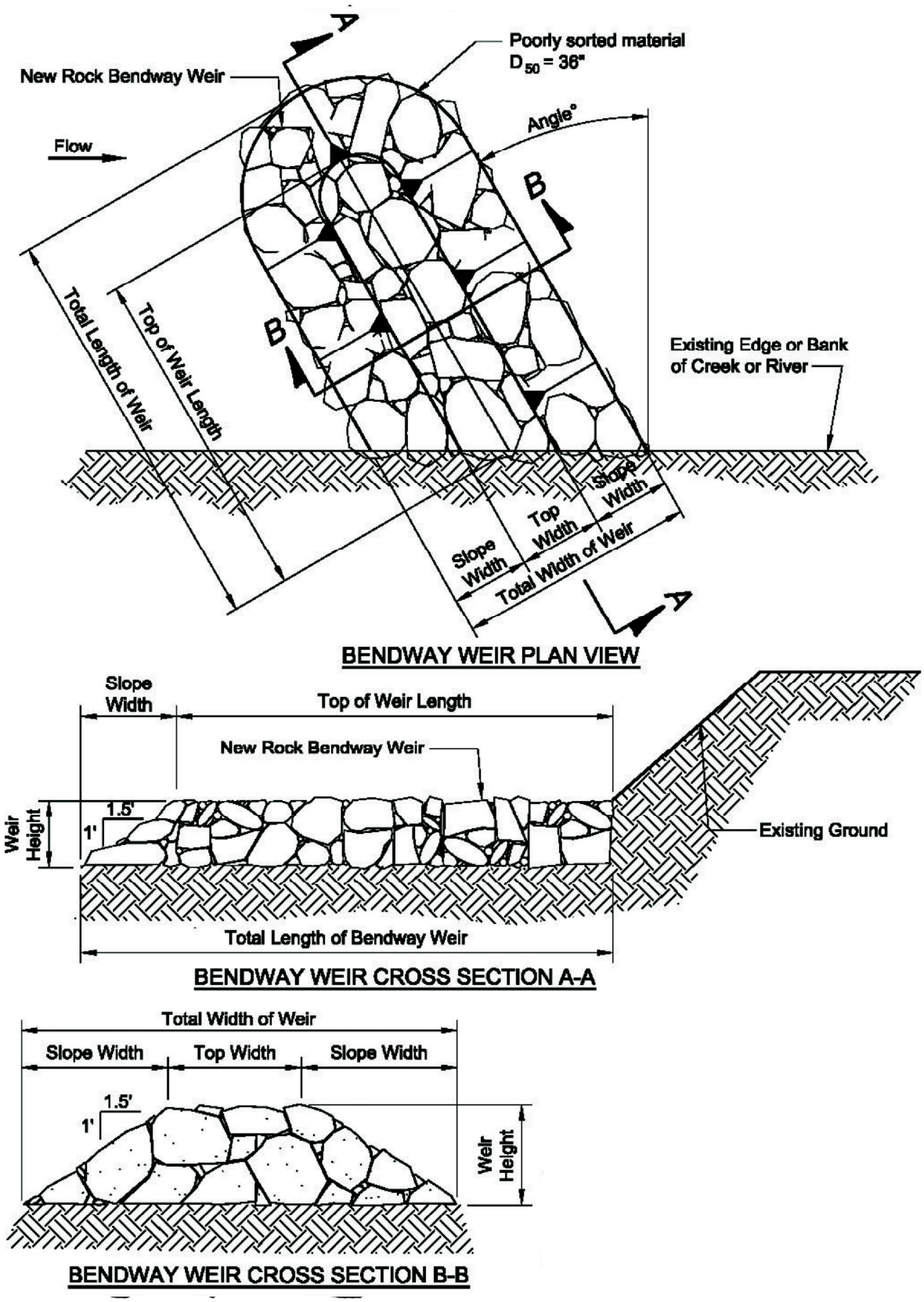
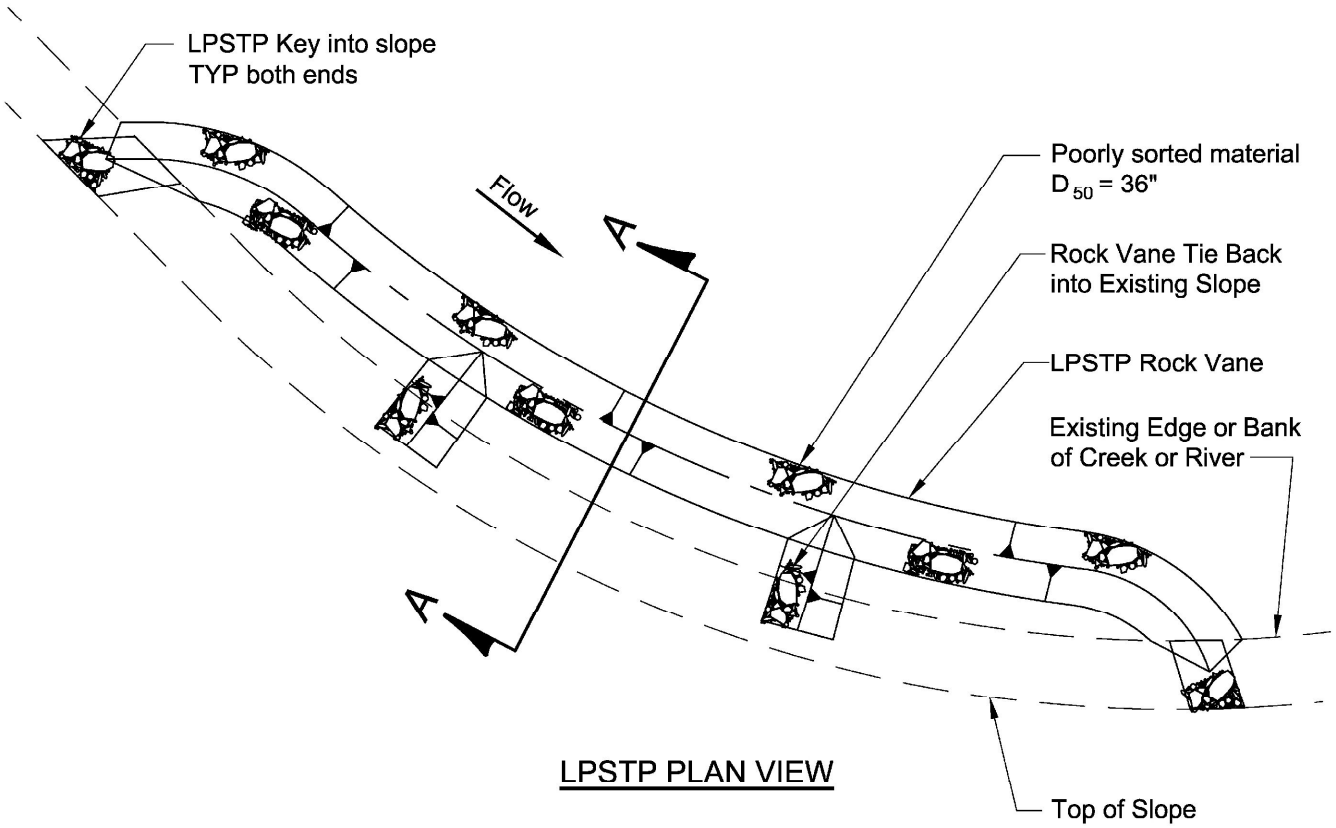
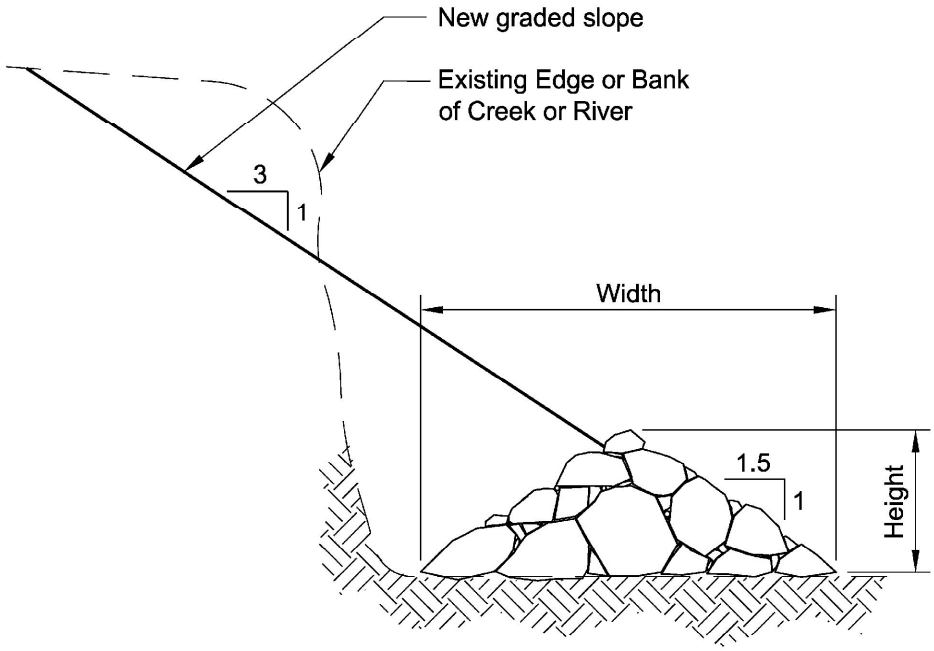


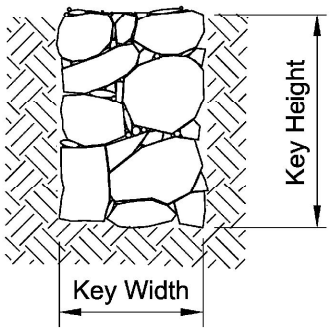
Figure 3-3: Details of Bendway Weirs



LPSTP PLAN VIEW



LPSTP CROSS SECTION A-A



KEY SECTION VIEW

Figure 3-4: Details of Longitudinal Peaked Stone Toe Protection (LPSTP)

trees and grasses. The vegetation's root matter stabilizes the soils and significantly reduces the potential for soils to erode during high water flows. Figure 3-5 presents a diagram of bank shaping and demonstrates the change in bank slope before and after bank shaping has occurred.

3.7 Cost Estimates for Streambank BMPs

To provide cost estimates for streambank BMPs, information was used from past streambank stabilization projects and U.S. Department of Agriculture, Natural Resources Conservation Service Environmental Quality Improvement Program (EQIP) information. Rock placement and bank shaping are the most expensive components of stream restoration. Previous estimates developed for adjacent watersheds have been as high as $97 per linear foot (TWI 2007). For stabilization projects, rock and rock delivery are the most costly items. A large, deep river will require more rock, thus requiring more funding. Rock quantities are usually proportional to the stream size.

Table 3-2 provides a comparison of estimated costs for rehabilitation alternatives. These values are estimates, since specific rock quantities, soil moving, and site condition information are unknown. The price estimates assume that the quarry distance is within 30 miles (typical for the area) and that the bank material is to be excavated and deposited as a thinly spread on the adjacent land.

Table 3-2. Estimated Costs to Implement Streambank Stabilization BMPs

BMP Description	Cost Estimate (per linear foot)
1. Survey and Design Rock Delivery and Placement As-built Certification Design Bank Excavation and Shaping	$5.00 to $10.00 $25.00 to $35.00 $5.00 to $10.00 $20.00 to $30.00
2. Vegetation (Material and Planting) Cover Crop Mulch Willow Stakes Bare Root Seedlings Grass Filter Strip	$5.00
3. Contingencies Unexpected Site Conditions Requiring Extra Materials and Construction Time	$3.00 - $5.50
TOTAL	**$63.00 - $95.50**

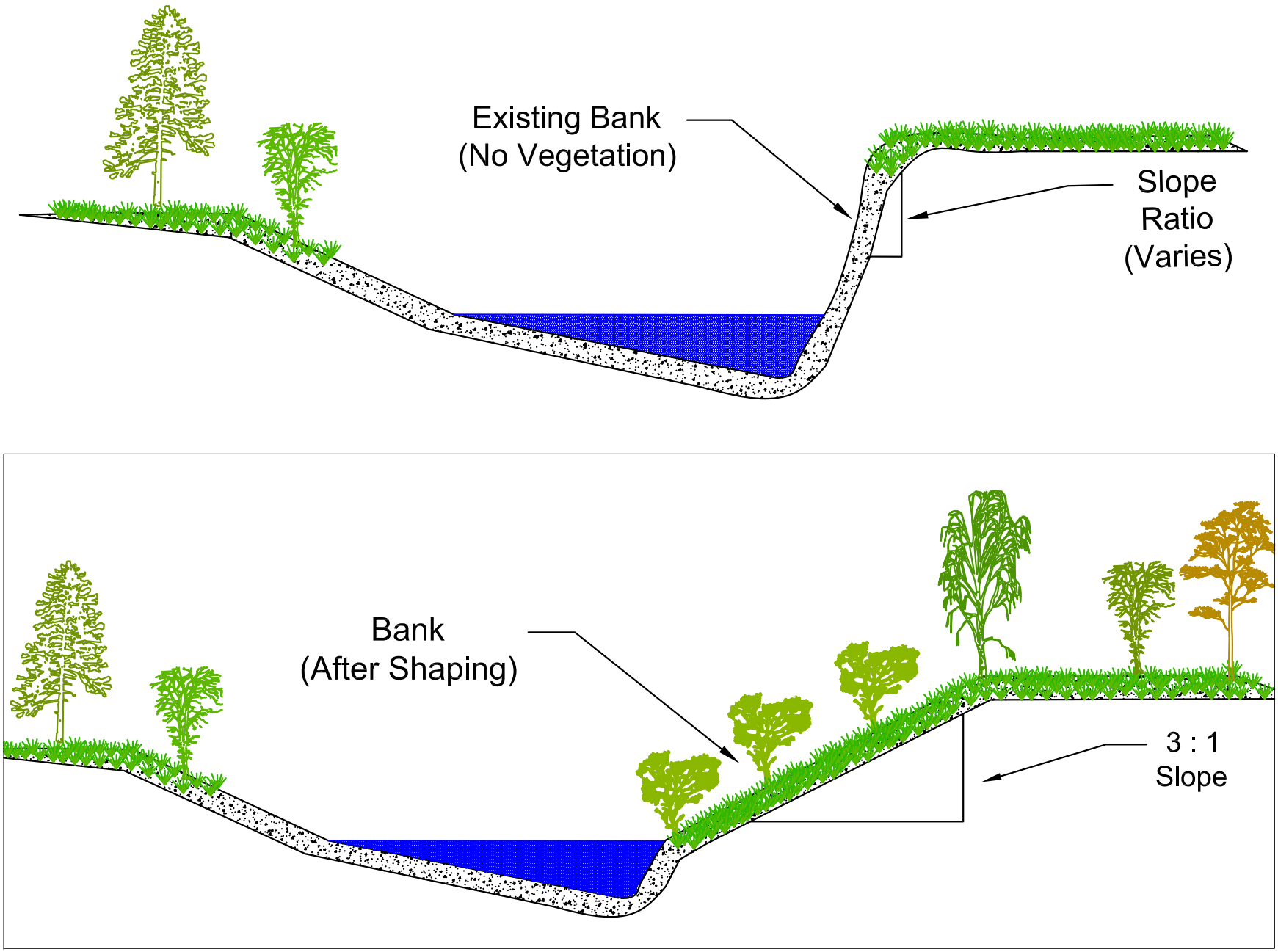


Figure 3-5. Example of Bank Shaping and Planting BMP

GSRC
May 2011

Bank shaping by excavating steep banks to a 3:1 slope are recommended to rehabilitate unstable banks on the river bends. Construction of a bankfull bench would increase stream stability by dissipating energy during high flow events. Excavating streambanks to suitable conditions are estimated to cost $20 to $30 per linear foot. Planting a riparian buffer consisting of live cuttings, bare root seedlings, and a native grass strip are estimated to cost approximately $5 per linear foot.

The cost estimated to implement BMPs on smaller stream systems would typically be near the lower cost range, since water depths are less and bank heights are lower. For work on larger streams, costs are estimated to trend toward the higher price range. It is difficult to accurately predict streambank stabilization costs without a more detailed survey. These cost estimates are reflective of current prices (2011) and may fluctuate based on material prices and fuel costs. For the purpose of this study, stream reaches are segregated into three size categories. A cost estimate for BMP implementation is proposed for each stream size category. Table 3-3 presents three stream size categories and estimated cost per linear foot.

Table 3-3. Stream Size and Associated BMP Implementation Expense

Size of Stream	Discharge Flow Rate at Bank Full (cfs)	Cost of BMP per Linear Foot
Small	1 to 2,000	$63.00
Medium	2,001 to 8,000	$80.00
Large	8,001 and greater	$95.00

Source: GSRC.

SECTION 4.0
RESULTS

4.0 RESULTS

In-depth stream and bank erosion analysis are presented sequentially beginning with six survey sites in the Perry Lake Watershed (Survey Sites 3a, 4a, 5a, 8a, 9a, and 10a), three in the Tuttle Creek Watershed (Survey Sites 1b, 3b, and 4b), and one in the Clinton Lake Watershed (Survey Site 1c). The results of these analyses are briefly discussed in the following paragraphs. Following the discussion, site summaries for each survey site are presented, which include stream reach data; BEHI scores; survey site description; bank length and recommended BMPS; and BMP reduction, cost, and soil reduction estimates. Photographs of each highly erodible bank type are presented for the survey sites. A map of the survey site delineating the different bank types along the stream reach is included in each summary. The location of the highly erodible banks and the recommended BMPs are described and presented on figure maps.

4.1 Discussion of Results

The three survey sites in the Tuttle Creek Lake Watershed produced higher rates of erosion than the survey sites in the Perry Lake Watershed and Clinton Lake Watershed. The Little Blue River survey site (1b) had the highest weighted erosion rate at 4.90 tons/foot/year. In this survey site, Bank Type 4 indicated an erosion rate of 8.08 tons/foot/year, which is the highest erosion rate of all the bank types observed. The length of the reach was 2,755 feet, and at its present rate of erosion it is discharging 10.61 acre-feet of sediment downstream annually. Bank Type 4 would benefit the most from the implementation of stream stabilization BMPs. It is estimated that BMPs would reduce the rate of erosion by 96 percent years 1 through 3 and 98 percent years 4 through 10. It is estimated that the cost of the soil stabilization is $1.22 per ton during the first 3 years, decreasing to $1.20 per ton during years 4 through 10.

The weighted erosion rate was 4.30 tons/foot/year for the Big Blue River survey site (3b). Bank Type 1 had an erosion rate of 7.46 tons/foot/year, which is the third highest erosion rate of all bank types observed. The length of the reach was 3,761 feet and at its present rate of erosion, it is discharging 13.38 acre-feet of sediment downstream annually. Stream stabilization BMPs would reduce the rate of erosion by 85 percent during years 1 through 3 and 94 percent during years 1 through 4, costing $1.50 per ton during the first 3 years and decreasing to $1.35 per ton during years 4 through 10.

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Perry Lake Survey Site 3a: Clear Creek (Figure 4-1)

Length of Survey Reach (feet):	1,742
Drainage Area (sq. mi.):	1.33
Bankfull Discharge at Site (cfs):	326

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	30.60	High	1.56	0.55	55
2	19.80	Low	1.97	0.00	22
3	30.00	High	2.51	2.51	23
			Weighted Average:	0.88	

Description of Survey Site: This survey reach was located in a cool season pasture and was slightly incised and highly unstable due to tortuous meanders and a narrow riparian corridor. In-stream BMPs are recommended for Bank Type 3 only, which constitutes 23 percent (408 feet) of the survey, because it is highly erosive and unstable. Modifications to the remaining stream reach are not recommended for this site due to the small size of the stream and low rate of erosion.

Hot-spot: Bank Type 3 **Length of Bank (feet):** 408

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	81%	93%
Reduction of Rate of Erosion (tons/foot/year):	2.03	2.33
Cost of BMP Per Linear Foot:	$63	$63
Cost to Install BMP in Reach:	$25,704	$25,704
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	830	952
***Cost of Soil Reduction Per Ton:**	**$3.10**	**$2.70**
***Cost of Soil Reduction Per Cubic Yard:**	**$4.03**	**$3.51**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-1	DESCRIPTION	Bank Type 3	Survey Site: 3a
	LOCATION	Perry Lake Watershed: Clear Creek	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	April 30, 2008

Photograph 4-2	DESCRIPTION	Bank Type 3	Survey Site: 3a
	LOCATION	Perry Lake Watershed: Clear Creek	Date
Direction: South-West	PHOTOGRAPHER	Brock Emmert	April 30, 2008

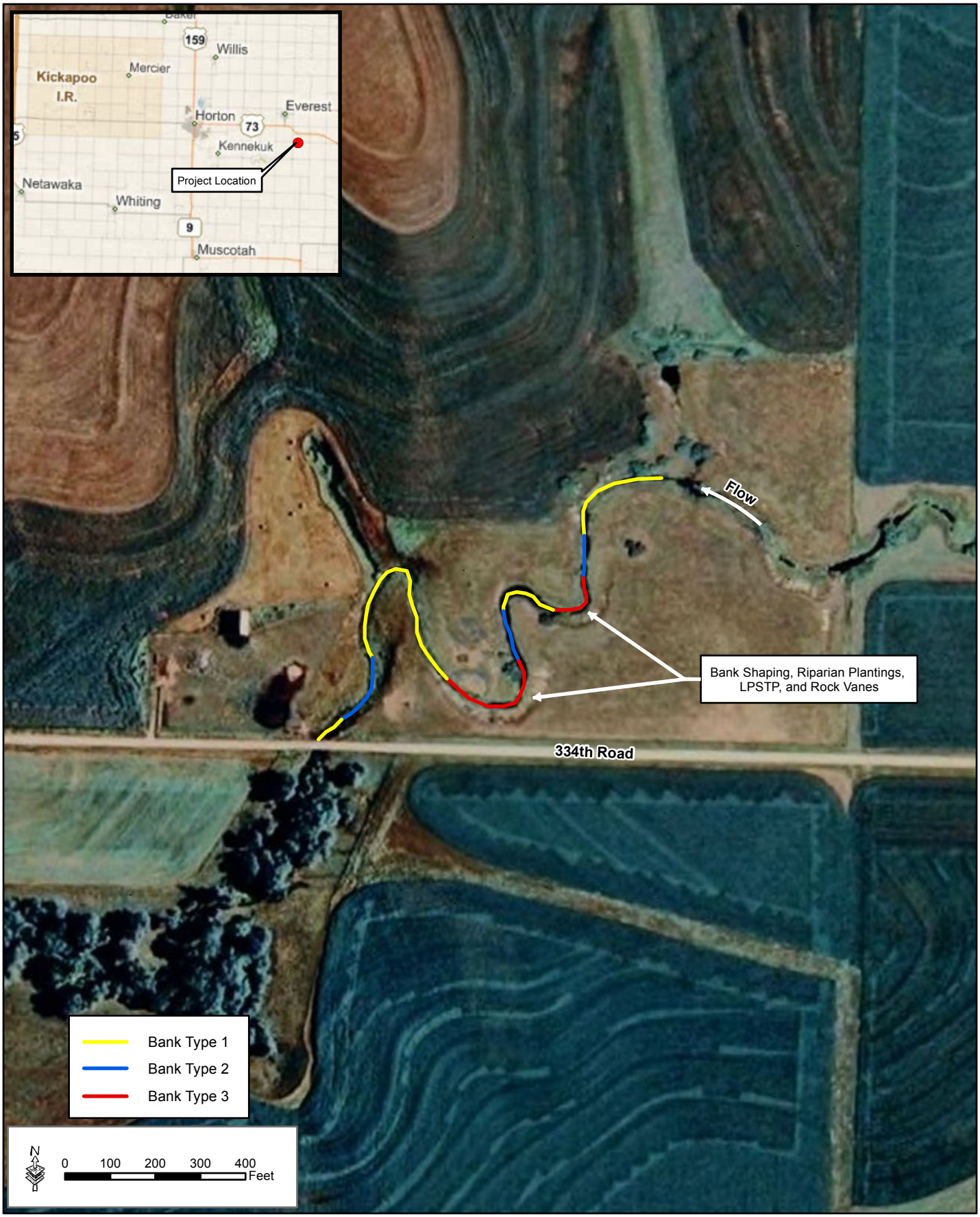

Figure 4-1: BMP Recommendations for Clear Creek, Survey Site 3a in the Perry Lake Reservoir Watershed

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Perry Lake Survey Site 4a: Delaware River at Kickapoo Nation (Figure 4-2)

Length of Survey Reach (feet):	3,638
Drainage Area (sq. mi.):	142
Bankfull Discharge at Site (cfs):	4,765

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	17.1	Low	1.41	0.00	33
2	20.90	Moderate	1.40	0.38	19
3	19.10	Low	1.45	0.00	33
4	17.80	Low	1.45	0.00	8
5	25.10	Moderate	1.59	2.05	7
			Weighted Average:	0.31	

Description of Survey Site: Five different bank types were identified. In-stream BMPs are recommended for Bank Type 5 only, which constitutes 7 percent (267 feet) of the survey, because it is highly erosive and the banks do not support vegetation. Modifications to the remaining stream reach are not recommended for this site due to the relatively low erosion rates.

Hot-spot: Bank Type 5 **Length of Bank (feet):** 267

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	81%	93%
Reduction of Rate of Erosion (tons/foot/year):	1.66	1.91
Cost of BMP Per Linear Foot:	$80	$80
Cost to Install BMP in Reach:	$21,360	$21,360
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	443	509
***Cost of Soil Reduction Per Ton:**	**$4.82**	**$4.20**
***Cost of Soil Reduction Per Cubic Yard:**	**$6.26**	**$5.46**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-3	DESCRIPTION	Bank Type 5	Survey Site: 4a
	LOCATION	Perry Lake Watershed: Delaware River at Kickapoo Nation	Date
Direction: Southwest	PHOTOGRAPHER	Brock Emmert	July 9, 2008

Photograph 4-4	DESCRIPTION	Bank Type 5	Survey Site: 4a
	LOCATION	Perry Lake Watershed: Delaware River at Kickapoo Nation	Date
Direction: South	PHOTOGRAPHER	Brock Emmert	July 9, 2008

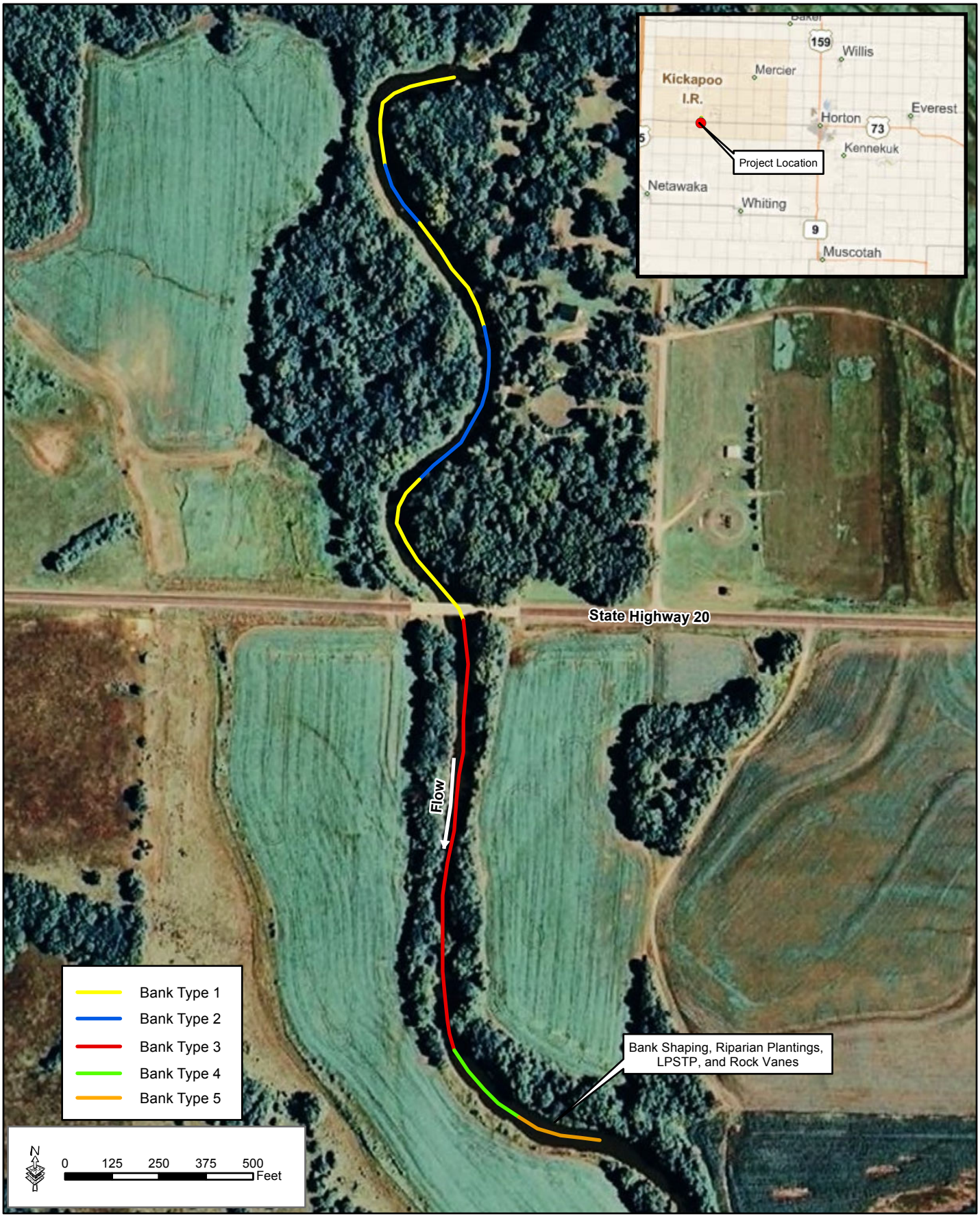

Figure 4-2: BMP Recommendations for Delaware River at Kickapoo Nation, Survey Site 4a in the Perry Lake Reservoir Watershed

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Perry Lake Survey Site 5a: Delaware River at Arrington (Figure 4-3)

Length of Survey Reach (feet):	3,280
Drainage Area (sq. mi.):	579
Bankfull Discharge at Site (cfs):	7,980

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	16.00	Low	1.47	0.00	32
2	17.60	Low	1.30	0.00	16
3	21.70	Moderate	1.45	0.46	14
4	17.00	Low	1.58	0.00	25
5	23.90	Moderate	1.94	4.55	13
			Weighted Average:	0.67	

Description of Survey Site: Five different bank types were identified. In-stream BMPs are recommended for Bank Type 5 only, which constitutes 13 percent (425 feet) of the survey, because it is highly erosive and the banks do not support vegetation. Modifications to the remaining bank types or stream reach is not recommended for this site due to the relatively low erosion rates.

Hot-spot: Bank Type 5 **Length of Bank (feet):** 425

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	81%	93%
Reduction of Rate of Erosion (tons/foot/year):	3.69	4.23
Cost of BMP Per Linear Foot:	$80	$80
Cost to Install BMP in Reach:	$34,000	$34,000
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	1,566	1,798
***Cost of Soil Reduction Per Ton:**	**$2.17**	**$1.89**
***Cost of Soil Reduction Per Cubic Yard:**	**$2.82**	**$2.46**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-5	DESCRIPTION	Bank Type 5	Survey Site: 5a
	LOCATION	Perry Lake Watershed: Delaware River near Arrington	Date
Direction: Northeast	PHOTOGRAPHER	Brock Emmert	July 10, 2008

Photograph 4-6	DESCRIPTION	Bank Type 5	Survey Site: 5a
	LOCATION	Perry Lake Watershed: Delaware River near Arrington	Date
Direction: East	PHOTOGRAPHER	Brock Emmert	July 10, 2008

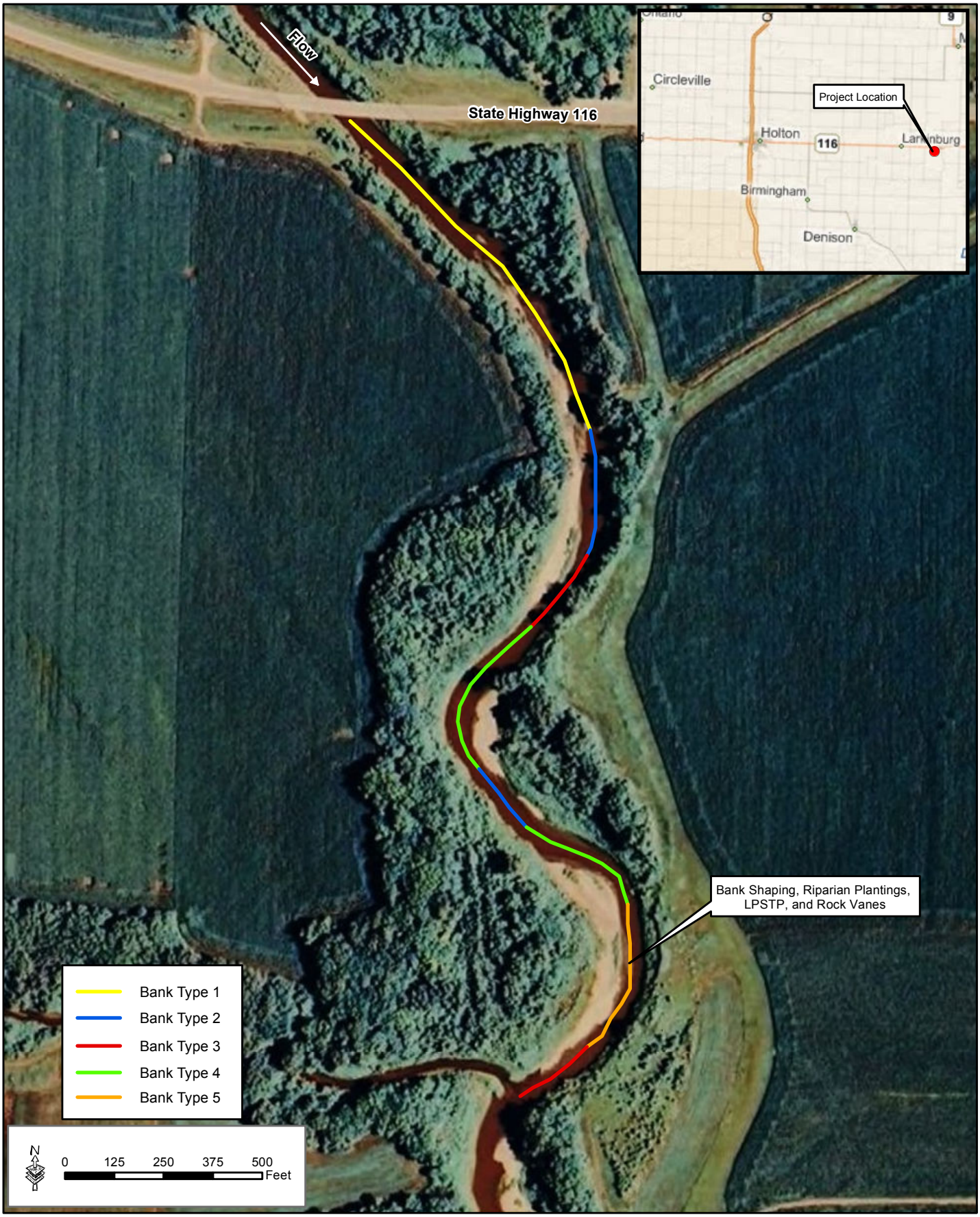

Figure 4-3: BMP Recommendations for Delaware River at Arrington, Survey Site 5a in the Perry Lake Reservoir Watershed

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Perry Lake Survey Site 8a: Delaware River at USGS Muscotah Gauge (Figure 4-4)

Length of Survey Reach (feet):	3,545
Drainage Area (sq. mi.):	439
Bankfull Discharge at Site (cfs):	6,342

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	15.00	Low	1.28	0.00	14
2	27.30	Moderate	1.41	2.37	55
3	15.20	Low	1.35	0.00	31
			Weighted Average:	1.31	

Description of Survey Site: Three different bank types were identified. In-stream BMPs are recommended for Bank Type 2 only, which constitutes 55 percent (1,962 feet) of the survey, because much of the bank exhibits signs of recent slumping and instability. Bank Type 2 is located along three different meanders.

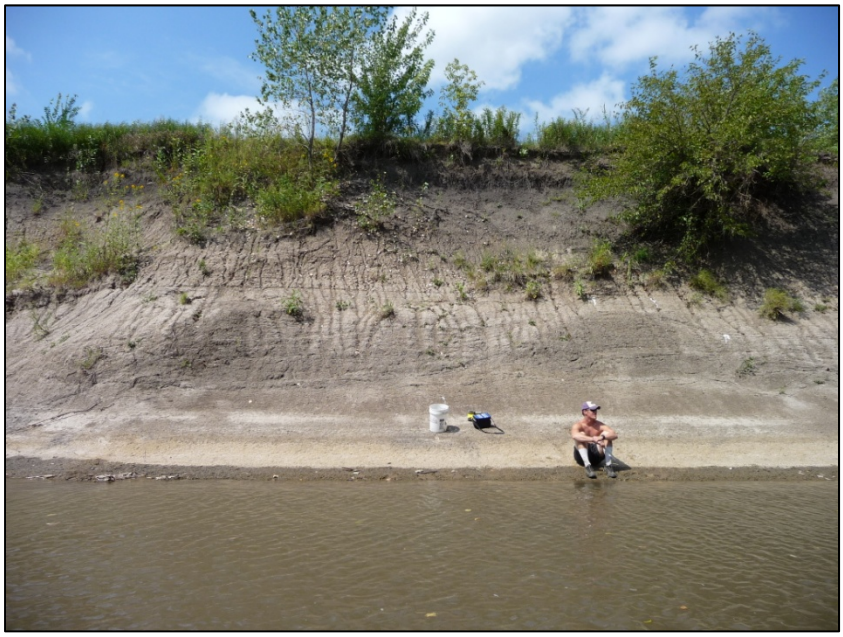
Hot-spot: Bank Type 2 **Length of Bank (feet):** 1,962

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	77%	91%
Reduction of Rate of Erosion (tons/foot/year):	1.82	2.16
Cost of BMP Per Linear Foot:	$80	$80
Cost to Install BMP in Reach:	$156,960	$156,960
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	3,580	4,231
***Cost of Soil Reduction Per Ton:**	**$4.38**	**$3.71**
***Cost of Soil Reduction Per Cubic Yard:**	**$5.70**	**$4.82**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-7	DESCRIPTION	Bank Type 2	Survey Site: 8a
	LOCATION	Perry Lake Watershed: Delaware River near USGS Muscotah Guage	Date
Direction: Southwest	PHOTOGRAPHER	Brock Emmert	August 31, 2009



Photograph 4-8	DESCRIPTION	Bank Type 2	Survey Site: 8a
	LOCATION	Perry Lake Watershed: Delaware River near USGS Muscotah Guage	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	August 31, 2009

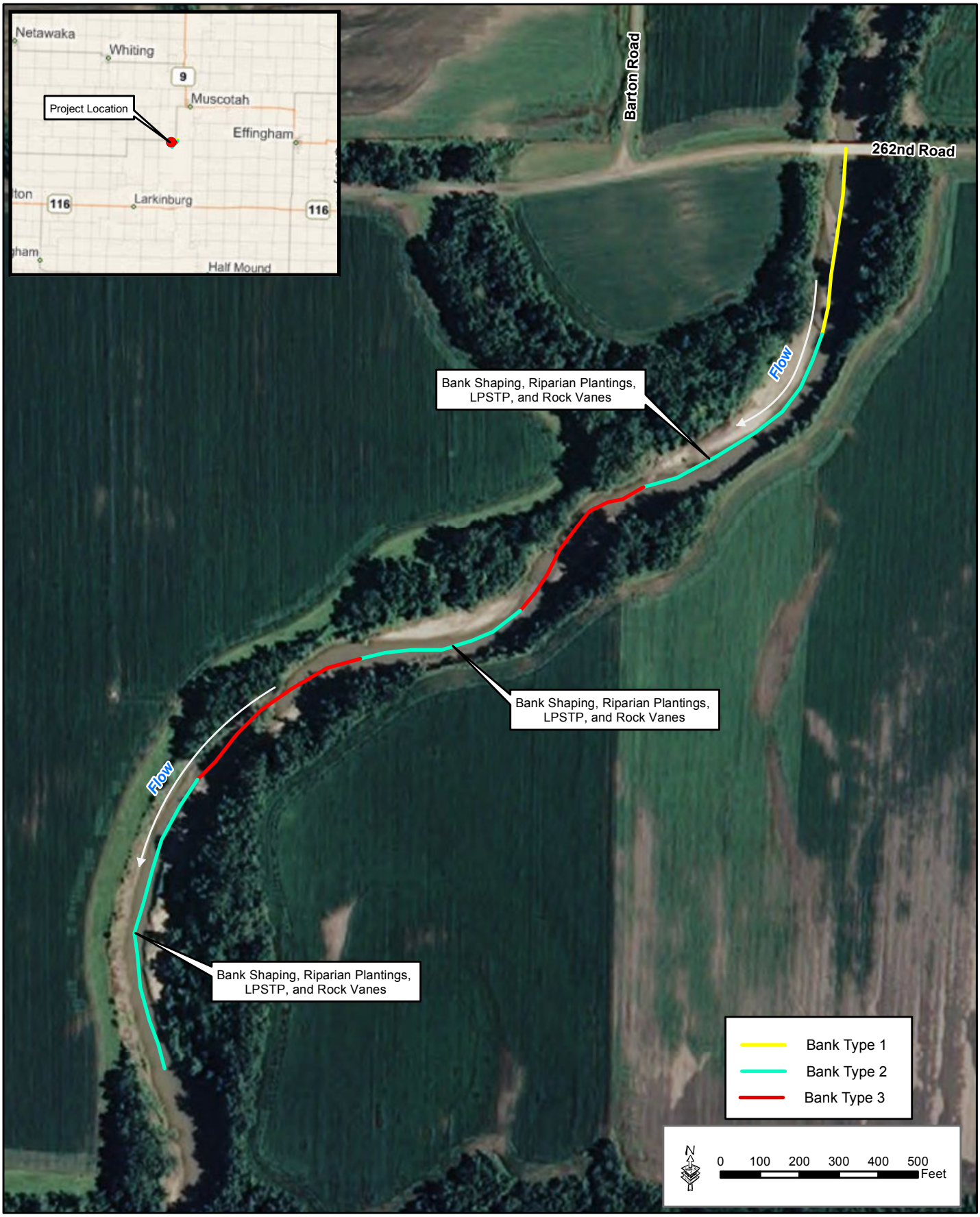


Figure 4-4: BMP Recommendations for Delaware River at USGS Muscotah Gauge, Survey Site 8a in the Perry Lake Reservoir Watershed

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Perry Lake Survey Site 9a: Delaware River at Highway 254 Bridge (Figure 4-5)

Length of Survey Reach (feet):	2,614
Drainage Area (sq. mi.):	445
Bankfull Discharge at Site (cfs):	6,423

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	23.20	Low	1.32	0.56	16
2	16.80	Low	1.36	0.00	8
3	24.60	Moderate	1.53	1.65	45
4	16.10	Low	1.44	0.00	31
			Weighted Average:	0.83	

Description of Survey Site: Four different bank types were identified. In-stream BMPs are recommended for Bank Type 3 only, which constitutes 45 percent (1,179 feet) of the survey, because much of the bank exhibits signs of recent slumping and instability. BMPs for Bank Type 3 include, bank shaping and riparian plantings, LPSTP and Rock Vanes. Bank Type 3 conditions are located on two different meanders.

Hot-spot: Bank Type 3 **Length of Bank (feet):** 1,179

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	78%	93%
Reduction of Rate of Erosion (tons/foot/year):	1.29	1.53
Cost of BMP Per Linear Foot:	$80	$80
Cost to Install BMP in Reach:	$94,320	$94,320
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	1,517	1,809
***Cost of Soil Reduction Per Ton:**	**$6.22**	**$5.21**
***Cost of Soil Reduction Per Cubic Yard:**	**$8.08**	**$6.78**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-9	DESCRIPTION	Bank Type 3	Survey Site: 9a
	LOCATION	Perry Lake Watershed: Delaware River near Highway 255 Bridge	Date
Direction: East	PHOTOGRAPHER	Brock Emmert	September 2, 2009

Photograph 4-10	DESCRIPTION	Bank Type 3	Survey Site: 9a
	LOCATION	Perry Lake Watershed: Delaware River near Highway 255 Bridge	Date
Direction: Southeast	PHOTOGRAPHER	Brock Emmert	September 2, 2009

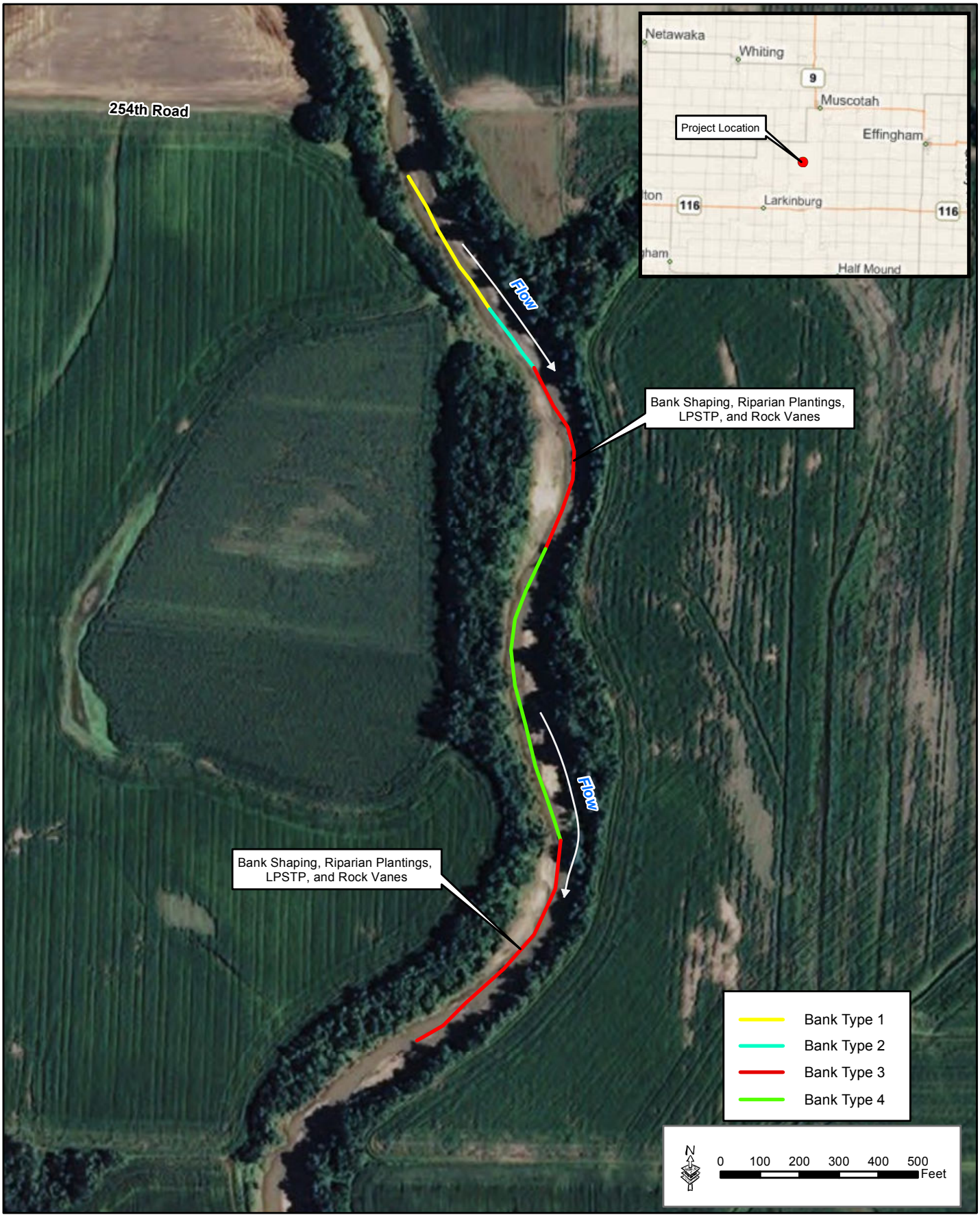

Figure 4-5: BMP Recommendations for Delaware River at Highway 254 Bridge, Survey Site 9a in the Perry Lake Reservoir Watershed

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Perry Lake Survey Site 10a: Delaware River at Muddy Creek Confluence (Figure 4-6)

Length of Survey Reach (feet):	4,070
Drainage Area (sq. mi.):	255
Bankfull Discharge at Site (cfs):	5,526

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	13.60	Low	1.48	0.00	10
2	27.90	Moderate	1.53	5.46	12
3	10.40	Low	1.37	0.00	45
4	27.40	Moderate	1.41	1.83	9
5	23.40	Moderate	1.55	4.87	24
			Weighted Average:	1.98	

Description of Survey Site: Five different bank types were identified. In-stream BMPs are recommended for Bank Type 2 and 5 only, which constitutes 12 percent (480 feet) and 24 percent (979 feet) of the survey, respectively, because they are highly erosive and the banks do not support vegetation. There was a large active gully within the Bank Type 5 reach. Modifications to the remaining bank types or stream reach is not recommended for this site due to the relatively low erosion rates.

Hot-spot: Bank Type 2 **Length of Bank (feet):** 480

Recommended BMPs for Erosion Hotspot: Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes.

	Year 1 - 3	Year 1 - 4
BMP Estimated Percent Reduction:	86%	94%
Reduction of Rate of Erosion (tons/foot/year):	4.70	5.13
Cost of BMP Per Linear Foot:	$80	$80
Cost to Install BMP in Reach:	$38,400	$38,400
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	2,254	2,464
***Cost of Soil Reduction Per Ton:**	**$1.70**	**$1.56**
Cost of Soil Reduction Per Cubic Yard:	**$2.21**	**$2.03**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Survey Site: 10a (continued)

Hot-spot: Bank Type 5 **Length (feet) of Bank:** 979

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	86%	90%
Reduction of Rate of Erosion (tons/foot/year):	4.19	4.38
Cost of BMP Per Linear Foot:	$95	$95
Cost to Install BMP in Reach:	$93,005	$93,005
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	4100	4291
***Cost of Soil Reduction Per Ton:**	**2.27**	**2.17**
***Cost of Soil Reduction Per Cubic Yard:**	**2.95**	**2.82**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-11	DESCRIPTION	Bank Type 2	Survey Site: 10a
	LOCATION	Perry Lake Watershed: Delaware River at Muddy Creek Confluence	Date
Direction: East	PHOTOGRAPHER	Brock Emmert	September 11, 2009

Photograph 4-12	DESCRIPTION	Bank Type 5	Survey Site: 10a
	LOCATION	Perry Lake Watershed: Delaware River at Muddy Creek Confluence	Date
Direction: Southeast	PHOTOGRAPHER	Brock Emmert	September 11, 2009

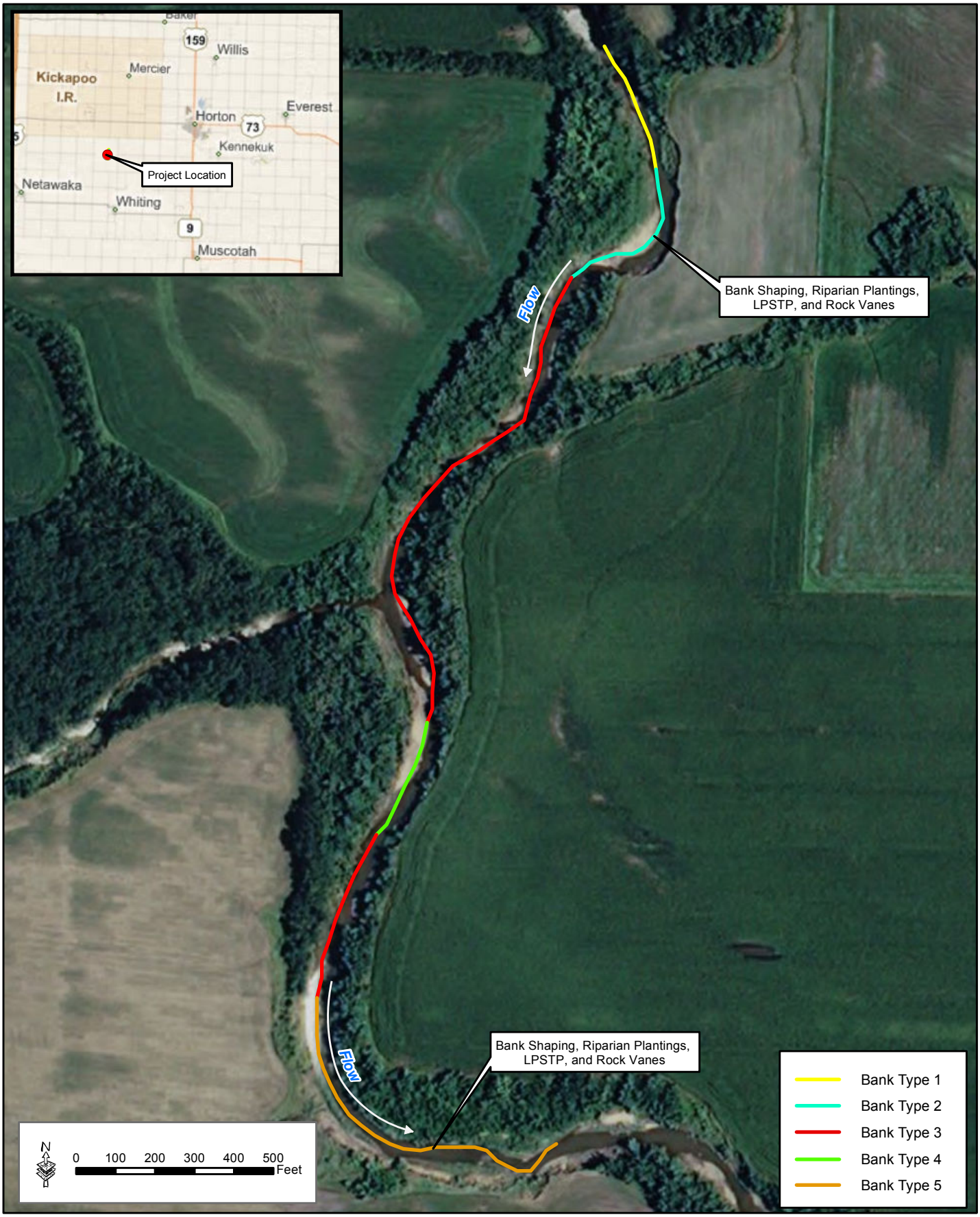

Figure 4-6: BMP Recommendations for Delaware River at Muddy Creek Confluence, Survey Site 10a in the Perry Lake Reservoir Watershed

Tuttle Creek Survey Site 1b: Little Blue River (Figure 4-7)

Length of Survey Reach (feet):	4,759
Drainage Area (sq. mi.):	3,548
Bankfull Discharge at Site (cfs):	11,474

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	50.30	Extreme	1.42	2.80	8
2	12.80	Low	1.24	0.00	24
3	22.00	Moderate	1.35	0.00	10
4	46.80	Extreme	1.74	8.08	58
			Weighted Average:	4.90	

Description of Survey Site: Four bank types were identified along the 4,759-foot-long survey reach. In-stream BMPs are recommended for Bank Type 1 and 4 only, which constitutes 8 percent (370 feet) and 58 percent (2,755 feet) of the survey, respectively. These bank types had low sinuosity and highly unstable banks. Bank Type 1 conditions extended further upstream from the survey reach. There was a large gully within the Bank Type 4 reach, which was actively contributing sediment to the river channel.

Hot-spot: Bank Type 1 **Length of Bank (feet):** 370

Recommended BMPs for Erosion Hotspot: Bank Shaping, Riparian Plantings, LPSTP, and Bendway Weirs.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	90%	96%
Reduction of Rate of Erosion (tons/foot/year):	2.52	2.69
Cost of BMP Per Linear Foot:	$95	$95
Cost to Install BMP in Reach:	$35,150	$35,150
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	932	995
***Cost of Soil Reduction Per Ton:**	**$3.77**	**$3.53**
Cost of Soil Reduction Per Cubic Yard:	**$4.90**	**$4.59**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Survey Site: 1b (continued)

Hot-spot: Bank Type 4 **Length (feet) of Bank:** 2,755

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, LPSTP, Rock Chute, and Bendway Weirs.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	96%	98%
Reduction of Rate of Erosion (tons/foot/year):	7.76	7.92
Cost of BMP Per Linear Foot:	$95	$95
Cost to Install BMP in Reach:	$261,725	$261,725
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	21,370	21,815
***Cost of Soil Reduction Per Ton:**	**$1.22**	**$1.20**
Cost of Soil Reduction Per Cubic Yard:	**$1.59**	**$1.56**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-13	DESCRIPTION	Bank Type 1	Survey Site: 1b
	LOCATION	Tuttle Creek Lake Watershed: Little Blue River	Date
Direction: Southwest	PHOTOGRAPHER	Brock Emmert	October 7, 2009

Photograph 4-14	DESCRIPTION	Bank Type 4	Survey Site: 1b
	LOCATION	Tuttle Creek Lake Watershed: Little Blue River	Date
Direction: North	PHOTOGRAPHER	Brock Emmert	October 7, 2009

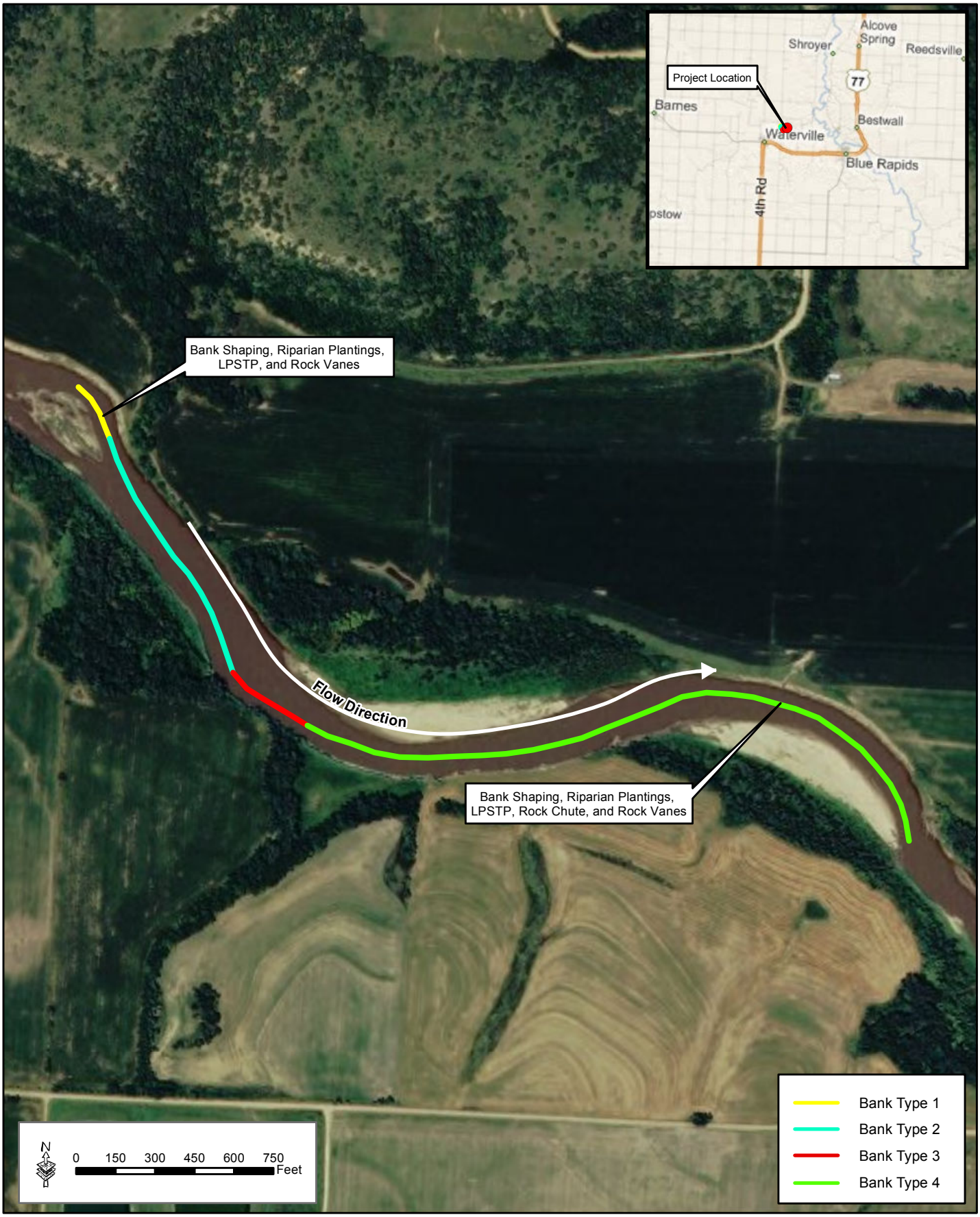

Figure 4-7: BMP Recommendations for Little Blue River, Survey Site 1b in the Tuttle Creek Reservoir Watershed

Tuttle Creek Survey Site 3b: Big Blue River at Alcove Springs (Figure 4-8)

Length of Survey Reach (feet):	6,529
Drainage Area (sq. mi.):	4,887
Bankfull Discharge at Site (cfs):	12,375

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	40.50	Very High	1.51	7.46	58
2	19.80	Low	1.35	0.00	42
			Weighted Average:	4.33	

Description of Survey Site: Two different bank types were identified. In-stream BMPs are recommended for Bank Type 1 only, which constitutes 58 percent (3,761) of the survey. Bank Type 1 showed signs of recent slumping and instability along two different meanders. There was no riparian corridor along the outside meander bends. These banks were steep with very little vegetation to stabilize the soils.

Hot-spot: Bank Type 2 **Length of Bank (feet):** 3,761

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, Bendway Weir, and Rock Chutes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	85%	94%
Reduction of Rate of Erosion (tons/foot/year):	6.34	7.01
Cost of BMP Per Linear Foot:	$95	$95
Cost to Install BMP in Reach:	$357,295	$357,295
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	23,849	26,374
***Cost of Soil Reduction Per Ton:**	**$1.50**	**$1.35**
Cost of Soil Reduction Per Cubic Yard:	**$1.95**	**$1.76**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-15	DESCRIPTION	Bank Type 1	Survey Site: 3b
	LOCATION	Tuttle Creek Lake Watershed: Big Blue River at Alcove Springs	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	November 9, 2009

Photograph 4-16	DESCRIPTION	Bank Type 1	Survey Site: 3b
	LOCATION	Tuttle Creek Lake Watershed: Big Blue River at Alcove Springs	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	November 9, 2009

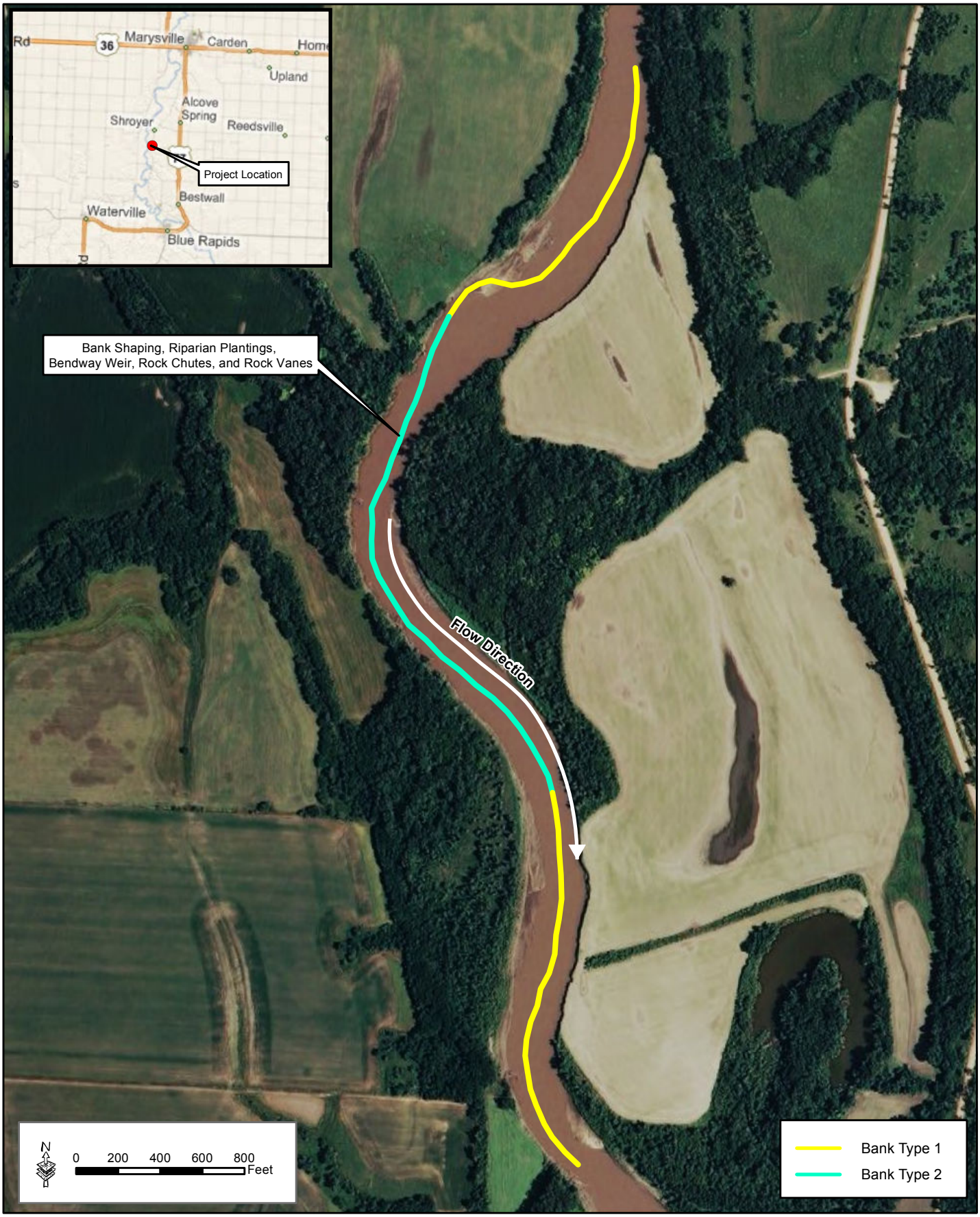

Figure 4-8: BMP Recommendations for Big Blue River at Alcove Springs, Survey Site 3b in the Tuttle Creek Reservoir Watershed

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Tuttle Creek Survey Site 4b: Big Blue River Near Oketo (Figure 4-9)

Length of Survey Reach (feet):	4,963
Drainage Area (sq. mi.):	4,655
Bankfull Discharge at Site (cfs):	11,739

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	13.60	Low	1.28	0.00	19
2	27.30	Moderate	1.32	0.23	37
3	39.00	High	1.49	7.78	21
4	19.80	Low	1.29	0.00	23
			Weighted Average:	1.72	

Description of Survey Site: This stream reach of the Little Blue River had a low sinuosity and moderate to highly unstable banks. Four bank types were identified along the 4,963-foot-long survey reach. In-stream BMPs are recommended for Bank Type 3 only, which constitutes 21 percent (1,057 feet) of the survey. The riparian corridor was absent along Bank Type 3, the bank was steep with very shallow roots and no vegetation to protect the surface soils.

Hot-spot: Bank Type 3 **Length of Bank (feet):** 1,057

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, Bendway Weir, Rock Chutes and Rock Vanes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	76%	91%
Reduction of Rate of Erosion (tons/foot/year):	5.91	7.08
Cost of BMP Per Linear Foot:	$95	$95
Cost to Install BMP in Reach:	$100,415	$100,415
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	6,250	7,483
***Cost of Soil Reduction Per Ton:**	**$1.61**	**$1.34**
Cost of Soil Reduction Per Cubic Yard:	**$2.09**	**$1.74**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-17	DESCRIPTION	Bank Type 3	Survey Site: 4b
	LOCATION	Tuttle Creek Lake Watershed: Big Blue River near Oketo	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	November 11, 2009

Photograph 4-18	DESCRIPTION	Bank Type 3	Survey Site: 4b
	LOCATION	Tuttle Creek Lake Watershed: Big Blue River near Oketo	Date
Direction: Northwest	PHOTOGRAPHER	Brock Emmert	November 11, 2009

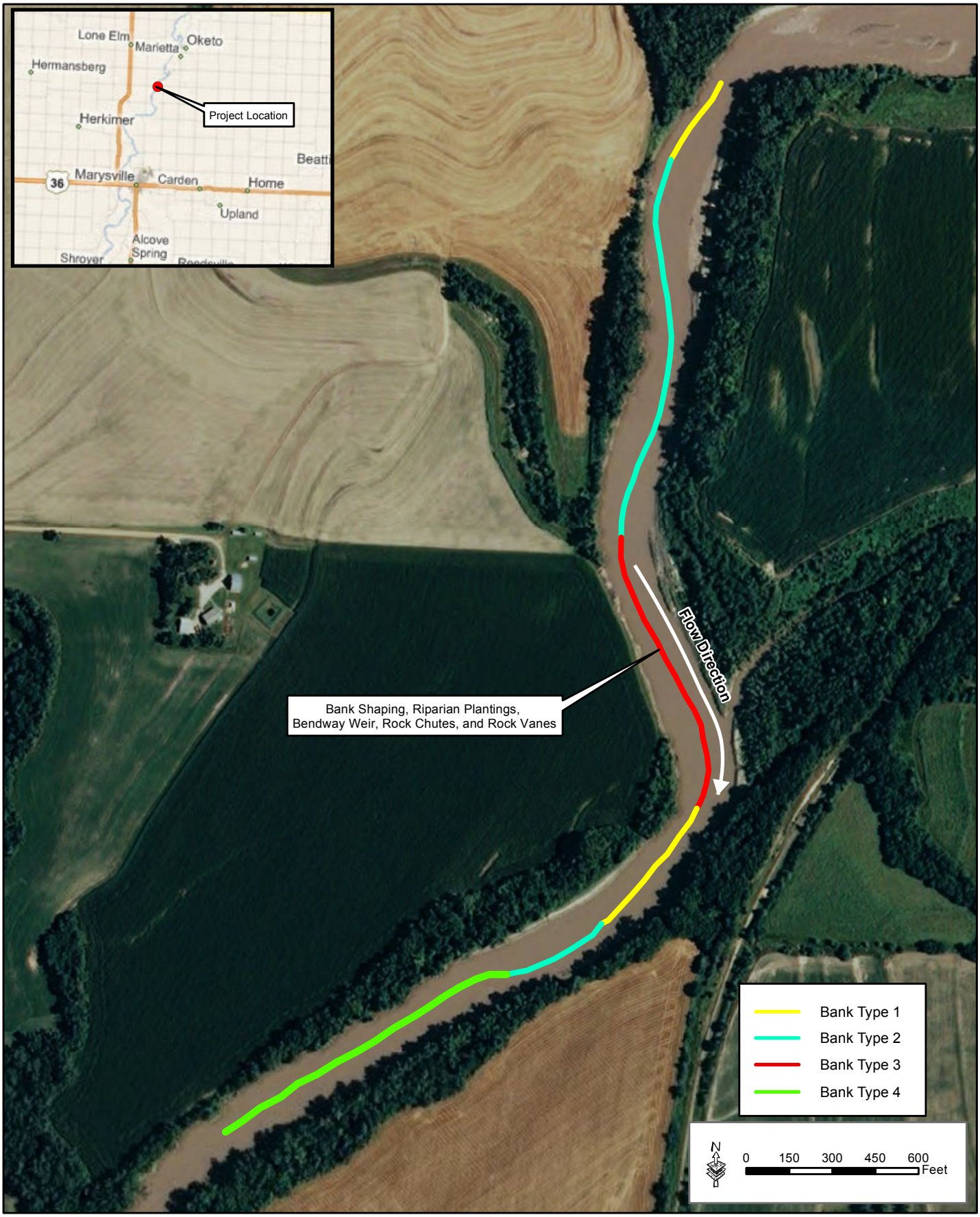

Figure 4-9: BMP Recommendations for Big Blue River near Oketo, Survey Site 4b in the Tuttle Creek Reservoir Watershed

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Clinton Lake Survey Site 1c: Lynn Creek (Figure 4-10)

Length of Survey Reach (feet):	1,870
Drainage Area (sq. mi.):	17.5
Bankfull Discharge at Site (cfs):	1,030

BEHI EROSION POTENTIAL SUMMARY

Bank Type	BEHI Score	BEHI Rating	NBS Ratio	Predicted Erosion (tons/foot/year)	Percent of Survey
1	14.10	Low	1.43	0.00	45
2	23.40	Moderate	2.06	0.31	9
3	28.00	Moderate	1.53	1.11	21
4	23.20	Very Low	1.23	0.00	13
5	29.20	Moderate	2.29	1.21	12
			Weighted Average:	0.41	

Description of Survey Site: Five different bank types were identified. In-stream BMPs are recommended for Bank Type 5 only, which constitutes 12 percent (220 feet) of the survey. Bank Type 5 was steep with no vegetation to protect surface soils and no woody riparian corridor and very little rooting depth. The site is also located along a utility easement. Modifications to the remaining bank types or stream reach is not recommended for this site due to the relatively low erosion rates.

Hot-spot: Bank Type 5 **Length of Bank (feet):** 220

Recommended BMPs for Erosion Hot-spot: Bank Shaping, Riparian Plantings, LPSTP, and Rock Vanes.

	Year 1 - 3	Year 4 - 10
BMP Estimated Percent Reduction:	81%	93%
Reduction of Rate of Erosion (tons/foot/year):	0.98	1.13
Cost of BMP Per Linear Foot:	$80	$80
Cost to Install BMP in Reach:	$17,600	$17,600
Total Soil Reduction Resulting from BMP Implementation (tons/reach/year):	216	248
***Cost of Soil Reduction Per Ton:**	**$8.16**	**$7.11**
Cost of Soil Reduction Per Cubic Yard:	**$10.61**	**$9.24**

*Costs are distributed over a 10-year period and assumes the BMP is fully functional and reduces erosion at the estimated rate over the 10-year period. Assume that 1 cubic yard of wet soils equals 1.3 tons.

Photograph 4-19	DESCRIPTION	Bank Type 5	Survey Site: 1c
	LOCATION	Clinton Lake Watershed: Lynn Creek	Date
Direction: North	PHOTOGRAPHER	Brock Emmert	September 29, 2010

Photograph 4-20	DESCRIPTION	Bank Type 5	Survey Site: 1c
	LOCATION	Clinton Reservoir Watershed : Lynn Creek	Date
Direction: East	PHOTOGRAPHER	Brock Emmert	September 29, 2010

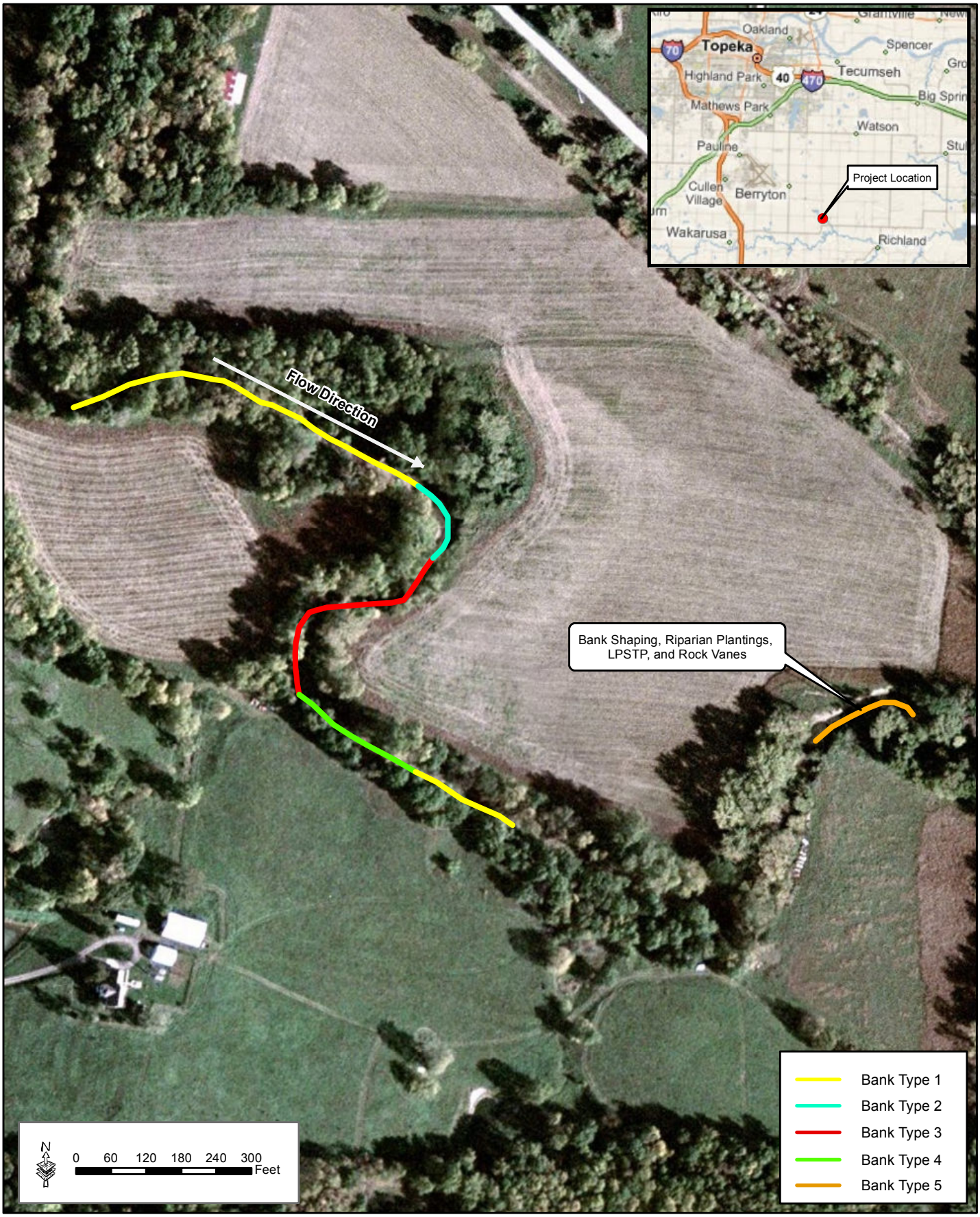

Figure 4-10: BMP Recommendations for Lynn Creek, Survey Site 1c in the Clinton Lake Reservoir Watershed

Bank Type 3 at the Big Blue River survey site (4b) produced the second highest rate of erosion of all bank types observed (7.78 tons/foot/year). It is estimated that stream stabilization BMPs would reduce the rate of erosion by 76 percent during the first 3 years and 91 percent during the following years. It is estimated that the cost of the soil stabilization is $1.61 per ton during years 1 through 3, decreasing to $1.34 per ton during years 4 through 10. The weighted erosion rate of survey site 4b was 1.74 tons/foot/year. The length of Bank Type 3 is 1,057 feet and at its present rate of erosion, it is discharging 3.92 acre-feet of sediment downstream annually.

Seven survey sites in the Perry Lake Watershed were analyzed and their weighted erosion rates, ranged from 0.89 to 2.11 tons/foot/year. Survey site (10a) had the highest rate of erosion of all sites investigated on the Delaware River. Bank Type 2 and Bank Type 5 at survey site 10a produced an erosion rate of 5.46 and 4.87 tons/foot/year respectively, which ranked fourth and sixth of all the bank types observed in this study. The length of Bank Type 2 was 480 feet, and at its present rate of erosion it is discharging 1.25 acre-feet of sediment downstream annually. Bank Type 5 is 979 feet, and at its present rate of erosion it is discharging 2.27 acre-feet of sediment downstream annually.

The Delaware River survey site (5a) produced a weighted erosion rate of 0.67 tons/foot/year; however, in this survey site, Bank Type 5 had an erosion rate of 4.55 tons/foot/year which is the fifth highest erosion rate of all the bank types observed. The length of the reach was 425 feet, and at its present rate of erosion it is discharging 0.92 acre-feet of sediment downstream annually. It was estimated that stream stabilization BMPs would reduce the rate of erosion by 81 percent during the first three years and 93 percent during the following years. It is estimated that the cost of the soil stabilization is $2.17 per ton the first 3 years, decreasing to $1.89 per ton during years 4 through 10.

The Clear Creek survey site (3a) produced a weighted erosion rate of 0.89 tons/foot/year; however, in this survey site, Bank Type 3 produced a higher rate of erosion of 2.51 tons/foot/year. The length of the reach was 408 feet and at its present rate of erosion, it is discharging 0.49 acre-feet of sediment downstream annually. It is estimated that stream stabilization BMPs for Bank Type 3 would reduce the rate of erosion by 81 percent the first 3 years and 93 percent the following years. It is estimated that the cost of the soil stabilization is $3.10 per ton the first three years and during years 4 through 10, $2.70 per ton.

The Little Blue River survey site (1b) produced a second hot-spot that is not as active as Bank Type 4. Bank Type 1 of survey site 1b produced an erosion rate of 2.80 tons/foot/year. The length of the reach was 370 feet, and at its present rate of erosion it is discharging 0.49 acre-feet of sediment downstream annually. It was estimated that BMPs would reduce the rate of erosion by 90 percent the first three years and 96 percent the following years. It is estimated that the cost of the soil stabilization is $3.77 per ton the first 3 years, decreasing to $3.53 per ton during the fourth through the tenth years.

Three Delaware River survey sites (4a, 8a, and 9a) contained hot-spots with erodible banks that ranged 1.65 to 2.37 tons/foot/year. The length of these three reaches was 3,408 feet, and at their present rate of erosion they are discharging 3.41 acre-feet of sediment downstream annually. Stream stabilization BMPs would reduce the rate of erosion up to 81 percent the first three years and 93 percent the following years. It is estimated that the cost of the soil stabilization could range from $4.38 to $6.22 per ton the first 3 years and during the fourth through the tenth years, $3.77 to $5.21 per ton.

The Lynn Creek survey site (1c) produced the lowest weighted erosion rate of 0.41 tons/foot/year. Bank Type 5 produced a rate of erosion of 1.21 tons/foot/year. The length of the reach was 220 feet and at its present rate of erosion, it is discharging 0.13 acre-feet of sediment downstream annually. It is estimated that stream stabilization BMPs would reduce the rate of erosion by 81 percent during the first three years and 93 percent during the following years. It is estimated that the cost of the soil stabilization is $8.16 per ton the first 3 years, decreasing to $7.11 per ton during the fourth through the tenth years. It should be noted that the BMPs may continue to provide erosion control benefits after year 10, which would reduce the cost per ton of sediment.

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SECTION 5.0
CONCLUSIONS

5.0 CONCLUSIONS

Sedimentation in the Perry Lake, Tuttle Creek Lake, and Clinton Lake reservoirs has led to a loss in water-storage capacity and recreation opportunities. They provide potable water to the local population, destinations for recreational activities, and habitat for aquatic life. Hargrove (2008) noted that bed and bank erosion from streams and rivers that flow into the reservoirs has accelerated sediment deposition in the reservoirs. Many of the reservoirs in Kansas were built with a projected lifespan of 150 to 200 years; current projections indicate the life span of these reservoirs could be reduced by 50 to 100 years, due to an accelerated rate of sedimentation from upstream sources.

Stream channels surveyed in the Tuttle Creek Watershed produced the greatest cost-benefit ratios for BMP implementation, followed by stream channels in the Perry Lake Watershed. Streambank erosion in these watersheds was amplified by incised channels, which were created by channel straightening. Channel modifications makes the streambanks more susceptible to erosion processes due to higher bank heights, steeper bank angles, and shallow rooting depths of riparian vegetation. As a result, a greater volume of water is confined to a smaller cross-sectional area.

The recommended BMP approach is to stabilize the streambanks in place. Restoring the river and streams to historical streambed and bank elevations is not practical, given the adjacent land use and level of effort required. For the stream channels surveyed in this report, stabilizing the bank toe with rock vanes and LPSTP measures is recommended. Also, shaping the bank slope to at least a 3:1 (18.4 degree) slope is recommended. Finally, establishing a vegetative riparian corridor on the streambank and on top-of-bank is recommended for long-term sustainability.

The results of the erosion loss and success of stream stabilization BMPs from the 10 sites are summarized in Table 5-1. The results are presented by the rate of erosion (ton/foot/year), from high to low. This ranking produced an inverse relationship in the cost of soil reduction per ton, which ranked from low to the high. This suggests the cost-benefits of BMP implementation are greater for stream banks exhibiting high rates of erosion.

Table 5-1. Estimated Cost and Effectiveness of Recommended BMPs

Survey Site ID Number	Watershed	Location of Hot-spot	Predicted Erosion (ton/foot/year)	Bank Length (feet)	Type of BMPs	Years 1 through 3				Years 4 through 10			
						Percent BMP Reduction	Total Soil Reduction (tons/reach/year)	Cost of Soil Reduction (per ton)	Cost of Soil Reduction (per cubic yard)	BMP Reduction	Total Soil Reduction (tons/reach/year)	Cost of Soil Reduction (per ton)	Cost of Soil Reduction (per cubic yard)
1b (cont.)	Tuttle Creek Lake	Bank Type 4	8.08	2,755	Bank Shaping, Riparian Planting, LPSTP, Rock Chute, and Bendway Weirs	96%	21,370	$1.22	$1.59	98%	21,815	$1.20	$1.56
3b	Tuttle Creek Lake	Bank Type 1	7.46	3,761	Bank Shaping, Riparian Planting, Bendway Weir, and Rock Chutes	85%	23,849	$1.50	$1.95	94%	26,374	$1.35	$1.76
4b	Tuttle Creek Lake	Bank Type 3	7.78	1,057	Bank Shaping, Riparian Planting, Bendway Weir, Rock Chutes, and Rock Vanes	76%	6,250	$1.61	$2.09	91%	7,483	$1.34	$1.74
10a	Perry Lake	Bank Type 2	5.46	480	Bank Shaping, Riparian Planting, LPSTP, and Rock Vanes	86%	2,254	$1.70	$2.21	94%	2,464	$1.56	$2.03
5a	Perry Lake	Bank Type 5	4.55	425	Bank Shaping, Riparian Planting, LPSTP, and Rock Vanes	81%	1,566	$2.17	$2.82	93%	1,798	$1.89	$2.46
10a (cont.)	Perry Lake	Bank Type 5	4.87	979	Bank Shaping, Riparian Planting, LPSTP, and Rock Vanes	86%	4,100	$2.27	$2.95	90%	4,291	$2.17	$2.82
3a	Perry Lake	Bank Type 3	2.51	408	Bank Shaping, Riparian Planting, LPSTP, and Rock Vanes	81%	830	$3.10	$4.03	93%	952	$2.70	$3.51
1b	Tuttle Creek Lake	Bank Type 1	2.8	370	Bank Shaping, Riparian Planting, LPSTP, and Bendway Weirs	90%	932	$3.77	$4.90	96%	995	$3.53	$4.59

Table 5-1, continued

Survey Site ID Number	Watershed	Location of Hot-spot	Predicted Erosion (ton/foot/year)	Bank Length (feet)	Type of BMPs	Years 1 through 3				Years 4 through 10			
						Percent BMP Reduction	Total Soil Reduction (tons/reach/year)	Cost of Soil Reduction (per ton)	Cost of Soil Reduction (per cubic yard)	BMP Reduction	Total Soil Reduction (tons/reach/year)	Cost of Soil Reduction (per ton)	Cost of Soil Reduction (per cubic yard)
8a	Perry Lake	Bank Type 2	2.37	1,962	Bank Shaping, Riparian Planting, LPSTP, and Rock Vanes	77%	3,580	$4.38	$5.70	91%	4,231	$3.71	$4.82
4a	Perry Lake	Bank Type 5	2.05	267	Bank Shaping, Riparian Planting, LPSTP, and Rock Vanes	81%	443	$4.82	$6.26	93%	509	$4.20	$5.46
9a	Perry Lake	Bank Type 3	1.65	1,179	Bank Shaping, Riparian Planting, LPSTP, and Rock Vanes	78%	1,517	$6.22	$8.08	93%	1,809	$5.21	$6.78
1c	Clinton Lake	Bank Type 5	1.21	220	Bank Shaping, Riparian Planting, LPSTP, and Rock Vanes	81%	216	$8.16	$10.61	93%	248	$7.11	$9.24

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SECTION 6.0
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6.0 REFERENCES

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SECTION 7.0
RESEARCH TEAM

7.0 RESEARCH TEAM

Name	Discipline/Expertise	Experience	Role In Preparing Report
Steve Kolian	Environmental and aquatic science	14 of environmental studies which includes 7 years of watershed modeling.	Project manager, report preparation, field survey
Brock Emmert	Fluvial geomorphology	12 years of geomorphology and riparian restoration	Field survey, report preparation, GIS
Chris Mammoliti	Fisheries and wildlife biology	26 years of stream ecology and habitat assessments	Field survey
Chris Ingram	Environmental studies	33 years environmental studies	QA/QC, peer review
Dr. Eric Webb	Environmental studies	15 years environmental studies	QA/QC, peer review
Steve Oivanki	Geology/Environmental Studies	20 years environmental studies	QA/QC, peer review
Randy Clear	Survey Tech	1 year surveying	Field survey
Ryan McCurdy	Surveyor	8 years surveying	Field survey

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APPENDIX A
BANK ERODIBILITY HAZARD INDEX (BEHI) SUMMARY

Survey Site 1a	Banner Creek S8-T7S-R14E	
	Bank Type 1	Bank Type 2
Erosion (ft/year)	0.46	0.46
Erosion Method	SASS 2011	SASS 2011
Time Period	2007-2010	2007-2010
Study Bank Height (ft)	11.05	17.02
Bankfull Height (ft)	1.67	2.22
Root Depth (ft)	11.05	14
Root Density (%)	50	20%
Bank Angle (degrees)	60	48
Surface Protection (%)	10	5%
Bank Material	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No
Near-Bank Stress Ratio	1.42	1.4
NBS Stress Method	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}
NBS Rating	Low	Low
BEHI Score	28.2	33.4
BEHI Rating	Moderate	High
Average Water Surface Slope (ft/ft)	0.00461	
Sinuosity	1.57	
Width/Depth Ratio	6.03	
Bankfull Area (sq. ft)	20.83	
Entrenchment Ratio	2.04	
Channel Materials (mm)	0.24	
Bankfull Width (ft)	11.21	
Channel Evolution Stage	V	
Stream Type	B 5c	
Watershed Draiange Area (sq. mi)	0.76	
Mean Annual Precipitation	36.73	
Bank Material at Toe	Silty Clay Loam	

Survey Site 2a	Tributary to Clear S8-T5S-R18E Bank type 1
Erosion (ft/year)	0.0
Erosion Method	SASS 2011
Time Period	2007-2010
Study Bank Height (ft)	6.86
Bankfull Height (ft)	3.56
Root Depth (ft)	6.86
Root Density (%)	30
Bank Angle (degrees)	58
Surface Protection (%)	50
Bank Material	Silt/Clay
Soil Stratification (Y/N)	No
Near-Bank Stress Ratio	1.85
NBS Stress Method	d_{nb}/d_{bkf}
NBS Rating	High
BEHI Score	22.6
BEHI Rating	Moderate
Average Water Surface Slope (ft/ft)	0.00187
Sinuosity	1.14
Width/Depth Ratio	7.05
Bankfull Area (sq. ft)	39.93
Entrenchment Ratio	3.41
Channel Materials (mm)	0.03
Bankfull Width (ft)	16.78
Channel Evolution Stage	IV and V
Stream Type	E6
Watershed Draiange Area (sq. mi)	1.82
Mean Annual Precipitation	36.97
Bank Material at Toe	Silt/Clay

Survey Site 3a	Tributary to Mission Creek S16-T4S-R17E	
	Bank Type 1	Bank Type 2
Erosion (ft/year)	0.81	0.61
Erosion Method	SASS 2011	SASS 2011
Time Period	2007-2010	2007-2010
Study Bank Height (ft)	11.66	14.25
Bankfull Height (ft)	2.73	2.07
Root Depth (ft)	11.66	12.02
Root Density (%)	20	40
Bank Angle (degrees)	50	30
Surface Protection (%)	10	10
Bank Material	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No
Near-Bank Stress Ratio	2.17	1.71
NBS Stress Method	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}
NBS Rating	High	Moderate
BEHI Score	30.6	29.3
BEHI Rating	High	Moderate
Average Water Surface Slope (ft/ft)	0.00781	
Sinuosity	1.1	
Width/Depth Ratio	15.30	
Bankfull Area (sq. ft)	32.69	
Entrenchment Ratio	1.34	
Channel Materials (mm)	0.03	
Bankfull Width (ft)	21.95	
Channel Evolution Stage	V	
Stream Type	F6	
Watershed Draiange Area (sq. mi)	0.26	
Mean Annual Precipitation	36.92	
Bank Material at Toe	Silt/Clay	

Survey Site 4a

Delaware River - Kickapoo Nation

S30-T4S-R16E

	Bank Type 1	Bank Type 2	Bank Type 3	Bank Type 4	Bank Type 5
Erosion (ft/year)	0.0	0.46	0.0	0.0	2.3
Erosion Method	SASS 2011	SASS 2011	SASS 2011	SASS 2011	Aerial Photo
Time Period	2007-2010	2007-2010	2007-2010	2007-2010	1991-2008
Study Bank Height (ft)	24	23.49	21.3	19.75	21.94
Bankfull Height (ft)	18.54	13.21	14.29	14.78	15.8
Root Depth (ft)	24	9.55	21.3	9.75	2.34
Root Density (%)	40	20	20	20	10
Bank Angle (degrees)	24	33	39	33	28
Surface Protection (%)	15	15	15	15	10
Bank Material	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No	No	No	No
Near-Bank Stress Ratio	1.41	1.4	1.45	1.45	1.59
NBS Stress Method	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}
NBS Rating	Low	Low	Low	Low	Moderate
BEHI Score	20.7	31.9	24.8	27.8	34.9
BEHI Rating	Moderate	High	Moderate	Moderate	High
Average Water Surface Slope (ft/ft)			0.0006		
Sinuosity			1.22		
Width/Depth Ratio			12.93		
Bankfull Area (sq. ft)			947.17		
Entrenchment Ratio			3.62		
Channel Materials (mm)			0.04		
Bankfull Width (ft)			110.64		
Channel Evolution Stage			V		
Stream Type			C6c-		
Watershed Draiange Area (sq. mi)			142		
Mean Annual Precipitation			36.92		
Bank Material at Toe			Silt/Clay		

Survey Site 5a

Delaware River - Arrington

S8-T7S-R17E

	Bank Type 1	Bank Type 2	Bank Type 3	Bank Type 4	Bank Type 5
Erosion (ft/year)	0.0	0.0	0.46	0.0	3.3
Erosion Method	SASS 2011	SASS 2011	SASS 2011	SASS 2011	Aerial
Time Period	2007-2010	2007-2010	2007-2010	2007-2010	1991-2008
Study Bank Height (ft)	25.22	26.9	26.76	21.41	28.36
Bankfull Height (ft)	19.79	20.82	18.85	14.13	23.31
Root Depth (ft)	25.22	19.91	7.55	21.41	2.62
Root Density (%)	40	30	20	50	10
Bank Angle (degrees)	19	31	19	14	27
Surface Protection (%)	20	10	30	20	10
Bank Material	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No	No	No	No
Near-Bank Stress Ratio	1.47	1.3	1.45	1.58	1.94
NBS Stress Method	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}
NBS Rating	Low	Low	Low	Moderate	High
BEHI Score	19.6	25.7	28.2	19.8	34
BEHI Rating	Low	Moderate	Moderate	Low	High
Average Water Surface Slope (ft/ft)		0.00099			
Sinuosity		1.16			
Width/Depth Ratio		12.15			
Bankfull Area (sq. ft)		2207.63			
Entrenchment Ratio		4.38			
Channel Materials (mm)		0.21			
Bankfull Width (ft)		202.68			
Channel Evolution Stage		V			
Stream Type		C5c-			
Watershed Draiange Area (sq. mi)		578.85			
Mean Annual Precipitation		36.97			
Bank Material at Toe		Silt/Clay			

Survey Site 6a	Banner Creek S24-T7s-R14E		
	Bank Type 1	Bank Type 2	Bank Type 3
Erosion (ft/year)	0.61	0.0	0.61
Erosion Method	SASS 2011	SASS 2011	SASS 2011
Time Period	2007-2010	2007-2010	2007-2010
Study Bank Height (ft)	8.59	8.41	7.21
Bankfull Height (ft)	4.88	5.77	5.28
Root Depth (ft)	8.07	8.41	2.78
Root Density (%)	33	50	10
Bank Angle (degrees)	44	37	48
Surface Protection (%)	13	43%	10%
Bank Material	Silt/Clay	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No	No
Near-Bank Stress Ratio	1.53	1.7	1.79
NBS Stress Method	$d_{nb/}d_{bkf}$	$d_{nb/}d_{bkf}$	$d_{nb/}d_{bkf}$
NBS Rating	Moderate	Moderate	Moderate
BEHI Score	25.4	16.1	32.4
BEHI Rating	Moderate	Low	High
Average Water Surface Slope (ft/ft)		0.00442	
Sinuosity		1.07	
Width/Depth Ratio		6.94	
Bankfull Area (sq. ft)		80.27	
Entrenchment Ratio		2.50	
Channel Materials (mm)		0.06	
Bankfull Width (ft)		24.75	
Channel Evolution Stage		V	
Stream Type		E6	
Watershed Draiange Area (sq. mi)		1.63	
Mean Annual Precipitation		36.73	
Bank Material at Toe		Silt/Clay	

Survey Site 7a	Clear Creek S33-T4S-R18E		
	Bank Type 1	Bank Type 2	Bank Type 3
Erosion (ft/year)	1.08	0.0	2.22
Erosion Method	SASS 2011	SASS 2011	SASS 2011
Time Period	2007-2010	2007-2010	2007-2010
Study Bank Height (ft)	10.53	11.21	23.49
Bankfull Height (ft)	2.78	4.79	4.26
Root Depth (ft)	2.32	11.21	2.32
Root Density (%)	15	40	10
Bank Angle (degrees)	44	28	30
Surface Protection (%)	10	15	10
Bank Material	Silt/Clay	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No	No
Near-Bank Stress Ratio	1.56	1.97	2.51
NBS Stress Method	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}
NBS Rating	Moderate	High	Very High
BEHI Score	39.1	16.6	39.9
BEHI Rating	High	Low	High
Average Water Surface Slope (ft/ft		0.00144	
Sinuosity		1.89	
Width/Depth Ratio		13.37	
Bankfull Area (sq. ft)		54.7	
Entrenchment Ratio		2.14	
Channel Materials (mm)		0.03	
Bankfull Width (ft)		36.15	
Channel Evolution Stage		V	
Stream Type		C6	
Watershed Draiange Area (sq. mi)		1.33	
Mean Annual Precipitation		36.97	
Bank Material at Toe		Silt/Clay	

Survey Site 8a	Delaware River-Muscotah Gage S20-T6E-R17E		
	Bank Type 1	Bank Type 2	Bank Type 3
Erosion (ft/year)	0.0	2.9	0.0
Erosion Method	Aerial Photographs	Aerial Photographs	Aerial Photographs
Time Period	1991-2008	1991-2008	1991-2008
Study Bank Height (ft)	21.74	23.93	28.1
Bankfull Height (ft)	15.09	13.92	13.94
Root Depth (ft)	21.74	10.8	28.1
Root Density (%)	60	20	50
Bank Angle (degrees)	36	46.5	30
Surface Protection (%)	50	10	75
Bank Material	Silt/Clay	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No	No
Near-Bank Stress Ratio	1.44	1.44	1.35
NBS Stress Method	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}
NBS Rating	Low	Low	Low
BEHI Score	17.1	28.7	18
BEHI Rating	Low	Moderate	Low
Average Water Surface Slope (ft/ft)		0.0005	
Sinuosity		1.13	
Width/Depth Ratio		10.82	
Bankfull Area (sq. ft)		1,761.72	
Entrenchment Ratio		3.19	
Channel Materials (mm)		0.95	
Bankfull Width (ft)		138.09	
Channel Evolution Stage		V	
Stream Type		E5	
Watershed Draiange Area (sq. mi)		438.8	
Mean Annual Precipitation		36.97	
Bank Material at Toe		Silt/Clay	

Survey Site 9a	Delaware River-Road 254 S28-T6S-R17E			
	Bank Type1	Bank Type 2	Bank Type 3	Bank Type4
Erosion (ft/year)	0.46	0.0	0.85	0.0
Erosion Method	SASS 2011	SASS 2011	Aerial Photographs	SASS 2011
Time Period	2007-2010	2007-2010	1991-2008	2007-2010
Study Bank Height (ft)	25.48	23.88	25.39	24.8
Bankfull Height (ft)	11.18	11.73	14.47	14.86
Root Depth (ft)	25.48	23.88	15.02	24.8
Root Density (%)	30	75	20	50
Bank Angle (degrees)	50	21	24	24
Surface Protection (%)	10	50	20	40
Bank Material	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No	No	No
Near-Bank Stress Ratio	1.32	1.36	1.53	1.44
NBS Stress Method	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}
NBS Rating	Low	Low	Moderate	Low
BEHI Score	27.6	17.6	27.8	18.9
BEHI Rating	Moderate	Low	Moderate	Low
Average Water Surface Slope (ft/ft)		0.00038		
Sinuosity		1.25		
Width/Depth Ratio		13.72		
Bankfull Area (sq. ft)		1360.79		
Entrenchment Ratio		2.85		
Channel Materials (mm)		0.17		
Bankfull Width (ft)		136.67		
Channel Evolution Stage		V		
Stream Type		C5c-		
Watershed Draiange Area (sq. mi)		445.3		
Mean Annual Precipitation		36.97		
Bank Material at Toe		Silt Loam		

Delaware River-Muddy Creek Confluence

S4-T5S-R16E

Survey Site 10a	Bank Type 1	Bank Type 2	Bank Type3	Bank Type4	Bank Type 5
Erosion (ft/year)	0.0	4.4	0.0	1.4	3.6
Erosion Method	SASS 2011	Aerial Photographs	SASS 2011	Aerial Photographs	Aerial Photographs
Time Period	2007-2010	1991-2008	2007-2010	1991-2008	1991-2008
Study Bank Height (ft)	18.04	25.95	14.89	26.9	28.09
Bankfull Height (ft)	12.6	14.31	14.89	15.66	14.67
Root Depth (ft)	18.04	0	12.89	26.9	1.6
Root Density (%)	75	0	50	10	20
Bank Angle (degrees)	23	50	33	47	27
Surface Protection (%)	60	10	50	10	40
Bank Material	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay
Soil Stratification (Y/N)	No	No	No	No	No
Near-Bank Stress Ratio	1.48	1.53	1.37	1.41	1.55
NBS Stress Method	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}	d_{nb}/d_{bkf}
NBS Rating	Low	Moderate	Low	Low	Moderate
BEHI Score	14.4	39.5	14.9	28.2	33.8
BEHI Rating	Low	High	Low	Moderate	
Average Water Surface Slope (ft/ft)			0.00099		
Sinuosity			1.32		
Width/Depth Ratio	Above Confluence 10.41			Below Confluence 10.35	
Bankfull Area (sq. ft)	Above Confluence 945.8			Below Confluence 1398.04	
Entrenchment Ratio	Above Confluence 6.05			Below Confluence 3.99	
Channel Materials (mm)			0.81		
Bankfull Width (ft)	Above Confluence 99.22			Below Confluence 120.32	
Channel Evolution Stage			V		
Stream Type			E5		
Watershed Draiange Area (sq. mi)	Above Confluence 151.1			Below Confluence 255.2	
Mean Annual Precipitation			36.73		
Bank Material at Toe			Silt/Clay		