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

Final 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

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EXECUTIVE SUMMARY

The 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. Sediment deposition in Kansas reservoirs affects water quality and reservoir water-storage capacity. The study area encompasses the Kansas River watershed above Perry Reservoir and a sub-watershed above Tuttle Creek Reservoir, which are both USACE Federal water supply reservoirs.

GSRC and The Watershed Institute (TWI) (Research Team) utilized geographic information systems (GIS) data and historic and current aerial photography, and conducted detailed fluvial geomorphology surveys for the preparation of this report. The Rosgen (2006) Bank Erodibility Hazard Index (BEHI) was used to determine bank erosion potential and near-bank stress. The Research Team also used aerial photography interpretation and unpublished northeast streambank erosion monitoring data (Dr. Timothy Keane, Kansas State University, personal communication) to calculate the erosion rates and to recommend best management practice (BMP) scenarios. The BMP scenarios were inserted into the RIVERMorph model to estimate the percent reduction of bank erosion using the Bank Assessment for Non-point Consequences of Sediment (BANCS) model developed by Rosgen (1996, 2001).

Fluvial geomorphology data were collected at six locations. Three stream reaches were located in small sub-watershed drainages and three were located on the main-stem Delaware River, which drains a significantly larger area. The locations on the small tributaries were chosen through aerial video reconnaissance; the three sites on the main-stem Delaware River were chosen based on aerial photography interpretation and on input from the Delaware River Watershed Restoration and Protection Strategy (WRAPS) stakeholder group.

A total of 18 different bank erodibility conditions or bank types were identified within the six survey locations. The survey locations included Banner Creek, a tributary to Clear Creek, a tributary to Centralia Lake, and three reaches on the Delaware River. For each survey, data were compiled on the bankfull dimension, pattern, and profile to classify each reach using the Rosgen stream classification system for natural rivers (Rosgen 1994).

Several disturbances were observed influencing the channel dimension and pattern, which affected the erosion rates of surveyed streams. These included cattle access to the stream channel and riparian corridor, upstream impoundments, and channelization.

Aerial photographs from 1991 and 2006 were used to document changes in lateral streambank erosion on the Delaware River. Based on the aerial photography interpretation and survey data, erosion losses at the three Delaware River survey sites were calculated for five different bank conditions. For the remaining bank conditions, erosion pin data were applied from a streambank erosion monitoring project in the Black Vermillion River Watershed (Dr. Timothy Keane, personal communication) to estimate erosion loss.

Based on the survey results, the Delaware River sites had the highest weighted erosion rates ranging from 1.18 to 2.11 tons/foot/year. The Delaware River has experienced extensive channelization, drastically reducing the channel sinuosity (Figure ES-1). The stream reach featured in Figure ES-1 was once 12.38 miles long but today is only 4.60 miles long. The natural tendency for the Delaware River is to re-establish a sinuous river course.

Some bank types experienced high erosion rates between 3.2 to 5.5 tons/foot/year and other bank types showed very little to no erosion occurring in the segments. Using the Black Vermillion River watershed data, the RIVERMorph model produced erosion results of zero for bank types in straight reaches, which indicates that this part of the stream was receiving sediments from upstream sources or the erosion rates were very low and difficult to determine. Bank types that have the highest erosion potential are along outside bends with little riparian vegetation.

For the three smaller sub-watershed surveys, the Centralia Lake tributary had the lowest predicted erosion rate of 0.05 ton/foot/year and Banner Creek had the highest predicted erosion rate of 0.45 ton/foot/year. For most surveys, the riparian corridor consisted of woodlands containing various hardwood communities. The corridor often varied in width from non-existent

Figure ES-1: Channelization of Delaware River at USGS Muscotah Gauge to well over two active channel widths; similar conditions were observed upstream and downstream from each site. It was found that deep and narrow channels, like the channels surveyed, need greater plant and tree rooting depth and density throughout the bank profile to improve and sustain bank stability. A gentle bank angle is important, since it allows vegetation to grow further down the bank slope. No specific soil series were found that contributed to excess erosion.

BMP scenarios were developed for all of the stream reaches, and the BMP modified stream scenarios were re-run in RIVERMorph using the Rosgen BANCS model to determine whether the bank erosion rates would decrease. Results indicated that the smaller stream reaches (Sites 1, 2, and 3) did not show a significant erosion reduction; however, the three sites on the Delaware River (Sites 4, 5, and 6) showed a significant reduction in bank erosion. Table ES-1 summarizes each survey site's erosion potential.

Table ES-1. Summary of Bank Erosion Results for Six Stream Segments

Stream Segment	Stream Sediment Erosion (tons/foot/year)[1]	BMP Percent Reduction Bank Erosion	Types of BMPs
Banner Creek	0.45	Negligible	Riparian Fencing
Tributary to Clear Creek	0.26	Negligible	Riparian Fencing
Tributary to Centralia Lake	0.05	Negligible	Riparian Fencing
Delaware River at USGS Muscotah Gauge	1.77	91	Riparian and Bank Modifications and Rock Vanes
Delaware River at Highway 254 Bridge	1.18	93	Riparian and Bank Modifications and Rock Vanes
Delaware River at Muddy Creek Confluence	2.11	88	Riparian and Bank Modifications and Rock Vanes and Chutes

[1] Erosion results are weighted averages for the different bank types of the surveyed stream reach.

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SECTION 1.0
INTRODUCTION

1.0 INTRODUCTION

The 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 Delaware River watershed of the Kansas River basin (Figure 1-1). 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 potential and contributes to planning efforts underway by the Kansas Water Office (KWO) and other state agencies for long term reservoir sustainability.

The objectives of this project were to:

- Identify six stream segments within the Kansas River basin to investigate.
- Conduct fluvial and stream channel morphological and riparian assessments to identify future sediment control opportunities in selected sub-watersheds above Federal water supply reservoirs in the Kansas River basin.
- Conduct an assessment of critical factors affecting stream geomorphology, bed transitions, and systemic erosion issues in selected sub-watersheds.
- Assign a Rosgen (2006) stream classification to each survey reach, estimate the amount of streambank erosion, and evaluate riparian conditions.
- Determine cost estimates to implement the erosion mitigation design for the most suitable erosion control measures.
- Determine the reduction in erosion resulting from implementation of erosion control measures.

Survey locations for the main-stem Delaware River were selected based on input from KWO, Delaware River Watershed Restoration and Protection Strategy (WRAPS) stakeholder group, and aerial photography. Landowner permission to survey the sites was also required for ultimate selection of survey locations. Input from Kansas University Engineering Department assisted in the identification of stream reaches in the Centralia Lake watershed, Atchison County Lake watershed, and Banner Creek Reservoir watershed using video from a recent

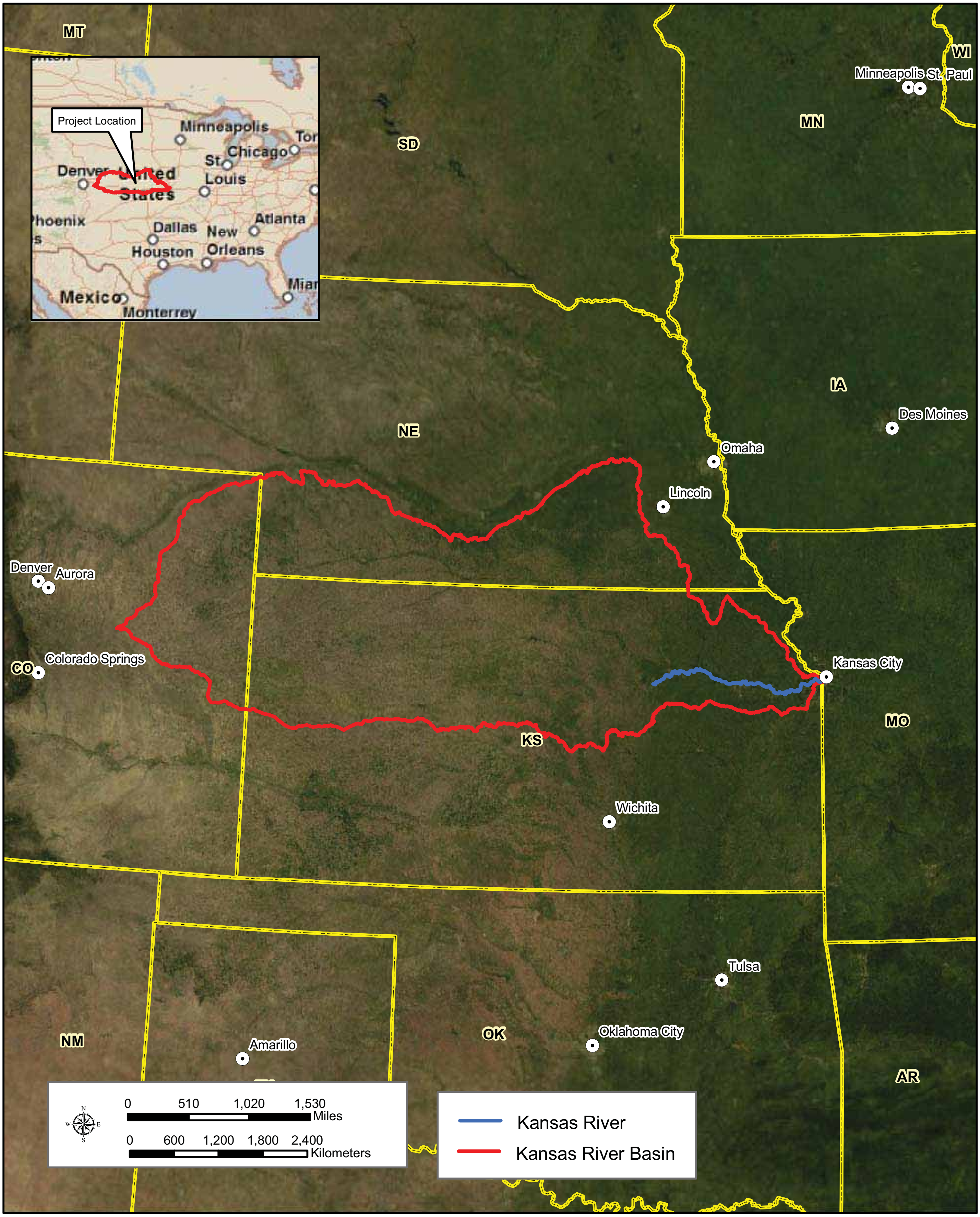

Figure 1-1: Kansas River Basin

April 2010

helicopter reconnaissance. One stream reach was identified in each of the three sub-watersheds for study.

This report evaluates sediment erosion at selected stream sites, identifies best management practices (BMPs) for stream reaches for future erosion control projects, and estimates the reduction of sediment erosion resulting from implementation of erosion control projects. This report was prepared by GSRC and its team member, The Watershed Institute (TWI), collectively referred to hereinafter as the Research Team.

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SECTION 2.0
STUDY AREA

2.0 STUDY AREA

The study area is located north of Topeka, Kansas, and comprises the following watersheds: Banner Creek, Atchison County Lake, Centralia Lake, and Delaware River. Six sites were selected for surveys, one each on Banner Creek, tributary to Clear Creek, and tributary to Centralia Lake and three survey sites on the Delaware River. The locations of the six survey sites areas are presented in Figure 2-1; the survey location description and dates of the six surveys are provided in Table 2-1.

Table 2-1. Location of Complete Fluvial Geomorphology Surveys

Site Number	Name of Watershed	Location (Section-Township-Range)	Survey Date(s)
1	Banner Creek Reservoir	SE ¼ S8-T7S-R14E	5/29/2009
2	Atchison County Lake	NW ¼ S8-T5S-R18E	6/19/2009, 6/23/2009
3	Centralia Lake	SW ¼ S25-T4S-R11E	5/28/2009
4	Delaware River	NW ¼ S21-T6S-R17E NE ¼ S20-T6S-R17E	8/31/2009, 9/1/2009
5	Delaware River	NW ¼ S28-T6S-R17E NE ¼ S29-T6S-R17E	9/2/2009
6	Delaware River	SE ¼ S4-T5S-R16E NE ¼ S9-T5S-R16E	9/11/2009, 9/14/2009

2.1 Survey Site 1: Banner Creek Reservoir Watershed

Survey Site 1 is located within the Banner Creek Reservoir watershed, which encompasses 19 square miles. The predominant land use is grassland for grazing livestock, occupying nearly 76% of the watershed (Juracek and Ziegler 2007). In the past, the Kansas Department of Health and Environment (KDHE) determined that the Banner Creek Reservoir was impaired due to high levels of nutrients and excessive eutrophication. Banner Creek was later removed from the Section 303(d) Impaired Waters list in 2008; however, eutrophication is still a lingering concern (Gnau 2010).

Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams, receive excess nutrients that stimulate excessive plant growth (e.g., algae, periphyton, and nuisance plants or weeds). This enhanced plant growth, often called an algal bloom,

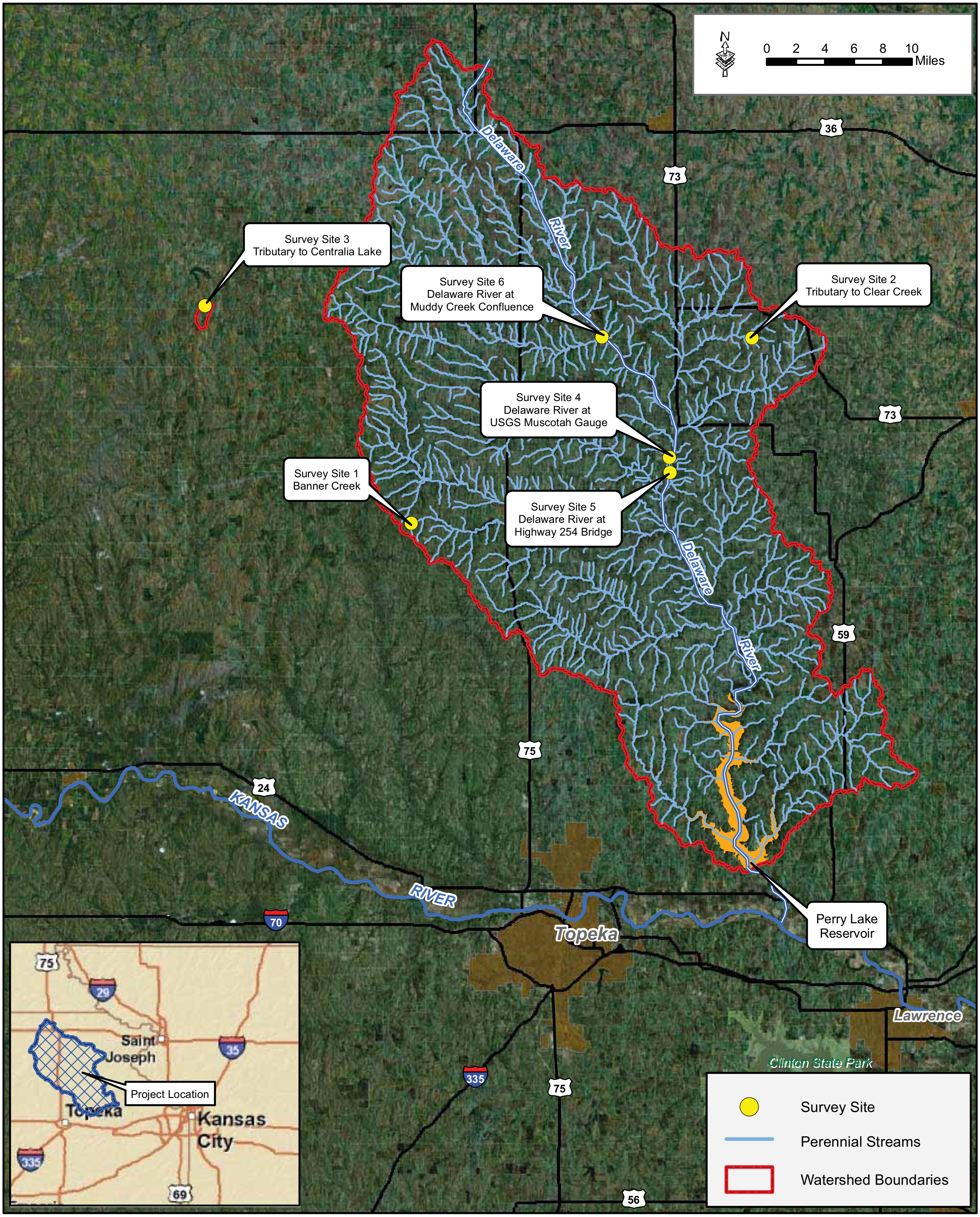

Figure 2-1: Survey Sites Locations

reduces dissolved oxygen in the water when dead plant material decomposes, and can cause other organisms to die. Nutrients can come from many sources, such as fertilizers applied to agricultural fields, erosion of soil containing nutrients, and livestock waste products. Helicopter reconnaissance video was used to select the survey site. The stream reach at the site displayed conditions typical of other stream reaches in the watershed.

2.2 Survey Site 2: Atchison County Lake Watershed

Survey Site 2, located on a tributary to Clear Creek, is located in the Atchison County Lake watershed. The watershed comprises 9.3 square miles and the land use was predominantly row crop agriculture. Although the lake is currently in compliance for all designated uses, the lake historically has not met water supply and aquatic life designated uses due primarily to siltation and eutrophication (KDHE 2008). It is believed that Atchison County Lake will not meet water quality limits in the future, and is expected to be listed again in 2010 as impaired due to siltation and eutrophication non-compliance in 2010 (Gnau 2010). The survey site is located along a narrow, wooded riparian corridor. Helicopter reconnaissance video was used to select the survey site, and showed that the survey site displayed conditions typical of the watershed.

2.3 Survey Site 3: Centralia Lake Watershed

Survey Site 3 is located on an unnamed tributary to Centralia Lake. The Centralia Lake watershed comprises 12.0 square miles. KDHE (2008a) concluded that Centralia Lake was impaired due to eutrophication and that all designated uses in Centralia Lake were impaired. The watershed land use is predominately (80%) cropland. The lake had elevated chlorophyll-a concentrations during summer months due to the run-off of phosphorus applied to agriculture row crops. Phosphorus from animal waste was another contributing factor to excessive aquatic plant growth (KDHE 2008a). The survey location was chosen based on information provided by helicopter reconnaissance video. This site is located along a straight reach with scattered trees, which was typical for this watershed.

2.4 Survey Sites 4, 5, and 6: Delaware River Watershed

The Delaware River watershed is located in northeastern Kansas and encompasses 1,117 square miles. The Delaware River flows into Perry Reservoir 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% 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 (KDHE 2008a). Most of the land use in the watershed consists of grassland for grazing livestock (50% of the area) or cropland (43% of the area) (KDHE 2008b). Three survey sites along the Delaware River were selected with help from the WRAPS stakeholder group.

The first main-stem Delaware River site (Site 4) surveyed is approximately 2 miles south of Muscotah near a U.S. Geological Survey (USGS) stream gaging station. Survey Site 5 was located on a reach approximately 1 mile south of Survey Site 4, near 254th Road. This location was ultimately chosen due to landowner permission difficulties on several reaches near Arrington. The final survey site, Site 6, is located at the confluence with Muddy Creek, a major Delaware River tributary, and 13 miles upstream of Site 4.

SECTION 3.0
DATA COLLECTION METHODOLOGY

3.0 DATA COLLECTION METHODOLOGY

3.1 Field Investigations

To best determine channel condition and stability, the Research Team used methods and procedures defined by Dave Rosgen at Wildland Hydrology (Rosgen 1996), which developed a hierarchy of river inventory and assessment protocols consisting of four levels, with each successive level building on the former (Keane 2004). The levels include: (I) Geomorphic Characterization, (II) Morphological Description, (III) Stream State or Condition, and (IV) Validation. Data collected during surveys fulfill levels I through III. The validation level requires long-term monitoring that was not a part of the scope of work. Data collection was divided into seven categories: drainage basin area; channel dimension; channel materials; channel pattern; channel profile; Bank Erodibility Hazard Index (BEHI); and Pfankuch channel stability evaluation. Additional data collection was conducted as necessary or as conditions presented themselves in the field. For all surveys, permission was obtained from the landowner before field work began.

For this project, the Level II morphological description and Level III stream "state" or condition classifications were followed to obtain a more refined view of stream reach condition. The Level III stream state examination provides a quantitative basis for comparing streams with similar morphologies, but exhibiting different states or conditions. Figure 3-1 presents the Rosgen classification key to natural rivers. The Rosgen (1996) stream classification protocol was favored for the following reasons:

- It employs consistent, objective, quantitative, and reproducible measures (Keane 2004).
- It predicts a river's behavior from its appearance.
- It develops specific hydraulic and sediment relationships for a given stream type and its state.
- It extrapolates site-specific data to stream reaches having similar characteristics.
- It provides a basis for communication among water resource professionals.
- The results are based upon measured morphologic characteristics and river formed variables obtained from hundreds of actual river sites.
- It incorporates all three dimensions of channel form while accounting for variability in channel forming materials (Thorne 1997).

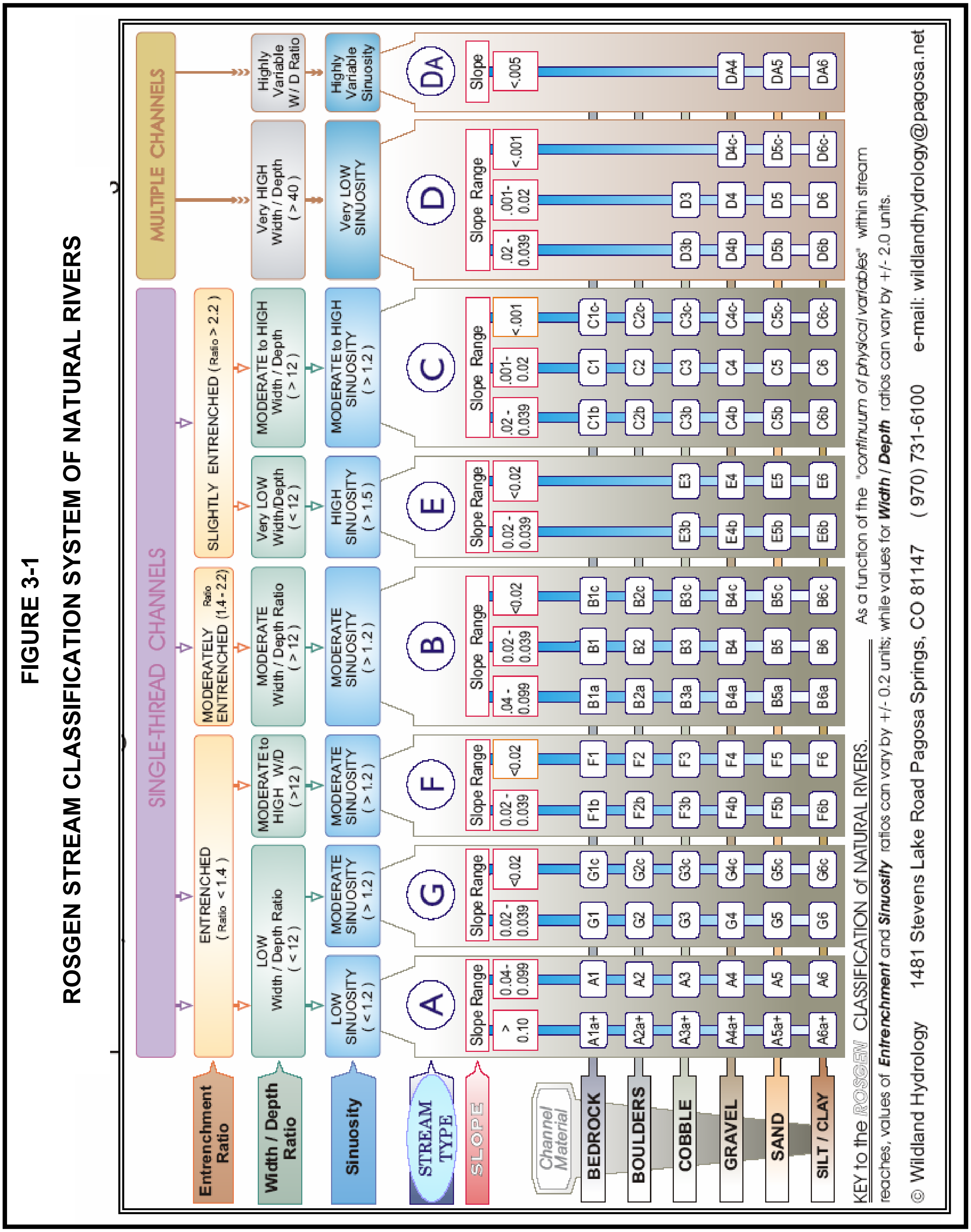
FIGURE 3-1
ROSGEN STREAM CLASSIFICATION SYSTEM OF NATURAL RIVERS
SINGLE-THREAD CHANNELS
MULTIPLE CHANNELS
Entrenchment Ratio
Width / Depth Ratio
Sinuosity
STREAM TYPE
SLOPE
Channel Material
ENTRENCHED (Ratio < 1.4)
MODERATELY ENTRENCHED (Ratio 1.4 - 2.2)
SLIGHTLY ENTRENCHED (Ratio > 2.2)
LOW Width / Depth Ratio (< 12)
MODERATE to HIGH W/D (>12)
MODERATE Width / Depth Ratio (> 12)
Very LOW Width/Depth (< 12)
MODERATE to HIGH Width / Depth (> 12)
Very HIGH Width / Depth (> 40)
Highly Variable W / D Ratio
LOW SINUOSITY (< 1.2)
MODERATE SINUOSITY (> 1.2)
HIGH SINUOSITY (> 1.5)
MODERATE to HIGH SINUOSITY (> 1.2)
Very LOW SINUOSITY
Highly Variable Sinuosity
A
G
F
B
E
C
D
DA
Slope Range
Slope
> 0.10
0.04- 0.099
0.02 - 0.039
<0.02
.04 - 0.099
.02 - 0.039
.001- 0.02
<.001
<.005
BEDROCK
BOULDERS
COBBLE
GRAVEL
SAND
SILT / CLAY
A1a+ A1 G1 G1c F1b F1 B1a B1 B1c C1b C1 C1c-
A2a+ A2 G2 G2c F2b F2 B2a B2 B2c C2b C2 C2c-
A3a+ A3 G3 G3c F3b F3 B3a B3 B3c E3b E3 C3b C3 C3c- D3b D3
A4a+ A4 G4 G4c F4b F4 B4a B4 B4c E4b E4 C4b C4 C4c- D4b D4 D4c- DA4
A5a+ A5 G5 G5c F5b F5 B5a B5 B5c E5b E5 C5b C5 C5c- D5b D5 D5c- DA5
A6a+ A6 G6 G6c F6b F6 B6a B6 B6c E6b E6 C6b C6 C6c- D6b D6 D6c- DA6
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.
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3.1.1 Channel Dimension

Channel cross sections were surveyed to obtain channel dimension parameters at each identified bank condition or type. The number of cross sections varied per site, based on identified changes in bank stability conditions. The surveys involved documenting riffle and pool dimensions to assess riffle-pool sequences. At least one cross section was surveyed at a riffle (if present) or cross-over reach for stream classification purposes. A Leica TCR407 Total Station was used to survey each cross section. Each cross section was oriented perpendicular to flow, and data were recorded at regular intervals to accurately depict the channel shape. In addition to the regular measurement intervals, special features on the cross sections were also documented. These features included edge of water, channel thalweg, terraces, rooting depth elevations, and bankfull stage indicators. Bankfull indicators included change in bank angle, vegetation changes, and top of sediment deposits. The cross section data were imported from the Leica TCR407 Total Station into RIVERMorph and the RIVERMorph software then plotted the survey data. Next, vertical exaggeration was eliminated to provide an accurate representation of each cross section survey. The cross section plots are shown in Appendix B and summarized in Section 4.0.

3.1.2 Channel Materials

Channel material surveys or "pebble counts" were conducted at each survey site. The Wolman (1954) pebble count procedure was used, which requires measuring the intermediate axis of randomly selected pebbles. To ensure random sampling, pebbles were collected by blindly reaching down until touching a particle (e.g., gravel, cobble, boulder, and bedrock), and then measuring the particle sample's intermediate axis. The samples from collection transects were discarded so the same particles would not be measured a second time. This method resulted in random, unbiased sampling. Approximately 100 samples per pebble count were measured. For pebble counts at surveyed cross sections, samples were measured across the active channel bottom. The survey reach "pebble count" was sampled to document the representative size distribution of the channel materials for the entire reach. A total of 10 transects were selected for each survey, and 10 measurements were recorded at each transect across the bankfull channel width. All pebble count data were entered into RIVERMorph, which then calculated the item and cumulative percentages of samples grouped into size categories developed by the Federal Interagency Sedimentation Project. Additionally, RIVERMorph calculated sediment size and determined the percent for each size class (e.g., silt/clay, sand, gravel, boulder, cobble, and bedrock).

3.1.3 Channel Profile

Longitudinal profiles were conducted along the entire study reach, equaling at least two meander wavelengths. The Leica TCR407 Total Station was used survey channel profile and thalweg. The thalweg is the line connecting the deepest parts of the channel. Each profile included a survey of the thalweg, water surface, bankfull indicators, and right and left top-of-bank. The bankfull indicators included "top-of-bank" or a change in bank slope. The left and right top-of-banks were plotted to determine bank height ratios.

The Total Station longitudinal profile survey data were imported into the RIVERMorph software to plot the data. Bankfull indicators identified in the stream served as the basis for determining the bankfull slope. The profile plots for each survey are presented in Appendix C and are summarized Section 4.0.

3.2 Field Results

3.2.1 Discharge Calculation

For each of the surveys, regional curves were used to estimate the bankfull discharge. Regional curves serve as a data-supported basis for estimating the bankfull discharge and associated channel dimension in ungaged watersheds (Rosgen 1998). Studies by Emmert and Hase (2001), Tetra Tech EM, Inc. (2004) and TWI (2005a and 2006a) involved data collection used to develop regional curves for various Kansas hydrophysiographic provinces. Hydrophysiographic provinces are discernable areas of homogeneity concerning landform, underlying geology and soils, climate, hydrology, and biotic communities (Keane 2004). For this study, regional curves from eastern Kansas hydrophysiographic provinces were used.

3.2.2 Stream Classification

Stream Classification

Bankfull parameters were determined from channel dimension, pattern, and profile. Bankfull parameters were used to aid in calculating actual stability indices. RIVERMorph was used to create fluvial geomorphology summary sheets based on forms from Watershed Assessment of River Stability and Sediment Supply (WARSS) by Rosgen (2006). The WARSS form summarizes all bankfull dimension, pattern, and profile data used to classify each survey. Appendix D contains the stream classification summary sheets for each of the six stream surveys.

3.2.3 Bank Erodibility Hazard Index (BEHI)

To determine streambank erosion potential, the BEHI model was used to obtain a quantitative, objective channel stability assessment for rating streambank erosion potential (Rosgen 1996). The assessment ranks the following series of parameters as important factors in streambank resistance to erosion:

- Ratio of streambank height to bankfull height;
- Ratio of riparian vegetation rooting depth to streambank height;
- Rooting density percentage;
- Composition of streambank materials;
- Streambank angle;
- Bank material stratigraphy and presence of soil lenses; and
- Bank surface protection provided by debris and vegetation.

BEHI assessment procedures rate these parameters and assign a numeric index rating for each parameter; the numeric parameter ratings were summed to achieve an overall erosion potential score. BEHI summarizes erosion potential (based on total score) as low, moderate, high, very high, and extreme. BEHI assessments were performed using survey data and field observations. When streambank parameters changed, the location was noted on the longitudinal profile survey and rated with the new streambank condition. A cross section was surveyed for every observed streambank condition.

The data were entered into RIVERMorph, where the software calculated the BEHI variables and overall BEHI rating. RIVERMorph exported the data into a WARSS worksheet.

In addition, near bank stress (NBS) criteria were used to estimate erosion rates. NBS determination is used to identify potential disproportionate energy distribution in the near bank region that can lead to accelerated bank erosion (Rosgen 2006). The NBS method selected was the ratio of near-bank maximum depth (d_{nb}) to mean bankfull depth (d_{bkf}). The near-bank maximum depth was the deepest part of the channel within the third of the cross section associated with the study bank (Rosgen 2006). RIVERMorph was used to determine the d_{nb}/d_{bk} ratio based on the surveyed cross sections. The ratios were then rated based on the NBS ratings developed by Rosgen (2006) as presented in Table 3-1.

Table 3-1. Near-Bank Stress Rating for d_{nb}/d_{bkf}

d_{nb}/d_{bkf} Ratio	NBS Rating
< 1.00	Very Low
1.00 - 1.50	Low
1.51 – 1.80	Moderate
1.81 – 2.50	High
2.51 – 3.00	Very High
> 3.00	Extreme

Source: Rosgen 2006

Aerial photography interpretation was used to determine streambank erosion rates. Aerial photography interpretation was applied only to the main-stem Delaware River surveys as channel change from streambank erosion was not detectable at the smaller, sub-watershed survey sites. Aerial photography from 1991 and 2006 was used to document changes in lateral streambank erosion. Based on the aerial photograph interpretation and survey data, erosion losses for five different bank conditions were calculated. The BEHI ratings, however, paralleled the aerial photograph estimates, reinforcing the ratings use for comparing erodibility at different locations.

The historic channel location was delineated from 1991 aerial photography and was overlaid on the 2006 aerial photography in ArcMap(™). The change in the lateral streambank erosion, where detectable, was then delineated. These changes did match bank types with the highest BEHI ratings. The ArcMap(™) software was used to calculate the surface area for each detectable change in streambank erosion and the length of bank. The surface area was divided by bank length to determine the amount of lateral movement in feet. Finally, the erosion loss (in feet) was divided by 15 years (the difference between aerial photographs) to compute the erosion rate (feet/year).

For the remaining bank types, the erosion monitoring data from the Black Vermillion River watershed were used (Dr. Timothy Keane 2010). For these data, the BEHI and NBS scores from the monitoring data were compared with the BEHI/NBS scores from the six surveys. Measured erosion rates of similar BEHI/NBS-rated banks were applied to the remaining 13 bank types.

3.2.4 Pfankuch Channel Stability Evaluation

The Pfankuch Channel Stability Evaluation Procedure (Pfankuch 1975) was completed on each stream survey. This procedure evaluates the entire channel anatomy (upper banks, lower banks, and channel bottom) by employing maps, aerial photographs, and field observations and measurements to achieve a total score. Rosgen (1996) developed a conversion of stability rating (based on total score) to reach condition by stream type in order to assign a rating of good, fair, or poor. Each survey was scored while on site using Pocket RIVERMorph, and later downloaded into RIVERMorph, which rated the stability scores.

3.2.5 Drainage Basin Area

The latitude/longitude coordinates were recorded with a global positioning system (GPS) unit at each survey reach, and the coordinates were then uploaded into ArcMap(™) Geographical Information System (GIS) software. By overlaying the coordinates with USGS digital raster graphs (DRG) and U.S. Department of Agriculture, Natural Resource Conservation Service (USDA NRCS) 14-digit hydrologic unit code (HUC) boundaries, the GIS program delineated drainage area boundaries and determined the drainage areas.

3.2.6 Channel Pattern

Aerial photography was used to measure channel patterns, which documented variations in meander geometry. Measurements included the lateral extent of meanders (belt width), the wavelengths of meanders (meander lengths), and the degree of curvature in meanders (radius of curvature). To determine sinuosity, the ratio of stream to valley length in the vicinity of the survey was measured. Multiple meanders were surveyed to document the variability of pattern dimensions.

RIVERMorph was used to perform channel pattern analysis, which allows a user to scale selected aerial photographs using a GIS interface. For this project, 2006 aerial photography from the USDA National Agriculture Imagery Program was used. RIVERMorph provides tools to measure sinuosity, meander wavelength, belt width, and radius of curvature. It determines the minimum, average, and maximum values for each parameter and records the values in the database.

3.3 Additional Data Collection

Additional field parameters were also collected to help characterize the stream stability rating, including stream type, riparian vegetation, flow regime, stream order/size, meander patterns, depositional patterns, channel blockages, width/depth ratio state, degree of channel incision, and degree of channel confinement, as defined by Rosgen (2006).

3.3.1 Simon Channel Evolution Sequence

Stream reaches were assessed based on their degree of degradation using the Simon Channel Evolution Sequence (Simon 1989). Incised channels are caused by an imbalance between sediment transport capacity and sediment supply that alters channel morphology through bed and bank erosion. Consistent sequential changes in incised channel morphology may be quantified and used to develop relationships describing quasi-equilibrium conditions in these channels. Each stage of individual sequences, as shown in Figure 3-2, is associated with unique quantitative relations of morphological, hydrological, sedimentological, and biological relations. The adverse adjustments due to an assortment of morphological sequential shifts in equilibrium can create accelerated sediment yields, loss of land, lowering of the water table, decreased land productivity, loss of aquatic habitat, and diminished recreational and visual values.

3.4 Modeling BMP Effectiveness

To predict the effectiveness of recommended BMPs, the BEHI scenarios were adjusted to model sediment reduction. The BMPs considered were rock vanes, shaping the banks to a

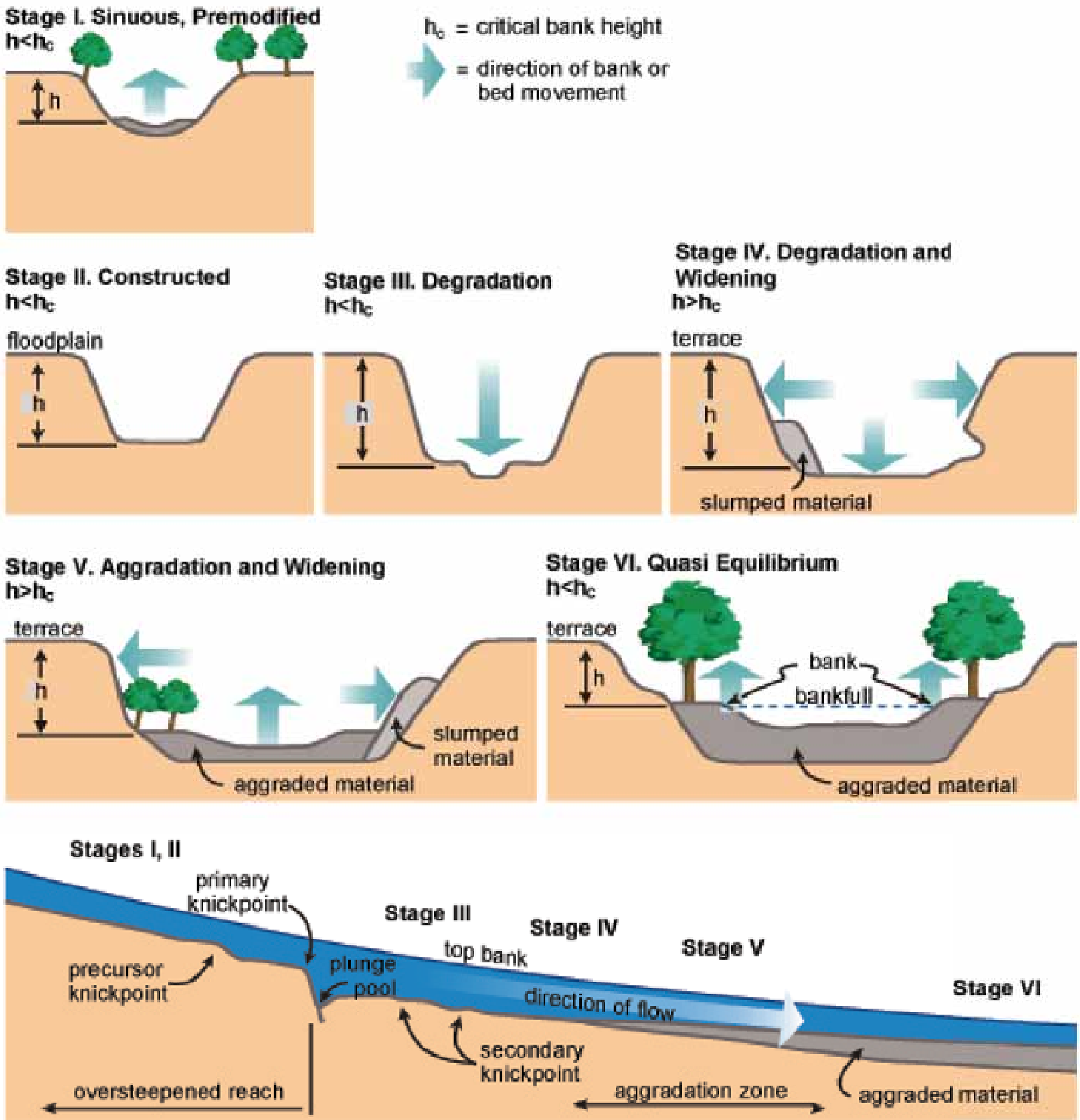

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Figure 3-2
Simon Channel Evolution Sequence

Source: Simon (1989)

three-foot horizontal to one-foot vertical slope, and restoring the riparian corridor with native trees, shrubs, and grasses. The BEHI modeling scenarios included:

- Current conditions
- First three years after BMP implementation
- BMP implementation after 3 years

The BMP implementation scenarios were split between the first 3 years and after three years to model the typical period of vegetation establishment. The BEHI parameters were changed to included bank angle, rooting depth, root density percentage, and surface protection. In addition, the NBS rating was adjusted to low to reflect the installation of rock vanes which will help reduce water velocities in the near bank region.

The Bank Assessment for Non-point Consequences of Sediment (BANCS) model was used to estimate the erosion loss of each BMP scenario. The BANCS is a feature in the Rosgen RiverMorph BEHI model and was used to determine the percent reduction in sediment loss between current conditions and the two BMP implementation scenarios.

SECTION 4.0
SURVEY AND MODELING RESULTS

4.0 SURVEY AND MODELING RESULTS

This section presents the survey and modeling results with respect to drainage area, discharge calculation, Rosgen stream classification, BEHI, Pfankuch Stream Stability Evaluation, and additional data that were collected and analyzed. The following results are presented by survey site. Hereinafter, the terms left bank and right bank are used to describe the left descending bank and right descending bank, respectively.

4.1 Drainage Area and Discharge Rate

Table 4-1 lists the drainage area and bankfull discharge for each stream survey. It was assumed that the entire drainage area was contributing flow at each of the survey sites. Figure 4-1a through 4-1d presents the drainage areas for each of the survey sites.

Table 4-1. Survey Sites and Drainage Areas

Fluvial Survey Site Geomorphology Survey (Site No.)	Drainage Area (mi^2)	Bankfull Discharge Cubic Feet/Second
1.0 Banner Creek	0.76	60
2.0 Clear Creek Tributary	1.82	97
3.0 Centralia Lake Tributary	1.22	268
4.0 Delaware River at USGS Muscotah Gauge	438.8	6,342
5.0 Delaware River at Highway 254 Bridge	445.3	6,423
6.0 Delaware River above Muddy Creek Confluence	151.1	3,990
6.0 Delaware River below Muddy Creek Confluence	255.2	5,526

4.2 Rosgen Stream Classification

After gathering survey and aerial photography information, a Rosgen stream type was assigned to each fluvial geomorphology survey (Table 4-2). Summary tables presenting the stream classification parameters and subsequent stream types are found in Appendix D.

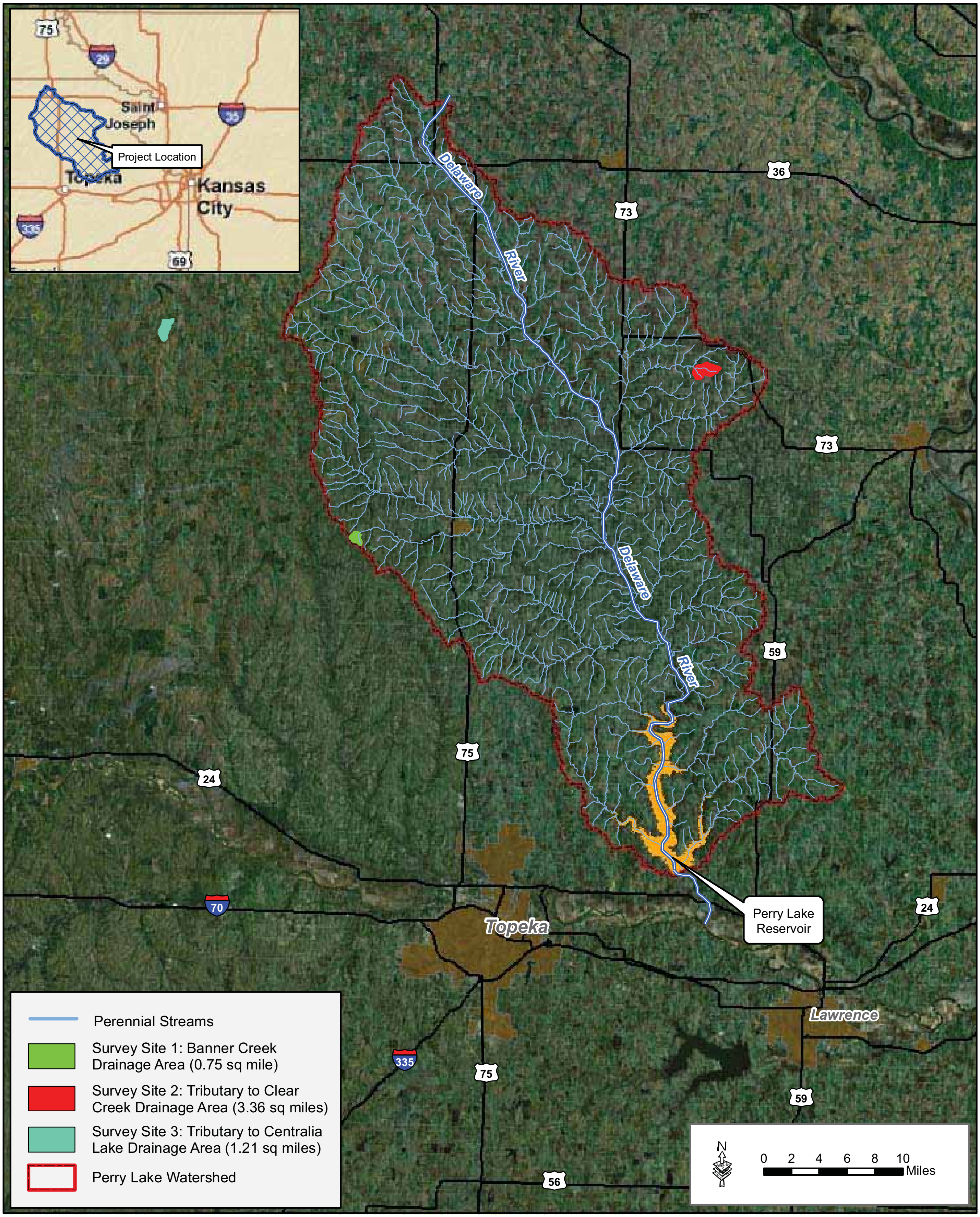

Figure 4-1a: Drainage Area of Survey Sites off Main Stem Delaware River

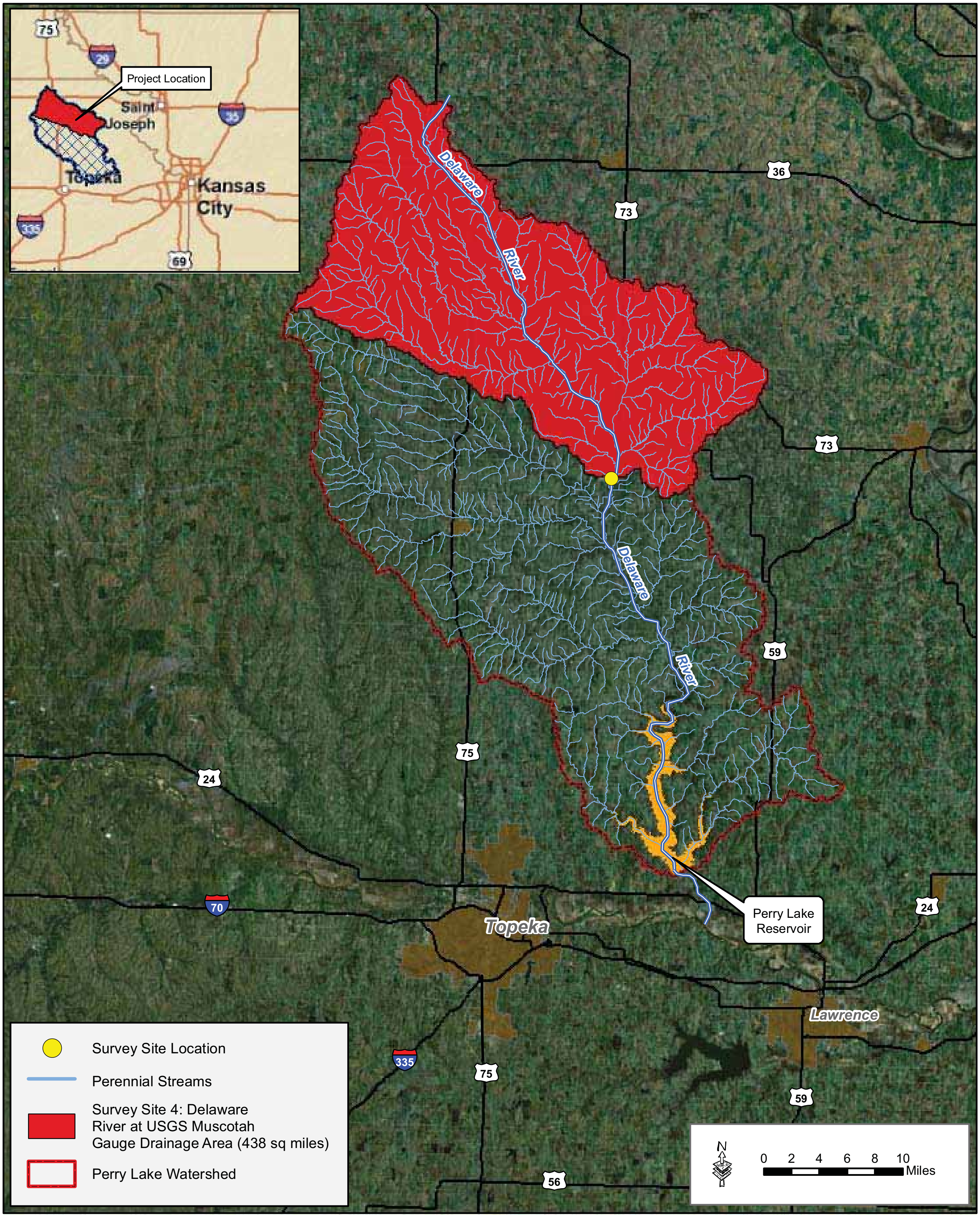

Figure 4-1b: Drainage Area of Survey Site 4

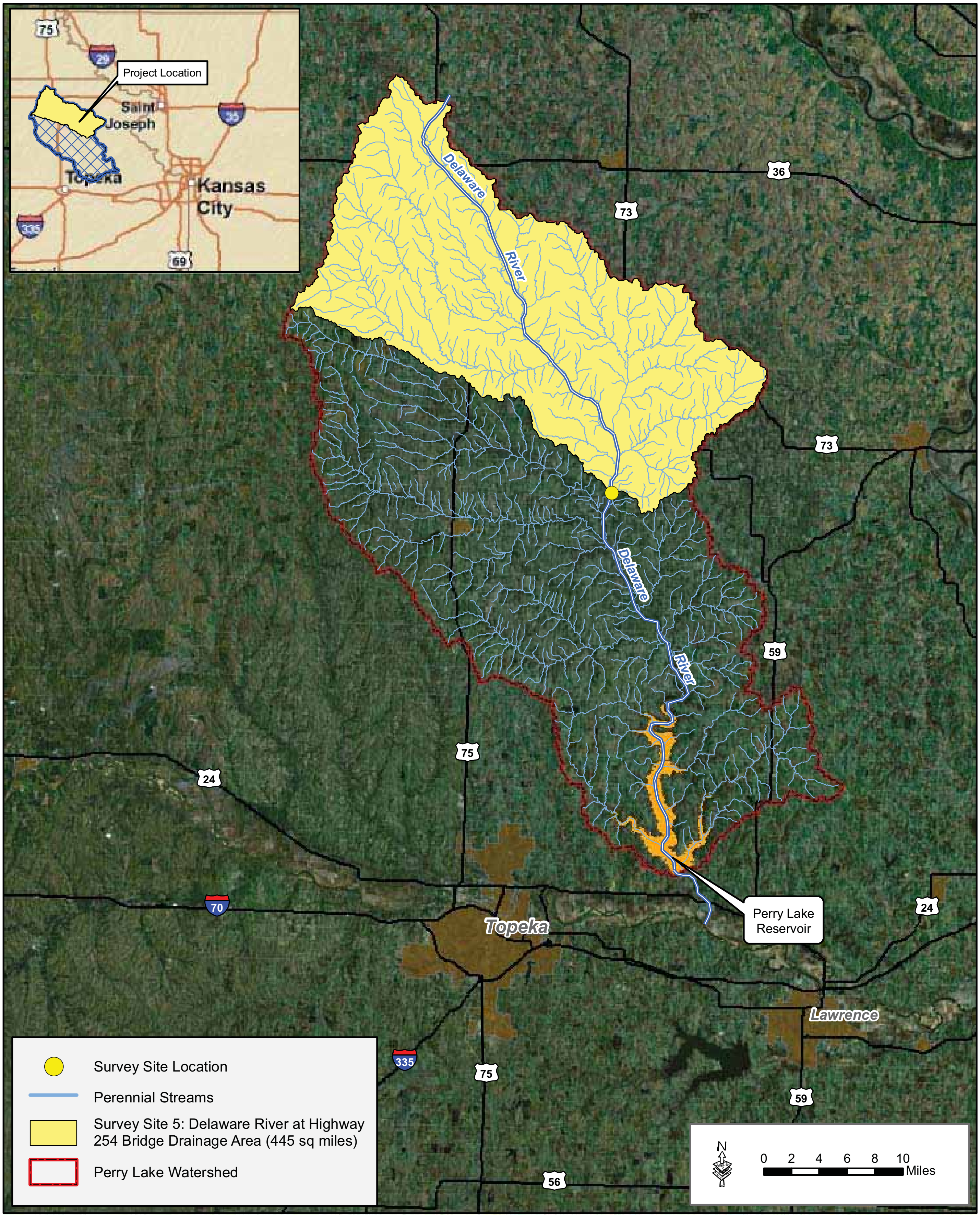

Figure 4-1c: Drainage Area of Survey Site 5

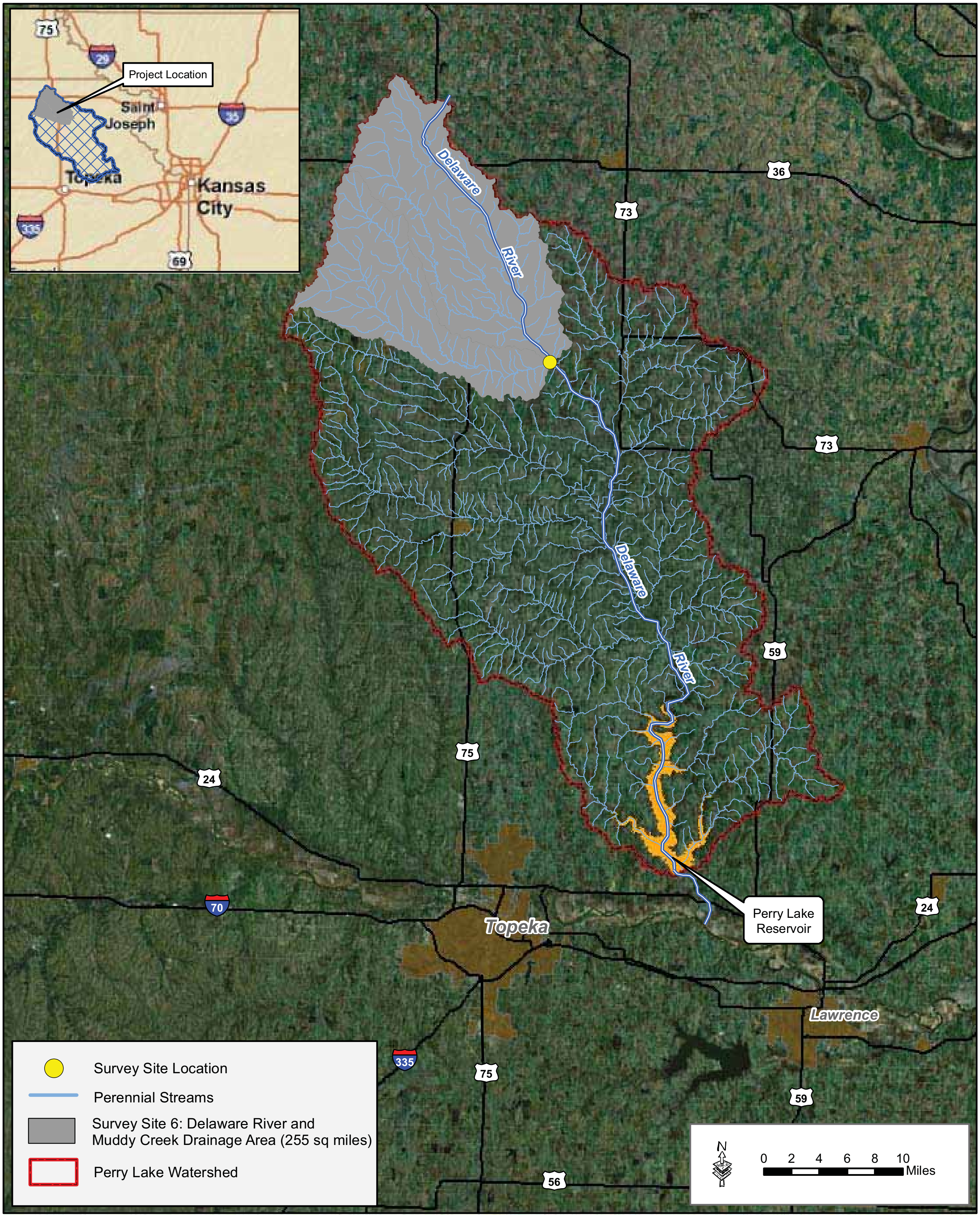

Figure 4-1d: Drainage Area of Survey Site 6

Table 4-2. Summary of Rosgen Stream Classification Results

Site No.	No. of Channels	Entrenchment Ratio (ft/ft)	Width/Depth Ratio (ft/ft)	Sinuosity	Slope Ratio (ft/ft)	Channel Material Size (mm)	Rosgen Stream Type*
1.0	1	2.04	6.03	1.57	0.00461	0.24	B5c
2.0	1	3.41	7.05	1.14	0.00187	0.03	E6
3.0	1	3.35	5.12	1.02	0.00537	0.03	E6
4.0	1	3.19	10.82	1.13	0.00050	0.95	E5
5.0	1	2.85	13.72	1.25	0.00038	0.17	C5c-
6.0	1	3.99	10.35	1.32	0.00099	0.81	E5

Entrenchment, width/depth, and slope ratios were calculated using width and depth in feet.
*See Figure 3-1 for description of Rosgen classification key.

4.3 Pfankuch Stream Stability Evaluation

After field observations of the various hydrologic, water quality, and riparian indicators, the results were inserted into the Pfankuch Stream Stability Evaluation model. Table 4-3 presents the Pfankuch scores and ratings for each of the six survey sites.

Table 4-3. Pfankuch Stream Stability Evaluation Results

Pfankuch Stream Results	Survey Site Number					
Stream Characteristic	**1**	**2**	**3**	**4**	**5**	**6**
Landform Slope	6	3	4	4	4	5
Mass Wasting	9	9	7	12	10	9
Debris Jam Potential	6	8	4	2	2	4
Vegetative Bank Protection	6	5	7	9	6	7
Channel Capacity	1	2	1	2	2	2
Bank Rock Content	8	8	8	8	8	8
Obstructions to Flow	5	6	4	2	4	4
Cutting	14	12	12	12	14	12
Deposition	10	8	14	12	12	12
Rock Angularity	2	2	2	2	2	2
Brightness	2	2	2	2	2	2
Consolidation of Particles	4	8	8	8	8	8
Bottom Size Distribution	8	8	8	8	8	10
Scouring and Deposition	12	12	16	24	24	24
Aquatic Vegetation	3	2	2	3	3	3
Sediment Supply	M	M	M	M	M	M
Stream Stability	A	A	A	A	A	A

Table 4-3, continued

Pfankuch Stream Results	Survey Site Number					
Stream Characteristic	**1**	**2**	**3**	**4**	**5**	**6**
Width/Depth Condition	N	N	N	N	N	N
Grand Total	96	95	99	110	109	112
Existing Stream Type	B5c	E6	E6	E5	C5c-	E5
Potential Stream Type	E5	E6	E6	C5c-	C5c-	C5c-
Stability Rating	Poor	Poor	Poor	Fair	Fair	Fair

Notes: A: Aggrading H: High L: Low M: Moderate N: Normal S: Stable
Key to the Pfankuch Stream Stability Evaluation is located in Appendix A, Page A-1.

4.4 Stream Analysis by Survey Site

Based on field notes and measurements, BEHI stream analysis was performed to summarize bank stability at each survey site. Worksheets from Rosgen (2006) were used to complete this analysis, and reference materials developed by Kuchler (1974) were used to determine the potential for native vegetation to reduce bank erosion. The results of the BEHI stream stability ratings and Rosgen stream analysis are presented in the following six subsections by survey site.

4.4.1 Survey Site 1: Banner Creek

4.4.1.1 Bank Erodibility Hazard Index

The Banner Creek survey site is located adjacent to a warm season pasture. There was a heavily wooded corridor throughout the survey reach which appears to be expanding into the warm season pasture. Common upper-story riparian species observed were cottonwood (*Populus deltoides*), catalpa (*Catalpa speciosa*), hackberry (*Celtis occidentalis*), red elm (*Ulmus rubra*), black walnut (*Juglans nigra*), and honey locust (*Gleditsia triacanthos*). Common lower story riparian species observed were coralberry (*Symphoricarpos orbiculatus)*, rough-leaf dogwood (*Cornus drummondii*), gooseberry (*Ribes grossularia)*, poison ivy (*Toxicodendron radicans),* and false indigo (*Amorpha fruticosa*). The lower banks are covered with a variety of herbaceous species that populate the area near the bank edge and water surface. The riparian corridor was fairly wide, exceeding 180 feet from the bank, with a diverse plant community containing mature trees.

The creek was fairly sinuous with high, moderately unstable banks. The survey identified two bank types along the 528 foot survey reach. Most of the survey reach (415 feet or 79% of survey reach) was representative of bank type 1 (Photograph 1, Appendix F). This bank was composed of two layers; the top was a dark silt loam and the lower was a dense yellow-brown silty-clay loam. The lower layer appeared to be fairly resistive to erosion, because very few active signs of erosion were observed. Plant roots extended down through the entire bank profile with a moderate density of approximately 50%.

Bank type 2 was identified along the last 113 feet of the reach (21% of survey reach). In this area, the stream was cutting into a high terrace, thus increasing the bank height (Photograph 2, Appendix F). The bank materials were similar to bank type 1; however, the roots were less dense and not as deep as bank type 1 and, therefore, bank type 2 exhibited a greater potential to erode. Throughout the Banner Creek reach, the most common sign of active erosion was fallen trees. Several small woody debris jams, leaning trees, and exposed roots were consistently observed (Photograph 3, Appendix F). Table 4-4 summarizes the erosion potential of the two bank types at Survey Site 1. Figure 4-2 illustrates the proportional extent of each bank type.

Table 4-4. Site 1 BEHI Erosion Potential Summary

Bank Type	BEHI Score	BEHI Rating	d_{nb}/d_{bkf} Ratio	NBS Rating	Predicted Erosion tons/foot/year	Percent of Survey
1	28.2	Moderate	1.42	Low	0.11	79
2	33.4	High	2.05	Moderate	1.70	21
				Weighted Average	0.45	

4.4.1.2 Rosgen Analysis

Historically, the vegetation in this region consists of bluestem prairie grasses populating the uplands and cottonwood forest inhabiting the lower floodplains (Kuchler 1974). The riparian vegetation along this stream reach was fairly dense and diverse, with several large trees likely exceeding 50 years of age. The tributary is a perennial stream dominated by stormwater runoff and the tributary is classified as a first order stream (KDHE 1996). The bankfull width was between 5 and 15 feet, resulting in a Rosgen stream order/stream size of S-3 (Appendix G, Page G-2).

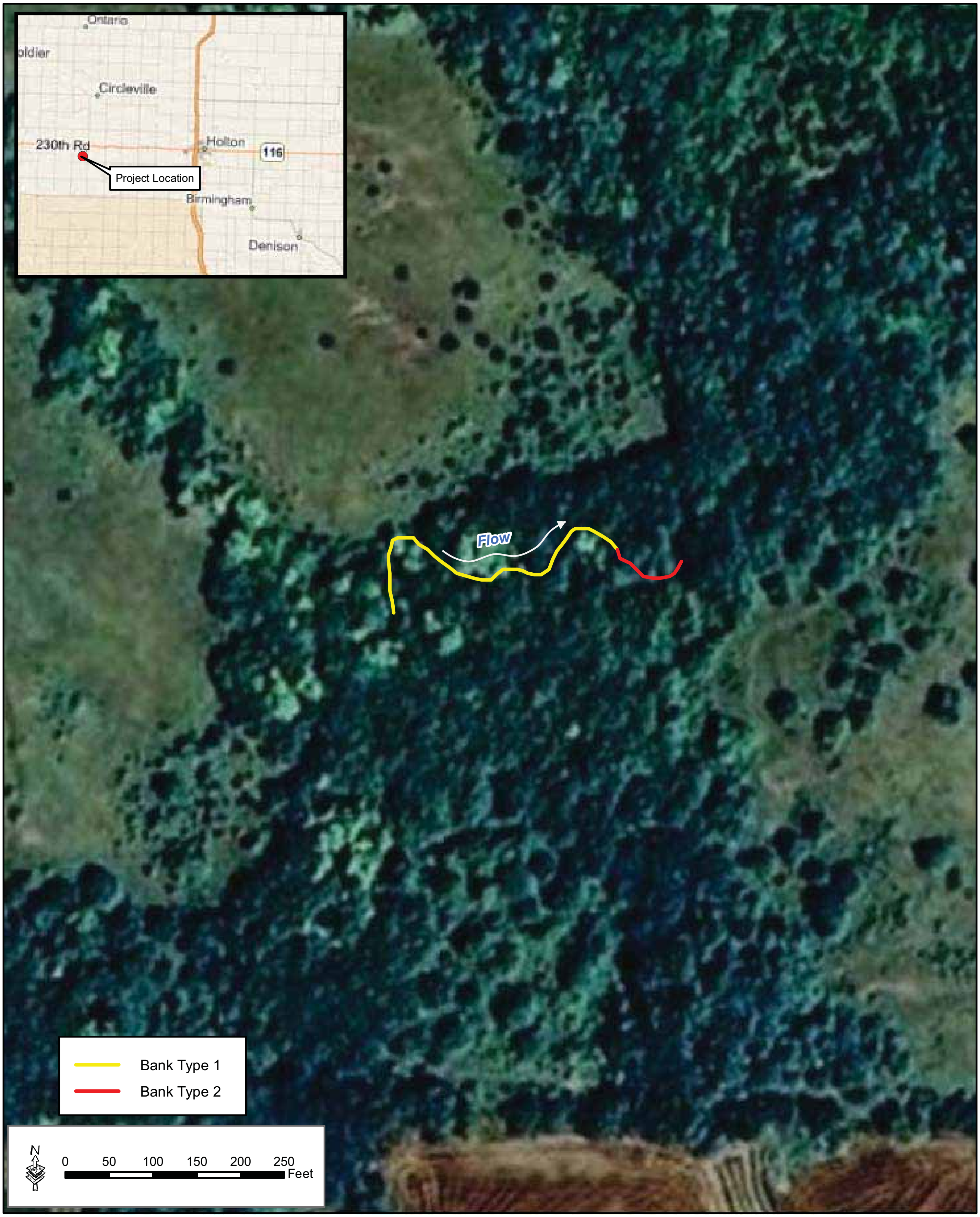

Figure 4-2: Bank Types at Banner Creek Survey Site 1

There was build-up of woody debris that caused channel blockages in the stream reach and caused the Rosgen depositional rating to be moderate (D-3) (Appendix G, page G-4). Fluvial deposits include point bars with some mid bars, indicating a Rosgen B-2 classification (Appendix G, page G-5). The width/depth ratio state was rated as moderately unstable, due to the lateral expansion of the channel which was an adjustment to streambed degradation.

Based on streambed degradation, the tributary was characterized as Stage V in the Simon Channel Evolution Sequence (Simon 1989) (see Figure 3-2). The tributary was beginning to widen and was forming narrow, floodplain benches, but the erosional processes are slow due to the vegetation and dense clay bank materials. Table 4-5 summarizes survey data by utilizing Rosgen's stream stability classifications. Details on Rosgen's stream ratings can be found in Appendix G.

Table 4-5. Summary of Rosgen Stream Stability Ratings for Tributary to Banner Creek

Stream Morphology Description	Rosgen Stream Rating	Rosgen Reference Number[1]
Stream type	B5c	See Figure 3-1
Riparian vegetation – existing species	Catalpa/Hackberry/Elm/Walnut	From Kuchler (1974)
Riparian vegetation – potential species	Cottonwood/Hackberry/Elm	From Kuchler (1974)
Flow regime	P-2	Appendix G-1: Exhibit 1
Stream order and size	S-3(1)	Appendix G-2: Exhibit 2
Meander patterns	M-3 Irregular meanders	Appendix G-3: Exhibit 3
Depositional patterns	B-2	Appendix G-4: Exhibit 4
Channel blockages	D-3	Appendix G-5: Exhibit 5
Width/Depth ratio	6.03	Appendix D-1
Width/Depth stability rating	Moderately unstable	Appendix G-6: Exhibit 6
Pfankuch channel stability rating	96- Fair	Appendix G-7: Exhibit 7
Bank – Height Ratio (BHR)	3.94	Appendix D-1
Stability rating	Deeply incised	Appendix G-8: Exhibit 8
MWR divided by MWR_{ref}	0.17	Not Applicable
Degree of confinement	Confined	Appendix G-9: Exhibit 9

1. Key to Rosgen's stream ratings is located in Appendix G.

4.4.1.3 Summary of Survey Site 1

The Research Team estimated a weighted erosion rate of 0.45 ton/feet/year, which is high when compared to the other sub-watershed surveys; however, streambed degradation at Survey Site 1 has decreased the streambank stability. The creek was fairly sinuous with high, moderately unstable banks. Evidence of Head-cutting or knickpoints was not observed within the survey reach; however, several knickpoints in two small tributaries that join Banner Creek were observed. It is the Research Team's opinion that the weighted erosion rate overestimates the actual erosion due to the more erosion-resistive clay banks. The monitoring sites from the Black Vermillion River watershed consisted of more silt loams and silty-clay loams that typically have a slightly higher erosion potential than dense clay layers (Dr. Timothy Keane 2010).

4.4.2 Survey Site 2: Tributary to Clear Creek

4.4.2.1 Bank Erodibility Hazard Index

The tributary to Clear Creek is located within a wooded riparian corridor along the entire reach. The wooded corridor on the left bank was wide, greater than 150 feet; however, the right bank corridor was fairly narrow, less than 25 feet. For most of the survey reach, the wooded riparian species are typical for the area and exhibit good species and age diversity. Common tree species were observed which included black walnut, bitternut hickory (*Carya cordiformis*), red elm, honey locust, catalpa, mulberry (*Morus rubra*), osage orange (*Maclura pomifera*), black willow (*Salix nigra*), cottonwood, green ash (*Fraxinus pennsylvanica*), and gooseberry. There was a variety of herbaceous vegetation along the lower banks. This vegetation was fairly dense, except in areas heavily grazed by cattle. Toward the lower end of the survey reach, honey locust and osage orange become the dominant species.

Only one consistent bank type was observed at Survey Site 2. The bank condition consisted of clay loam materials, and the slope of the streambank was moderately steep (Photograph 4, Appendix F). The riparian vegetation provided moderate rooting density and depth that extended down through the entire bank profile. The streambank height was typically two times the bankfull height increasing the bank erodibility. Exposed roots and trees beginning to lean into the stream channel were observed. The NBS rating was high due to a high d_{nb}/d_{bkf} ratio. The predicted erosion loss was derived from monitoring data from the Black Vermillion River watershed. Table 4-6 summarizes the erosion potential for the bank type. Figure 4-3 presents the stream reach at Survey Site 2, which consists of one bank type.

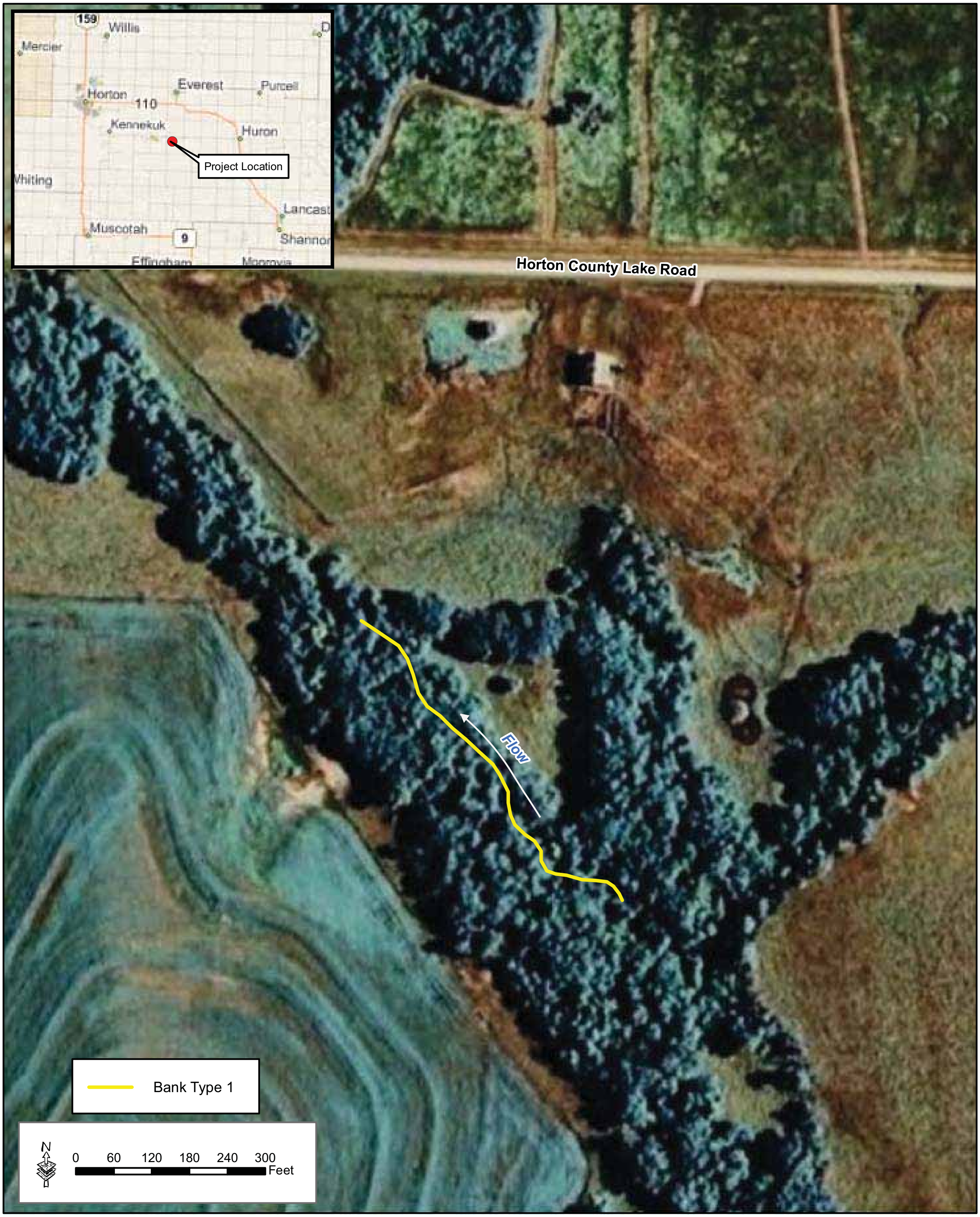

Figure 4-3: Bank Types at Tributary to Clear Creek Survey Site 2

Table 4-6. Site 2 BEHI Erosion Potential Summary

Bank Type	BEHI Score	BEHI Rating	d_{nb}/d_{bkf} Ratio	NBS Rating	Predicted Erosion tons/foot/year	Percent of Survey
1	21.8	Moderate	1.85	High	0.26	100

4.4.2.2 Rosgen Analysis

The overall riparian corridor was wide along the left bank, but fairly narrow on the right bank. Honey locust and osage orange were the dominant species, which represented a departure from the historic oak-hickory mosaic (Kuchler 1974). This tributary flow regime was dominated by stormwater runoff and was classified as a second order stream (KDHE 1996). Side bars (B-4) were observed throughout the survey reach, indicating an excess of sediment (Appendix G, page G-4). Extensive woody debris jams were observed along the stream reach, with many of the jams extending across the entire channel (Photograph 5, Appendix F). The width/depth ratio state was moderately unstable due to channelization on site and downstream. At the survey site, it appeared that a meander in the stream had been straightened, triggering degradation. The channel was slightly incised and severely confined. It was evident that the tributary width was expanding due to both degradation and aggradation processes. A small knickpoint was found in the upstream portion of the survey reach (Photograph 6, Appendix F).

The survey reach exemplifies both a Stage IV and a Stage V channel (see Figure 3-2). The stream reach at the survey site was also influenced by four upstream impoundments which modify the flow of stormwater over 85% of the 1.82-square-mile drainage area. These impoundments have reduced the runoff volumes and, thus, the bankfull dimensions and discharge rates are less than bankfull parameters derived from regional curves. Table 4-7 summarizes survey data by utilizing Rosgen's stream stability classifications.

4.4.2.3 Summary of Survey Site 2

The Research Team estimated a weighted erosion rate of 0.26 ton/feet/year, which is about average when compared to the other two sub-watershed surveys. This survey reach was impacted by past channelization, upstream stormwater impoundments, and cattle access to the channel. Side bars were observed throughout the survey reach, indicating an excess of sediment. Extensive woody debris jams were observed along the stream reach with many of the jams extending across the entire channel.

Table 4-7. Summary of Rosgen Stream Stability Ratings for Tributary to Clear Creek

Stream Morphology Description	Rosgen Stream Rating	Rosgen Reference Number[1]
Stream type	E6	See Figure 3-1
Riparian vegetation – existing species	Osage orange/honey locust/black walnut/bitternut hickory	From Kuchler (1974)
Riparian vegetation – potential species	Oak/hickory/walnut	From Kuchler (1974)
Flow regime	P-2	Appendix G-1: Exhibit 1
Stream order and size	S-4(2)	Appendix G-2: Exhibit 2
Meander patterns	Straightened Channel	Appendix G-3: Exhibit 3
Depositional patterns	B-4-Side Bars	Appendix G-4: Exhibit 4
Channel blockages	D-5-Extensive	Appendix G-5: Exhibit 5
Width/Depth ratio	7.05	Appendix D-2
Width/Depth stability rating	Moderately unstable	Appendix G-6: Exhibit 6
Pfankuch channel stability rating	95-Poor	Appendix G-7: Exhibit 7
Bank – Height Ratio (BHR)	1.3	Appendix D-2
Stability rating	Slightly incised	Appendix G-8: Exhibit 8
MWR divided by MWR_{ref}	0.08	Not applicable
Degree of confinement	Severely confined	Appendix G-9: Exhibit 9

1. Key to Rosgen's stream ratings is located in Appendix G.

4.4.3 Survey Site 3: Tributary to Centralia Lake

4.4.3.1 Bank Erodibility Hazard Index

The tributary to Centralia Lake is located in a pasture setting with scattered trees. The dominant vegetation was smooth brome (*Bromus inermis*), false indigo, and green ash saplings. There are also mature cottonwood and black willow located on a relic floodplain (current low terrace). Along the water fringe, a variety of sedges (*Carex* spp.) was observed.

The survey reach was divided into three bank types. Bank type 1 was the dominant bank condition, representing 65% of the survey reach. The stream banks were steep, but densely vegetated with smooth brome, false indigo, and saplings (Photo 7, Appendix F). At least one bank was connected to a narrow floodplain, while the other bank was connected to the low terrace elevation. There were locations where the stream was eroding the bank toe and has caused the bank to slump. Even after bank slumping, the vegetation was still well established.

Bank type 2 occupies a short segment (7% of survey) where the bank was unstable. The bank surface was void of vegetation except for a few scattered trees. The root density and depth along bank type 2 was low due to the absence of vegetative cover (Photograph 8, Appendix F).

Some vegetation was present along the bank toe due to slumping material providing some surface protection.

The remaining 28% of the survey reach was bank type 3. The segment was characterized by a densely vegetated V-shaped channel (Photograph 9, Appendix F). The banks showed signs of slumping, but the vegetation remains well established. There was no floodplain bench in this segment, creating a very confined channel. Table 4-8 summarizes Survey Site 3 erosion potential. Figure 4-4 presents the three bank types present at Survey Site 3.

Table 4-8. Site 3 BEHI Erosion Potential Summary

Bank Type	BEHI Score	BEHI Rating	d_{nb}/d_{bkf} Ratio	NBS Rating	Predicted Erosion tons/foot/year	Percent of Survey
1	14.4	Low	1.52	Moderate	0.00	65
2	28.9	Moderate	1.36	Low	0.65	7
3	20.3	Moderate	1.67	Moderate	0.00	28
Weighted Average					0.05	

4.4.3.2 Rosgen Analysis

The riparian corridor was a cool-season pasture. In the past, the vegetative community would have consisted of bluestem prairie (Kuchler 1974). A relic stream channel was found adjacent to the existing stream reach, which is depicted in Figure 4-4. The relic channel area contained cottonwood-willow community that was slowly being replaced by osage orange and green ash. Stormwater runoff contributes most of the water flow to the tributary, which is characteristic of a first-order stream (KDHE 2008a). The stream reach has been straightened and there are no consistent meander patterns or depositional features along most of the survey area. The channelization has created a narrow, incised channel that was starting the Simon Stage V evolution sequence (see Figure 3-2).

To gain further insight on relic channel dimensions, a channel cross section was surveyed (Cross Section 5, Appendix B). The old channel bottom has likely filled, but the bankfull cross section area was similar to the active channel. The width/depth ratio was larger (11.54) than the active channel (5.12) suggesting the present stream channel will continue to evolve. Finally, a knickpoint on an east-flowing tributary was observed (Photograph 10, Appendix F) and the

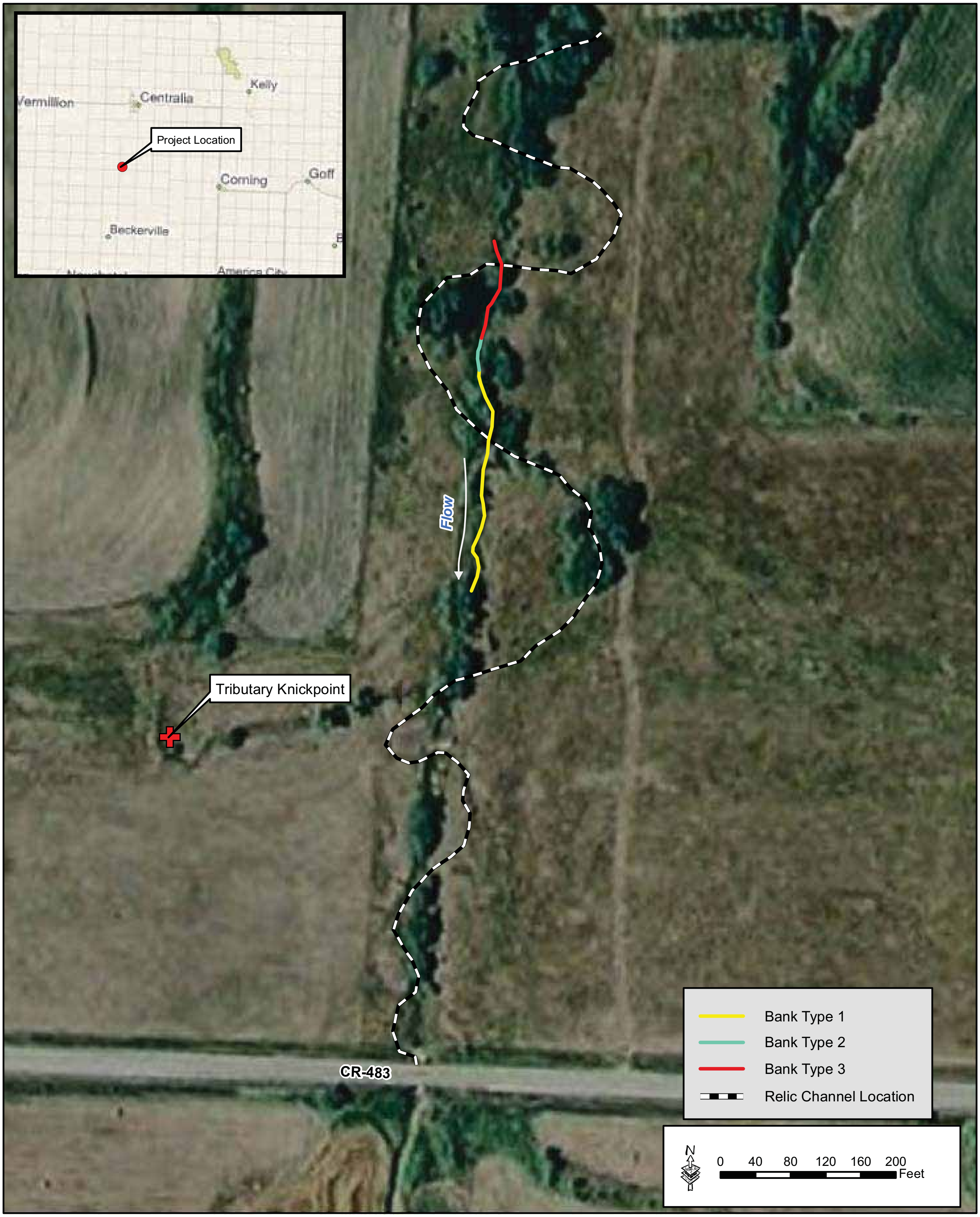

Figure 4-4: Bank Types at Tributary to Centralia Lake Survey Site 3

location is marked on Figure 4-4. Table 4-9 summarizes the survey data utilizing Rosgen's stability indices.

Table 4-9. Summary of Rosgen Stream Stability Ratings for Tributary to Centralia Lake – Tuttle Creek Watershed

Stream Morphology Description	Rosgen Stream Rating	Rosgen Reference Number[1]
Stream type	E6	See Figure 3-1
Riparian vegetation – existing species	Cool-season grass	From Kuchler (1974)
Riparian vegetation – potential species	Bluestem prairie	From Kuchler (1974)
Flow regime	P-2	Appendix G-1: Exhibit 1
Stream order and size	S-4(1)	Appendix G-2: Exhibit 2
Meander patterns	Not applicable	Appendix G-3: Exhibit 3
Depositional patterns	Not applicable	Appendix G-4: Exhibit 4
Channel blockages	D-3	Appendix G-5: Exhibit 5
Width/Depth ratio	5.12	Appendix D-3
Width/Depth stability rating	Unstable	Appendix G-6: Exhibit 6
Pfankuch channel stability rating	99-Poor	Appendix G-7: Exhibit 7
Bank – Height Ratio (BHR)	1.32	Appendix D-3
Stability rating	Moderately Incised	Appendix G-8: Exhibit 8
MWR divided by MWR_{ref}	0.09	Not applicable
Degree of confinement	Severely Confined	Appendix G-9: Exhibit 9

[1] Key to Rosgen's stream ratings is located in Appendix G.

4.4.3.3 Summary of Survey Site 3

The Research Team estimated a weighted erosion rate of 0.05 ton/foot/year. This is the lowest erosion rate of all the surveys conducted in the study. However, several disturbances on the stream reach, which included channelization and cattle access, were documented in this reach. The segment was characterized by a densely vegetated V-shaped channel. The banks show signs of slumping; however, the vegetation remains well established. The channel form was not stable and will continue to evolve, but at a slow rate.

4.4.4 Survey Site 4: Delaware River at USGS Muscotah Gauge

4.4.4.1 Bank Erodibility Hazard Index

Land adjacent to the survey site contained a narrow wooded corridor with row crop agriculture on both sides. The dominant woody species observed on the upper banks were cottonwood, red elm, silver maple (*Acer saccharinum*), honey locust, green ash, and buckeye (*Aesculus glabra*), while black willow and box elder (*Acer negundo*) inhabited the lower bank.

The survey reach was divided into three bank types. Bank type 1 occupies the first 474 feet (14% of survey). This part of the river was straight with highly vegetated banks and showed no signs of active erosion (Photograph 11, Appendix F).

Downstream, however, bank conditions quickly changed to bank type 2 where the river cuts into the left bank. Bank type 2 had tall, steep banks, consisting of silt loams with little surface protection (Photograph 12, Appendix F). Saplings at the top-of-bank produced some rooting depth, but the density was fairly low. The next two meander bends exhibited the same eroding bank conditions. Bank type 2 constituted 60% of the survey.

Bank type 3, was located along two meanders (26% of survey) that had a more established riparian corridor. The banks were more gently sloping and supported a thick stand of willows on the lower bank (Photograph 13, Appendix F). Table 4-10 summarizes the erosion potential of Survey Site 4. Figure 4-5 presents the location of the three bank types present at Survey Site 4.

Table 4-10. Site 4 BEHI Erosion Potential Summary

Bank Type	BEHI Score	BEHI Rating	d_{nb}/d_{bkf} Ratio	NBS Rating	Predicted Erosion tons/ft/year	Percent of Survey
1	17.1	Low	1.28	Low	0.00	14
2	31.8	High	1.41	Low	3.19*	60
3	18.0	Moderate	1.35	Low	0.10	26
Weighted Average					1.77	

*Erosion rate delineated from aerial photographs, 1991 and 2006.

4.4.4.2 Rosgen Analysis

The historic bluestem prairie formerly characteristic of the region has been converted to row crop agriculture throughout the Delaware River valley. The existing wooded riparian corridor still resembled the historic lowland cottonwood vegetation described in Kuchler (1974). The river flow regime was influenced by stormwater runoff and was classified as a fifth order stream (KDHE 1996). Large point bars with some mid and side bars were observed throughout the reach (Photograph 14, Appendix F). E-stream types (see Figure 3-1) are hydraulically efficient channel forms and maintain a high sediment transport capacity (Rosgen 1996). The large bars suggest that the river was not stable because it cannot transport all the material delivered to the stream reach. Small hangs of woody debris occasionally blocked the flow of the river.

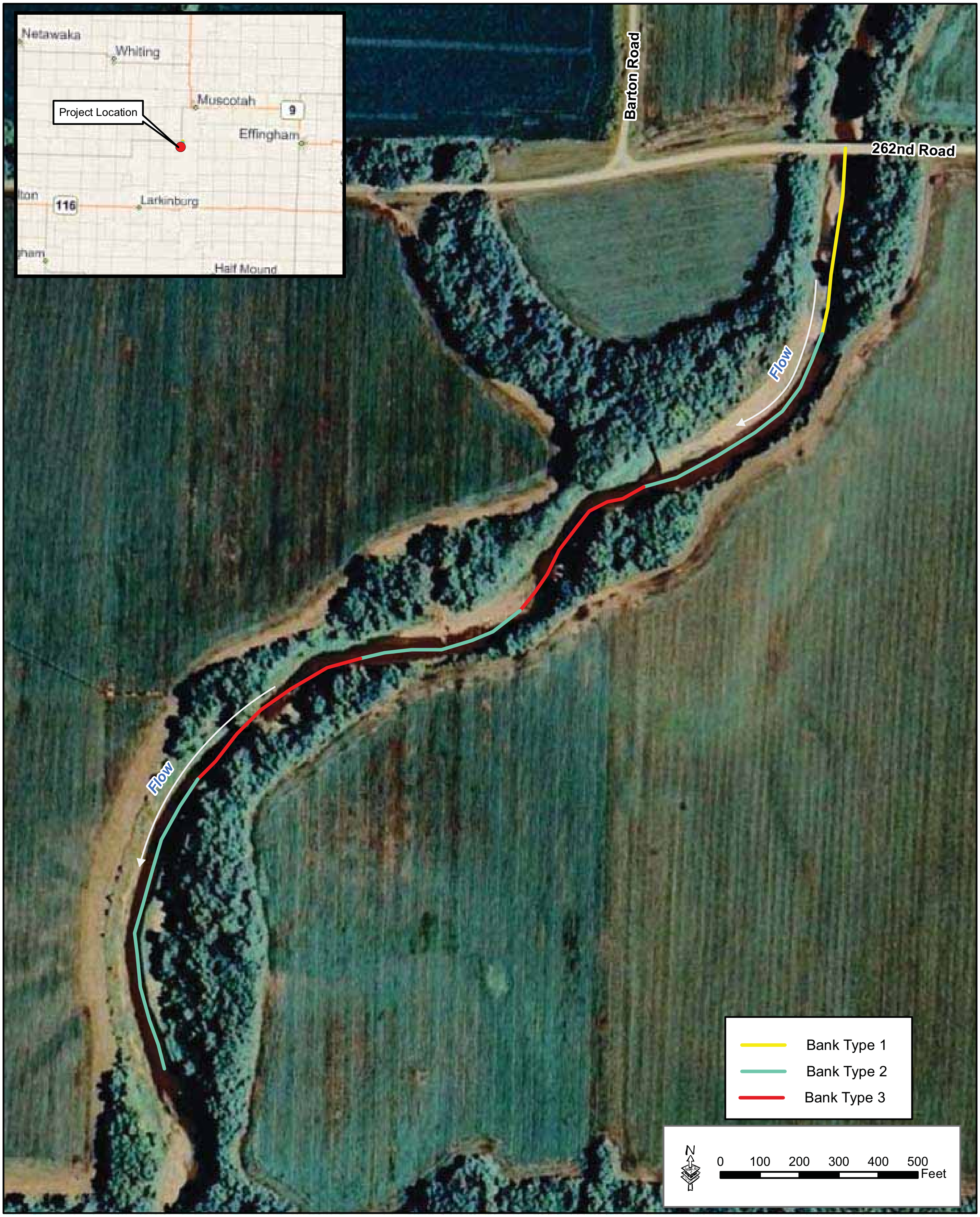

Figure 4-5: Bank Types at Delaware River at USGS Muscotah Gauge Survey Site 4

The Delaware River has been channelized extensively as indicated by the relic channel pattern delineation displayed in historical aerial photographs. Figure 4-6 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. The stream reach shown in Figure 4-6 was once 12.38 miles long, but today it is only 4.60 miles long. The natural tendency for the Delaware River is to re-establish a sinuous river course.

The channel was deeply incised and the width/depth ratio was moderately unstable. Due to extensive channelization, the river was laterally confined. The channel was classified as Stage V due to the presence of large bars and channel aggradations (see Figure 3-2). Table 4-11 summarizes survey data by utilizing Rosgen's stream stability indices. Figure 4-5, presented previously, shows the location of Survey Site 4.

Table 4-11. Summary of Rosgen Stream Stability Ratings for Delaware River at Muscotah Gauge – Delaware River Watershed

Stream Morphology Description	Rosgen Stream Rating	Rosgen Reference Number[1]
Stream type	E5	See Figure 3-1
Riparian vegetation – existing species	Cottonwood/Elm/Willow	From Kuchler (1974)
Riparian vegetation – potential species	Cottonwood/Hackberry/Oak	From Kuchler (1974)
Flow regime	P-2	Appendix G-1: Exhibit 1
Stream order and size	S-8(5)	Appendix G-2: Exhibit 2
Meander patterns	M-3	Appendix G-3: Exhibit 3
Depositional patterns	B-2	Appendix G-4: Exhibit 4
Channel blockages	D-2	Appendix G-5: Exhibit 5
Width/Depth ratio	10.82	Appendix D-3
Width/Depth stability rating	Moderately Unstable	Appendix G-6: Exhibit 6
Pfankuch channel stability rating	110-Fair	Appendix G-7: Exhibit 7
Bank – Height Ratio (BHR)	1.51	Appendix D-3
Stability rating	Deeply Incised	Appendix G-8: Exhibit 8
MWR divided by MWR_{ref}	0.24	Not applicable
Degree of confinement	Confined	Appendix G-9: Exhibit 9

1. Key to Rosgen's stream ratings is located in Appendix G.

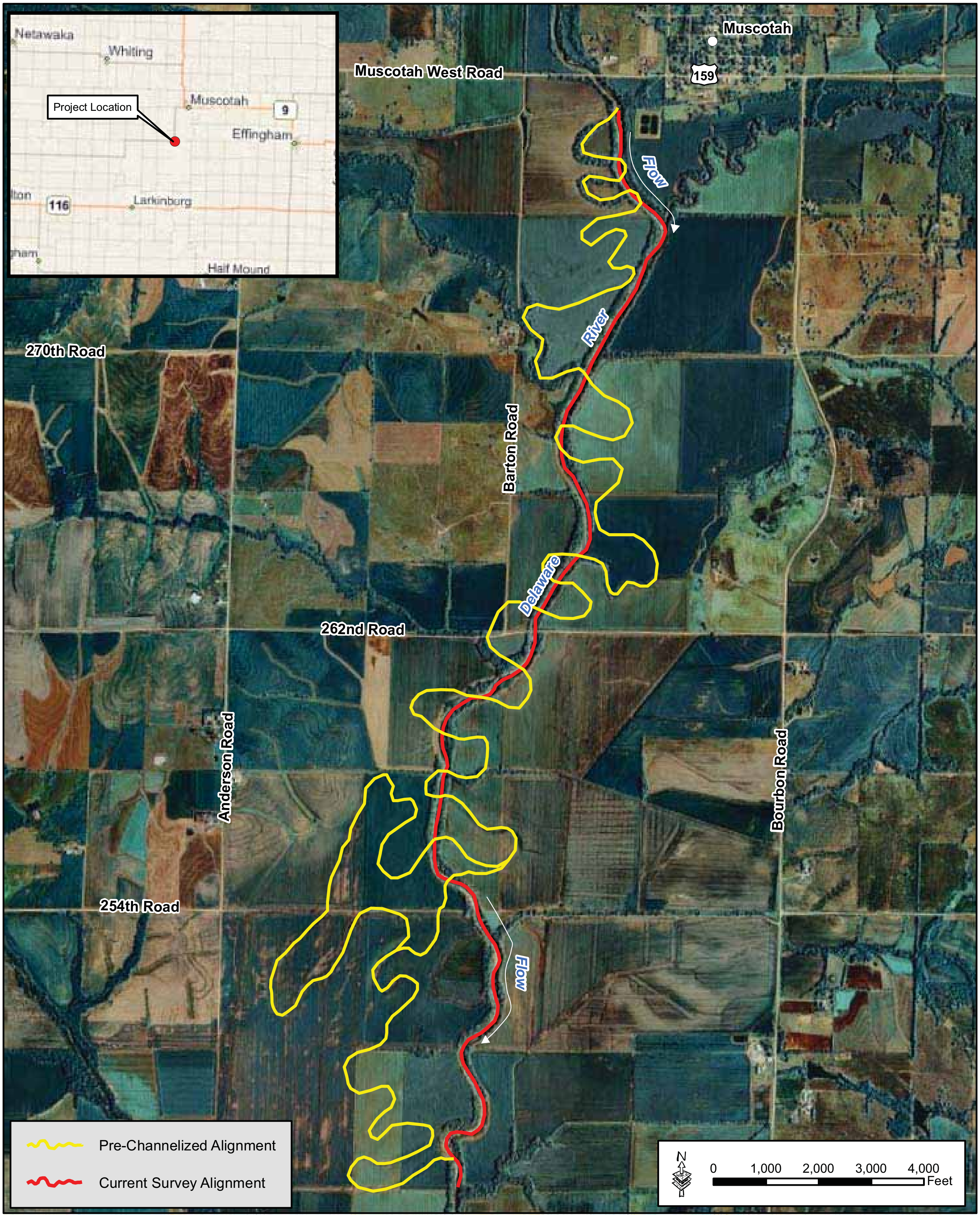

Figure 4-6: Channelization of Delaware River at USGS Muscotah Gauge

4.4.4.3 Summary of Survey Site 4

Aerial photography from 1991 and 2006 was used to delineate the area lost due to streambank erosion for bank type 2, and determined that the bank type was experiencing an erosion rate of 3.19 tons/foot/year. The Research Team was not able to delineate any sediment loss from the other two bank types, and it appeared that these segments have a very low erosion rate. RIVERMorph was used to input the streambank erosion monitoring data from the Black Vermillion River watershed, and results indicated that very little to no erosion occurred in bank types 1 and 3. Based on the erosion surface area and the surveyed bank heights, a weighted erosion rate of 1.77 tons/foot/year was calculated. However, the losses for bank types 1 and 3 were zero, which indicates that this part of the stream was receiving sediment from upstream sources or the erosion rate was very slow.

4.4.5 Survey Site 5: Delaware River

4.4.5.1 Bank Erodibility Hazard Index

The width of the riparian corridor significantly influenced the erosion rate of stream banks along the Delaware River near the 254 Road survey site. The riparian corridor was narrow and row crop agriculture was located on both sides. Dominant, upper-bank woody species included cottonwood, red elm, green ash, silver maple, hackberry, red mulberry, bur oak (*Quercus macrocarpa*), and buckeye. Black willow was the dominant low-bank woody species. Soils at the survey site were predominantly silt loams.

Four bank types were identified. Bank type 1 was located along the first 16% of the survey. The narrow wooded corridor provided good rooting depth, but the root density was low. The reach showed active slumping along this segment with continuous exposed roots (Photograph 15, Appendix F). Bank type 1 was located on a slightly curved stream reach and experienced erosion on the left bank.

Bank type 2 was a short, straight segment (8% of survey) with gently sloping, well-vegetated banks. Willows in the lower banks provided good rooting depth and density plus surface protection (Photograph 16, Appendix F). This segment was fairly stable and sediments tended to be deposited along the stream reach.

Bank type 3 was the most prevalent (45% of survey) and unstable bank condition. This bank condition was located along two left bank meanders. The banks are steep with green ash saplings at top-of-bank (Photograph 17, Appendix F). Water seepage from a spring at the lower bank also created bank instability (Photograph 18, Appendix F). The recently fallen trees caused the banks to slump along these meanders. There were two bank type 3 stream reaches located in the middle of and at the end of the survey site, which experienced the greatest erosion rates along this survey site.

Bank type 4 encompasses 31% of the survey and is located between the two bank type 3 reaches. Bank type 4 was similar to bank type 1, but with a more gentle slope. The lesser slope supports a greater root density and there was more soil surface protection (Photograph 19, Appendix F). Some bank toe erosion was observed, but the erosion point was small and the rate of erosion appeared slow. Table 4-12 summarizes the bank types and Figure 4-7 presents the location of the bank types along the survey reach.

Table 4-12. Site 5 BEHI Erosion Potential Summary

Bank Type	BEHI Score	BEHI Rating	d_{nb}/d_{bkf} Ratio	NBS Rating	Predicted Erosion tons/ft/year	Percent of Survey
1	27.6	Moderate	1.32	Low	1.65	16
2	17.6	Low	1.36	Low	0.00	8
3	27.8	Moderate	1.53	Moderate	2.02*	45
4	18.9	Low	1.44	Low	0.00	31
				Weighted Average	1.18	

*Erosion rate delineated from aerial photographs, 1991 and 2006.

4.4.5.2 Rosgen Analysis

The vegetative species inhabiting the riparian corridor are native to the region. The width of the riparian buffer was not consistent and becomes fairly narrow in places. The river is a fifth order stream and the Rosgen stream size classification is an S-8 (100 to 150 feet bankfull width) (Appendix G, Page G-2). Regular meanders (M-1) with point bars and a few mid-channel bars were observed, as well as moderate blockages from fallen trees (Appendix G, Page G-3). The channel was deeply incised; however, width/depth ratio was stable. Due to past channelization, the stream reach was moderately confined and was in a Stage V evolution phase (Figure 3-2).

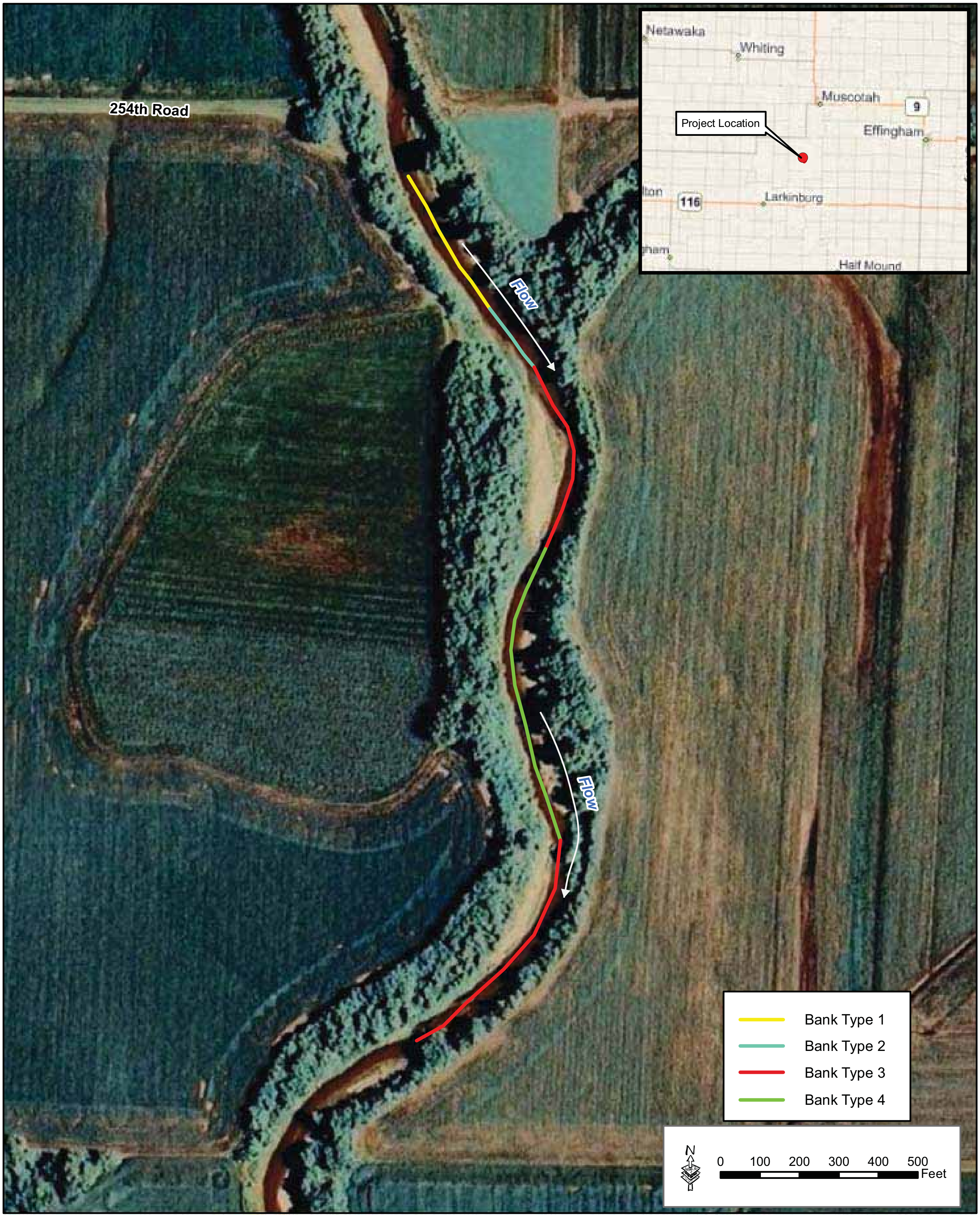

Figure 4-7: Bank Types at Delaware River at Highway 254 Bridge Survey Site 5

Table 4-13 summarizes survey data by utilizing Rosgen's stream stability classifications. Details on Rosgen's stream ratings can be found in Appendix G.

Table 4-13. Summary of Rosgen Stream Stability Ratings for Delaware River at Highway 254 Bridge

Stream Morphology Description	Rosgen Stream Rating	Rosgen Reference Number[1]
Stream type	C5c-	See Figure 3-1
Riparian vegetation – existing species	Cottonwood/Elm/Willow	From Kuchler (1974)
Riparian vegetation – potential species	Cottonwood/Hackberry/Oak	From Kuchler (1974)
Flow regime	P-2	Appendix G-1: Exhibit 1
Stream order and size	S-8(5)	Appendix G-2: Exhibit 2
Meander patterns	M1	Appendix G-3: Exhibit 3
Depositional patterns	2	Appendix G-4: Exhibit 4
Channel blockages	D3	Appendix G-5: Exhibit 5
Width/Depth ratio	0.85	Appendix D-3
Width/Depth stability rating	Stable	Appendix G-6: Exhibit 6
Pfankuch channel stability rating	109-Fair	Appendix G-7: Exhibit 7
Bank – Height Ratio (BHR)	1.83	Appendix D-3
Stability rating	Deeply incised	Appendix G-8: Exhibit 8
MWR divided by MWR_{ref}	0.58	Not applicable
Degree of confinement	Moderately Confined	Appendix G-9: Exhibit 9

1. Key to Rosgen's stream ratings is located in Appendix G.

4.4.5.3 Summary of Survey Site 5

The 1991 and 2006 aerial photography provided a basis to determine erosion loss for bank type 3. The weighted average erosion rate for the two meander bends was 2.02 tons/foot/year. The stream banks were steep and unstable along the river bends, and slumping was observed along these meanders with recently fallen trees. For bank types 1, 2, and 4, RIVERMorph was calibrated using streambank erosion monitoring data from the Black Vermillion River watershed, and results showed that very little to no erosion occurred in bank types 2 and 4. The lack of erosion for bank types 2 and 4 indicates that this part of the stream was receiving sediment from upstream sources or the erosion loss was very low.

4.4.6 Survey Site 6: Delaware River at Muddy Creek Confluence

4.4.6.1 Bank Erodibility Hazard Index

The riparian corridor at the Muddy Creek confluence was found to be similar to Survey Sites 4 and 5, which possessed a narrow, fragmented riparian buffer zone. The dominant upper-bank species included cottonwood, silver maple, green ash, and black walnut. Black willow was the dominant low bank vegetation. The width of the riparian buffer varied significantly throughout the survey reach. The narrow widths of the riparian zone significantly affected the bank erosion rates. Five distinct bank types were identified along the surveyed stream reach.

Bank type 1 was a straight section that was 401 feet long (10% of survey). The banks were gently sloping and well vegetated with silver maple and black willow. The river was flowing over bedrock and the segment has a low erosion potential (Photograph 20, Appendix F).

Bank type 2 was a highly erosive bank with little to no vegetation (12% of survey). The bank was high and actively slumping (Photograph 21, Appendix F). Gravel lenses and seeps were found along the lower bank, increasing the erosion potential (Photograph 22, Appendix F).

Bank Type 3 was the prevailing bank condition (45% of survey). There was a narrow riparian corridor that provides moderate erosion resistance. The banks were fairly steep and there were signs of active bank toe erosion and slumping. However, the erosion potential for bank type 3 was low due to the presence of a bankfull bench (Photograph 23, Appendix F). The bench provided some energy dissipation by allowing high flow events to spread into the riparian corridor.

Bank type 4 was a short segment (9% of survey) that consists of a high, steep bank. Bank type 4 was a bend in the river just downstream the muddy creek confluence where the riparian corridor narrows and bank vegetation was sparse, leading to poor root density (Photograph 24, Appendix F).

Bank type 5 was located along the remaining 979 feet of the survey site (24% of reach). The bank was tall, fairly unstable, and subject to significant gulley erosion. There was a stand of black willows growing along the bank toe that provided some protection to bank soil erosion; however, during high flow events, the river flows behind the willows creating a small island (Photograph 25, Appendix F). The willow stand will eventually dislodge during a severe weather event. Once that occurs, bank type 5 will have a much higher erosion potential (Photograph 26, Appendix F). In addition, several gullies were observed headcutting into the adjacent cropland and are a major source of sediment within the survey reach (Photographs 27 and 28, Appendix F). Table 4-14 summarizes the bank types and Figure 4-8 presents the location of the bank types along the survey reach.

Table 4-14. Site 6 BEHI Erosion Potential Summary

Bank Type	BEHI Score	BEHI Rating	d_{nb}/d_{bkf} Ratio	NBS Rating	Predicted Erosion tons/ft/year	Percent of Survey
1	14.4	Low	1.48	Low	0.00	10
2	39.4	High	1.53	Moderate	5.46*	12
3	14.9	Low	1.37	Low	0.27	45
4	28.3	Moderate	1.41	Low	1.83*	9
5	33.8	High	1.55	Moderate	4.87*	24
				Weighted Average	2.11	

*Erosion rate delineated from aerial photographs, 1991 and 2006.

4.4.6.2 Rosgen Analysis

The riparian vegetation was similar to the vegetation historically found in the area, but the corridor width was variable. The river was determined to be a fourth order stream above the Muddy Creek confluence and becomes a fifth order stream at the confluence (KDHE 1996). The meander pattern most resembles regular meanders, but the pattern was inconsistent due to past channelization. There are large point bars with a few mid-channel bars. The width/depth ratio was moderately unstable, and the channel was slightly incised. The presence of a bankfull bench reduced the degree of channel incision. This bench was not wide, but helps to dissipate energy during high flow events. Past channelization has created a confined channel and the survey results indicate that the stream reach is Stage V in the evolution sequence (Figure 3-2). Table 4-15 summarizes the survey data by utilizing Rosgen's stream stability classifications.

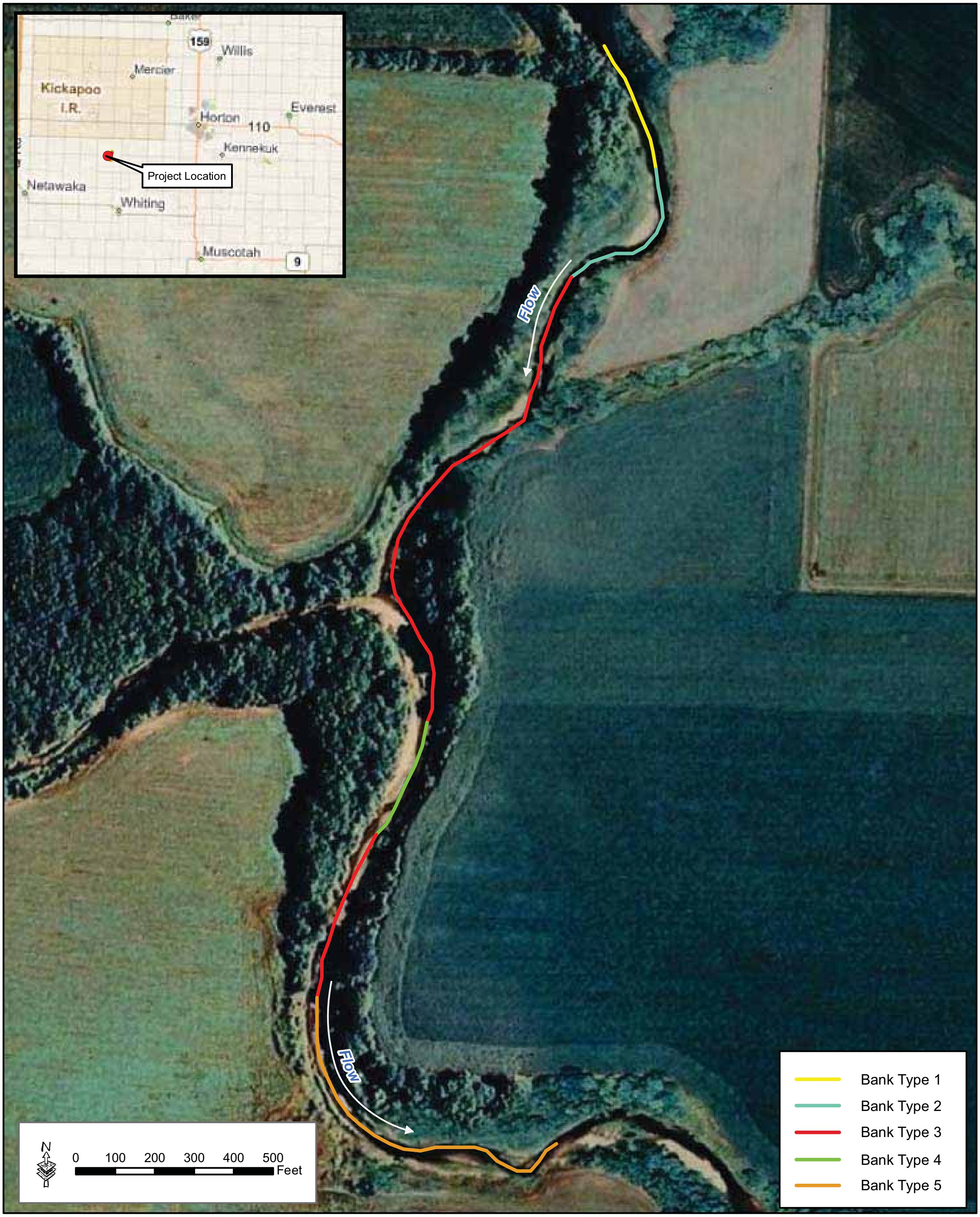

Figure 4-8: Bank Types at Delaware River at Muddy Creek Confluence Survey Site 6

Table 4-15. Summary of Rosgen Stream Stability Ratings for Delaware River at the Muddy Creek Confluence

Stream Morphology Description	Rosgen Stream Rating	Rosgen Reference Number (1)
Stream type	E5/1	See Figure 3-1
Riparian vegetation – existing species	Cottonwood/Maple/Willow	From Kuchler (1974)
Riparian vegetation – potential species	Cottonwood/Elm/Oak	From Kuchler (1974)
Flow regime	P-2	Appendix G-1: Exhibit 1
Stream order and size	S-7(4) – S-8(5)	Appendix G-2: Exhibit 2
Meander patterns	M-1	Appendix G-3: Exhibit 3
Depositional patterns	B-2	Appendix G-4: Exhibit 4
Channel blockages	D-2	Appendix G-5: Exhibit 5
Width/Depth ratio	0.65	Appendix D-3
Width/Depth stability rating	Moderate Unstable	Appendix G-6: Exhibit 6
Pfankuch channel stability rating	112-Poor	Appendix G-7: Exhibit 7
Bank – Height Ratio (BHR)	1.17	Appendix D-3
Stability rating	Slightly Incised	Appendix G-8: Exhibit 8
MWR divided by MWR_{ref}	0.14	Not applicable
Degree of confinement	Confined	Appendix G-9: Exhibit 9

1. Key to Rosgen's stream ratings is located in Appendix G.

4.4.6.3 Summary of Survey Site 6

Erosion rates were delineated using 1991 and 2006 aerial photographs for bank types 2, 4, and 5. Bank type 2 was actively eroding at an annual erosion loss of 5.46 tons/foot/year. Bank type 4 erosion loss was estimated at 1.83 tons/foot/year. Finally, annual erosion loss for bank type 5 was estimated to be of 4.87 tons/foot/year. The banks were fairly steep and there were signs of active bank toe erosion and slumping. RIVERMorph was employed to determine the erosion rates of bank types 1 and 3. The bank types were calibrated using streambank erosion monitoring data from the Black Vermillion River watershed, and results showed that very little to no erosion occurred in the segments. The RIVERMorph produced a result of zero for bank type 1, which indicates that this part of the stream was receiving sediment from upstream sources or the erosion rate was very low.

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SECTION 5.0
COST ESTIMATES AND BMP RECOMMENDATIONS

5.0 COST ESTIMATES AND BMP RECOMMENDATIONS

It was observed that the small stream reaches at Survey Sites 1, 2, and 3, exhibited a healthy stand of adult trees indigenous to the region, but the riparian corridors were fragmented with some areas extending outward more than two bankfull widths from the edge of streams. When BMP data were inserted into the BANCS model, the erosion rate did not reduce significantly. Therefore, it is recommended that no BMPS be installed at Survey Sites 1, 2, and 3, with the exception of riparian fencing. Consequently, the following discussions focus on the three survey reaches along the main stem of the Delaware River.

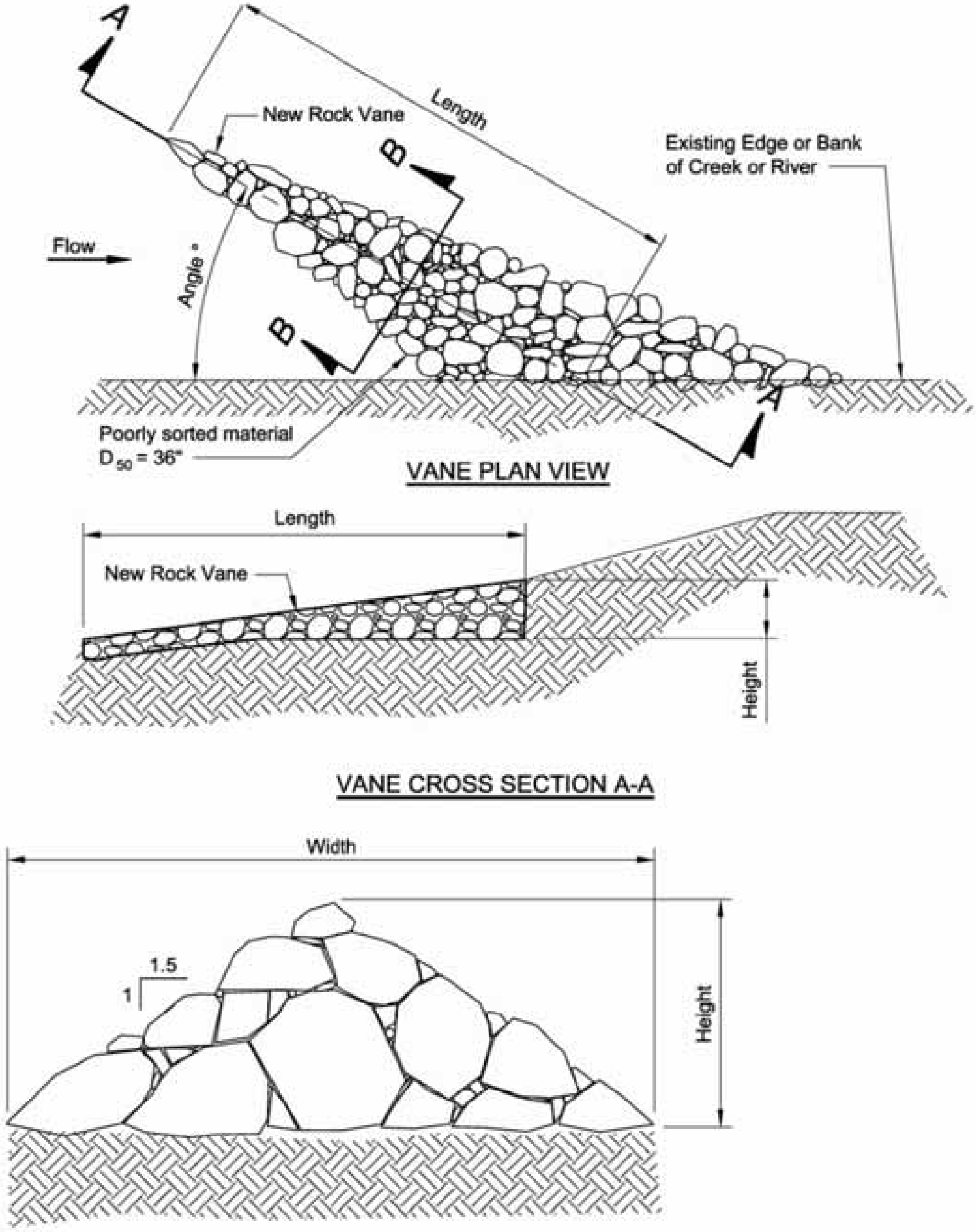
5.1 BMP Recommendations for Remaining Survey Sites

The field survey indicate that the bank types that were experiencing the greatest erosion rates were banks along outside meander bends with narrow or non-existent riparian corridors. These reaches have steep slopes and little surface protection and will continue to move laterally unless proper BMPs are implemented. These reaches have steep slopes due to accelerated water velocities created by straightened channels immediately upstream.

5.1.1 Rock Vanes, Rock Chutes, and Bank Toe Protection

Several structural BMPs were evaluated and recommended for installation along Survey Sites 4, 5, and 6. Rock vanes, recommended to address the problem of accelerated streambank erosion, are rock structures designed to reduce water velocities and re-direct flow away from the near bank region (Figure 5-1). They are the most effective stabilization structure for channels with low width/depth ratios.

In addition, longitudinal peaked stone toe protection (LPSTP) is recommended on streams with similar dimensions (Figure 5-2). This method provides continuous bank toe reinforcement. It is recommended that any excavated material be removed from the site. The channel already has a low width/depth ratio and filling the channel with excavated material will decrease the meander width, which is already too low.

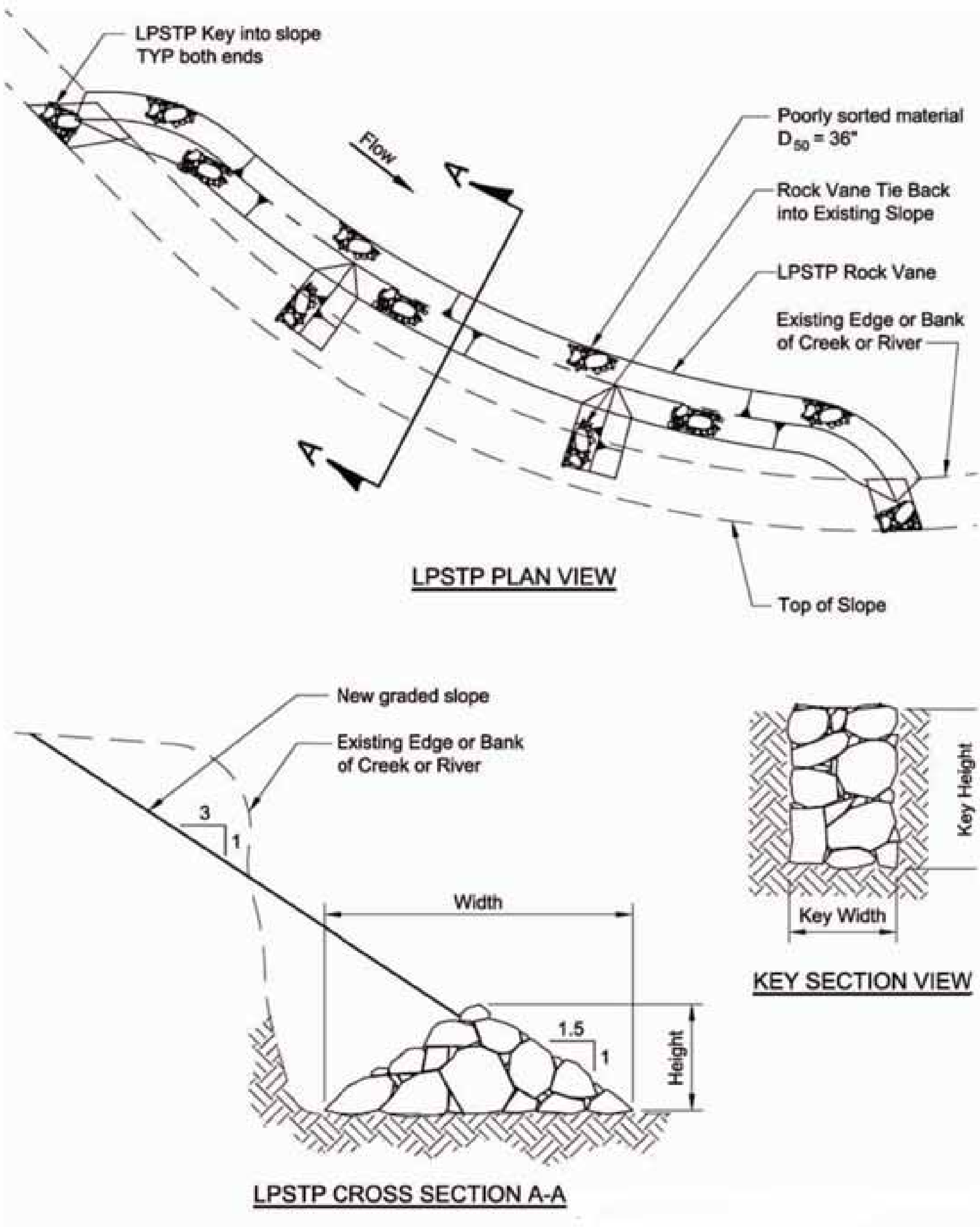


Kansas River Basin Stream and River Channel Assessment

Figure 5-1

Rock Vane Detail

Source: TWI (2004)



Kansas River Basin Stream and River Channel Assessment

Figure 5-2
LPSTP Details

Source: TWI (2004)

Rock chutes (Figure 5-3) are recommended to stabilize active gully erosion, which was observed at Survey Sites 4, 5, and 6. Rock chutes require streambank shaping and the placement of graded rock over a geotextile fabric. Water is directed over the rock chutes, dissipating the energy of the stream flow and helping to reduce bank erosion potential.

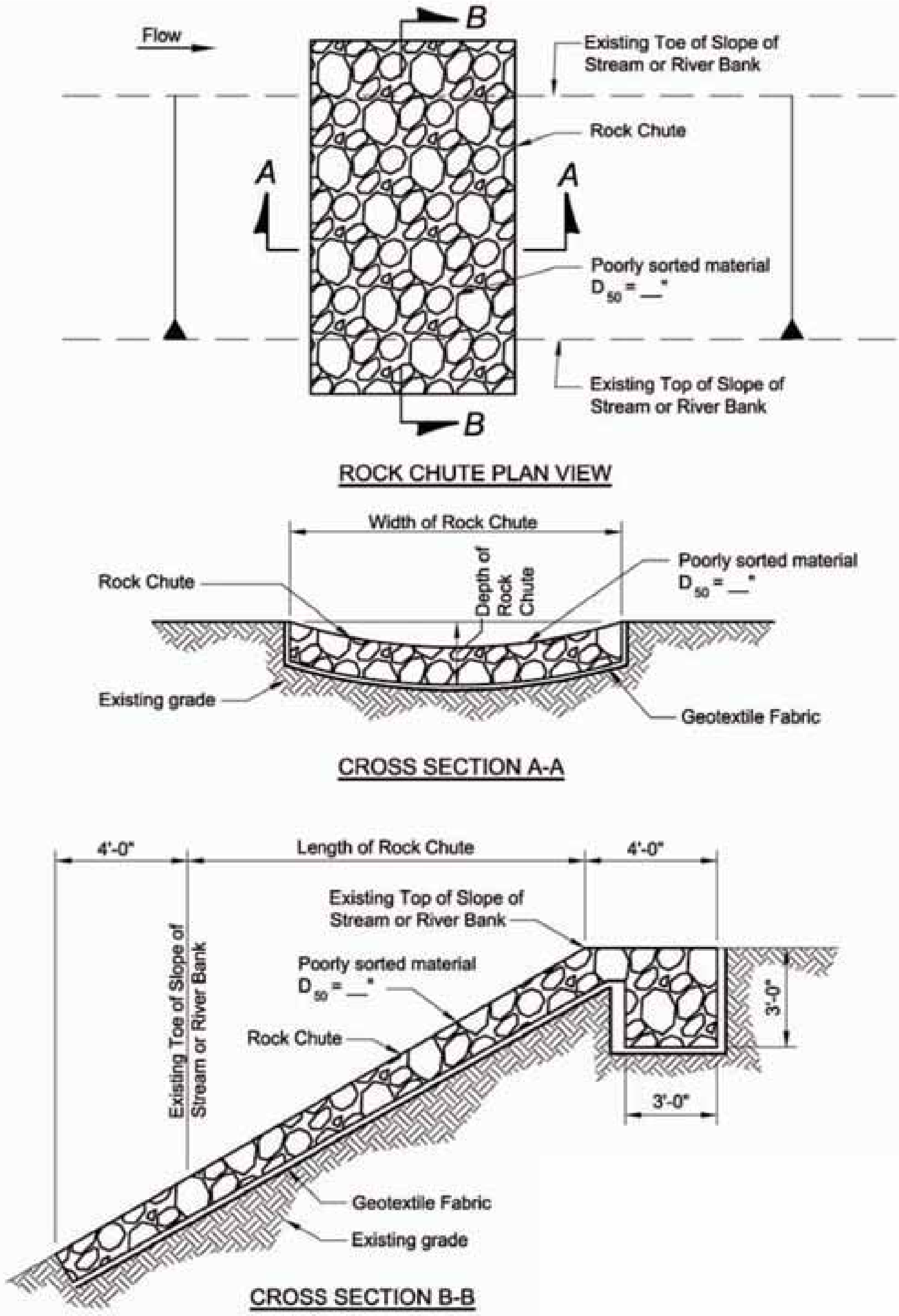
5.1.2 Bank Shaping

Bank shaping, such as constructing a bankfull bench, is recommended to increase stream stability by dissipating energy during high flow events. Bank shaping is employed at river bends where the slope of the bank is so great that it is difficult for vegetation to grow. Photograph 5-1 presents a highly erodible river bend bank that was unable to support vegetation. This bank would require excavation to reduce the angle and create a gentle slope (3 horizontal to 1 vertical) that would support indigenous trees and grasses. The vegetation's root matter stabilizes the soils and significantly reduces the potential for soils to erode during high water flows.

Photograph 5-1. Highly erodible bank on Delaware River with steep slope and no vegetation.

5.1.3 Riparian Fencing

Several of the surveyed stream reaches were found to be impaired by cattle. In these cases, cattle have access to the riparian area where they tend to congregate for shelter and water. Degradation in the riparian corridor was observed with increased erosion potential from cattle overgrazing and hoof action. It is recommended that the riparian corridor is fenced off to restrict cattle access. In many instances, the landowner will need an alternative water supply to supplement previously available stream water.



Source: TWI (2004)

Kansas River Basin Stream and River Channel Assessment

Figure 5-3
Rock Chute Details

5.1.4 BMP Recommendations for Selected Stream Reaches

The BMPs discussed above are recommended for bank types on the Delaware River that are experiencing high erosion rates. Figures 5-4 through 5-6 present field maps which illustrate where to install the BMPs and the type of BMP to be installed.

5.2 Cost Estimates for Stream Restoration

To provide a cost estimate, information was used from past streambank stabilization projects and USDA NRCS Environmental Quality Improvement Program (EQIP) information. Rock placement and bank shaping are the most expensive components of stream restoration. Previous estimates for adjacent watersheds have been as high as $97.00 per linear foot (TWI 2007); however, these estimates are considered high for the Delaware River system. For stabilization projects, rock and rock delivery are the most costly items. Secondly, the Delaware River is not as deep as the rivers referenced in adjacent watersheds and a large, deep river will require more rock, thus requiring more funding. Rock quantities are usually proportional to the stream size. Table 5-1 provides a comparison of estimated costs for rehabilitation alternatives based on one of the survey sites on the Delaware River. These figures are estimates, since specific rock quantities, soil moving, and site condition information are unknown.

Table 5-1. Estimated Costs to Implement Streambank Stabilization BMPs

BMP Cost Description	Cost Estimate per Linear Foot (in dollars)
1. Survey and Design Rock Delivery and Placement As-built Certification Design Bank Excavation and Shaping	$50 - $75
2. Vegetation (Material and Planting) Cover Crop Mulch Willow Stakes Bare Root Seedlings Grass Filter Strip	$5
3. Contingencies Unexpected Site Conditions Requiring Extra Materials and Construction Time	$3 - $5.5
TOTAL	**$58 - $85.5**

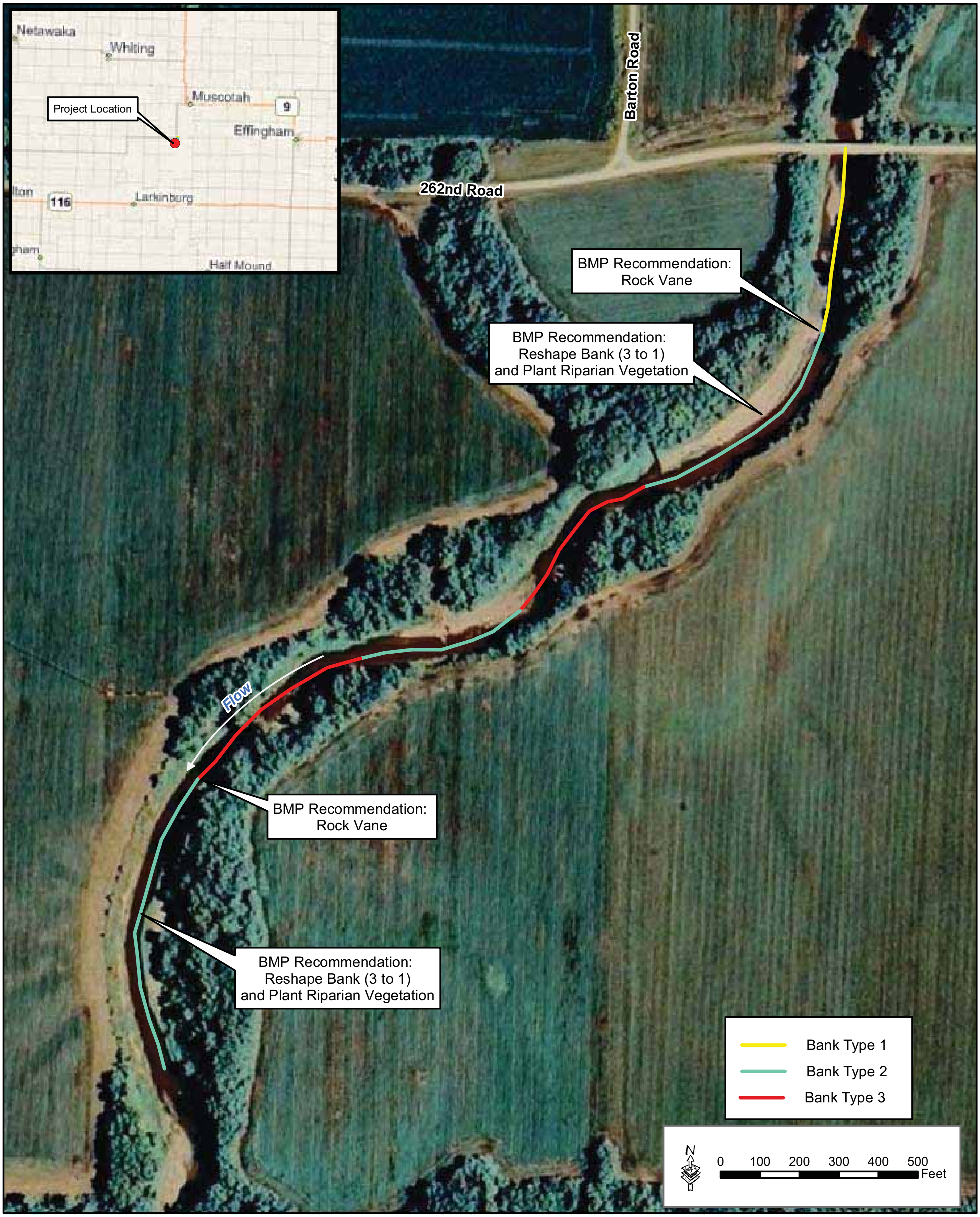


Figure 5-4: BMP Recommendations at USGS Muscotah Gauge Survey Site

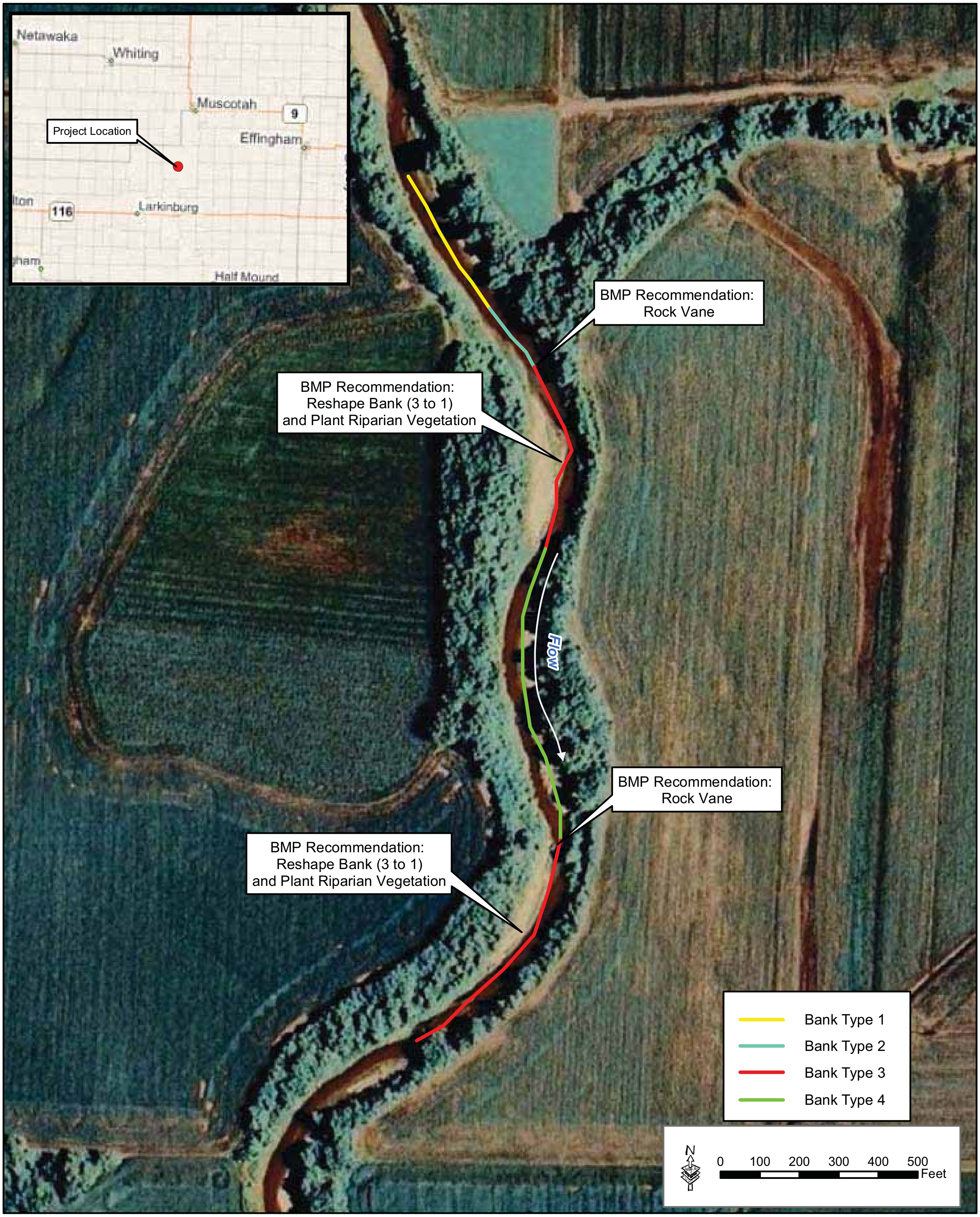


Figure 5-5: BMP Recommendations at Highway 254 Bridge Survey Site

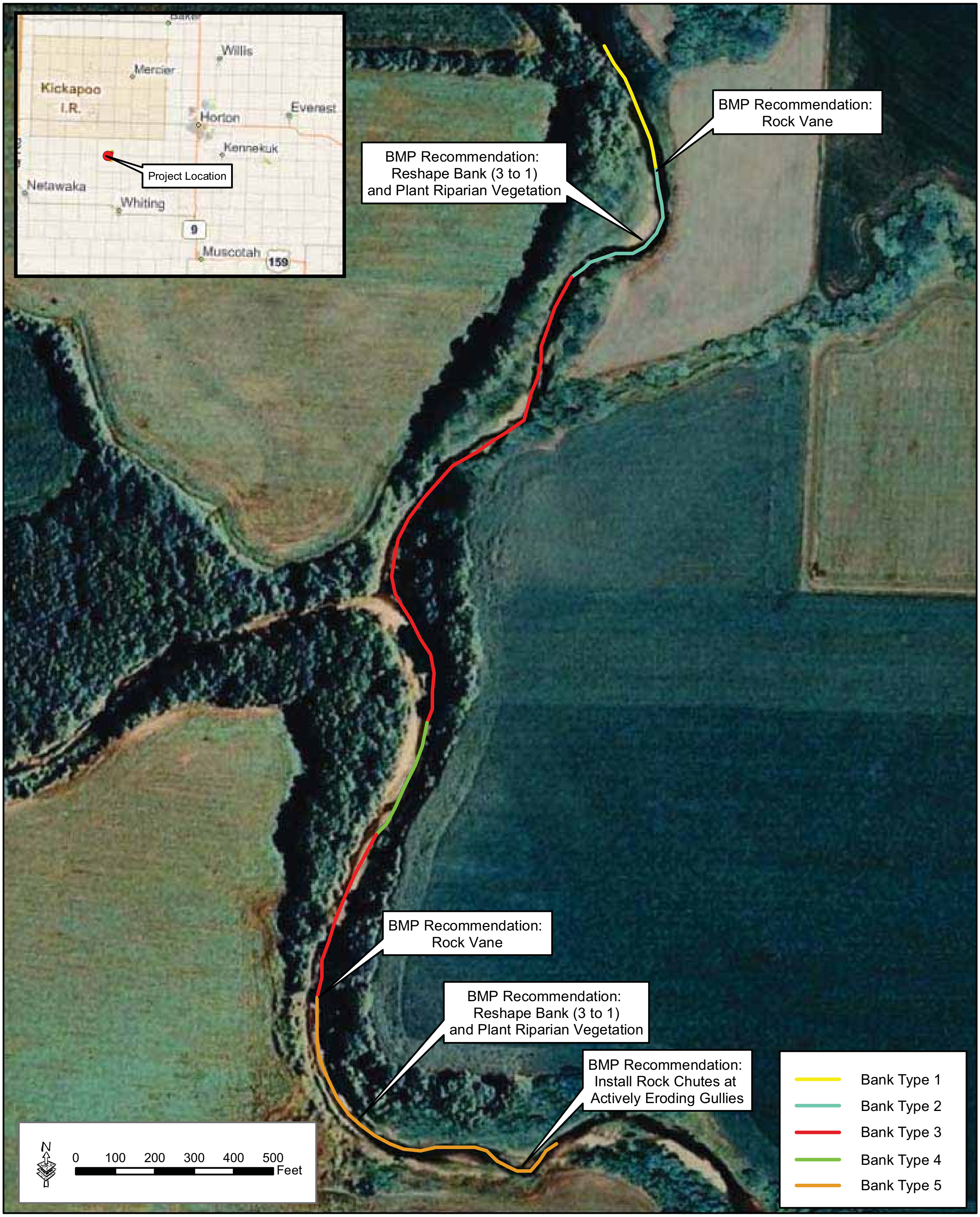


Figure 5-6: BMP Recommendations at Muddy Creek Confluence Survey Site

Bank shaping by excavating steep banks to a 3 to 1 horizontal to vertical slope will be required to rehabilitate unstable banks on the river bends. Constructing a bankfull bench will help increase stream stability by dissipating energy during high flow events. The bench does not have to be wide, as any bankfull features will be an improvement to the stream stability. Excavating stream banks to suitable conditions will cost $30 to $40 per linear foot. Planting a riparian buffer consisting of live cuttings, bare root seedlings, and a native grass strip will cost approximately $5.00 per linear foot.

Finally, projects that require riparian fencing will cost $1.25 to $2.50 per linear foot depending on the type of fence. The implementation of BMPs on smaller stream systems will typically be at the lower end of the cost range, since water depths are less and bank heights are lower. For work on larger streams, costs are anticipated to trend toward the higher price range. It is difficult to accurately predict streambank stabilization costs without a more detailed survey. The cost guidelines are reflective of current prices and may fluctuate based on material prices and fuel costs.

SECTION 6.0
BMP IMPACTS: ESTIMATED REDUCTION OF SEDIMENT EROSION

6.0 BMP IMPACTS: ESTIMATED REDUCTION OF SEDIMENT EROSION

The Rosgen BANCS model was used to determine whether BMPs could reduce erosion at the survey sites. As mentioned previously, BMP implementation on the smaller sub-watershed sites (Sites 1, 2, and 3) would not be cost effective due to the loss of mature, well-established riparian trees. The Delaware River sites (Survey Sites 4, 5, and 6), with steep banks and a narrow riparian corridor, were modeled with BMP scenarios.

BMP scenarios were modeled for each of the Delaware River bank types over two time periods:

- Scenario A: includes the first 3 years where the vegetation foliage and root materials are maturing.
- Scenario B: includes 3+ years where the vegetation foliage and root materials are mature.

A root density of 25% and surface protection of 50% was used to mimic the period of newly planted vegetation (Scenario A). A root density and surface protection of 75% was used for well-established riparian vegetation (Scenario B). The advantage of the suggested BMPs is that, with proper operation and maintenance, the vegetation roots will increase soil stability over time. As a result, a well established riparian corridor will provide more erosion resistance compared to a recently planted riparian corridor that is not well established.

A 3 to 1 horizontal to vertical slope for an 18.4 degree bank angle was applied in the model for the eroding bank types on the Delaware River. Next, the rooting depth was changed to encompass the entire bank height. This assumption was made because the entire bank slope would be planted with native riparian species. For NBS, the assumption was made that the rock structures, such as rock veins and rock chutes, would slow velocities in the near bank region, and thus would lower the bank shear stress. As a result, the NBS rating was lowered. The BANCS model in RIVERMorph was used to determine the erosion loss percent reduction and compared the percent reduction to the measured erosion loss estimated through the 1991 and 2006 aerial photography interpretation. Table 6-1 presents a summary of the erosion rates resulting from the implementation of BMPs on the Delaware River and estimates the percent reduction of bank erosion for BMP Scenario A.

Table 6-1. BMP Estimated Sediment Reduction Scenario A (Years 1-3)

Survey Site Number	Bank Type	BEHI Rating	Current Rate of Erosion (tons/foot/year)	BMP Rate of Erosion (tons/foot/year)	Percent Reduction
4	2	20.3	3.74	0.86	77
5	3	20.3	2.04	0.45	78
6	2	20.7	5.24	0.76	86
	4	22.5	1.83	0.86	53
	5	21.1	4.87	0.68	86

Scenario A represents the vegetative cover during first 3 years.

Table 6-2 presents a summary of the erosion rates resulting from the implementation of BMPs on the Delaware River and estimates the percent reduction of bank erosion for BMP Scenario B.

Table 6-2. BMP Estimated Sediment Reduction Scenario B (Year 3 plus)

Survey Site Number	Bank Type	BEHI Rating	Current Rate of Erosion (tons/foot/year)	BMP Rate of Erosion (tons/foot/year)	Percent Reduction
4	2	14.0	3.74	0.33	91
5	3	14.2	2.04	0.14	93
6	2	14.5	5.24	0.33	94
	4	14.0	1.83	0.35	81
	5	14.9	4.87	0.49	90

Scenario B represents the vegetative cover after year 3.

SECTION 7.0
CONCLUSIONS

7.0 CONCLUSIONS

The USACE Kansas City District contracted 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 contractual objectives of this project were to:

- Identify six stream segments within the Kansas River basin to investigate.
- Conduct fluvial and stream channel morphological and riparian assessments to identify future sediment control opportunities in selected sub-watersheds above Federal water supply reservoirs in the Kansas River basin.
- Conduct an assessment of critical factors affecting stream geomorphology, bed transitions, and systemic erosion issues in selected sub-watersheds.
- Assign a Rosgen stream classification to each survey reach, estimate the amount of streambank erosion, and evaluate riparian conditions.
- Determine cost estimates to implement the erosion mitigation design for the most suitable erosion control measures.
- Determine the reduction in erosion resulting from implementation of erosion control measures.

The survey locations were based on input from KWO and the Delaware WRAPS stakeholder group. Aerial photography and video from recent helicopter reconnaissance were also used to select the survey sites.

Geomorphology data analysis suggests that all stream reaches surveyed are incised, laterally confined, and still evolving to a stable dimension, pattern, and profile. The Research Team found 18 distinct bank types at the six survey sites, and these were defined as B, C, and E stream types in the Rosgen classification system. All stream reaches have experienced streambed degradation and are naturally developing a new floodplain by lateral migration and aggradation. Narrow floodplain benches were observed, but normally such features were scarce. Evidence of channelization was found on most survey reaches, which explains the streambed degradation at all of the survey sites. Small impoundments and cattle access to the riparian corridor also influenced stream stability, but were less significant than channelization for larger streams such as the Delaware River.

The BEHI ratings ranged from 39.4 (high) to 14.4 (low) and the dominant influence on bank erodibility was bank angle and vegetation. Where there was a riparian corridor with gently sloping banks, the erodibility potential was very low. Conversely, the erodibility potential was very high on outside meander bends with steep banks and little riparian vegetation. The tributary to Clear Creek site had the highest predicted erosion loss for the smaller sub-watershed surveys at 0.12 ton/foot/year. The other two sub-watershed survey reaches scored below 0.10 ton/foot/year. Even though all three of these survey reaches did not exhibit a stable stream form, the erosion rate appeared slow.

For the three main-stem Delaware River surveys, the predicted erosion rate ranged from 2.04 to 5.46 tons/foot/year for five bank types. The Delaware River has been channelized extensively resulting in a narrow, deep, confined channel. Aerial photos from 1991 and 2006 allowed further examination of stream bank erosion. These bank types on the Delaware River also had the highest BEHI ratings. The aerial photography interpretation estimates suggest that the BANCS model under-predicts erosion loss for the Delaware River. However, the aerial photography interpretation results and BEHI ratings do correlate well, and suggest that the use of BEHI ratings and prediction loss are appropriate to use when comparing and ranking stream erosion bank types. For bank types where aerial photography interpretation was not applicable, erosion monitoring data were utilized from the Black Vermillion River watershed, an adjacent watershed to the Delaware River watershed, to predict erosion loss. Although the monitoring data were not located within the Delaware River watershed, it is the Research Team's opinion that it is more accurate than the BANCS model.

For all surveys, the riparian corridor consisted of woodlands. The corridor often varied in width from non-existent to well over two times the active channel widths. Similar conditions were observed upstream and downstream from each site. The riparian fragmentation often occurred with changes in land ownership and river proximity to row-crop agriculture. Erosion rates tended to increase when the wooded riparian corridor width decreased. It was concluded that deep and narrow channels, like the channels surveyed, need greater rooting depth and density throughout the bank profile to improve and sustain bank stability. Also, a gentle bank angle and floodplain benches are important, as vegetation is able to grow further down the bank slope and stabilize the bank toe.

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SECTION 8.0
REFERENCES

8.0 REFERENCES

Barnes, P. L. and P. K. Kalita, 2002. Total Maximum Daily Load (TMDL) Environmental Regulations: Proceedings of the March 11-13, 2002 Conference, Pp. 69-74 (Fort Worth, Texas, USA) 701P0102.

Emmert, B.E. and K. Hase. 2001. *Geomorphic Assessment and Classification of Kansas Riparian Systems*. Prepared for EPA under Contract No. CD 997520-01. December 2001.

Gnau, Chris, 2010. Personal communication in regarding the status of water body attainment status. Kansas Water Office. November 01, 2009.

Juracek, K.E. and Ziegler, A.C. 2007. *Estimation of Sediment Sources Using Selected Chemical Tracers in the Perry Lake and Lake Wabaunsee Basins, Northeast Kansas*. U.S. Geological Survey Scientific Investigations Report: 2007-5020. 53p.

Kansas Department of Health and Environment. 2007. *Stream Chemistry Monitoring Program Quality Assurance Management Plan*. February 2007. Available on-line: http://www.kdheks.gov/environment/qmp_2000/download/2007/SCMP_QAMP.pdf.

Kansas Department of Health and Environment (KDHE). 1996. Surface Waters Information Management System (SWIMS). Accessed on-line at: http://gisdasc.kgs.ukans.edu.

KDHE 2008a. Kansas – Lower Republican Basin Total Maximum Daily Load. Waterbody: Centralia Lake, Water Quality Impairment: Eutrophication.

KDHE 2008b. Kansas Department of Health and Environment 2008 303(d) List of Impaired Waters Kansas Lower Republican Basin.

Keane, T.D. 2004. "Leaning from nature's stability: building a multi-purpose database applicable to stream assessment, restoration, and education." In *Proceedings of the ASAE Conference: Self-Sustaining Solutions for Streams, Watersheds, and Wetlands Conference.* St. Paul, Minnesota. Pages 99-108.

Keane, T.D. 2010. Personal communication regarding monitoring data in the Black Vermilion River.

Kuchler, A.W. 1974. "A new vegetation map of Kansas." *Ecology*. Vol. 55: 586-604 Pfankuch, D.J. 1975. *Stream Reach Inventory and Channel Stability Evaluation*. USDA Forest Service—Northern Region.

Rosgen, D.L. 1994. "A Classification of Natural Rivers." *Catena*. Volume 22. Pages 169-199.

---------------. 1996. *Applied River Morphology*. Wildland Hydrology Books. Pagosa Springs, Colorado.

---------------. 1998. *The Reference Reach Field Book*. Wildland Hydrology Books. Pagosa Springs, Colorado.

---------------. 2006. *Watershed Assessment of River Stability and Sediment Supply (WARSS)*. Wildland Hydrology Books. Fort Collins, Colorado.

Simon, A. 1989. "A model of channel response in disturbed alluvial channels." *Earth Surface Processes and Landforms*. Volume 14. Pages 11-26.

Tetra Tech EM Inc. 2004. *Geomorphic Definition, and Documentation of Kansas Stream Corridor Reference Reaches*. Prepared for EPA on behalf of the Kansas State Conservation Commission under Contract No. CD 987073-01. December.

Thorne, C.R. 1997. "Chapter 7: Channel Types and Morphological Classification." In C.R. Thorne, R.D. Hey, and M.D. Newson (editors). *Applied Fluvial Geomorphology for River Engineering and Management.*

U.S. Department of Agriculture Natural Resource Conservation Service. 2008. Web Soil Survey. Accessed on-line at http://websoilsurvey.nrcs.usda.gov.

The Watershed Institute, Inc. 2005a. *Kansas Department of Wildlife and Parks 2005 Geomorphology Report*. December 2005.

-----------------. 2005b. *Fall River Watershed Joint District No. 21 Fluvial Geomorphology Report*. March 2005.

-----------------. 2006a. *Kansas Department of Wildlife and Parks 2006 Geomorphology Report*. December 2006.

----------------. 2006b. *Deer Creek Bank Stability Assessment. December 2006*. Available on-line at http://www.wakarusawatershed.org/projects.html#DeerCreek.

-----------------. 2007. Enhanced Riparian Area/Stream Channel Assessment for John Redmond Feasibility Study. December 2007. Available on-line: http://www.kwo.org/Reports%20%26%20Publications/Enhanced%20Riparian%20Area%20Stream%20Channel%20Assessment%20Report.pdf

Wolman, M.G. 1954. "A method of sampling coarse river-bed material." *Transactions of American Geophysical Union.* Volume 35. Pages 54-74.

SECTION 9.0
RESEARCH TEAM

9.0 RESEARCH TEAM

Name	Discipline/Expertise	Experience	Role In Preparing Report
Steve Kolian	Environmental and aquatic science	14 years of watershed modeling and NEPA assessment	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	2 years surveying	Field survey
Ryan McCurdy	Surveyor	8 years surveying	Field survey

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APPENDIX A
KEY TO PFANKUCH EVALUATION

CHANNEL STABILITY (PFANKUCH) EVALUATION (PFANKUCH, 1975)

Stream: ______________________ Date: __________

Location: Observers:

Category			EXCELLENT	
Upper	1	Landform Slope	Bank Slope Gradient < 30%	2
Banks	2	Mass Wasting	No Evidence of past or future mass wasting	3
	3	Debris Jam Potential	Essentially absent from immediate channel area	2
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep dense soil binding root mass.	3
Lower	5	Channel Capacity	Ample for present plus some increases. Peak Flows contained. W/D ratio < 7.	1
Banks	6	Bank Rock Content	65%+ with large angular boulders. 12"+ common.	2
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern without cutting or deposition. Stable bed.	2
	8	Cutting	Little or none. Infrequent raw banks less than 6".	4
	9	Deposition	Little or no enlargement of channel or point bars.	4
Bottom	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1
	11	Brightness	Surfaces dull, dark or stained. Generally not bright.	1
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2
	13	Bottom Size Distribution	No size change evident. Stable mater. 80-100%	4
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	6
	15	Aquatic Vegetation	Abundant growth moss-like, dark green perennial, in swift water also.	1
			TOTAL	

Category			GOOD	
Upper	1	Landform Slope	Bank Slope Gradient 30-40%	4
Banks	2	Mass Wasting	Infrequent, mostly healed over. Low future potential	6
	3	Debris Jam Potential	Present, but mostly small twigs and limbs.	4
	4	Vegetative Bank Protection	70-90% density, fewer species or less vigor suggest less dense or deep root mass	6
Lower	5	Channel Capacity	Adequate, bank overflows rare. W/D ratio 8-15.	2
Banks	6	Bank Rock Content	40-65%, mostly small boulders to cobbles 6-12"	4
	7	Obstructions to Flow	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4
	8	Cutting	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6
	9	Deposition	Some new bar increase, mostly from course gravel.	8
Bottom	10	Rock Angularity	Rounded corners and edges, surfaces smooth and flat.	2
	11	Brightness	Mostly dull, but may have <35% bright surfaces.	2
	12	Consolidation of Particles	Moderately packed with some overlapping.	4
	13	Bottom Size Distribution	Distribution shift light, stable material 50-80%.	8
	14	Scouring and Deposition	5-30% affected, scour at constrictions and where grades steepen. Some deposition in pools.	12
	15	Aquatic Vegetation	Common. Algae forms in low velocity and pool area, as well as moss.	2
			TOTAL	

Category			FAIR	
Upper	1	Landform Slope	Bank slope gradient 40-60%	6
Banks	2	Mass Wasting	Frequent or large, causing sediment nearly year long.	9
	3	Debris Jam Potential	Moderate to heavy amounts, mostly larger sizes.	6
	4	Vegetative Bank Protection	<50-70% density, lower vigor and fewer species from a shallow discontinuous root mass	9
Lower	5	Channel Capacity	Barely contains present peaks, occasional overbank floods. W/D ratio 15 to 25.	3
Banks	6	Bank Rock Content	20-40% with most in the 3-6" diameter class.	6
	7	Obstructions to Flow	Moderate, frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6
	8	Cutting	Significant, cuts 12-24" high. Root mat overhangs and sloughing evident.	12
	9	Deposition	Moderate deposition of now gravel and course sand on old and some new bars.	12
Bottom	10	Rock Angularity	Corners and edges well rounded in two dimensions.	3
	11	Brightness	Mixture dull and bright, 35-65% mixture range.	3
	12	Consolidation of Particles	Mostly loose assortment with no apparent overlap.	6
	13	Bottom Size Distribution	Moderate change in sizes, stable material 20-50%.	12
	14	Scouring and Deposition	30-50% affected. Deposits and scour at obstructions, constrictions, and bends. Some pool filling.	18
	15	Aquatic Vegetation	Present but spotty, mostly in backwater. Seasonal algae growth make rocks slick.	3
			TOTAL	

CHANNEL STABILITY (PFANKUCH) EVALUATION (PFANKUCH, 1975)

Stream: ____________________ Date: ________

Location: Observers:

Category			POOR	
Upper Banks	1	Landform Slope	Bank slope gradient 60%+	8
	2	Mass Wasting	Frequent or large causing sediment nearly year long or imminent danger of same.	12
	3	Debris Jam Potential	Moderate to heavy amounts, predominately larger sizes.	8
	4	Vegetative Bank Protection	<50% density, fewer species and less vigor indicate poor discontinuous and shallow root mass.	12
Lower Banks	5	Channel Capacity	Inadequate. Overbank flows common. W/W ratio >25.	4
	6	Bank Rock Content	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7	Obstructions to Flow	Sediment traps full, channel migration occurring.	8
	8	Cutting	Almost continuous cuts, come over 24" high. Failure or overhangs frequent.	16
	9	Deposition	Extensive deposits of predominately and fine particles, accelerated bar development.	16
Bottom	10	Rock Angularity	Well rounded in all dimensions, surfaces smooth.	4
	11	Brightness	Predominately, bright, 65%+ exposed to scoured surfaces.	4
	12	Consolidation of Particles	No packing evident, loose assortment easily moved.	8
	13	Bottom Size Distribution	Marked distribution change, stable materials 0-20%.	16
	14	Scouring and Deposition	More then 50% of the bottom in a state of flux or change nearly year long.	24
	15	Aquatic Vegetation	Perennial types scarce or absent, yellow-green, short term bloom may be present.	4
			TOTAL	

Sediment Supply		Stream Bed Stability		Width/Depth Ratio Condition	
Extreme	____	Aggrading	________	Normal	_____
Very High	____	Degrading	________	High	_____
High	____	Stable	________	Very High	_____
Moderate	____				
Low	____				

Remarks The channel is straightened, but is rather stable. Dense grasses cover the bank and some of channel.

TOTAL SCORE for Reach

E ____________________ F ________

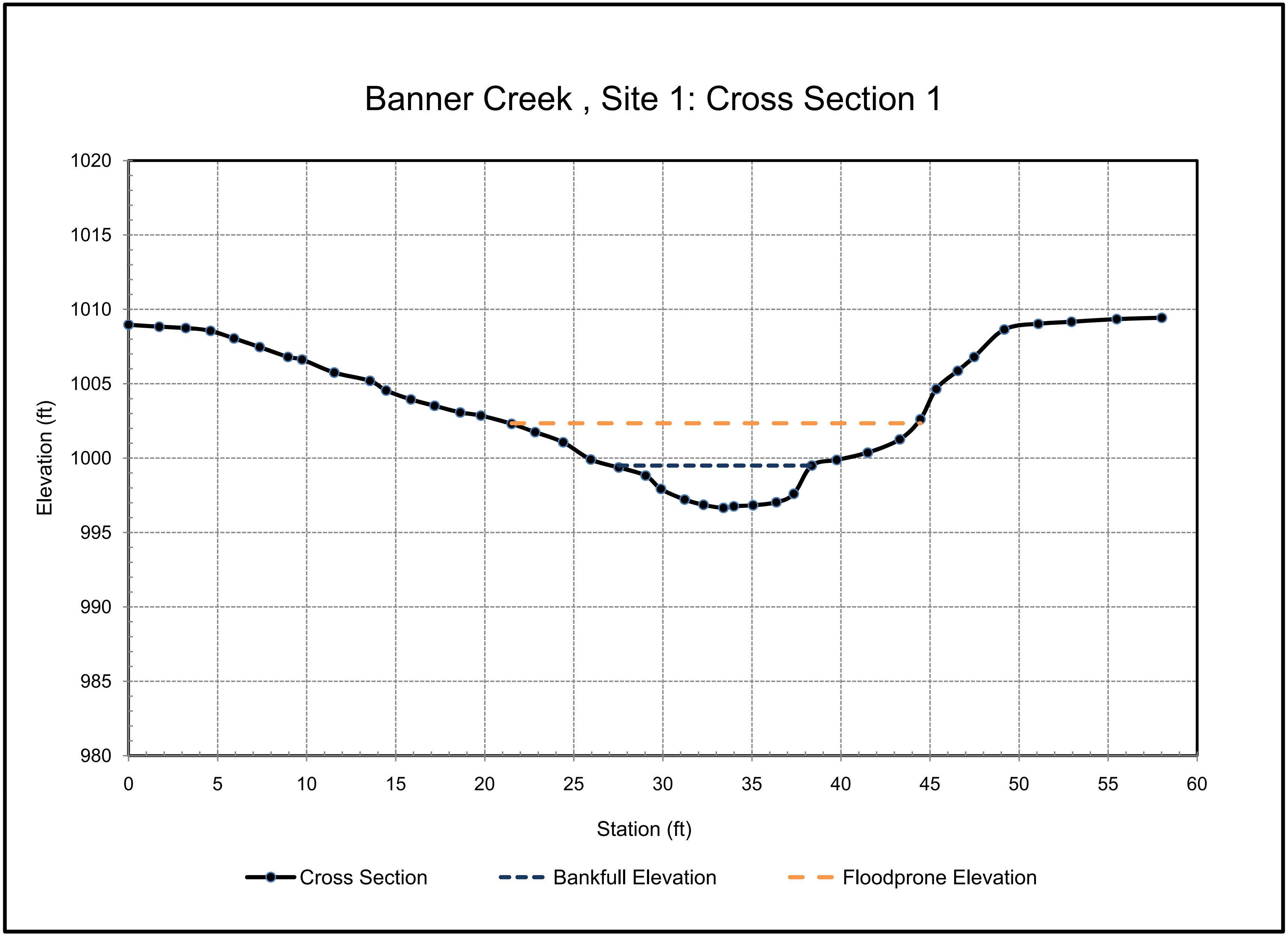
G ____________________ P ________

[ ]	Grand Total
[ ]	Existing Stream Type
[ ]	Potential Stream Type
[ ]	Channel Stability Rating

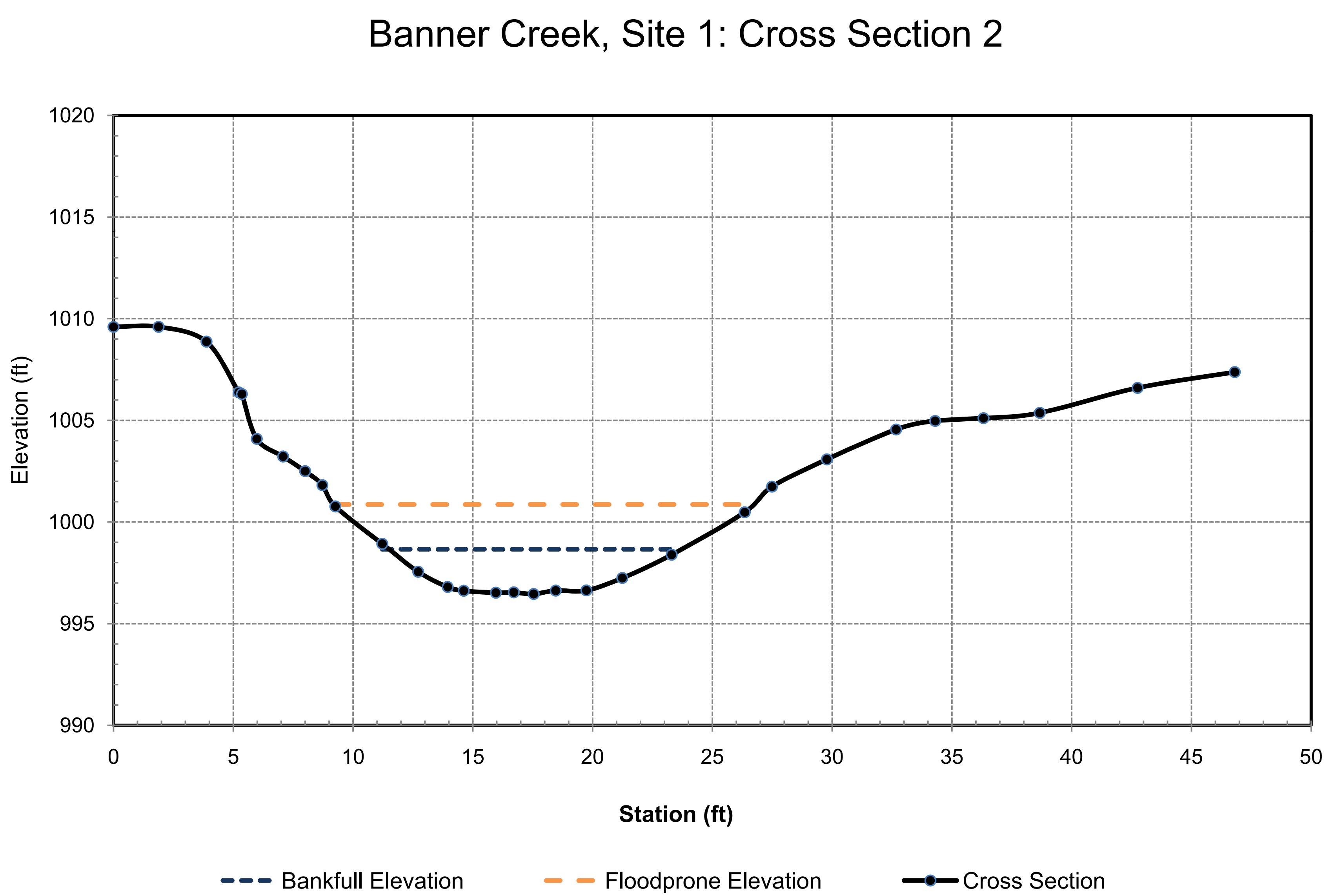
APPENDIX B
CROSS SECTION PLOTS

APPENDIX B:

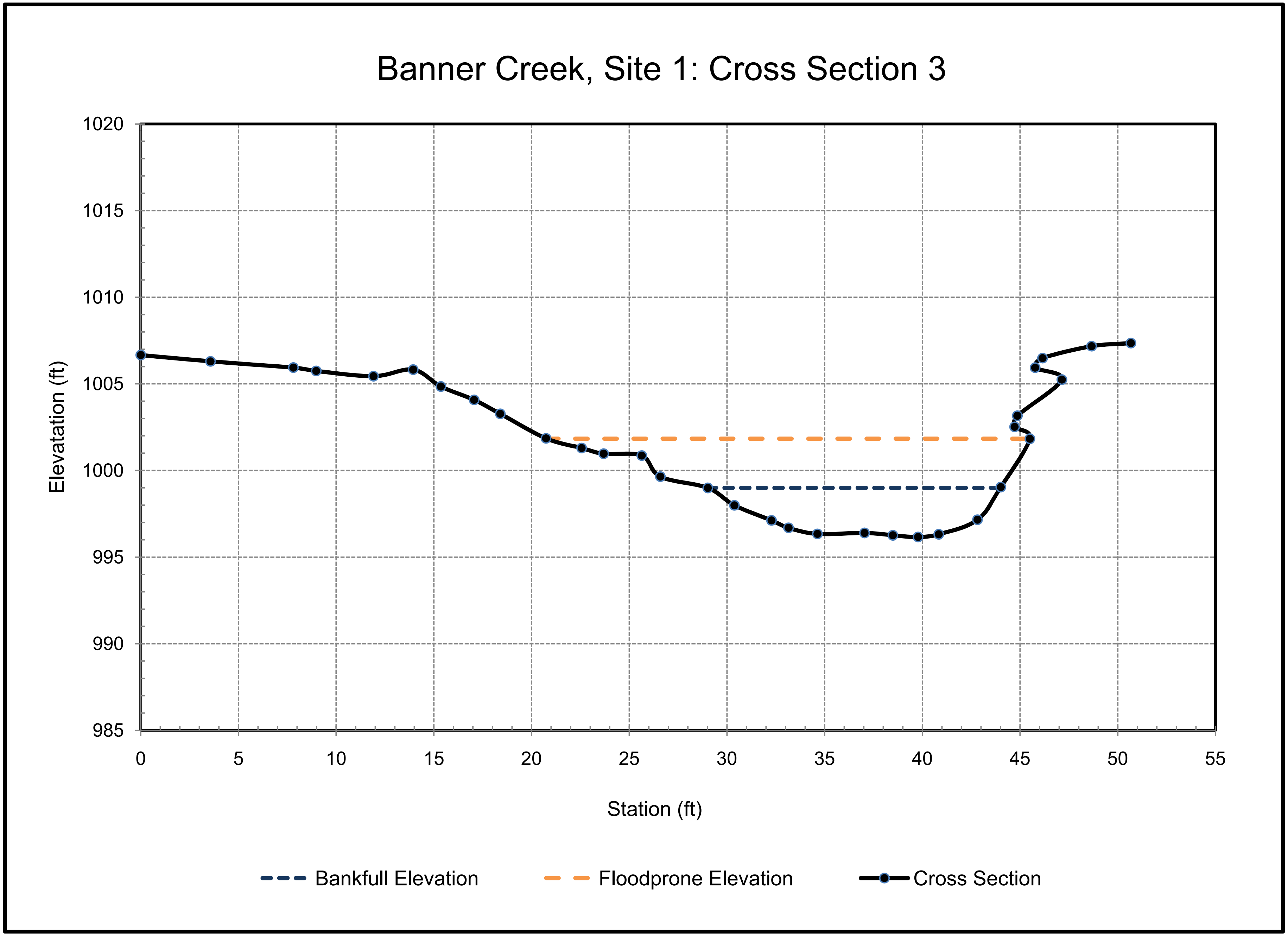
CROSS SECTION PLOTS



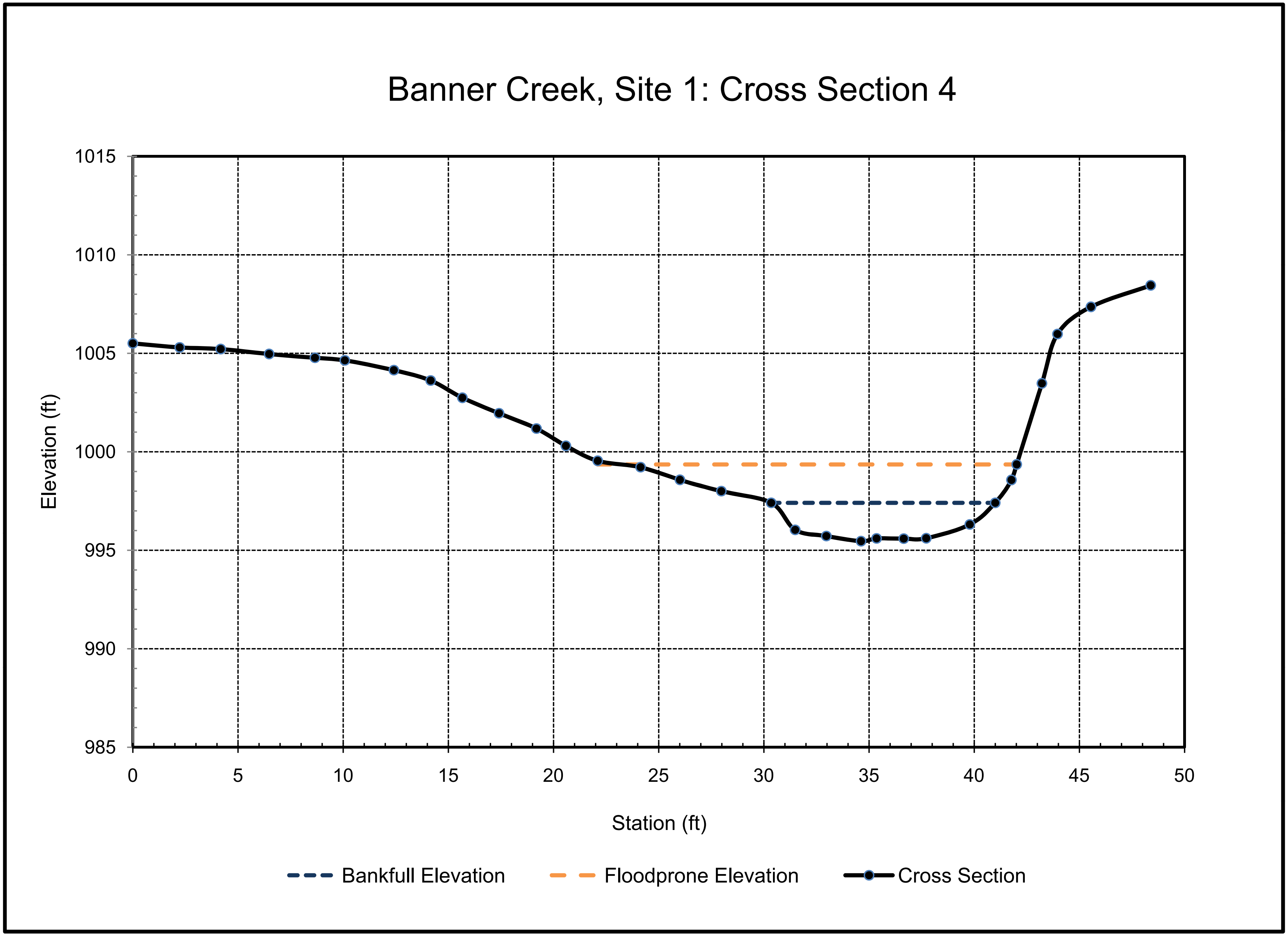
Banner Creek , Site 1: Cross Section 1
Elevation (ft)
1020
1015
1010
1005
1000
995
990
985
980
0
5
10
15
20
25
30
35
40
45
50
55
60
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation

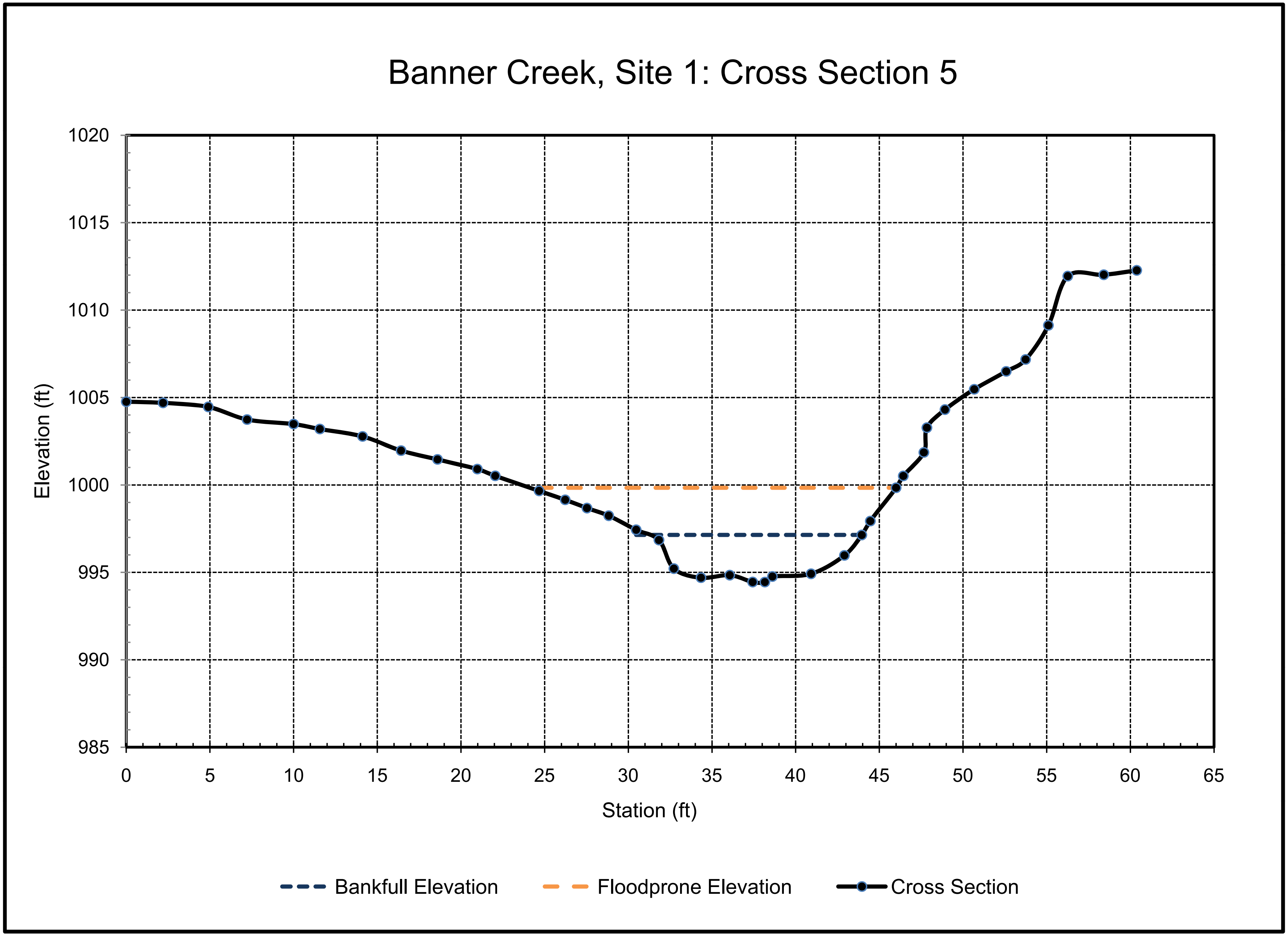


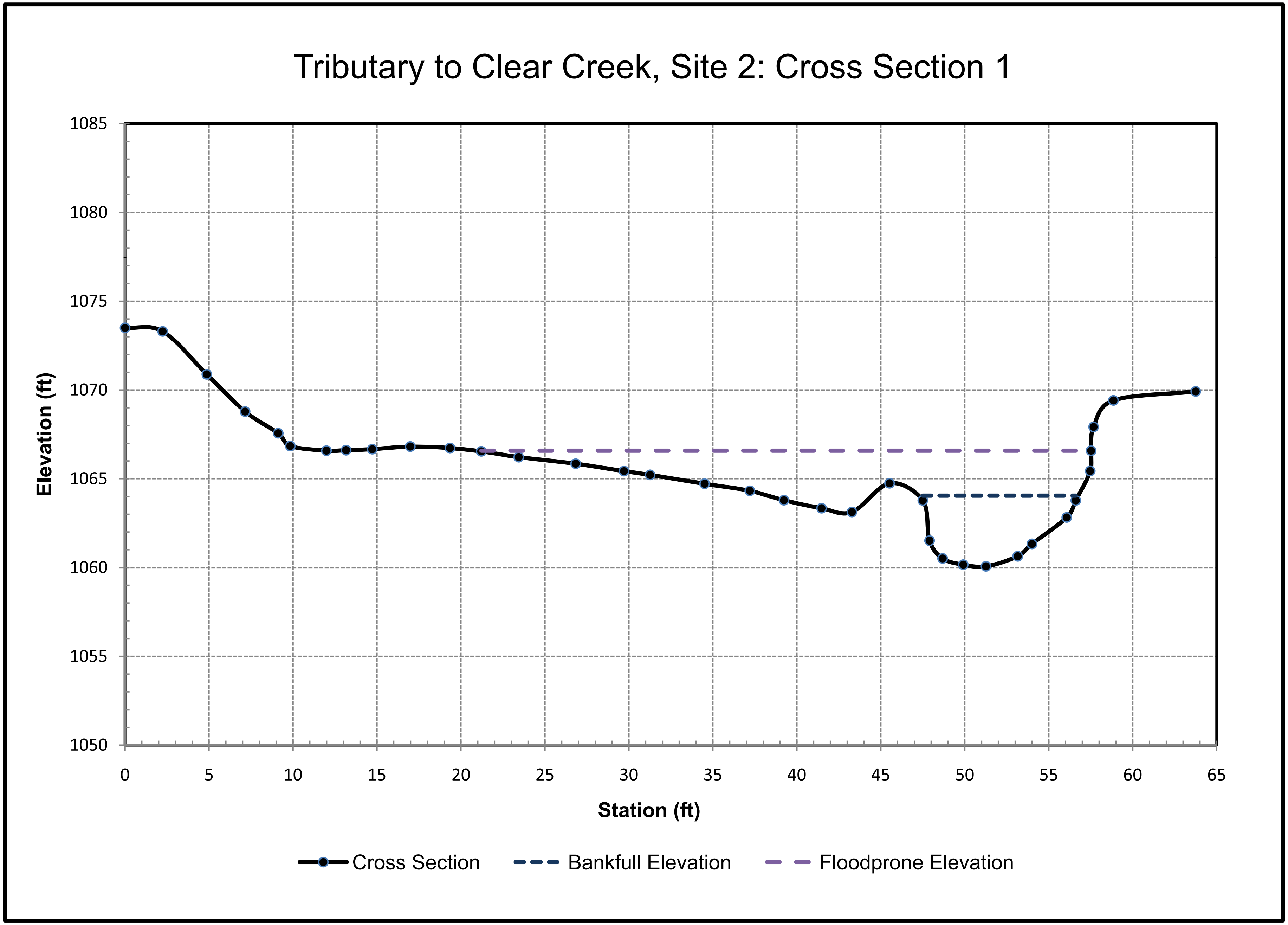
Banner Creek, Site 1: Cross Section 2
Elevation (ft)
1020
1015
1010
1005
1000
995
990
0
5
10
15
20
25
30
35
40
45
50
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

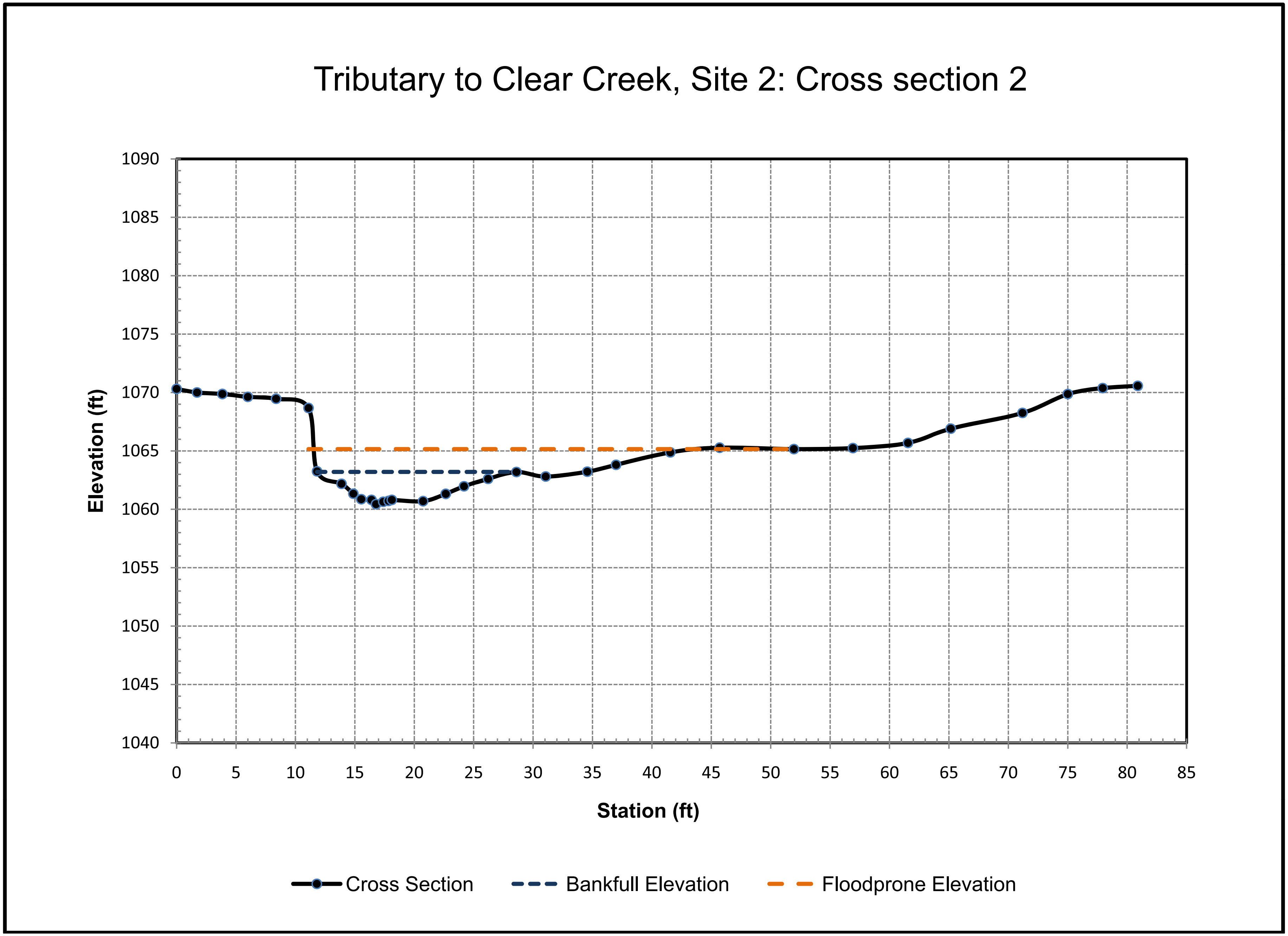


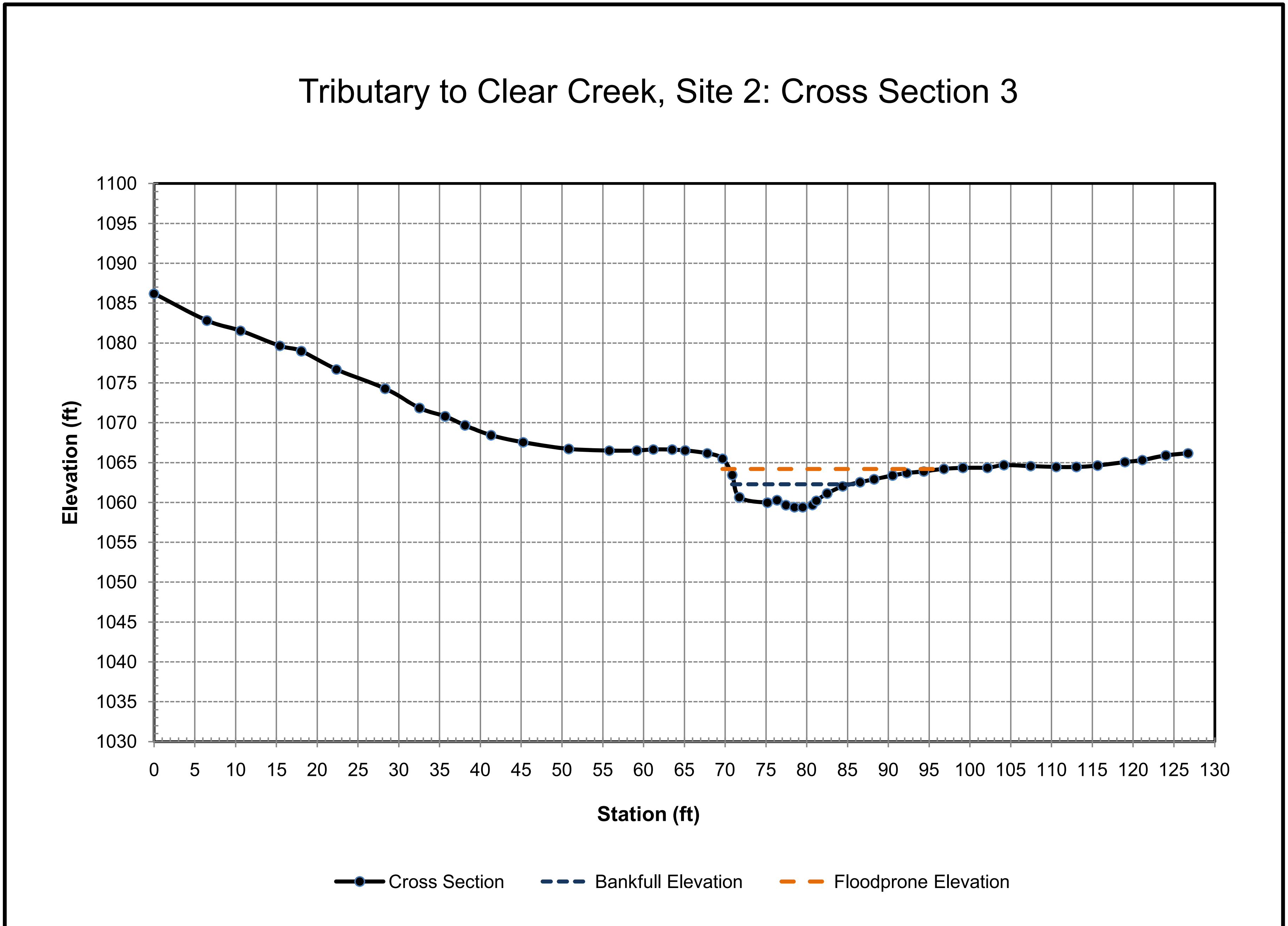
Banner Creek, Site 1: Cross Section 3
Elevatation (ft)
1020
1015
1010
1005
1000
995
990
985
0
5
10
15
20
25
30
35
40
45
50
55
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section


Banner Creek, Site 1: Cross Section 4
1015
1010
1005
1000
995
990
985
Elevation (ft)
0
5
10
15
20
25
30
35
40
45
50
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

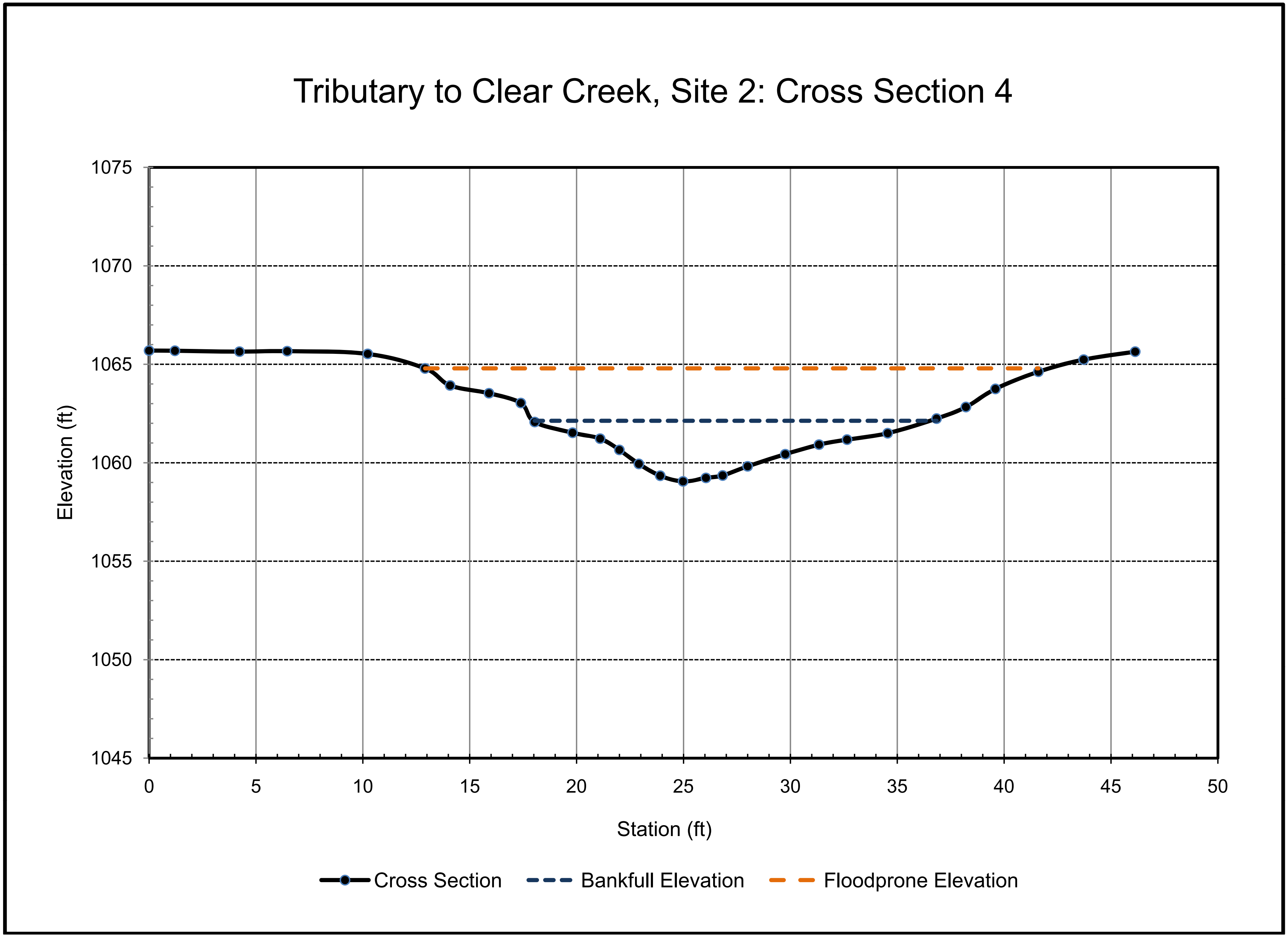

Banner Creek, Site 1: Cross Section 5
Elevation (ft)
1020
1015
1010
1005
1000
995
990
985
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

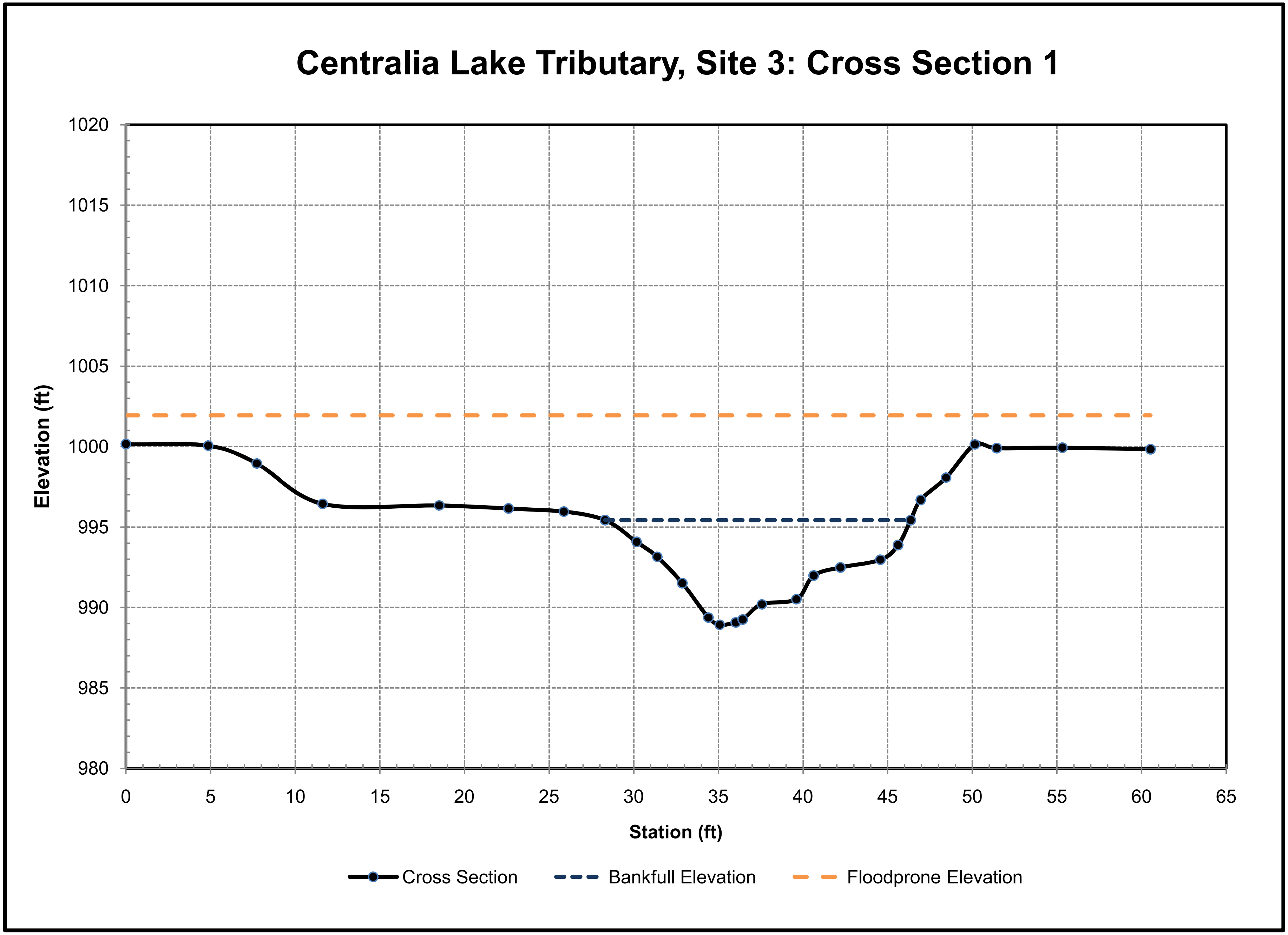

Tributary to Clear Creek, Site 2: Cross Section 1
Elevation (ft)
1085
1080
1075
1070
1065
1060
1055
1050
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation


Tributary to Clear Creek, Site 2: Cross section 2
1090
1085
1080
1075
1070
1065
1060
1055
1050
1045
1040
Elevation (ft)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation

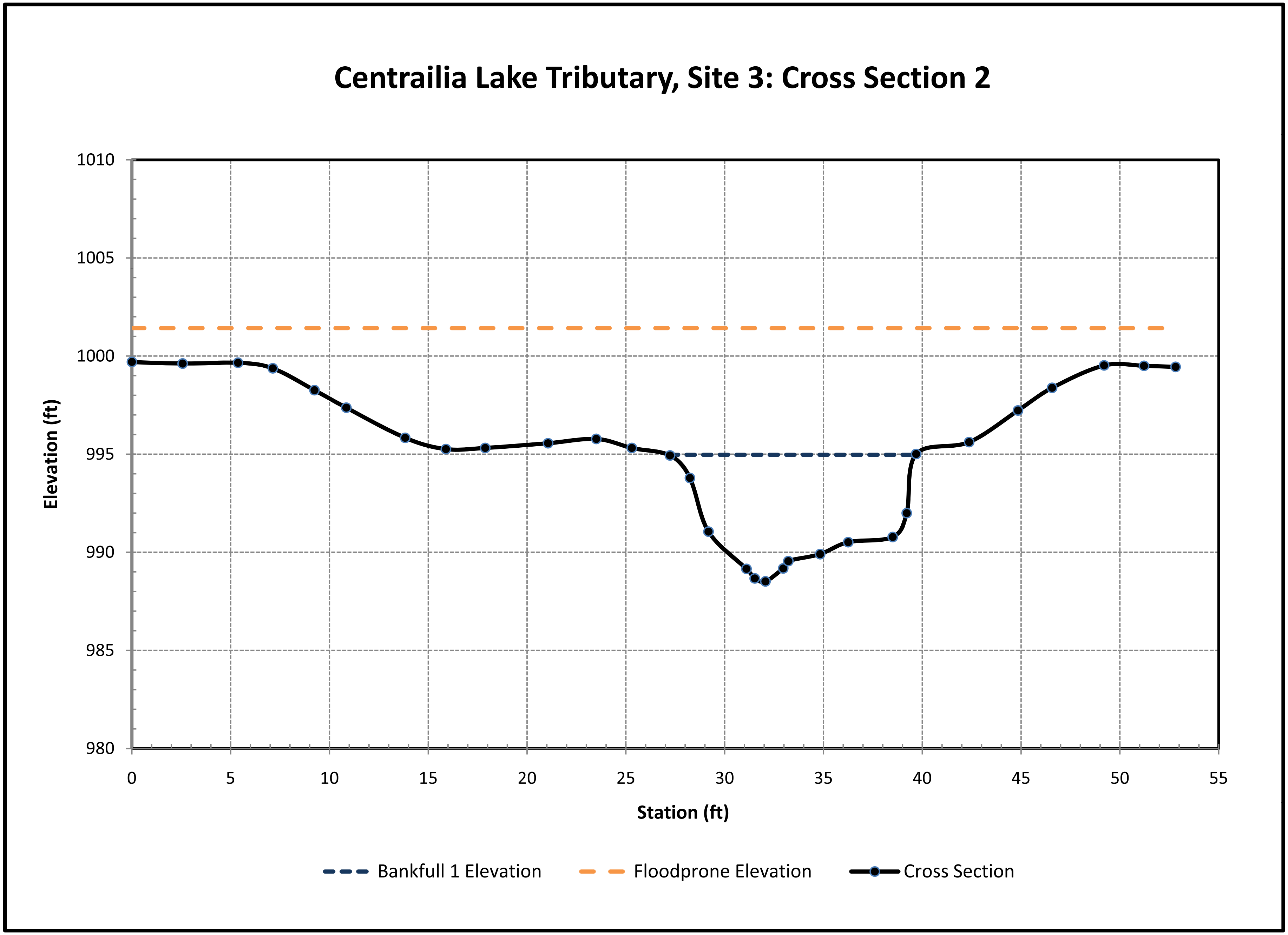


Tributary to Clear Creek, Site 2: Cross Section 3
Elevation (ft)
1100
1095
1090
1085
1080
1075
1070
1065
1060
1055
1050
1045
1040
1035
1030
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation

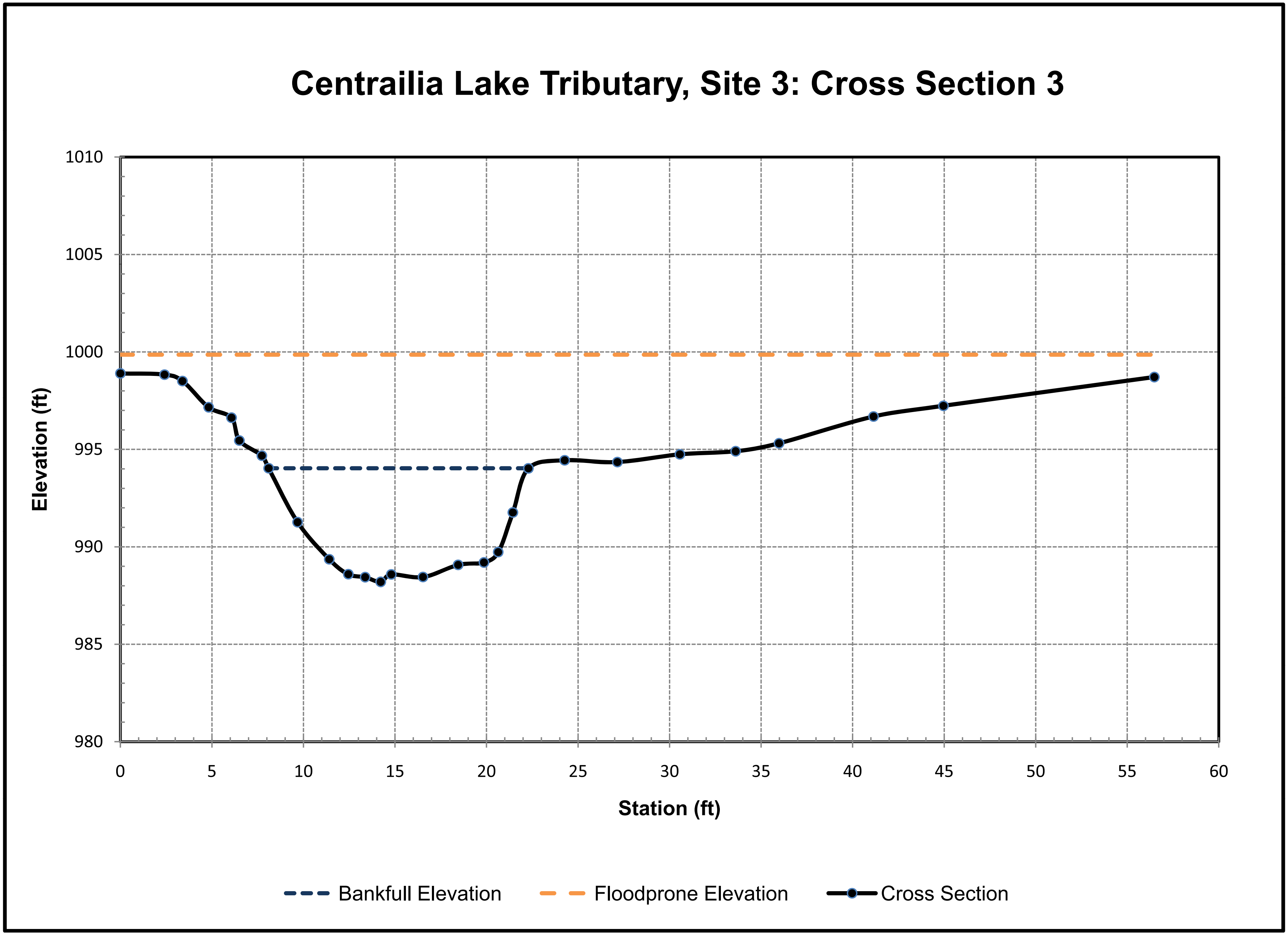

Tributary to Clear Creek, Site 2: Cross Section 4
1075
1070
1065
1060
1055
1050
1045
Elevation (ft)
0
5
10
15
20
25
30
35
40
45
50
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation



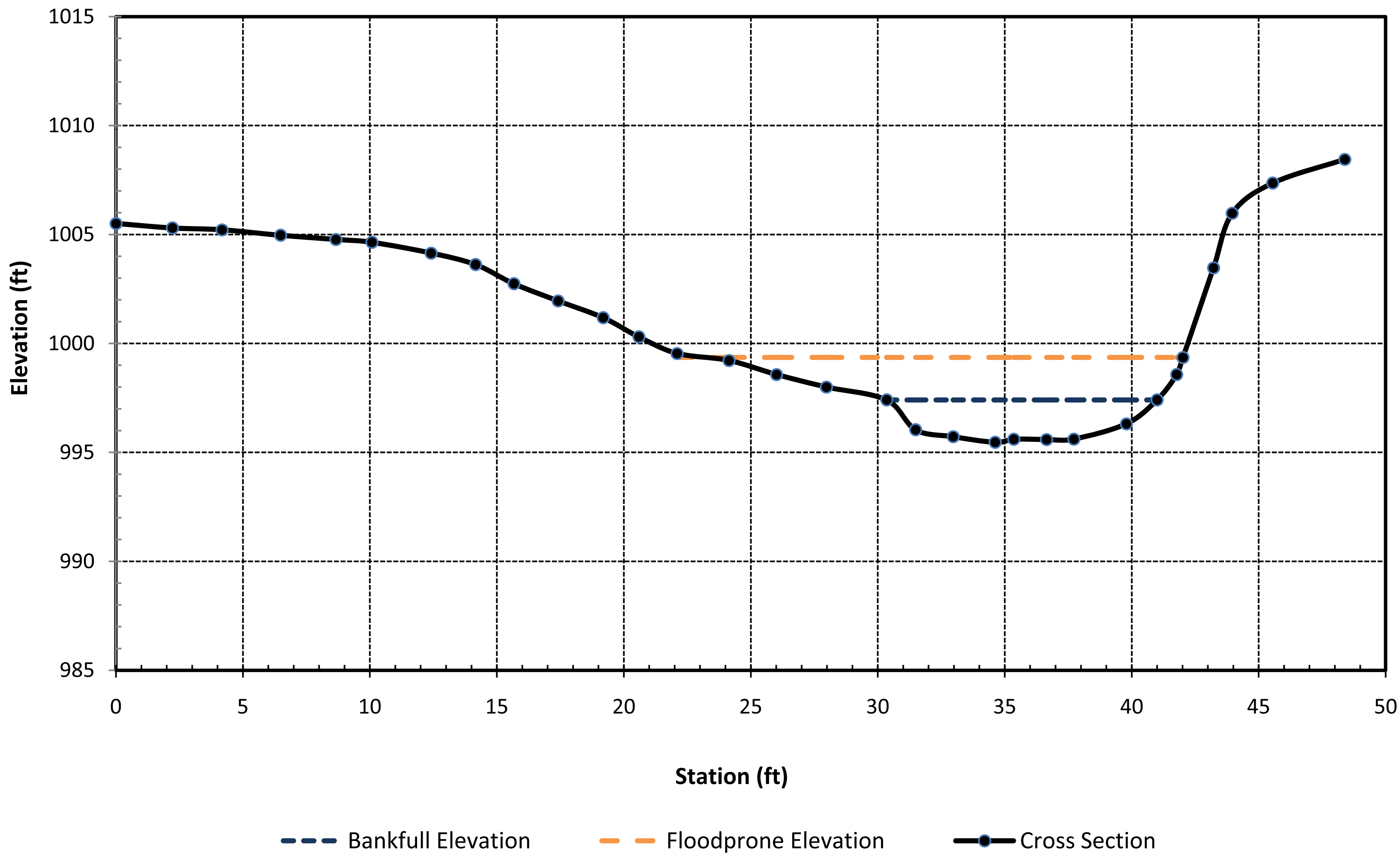
Centralia Lake Tributary, Site 3: Cross Section 1
Elevation (ft)
1020
1015
1010
1005
1000
995
990
985
980
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation

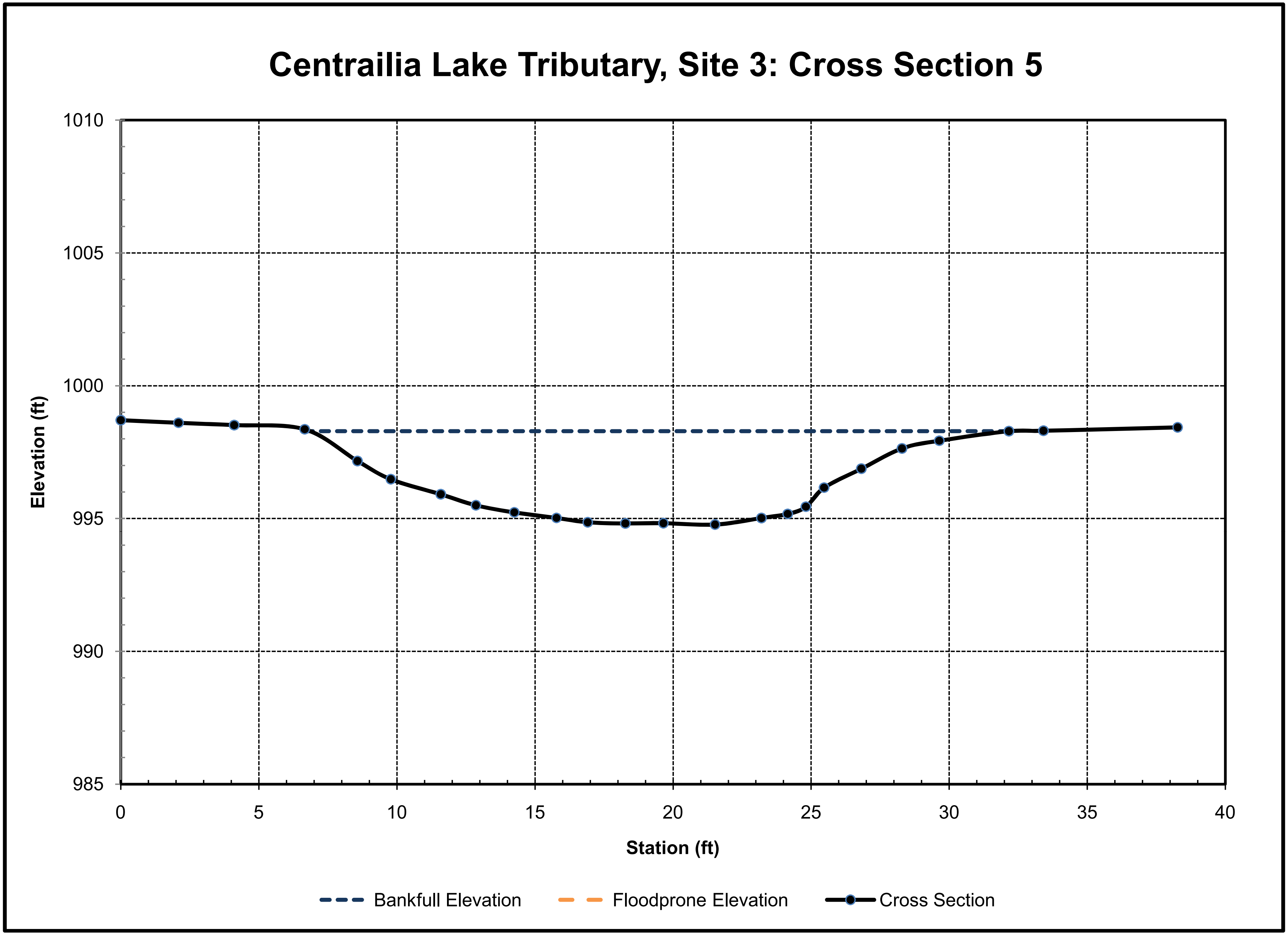


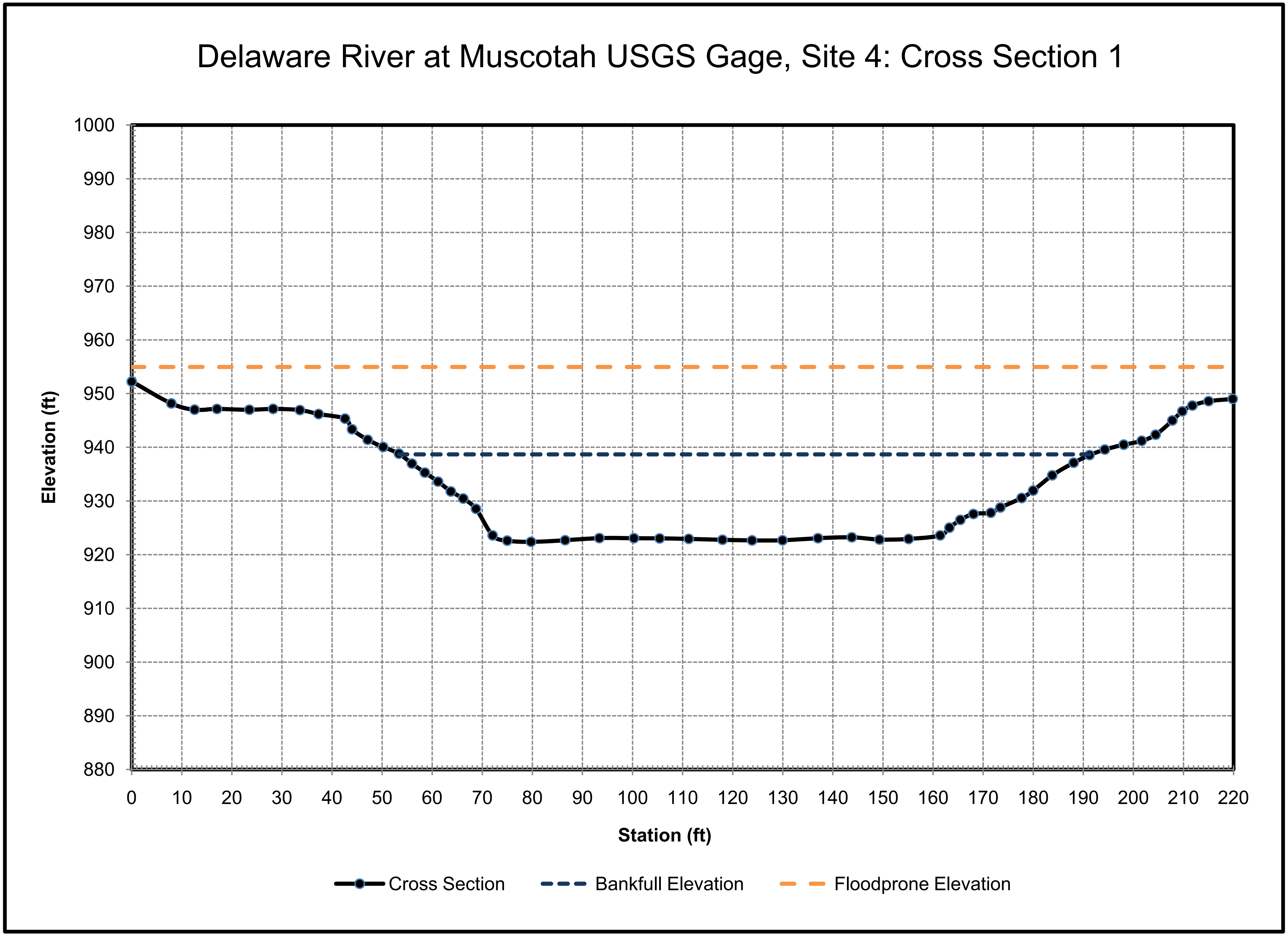
Centrailia Lake Tributary, Site 3: Cross Section 2
Elevation (ft)
1010
1005
1000
995
990
985
980
0
5
10
15
20
25
30
35
40
45
50
55
Station (ft)
Bankfull 1 Elevation
Floodprone Elevation
Cross Section


Centrailia Lake Tributary, Site 3: Cross Section 3
Elevation (ft)
1010
1005
1000
995
990
985
980
0
5
10
15
20
25
30
35
40
45
50
55
60
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

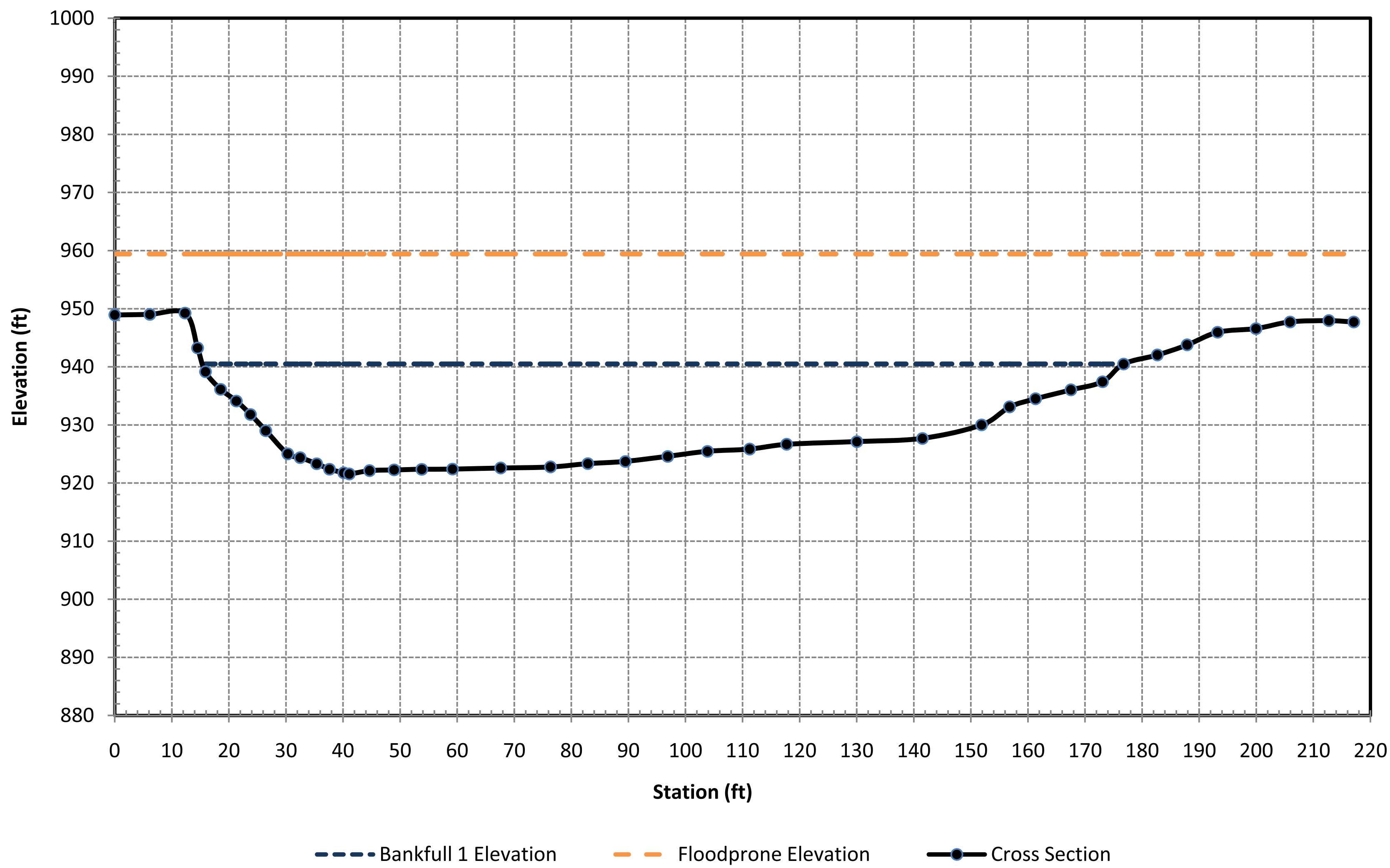
Tributary to Centrailia Lake, Site 3: Cross Section 4

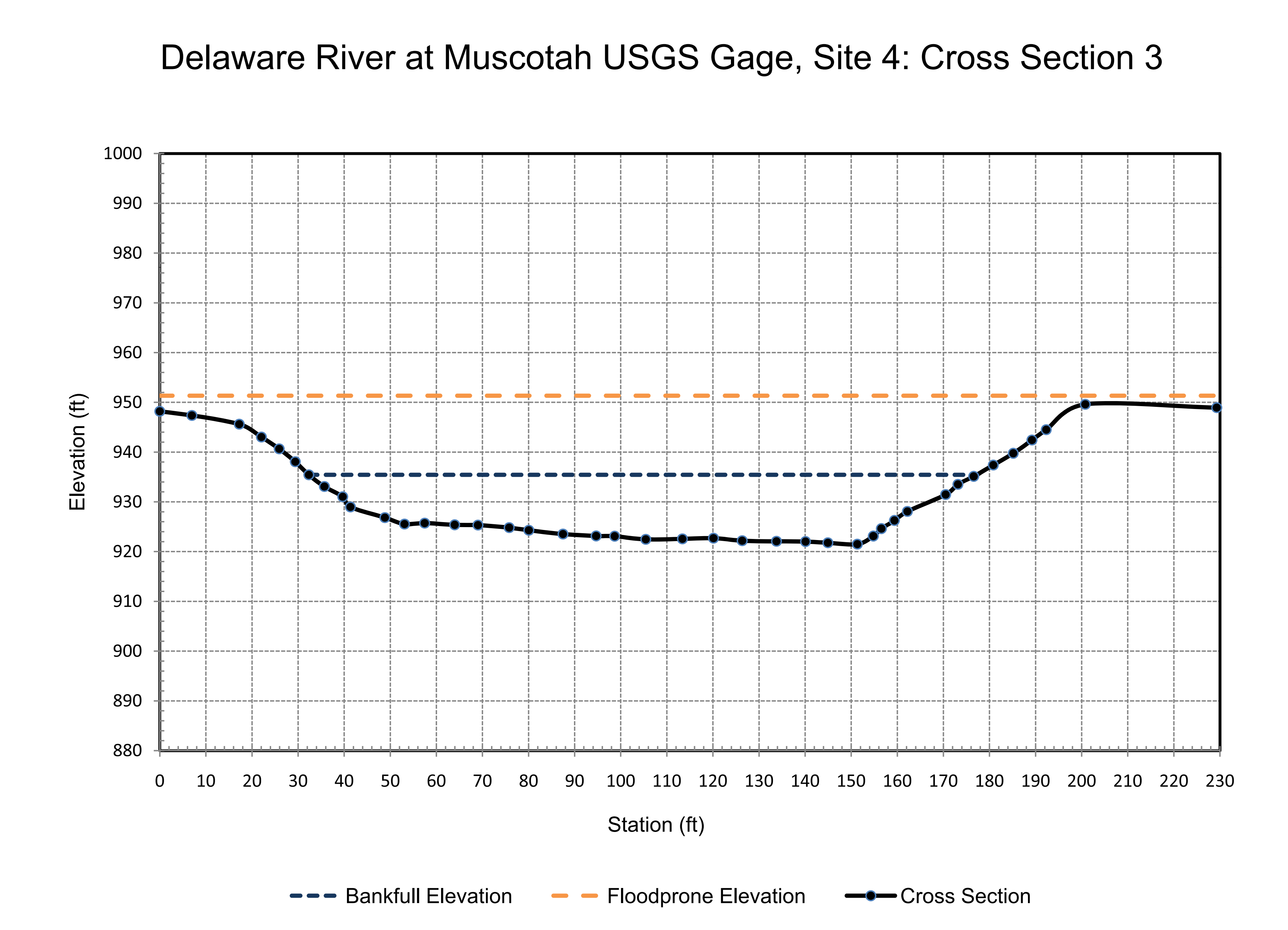


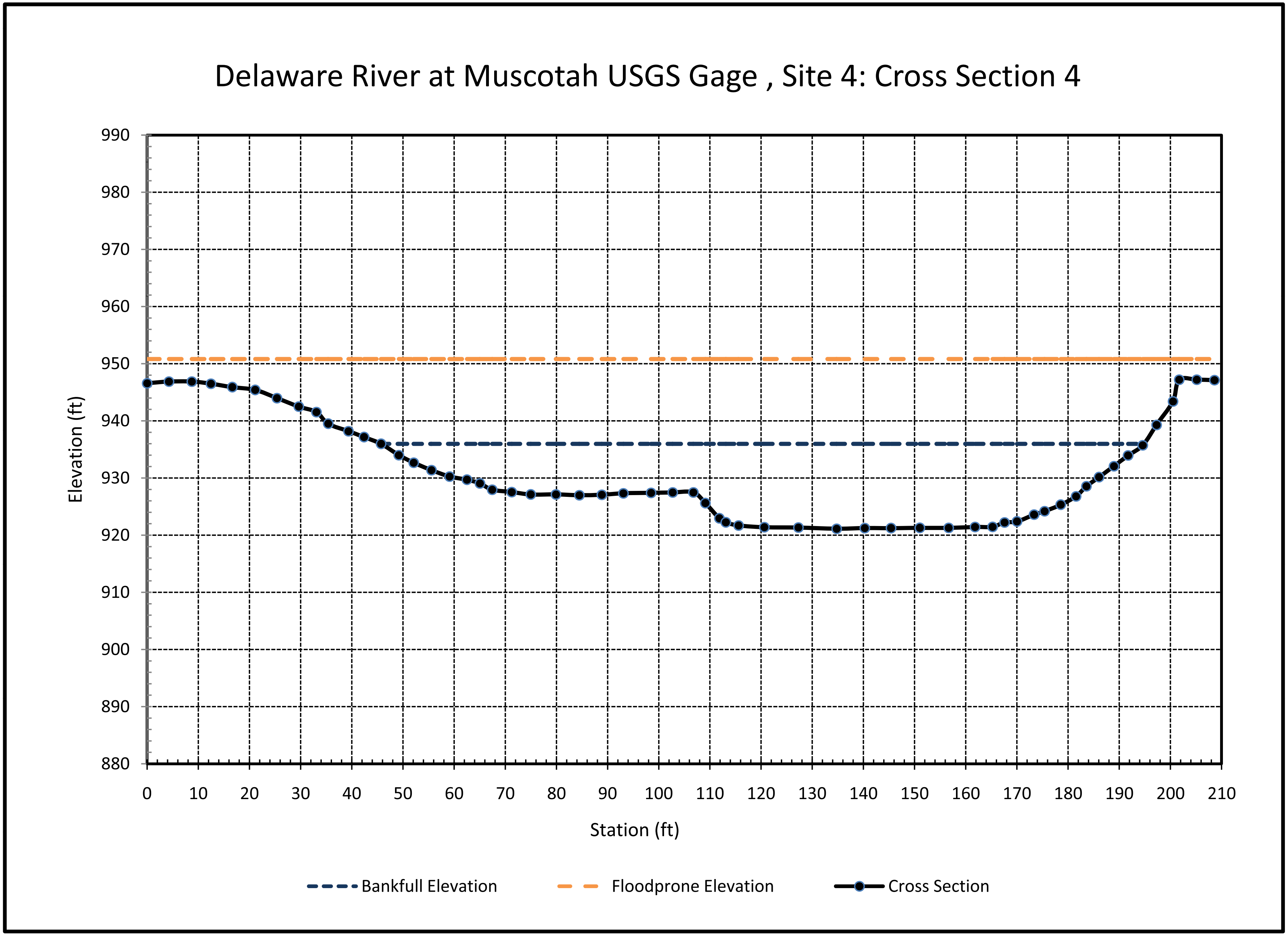

Centrailia Lake Tributary, Site 3: Cross Section 5
1010
1005
1000
995
990
985
Elevation (ft)
0
5
10
15
20
25
30
35
40
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section


Delaware River at Muscotah USGS Gage, Site 4: Cross Section 1
Elevation (ft)
1000
990
980
970
960
950
940
930
920
910
900
890
880
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation

Delaware River at Muscotah USGS Gage , Site 4: Cross Section 2




Delaware River at Muscotah USGS Gage, Site 4: Cross Section 3
Elevation (ft)
1000
990
980
970
960
950
940
930
920
910
900
890
880
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section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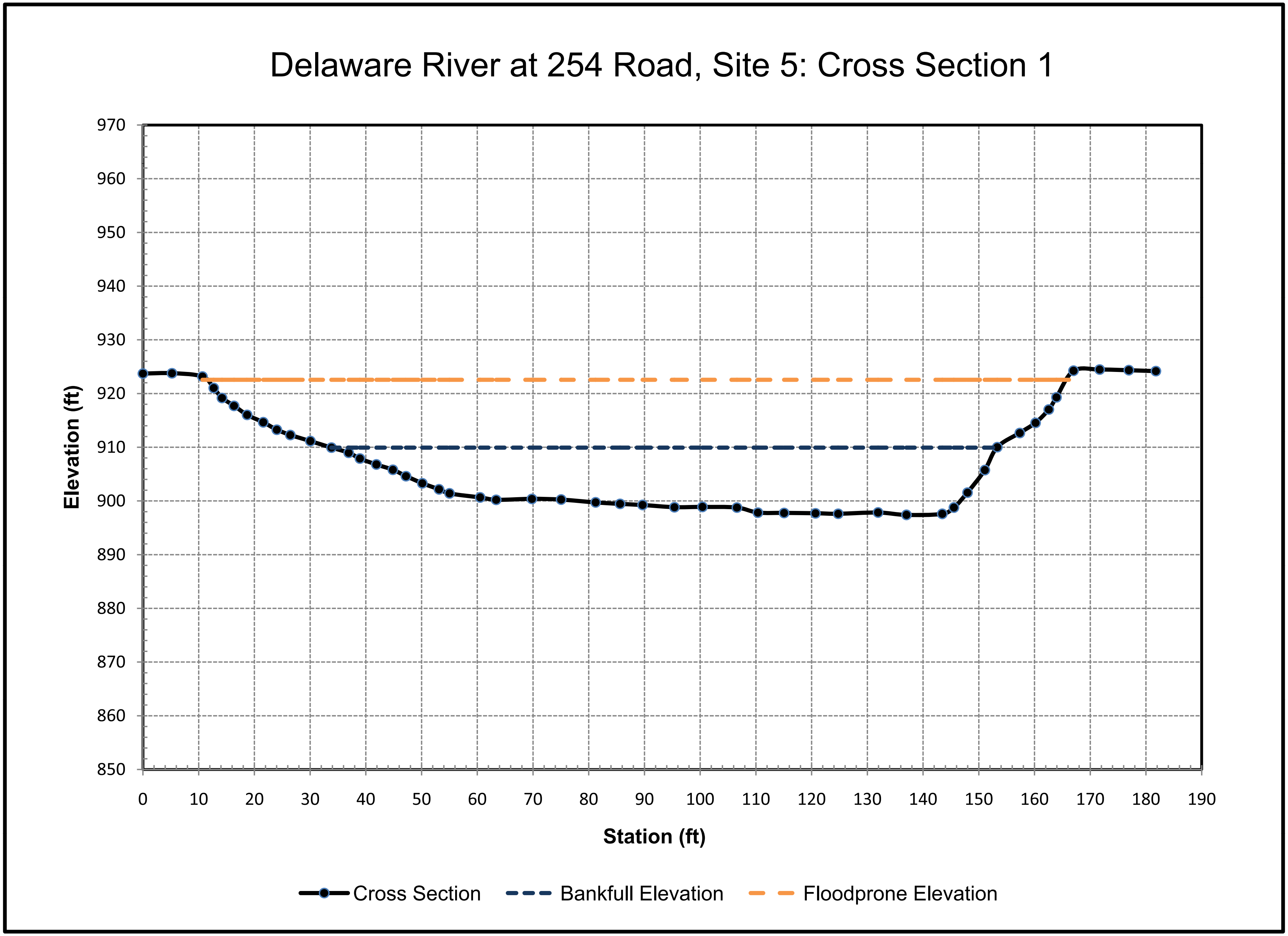
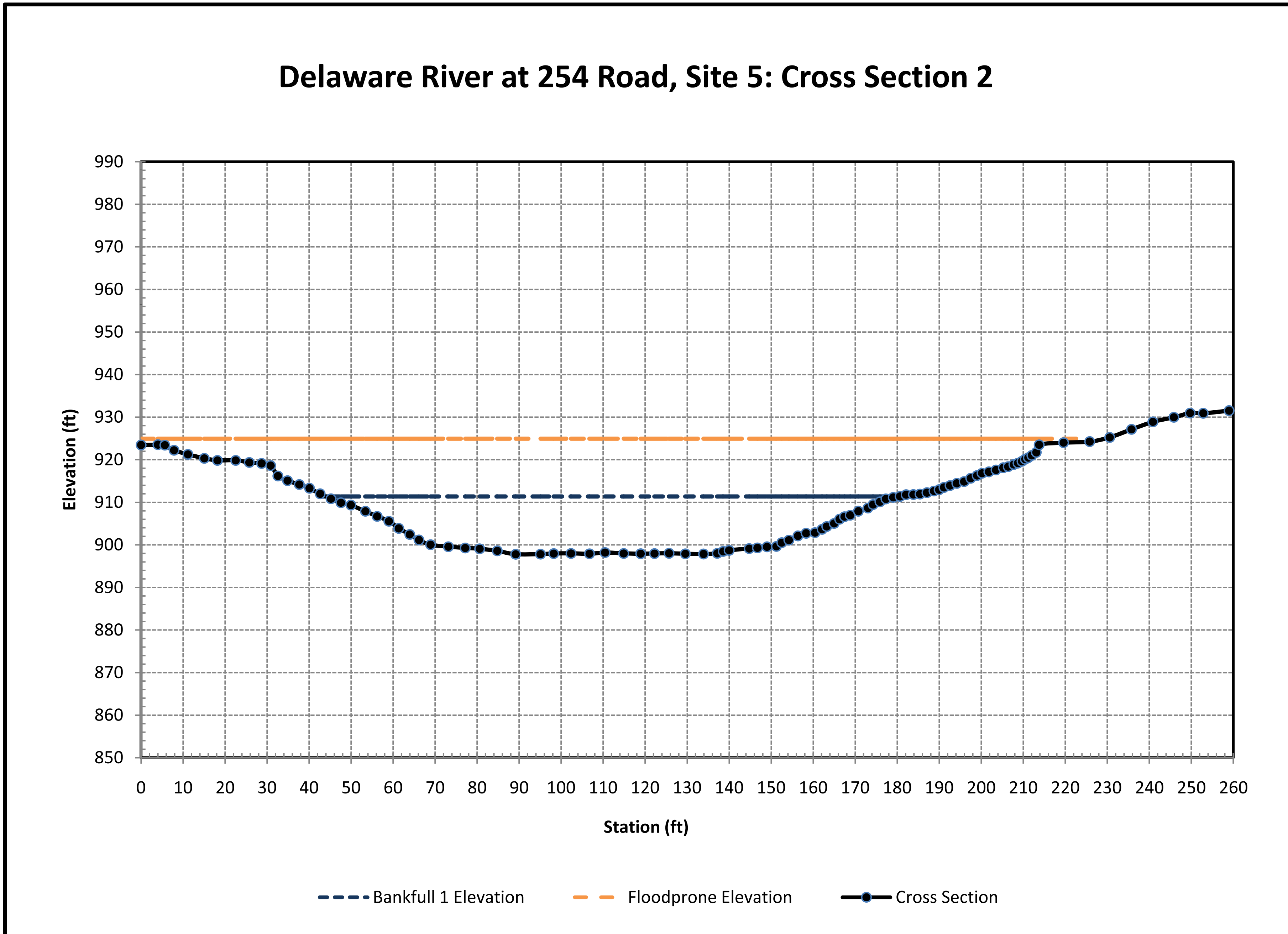
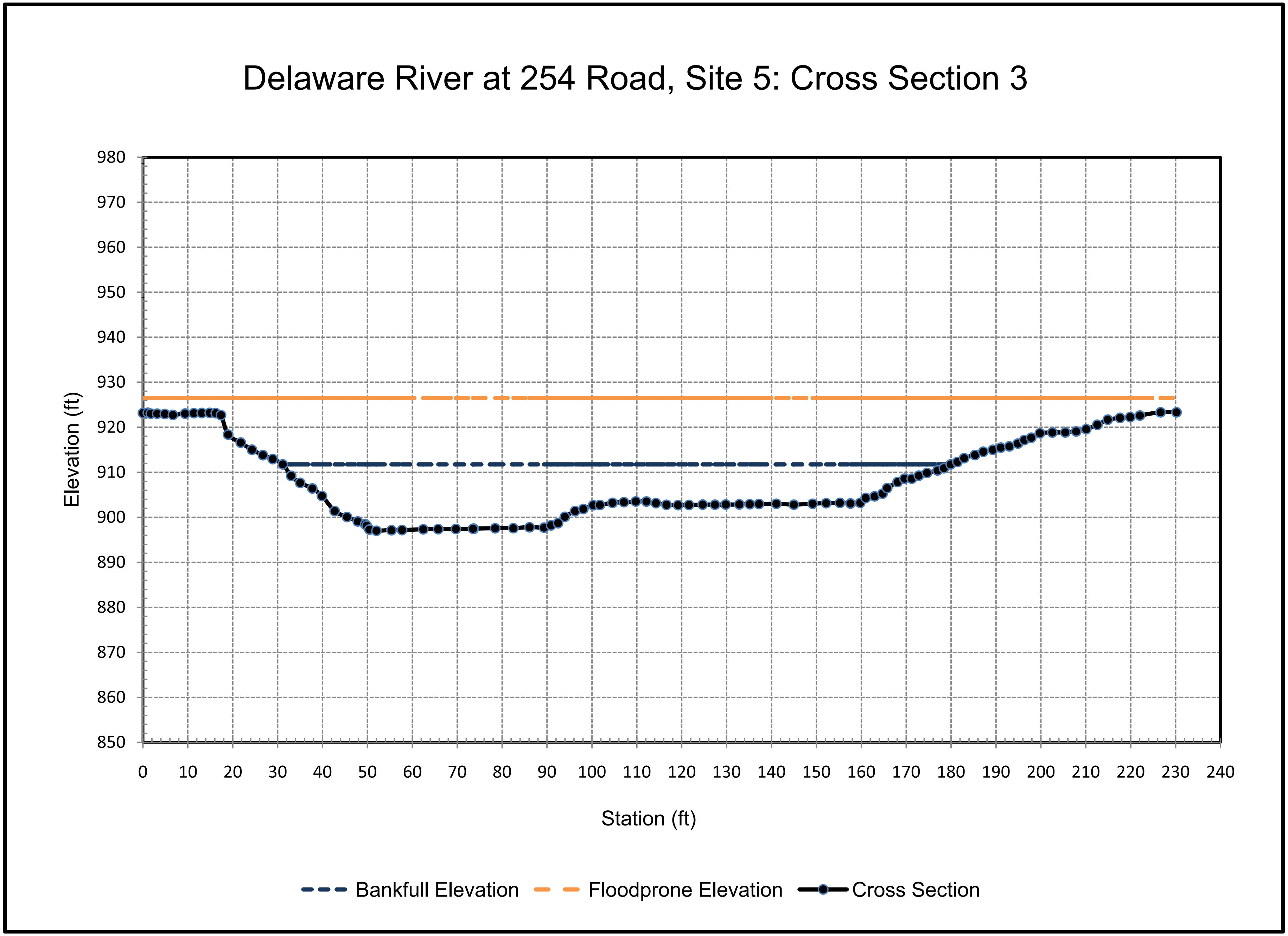
Elevation (ft)
990
980
970
960
950
940
930
920
910
900
890
880
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

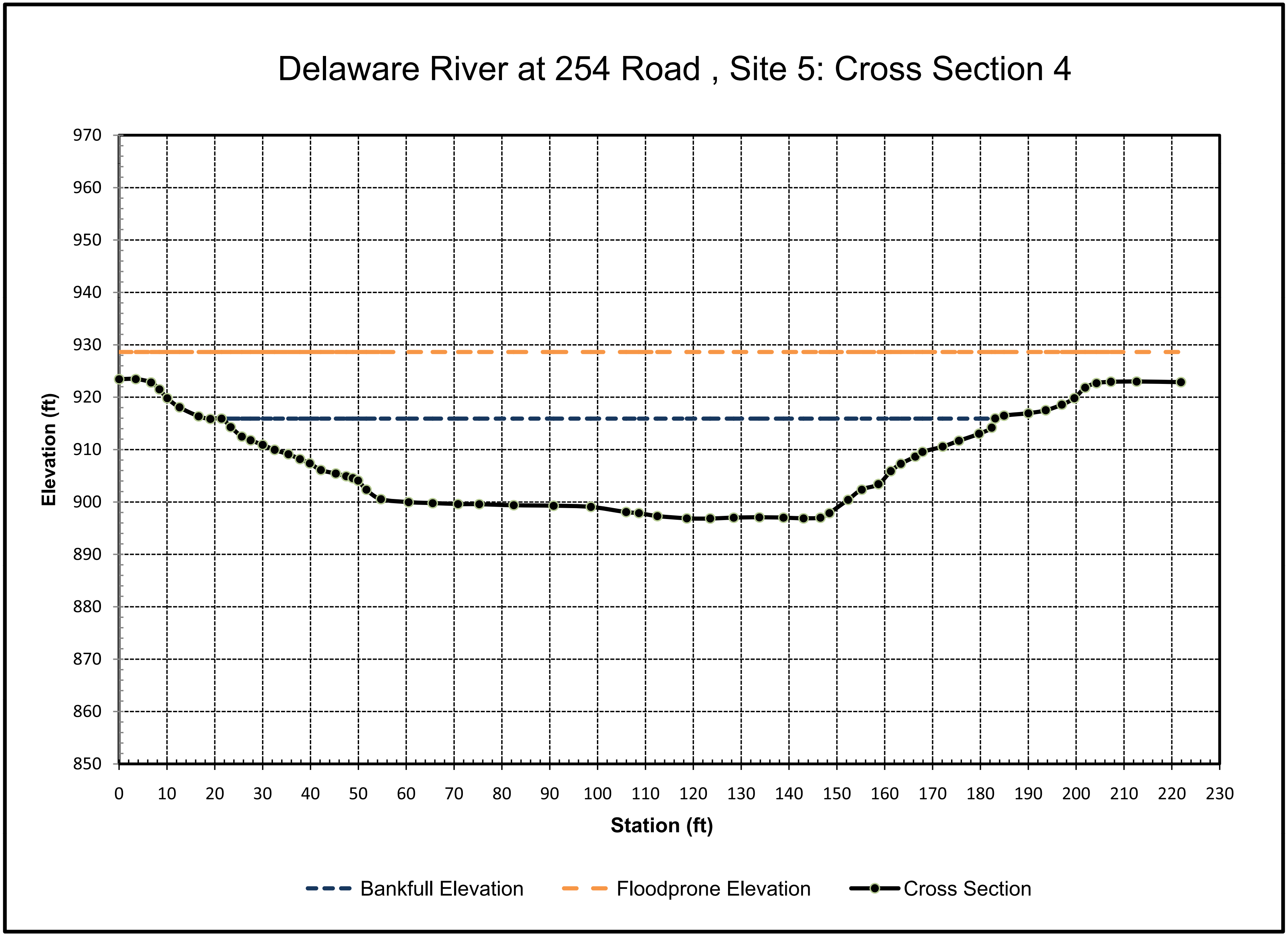

Delaware River at 254 Road, Site 5: Cross Section 1
Elevation (ft)
970
960
950
940
930
920
910
900
890
880
870
860
850
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation

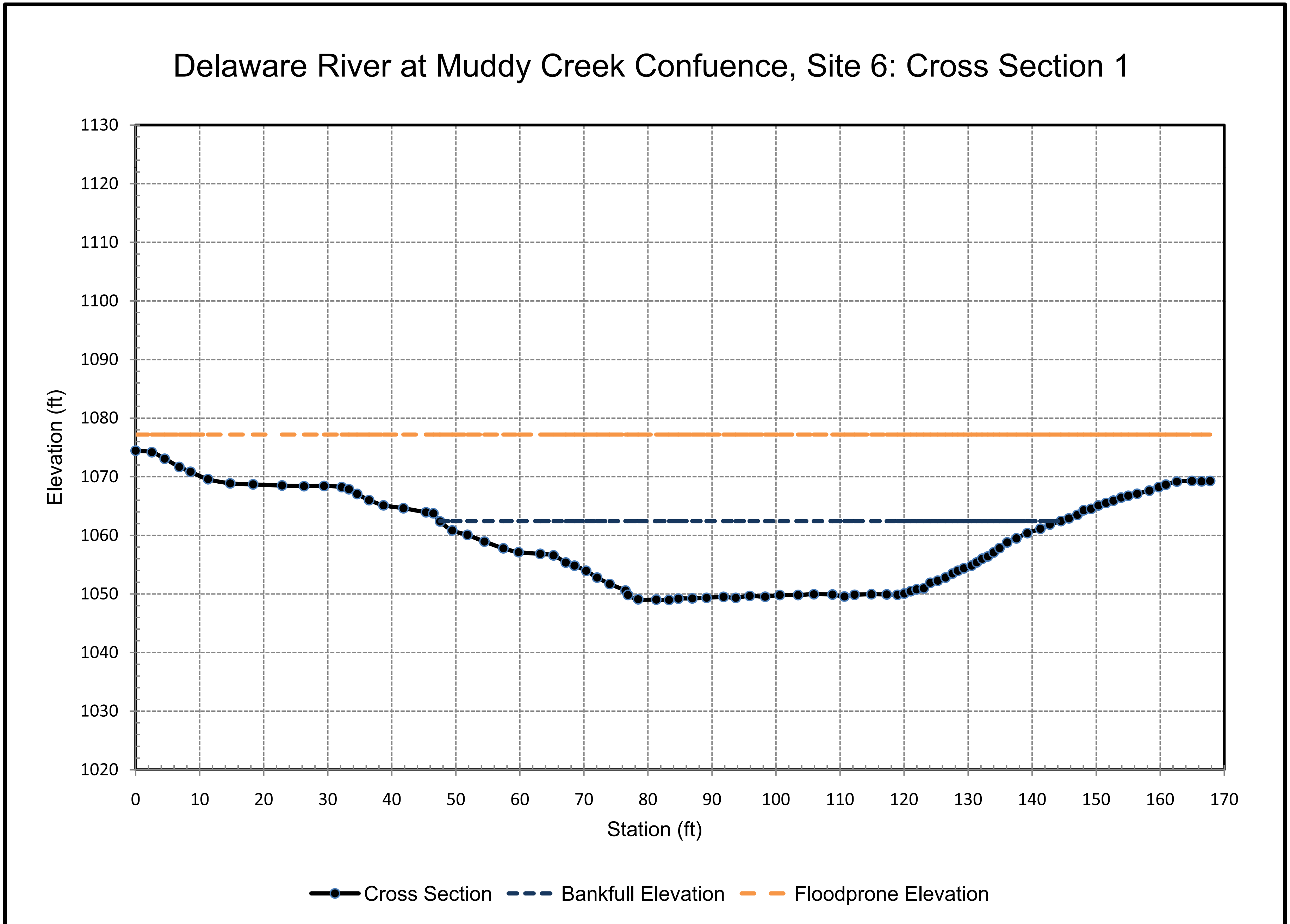


Delaware River at 254 Road, Site 5: Cross Section 2
Elevation (ft)
990
980
970
960
950
940
930
920
910
900
890
880
870
860
850
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
Station (ft)
Bankfull 1 Elevation
Floodprone Elevation
Cross Section

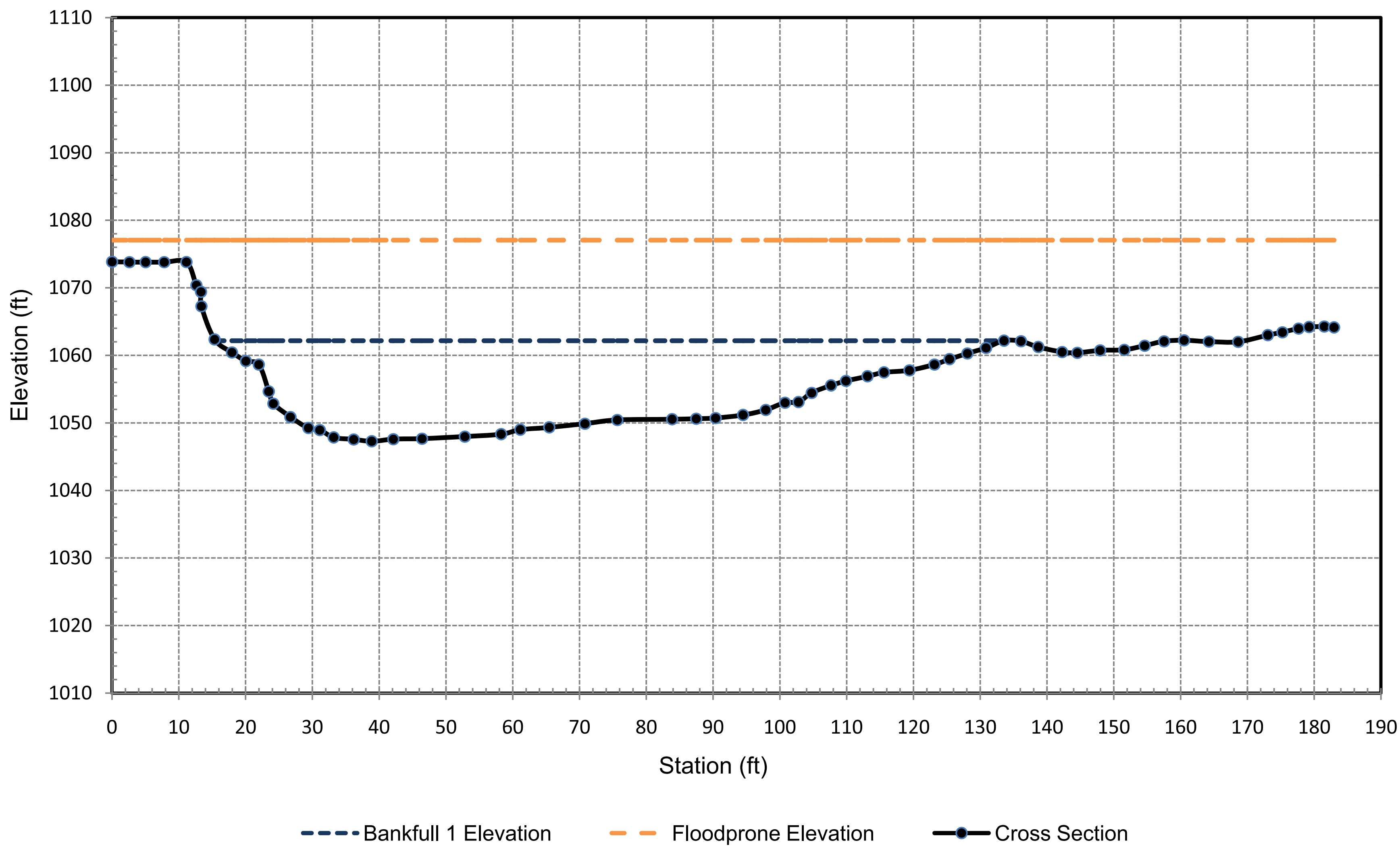


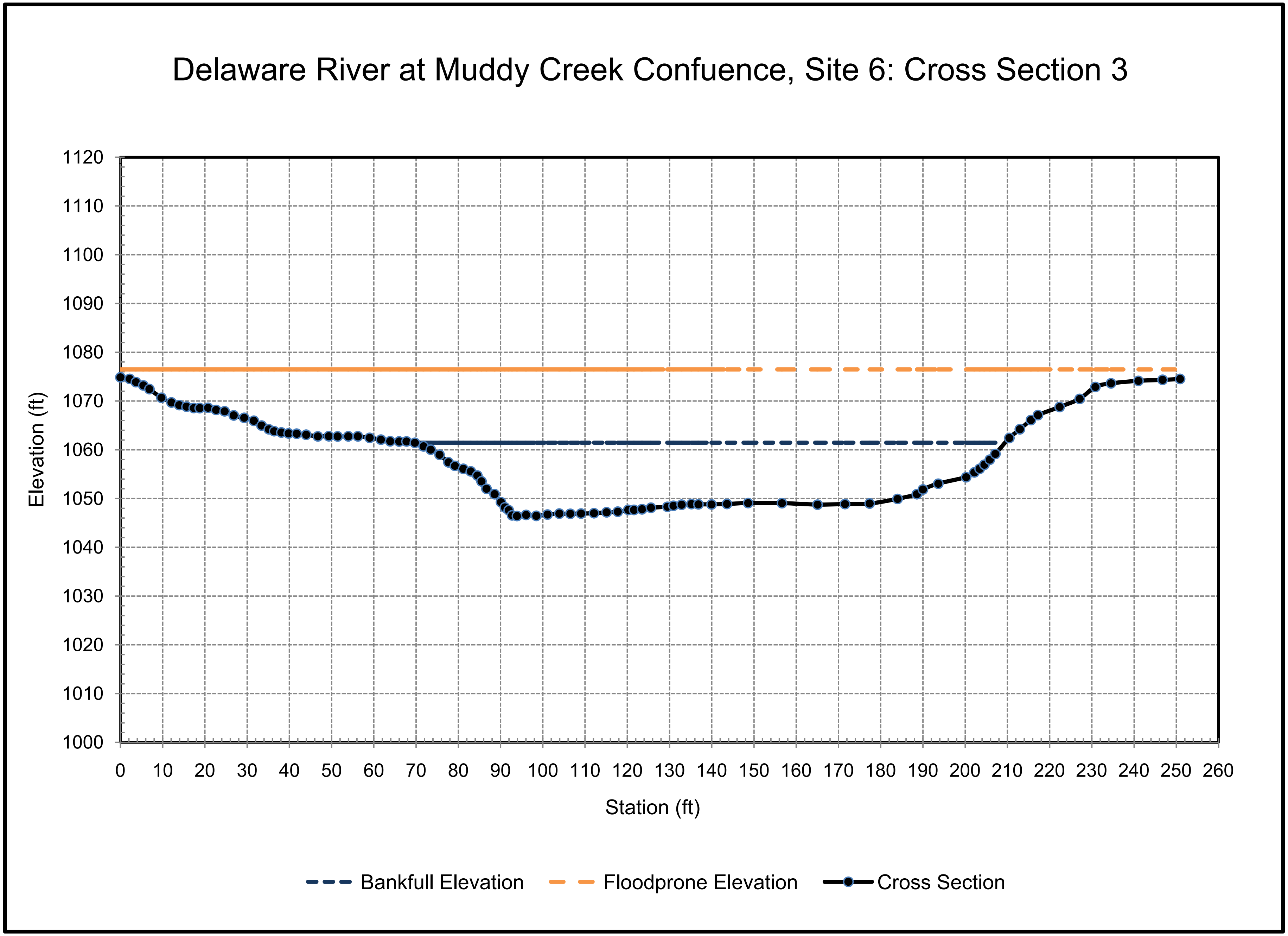
Delaware River at 254 Road, Site 5: Cross Section 3
Elevation (ft)
980
970
960
950
940
930
920
910
900
890
880
870
860
850
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

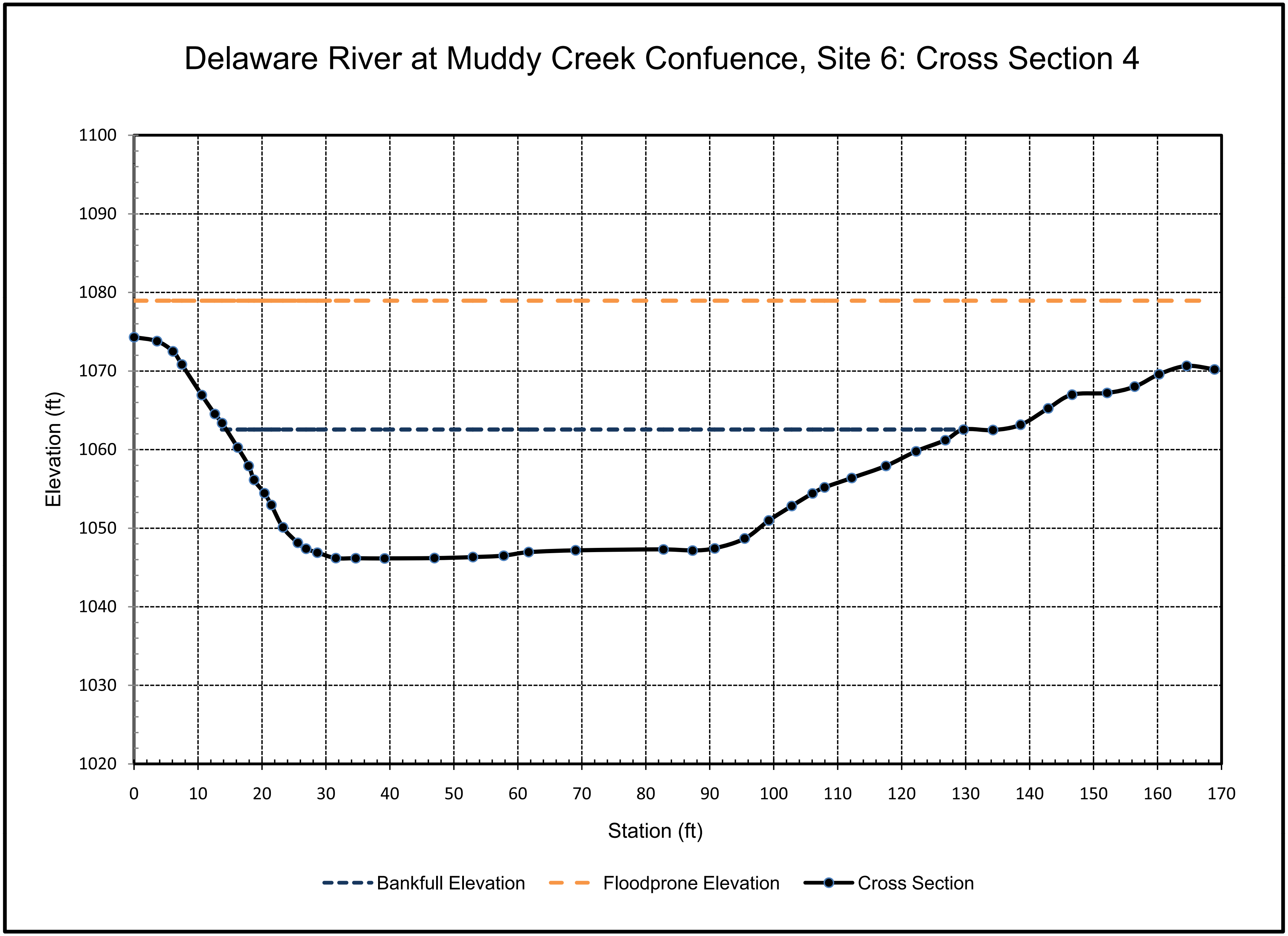

Delaware River at 254 Road , Site 5: Cross Section 4
Elevation (ft)
970
960
950
940
930
920
910
900
890
880
870
860
850
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

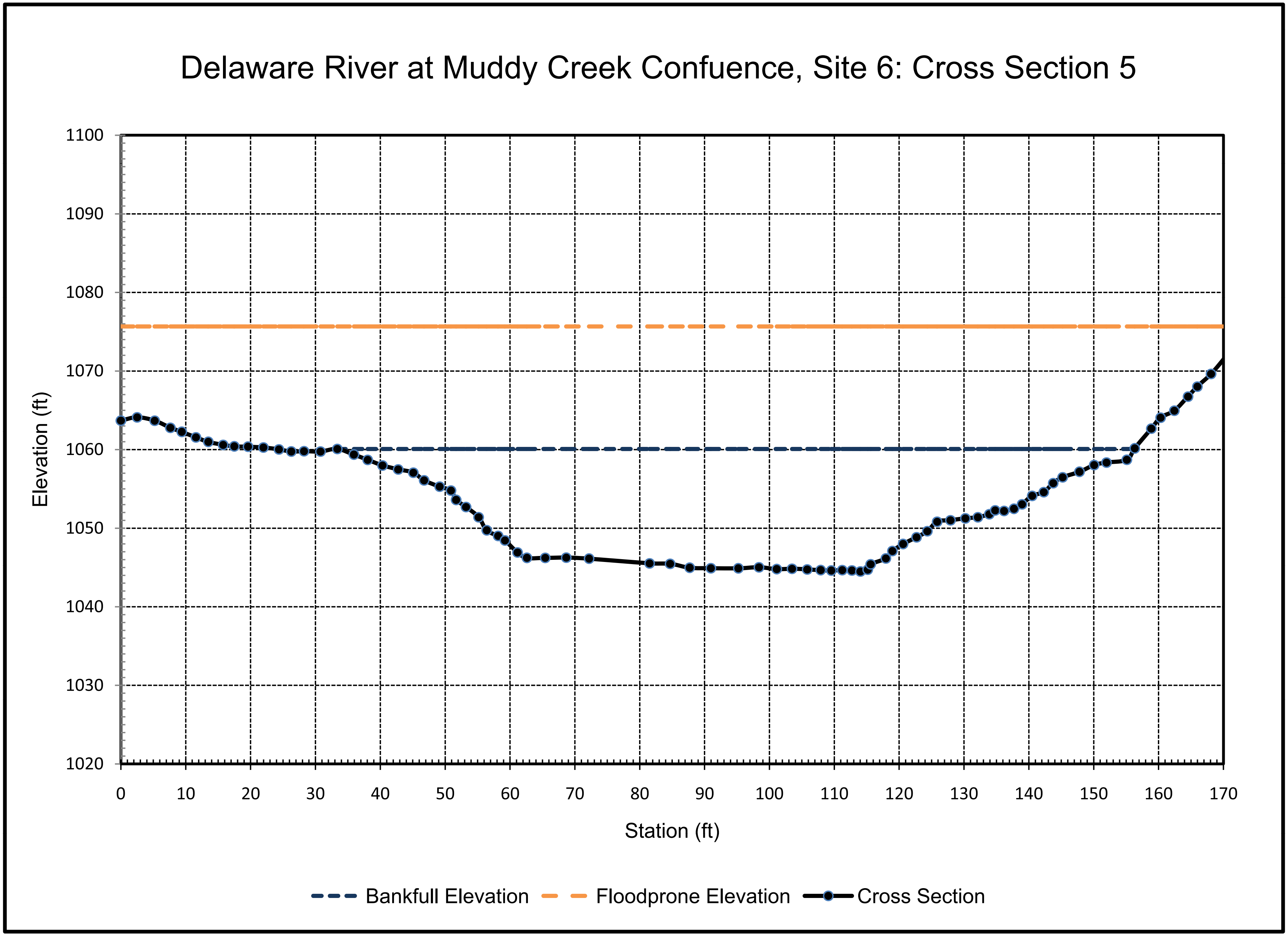

Delaware River at Muddy Creek Confuence, Site 6: Cross Section 1
Elevation (ft)
1130
1120
1110
1100
1090
1080
1070
1060
1050
1040
1030
1020
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Station (ft)
Cross Section
Bankfull Elevation
Floodprone Elevation

Delaware River at Muddy Creek Confuence, Site 6: Cross Section 2




Delaware River at Muddy Creek Confuence, Site 6: Cross Section 3
Elevation (ft)
1120
1110
1100
1090
1080
1070
1060
1050
1040
1030
1020
1010
1000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

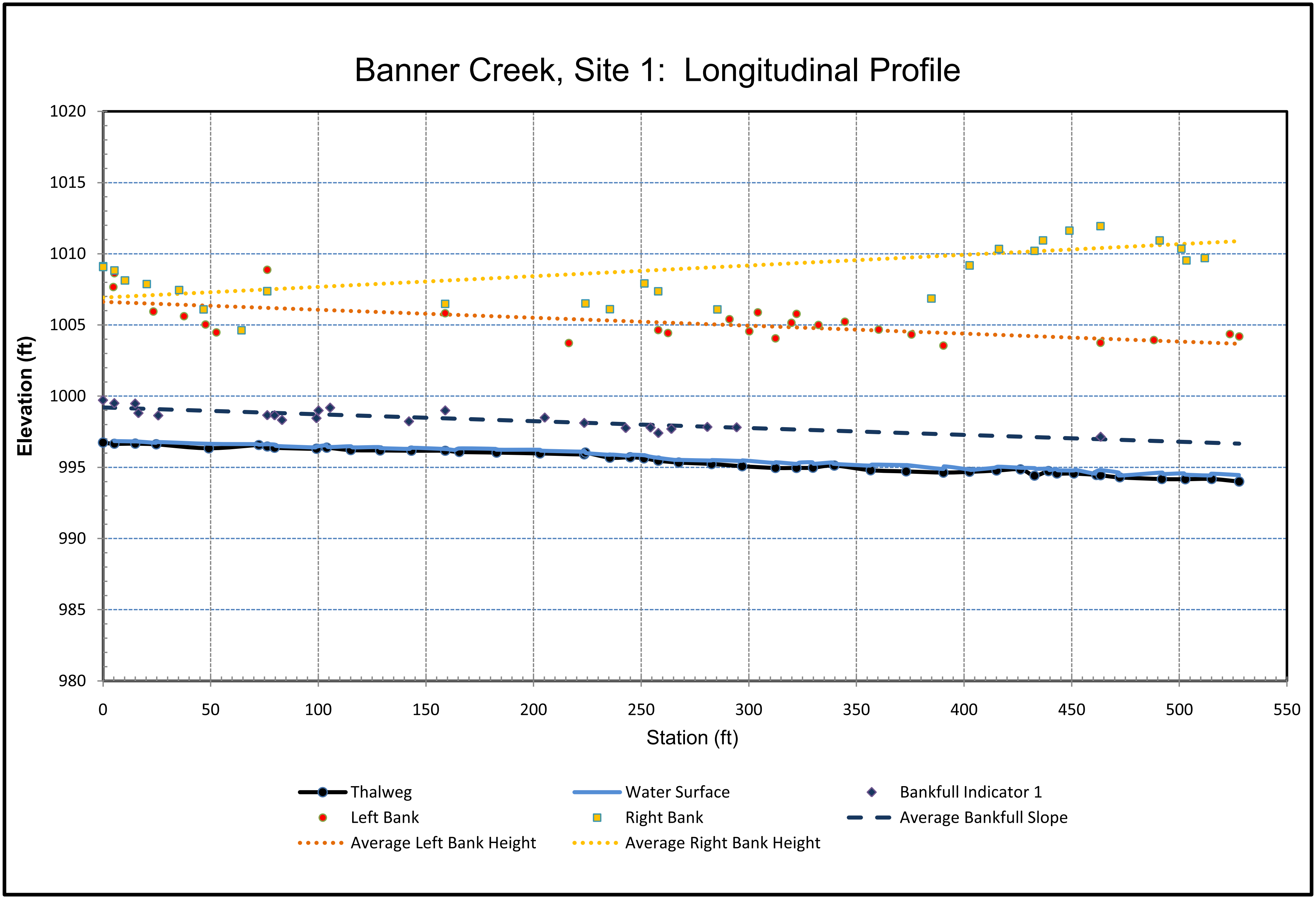

Delaware River at Muddy Creek Confuence, Site 6: Cross Section 4
Elevation (ft)
1100
1090
1080
1070
1060
1050
1040
1030
1020
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section


Delaware River at Muddy Creek Confuence, Site 6: Cross Section 5
Elevation (ft)
1100
1090
1080
1070
1060
1050
1040
1030
1020
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
Station (ft)
Bankfull Elevation
Floodprone Elevation
Cross Section

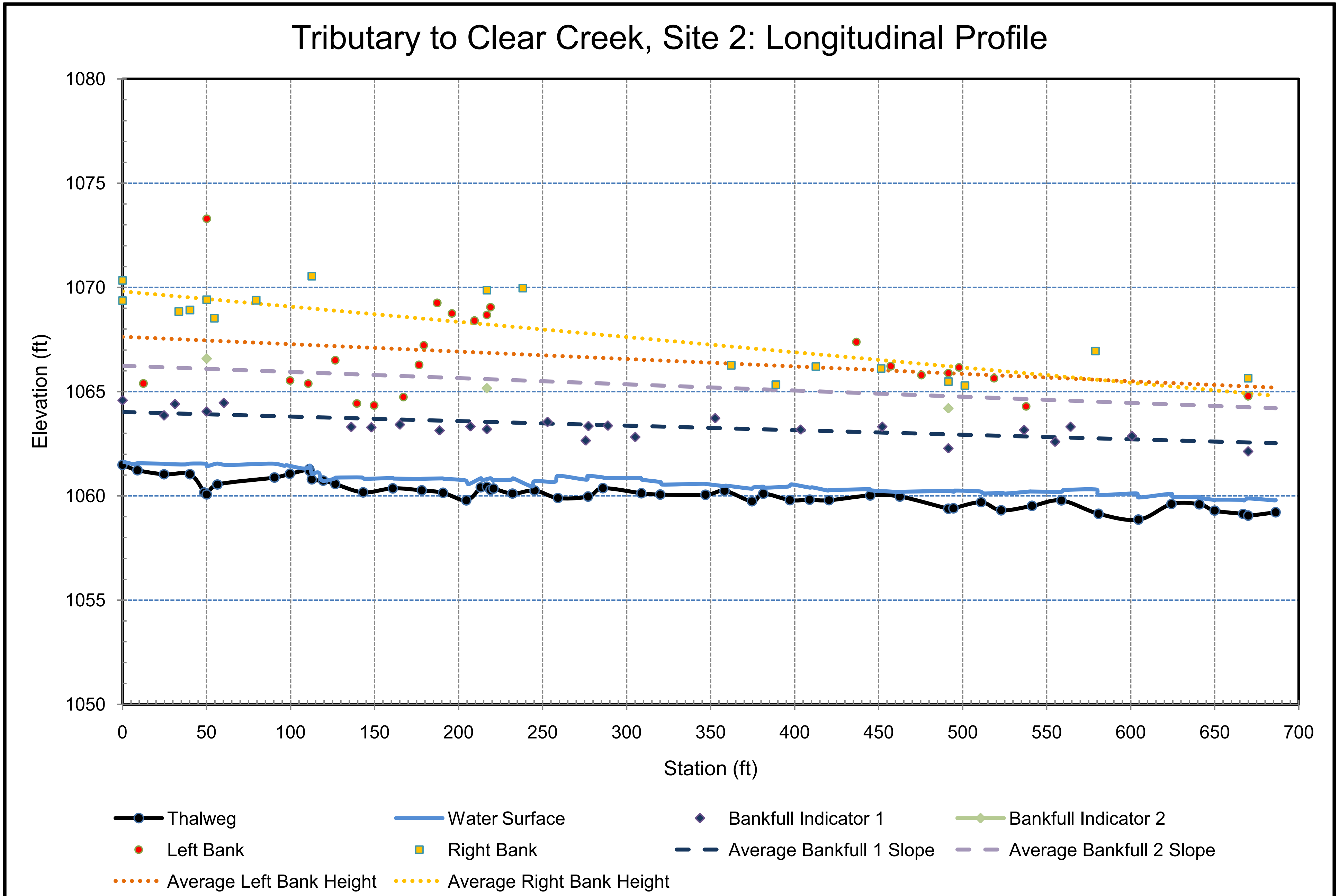
APPENDIX C
LONGITUDINAL PROFILE PLOTS

APPENDIX C:

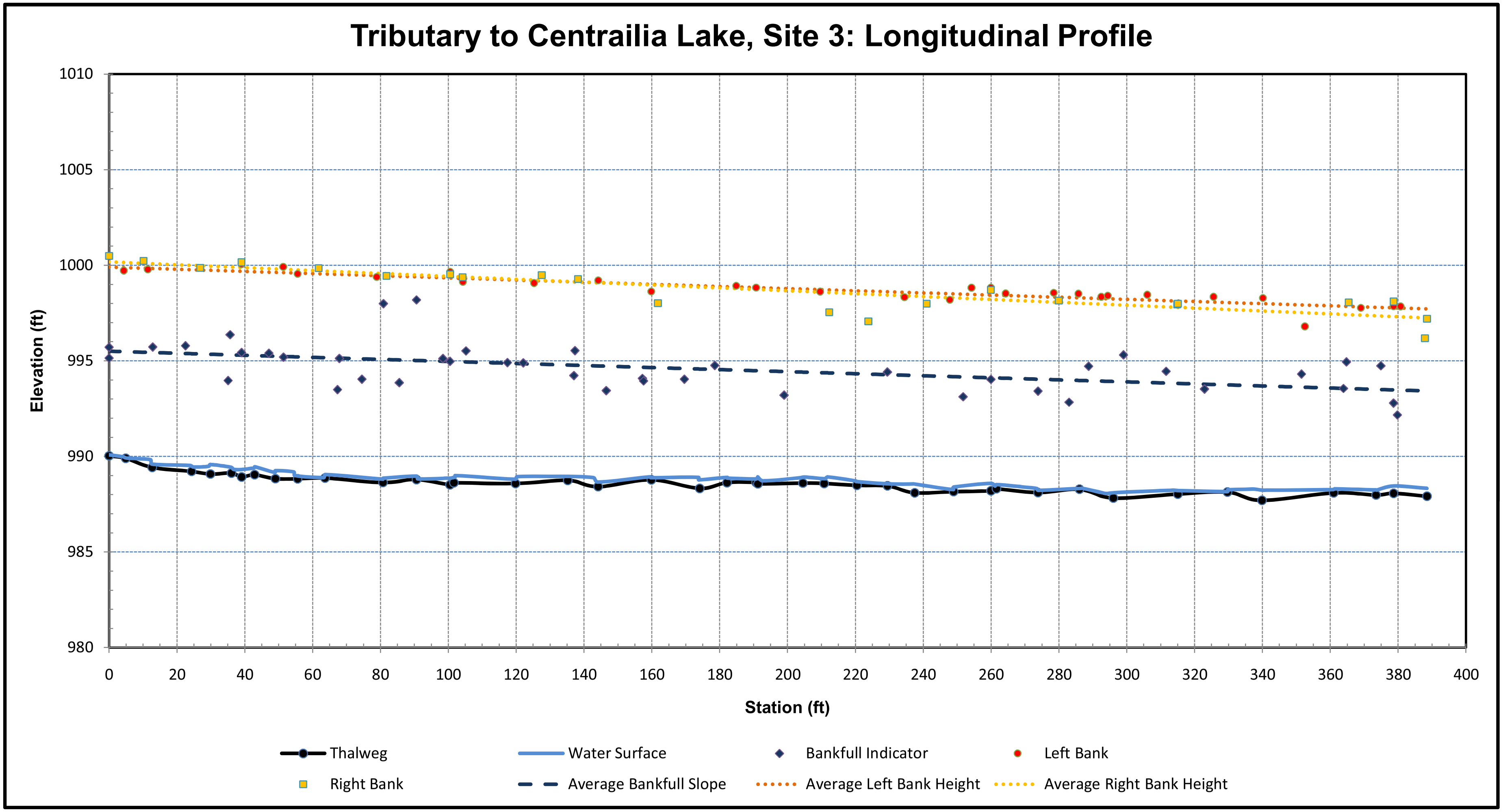
LONGITUDINAL PROFILE PLOTS

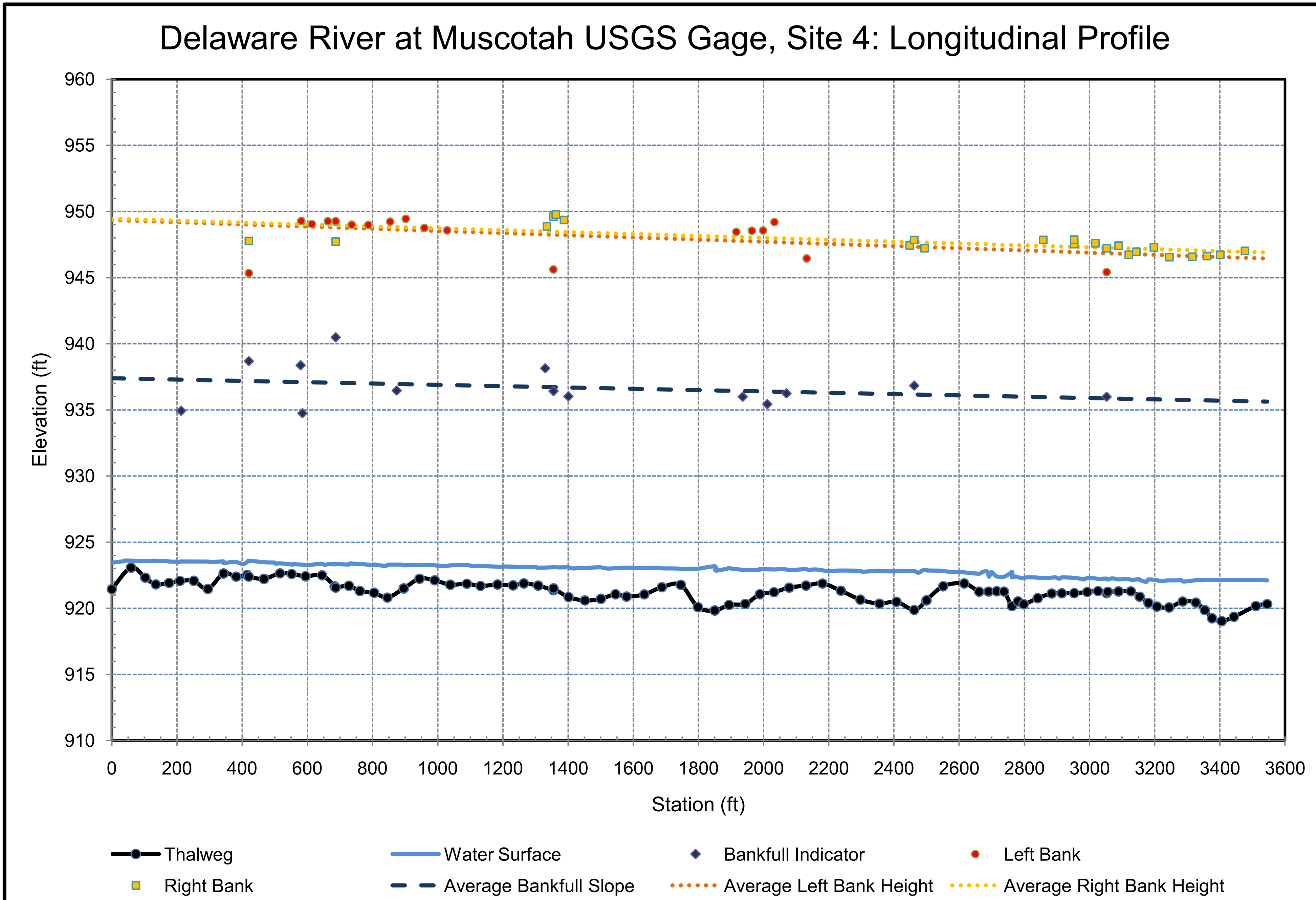


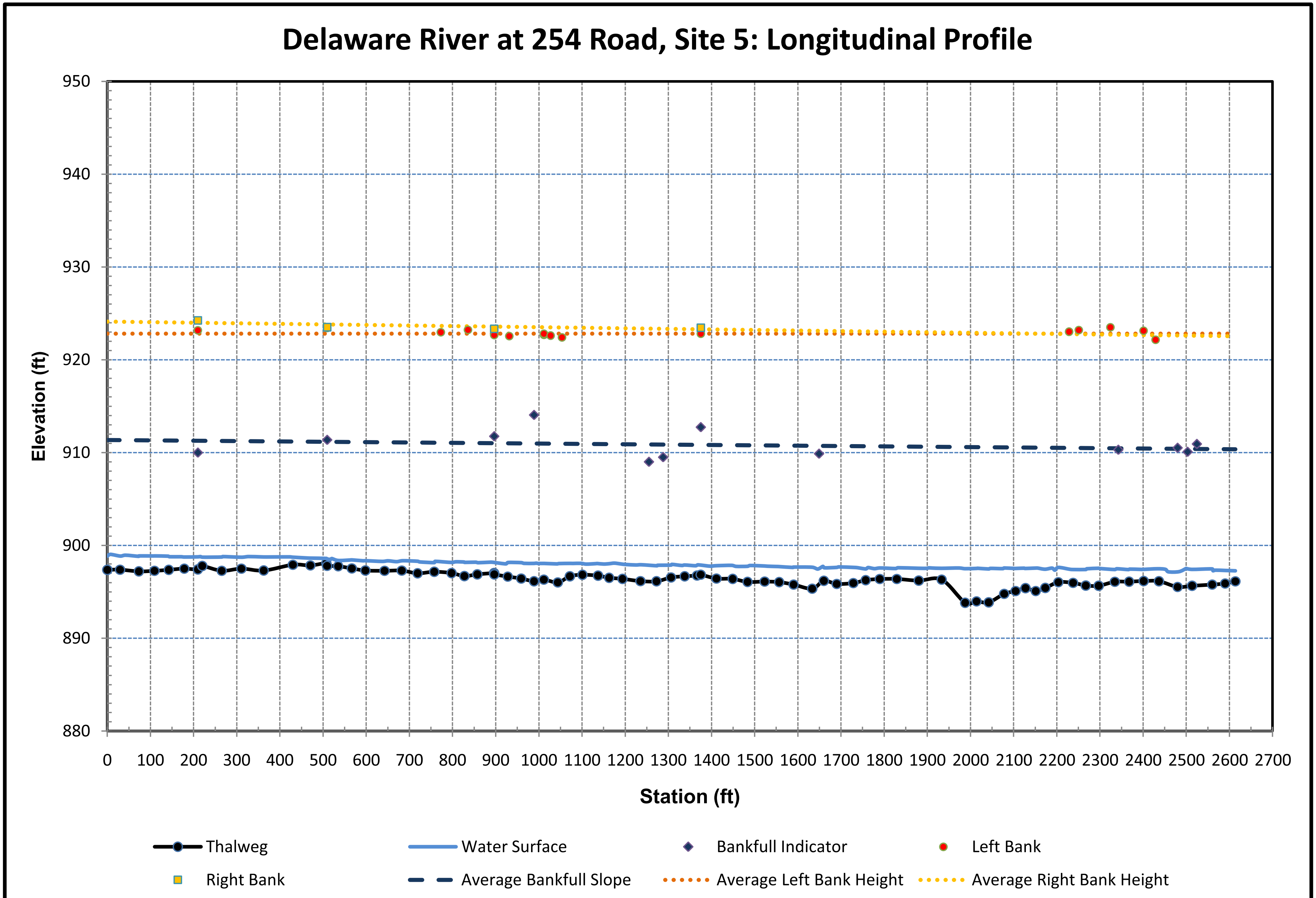
Banner Creek, Site 1: Longitudinal Profile
Elevation (ft)
1020
1015
1010
1005
1000
995
990
985
980
0
50
100
150
200
250
300
350
400
450
500
550
Station (ft)
Thalweg
Water Surface
Bankfull Indicator 1
Left Bank
Right Bank
Average Bankfull Slope
Average Left Bank Height
Average Right Bank Height

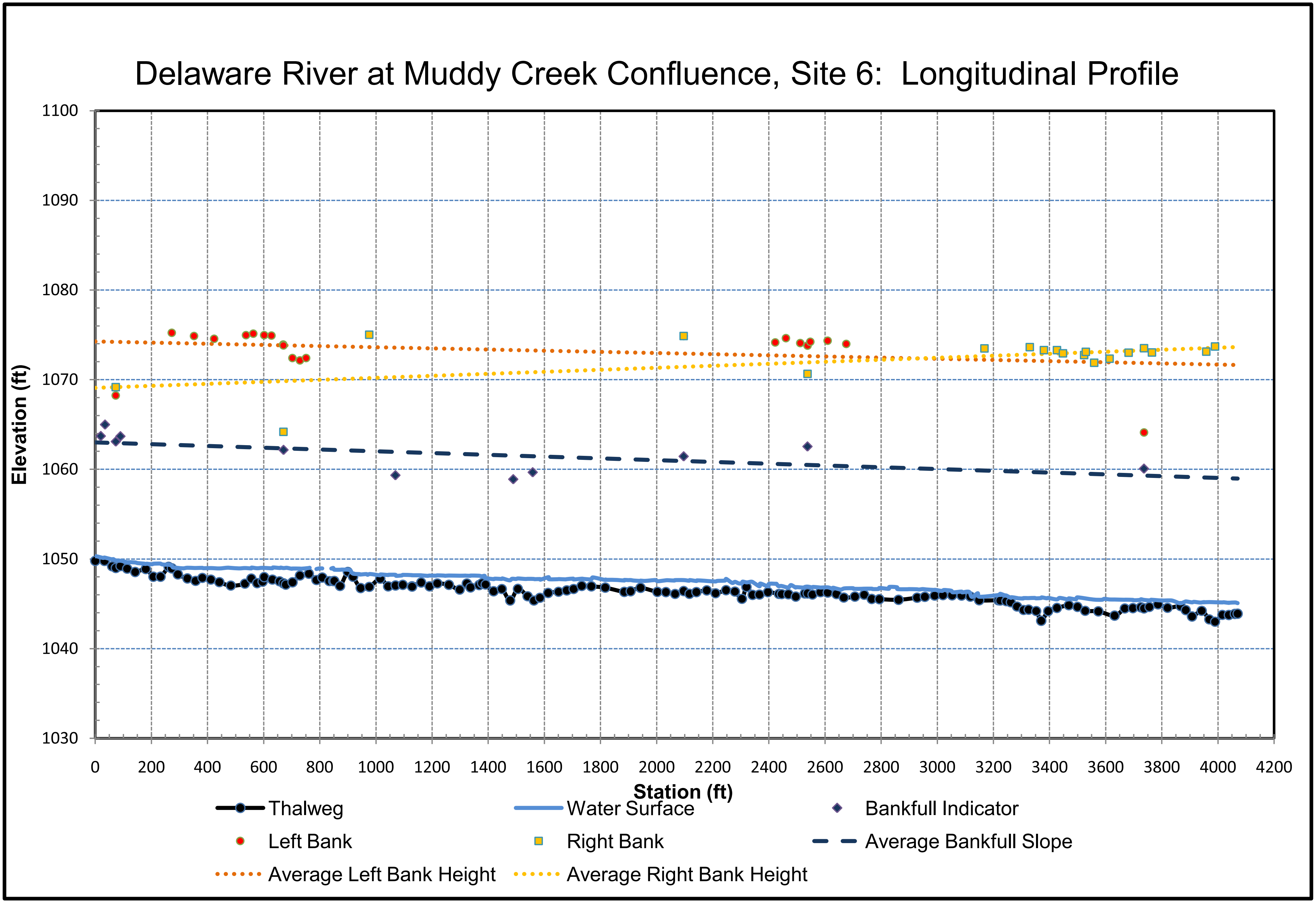


Tributary to Clear Creek, Site 2: Longitudinal Profile
Elevation (ft)
1080
1075
1070
1065
1060
1055
1050
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
Station (ft)
Thalweg
Water Surface
Bankfull Indicator 1
Bankfull Indicator 2
Left Bank
Right Bank
Average Bankfull 1 Slope
Average Bankfull 2 Slope
Average Left Bank Height
Average Right Bank Height


Tributary to Centrailia Lake, Site 3: Longitudinal Profile
Elevation (ft)
1010
1005
1000
995
990
985
980
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
Station (ft)
Thalweg
Water Surface
Bankfull Indicator
Left Bank
Right Bank
Average Bankfull Slope
Average Left Bank Height
Average Right Bank Height


Delaware River at Muscotah USGS Gage, Site 4: Longitudinal Profile
Elevation (ft)
960
955
950
945
940
935
930
925
920
915
910
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
Station (ft)
Thalweg
Water Surface
Bankfull Indicator
Left Bank
Right Bank
Average Bankfull Slope
Average Left Bank Height
Average Right Bank Height


Delaware River at 254 Road, Site 5: Longitudinal Profile
950
940
930
920
910
900
890
880
Elevation (ft)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
Station (ft)
Thalweg
Water Surface
Bankfull Indicator
Left Bank
Right Bank
Average Bankfull Slope
Average Left Bank Height
Average Right Bank Height


Delaware River at Muddy Creek Confluence, Site 6: Longitudinal Profile
Elevation (ft)
1100
1090
1080
1070
1060
1050
1040
1030
Station (ft)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
Thalweg
Water Surface
Bankfull Indicator
Left Bank
Right Bank
Average Bankfull Slope
Average Left Bank Height
Average Right Bank Height

APPENDIX D
GEOMORPHIC SUMMARIES AND DIMENSIONLESS RATIOS

APPENDIX D:

Rosgen Level II Stream Classification System

(WARSS Worksheet 4-1, Rosgen 2006)

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

Stream:	**Banner Creek**				
Basin:	**Delaware**	Drainage Area:	**486.4** acres	**0.76**	mi^2
Location:	**Banner Creek Reservoir**				
Twp.&Rge:	**7; 14**	Sec.&Qtr.:	**8; SE**		
Cross-Section Monuments (Lat./Long.):	**39.454182 Lat / -95.872133 Long**			Date:	**05/28/09**
Observers:	**GSRC, TWI**			Valley Type:	VIII

Parameter	Value	Unit
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**11.21**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**1.86**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**20.83**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**6.03**	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.	**2.84**	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.	**22.85**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**2.04**	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.	**0.24**	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.	**0.00461**	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).	**1.57**	

Stream Type → **B 5c** ← (See **Figure 2-14**)

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

Stream:	**Clear Creek Tributary**				
Basin:	**Delaware**	Drainage Area:	**1164.8** acres	**1.82**	mi^2
Location:	**Atchison County Lake**				
Twp.&Rge:	**5; 18**	Sec.&Qtr.:	**8; NE**		
Cross-Section Monuments (Lat./Long.):	**39.63648 Lat / -95.427925 Long**			Date:	**06/23/09**
Observers:	**GSRC, TWI**			Valley Type:	VIII

Parameter	Value	Units
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**16.78**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**2.38**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**39.93**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**7.05**	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.	**3.6**	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.	**57.2**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**3.41**	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.	**0.03**	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.	**0.00187**	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).	**1.14**	

Stream Type **E 6** (See **Figure 2-14**)

Field Form fo Level II stream Classification

Stream:	**Centralia Lake Tributary**				
Basin:	**Lower Big Blue**	Drainage Area:	**780.8** acres	**1.22**	mi^2
Location:	**Centralia Lake**				
Twp.&Rge:	**4; 11**	Sec.&Qtr.:	**25; SW**		
Cross-Section Monuments (Lat./Long.):	**39.66971 Lat / -96.140965 Long**			Date:	**05/29/09**
Observers:	**GSRC, TWI**			Valley Type:	VIII

Parameter	Value	Unit
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**18.06**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**3.53**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**63.8**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**5.12**	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.	**6.51**	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.	**60.53**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**3.35**	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.	**0.03**	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.	**0.00537**	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).	**1.02**	

Stream Type **E 6** (See **Figure 2-14**)

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

Stream: **Delaware River**	
Basin: **Delaware**	Drainage Area: **280832** acres **438.8** mi^2
Location: **Near Muscotah USGS Gage Station**	
Twp.&Rge: **6; 17**	Sec.&Qtr.: **21; NW**
Cross-Section Monuments (Lat./Long.): **39.52125 Lat / -95.53242 Long**	Date: **09/01/09**
Observers: **GSRC, TWI**	Valley Type: VIII

Parameter	Value	Units
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**138.09**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**12.76**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**1,761.72**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**10.82**	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.	**16.28**	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.	**440**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**3.19**	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.	**0.95**	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.	**0.0005**	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).	**1.13**	

Stream Type **E 5** (See **Figure 2-14**)

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

Stream:	**Delaware River**		
Basin:	**Delaware**	Drainage Area: **284992** acres	**445.3** mi^2
Location:	**Near 254th Road**		
Twp.&Rge:	**6; 17**	Sec.&Qtr.: **21; NW**	
Cross-Section Monuments (Lat./Long.):	**39.503085 Lat / -95.534587 Long**		Date: **09/02/09**
Observers:	**GSRC, TWI**		Valley Type: VIII

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**136.67**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**9.96**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**1360.79**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**13.72**	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.	**13.57**	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.	**389**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**2.85**	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.	**0.17**	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.	**0.00038**	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).	**1.25**	

Stream Type **C 5c-** (See **Figure 2-14**)

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

Stream:	**Delaware River**		
Basin:	**Delaware**	Drainage Area: **96704** acres	**151.1** mi^2
Location:	**Above Muddy Creek Confluence**		
Twp.&Rge:	**5; 16**	Sec.&Qtr.: **4; SE**	
Cross-Section Monuments (Lat./Long.):	**39.63782 Lat / -95.623893 Long**		Date: **09/14/09**
Observers:	**GSRC, TWI**		Valley Type: VIII

Parameter	Value	Units
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**99.22**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**9.53**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**945.8**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**10.41**	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.	**14.1**	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.	**600**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**6.05**	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.	**0.81**	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.	**0.00099**	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).	**1.32**	

Stream Type **E 5** (See **Figure 2-14**)

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

Stream:	**Delaware River**
Basin:	**Delaware** Drainage Area: **163328** acres **255.2** mi^2
Location:	**Below Muddy Creek Confluence**
Twp.&Rge:	**5; 16** Sec.&Qtr.: **9; NE**
Cross-Section Monuments (Lat./Long.):	**39.63782 Lat / -95.623893 Long** Date: **09/14/09**
Observers:	**GSRC, TWI** Valley Type: VIII

Parameter	Value	Units
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**120.32**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**11.62**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**1398.04**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**10.35**	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.	**16.4**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**480**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**3.99**	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.	**0.81**	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.	**0.00099**	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).	**1.32**	

Stream Type **E 5** (See **Figure 2-14**)

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APPENDIX E
BEHI SUMMARIES

APPENDIX E:

BANK ERODIBILITY HAZARD INDEX (BEHI)

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: **Banner Creek**		Location: **Banner Creek Reservoir**
Station: **Bank Type 1**		Observers: **GSRC, TWI**
Date: **05/28/09**	Stream Type: **B 5c**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	11.05 (A)	Bankfull Height (ft) =	1.67 (B)	(A) / (B) =	6.61677 (C)	10

Root Depth / Study Bank Height (E)

Root Depth (ft) =	11.05 (D)	Study Bank Height (ft) =	11.05 (A)	(D) / (A) =	1 (E)	1

Weighted Root Density (G)

Root Density as % =	50 (F)	(F) x (E) =	50 (G)	4.32

Bank Angle (H)

Bank Angle as *Degrees* =	60 (H)	3.9

Surface Protection (I)

Surface Protection as % =	10 (I)	9

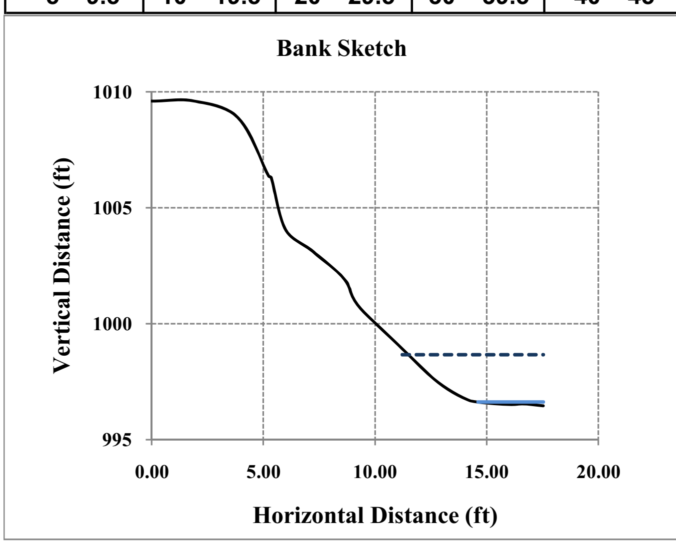
Bank Material Adjustment:

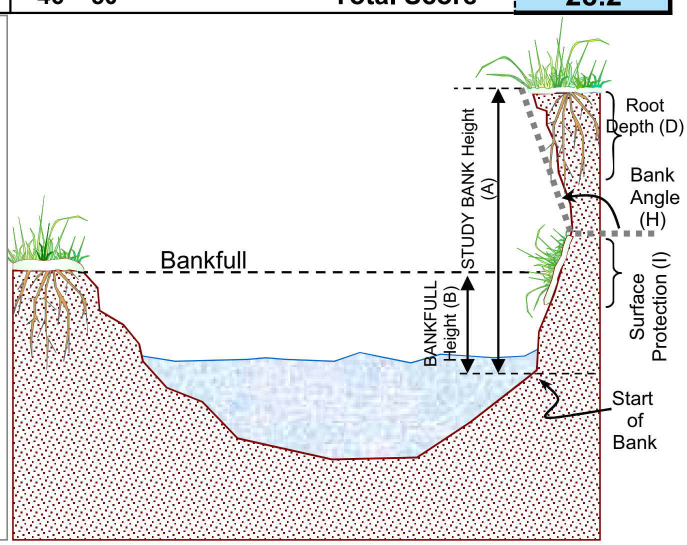
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no 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	**Moderate** 28.2





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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:	**Banner Creek**	Location:	**Banner Creek Reservoir**
Station:	**Bank Type 2**	Observers:	**GSRC, TWI**
Date:	**05/28/09**	Stream Type: **B 5c**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	17.02 (A)	Bankfull Height (ft) =	2.22 (B)	(A) / (B) =	7.66667 (C)	BEHI Score: 10

Root Depth / Study Bank Height (E)

Root Depth (ft) =	14 (D)	Study Bank Height (ft) =	17.02 (A)	(D) / (A) =	0.82256 (E)	BEHI Score: 2.34

Weighted Root Density (G)

Root Density as % =	20 (F)	(F) x (E) =	16.4512 (G)	BEHI Score: 7.7

Bank Angle (H)

Bank Angle as *Degrees* =	48 (H)	BEHI Score: 3.32

Surface Protection (I)

Surface Protection as % =	5 (I)	BEHI Score: 10

Bank Material Adjustment:

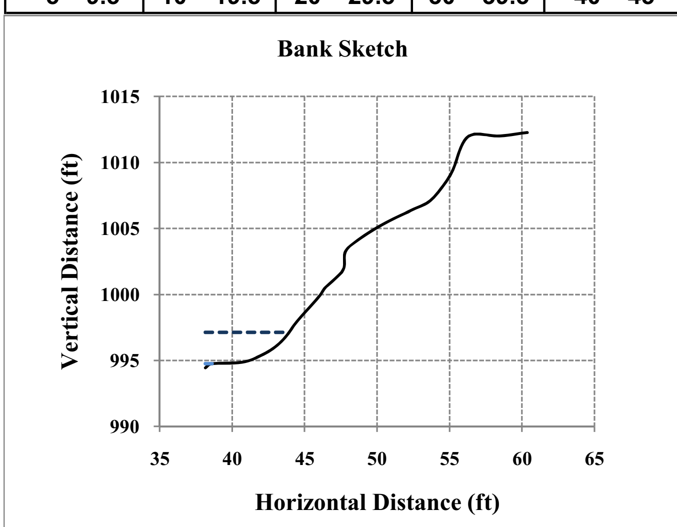
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

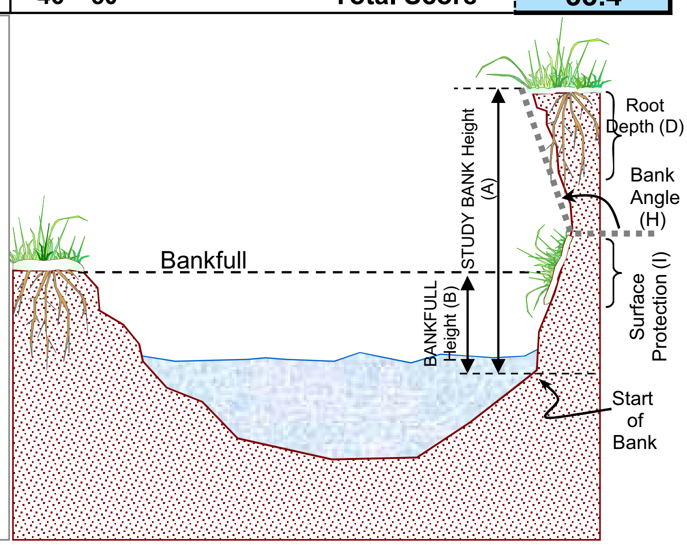
Bank Material Adjustment: 0

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**: **High** / **33.4**





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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:	**Clear Creek Tributary**	Location:	**Atchison County Lake**
Station:	**Bank Type 1**	Observers:	**GSRC, TWI**
Date: **06/23/09**	Stream Type: **E 6**	Valley Type:	**VIII**

Variable	Inputs	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 6.86 (A); Bankfull Height (ft) = 3.56 (B)	(A) / (B) =	1.92697 (C)	7.57
Root Depth / Study Bank Height (E)	Root Depth (ft) = 6.86 (D); Study Bank Height (ft) = 6.86 (A)	(D) / (A) =	1 (E)	1
Weighted Root Density (G)	Root Density as % = 40 (F)	(F) x (E) =	40 (G)	5.11
Bank Angle (H)	Bank Angle as *Degrees* =		58 (H)	3.8
Surface Protection (I)	Surface Protection as % =		50 (I)	4.32
Bank Material Adjustment				0
Stratification Adjustment				0

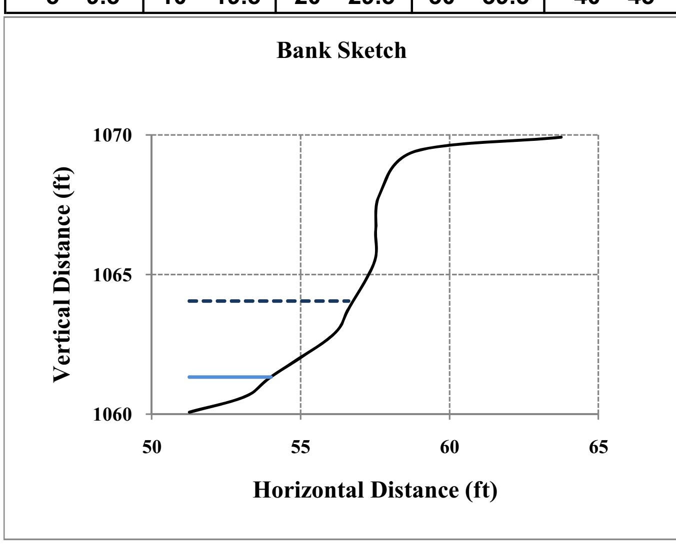
Bank Material Adjustment:

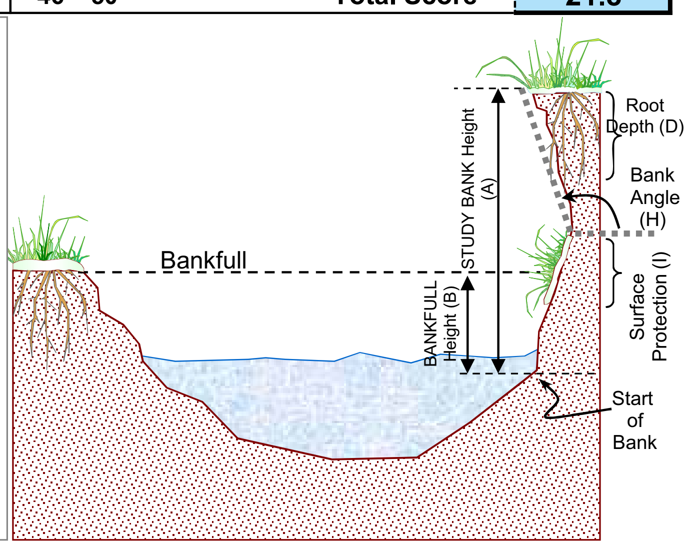
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no 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	**Moderate** 21.8





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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:	**Centralia Lake Tributary**	Location:	**Centralia Lake**
Station:	**Bank Type 1**	Observers:	**GSRC, TWI**
Date:	**05/29/09**	Stream Type: **E 6**	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) = 3.33 (A)	Bankfull Height (ft) = 3.33 (B)	(A) / (B) =	1 (C)	1
Root Depth / Study Bank Height (E)	Root Depth (ft) = 3.33 (D)	Study Bank Height (ft) = 3.33 (A)	(D) / (A) =	1 (E)	1
Weighted Root Density (G)		Root Density as % = 75 (F)	(F) x (E) =	75 (G)	2.32
Bank Angle (H)			Bank Angle as *Degrees* =	63 (H)	4.2
Surface Protection (I)			Surface Protection as % =	30 (I)	5.9

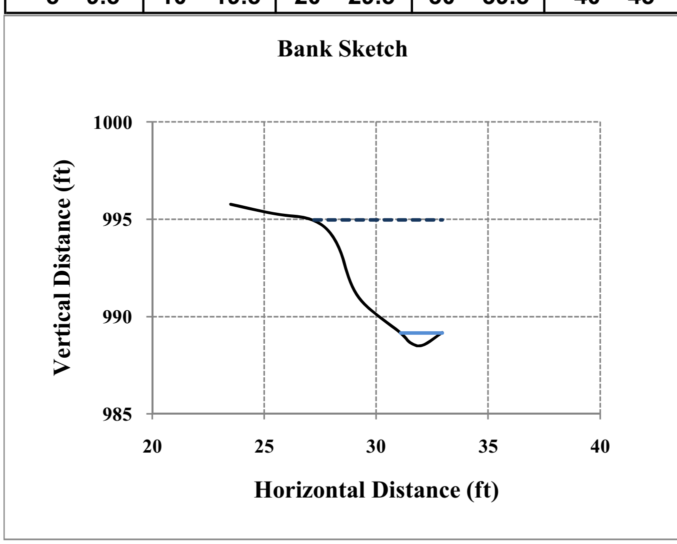
Bank Material Adjustment:

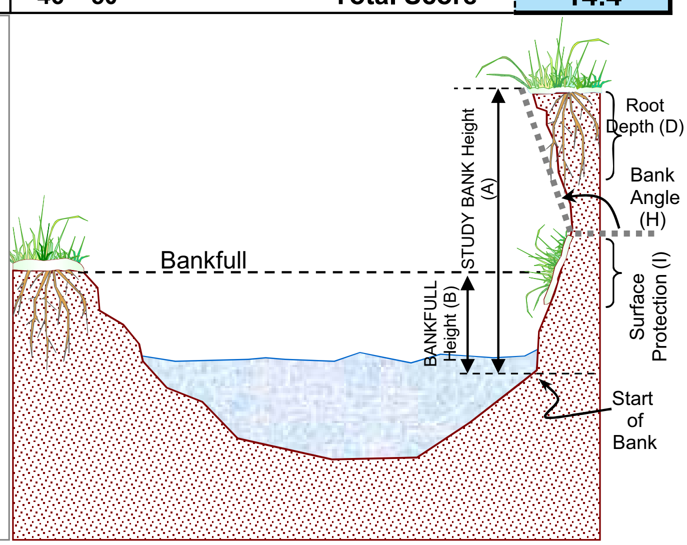
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no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

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 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 / 14.4





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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: **Centralia Lake Tributary** Location: **Centralia Lake**

Station: **Bank Type 2** Observers: **GSRC, TWI**

Date: **05/29/09** Stream Type: **E 6** Valley Type: **VIII**

Variable	Inputs	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 9.92 (A); Bankfull Height (ft) = 5.44 (B); (A) / (B) =	1.82353 (C)	7.05
Root Depth / Study Bank Height (E)	Root Depth (ft) = 8.78 (D); Study Bank Height (ft) = 9.92 (A); (D) / (A) =	0.88508 (E)	2
Weighted Root Density (G)	Root Density as % = 20 (F); (F) x (E) =	17.7016 (G)	7.53
Bank Angle (H)	Bank Angle as *Degrees* =	48 (H)	3.32
Surface Protection (I)	Surface Protection as % =	10 (I)	9

Bank Material Adjustment:

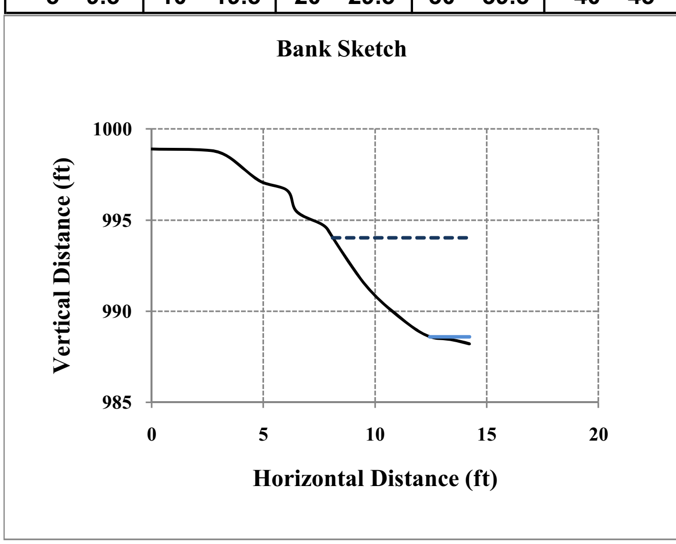
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no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

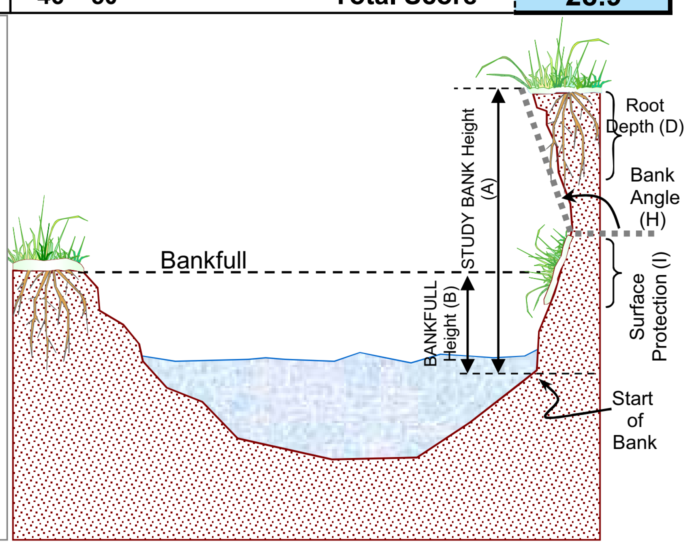
Bank Material Adjustment: 0

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
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and **Total Score**: **Moderate** **28.9**





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:	**Centralia Lake Tributary**		Location:	**Centralia Lake**	
Station:	**Bank Type 3**		Observers:	**GSRC, TWI**	
Date:	**05/29/09**	Stream Type: **E 6**	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) = **9.91** **(A)**	**Bankfull Height** (ft) = **4.09** **(B)**	(A) / (B) =	**2.42298** **(C)**	**8.46**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) = **9.91** **(D)**	**Study Bank Height** (ft) = **9.91** **(A)**	(D) / (A) =	**1** **(E)**	**1**
Weighted Root Density (G)		**Root Density** as **%** = **75** **(F)**	(F) x (E) =	**75** **(G)**	**2.32**
Bank Angle (H)			**Bank Angle** as *Degrees* =	**63** **(H)**	**4.2**
Surface Protection (I)			**Surface Protection** as **%** =	**50** **(I)**	**4.32**

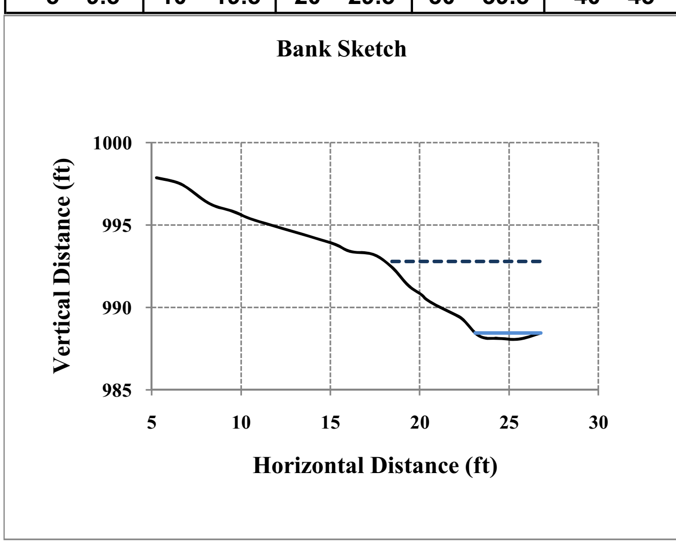
Bank Material Adjustment:

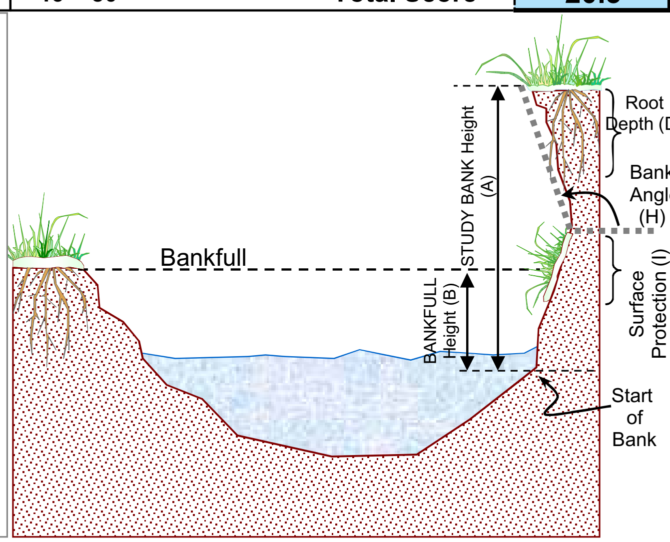
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no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

Bank Material Adjustment: **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** **20.3**





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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: **Delaware River**		Location: **Muscotah USGS Gage**	
Station: **Bank Type 1**		Observers: **GSRC, TWI**	
Date: **08/31/09**	Stream Type: **E 5**	Valley Type: **VIII**	

Variable	Input 1	Input 2	Calculation	Value	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) = **21.74** **(A)**	**Bankfull Height** (ft) = **15.09** **(B)**	(A) / (B) =	**1.44069** **(C)**	**5.52**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) = **21.74** **(D)**	**Study Bank Height** (ft) = **21.74** **(A)**	(D) / (A) =	**1** **(E)**	**1**
Weighted Root Density (G)		**Root Density** as **%** = **60** **(F)**	(F) x (E) =	**60** **(G)**	**3.5**
Bank Angle (H)			**Bank Angle** as *Degrees* =	**36** **(H)**	**2.73**
Surface Protection (I)			**Surface Protection** as **%** =	**50** **(I)**	**4.32**

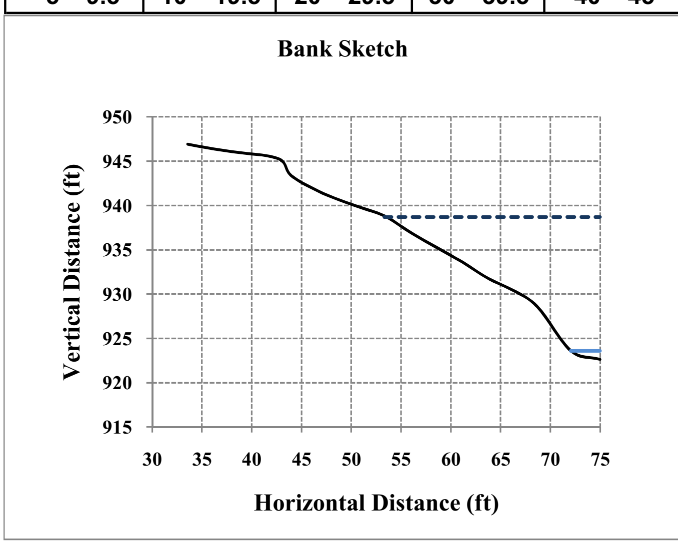
Bank Material Adjustment:

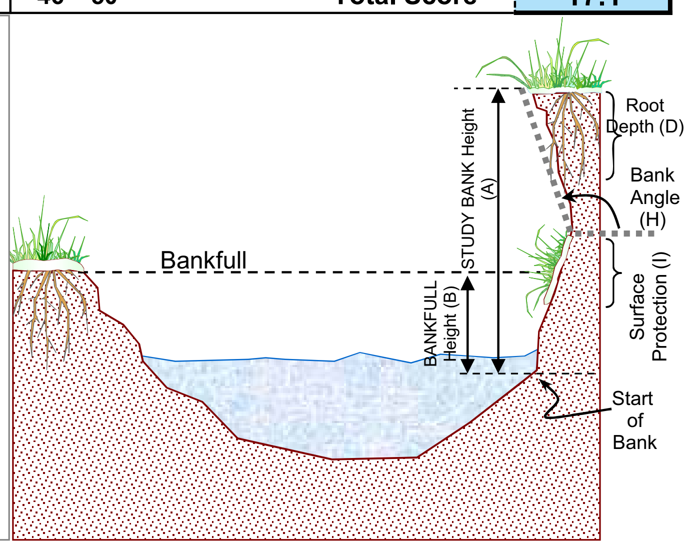
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no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

Bank Material Adjustment: **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** / **17.1**





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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:	**Delaware River**	Location:	**Muscotah USGS Gage**
Station:	**Bank Type 2**	Observers:	**GSRC, TWI**
Date:	**08/31/09**	Stream Type: **E 5**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	23.93 (A)	Bankfull Height (ft) =	13.92 (B)	(A) / (B) =	1.71911 (C)	6.57

Root Depth / Study Bank Height (E)

Root Depth (ft) =	10.8 (D)	Study Bank Height (ft) =	23.93 (A)	(D) / (A) =	0.45132 (E)	4.4

Weighted Root Density (G)

Root Density as % =	20 (F)	(F) x (E) =	9.02633 (G)	8.55

Bank Angle (H)

Bank Angle as *Degrees* =	46.5 (H)	3.24

Surface Protection (I)

Surface Protection as % =	10 (I)	9

Bank Material Adjustment:

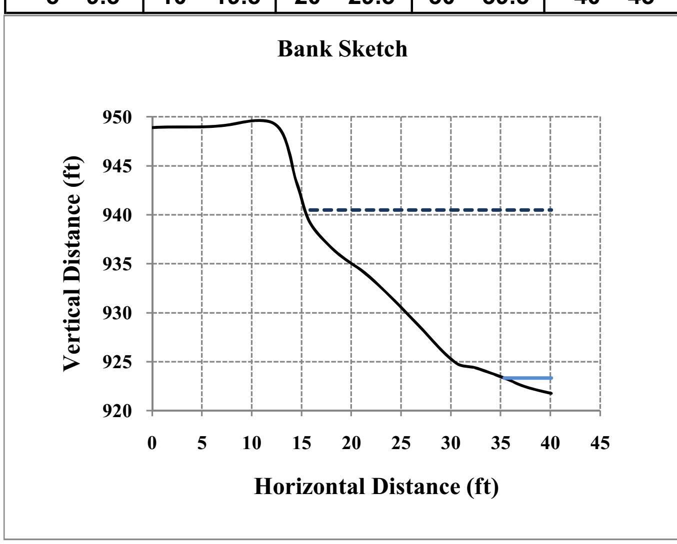
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no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

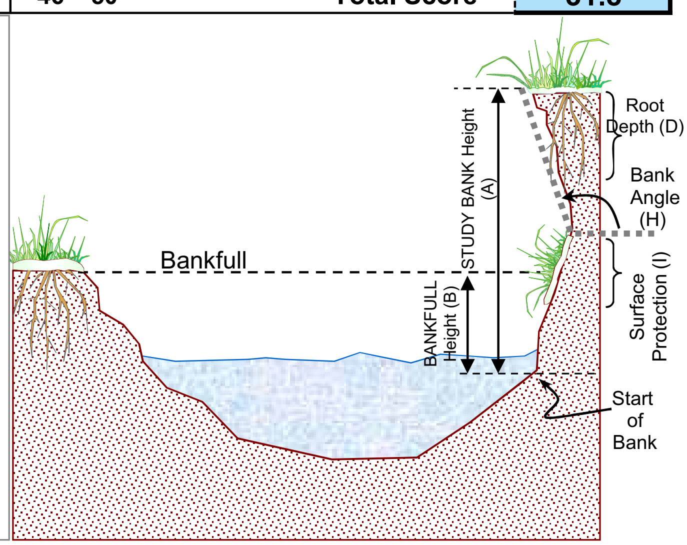
Bank Material Adjustment: 0

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** / **31.8**





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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:	**Delaware River**	Location:	**Muscotah USGS Gage**
Station:	**Bank Type 3**	Observers:	**GSRC, TWI**
Date:	**08/31/09**	Stream Type: **E 5**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	28.1 (A)	Bankfull Height (ft) =	13.94 (B)	(A) / (B) =	2.01578 (C)	7.89

Root Depth / Study Bank Height (E)

Root Depth (ft) =	28.1 (D)	Study Bank Height (ft) =	28.1 (A)	(D) / (A) =	1 (E)	1

Weighted Root Density (G)

Root Density as % =	50 (F)	(F) x (E) =	50 (G)	4.32

Bank Angle (H)

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

Surface Protection (I)

Surface Protection as % =	75 (I)	2.32

Bank Material Adjustment:

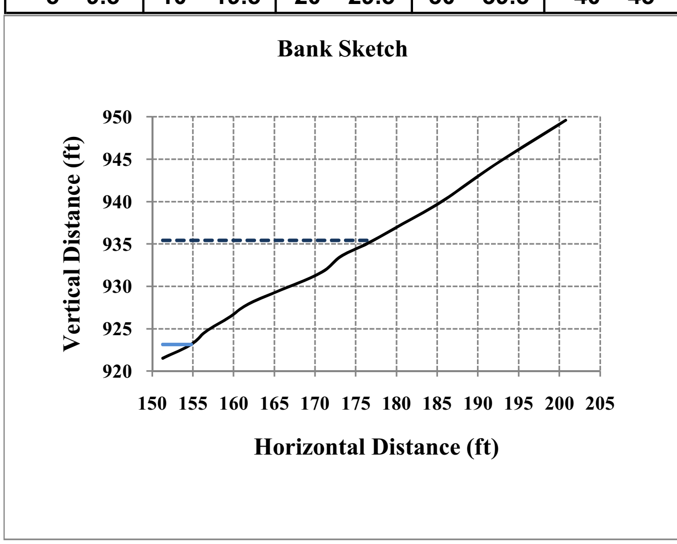
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

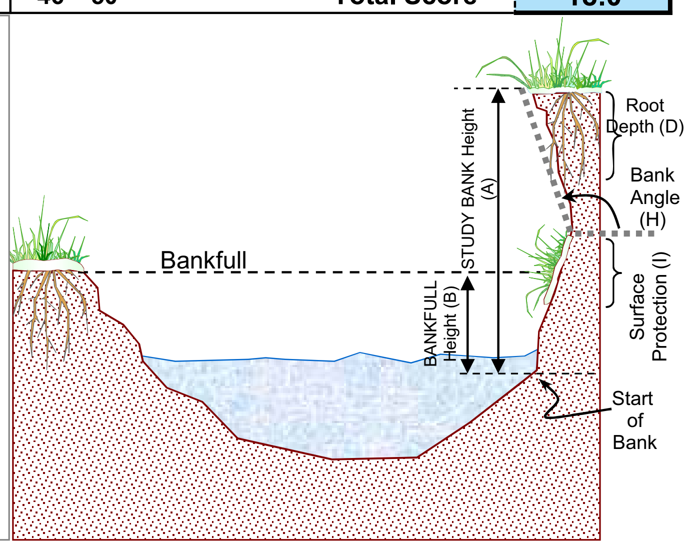
Bank Material Adjustment 0

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**: **Low** **18.0**





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:	**Delaware River**	Location:	**254 Road**
Station:	**Bank Type 1**	Observers:	**GSRC, TWI**
Date:	**09/02/09**	Stream Type: **C 5c-**	Valley Type: **VIII**

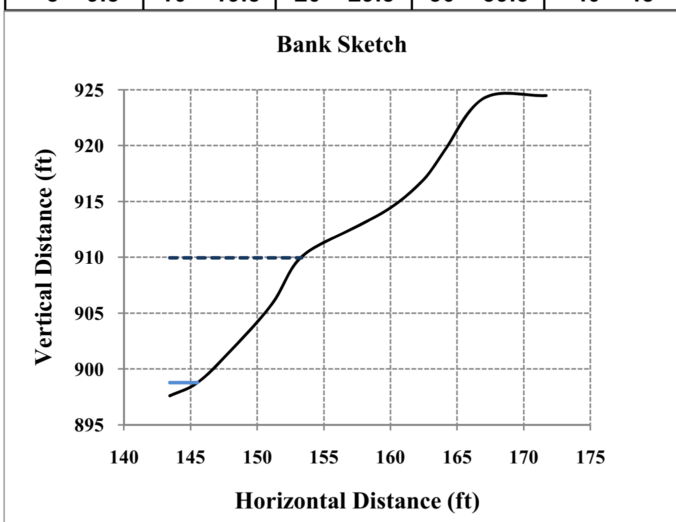
Variable	Input 1	Input 2	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 25.48 (A)	Bankfull Height (ft) = 11.18 (B)	(A) / (B) =	2.27907 (C)	8.26
Root Depth / Study Bank Height (E)	Root Depth (ft) = 25.48 (D)	Study Bank Height (ft) = 25.48 (A)	(D) / (A) =	1 (E)	1
Weighted Root Density (G)		Root Density as % = 30 (F)	(F) x (E) =	30 (G)	5.9
Bank Angle (H)			Bank Angle as *Degrees* =	50 (H)	3.41
Surface Protection (I)			Surface Protection as % =	10 (I)	9
Bank Material Adjustment					0
Stratification Adjustment					0

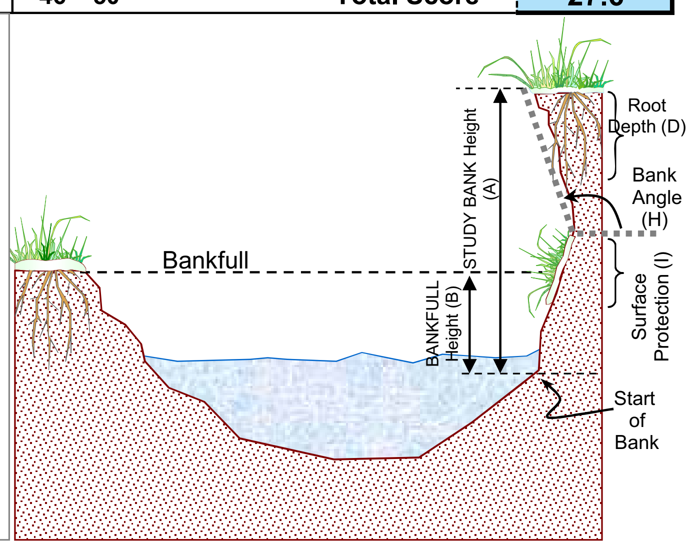
Bank Material Adjustment:

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	**Moderate** 27.6





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:	**Delaware River**	Location:	**254 Road**
Station:	**Bank Type 2**	Observers:	**GSRC, TWI**
Date:	**09/02/09**	Stream Type: **C 5c-**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	23.88 (A)	Bankfull Height (ft) =	11.73 (B)	(A) / (B) =	2.03581 (C)	**7.91**

Root Depth / Study Bank Height (E)

Root Depth (ft) =	23.88 (D)	Study Bank Height (ft) =	23.88 (A)	(D) / (A) =	1 (E)	**1**

Weighted Root Density (G)

Root Density as % =	75 (F)	(F) x (E) =	75 (G)	**2.32**

Bank Angle (H)

Bank Angle as *Degrees* =	21 (H)	**2**

Surface Protection (I)

Surface Protection as % =	50 (I)	**4.32**

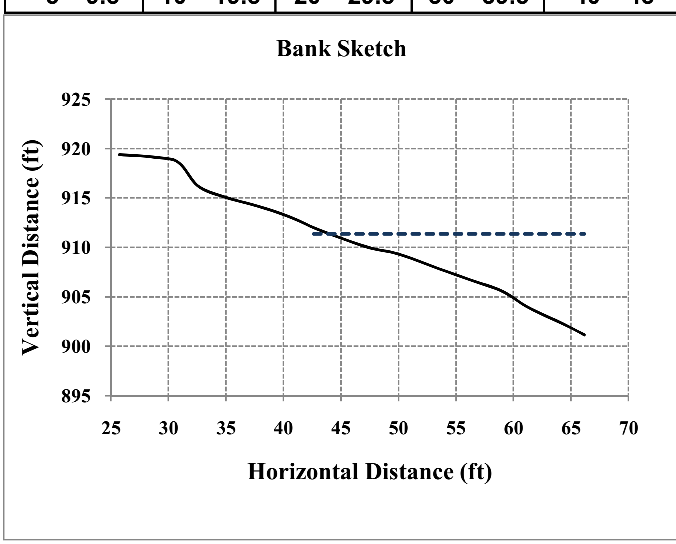
Bank Material Adjustment:

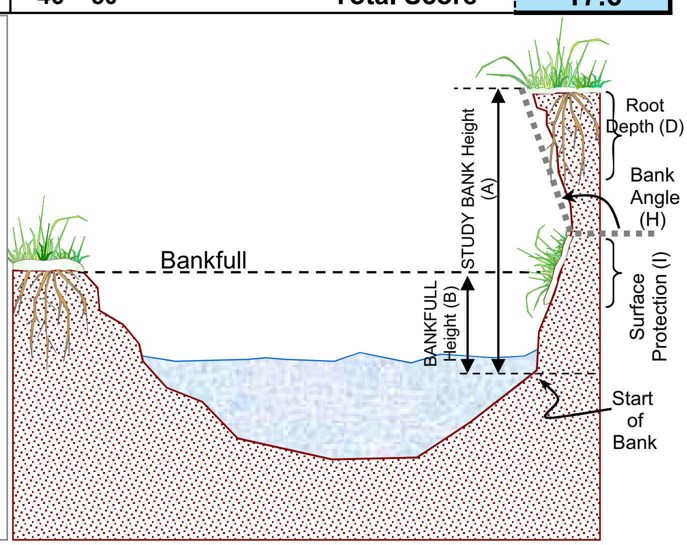
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: **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** / **17.6**





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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: **Delaware River** Location: **254 Road**

Station: **Bank Type 3** Observers: **GSRC, TWI**

Date: **09/02/09** Stream Type: **C 5c-** Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	**25.39 (A)**	**Bankfull Height** (ft) =	**14.47 (B)**	(A) / (B) =	**1.75466 (C)**	**6.71**

Root Depth / Study Bank Height (E)

Root Depth (ft) =	**15.02 (D)**	**Study Bank Height** (ft) =	**25.39 (A)**	(D) / (A) =	**0.59157 (E)**	**3.46**

Weighted Root Density (G)

Root Density as **%** =	**20 (F)**	(F) x (E) =	**11.8314 (G)**	**8.24**

Bank Angle (H)

Bank Angle as *Degrees* =	**24 (H)**	**2.15**

Surface Protection (I)

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

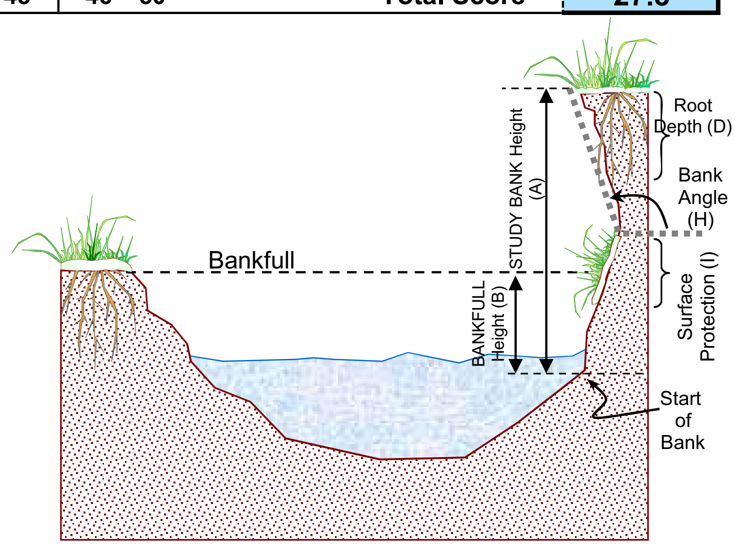
Bank Material Adjustment:

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	**Moderate** **27.8**



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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:	**Delaware River**	Location:	**254 Road**
Station:	**Bank Type 4**	Observers:	**GSRC, TWI**
Date:	**09/02/09**	Stream Type: **C 5c-**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	24.8 (A)	Bankfull Height (ft) =	14.86 (B)	(A) / (B) =	1.66891 (C)	6.33

Root Depth / Study Bank Height (E)

Root Depth (ft) =	24.8 (D)	Study Bank Height (ft) =	24.8 (A)	(D) / (A) =	1 (E)	1

Weighted Root Density (G)

Root Density as % =	50 (F)	(F) x (E) =	50 (G)	4.32

Bank Angle (H)

Bank Angle as *Degrees* =	24 (H)	2.15

Surface Protection (I)

Surface Protection as % =	40 (I)	5.11

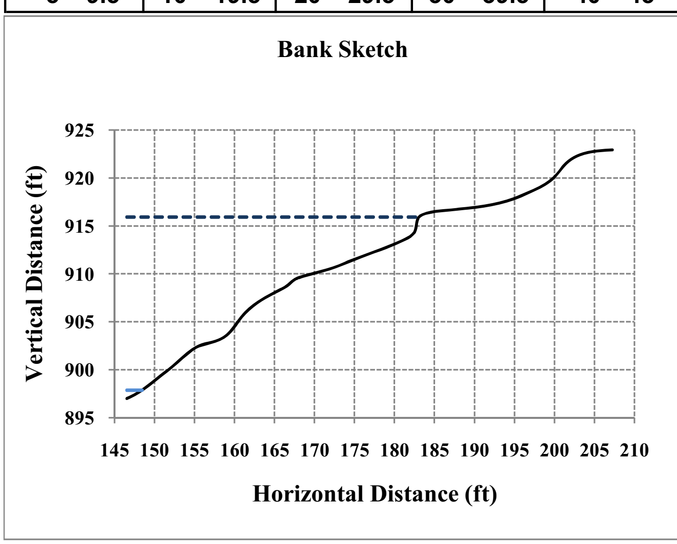
Bank Material Adjustment:

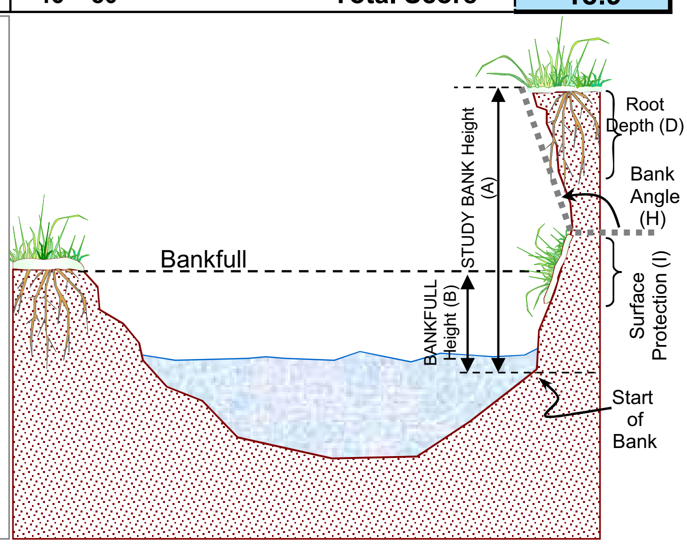
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

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 18.9





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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:	**Delaware River**	Location:	**Muddy Creek Confluence**
Station:	**Bank Type 1**	Observers:	**GSRC, TWI**
Date:	**09/11/09**	Stream Type: **E 5**	Valley Type: **VIII**

Calculation					Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)						
Study Bank Height (ft) =	18.04 **(A)**	**Bankfull Height** (ft) =	12.6 **(B)**	(A) / (B) =	1.43175 **(C)**	**5.46**
Root Depth / Study Bank Height (E)						
Root Depth (ft) =	18.04 **(D)**	**Study Bank Height** (ft) =	18.04 **(A)**	(D) / (A) =	1 **(E)**	**1**
Weighted Root Density (G)						
		Root Density as % =	75 **(F)**	(F) x (E) =	75 **(G)**	**2.32**
Bank Angle (H)						
				Bank Angle as *Degrees* =	23 **(H)**	**2.1**
Surface Protection (I)						
				Surface Protection as % =	60 **(I)**	**3.5**

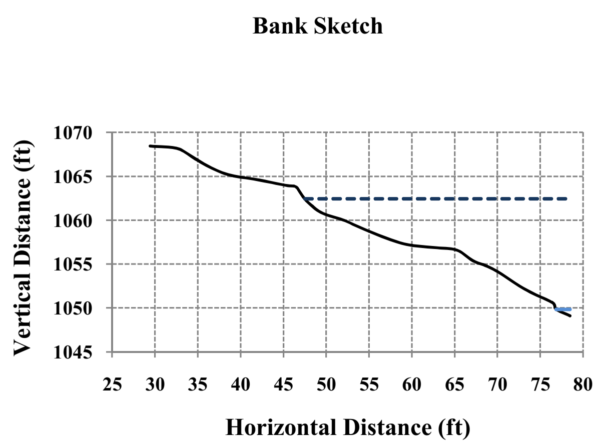
Bank Material Adjustment:

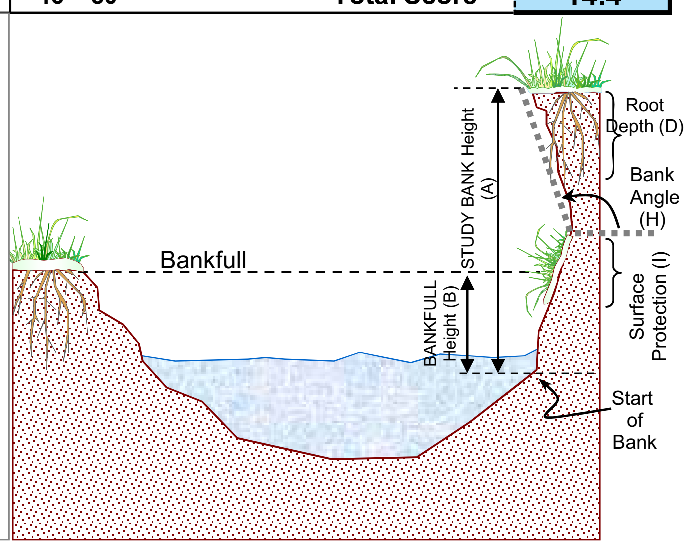
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

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** **14.4**





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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:	**Delaware River**	Location:	**Muddy Creek Confluence**
Station:	**Bank Type 2**	Observers:	**GSRC, TWI**
Date:	**09/11/09**	Stream Type: **E 5**	Valley Type: **VIII**

Variable	Inputs	Calculation	Value	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) = **25.95 (A)**; **Bankfull Height** (ft) = **14.31 (B)**	(A) / (B) =	**1.81342 (C)**	**7**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) = **0 (D)**; **Study Bank Height** (ft) = **25.95 (A)**	(D) / (A) =	**0 (E)**	**10**
Weighted Root Density (G)	**Root Density** as **%** = **0 (F)**	(F) x (E) =	**0 (G)**	**10**
Bank Angle (H)	**Bank Angle** as *Degrees* =		**50 (H)**	**3.41**
Surface Protection (I)	**Surface Protection** as **%** =		**10 (I)**	**9**

Bank Material Adjustment:

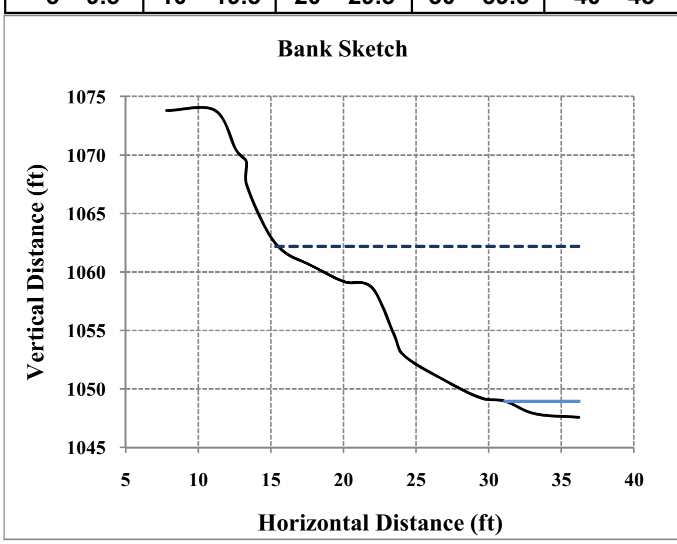
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no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

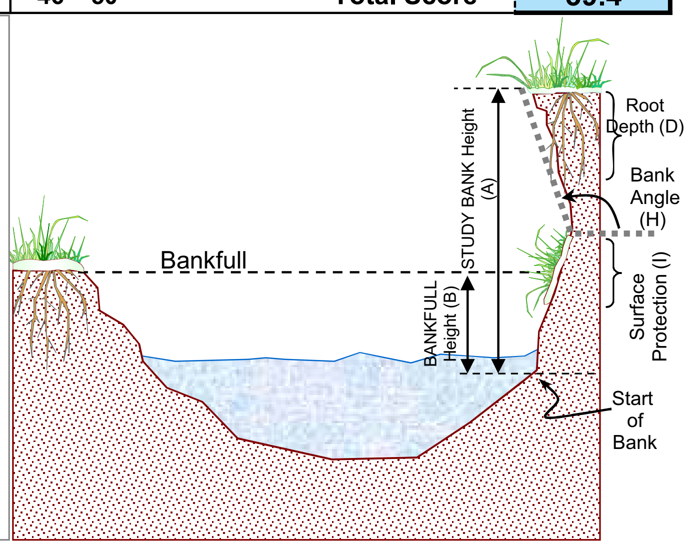
Bank Material Adjustment: **0**

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** / **39.4**





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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: **Delaware River**		Location: **Muddy Creek Confluence**	
Station: **Bank Type 3**		Observers: **GSRC, TWI**	
Date: **09/11/09**	Stream Type: **E 5**	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) = 14.89 (A)	Bankfull Height (ft) = 14.89 (B)	(A) / (B) =	1 (C)	1
Root Depth / Study Bank Height (E)	Root Depth (ft) = 12.89 (D)	Study Bank Height (ft) = 14.89 (A)	(D) / (A) =	0.86568 (E)	2.1
Weighted Root Density (G)		Root Density as % = 50 (F)	(F) x (E) =	43.2841 (G)	4.85
Bank Angle (H)			Bank Angle as *Degrees* =	33 (H)	2.58
Surface Protection (I)			Surface Protection as % =	50 (I)	4.32

Bank Material Adjustment:

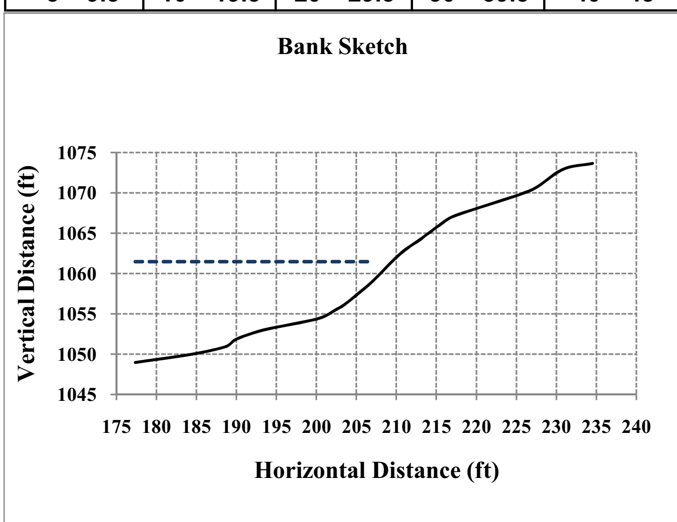
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no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

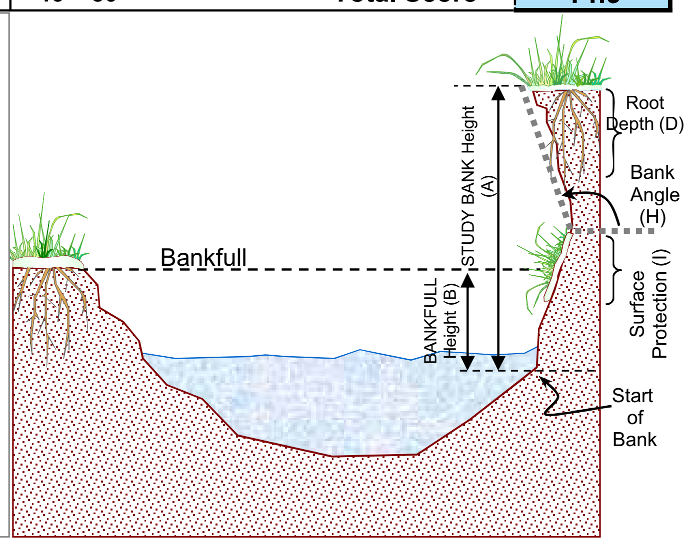
Bank Material Adjustment: 0

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**: Low, 14.9





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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: **Delaware River**		Location: **Muddy Creek Confluence**
Station: **Bank Type 4**		Observers: **GSRC, TWI**
Date: **09/14/09**	Stream Type: **E 5**	Valley Type: **VIII**

BEHI Score (Fig. 5-19)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	26.9 **(A)**	**Bankfull Height** (ft) =	15.66 **(B)**	(A) / (B) =	1.71775 **(C)**	**6.57**

Root Depth / Study Bank Height (E)

Root Depth (ft) =	26.9 **(D)**	**Study Bank Height** (ft) =	26.9 **(A)**	(D) / (A) =	1 **(E)**	**1**

Weighted Root Density (G)

Root Density as % =	10 **(F)**	(F) x (E) =	10 **(G)**	**8.44**

Bank Angle (H)

Bank Angle as *Degrees* =	47 **(H)**	**3.27**

Surface Protection (I)

Surface Protection as % =	10 **(I)**	**9**

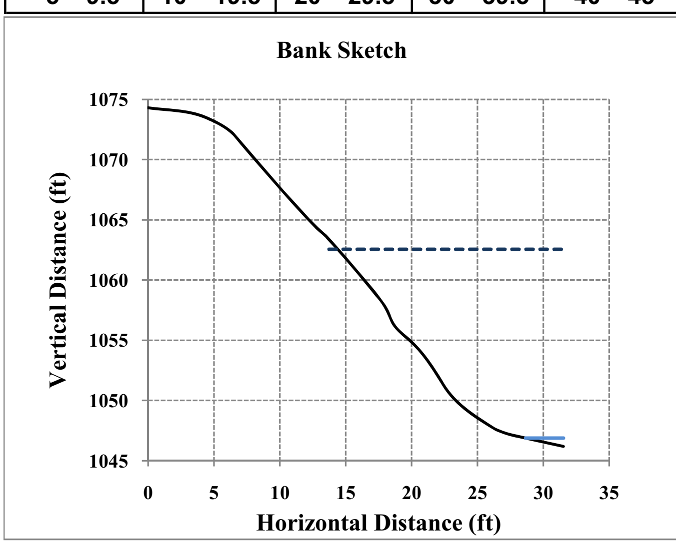
Bank Material Adjustment:

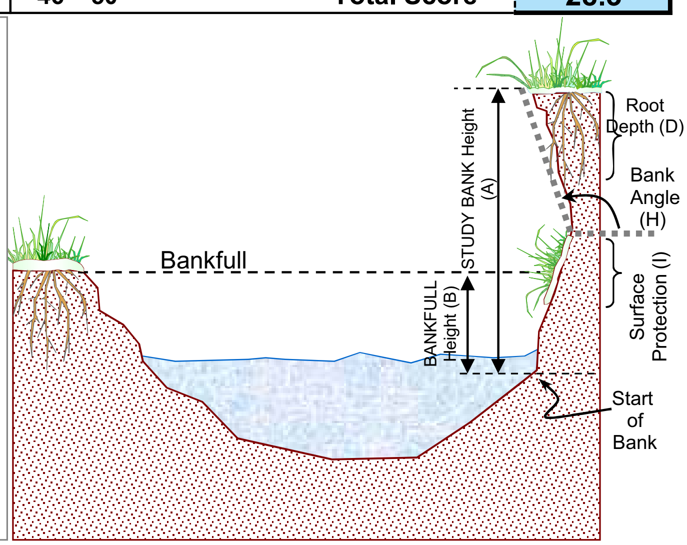
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

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	**Moderate** / **28.3**





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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: **Delaware River** Location: **Muddy Creek Confluence**

Station: **Bank Type 5** Observers: **GSRC, TWI**

Date: **09/14/09** Stream Type: **E 5** Valley Type: **VIII**

Variable	Inputs	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 28.09 (A); Bankfull Height (ft) = 14.67 (B); (A) / (B) =	1.91479 (C)	7.47
Root Depth / Study Bank Height (E)	Root Depth (ft) = 1.6 (D); Study Bank Height (ft) = 28.09 (A); (D) / (A) =	0.05696 (E)	8.89
Weighted Root Density (G)	Root Density as % = 20 (F); (F) x (E) =	1.1392 (G)	10
Bank Angle (H)	Bank Angle as *Degrees* =	27 (H)	2.29
Surface Protection (I)	Surface Protection as % =	40 (I)	5.11

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)

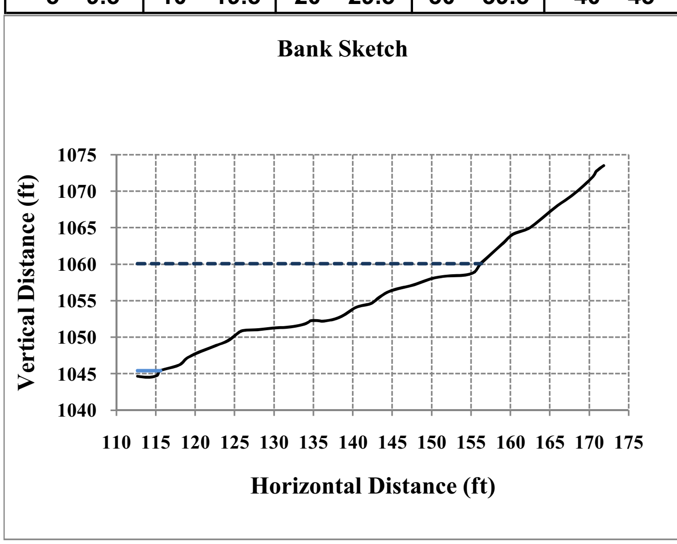
Bank Material Adjustment: 0

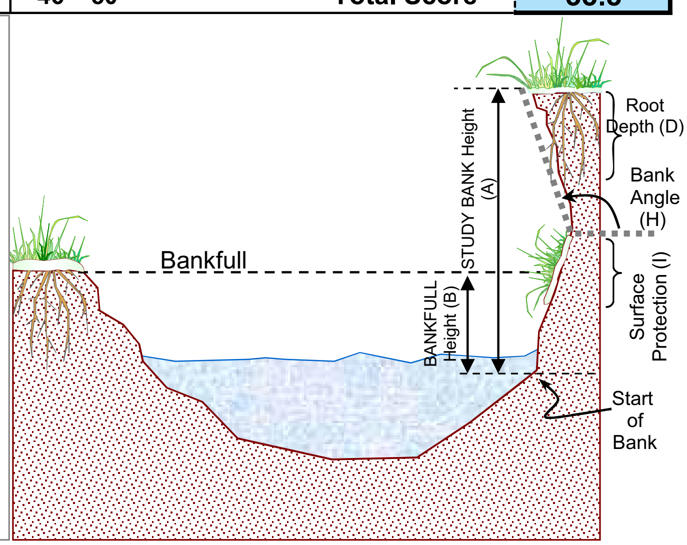
Stratification Adjustment

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**: **High** **33.8**





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APPENDIX F
PHOTOGRAPHIC LOG

APPENDIX F:

PHOTO LOG

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 1 conditions	1
	LOCATION	Banner Creek	Date
Direction: East	PHOTOGRAPHER	Brock Emmert	May 28, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 2 conditions	2
	LOCATION	Banner Creek	Date
Direction: Northeast	PHOTOGRAPHER	Brock Emmert	May 28, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Root exposure and tree leaning	3
	LOCATION	Banner Creek	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	May 28, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Typical bank conditions	4
	LOCATION	Clear Creek Tributary	Date
Direction: South	PHOTOGRAPHER	Brock Emmert	June 19, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Large woody debris	5
	LOCATION	Clear Creek Tributary	Date
Direction: Southwest	PHOTOGRAPHER	Brock Emmert	June 19, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Small knickpoint	6
	LOCATION	Clear Creek Tributary	Date
Direction: Southwest	PHOTOGRAPHER	Brock Emmert	June 19, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 1 conditions	7
	LOCATION	Centralia Lake Tributary	Date
Direction: South	PHOTOGRAPHER	Brock Emmert	May 29, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 2 conditions	8
	LOCATION	Centralia Lake Tributary	Date
Direction: Northwest	PHOTOGRAPHER	Brock Emmert	May 29, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 3 conditions	9
	LOCATION	Centralia Lake Tributary	Date
Direction: Northeast	PHOTOGRAPHER	Brock Emmert	May 29, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Tributary knickpoint	8
	LOCATION	Centralia Lake Tributary	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	May 29, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 1 conditions	11
	LOCATION	Delaware River near Muscotah USGS gage	Date
Direction: North	PHOTOGRAPHER	Brock Emmert	August 31, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 2 conditions	12
	LOCATION	Delaware River near Muscotah USGS gage	Date
Direction: Southeast	PHOTOGRAPHER	Brock Emmert	August 31, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 3 conditions	13
	LOCATION	Delaware River near Muscotah USGS gage	Date
Direction: North	PHOTOGRAPHER	Brock Emmert	August 31, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Mid and point bar	14
	LOCATION	Delaware River near Muscotah USGS gage	Date
Direction: Southwest	PHOTOGRAPHER	Brock Emmert	August 31, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 1	15
	LOCATION	Delaware River near 254 Road	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	Sept. 2, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank Type 2	16
	LOCATION	Delaware River near 254 Road	Date
Direction: South	PHOTOGRAPHER	Brock Emmert	Sept. 2, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank Type 3 with bank slump in background	17
	LOCATION	Delaware River near 254 Road	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	Sept. 2, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Groundwater seeps at lower bank type 3	18
	LOCATION	Delaware River near 254 Road	Date
Direction: Southwest	PHOTOGRAPHER	Brock Emmert	Sept. 2, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 4	19
	LOCATION	Delaware River near 254 Road	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	Sept. 2, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank Type 1	20
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: North	PHOTOGRAPHER	Brock Emmert	Sept. 11, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank Type 2	21
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: Southeast	PHOTOGRAPHER	Brock Emmert	Sept. 11, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Active bank type 2 erosion	22
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: East	PHOTOGRAPHER	Brock Emmert	Sept. 11, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank Type 3	23
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: Northwest	PHOTOGRAPHER	Brock Emmert	Sept. 11, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank Type 4	24
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: East	PHOTOGRAPHER	Brock Emmert	Sept. 14, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Willow along bank type 5	25
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: West	PHOTOGRAPHER	Brock Emmert	Sept. 14, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Bank type 5	26
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: East	PHOTOGRAPHER	Brock Emmert	Sept. 14, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Active gully erosion at bank type 5	27
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: Northeast	PHOTOGRAPHER	Brock Emmert	Sept. 14, 2009

Kansas River Basin Stream and River Channel Assessment	DESCRIPTION	Active gully erosion at bank type 5	28
	LOCATION	Delaware River near Muddy Creek Confluence	Date
Direction: Southwest	PHOTOGRAPHER	Brock Emmert	Sept. 14, 2009

APPENDIX G
ROSGEN STREAM CLASSIFICATION SYSTEM

APPENDIX G:

ROSGEN STREAM CLASSIFICATION SYSTEM

Exhibit 1

FLOW REGIME VARIABLES (from Rosgen 2006, Figure 5-9)

General Category

E. Ephemeral stream channels - flows only in response to precipitation. Often used in conjunction with intermittent.

S. Subterranean stream channel - flows parallel to and near the surface for various seasons - a sub-surface flow which follows the stream bed.

I. Intermittent stream channel - one which flows only seasonally, or sporadically. Surface sources involve springs, snow melt, artificial controls, etc. Often this term is associated with flows that re-appear along various location of a reach, then run subterranean.

P. Perennial stream channels. Surface water persists year long.

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 Stream flow regulated by glacial melt.

5 Ice flows, ice torrents from ice dam breaches

6 Alternating flow/backwater due to tidal influence

7 Regulated stream flow due to diversions, dam release, dewatering, etc.

8 Altered due to development, such as urban streams, cut0over watersheds, vegetation conversions (forested to grassland) that changes flow response to precipitation events.

9 Rain-on-snow generated runoff

Exhibit 2

STREAM SIZE (from Rosgen 2006, Table 5-3)

S-1	Bankfull width less than 0.305 m (1 foot)
S-2	Bankfull width 0.3 - 1.5 m (1 - 5 feet)
S-3	Bankfull width 1.5 - 4.6 m (5 - 15 feet)
S-4	Bankfull width 4.6 - 9 m (15 - 30 feet)
S-5	Bankfull width 9 - 15 m (30 - 50 feet)
S-6	Bankfull width 15 - 22.8 m (50 - 75 feet)
S-7	Bankfull width 22.8 - 30.5 m (75 - 100 feet)
S-8	Bankfull width 30.5 - 46 m (100 - 150 feet)
S-9	Bankfull width 46 - 76 m (150 - 250 feet)
S-10	Bankfull width 76 - 107 m (250 - 350 feet)
S-11	Bankfull width 107 - 150 m (350 - 500 feet)
S-12	Bankfull width 150 - 305 m (500 - 1000 feet)
S-13	Bankfull width greater than 305 m (1000 feet)

STREAM ORDER

Add categories in parenthesis for specific stream order of reach. For example, a third order stream with a bankfull width of 6.1 meters (20 feet) would be indexed as: S-4(3).

Exhibit 3

MEANDER PATTERNS
Rosgen 2006)

M-1	Regular Meander
M-2	Tortuous Meander
M-3	Irregular Meander
M-4	Truncated Meanders
M-5	Unconfined Meander Scrolls
M-6	Confined Meander Scrolls
M-7	Distorted Meander Loops
M-8	Irregular with Oxbows, Oxbow Cutoffs

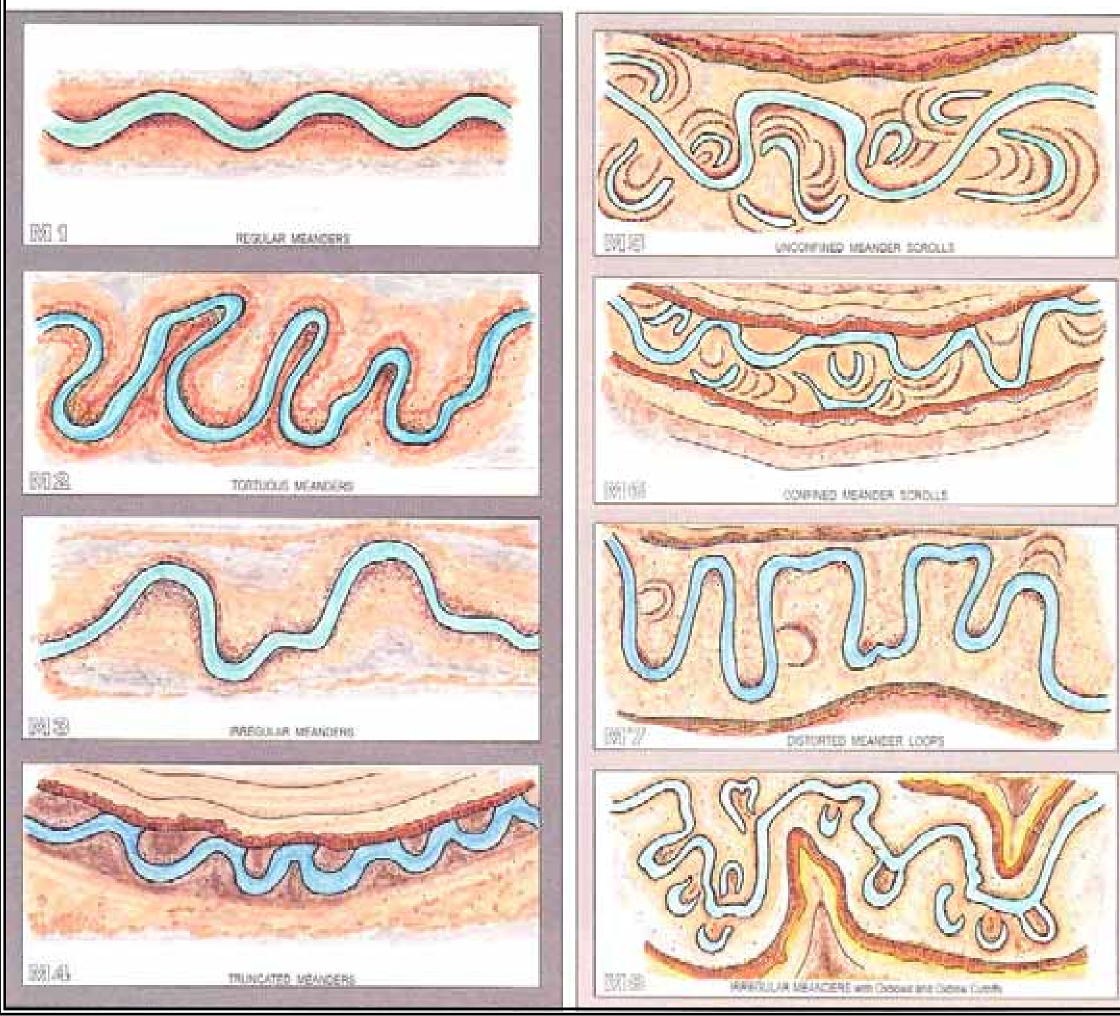

Exhibit 4

DEPOSITIONAL FEATURES OR BARS
(Rosgen 2006)

B-1	Point bars
B-2	Point Bars with Few Mid Channel Bars
B-3	Many Mid Channel Bars
B-4	Side Bars
B-5	Diagonal Bars
B-6	Main Branching with Many Mid Bars and Islands
B-7	Mixed Side Bar and Mid Channel Bars (Exceeding 2 - 3 X Width)
B-8	Delta Bars

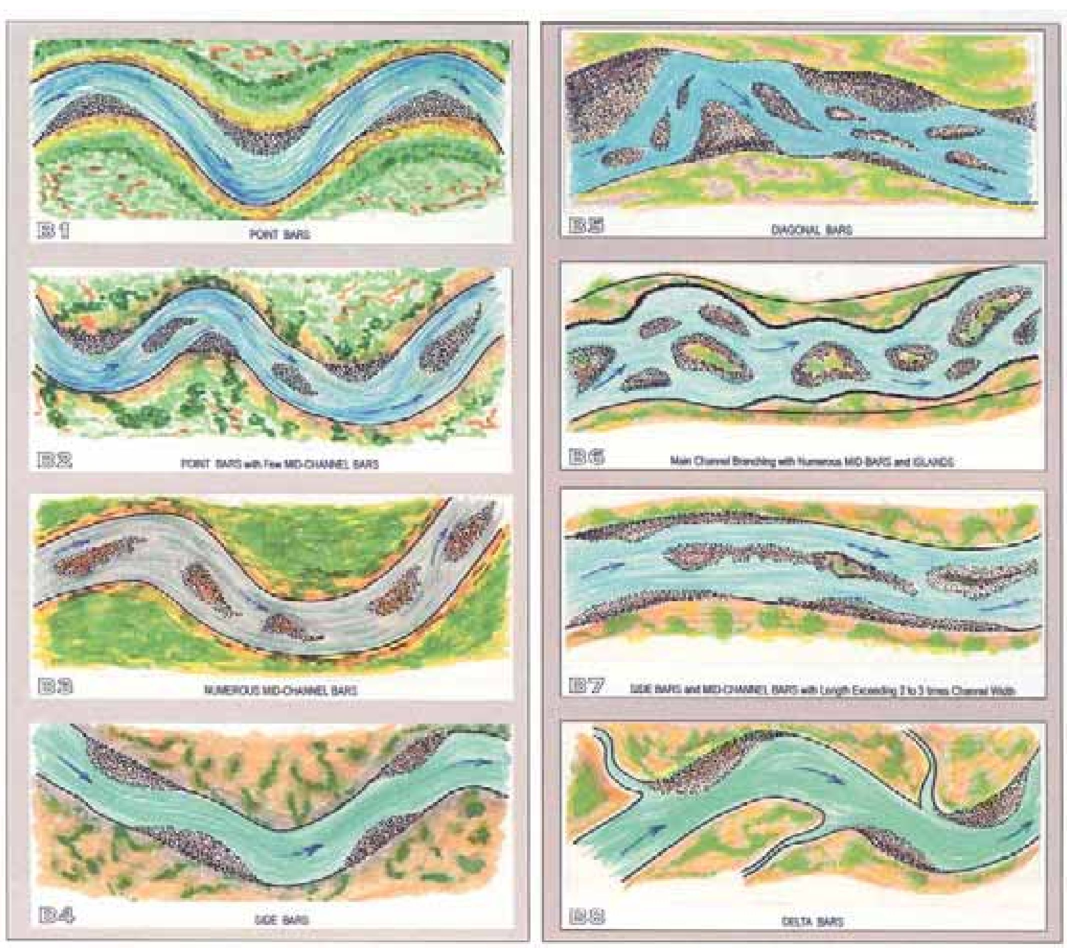

Exhibit 5

STREAM CHANNEL DEBRIS/BLOCKAGES
(Rosgen 2006)

DESCRIPTION/ EXTENT		Materials, which upon placement into the active channel or floodprone area may cause an adjustment in channel dimensions or conditions, due to influences on the existing flow regime.
D1	NONE	Minor amounts of small, floatable material.
D2	INFREQUENT	Debris consists of small, easily moved, floatable material; i.e. leaves, needles, small limbs, twigs, etc.
D3	MODERATE	Increasing frequency of small to medium sized material, such as large limbs, branches, and small logs that when accumulated effect 10% or less of the active channel cross-sectional area.
D4	NUMEROUS	Significant build-up of medium to large sized materials, i.e. large limbs, branches, small logs or portions of trees that may occupy 10 to 30% of the active channel cross-section area.
D5	EXTENSIVE	Debris "dams" of predominantly larger materials, i.e. branches, logs, trees, etc., occupying 30 to 50% of the active channel cross-section; 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. Such accumulations may divert water into the floodprone area and form fish migration barriers, even when flows are at less than bankfull.
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, evulsion, aggradation and degradation.
D10	HUMAN INFLUENCES	Structures, facilities, or materials related to land uses or development located within the floodprone 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.

Exhibit 6

Width/Depth Ratio Stability Ratings

Stability Rating	Width/Depth Ratio to Reference Width/Depth Ratio
Stable	1-1.2
Moderately Unstable	1.2-1.4
Unstable	1.4-1.6
Highly Unstable	> 1.6
For Incising Channel (Bank Height Ratio > 1)	
Stable	1-0.8
Moderately Unstable	0.8-0.6
Unstable	0.6-0.4
Highly Unstable	0.4-0.2

(Adapted from Rosgen 2006, Figure 5-13)

Exhibit 7

Pfankuch (1975) Stream Channel Stability Ratings

Stream Type	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**
GOOD	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60
FAIR	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78
POOR	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+
Stream Type	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**D3**	**D4**	**D5**	**D6**		
GOOD	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98		
FAIR	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125		
POOR	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+		
Stream Type	**DA3**	**DA4**	**DA5**	**DA6**	**E3**	**E4**	**E5**	**E6**				
GOOD	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63				
FAIR	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86				
POOR	87+	87+	87+	87+	87+	97+	97+	87+				
Stream Type	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
GOOD	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	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	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

(Adapted from Rosgen 2006, Worksheet 5-7)

Exhibit 8

Degree of Channel Incision

Stability Rating	Bank Height Ratio
Stable	1-1.1
Slightly Incised	1.1-1.3
Moderately Incised	1.3-1.5
Deeply Incised	>1.5

(Adapted from Rosgen 2006, Figure 5-15)

Exhibit 9

Degree of Confinement

Degree of Confinement	Meander Width Ratio (MWR) / Reference MWR*
Unconfined	0.80-1.00
Moderately Confined	0.30-.79
Confined	0.10-0.29
Severely Confined	<0.10

* Reference MWR determined by average MWR by stream type from Tetra Tech (2004)
(Adapted from Rosgen 2006, Figure 5-17)