ANALYZING EFFECTS OF LOW WATER FORDS ON STREAM STABILITY AT FORT RILEY, KANSAS

by

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Abstract

Military maneuvers involve effectively moving soldiers and equipment across training lands, and this often involves crossing streams. Fording of streams by military vehicles poses a potential for degradation of stream habitats through change of bank angle or excess shear of stream banks and the resultant generation of excessive quantities of sediment, possibly exceeding Total Maximum Daily Loads (TMDL) limits for water quality downstream. This study examines the impact of low water fords on stability of six stream reaches at Fort Riley. Streams with constructed low water fords were mapped and classified according to Rosgen Stream Classification System (1996). Results indicate that some of these streams exhibit some level of instability, which includes bed form changes, accelerated stream bank erosion and backwater pool formation in the vicinity of stream crossings. Poorly constructed fords may act as dams disrupting the transport of sediment along the stream reaches, posing a potential shift in stream equilibrium. Another factor contributing to stream instability is sediment generated from upland areas and routed through approach roads leading to stream crossing sites. The sediment deposited into streams at these crossing locations is a water quality concern, and again poses the potential of disrupting stream equilibrium. Field observations indicate that poorly located stream crossings can alter the direction of stream flow, causing bank erosion on areas immediately below stream crossings. This demonstrates the importance of locating stream crossings on stable locations along a stream reach. Some of the stream reaches also show signs of successional change. These stream changes have direct implications on the low water fords on Fort Riley. As a result of these stream changes, there will be need to constantly modify the designs and construction techniques of the low water fords in order to accommodate changes in stream dimensions, pattern and profile. Finally, criteria for site selection, design and construction of low water fords are discussed.

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INTRODUCTION

Low water fords are generally considered as stream crossing structures constructed on the bottom of a waterway over which water flows while still allowing passage of traffic across the waterway (Milauskas, 1988; Sample et al., 1998). Low water fords are widely used as a stream crossing structure in agricultural, forestry and military applications. The popularity of low water fords can be attributed to their ease of construction, low cost and maintenance. This thesis discusses the application of low water fords in a military environment. Fort Riley Installation has approximately eighty constructed low water fords that the military uses as a means of crossing streams during training exercises. Fording of streams by military vehicles poses a potential for degradation of stream habitats through change of stream bank angle or excess shear of stream banks and the resultant generation of excessive quantities of sediment. Low water fords are a major source of sediment since fords act as central locations where sediment laden runoff from upland areas collects and enters stream channels (Brown, 1994; Sample et al., 1998; and Taylor et al., 1999).

Stream function in many of the streams at Fort Riley, Kansas may be threatened by the presence of low water fords and changes in watershed hydrology. Potential impacts of changes in stream function include degradation of stream habitat for aquatic life and changes in water quality. Causes of channel degradation include poorly located and constructed stream crossings, and sediment generated at crossing sites. In addition, military maneuvers on upland areas alter land topography (Rice et al., 2006; Svendsen et al., 2006) causing changes in the quantity and patterns of storm runoff. The storm runoff laden with sediment is usually routed into streams through approach roads (leading to stream crossing sites), increasing the runoff and amount of sediment delivered to these streams. The extra sediment introduced into these streams has a potential of causing stream instability.

Streams on Fort Riley are still adjusting to disturbances caused by historic land use practices such as agriculture and grazing (Ingrisano, 2005); however, these disturbances are minor. Stream crossings and changes in land use practices on Fort Riley have a potential to affect stream stability. According to Rosgen (1996), stream stability is defined as the ability of the stream to convey the discharge and sediment of its watershed, such that over time, it maintains its stream dimension, pattern and profile while neither aggrading nor degrading.

Background on Low Water Stream Crossing (LWSC) Project

Prior to 1992, the military at Fort Riley randomly selected where they would cross a stream or constructed earthen fords to cross a stream. During or after high-flow events, both the randomly selected sites and earthen fords posed a safety issue for soldiers and equipment. Furthermore, use of the randomly selected sites and earthen fords caused tremendous degradation to the streams through shearing of stream banks and generating excessive amounts of sediment. In 1992, a Low Water Stream Crossing (LWSC) project was initiated at Fort Riley to address problems related to the use of earthen fords and randomly selected crossing sites. New designs were developed. Selected stream crossing sites were modified by hardening stream beds and approach roads with rock and gravel (Sample et al., 1998). By 2002, the LWSC project was generally considered a success. Project achievements realized were: provided safer training conditions for military, improved access to additional training areas, and alleviated some of the environmental impacts related to crossing streams. After a decade of operation, a need exists to re-evaluate performance of the constructed stream crossings and their impact on stream stability. Although numerous studies have been conducted to assess environmental impacts associated with low water fords, relatively few studies have been conducted to assess long term impacts of fords on stream stability or morphology. Impacts of low water fords (at military installations) on stream stability are still unknown. This study therefore assesses the impact of low water fords on stream stability. Additional objectives of this study include the development of site selection, design and construction guidelines for low water fords.

CHAPTER 1 - LITERATURE REVIEW

Compared to other stream crossing options (such as culverts or low water bridges), low water fords exert the greatest impact on water quality. Various workers have documented environmental impacts associated with the use of low water fords. Brown (1994) studied impact of vehicular traffic crossing low water fords on two rivers in Eastern Victoria, Australia. This study showed that vehicles crossing streams at low water fords were responsible for generating significant amounts of sediment from the river bed, which was then carried and deposited downstream. Sediment source areas were identified as being the approach roads to the fords and stream banks on either side of the fords. The study also showed that a great deal of the sediment produced and deposited at crossing sites was as a result of the following processes:

1. Wheel ruts created by the vehicles act as conduits for surface runoff during and after storm events.
2. Vehicles crossing streams create backwash which is a result of water draining from the vehicles after crossing the stream.
3. Detached soil from approach roads (to the fords) is carried and deposited at crossing sites.

Furthermore, the study revealed that the amount of sediment deposited in a particular location of the river was related to stream velocity, distance from river bank and frequency of use of the crossing site. Based on findings of the study, the author suggested that gravelling or paving of the approach roads would reduce the amount of sediment deposited into the river at crossing sites.

Thompson et al. (1996) and Welch et al. (1998) reported long-term impacts on water quality resulting from use of two gravel fords for forestry operations in Tuskegee, Alabama. The researchers studied impacts on water quality resulting from construction, use and deconstruction of the low water fords. In an earlier study, Thompson et al. (1996) evaluated the movement and quantity of sediment generated at the gravel fords as a result of vehicle traffic. The amount of sediment produced was measured for three conditions; prior to, during and after renovation of the gravel fords. Findings of the study indicated that peak sediment concentrations were highest during the renovation phase of the fords. However, during the post renovation phase of the fords, a storm event (127.8 mm) generated 18 times more sediment than that generated during the renovation phase.

During a two-month timber harvest, Welch et al. (1998) conducted measurements of sediment concentration increases upstream and downstream from the two gravel fords used in the Thompson et al. (1996) study. Mean and peak sediment concentration measured immediately below one of the fords was 50 and 1200 mg/l respectively. After the timber harvest, fords were deconstructed and the original stream bed elevation at the fording site was restored. The peak sediment concentration measured immediately below one of the fords was 17 times more than that measured during the timber harvest. However, because of the length of the timber harvest, the high levels of sediment concentration observed during the timber harvest period posed the greatest water quality impact. Storm events during the harvest season contributed to the amount of sediment produced and delivered at the fords. Sediment concentrations were directly related to precipitation amounts and stream flows. The study revealed that gravelling the fords and approach roads (after the timber harvest) resulted in a reduction of sediment produced at the fords.

In a similar study, Sample et al. (1998) reported water quality impacts resulting from use of two types of low water fords on Fort Riley, Kansas. The authors investigated the effects on water quality resulting from vehicular traffic traversing hardened and earthen low water fords. Water quality parameters studied included; turbidity, total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), and settleable solids (SS). In order to determine the net amount of sediment deposited at the low water fords, water samples were collected manually from upstream and downstream of the fording sites, prior to and after vehicles had crossed the fording sites. Findings of the study revealed that no significant changes in water quality were observed prior to vehicles crossing both hardened and earthen fords. However, a difference in turbidity was observed between upstream and downstream reaches at one hardened crossing site. The higher levels of turbidity at the downstream location were attributed to increased production of phytoplankton at the stream crossing site. Significant changes in water quality parameters (except for TDS) were observed after vehicles had crossed both types of low water fords. The water quality changes at the earthen fords were significantly greater than those at the hardened fords. The turbidity measured at the earthen crossing sites was sixteen times the amount measured at the hardened crossing sites, and suspended sediment concentration generated at the earthen fords was approximately fifteen times more than the sediment concentration produced at the hardened fords. In addition, the total solids concentration from the earthen fords was nearly a dozen times higher than the concentration at the hardened low water fords. Based on findings of the study, Sample et al. (1998) recommended replacing earthen fords with hardened fords so as to decrease the amount of stream disturbance caused by vehicular traffic crossing streams. Such change would not only preserve stream habitat, but also provide improved crossing conditions for military personnel and equipment.

CHAPTER 2 - METHODS AND MATERIALS

Study Sites

The bedrock in the study areas (which is fairly shallow) is composed of shale and limestone of Pennsylvanian and Permian age (Jewett, 1940 and Ingrisano, 2005). Mudstone formations of Permian age occur in some parts of the study sites (Ingrisano, 2005). According to Ingrisano, 2005, the Flint Hills are characterized by the presence of bench and slope topography. As shown in Figure 2-1, the bedrock formations in the study areas are Permian in age and belong to the Council Grove and Chase groups. These groups are composed of different types of shale and limestone as shown in Figure 2-2. The limestone formations in the study areas are of two types: flint and non-flint bearing formations. The non-flint limestone formations are more resistant to weathering (forming extensive plateaus), while the flint bearing limestone formations are easily eroded forming steep slopes and rounded knobs (Jewett, 1941 and Ingrisano, 2005). Stream channels in the area reflect the underlying geology and bed material formations are composed of clay, silt and gravel.

The soils in the study watersheds belong to the following soil series: Benfield (Udic Argiustolls), Florence (Udic Argiustolls), Wymore (Aquic Argiudolls), Irwin (Pachic Argiustolls), Clime (Udic Haplustolls), Sogn (Lithic Haplustolls) (Clark and Worley, 1975). These soils (Mollisols) are silty clay loams, cherty silt loams and silt loam. The Benfield-Florence association comprises of moderately deep, sloping and moderately steep silty clay loams and cherty silt loams. The Wymore-Irwin association comprises of silty clay loams that range from level to sloping. The Clime-Sogn association comprises of silty clay loams that are moderately deep and shallow, sloping and moderately steep.

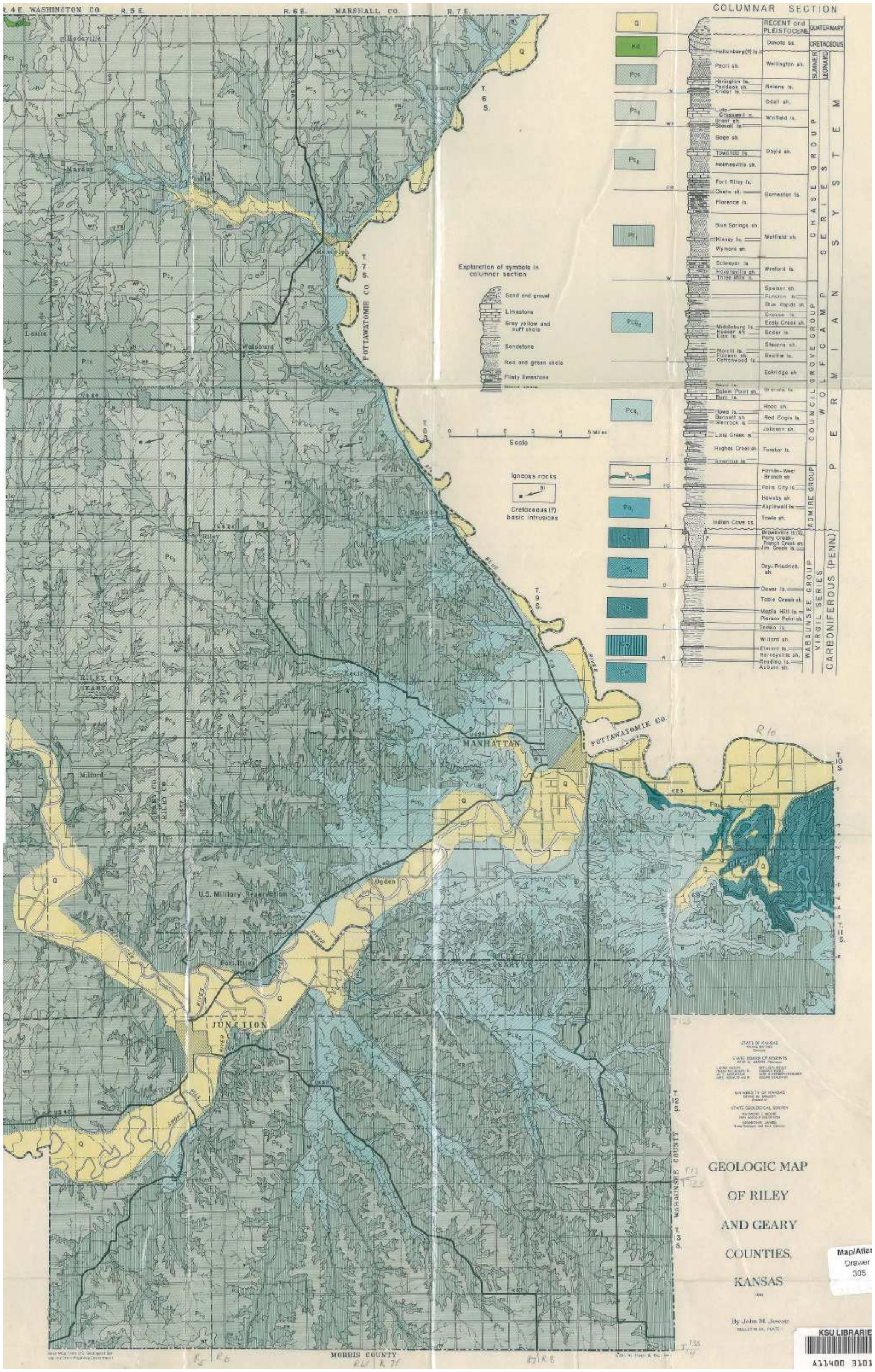

Figure 2-1. Geologic map of Riley and Geary counties, Kansas. Adapted after Jewett, 1941.

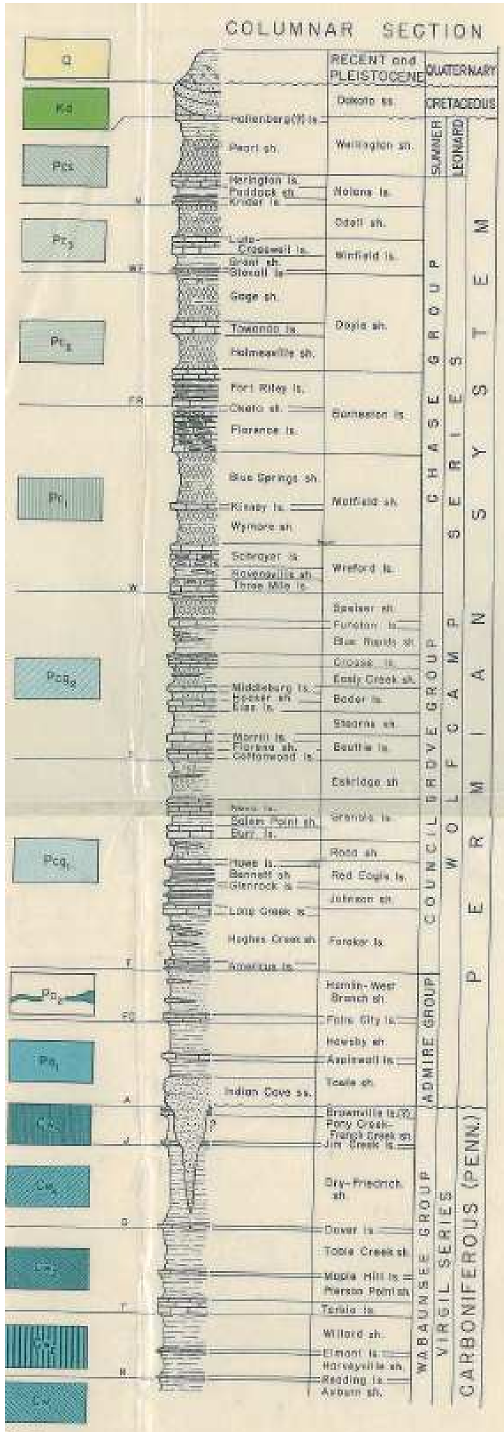

Figure 2-2. Stratigraphic column of geologic formations in Riley and Geary counties, Kansas. Adapted after Jewett, 1941.

Fort Riley has a continental climate which is characterized by warm to hot summers and cold winters (Brown, 1975). The region experiences abundant sunshine, moderate winds and low to moderate humidity (Brown, 1975). The average annual precipitation is approximately 800 mm (Ingrisano, 2005). The largest part of annual precipitation is received during the spring and early summer seasons (Brown, 1975 and Ingrisano, 2005). The mean annual temperature is 12.94 ^{o}C (Ruffner, 1974).

The vegetation in the study areas is riparian woodland, and native tall grass prairie in the uplands. The main land use practice on Fort Riley is military maneuvers. These maneuvers take place in designated areas known as training areas and provide the mechanized infantry units the opportunity to practice (Figures 2-3 and 2-4). In addition, the training areas are co-used for agriculture and as a habitat for wildlife (Ingrisano, 2005). Fort Riley occasionally leases out approximately 200 km^2 of land to the public for farming. These areas under agriculture serve as buffer zones against fire around firing ranges (Ingrisano, 2005).

Figure 2-3. Military maneuvers on Fort Riley.

Figure 2-4. Mechanized infantry units training on Fort Riley.

The study sites represent a wide range of stream conditions and types. Selection of study sites was based on the following criteria:

1. Size of stream and type of stream bed.
2. Presence of low water fords and frequency of their use.
3. Location of a stream reach within a watershed, i.e. reaches in the upland and lowland areas.
4. Size of drainage area of the study reaches.

The study areas are located at Fort Riley in the Flint Hills physiographic province of Kansas (Figure 2-5).

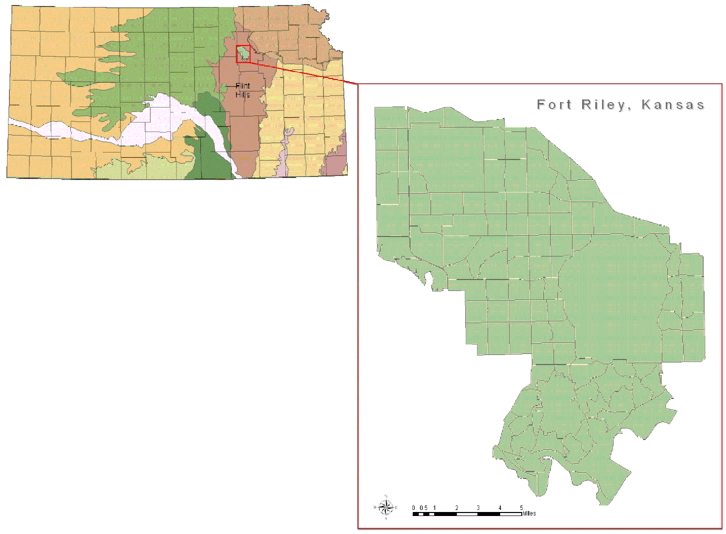

Figure 2-5. Map of Kansas showing different eco-regions. Inset is a map of Fort Riley. Adapted after Ingrisano (2005).

Six separate study reaches were established on Farnum Creek (Figure 2-6), Seven Mile Creek (Figure 2-7), Silver Creek (Figure 2-8) and Wind Creek (Figure 2-9). Farnum Creek is an ephemeral stream which flows into Milford Lake. Seven Mile Creek (also an ephemeral stream), flows into the Kansas River while Silver and Wind Creek are both perennial streams which flow into Wildcat Creek that flows into the Kansas River. Three of the six separate stream reaches are located along Wind Creek. The reaches on Wind Creek are designated as upland, midland and lowland reaches. Drainage areas for Farnum Creek, Seven Mile Creek, Silver Creek and Wind Creek reaches are 2.53 km^2, 2.30 km^2, 24.40 km^2, and 20.30 km^2, respectively. The three reaches on Wind Creek (i.e. Wind Creek upland, midland and lowland) have drainage areas of 16.24 km^2, 17.61 km^2 and 20.30 km^2, respectively.

Figure 2-10 shows the location of the study sites on Fort Riley. All the study sites, except for Silver Creek, have hardened low water fords located along the study stream reaches. The Silver Creek site was included in this study because the military plans to construct a low water ford at this study site. Monitoring the Silver Creek study site, before and after a low water ford is constructed provides a basis for tracking changes to the stream brought about by construction and use of a low water ford.

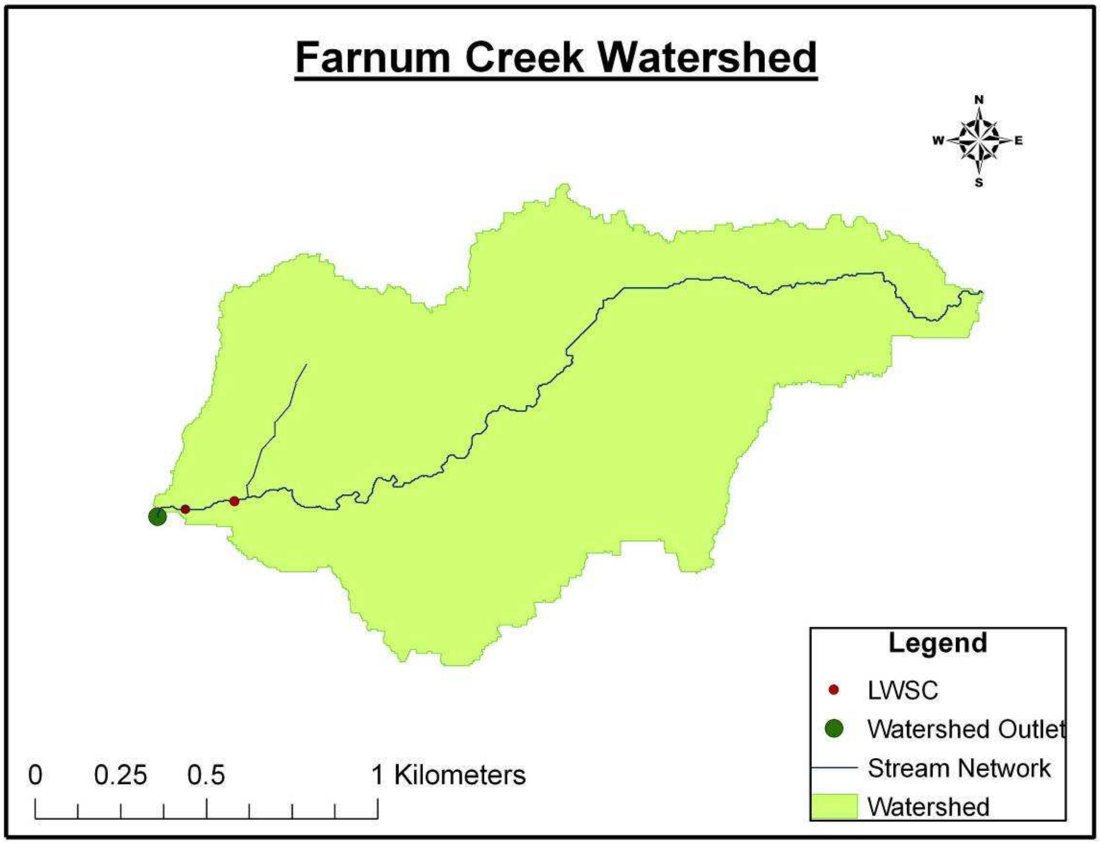

Figure 2-6. Farnum Creek watershed, Fort Riley, Kansas.

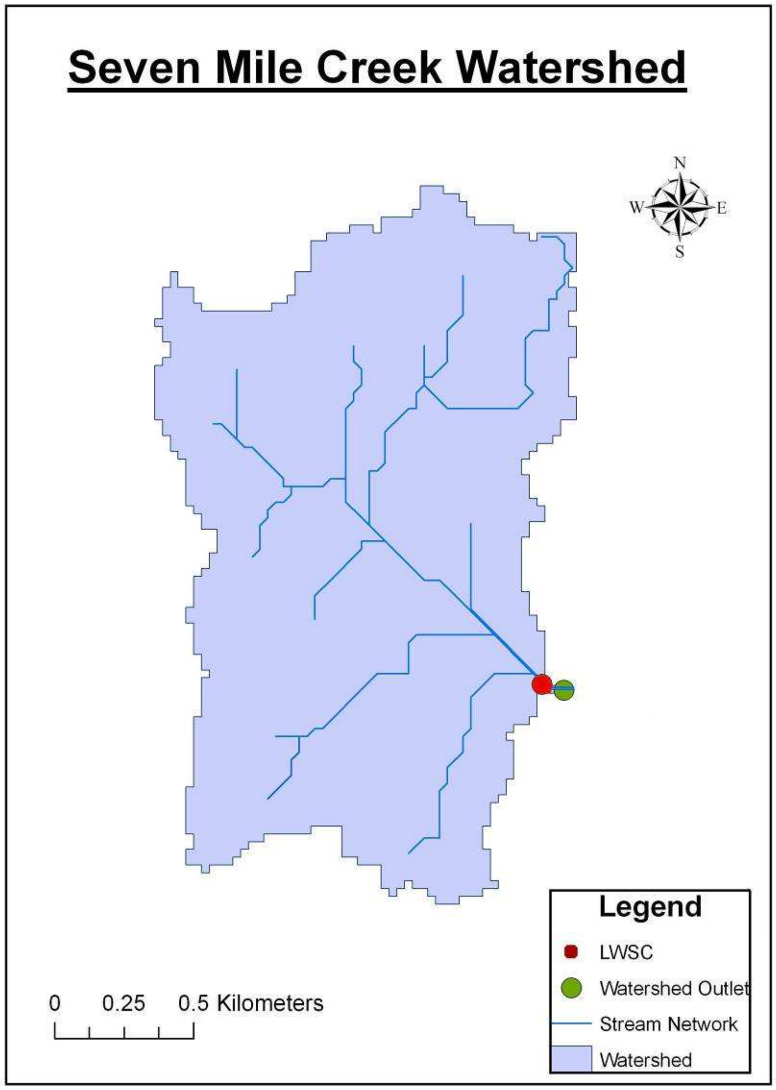

Figure 2-7. Seven Mile Creek watershed, Fort Riley, Kansas.

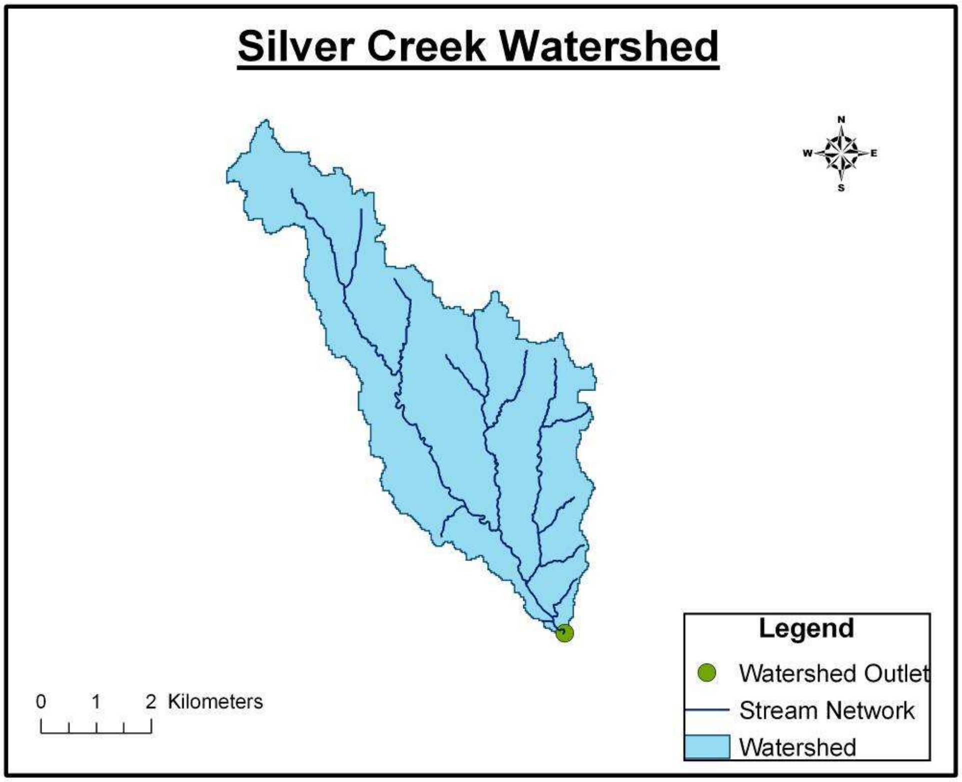

Figure 2-8. Silver Creek watershed, Keats, Kansas.

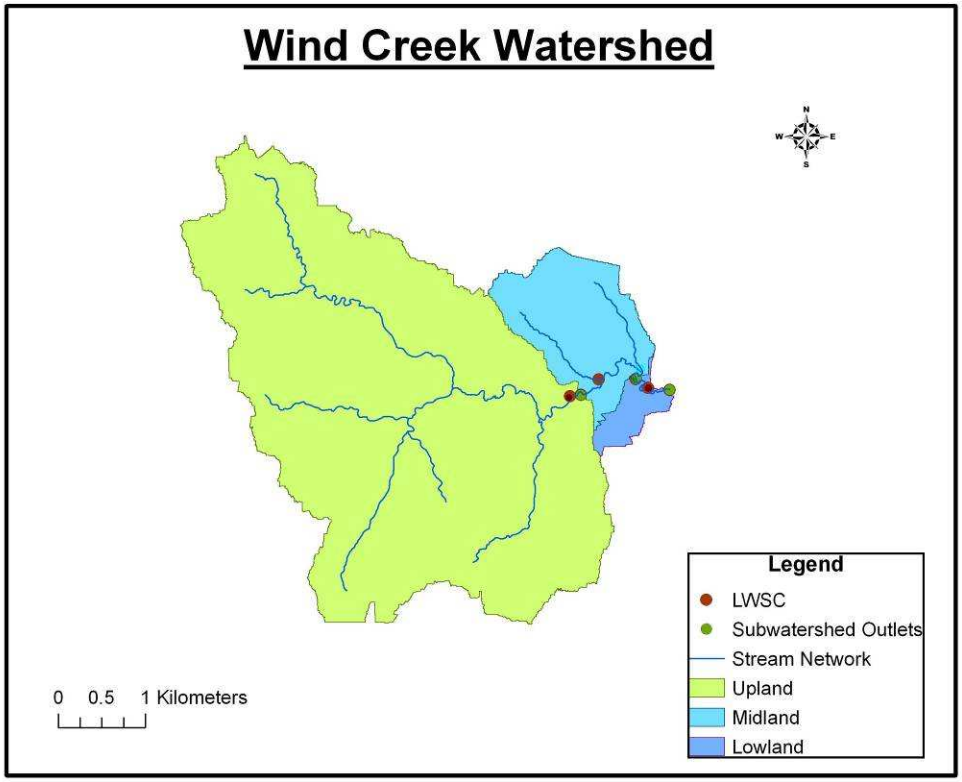

Figure 2-9. Wind Creek watershed, Fort Riley, Kansas.

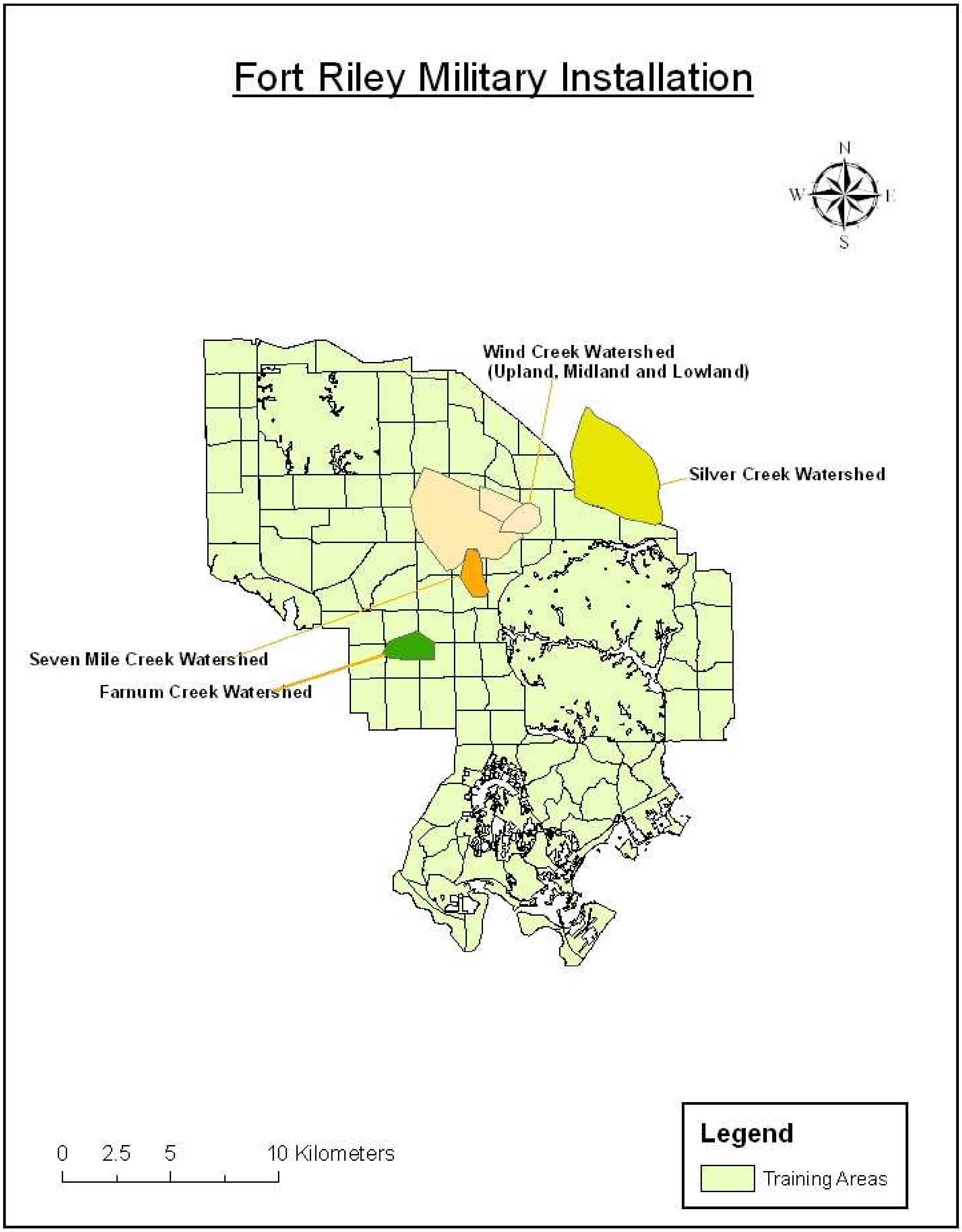

Figure 2-10. Location of study reaches at Fort Riley, Kansas.

Stream Classification

Stream reaches selected for the study were surveyed and classified using the Rosgen stream classification system (Rosgen, 1996). The Rosgen stream classification system is a hierarchical methodology that consists of four levels of stream classification. Level I classification provides a broad description of streams based on geomorphic characteristics. Level II classification, characterizes streams with a more detailed morphological description of stream type from field measurements of channel dimensions and bed composition. Level III assessment considers current conditions of the stream by characterizing streams according to stability, potential and function. At Level IV, predicated stream conditions are verified through analysis of stream flows, sediment loads, and additional geomorphic parameters (Rosgen, 1996). The first three levels of the Rosgen stream classification system are used in this study.

Stream Surveys

Longitudinal Profile Surveys

A systematic survey of each study reach was performed using conventional survey methods (Harrelson et al., 1994). Longitudinal profile surveys began and ended at riffle crests (head of riffle). Stationing along the longitudinal profile was conducted at 6.1 m intervals or where the stream bed had a change in slope. Sharp changes in channel slope were always observed at transition points (Figure 2-11) between the different stream features (i.e. pool, glide, riffle and run). Pools are generally considered the deepest points within a stream, while riffles are the shallow points. Glides and runs are transition features between pools and riffles. Stream bed, water surface and bankfull elevations were established using a laser level and leveling rod with an attached receiver. Stream bed elevations were taken at the deepest points (thalweg) along each stream reach, while bankfull elevations were taken on the active floodplain. Elevations are based on permanent benchmarks established within each study reach. Selected study reaches were approximately 20-30 bankfull widths long. Morphometric parameters determined from the longitudinal profile survey were: bankfull slope, water surface slope (S), channel slope and channel sinuosity (K). Bankfull slope was determined as ratio of the difference in bankfull elevation (between the beginning and end point of each study reach), and the length of the study reach. Channel slope was determined as a ratio of the difference in elevation of the channel bed (between the beginning and end point of each study reach) and the length of study reach. Water surface slope was determined as a ratio of the difference in elevation of the water surface (between the beginning and end point of each study reach) and the length of study reach. Channel sinuosity (K) was determined by computing the ratio between stream reach length and valley length. Repeat longitudinal profile surveys of each reach were conducted to quantify changes in stream bed elevation and slope.

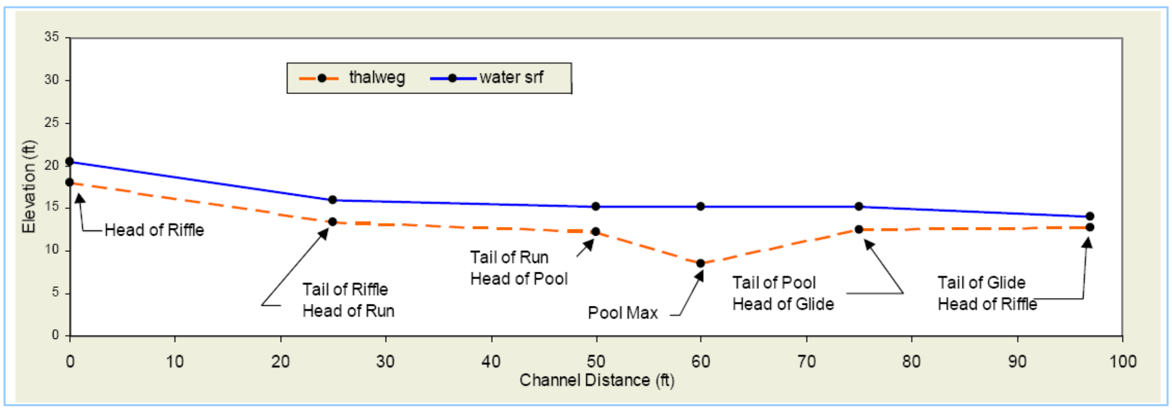

Figure 2-11. Longitudinal profile along a stream reach. Source: Vermont Stream Geomorphic Assessment Handbook, 2003.

Cross Section Surveys

Cross section transects were selected along each study reach. The selected cross section transects were at riffles and pools (and sometimes at runs and glides) on each study reach. Cross section transects were monumented with iron rebar on the left and right bank of the channel. With a cam line strung across the channel for stationing, elevation measurements were established across the channel, and tied to benchmarks on the left and right banks of the channel as well as to the longitudinal profile survey. Cross section profiles were then plotted from channel bed elevations and distance measurements (Figure 2-12). Bankfull stage (Figure 2-13) was identified at each channel cross section surveyed; bankfull stage was taken as the elevation of the active floodplain (Wolman and Leopold, 1957).

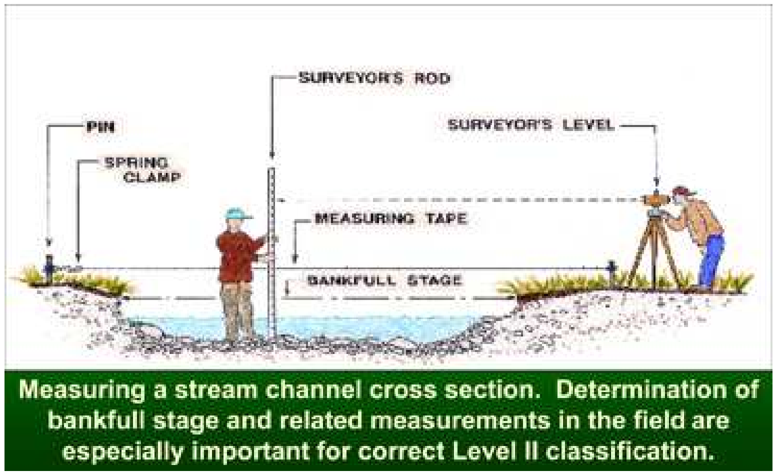

Figure 2-12. Cross section profile. Adapted from Rosgen, 1996.

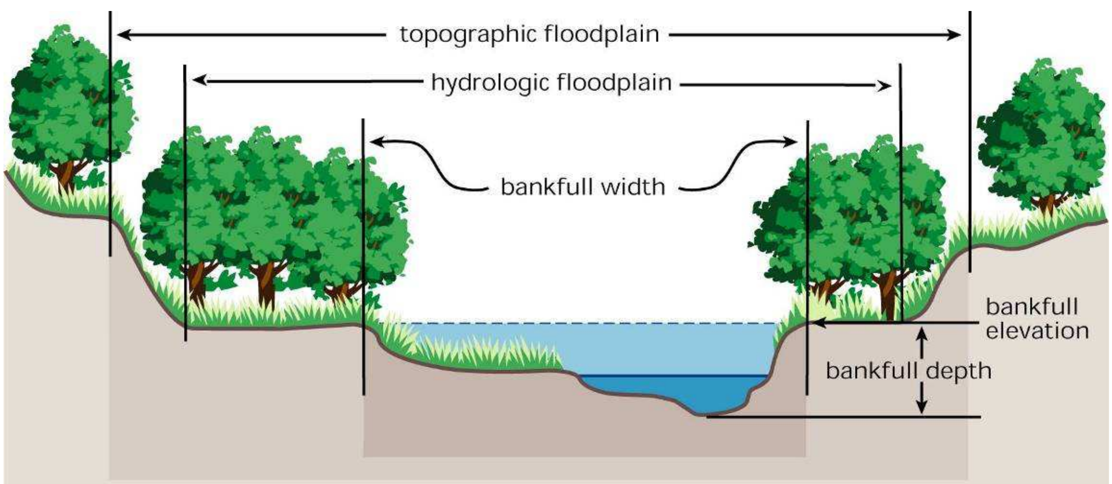

Figure 2-13. Cross section profile showing bankfull stage. Source: NRCS-USDA Stream Restoration Handbook, 2001.

Morphometric indices computed from the cross section survey data include: bankfull width (W_{bkf}), mean bankfull depth (D_{bkf}), bankfull area (A_{bkf}), width of flood prone area (W_{fpa}), bankfull velocity (u), bankfull discharge (Q_{bkf}), entrenchment ratio (ER) and width-depth ratio (W/D). Bankfull area was computed as the area of the channel below bankfull stage, while the width of flood prone area was determined at an elevation corresponding to twice the maximum bankfull depth, and entrenchment ratio was computed as a ratio of width of flood prone area (W_{fpa}) to bankfull width (W_{bkf}). Bankfull width was considered as the channel width corresponding to bankfull stage. Mean bankfull depth was computed by dividing bankfull area by bankfull cross section width. In order to calculate bankfull velocity, a Manning's resistance coefficient of the channel was determined using a relationship (developed by Rosgen, 2006) between channel friction factor (computed from Equation 1) and Manning's resistance coefficient. Bankfull velocity was computed using Manning's equation (Equation 2), while bankfull discharge was computed using Equation 3. The width-depth ratio indicates the shape of channel cross section while the entrenchment ratio indicates degree of vertical containment of the stream channel (Rosgen, 1996). Bankfull parameters determined from field data were validated using regional curves (Leopold, 1953) developed for the Kansas Flint Hills (Kansas State Conservation Commission, 2005).

$$\frac{u}{u^*} = \left[2.83 + 5.66 \times Log\left(\frac{R}{D_{84}} \right) \right] \quad \textbf{(1)}$$

$$u = \frac{1}{n} \times R^{2/3} \times S^{1/2} \quad \textbf{(2)}$$

$$Q = u \times A_{bkf} \quad \textbf{(3)}$$

Where:

$\frac{u}{u^*}$ = friction factor

u = Bankfull velocity (m/s)

A_{bkf} = Bankfull Area (m^2)

R = Hydraulic radius of the channel ($R = A_{bkf}$/ bankfull channel wetted perimeter (P)) (m)

S = Channel slope (m/m)

D_{84} = Bed material size of a particle size of the 84^{th} percentile.

n = Manning's resistance coefficient for the channel

Q = Bankfull discharge (m^3/s)

Repeat surveys of the cross section transects were conducted in the summer of 2007 (June-July) to determine rates of lateral and vertical migration of the stream channels. These rates of migration were quantified by measuring the net percentage change in channel cross section area (determined using Equation 4). A negative value indicates aggradation, while a positive value indicates degradation.

$$(\Delta A\%) = \frac{A_{after} - A_{before}}{A_{before}} \times 100 \quad \textbf{(4)}$$

Where:

$\Delta A\%$ = Net percentage change in channel cross section area

A_{after} = Channel cross section area from 2007 survey

A_{before} = Channel cross section area from 2006 survey

Bed Material Characterization

Reach Pebble Count

A modified Wolman pebble count (Wolman, 1954) was conducted at each study site to determine the particle size distribution in each study reach. The reach pebble count (detailed procedure is presented in Rosgen, 2007) was stratified such that a representative sample was collected from each reach. One hundred particles were collected and their median axis measured and recorded. A particle size distribution curve was plotted using the data collected. Information derived from the particle size distribution curve (from the reach pebble count) was later used during classification of the streams.

Active Bed Pebble Count

The active bed pebble count characterizes bed material at a riffle (Rosgen, 2007). One hundred particles were collected (from the active bed at the riffle) and their median axis measured and recorded. A particle size distribution curve was plotted using the data collected. Information derived from the particle size distribution curve (from the active bed pebble count) was later used in velocity and sediment competence calculations.

Bar Core Sample

Additionally, bar core samples were collected from point bars (at a position on the downstream third of a point bar between bankfull stage and thalweg), (Figure 2-14) at the Farnum Creek, Silver Creek, and Wind Creek study sites to determine the size of sediment particles available for entrainment at bankfull discharge. According to Rosgen, 2006, the bar core sample represents the size gradation of bedload at bankfull stage. Data from the bar core sample was analyzed to determine sediment transport competence of each reach. A detailed procedure used for the bar core sample collection and analysis is presented by Bunte and Abt (2001), US EPA (2006), and Rosgen (2006). A brief description of the procedure is presented below:

1. The bar sample was collected from a location, on the downstream third of a point bar, between the thalweg and bankfull stage (Figure 2-14).
2. Two largest particles on the surface of the bar sample location were collected, and their median axes and weights were measured and recorded.
3. Using a bottomless bucket, to define the area where the sample would be collected, bed materials were excavated up to a depth of twice the diameter of the largest surface particle measured in step 2 above.
4. Excavated materials were collected and weighed. Materials were then wet sieved (Figure 2-15) using sieves of sizes 63 mm, 31.5 mm, 16 mm, 8 mm, 4 mm and 2 mm. Net weights of materials retained on each sieve was measured and recorded.

5. Particle size distribution curve was then developed by plotting cumulative weights of materials (passing each sieve) against particle size. The particle size class index D_{50} was then determined from the curve.

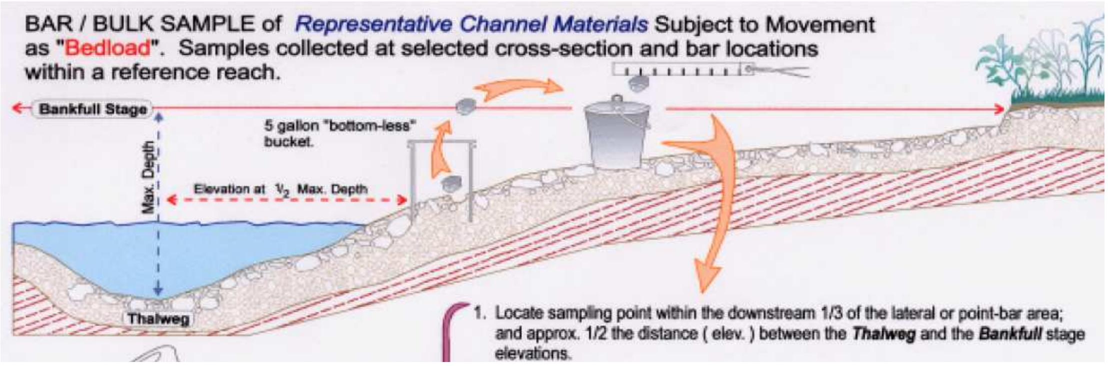

Figure 2-14. Bar sample collection and analysis. Source: Rosgen (2006).

Figure 2-15. Sieve analysis of a bar core sample at Silver Creek, Keats.

Scour Chain Surveys

Scour chains can be used to measure the amount of scour or fill at riffles and glides. In order to measure the amount of scour or fill along a reach, chains were installed into the stream bed at a riffle, upstream and downstream within each study reach. The scour chains were driven flush with the stream bed (Figure 2-16) and elevations of scour chain locations were taken. The two largest particles in the vicinity of each chain were measured and recorded. Repeat surveys (Figure 2-17) of the chains were conducted to measure the amount of scour or fill at a particular riffle along a study reach. Chains were resurveyed by measuring the length of chain exposed or buried into the stream bed, after major flow events. Again, the two largest particles in the vicinity of the chains were measured.

Figure 2-16. Installing a scour chain at riffle on Wind Creek, upland reach.

Figure 2-17. Repeat survey of scour chains at Wind Creek upland reach.

Stream Bank Surveys

Stream bank erosion monitoring was conducted at each study reach. Bank erosion monitoring was conducted by establishing permanent bank transects along each study reach. These bank transects were established in the summer of 2006. The bank transects were selected to represent a range of stream bank conditions along each study reach. At each transect, erosion pins (12.7mm diameter and 0.61m long) were installed in the bank (Figure 2-18), with the bottom most pin at an elevation of 0.30 m above a toe pin (installed into stream bed) and subsequent pins at elevations of 0.61 m apart. The erosion pins were driven into the stream bank with a hammer until the pins were flush with the stream bank. By placing a plumb survey rod on top of the toe pin (Figure 2-18), horizontal distance measurements (between the stream bank and the edge of the vertical survey rod) were determined using a pocket rod (with a spirit level attached to the pocket rod). The process was repeated at incremental elevations of 0.15 m along the vertical survey rod placed on the toe pin, each time the vertical distance and corresponding horizontal distance was measured and recorded. A bank profile of each transect was developed by plotting the vertical distance against horizontal distance. Using the same procedures above, repeat surveys of the bank transects were conducted (in the summer of 2007) to measure the actual rates of lateral migration of the stream bank transects surveyed in 2006. The length of erosion pins exposed (at each bank transect) was also measured and recorded. The pins were then pounded flush with the stream bank.

In order to estimate the amount of annual erosion generated from stream banks in each of the study reaches, the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) ratings (Rosgen, 1996, 2001a, 2006, and US EPA, 2006) of each bank transect surveyed were determined. The BEHI characterizes stream banks according to following variables: stream bank height, bankfull height, root depth, root density, surface protection, bank materials, and bank angle. The NBS is the stress placed on near bank region associated with the stream bank transects being evaluated (Rosgen, 2001a, 2006, and US EPA, 2006). The NBS rating characterizes a stream bank transect according to its location within the reach. The BEHI variables and NBS condition for each bank transect were evaluated and recorded. Using the methods presented in Level III of the Rosgen stream classification system (1996, 2001a, and 2006), cumulative BEHI and NBS ratings were determined for each bank transect (see appendices A through F for calculation details). Bank erosion rates were estimated using Colorado data, Rosgen (1996) and the computed BEHI and NBS ratings at each bank transect. The Colorado rating curves were used to estimate bank erosion rates because of the lack of bank erosion prediction curves for the Flint Hills region.

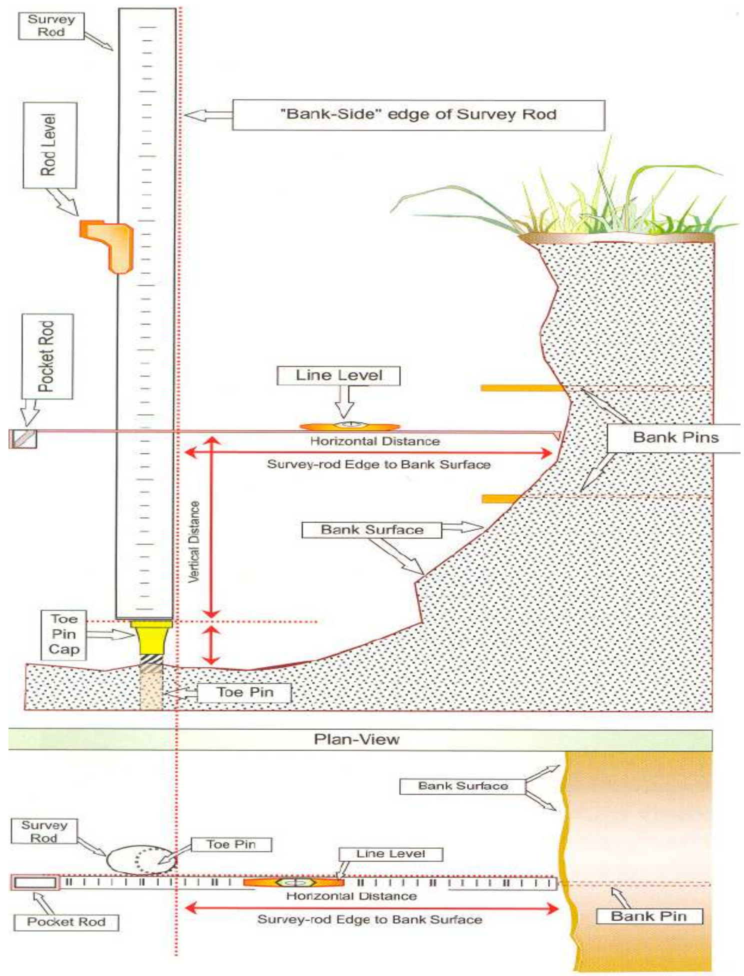

Figure 2-18. Measurement of stream bank profile. Source: Rosgen (1996).

Sediment Competence

A stream in equilibrium is able to move its sediment and discharge in such a manner that it maintains its pattern, profile and dimension, without aggrading or degrading (Rosgen, 1996). Entrainment calculations were performed to determine the stability of each study reach. This was accomplished by determining the channel depth and slope necessary for the entrainment of the largest particle on the downstream a third of a point bar at a location between bankfull stage and the thalweg. The critical dimensionless shear stress (τ_c), (Andrews, 1984; Rosgen, 2006) was computed at bankfull stage from Equation 5 while bankfull shear stresses were computed using

Equation 6. The bankfull mean depth and water surface slope (necessary for entrainment of the largest particle on the downstream third of a point bar at a location between bankfull stage and the thalweg) are calculated from Equations 7 and 8, respectively. Equation 9 was used to calculate the size of the largest particle entrained by bankfull shear stress.

$$\tau_c = 0.0384 \times \left[\frac{D_{50}}{Db_{50}} \right]^{-0.887} \qquad \textbf{(5)}$$

$$\tau_b = \rho_w \times g \times R \times S \qquad \textbf{(6)}$$

$$D_r = \tau_c \times \gamma \times \frac{D_i}{S} \qquad \textbf{(7)}$$

$$S_r = \tau_c \times \gamma \times \frac{D_i}{D_{bkf}} \qquad \textbf{(8)}$$

$$D_{ib} = 152.02 \times \tau_c^{0.7355} \qquad \textbf{(9)}$$

Where:

τ_b = Bankfull shear stress (lb/ft^2)

τ_c = Critical shear stress

g = Gravitational acceleration (ft^2/s)

γ = Submerged specific weight of sediment

ρ_w = Density of water (lb/ft^3)

R = Hydraulic radius (ft)

S_b = Existing bankfull water surface slope (ft/ft)

S_r = required bankfull water surface slope (ft/ft)

D_{50} = Median size particle from reach pebble count (mm)

D_{A50} = Median size particle from active bed pebble count (mm)

D_{s50} = Median particle size from bar sample (mm)

D_l = Largest particle from bar sample (mm)

D_{le} = Largest particle entrained by available bankfull shear stress (mm)

D_{Rbkf} = Bankfull mean depth required for entrainment of largest particle (ft)

D_{bkf} = Existing bankfull mean depth (ft)

Mapping of Roads and Stream Crossings

Approach roads are critical areas that often act as conduits for sediment laden storm runoff generated from upland areas and delivered to stream channels. Fort Riley has approximately eighty hardened fords across the training ranges. Fords are considered sources of sediment (Figures 2-19 and 2-20) delivered into streams through approach roads leading to stream crossing locations (Milauskas, 1988; Thompson et al., 1989; Brown, 1994; Sample et al., 1998; Blinn et al., 1999). Due to the poor state of some of the approach roads, sediment is generated from the roads and deposited at stream crossing sites. Roads were surveyed to develop a better understanding of erosion dynamics on these roads. Road slopes, vegetation and erosion variables were determined at each of the study sites. Stream crossings were also mapped to determine the area of the stream prone to traffic disturbance.

Figure 2-19. Gully forming on a road leading to stream crossing site.

Figure 2-20. Approach roads can be a source of sediment.

CHAPTER 3 - RESULTS AND DISCUSSION

Results from the stream survey of each study reach are presented and discussed in this chapter. Photographs and figures of longitudinal profile, cross section profiles, active and reach pebble counts, bank profiles, BEHI and NBS calculations for each individual reach are presented in a separate appendix for each study reach. Geographical Position System (GPS) coordinates taken at the beginning and end of each study reach, cross section transects and stream crossing locations are also presented in the appendix of each individual reach.

Farnum Creek

Stream Classification

The Farnum Creek study reach (shown in the photograph Figure A-1 in Appendix A) was classified according the Rosgen stream classification system (Rosgen, 1996). Morphometric parameters (Table 3-1) developed from the longitudinal profile and riffle cross section surveys were used in stream classification to determine the stream type for this study reach. Farnum Creek was classified as a G4c stream. A stream classified as a G4c stream is a deeply incised channel, with a stream bed composed of a mixture of gravel, cobble and silt/clay. The stream banks are composed of silt and clay. Streams of G4c classification are generally considered unstable due to their high stream power and high supply of sediment from upland areas and stream banks (Rosgen, 1996). This reach is located in valley type II. According to Rosgen (1996), valley type II exhibits moderate relief and G streams in this valley type exist under unstable conditions. Figures A-1 through A-16 are photographs taken at this study reach. Table 3-2 shows the variables used in the calculation of bankfull velocity and discharge.

Table 3-1. Stream classification protocol for Farnum Creek.

Morphometric Variable	Magnitude	Units
Bankfull Width (W_{bkf}) Width of the stream channel at bankfull stage elevation, in a riffle section.	4.40	m
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}).	0.45	m
Bankfull Cross Section Area (A_{bkf}) Area of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	2.00	m^2
Width/Depth Ratio (W_{bkf} /d_{bkf}) Bankfull width divided by bankfull mean depth, in a riffle section.	9.68	m/m
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.	0.80	m
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.	5.50	m
Entrenchment Ratio (ER) The ratio of flood-prone area width divided by bankfull channel width (W_{fpa} / W_{bkf}) (riffle section).	1.25	m/m
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.	20	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.	0.101	m/m
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).	1.10	m/m
Stream Type	**G4c**	

Table 3-2. Bankfull discharge variables at Farnum Creek.

Variable	Magnitude
W_{bkf} (m)	4.40
D_{bkf} (m)	0.45
W_{pbkf} (m)	5.31
A_{bkf} (m)	2.00
R (m)	0.38
D_{84} (mm)	62
R/D_{84}	6.10
S (m/m)	0.0101
u*	0.193
u (m/s)	1.28
u/u*	6.80
n	0.0410
Q_{bkf} (m^3/s)	2.56

Changes in Stream Geometry

Stream channel adjustments occur over time due to changes or alterations in stream discharge, sediment concentration and sediment size. A stable stream will undergo a series of channel adjustments in response to changes in one or more of the stream variables (i.e. stream discharge, sediment size and quantity) but still be able to maintain its dimension, pattern and profile without aggrading or degrading (Rosgen, 1996). The longitudinal profile and cross sectional surveys conducted at this site provided a means to track changes in stream dimension and profile. Figure A-14 shows the longitudinal profile while Figures A-15 through A-25 show repeat surveys of channel cross section transects at this study reach. Tables 3-3 through 3-5 show the channel geometry data collected. Figures A-15 through A-25 indicate slight changes in channel cross sectional area at this reach. The changes at these cross section transects suggest fill or/and scour. A comparison of changes in channel cross section area (Table 3-5 and Figure 3-1) showed approximately equal change in channel cross section area for transects (riffles and pools combined) above and below the stream crossing. Reworking of channel bed and bank material was minimal at this site because of the ephemeral nature of Farnum Creek. Therefore minor changes in channel geometry were observed.

Table 3-3. A summary of channel geometry variables at Farnum Creek.

Study Reach	Number of cross section transects	Range of width (m)	Range of depth (m)	Number of cross sections	
				Fill	Scour
Farnum Creek	11	6.4-10.7	1.6-2.8	6	5

Table 3-4. Changes in cross sectional area between the original survey (2006) and the resurvey in 2007 at Farnum Creek.

Study Reach	Cross section number	Cross section designation	Change in cross section area (m^2)	Percent change in cross section area
Farnum Creek	1	Riffle	-0.50	< = 0.50
	2	Riffle	-0.42	< = 0.50
	3	Pool	0.02	< = 0.50
	4	Pool	-0.15	< = 0.50
	5	Riffle	0.26	< = 0.50
	6	Run	-0.02	< = 0.50
	7	Pool	0.54	< = 0.50
	8	Riffle	-0.04	< = 0.50
	9	Pool	0.05	< = 0.50
	9B	Pool	0.13	< = 0.50
	10	Riffle	-0.04	< = 0.50

[Negative values indicate fill while positive values indicate scour].

Table 3-5. A comparison of changes in cross section areas between cross section transects above and below stream crossing at Farnum Creek.

Study Reach	Average change in channel cross section area (above ford), (m^2)		Average change in channel cross section area (below ford), (m^2)		Average change in channel cross section area for whole reach (m^2)	
	Riffle	Pool	Riffle	Pool	Riffle	Pool
Farnum Creek	-0.22	-0.07	-0.03	0.24	-0.13	0.09

[Negative values indicate fill while positive values indicate scour].

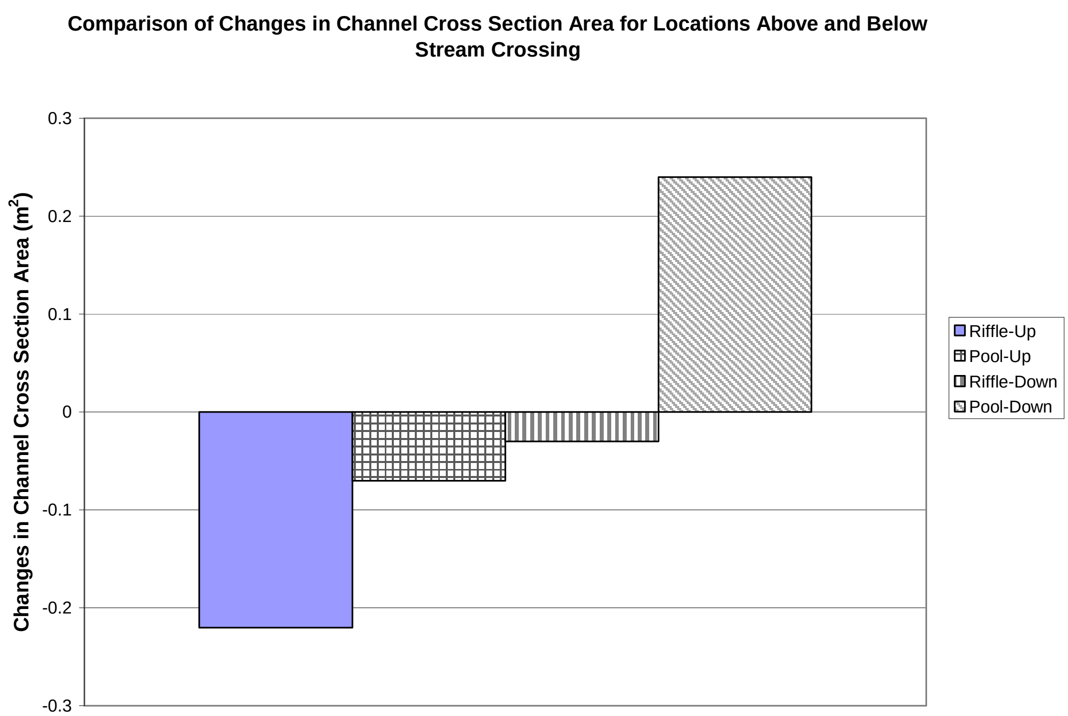

Figure 3-1. A comparison of changes in channel cross section area for cross section transects above and below stream crossing at Farnum Creek.

Changes in Bed Material Composition

Repeat surveys of stream bed material composition using active bed and reach pebble counts serves a function of tracking changes in bed material composition and distribution. These changes in bed material composition provide insight to sediment transport and bank erosion processes at reach scale. Results of the repeat surveys of bed material composition (active pebble count and reach pebble count) are shown in Figures A-26 through A-28. Results from the active bed pebble count (Figures A-26 and A-27) indicate no significant change in the median particle size and particle size distribution at cross section transects 1 and 10 respectively. However, the reach pebble count (Figure A-28 and Table 3-6) indicates slight shift towards to finer particles for the D_{35} and D_{50} particle sizes, between the years 2006 and 2007.

Table 3-6. Changes in particle size distribution from reach pebble count at Farnum Creek reach.

	Particle Size (mm)				
Year	D_{35}	D_{50}	D_{84}	D_{95}	D_{100}
2006	18	31	64	114	180
2007	0.4	20	65	115	256

Stream Bank Surveys and Bank Erosion Prediction

Data collected from bank erosion surveys were analyzed and plots of bank profiles were developed. The BEHI and NBS ratings developed for the Farnum Creek study reach are shown in Table 3-7. The method and calculations used to determine the BEHI and NBS ratings are shown in Tables A-1 through A-6. There was a marked difference between the BEHI and NBS ratings for bank transects above and below the stream crossing. Higher BEHI and NBS ratings indicate increased potential for stream bank erosion as well as stream bank instability, while lower ratings indicate low potential for stream bank instability. The combination of BEHI and NBS ratings were used to predict stream bank erosion rates. The Colorado stream bank erosion prediction curve (Figure 3-2) was used for estimating the bank erosion rate from the bank transects surveyed.

Results of the repeat surveys of bank transects at Farnum Creek reach are shown in Figures A-29 through A-31. Table 3-8 shows the predicted and measured bank erosion rates and annual sediment yield for the Farnum Creek reach. When compared with the actual measured bank erosion rates, the predicted bank erosion rates are higher than the measured erosion rates. It is important to note that these predicted erosion estimates are higher than would be expected for streams in the Flint Hills physiographic region, due to the differences in stream bank composition. Stream banks in the Flint Hills region are mainly composed of silt and clay materials which tend to be highly cohesive in nature and therefore less susceptible to bank erosion, while streams in Colorado tend to have banks composed of friable materials which are easily eroded. Another factor that explains the differences in stream bank erosion rates is the difference in stream regimes in Kansas and Colorado. Stream regimes in the Flint Hills region are mainly storm runoff generated, while streams in Colorado are snow melt runoff generated. Storm runoff tends to be spatially and temporally variable in nature, thus stream bank erosion rates in the Flint Hills are highly variable. On the other hand, snow melt runoff generated regimes in Colorado tend to have less variation because of slight variation in the magnitude and time of occurrence of snow melt runoff. Therefore, stream bank erosion rates in Colorado streams are likely to be more constant annually.

Repeat surveys of the stream banks are therefore necessary to determine the actual annual stream bank erosion rates at each study site. The repeat surveys will enable validation of the predicted stream bank erosion rates developed using the BEHI and NBS ratings. Over time, this erosion data can be incorporated in a vigil network for developing bank erosion prediction curves for the Flint Hills region.

Table 3-7. BEHI and NBS ratings developed for bank transects at Farnum Creek.

BEHI Rating			NBS Rating		
Upstream	Downstream		Upstream	Downstream	
Moderate	Moderate	High	High (4)	Extreme(6)	Extreme(6)

Table 3-8 . Predicted and measured bank erosion rates at Farnum Creek.

Predicted Annual Bank Erosion Rates (m/yr)	Measured Annual Bank Erosion Rates (m/yr)	Measured Annual Sediment Yield (kg/m/yr).
0.13-0.40	0.07-0.14	200

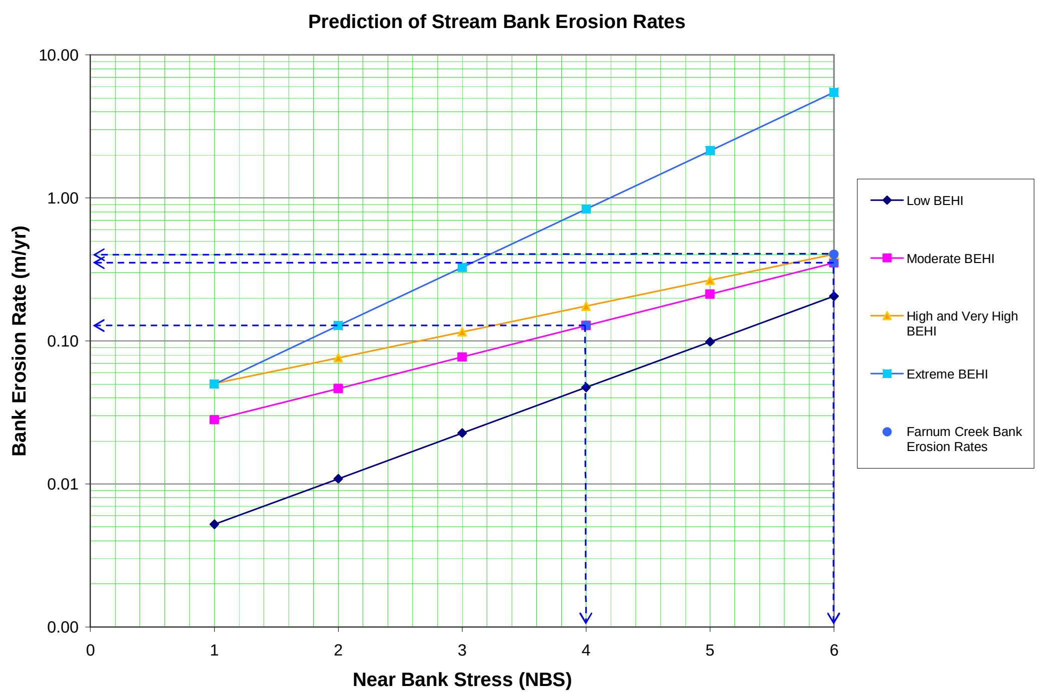

Figure 3-2. Relationship of BEHI and NBS ratings used to predict annual stream bank erosion rates on Farnum Creek. Adapted after Rosgen (1996 and 2006).

The measured bank erosion rates and annual sediment yield (Table 3-8) at Farnum Creek were fairly moderate. Farnum Creek (classified as a G stream) is an ephemeral stream that experiences stream flow less frequently. The periodic nature of stream flow in this stream allows adequate time for riparian vegetation to grow in the channel and on the stream banks. The riparian vegetation (in the channel and on the banks) provides adequate protection against erosive action of flow. The bank material composition (mainly silt and clay) of this stream also plays a role in controlling bank erosion rates.

The bank erosion rates (and the sediment yield) on this ephemeral stream are therefore lower than would be expected for a G4c stream. Figure 3-3 shows a comparison of sediment yield generated from segments of the study reach upstream and downstream of stream crossing one at this study reach. It is shown that the sediment yield generated from stream segments below the stream crossing is higher than that generated from stream segments above the stream crossing. Erosion rates generally increase in the downstream direction because discharge (or stream power) increases in the downstream direction. A tributary located immediately above the stream crossing introduces extra discharge and sediment into the main stream at this study reach. In addition, the approach roads to the stream crossing location concentrate and channel runoff (generated from upland areas) into the main stream increasing the magnitude of discharge introduced into the main stream. However, the amount of runoff generated through these roads is still unknown, and additional studies are required to investigate erosion dynamics and hillslope hydrology on these roads. Overall, the increase in discharge (in the downstream direction), among other factors, explains the higher bank erosion rates at locations below the stream crossing.

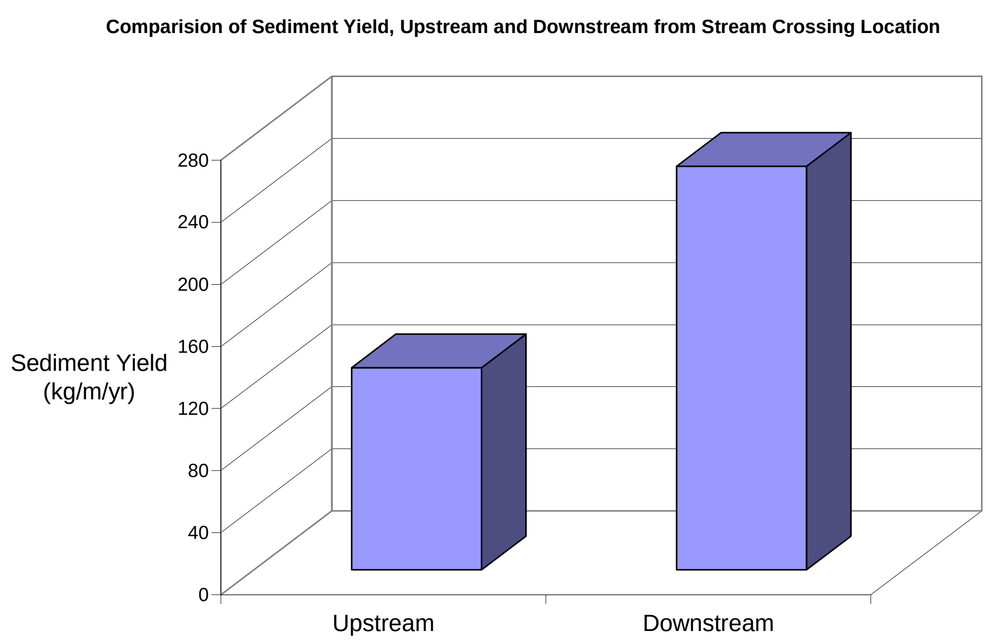

Figure 3-3. A comparison of sediment yield between upstream and downstream locations from stream crossing one at Farnum Creek.

Sediment Competence

The results of sediment competence calculations are shown in Table 3-9. The Farnum Creek reach has a slope and mean bankfull depth larger than what is required to entrain the largest particle on the point bar. This implies that this reach has excessive stream power, and channel degradation is predicted to occur as the channel tries to adjust its slope and depth to a level where stream equilibrium is restored. From the modified Shields diagram (Figure 3-4) (Shields, 1936; Leopold et al, 1964; Rosgen, 2006), the calculated bankfull shear stress is capable of transporting D_{97} (156 mm) particle size at the reach.

Table 3-9. A Summary of sediment competence variables at Farnum Creek.

Variable	S_b (%)	S_r (%)	D_{bkf} (m)	D_{Rbkf} (m)	D_{s50} (mm)	D_{A50} (mm)	D_{50} (mm)	D_l (mm)	D_{le} (mm)	τ_c	τ_b (lb/ft^2)
Magnitude	1.01	0.47	0.50	0.24	11	35	20	64	156	0.024	1.03

Stream Channel Successional Changes

Streams undergo a series of channel adjustments over time so as to accommodate changes or alterations in discharge, sediment concentration, and sediment size (Rosgen, 1996). Channel adjustments at the study sites can be attributed to past and current land use practices. Past land use practices in the study watersheds include agriculture and grazing. Agriculture and grazing in riparian areas poses a potential of accelerating stream bank erosion rates due to increased storm runoff rates (resulting from the reduction in protective vegetative cover in the riparian areas). Current land use practice in the study watersheds is military maneuvers. Military maneuvers are destructive to vegetation and cause compaction of soil (Rice et al. 2006; Svendsen et al. 2006). As a result of reduced vegetative cover and increased soil compaction, runoff as well as soil erosion rates on the rangelands can increase. This runoff from the upland areas (usually rich in sediment) is transported to the streams, posing a potential of causing stream stability.

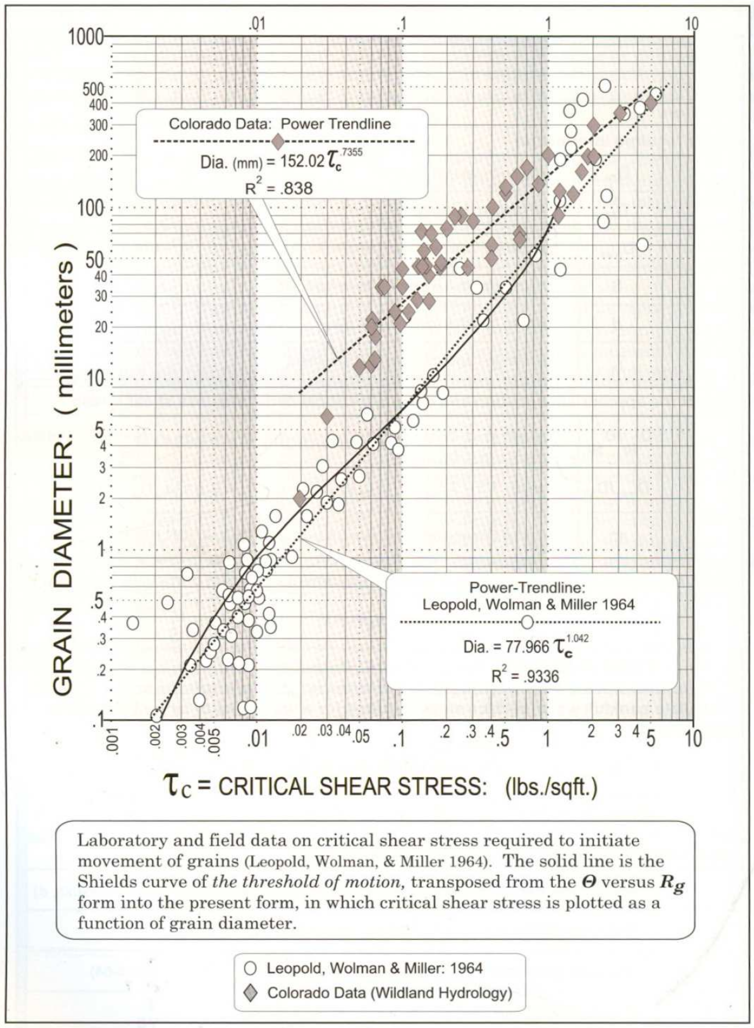

Figure 3-4. Shields diagram showing the critical shear stress required to initiate particle or grain movement (Leopold et al., 1964; Rosgen, 2006).

The Farnum Creek stream reach (G4c stream type) is a disturbed stream type in the Flint Hills region. This reach is probably transitioning into an F4 stream and then eventually to a C4 stream type (Figure 3-5). The transition sequence ends at a C4 stream because streams of a C4 classification are considered relatively stable (unless disturbed) in the Flint Hills region. The transition from stream type G4c to F4 involves an increase in channel depth followed by an increase in channel width. During this transition stage, accelerated rates of bank erosion will be observed at this study reach. The next step in the successional sequence is the transition of the F4 channel to a C4 stream type. This transition stage involves an additional increase in channel depth and a reduction in channel width. This stage also involves adjustment of channel slope. Beyond this stage, the stream will have attained stability and will be able to transport its sediment and discharge in an effective manner without any adverse impacts. These stream changes have direct implications on the low water fords on Fort Riley. As a result of these stream changes, there will be a need to constantly modify the designs and construction techniques of the low water fords in order to accommodate changes in stream dimensions and profile.

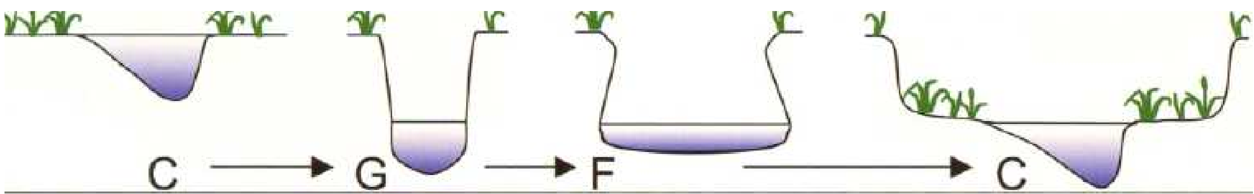

Figure 3-5. Stream channel successional changes (adapted from Rosgen, 1996).

Seven Mile Creek Reach

Stream Classification

Morphometric variables listed in Table 3-10 were used for classifying the Seven Mile Creek study reach (shown in the photograph Figure B-1 in Appendix B). This reach was classified as a G6c stream type. This stream type is considered an entrenched gully (with a gentle channel slope) incised in a clay bed (Rosgen, 1996). Streams of G6c classification are associated with high bank erosion rates. However, due to the high density of riparian vegetation along the stream banks at this study reach, low bank erosion rates are expected. Streams of G6c classification are very sensitive to disturbances due to changes in watershed and channel conditions (Rosgen, 1996). This reach is located in valley type II. According to Rosgen (1996), valley type II exhibits moderate relief and G streams in this valley type exist under unstable conditions. Figures B-2 through B-9 are photographs taken at this study reach. Table 3-11 shows the variables used in the calculation of bankfull velocity and discharge.

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Table 3-10. Stream classification protocol for Seven Mile Creek.

Morphometric Variable	Magnitude	Units
Bankfull Width (W_{bkf}) Width of the stream channel at bankfull stage elevation, in a riffle section.	3.66	m
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}).	0.51	m
Bankfull Cross Section Area (A_{bkf}) Area of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	1.87	m^2
Width/Depth Ratio (W_{bkf} /d_{bkf}) Bankfull width divided by bankfull mean depth, in a riffle section.	7.14	m/m
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.	0.61	m
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.	5.76	m
Entrenchment Ratio (ER) The ratio of flood-prone area width divided by bankfull channel width (W_{fpa} / W_{bkf}) (riffle section).	1.57	m/m
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.	< 2	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.	0.0038	m/m
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).	1.79	m/m
Stream Type	**G6c**	

Table 3-11. Bankfull discharge variables at Seven Mile Creek.

Variable	Magnitude
W_{bkf} (m)	3.66
D_{bkf} (m)	0.51
W_{pbkf} (m)	4.68
A_{bkf} (m)	1.87
R (m)	0.40
D_{84} (mm)	60
R/D_{84}	6.70
S (m/m)	0.0038
u*	0.122
u (m/s)	0.84
u/u*	7.50
n	0.040
Q_{bkf} (m^3/s)	1.56

Changes in Stream Geometry

Figure B-10 shows the repeat survey of the longitudinal profile while Figures B-11 through B-18 show changes in channel cross section geometry at the Seven Mile Creek study reach. Tables 3-12 through 3-14 show channel geometry data collected. In comparing the changes in cross section area (Figures B-11 through B-18 and Table 3-14), it is shown that more change occurred at the cross section transects above the stream crossing than those below. However, the overall magnitude of change was small. Reworking of channel bed and bank material was minimal at this site because of the ephemeral nature of Seven Mile Creek. Therefore the magnitude of change in channel geometry was minor. Results from the scour chains (Table B-1) indicate no scour or fill on the channel bed at cross section transects 0 and 6, respectively. Results from the longitudinal profile (Figure B-10) at Seven Mile Creek corroborate findings from the cross section survey. No change was observed in channel slope at this reach.

Table 3-12. Changes in cross sectional area between the original survey (2006) and the resurvey in 2007 at Seven Mile Creek.

Study Reach	Cross section number	Cross section designation	Change in cross section area (m^2)	Percent change in cross section area
Seven Mile Creek	0	Run	0.46	<= 0.50
	1	Pool	-0.05	<= 0.50
	2	Pool	0.16	<= 0.50
	2B	Pool	0.36	<= 0.50
	3	Pool	0.06	<= 0.50
	4	Glide	0.09	<= 0.50
	5	Pool	0.05	<= 0.50
	6	Riffle	0.08	<= 0.50

[Negative values indicate fill while positive values indicate scour].

Table 3-13. A summary of channel geometry variables at Seven Mile Creek.

Study Reach	Number of cross section transects	Range of width (m)	Range of depth (m)	Number of cross sections	
				Fill	Scour
Farnum Creek	11	6.4-10.7	1.6-2.8	6	5

Table 3-14. A comparison of changes in channel cross section area between cross section transects above and below stream crossing at Seven Mile Creek.

Study Reach	Average change in cross section area (above ford), (m^2)		Average change in cross section area (below ford), (m^2)		Average change in cross section area for whole reach (m^2)	
	Riffle	Pool	Riffle	Pool	Riffle	Pool
Seven Mile Creek	-0.22	-0.07	-0.03	0.24	-0.13	0.09

[Negative values indicate fill while positive values indicate scour].

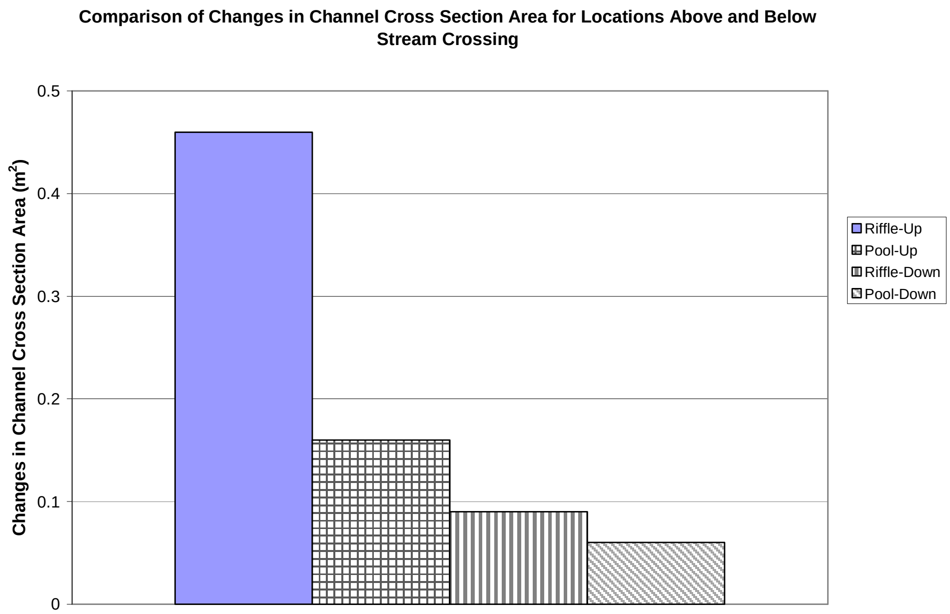

Figure 3-6. A comparison of changes in channel cross section area for cross section transects above and below stream crossing at Seven Mile Creek.

Changes in Bed Material Composition

Results of the active bed pebble count and reach pebble count (Figures B-19 and B-21 and Table 3-15) at the Seven Mile Creek reach indicate a shift towards finer sediment for the particle sizes $D_{50,}$ D_{84} and $D_{95.}$ This suggests an influx of sediment into this stream reach, probably sediment carried from upland areas since there is minimal erosion at this study reach. The active bed pebble count at the downstream end (Figure B-20) of the reach indicates a minor shift towards coarse sediment. Results from the scour chains (Table B-1) indicate a no significant shift in particle sizes.

Table 3-15. Changes in particle size distribution from reach pebble count at Seven Mile Creek reach.

	Particle Size (mm)				
Year	D_{35}	D_{50}	D_{84}	D_{95}	D_{100}
2006	< 2	26	59	110	180
2007	< 2	< 2	42	62	180

Stream Bank Surveys and Bank Erosion Prediction

The BEHI and NBS ratings developed for the Seven Mile Creek study reach are shown in Table 3-16. The method and calculations used to determine the BEHI and NBS ratings are shown in Tables B-2 through B-5. There was a difference in BEHI and NBS ratings between the bank transects upstream and downstream from the stream crossing. High BEHI and NBS ratings indicate increased potential for stream bank erosion as well as stream bank instability, while moderate ratings indicate low potential for stream bank instability. Changes in bank profile at the Seven Mile Creek study reach are shown in Figures B-22 and B-23. Table 3-17 shows the predicted and actual bank erosion rates and annual sediment yield for the Seven Mile Creek study reach. The predicted bank erosion rates (Table 3-17 and Figure 3-7) are fairly higher than the erosion rates measured at this site for the same reasons presented above (see discussion on bank erosion at Farnum Creek).

Table 3-16. BEHI and NBS ratings of bank transects at Seven Mile Creek.

BEHI Rating		NBS Rating	
Upstream	Downstream	Upstream	Downstream
Moderate	High	Moderate (3)	High (4)

Table 3-17. Predicted and measured bank erosion rates at Seven Mile Creek reach.

Predicted Annual Bank Erosion Rates (m/yr)	Measured Annual Bank Erosion Rates (m/yr)	Measured Annual Sediment Yield (kg/m/yr)
0.08-0.18	0.04-0.09	100

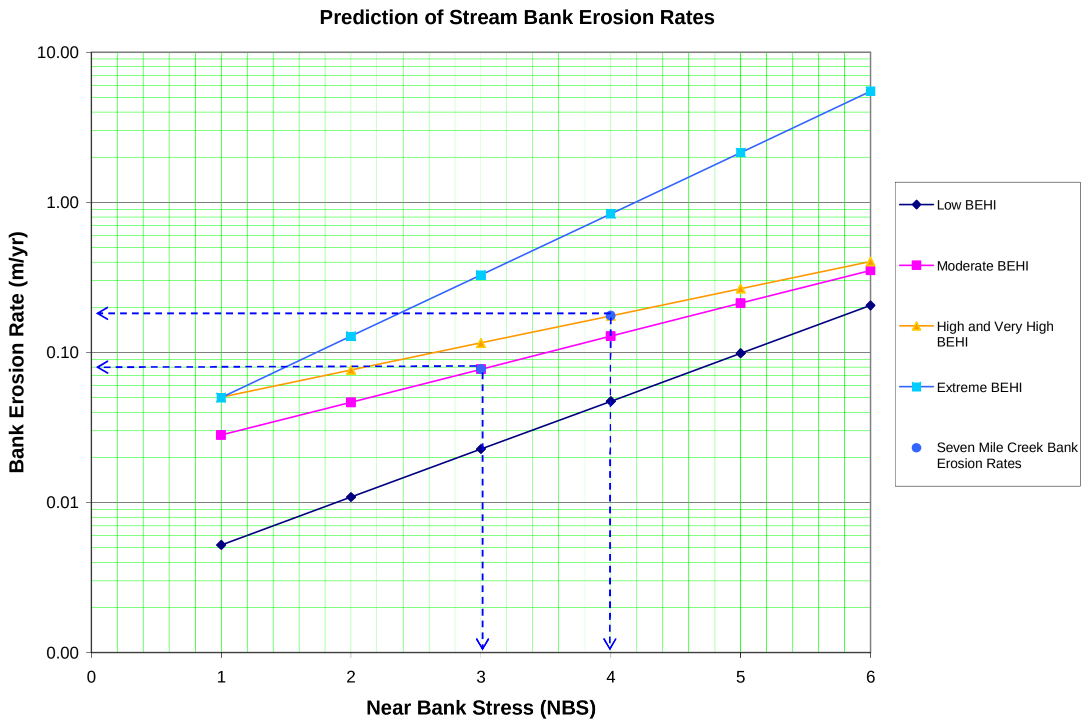

Figure 3-7. Relationship of BEHI and NBS ratings used to predict annual stream bank erosion rates on Seven Mile Creek. Adapted after Rosgen (1996 and 2006).

The measured bank erosion rates and annual sediment yield (Table 3-17) at Seven Mile Creek were quite low. Like Farnum Creek, Seven Mile Creek (classified as a G stream) is an ephemeral stream that experiences stream flow less frequently. The periodic nature of stream flow in this study reach allows adequate time for riparian vegetation to grow in the channel and along the stream banks. The riparian vegetation in the channel and along stream banks provides adequate protection against erosive action of flow. The bank material composition (mainly silt and clay) of this stream also plays a role in controlling bank erosion rates. The bank erosion rates (and the sediment yield) at this ephemeral stream are therefore lower than would be expected for a G6c stream. Figure 3-8 shows a comparison of sediment yield generated from segments of the study reach upstream and downstream of the stream crossing at this study reach. It is shown that the sediment yield generated from stream segments below the stream crossing at this study reach is higher than that generated from stream segments above the stream crossing. Erosion rates generally increase in the downstream direction because discharge (or stream power) increases in the downstream direction. Like the Farnum Creek reach, a tributary located immediately above the stream crossing introduces extra discharge and sediment into the main stream at this study reach. In addition, the approach roads to the stream crossing location concentrate and channel runoff (generated from upland areas) into the main stream increasing the magnitude of discharge introduced into the main stream. The overall increase in stream discharge (in the downstream direction) among other factors explains the higher bank erosion rates at locations below the stream crossing.

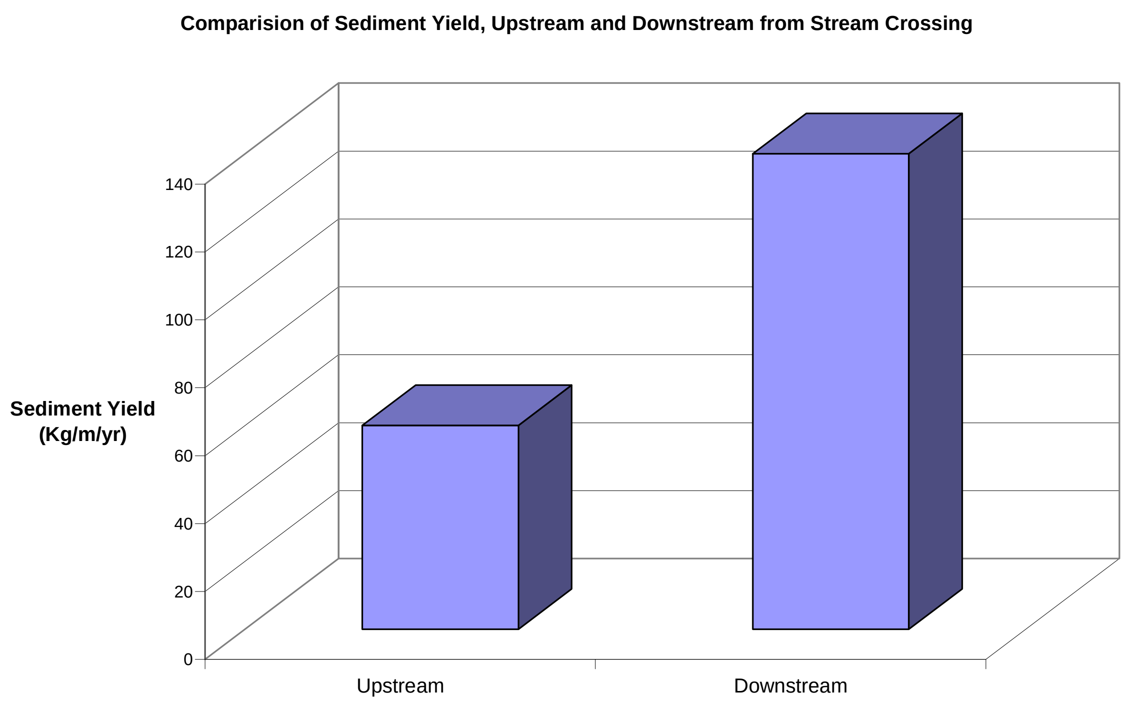

Figure 3-8. A comparison of sediment yield between upstream and downstream locations from stream crossing at Seven Mile Creek.

Sediment Competence

The results of sediment competence calculations are shown in Table 3-18. These results indicate that the Seven Mile Creek reach lacks adequate slope and mean bankfull depth required to entrain the largest particle on the point bar. This implies that this reach lacks adequate stream power to transport its sediment and channel aggradation is predicted to occur as the stream tries to adjust its slope and depth to a level where stream equilibrium is restored. From the modified Shields diagram (Shields, 1936; Leopold et al, 1964; Rosgen, 2006), the calculated bankfull shear stress is capable of transporting D_{98} (78) particle at the reach.

Table 3-18. A Summary of sediment competence variables at Seven Mile Creek.

Variable	S_b (%)	S_r (%)	D_{bkf} (m)	D_{Rbkf} (m)	D_{s50} (mm)	D_{A50} (mm)	D_{50} (mm)	D_l (mm)	D_{le} (mm)	T_c	T_b(lb/ft^2)
Magnitude	0.38	0.47	0.52	0.65	-	35	< 2	90	78	0.021	0.40

[- implies missing data].

Stream Channel Successional Changes

Seven Mile Creek reach; currently a G6c stream shows signs of instability which include meander cutoffs and a sediment shift towards finer sediment. The Seven Mile Creek reach is probably transitioning into an F6 stream type then eventually to a C6 stream type (Figure 3-9). The C6 stream type is considered relatively stable. The transition from stream type G6c to F6 involves an increase in channel depth followed by an increase in channel width. During this transition stage, accelerated rates of bank erosion will be observed at this study reach. The next step in the successional sequence is the transition of the F6 channel to a C6 stream type. This transition stage involves an additional increase in channel depth and a reduction in channel width. This stage also involves adjustment of channel slope. Beyond this stage, the stream will have attained stability (if left undisturbed) and will be able to transport its sediment and discharge in an effective manner without any adverse impacts.

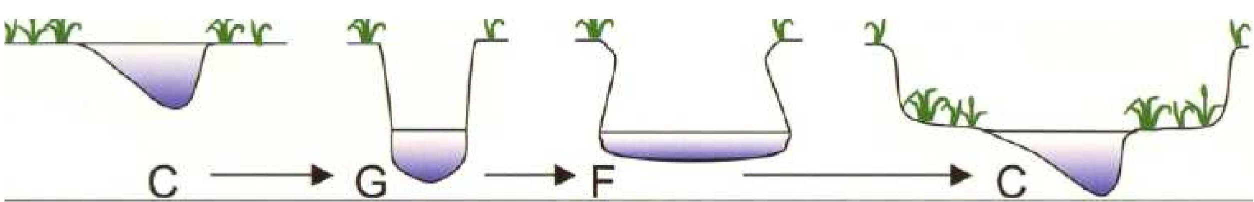

Figure 3-9. Stream channel successional changes (adapted from Rosgen, 1996).

Silver Creek Reach

Stream Classification

Morphometric variables listed in Table 3-19 were used for classifying the Silver Creek study reach. Silver Creek was classified as an F4 stream type. Streams of F4 classification have gentle channel slopes and are entrenched channels (with high width-depth ratio) with gravel dominated beds. The stream banks at this study reach are composed of silt and clay. These stream types have well developed pool-riffle morphology. Silver Creek, like any unstable F4 stream has accelerated rates of stream bank erosion and is considered a transitional stream type in the Flint Hills region. This reach is located in valley type VIII; considered to have a wide and gentle slope with a well developed floodplain adjacent to river terraces (Rosgen, 1996). Figures C-1 through C-6 (shown in Appendix C) are photographs taken at this study reach. Table 3-20 shows the variables used in the calculation of bankfull velocity and discharge.

Changes in Stream Geometry

Figure C-7 shows the repeat survey of the longitudinal profile while Figures C-8 through C-11 show changes in channel cross section geometry at the Silver Creek study reach. Tables 3-21 through 3-23 show channel geometry data collected. Changes in cross section area at the Silver Creek study reach are shown in Tables 3-21 and 3-23. These changes in cross section area are of variable magnitude. Moderate to large changes in cross sectional area were observed at both pools and riffles at this study reach. These changes were mainly due to fill and accelerated bank erosion at cross section transects shown in Figures C-8 through C-11. Overall, the pools experienced greater filling compared to the riffles. Results from the scour chains (Table C-1) indicated moderate scour (followed by fill) at the scour chain locations at cross section transect 2.The longitudinal profile (Figure C-7) indicates localized scour and fill at certain points along the reach. Major reworking of the channel bed and bank materials was observed. An increase in channel slope from 0.0062 (in 2006) to 0.0079 (in 2007), (27.4% increase) was observed at the reach. This change in channel slope is associated with channel degradation in the lower locations of the reach. All these changes suggest that this reach is striving to regain stream equilibrium.

Table 3-19. Stream classification protocol for Silver Creek reach.

Morphometric Variable	Magnitude	Units
Bankfull Width (W_{bkf}) Width of the stream channel at bankfull stage elevation, in a riffle section.	12.66	m
Bankfull Depth(d_{bkf}) Mean depth of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	0.79	m
Bankfull Cross Section Area (A_{bkf}) Area of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	9.96	m^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull width divided by bankfull mean depth, in a riffle section.	16.07	m/m
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.	0.92	m
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.	14.95	m
Entrenchment Ratio (ER) The ratio of flood-prone area width divided by bankfull channel width (W_{fpa} / W_{bkf}) (riffle section).	1.18	m/m
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.	37	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.	0.0027	m/m
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).	1.24	m/m
Stream Type	**F4**	

Table 3-20. Bankfull discharge variables at Silver Creek.

Variable	**Magnitude**
W_{bkf} (m)	12.66
D_{bkf} (m)	0.79
W_{pbkf} (m)	14.23
A_{bkf} (m)	9.96
R (m)	0.70
D_{84} (mm)	48
R/D_{84}	14.60
S (m/m)	0.0027
u*	0.136
u (m/s)	1.24
u/u*	9.00
n	0.0330
Q_{bkf} (m^3/s)	12.36

Table 3-21. Changes in cross sectional area between the original survey (2006) and the resurvey in 2007 at Silver Creek.

Study Reach	Cross section number	Cross section designation	Change in cross section area (m^2)	Percent change in cross section area
Silver Creek	1	Pool	-1.48	-2.6
	2	Riffle	0.97	1.8
	3	Riffle	- 1.49	-2.5
	4	Pool	- 0.20	-0.4

[Negative values indicate fill while positive values indicate scour].

Table 3-22. A summary of channel geometry variables at Silver Creek.

Study Reach	Number of cross section transects	Range of width (m)	Range of depth (m)	Number of cross sections	
				Fill	Scour
Silver Creek	4	18.9-21.4	3.2-4.3	3	1

Table 3-23. A comparison of changes in channel cross section area between pool and riffle cross section transects at Silver Creek.

Study Reach	Average change in cross section area for whole reach (m^2)	
	Riffle	Pool
Silver Creek	-0.25	-0.84

[Negative values indicate fill while positive values indicate scour].

Changes in Bed Material Composition

Results of the active bed pebble count and reach pebble count at the Silver Creek reach are shown in Figures C-12 and C-13, respectively. The results shown in Table 3-24 indicate a significant shift towards coarse sediment along this study reach. However, results from the active bed pebble count (Figure C-12) indicated no shift in particle size and distribution at cross section transect 2. This shift in sediment size along the reach is associated with an increase in particle size of the sediment in the pools. The frequent flow events experienced between March-June 2007 were responsible for flushing fine sediment (from previous seasons) stored in the pools and coarse sediment from upstream has replaced the fine sediment that was evacuated from the pools, and this explains the shift towards coarse sediment along this reach. Results from the scour chains (Table C-1) indicate no significant change in bed material sizes at the scour chain locations at cross section transect 2.

Table 3-24. Changes in particle size distribution from reach pebble count at Silver Creek reach.

	Particle Size (mm)				
Year	D_{35}	D_{50}	D_{84}	D_{95}	D_{100}
2006	12	20	39	60	128
2007	26	36	85	120	256

Stream Bank Surveys and Bank Erosion Prediction

The BEHI and NBS ratings developed for the Silver Creek study reach are shown in Table 3-25. The method and calculations used to determine the BEHI and NBS ratings are shown in Tables C-2 through C-5. There was a marked difference in both the BEHI and NBS ratings between the bank transects along this reach. High BEHI and NBS ratings indicate increased potential for stream bank erosion as well as stream bank instability, while low and moderate ratings indicate low potential for stream bank instability. Changes in bank profiles at Silver Creek study reach are shown in Figures C-14 and C-15. Table-26 shows the predicted and measured bank erosion rates and annual sediment yield for this study reach. The predicted bank erosion rate (Table 3-26 and Figure 3-10) is slightly lower than the erosion rate measured at the downstream bank transects at this study reach. However, the predicted erosion rate at the upstream bank transects was higher than that measured. This reach is experiencing accelerated bank erosion rates along the mid and downstream locations of the reach.

Table 3-25. BEHI and NBS ratings of bank transects at Silver Creek.

BEHI Rating		NBS Rating	
Upstream	Downstream	Upstream	Downstream
Moderate	High	High (4)	Extreme (6)

Table 3-26. Predicted and measured bank erosion rates at Silver Creek.

Predicted Annual Bank Erosion Rates (m/yr)	Measured Annual Bank Erosion Rates (m/yr)	Measured Annual Sediment Yield (kg/m/yr)
0.13-0.40	0.04-0.48	800

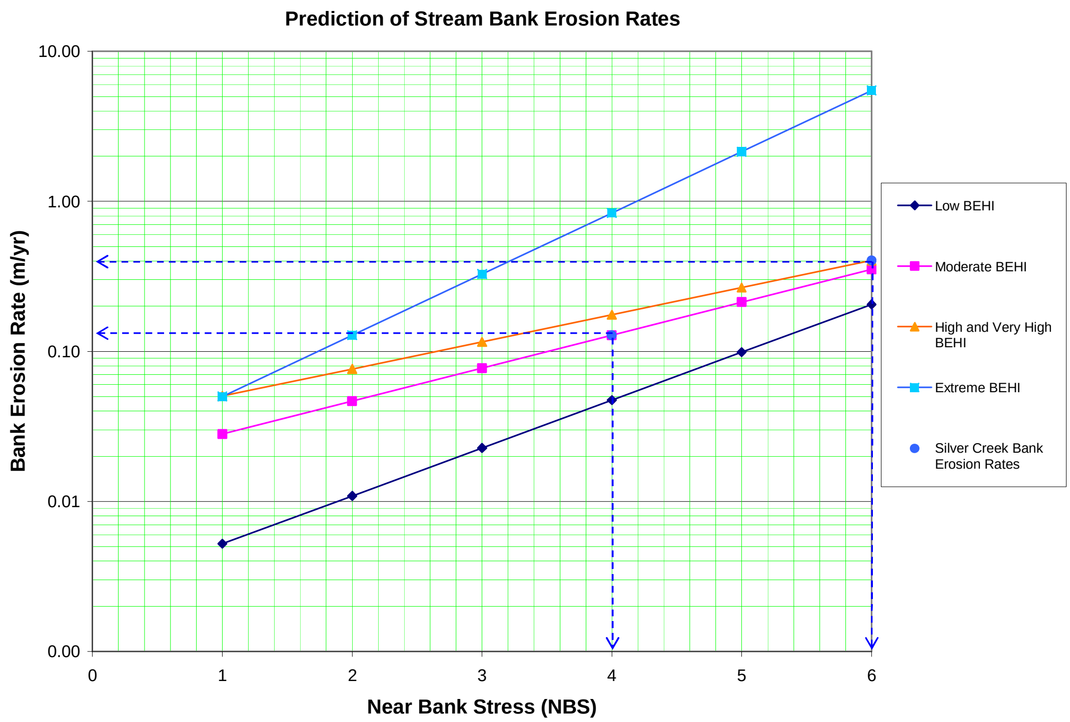

Figure 3-10. Relationship of BEHI and NBS ratings used to predict annual stream bank erosion rates on Silver Creek. Adapted after Rosgen (1996 and 2006).

The high rates of bank erosion at this reach can be attributed to increased discharge (due to the high number of runoff events experienced in March-June, 2007 as well as increase in drainage area) and the nature of this stream type. Generally, bank erosion rates increase with increase in drainage area, however, the nature of this study reach (ceteris paribus) explains the accelerated stream bank erosion at this reach. F4 streams are generally known for very high stream bank erosion rates (Rosgen, 1996, 2006). Disturbance caused by piers of an abandoned railway bridge crossing, upstream of this study reach serves to accelerate bank erosion rates at the middle and downstream locations. Analysis of bank profiles at Silver Creek indicates that the dominant erosion mechanisms are hydraulic action and bank slumping.

Sediment Competence

Results of the sediment competence calculations are shown in Table 3-27. The Silver Creek reach has a slope and mean bankfull depth approximately equivalent to what is required to entrain the largest particle on the point bar. This reach has adequate stream power to transport its sediment. However, the Silver Creek reach (an F4 stream type) is transitional, and is in the process of adjusting its stream profile to regain meander belt width so that it can effectively dissipate energy. From the modified Shields diagram (Figure 3-4), (Shields, 1936; Leopold et al, 1964; Rosgen, 2006), the calculated bankfull shear stress is capable of transporting D_{80} (79 mm) particle size at the reach.

Table 3-27. A Summary of sediment competence variables at Silver Creek.

Variable	S_b (%)	S_r (%)	D_{bkf} (m)	D_{Rbkf} (m)	D_{s50} (mm)	D_{A50} (mm)	D_{50} (mm)	D_l (mm)	D_{le} (mm)	T_c	T_b(lb/ft^2)
Magnitude	0.27	0.23	0.74	0.64	22	24	36	75	79	0.014	0.41

Stream Channel Successional Changes

The Silver Creek stream reach is a transitional stream type in the Flint Hills region. This study reach shows signs of channel adjustment, and is likely to transition into a C4 stream type. The transition sequence from stream type F4 to C4 (Figure 3-11) usually involves an increase in channel depth and a reduction in channel width. This study reach has attained the adequate channel depth and slope required for stability, however, the reach is experiencing accelerated rates of stream bank erosion as the stream strives to regain adequate meander belt width. Beyond this stage, the stream will have attained stability (if left undisturbed) and will be able to transport its sediment and discharge in an effective manner without any adverse impacts.

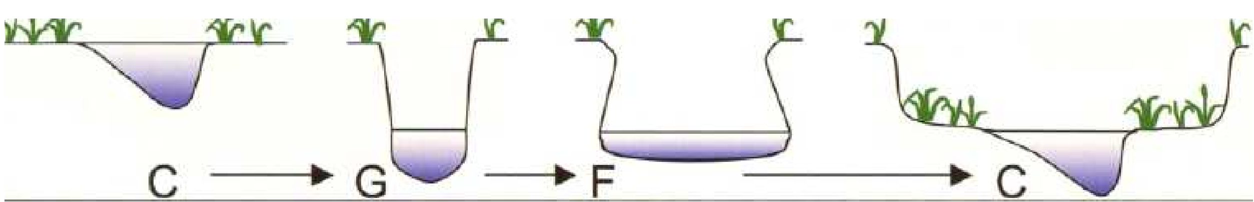

Figure 3-11. Stream channel successional changes (adapted from Rosgen, 1996).

Wind Creek, Upland Reach

Stream Classification

Morphometric variables listed in Table 3-28 were used for classifying the Wind Creek upland study reach (photograph shown in Figure D-1 in Appendix D). This reach was classified as a C4 stream. This stream type is a slightly entrenched meandering stream with well developed pool-riffle morphology. The channel bed material is predominately gravel and cobble, and stream banks are composed of silt and clay. Streams of C4 classification are sensitive to disturbances caused by changes in watershed conditions. This stream type is susceptible to accelerated bank erosion (Rosgen, 1996). However, due to the high density of riparian vegetation on stream banks at this reach, low bank erosion rates are expected. This reach is located in valley type VIII, considered to have a wide and gentle slope with a well developed floodplain adjacent to river terraces (Rosgen, 1996). Figures D-1 through D-16 are photographs taken at this study reach. Table 3-29 shows the variables used in the calculation of bankfull velocity and discharge at this study reach.

Table 3-28. Stream classification protocol for Wind Creek upland reach.

Morphometric Variable	Magnitude	Units
Bankfull Width (W_{bkf}) Width of the stream channel at bankfull stage elevation, in a riffle section.	12.93	m
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}).	0.50	m
Bankfull Cross Section Area (A_{bkf}) Area of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	6.50	m^2
Width/Depth Ratio (W_{bkf} /d_{bkf}) Bankfull width divided by bankfull mean depth, in a riffle section.	25.68	m/m
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.	1.16	m
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.	30.50	m
Entrenchment Ratio (ER) The ratio of flood-prone area width divided by bankfull channel width (W_{fpa} / W_{bkf}) (riffle section).	2.36	m/m
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.	50	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.	0.0043	m/m
Channel Sinuosity (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	1.36	m/m
Stream Type	**C4**	

Table 3-29. Bankfull discharge variables at Wind Creek, upland reach.

Variable	Magnitude
W_{bkf} (m)	12.93
D_{bkf} (m)	0.50
W_{pbkf} (m)	13.94
A_{bkf} (m)	6.50
R (m)	0.47
D_{84} (mm)	72
R/D_{84}	9.00
S (m/m)	0.0043
u*	0.140
u (m/s)	1.10
u/u*	7.80
n	0.037
Q_{bkf} (m^3/s)	6.90

Changes in Stream Geometry

Figure D-17 shows the repeat survey of the longitudinal profile while Figures D-18 through D-21 show changes in channel cross section geometry at this study reach. Tables 3-30 through 3-32 show channel geometry data collected. Figure 3-12 shows a comparison of changes in channel cross section area for cross section transects above and below the stream crossing. The changes at these cross section transects indicate fill or/and scour. The cross section transects below the stream crossing showed a greater change in channel cross section area than those above. Overall, these changes in cross sectional area (pool and riffle cross section transects combined) were minor. Results of the repeat longitudinal profile survey corroborate findings from the cross sectional survey. Moderate changes in bed elevation were observed in the pools while the riffles experienced minor change. The moderate changes at the pools can be attributed to the frequent flow events (experienced between March-June, 2007) which flushed out sediment (from previous seasons) previously resident in the pools to the downstream locations. Results from the scour chains (Table D-1) indicated significant scour at cross section transect 1, and no scour or fill at cross section transect 4. No appreciable change in channel slope was observed at this study reach.

Table 3-30. Changes in cross sectional area between the original survey (2006) and the resurvey in 2007 at Wind Creek upland reach.

Study Reach	Cross section number	Cross section designation	Change in cross section area (m^2)	Percent change in cross section area
Wind Creek (Upland)	1	Riffle	0.23	0.55
	2	Pool	-0.12	-0.31
	3	Pool	0.50	1.8
	4	Riffle	-0.08	-0.2

[Negative values indicate fill while positive values indicate scour].

Table 3-31. A summary of channel geometry variables at Wind Creek upland reach.

Study Reach	Number of cross section transects	Range of width (m)	Range of depth (m)	Number of cross sections	
				Fill	Scour
Wind Creek upland	4	12.2-13.5	1.2-3.0	2	2

Table 3-32. A comparison of changes in channel cross section area between cross section transects above and below stream crossing at Wind Creek upland reach.

Study Reach	Average change in cross section area (above ford), (m^2)		Average change in cross section area (below ford), (m^2)		Average change in cross section area for whole reach (m^2)	
	Riffle	Pool	Riffle	Pool	Riffle	Pool
Wind Creek upland	0.23	-0.12	-0.08	0.50	0.08	0.19

[Negative values indicate fill while positive values indicate scour].

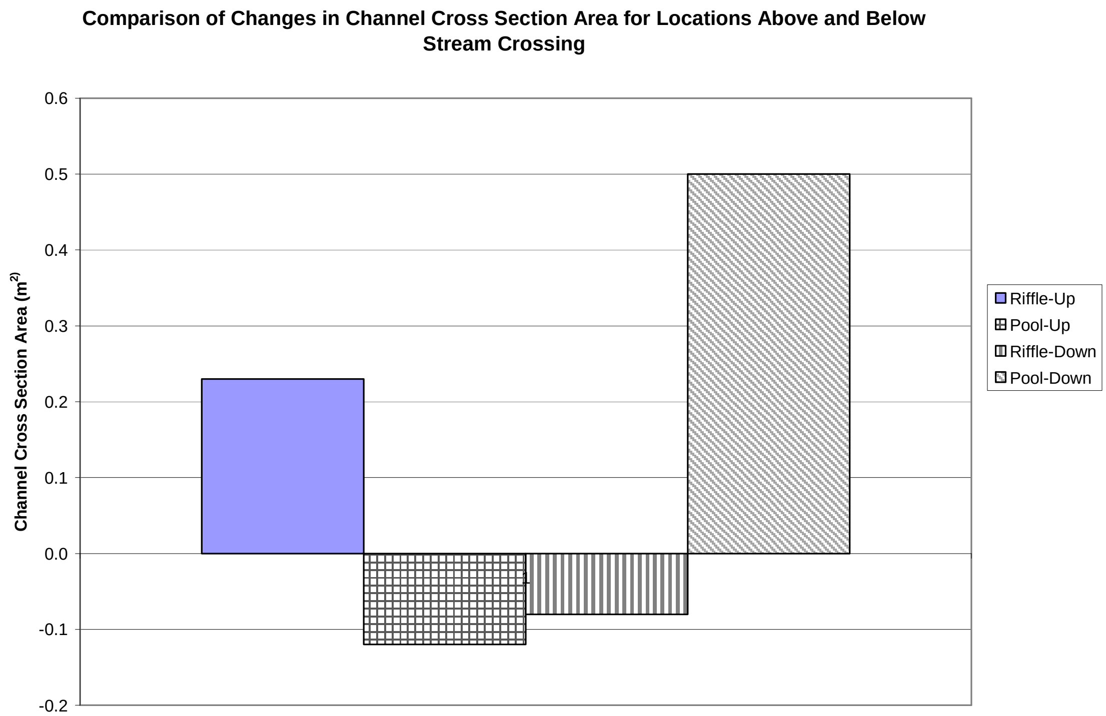

Figure 3-12. A comparison of changes in channel cross section area for cross section transects above and below stream crossing at Wind Creek, upland reach.

Changes in Bed Material Composition

Results from the active and reach pebble counts at the Wind Creek upland reach are shown in Figures D-22 through D-24 and Table 3-33. The results from the pebble count (Table 3-3) indicate a shift towards more coarse sediment. This shift in sediment size is due to the replacement of finer sediment (previously stored in pools) with coarse sediment transported from upstream locations. Results from the active bed count at cross section transects 1 and 4 (Figures D-22 and D-23) also indicates a shift towards coarser sediment at the riffles. Results from the scour chain survey (Table D-1) indicated a shift towards smaller size bed material at the scour chain location at cross section transect 1. However, results from the scour chain location at cross section transect 4 indicated no significant change in bed material size.

Table 3-33. Changes in particle size distribution from reach pebble count at Wind Creek, upland reach.

	Particle Size (mm)				
Year	D_{35}	D_{50}	D_{84}	D_{95}	D_{100}
2006	11	28	90	120	180
2007	31	50	100	180	362

Stream Bank Surveys and Bank Erosion Prediction

The BEHI and NBS ratings developed for the Wind Creek upland study reach are shown in Table 3-34. The method and calculations used to determine the BEHI and NBS ratings are shown in Tables D-2 through D-5. There was no difference in BEHI ratings between the bank transects above and below the stream crossing at this study reach, however the NBS ratings were different. High, very high and extreme BEHI and NBS ratings indicate increased potential for stream bank erosion as well as stream bank instability. The changes in bank profiles at this study reach are shown in Figures D-25 and D-26. Table 3-35 shows the predicted and measured bank erosion rates and annual sediment yield. The predicted bank erosion rates (Table 3-35 and Figure 3-13) are quite high compared to the erosion rates measured at this study reach for the same reasons explained above.

Table 3-34. BEHI and NBS ratings of bank transects at Wind Creek, upland reach.

BEHI Rating		NBS Rating	
Upstream	Downstream	Upstream	Downstream
High	High	Very High (5)	Extreme (6)

Table 3-35. Predicted and actual bank erosion rates at Wind Creek, upland reach.

Predicted Annual Bank Erosion Rates (m/yr)	Actual Annual Bank Erosion Rates (m/yr)	Actual Annual Sediment Yield (kg/m/yr)
0.27-0.40	0.08-0.17	370

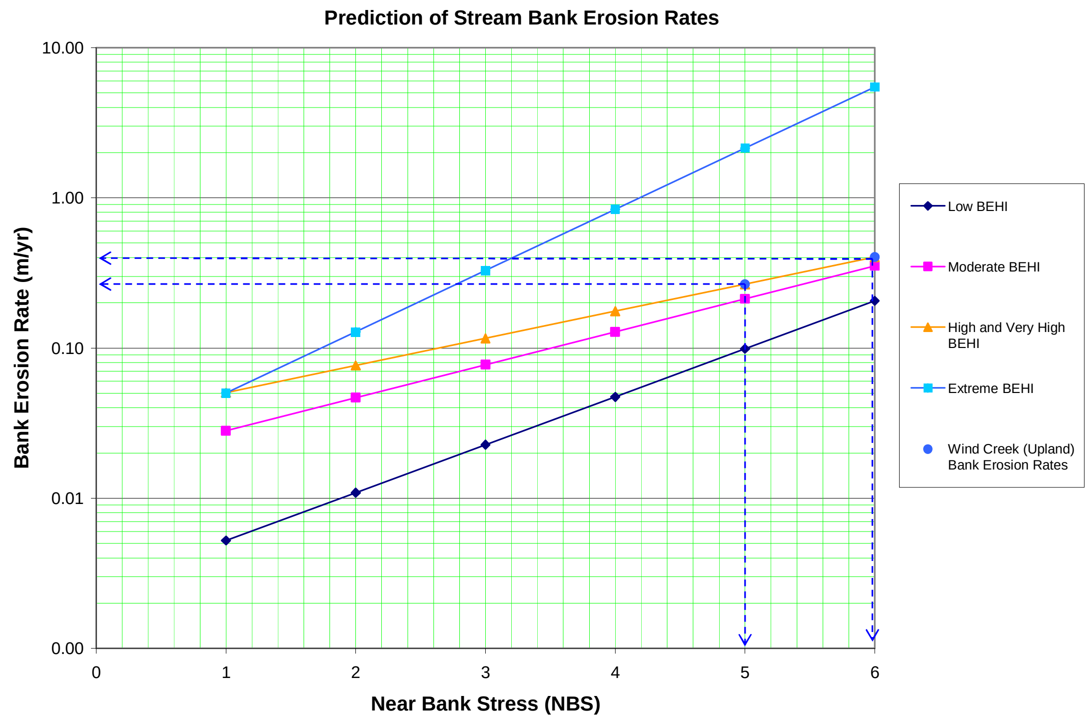

Figure 3-13. Relationship of BEHI and NBS ratings used to predict annual stream bank erosion rates on Wind Creek, Upland reach. Adapted after Rosgen (1996 and 2006).

The measured bank erosion rates and annual sediment yield (Table 3-35) at Wind Creek upland reach were moderately high due the high frequency and duration of flow events experienced in March-June, 2007. Figure 3-14 shows a comparison of sediment yield generated from segments of the stream upstream and downstream of a low water ford, for each study reach. It is shown that the sediment yield generated from locations above the stream crossing at this study reach was more than that generated from locations below the stream crossing. The stream crossing (and approach roads leading up to it) at this reach is closed to traffic, and therefore riparian vegetation has been allowed to grow back, slowing down discharge from upstream and runoff transported from upland areas. The dense vegetation (on the banks at the regions immediately above and below the stream crossing) provides protection against stream bank erosion. Therefore the bank erosion rate below the stream crossing was lower than that above the stream crossing.

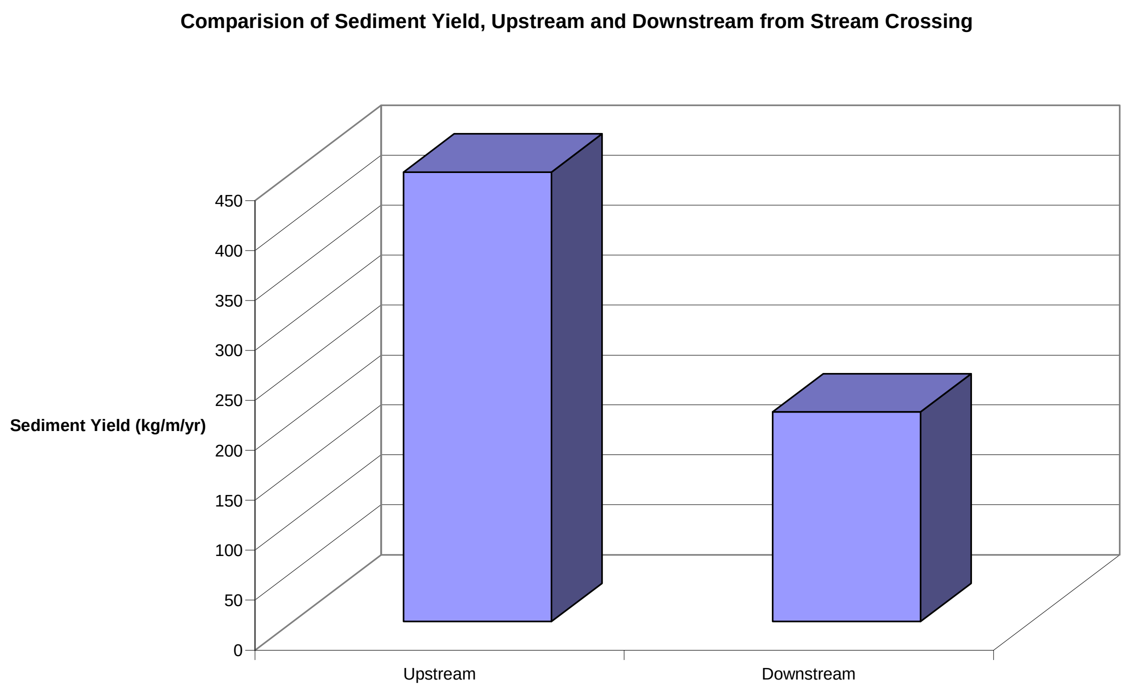

Figure 3-14. A comparison of sediment yield between upstream and downstream locations from stream crossing at Wind Creek upland reach.

Sediment Competence

The results of the sediment competence calculations are shown in Table 3-36. These results suggest that the Wind Creek upland reach lacks adequate slope and mean bankfull depth required to entrain the largest particle on the point bar. This implies that the reach lacks adequate stream power to transport its sediment and channel aggradation is predicted to occur as the stream tries to adjust its slope and depth to a level where stream equilibrium is restored. However, these results do not corroborate with findings from cross section, longitudinal profile surveys. This discrepancy can be attributed to the difficulty in collecting a representative bar core sample from this reach. Therefore, the bar core samples collected may not represent the bed load gradation of particles mobile at bankfull stage. In order to address this concern, bed load sampling during bankfull events (and other high flow events) is recommended. The bed load sampling will enable determination of the bed load gradation mobile during a bankfull event. Data collected from the bed load sampling exercise can then be used to verify the sediment competence of this study reach.

Table 3-36. A Summary of sediment competence variables at Wind Creek upland study reach.

Variable	S_b (%)	S_r (%)	D_{bkf} (m)	D_{Rbkf} (m)	D_{s50} (mm)	D_{A50} (mm)	D_{50} (mm)	D_l (mm)	D_{le} (mm)	T_c	T_b(lb/ft^2)
Magnitude	0.43	0.55	0.50	0.64	20	40	50	87	84	0.019	0.44

Stream Channel Successional Changes

The Wind Creek upland reach (C4 stream type) is considered relatively stable; however, this reach has a high supply of sediment from upland areas which is likely to cause channel instability. Results from the stream survey do not indicate any major signs of channel adjustment, and therefore this reach may be considered relatively stable. Continued monitoring of this study reach will provide additional information required to verify the above the predictions.

Wind Creek, Midland Reach

Stream Classification

Morphometric variables listed in Table 3-37 were used for classifying the Wind Creek midland study reach (photograph shown in Figure E-1 in Appendix E). The Wind Creek midland reach, was classified as a B4c stream type. Streams of B4c classification are considered moderately entrenched with gentle channel slopes. Channel bed material is predominately gravel, and stream banks are composed of silt and clay. This stream type is generally considered relatively stable with a low supply of sediment (Rosgen, 1996). However, this study reach has a high supply of sediment from upland areas. The high supply of sediment at this reach poses the potential of causing instability. This reach is located in valley type VIII, considered to have a wide and gentle slope with well developed floodplain adjacent to river terraces (Rosgen, 1996). Figures E-1 through E-22 are photographs taken at this study reach. Table 3-38 shows the variables used in the calculation of bankfull velocity and discharge.

Changes in Stream Geometry

Figure E-17 shows the repeat survey of the longitudinal profile while Figures E-21 through E-32 show changes in channel cross section geometry at this study reach. Tables 3-39 through 3-41 show channel geometry data collected. Figure 3-15 shows a comparison of changes in channel cross section area for cross section transects above and below the stream crossing. The changes at these cross section transects indicate fill or/and scour. The cross section transects above the stream crossing showed a slightly greater change in channel cross section area than those below. Overall, these changes in cross sectional area (pool and riffle cross section transects combined) were minor. Results of the repeat longitudinal profile survey corroborate findings from the cross sectional survey. Moderate changes in bed elevation were observed in the pools while the riffles experienced minor changes, except for the riffle transect 12 where moderate fill was observed. The moderate changes at the pools can be attributed to the frequent flow events (experienced between March-June, 2007) which flushed out sediment (from previous seasons) previously resident in the pools to the downstream locations. The results from the scour chains survey (Table E-1) indicated moderate fill at cross section transect 12. No appreciable change in channel slope was observed at this study reach.

Table 3-37. Stream classification protocol for Wind Creek midland reach.

Morphometric Variable	Magnitude	Units
Bankfull Width (W_{bkf}) Width of the stream channel at bankfull stage elevation, in a riffle section.	8.78	m
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}).	0.85	m
Bankfull Cross Section Area (A_{bkf}) Area of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	7.44	m^2
Width/Depth Ratio (W_{bkf} /d_{bkf}) Bankfull width divided by bankfull mean depth, in a riffle section.	10.37	m/m
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.	1.22	m
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.	12.93	m
Entrenchment Ratio (ER) The ratio of flood-prone area width divided by bankfull channel width (W_{fpa} / W_{bkf}) (riffle section).	1.47	m/m
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.	48	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.	0.0023	m/m
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).	2.24	m/m
Stream Type	**B4c**	

Table 3-38. Bankfull discharge variables at Wind Creek, midland reach.

Variable	Magnitude
W_{bkf} (m)	8.78
D_{bkf} (m)	0.85
W_{pbkf} (m)	10.48
A_{bkf} (m)	7.44
R (m)	0.71
D_{84} (mm)	80
R/D_{84}	8.90
S (m/m)	0.0023
u*	0.126
u (m/s)	1.00
u/u*	7.70
n	0.0375
Q_{bkf} (m^3/s)	7.50

Table 3-39. Changes in cross sectional area between the original survey (2006) and the resurvey in 2007 at Wind Creek midland reach.

Study Reach	Cross section number	Cross section designation	Change in cross section area (m^2)	Percent change in cross section area
Wind Creek (Midland)	1	Riffle	-0.06	-0.3
	2	Pool	1.12	3.7
	3	Run	0.10	0.3
	4	Riffle	0.34	1.2
	5	Run	0.38	-1.4
	6	Pool	-0.36	-1.6
	7	Riffle	-0.56	-2.5
	8	Pool	-0.50	-1.5
	9	Riffle	-0.21	-0.7
	10	Run	-0.18	-0.5
	11	Pool	0.55	1.5
	12	Riffle	-0.66	-1.8

[Negative values indicate fill while positive values indicate scour].

Table 3-40. A summary of channel geometry variables at Wind Creek midland reach.

Study Reach	Number of cross section transects	Range of width (m)	Range of depth (m)	Number of cross sections	
				Fill	Scour
Wind Creek (Midland)	12	12.2-14.7	1.4-3.4	7	5

Table 3-41. A comparison of changes in channel cross section area between cross section transects above and below stream crossing at Wind Creek midland reach.

Study Reach	Average change in cross section area (above ford), (m^2)		Average change in cross section area (below ford), (m^2)		Average change in cross section area for whole reach (m^2)	
	Riffle	Pool	Riffle	Pool	Riffle	Pool
Wind Creek (Midland)	0.19	0.38	-0.40	0.03	-0.11	0.20

[Negative values indicate fill while positive values indicate scour].

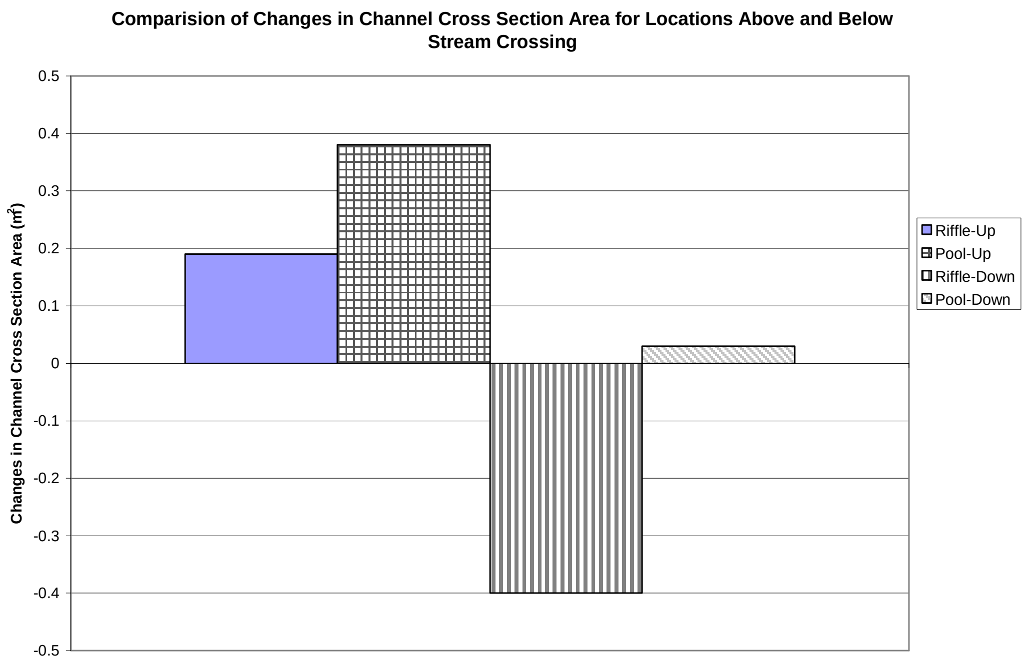

Figure 3-15. A comparison of changes in channel cross section area for cross section transects above and below stream crossing at Wind Creek, midland reach.

Changes in Bed Material Composition

Results from the active and reach pebble counts at the Wind Creek midland reach are shown in Figures E-33 through E-35. Results of the reach pebble count (Figure E-35 and Table 3-42 indicate no significant shift in sediment size except for the D_{84} and D_{95} sizes that showed a shift towards coarser sediment. This shift in sediment size is due to the replacement of finer sediment (previously stored in pools) with coarse sediment transported from the upstream locations. Results from the active bed count at cross section transect 1 and 12 (Figures E-33 and E-34) also indicate a shift towards coarser sediment at the riffles. Results from the scour chains (Table E-1) at cross section transect 12 corroborate the findings from the active bed pebble count.

Table 3-42. Changes in particle size distribution from reach pebble count at Wind Creek, midland reach.

	Particle Size (mm)				
Year	D_{35}	D_{50}	D_{84}	D_{95}	D_{100}
2006	32	50	84	128	256
2007	34	48	140	180	256

Stream Bank Surveys and Bank Erosion Prediction

The BEHI and NBS ratings developed for the Wind Creek upland study reach are shown in Table 3-43. The method and calculations used to determine the BEHI and NBS ratings are shown in Tables E-2 through E-5. There was no difference in BEHI and NBS ratings between the bank transects above and below the stream crossing at this study reach. High and extreme BEHI and NBS ratings indicate increased potential for stream bank erosion as well as stream bank instability. Results of the repeat surveys of the bank transects at this study reach are shown in Figures E-36 and E-37. Table 3-44 shows the predicted and measured bank erosion rates and annual sediment yield. The predicted bank erosion rates are fairly high compared to the erosion rates measured at this study reach for the same reasons explained above (see discussion on bank erosion at the Farnum Creek reach).

Table 3-43. BEHI and NBS ratings of bank transects at Wind Creek, midland reach.

Study Reach	BEHI Rating		NBS Rating	
	Upstream	Downstream	Upstream	Downstream
Wind Creek, Midland	High	High	Extreme (6)	Extreme (6)

Table 3-44. Predicted and measured bank erosion rates at Wind Creek, midland reach.

Study Reach	Predicted Annual Bank Erosion Rates (m/yr)	Measured Annual Bank Erosion Rates (m/yr)	Measured Annual Sediment Yield (kg/m/yr)
Wind Creek, Midland	0.40	0.10-0.21	430

The measured bank erosion rates and annual sediment yield (Table 3-44) at this reach were moderately high due to the high frequency and duration of flow events experienced in March-June, 2007. Figure 3-17 shows a comparison of sediment yield for locations upstream and downstream of a low water ford, for each study reach. It is shown that the sediment yield generated from locations above the stream crossing at this study reach was higher than that generated from locations below the stream crossing. The low bank erosion rates at locations immediately below the crossing can be attributed to the excellent location of the stream crossing and the good condition of the approach roads (leading to the stream crossing).The stream crossing at this reach is well located on a riffle and the approach roads are well vegetated. The excellent location of the stream crossing at this reach explains the stability of the banks immediately above and below the stream crossing. The vegetation on the approach roads serves to reduce the velocity of runoff and filter sediment transported from upland areas.

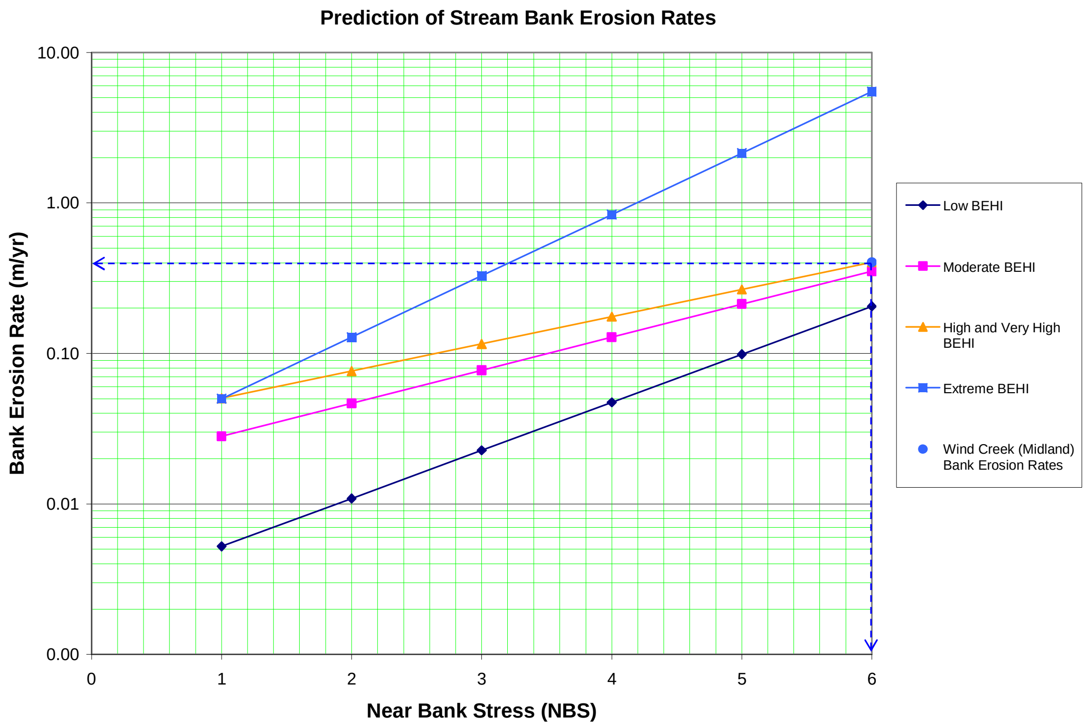

Figure 3-16. Relationship of BEHI and NBS ratings used to predict annual stream bank erosion rates at Wind Creek, midland reach. Adapted after Rosgen (1996 and 2006).

However, it is important to note that erosion rate estimated from the bank transect below the stream crossing at this reach could be under estimated due to the different erosion processes acting at this location. The upper region of the bank transect at the downstream location deposited material onto the lower region of this bank transect (due to the concave nature of the bank), reducing the actual length or area of eroded material. Therefore, the average erosion rate at this site may not reflect the true lateral migration of the stream channel at this location. It would be helpful to establish multiple bank erosion sites to get a representative rate of bank erosion along the study reach.

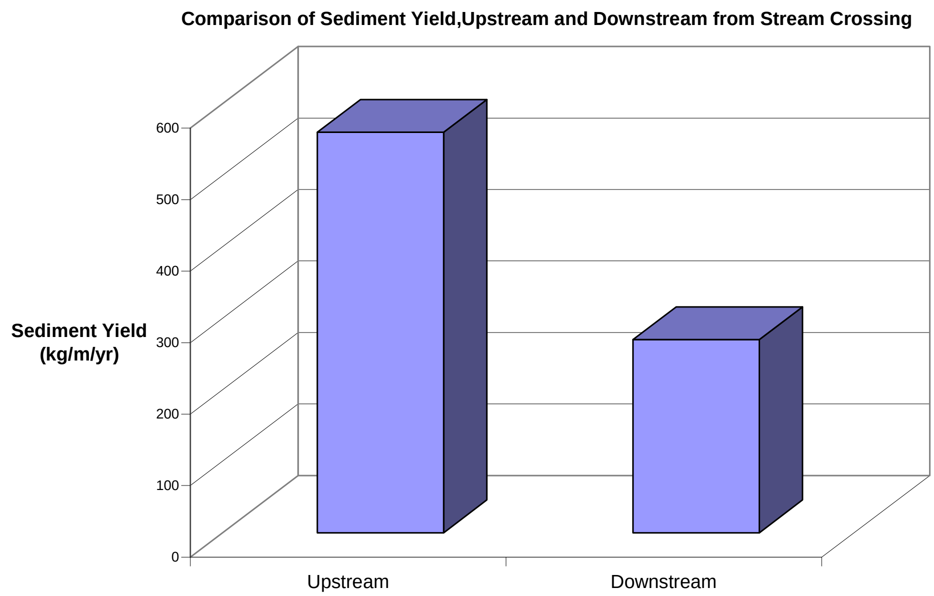

Figure 3-17. A comparison of sediment yield between upstream and downstream locations from stream crossing at Wind Creek, midland reach.

Sediment Competence

Results of the sediment competence calculations are shown in Table 3-45. Results suggest that the Wind Creek midland reach lacks adequate slope and mean bankfull depth required to entrain the largest particle on the point bar. This implies that the reach lacks adequate stream power to transport its sediment and channel aggradation is predicted to occur as the stream tries to adjust its slope and depth to a stage where stream equilibrium is restored. However, these results do not corroborate with findings from cross section and longitudinal profile surveys for the same reason explained above (see discussion on sediment competence at Wind Creek, upland reach). From the modified Shields diagram (Figure 3-4) (Shields, 1936; Leopold et al, 1964; Rosgen, 2006), the calculated bankfull shear stress is capable of transporting D_{62} (77 mm) particle size at this reach.

Table 3-45. A Summary of sediment competence variables at Wind Creek midland study reach.

Variable	S_b (%)	S_r (%)	D_{bkf} (m)	D_{Rbkf} (m)	D_{s50} (mm)	D_{A50} (mm)	D_{50} (mm)	D_l (mm)	D_{le} (mm)	T_c	T_b(lb/ft^2)
Magnitude	0.23	0.40	0.85	1.48	14	51	48	80	77	0.026	0.40

Stream Channel Successional Changes

The Wind Creek midland reach (B4c stream type) is considered relatively stable; however, this reach has a high supply of sediment from upland areas which is likely to cause channel instability. Results from the stream resurvey do not indicate any major signs of channel adjustment, and therefore this reach may be considered relatively stable. However, continued monitoring of this study reach will provide additional information required to verify the above the predictions

Wind Creek, Lowland Reach

Stream Classification

Morphometric variables listed in Table 3-46 were used for classifying the Wind Creek, lowland study reach (photograph shown in Figure F-1 in Appendix F).Wind Creek lowland reach was classified as an F4 stream type. Streams of F4 classification have gentle channel slopes and are entrenched channels (with high width-depth ratio) with gravel dominated beds. A stream of F4 classification has well developed pool-riffle morphology. This stream reach, like any unstable F4 stream has accelerated rates of stream bank erosion at locations below the stream crossing. Locations above the stream crossing experienced moderate bank erosion rates due to the good stability of the stream banks in these locations. The dense vegetation on these banks plays a role in reducing the amount of bank erosion at these locations. This reach is located in valley type VIII, considered to have a wide and gentle slope with well developed floodplain adjacent to river terraces (Rosgen, 1996). Figures F-1 through F-19 are photographs taken at this study reach. Table 3-47 shows the variables used in the calculation of bankfull velocity and discharge at this reach.

Table 3-46. Stream classification protocol for Wind Creek lowland reach.

Morphometric Variable	Magnitude	Units
Bankfull Width (W_{bkf}) Width of the stream channel at bankfull stage elevation, in a riffle section.	10.07	m
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}).	0.80	m
Bankfull Cross Section Area (A_{bkf}) Area of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	8.09	m^2
Width/Depth Ratio (W_{bkf} /d_{bkf}) Bankfull width divided by bankfull mean depth, in a riffle section.	12.52	m/m
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.	1.22	m
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.	13.73	m
Entrenchment Ratio (ER) The ratio of flood-prone area width divided by bankfull channel width (W_{fpa} / W_{bkf}) (riffle section).	1.36	m/m
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.	52	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.	0.0032	m/m
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).	1.89	m/m
Stream Type	**F4**	

Table 3-47. Bankfull discharge variables at Wind Creek, lowland reach.

Variable	Magnitude
W_{bkf} (m)	10.07
D_{bkf} (m)	0.80
W_{pbkf} (m)	11.67
A_{bkf} (m)	8.09
R (m)	0.69
D_{84} (mm)	89
R/D_{84}	7.80
S (m/m)	0.0032
u*	0.148
u (m/s)	1.20
u/u*	7.40
n	0.0380
Q_{bkf} (m^3/s)	9.40

Changes in Stream Geometry

Figure F-20 shows the repeat survey of the longitudinal profile while Figures F-21 through F-31 show changes in channel cross section geometry at this study reach. Tables 3-48 through 3-50 show channel geometry data collected. Figure 3-15 shows a comparison of changes in channel cross section area for cross section transects above and below the stream crossing. The changes at these cross section transects indicate fill or/and scour. The changes in cross section area at the Wind Creek lowland reach ranged from moderate to large. As shown in Figure 3-18, the cross section transects above the stream crossing indicated moderate change while the transects below the stream crossing indicated fairly large change. Cross section transect 7 (Figure F-27), immediately below the stream crossing, indicated a 5.1% change in cross sectional area due to bank erosion (average of 0.39 m/yr) on the left bank. Further downstream, cross section transect 8 (Figure F-28) indicated 18.6% increase in channel cross section area. These changes were associated with scour at the stream bed and bank erosion on the left bank. Cross section transect 9 (Figure F-29) indicated moderate scour at the thalweg (0.61m increase in thalweg depth) and deposition on the left bank. Cross section transects 10 and 11 (Figures F-30 and F-31 respectively) indicated moderate fill and slight scour respectively. Results from the scour chains (Table F-1) at cross section transect 1, 9 and 11 corroborate the findings from the cross section survey. The major changes in cross section area observed at cross section locations immediately below the stream crossing suggest that the stream crossing could be causing some of this change. The stream crossing at this reach is located in a meander bend, between cross section transects 6 and 7. The stream crossing at this location changes the alignment of stream flow during high flow events. This change in flow alignment directs flow onto the banks immediately below the stream crossing, causing accelerated bank erosion at locations below the stream crossing. The results from the longitudinal profile survey corroborate findings from the cross section survey. Moderate changes in stream bed elevation were observed at locations above the stream crossing, while locations below the stream crossing indicated significant change. No appreciable change in channel slope was observed at this reach.

Table 3-48. Changes in cross sectional area between the original survey (2006) and the resurvey in 2007 at Wind Creek, lowland reach.

Study Reach	Cross section number	Cross section designation	Change in cross section area (m^2)	Percent change in cross section area (%)
Wind Creek (Lowland)	1	Riffle	0.62	1.7
	2	Pool	0.05	0.2
	3	Riffle	0.28	0.9
	4	Pool	1.27	3.1
	5	Riffle	0.73	2.5
	6	Run	1.66	5.5
	7	Riffle	2.25	5.1
	8	Pool	5.28	18.6
	9	Run	0.14	0.5
	10	Pool	-0.96	-2.7
	11	Riffle	0.78	1.6

[Negative values indicate fill while positive values indicate scour].

Table 3-49. A summary of channel geometry variables at Wind Creek, lowland reach.

Study Reach	Number of cross section transects	Range of width (m)	Range of depth (m)	Number of cross sections	
				Fill	Scour
Wind Creek, lowland	11	12.8-16.8	2.9-4.4	1	10

Table 3-50. A comparison of changes in channel cross section area between cross section transects above and below stream crossing at Wind Creek, lowland reach.

Study Reach	Average change in cross section area (above ford), (m^2)		Average change in cross section area (below ford), (m^2)		Average change in cross section area for whole reach (m^2)	
	Riffle	Pool	Riffle	Pool	Riffle	Pool
Wind Creek, lowland	0.82	0.66	1.06	2.16	0.94	1.41

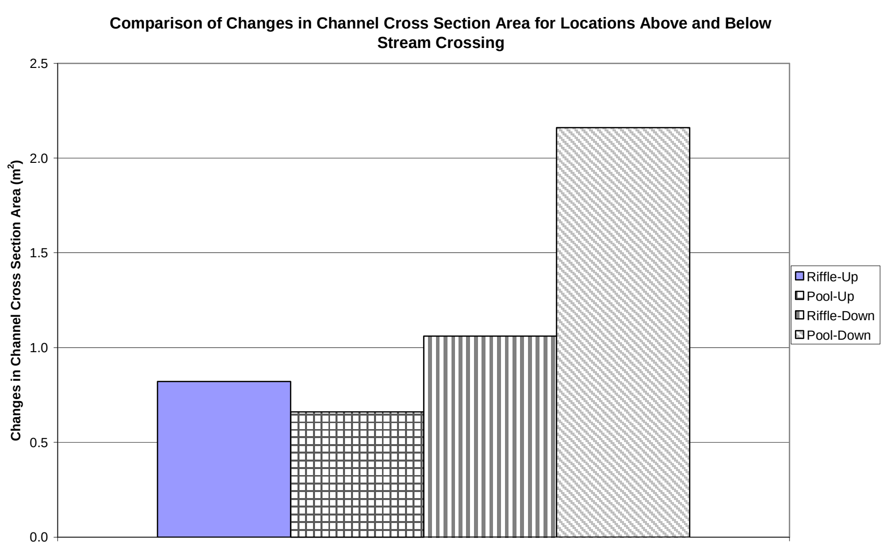

Figure 3-18. A comparison of changes in channel cross section area for cross section transects above and below stream crossing at Wind Creek, lowland reach.

Changes in Bed Material Composition

Results from the active and reach pebble counts at the Wind Creek lowland reach are shown in Figures F-32 through F-34. Results of the reach pebble count (Table 3-51) indicated a significant shift towards more coarse sediment. This shift in sediment size is due to the replacement of finer sediment (previously stored in pools) with coarse sediment transported from the upstream locations. Results from the active bed count at cross section transects 1 and 11 (Figures 32 and F-33) also indicated a shift towards coarser sediment at the riffles.

Table 3-51. Changes in particle size distribution from reach pebble count at Wind Creek, lowland reach.

	Particle Size (mm)				
Year	D_{35}	D_{50}	D_{84}	D_{95}	D_{100}
2006	2	22.6	82	140	180
2007	28	54	150	220	512

Stream Bank Surveys and Bank Erosion Prediction

The BEHI and NBS ratings developed for the Wind Creek lowland study reach are shown in Table 3-52. The method and calculations used to determine the BEHI and NBS ratings are shown in Tables F-2 through F-5. There was a difference in BEHI ratings between the bank transects above and below the stream crossing at this study reach. The NBS rating was the same for bank transects upstream and downstream from the stream crossing. High and extreme BEHI and NBS ratings indicate increased potential for stream bank erosion as well as stream bank instability. Results of the repeat surveys of the bank transects at this study reach are shown in Figures F-35 and F-36. Table 3-53 shows the predicted and measured bank erosion rates and annual sediment yield. The predicted bank erosion rate lies within the range of the bank erosion rates measured at this study reach.

Table 3-52. BEHI and NBS ratings of bank transects at Wind Creek, Lowland reach.

Study Reach	BEHI Rating		NBS Rating	
	Upstream	Downstream	Upstream	Downstream
Wind Creek, Lowland	High	Very High	Extreme (6)	Extreme (6)

Table 3-53. Predicted and measured bank erosion rates at Wind Creek, Lowland reach.

Study Reach	Predicted Annual Bank Erosion Rates (m/yr)	Actual Annual Bank Erosion Rates (m/yr)	Actual Annual Sediment Yield (kg/m/yr)
Wind Creek, lowland	0.40	0.23-0.65	0.88

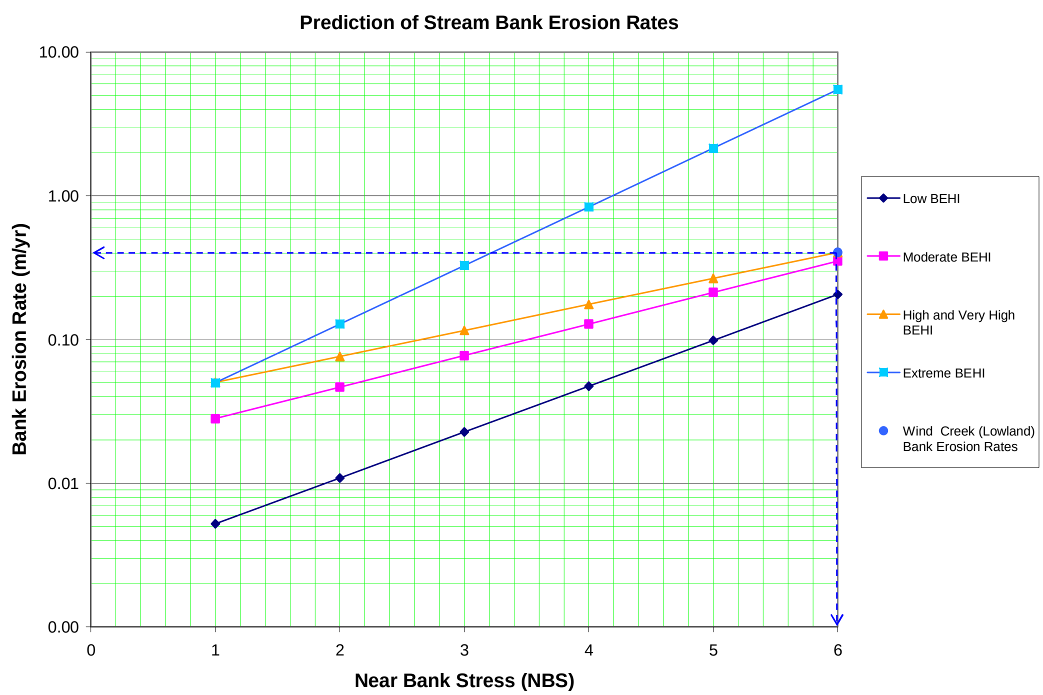

Figure 3-19. Relationship of BEHI and NBS ratings used to predict annual stream bank erosion rates on Wind Creek, lowland reach. Adapted after Rosgen (1996 and 2006.

The measured bank erosion rates and annual sediment yield (Table 3-53) at Wind Creek lowland reach were quite high due to the increased stream discharge (due to increase in drainage area), high frequency and magnitude of flow events experienced in March-June, 2007. The stream crossing also contributes to the increase in bank erosion rates in the downstream locations of this study reach. Based on runoff estimates (Figure 3-20) from March-June 2007 precipitation data, it is shown that this stream reach experienced at least two bankfull events (with 1.4 year return interval) and two events higher than bankfull stage (with 4 year return interval). Figure 3-21 shows a relationship between the peak flow rates and their corresponding percent non exceedance for the Wind Creek lowland reach. In comparing precipitation patterns (Figures 3-22 and 3-23) over the previous five years, it is indicated that the 2007 rainfall season had significantly higher precipitation totals due to the high frequency and magnitude of precipitation events experienced. Given the high frequency and duration of the precipitation events experienced during the 2007 rainfall season, erosion rates of a high magnitude were observed.

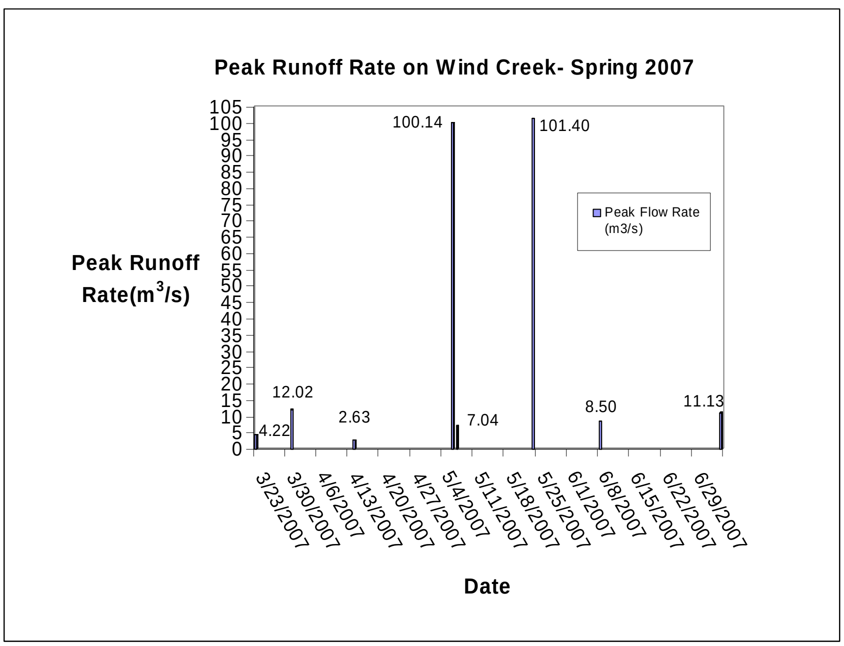

Figure 3-20. Peak runoff rates experienced during March-June, 2007 at Wind Creek lowland watershed.

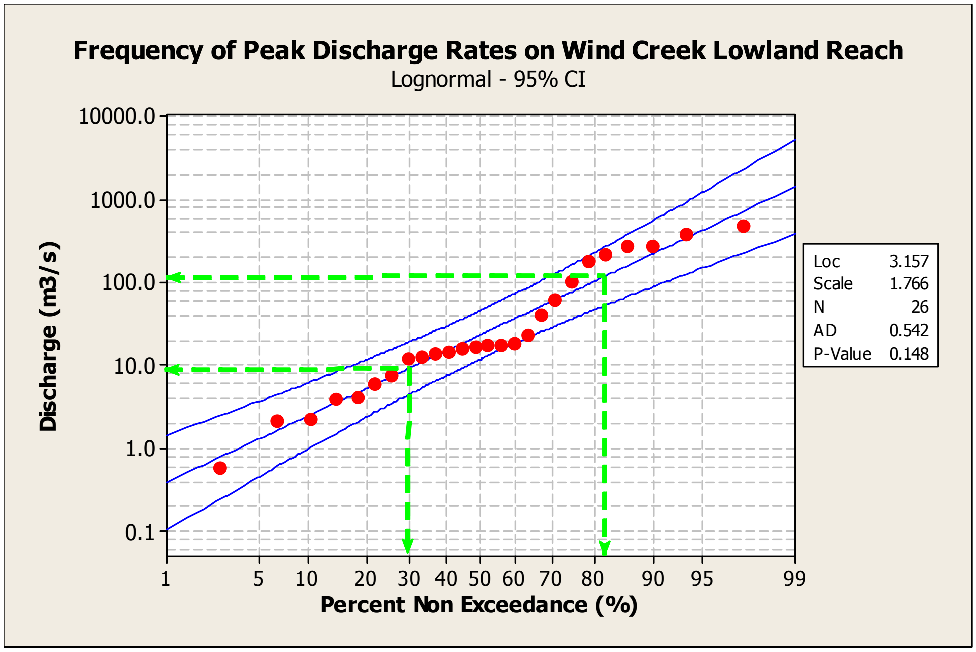

Figure 3-21. Frequency of peak stream flow rates at Wind Creek Lowland reach.

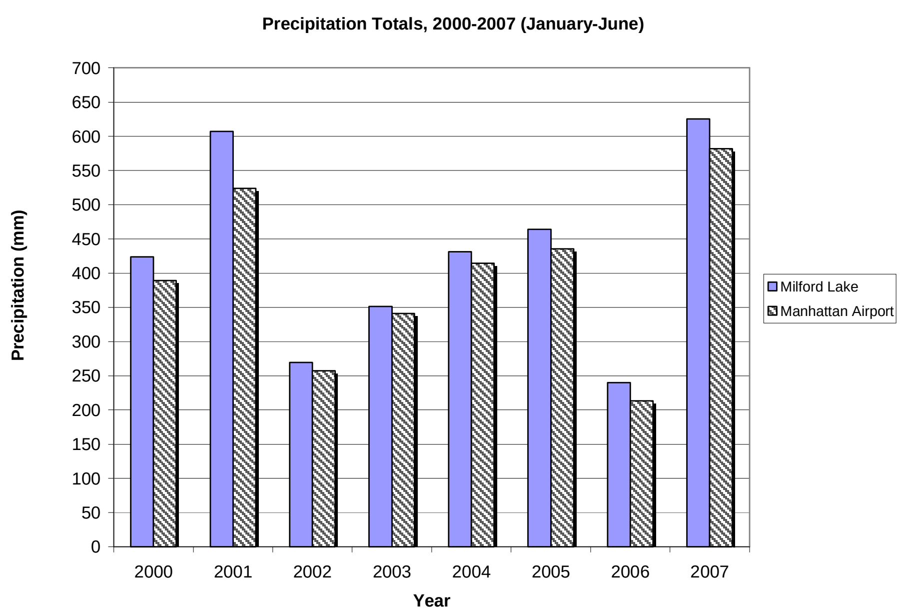

Figure 3-22. Precipitation totals (January-June) for Milford Lake and Manhattan Airport. Source: Knapp (2007).

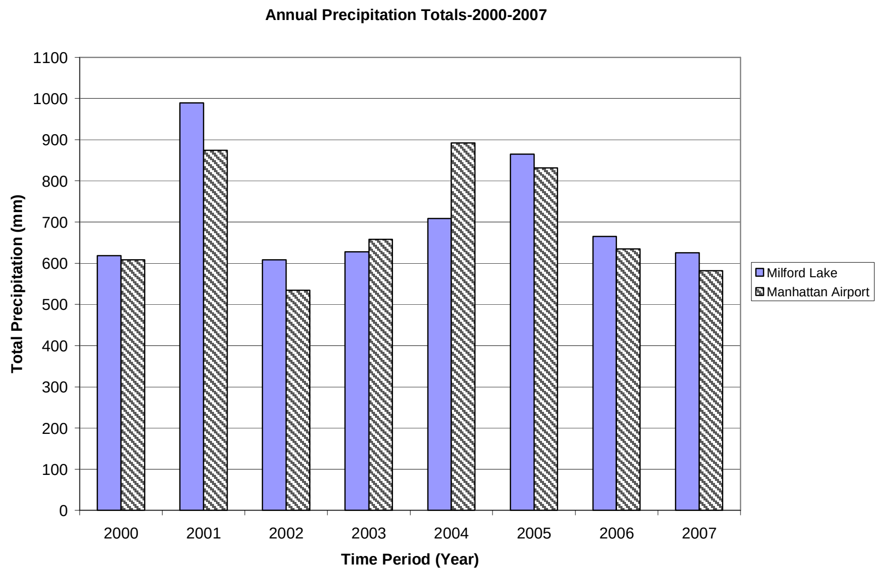

Figure 3-23. Annual precipitation totals for Milford Lake and Manhattan Airport. [Precipitation totals for 2007 are semi-annual totals (January- June)]. Source: Knapp (2007).

Figure 3-24 show a comparison of sediment yield from stream segments upstream and downstream of a low water ford at this study reach. It is shown that the sediment yield generated from locations below the stream crossing at this study reach was approximately three times greater than the sediment yield generated from the stream segments above the stream crossing. As mentioned previously, the stream crossing at this study reach could potentially be causing the high rates of bank erosion at locations below the stream crossing. However, erosion rates generally increase in the downstream direction because discharge (or stream power) increases in the downstream direction. This trend (downstream increase in erosion rates) has a tendency to mask the impact of any other factors contributing to the increase in bank erosion rates in the downstream direction. A poorly constructed low water ford for example, can alter the direction of stream flow in such a manner that stream banks immediately below the crossing are subjected to increased shear stresses. Increased shear stresses on the banks cause a lot of bank erosion. Because of the downstream increase in erosion rates, it is therefore difficult to apportion the magnitude of bank erosion (along the downstream location of a reach) caused by poorly located constructed stream crossings. It is also worth noting that stream crossings concentrate runoff from upland areas, increasing the amount of runoff and sediment discharged into streams. Increased runoff and sediment entering streams poses a potential of causing stream instability. Increased sediment in streams has adverse impacts on aquatic life as well as water quality.

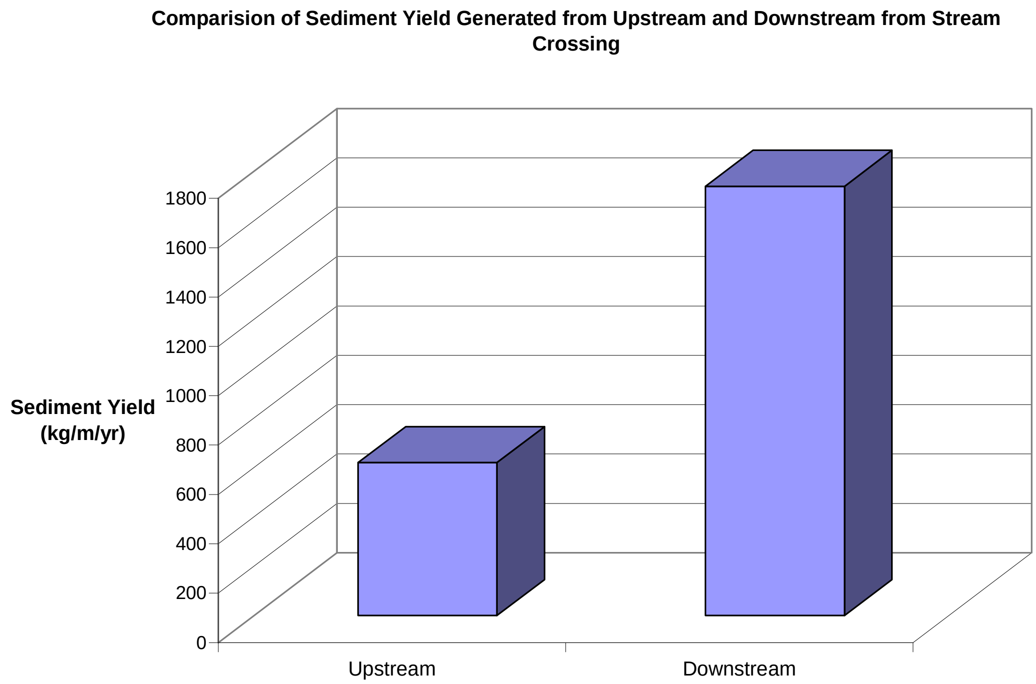

Figure 3-24. A comparison of sediment yield between upstream and downstream locations from stream crossing at Wind Creek, lowland reach.

It is also interesting to note that the Wind Creek lowland reach generated a higher sediment yield compared to Silver Creek which is also an F4 stream type draining a large area. The different land use types on these two watersheds, partly explain the difference in bank erosion rates at the two sites. Silver Creek has no stream crossings and drains an agricultural watershed (with best management practices) while Wind Creek lowland reach drains areas heavily disturbed by military training exercises and has stream crossings. Military training exercises disturb soil and vegetation, making the land susceptible to high rates of runoff and as well as soil erosion. Increased runoff from military training areas and stream crossings has an impact on the Wind Creek lowland reach, possibly causing the increased stream instability.

Sediment Competence

The results of sediment competence calculations at the Wind Creek lowland reach are shown in Table 3-54. These results suggest that this reach lacks adequate slope and mean bankfull depth required to entrain the largest particle on the downstream a third of the point bar at a location between the thalweg and bankfull. This implies that the reach lacks adequate stream power to transport its sediment and channel aggradation is predicted to occur as the stream tries to adjust its slope and depth to a stage where stream equilibrium is restored. However, these results do not corroborate with findings from cross section, longitudinal profile surveys for reasons explained above (see discussion on sediment competence at the Wind Creek, upland reach). From the modified Shields diagram (Figure 3-4) (Shields, 1936; Leopold et al, 1964; Rosgen, 2006), the calculated bankfull shear stress is capable of transporting D_{70} (95 mm) particle size at this reach.

Table 3-54. A Summary of sediment competence variables at Wind Creek lowland study reach.

Variable	S_b (%)	S_r (%)	D_{bkf} (m)	D_{Rbkf} (m)	D_{s50} (mm)	D_{A50} (mm)	D_{50} (mm)	D_l (mm)	D_{le} (mm)	T_c	$T_b(lb/ft^2)$
Magnitude	0.32	0.41	0.80	1.03	29	48	52	100	95	0.020	0.53

Stream Channel Successional Changes

The Wind Creek lowland reach classified as an F4 stream type shows signs of channel adjustment in the lower locations of the study reach. This reach is probably at the end of the F4 to C4 transition sequence (Figure 3-25). However, increased supply of sediment from the stream banks and upland areas is likely to cause increased stream instability. The stream crossing at this reach is another concern from a stream stability standpoint. Continued monitoring of this study reach will provide additional information required to verify the above the predictions

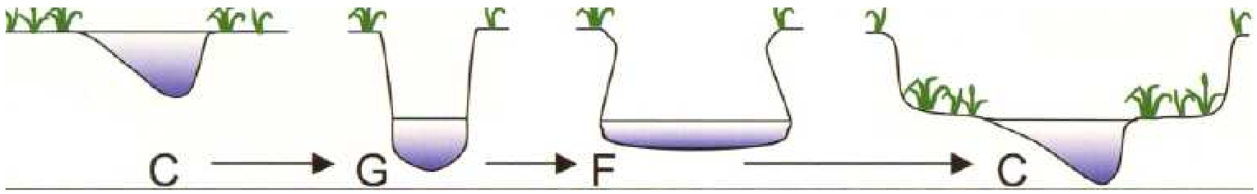

Figure 3-25. Stream channel successional changes (adapted from Rosgen, 1996).

General Discussion: Roads and Stream Crossings

Characteristics of approach roads at each study site were measured and recorded as shown in Table 3-55. Approach roads to stream crossing locations are critical areas that often act as conduits for sediment laden runoff generated from upland areas and deposited into streams at stream crossing locations. This sediment is a water quality concern and again poses the potential of disrupting stream equilibrium. A stream in equilibrium shows a balance between its sediment discharge (Qs), sediment particle size (D_{50}), stream flow (Qw) and stream slope (S), (Lane, 1955; Rosgen, 1996). Lane (1955) showed this relationship (Figure 3-26) qualitatively as $[Qs \times D_{50}] \propto [Qw \times S]$. A change in one or more of these stream variables triggers a change in stream equilibrium. Extra sediment introduced into the stream through the approach roads is likely to disrupt the equilibrium of the stream in the long run. As a consequence, channel aggradation and a shift in bed material composition to finer particles is predicted to follow stream channel alterations. Erosion dynamics and hillslope hydrology on these approach roads is still not well understood. Future studies should be focused at addressing these concerns.

Table 3-55. Summary of variables measured on approach roads to stream crossings at the study reaches.

Variable/Reach	SR (%)	SL (%)	Hg (m)	Av (%)	Hv (m)
Seven Mile Creek	2.4	8.5	0.15	83	0.58
Farnum Creek	13.3	13.6	0.40	73	0.55
Wind Creek (upland)	6.1	8.9	0.35	100	0.96
Wind Creek (midland)	7.7	7.4	0.0	90	0.69
Wind Creek (lowland)	8.1	12.2	0.61	20	0.31

SR –slope of road ,right side; SL-slope of road, left side; Hg-average depth of gully; Av-percentage of road area covered by vegetation;Hv-average height of vegetation on road.

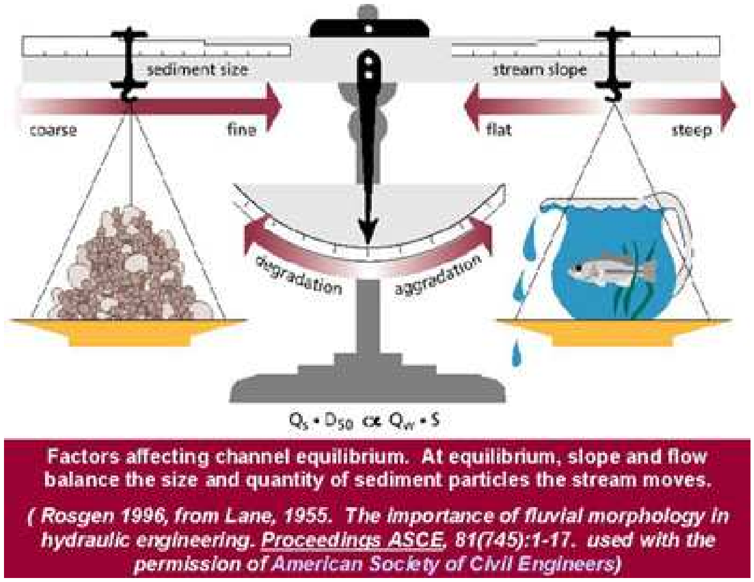

Figure 3-26. A generalized relationship between factors affecting stream equilibrium. Adapted after Lane, 1955. Source: USDA-NRCS Stream Restoration Handbook, 2001.

Furthermore, during low flow events, stream velocities at stream crossing sites are often reduced due to the widening of the channel at these locations. The reduced flow velocity at stream crossings often leads to sediment deposition at the stream crossings. It is also worth noting that poorly designed or constructed low water fords can act as dams, disrupting transport of sediment downstream. At poorly constructed stream crossings, back water pools usually form immediately upstream of the stream crossing site. During low flow events, backwater pools upstream of the ford act as sinks for sediment, which disrupts transport of sediment to the downstream reaches of the stream. During high flow events, the sediment deposited in the backwater pools and stream crossing locations is flushed downstream causing spikes in turbidity and suspended sediment in the stream. Increased turbidity and suspended sediment in the water is a concern from a water quality standpoint. In addition, high levels of turbidity and suspended sediment in the streams are a threat to aquatic life, especially the Topeka Shiner, an endangered species which resides in Flint Hills streams (Sample et al., 1998; Ingrisano, 2005).

CHAPTER 4 - SITE SELECTION, DESIGN AND CONSTRUCTION OF LOW WATER FORDS.

Low Water Fords: Development Process

Observations made and data collected during stream surveys should be applied to designing and constructing low water fords. Constructed fords should be designed to mimic natural stream features (i.e. riffles) in form, materials, and function as closely as possible. Ford designs based on stream function can mitigate some of the environmental impacts associated with constructed low water fords. The design of low water fords is site specific, and depends on a number of factors such as soil types, topography, stream type, size and size of drainage area. It is therefore important to conduct a site assessment study in order to collect data required before any designs can be developed. Figure 4-1 shows a sequence of the process that should be followed during the development of low water fords.

Data Collection

This step involves collecting all the data required during the design process. Data collected includes stream data, soil types, topographical variables (slope and nature of terrain) and size of drainage area. The stream data collected should include channel slope, dimensions and stream type. The size of drainage area gives an indication of the magnitude of stream flows routed through a proposed stream crossing location. Information on soil types gives an idea on soil strength and susceptibility of the soils to erosion. Once channel dimensions and the range of flows at the proposed site are determined, flow velocities and dimensions of the stream crossing can be determined.

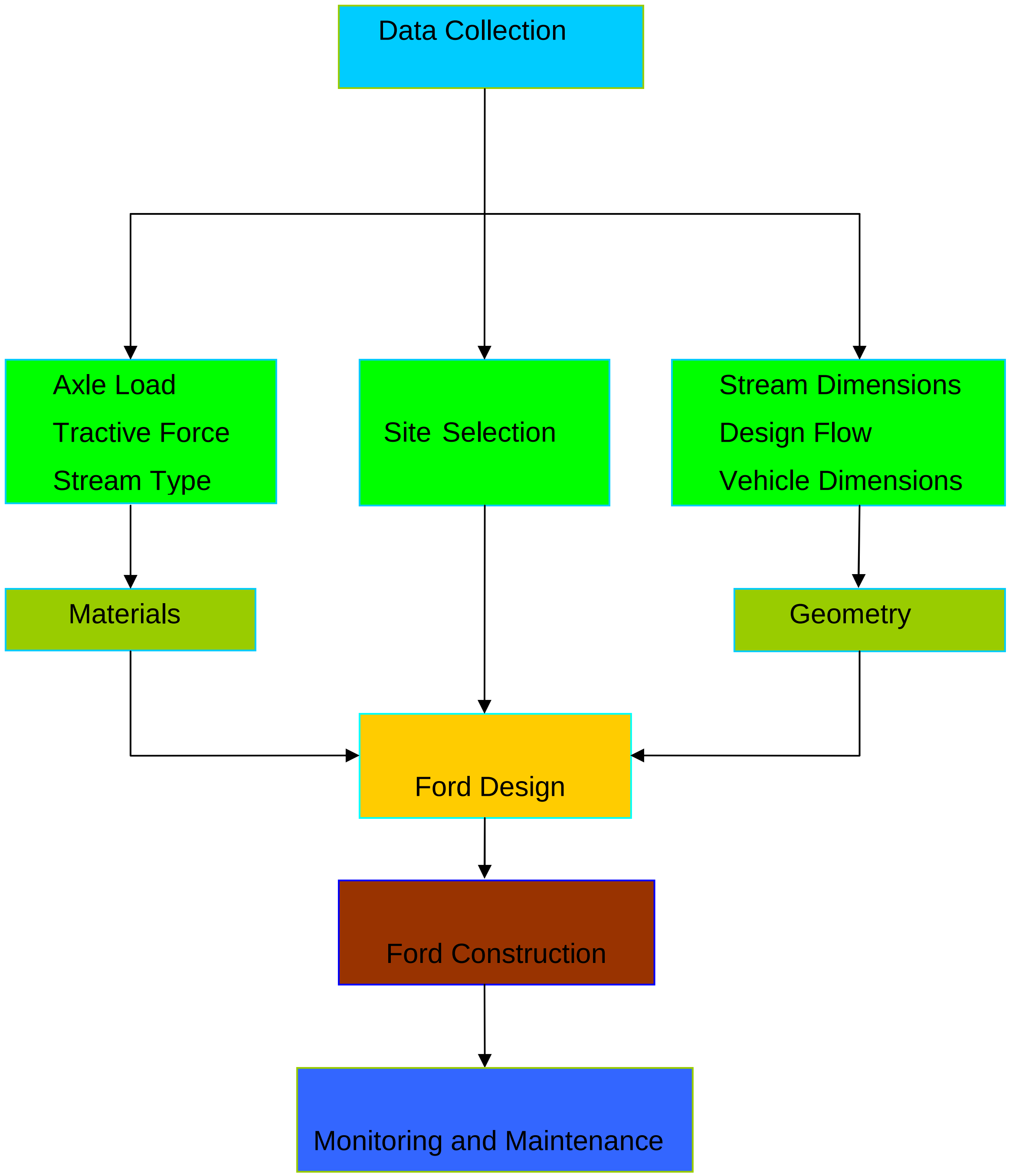

Figure 4-1. Development process for low water fords.

Site Selection

The location of a low water ford determines if a ford will successfully function as designed or fail. Based on observations of constructed fords on Fort Riley, some fords are performing well while others are not. The successfully performing fords are those that were well located while the failing fords are those that were located poorly. The following site selection criteria will help avoid some of the problems associated with poorly located stream crossings.

1. It is desirable to locate stream crossings on riffles. Riffles (Figure 4-2 and 4-4) are shallow places along a stream and are generally considered to be stable. Riffles provide a strong foundation for stream crossing since there is plenty of gravel at these locations.
2. In all cases, pools and meander bends (Figure 4-4) along a stream reach should be avoided when selecting a location for a stream crossing. These areas are prone to be unstable. A stream crossing in a pool or a meander bend can instigate stream instability. Bends tend to receive large quantities of both fine and coarse sediment which can act as an obstacle to vehicular traffic if located in the vicinity of a stream crossing (Figure 4-5- 4-10).
3. Tributary entry points (Figure 4-10 and 4-12) along streams should be avoided because of the large quantities of sediment carried by tributaries. This sediment often gets deposited at these entry locations along the main stream. These points experience high turbulent conditions during high flows and have a potential of compromising the stability of any constructed structure in the vicinity of the area of influence.
4. Stream crossings should be located perpendicular to the direction of stream flow. Locating a stream crossing structure a skew direction to the stream flow has a tendency of changing the alignment of flow in a stream. The misalignment of flow path of a stream can cause undesirable effects on the reach downstream of the crossing structure.
5. Areas with gentle bank slopes provide excellent sites to locate approach roads to a stream crossing. However, all the above factors must be taken into account.

The above site selection criteria demonstrate the importance of adequately locating a suitable site for a stream crossing. The performance of a stream crossing is totally dependant on the choice of site, among other considerations.

Figure 4-2. A riffle (in the foreground) is a relatively stable point along a stream reach.

Figure 4-3. Properly functioning low water ford, located on a riffle.

Figure 4-4. A stream crossing site located on a meander bend at Wind Creek, lowland reach.

Figure 4-5. Wind Creek lowland stream crossing site, before May 05, 2007 flood event.

Figure 4-6. Sediment deposited on road at Wind Creek lowland stream crossing site, after May 05, 2007 flood event.

Figure 4-7. Sediment bar deposited on road at a stream crossings site, upstream view.

Figure 4-8. Sediment bar deposited on road at a stream crossings site, downstream view.

Figure 4-9. Sediment bar deposited on road at a stream crossings site, a view from left bank to right bank.

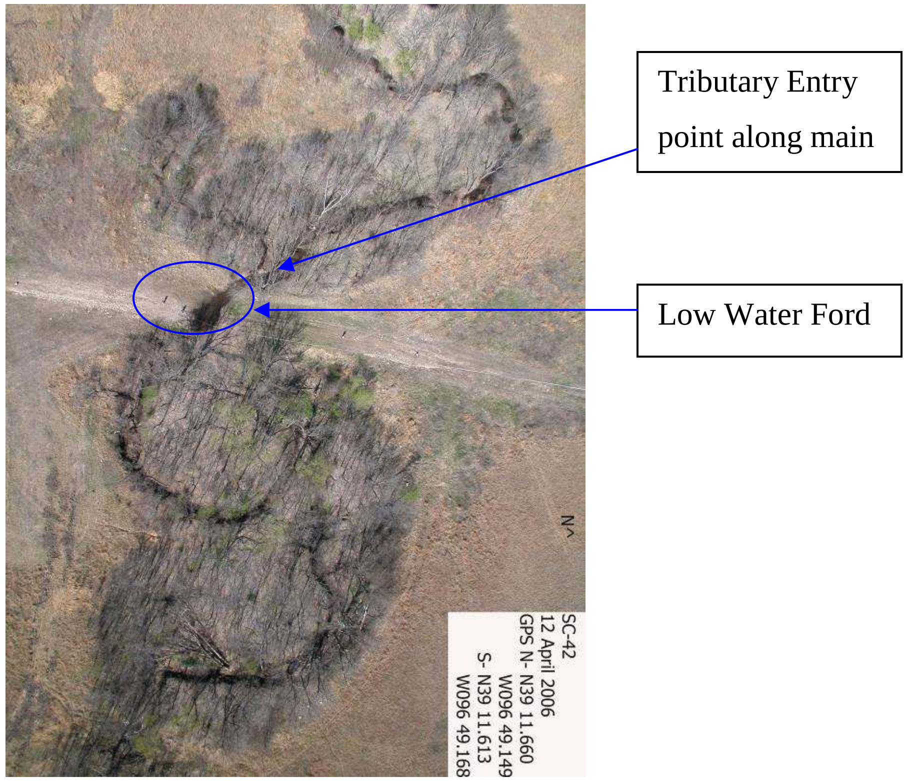

Figure 4-10. Tributary entry point at a location upstream of a stream crossing site at Seven Mile Creek, an aerial view.

Figure 4-11. Tributary entry point upstream of stream crossing site at Seven Mile Creek reach, upstream view.

Design and Construction Guidelines

Dimensions of the stream crossings should be developed based on a compromise between dimensions required for adequate vehicle ingress and egress, and stream stability. The stream crossing dimensions should be sized to allow easy crossing conditions for traffic but still be able to adequately convey stream flow through the stream crossing site without any adverse impacts on the stream. Tendency to oversize a stream crossing should be avoided. Overly sized stream crossings cause a reduction in flow velocities which leads to sediment deposition at the crossing site. The original stream bed elevation at the crossing site should be maintained to allow flow, sediment transport and migration of fish through the crossing site during periods of low stream flow. Materials used at the stream crossing should be adequately selected to mimic natural riffles and also withstand large axle loads of the traffic crossing these streams. The stream crossing should be built with a range of rock sizes. The largest rocks (usually placed in the lower layers beneath the stream crossing) should be selected to withstand both high flow events and large axle loads due to traffic. Size of the largest stable rock should be determined by analyzing tractive forces at the proposed site (Newbury et al., 1997). According to Newbury et al., 1997 and Chow, 1959, tractive force at a riffle site can be estimated from Equation 10, while the diameter of the largest stable rock can be determined from Equation 11.

$$T = 1000 \times D \times S \qquad \textbf{(10)}$$

$$\theta = 1500 \times D \times S \qquad \textbf{(11)}$$

Where:

T = Tractive force (kg/m^2)

D = Flow depth (m)

S = Slope of the downstream face of the riffle.

θ = Diameter of stable rock size (cm).

Geotextile materials (non-woven recommended) should be used to provide additional stability and structural strength to the stream crossing. Geotextile materials are especially helpful when working with streams with clayey or silty bottoms that are susceptible to movement. Construction guidelines discussed here are based on modifications of earlier recommendations presented by Sample et al., 1998. Fort Riley is investigating two design options for approach roads. This chapter discusses one of the design options described above. The stream crossing and approach road construction process follows a sequence of steps listed below:

1. Cut or fill the approach roads to the stream crossing site to a suitable grade. Grades of less than or equal to 12 % (Figure 4-12) are recommended. The minimum recommended roads widths are 5.5m (Figure 4-13).
2. Water bars (Figure 4-14) shall be constructed on approach road. Spacing of water bars will depend on the slopes of the approach roads.
3. Excavate the stream crossing bed to a depth of 0.9-1.2m. The width and length of excavation (Figure 4-14) should conform to the stream crossing dimensions determined during the design phase.
4. A geotextile material (Amoco 2016) shall be laid down on the excavated stream bed. The excavated stream bed area should be back filled in 3 layers of rocks (Figure 4-15) until the original bed elevation is reached. The bottom most layer shall be composed of rock of diameter 46-61 cm. The preceding layer shall be filled with rock of diameter determined from Equation 9, while the top most layer shall be filled with rock of the same diameter as the D_{84} particle size on the riffle upstream of the stream crossing at the proposed crossing site. As shown in Figure 4-16, the longitudinal profile along the low water ford should conform to the original longitudinal profile of the stream.
5. Geotextile material (Amoco 2006) shall be laid on the graded approach roads (Figure 4-12). Rock is placed over the geotextile material in 2 layers of 0.30 m. Rock of 20-30 cm and 7.5- 10 cm diameter shall be placed in the bottom and upper layers respectively of the road base. Table 4-1 shows an estimate of materials required for the construction of a hardened low water ford.

6. Provide adequate drainage on the sides of the roads to funnel runoff to the surrounding vegetation close to the road sides (Figures 4-13 and 4-14).
7. Best management practices shall be employed during and after the construction phase.

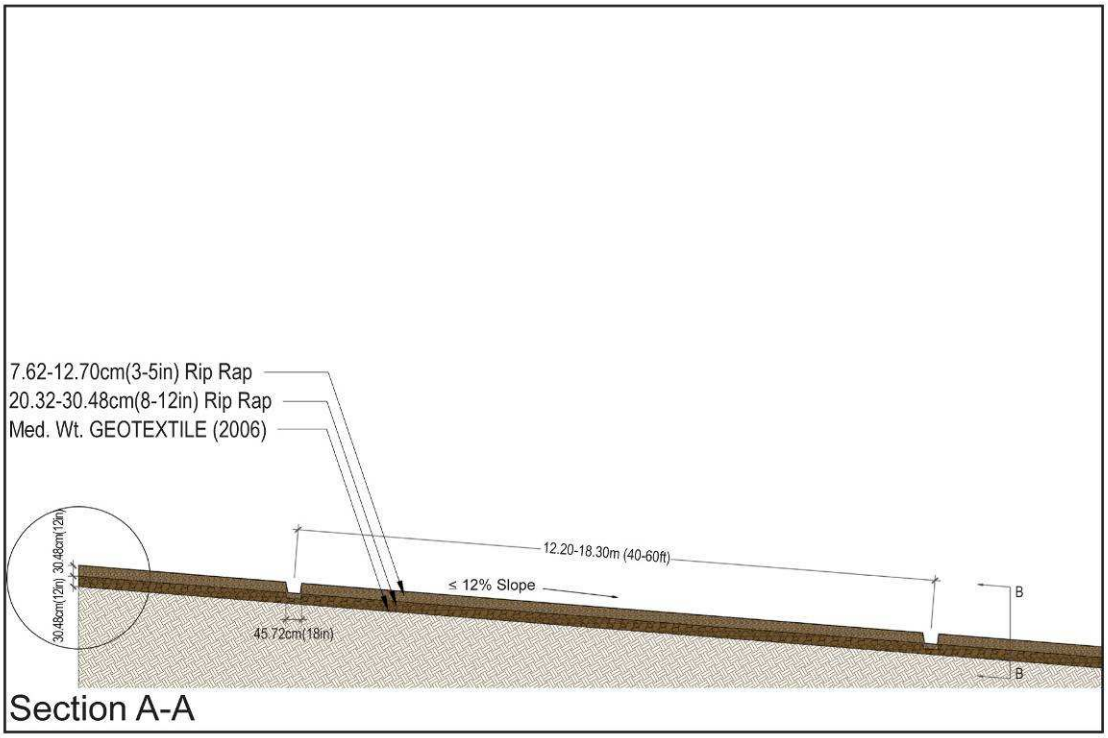

Figure 4-12. Longitudinal profile along approach road leading to a stream crossing site.

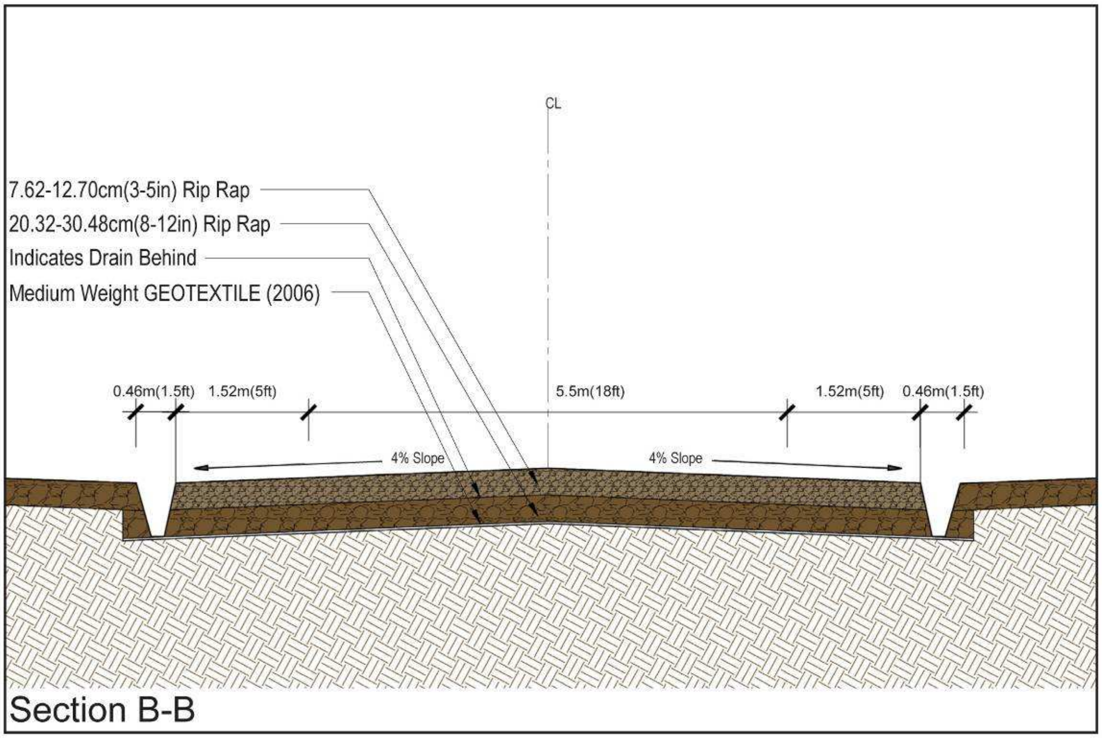

Figure 4-13. Cross section across approach road leading to a stream crossing site.

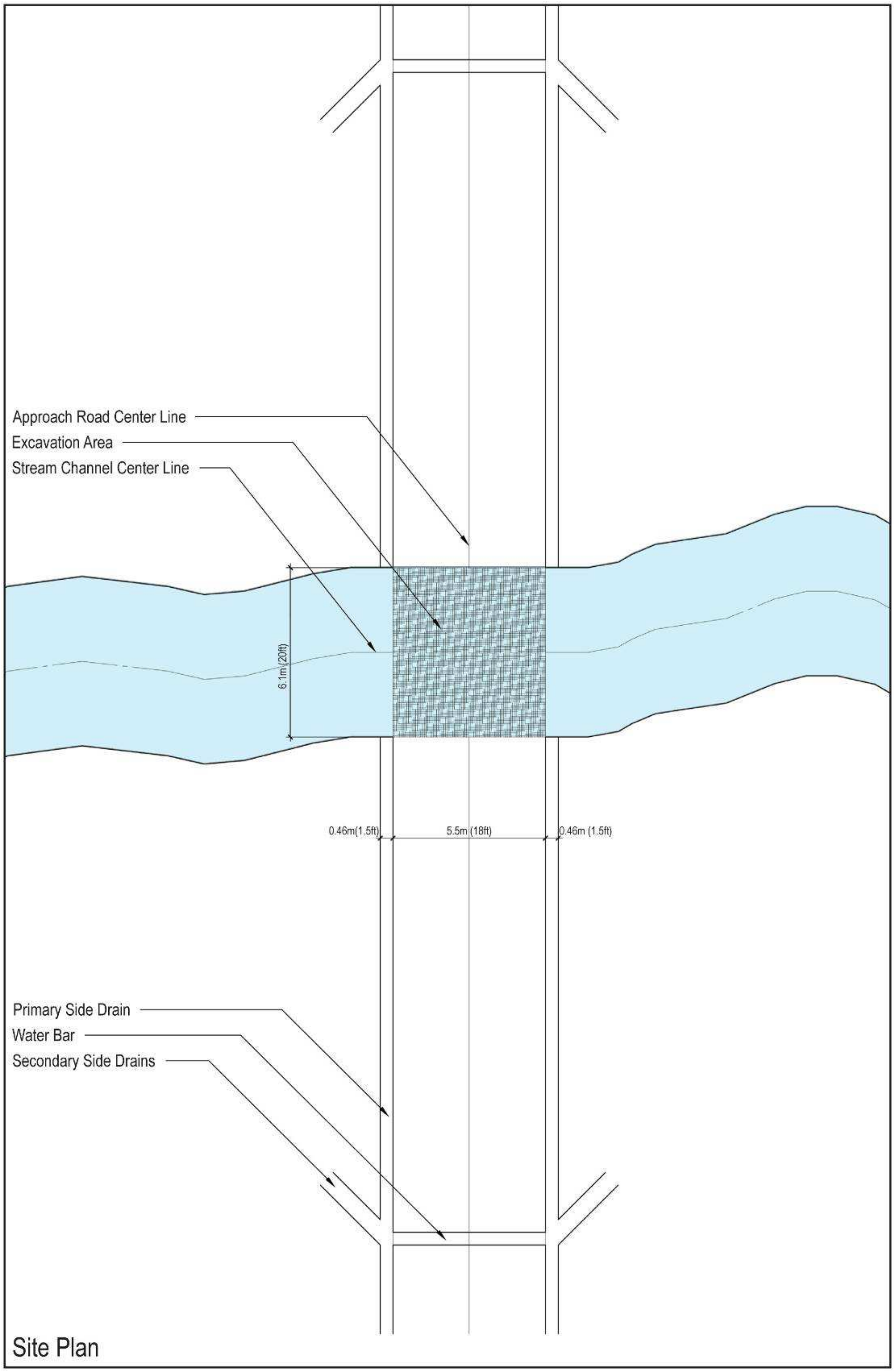

Figure 4-14. Plan of a stream crossing site.

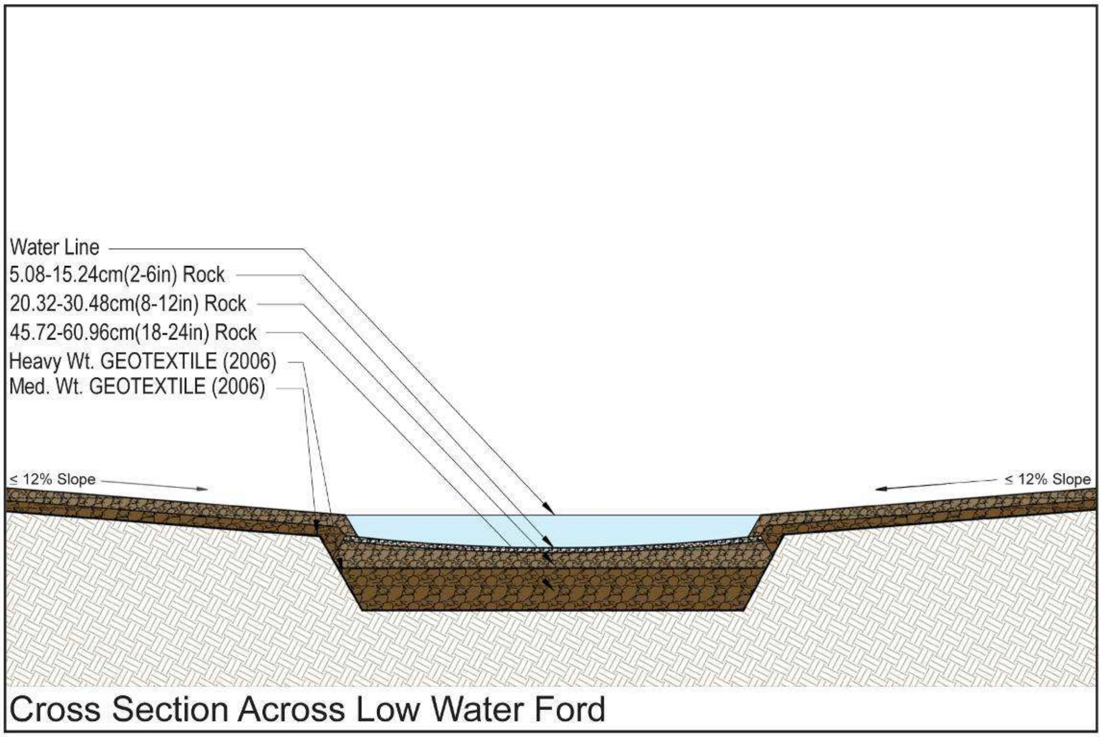

Figure 4-15. Cross section across a low water ford.

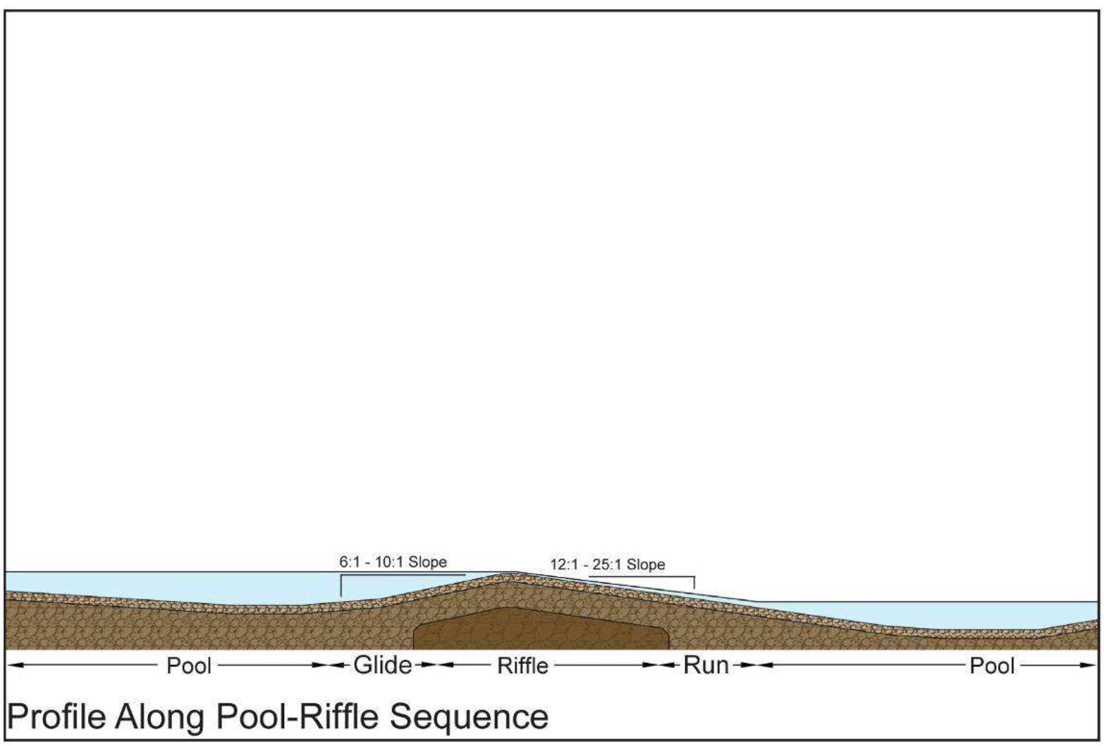

Figure 4-16. Longitudinal profile along a low water ford.

Table 4-1. Estimates of quantities of material required for construction of a hardened low water ford. Source: Sample et al., 1998.

Material	Quantity
Largest rock (e.g. 30-46 cm diameter)	54 m^3
20-30 cm diameter	69 m^3
7.5-10 cm diameter	200 m^3
Geotextile (Amoco 2006)	1000 m^2
Geotextile (Amoco 2016)	42 m^2

Monitoring and Maintenance

Structural integrity and function of low water fords should be regularly monitored. The regular monitoring can help assess the performance of the structures and their effect on stream stability and aquatic life. In addition, the data gathered from this monitoring process can be used to develop an excellent maintenance plan for the low water fords. This data can also be used to improve the designs of low water fords. Adequately designed and maintained low water fords will provide the military with better stream crossing conditions as well as mitigate environmental impacts associated with crossing streams.

Best Practices and Maintenance Considerations

Adequately located, designed and constructed low water fords can address some of the environmental concerns associated with use of stream crossings. The following are some of the best practices and maintenance considerations associated with low water fords:

1. Fords should be constructed during periods of low stream flow to minimize the impact on water quality and aquatic life in streams.
2. Stabilize approach roads by using non-erodible material (geotextile and gravel). Hardened and stabilized roads have a higher life span and require less maintenance.

3. Minimize modifications made to the stream dimensions at crossing sites. Overly modifying stream dimensions at crossing site can cause undesirable impacts on the stream.
4. Locate the stream crossing site on a riffle and in a direction perpendicular to stream flow. Maintain original stream bed elevation to allow free passage of aquatic life and stream flow during low flow events.
5. Minimize removal of vegetation adjacent to crossing site. Vegetation provides protection against erosion.
6. Maintenance of stream crossings is important. Stream crossings should be regularly maintained in order to provide better conditions for crossing streams as well as mitigate any undesirable environmental impacts associated with poorly maintained stream crossings. Regular maintenance also increases the life span of stream crossings.

CHAPTER 5 - CONCLUSION AND RECOMMENDATIONS

Poorly located and constructed low water fords pose a potential for causing stream instability through accelerated bank erosion at locations in the vicinity of the stream crossing, and possibly further downstream. The accelerated bank erosion at these sites can be caused by a low water ford which alters stream flow alignment and therefore accelerating flow in the downstream direction causing increased erosion downstream. Stream crossings in a poor location can be unstable and therefore pose a safety threat to military personnel and equipment crossing these streams. This demonstrates the need to locate and construct stream crossings in proper locations along a stream. Furthermore, poorly designed stream crossings may act as dams, trapping sediment in backwater pools created upstream of stream crossing locations. On high stream flows, trapped sediment in backwater pools is flushed downstream generating high levels of turbidity and suspended sediment in the streams. High levels of sediment and turbidity in streams is a threat to aquatic life as well as a water quality concern. Poorly designed or/and constructed stream crossing can also act as a migration barrier to aquatic life affecting breeding cycles of fish and other aquatic life. This emphasizes the need for proper design and construction techniques for low water fords.

Military maneuvers on training lands have a potential of causing undesirable impacts on the environment. These impacts include increased runoff (rich in sediment) generated from upland areas and delivered to streams often through roads leading to stream crossing locations. Need still exists to study hillslope hydrology and erosion dynamics on approach roads (to stream crossing locations). The impact of runoff and sediment (from upland areas) transported through approach roads to stream crossing sites is still unknown. Future studies should be targeted at assessing the impact of runoff and sediment (from upland areas) on stream stability. Furthermore, the sediment introduced into these streams is generally considered a water quality issue as well as a problem to aquatic life in streams. This extra sediment can offset the balance of sediment in a stream system triggering instability in the stream.

Residual effects of past land use practices such as agriculture and grazing may still be felt in the study watersheds on Fort Riley, however, these effects may be minimal. As mentioned earlier, military maneuvers on Fort Riley rangelands are destructive to vegetation and cause soil compaction increasing runoff and soil erosion rates in the study watersheds. Increased runoff and upland erosion rates in these watersheds affect the streams because of the excess sediment delivered to the streams. Some of the streams in the study watersheds show signs of stream transition from the current stream types to different stream types. These stream successional changes involve change in stream dimensions such as channel deepening which is usually followed by widening. These stream changes have direct implications on the low water fords on Fort Riley. As a consequence, there will be constant need to modify the design and construction techniques of these fords in order to accommodate changes in the stream morphology. Benefits of doing so include better stream crossing conditions for the military and less impacts on the environment.

Some of the streams investigated show signs of instability which may compromise or threaten the stream functions in these streams. Continued monitoring of these streams will provide additional information required for decision making. Furthermore, need still exists to implement and monitor the performance of the modified designs of stream crossings. Through adaptive management, better designs of stream crossings can be developed. Better designs of low water fords will provide the military with better stream crossing conditions as well as mitigate any environment impacts associated with crossing streams. Finally, need still exists develop to bank erosion rating curves for the state of Kansas, especially for the Flint Hills region. Continued monitoring of the study sites will provide some of the data required for the development of erosion rating curves for the Flint Hills region.

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Appendix A - Farnum Creek

Photographs

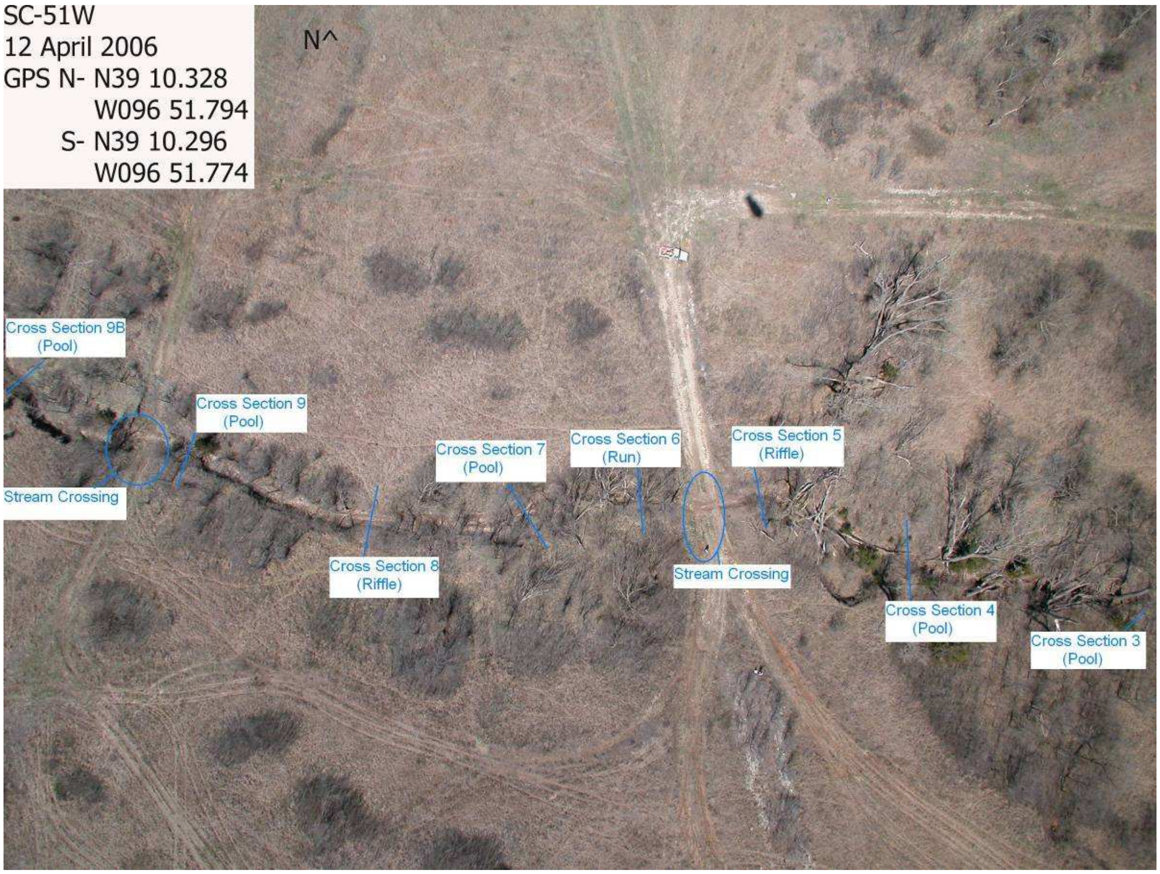


Figure A-1. Farnum Creek study reach.

Figure A-2. Cross section transect 1 (riffle), view from left bank to right bank at Farnum Creek.

Figure A-3. Cross section transect 1 (riffle) at Farnum Creek, upstream view.

Figure A-4. Cross section transect 1 (riffle) at Farnum Creek, downstream view.

Figure A-5. Cross section transect 4 (pool), view from left bank to right bank at Farnum Creek.

Figure A-6. Cross section transect 4 (pool) at Farnum Creek, upstream view.

Figure A-7. Cross section transect 4 (pool) at Farnum Creek, downstream view.

Figure A-8. Stream crossing, view from left bank to right bank at Farnum Creek.

Figure A-9. Stream crossing at Farnum Creek, upstream view.

Figure A-10. Stream crossing at Farnum Creek, downstream view.

Figure A-11. Cross section transect 7 (pool) at Farnum Creek, upstream view.

Figure A-12. Cross section transect 7 (pool) at Farnum Creek, downstream view.

Figure A-13. Cross section transect 7 (pool), view from left bank to right bank at Farnum Creek.

Figure A-14. Cross section transect 8 (riffle) at Farnum Creek, upstream view.

Figure A-15. Cross section transect 8 (riffle) at Farnum Creek, downstream view.

Figure A-16. Cross section transect 8 (riffle), view from left bank to right bank at Farnum Creek.

Changes in Channel Geometry

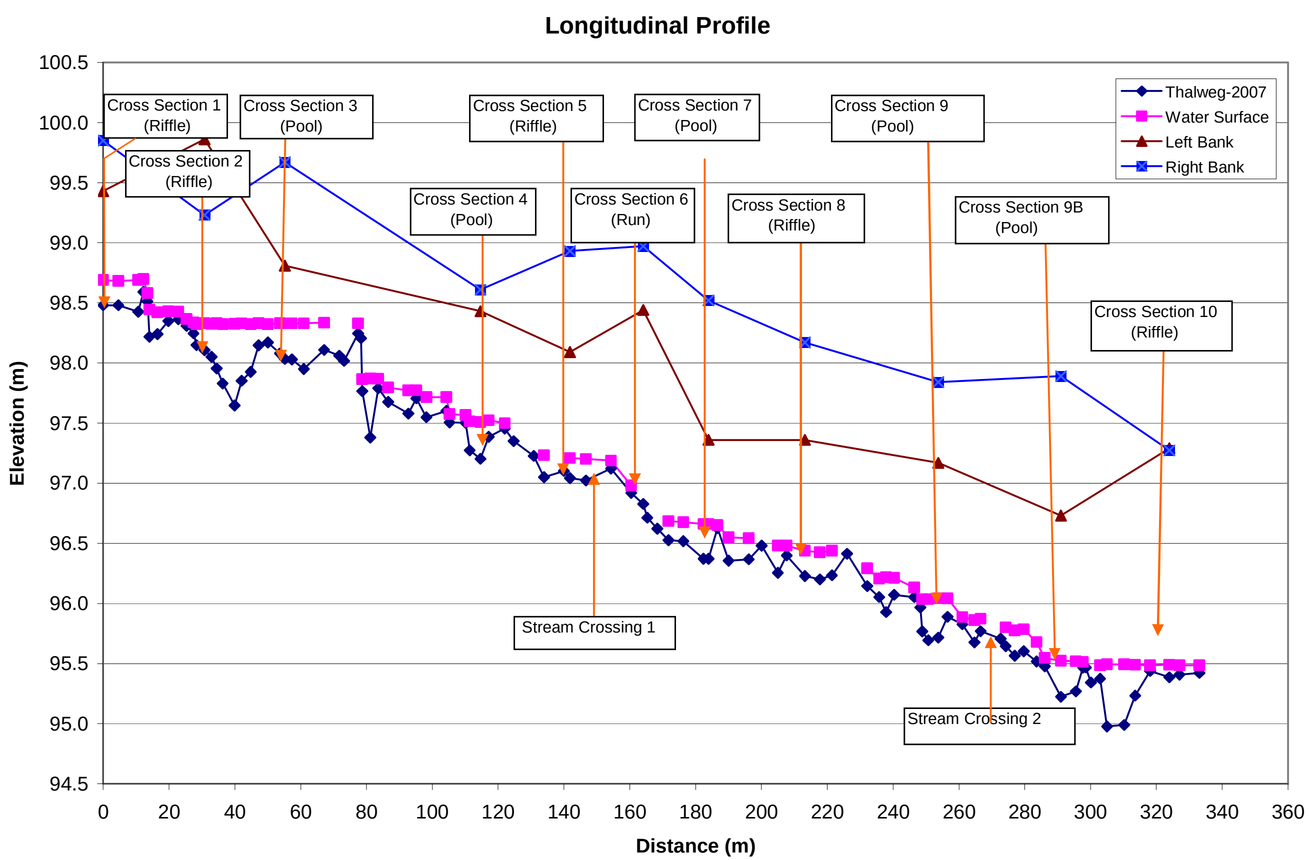


Figure A-17. Longitudinal profile along Farnum Creek.

Figure A-18. Repeat survey of cross section transect 1 at Farnum Creek.

Figure A-19. Repeat survey of cross section transect 2 at Farnum Creek.

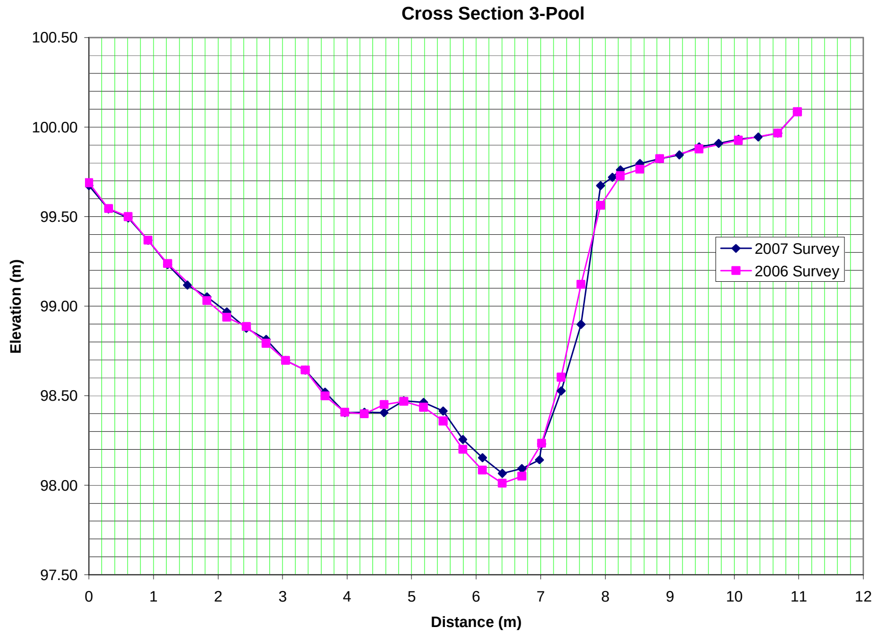


Figure A-20. Repeat survey of cross section transect 3 at Farnum Creek.

Figure A-21. Repeat survey of cross section transect 4 at Farnum Creek.

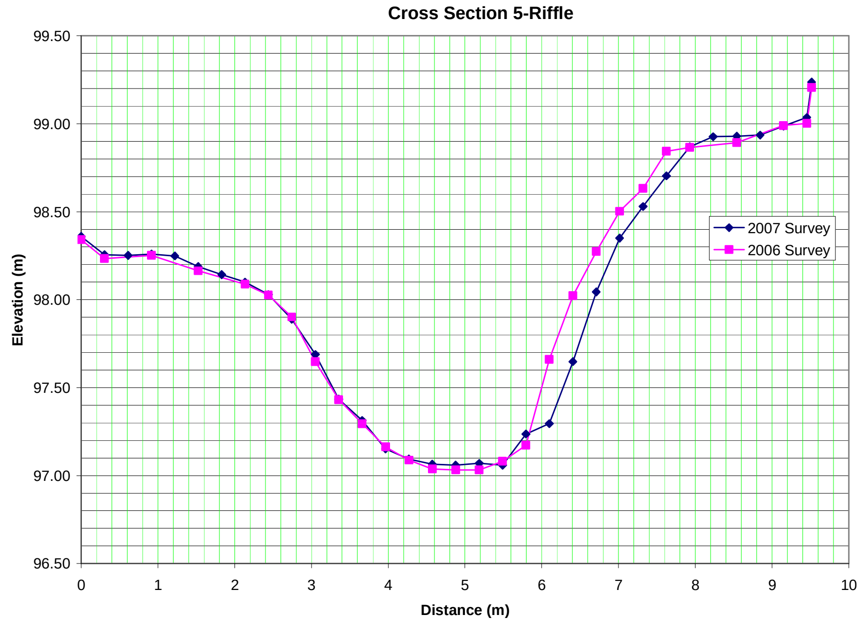


Figure A-22. Repeat survey of cross section transect 5 at Farnum Creek.

Figure A-23. Repeat survey of cross section transect 6 at Farnum Creek.

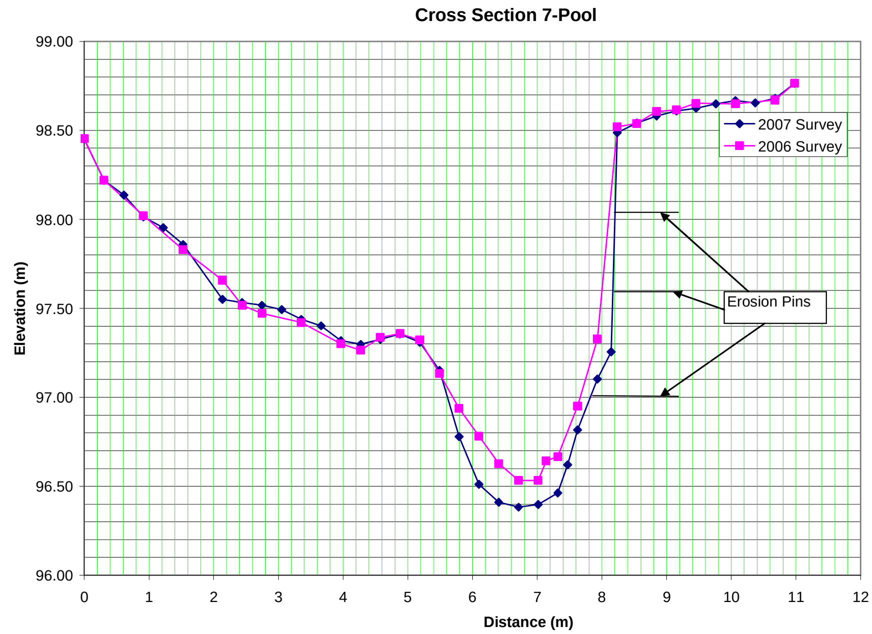


Figure A-24. Repeat survey of cross section transect 7 at Farnum Creek.

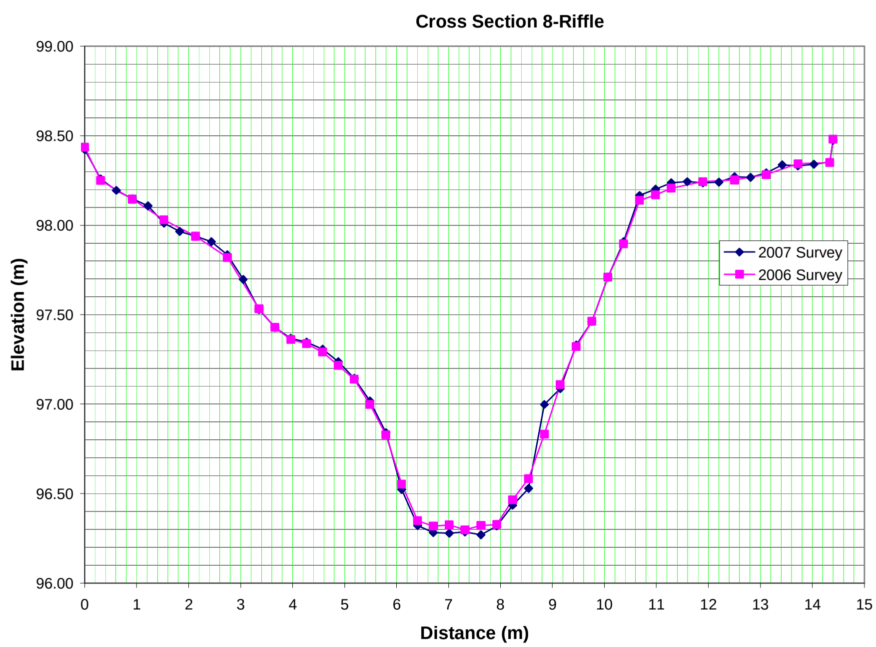


Figure A-25. Repeat survey of cross section transect 8 at Farnum Creek.

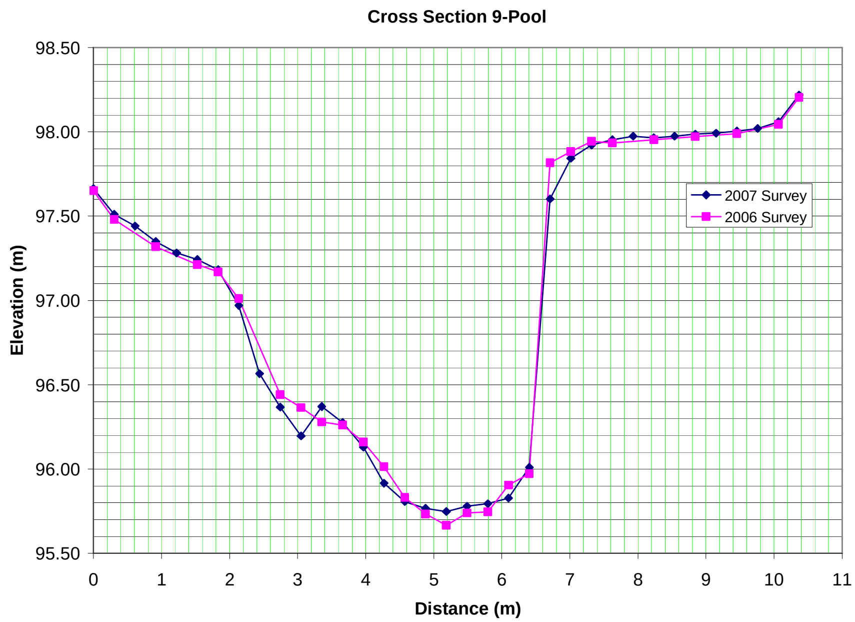


Figure A-26. Repeat survey of cross section transect 9 at Farnum Creek.

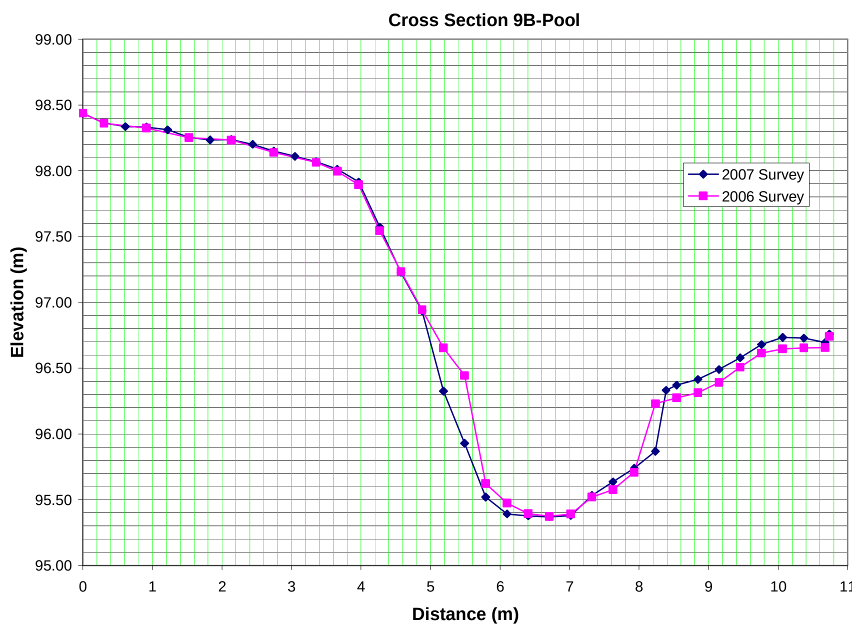


Figure A-27. Repeat survey of cross section transect 9B at Farnum Creek.

Figure A-28. Repeat survey of cross section transect 10 at Farnum Creek.

Bed Material Characterization

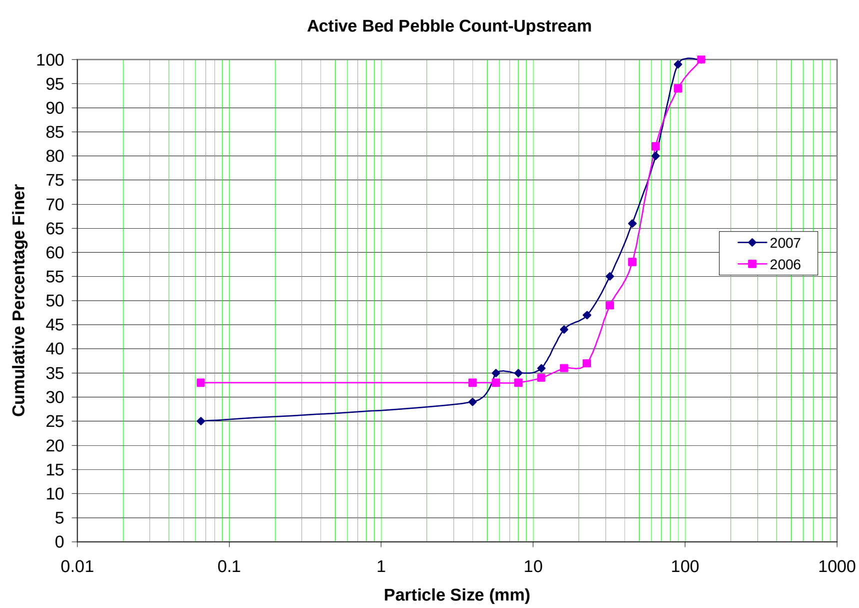


Figure A-29. Particle size distribution at cross section transect 1, Farnum Creek reach.

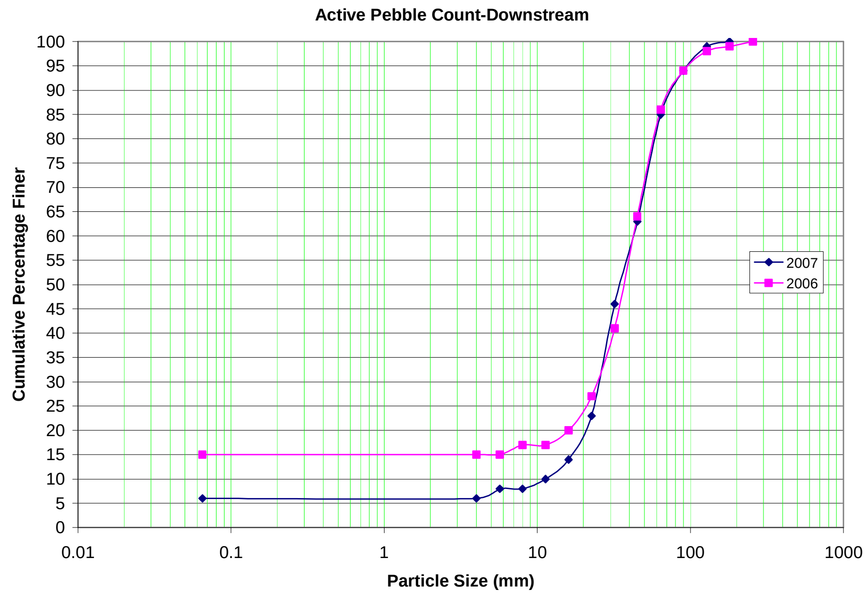


Figure A-30. Particle size distribution at cross section transect 10, Farnum Creek reach.

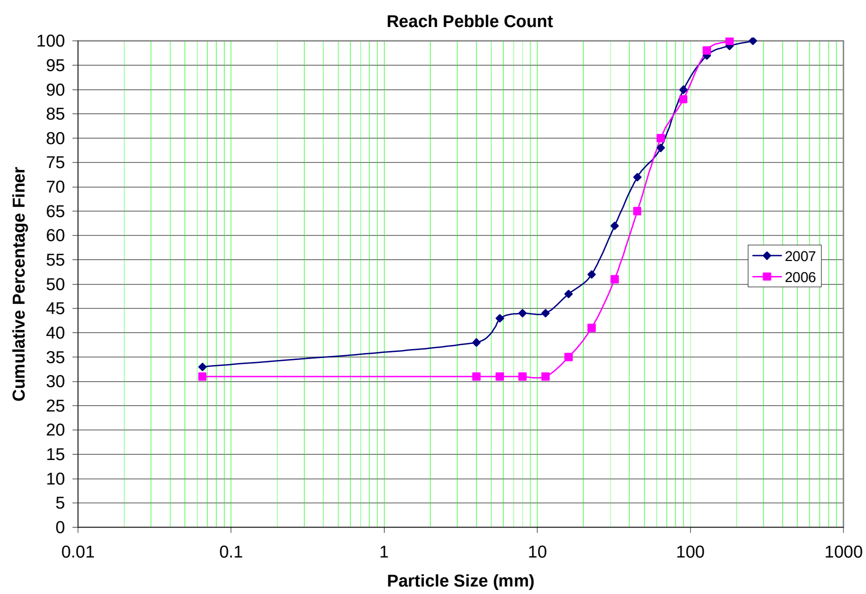


Figure A-31. Particle size distribution along Farnum Creek reach.

Repeat Survey of Bank Profiles

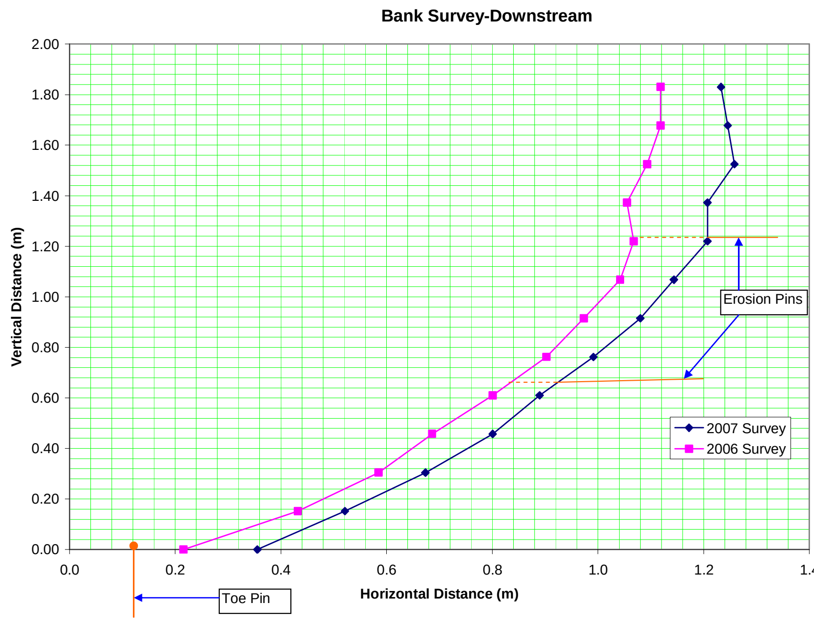


Figure A-32. Measure of bank migration rate at bank transect 1, Farnum Creek.

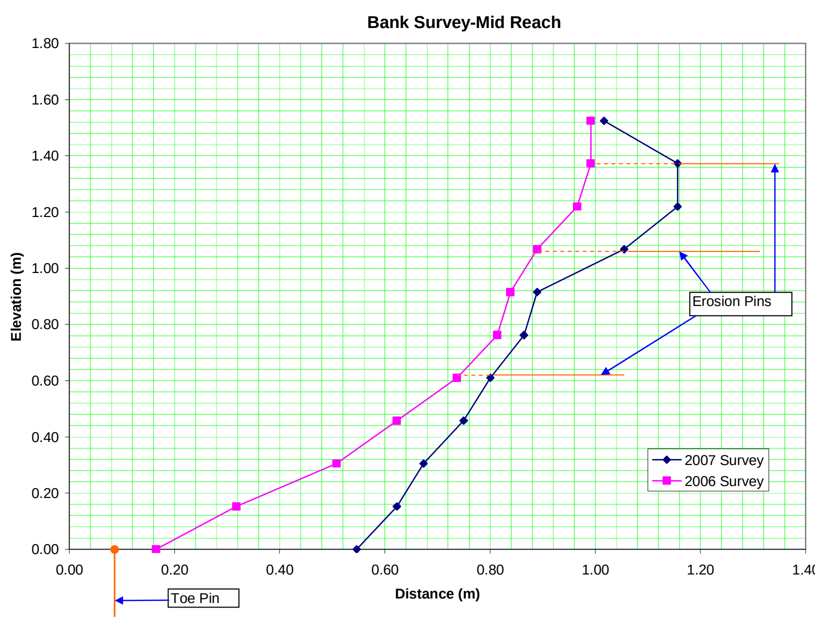


Figure A-33. Measure of bank migration rate at bank transect 2, Farnum Creek.

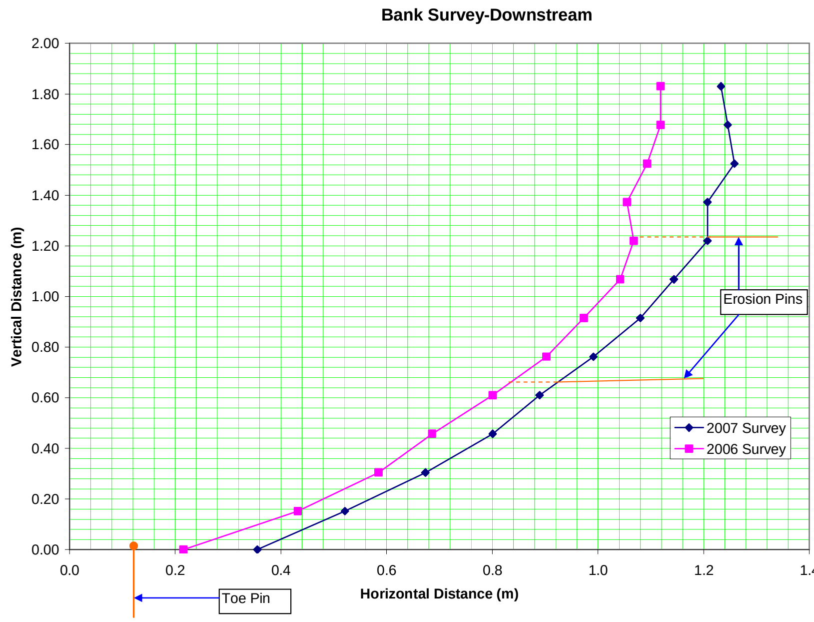


Figure A-34. Measure of bank migration rate at bank transect 3, Farnum Creek.

Calculation of BEHI and NBS

Table A-1. Calculation of BEHI variables and overall BEHI rating at bank transect 1, Farnum Creek.

Stream:	**Farnum Creek**	Location:	**Fort Riley,Kansas**
Station:	**Bank Transect 1**	Observers:	
Date:	**06/2007**	Stream Type: **G4c**	Valley Type: **II**

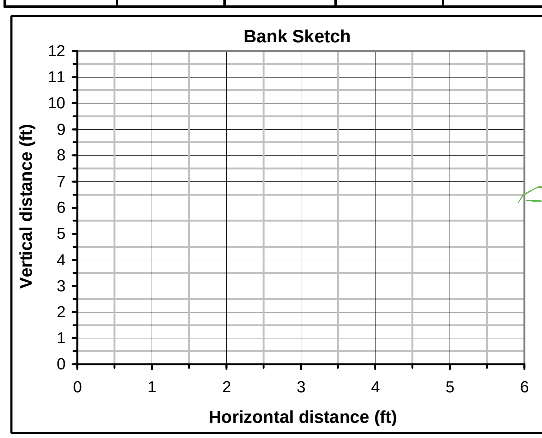
Variable	Input 1		Input 2		Calculation	Value	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) =	5.5 **(A)**	**Bankfull Height** (ft) =	3 **(B)**	(A) / (B) =	1.83 **(C)**	7.0
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	4.5 **(D)**	**Study Bank Height** (ft) =	5.5 **(A)**	(D) / (A) =	0.82 **(E)**	1.8
Weighted Root Density (G)			**Root Density** as **%** =	15% **(F)**	(F) × (E) =	12.3 **(G)**	8.2
Bank Angle (H)					**Bank Angle** as *Degrees* =	30 **(H)**	2.2
Surface Protection (I)					**Surface Protection** as **%** =	10% **(I)**	9.0

Bank Material Adjustment:
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large
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: 0.0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0.0

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



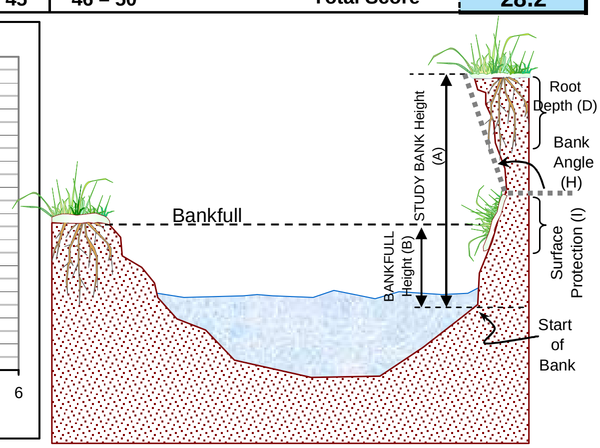


Table A-2. Calculation of NBS variables and overall NBS rating at bank transect 1, Farnum Creek.

Estimating Near-Bank Stress (NBS)		
Stream: **Farnum Creek**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 1**	Stream Type: **G4c**	Valley Type: **II**
Observers:		Date: **06/2006**

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

Level I

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

Level II

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

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.0015	**0.0101**	**0.15**	**Very Low**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.0015	**0.0226**	**0.07**	**Very Low**

Dominant Near-Bank Stress
High

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	3.00	**1.49**	**2.01**	**High**

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

Level IV

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

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

Table A-3. Calculation of BEHI variables and overall BEHI rating at bank transect 2, Farnum Creek.

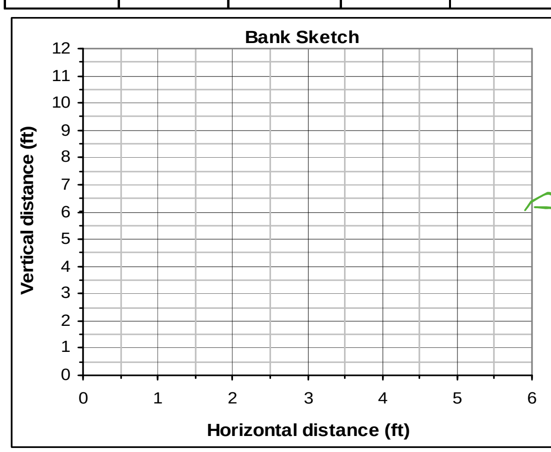
Stream:	**Farnum Creek**	Location:	**Fort Riley, Kansas**
Station:	**Bank Transect 2**	Observers:	
Date:	**06/2007**	Stream Type: **G4c**	Valley Type:

Variable						Value	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) =	6.2 (A)	Bankfull Height (ft) =	3.5 (B)	(A) / (B) =	1.77 (C)	7.0
Root Depth / Study Bank Height (E)	Root Depth (ft) =	5 (D)	Study Bank Height (ft) =	6.2 (A)	(D) / (A) =	0.81 (E)	2.2
Weighted Root Density (G)			Root Density as % =	20% (F)	(F) × (E) =	16.13 (G)	7.5
Bank Angle (H)					Bank Angle as *Degrees* =	45 (H)	3.0
Surface Protection (I)					Surface Protection as % =	10% (I)	9.0

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

Bank Material Adjustment	0.0
Stratification Adjustment Add 5–10 points, depending on position of unstable layers in relation to bankfull stage	0.0

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** 28.7



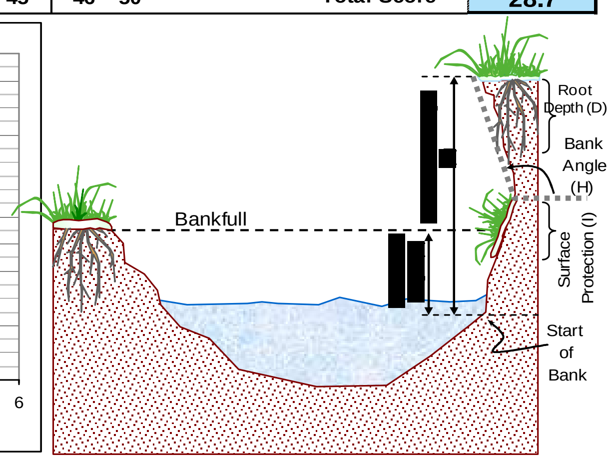


Table A-4. Calculation of NBS variables and overall NBS rating at bank transect 2, Farnum Creek.

Stream: **Farnum Creek**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 2**	Stream Type: **G4c**	Valley Type: **II**
Observers:		Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

Level I

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

Level II

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

	Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)
(3)	**0.0154**	**0.0101**	**1.52**	**Extreme**

	Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.0154**	**0.0197**	**0.78**	**Moderate**

Dominant Near-Bank Stress
Extreme

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**3.5**	**1.49**	**2.35**	**High**

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

Level IV

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

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

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

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

Table A-5. Calculation of BEHI variables and overall BEHI rating at bank transect 3, Farnum Creek.

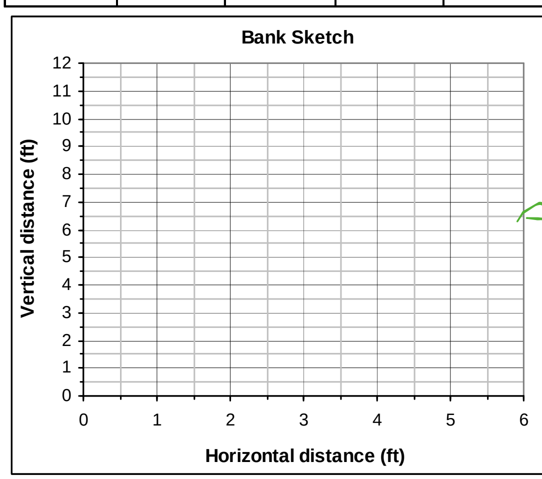
Stream:	**Farnum Creek**	Location:	**Fort Riley, Kansas**
Station:	**Bank Transect 3**	Observers:	
Date:	**6/2007**	Stream Type: **G4c**	Valley Type:

Variable	Inputs	Calculation	Value	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 8.2 (A); Bankfull Height (ft) = 3.5 (B)	(A) / (B) =	2.34 (C)	8.2
Root Depth / Study Bank Height (E)	Root Depth (ft) = 4 (D); Study Bank Height (ft) = 8.2 (A)	(D) / (A) =	0.49 (E)	4.0
Weighted Root Density (G)	Root Density as % = 15% (F)	(F) x (E) =	7.32 (G)	8.8
Bank Angle (H)	Bank Angle as *Degrees* =		35 (H)	2.3
Surface Protection (I)	Surface Protection as % =		10% (I)	9.0

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

Bank Material Adjustment	0.0
Stratification Adjustment Add 5–10 points, depending on position of unstable layers in relation to bankfull stage	0.0

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** 32.3



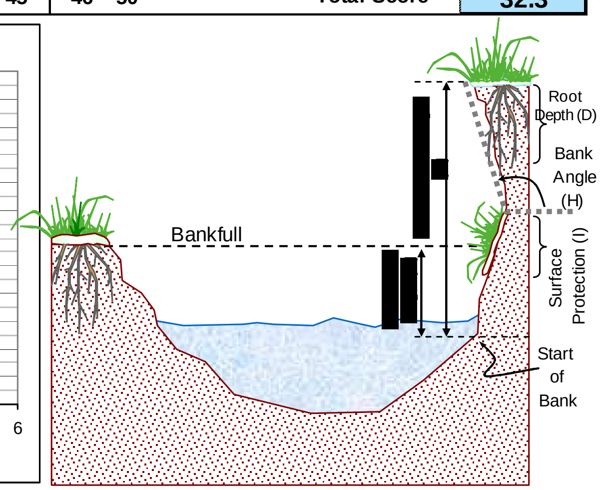


Table A-6. Calculation of NBS variables and overall NBS rating at bank transect 3, Farnum Creek.

Stream: **Farnum Creek**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 3**	Stream Type: **G4c**	Valley Type: **II**
Observers:		Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

Level I

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

Level II

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

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.023**	**0.0101**	**2.28**	**Extreme**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.023**	**0.006**	**3.83**	**Extreme**

Dominant Near-Bank Stress
Extreme

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**3.5**	**1.49**	**2.35**	**High**

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

Level IV

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

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

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

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

Geographical Position System Coordinates

Table A-7. GPS coordinates taken at Farnum Creek.

Feature	Northing (m)	Easting (m)
Bench Mark 1	4338043	684745
Head of Reach	4338071	684738
Cross Section 1- Left Pin	4338058	684749
Cross Section 1- Right Pin	4338057	684741
Cross Section 2- Left Pin	4338030	684722
Cross Section 2- Right Pin	4338037	684712
Cross Section 3- Left Pin	4338034	684701
Cross Section 3- Right Pin	4338041	684700
Cross Section 4- Left Pin	4338014	684650
Cross Section 4- Right Pin	4338048	684654
Cross Section 5- Left Pin	4338025	684606
Cross Section 5- Right Pin	4338032	684608
Cross Section 6- Left Pin	4338012	684591
Cross Section 6- Right Pin	4338023	684589
Cross Section 7- Left Pin	4338001	684588
Cross Section 7- Right Pin	4338007	684572
Cross Section 8- Left Pin	4337986	684552
Cross Section 8- Right Pin	4338004	684549
Cross Section 9- Left Pin	4337981	684516
Cross Section 9- Right Pin	4337999	684511
Cross Section 10- Left Pin	4338000	684451
Cross Section 10- Right Pin	4338009	684452
End of Reach	4338006	684448

GPS measurement grid is Universal Transverse Mercator (UTM) and map datum is North American Datum 83 (NAD 83).

Appendix B - Seven Mile Creek

Photographs

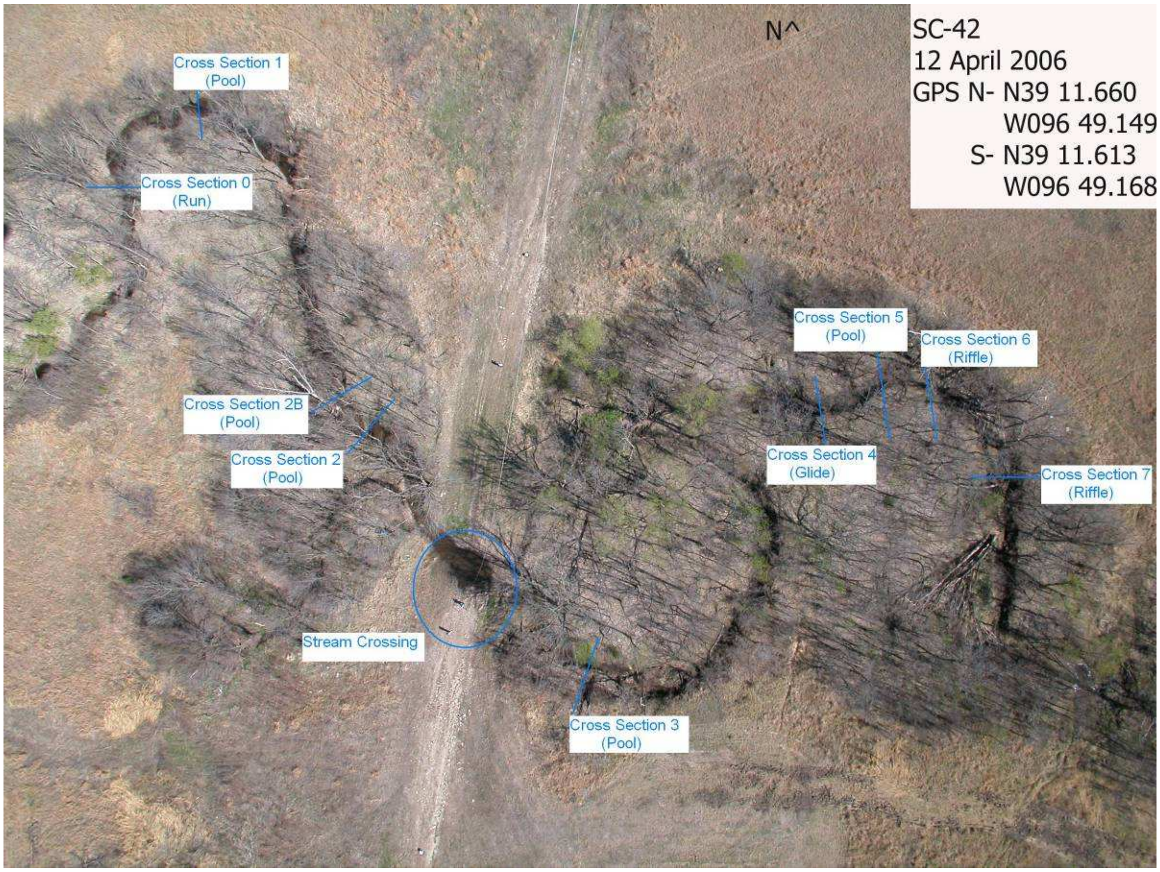


Figure B-1. Seven Mile Creek study reach.

Figure B-2. Cross section transect 2 (pool), view from left bank to right bank at Seven Mile Creek.

Figure B-3. Cross section transect 2 (pool) at Seven Mile Creek, upstream view.

Figure B-4. Cross section transect 2 (pool) at Seven Mile Creek, downstream view.

Figure B-5. Stream crossing at Seven Mile Creek, upstream view.

Figure B-6. Stream crossing at Seven Mile Creek, downstream view.

Figure B-7. Cross section transect 4 (glide), view from left bank to right bank at Seven Mile Creek.

Figure B-8. Cross section transect 2 (pool) at Seven Mile Creek, upstream view.

Figure B-9. Cross section transect 4 (glide) at Seven Mile Creek, downstream view.

Changes in Channel Geometry

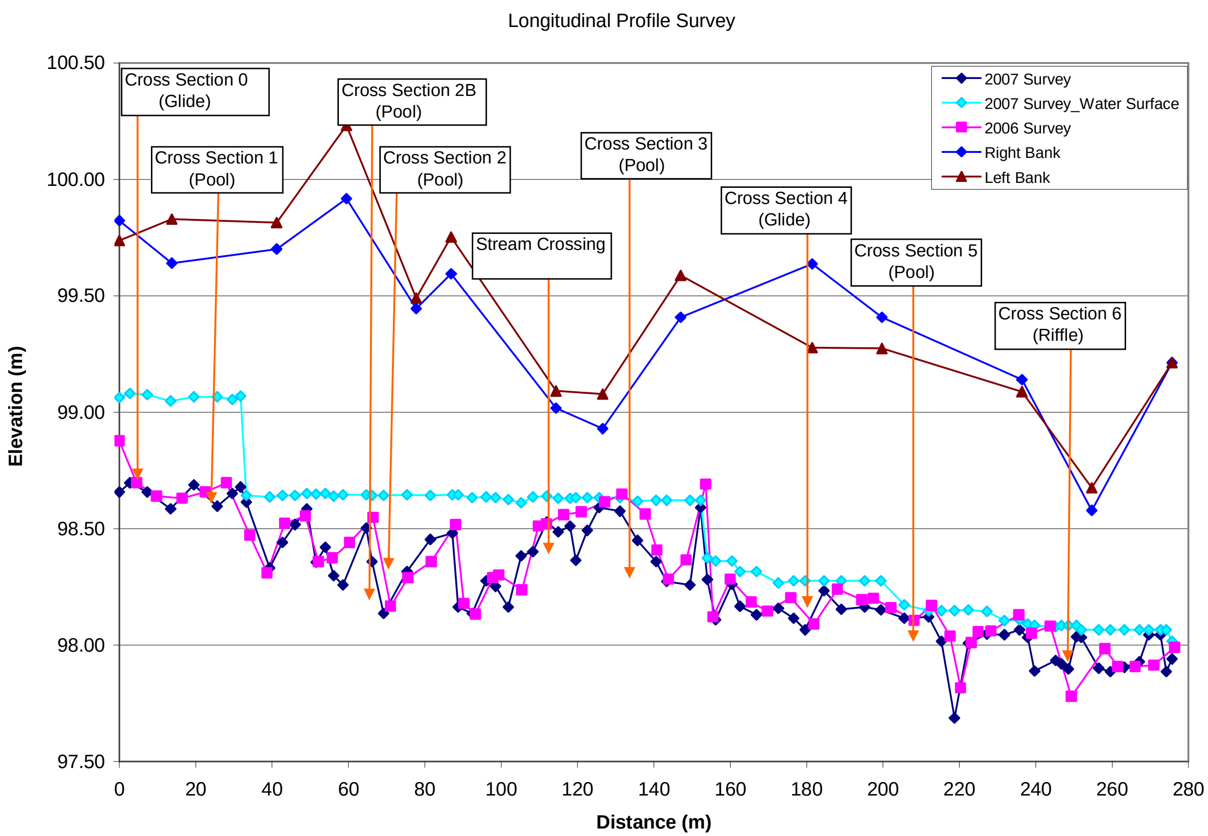


Figure B-10. Longitudinal profile of Seven Mile Creek.

Figure B-11. Repeat survey of cross section transect 0 at Seven Mile Creek.

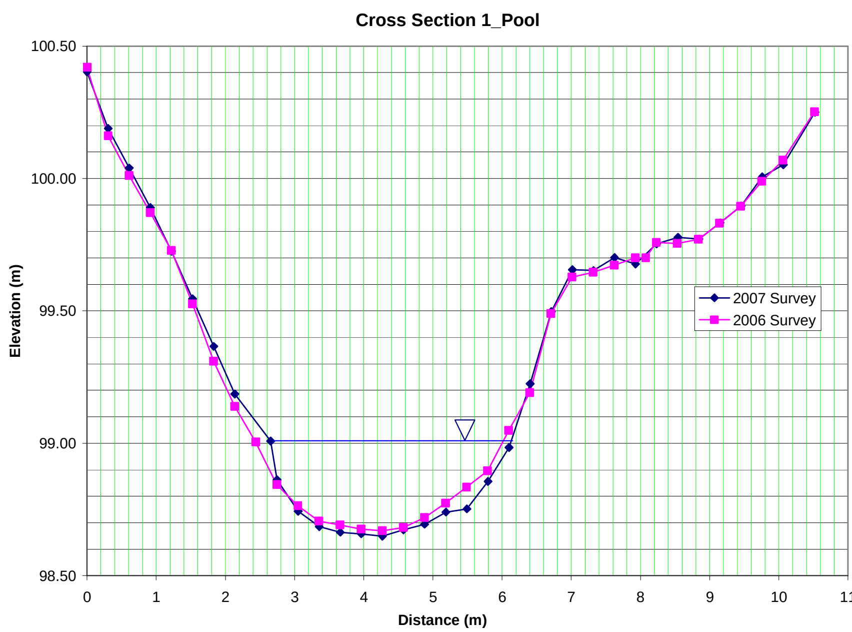


Figure B-12. Repeat survey of cross section transect 1 at Seven Mile Creek.

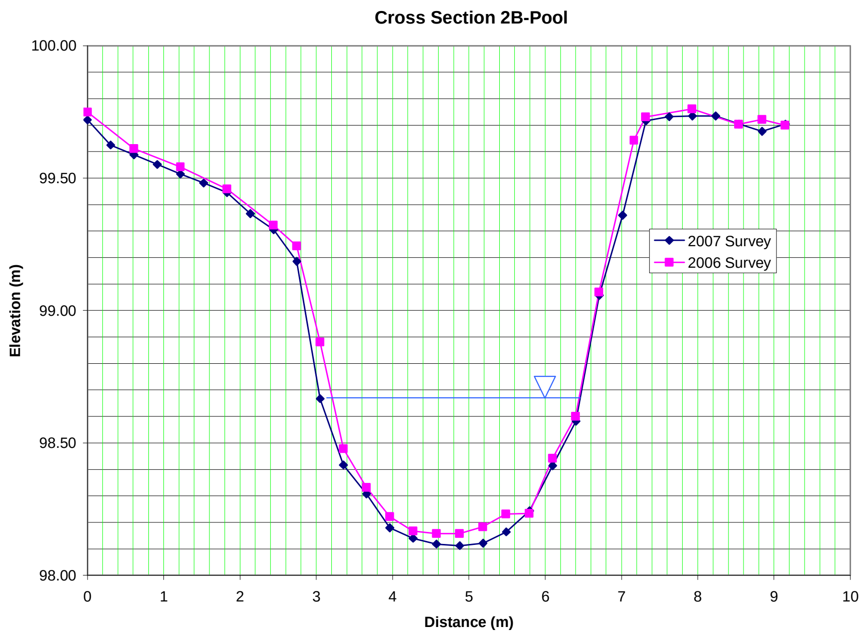


Figure B-13. Repeat survey of cross section transect 2B at Seven Mile Creek.

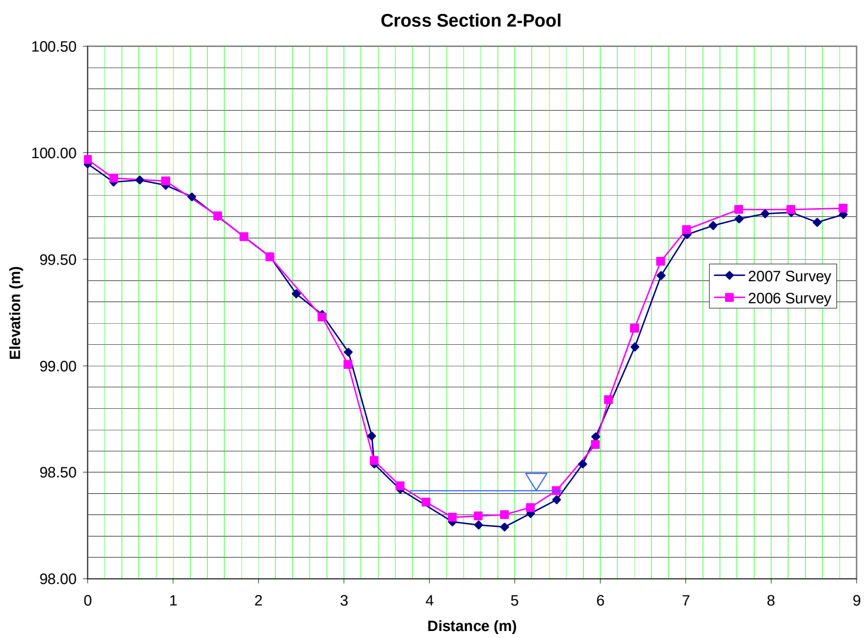


Figure B-14. Repeat survey of cross section transect 2 at Seven Mile Creek.

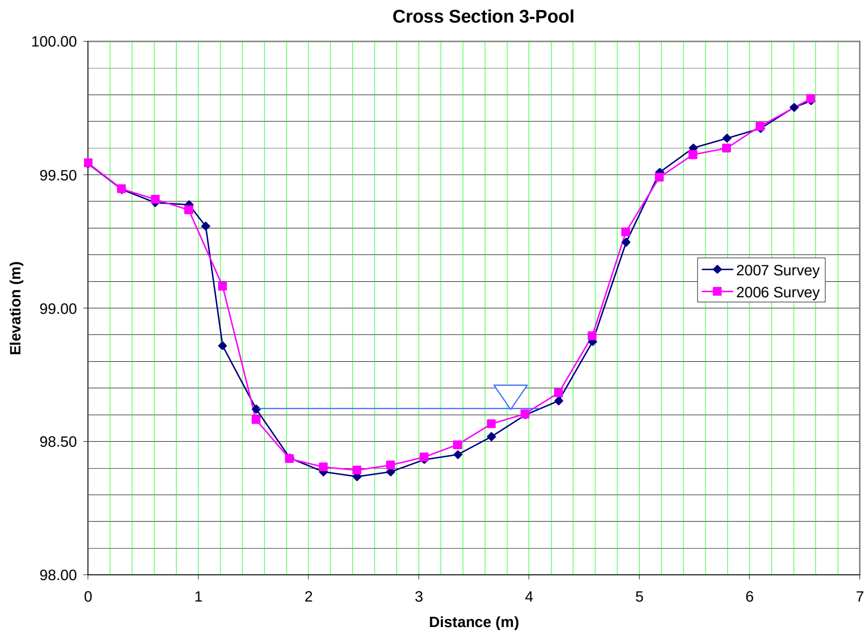


Figure B-15. Repeat survey of cross section transect 3 at Seven Mile Creek.

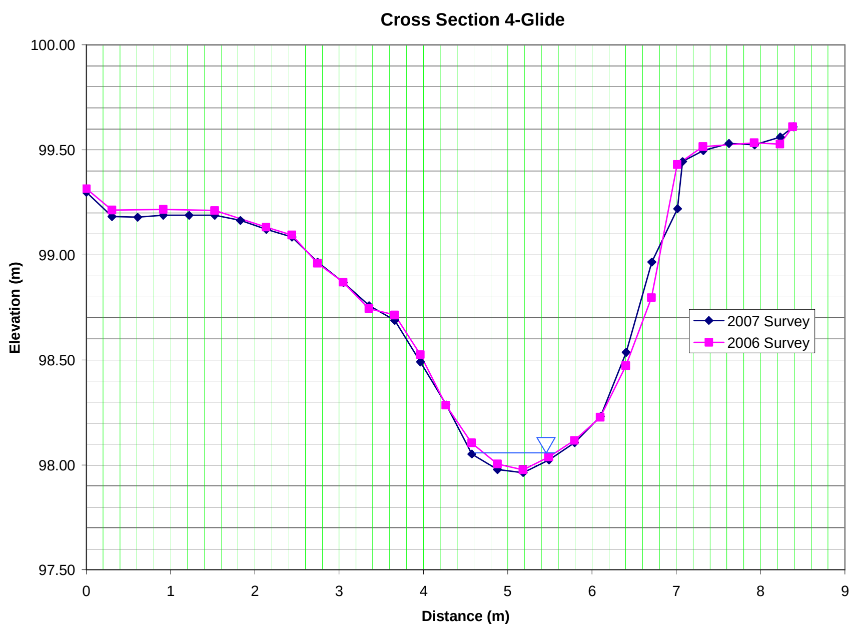


Figure B-16. Repeat survey of cross section transect 4 at Seven Mile Creek.

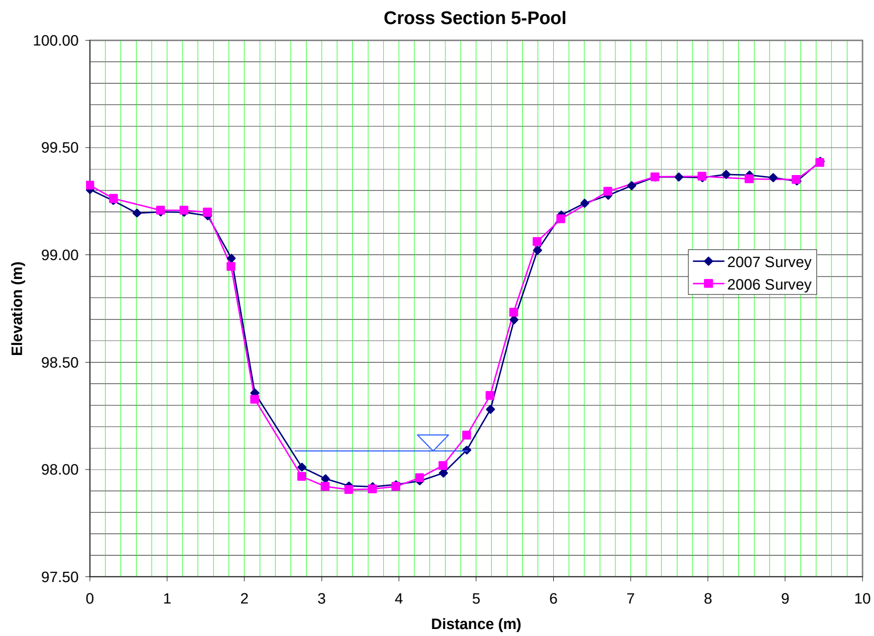


Figure B-17. Repeat survey of cross section transect 5 at Seven Mile Creek.

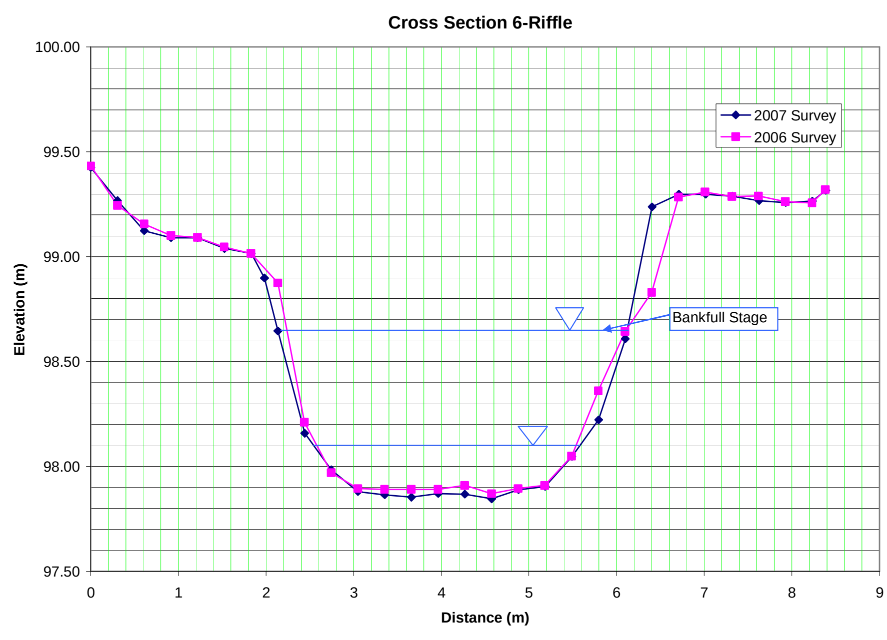


Figure B-18. Repeat survey of cross section transect 6 at Seven Mile Creek.

Bed Material Characterization

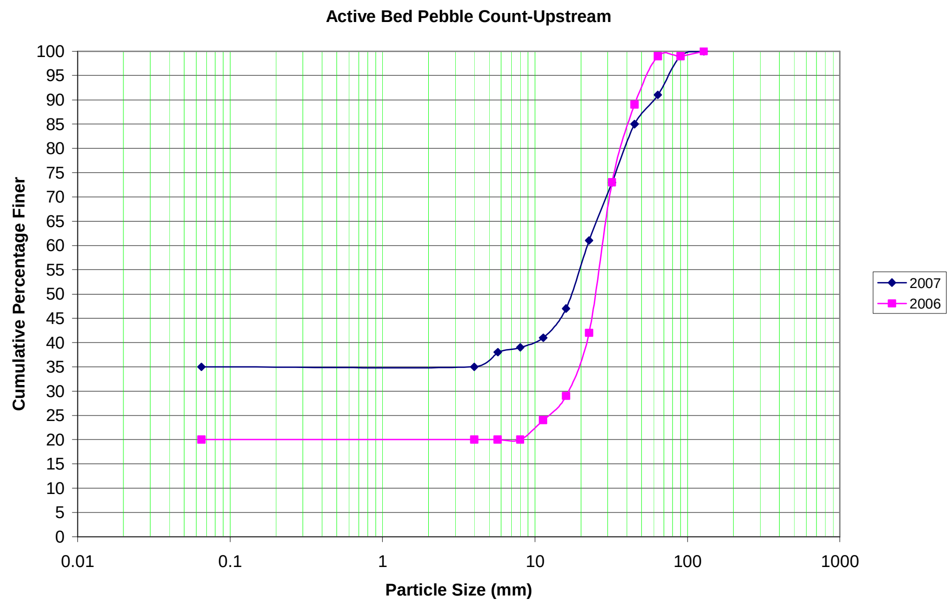


Figure B-19. Particle size distribution at cross section transect 1, Seven Mile Creek reach.

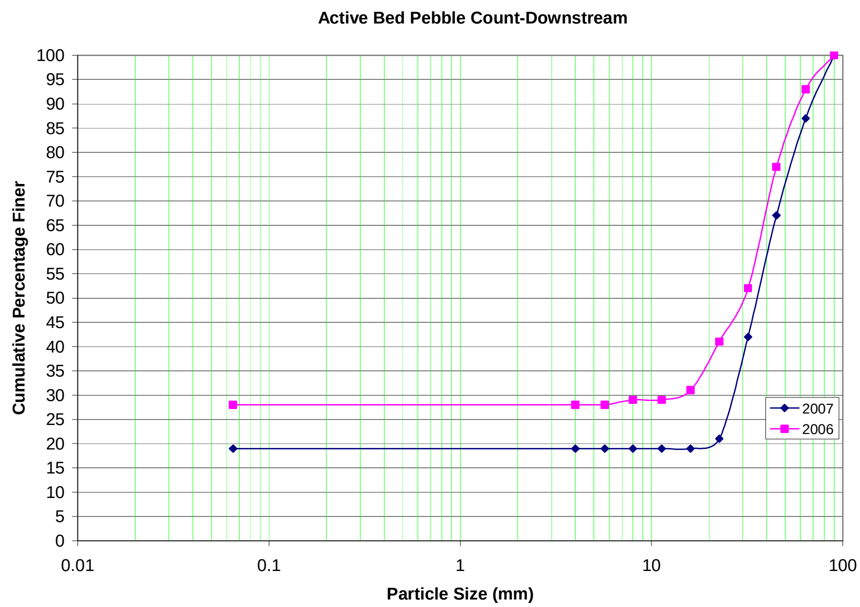


Figure B-20. Particle size distribution at cross section transect 6, Seven Mile Creek reach.

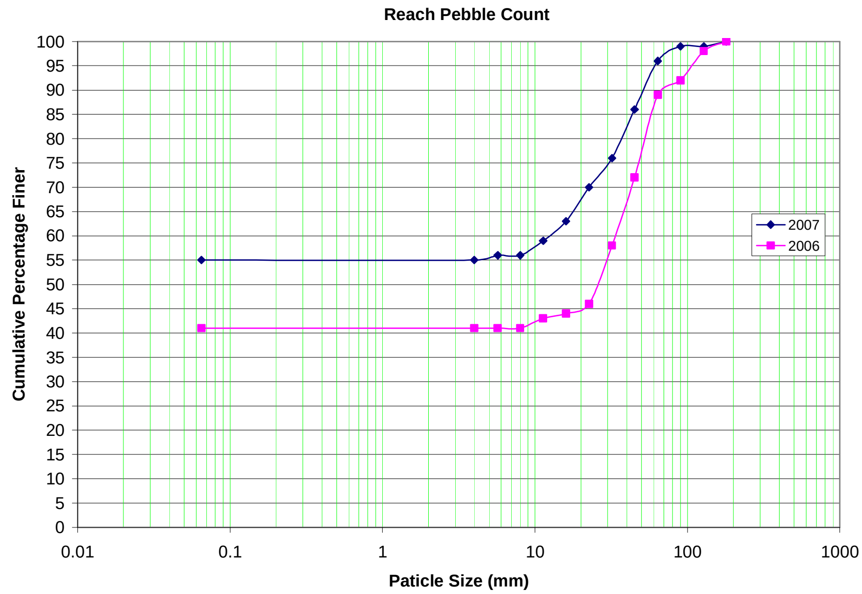


Figure B-21. Particle size distribution along Seven Mile Creek reach.

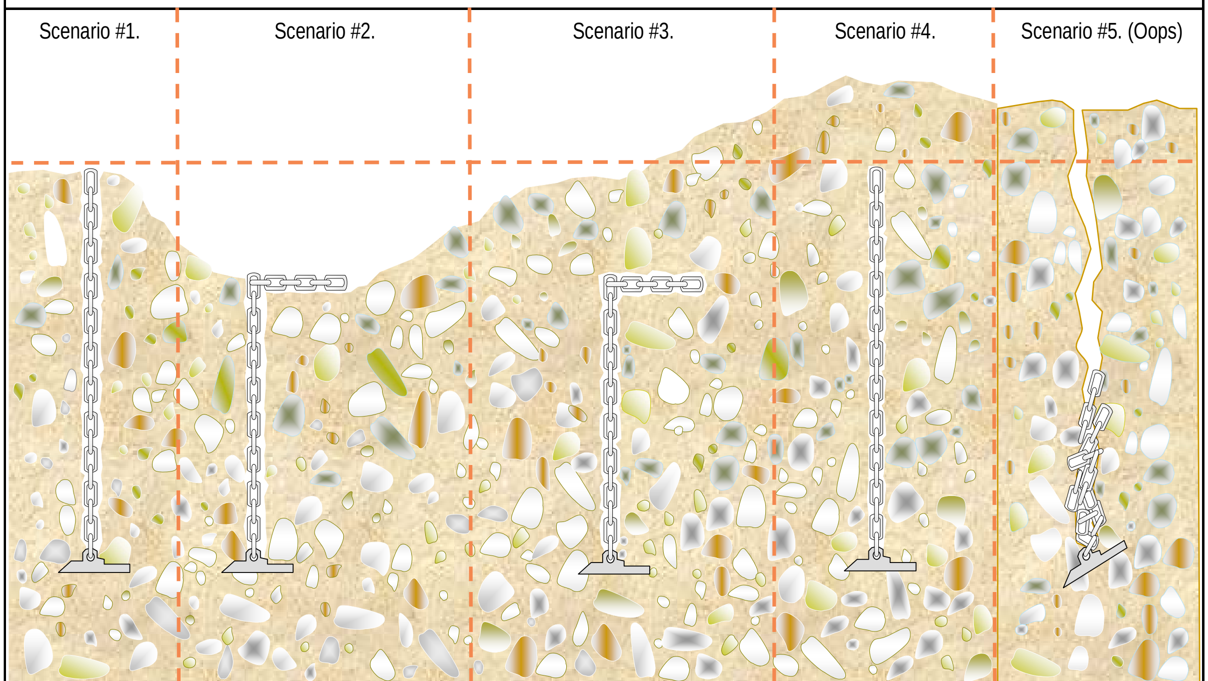
Scour Chains Data

Table B-1. Scour chain data, Seven Mile Creek.

Stream name: **Seven Mile Creek** Location: **Fort Riley, Kansas**

Observers: Stream Type: **G6c** Valley Type: **VIII** Date: **06/2007**

		Installation Data (1st Year)				Recovery Data (2nd Year)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1	**0+18.5**	**98.71**	**33**	**28**	**1**	**0**	**98.69**	**-0.02**	**40**	**30**
Riffle	Chain #2	**0+12**	**97.89**	**46**	**43**	**1**	**0**	**97.85**	**-0.04**	**67**	**59**
Glide	Chain #3										
Glide	Chain #4										



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

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

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

Repeat Survey of Bank Profiles

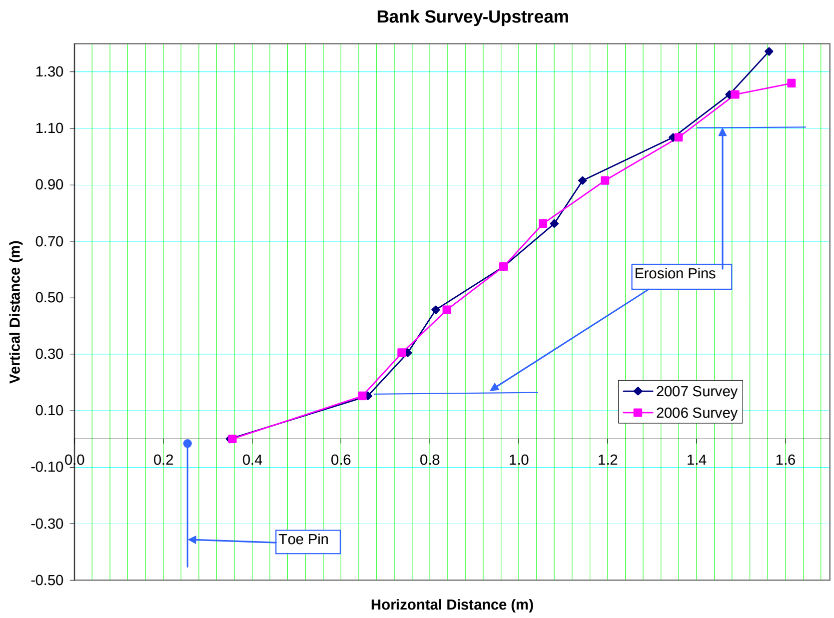


Figure B-22. A measure of bank migration rate at bank transect 1, Seven Mile Creek.

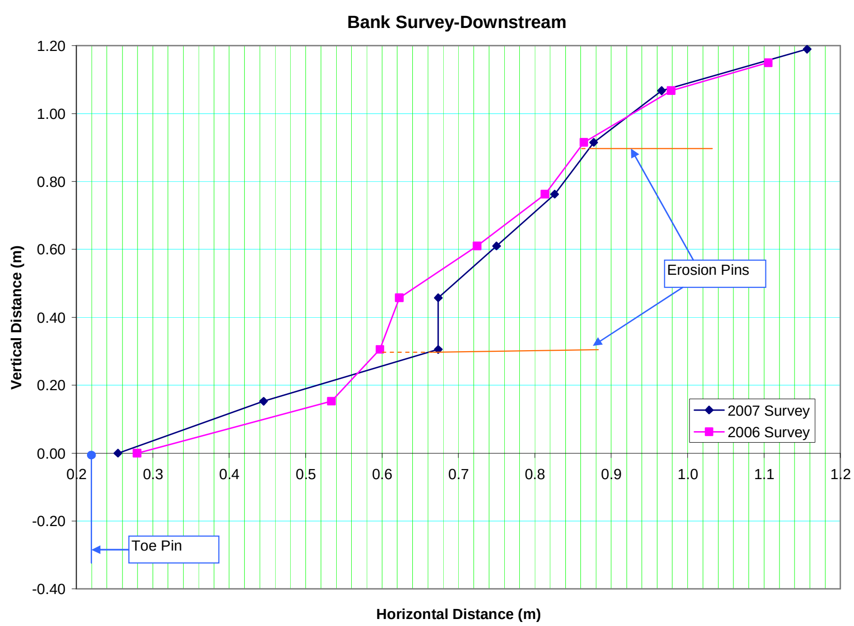


Figure B-23. A measure of bank migration rate at bank transect 2, Seven Mile Creek.

Calculation of BEHI and NBS

Table B-2. Calculation of BEHI variables and overall BEHI rating at bank transect 1, Seven Mile Creek.

Stream: **Seven Mile Creek** Location: **Fort Riley, Kansas**

Station: **Bank Transect 1** Observers:

Date: **06/2007** Stream Type: **G6c** Valley Type: **II**

Variable	Inputs	Calculation	Value	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) = 4.13 **(A)**; **Bankfull Height** (ft) = 3 **(B)**	(A) / (B) =	1.38 **(C)**	**5.5**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) = 4 **(D)**; **Study Bank Height** (ft) = 4.13 **(A)**	(D) / (A) =	0.97 **(E)**	**1.4**
Weighted Root Density (G)	**Root Density** as **%** = 15% **(F)**	(F) × (E) =	14.3 **(G)**	**7.7**
Bank Angle (H)	**Bank Angle** as *Degrees* =		45 **(H)**	**3.1**
Surface Protection (I)	**Surface Protection** as **%** =		15% **(I)**	**7.9**

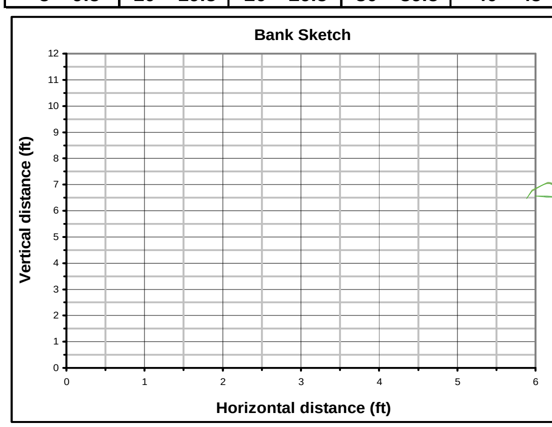
Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large
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** / **25.6**



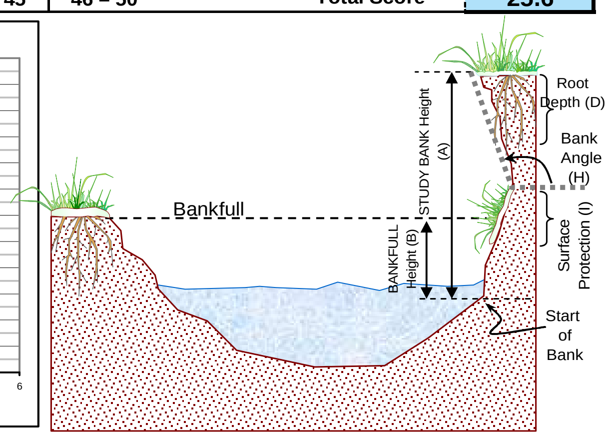


Table B-3. Calculation of NBS variables and overall NBS rating at bank transect 1, Seven Mile Creek.

Estimating Near-Bank Stress (NBS)

Stream: **Seven Mile Creek** Location: **Fort Riley, Kansas**

Station: **Bank Transect 1** Stream Type: **G6c** Valley Type: **II**

Observers: Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

Level I

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

Level II

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

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.0056	**0.0038**	**1.47**	**Extreme**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.0056	**0.0052**	**1.08**	**Extreme**

Dominant Near-Bank Stress
Moderate

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	3.00	**1.68**	**1.79**	**Moderate**

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

Level IV

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

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

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

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

Table B-4. Calculation of BEHI variables and overall BEHI rating at bank transect 2, Seven Mile Creek.

Stream: **Seven Mile Creek** Location: **Fort Riley, Kansas**

Station: **Bank Transect 2** Observers:

Date: **06/2007** Stream Type: **G6c** Valley Type:

Variable	Input 1		Input 2		Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) =	3.77 (A)	Bankfull Height (ft) =	3 (B)	(A) / (B) =	1.26 (C)	5.0
Root Depth / Study Bank Height (E)	Root Depth (ft) =	1 (D)	Study Bank Height (ft) =	3.77 (A)	(D) / (A) =	0.27 (E)	7.2
Weighted Root Density (G)			Root Density as % =	15% (F)	(F) × (E) =	3.98 (G)	10.0
Bank Angle (H)					Bank Angle as *Degrees* =	50 (H)	3.0
Surface Protection (I)					Surface Protection as % =	10% (I)	9.0

Bank Material Adjustment:

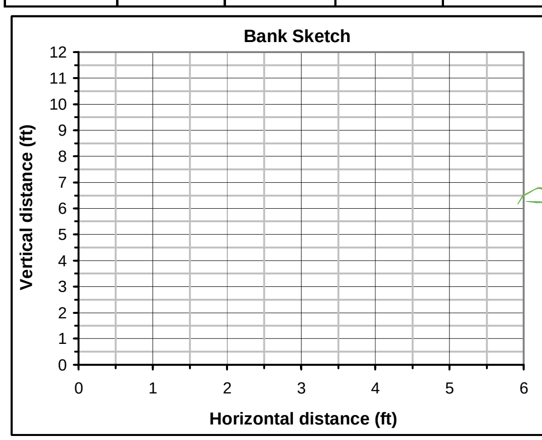
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: 0.0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0.0

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

Adjective Rating and Total Score: **High** — **34.2**



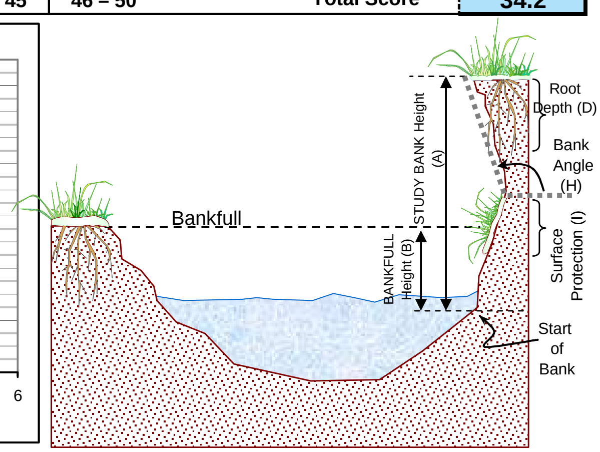


Table B-5. Calculation of NBS variables and overall NBS rating at bank transect 2, Seven Mile Creek.

Estimating Near-Bank Stress (NBS)

Stream: **Seven Mile Creek**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 2**	Stream Type: **G6c**	Valley Type: **II**
Observers:		Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

Level I

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

Level II

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

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.0025**	**0.0038**	**0.66**	**High**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.0025**	**0.0047**	**0.53**	**Low**

Dominant Near-Bank Stress
High

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**3.00**	**1.68**	**1.79**	**Moderate**

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

Level IV

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

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

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

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

Geographical Position System Coordinates

Table B-6. GPS coordinates taken at Seven Mile Creek.

Feature	N (m)	E (m)
Head of Reach	4340650	688259
Cross Section 0- Left Pin	4340633	688264
Cross Section 0-Right Pin	4340621	688271
Cross Section 1- Left Pin	4340649	688283
Cross Section 1- Right Pin	4340632	688284
Cross Section 2- Left Pin	4340590	688312
Cross Section 2- Right Pin	4340584	688308
Cross Section 3- Left Pin	4340549	688335
Cross Section 3- Right Pin	4340550	688339
Cross Section 4- Left Pin	4340585	688377
Cross Section 4- Right Pin	4340579	688370
Cross Section 5- Left Pin	4340590	688388
Cross Section 5- Right Pin	4340582	688383
Cross Section 6- Left Pin	4340585	688398
Cross Section 6- Right Pin	4340577	688392
End of Reach	4340580	688396
Stream Crossing	434055	688320

GPS measurement grid is Universal Transverse Mercator (UTM) and map datum is North American Datum 83 (NAD 83).

Appendix C - Silver Creek

Photographs

Figure C-1. Cross section transect 1 (pool), view from left bank to right bank at Silver Creek.

Figure C-2. Cross section transect 1 (pool) at Silver Creek, upstream view.

Figure C-3. Cross section transect 1 (pool) at Silver Creek, downstream stream view.

Figure C-4. Cross section transect 2 (riffle), view from left bank to right bank at Silver Creek.

Figure C-5. Cross section transect 2 (riffle) at Silver Creek, upstream view.

Figure C-6. Cross section transect 2 (riffle) at Silver Creek, downstream stream view.

Changes in Channel Geometry

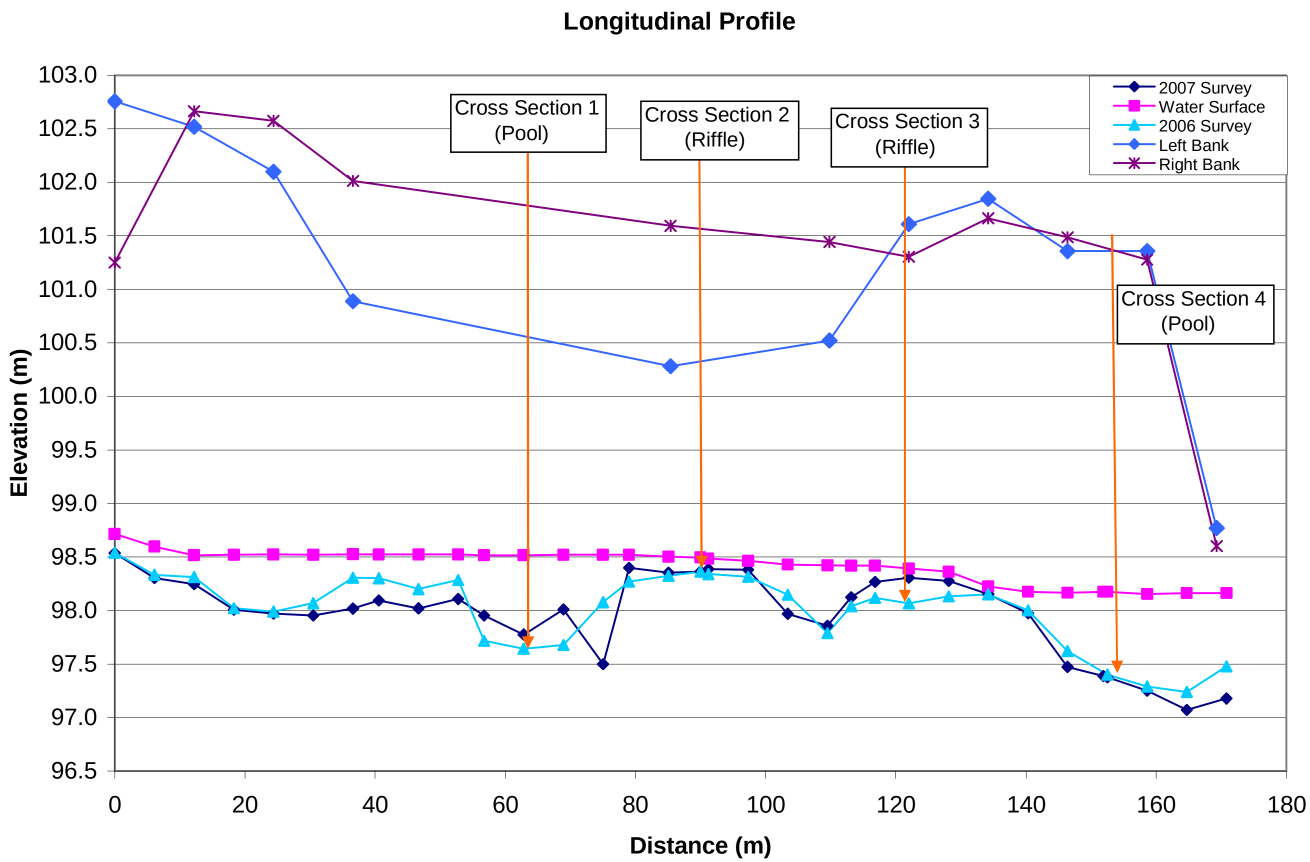


Figure C-7. Longitudinal profile along Silver Creek.

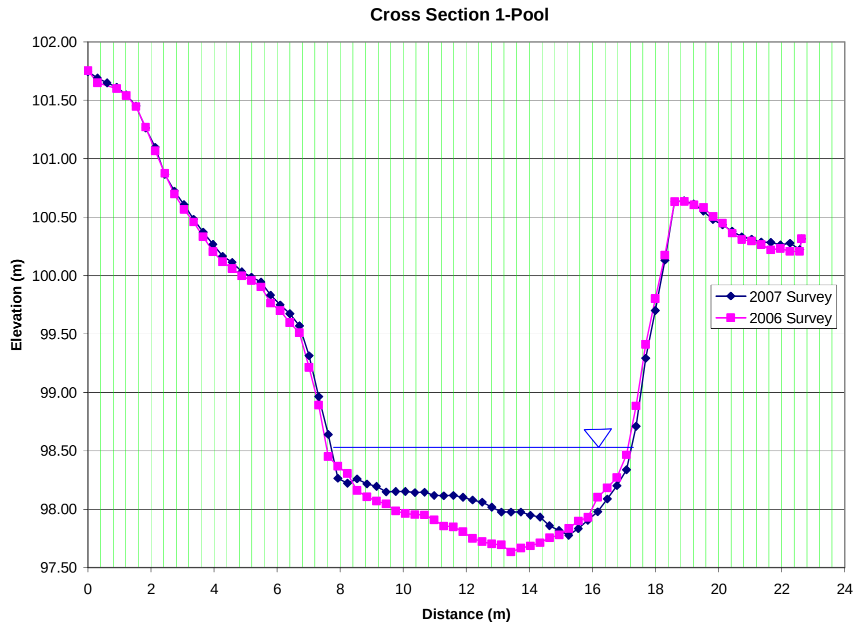


Figure C-8. Repeat survey of cross section transect 1 at Silver Creek.

Figure C-9. Repeat survey of cross section transect 2 at Silver Creek.

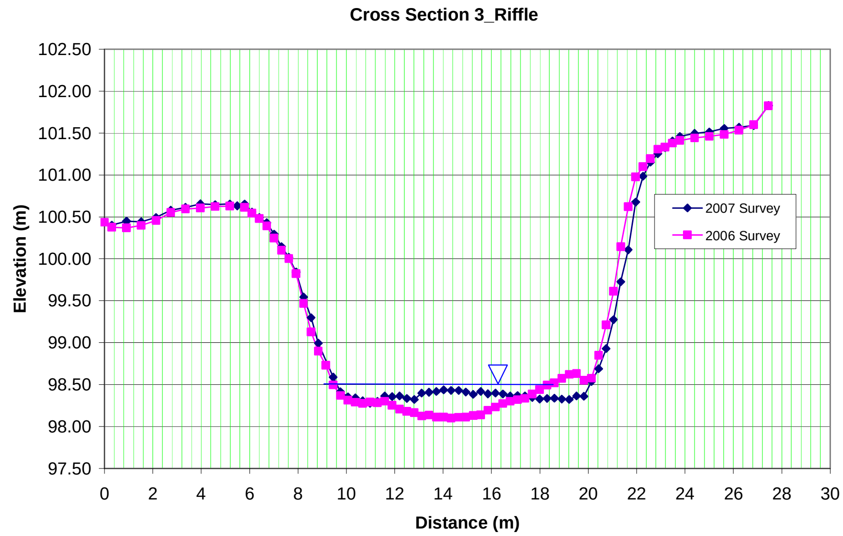


Figure C-10. Repeat survey of cross section transect 3 at Silver Creek.

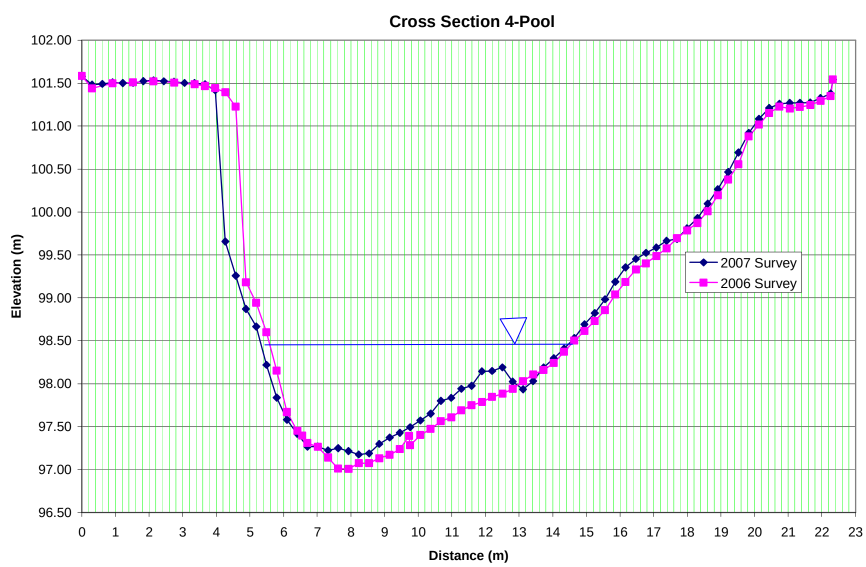


Figure C-11. Repeat survey of cross section transect 4 at Silver Creek.

Bed Material Characterization

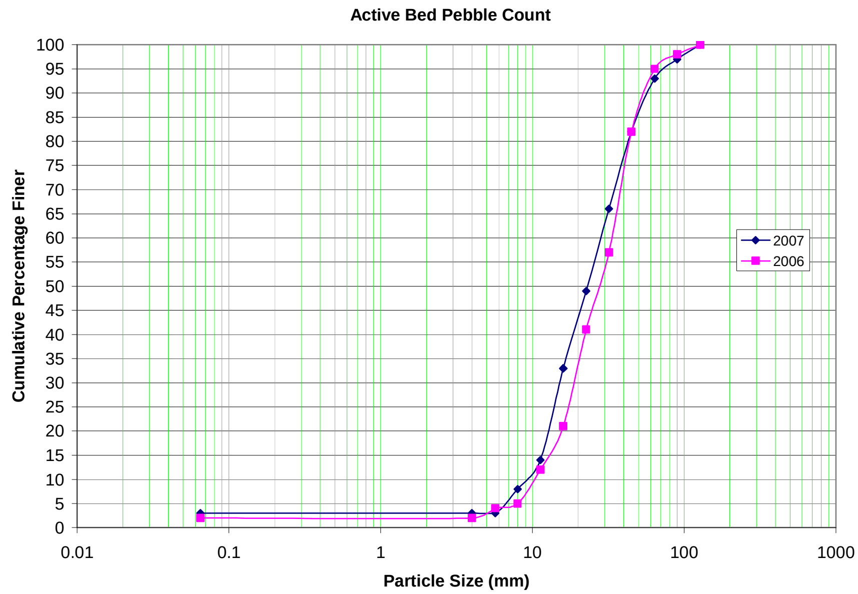


Figure C-12. Particle size distribution at cross section transect 2, Silver Creek reach.

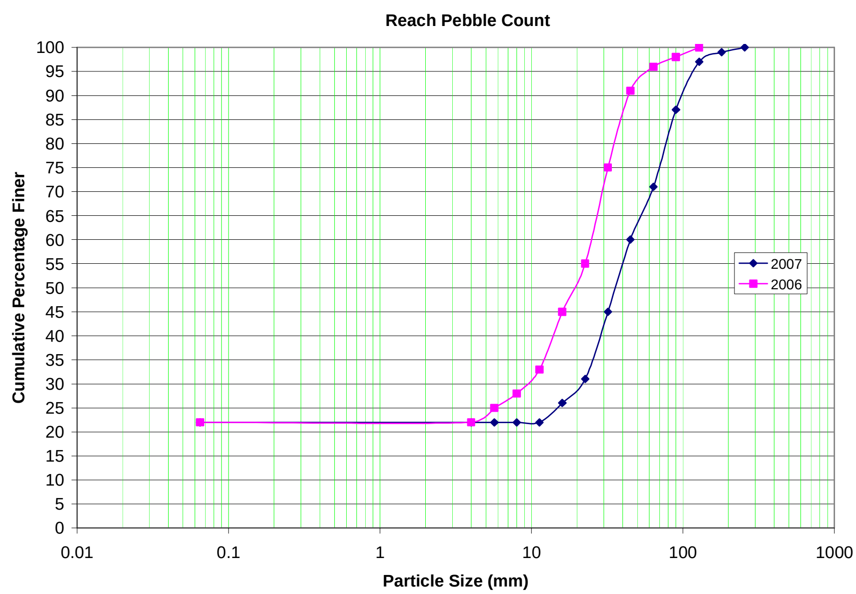


Figure C-13. Particle size distribution along Silver Creek reach.

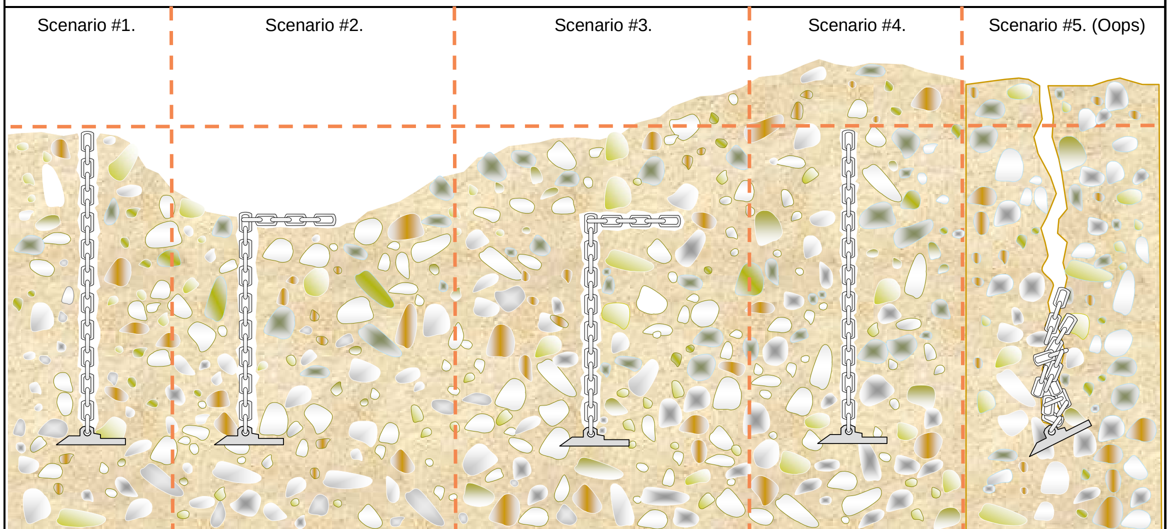
Scour Chains Data

Table C-1. Scour chains data, Silver Creek.

Stream name: **Silver Creek** Location: **Keats, Kansas**

Observers: Stream Type: **F4** Valley Type: **VIII** Date: **06/2007**

		Installation Data (1st Year)				Recovery Data (2nd Year)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2^{nd} Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2^{nd} Largest (mm)
Riffle	Chain #1	**0+30**	**94.67**	**79**	**57**	**3**	**0.5**	**94.83**	**0.16**	**64**	**44**
	Chain #2	**0+48.5**	**94.79**	**125**	**70**	**3**	**0.6**	**95.13**	**0.34**	**120**	**70**
Glide	Chain #3										
	Chain #4										



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

Repeat Survey of Bank Profiles

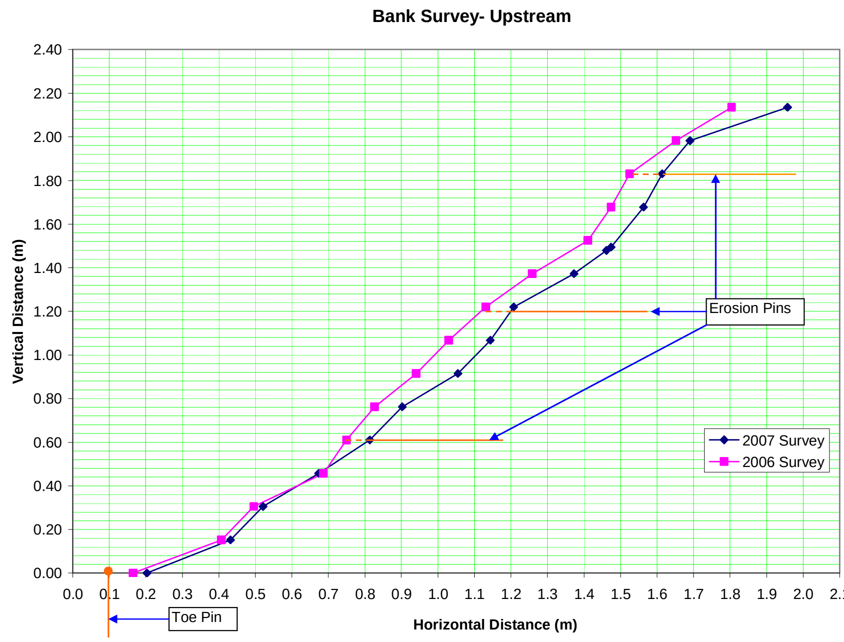


Figure C-14. A measure of bank migration rate at bank transect 1, Silver Creek.

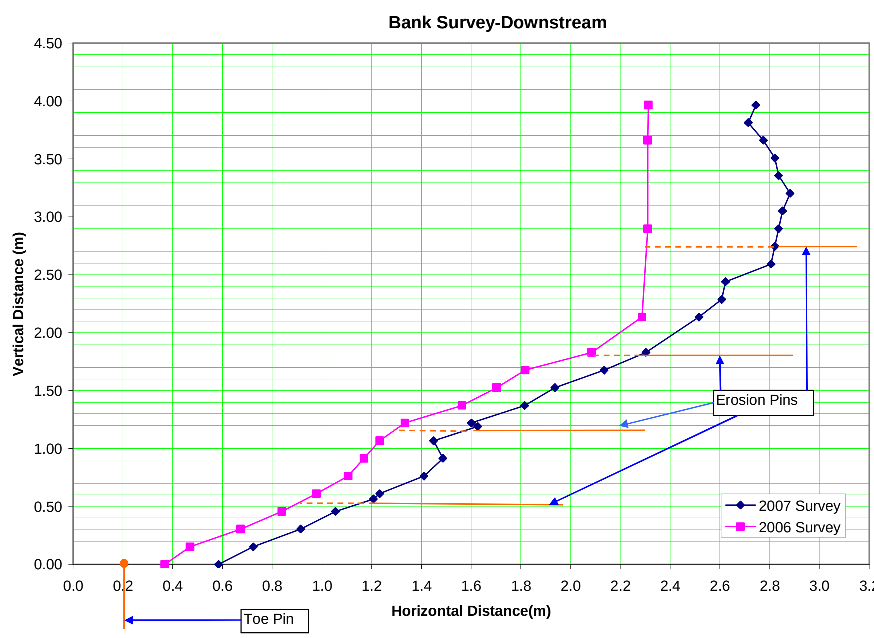


Figure C-15. A measure of bank migration rate at bank transect 2, Silver Creek.

Calculation of BEHI and NBS

Table C-2. Calculation of BEHI variables and overall BEHI rating at bank transect 1, Silver Creek.

Stream: **Silver Creek**		Location: **Keats, Kansas**	
Station: **Bank Transect 1**		Observers:	
Date: **06/2007**	Stream Type: **F4**	Valley Type: **VIII**	

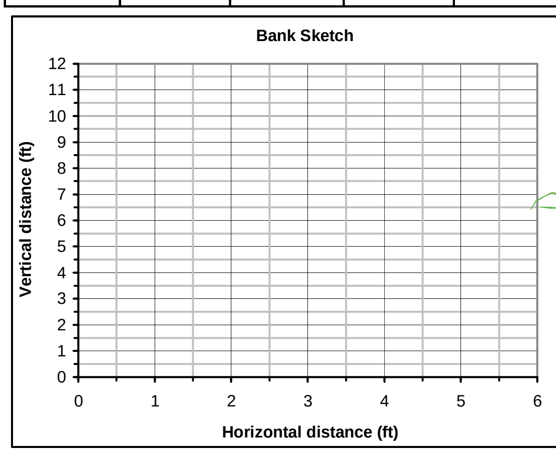
Variable	Input 1	Value	Input 2	Value	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) =	7.5 **(A)**	**Bankfull Height** (ft) =	4 **(B)**	(A) / (B) =	1.88 **(C)**	**7.7**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	6.5 **(D)**	**Study Bank Height** (ft) =	7.5 **(A)**	(D) / (A) =	0.87 **(E)**	**2.2**
Weighted Root Density (G)			**Root Density** as **%** =	10% **(F)**	(F) × (E) =	8.67 **(G)**	**8.5**
Bank Angle (H)					**Bank Angle** as *Degrees* =	45 **(H)**	**3.2**
Surface Protection (I)					**Surface Protection** as **%** =	15% **(I)**	**7.9**

Bank Material Adjustment:
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large
- **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** / **29.5**



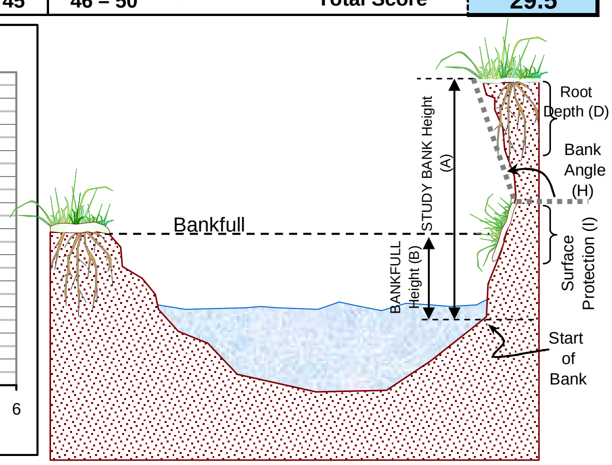


Table C-3. Calculation of NBS variables and overall NBS rating at bank transect 1, Silver Creek.

Estimating Near-Bank Stress (NBS)		
Stream: **Silver Creek**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 1**	Stream Type: **F4**	Valley Type: **VIII**
Observers:		Date: **06/2006**

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

Level I

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

Level II

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

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.00076**	**0.0027**	**0.28**	**Low**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.00076**	**0.00062**	**1.23**	**Low**

Dominant Near-Bank Stress
Moderate

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**4.00**	**2.58**	**1.55**	**Moderate**

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

Level IV

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

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

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

Table C-4. Calculation of BEHI variables and overall BEHI rating at bank transect 2, Silver Creek.

Stream: **Silver Creek**		Location: **Keats, Kansas**	
Station: **Bank Transect 2**		Observers:	
Date: **06/2007**	Stream Type: **F4**	Valley Type: **VIII**	

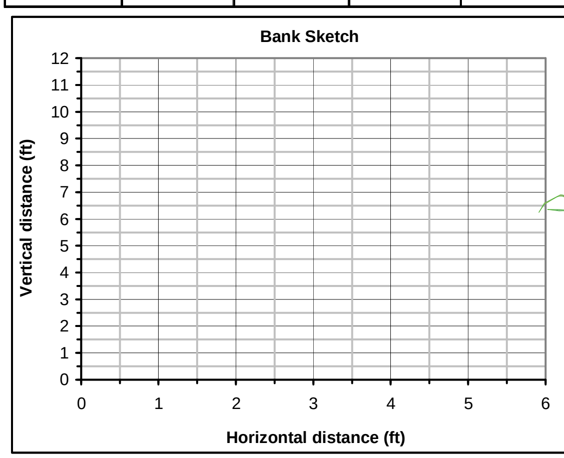
Variable	Input 1	Input 2	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 13 (A)	Bankfull Height (ft) = 5 (B)	(A) / (B) =	2.6 (C)	8.8
Root Depth / Study Bank Height (E)	Root Depth (ft) = 7 (D)	Study Bank Height (ft) = 13 (A)	(D) / (A) =	0.54 (E)	3.8
Weighted Root Density (G)		Root Density as % = 25% (F)	(F) × (E) =	13.46 (G)	7.8
Bank Angle (H)			Bank Angle as *Degrees* =	45 (H)	3.2
Surface Protection (I)			Surface Protection as % =	20% (I)	7.1

Bank Material Adjustment:
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large
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: 0
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	**High** 30.7



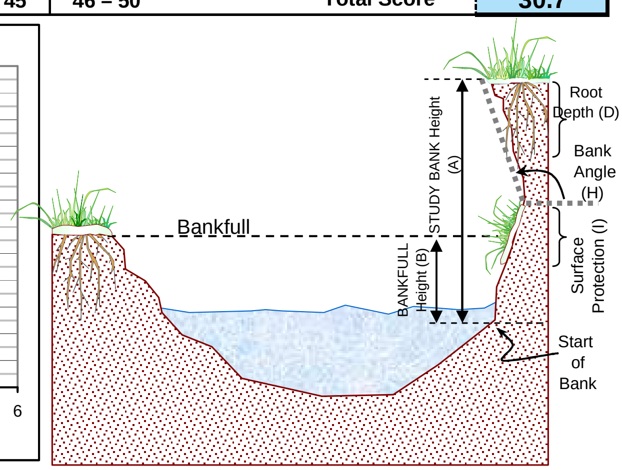


Table C-5. Calculation of NBS variables and overall NBS rating at bank transect 2, Silver Creek.

Estimating Near-Bank Stress (NBS)

Stream: **Silver Creek** Location: **Fort Riley, Kansas**

Station: **Bank Transect 2** Stream Type: **F4** Valley Type: **VIII**

Observers: Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

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

Level II

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

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.0183**	**0.0027**	**6.78**	**Extreme**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.0183**	**0.0052**	**3.52**	**Extreme**

Dominant Near-Bank Stress
Extreme

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**5.00**	**2.58**	**1.94**	**High**

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

Level IV

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

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

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

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

Geographical Position System Coordinates

Table C-6. GPS coordinates taken at Silver Creek.

Feature	Northing (m)	Easting (m)
Bench Mark 1	4344202	696759
Head of Reach	4344148	696711
Cross Section 1- Left Pin	4344087	696731
Cross Section 1- Right Pin	4344089	696716
Cross Section 2- Left Pin	4344069	696732
Cross Section 2- Right Pin	4344065	696717
Cross Section 2- Right Pin(B)	4344061	696721
Cross Section 3- Left Pin	4344052	696748
Cross Section 3- Left Pin(B)	4344047	696754
Cross Section 3- Right Pin	4344038	696731
Cross Section 3- Right Pin(B)	4344041	696722
Cross Section 4- Left Pin	4344018	696759
Cross Section 4- Right Pin	4344012	696737
End of Reach	4343999	696747

GPS measurement grid is Universal Transverse Mercator (UTM) and map datum is North American Datum 83 (NAD 83).

Appendix D - Wind Creek, Upland Reach

Photographs

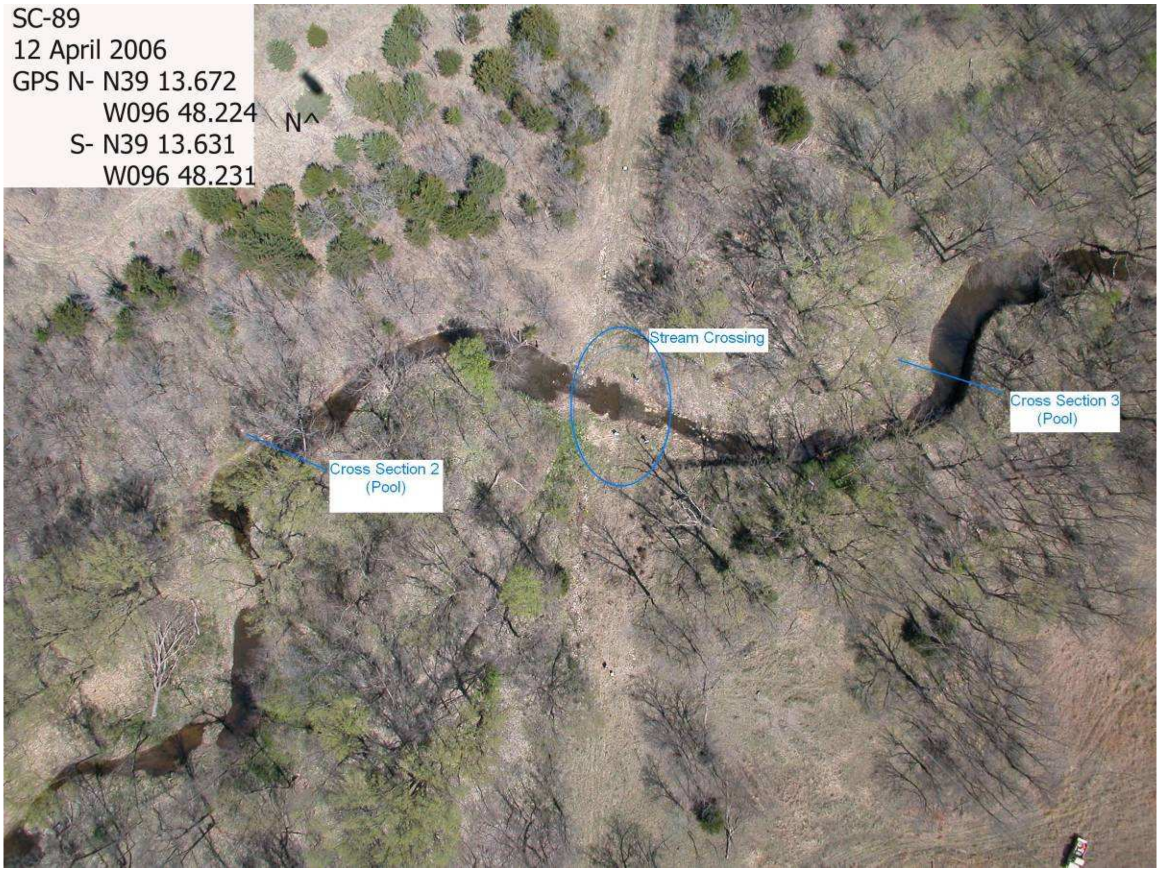


Figure D-1. Wind Creek upland study reach.

Figure D-2. Cross section transect 1 (riffle), view from left bank to right bank at Wind Creek, upland reach.

Figure D-3. Cross section transect 1 (riffle) at Wind Creek upland reach, upstream view.

Figure D-4. Cross section transect 1 (riffle) at Wind Creek upland reach, downstream stream view.

Figure D-5. Cross section transect 2 (pool), view from right bank to left bank at Wind Creek, upland reach.

Figure D-6. Cross section transect 2 (pool) at Wind Creek, upland reach, upstream view.

Figure D-7. Cross section transect 2 (pool) at Wind Creek, upland reach, downstream stream view.

Figure D-8. Abandoned stream crossing at Wind Creek, upland reach, view from left bank to right bank.

Figure D-9. Abandoned stream crossing at Wind Creek upland reach, upstream view.

Figure D-10. Abandoned stream crossing at Wind Creek upland reach, downstream stream view.

Figure D-11. Cross section transect 3 (pool), view from left bank to right bank at Wind Creek, upland reach.

Figure D-12. Cross section transect 3 (pool) at Wind Creek, upland reach, upstream view.

Figure D-13. Cross section transect 3 (pool) at Wind Creek, upland reach, downstream stream view.

Figure D-14. Cross section transect 4 (riffle), view from left bank to right bank at Wind Creek, upland reach.

Figure D-15. Cross section transect 4 (riffle) at Wind Creek, upland reach, upstream view.

Figure D-16. Cross section transect 4 (riffle) at Wind Creek, upland reach, downstream stream view.

Changes in Channel Geometry

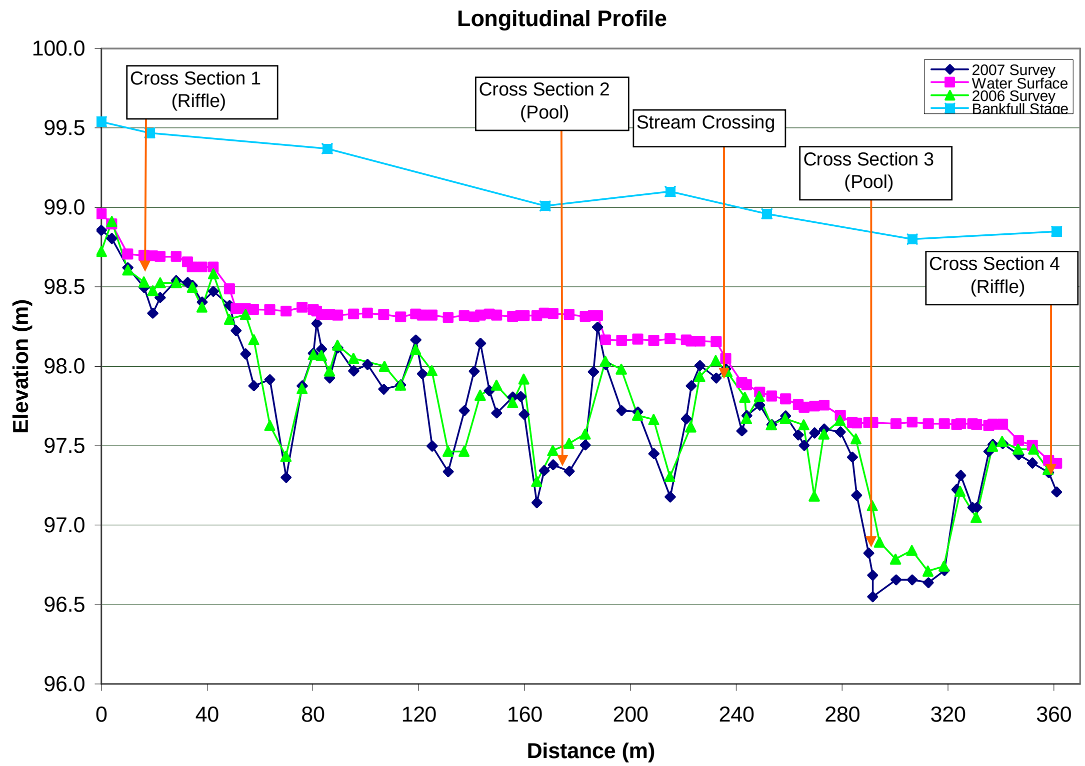


Figure D-17. Longitudinal profile along Wind Creek, upland reach.

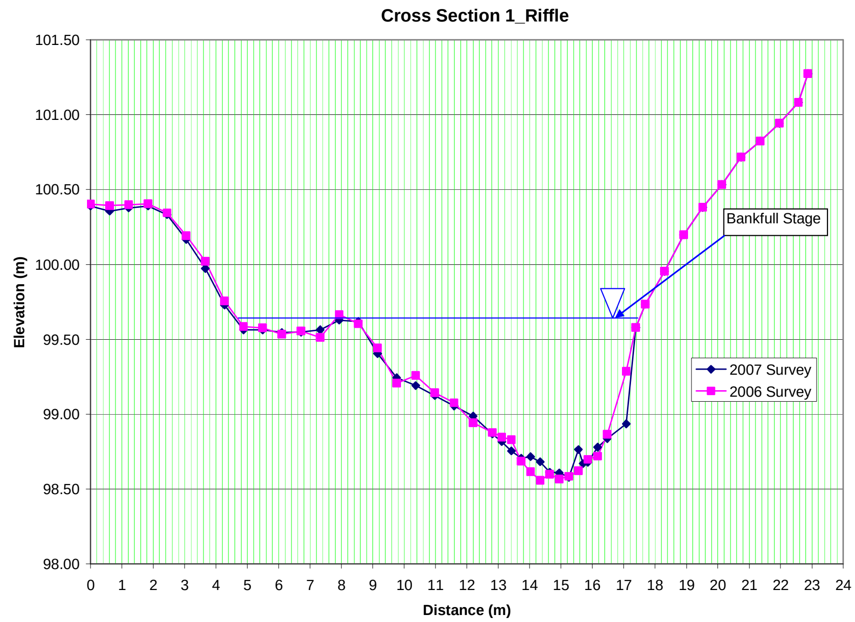


Figure D-18. Repeat survey of cross section transect 1 at Wind Creek, upland reach.

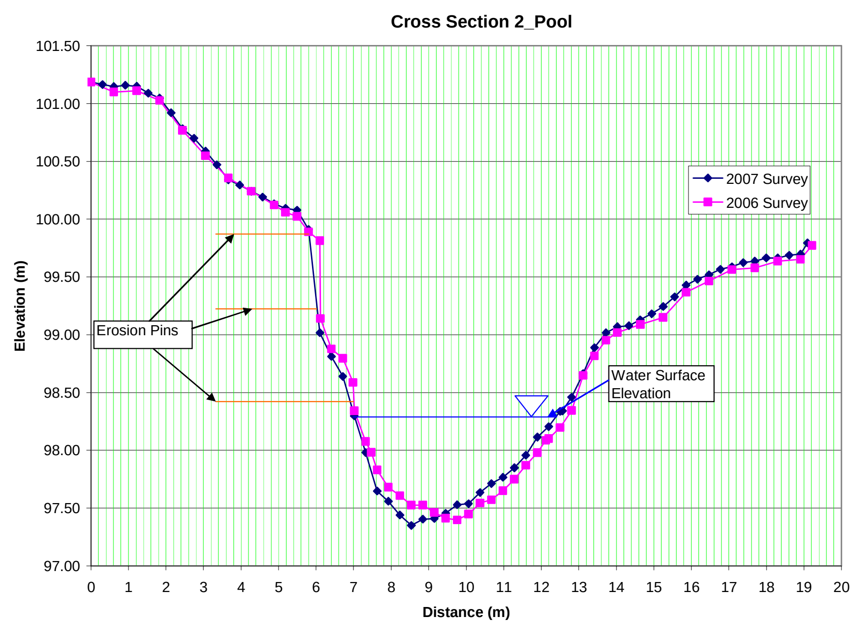


Figure D-19. Repeat survey of cross section transect 2 at Wind Creek, upland reach.

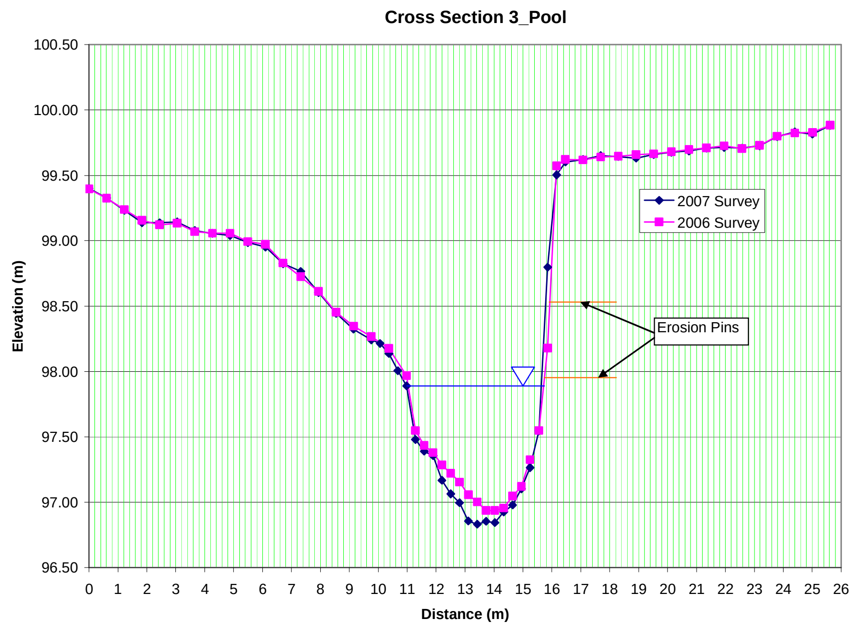


Figure D-20. Repeat survey of cross section transect 3 at Wind Creek upland reach.

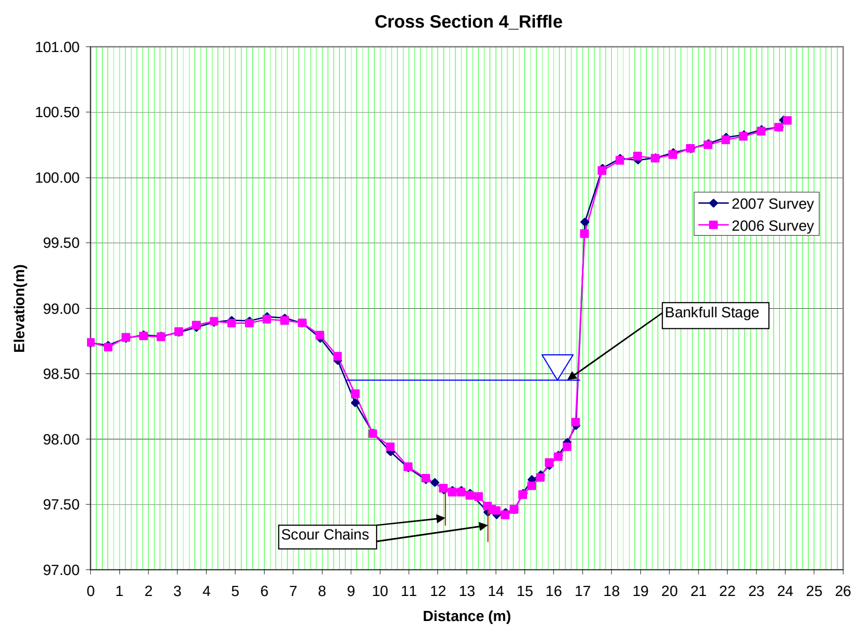


Figure D-21. Repeat survey of cross section transect 4 at Wind Creek upland reach.

Bed Material Characterization

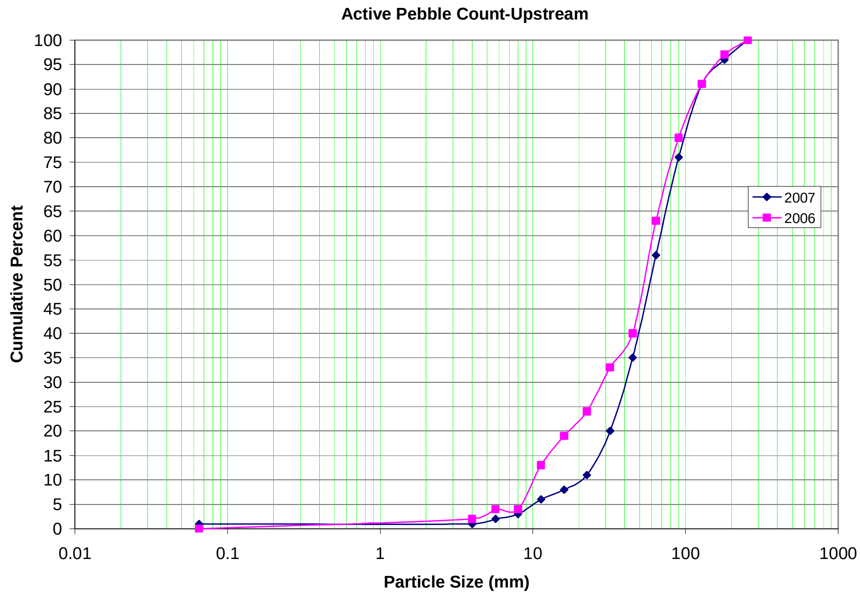


Figure D-22. Particle size distribution at cross section transect 1, Wind Creek upland reach.

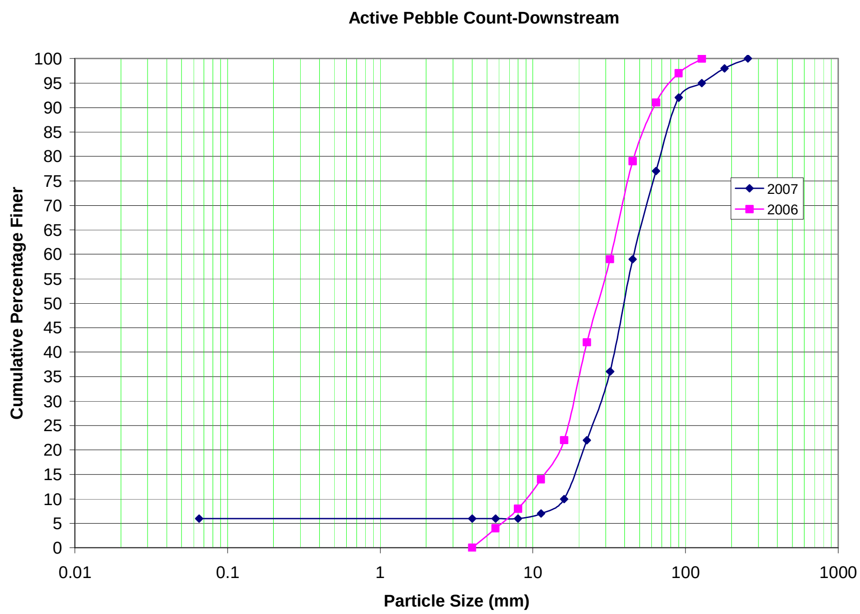


Figure D-23. Particle size distribution at cross section transect 4, Wind Creek upland reach.

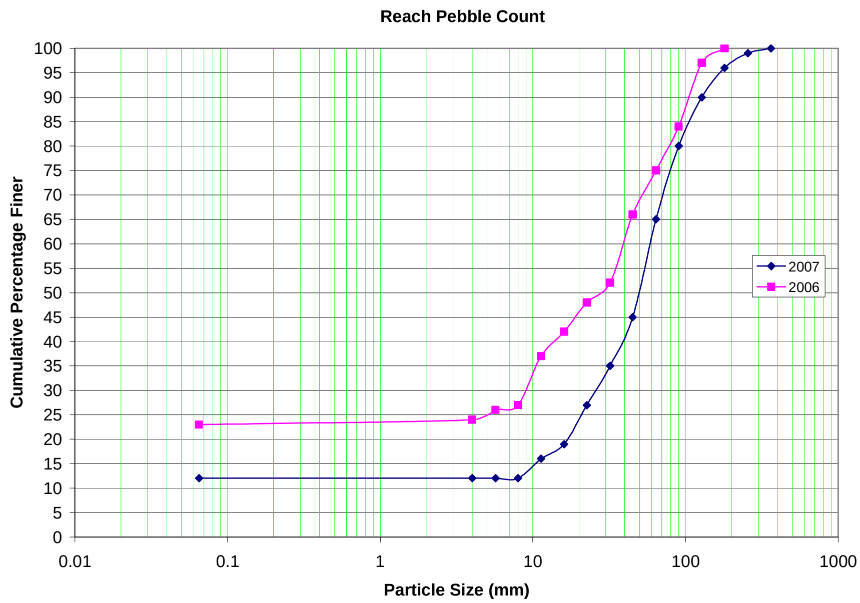


Figure D-24. Particle size distribution along Wind Creek upland reach.

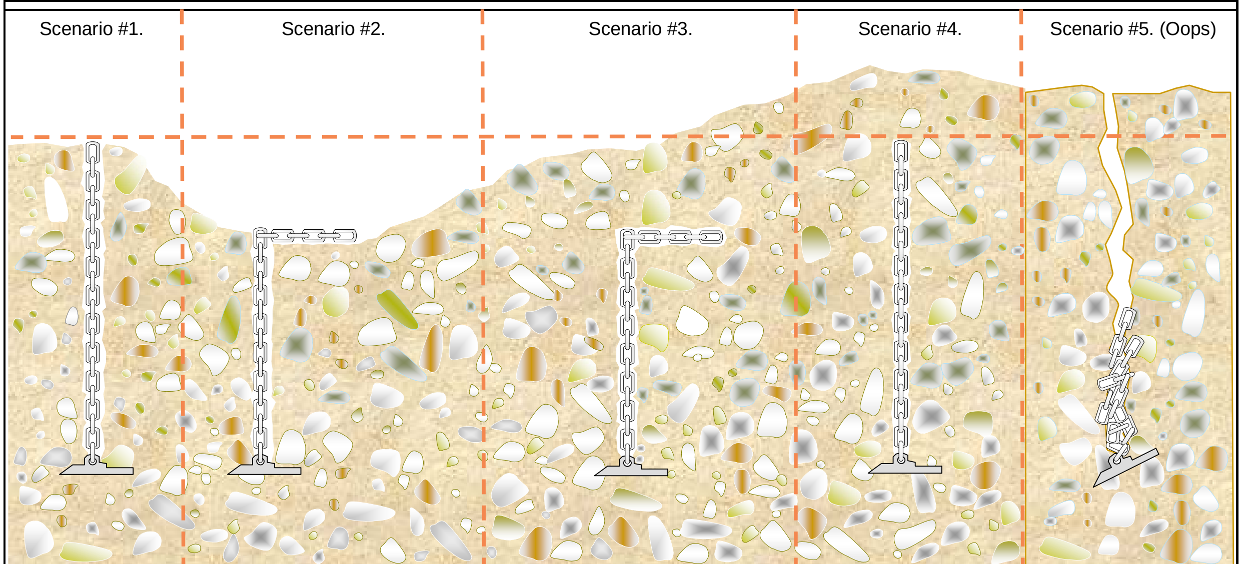
Scour Chains Data

Table D-1. Scour chains data, Wind Creek, upland reach.

Stream name: **Wind Creek, Upland Reach** Location: **Fort Riley, Kansas**

Observers: Stream Type: **C4** Valley Type: **VIII** Date: **06/2007**

		Installation Data (1st Year)				Recovery Data (2nd Year)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1	**0+49**	**95.3**	**120**	**100**	**3**	**1.1**	**95.44**	**0.14**	**87**	**75**
Riffle	Chain #2	**0+47**	**91.53**	**66**	**65**	**1**	**0**	**91.6**	**0.07**	**63**	**50**
Glide	Chain #3										
Glide	Chain #4										



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

Repeat Survey of Bank Profiles

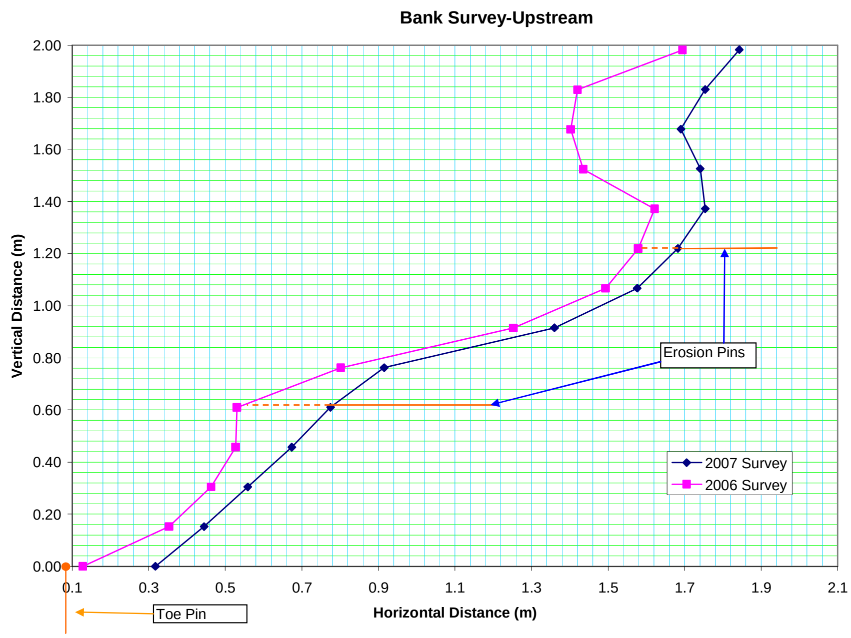


Figure D-25. A measure of bank migration rate at bank transect 1, Wind Creek, upland reach.

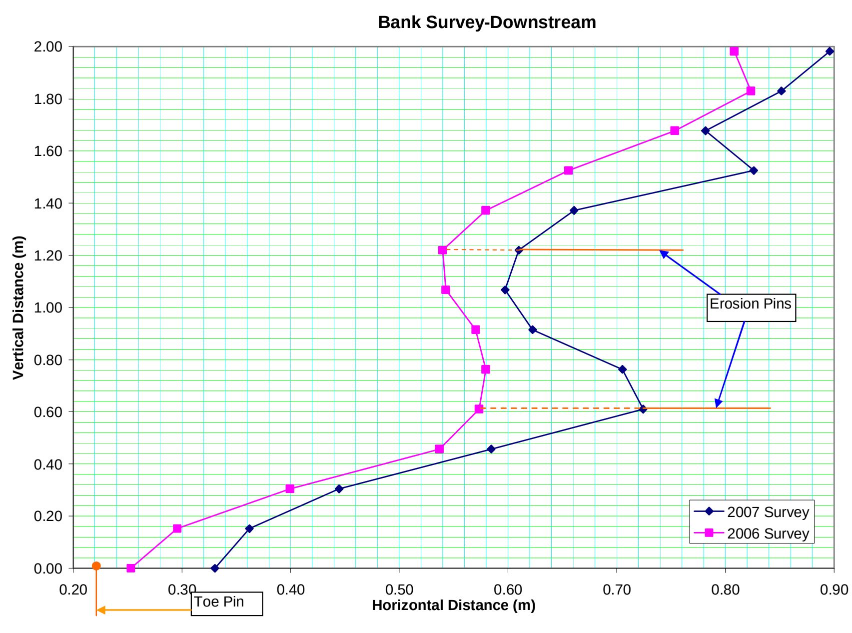


Figure D-26. A measure of bank migration rate at bank transect 2, Wind Creek, upland reach.

Calculation of BEHI and NBS

Table D-2. Calculation of BEHI variables and overall BEHI rating at bank transect 1, Wind Creek, upland reach.

Stream:	**Wind Creek, Upland Reach**	Location:	**Fort Riley, Kansas**
Station:	**Bank Transect 1**	Observers:	
Date:	**06/2007**	Stream Type: **C4**	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) =	7.5 **(A)**	**Bankfull Height** (ft) =	3 **(B)**	(A) / (B) =	2.5 **(C)**	**8.5**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	3 **(D)**	**Study Bank Height** (ft) =	7.5 **(A)**	(D) / (A) =	0.4 **(E)**	**5.0**
Weighted Root Density (G)			**Root Density** as **%** =	15% **(F)**	(F) × (E) =	6 **(G)**	**8.1**
Bank Angle (H)					**Bank Angle** as *Degrees* =	110 **(H)**	**8.5**
Surface Protection (I)					**Surface Protection** as **%** =	10% **(I)**	**9.0**

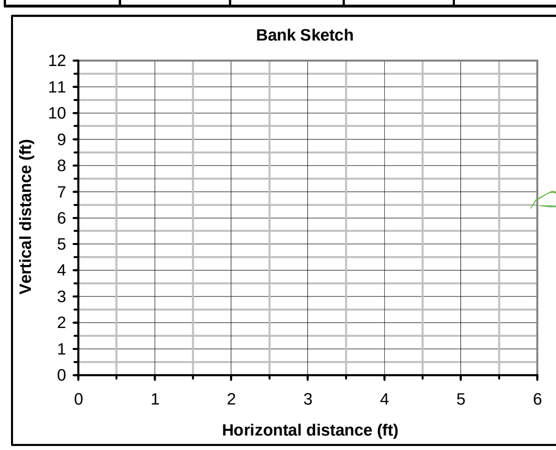
Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large
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** / **39.1**



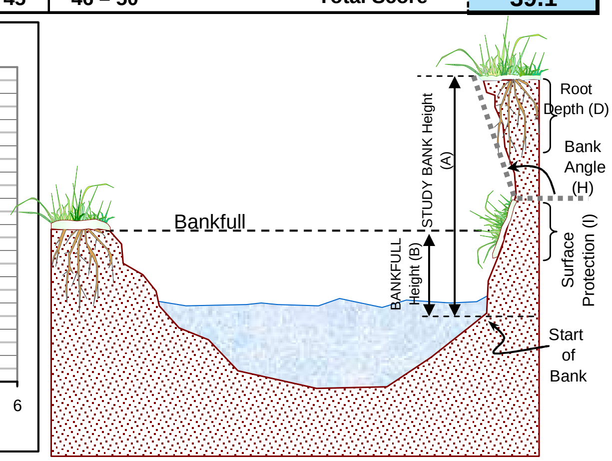


Table D-3. Calculation of NBS variables and overall NBS rating at bank transect 1, Wind Creek, upland reach.

Estimating Near-Bank Stress (NBS)

Stream: **Wind Creek, Upland**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 1**	Stream Type: **C4**	Valley Type: **VIII**
Observers:		Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

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

Level	Method				
Level II	(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	Ratio R_c / W_{bkf}	Near-Bank Stress (NBS)
	(3)	Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)
		0.0036	**0.0043**	**0.84**	**Very High**
	(4)	Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)
		0.0036	**0.0061**	**0.59**	**Low**
Level III	(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
		3.00	**1.65**	**1.82**	**High**

Dominant Near-Bank Stress
Very High

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

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

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

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

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

Table D-4. Calculation of BEHI variables and overall BEHI rating at bank transect 2, Wind Creek, upland reach.

Stream:	**Wind Creek, Upland Reach**	Location:	**Fort Riley, Kansas**
Station:	**Bank Transect 2**	Observers:	
Date:	**06/2007**	Stream Type: **C4**	Valley Type: **VIII**

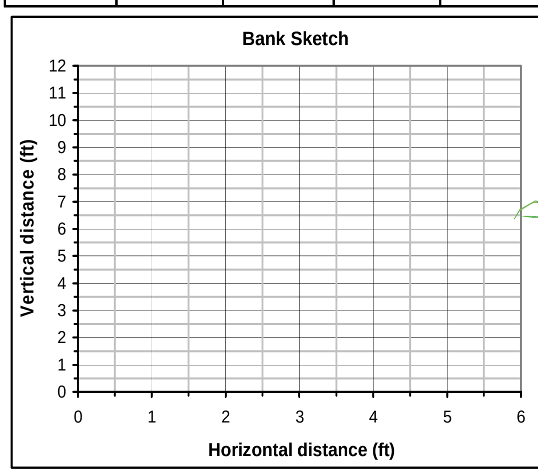
Variable	Input 1	Value	Input 2	Value	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) =	7 **(A)**	**Bankfull Height** (ft) =	3.5 **(B)**	(A) / (B) =	2 **(C)**	**7.9**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	6.5 **(D)**	**Study Bank Height** (ft) =	7 **(A)**	(D) / (A) =	0.93 **(E)**	**1**
Weighted Root Density (G)			**Root Density** as **%** =	10% **(F)**	(F) × (E) =	9.3 **(G)**	**8.5**
Bank Angle (H)					**Bank Angle** as *Degrees* =	90 **(H)**	**7.9**
Surface Protection (I)					**Surface Protection** as **%** =	0% **(I)**	**10**

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large
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** **35.3**



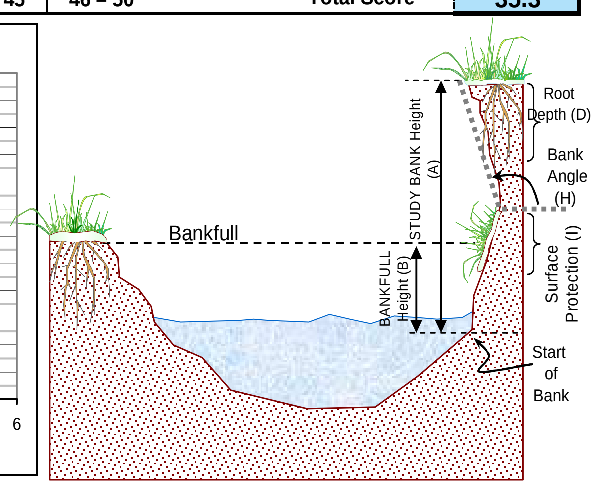


Table D-5. Calculation of NBS variables and overall NBS rating at bank transect 2, Wind Creek, upland reach.

Estimating Near-Bank Stress (NBS)		
Stream: **Wind Creek, Upland**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 2**	Stream Type: **C4**	Valley Type: **VIII**
Observers:		Date: **06/2006**

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

Level	Method				
Level I	(1)	Transverse and/or central bars-short and/or discontinuous...........................NBS = High / Very High			
		Extensive deposition (continuous, cross-channel)..NBS = Extreme			
		Chute cutoffs, down-valley meander migration, converging flow.................................NBS = Extreme			
Level II	(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
	(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
		0.0099	**0.0043**	**2.30**	**Extreme**
	(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
		0.0099	**0.0049**	**2.02**	**Extreme**
Level III	(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
		3.50	**1.65**	**2.12**	**High**

Dominant Near-Bank Stress
Extreme

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

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

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

Overall Near-Bank Stress (NBS) rating	Extreme

Geographical Position System Coordinates

Table D-6. GPS coordinates taken at Wind Creek, upland reach.

Feature	N (m)	E (m)
Bench Mark 1	4344226	689492
Bench Mark at LWSC	4344332	689524
Head of Reach	4344195	689476
Cross Section 1- Left Pin	4344228	689478
Cross Section 1- Right Pin	4344226	689501
Cross Section 2- Left Pin	4344335	689516
Cross Section 2- Right Pin	4344322	689519
Cross Section 3- Left Pin	4344329	689598
Cross Section 3- Right Pin	4344327	689641
Cross Section 4- Left Pin	4344367	689673
Cross Section 4- Right Pin	4344345	689683
End of Reach	4344352	689688

GPS measurement grid is Universal Transverse Mercator (UTM) and map datum is North American Datum 83 (NAD 83).

Appendix E - Wind Creek, Midland Reach

Photographs

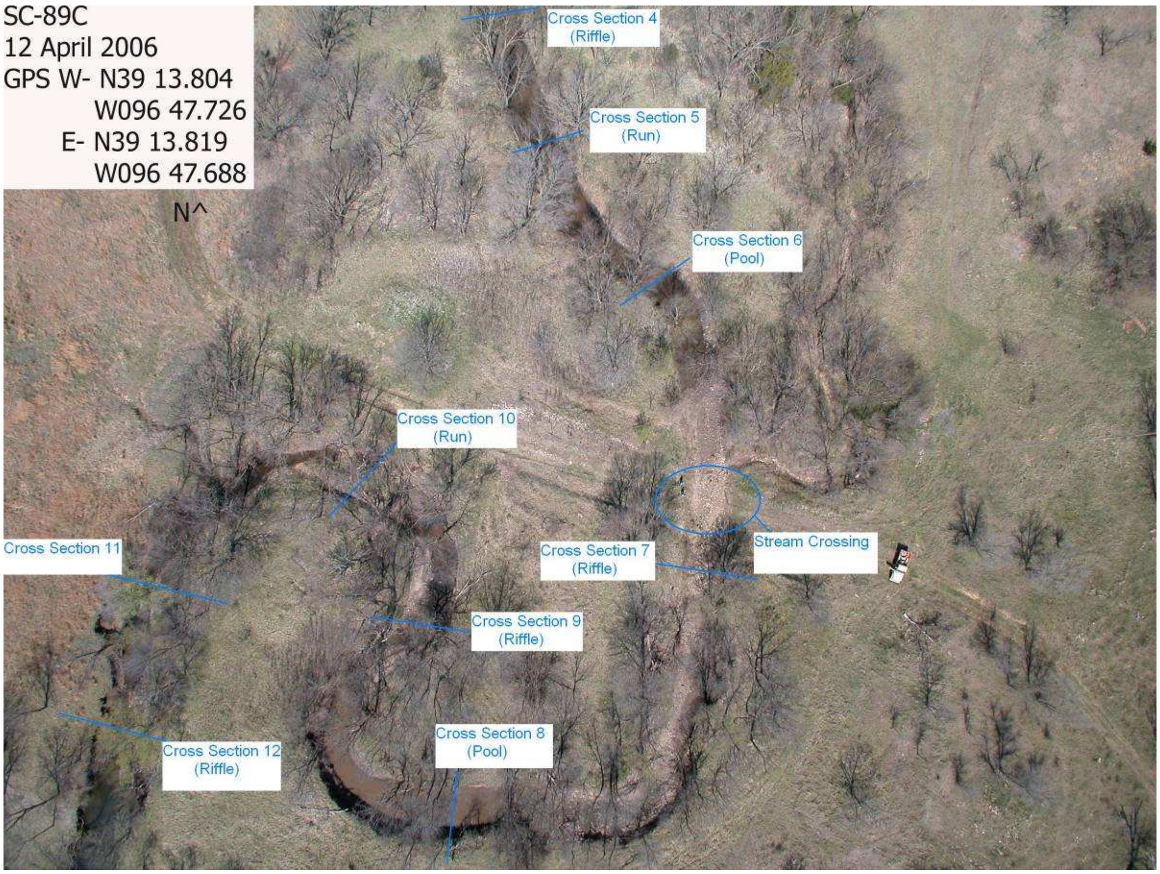


Figure E-1. Wind Creek midland study reach.

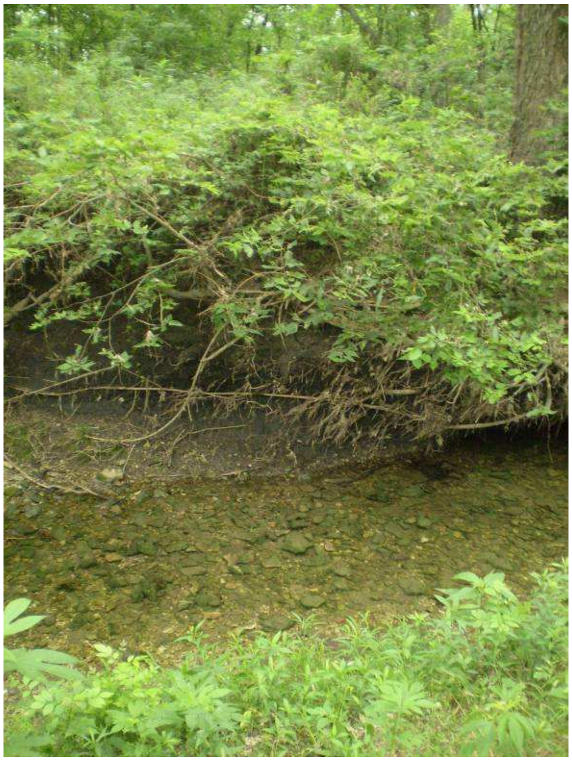


Figure E-2. Cross section transect 1 (riffle), view from left bank to right bank at Wind Creek, midland reach.

Figure E-3. Cross section transect 1 (riffle) at Wind Creek, midland reach, upstream view.

Figure E-4. Cross section transect 1 (riffle) at Wind Creek, midland reach, upstream view.

Figure E-5. Cross section transect 5, view from left bank to right bank at Wind Creek, midland reach.

Figure E-6. Cross section transect 5 at Wind Creek, midland reach, upstream view.

Figure E-7. Cross section transect 5 at Wind Creek, midland reach, downstream view.

Figure E-8. Stream crossing, view from left bank to right bank at Wind Creek, midland reach.

Figure E-9. Stream crossing at Wind Creek, midland reach, upstream view.

Figure E-10. Stream crossing at Wind Creek, midland reach, downstream view.

Figure E-11. Cross section transect 7 (riffle), view from left bank to right bank at Wind Creek, midland reach.

Figure E-12. Cross section transect 4 (pool) at Wind Creek, midland reach, upstream view.

Figure E-13. Cross section transect 7 (riffle) at Wind Creek, midland reach, downstream stream view.

Figure E-14. Cross section transect 8 (pool), view from left bank to right bank at Wind Creek, midland reach.

Figure E-15. Cross section transect 8 (pool) at Wind Creek, midland reach, upstream view.

Figure E-16. Cross section transect 8 (pool) at Wind Creek, midland reach, downstream stream view.

Figure E-17. Cross section transect 9 (riffle), view from left bank to right bank at Wind Creek, midland reach.

Figure E-18. Cross section transect 9 (riffle) at Wind Creek, midland reach, upstream view.

Figure E-19. Cross section transect 9 (riffle) at Wind Creek, midland reach, downstream view.

Figure E-20. Cross section transect 12 (riffle), view from left bank to right bank at Wind Creek, midland reach.

Figure E-21. Cross section transect 12 (riffle) at Wind Creek, midland reach, upstream view.

Figure E-22. Cross section transect 12 (riffle) at Wind Creek, midland reach, downstream view.

Changes in Channel Geometry

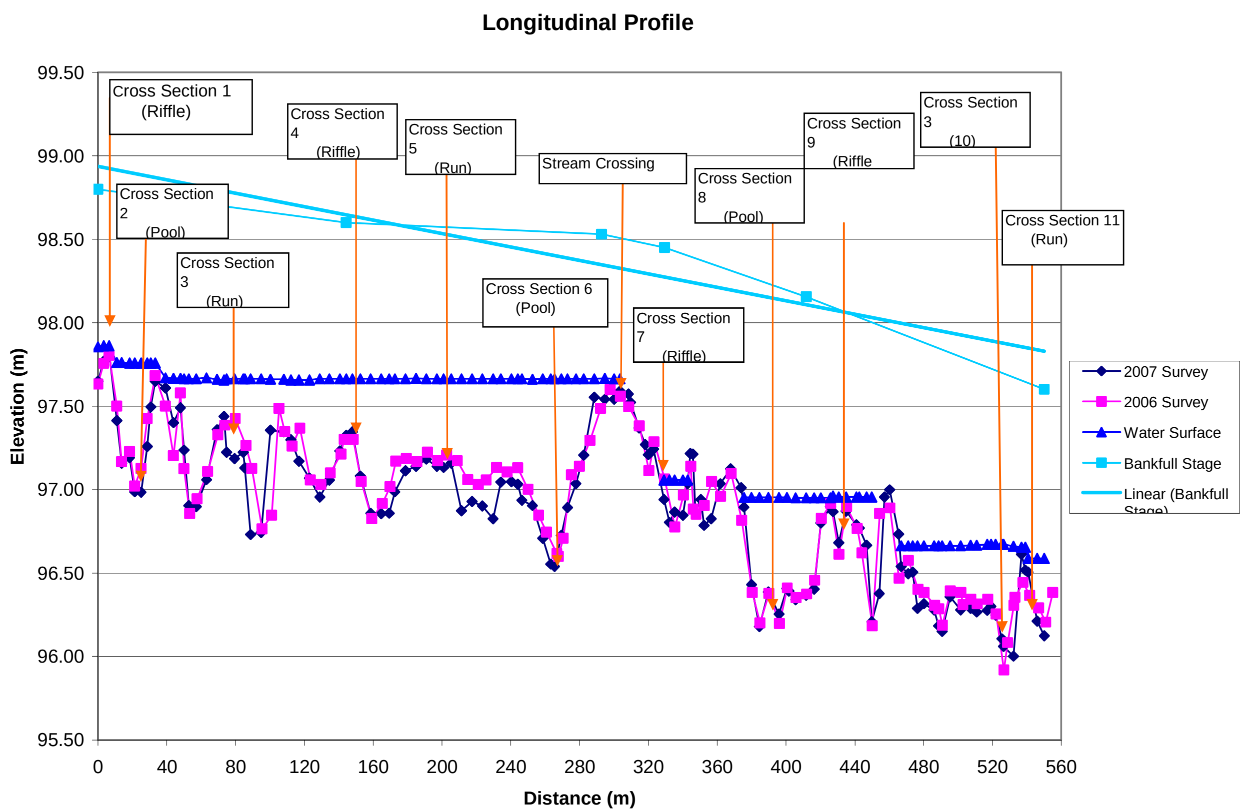


Figure E-23. Longitudinal profile along Wind Creek, midland reach.

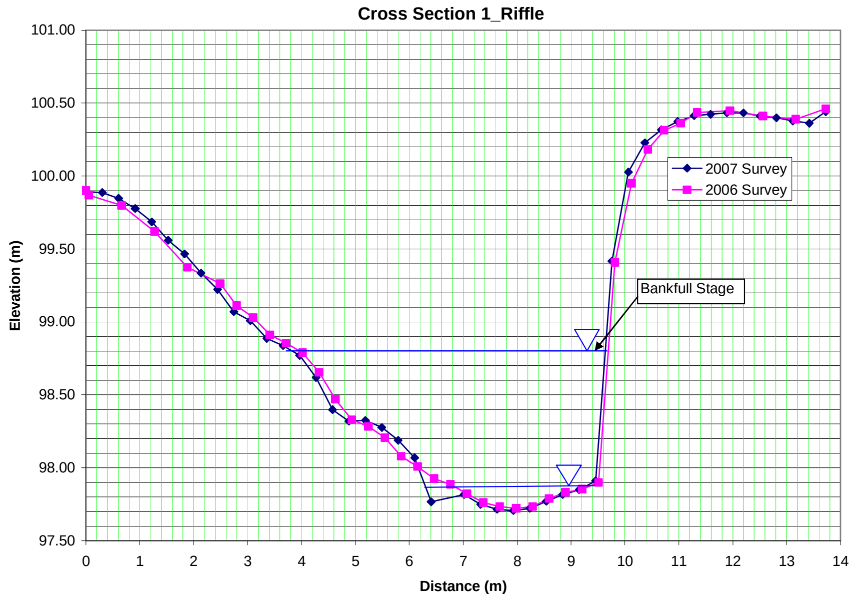


Figure E-24. Repeat survey of cross section transect 1 at Wind Creek, midland reach.

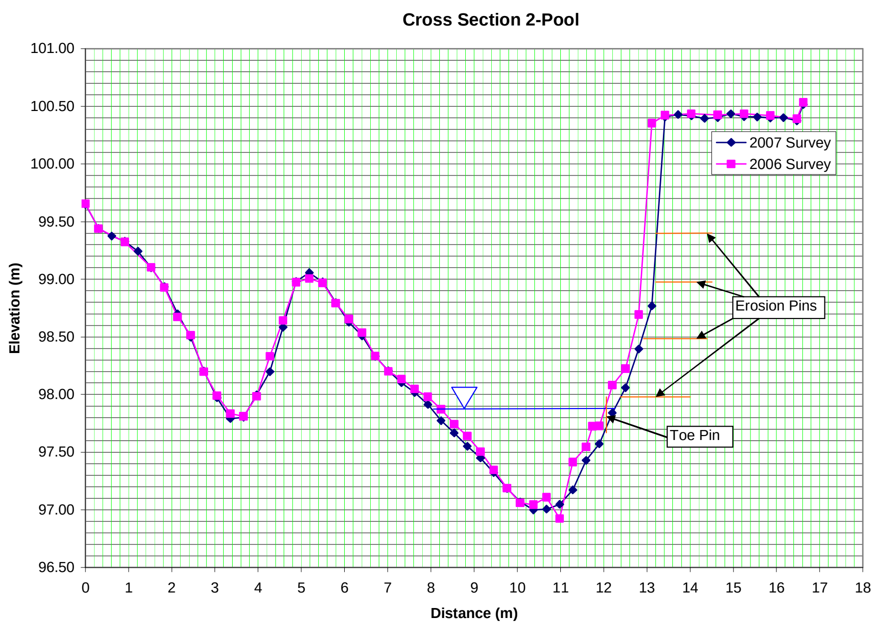


Figure E-25. Repeat survey of cross section transect 2 at Wind Creek, midland reach.

Figure E-26. Repeat survey of cross section transect 3 at Wind Creek midland reach.

Figure E-27. Repeat survey of cross section transect 4 at Wind Creek midland reach.

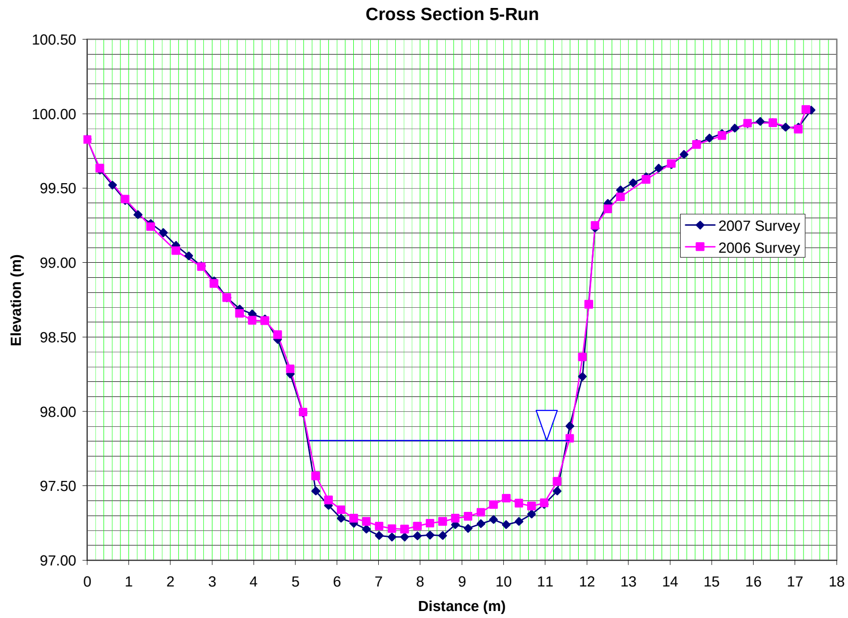


Figure E-28. Repeat survey of cross section transect 5 at Wind Creek midland reach.

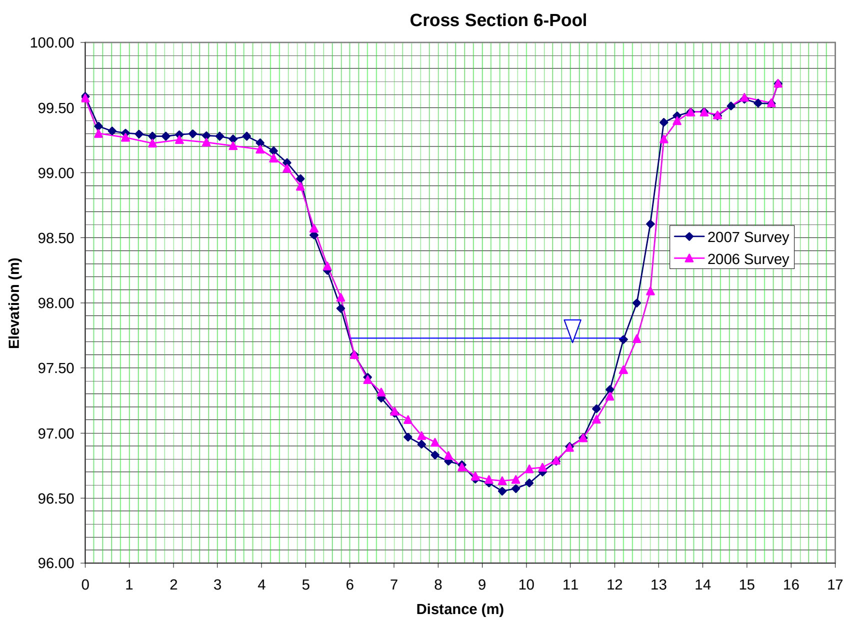


Figure E-29. Repeat survey of cross section transect 6 at Wind Creek midland reach.

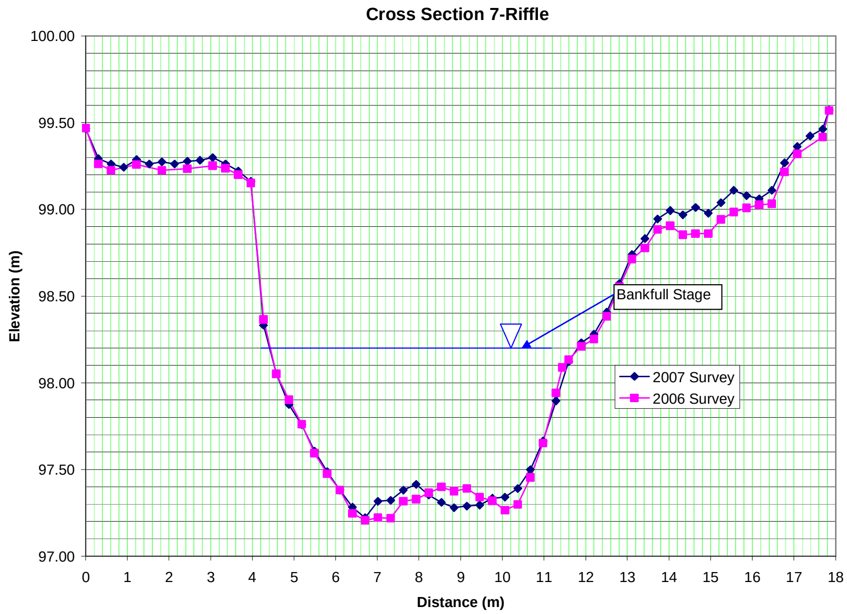


Figure E-30. Repeat survey of cross section transect 7 at Wind Creek midland reach.

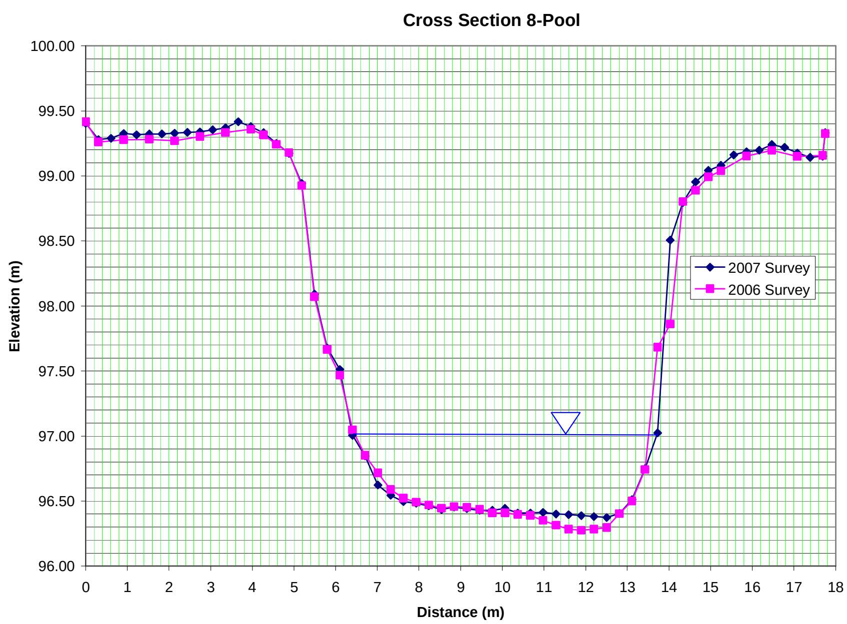


Figure E-31. Repeat survey of cross section transect 8 at Wind Creek midland reach.

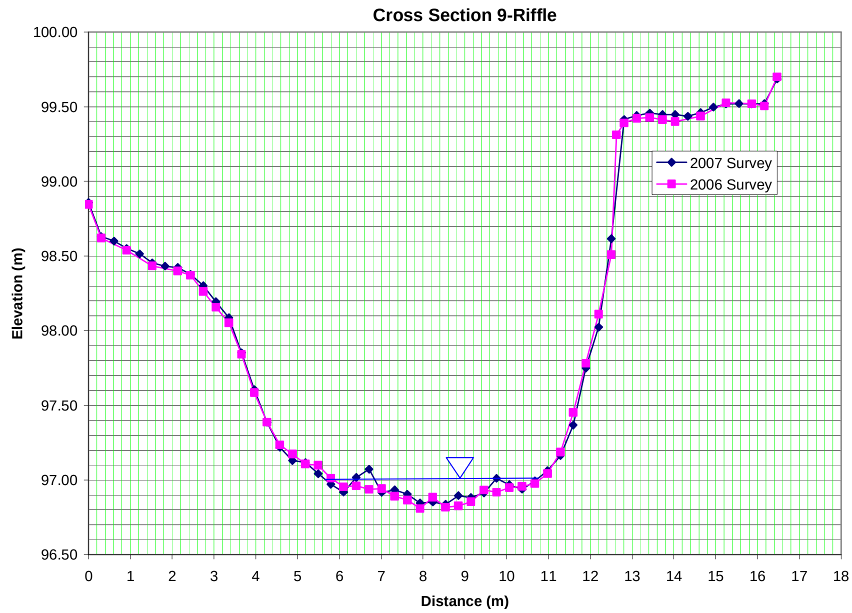


Figure E-32. Repeat survey of cross section transect 9 at Wind Creek midland reach.

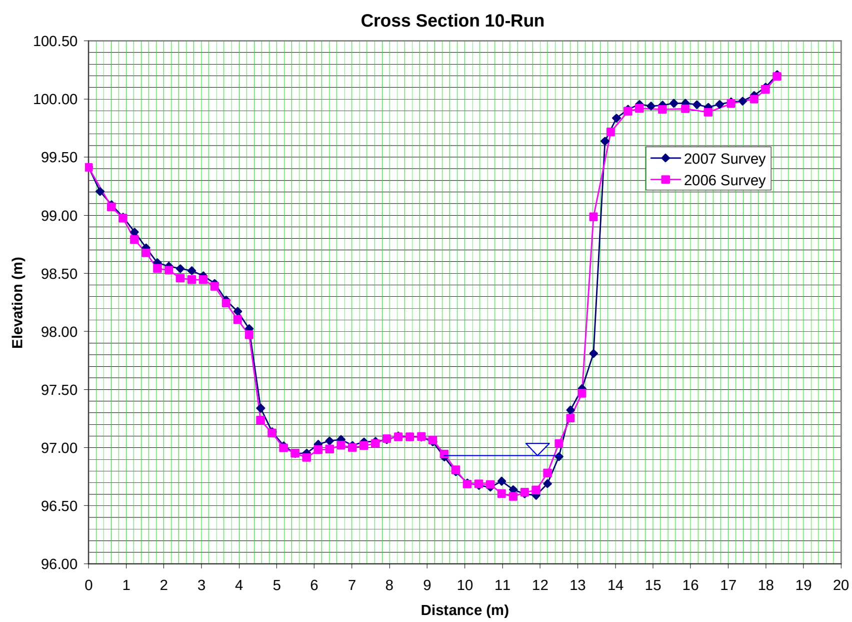


Figure E-33. Repeat survey of cross section transect 10 at Wind Creek midland reach.

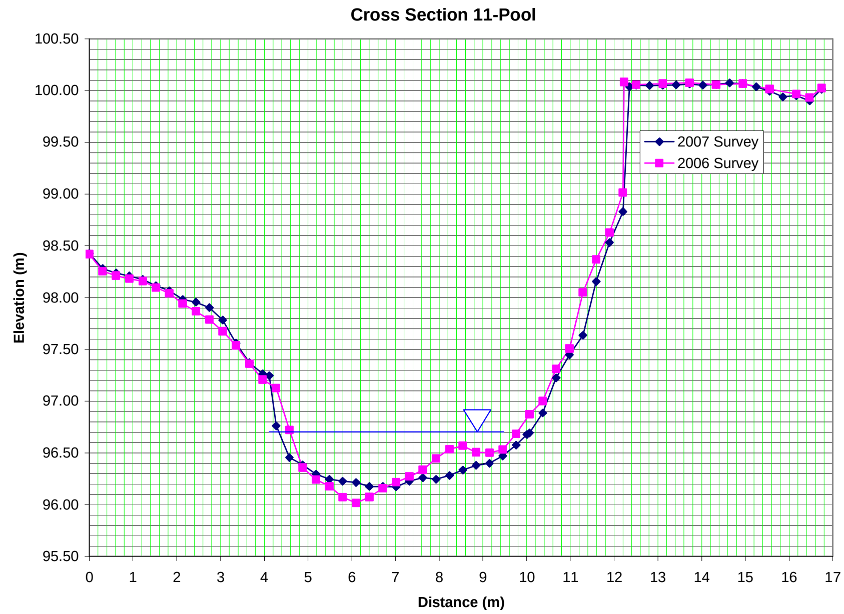


Figure E-34. Repeat survey of cross section transect 11 at Wind Creek midland reach.

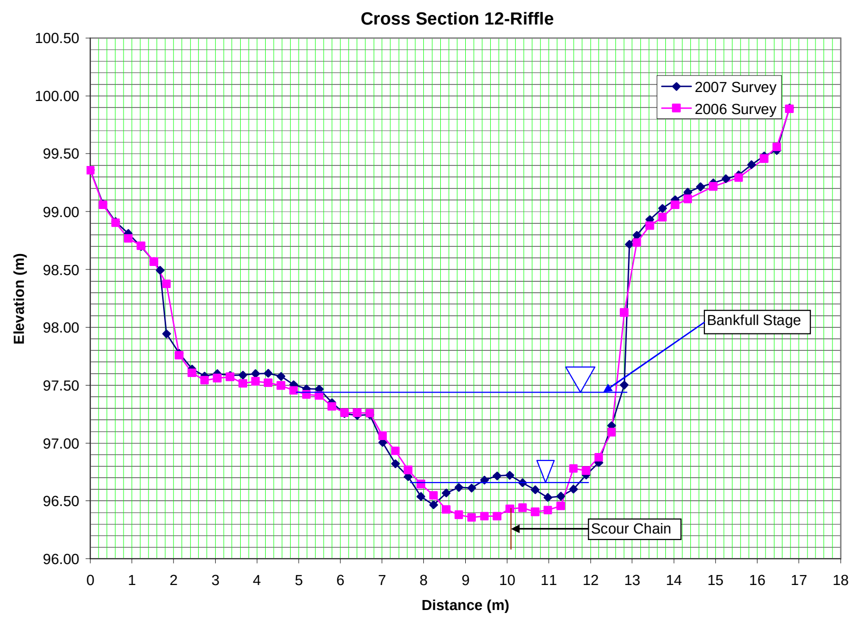


Figure E-35. Repeat survey of cross section transect 12 at Wind Creek midland reach.

Bed Material Characterization

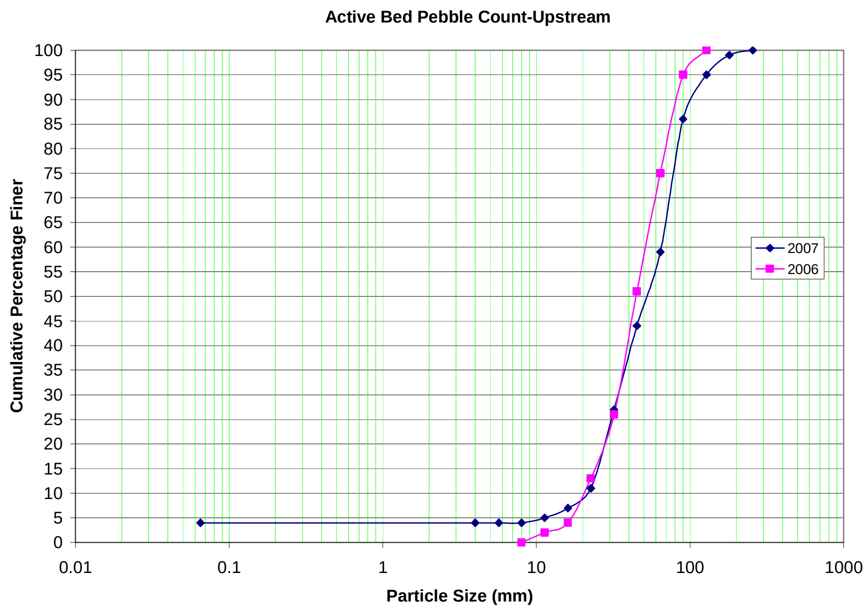


Figure E-36. Particle size distribution at cross section transect 1, Wind Creek midland reach.

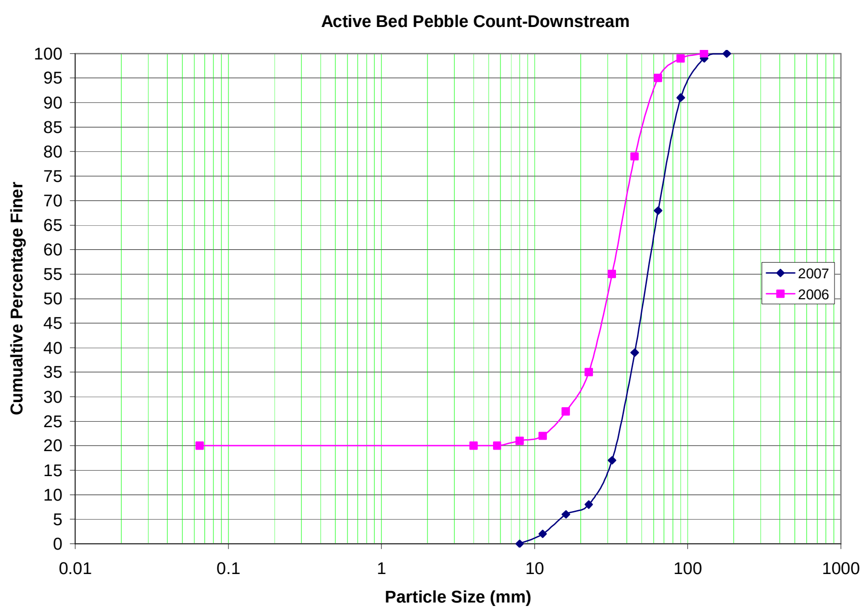


Figure E-37. Particle size distribution at cross section transect 4, Wind Creek midland reach.

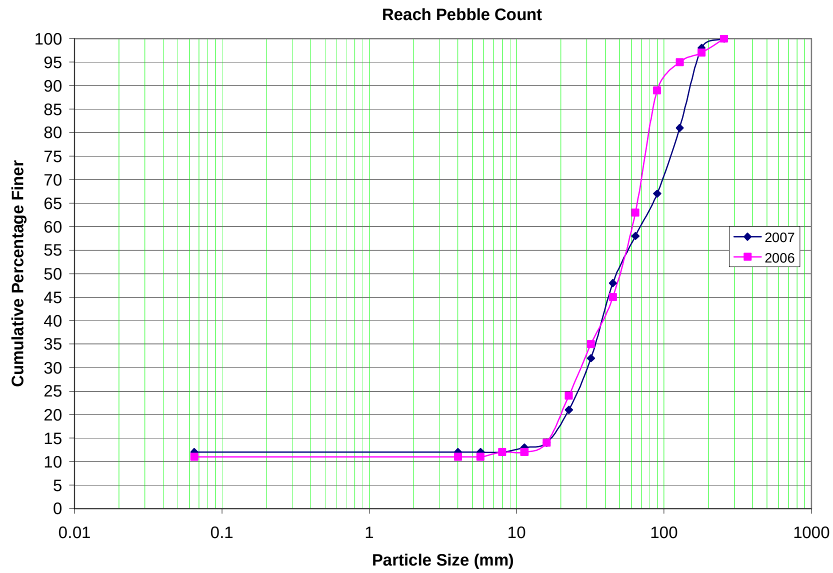


Figure E-38. Particle size distribution along Wind Creek midland reach.

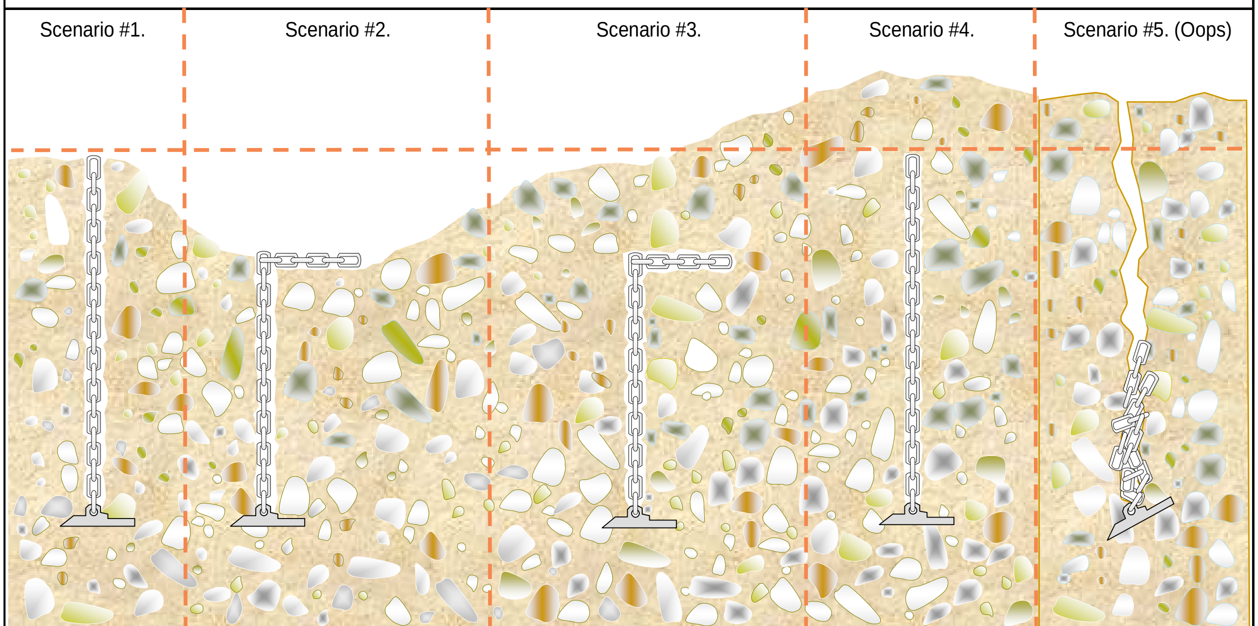
Scour Chains Data

Table E-1. Scour chains data, Wind Creek, midland reach.

Stream name: **Wind Creek, Midland Reach** Location: **Fort Riley, Kansas**

Observers: Stream Type: **B4c** Valley Type: **VIII** Date: **06/2007**

		Installation Data (1st Year)				Recovery Data (2nd Year)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1										
Riffle	Chain #2	**0+32**	**88.08**	**70**	**57**	**4**	**0**	**89.23**	**1.15**	**85**	**80**
Glide	Chain #3										
Glide	Chain #4										



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

Repeat Survey of Bank Profiles

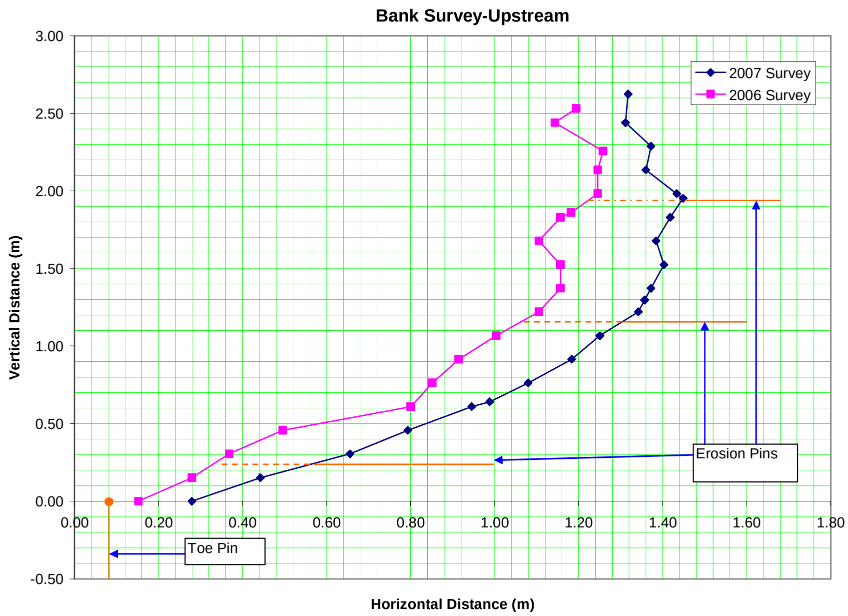


Figure E-39. A measure of bank migration rate at bank transect 1, Wind Creek, midland reach.

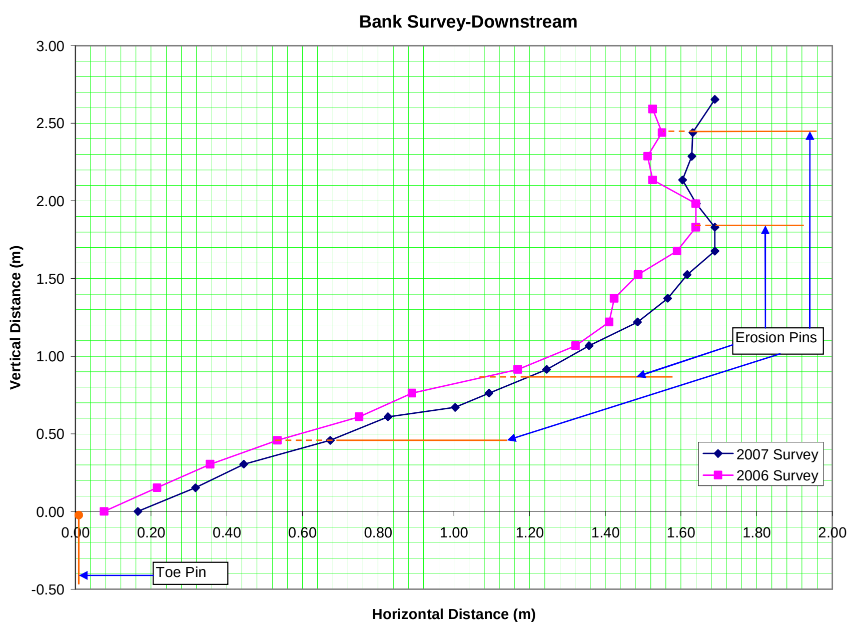


Figure E-40. A measure of bank migration rate at bank transect 2, Wind Creek midland reach.

Calculation of BEHI and NBS

Table E-2. Calculation of BEHI variables and overall BEHI rating at bank transect 1, Wind Creek, midland reach.

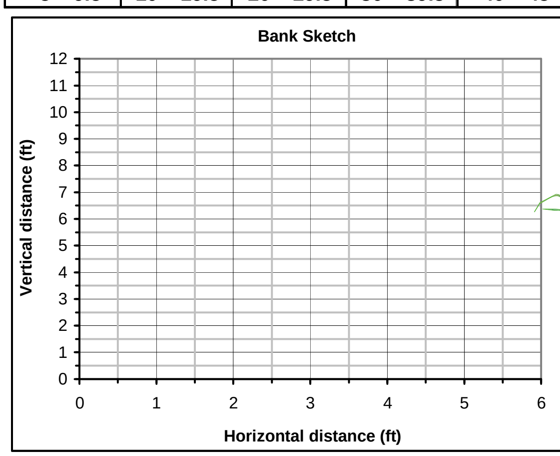
Stream:	**Wind Creek, Midland Reach**	Location:	**Fort Riley, Kansas**
Station:	**Bank Transect 1**	Observers:	
Date:	**06/2007**	Stream Type: **B4c**	Valley Type: **VIII**

Variable	Input 1	Input 2	Calculation	Value	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) = 8.9 **(A)**	**Bankfull Height** (ft) = 3 **(B)**	(A) / (B) =	2.97 **(C)**	**8.3**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) = 4 **(D)**	**Study Bank Height** (ft) = 8.9 **(A)**	(D) / (A) =	0.45 **(E)**	**5**
Weighted Root Density (G)		**Root Density** as **%** = 10% **(F)**	(F) × (E) =	4.5 **(G)**	**10**
Bank Angle (H)			**Bank Angle** as *Degrees* =	65 **(H)**	**4.2**
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
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

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

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score	
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50		**High** **36.5**



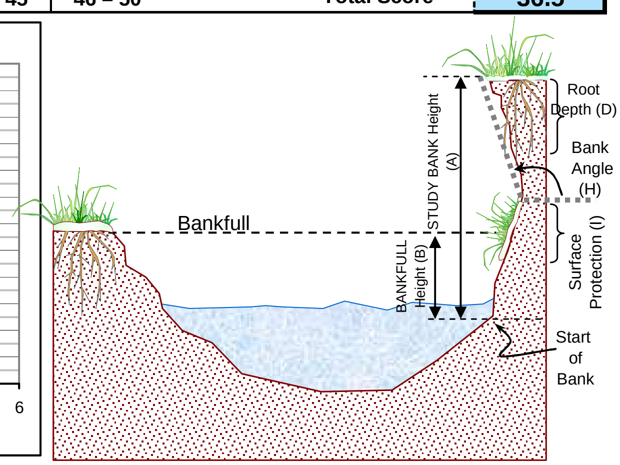


Table E-3. Calculation of NBS variables and overall NBS rating at bank transect 1, Wind Creek, midland reach.

Estimating Near-Bank Stress (NBS)		
Stream: **Wind Creek, Midland**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 1**	Stream Type: **B4c**	Valley Type: **VIII**
Observers:		Date: **06/2006**

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

Level I

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

Level II

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

(3)	Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)
	0.0045	**0.0023**	**1.96**	**Extreme**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)
	0.0045	**0.0265**	**0.17**	**Very Low**

Dominant Near-Bank Stress
Extreme

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	4.50	**2.78**	**1.62**	**Moderate**

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

Level IV

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

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

Overall Near-Bank Stress (NBS) rating: Extreme

Table E-4. Calculation of BEHI variables and overall BEHI rating at bank transect 2, Wind Creek, midland reach.

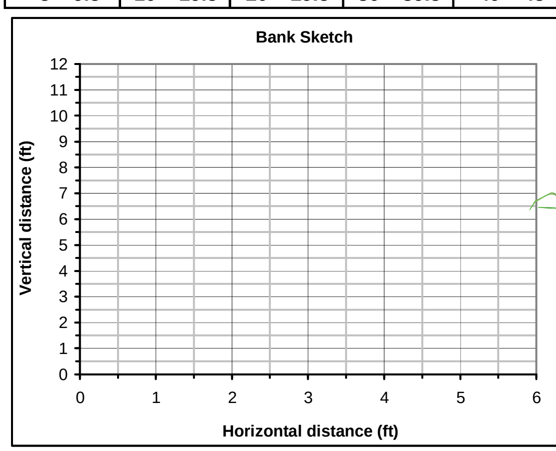
Stream:	**Wind Creek, Midland Reach**	Location:	**Fort Riley, Kansas**
Station:	**Bank Transect 2**	Observers:	
Date:	**06/2007**	Stream Type: **B4c**	Valley Type: **VIII**

Variable	Input 1	Input 2	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) = 8.75 **(A)**	**Bankfull Height** (ft) = 4 **(B)**	(A) / (B) =	2.19 **(C)**	**8.2**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) = 5 **(D)**	**Study Bank Height** (ft) = 8.75 **(A)**	(D) / (A) =	0.57 **(E)**	**3.5**
Weighted Root Density (G)		**Root Density** as **%** = 10% **(F)**	(F) × (E) =	5.7 **(G)**	**8.1**
Bank Angle (H)			**Bank Angle** as *Degrees* =	80 **(H)**	**5.9**
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
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** / **34.7**



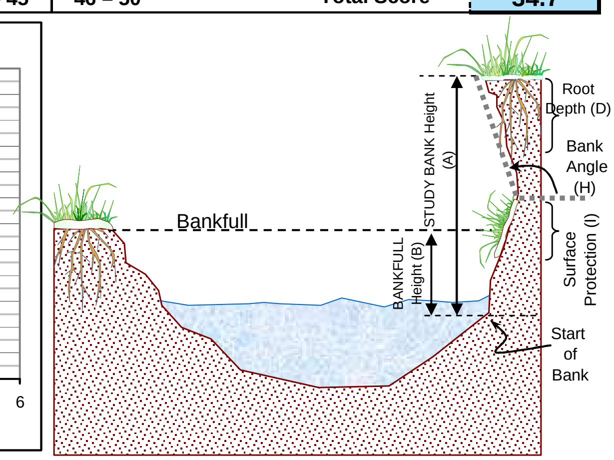


Table E-5. Calculation of NBS variables and overall NBS rating at bank transect 2, Wind Creek, midland reach.

Estimating Near-Bank Stress (NBS)

Stream: **Wind Creek, Midland**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 2**	Stream Type: **B4c**	Valley Type: **VIII**
Observers:		Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

Level I (1)

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

Level II

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

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.0031	**0.0023**	**1.35**	**Extreme**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.0031	**0.0096**	**0.32**	**Very Low**

Dominant Near-Bank Stress
Extreme

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	5.50	**2.78**	**1.98**	**High**

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

Level IV

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

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

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

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

Geographical Position System Coordinates

Table E-6. GPS coordinates taken at Wind Creek, midland reach.

Wind Creek Midland Reach – LWSC 6		
Feature	**N (m)**	**E (m)**
Head of Reach	4344733	690112
Cross Section 1- Left Pin	4344738	690101
Cross Section 1- Right Pin	4344721	690101
Cross Section 2- Left Pin	4344737	690103
Cross Section 2- Right Pin	4344737	690127
Cross Section 3- Left Pin	4344738	690174
Cross Section 3- Right Pin	4344734	690160
Cross Section 4- Left Pin	4344707	690172
Cross Section 4- Right Pin	4344693	690157
Cross Section 5- Left Pin	4344681	690224
Cross Section 5- Right Pin	4344669	690220
Cross Section 6- Left Pin	4344660	690288
Cross Section 6- Right Pin	4344651	690279
Cross Section 7- Left Pin	4344625	690340
Cross Section 7- Right Pin	4344623	690301
Cross Section 8- Left Pin	4344565	690326
Cross Section 8- Right Pin	4344570	690314
Cross Section 9- Left Pin	4344587	690296
Cross Section 9- Right Pin	4344595	690301
Cross Section 10- Left Pin	4344593	690272
Cross Section 10- Right Pin	4344598	690270
Cross Section 11- Left Pin	4344563	690273
Cross Section 11- Right Pin	4344569	690257
Cross Section 12- Left Pin	4344550	690280
Cross Section 12- Right Pin	4344548	690263
End of Reach	4344540	690272

GPS measurement grid is Universal Transverse Mercator (UTM) and map datum is North American Datum 83 (NAD 83).

Appendix F - Wind Creek, Lowland Reach

Photographs

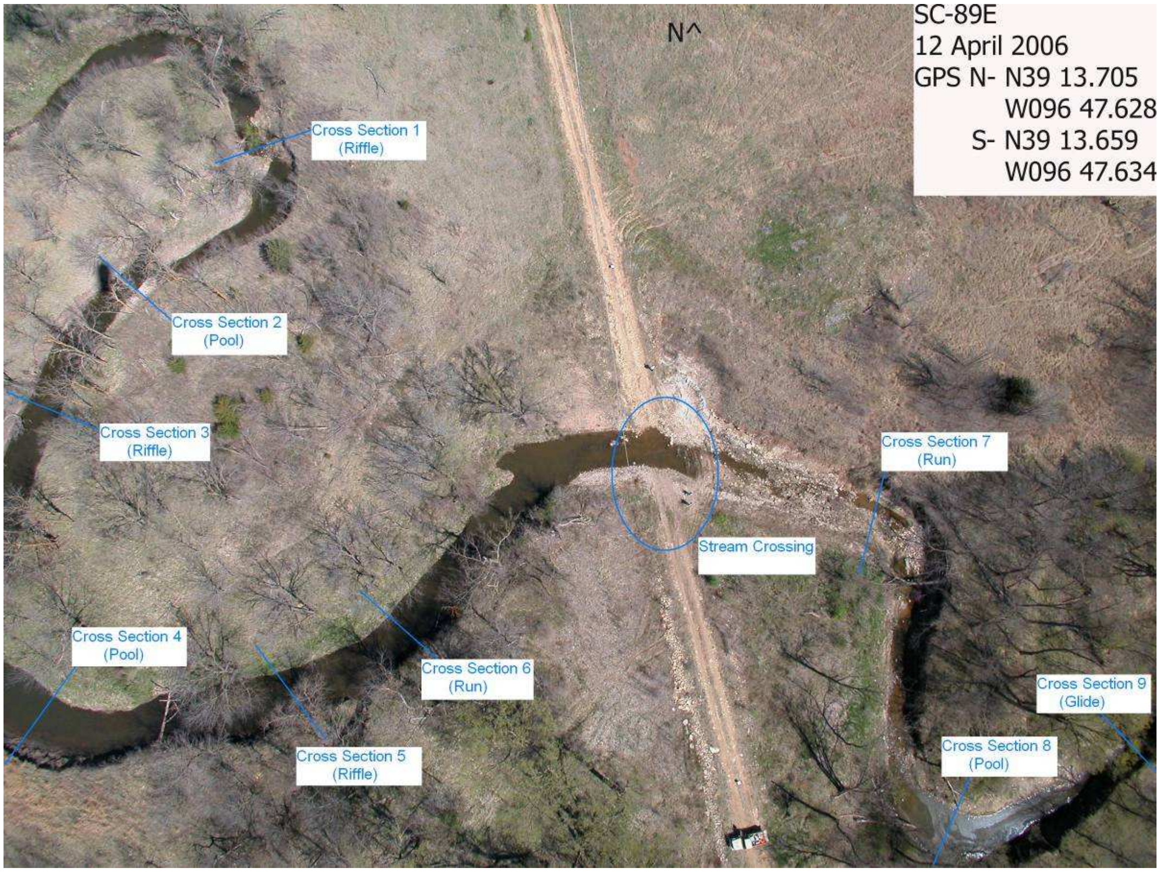


Figure F-1. Wind Creek lowland study reach.

Figure F-2. Cross section transect 1 (riffle), view from left bank to right bank at Wind Creek, lowland reach.

Figure F-3. Cross section transect 1 (riffle) at Wind Creek, lowland reach, upstream view.

Figure F-4. Cross section transect 1 (riffle) at Wind Creek, lowland reach, downstream view.

Figure F-5. Cross section transect 2 (pool), view from left bank to right bank at Wind Creek, lowland reach.

Figure F-6. Cross section transect 2 (pool) at Wind Creek, lowland reach, upstream view.

Figure F-7. Cross section transect 2 (pool) at Wind Creek, lowland reach, downstream view.

Figure F-8. Stream crossing, view from left bank to right bank at Wind Creek, lowland reach.

Figure F-9. Stream crossing at Wind Creek, lowland reach, upstream view.

Figure F-10. Stream crossing at Wind Creek, lowland reach, downstream view.

Figure F-11. Cross section transect 8 (pool), view from left bank to right bank at Wind Creek, lowland reach.

Figure F-12. Cross section transect 2 (pool) at Wind Creek, lowland reach, upstream view.

Figure F-13. Cross section transect 8 (pool) at Wind Creek, lowland reach, downstream stream view.

Figure F-14. Cross section transect 9 (run), view from left bank to right bank at Wind Creek lowland reach.

Figure F-15. Cross section transect 9 (run) at Wind Creek lowland reach, upstream view.

Figure F-16. Cross section transect 9 (run) at Wind Creek lowland reach, downstream stream view.

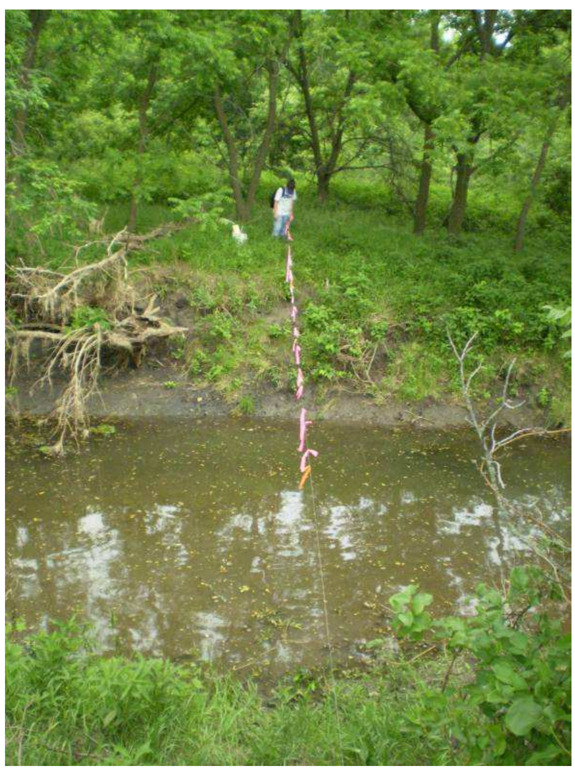


Figure F-17. Cross section transect 11 (riffle), view from left bank to right bank at Wind Creek lowland reach.

Figure F-18. Cross section transect 11 (riffle) at Wind Creek lowland reach, upstream view.

Figure F-19. Cross section transect 11 (riffle) at Wind Creek lowland reach, downstream stream view.

Changes in Channel Geometry

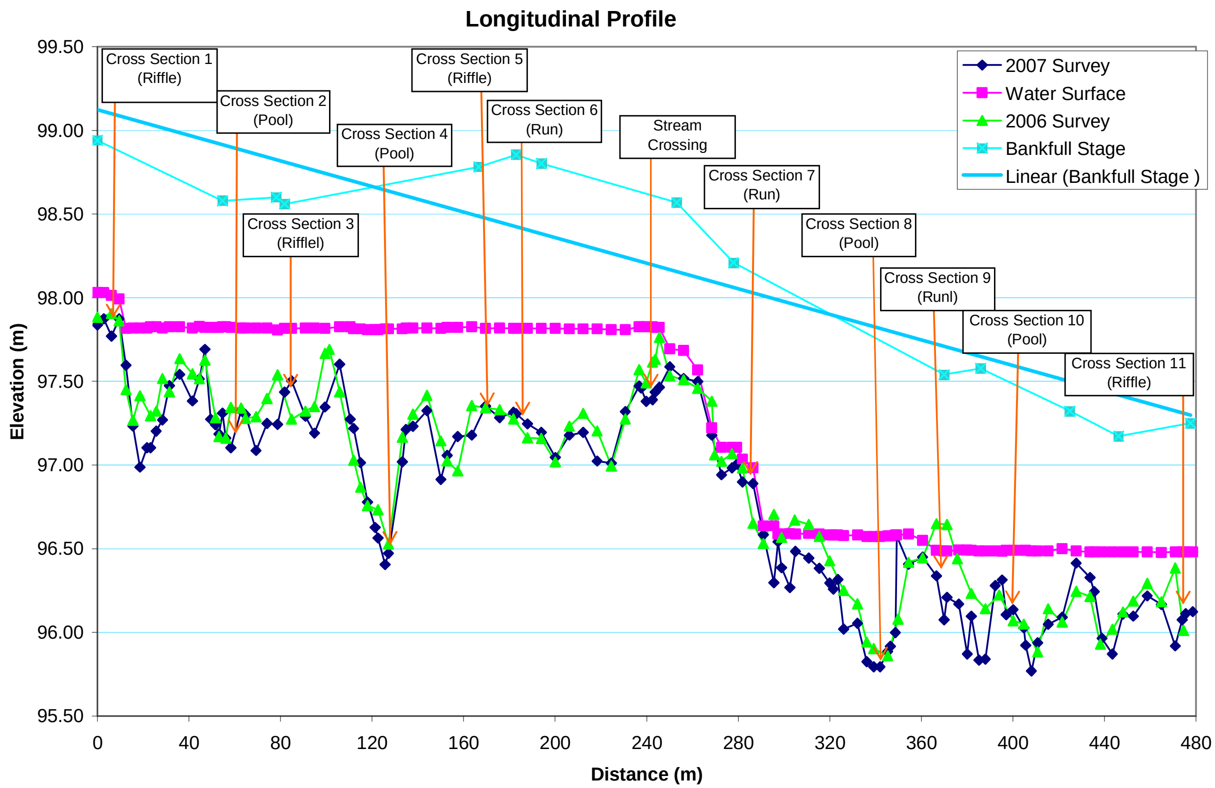


Figure F-20. Longitudinal profile along Wind Creek, lowland reach.

Figure F-21. Repeat survey of cross section transect 1 at Wind Creek, lowland reach.

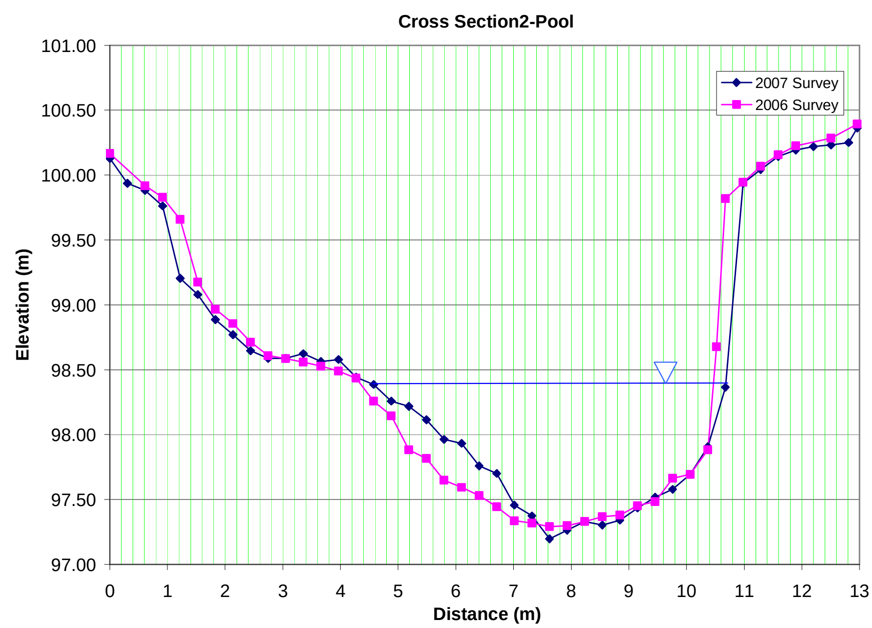


Figure F-22. Repeat survey of cross section transect 2 at Wind Creek, lowland reach.

Figure F-23. Repeat survey of cross section transect 3 at Wind Creek lowland reach.

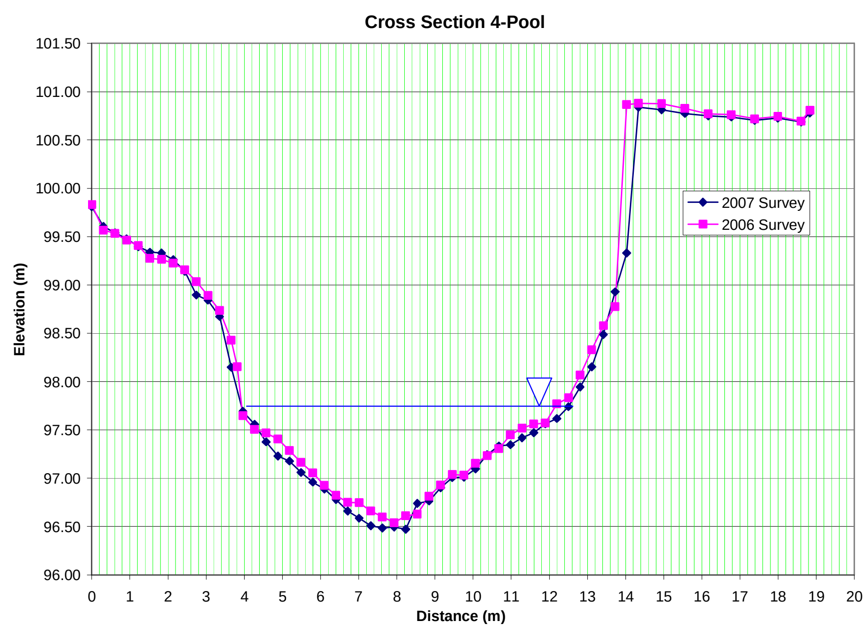


Figure F-24. Repeat survey of cross section transect 4 at Wind Creek lowland reach.

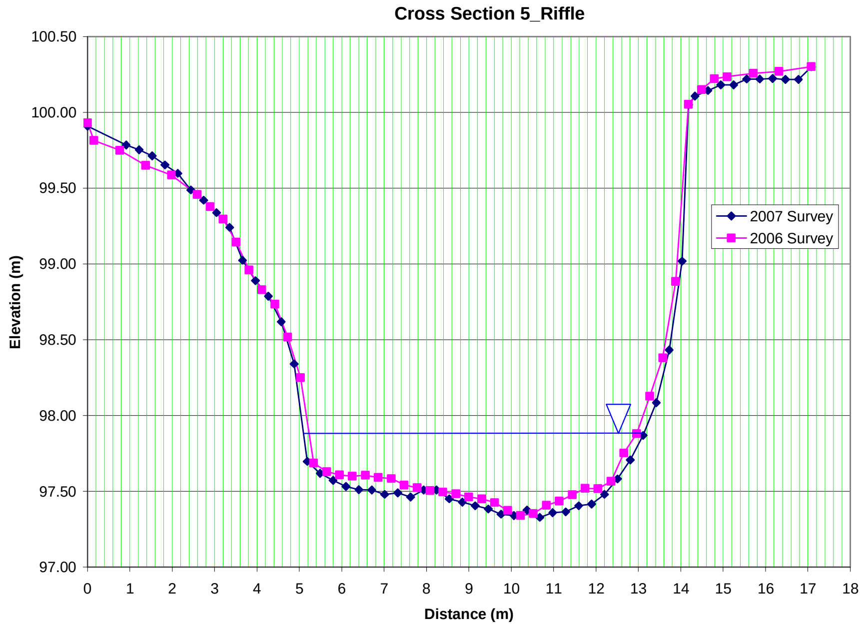


Figure F-25. Repeat survey of cross section transect 5 at Wind Creek lowland reach.

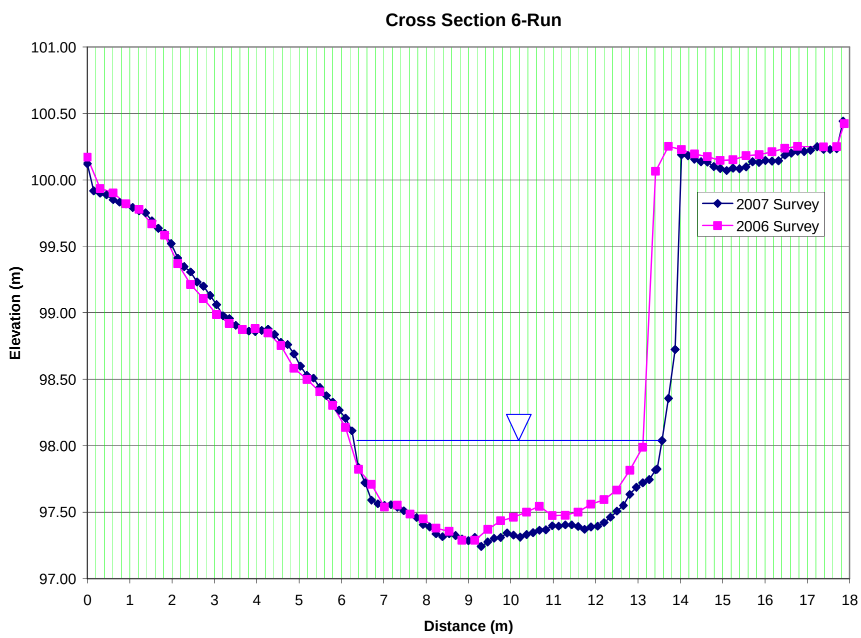


Figure F-26. Repeat survey of cross section transect 6 at Wind Creek lowland reach.

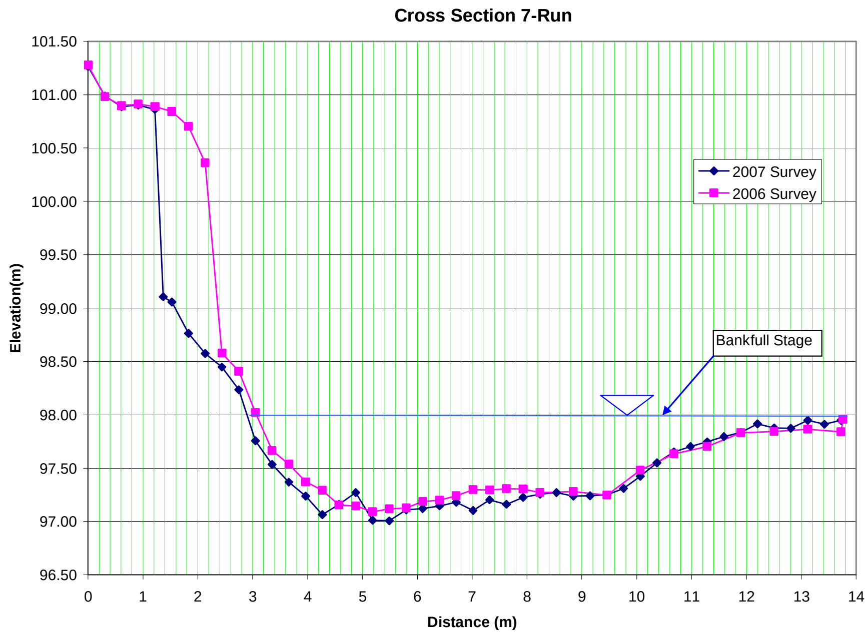


Figure F-27. Repeat survey of cross section transect 7 at Wind Creek lowland reach.

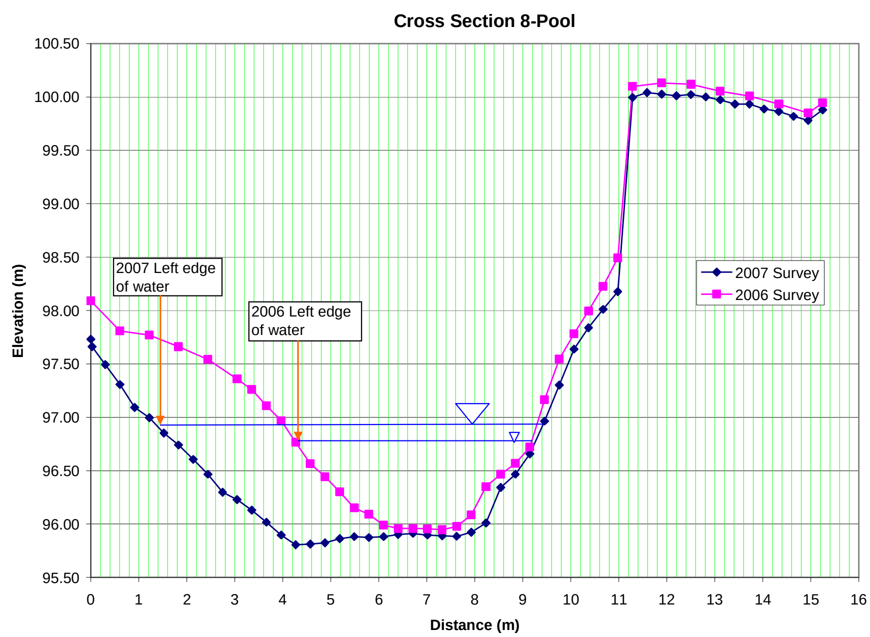


Figure F-28. Repeat survey of cross section transect 8 at Wind Creek lowland reach.

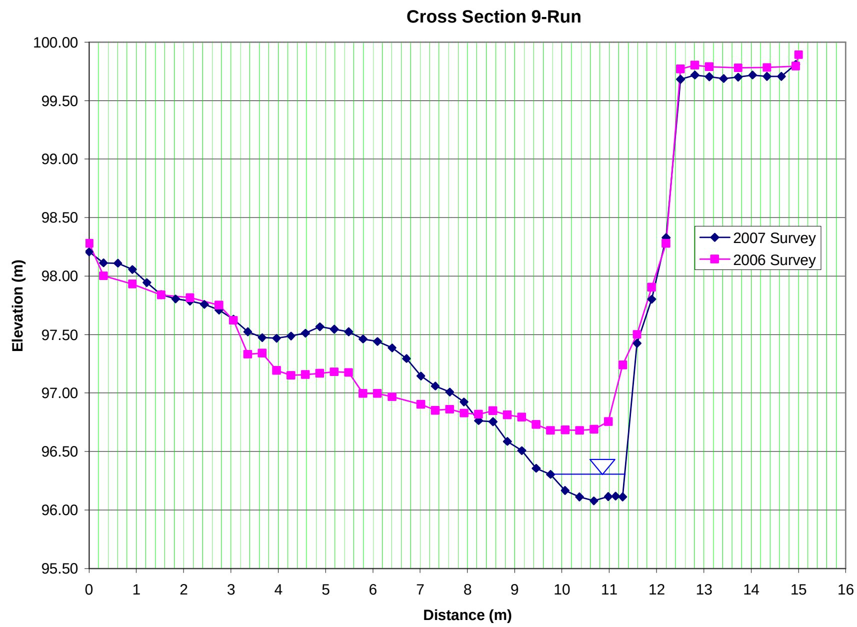


Figure F-29. Repeat survey of cross section transect 9 at Wind Creek lowland reach.

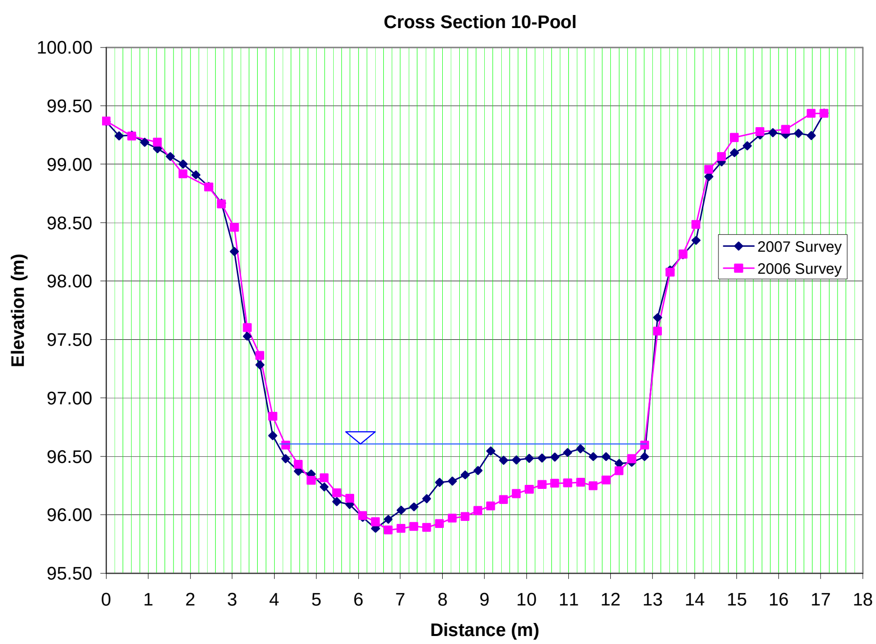


Figure F-30. Repeat survey of cross section transect 10 at Wind Creek lowland reach.

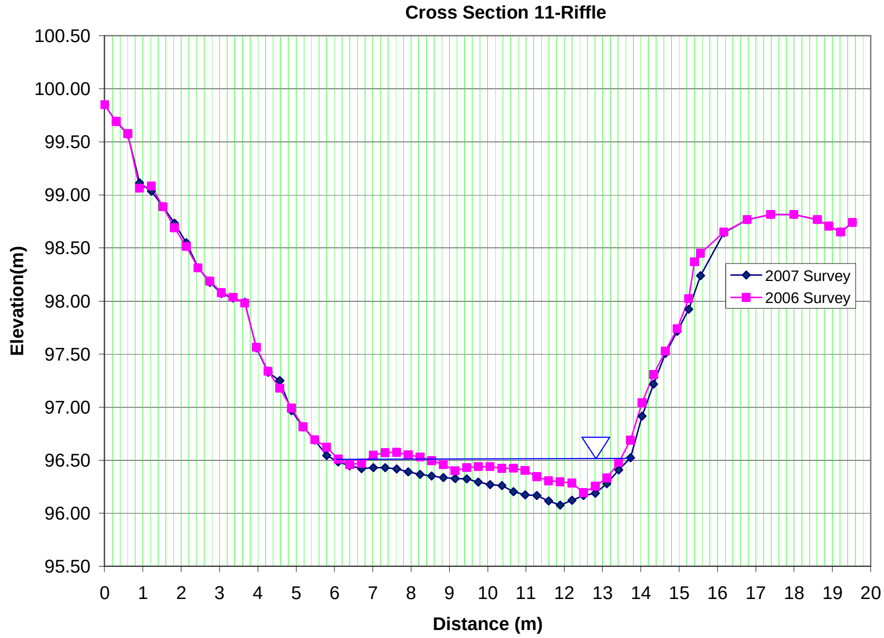


Figure F-31. Repeat survey of cross section transect 11 at Wind Creek lowland reach.

Bed Material Characterization

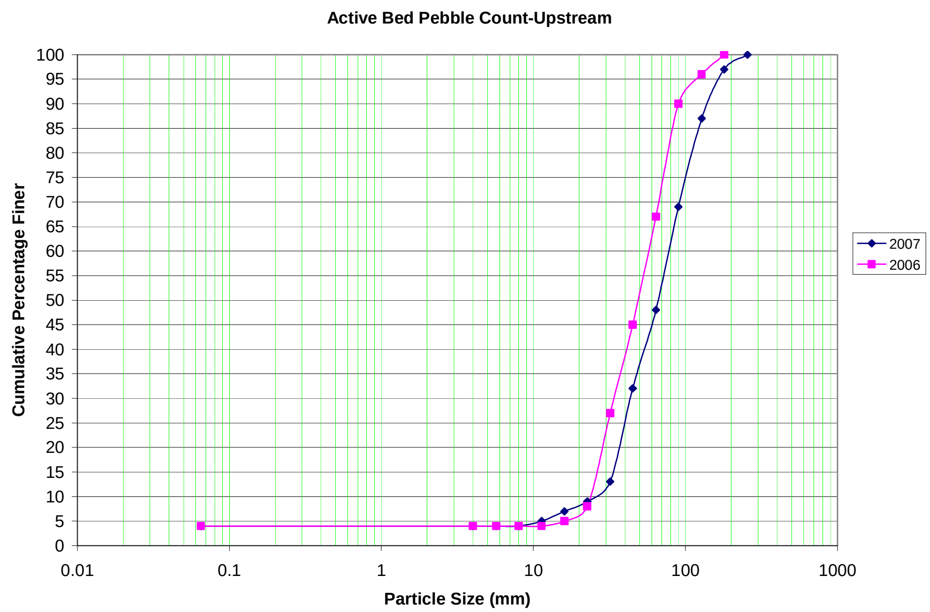


Figure F-32. Particle size distribution at cross section transect 1, Wind Creek lowland reach.

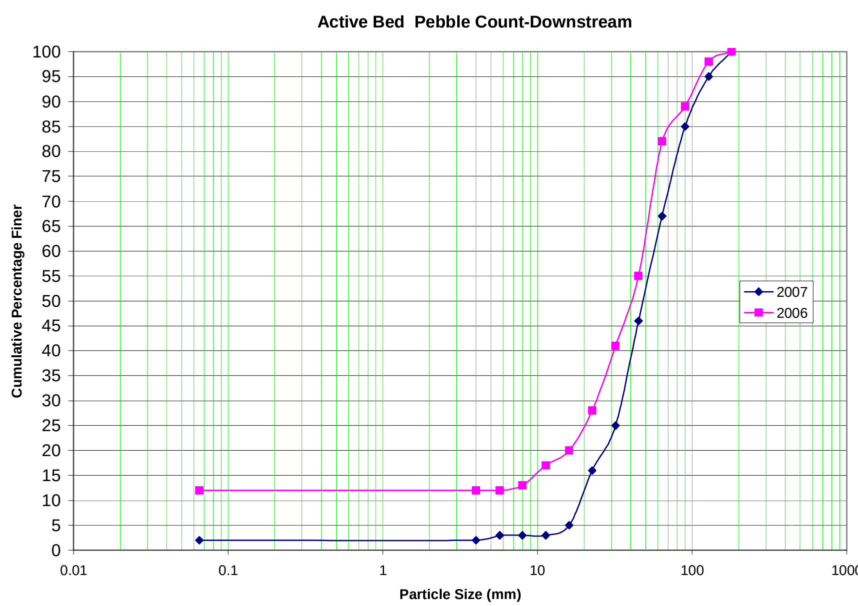


Figure F-33. Particle size distribution at cross section transect 4, Wind Creek lowland reach.

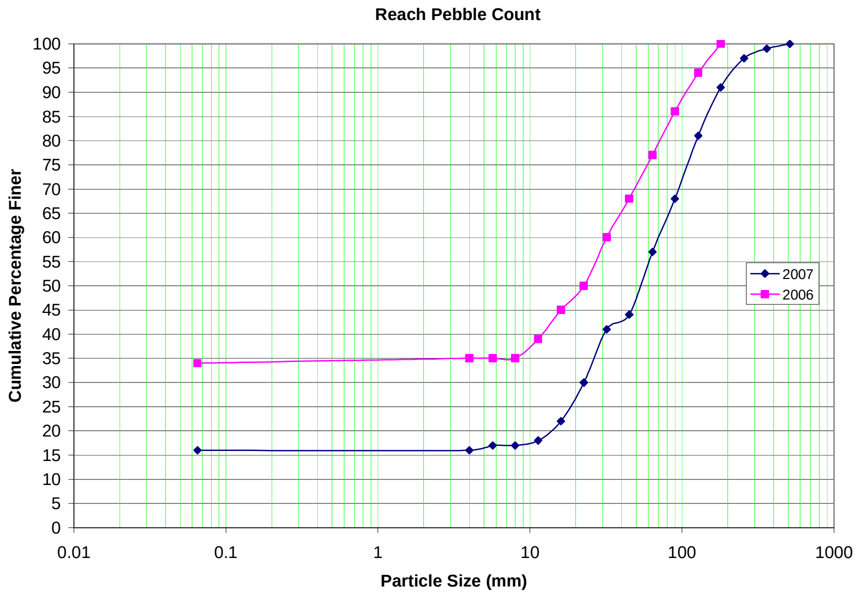


Figure F-34. Particle size distribution along Wind Creek lowland reach.

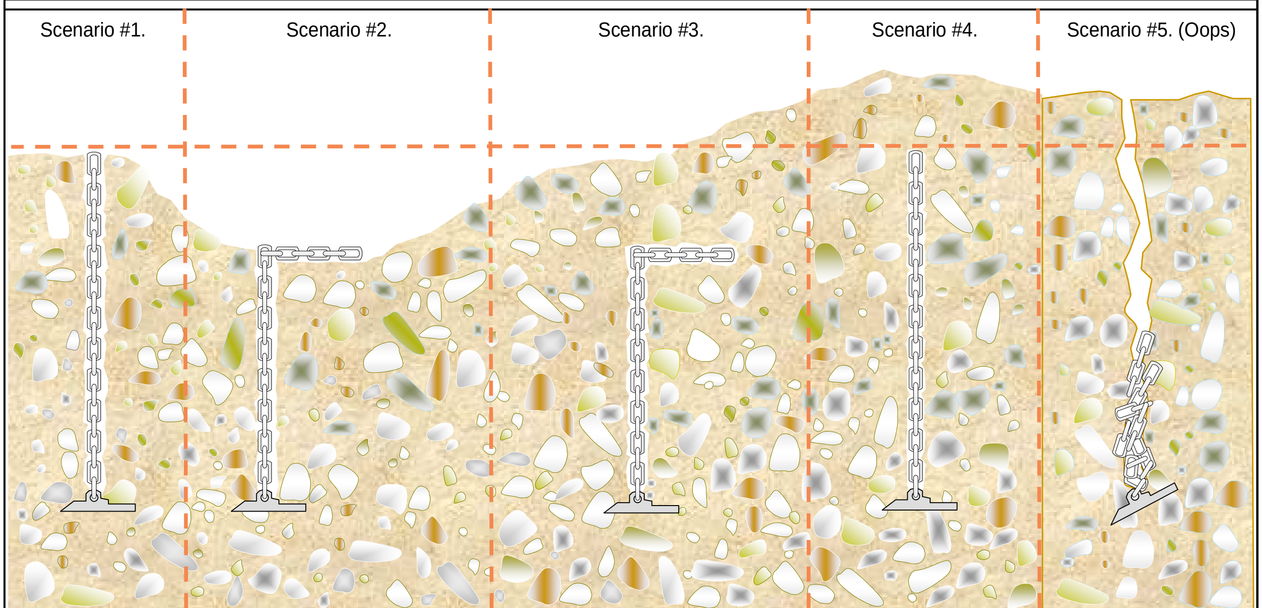
Scour Chains Data

Table F-1. Scour chains data, Wind Creek, lowland reach.

Stream name: **Wind Creek, Lowland Reach** Location: **Fort Riley, Kansas**

Observers: Stream Type: **F4** Valley Type: **VIII** Date: **06/2007**

		Installation Data (1st Year)				Recovery Data (2nd Year)					
		From cross-section		Particles near chain		Chain recovery				Particles near chain	
		Station (ft)	Elevation (ft)	Largest (mm)	2nd Largest (mm)	Scenario # (1–5)	Scour depth[a] (ft)	Elevation[b] (ft)	Net change[c] (ft)	Largest (mm)	2nd Largest (mm)
Riffle	Chain #1	**0+16**	**92.98**	**89**	**80**	**1**	**0**	**93.05**	**0.07**	**195**	**160**
	Chain #2	**0+16**	**90.63**	**95**	**75**	**N/A**	**-3.38**	**87.25**	**-3.38**	**180**	**150**
Glide	Chain #3	**0+29**	**88.36**	**150**	**107**	**2**	**-0.40**	**87.96**	**-0.40**	**90**	**60**
	Chain #4										



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

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

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

N/A implies scour chains got scoured out.

Repeat Survey of Bank Profiles

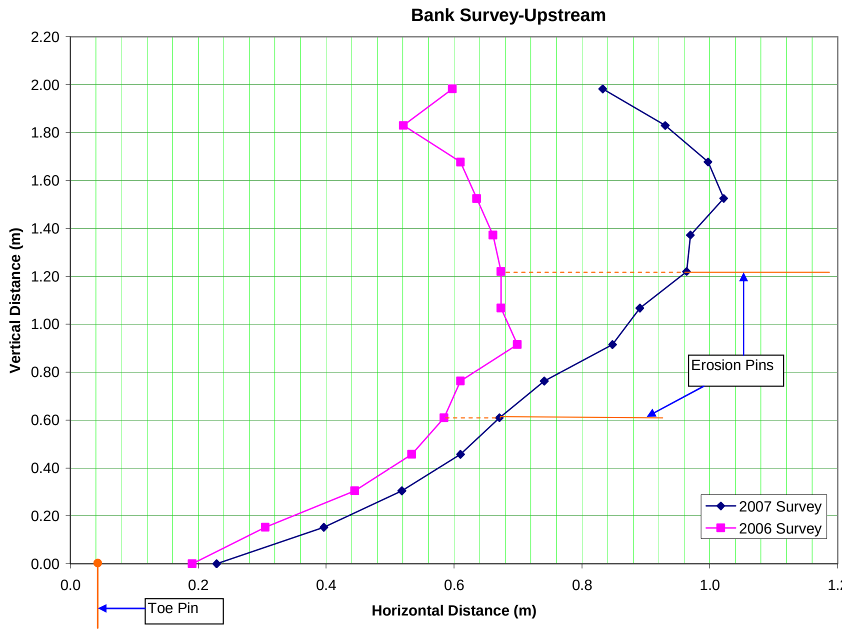


Figure F-35. A measure of bank migration rate at bank transect 1, Wind Creek lowland reach.

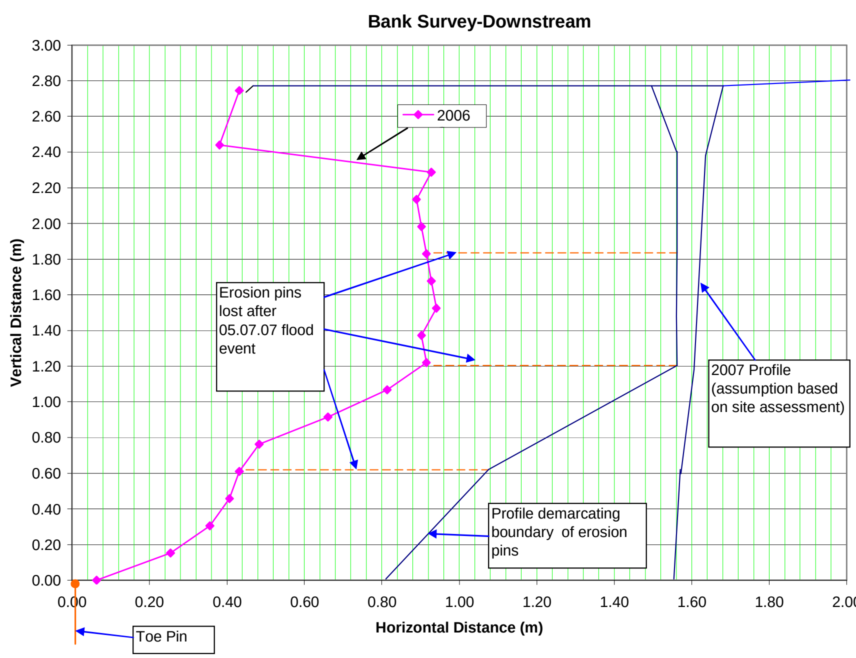


Figure F-36. A measure of bank migration rate at bank transect 2, Wind Creek, lowland reach.

Calculation of BEHI and NBS

Table F-2. Calculation of BEHI variables and overall BEHI rating at bank transect 1, Wind Creek, lowland reach.

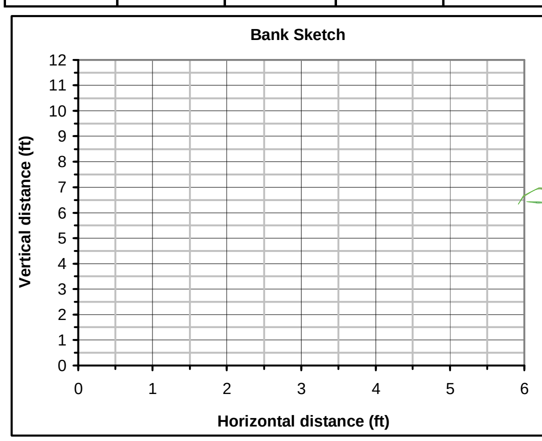
Stream:	**Wind Creek, Lowland Reach**	Location:	**Fort Riley, Kansas**
Station:	**Bank Transect 1**	Observers:	
Date:	**06/2007**	Stream Type: **F4**	Valley Type: **VIII**

Variable	Input 1	Value	Input 2	Value	Calculation	Result	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) =	**7.3 (A)**	**Bankfull Height** (ft) =	**4 (B)**	(A) / (B) =	**1.83 (C)**	**7.1**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	**5 (D)**	**Study Bank Height** (ft) =	**7.3 (A)**	(D) / (A) =	**0.68 (E)**	**3.5**
Weighted Root Density (G)			**Root Density** as **%** =	**15% (F)**	(F) × (E) =	**10.3 (G)**	**8.5**
Bank Angle (H)					**Bank Angle** as *Degrees* =	**90 (H)**	**7.9**
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
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	Adjective Rating	**High**
						Total Score	**36**



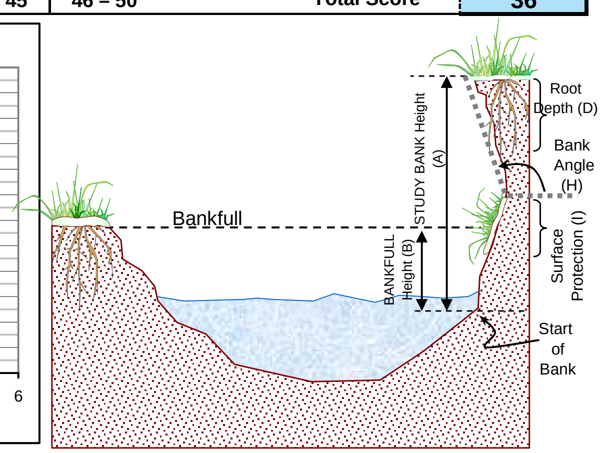


Table F-3. Calculation of NBS variables and overall NBS rating at bank transect 1, Wind Creek, lowland reach.

Estimating Near-Bank Stress (NBS)

Stream: **Wind Creek, Lowland** Location: **Fort Riley, Kansas**

Station: **Bank Transect 1** Stream Type: **F4** Valley Type: **VIII**

Observers: Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

Level I

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

Level II

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

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.0221**	**0.0032**	**6.91**	**Extreme**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.0221**	**0.0137**	**1.61**	**Extreme**

Dominant Near-Bank Stress
Extreme

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**4.00**	**2.64**	**1.52**	**Moderate**

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

Level IV

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

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

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

Overall Near-Bank Stress (NBS) rating: Extreme

Table F-4. Calculation of BEHI variables and overall BEHI rating at bank transect 2, Wind Creek, lowland reach.

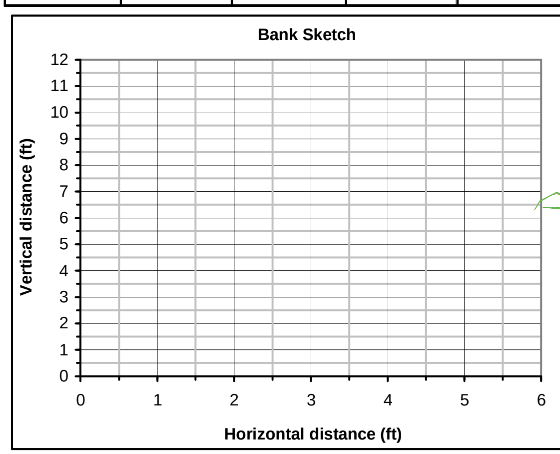
Stream:	**Wind Creek, Lowland Reach**	Location:	**Fort Riley, Kansas**
Station:	**Bank Transect 2**	Observers:	
Date:	**06/2007**	Stream Type: **F4**	Valley Type: **VIII**

Variable					Calculation	Value	BEHI Score (Fig. 5-19)
Study Bank Height / Bankfull Height (C)	**Study Bank Height** (ft) =	10.2 **(A)**	**Bankfull Height** (ft) =	4.5 **(B)**	(A) / (B) =	2.3 **(C)**	**10**
Root Depth / Study Bank Height (E)	**Root Depth** (ft) =	4.5 **(D)**	**Study Bank Height** (ft) =	10.2 **(A)**	(D) / (A) =	0.44 **(E)**	**4.6**
Weighted Root Density (G)			**Root Density** as **%** =	15% **(F)**	(F) × (E) =	6.62 **(G)**	**10**
Bank Angle (H)					**Bank Angle** as *Degrees* =	95 **(H)**	**8**
Surface Protection (I)					**Surface Protection** as **%** =	0% **(I)**	**9**
Bank Material Adjustment							**0**
Stratification Adjustment					Add 5–10 points, depending on position of unstable layers in relation to bankfull stage		**0**

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large
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)

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	**V.High** **41.6**



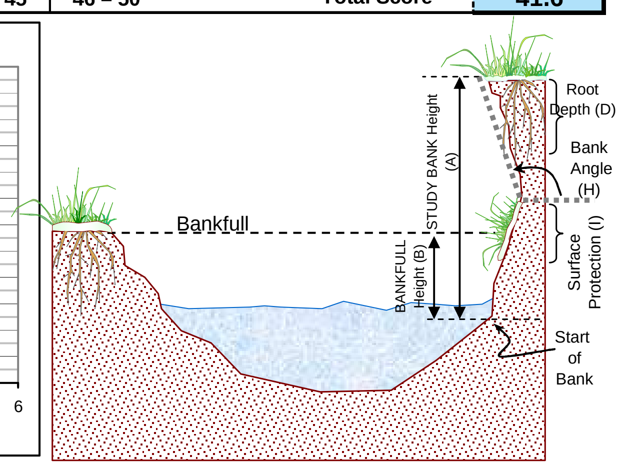


Table F-5. Calculation of NBS variables and overall NBS rating at bank transect 2, Wind Creek, lowland reach.

Estimating Near-Bank Stress (NBS)

Stream: **Wind Creek, Lowland**	Location: **Fort Riley, Kansas**	
Station: **Bank Transect 2**	Stream Type: **F4**	Valley Type: **VIII**
Observers:		Date: **06/2006**

Methods for estimating Near-Bank Stress (NBS)

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

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

Level	Method				
Level II	(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	Ratio R_c / W_{bkf}	Near-Bank Stress (NBS)
Level II	(3)	Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)
		0.0069	**0.0032**	**2.16**	**Extreme**
Level II	(4)	Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)
		0.0069	**0.0147**	**0.47**	**Low**
Level III	(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
		4.50	**2.64**	**1.70**	**Moderate**

Dominant Near-Bank Stress
Extreme

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

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

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

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

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

Geographical Position System Coordinates

Table F-6. GPS coordinates taken at Wind Creek, lowland reach

Feature	N (m)	E (m)
Bench Mark 1	4344478	690367
Head of Reach	4344487	690368
Cross Section 1- Left Pin	4344490	690378
Cross Section 1- Right Pin	4344488	690369
Cross Section 2- Left Pin	4344457	690349
Cross Section 2- Right Pin	4344464	690339
Cross Section 3- Left Pin	4344356	690432
Cross Section 3- Right Pin	4344442	690321
Cross Section 4- Left Pin	4344411	690328
Cross Section 4- Right Pin	4344391	690318
Cross Section 5- Left Pin	4344402	690364
Cross Section 5- Right Pin	4344385	690364
Cross Section 6- Left Pin	4344390	690318
Cross Section 6- Right Pin	4344386	690380
Cross Section 7- Left Pin	4344408	690460
Cross Section 7- Right Pin	4344397	690452
Cross Section 8- Left Pin	4344357	690463
Cross Section 8- Right Pin	4344341	690470
Cross Section 9- Left Pin	4344398	690590
Cross Section 9- Right Pin	4344368	690497
Cross Section 10- Left Pin	4344390	690519
Cross Section 10- Right Pin	4344372	690528
Cross Section 11- Left Pin	4344385	690525
Cross Section 11- Right Pin	4344385	690597
LWSC 8B	4344421	690425
End of Reach	4344389	690594

GPS measurement grid is Universal Transverse Mercator (UTM) and map datum is North American Datum 83 (NAD 83).