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I am submitting herewith a thesis written by Daniel L. Carter entitled "Stream Restoration Assessment of Abrams Creek in the Great Smoky Mountains National Park: Management Implications and Comparison of Empirical and Analytical Physical Assessment Approaches." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

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**STREAM RESTORATION ASSESSMENT OF ABRAMS CREEK IN THE
GREAT SMOKY MOUNTAINS NATIONAL PARK: MANAGEMENT
IMPLICATIONS AND COMPARISON OF EMPIRICAL AND ANALYTICAL
PHYSICAL ASSESSMENT APPROACHES**

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Abstract:

Natural resource managers in the Great Smoky Mountains National Park requested the assistance of the University of Tennessee Department of Civil and Environmental Engineering to assess Abrams Creek for potential stream restoration needs. A presumed, unstable study reach and a stable reference reach were identified on Abrams Creek in Cades Cove. Chemical, biological and physical assessments were completed on Abrams Creek in order to evaluate ecological health and channel stability of the stream. Water quality and ecological (fish and habitat surveys) data acquired by National Park Service, Tennessee Valley Authority and the University of Tennessee were assessed. The physical assessment included two approaches; they were: 1) empirical or reference reach approach; and 2) analytical or non-reference reach approach. The current empirical technique used was the analog Natural Channel Design. The current analytical techniques were the hydraulic, sediment transport and erosion models (HEC-RAS, CONCEPTS). These physical assessment techniques were used to determine bankfull or effective flows, sedimentation, stream stability, and ecohydraulics. In addition to using these techniques for the Park's management objectives, they were applied to both reaches for comparison in order to clarify areas where professional judgment may introduce uncertainty. From comprehensive physical assessments no system wide instabilities were observed but some riparian area differences and localized erosion were noted. Recommendations for potential restoration needs on Abrams Creek include localized stabilization of stream banks and vegetating the riparian corridor along the study reach.

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Chapter 1: Introduction

Abrams Creek, a stream in Cades Cove in the Great Smoky Mountains National Park (GRSM), has been historically disturbed by agricultural practices and channel alterations from the 1820s, when the first pioneers settled, until 1999, when all cattle were removed. Observations of local bank failures by GRSM natural resource managers have led to the question of whether the channel is currently stable and if intervention by restoration measures is needed. GRSM resource managers requested researchers at the University of Tennessee (UT) to assess the channel stability and restoration needs of Abrams Creek.

In general, the need to address stream channel problems caused by land-use disturbances, such as agricultural practices, forest harvesting and urbanization has made stream restoration a widely applied practice today. Disturbances by land-use changes have led to channels responding systematically, including down-cutting and widening, resulting in bank failures, followed by slow recovery with bed aggradation (Simon 1999). Practitioners assessing a stream spend much effort addressing these channel responses.

Two general physical assessment approaches are used; they are the empirical and analytical approaches. The empirical approach is more commonly applied and requires a presumed stable reference reach. Geomorphic metrics are compared between the reference reach and the disturbed channel. The analytical approach does not require a reference reach but does use technical field data collection and computer models. Both approaches require similar input including channel geometry, hydrological and sediment data. However, in many restoration projects, including Abrams Creek, hydrological and

sediment transport data are commonly unavailable, which creates uncertainties when applying techniques. This point and the fact that Abrams Creek is no longer disturbed make it an excellent location to conduct and compare physical assessment approaches for stream restoration assessments.

Physical disturbances have not only affected the physical aspect of a stream but in turn also affect the ecological health. Lack of water quality (chemical) and biological assessments can lead to restoration designs that cause environmental harm. Fortunately, reasonable levels of these data were available on Abrams Creek for general assessments to be made. A stream is a very complex system, due to chemical, biological and physical elements. All of these elements are inter-related and necessary to consider, which requires involving many fields and interests (Figure 1), for a comprehensive stream assessment (Thompson 1996, Schwartz et al. 2001, Slate et al. 2007).

The objectives of the Abrams Creek study were to: 1) use empirical and analytical approaches for physical assessment to determine the channel stability condition in Cades Cove, 2) compare commonalities and differences between the two physical assessment techniques, and 3) assess the overall condition of Abrams Creek by integrating available chemical and biological assessments with the physical assessment, in order to support GRSM management needs.

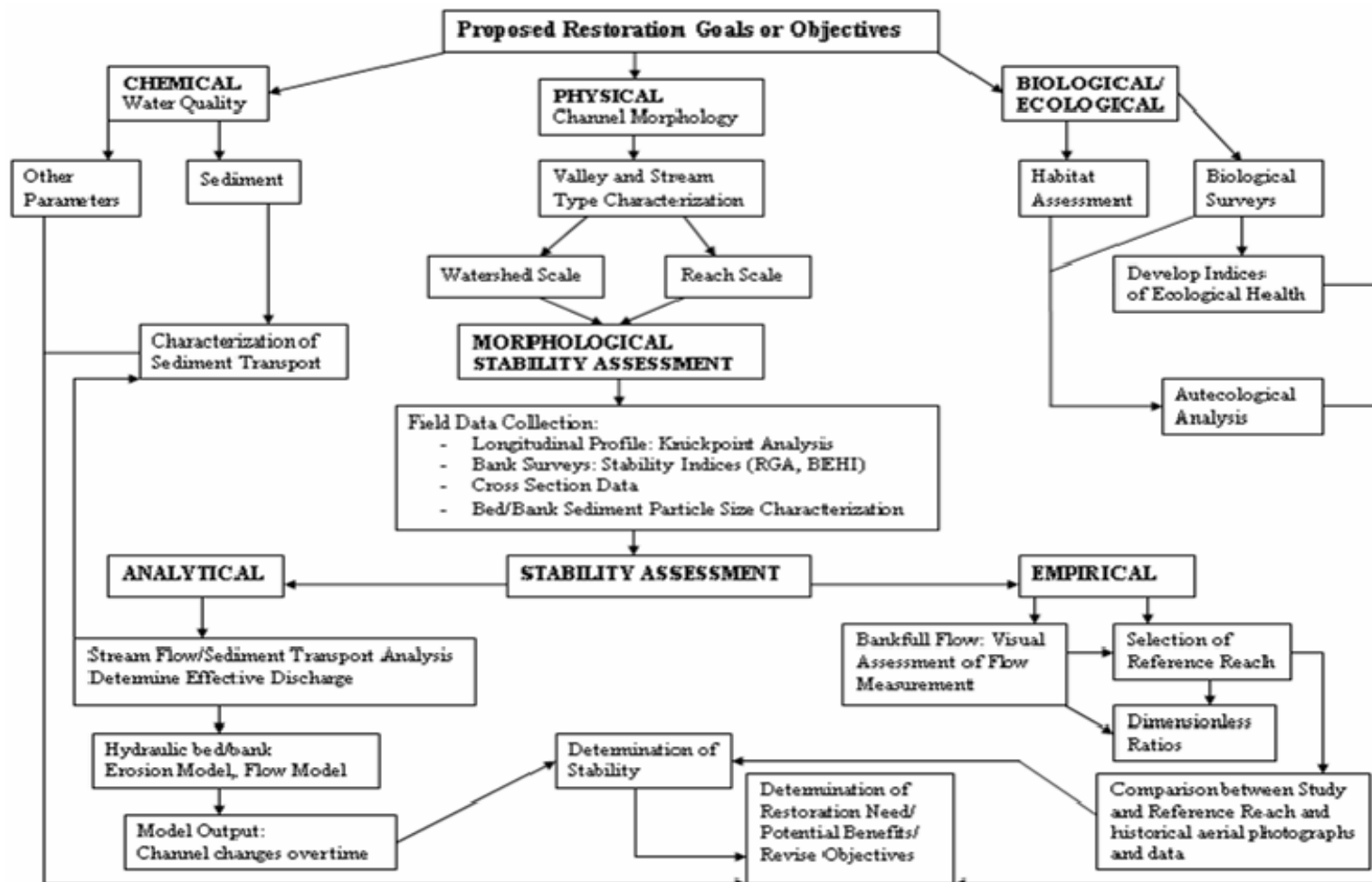


Figure 1: Flowchart of Stream Restoration Assessment Approaches

Chapter 2: Cades Cove Land Use History

Abrams Creek is located in Cades Cove, in the northwest region of the GRSM (Figure 2). The Cades Cove area was the site for pioneer farms and houses in the 19th and 20th centuries, agricultural practices (livestock and plant), and several population booms (GRSM 1998). Abrams Creek has been disturbed by deforestation, channelization, agriculture practices, and channel alterations (GRSM 1998).

Settlement in Cades Cove began in the 1820's. The first settlers cleared the forest for mostly subsistence farming and very little livestock. From the middle of the 19th century through the turn of the 20th century, Cades Cove experienced a couple of population booms, land divisions, and an increase in agriculture and livestock. By the 1930's the population had decreased to only 300 and disturbances due to agricultural practices and livestock were noted in GRSM documents.

From the 1930's to the 1960's, channel alteration and wetland destruction was prevalent. Channel alterations included channelization of streams, as well as dredging and clearing of debris, vegetation and sediment to manipulate flows (GRSM 1998). Channelization of the tributaries of Abrams Creek such as McCaulley and Maples Branches occurred until the 1970's (GRSM 1998). However, channelization was not performed in the Abrams Creek channel. Channelization led to the straightening and relocation of streams for irrigation and draining purposes and property boundaries. During this time, cattle activities such as overgrazing and free access to the streams were common. Incision, erosion and sedimentation resulted from these practices (GRSM 1998). During the 1970's studies were performed that showed that high siltation,

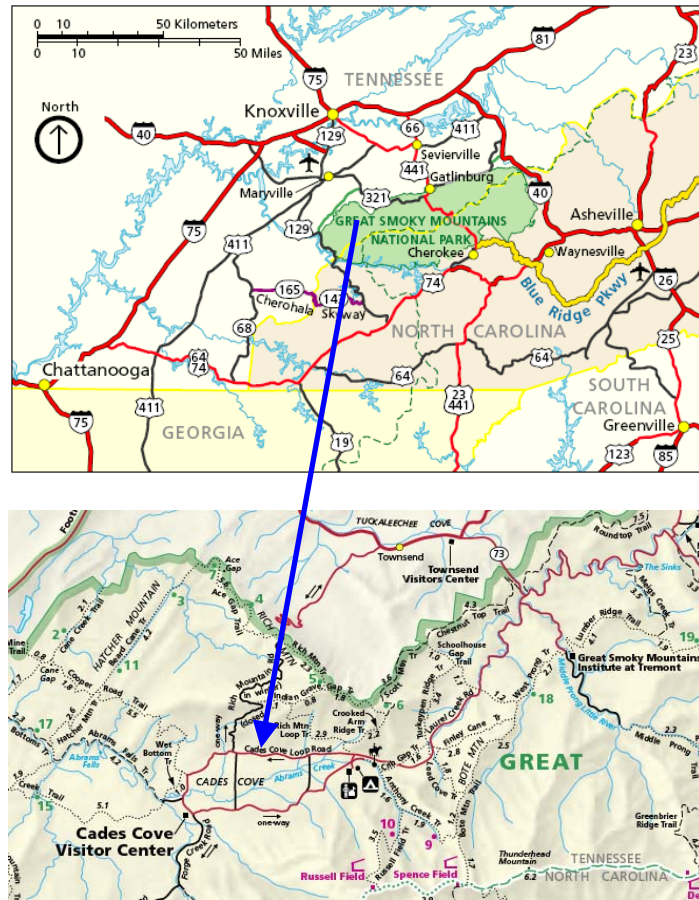


Figure 2: Site Location Map
(<http://www.nps.gov/grsm/planyourvisit/maps.htm>)

turbidity and bacteria levels present in the streams were detrimental to aquatic life (Kelly 1974, Silsbee 1976). Fencing was added due to these findings but improper maintenance of the fences occurred into the 1990's (GRSM 1998). However, these were not the first efforts at managing the streams in Cades Cove.

The first stream restoration measures in Cades Cove, under the CCC, came along when work on the GRSM began in 1933. These early measures included bank alterations and mulching. The dredging and channelization was part of a 1946 land use management plan. These channel management activities, along with bank stabilization, including rip rap and hay, were noted until 1970. During the 1970's fences were built and grasses and trees were planted to help prevent erosion. These activities continued through the 1990's until in 1999 all cattle were removed from Cades Cove.

Today, the Cades Cove area, encompassing approximately 4869 ha (18.8 mi²), is one of the most visited areas in the GRSM and preserves elements of pioneer life, with cabins, barns and meadows. It is home to a variety of wildlife, including bear, wild turkey, fox, deer, birds and, at one time, wolves. Within the Cades Cove watershed, Abrams Creek has a total change in elevation of 15 m (49 ft) over a total stream length of 9.7 km (6 mi) stream. Abrams Creek and its tributaries support an abundance of aquatic life such as macroinvertebrates and fish including endangered species such as the smoky madtom, yellowfin madtom, and spotfin chub (GRSM 1998).

Chapter 3: Methods

3.1 Study Design

The GRSM was approached to use Abrams Creek as a possible location for stream restoration/mitigation efforts (pers. comm. with GRSM staff 2005). Mitigation can involve restoration, enhancement or preservation of streams (Tweedy *et al.* 2006). First, though, the need for stream restoration must be based on a full examination of potential impacts and ecological stressors on a stream. Thus, a comprehensive approach to stream restoration assessment must include three key elements: chemical, biological and physical (Figure 1). Figure 1 illustrates the need for and inter-relationships of the chemical, biological and physical aspects of stream assessments, which was developed to guide the overall assessment for Abrams Creek.

An initial watershed assessment was performed on a section of Abrams Creek (Figure 3) to identify all possible channel instabilities in the three areas identified in Figure 1. The segment of the creek under inspection for this study is between Sparks Lane (upstream) and Hyatt Lane (downstream) (Figure 3). These are two “cut-through” roads along the Cades Cove Loop Road (GRSM 1998). Also, a section of creek located near the lower end of the Cades Cove Loop Road served as a reference reach.

Information on Abrams Creek and Cades Cove was gathered from the GRSM for this research. Information included reports on previous disturbances and restoration efforts, studies on aquatic life and water quality, and historic aerial photographs. The water quality data were used for the chemical assessment. The biological assessment was based on fish and habitat surveys. The historic aerial photographs provided an evaluation

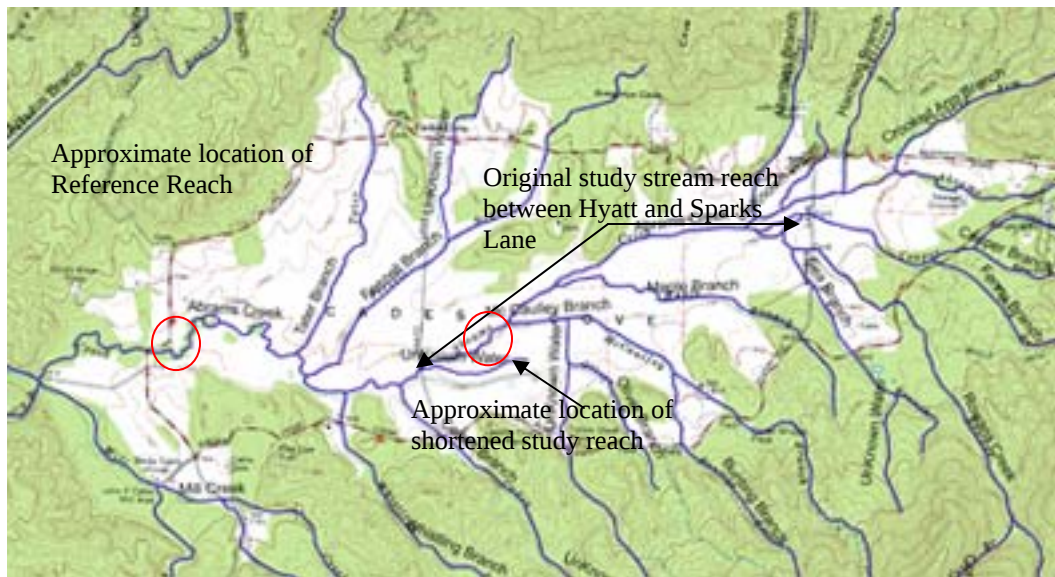


Figure 3: Location of Reference and Study Reaches in Cades Cove (USGS Cades Cove Quad 1997)

of physical channel changes over time. The chemical and biological data can help provide an assessment of the natural system and guide further physical assessments and designs. However, in many current stream restoration projects these assessment elements are not taken into account and the focus is based on the physical assessment. The main focus of the stream assessment for this study was also on the physical stability assessment of the stream, utilizing both empirical and analytical geomorphic approaches.

3.2 Chemical Assessment

For this study, water quality data were compiled and compared, qualitatively, to Tennessee Department of Environment and Conservation (TDEC) standards for potential chemical stressors to the stream ecosystem. Tennessee Valley Authority (TVA)

conducted a water quality assessment on Abrams Creek and surrounding streams in 1993 and 1994. These data were compared to current TDEC water quality standards. Sediment loads were also analyzed using CONCEPTS as part of the water quality analysis.

3.3 Biological Assessment

Biological assessments included the evaluation of existing fish data from the GRSM staff and physical habitat surveys conducted by UT. Fish surveys were conducted by the GRSM staff from 1993 to 2002 in locations upstream and downstream of the section of Abrams Creek being assessed in this study (Figure 4). The occurrences of species at these sites were compared throughout the years to observe biota quality. Physical habitat surveys were conducted along the study and reference reaches in the fall of 2006 by UT. Mesohabitat units, including riffle, pool, run, and glide, were defined along the reaches according to Arend (1999). Boundaries of the units were determined using visual estimates and a 30-m tape and plotted on the longitudinal profile. Metrics of the habitat survey include bed substrate, large woody debris and vegetation (Kaufmann 1999). Physical dimensions such as average and maximum depth, width and length were collected as well (Schwartz 2002, Schwartz and Herricks 2007). The habitat metrics were compared in reference and study reaches. From these two surveys a qualitative evaluation of ecological health can be made.

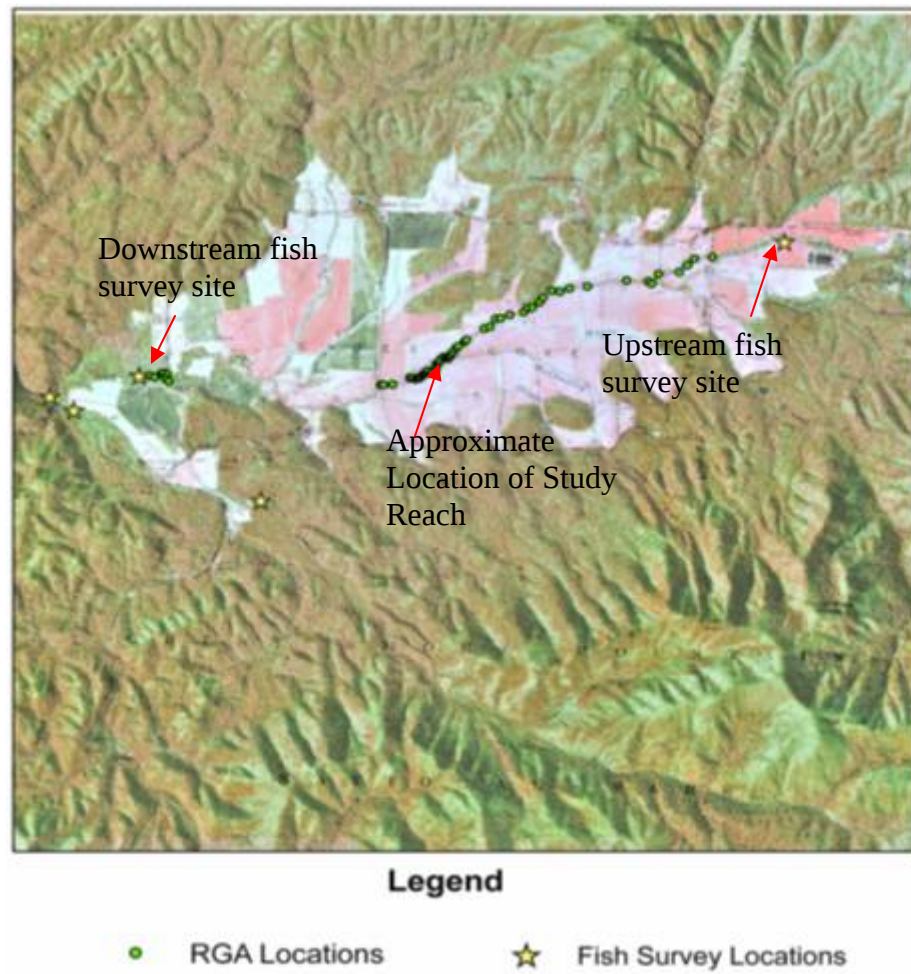


Figure 4: Fish Sampling and RGA Locations

3.4 Physical Assessment

The physical assessment included analysis of aerial photographs, field data collection (longitudinal profiles, cross-section geometries, bed and bank sediment particle characterization and bank stability surveys) and empirical and analytical stability assessments. One bank stability survey is the Bank Erosion Hazard Index (BEHI), which is a component of Natural Channel Design (NCD) and was used in this context for this study (Section 4.4). However, the BEHI could be used independently as a qualitative bank stability survey (Figure 1). The rapid geomorphic assessment (RGA) is another bank stability survey conducted in this study. The longitudinal profiles and RGA's were collected between Hyatt and Sparks lanes and in the reference reach near the Cades Cove Loop Road (Figure 4). All other field data was only taken from a shorter section, between Hyatt and Sparks lanes, and in the reference reach (Figure 3). The field data was required for both the empirical and analytical stability assessment approaches. The empirical physical assessment approach followed NCD protocol for a level III assessment. This technique required a reference reach, which was located downstream of the study reach (Figure 4). The analytical physical assessment approach used the field data as input for hydrologic, sediment transport and bed and bank erosion computer models.

3.4.1 Aerial Photograph Analysis

Aerial photographs, provided by GRSM staff, were used to conduct a watershed scale analysis of Cades Cove. Historical aerial photographs from the years 1953, 1963,

1979 and 1997 were digitized and entered into ArcGIS to analyze physical changes in Abrams Creek over time. The aerial photographs also aided in performing level I of the NCD (Section 4.4).

3.4.2 Channel Survey Data

Channel survey data included longitudinal profiles and cross-section geometries. Survey data were collected using a Nikon level, stadia rod, 30-m tape and survey compass. The longitudinal profile determined slope and sinuosity, and assisted in a knickpoint analysis. A knickpoint is a location in a channel where bed characteristics change, indicating instability (Hey 2006). The point of beginning was established at a bridge on Hyatt Lane and continued along the thalweg of the creek to the crossing of Sparks Lane. The tape was stretched straight in varying lengths in order to include the meanders of the creek. Elevation measurements were taken at horizontal increments in order to adequately represent bed topography. As each tape was stretched out, a bearing was taken using a survey compass. Station and tape numbers and tape length were recorded and marked with survey tape to later reference for other data collections. The survey covered approximately 3.5 km and a change in elevation of 11.5 m. This same procedure was conducted on the reference reach site at the lower end of Abrams Creek near the Cades Cove Loop road. The point of beginning was a bridge, along the loop road, crossing Abrams Creek and followed the thalweg of the stream approximately 267 m and an elevation change of 0.4 m to a beaver dam upstream.

Cross-sections were surveyed using the same tools as the longitudinal profiles. Locations and plots of the cross-sections can be found in Appendix A. Cross-sections were located at a spacing and distribution of habitat units to give a proper representation of the stream. A total of 16 cross-sections were surveyed on the study reach and six cross-sections along the reference reach. Three cross-sections were surveyed near Sparks Lane in order to classify the entire study reach.

3.4.3 Bed and Bank Sediment Data

Sediment data were required for both physical stability assessments. Sediment data were collected in two distinct populations (channel bed and banks) of the study and reference reaches of Abrams Creek to characterize the particle distribution in each distinct population. The two techniques used were the Wolman pebble count for the bed and sieve and hydrometer particle size distribution tests for the banks and some of the bed, such as pools and bars (Wolman 1954, ASTM D421 and D422). The bank samples were taken within the bankfull channel. A pebble count was performed with all habitat units. Particle size distributions were developed from these data.

The Wolman pebble count was conducted following standard procedures in the riffle physical habitat units. However, due to extreme weather conditions, a modified version of the Wolman pebble count method was used to determine a particle size distribution on the bed of the stream. The channel bed of areas with greater depths, such as in pools, were more difficult to reach and the temperature of the water required gloves in order for prolonged contact. This modified version consisted of stretching a 30-m tape

across riffles and collecting 100 particle samples at random. Samples were taken at approximately 0.2-m increments in a zigzag pattern across the riffle habitat unit until all samples were collected. At each 0.2-m increment, a handful of bed material was taken and a representative particle size taken from this grab sample. If the majority of the grab sample appeared to be less than 2 mm, the sample was considered fines. If the majority of the grab sample was greater than 2 mm, with eyes averted, a random particle was selected and measured. If greater than 40% of the samples were labeled fines, a grab sample of the bed was taken to perform a sieve and hydrometer lab test for proper particle size distribution. This grab sample lab test was also used for particle size distribution in pools. Grab samples from the banks were gathered and tested using the same sieve and hydrometer technique.

3.4.4 Rapid Geomorphic Assessment

The RGA assessment was applied to Abrams Creek in the section of stream between Hyatt and Sparks lanes and in the reference reach at the lower end of the creek, near the Cades Cove Loop Road (Figure 4). This assessment allowed a rapid means of selecting a locally disturbed section of stream for purposes of this study. RGA's and visual assessment, also, determined a section of Abrams Creek, located near the southern end of Cades Cove, to be used as a reference reach. The protocol for the RGA survey can be found in Appendix B.

RGA is a process-based classification system that determines geomorphic mechanisms acting upon a channel at a particular site, at a particular point in time (Simon

and Darby 1999). Among other channel geomorphic characteristics, RGA's use the channel evolution system (Simon and Hupp 1989). Determining the evolutionary stage of a stream is critical for assessing the current stability, future potential, and need for and means of restoration (Hey 2003, Rosgen 2006, Shields *et al.* 2003, Simon 2007). The evolutionary classification scheme used in the RGA was developed primarily for and limited to channelized, degrading (incised) streams that have adequate time and space to adjust through all stages of evolution (Niezgoda and Johnson 2005). The channel evolution of a stream has six stages according to Simon and Hupp (1989) (Figure 5). Following the RGA data form, stream reaches are scored (0-36). Scores less than 10 are considered, stable and those greater than 20 are unstable (Simon *et al.* 2004).

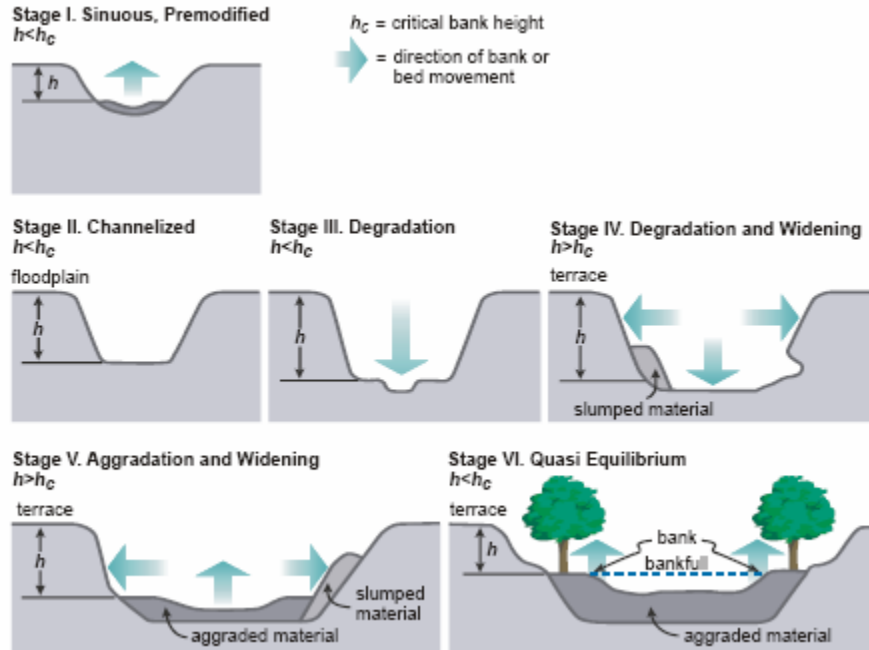
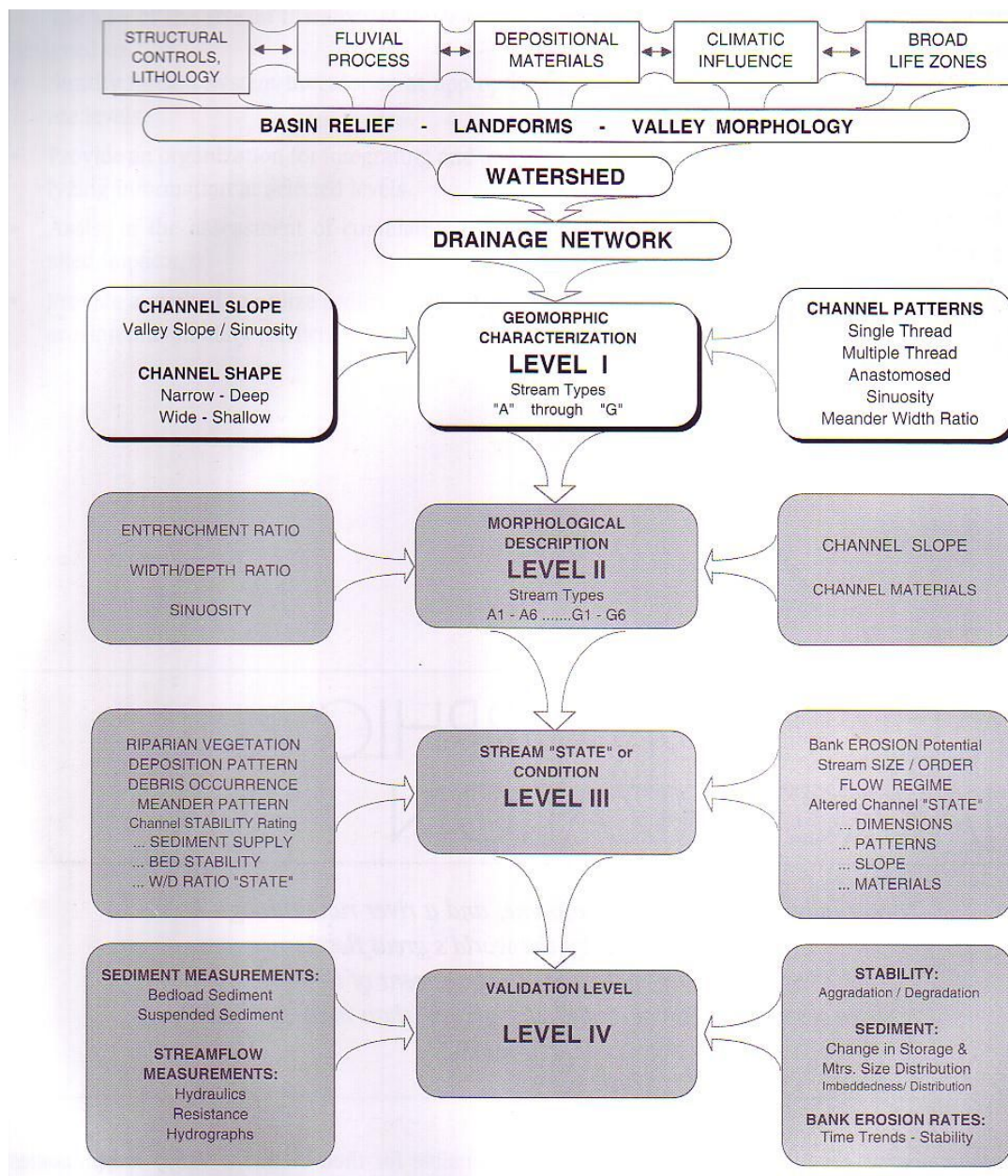


Figure 5: Stages of Channel Evolution
(Simon *et al.* 2004)

3.4.5 Empirical Physical Stability Assessment

The empirical physical assessment used the channel survey and sediment data to perform the NCD Level III stability assessment. NCD uses the form-based Rosgen classification system as a basis for predicting stream stability. Because of its widespread usage, NCD will be the focus of the empirical physical assessment analysis. The data sheets can be found in Appendix B.

NCD is a method applied to assess streams and create channel designs for restoration purposes. NCD consists of four levels; however, for this study only a Level III assessment was applied (Figure 6). This empirically-based assessment requires a reference reach. This approach is the basis for NCD, as found in the book “Applied River Morphology” and papers by David Rosgen (Rosgen 1996). Level I of NCD uses historical documents, aerial photographs and maps to generally classify a stream based on geomorphic properties (Rosgen 1996). The benefit of Level I classification is to provide a rapid assessment of the types of streams, landforms, soils, and morphologies that can exist in an area. Level II uses the channel survey and sediment data to further classify the stream into certain stream types. Bankfull measurements play a critical role in this level of classification (Rosgen 1996). Bankfull level was determined visually, from regional curves, and checked using the HEC-RAS model (Section 4.5.1). Average values, throughout each reach, were used for classification. After classifying the study stream, a reference reach of the same stream type but in a stable condition was chosen to perform Level III assessment (Figure 3).



**Figure 6: Levels of NCD
(Rosgen 1996)**

Level III of NCD incorporates hydrologic, biological, ecological and human factors into the classified morphology. This level of assessment uses a departure analysis, comparing the study reach to a stable reference reach, in order to further describe a stream's existing condition, stability, and maximum potential. Data such as the Pfankuck channel stability evaluation and reference reach geometry are used to determine departure from the stable, reference reach. The BEHI and Near Bank Stress (NBS) assessments are part of this level of assessment. The BEHI uses bankfull channel geometry and bank characteristics to qualitatively assess bank erosion potential. Method 5 of NBS was used for the near bank stress evaluation. NBS is another technique in the Level III NCD that qualitatively assesses erosion potential due to stresses near the bank. Method 5 uses a ratio of the near-bank maximum bankfull depth divided by the average bankfull depth to get a stress rating (Rosgen 1996). A modified Pfankuch evaluation was developed by Dr. Ray Albright at UT (Albright, pers. comm.). Originally the Pfankuch evaluation was developed for streams in the Northwest United States. The modified evaluation regionalizes the form for the Southeast United States. The field sheets for each assessment can be found in Appendix B.

STREAMS, a robust suite of spreadsheet tools designed by the Ohio Department of Natural Resources and Ohio State University, aided in calculating reach parameters such as slope and bankfull measurements needed for the empirical-based assessment. Modules included in STREAMS include: reference reach spreadsheet, regime equations, cross section and profile, sediment equations and contrasting channels. Only the cross-

section and profile module was used in this study. Cross-section and longitudinal profile plots can be see in Appendix A.

3.4.6 Analytical Physical Assessment

Two computer models, HEC-RAS and CONCEPTS, were used in this study to determine hydrologic and sediment transport and bank erosion properties, respectively, for stability analysis. Analytical physical assessment techniques do not require a reference reach. This approach used field data collection (Sections 3.4.2 and 3.4.3) as input for hydrologic and sediment computer models.

3.4.6a HEC-RAS

HEC-RAS river analysis system is a modeling program developed by the Army Corp of Engineers to assist in hydraulic analysis of open channel systems. Steady flow was simulated in Abrams Creek using HEC-RAS. This model is also capable of simulating unsteady flow and the effects of in-stream structures and tributaries. However, these factors were not relevant for this study. The steady gradually varied flow component of HEC-RAS uses a one-dimensional energy equation for computation. Manning's equation and expansion/contraction equations are used to evaluate friction (USACE 2006).

Input for the model included channel geometry (longitudinal and cross-sectional), boundary roughness conditions (Manning's n) and flow information. The channel geometry was collected through field surveys. Typical Manning's n values from

hydraulic texts were used for roughness boundaries. HEC-RAS was applied to Abrams Creek in order to determine an effective discharge and verify bankfull measurements used in the empirical physical assessment approach. The use of a check is recommended in the NCD approach (Rosgen 1996). The output includes cross-sectional and longitudinal water surface profiles (Appendix C).

A synthetic flow data set was required for the CONCEPTS model (Section 3.4.6b). No gauges and very limited historical flow data were available on Abrams Creek. Using the effective discharge, determined by HEC-RAS, and storm data from a nearby United States Geological Survey (USGS) gauge (Little River near Maryville, TN), a synthetic flow data set was created. A couple of assumptions were made to create this flow data set. First, the bankfull flow was assumed to be the effective flow. Second, the recurrence interval for this flow was assumed to two years, so two years' worth of data from the nearby gauge was used. Third, the USGS gauge was on a much larger stream, so the hydrograph was normalized using the bankfull flow for Abrams Creek. A ratio of the two-year peak gauge reading and modeled effective flow was developed and the rest of the flow data were multiplied by the ratio to get a flow data set following the same storm pattern. To represent the intermittent subsurface flow during June through August, a value of zero was used for the synthetic flow data.

3.4.6b CONCEPTS

The CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) model is a one-dimensional sediment transport model (Langendoen 2000).

CONCEPTS is composed of three physical-process components, including: 1) hydrodynamics for unsteady flow hydraulics, 2) mobile bed dynamics accounting for sediment transport and bed adjustment, and 3) bank erosion and channel widening from fluvial and geotechnical processes. CONCEPTS utilizes distributed flow routing for the hydrodynamic model through the application of the conservation of mass and momentum. The continuity and momentum equations are shown as follow, respectively:

$$B \frac{\partial y}{\partial t} + \frac{\partial Q}{\partial x} = q_L$$

where, B = top width
Q = discharge
t = time
x = distance in stream wise direction
q_L = lateral flow into channel per unit length of channel

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q^2}{A} \right) + gA \left(\frac{\partial y}{\partial x} + S_f \right) = 0$$

where, Q = discharge
t = time
x = distance in stream wise direction
A = cross-sectional area
g = gravitational acceleration
y = flow depth
 $S_f = \frac{n^2 Q^2}{A^2 R^{4/3}}$; energy slope
n = Manning's roughness coefficient
R = hydraulic radius

Momentum and mass conservation laws are applied as either dynamic and diffusion wave model, depending on whether inertia terms are neglected and the expression can be

simplified for subcritical flow conditions (Sturm 2001). CONCEPTS uses the generalized Preissmann method (Cunge *et al.* 1980) of discretization to solve for the dynamic and diffusion wave hydrodynamic models. This method is compatible to a spatially varying grid, and it is implicit in time (Langendoen 2000). The Preissmann method is a forward time finite difference numerical method.

Sediment transport is directly related to flow hydraulics, bed-material composition, and upstream sediment contribution (Langendoen 2000). CONCEPTS represents the total sediment load, the sum of the bed and suspended load, utilizing different empirical transport functions for a range of sediment size classes. CONCEPTS uses a modification of the SEDTRA sediment transport capacity predictor developed by Garbrecht *et al.* (1996) to predict the sediment transport of the 14 individual size classes (Table 1). Conservation of mass for each size class is achieved using the following advection equation:

$$\frac{\partial C_k}{\partial t} + \frac{\partial u C_k}{\partial x} = E_k - D_k + q_{s_k}$$

where, t = time
 x = stream wise distance
 u = flow velocity
 E_k = entrainment rate of particles, per k size class
 D_k = deposition rate of particles, per k size class
 q_{s_k} = rate of sediment inflow from banks and fields adjacent to channel
 $k = k^{\text{th}}$ size class
 C = sediment mass

Table 1: Sediment size classes used in CONCEPTS and the empirical transport equations used per size class

Size Class	Upper Bound (mm)	Representative diameter (mm)	Description	Transport Equation
1	0.010	---	clay-very fine silt	Washload
2	0.025	0.016	fine-medium silt	Laursen
3	0.065	0.040	medium-coarse silt	Laursen
4	0.250	0.127	fine sand	Laursen
5	0.841	0.458	medium-coarse sand	Yang
6	2.000	1.297	very coarse sand	Yang
7	3.364	2.594	very fine gravel	Meyer-Peter and Mueller
8	5.656	4.362	fine gravel	Meyer-Peter and Mueller
9	9.514	7.336	fine gravel	Meyer-Peter and Mueller
10	16.000	12.338	medium gravel	Meyer-Peter and Mueller
11	26.909	20.749	coarse gravel	Meyer-Peter and Mueller
12	38.055	32.000	coarse gravel	Meyer-Peter and Mueller
13	64.000	49.351	very coarse gravel	Meyer-Peter and Mueller
14	128.000	90.510	small cobbles	Meyer-Peter and Mueller

Temporal variations of the bed material, expressed as an Exner formulation is given as:

$$(1 - \lambda) \frac{\partial A_{b_k}}{\partial t} = D_k - E_k$$

where, A_b = cross-sectional area of the mixing layer
 λ = bed sediment porosity

Entrainment and deposition rates differ for cohesiveless and cohesive bed material, and they are computed by different methods, and explained by Langendoen (2000). For cohesiveless bed material, key physical parameters include particle fall velocity (w), flow depth, (h), and shear velocity (u^*). For cohesive bed material, key physical parameters for erosion include the bed shear stream (τ_b), shear strength of the bed material (τ_e), and erosion-rate constant (e). Bank shear strength and erosion-rate constant were determined

in-situ using the submerged jet tester developed by the USDA National Sedimentation Laboratory (Clark and Wynn 2006). Entrainment and sediment transport occurs when bed shear stress (τ_b) is greater than some critical shear (τ_c) for Shields incipient motion, and is the fundamental basis for the Laursen, Yang, and Meyer-Peter and Mueller equations. Critical shear for Shields incipient motion is based on uniform sand transport, and therefore needs to be corrected by mixed size compositions of bed sediment. This is done in CONCEPTS by a hiding coefficient (χ), which ranges from 0 to 1, and adjusted per particle size class as follow:

$$d_{c,k} = d_k \left(\frac{\bar{d}}{d_k} \right)^\chi$$

where, $\bar{d}$ = mean size of the bed material
 d_k = representative diameter of k size class
 $d_{c,k}$ = adjusted representative diameter of k size class
 χ = hiding coefficient

Computation of fraction bed concentration from discretized spatial nodes (upstream to downstream) for bed sediment transport is accomplished by numerical solution using the method of characterization. Numerical stability is achieved by selecting the appropriate discretization scheme based on the Countant number. CONCEPTS compute variations in streambed elevations over time accounting for changes in bed material area (ΔA_{bk}) based on the difference between intermediate sediment concentrations (C_k), expressed as:

$$\Delta A_{b_k} = (A_{b_k})_j^{n+1} - (A_{b_k})_j^n = \frac{1}{1-\lambda} \left[(C_k)_j^n - (C_k)_j^{n+1} \right]$$

CONCEPTS vertically divides the bed into a surface layer (area) and several subsurface layers, and keeps track of the different bed sediment compositions of surface and subsurface sediment layers. Initial boundary conditions for the bed sediment layer are entered from field collection of bed sediment at channel cross-sections (model nodes). An external boundary condition requires information at the upstream most on sediment discharge over time by particle size class. An external boundary condition at the downstream end is not required, whereby the model processes determine the bed elevation and sediment composition at the model outlet location. Bed elevation at the model outlet can be controlled by adjusting the change in bed area material, as expressed as follows:

$$\Delta A_{b_b} = (1 - m) \Delta A_{b_k}$$

where, m = adjustment factor (0 = no control, 1 = full control)

Sediment delivery (or inputs) at model nodes determine using Wolman pebble counts and sieve and hydrometer lab testing on channel banks and bed. Data input at designated model nodes (cross-sections) are organized in appropriate particle size classes (k) as classified in CONCEPTS. Sediment contributions by particle size are then routed through the channel.

The final physical component of CONCEPTS is modeling bank erosion and channel widening. This component provides the user with the ability to model channel width adjustment by incorporating the fundamental physical processes for bank retreat; they are:

- 1.) fluvial erosion or entrainment of bank material particles by flow, and
- 2.) mass bank failure (wasting), typically occurring as channel incise.

CONCEPTS accounts for cohesiveless and cohesive bank material, and uses a multi-layer modeling approach for vertical differences in soil properties. Lateral bank erosion by fluvial processes is based on the relationship:

$$W_i = \frac{0.037}{\rho_s} \tau_e e^{(-1.3\tau_e)}$$

where, τ_e is the critical shear stress for soil entrainment.

The rate of soil erosion is assumed to be approximately linear with increases in boundary shear stress (τ); thus the actual erosion rate for a given time step is given as:

$$\Delta W = W_i \left(\frac{\tau}{\tau_e} - 1 \right) \Delta t$$

Fluvial erosion at the bank toe eventually causes bank instability resulting in mass wasting of the bank material. Bank instability depends on the balance between gravitational forces that tend to drive the soil mass downwards and the forces of friction and cohesion that resist mass movement. Vegetation on the bank affects the rate of width adjustment and mass failures, where its influence can be both stabilizing or destabilizing. Bank stability analysis is accomplished by limit equilibrium methods, based on static equilibriums of forces and and/or moments of a failure block. The forces acting on a failure block include (Figure 7):

- 1.) the weight of the failure block, W_s
- 2.) the weight of surface water on the failure block, W_w
- 3.) the hydrostatic force exerted by the surface water on the vertical slip face, F_w
- 4.) the hydrostatic force exerted by water in the tension crack, F_t
- 5.) the seepage force, F_s
- 6.) the shear force at the base of the failure block, S
- 7.) the total normal force at the base of the failure block, N

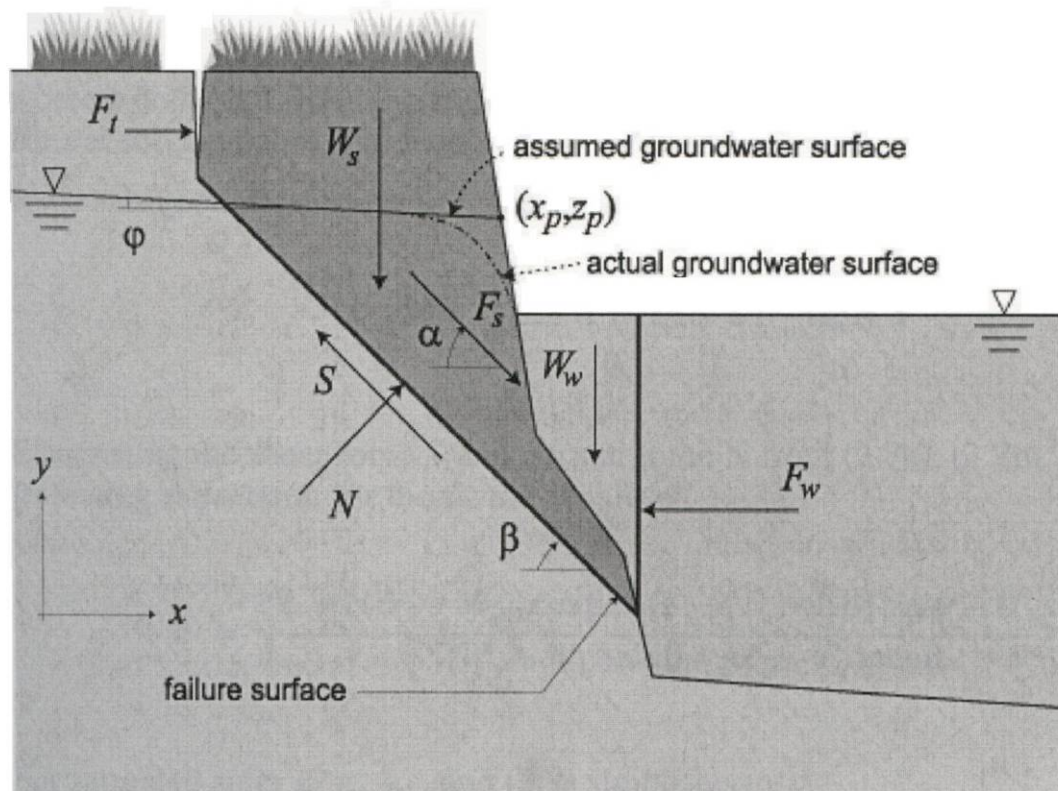
The total stress normal to the base of the failure block can be expressed as follows:

$$S = \frac{L}{F} \left[c' + (\sigma_n - u_a) \tan \phi' + (u_a - u_w) \tan \phi^b \right]$$

where, L = length of the inclined slip surface
 c' = effective cohesion
 $(\sigma_n - u_a)$ = normal stress state variable
 ϕ' = effective angle of internal friction
 $(u_a - u_w)$ = matric suction
 ϕ^b = angle for shear strength due to matric suction

The seepage force is dependent on pore-water pressure, which can be hydrostatic or non-hydrostatic dependent on a hydraulic gradient and assuming Darcian flow. Pore-water pressure ratio (r_u) is used rather than pore-water pressure (u_w), expressed as:

$$r_u = \frac{u_w}{\gamma \cdot d}, \text{ where } d \text{ is the depth below the soil surface.}$$



is partitioned by size class, and added to the sediment mass governed by conservation laws.

Chapter 4: Results and Discussion

4.1 Chemical Assessment

According to the 1995 TVA report and comparison with TDEC standards the water quality in Abrams Creek is good. Table 1 is a summary of water quality values from the TVA water quality studies (1993 and 1994) and current TDEC water quality standards. As shown in Table 1 below and stated in the TVA report (1995), all water quality parameters were within TDEC standards. A few pH readings below the allowable 6.5 were detected at some of the sites. The report states that the methods used to measure pH could have introduced a discrepancy of 0.3 to 1.0 pH units. So on average the pH was within EPA limits. Phosphorus was the only nutrient that was suspected of creating water quality concerns, but the readings were well within the limits. High dissolved oxygen and low biological oxygen demand (BOD) levels indicated good water quality (TVA 1995). During the period of sampling, cattle were still present in Cades Cove. However, all of the cattle were removed in 1999.

Table 2: Summary of Water Quality Data

Station	Average pH	Turbidity (NTU)	Ammonia Loadings (ug/L)	N0x Loadings (ug/L)	Phosphorous Loadings (ug/L)
4	6.2	0.92	0.05843	0.19791	0.02114
5	6.6	2.2			
6	7.6	2.04			
7	7.4	1.65	0.06293	0.30721	0.04853
TDEC Standard	6.5 - 9	1.0 - 5.2	0.21-0.58		5.63 - 10.47

*Ammonium and N0x loadings standards are for total nitrogen

4.2 Biological Assessment

4.2.1 Fish Survey

The majority of fish species located in the sampling sites were found both upstream and downstream of the study reach, indicating a good level of biota in Abrams Creek. However, this biological assessment of fish was only a qualitative examination of data to evaluate whether an obvious problem exists. Table 3 summarizes the year different fish species were found in sites upstream of the study reach and downstream of the reference reach (Figure 4). The fish surveys were conducted once a year by the GRSM, except in 2003. The white sucker, warpaint shiner, fantail darter and longnose dace are the only species that were never found in both locations. The first two were only in the downstream sampling site and the latter two were only found in the upstream site. Most species were highly tolerant of stressors and siltation and high turbidity were the only intolerances of the fish species found in Abrams Creek. There was no evident explanation as to why some species disappeared from yearly surveys. However, cattle were still present during most of these years which could have affected the fish populations.

4.2.2 Habitat Survey

The habitat characteristics of the reference and study reaches were similar, thus a good level of habitat availability in the study reach. Table 4 is a summary of the habitat metrics surveyed in the study and reference reaches of Abrams Creek in the fall 2006. The reference and study reaches both have similar physical habitat attributes, as seen in

Table 3: Summary of Fish Surveys (GRSM)

Species	Species Name	Year Present Upstream of Study	Year Present downstream of study
BND	Blacknose Dace	93,94,95,96,97,98,99,00,02	93,94,95,96,97,98,99,00,02
CKC	Creek Chub	93,94,95,96,97,98,99,00,02	93,94,95,96,97,98,99,00,02
NHS	Northern Hogsucker	93,94,95,97,98	93,94,95,96,97
RBT	Rainbow Trout	93,94,95,96,97,98,99,00,02	93,94,95,96,97,98,99,00,02
RIC	River Chub	93	93,95,97,98,99,00
RSD	Rosyside Dace	93,94,95,96,97,98,99,00,02	93,94,95,96,97,98,99,00,02
STR	Stone Roller	93,94,95,96,97,98,99,00,02	93,94,95,96,97,98,99,00,02
TSD	TN Snubnose Darter	93,94,95,96,97,98,99,00,02	93,94,95,96,97,98,99,00,02
WHS	White Sucker		93,94,95,96,97,98,99,00,02
WPS	Warpaint Shiner		93,94,95,96,97,98,99,00,02
FTD	Fantail Darter	93,95,96,97,98,99,00,02	
LND	Longnose Dace	93,94,95,96,97,98,99,00,02	
TNS	Tennessee Shiner	93	

Table 3. They both also contain many of the same species of fish (Table 3). The dominant bed material in both reaches was sand and gravel. The bank vegetation along both banks of the reference reach was much more abundant with large woody vegetation and had a greater density overall than the study site. This correlates with the ratio of total and volume of large woody debris (LWD) by reach length in the channel. The ratio of volume LWD in the reference reach is twice that of the study and the number is pieces is 1.5 times greater in the reference than the study reach. The pool-riffle spacing in both reaches is 3 to 4 channel widths. This is less than the proposed stable spacing of 5 to 7 channels widths by Rosgen (1996).

Although the study reach has intermittent seasonal flows, it serves as a corridor for the fish species found in both locations. The habitat structure used by these fish provides a corridor so that they can move throughout the stream when flow is present, providing longitudinal connectivity.

Table 4: Summary of Habitat Survey

	Length (m)		Reach slope	Avg. Pool-Riffle Spacing (m)	Total LWD	Ratio of LWD/Length	Volume of LWD (m³)	Ratio of Volume of LWD/Length
Study Reach	466.5		0.0027	18	47	10	38.2	8.2
Reference Reach	267		0.0015	25	48	16	42.6	16
	Habitat Unit	Total Habitat Units	% by Length	Avg. Depth (m)	Avg. Width (m)	Total Root Wads		
Study Reach	Pool	16	53.5	0.65	4.39	17		
	Riffle	12	30.8	0.23	4.87			
	Glide	1	1.1	0.32	5.49			
	Run	5	14.6	0.33	4.29			
Reference Reach	Pool	6	62.6	0.67	6.94	14		
	Riffle	5	29.7	0.39	7.73			
	Glide	1	7.7	0.58	8.64			
	Run	0	0	0	0			

4.3 Physical Assessment

4.3.1 Aerial Photograph Interpretation

After comparing historical aerial photographs over a 40 year period (Figure 8), very little stream lateral migration was observed. Throughout all of these years, except 1973 and 1997, Abrams Creek was still being affected by dredging and channelization of its tributaries (GRSM 1998). Some reforestation, reseeding and fencing were done in the early 1970's and mid 1990's. However, comparing aerial photographs, dating back to 1925, shows very little increase in riparian vegetation. Some loss of large woody vegetation in the riparian corridor has occurred, based on observation of fallen trees within the time of the current study.

The tributaries McCaulley, Oliver and Maples Branches were all noted in reports to have been channelized (GRSM 1998). However, these do not appear to be migrating laterally either. Unlike Abrams Creek, visual observations of these tributaries exhibit down-cutting due to an increase in bed shear stress. This could be preventative of lateral migration, which could aid in reconnecting the flood plain and decreasing the down-cutting.

4.3.2 Channel Survey Data – Longitudinal Profile

The longitudinal profile between Hyatt and Sparks lanes identified a small knickpoint downstream of the karst sinks and Maples Branch (Figure 9). From observation, the section downstream of the knickpoint was determined to be less stable.



Figure 8: Comparison of Historical Aerial Photographs of Cades Cove

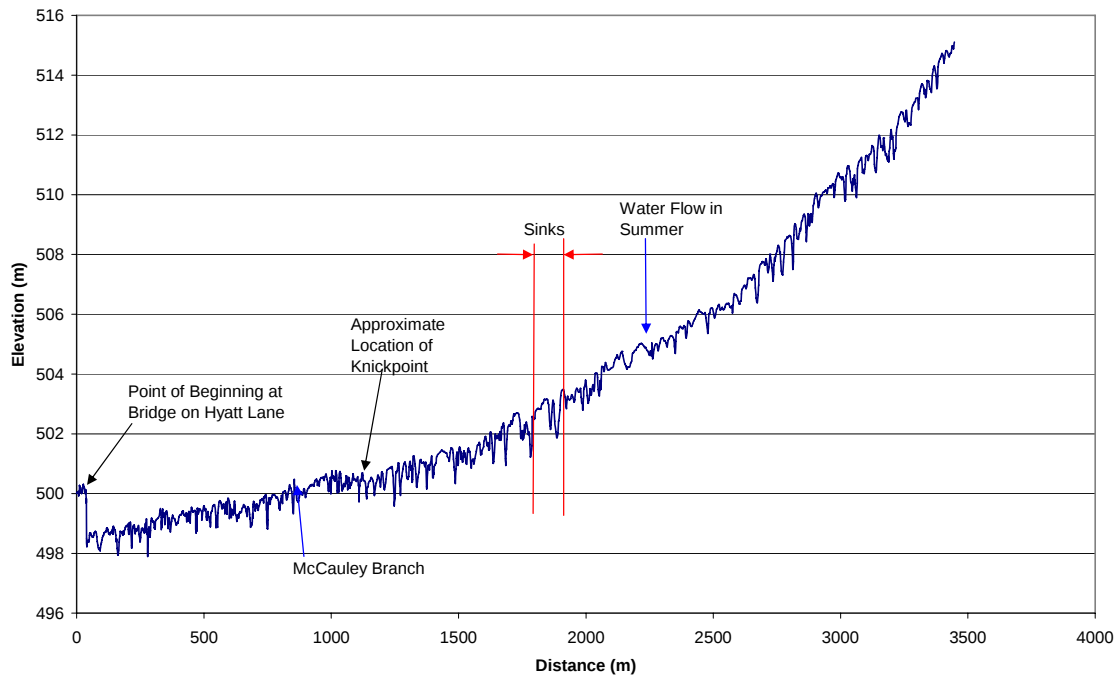


Figure 9: Longitudinal Profile of Abrams Creek between Hyatt and Sparks Lanes

Visual observations of the channel indicated increased incision and decreased riparian vegetation downstream of the knickpoint. A change in slope, from approximately 0.007 to 0.0025, can be seen from this plot. Also, a change in bed material from cobbles and gravel to small gravel and sand occurred at this point. Further assessments were conducted on a section downstream of this knickpoint. The shorter longitudinal profiles of the reference and study reaches can be found in Appendix A. The karst sinks carry the flow underground during part of the year and create a geological barrier for any upstream channel influences to carry on downstream past the sinks. The karst sinks and

channelized tributaries could have led to the development of the knickpoint and lessened stability in Abrams Creek.

4.3.3 Bed and Bank Survey Data

The D_{50} particle size for the most upstream section (between the sinks and Sparks Lane) was in the cobble range (64-256 mm); the study and reference reaches were in the small gravel class (2-22 mm). The D_{50} is the particle size that 50% of the sediment samples are equal to or smaller than. Table 5 summarizes average D_{50} values for individual channel features. As shown in this table, the particle sizes for the channel bed and banks are not necessarily the same or even within the same sediment particle classification. The banks are in the fine sand and silt category, whereas the riffle channel bed is gravel. The particle size distributions can be seen in the appendix.

Table 5: Summary of Particle Sizes in Bed and Banks

	Bank, Avg. D_{50} (mm)	Pool, Avg. D_{50} (mm)	Riffle, Avg. D_{50} (mm)
Study Reach	0.5	0.5	10
Reference Reach	0.15	3.0	7

4.3.4 Rapid Geomorphic Assessment

The RGA scored the study reach as less stable on average than the reference reach. Table 6 is a summary of the total RGA scores and channel evolution stages for Abrams Creek. Figure 4 shows the locations of the RGA's. The RGA also shows a change in channel stability below the knickpoint. The study reach scored some RGA indices above 20, indicating instability, and the evolution stage was also a less stable stage than the pre-disturbed reference reach. The stages evolution in the study reach involves degradation, aggradation, and widening. A channel evolution stage of V or VI is required for stability (Table 2 in Shields *et al.* 2003). However, these scores and evolution stages indicate that the stream is in dynamic equilibrium. According to the RGA and aerial photograph analysis, the stream is slowly adjusting naturally to a stable state.

Table 6: Summary of RGA

Section of Stream	Avg. and range of RGA scores	Avg. and range of Channel Evolution Stages
Hyatt to Sparks Lanes	17; 11.25-21.5	III - VI
Between Hyatt Lane and Sinks	18; 12.75-21.5	III - V
Between Sinks and Sparks Lane	16; 12.5-21.5	III -VI
Study Reach	19; 18-21.5	IV-V
Reference Reach	9.5; 8-11	I

4.3.5 Empirical Physical Assessment - Natural Channel Design

Abrams Creek is valley type VI and type C stream, according to the Rosgen classification system. The form-based, Rosgen Classification system is a key element of the NCD empirical assessment. Type VI valley is termed a fault-line valley according to Rosgen (1996). Type “B”, “C”, and “F” streams and “G”, when in disequilibrium, are found in this valley type (Rosgen 1996). Also, according to Rosgen (1996), this valley type exhibits a slope less than 4 percent and a low sediment supply. Type “C” streams usually feature sinuous, low relief channels, well developed floodplains, point bars and pool-riffle sequences (Rosgen 1996).

The Level II assessment used dimensionless ratios, determined from bankfull level, to further classify Abrams Creek into a specific stream type. Figure 10 shows several visual field indicators of bankfull flow. Initially vegetation and flow lines were identified and applied for bankfull determination. However, after further inspection these indicators did not produce a level near the top of bank (bankfull) channel capacity. Therefore, the top of bank was used as the bankfull level for classification. Regional curves are also commonly applied to determine bankfull parameters such as depth, width and discharge. Abrams Creek is in the Blue Ridge physiographic region. Field measurements were compared to the regional curve values as a check (Table 7). The percent differences between the regional curve predictions and field values were great for all measurements except bankfull depth in the reference reach. This indicates that for Abrams Creek, the regional curve method is not reliable.



Figure 10: Visual Observation of Bankfull

Table 7: Comparison of Regional Curve and Study Bankfull Values

		Drainage Area (mi ²)	Bankfull Flow (cms)	Cross Sectional Area (m ²)	Bankfull Width (m)	Average bankfull depth (m)
Value From Regional Curve	Study Reach	14.6	21.9	16.1	12.5	0.76
	Reference Reach	19.7	27.5	15.3	18.0	0.84
Avg. Value from Study and Percent differences b/t methods	Study Reach	14.6	10; 120%	5; 222%	7.4; 69%	0.64; 19%
	Reference Reach	19.7	10; 175%	8; 91%	9.6; 88%	0.84; 0%

* Regional curve and equations for above parameters can be found in the Appendix

Following the Level II protocol, the study and reference reaches were both classified as C4 stream types, according to Level II classification or morphological description. The reference reach was suitable because it possessed stable conditions and was of the same stream type and in the physiographic region as the study reach. The C4 stream is classified as having a slope less than 2%, have a high width/depth ratio, contain predominantly gravel with some cobbles, sand and silt/clay beds. The upper section, above the sinks, near Sparks Lane was classified as a type C3 stream. A “C3” stream contains the same features as the “C4” except the bed is predominantly composed of cobble with some gravel and sand. It is usually less sinuous than the “C4” stream type (Rosgen 1996). Table 8 shows a summary of the classification values on Abrams Creek. The criteria, forms and cross sections indicating bankfull level can be found in the appendix.

The whole NCD Level II classification hinges on the correct determination of bankfull level (Rosgen 1996). Three methods were utilized to determine bankfull; visual field indicators, regional curves, and HEC-RAS computer model (section 4.3.6a). Uncertainties using field bankfull indicators were recognized on the Abrams Creek study. Flow and vegetation lines on individual banks could show two different bankfull levels, sometimes well below the top of bank. The regional curve offered one form of a check but produced differing values from the analytically determined bankfull flow modeled in HEC-RAS. The regional curve prediction of bankfull flow was much greater than that observed in the field and modeled with HEC-RAS. Also, regional curves and NCD do not

account for karst geology. This unique feature to Abrams Creek inhibits use of classification systems developed for streams without karst.

According to the Level III NCD assessment the study reach is in a stable condition. This is indicated by very little departure from the reference reach and stable BEHI, NBS and Pfancuck analyses. Table 9 summarizes Level III assessment parameters according to Rosgen 1996. The Pfankuch score for the study reach ranged from a 59 to a 78. For a C4 stream type, this score range is considered good (Rosgen 1996). At the study reach, the NBS rating, according to method 5 (Level III prediction) in Rosgen 1996, is very low to low. The BEHI rating for the study reach was an average of 20.7, a minimum value of 8.8 and a maximum value of 35.4. This is a rating of low to high. The average BEHI value for the reference reach was 12.7 with a minimum of 6.4 and a maximum value of 21.4. The BEHI rating for this reach was very low to moderate. The BEHI is useful, apart from the rest of NCD, as an initial bank stability survey, comparable to the RGA.

Table 8: Summary of Stream Classifications on Abrams Creek

	Entrenchment Ratio	Width/Depth Ratio	Sinuosity	Slope	Channel Materials	Valley & Stream Type
Upper Abrams	7.5	19.9	1.3	0.011	Cobble	VI; C3
Study Reach	2.7	12.4	1.21	0.0025	Gravel/Sand	VI; C4,C5
Reference Reach	6.36	11.44	1.51	0.0015	Gravel/Sand	VI; C4,C5

Table 9: Summary of Level III Natural Channel Design

	Riparian Vegetation	Flow Regime	Stream Size	Depositional Pattern	Meander Pattern	Debris and Channel Blockages	Pfankuch Stream Channel Stability	BEHI
Study Reach	Deciduous with brush and grass understory, Moderate density	Intermittent/subterranean	S-4,S-5 Bankfull Width = 4.6-15m	B-2 Point Bars with few mid channel bars	M1 - regular meanders	D4 - numerous blockages with some D5, extensive blockages	Good	20.7, low to high
Reference Reach	Deciduous with brush and grass understory, High density with wetland vegetation	Perennial	S-4,S-5 Bankfull Width = 4.6-15m	B-2 Point Bars with few mid channel bars	M1 - regular meanders	D3 – moderate blockages D8 - beaver dams frequent	Good	12.7, low to moderate

Unlike the previous two levels of NCD, Level III does provide a qualitative stability assessment by comparing the study reach to a “stable” reference reach. If a wrong reference reach is selected due to misclassification (from incorrect bankfull flow or sediment analysis), then the stability assessment will also be incorrect. Using the Level III assessment, minor departure from the reference reach was determined in the study reach. Some notable differences between the study and reference reaches according to the Level III NCD assessment include:

1. Differing Flow Regimes - The study reach is intermittent due to the karst geology and the reference reach is perennial.
2. Beaver Activity – Beaver activity, including beaver dams, was located upstream of the reference reach. This made location of a reference reach difficult, but a short section downstream of the beaver activity was found. This activity will probably not locate upstream to the study reach due to its intermittent flow.
3. BEHI Rating - the study reach did have a higher BEHI rating, which could indicate some localized bank erosion areas of concern. Isolated areas of bank erosion were also observed in the field at locations where LWD directs flow toward the bank.
4. Riparian Vegetation – The reference reach contains a much wider and dense riparian vegetation zone compared to the study reach. Studies show a change in vegetation can affect the stability of a stream (Rosgen 2006).

5. Sediment particle size differed between the two reaches as seen in Table 4, in which the study reach was less than the reference reach.

4.3.6 Analytical Physical Assessment – Computer Models

4.3.6a HEC-RAS

HEC-RAS was used to determine bankfull flow and check the bankfull estimated from visual indicators and the regional curve. From HEC-RAS, a bankfull flow of approximately 10 cms was determined. Figure 11 is the model output of the bankfull flow. Figure 12 is the output for the bankfull flow predicted by the Blue Ridge physiographic province regional curve. The simulated flow level at each cross section can be seen Appendix C.

When the bankfull flow predicted by the regional curve was modeled, the flow was much greater than the channel bankfull capacity, as shown in Figures 11 and 12. The use of a hydraulic model such as HEC-RAS allows for a check and correct determination of bankfull flow and any other flows that may be critical to sediment transport.

4.3.6b CONCEPTS

The CONCEPTS model predicted some bank failures in the study reach and degradation and aggradation in both reaches. However, the lack of field data makes the comparison to natural processes rates very uncertain. Table 10 summarizes the sediment loads in Abrams Creek study reach during a bankfull flow event and sediment loads

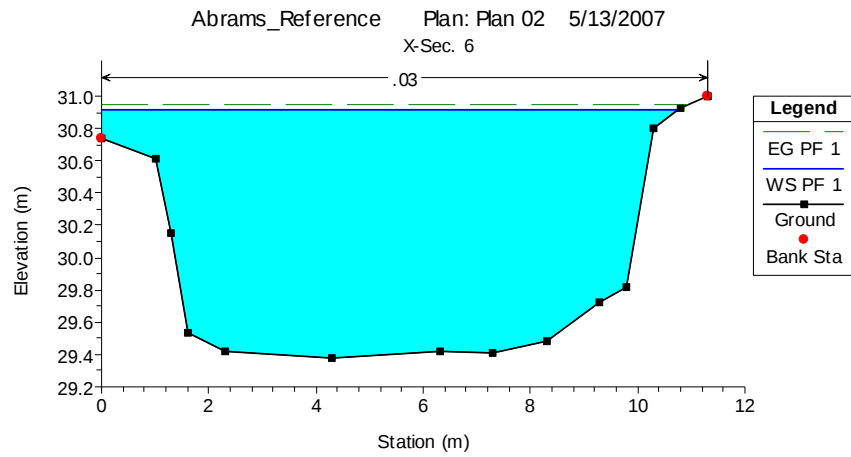


Figure 11: Flow at top of bank (10 cms) modeled in HEC-RAS

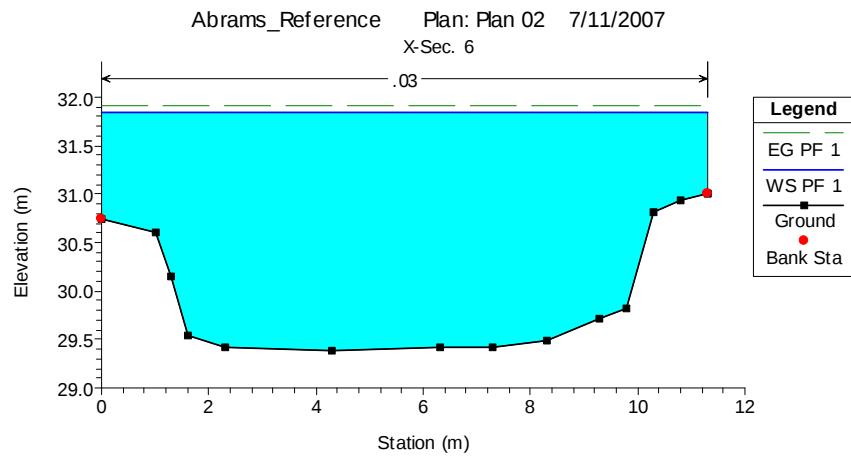


Figure 12:Regional Curve Bankfull Flow (27.5 cms) modeled in HEC-RAS

during large flow events on other streams monitored by USGS and limited suspended sediment values taken by TVA in 1993 and 1994 on Abrams Creek near Hyatt Lane.

The sediment data obtained for a comparison of the CONCEPTS output and field data is also uncertain. From observation of USGS data, readings of sediment loads varied greatly for discharges of similar magnitudes. However, this could be a result of bank failures during the sampling time. Also, land-use effects on sediment discharge rates are neglected due to limited information on the sites. In order to compare the CONCEPTS and TVA data, a conversion from concentration to rate of sediment load was required. The assumption that the sediment discharge rate was constant for a period of time was made for this conversion. The two values in Table 10 are for a sediment load with a flow duration of 2 hours (1) and for 3 hours (2). Although very rough estimates, these give some means of comparison with real stream data, which is commonly non-existent. The CONCEPTS output during a bankfull event is within the same degree of magnitude as the other readings in Table 10. The sediment loads for the reference and study reaches on Abrams Creek differed but from other assessment techniques applied, this difference appeared to be acceptable and within a stable level. The sediment load in the study reach decreased from 6 metric tons/km² to 4 metric tons/km² and the reference reach had a decreased from 0.4 metric tons/km² to 0.2 metric tons/km². This shows a decrease in sediment load in the stream from when cattle were still present, indicating an improvement in the stream.

During the two year period, one bank failure was encountered, after a bankfull event, in the study reach at cross-section two. From the CONCEPTS longitudinal plot,

this bank failure appears to be a product of down-cutting. A 10-year simulation was performed on the reference reach but could not be completed for the study reach due to an instability in the model. During this time, no bank failures occurred in the reference reach. The CONCEPTS output plots are in Appendix C.

Table 10: Total Sediment Discharge During Large Flow Events

Site and Source of Data	Drainage Area (mi², km²)	Flow (cfs, cms)	Sediment Load (T/y) (Metric T/y)	Sediment Load/Area (T/y/mi², Metric T/y/km²)
Abrams Creek Study Reach (CONCEPTS)	14.6, 37.8	353, 10	156, 142	11, 4
Abrams Creek nr. Hyatt Lane (1) (TVA Report 1995)	14.6, 37.8	160, 4.5	252, 229	17, 6
Abrams Creek nr. Hyatt Lane (2) (TVA Report 1995)	14.6, 37.8	160, 4.5	378, 343	26, 9
Abrams Creek nr. Lower Loop Road (1) (TVA Report 1995)	19.7, 51.0	5.03, 0.14	22, 20	1.1, 0.4
Abrams Creek Reference Reach (CONCEPTS)	19.7, 51.0	353, 10	11, 10	0.6, 0.2
SF Quantico Creek near Independent Hill, VA (USGS)	7.62, 19.7	256, 7.2	254, 230	33, 12
Hellbranch Run near Harrisburg, OH (USGS)	35.8, 92.7	388, 11	234, 212	7, 2
Hotopha Creek near Batesville, MS (USGS)	35.1, 90.9	317, 9.0	249, 226	7, 3
Topashaw Creek Near Hohenlinden, MS (USGS)	42.1, 109.0	312, 8.8	180, 163	4, 2
Cedar Run at Route 646 near Aden, VA (USGS)	175, 453.3	4310, 122	1400, 1270	8, 3

Chapter 5: Comparison of Physical Assessment Techniques

Both of the evaluated empirical and analytical physical assessment techniques produced comparable stability measures, yet uncertainties were recognized in each method. These uncertainties were due to professional judgment of field data collection and interpretation the technique's output. Table 11 summarizes the level of uncertainty and variables involved for each method.

Table 11: Comparison of Physical Assessment Approaches

Method Applied	Type of Assessment	Level of uncertainty and judgment call	References
Review of Historical Documents, Aerial Photographs and Maps	Empirical	Low.	Rosgen, 1996, Shields et al., 2003
Channel Survey Data and Analysis	Analytical	Low.	Hey, 2006
Bed and Bank Sediment Data and Analysis	Analytical	Low.	Rosgen, 2006, Simon, 2007
RGA	Empirical	Low.	Niezgoda and Johnson, 2005, Simon, 1999, 2007
Natural Channel Design	Empirical	High. Bankfull and reference reach determination and applicability. Lack of quantitative measurements	Rosgen, 1996, 2006; Hey, 2003; Niezgoda and Johnson 2005, Shields et al. 2005, Smith and Prestegard 2005; Doyle et al. 2007, Nagle 2007, Simon 2007, Schwartz and Herricks 2007
HEC-RAS	Analytical	Low. Boundary condition variables must be chosen	HEC-RAS Manual
CONCEPTS	Analytical	High. Model is subjective to input and interpretation. Soil and sediment properties affect output greatly. Limited to certain site constraints	Langendoen 2000, 2002; Wells et al. 2007

5.1 Uncertainties in Natural Channel Design

Determination of bankfull level was the most important, yet uncertain, variable in NCD. Bankfull level, the most important parameter of NCD, can be a difficult and uncertain field variable to identify. Depending on experience and specific site restrictions, bankfull determination creates a high level of uncertainty. The Rosgen stream classification, the reference reach identification and comparison and BEHI stability survey all hinge on the bankfull determination.

Field experience using NCD and field indicators is one mode of reducing uncertainty in this technique (Rosgen 1996, 2006). Field indicators such as channel vegetation, flow lines, and depositional areas, such as bars, can aid in determining bankfull level. However, these indicators can be misleading. Experience, including knowledge of vegetation and channel processes, is critical when using field indicators for bankfull determination but often is lacking (Rosgen 1996, 2006, Nagle 2007, Hey 2006). Even with proper experience, certain site constraints, such as in urban areas with actively incising channels, make identification difficult or irrelevant as the channel forming flow (Doyle *et al.* 2007).

Regional curves, developed from regional flow gauge data, can also help determine bankfull level but still can be uncertain. Without current, site specific flow data to calibrate regional curves, the bankfull values can be incorrect (Sections 4.3.5 and 4.3.6a). However, computer models such as HEC-RAS can aid in situations lacking in flow data. Also, regional curves sometimes include inadequate amounts of data or combines data from both stable and unstable streams which could lead to incorrect

bankfull values (Hey 2006). One site-specific factor that affects the flow in Abrams Creek, but is not accounted for in regional curves, is karst geology. This variable makes regional curves irrelevant to this particular site.

The reference reach is the key element of the empirical, physical assessment approach and another uncertain factor of NCD. Identifying an appropriate reference reach can be problematic. According to Hey (2006), the reference must be of the same stream type and in the same physiographic region as the study reach. Unique, specific site characteristics, such as karst geology in Cades Cove, make any reference reach outside Abrams Creek improper. Such features affect channel processes uniquely and would be very difficult, if not impossible, to locate elsewhere. Like bankfull determination, reference reach application is difficult in urban streams due to specific environmental constraints. Studies on urban streams have faced difficulties in the locating and applicability of a reference reach (Tweedy *et al.* 2000, Niezgoda and Johnson 2005, Schwartz and Herricks 2006). Urban streams behave much differently than stable references and surrounding infrastructure commonly restricts natural adjustments or the recreation of a stable reference form (Tweedy *et al.* 2000, Thompson 1996).

Even with the proper determination of bankfull and location of an applicable reference reach, NCD does not specify or quantify a degree of departure for an acceptable stability level. NCD is based on the assumption that streams of the same type will behave similarly, however few quantifiable measurements are made to insure this is true throughout time. Only current channel form is assessed to account for future change due

to channel processes. Projects have shown this assumption to be valid in some locations but failures have also been noted as a result (Rosgen 2006, Simon *et al.* 2007, Nagle 2007). Without some known threshold of stable departure, be it ecologically or physically based, between the reference and study reaches the naturally occurring variance channels, such as alluvial, meandering streams, is not known. At this point in the NCD assessment, professional judgment must be made to determine if the departure amount is acceptable. Lack of experience and evaluation channel processes through field data (flow and sediment) monitoring can make this judgment call very uncertain. However, analytical models, although not flawless, can aid in quantifying channel processes over time.

5.2 Uncertainties in CONCEPTS

Although readily able to quantify rates of channel processes, CONCEPTS, like NCD, holds uncertainties due to input and judgments of output. Soil and sediment properties along with channel form can create instabilities in the model, preventing successful simulations. To account for these instabilities, adjustments must be made through judgments in order to produce an acceptable, operating model.

To account for these instabilities, the adjustment of soil and sediment properties, which affect the performance of the model greatly, was required in order to produce a successful simulation. The particle size distribution of the uppermost cross-sections was weighted to account for the initial sediment transport capacity of the system, in order for the model to run the desired simulation length. Without this adjustment the first cross-

section would aggrade with sediment to channel capacity and terminate the simulation. However, this was not very realistic and the upstream weighting capacity was simply adjusted until a successful simulation was created. However, actual sediment transport capacity of Abrams Creek was not known due to lack of sediment transport data, making weighting judgment uncertain.

Channel form, including meanders, longitudinal distance and in-channel debris is not accounted for in CONCEPTS but realistically affects channel stability. Channel hydraulics and erosion (bed and bank) can be affected greatly by all of these factors. CONCEPTS was developed to model longer, straight stream corridors with greater spacing between cross-sections (pers. comm. with E. Langendoen 2007). However, the reaches on Abrams Creek were short compared to other reach analyses performed using CONCEPTS (Simon *et al.* 2002, Wells *et al.* 2007). Adjustments in the model input probably could be made to account for these effects but without in-stream measurements of suspended sediments and bank erosion, the output of the model is uncertain. The use of reference data to account for existing environmental factors could improve the ability to interpret the reality of model results.

Similar to NCD, assessing whether the difference between reference and study reach sediment transport rates is within a naturally occurring level, is an uncertain judgment decision. Data was not available on either reach so a realistic sediment transport rate was difficult to judge. Comparing the two reaches was based on the results of other assessments as well to determine if the difference was still in a stable level.

As shown in Figure 1 and Table 11, both empirical and analytical physical assessments require similar input and judgment decisions and can lead to the similar outcome. Any amount of field monitoring, although difficult, can reduce the uncertainty in both techniques. Also, as shown in this study the application of both analytical and empirical techniques can provide a more thorough and certain assessment with checks on one another and produce a hybrid physical assessment approach.

Chapter 6: Management Implications for Abrams Creek

Abrams Creek was determined that to be in a stable, dynamic equilibrium state from physical assessments. From historical photographs and RGA's, a system-wide instability was not identified. Therefore, large-scale stream relocation or construction is not warranted. However, the study reach contained some local areas of bank erosion, mostly where LWD directed high flows into the banks. The CONCEPTS model also simulated some bank failures, indicating a potential for localized channel instabilities. In addition, the study reach lacked some of the riparian vegetation qualities found in the reference reach.

Sediment loads in Abrams Creek appeared to be within a natural geomorphic transport range, in which localized aggradation and degradation process bed sediment. Some evidence suggests suspended sediment levels have improved since 1994 (Section 4.3.6b). Bed sediment quality was found to be adequate for maintenance of stream habitat, and fish bio-assessments do not appear to indicate an environmental stress caused by excessive fine sediment.

Because no system-wide instability of the channel was found through the applied physical assessments, immediate recommendations based on this study include:

1. Stabilize banks with local failures using existing in-stream woody debris and adjust the in channel position to hydraulically deflect flows away from failing banks.
2. For long-term management, trees can be planted along the stream channel providing a 200-ft wide vegetated riparian corridor. In the

future, trees will aid in stabilizing stream banks and supply the stream with debris needed for aquatic habitat.

Of consequence to note, Abrams Creek did not exhibit any signs of chemical impairment as evaluated from the water quality data collected by TVA in 1994 (Table 2). In addition, according to the biological assessment, both fish biota and physical habitat appear to be adequately present.

Recommendations in this study are based on physical assessments that required some professional judgments when data were limited. Data limitations in stream restoration assessments are common because of availability of resources. It is possible to improve the analytical assessment with the collection of additional data. Some other recommendations are:

1. Using CONCEPTS, further assess sediment transport and bank erosion in Abrams Creek by expanding the reach length; also apply similar analysis to the tributaries.
2. Monitor Abrams Creek and tributaries by collecting flow and sediment data in reaches to optimize the CONCEPTS model and physically compare actual erosion and transport rates with those predicted by the model.
3. Conduct current fish surveys along with the above sediment and flow data to provide a correlation between existing species and sedimentation rates over time

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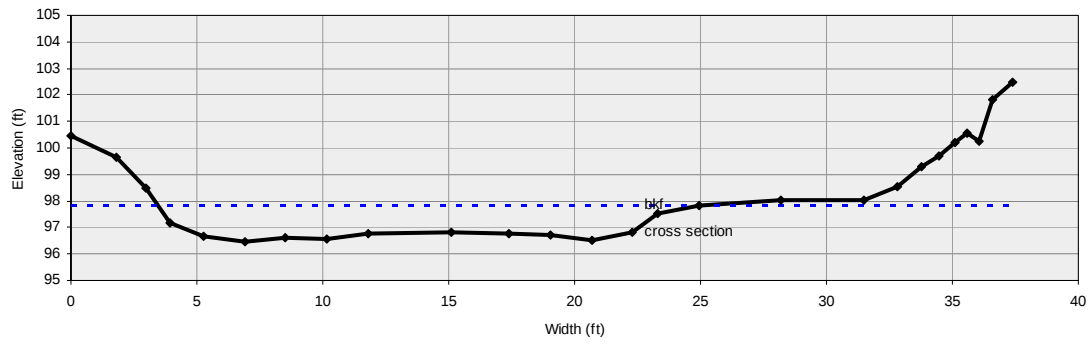
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Appendices

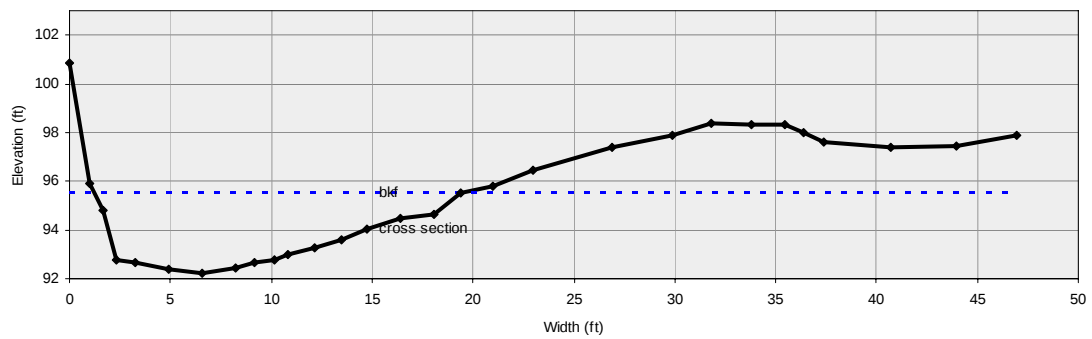
Appendix A: Field Data Collection

Study Reach Cross-Sectional Profile with Bankfull Level

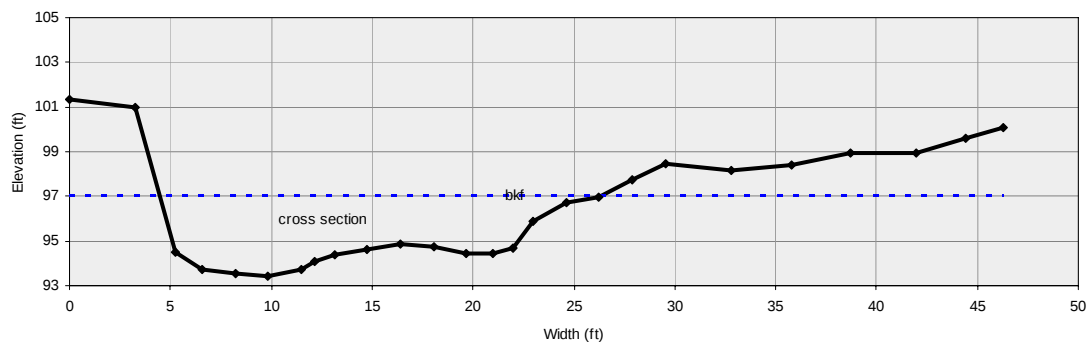
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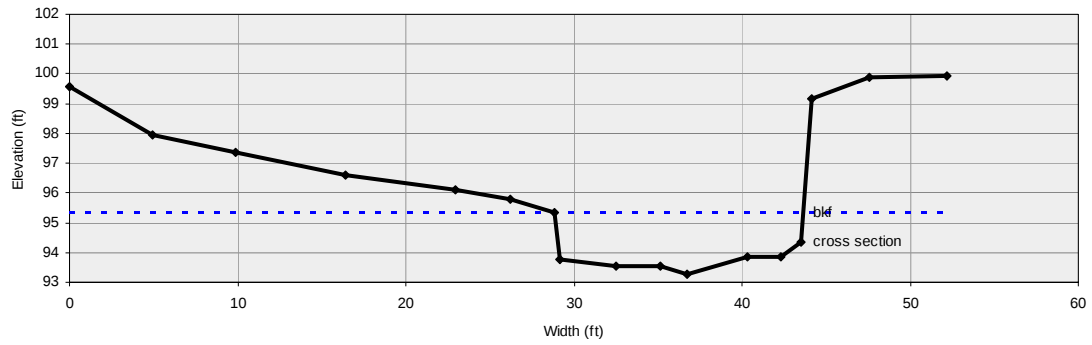
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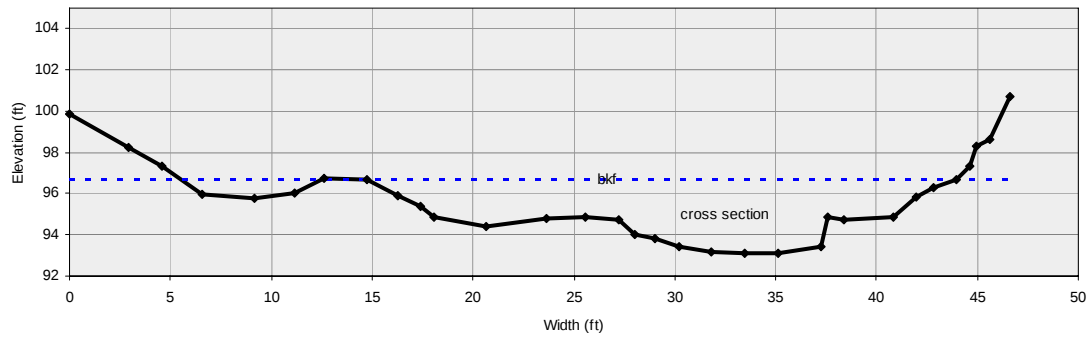
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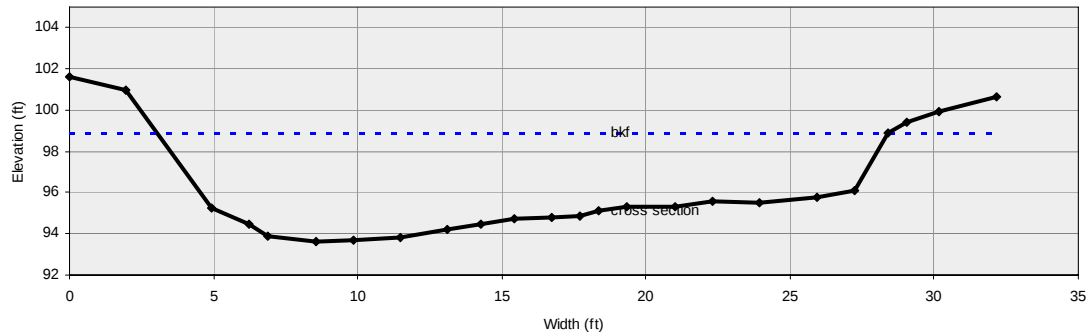
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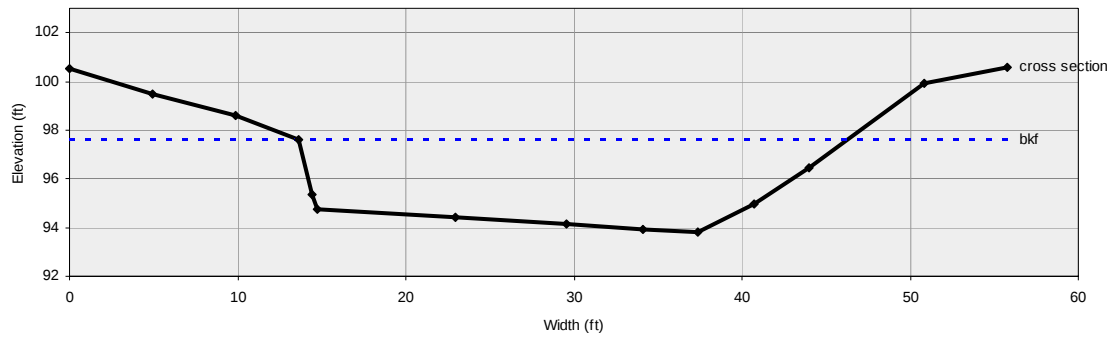
Cross Sectional Profile - Xsec.12



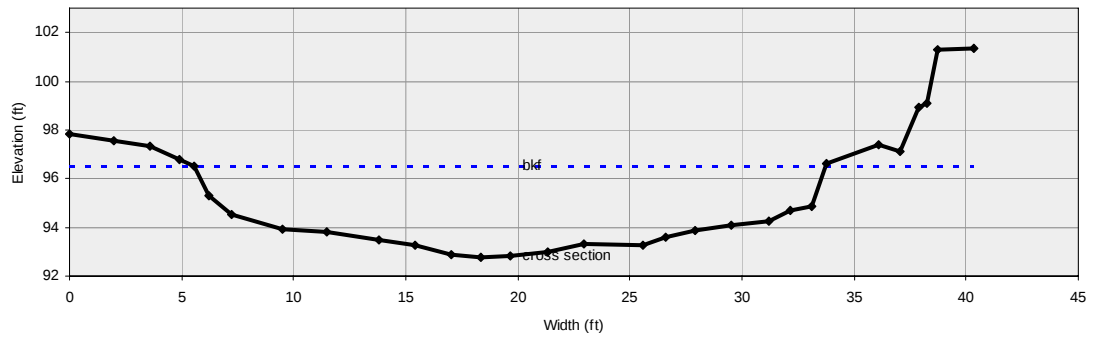
Cross Sectional Profile - Xsec.11



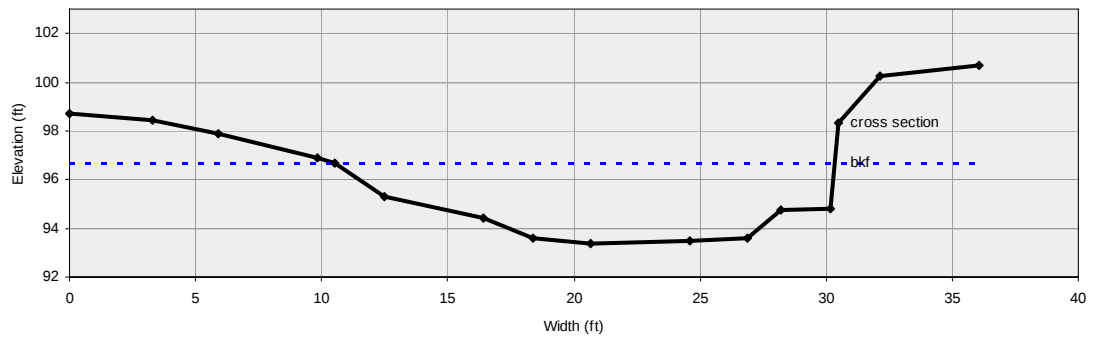
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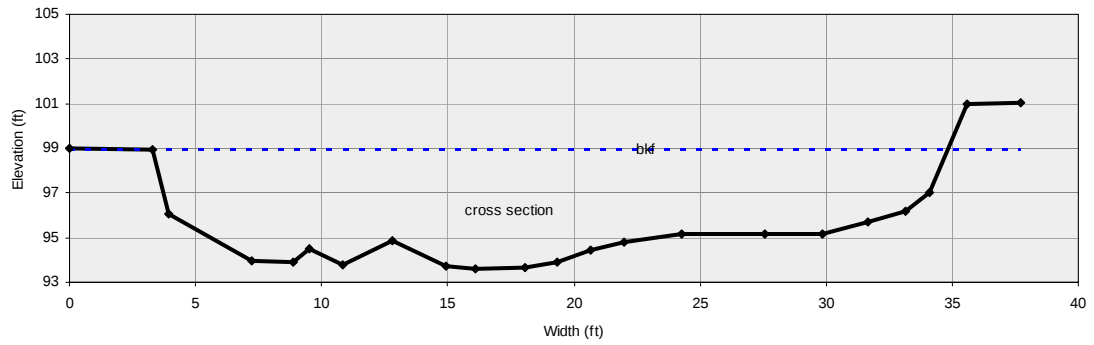
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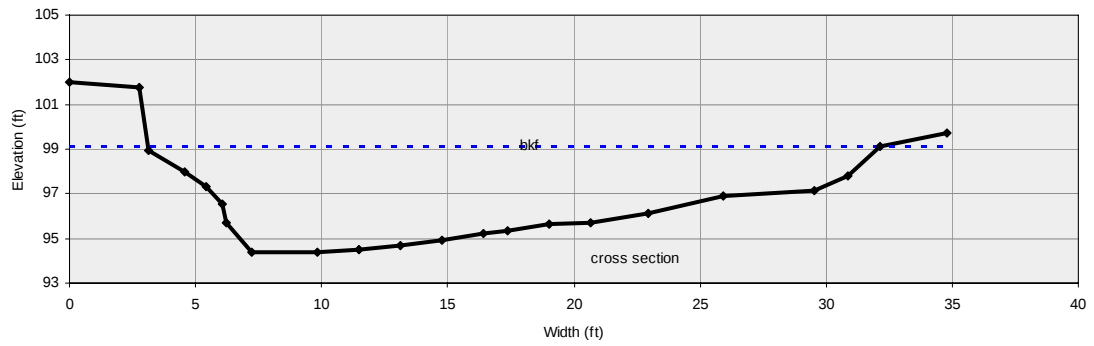
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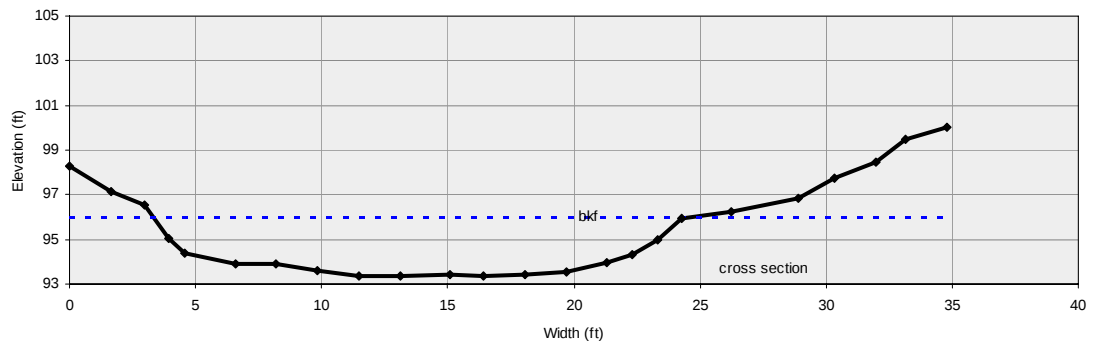
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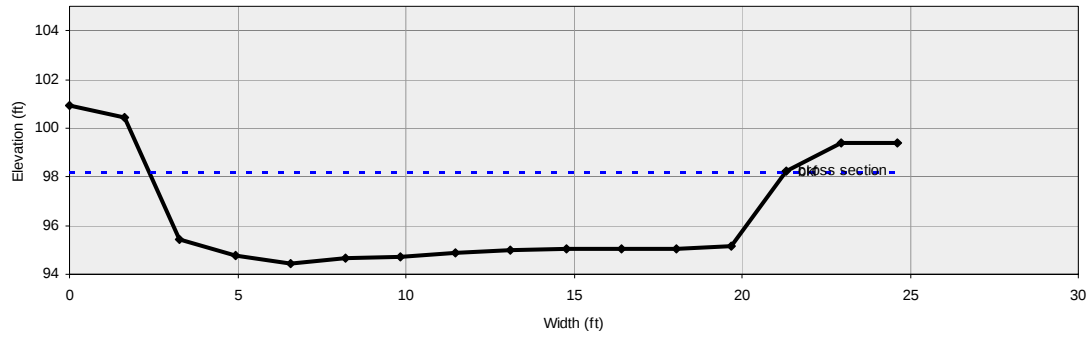
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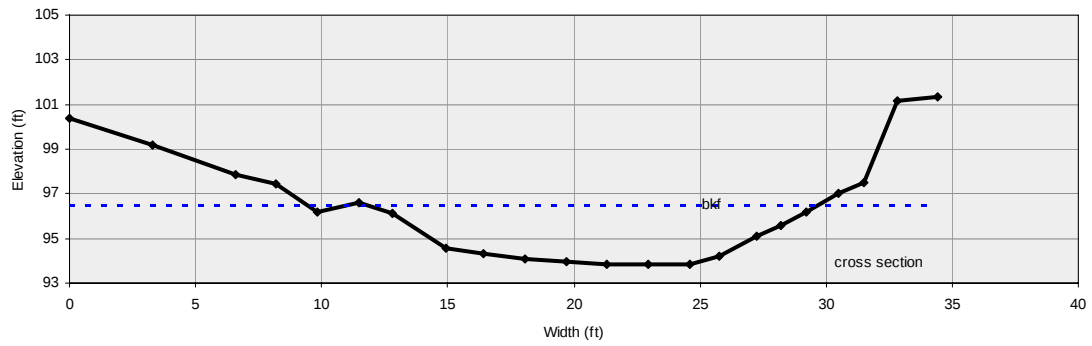
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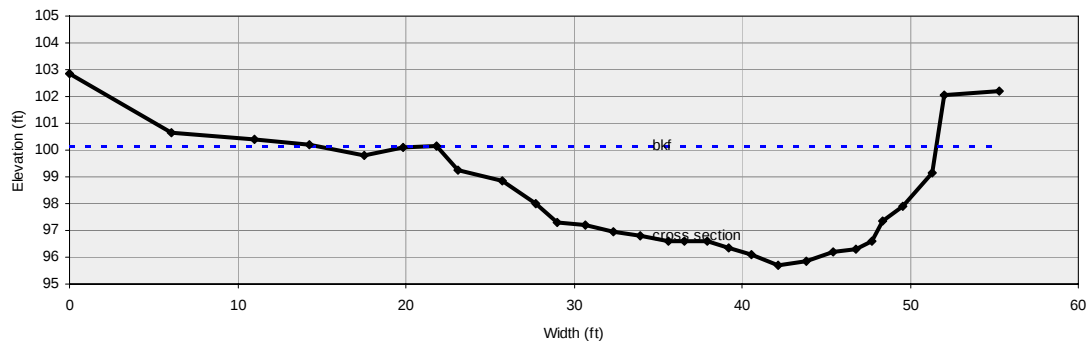
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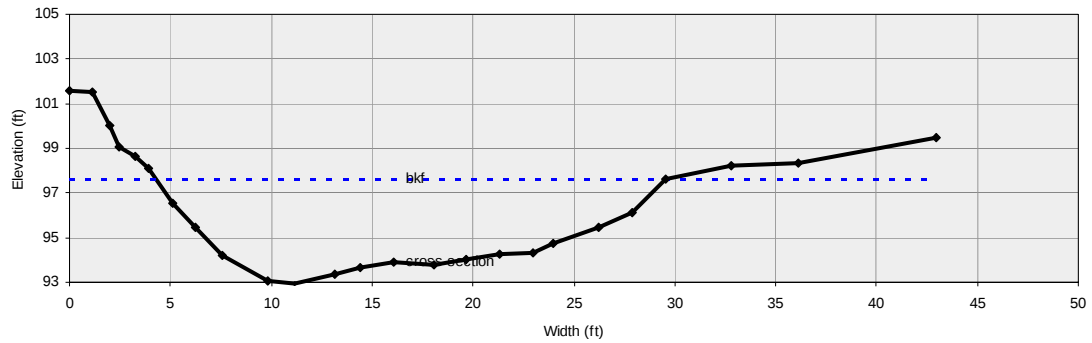
Cross Sectional Profile - Xsec.3



Cross Sectional Profile - Xsec.2



Cross Sectional Profile - Xsec.1



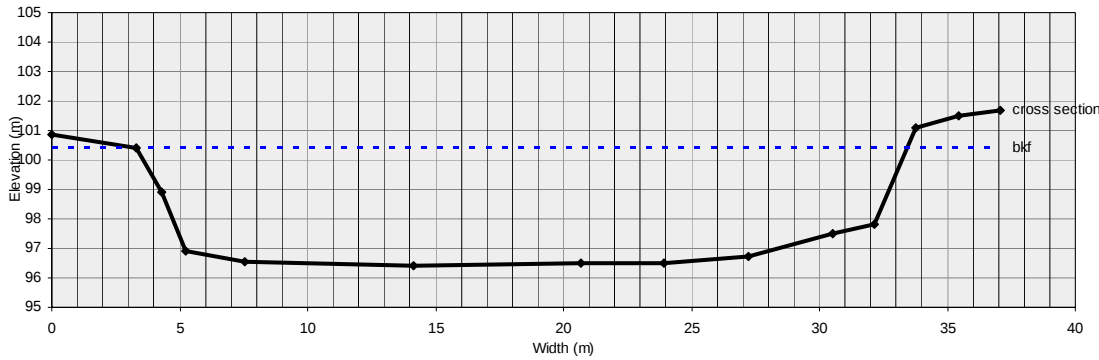
Study Reach Cross-Sectional Data for Rosgen Stream Classification

X-Sec.	Bankfull Width (m)	Bankfull Area (m ²)	*Mean Depth (m)	Width/Depth Ratio	Maximum Depth (m)
8	6.1	4.5	0.73	8.2	1.0
10	9.9	8.8	0.88	11.3	1.2
13	4.5	2.3	0.52	8.9	0.6
16	6.6	2.0	0.30	21.0	0.4
Avg.	6.8	4.4	0.61	12.4	0.8
X-Sec.	Width of Flood Prone Area (m)	Entrenchment Ratio	Channel Materials D50 (mm)	Water Surface Slope	Channel Sinuosity (k)
8	30.5	5.0	8	0.0033	1.21
10	17.1	1.7	6	0.0033	1.21
13	10.3	2.3	7	0.0033	1.21
16	9.8	1.5	10	0.0033	1.21
Avg.	16.9	2.6	7.75	0.0033	1.21

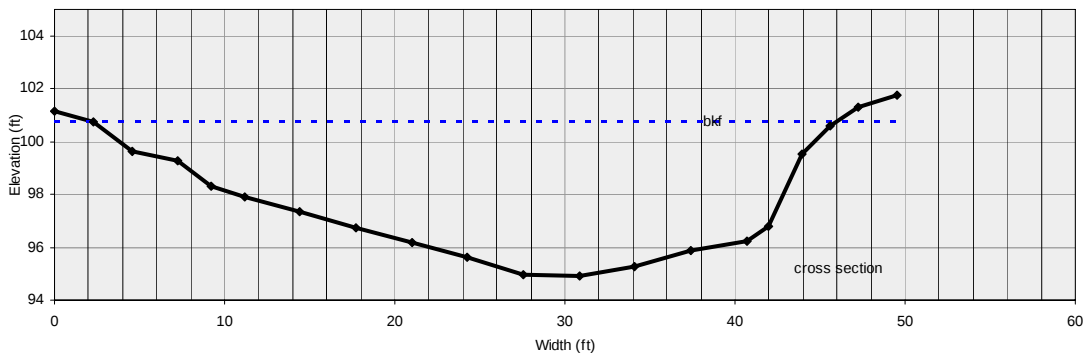
*Note Data measured only in riffles

Reference Reach Cross-Sectional Profile with Bankfull Level

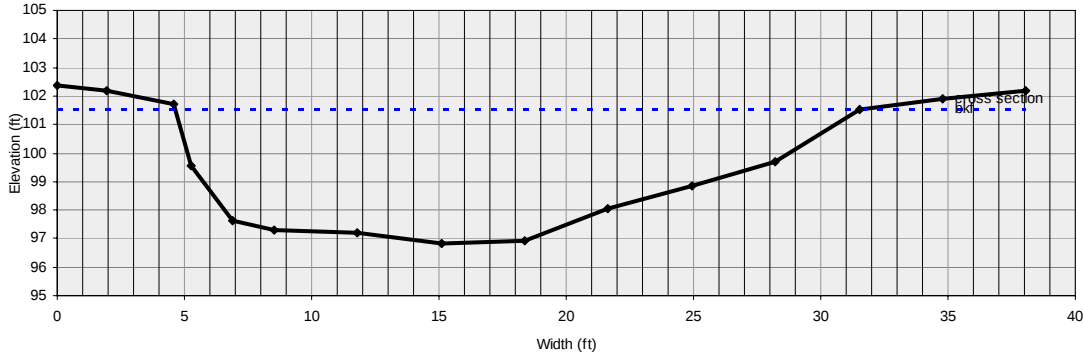
Cross Sectional Profile 6 - Abrams Reference



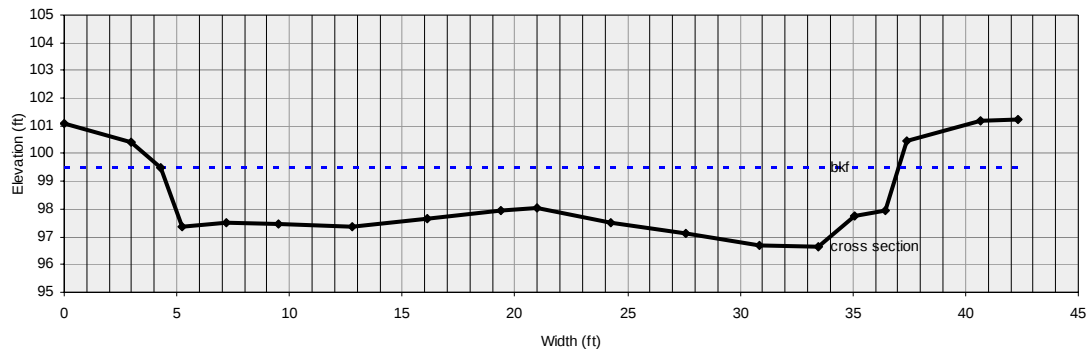
Cross Sectional Profile 5 - Abrams Reference



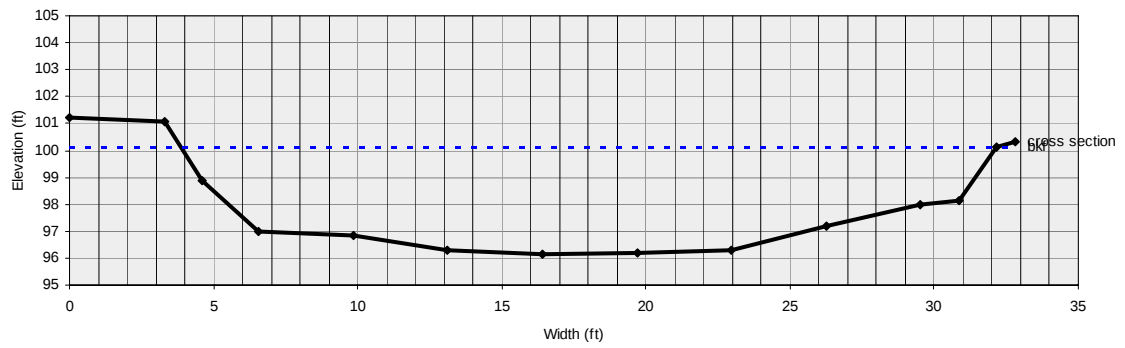
Cross Sectional Profile 4 - Abrams Reference



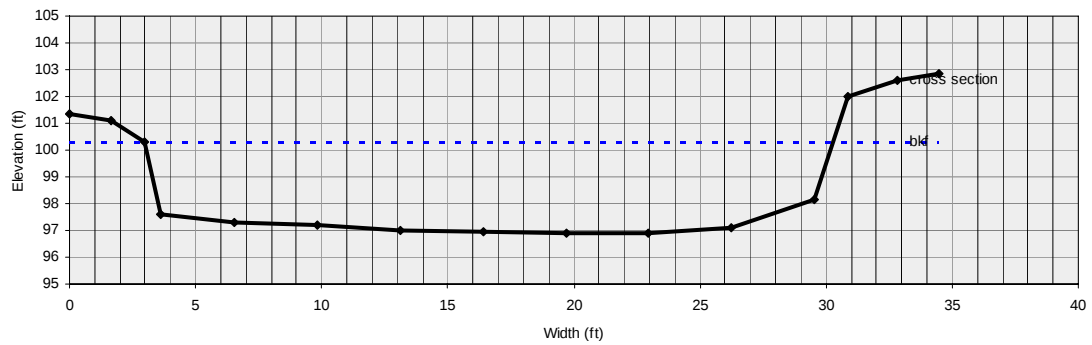
Cross Sectional Profile 3 - Abrams Reference



Cross Sectional Profile 2 - Abrams Reference



Cross Sectional Profile 1 - Abrams Reference

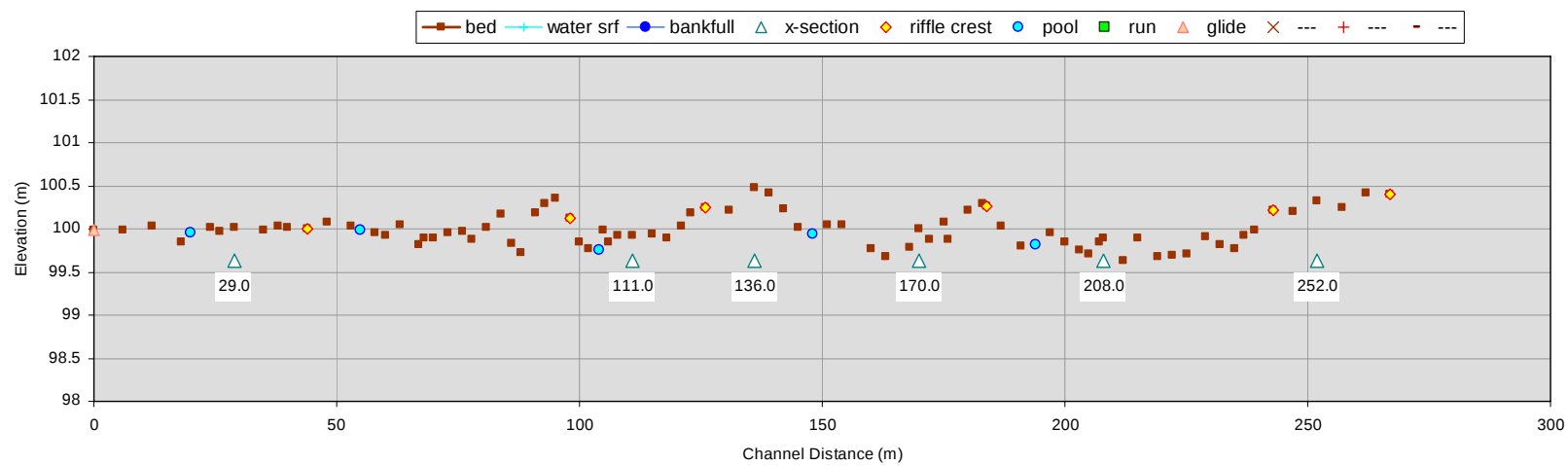


Reference Reach Cross-Sectional Data for Rosgen Stream Classification

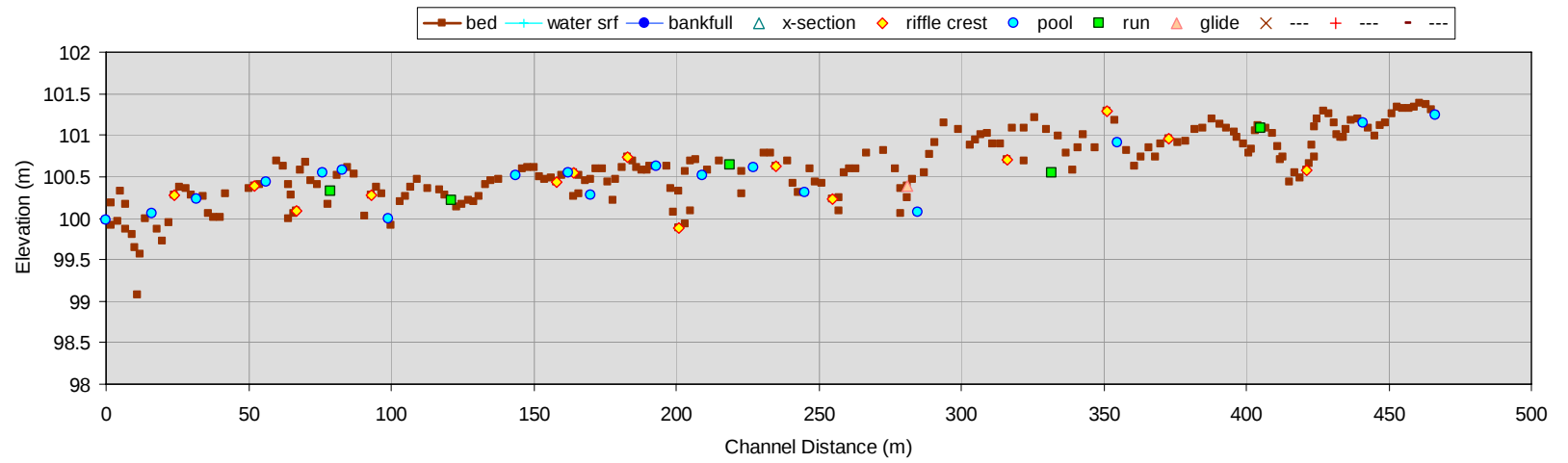
X-Sec.	Bankfull Width (m)	Bankfull Area (m²)	*Mean Depth (m)	Width/Depth Ratio	Maximum Depth (m)
3	10.0	6.2	0.61	16.2	0.88
6	9.2	9.9	1.07	8.6	1.23
Avg.	9.6	8.1	0.84	12.4	1.06
X-Sec.	Width of Flood Prone Area (m)	Entrenchment Ratio	Channel Materials D50 (mm)	Water Surface Slope	Channel Sinuosity (k)
3	61.0	6.1		0.0015	1.51
6	61.0	6.6		0.0015	1.51
Avg.	61.0	6.4		0.0015	1.51

*Note Data measured only in riffles

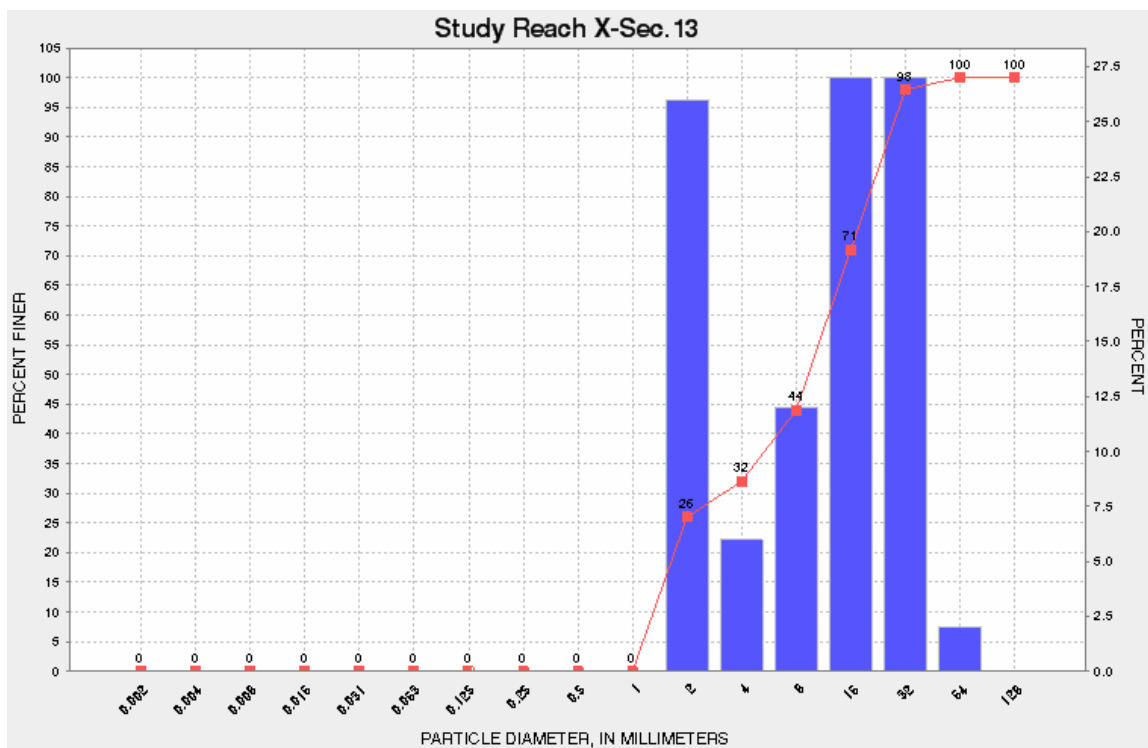
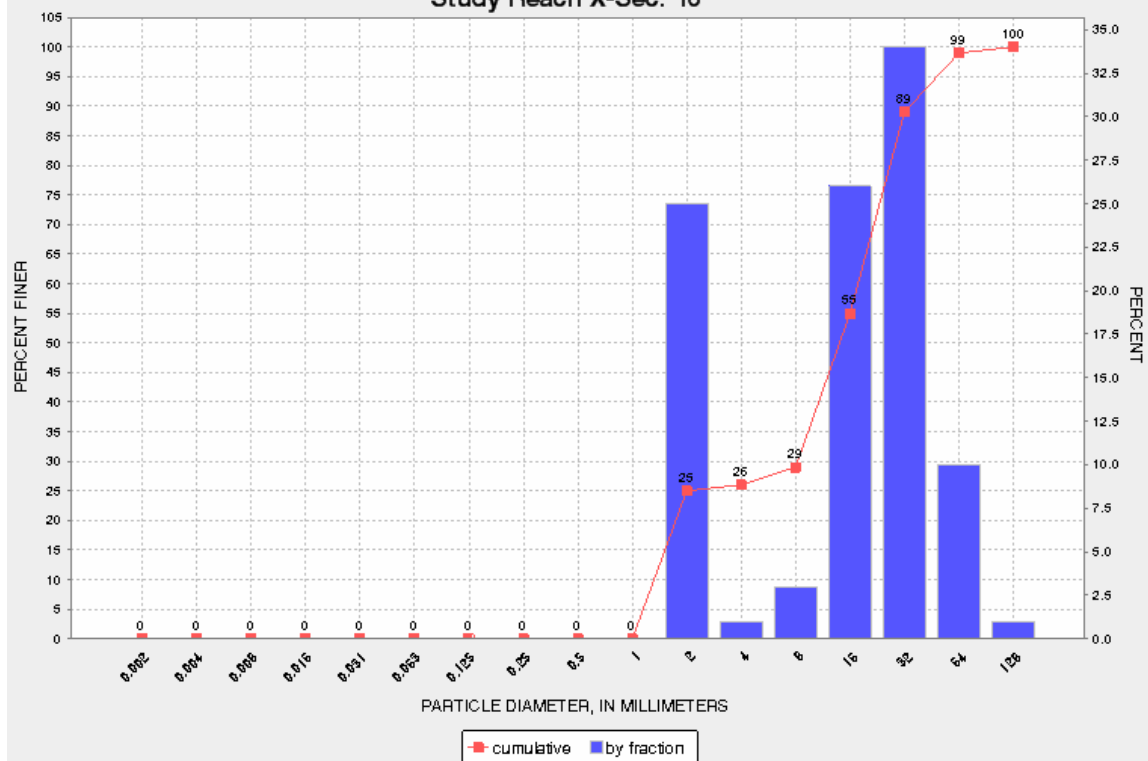
Reference Reach Longitudinal Profile with Habitat Units

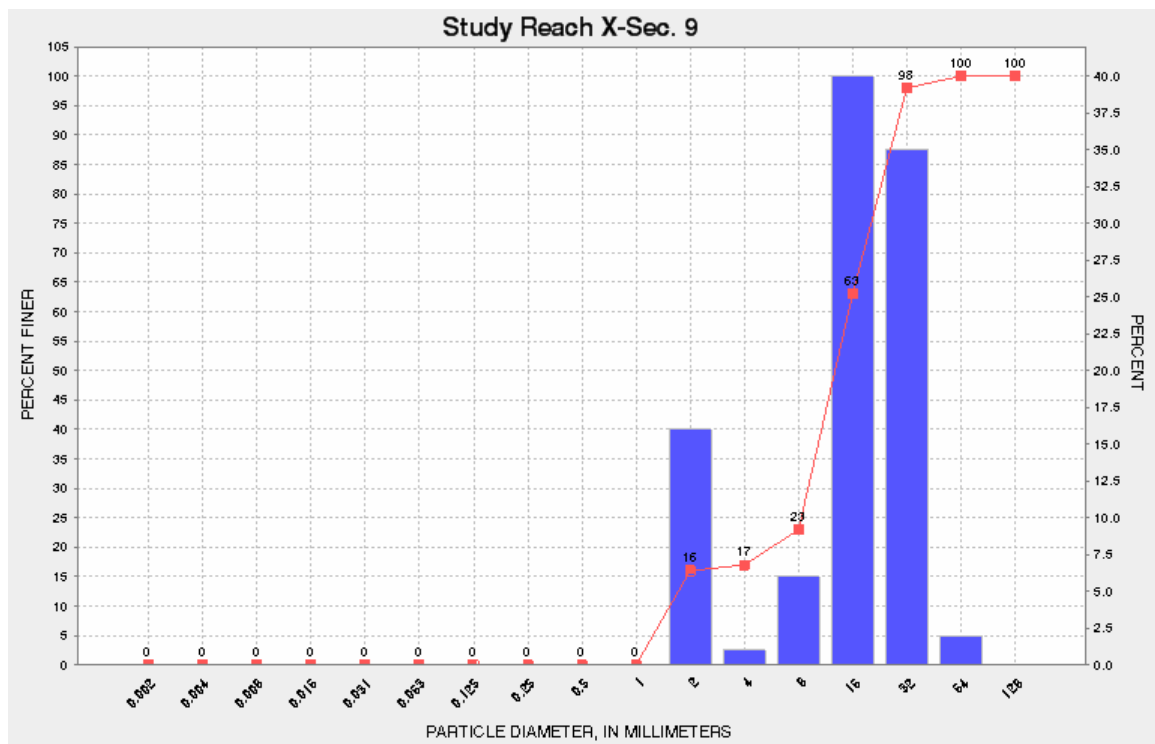
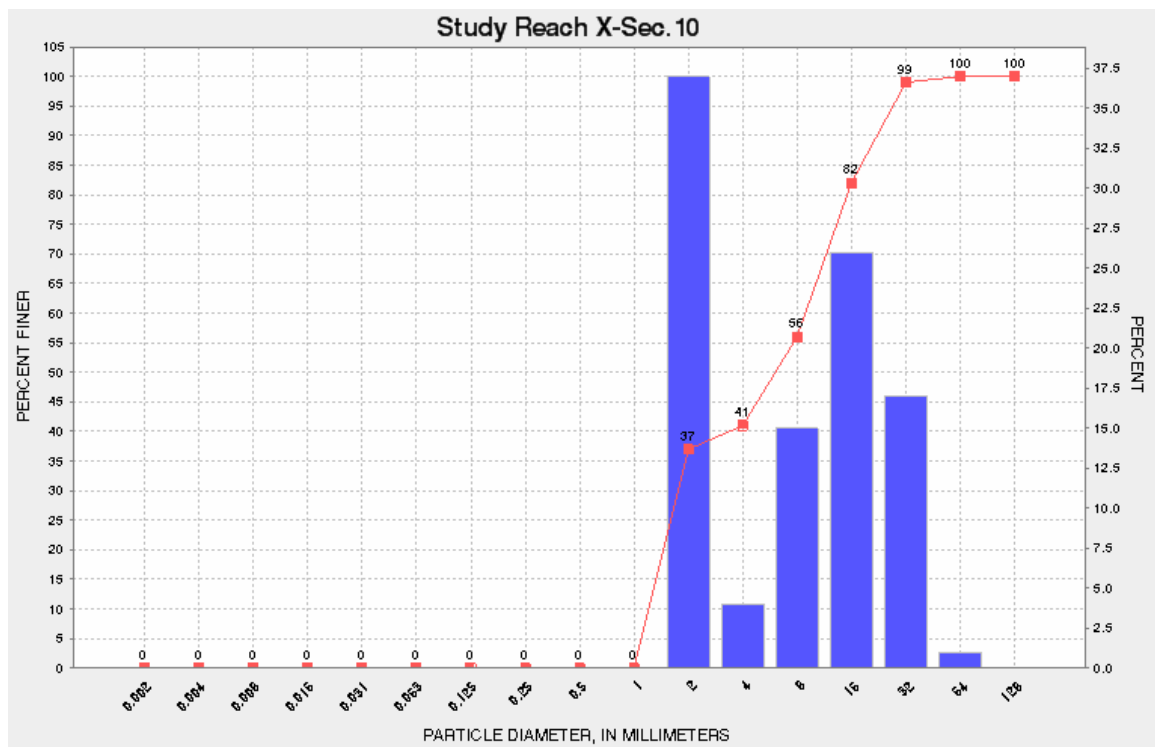


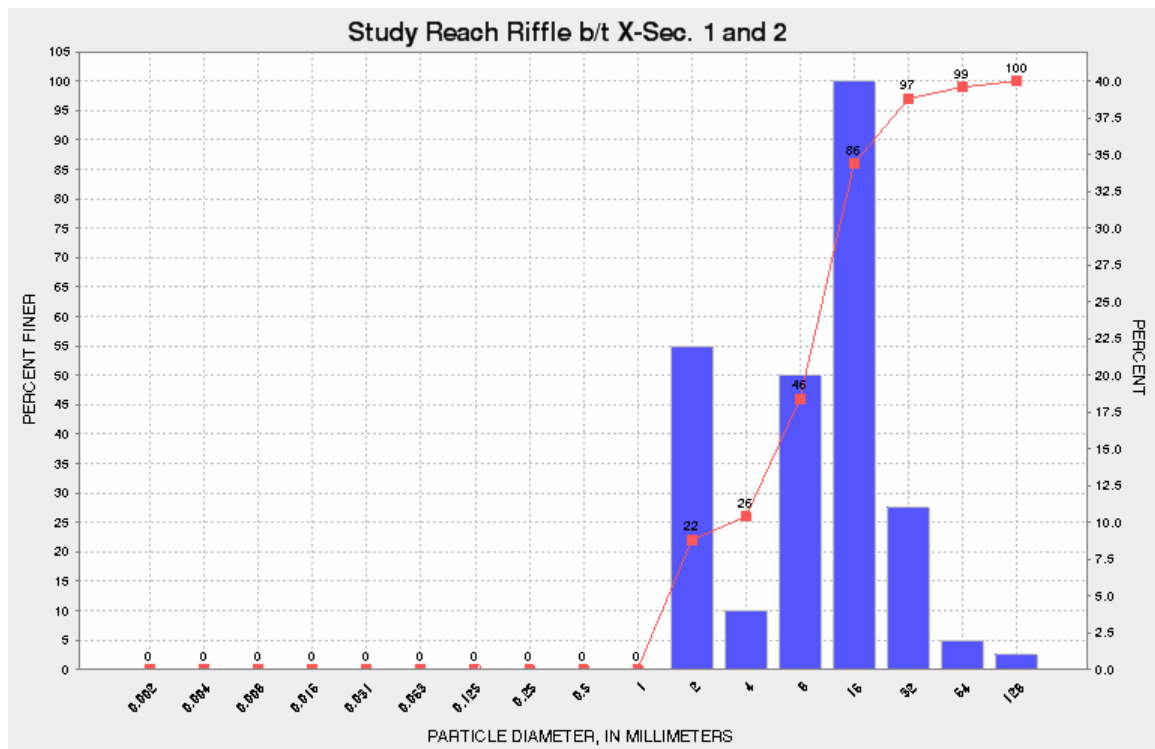
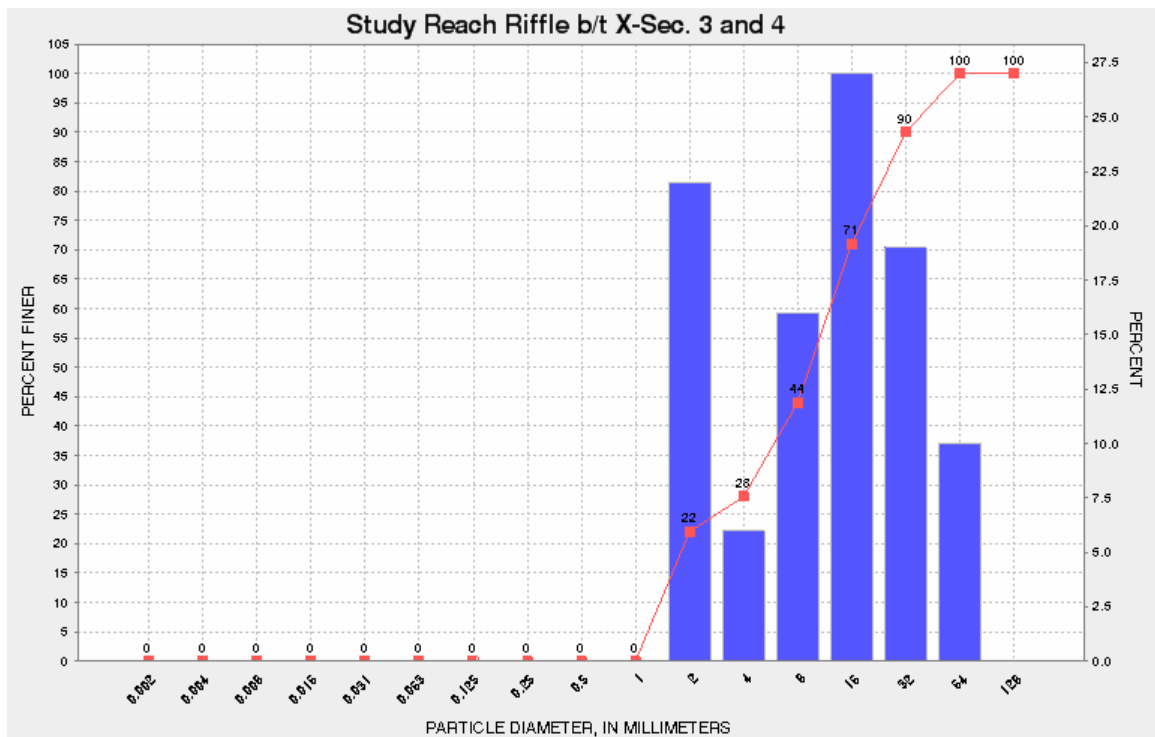
Study Reach Longitudinal Profile with Habitat Units

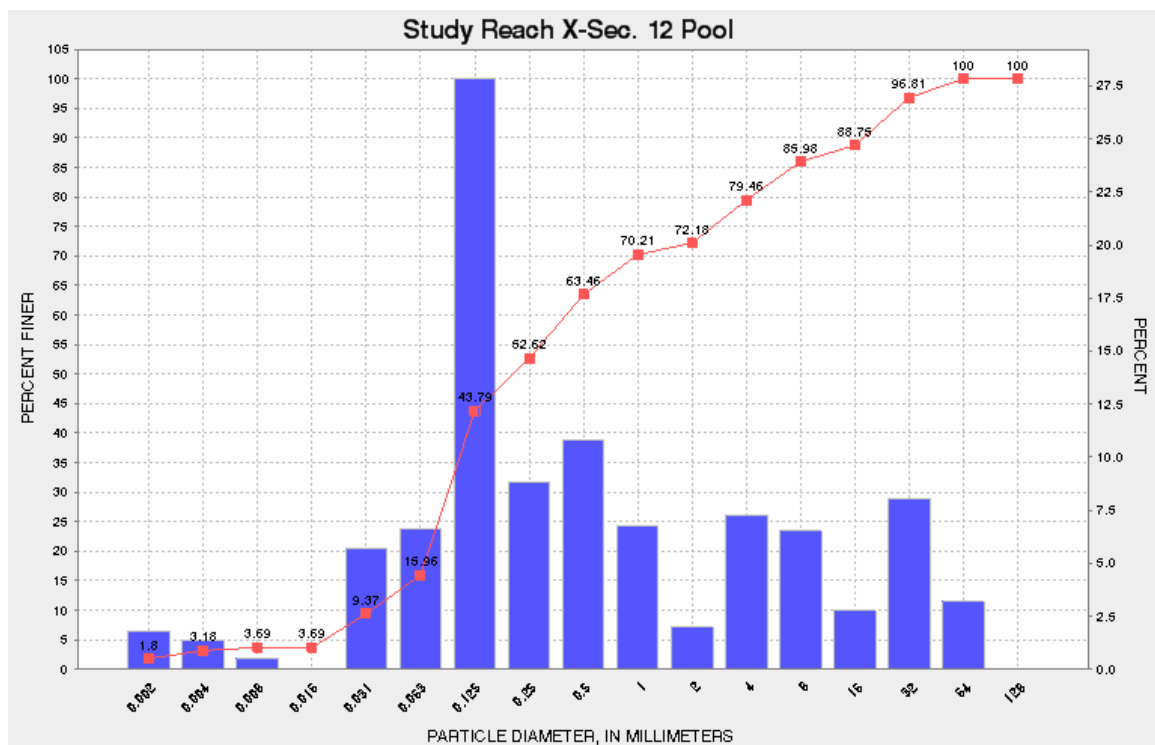
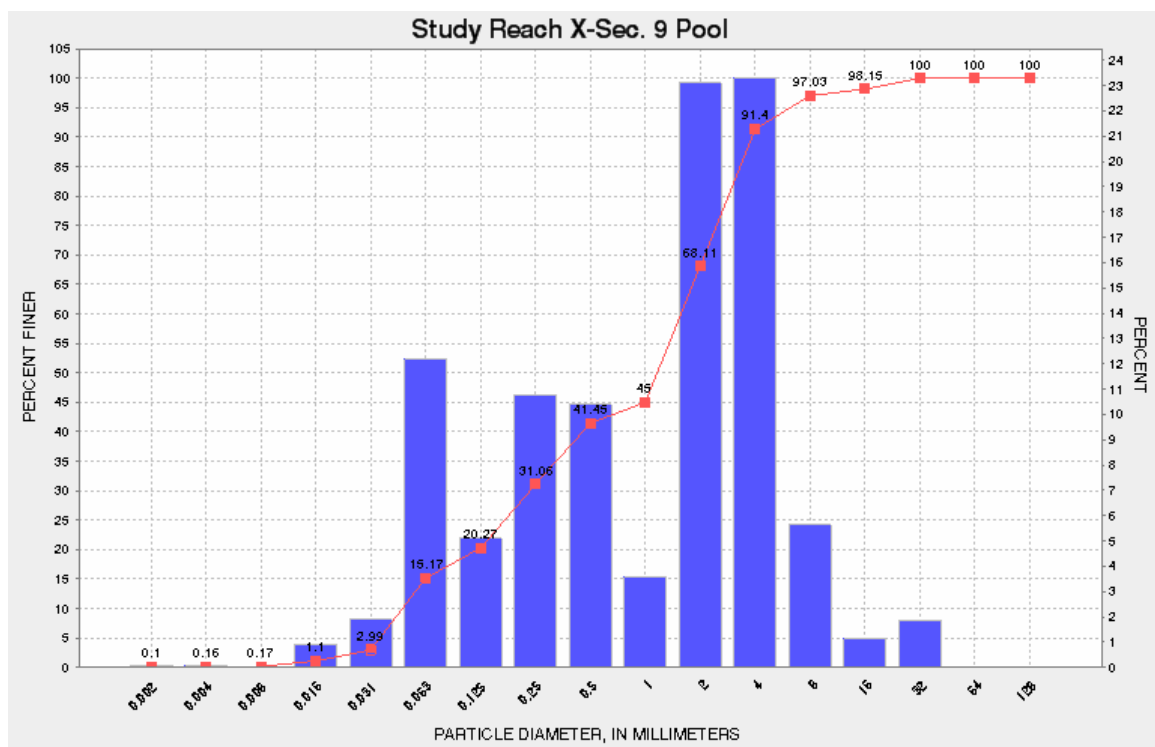


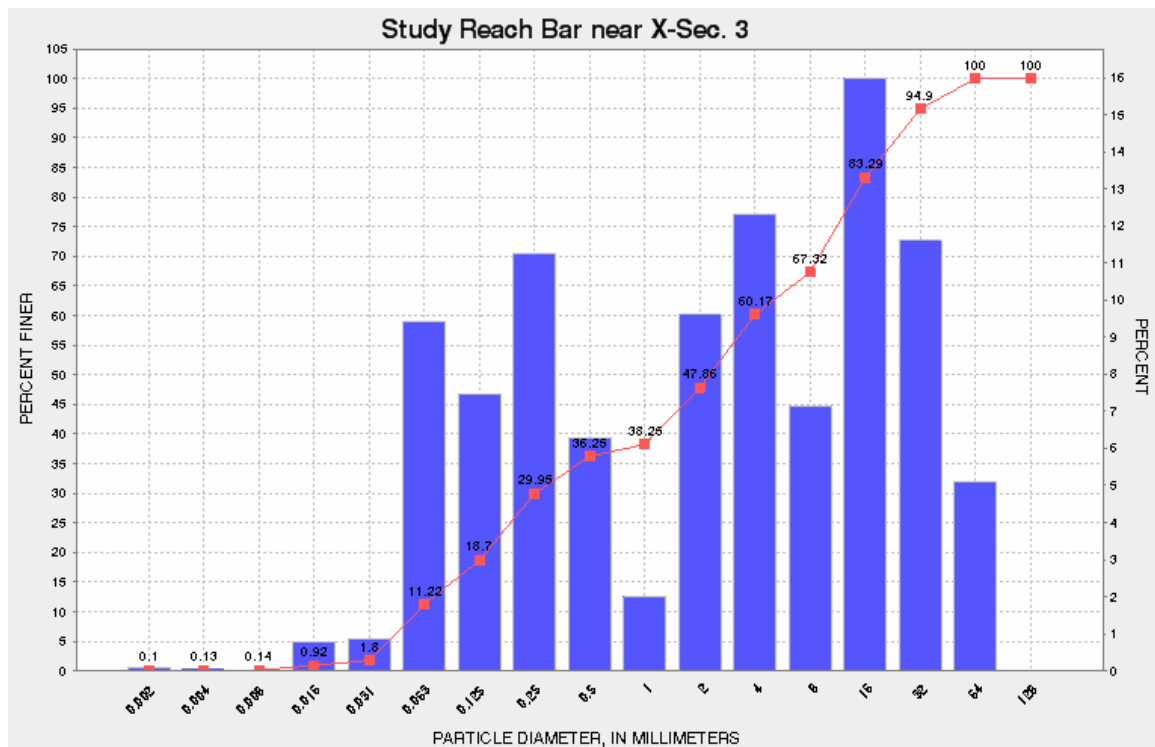
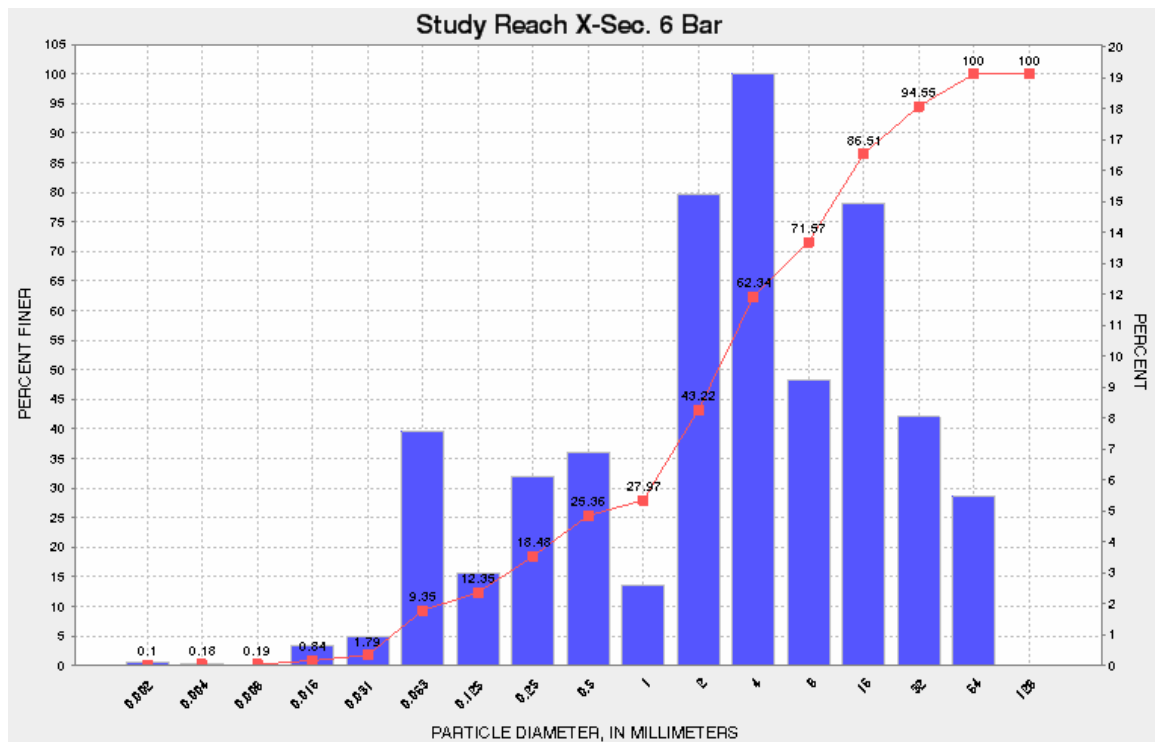
Particle Size Distributions of Bed and Banks for Study and Reference Reaches Study Reach X-Sec. 16

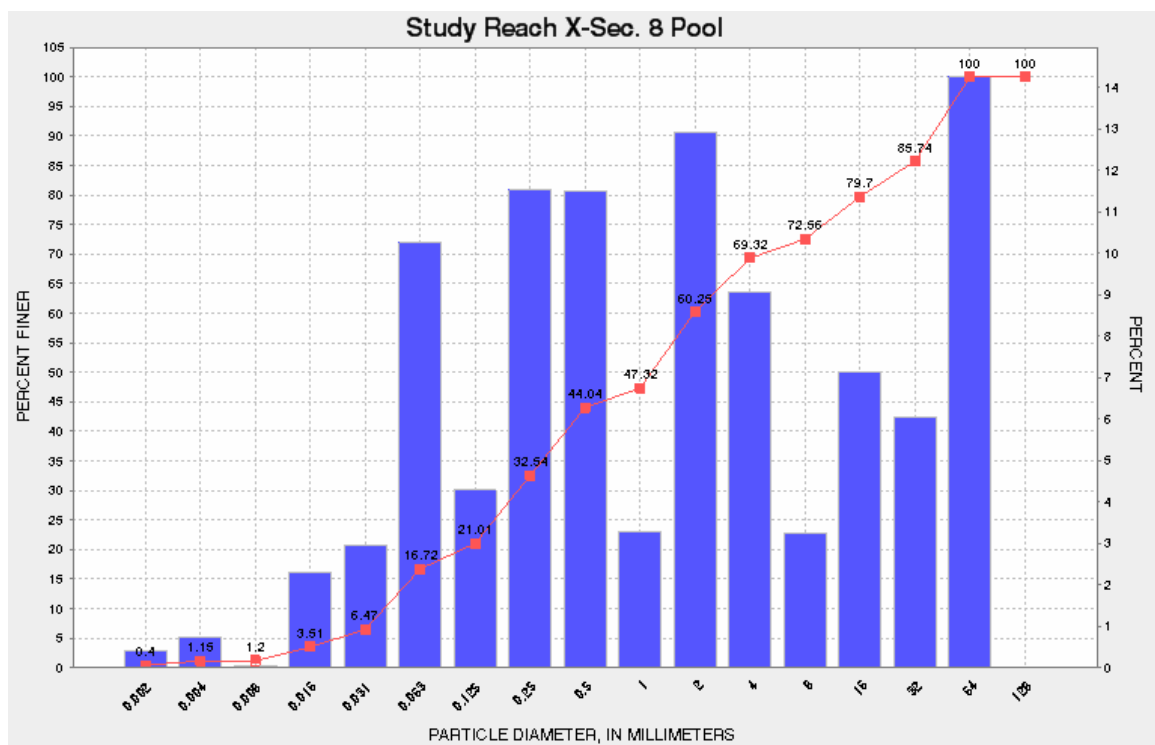
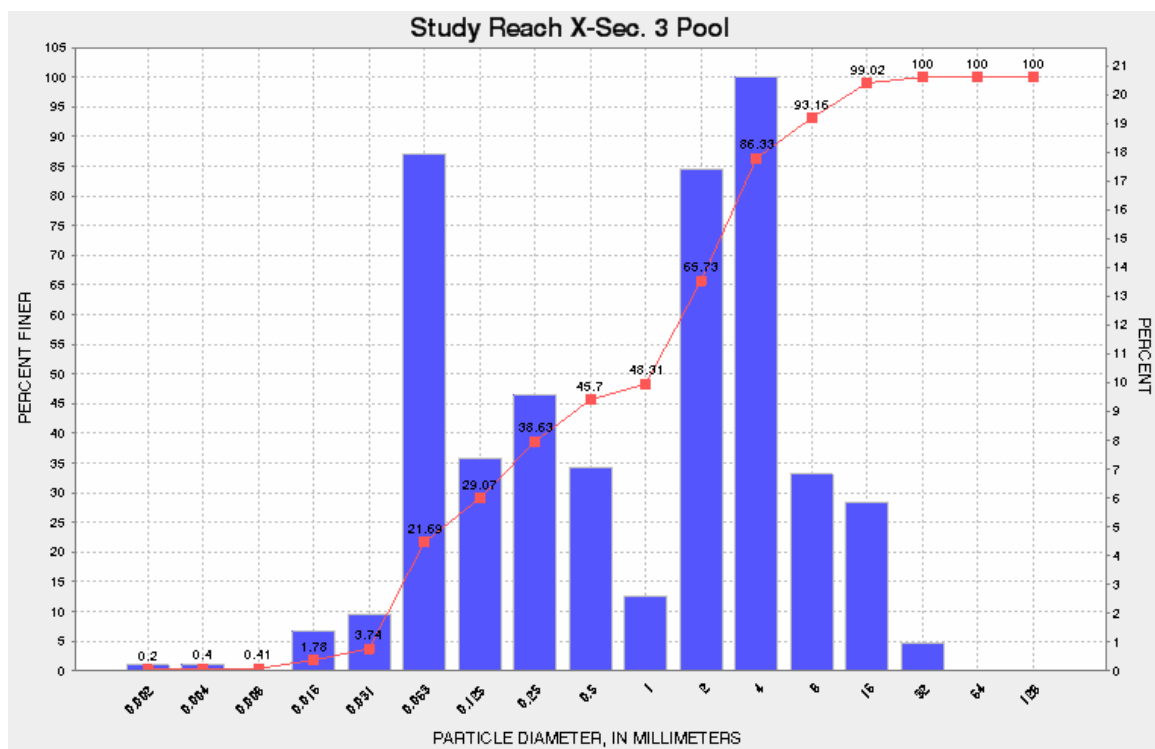


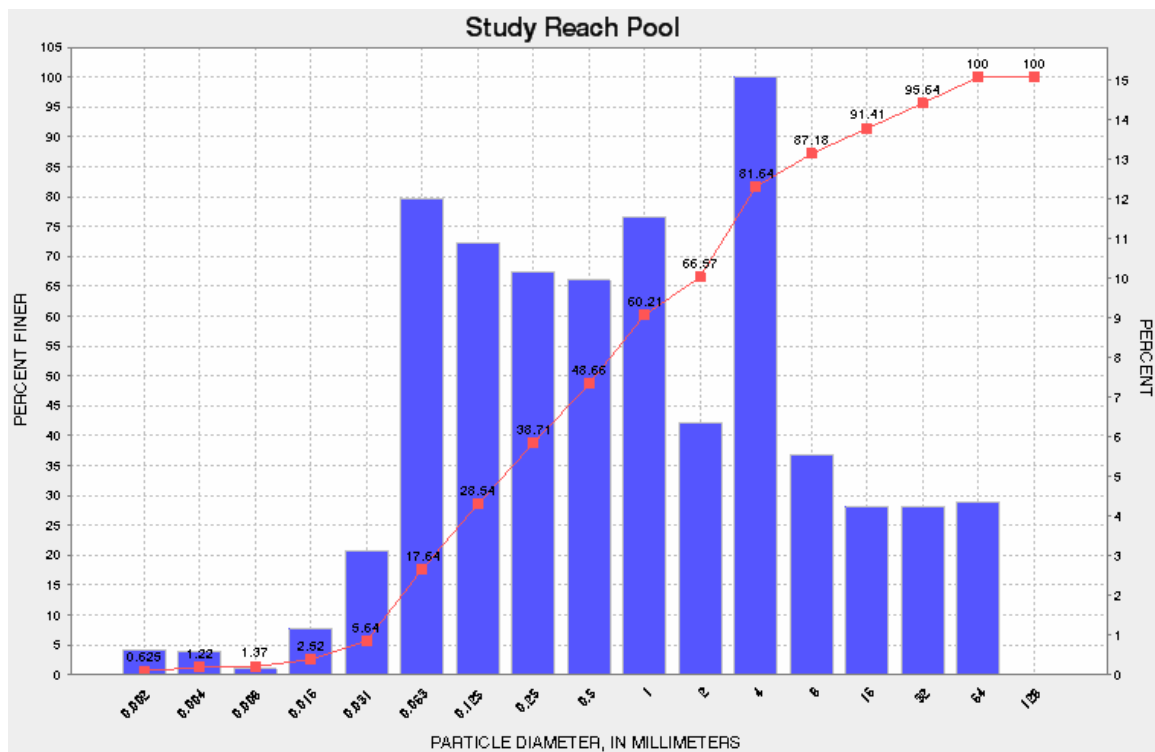
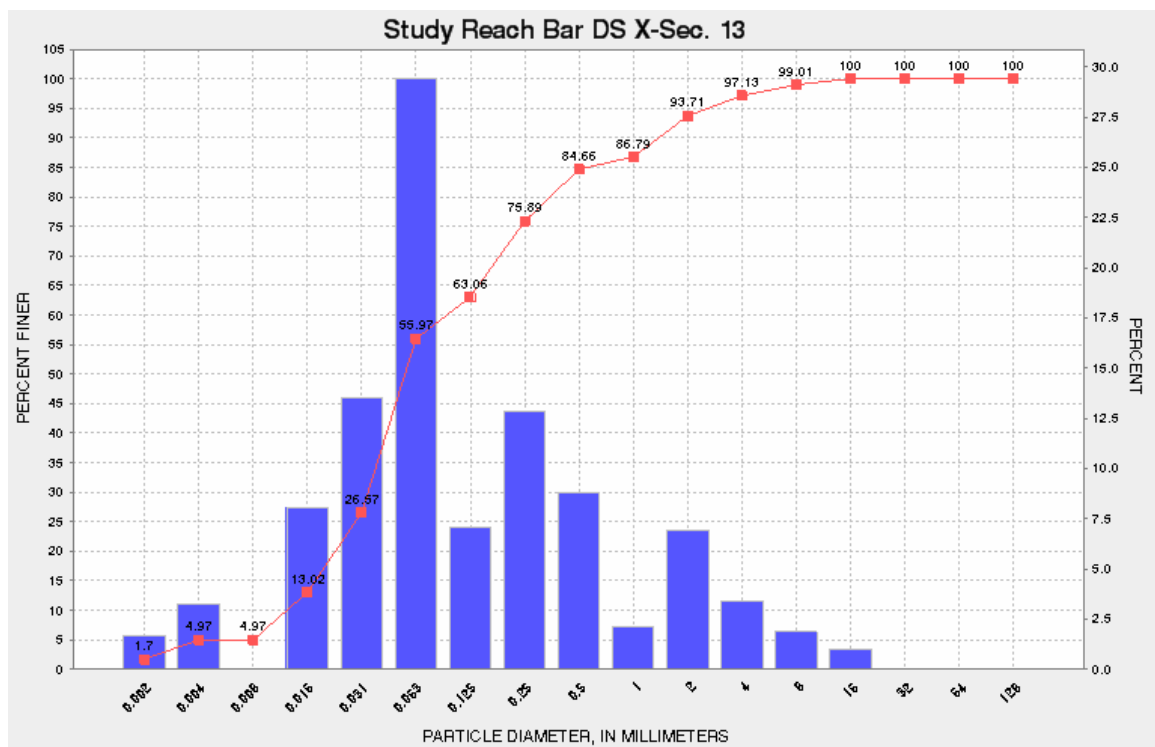


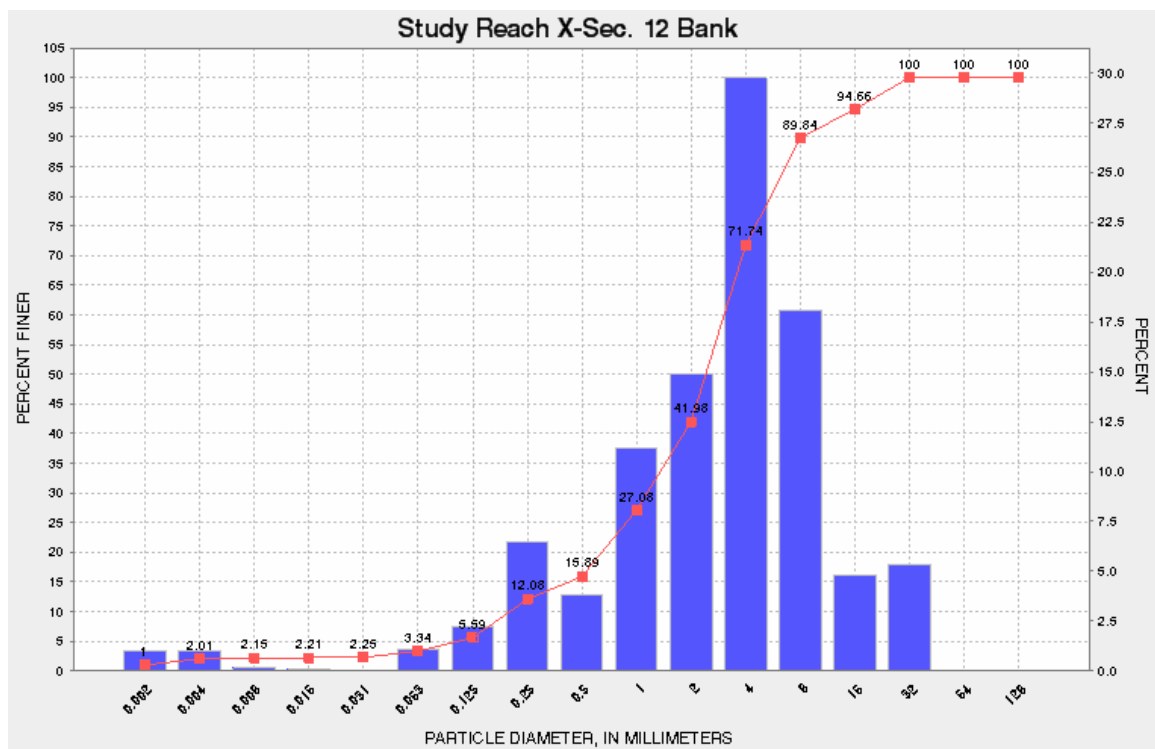
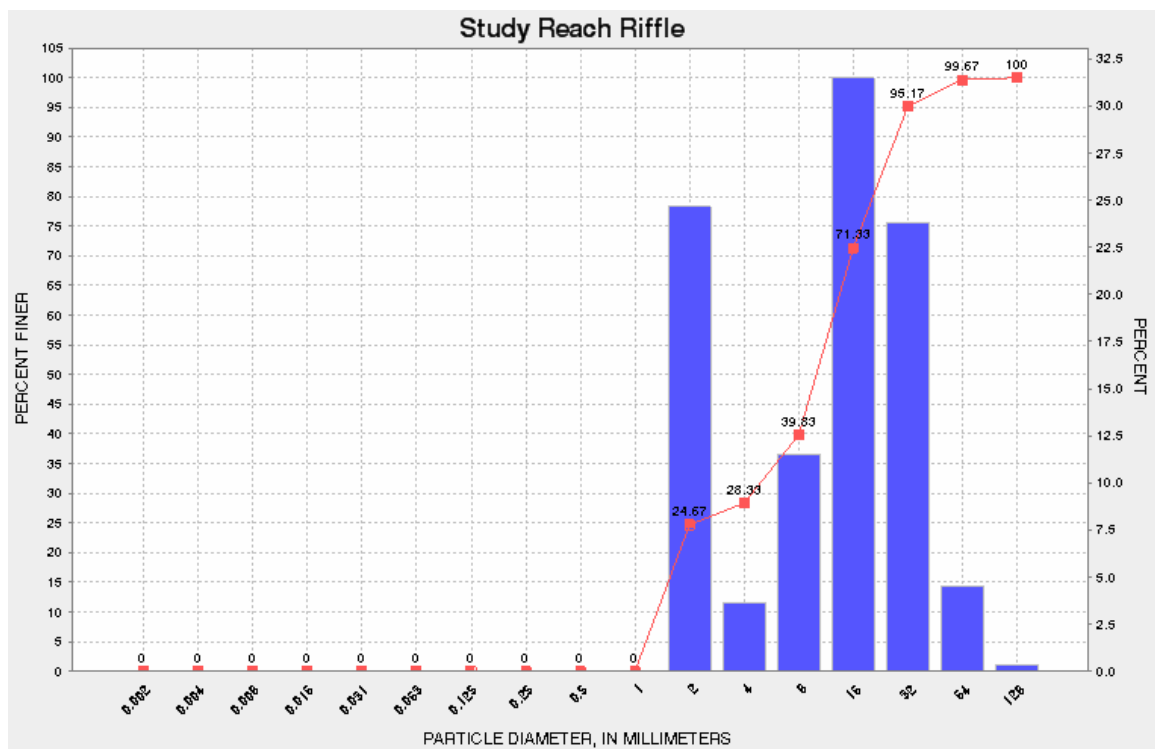


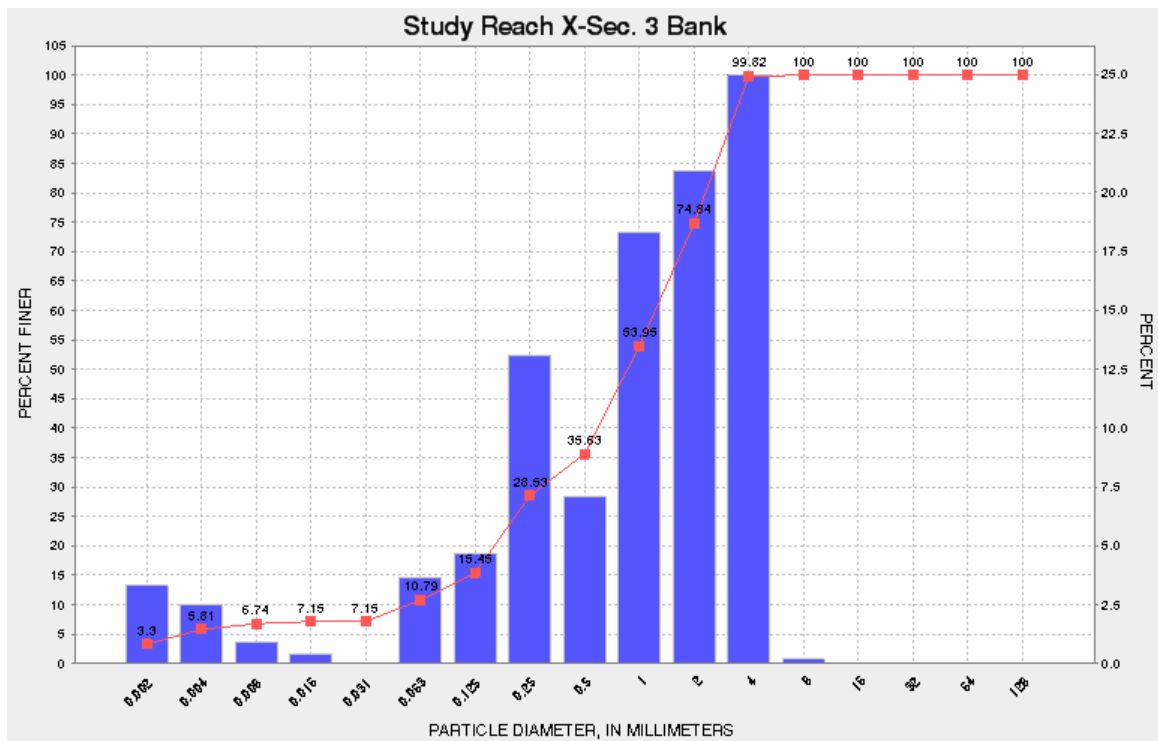
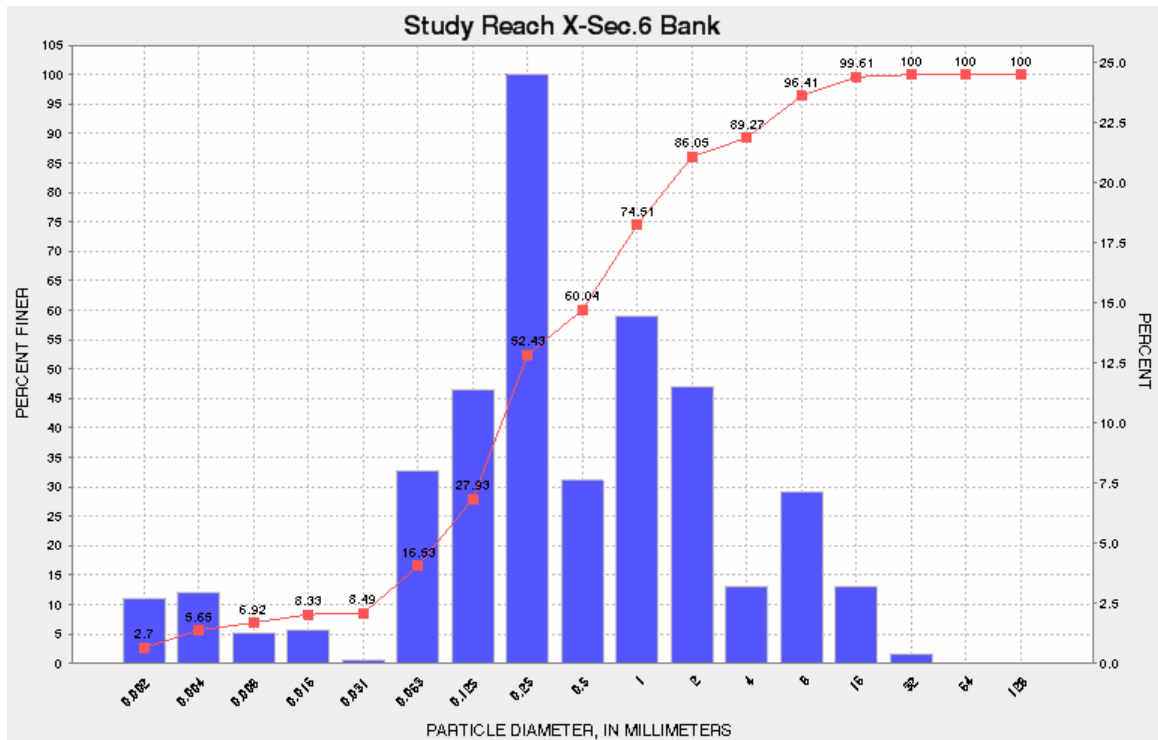


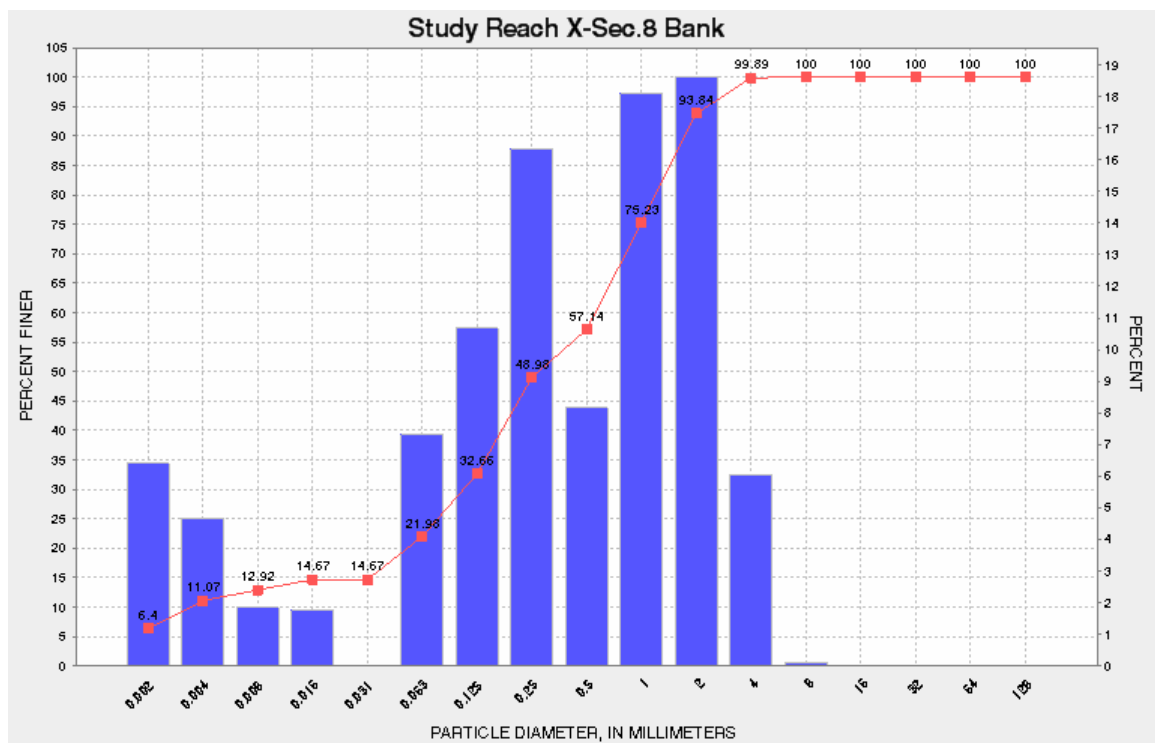
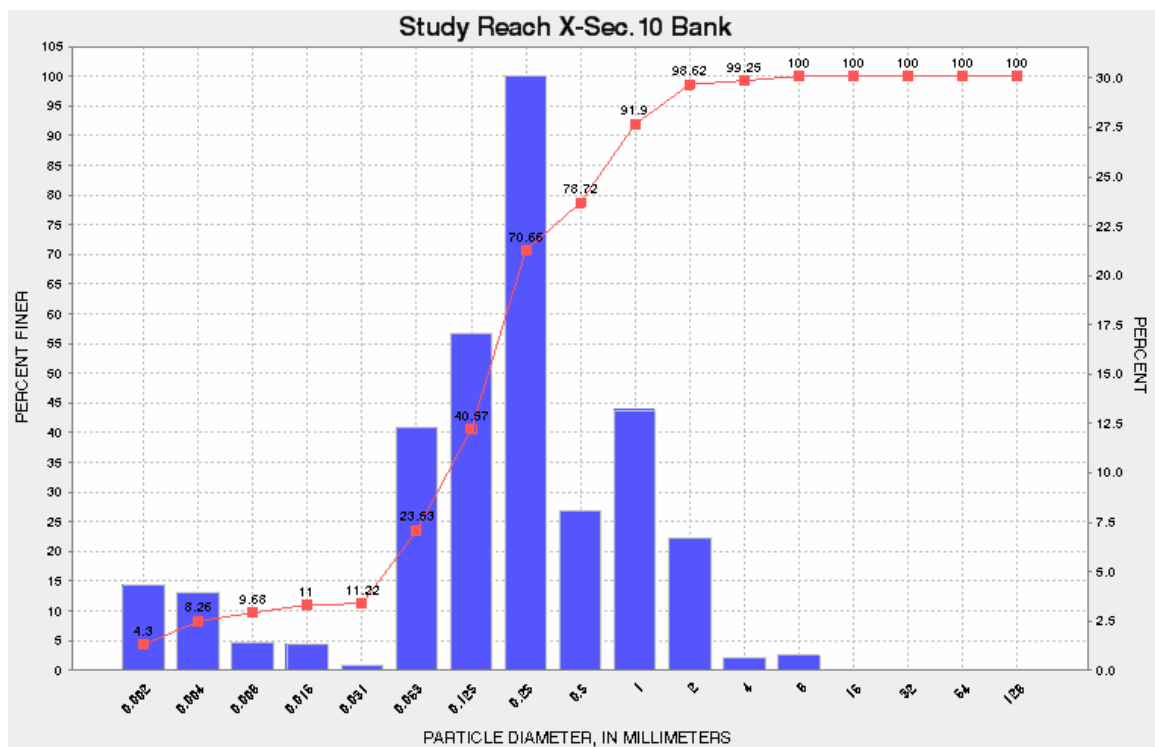


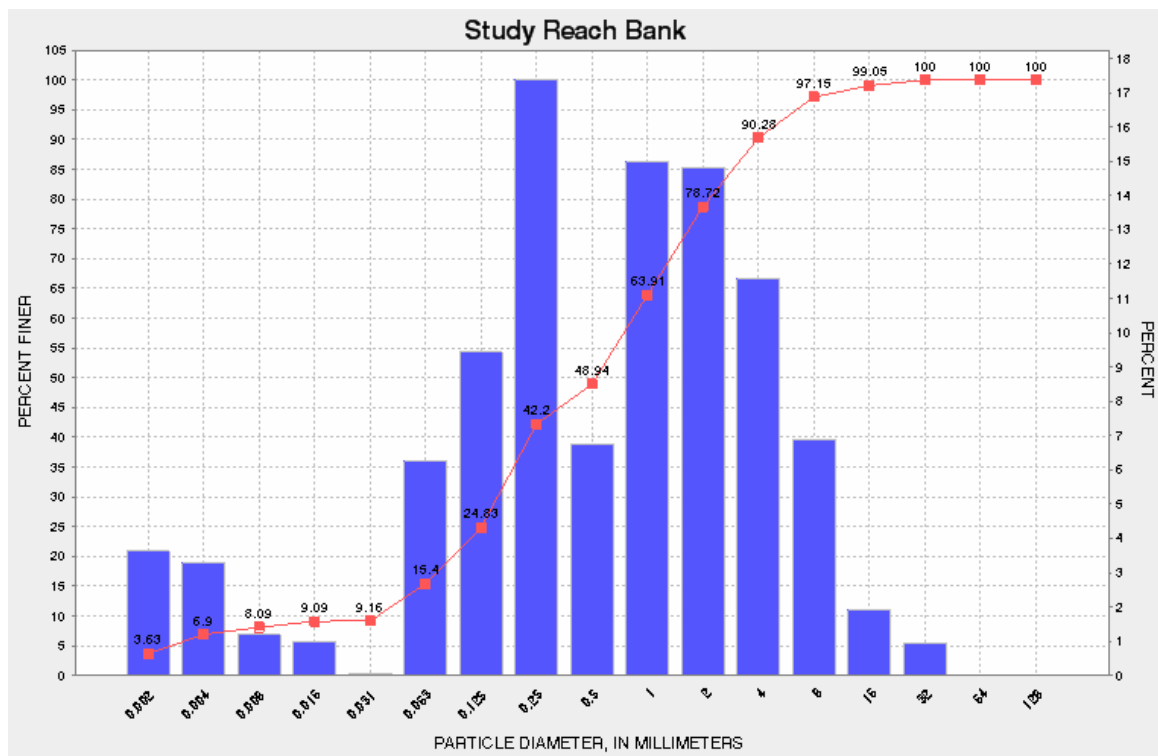
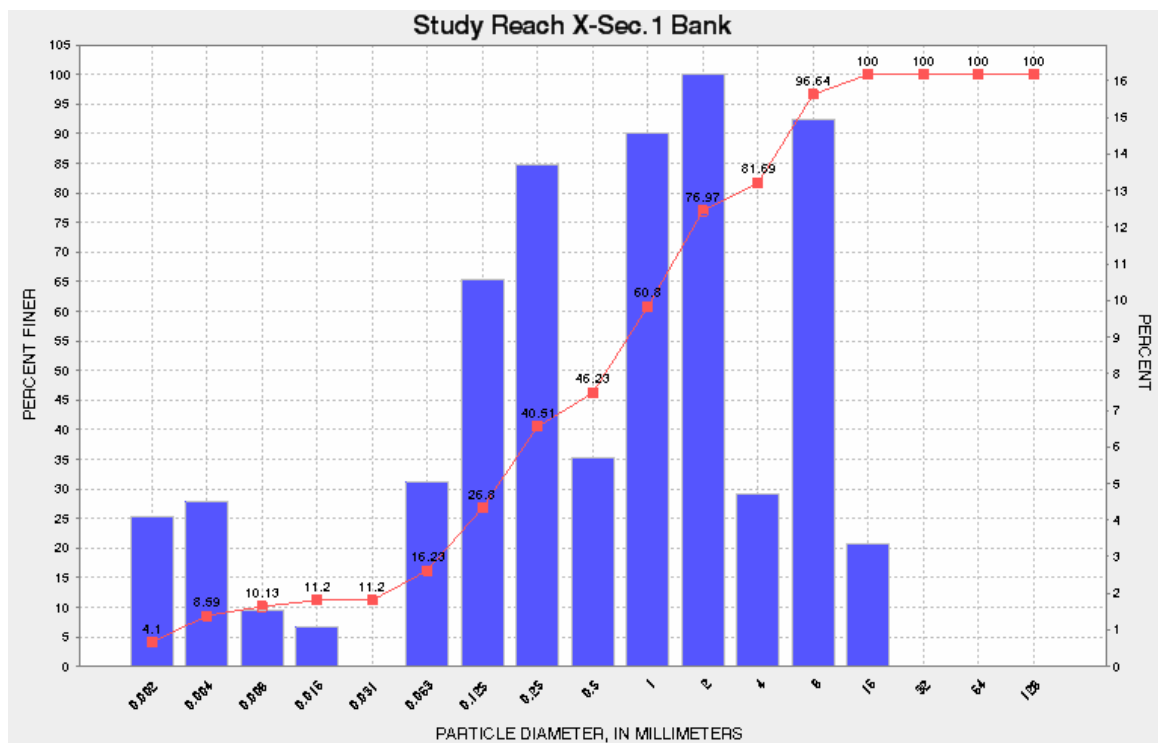


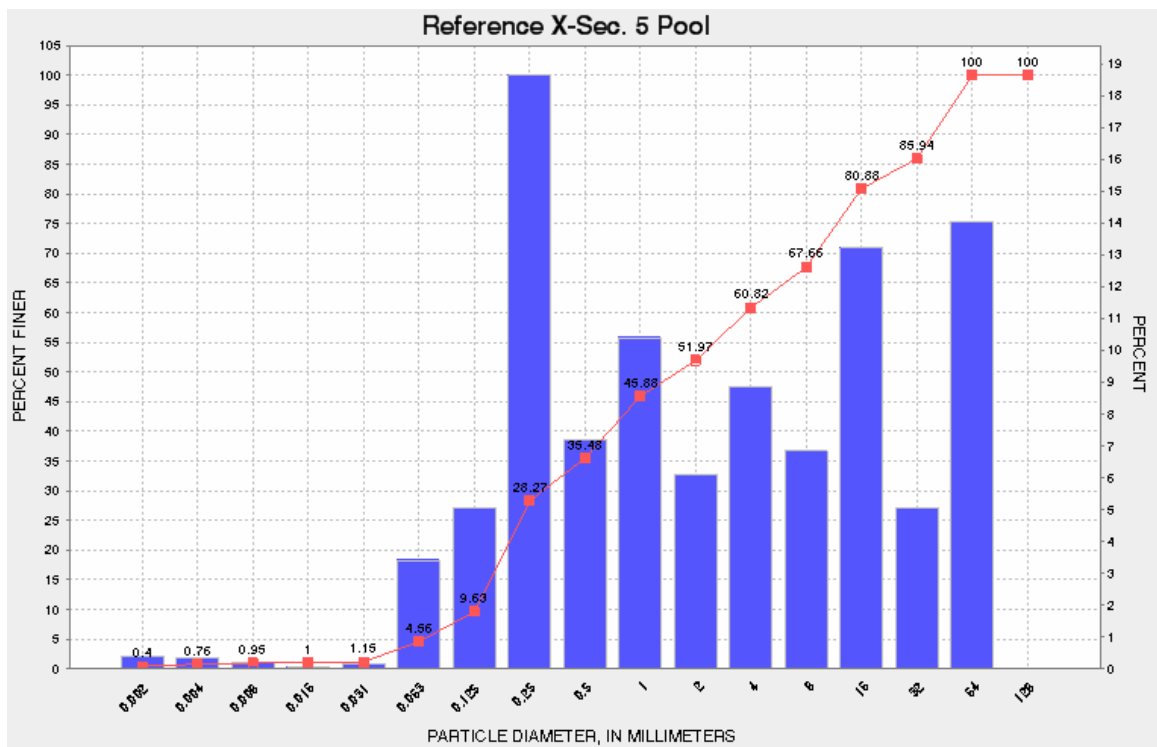
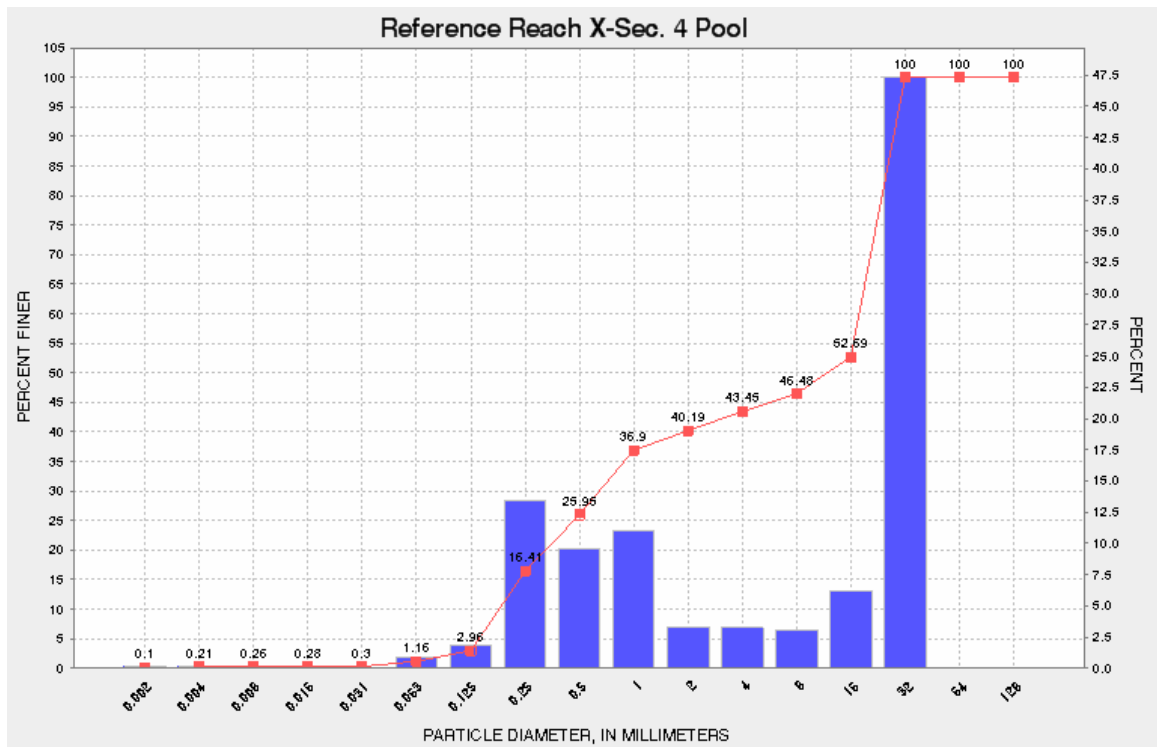


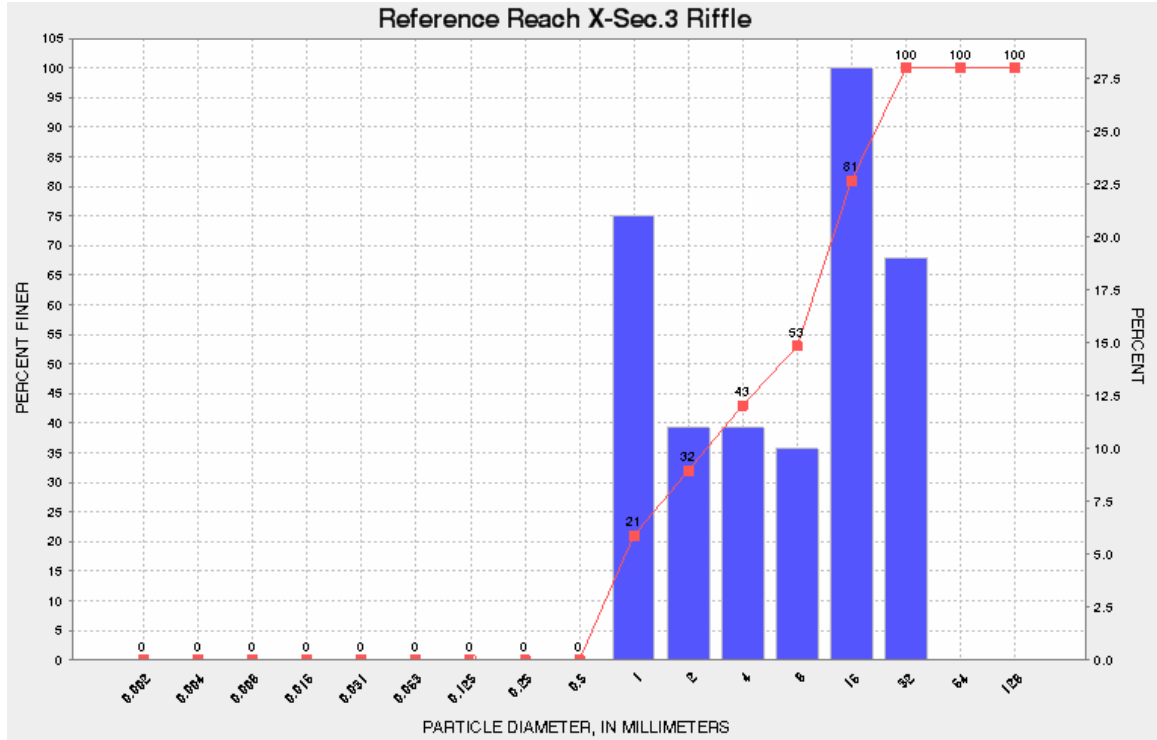
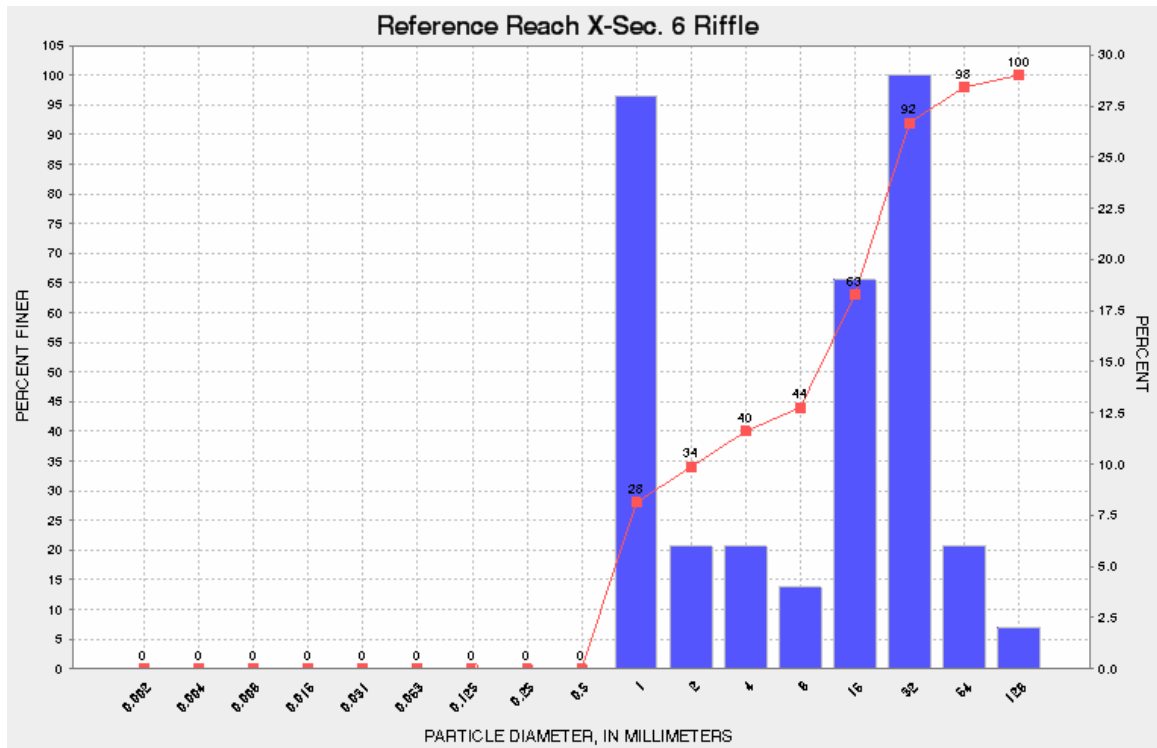


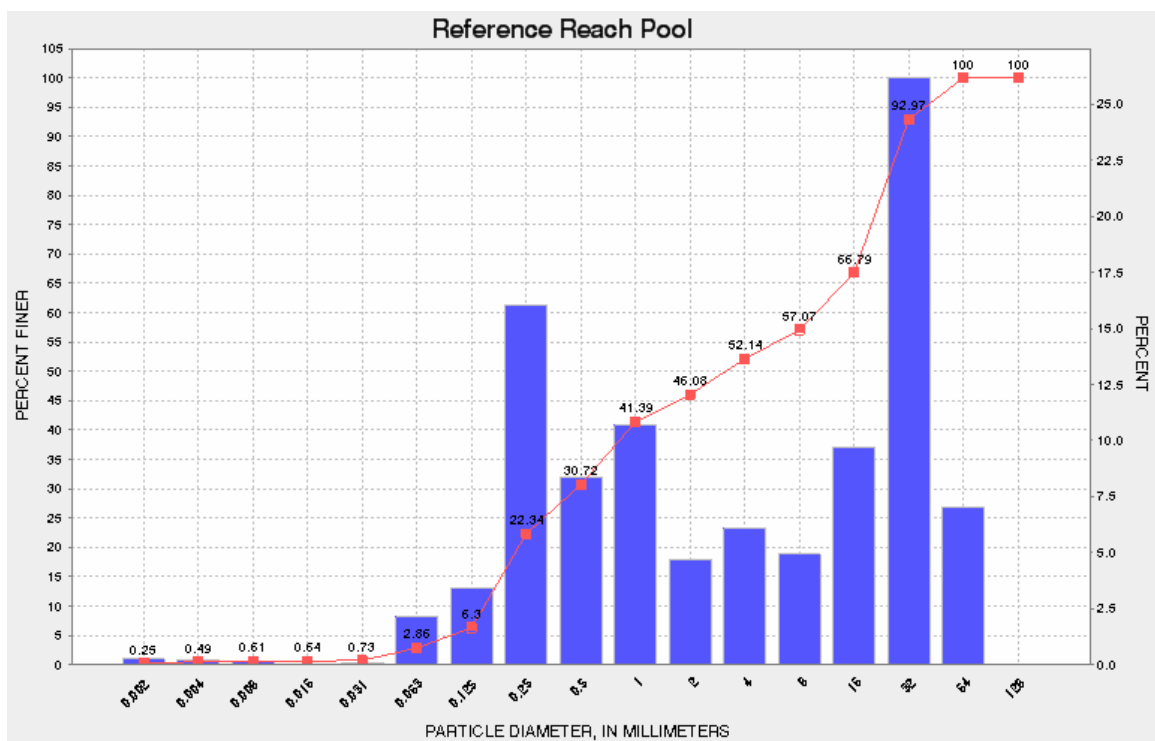
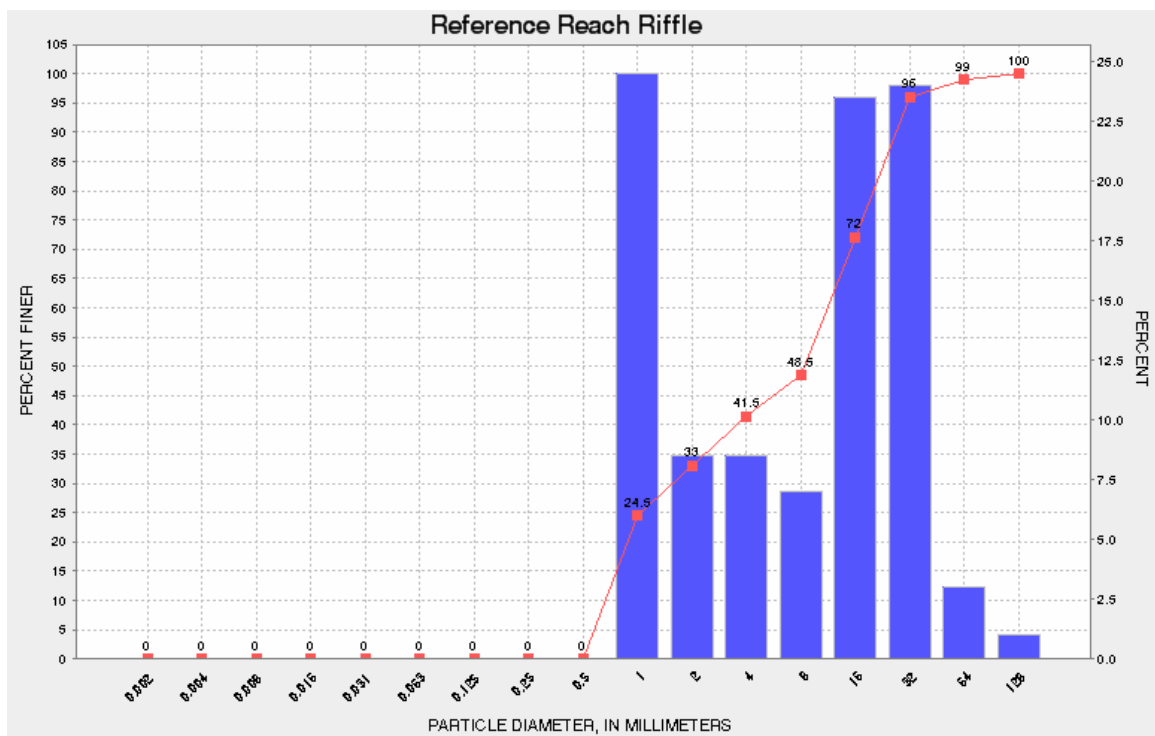


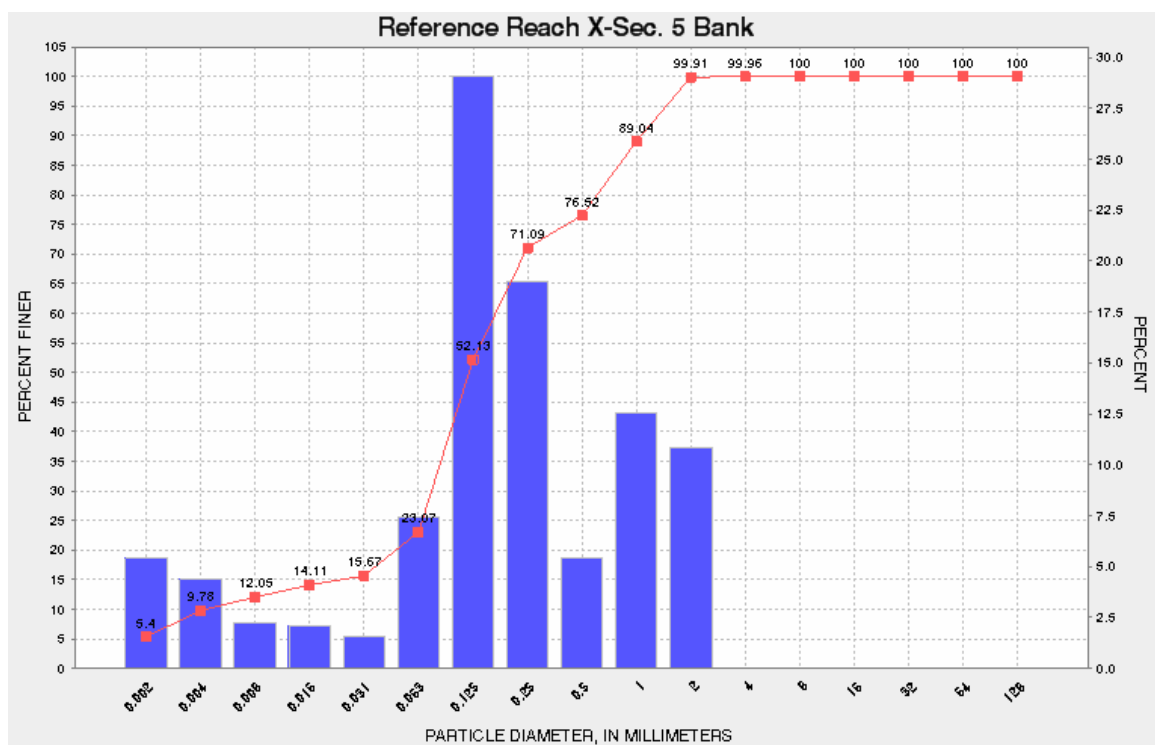
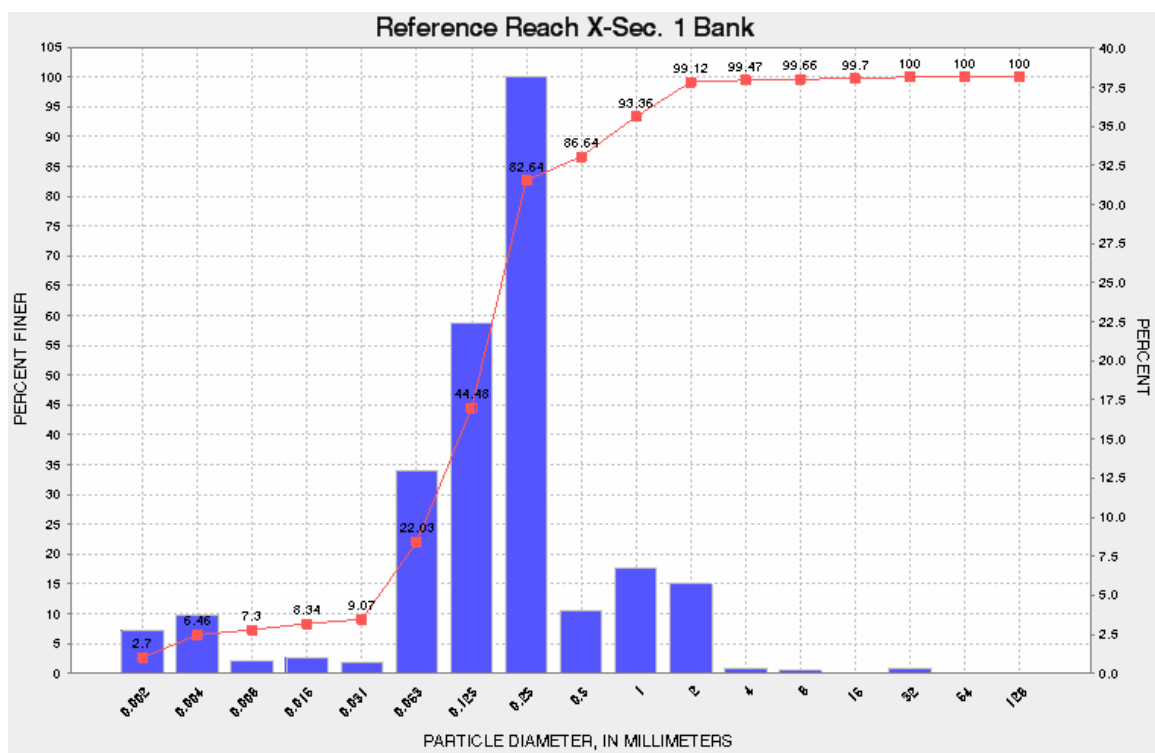


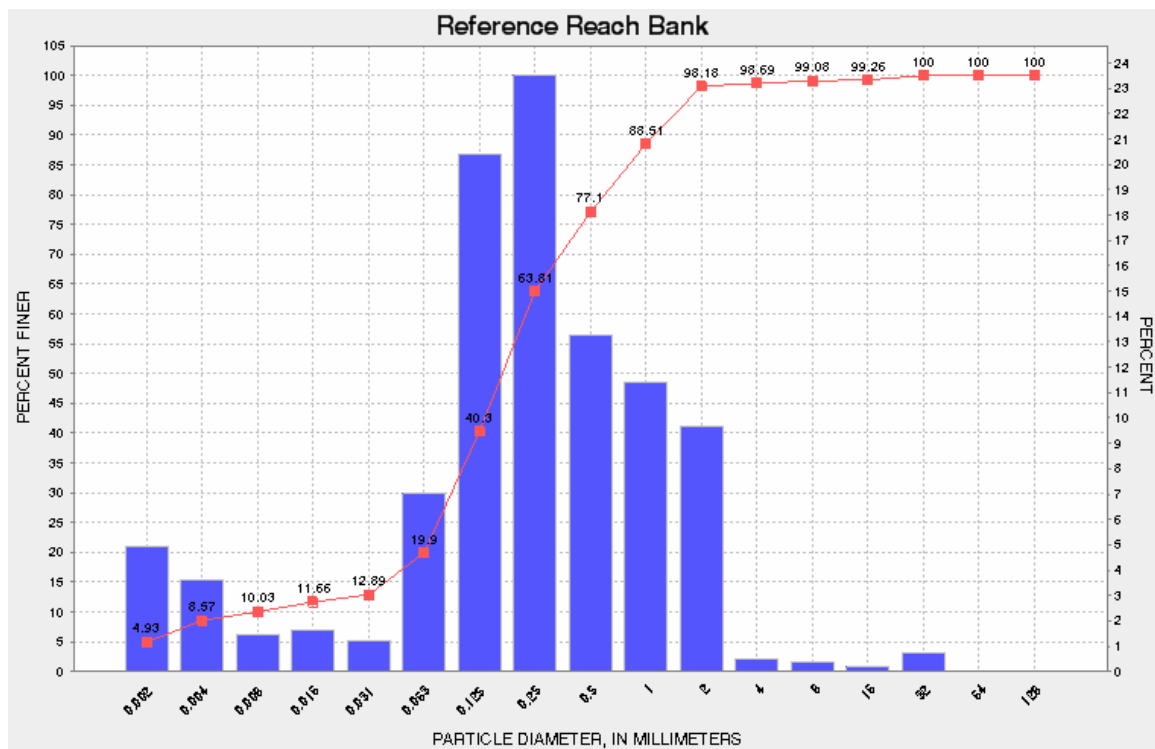
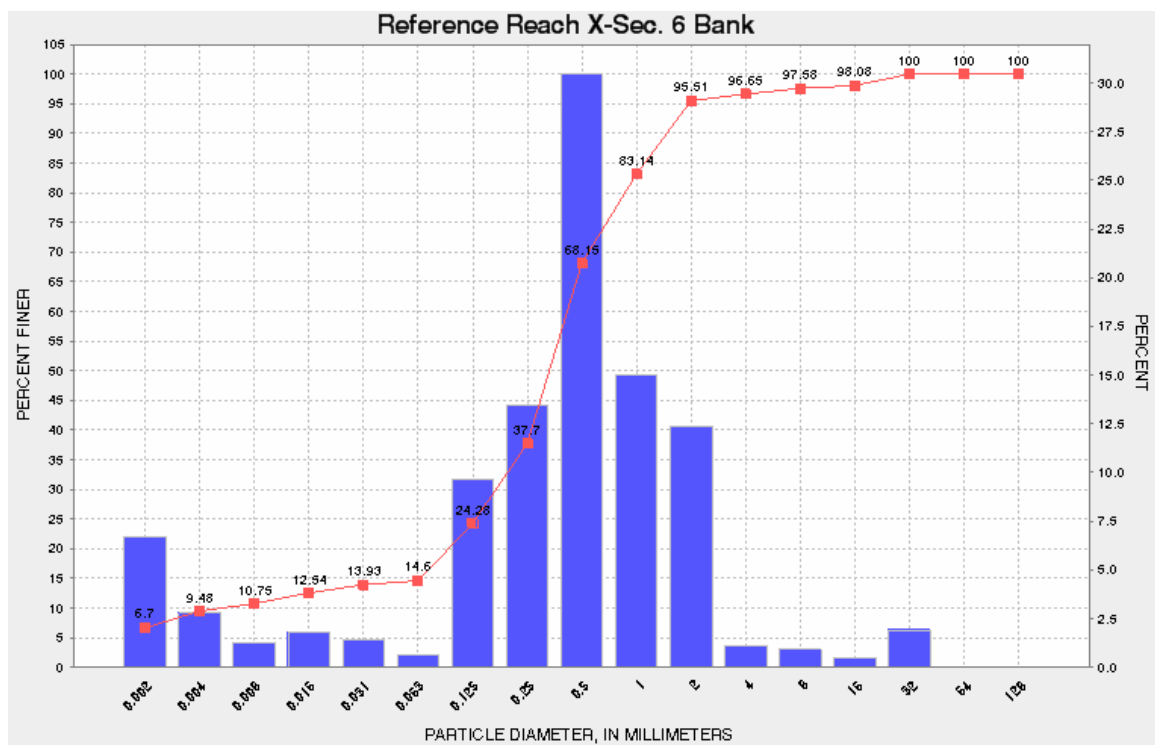












Appendix B: Data Forms and Figures

BEHI Variable Computations

Stream:

Cross Section:

Date:

Observers:

Study Bank Height (ft)

(A)

Bankfull Height (ft)

(B)

(A)/(B) =

(C)

Root Depth (ft)

(D)

Study Bank Height (ft)

(A)

(D)/(A) =

(E)

Root Density (%)

(F)

(F)*(E) =

(G)

Bank Angle (H)

Bank Angle (Degrees)

(H)

Surface Protection (I)

Surface Protection (%)

(I)

Bank Sketch

Vertical Distance (ft)

Horizontal Distance (ft)

Bankfull

Bankfull Height

Study Bank Height

Root Depth

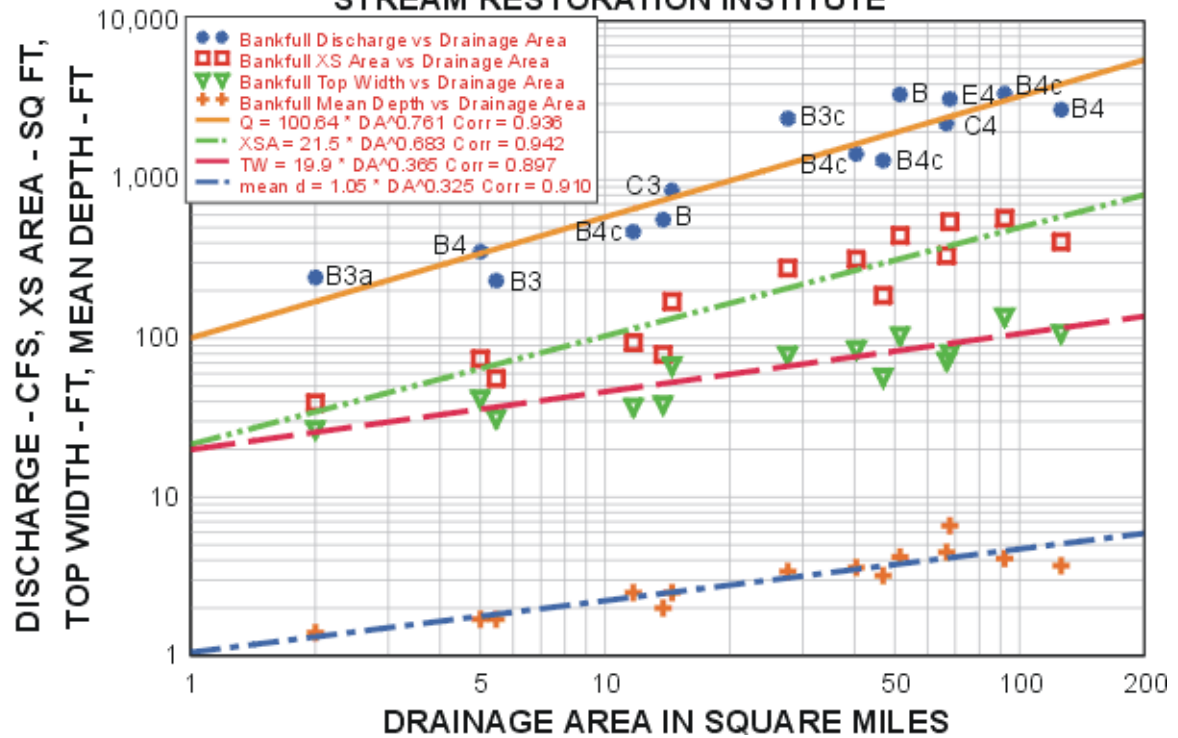
Bank Angle

Surface Protection

Start of Bank

(Rosgen 1996)

**REGIONAL CURVE FOR BLUE RIDGE MTN
PHYSIOGRAPHIC PROVINCE
FROM NORTH CAROLINA STATE UNIVERSITY
STREAM RESTORATION INSTITUTE**



Location: _____

Stability Condition: _____

Observer: _____ Date: _____

(Score each indicator to nearest whole number based on condition. Interpolate between listed scores for a condition that includes a mix of two descriptions.)

Modified Pfankuch Stream Channel Stability Evaluation

Indicator		Condition Description	
1. Channel Source Area			
A	Source Area Function	Unimpaired function. No evidence of adverse impacts (land-use)	1
		Unimpaired function with some evidence (compaction, ditching)	2
		Functional, but adverse impacts evident	3
		Impaired function with obvious adverse impacts	4
B	Protection & Cover	Ground surface cover 90%+, deep litter layer, healthy root mat	2
		Cover 75-90%, sufficient litter layer, root mat mostly continuous	4
		Cover 50-75%, little or light litter layer, root mat present but broken up	6
		Cover <50%, litter layer and root mat largely lacking	8
C	Slippages & Slumps	No evidence in past or present. Side-slopes stable.	2
		Some small, infrequent movement. Side-slopes vegetated and stable	4
		Mod. frequency & size, spots eroded by high water	6
		Active, frequent and larger sizes. High water might trigger more	8
2. Channel Form			
A	Bed Resistance	Predom of stable material (boulders, bedrock) tightly packed and overlapped	6
		Bed adequately armored with stable material. Mod tight packing w/ some overlapping	12
		Predom of small sized material (small boulder, cobble, gravel). Loose packing with little overlap	18
		Predom of fines with no to slight armor. No packing, loose arrangement.	24
B	Bedload Movement (Riffle or Run)	No signs of bedload movement. Platy shape may be dom. Sharp edges & corners	3
		Few signs of movement. Mix of shapes but mostly platy, rounded edges and corners	6
		Seasonal bedload movement common. Mix of shapes, well rounded edges and corners	9
		Yearlong movement occurring. Elongated shape may be predom. Well rounded on all edges	12
C	Bank Cutting & Sloughing	Little or none evident	3
		Some, intermittently with no to low impacts	6
		Significant and frequent. Mod to high impacts. Some raw, vertical banks	9
		Nearly continuous, frequent failures of vertical banks. High impact.	12

D	Bank Resistance To Wear	Banks well protected by rocks, plants, roots, stable material with no obvious flood damage. High resistance.	4
		Banks adequately protected. Some interspaces but stable. Some flood damage	8
		Protection present but limited. Interspaces unstable, frequent signs of flood damage	12
		Banks not well protected. Poor resistance to wear.	16
E	Aggregation / Downcutting	Longitudinal profile stable and within normal rates of adjustment	3
		Minor instability to profile, but affect is slight and not widespread	6
		Instability has occurred to profile but channel recovering well	9
		Active instability to profile occurring. Channel redefining itself.	12
3. Channel Function			
A	Channel Capacity	Ample to contain mean annual flood peak plus more. Over-bank flows 5-yr events or greater. Width to depth ratio <10	4
		Adequately transmits mean annual flood. Over-bank flows at least every 2-3 years. W/D is 10-20.	8
		Channel cross section barely contains mean annual flood. Over-bank flows are annual. W/D ratio is 20-30.	12
		Mean annual floods are not contained in the cross section. Over-bank flows occur many times a year. W/D ratio is > 30.	16
B	Bar Deposits	Bar deposits are fairly stable (vegetated over, old deposits clearly evident). Little or no enlargement. Pattern is fixed (bar types not shifting).	1
		Bars showing some new changes (growing, shrinking) but not widespread and generally stable. Pattern is fairly fixed with no new bars.	2
		Bar deposits showing mod changes in age and shape. New bars may be present and bar types may be changing.	3
		Significant changes occurring to bar deposits. Instability of bars clearly evident. New bars present. The pattern is shifting or is uncertain.	4
C	Sediment Traps	None to low sediment buildup behind traps (logs, boulders). Next high flow should flush the traps. Pools are fairly clean.	2
		Some sediment trapped plus visible in some pools. Trapped sediment has not noticeably affected channel cross section.	4
		Considerable sediment trapped forming small - mod bars. High flows not able to flush most traps. Cross section and most pools affected.	6
		Sediment traps filled forming mod - large sized bars. High flows not flushing traps. Pool volume filling and mod-high changes in cross section	8
D	Sediment Deposition On Upper Banks	Not much evidence of historic or recent sediment deposition along the upper bank. No contrib from this zone to the channel sediment budget.	1
		Some scattered evidence of depositions. None to little contribution to the sediment budget.	2
		Sediment deposition along upper bank fairly widespread. A low to moderate contribution to the sediment budget.	3
		Extensive sediment deposits (historic or recent) along the upper banks. Contribution from this zone to sediment budget moderate to high.	4

E	Fast Water Sediment Deposition (Riffle or Run)	Coarse channel bottom material (boulders, cobble, gravel) not embedded by sediment. Channel roughness is fully pronounced.	4
		Coarse channel bottom material is slightly embedded. Channel roughness is well pronounced.	8
		Coarse channel bottom material is moderately embedded. Channel roughness is visibly reduced and being compromised.	12
		Coarse channel bottom material almost to completely buried and severely embedded. Channel roughness has been significantly reduced or lost.	16
F	Large Woody Debris Component	LWD is so situated or so large that the stream is not normally able to move it. Any scouring due to LWD is now stable.	2
		Few pieces of LWD can be moved with normal high flows. Fresh scouring is infrequent LWD showing strong benefits to the channel.	4
		Several LWD pieces can be floated with normal high flows. Fresh scouring is scattered to common. LWD offers limited benefits	6
		Most LWD can be moved by normal high flows. Fresh scouring is common to widespread. LWD offers none to little benefits to the channel.	8

Total Rating _____

Rating	Stability Condition
38	Excellent
39 - 51	High – Good
52 - 64	Good
65 – 76	Low – Good
77 – 89	High – Fair
90 – 102	Fair
103 – 114	Low – Fair
115 – 127	High – Poor
128 – 139	Poor
140 - 152	Low - Poor

Stability Condition _____

Source:

Albright, R.C. 1994 (Revised 2007). A Fluvial Geomorphic Stability Index for Rainfall Generated Stream Channels. Unpublished Paper. USDA Forest Service. 12 p.

CHANNEL-STABILITY RANKING SCHEME

River _____ Site Identifier _____

Date _____ Time _____ Crew _____ Samples Taken _____

Pictures (circle) U/S D/S X-section Slope _____ Pattern: Meandering
Straight
Braided

1. Primary bed material

Bedrock	Boulder/Cobble	Gravel	Sand	Silt Clay
0	1	2	3	4

2. Bed/bank protection

Yes	No	(with)	1 bank protected	2 banks
0	1	2	3	

3. Degree of incision (Relative elevation of "normal" low water; floodplain/terrace @ 100%)

0-10%	11-25%	26-50%	51-75%	76-100%
4	3	2	1	0

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

0-10%	11-25%	26-50%	51-75%	76-100%
0	1	2	3	4

5. Stream bank erosion (Each bank)

	None	Fluvial	Mass wasting (failures)
Left	0	1	2
Right	0	1	2

6. Stream bank instability (Percent of each bank failing)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

7. Established riparian woody-vegetative cover (Each bank)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

9. Stage of channel evolution

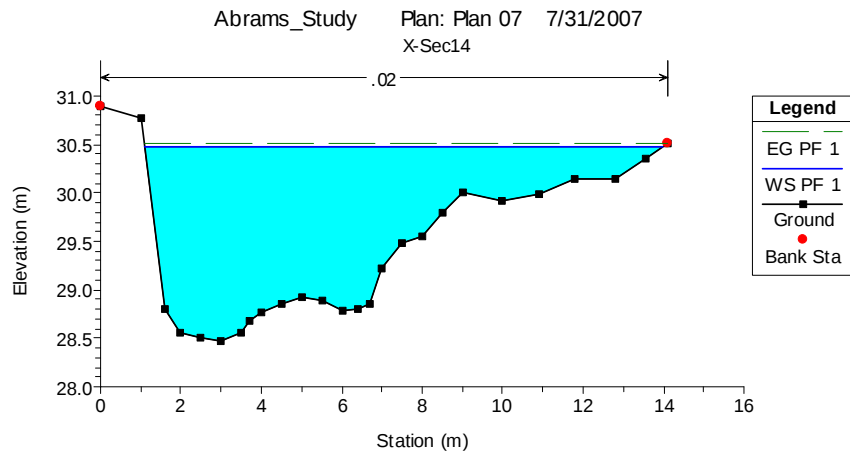
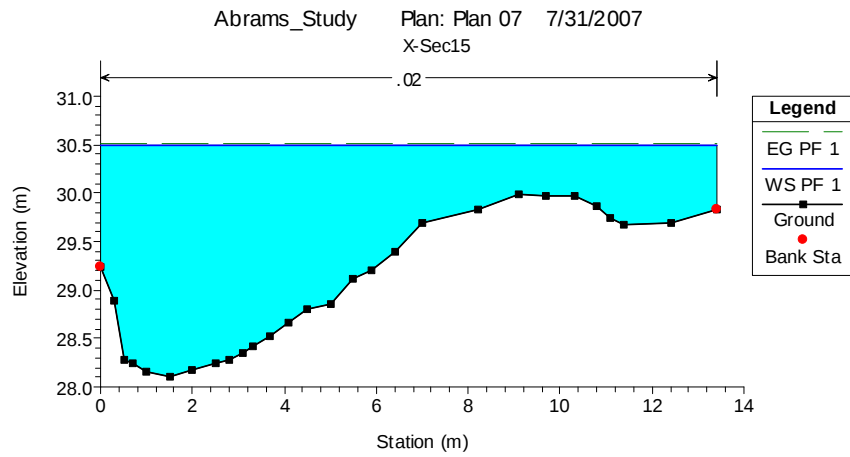
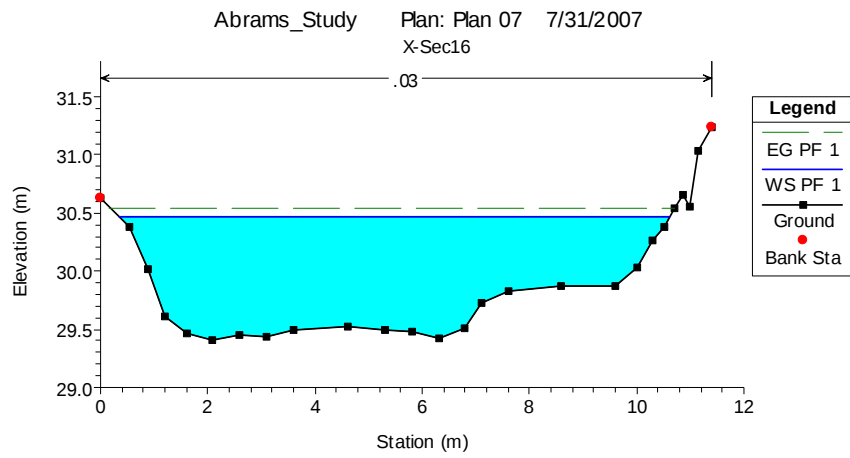
I	II	III	IV	V	VI
0	1	2	4	3	1.5

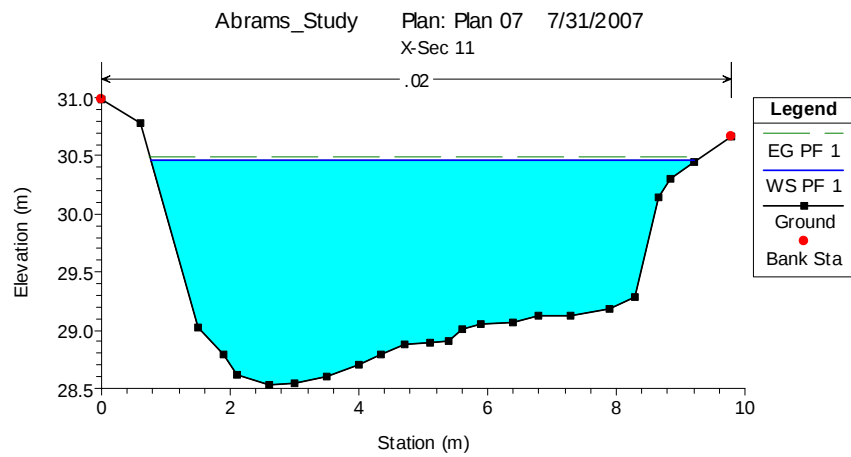
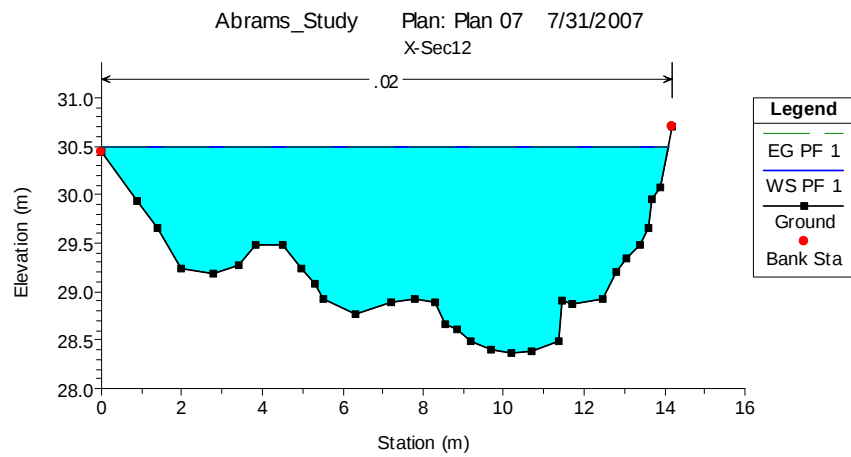
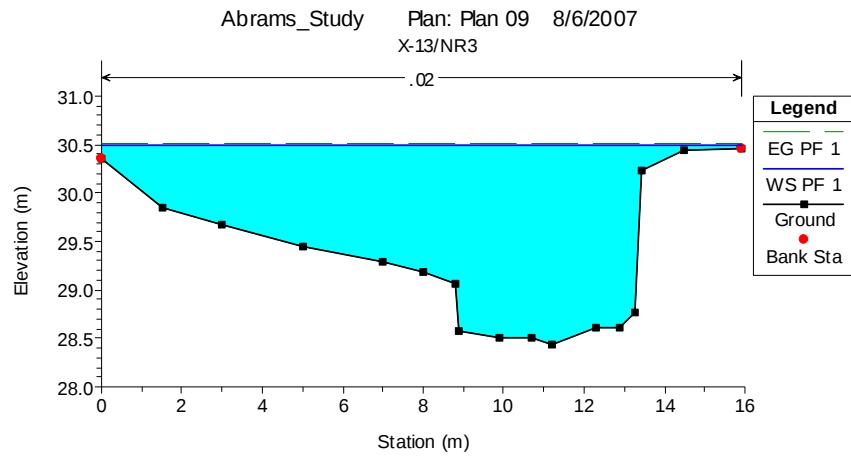
Total Score _____

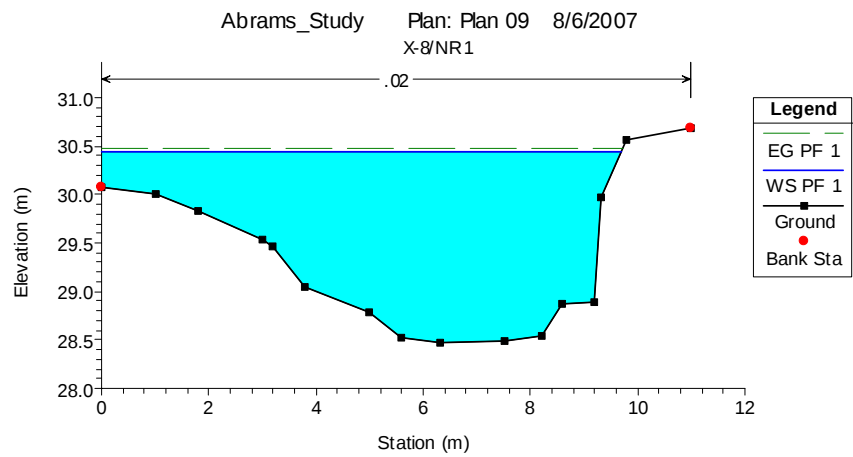
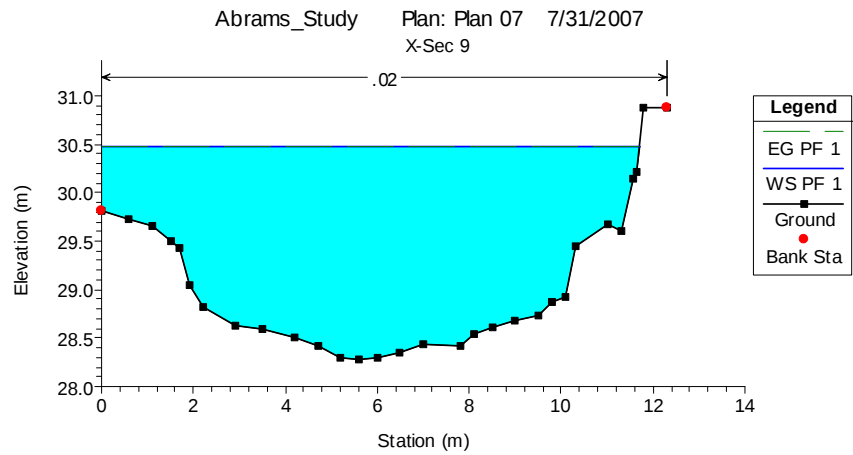
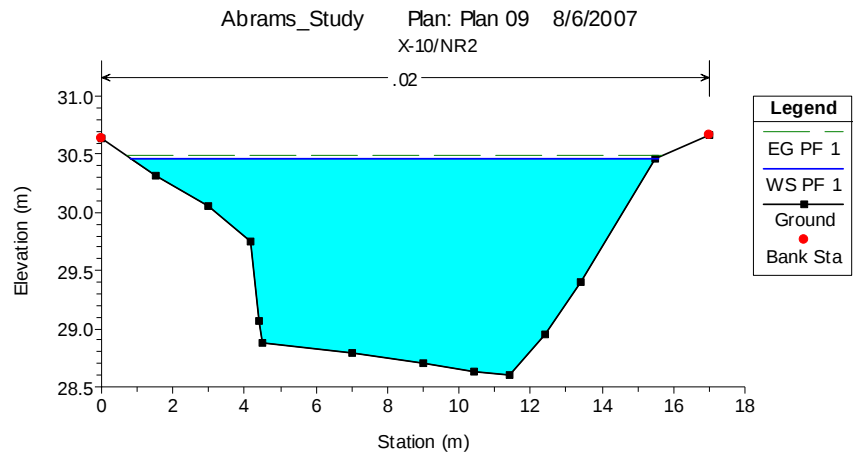
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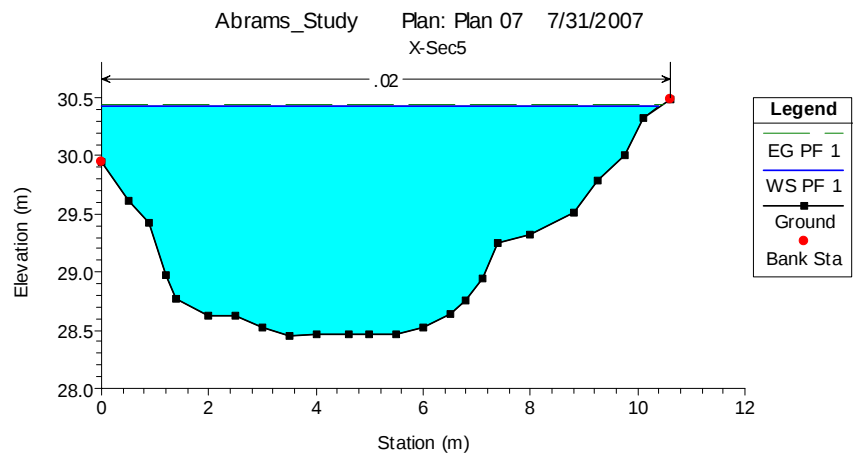
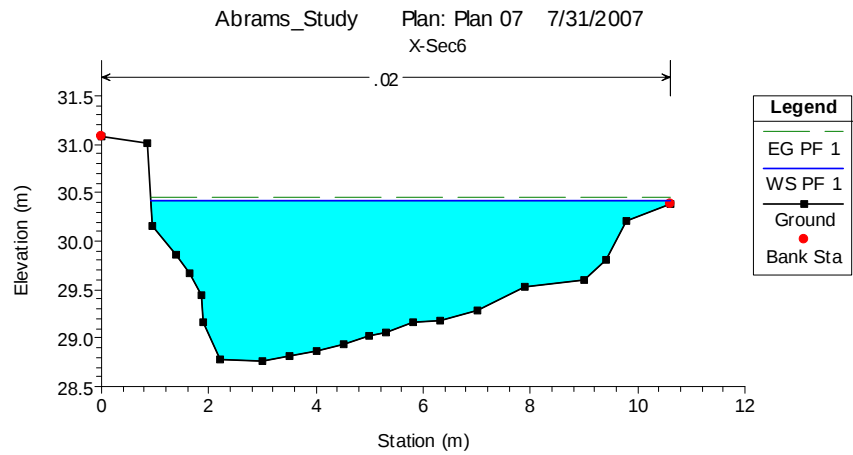
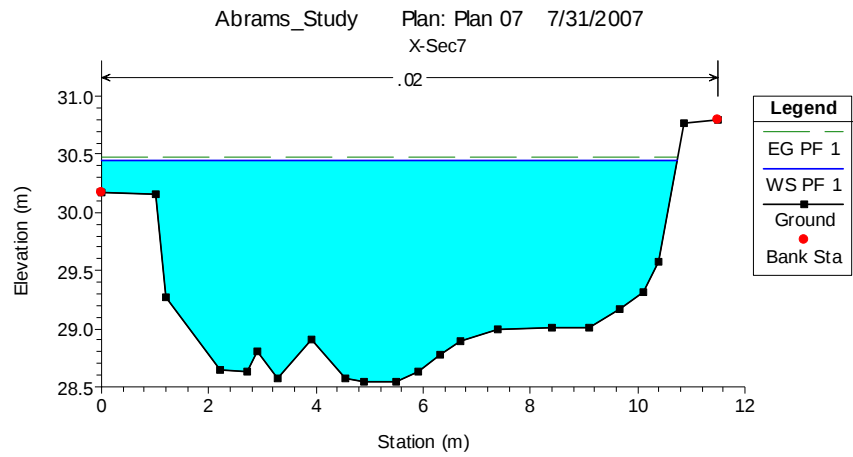
Appendix C: Model Output

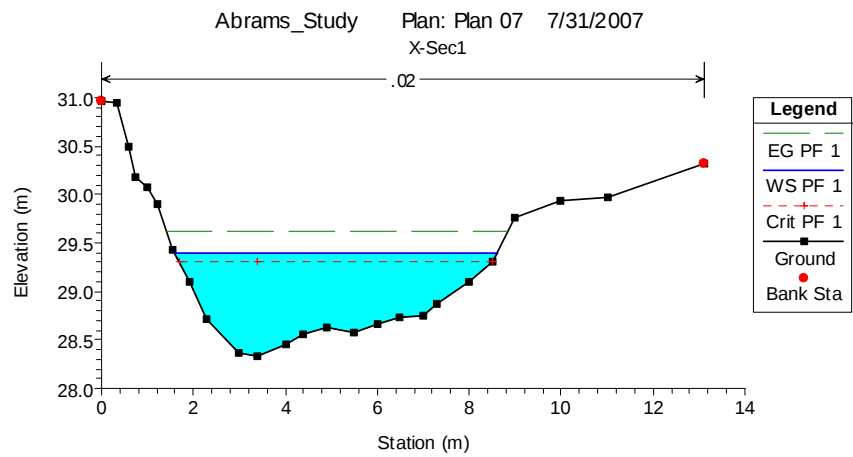
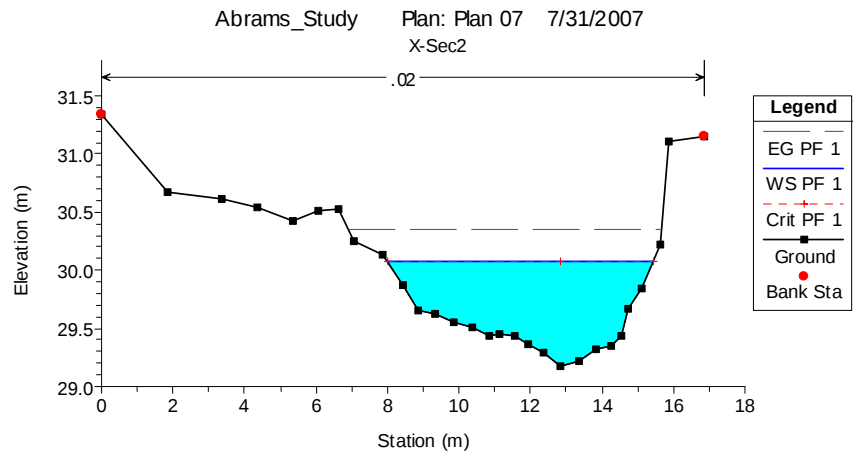
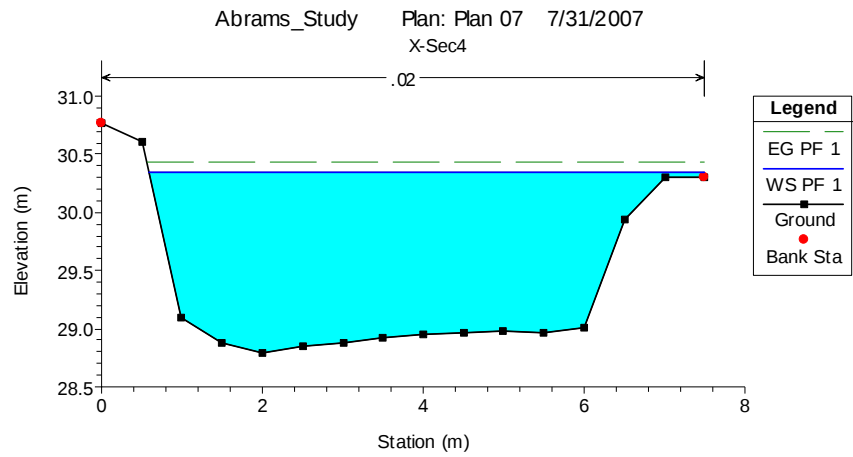
HEC-RAS simulated bankfull discharges

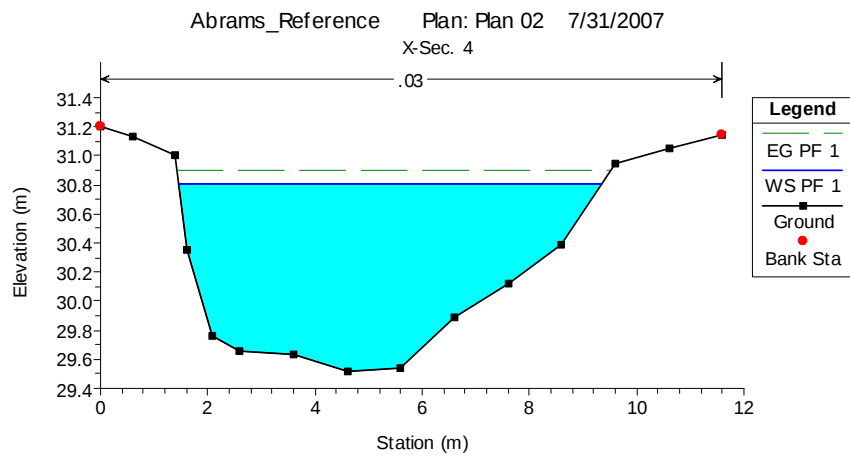
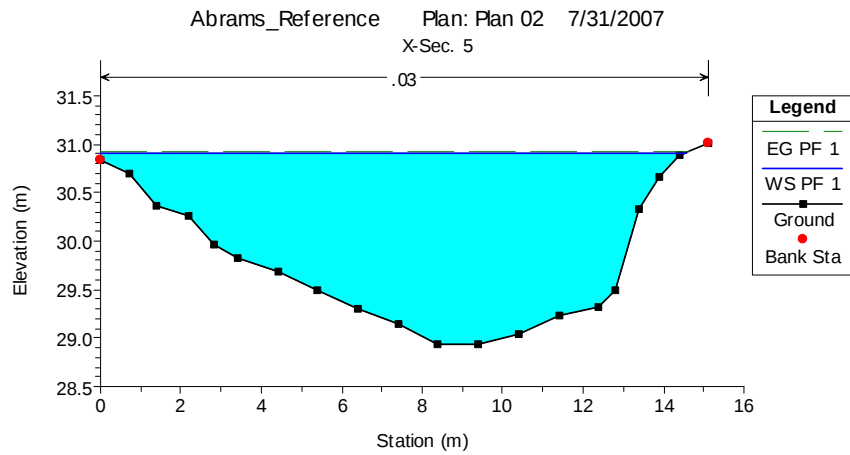
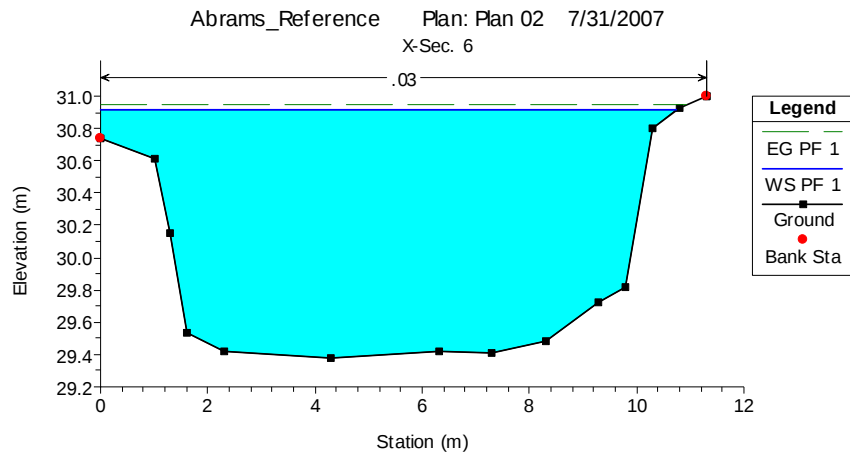


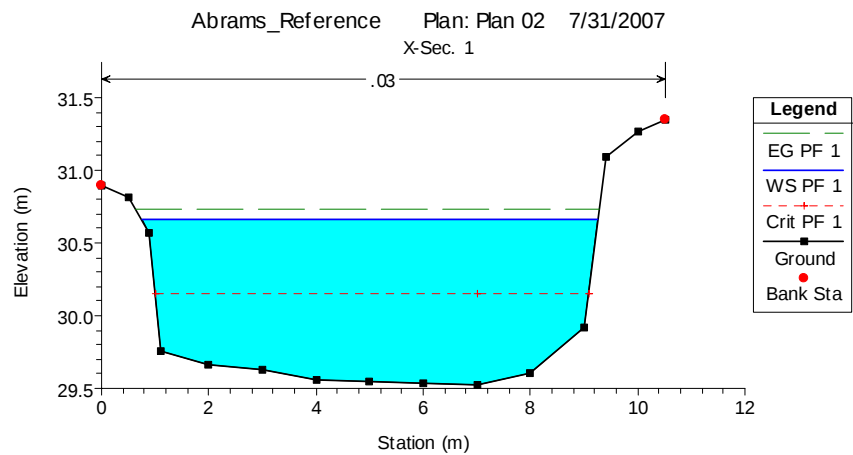
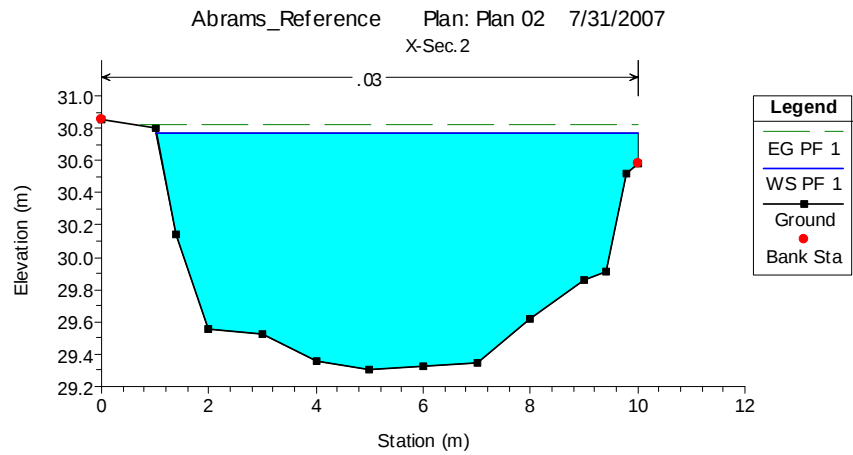
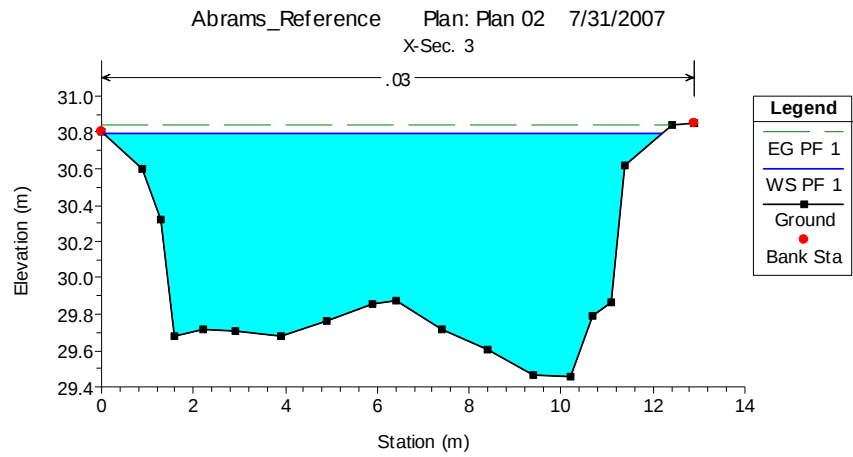




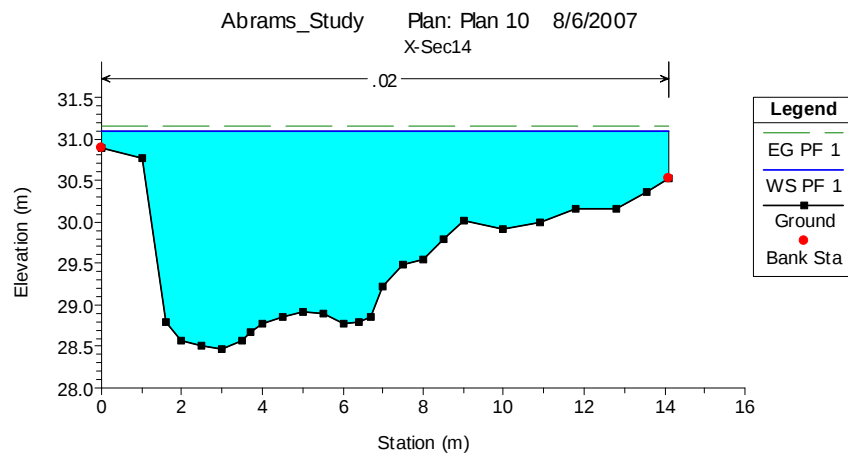
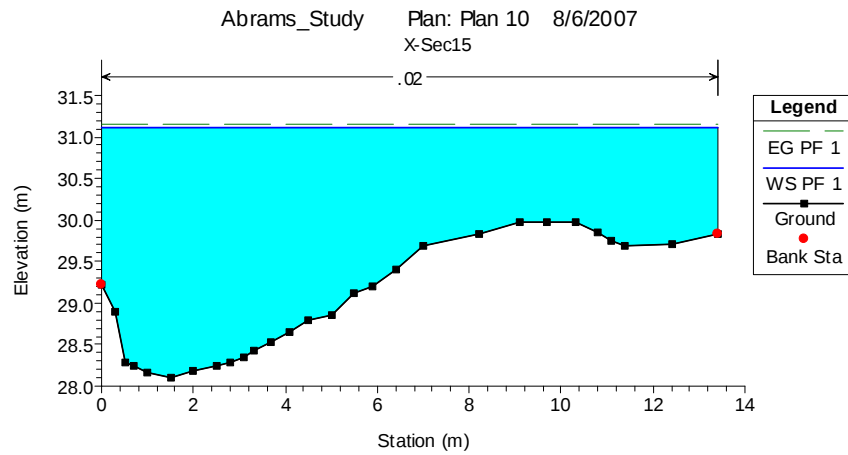
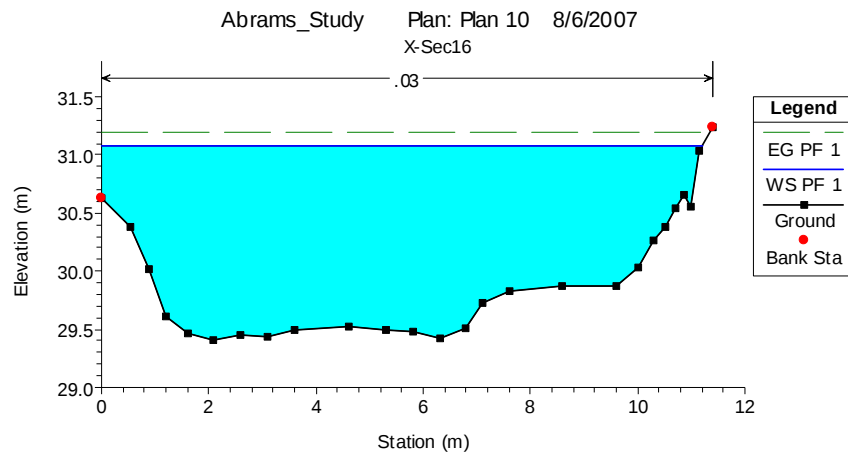


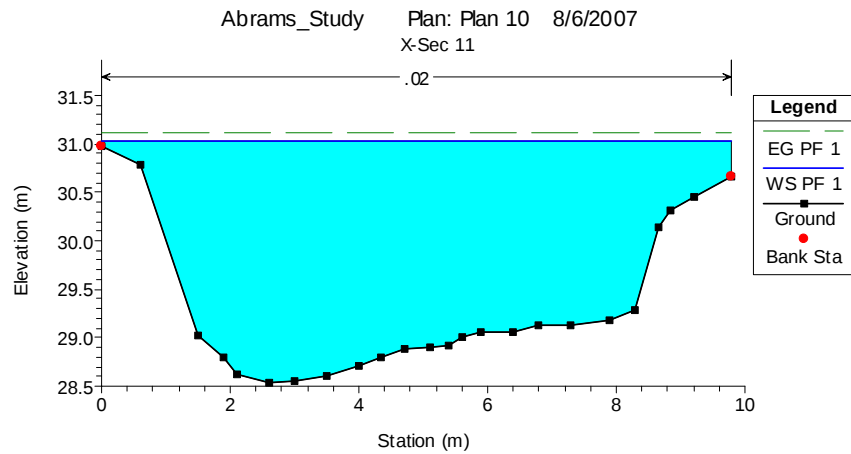
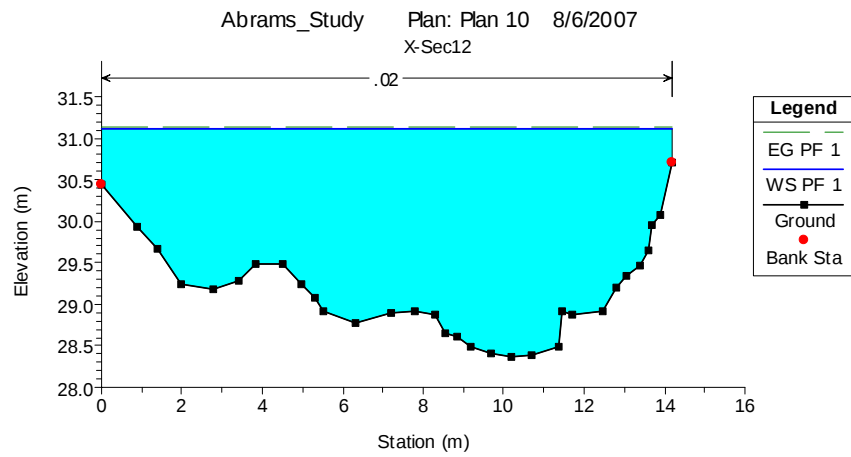
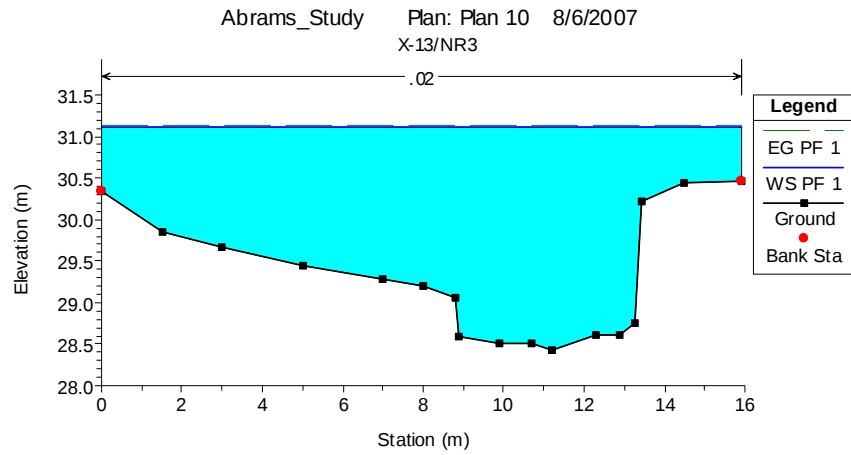


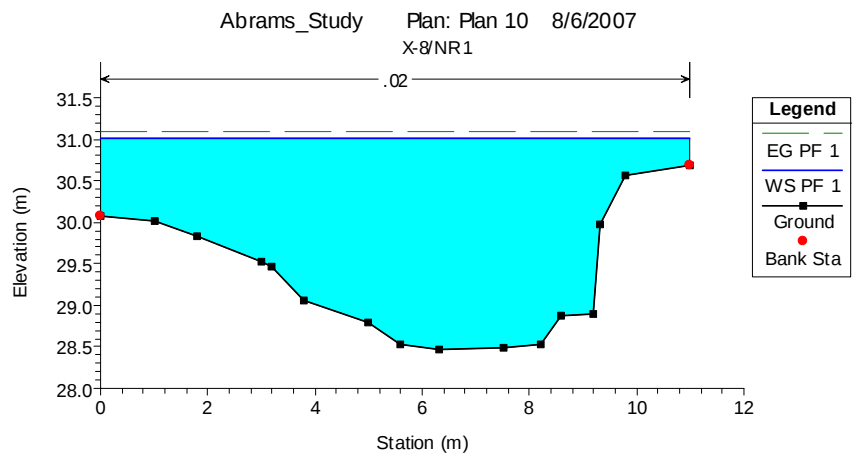
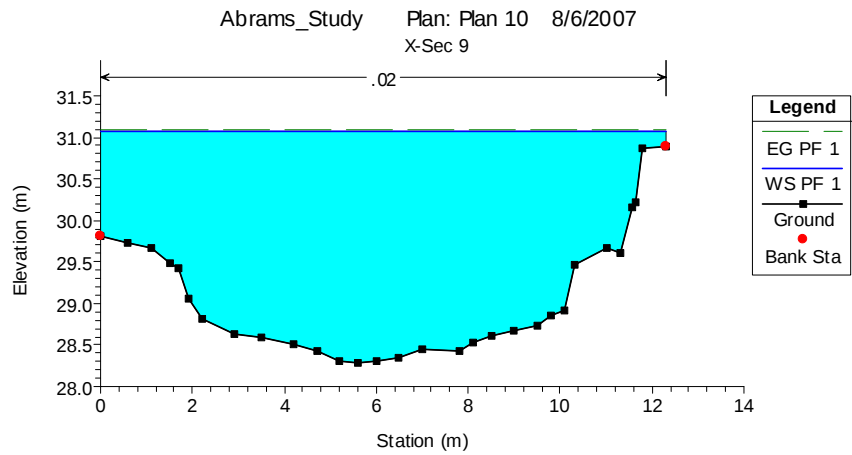
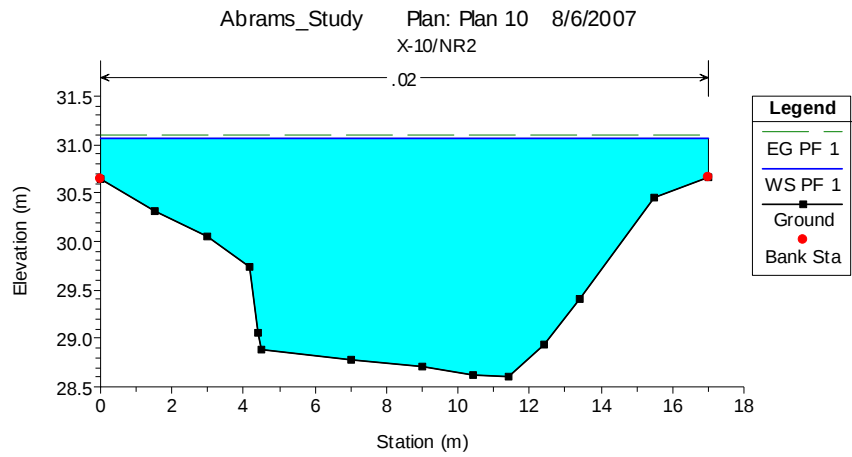


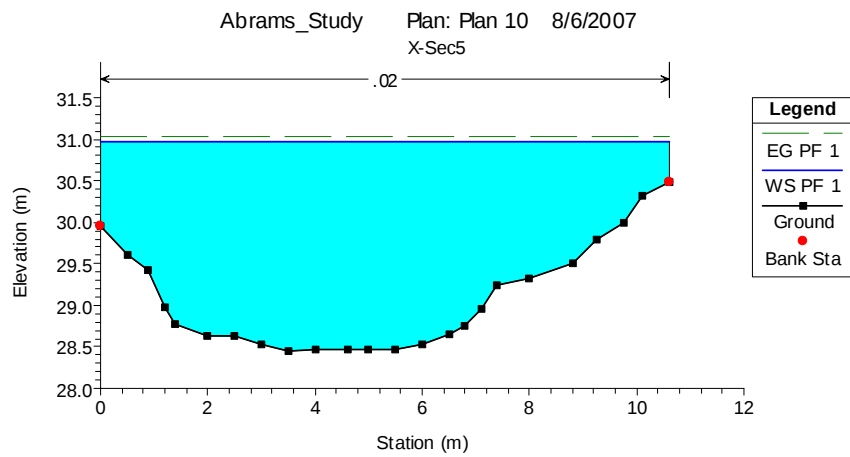
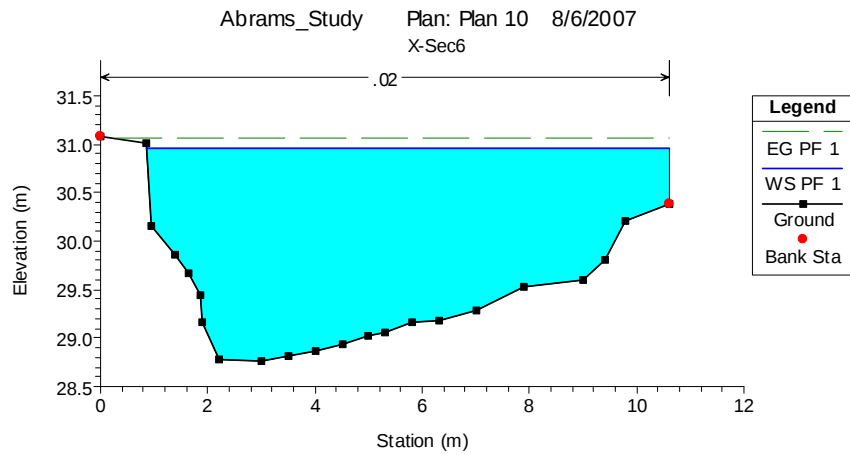
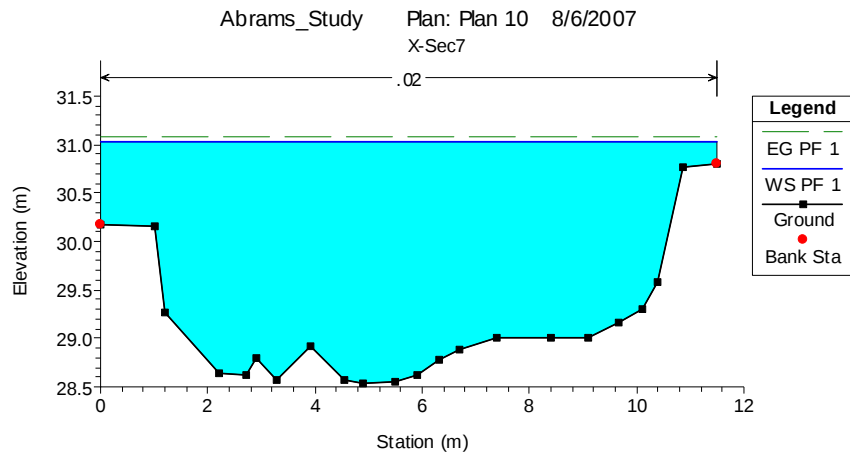


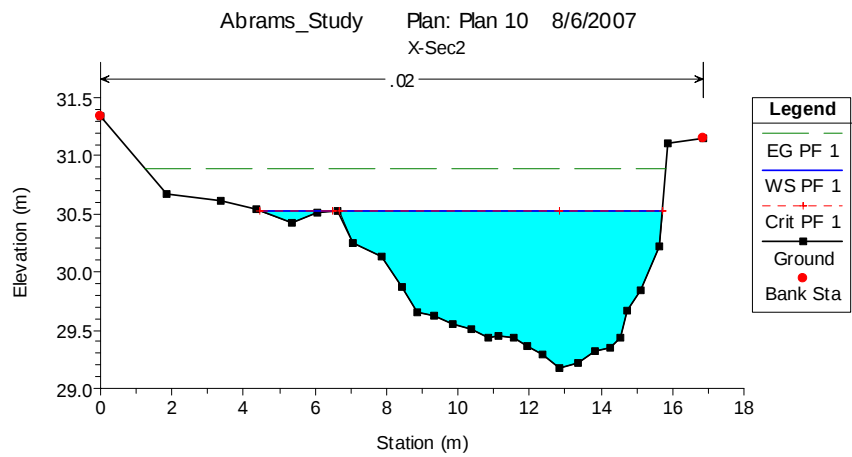
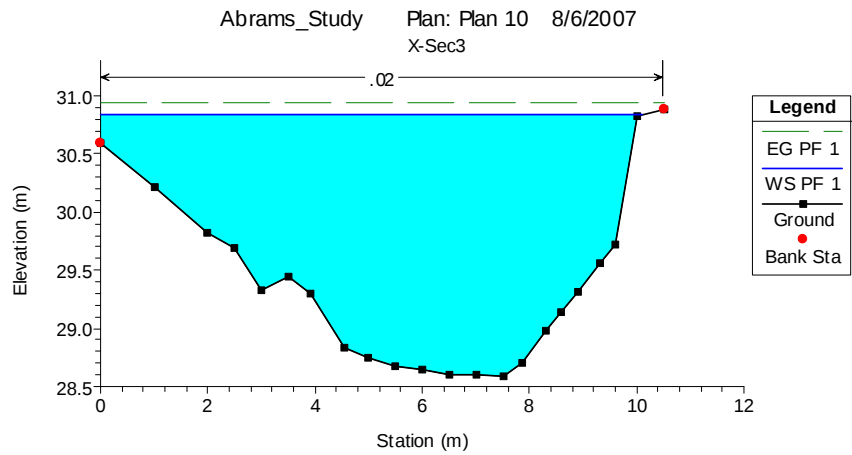
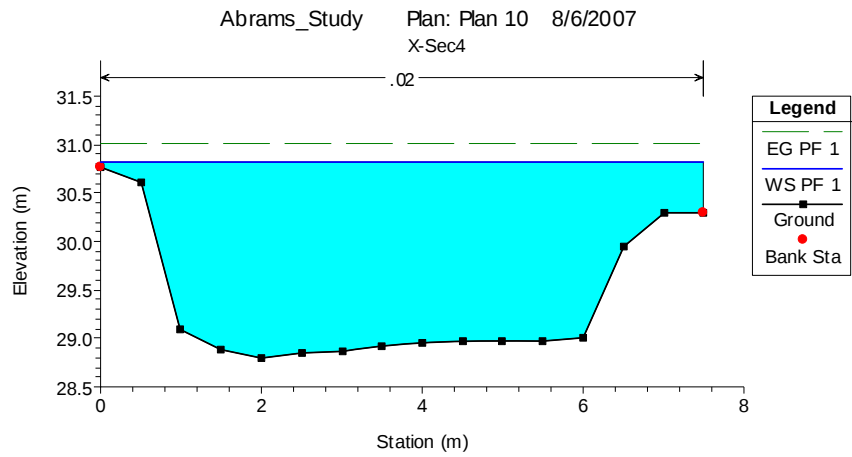
HEC-RAS simulated bankfull discharge (21.9 cms) using regional curve

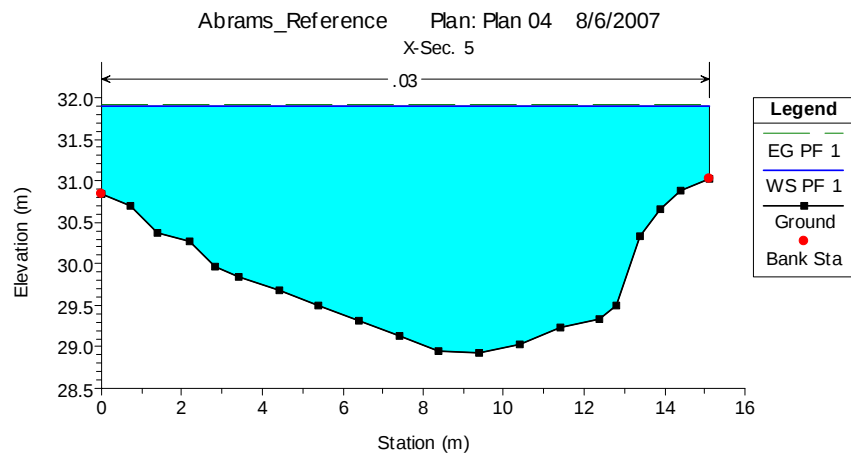
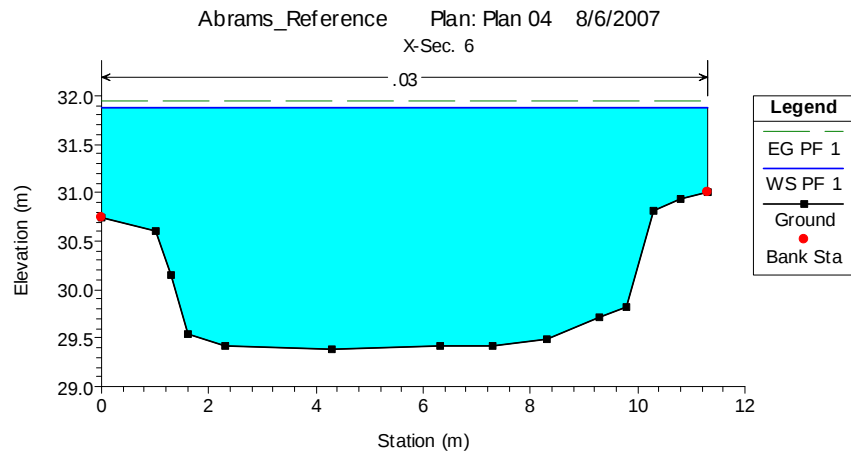
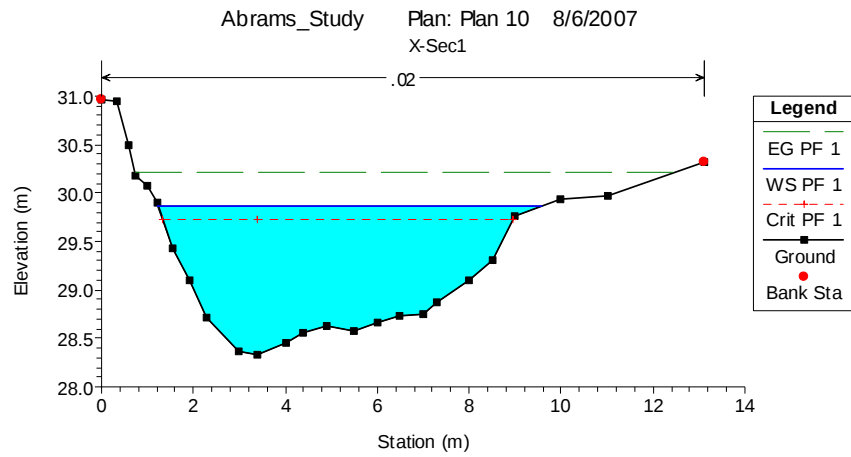


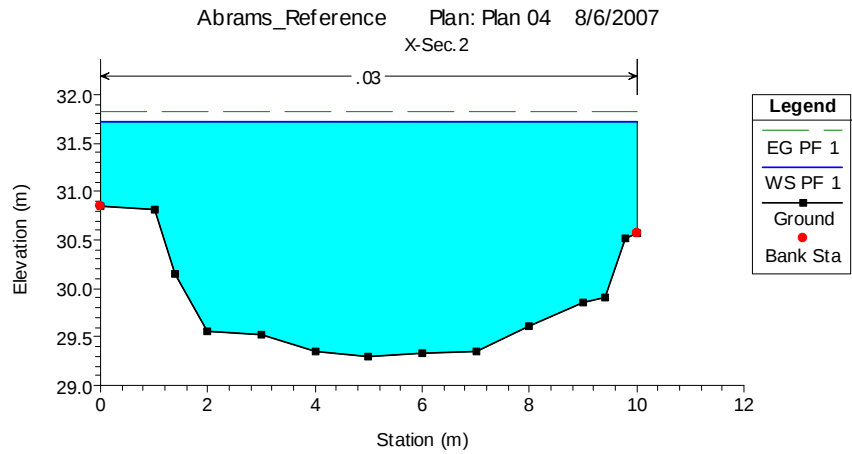
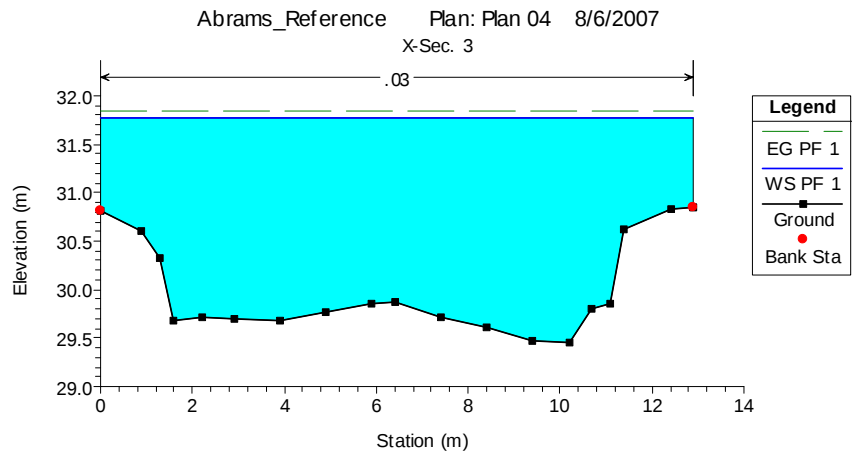
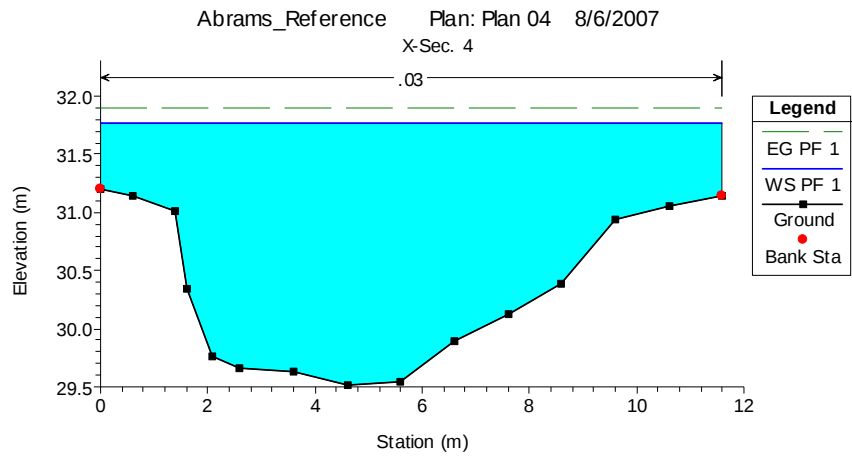


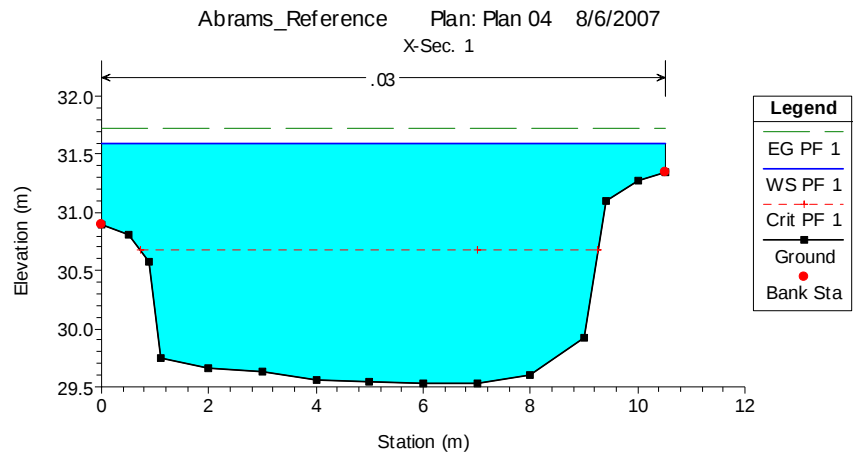






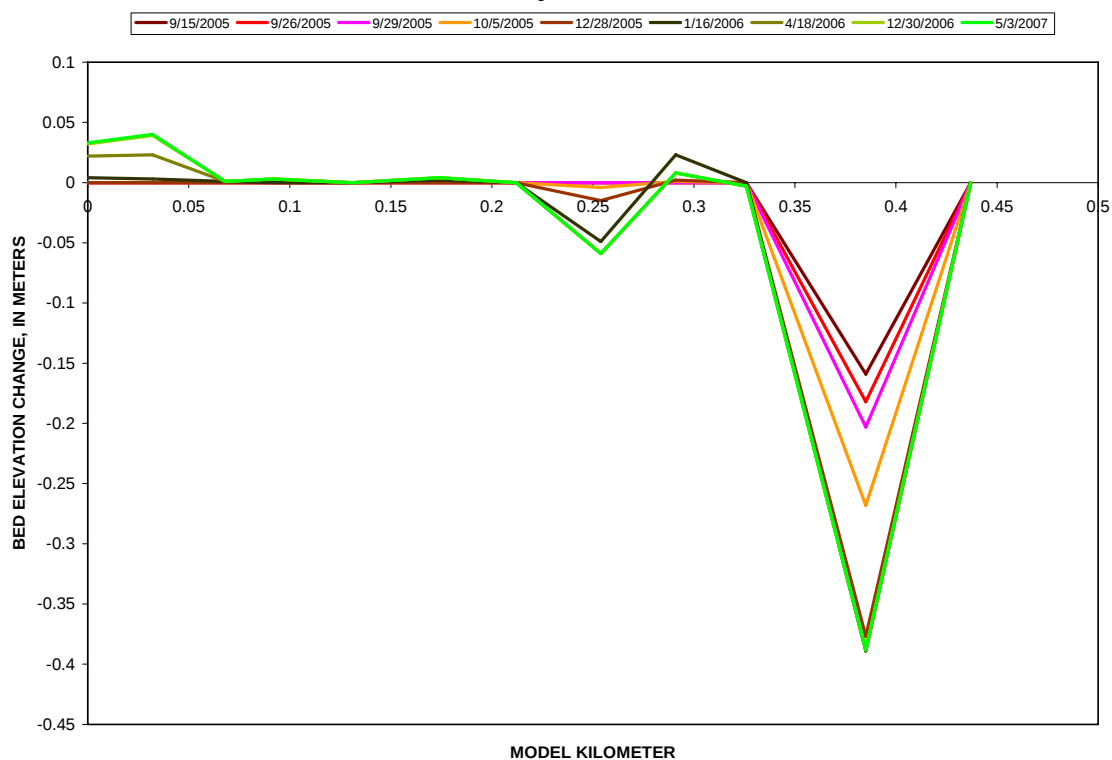




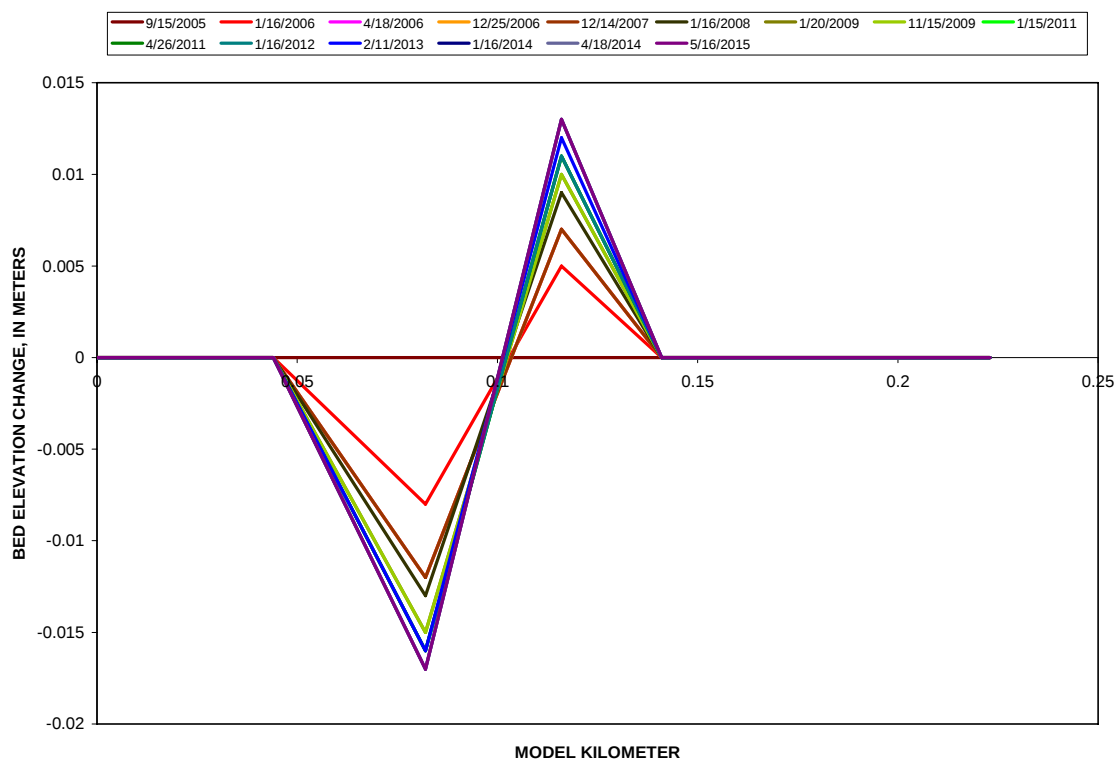


CONCEPTS Longitudinal Change in Bed Elevation

Study Reach



Reference Reach



Vita

Daniel Carter was born February 26, 1982 Jackson Tennessee. He grew up in Saltillo, TN. He graduated from Hardin County High School in Savannah, TN in May 2000. After high school he continued his education at The University of Tennessee in Knoxville. While at UT for undergraduate studies, he spent a semester abroad at the University of Maastricht in the Netherlands studying Arts and Culture. He graduated from UT in December 2004 with a Bachelor's of Science in Civil Engineering. After spending a semester interning at a civil engineering consulting firm, he returned to UT to pursue a Master's degree in Environmental Engineering. During his graduate career, he was also active in Engineer's Without Borders and traveled to the Dominican Republic to carry out a water supply project. He will receive his Master's of Science Degree in Environmental Engineering in December 2007, majoring in water resources.