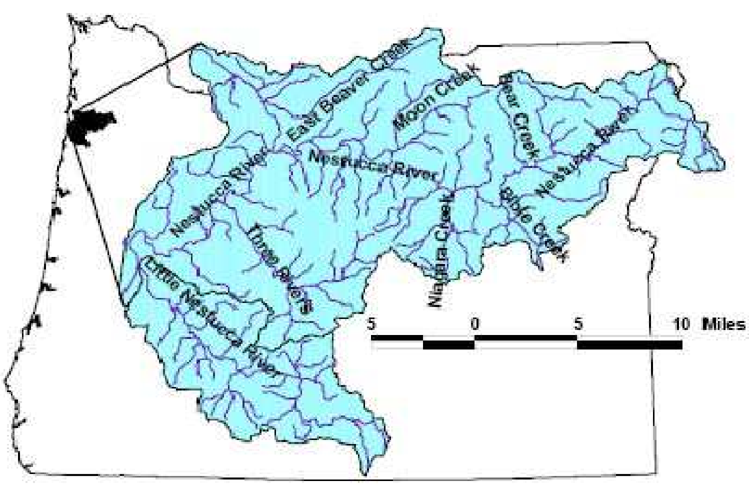
Sediment, Shade, and Habitat Complexity in the Upper Nestucca River Stream Network

Prepared for the Bureau of Land Management by Demeter Design LLC



From the Nestucca River TMDL

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March 8, 2007

Sediment, Shade, and Complexity; Characterizing Ambient Water Quality and Physical Habitat in the Upper Nestucca River Stream Network

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This document should be referenced as;
Mico, C. and Mico L. *Sediment, Shade, and Complexity: Characterizing Ambient Water Quality & Physical Habitat in the Upper Nestucca River Stream Network.* Technical Report Prepared for the Bureau of Land Management, contract #HAP064172. 2007

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Executive Summary

The Nestucca River is located in Oregon's north coast region. The majority of the Nestucca River watershed is administrated by the Bureau of Land Management (BLM) (17%) and the United States Forest Service (USFS) (34%.) In 2002 the Oregon Department of Environmental Quality (ODEQ) issued a Total Maximum Daily Load (TMDL) for sediment and temperature impairment in the Nestucca Bay watershed. Additionally, the Nestucca River was listed as water quality limited by habitat modification in the 1998 303(d) list but is not on the current list as habitat modification is no longer a criteria for listing. The BLM initiated a three year ambient water quality and physical habitat assessment of the Nestucca River stream network in 2004 to validate the initial 303(d) listing for sediment impairment and to provide the data necessary for the development of a Water Quality Restoration Plan (WQRP) on BLM administered land within the basin. In 2006 the study was expanded to address the temperature TMDL and the influence of geology on fine sediments. In order to characterize the condition of the stream network in regards to fine sediment and habitat complexity, an adaptation of the Environmental Monitoring and Assessment Program (EMAP) protocol was used. Developed by the Environmental Protection Agency (EPA), EMAP has been endorsed by the ODEQ for water quality assessments and will be the foundation of upcoming water quality assessment guidelines for the 2008 303(d)/305(b) water quality reports.[1] The three year Nestucca River study was the first comprehensive field test combining relative bed stability (RBS), % sands and fines (%SAFN), reference data, and General Random Tessellation Stratified (GRTS) and neighborhood based variance statistical methods. Additionally, effective shade was measured as a surrogate for temperature and was compared with the Heat Source model and the TMDL target provided by the ODEQ. This process is appropriate for use in future water quality assessments as it results in a direct comparison with existing TMDLs and greatly reduces much of the uncertainty associated with single metric studies.

The results of the three year study indicate that the Nestucca River stream network administered by the BLM is not impaired by fine sediments and that the effective shade deviates only slightly from modeled system potential effective shade. Furthermore, the amount of large woody debris, pool frequency, and bankfull width to depth ratios do not deviate from the normal ranges of the reference data. However, when the mainstem Nestucca River was analyzed separately from the overall stream network, it became clear that it lacks large woody debris, has a width to depth ratio greater than expected, and appears to have an elevated fine sediment supply. Additionally, tributaries of the Nestucca River have a decreased residual pool depth (RP100.) The upland Nestucca River watershed administered by the BLM is currently managed as a late-successional adaptive management area (LSA). Under this regime, actions taken within the watershed are aimed at restoring healthy late-successional forested ecosystems. The stream network is managed according to the Aquatic Conservation Strategy (ACS) objectives which include protecting water quality.[2] The data collected in this study indicate that the water quality objective of the ACS is being met.

1 Doug Drake, ODEQ, Personal Communication
2 Veneman, A and Norton, G 2003

Objectives

- **Validate the 303(d) listing for fine sediment impairment in the Nestucca River stream reaches administered by the BLM**
- **Compare the contributions of fine sediments from erodible and resistant lithologies**
- **Compare the sediment distribution of the mainstem Nestucca River to the contributing tributaries**
- **Evaluate fine sediment conditions in reaches downstream from road crossings**
- **Assess effective shade and habitat modification**

The Nestucca Bay watershed has a TMDL for sediment and temperature impairment. The Nestucca River was also listed as water quality limited for habitat modification on the 1998 303(d) list, although it is no longer listed as habitat modification is no longer a basis for listing. This study initiated by the Bureau of Land Management (BLM) had several objectives, listed above. It is well documented that a healthy and functioning habitat is the foundation of a healthy ecosystem. Perturbation of that habitat from over-sedimentation or excess solar radiation can strongly impact the health of the aquatic ecosystem. As a designated management agency (DMA), the BLM assessed their lands within the Nestucca River watershed. The following describes the most salient characteristics of the issues addressed in this study.

•**Over-sedimentation** degrades fish spawning habitat for many species such as Coho, Steelhead, and other salmonids. Even a slight increase in fine sediments can smother developing eggs which need adequate oxygen to survive. Additionally, sediment impairment can act as an indicator of other problems such as bank instability. The Nestucca River watershed was listed for sediment impairment using qualitative data which had not previously been quantitatively validated. This study was designed to address the existing sediment TMDL.

•**Temperature impairment** is a primary stressor for many species dependent on the riparian ecosystem for survival. Temperature impairment causes direct mortality to adult salmonids and many other fish species by decreasing the concentration of dissolved oxygen. Additionally, temperature impairment can exacerbate existing water quality problems.[1] Prior to this study, there was no comprehensive method for evaluating compliance with existing temperature TMDLs. In Oregon, effective shade is used as a surrogate to measure temperature via incoming solar radiation. Although the initial 303(d) listing is based on direct temperature measurements, effective shade was evaluated in this study to assess compliance with the existing TMDL.

•**Habitat modification** due to anthropogenic disturbance can also degrade the health of aquatic ecosystems. Residual pool depth was measured to evaluate bedform complexity and pool frequency, the bankfull width to depth ratio for floodplain connectivity and bank condition, and large woody debris volume per square meter for hydraulic complexity. Large wood in particular is an important component of ecosystems as it captures gravels and other debris which provide spawning and refuge habitat for many species. It is important to note that many of the sites surveyed included restoration projects.

•**Geology** is a controlling factor on bedded fine sediments. Anthropogenic disturbances such as road construction or silvicultural practices have a greater impact on fine sediment levels in systems draining erodible lithologies than they do in resistant lithologies.[2] Therefore care should be taken to control potential sediment impacts in areas with erodible geologies. This study provides a quantitative characterization of the role geology plays on sedimentation in the Nestucca River watershed.

1 Helfman, et al 1997
2 Kaufmann and Hughes (in Press)

Justifications

> "It is the responsibility of the United States Forest Service and the Bureau of Land Management as Federal land management agencies through implementation of the Clean Water Act (CWA), to protect and restore the quality of public waters under their jurisdiction."[1]

> "The MOA between ODEQ and the BLM will reaffirm the designation of the BLM as a Designated Management Agency (DMA) responsible for managing federal forest lands in a manner consistent with the Clean Water Act. The MOA will also establish a process for federal and state coordination over issues relating to non-point source water quality management and water quality compliance...BLM will manage BLM lands to protect, restore, and maintain water quality so that federal and state water quality standards are met or exceeded to support beneficial uses, in accordance with applicable laws and regulations."[2]

The USFS and BLM protocol for addressing the Clean Water Act (CWA) section 303(d) listed waters was developed to provide a consistent approach to protecting and restoring water quality.[3] The protocol outlines a decision making framework to guide the development and implementation of water quality restoration plans (WQRP) that are the vehicles for conveying how the BLM and USFS will address impaired waters which they administer. The first step to developing a WQRP is the validation of the 303(d) listing. For sediment impairment, this can pose a challenge both technically and analytically. It is difficult to disentangle natural sediment levels from those influenced by anthropogenic disturbance. This report describes a rigorous and scientifically defensible approach to address this challenge.

The EPA estimates that roughly 40% of the nations water bodies are impaired by fine sediment, making it the leading water quality stressor.[4] Despite the salient need to address the problem, efforts to implement water quality standards for sediment have been hampered by a lack of a consistent, rigorous, and cost effective procedure for evaluating impairment. Currently most 303(d) listings for sediment impairment are based on best professional judgment or marginal data. Recognizing this the EPA has developed a set of indicators for evaluating the effects of suspended and bedded sediments on water quality. The Upper Nestucca Sediment & Physical Habitat Study was initiated by the BLM's Salem District to test the method's applicability for evaluating water quality on federally administered lands. This study provided the data required for the BLM to satisfy their responsibilities as a DMA.

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1 USFS/BLM Protocol for Addressing CWA 303(d) Listed Waters.
2 BLM/ODEQ MOA as amended 2001
3 USFS/BLM Protocol for Addressing CWA 303(d) Listed Waters.
4 EPA Framework for Developing Suspended and Bedded Sediment Water Quality Criteria.

Potential Applications of the Nestucca Ambient Water Quality and Physical Habitat Study

303(d) Validation – This study was initiated to validate the sediment listing for the Nestucca River watershed for the stream reaches administered by the BLM.

Water Quality Restoration Plan (WQRP) – This project generated baseline data on ambient water quality necessary to develop a WQRP. WQRPs are the vehicle by which the BLM delivers the agencies responsibility as a DMA administering water bodies with an existing TMDL. The first step in developing a WQRP is to assess the condition of the water body and to validate the listing. This allows the BLM and other agencies to allocate resources more effectively to the improvement of water quality in other areas.

The NEPA Process – This study provides quantitative baseline data on the condition of the stream network administered by the BLM. This data can be directly integrated into future planning documents.

Baseline Water Quality for Evaluating the Effects of Management Planning – The dataset generated in this study will provide important input for assessing potential changes in water quality as a result of on-going and future management actions.

Potential Defense During Future Litigation – This project demonstrates the commitment of the BLM to protecting and improving water quality and fulfills the agencies commitment as a DMA to working with the ODEQ to improve impaired waters.

Materials and Methods

Sampling Methods

All sites were selected using a Generalized Random Tessellation Stratified (GRTS) sampling design.[1] A total of three samples were used over of the course of the study. The original sample used during 2004 and 2005 was developed by Dr. Tony Olsen of the EPA. The target population was originally defined as all streams 2nd order and greater in the upper Nestucca River watershed, including non-BLM land. The sample frame was the GIS stream coverage provided by the BLM (1:24,000 scale). This coverage is significantly more detailed than the usual United States Geological Survey (USGS) stream coverage. As a result, streams are generally assigned to a class one or more stream orders higher than found in the USGS coverage. This should be considered when planning projects using USGS stream coverage. Three multi-density categories were initially specified: 2nd, 3rd, and 4th order streams. 1st order streams were excluded. Sampling inclusion probabilities were adjusted to produce a roughly equal number of sites. The original design assumed that 60 sites per year would be sampled for three years totalling 180 sites sampled.

Three modifications were made to the original sampling plan. The first modification was made when it became clear that many 2nd order streams were dry during the low-flow protocol window, June-September, and could not be sampled. Therefore the target population was modified to include only 3rd order and larger stream systems. The second modification was made to exclude non-BLM lands. Finally, there was sufficient statistical power to address the major objectives of the study after sampling only 80 sites. Additionally, two new samples were drawn for the 2006 field season. The first was a sample of all culverts in the Nestucca River watershed. Stream surveys were carried out directly below these culverts to assess the effect of road crossings on fine sediment loads and physical habitat. The second sample was drawn from the same sample frame as the 2004 and 2005 sample generated by the EPA. The sample was stratified on the basis of erodible and resistant lithology and stream order. USGS maps were used to determine the predominant lithology of each stream reach. Each geologic type was classified as either erodible or resistant (Table 5). Preliminary assessments showed that many stream reaches defined as erodible on the basis on the USGS GIS coverage appeared to in fact reflect a resistant lithology. Therefore the sample was drawn to include twice as many erodible sites as resistant. Field-truthing of the classifications was carried out with the expectation that a significant number of sites would be reclassified.

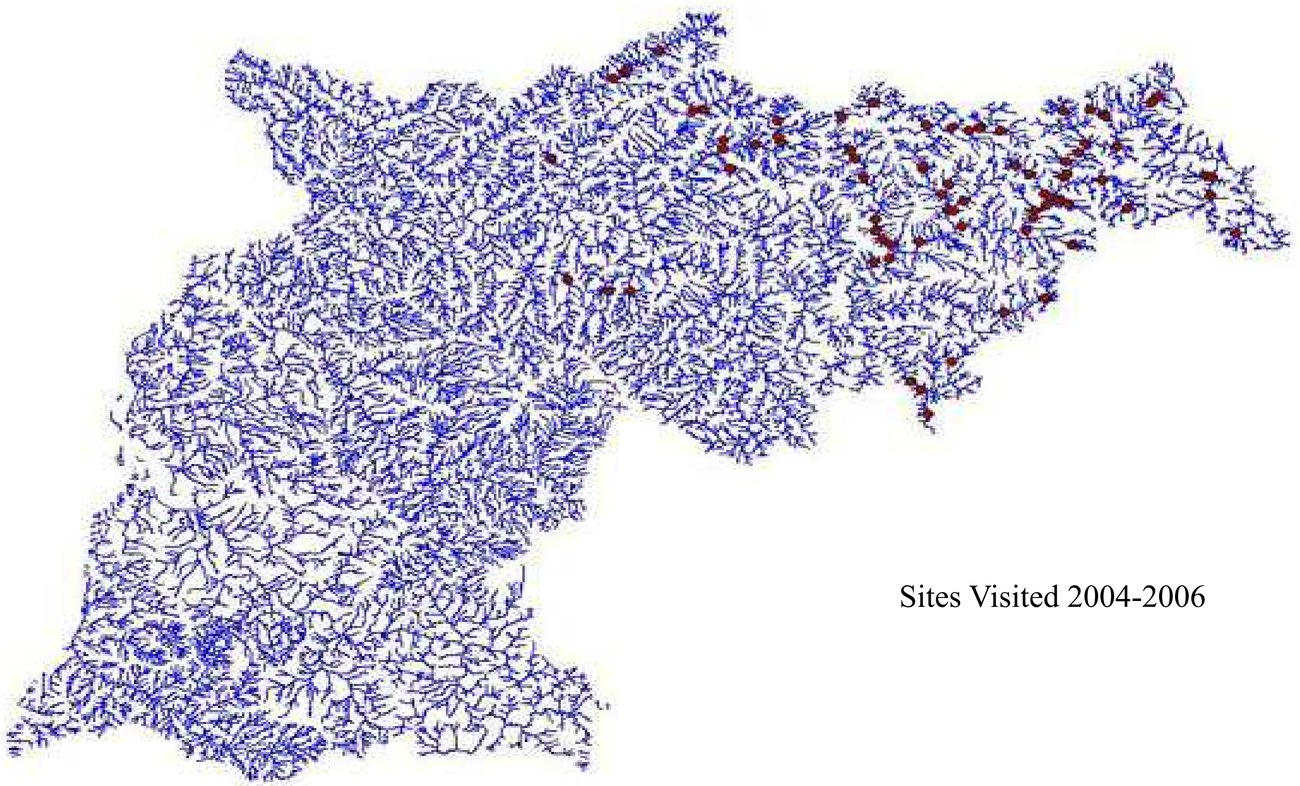
The total length of the sample frame was 803.56 km.

Stream length (km) by Strahler order is listed in Table 1,

Stream Order	1st & 2nd	3rd	4th+
km	661.4	67.92	74.24

Table 1. Final Sample Frame Summary

1 Stevens and Olsen 2004



Map 1 - Nestucca River Watershed, The upper watershed is predominantly owned by the BLM. Sites evaluated are marked in red.

Subpopulations Analyzed

- **Mainstem Nestucca River**
- **Nestucca River tributaries**
- **Erodible lithology**
- **Resistant lithology**
- **Reaches downstream of culverts**
- **Bear Creek**

Field Data Collection

The field protocol used in this study is described in detail in the EMAP field manual.[1] The full EMAP protocol includes measures of biological, chemical, and hydraulic function in addition to the physical habitat data used for sediment assessment. Section 7 of this manual describes the Physical Habitat protocol. A quantitative analysis of the process is available as well from the EPA's website.[2] The measurements used in this process are listed below. Those which have the greatest influence on the final calculations are marked as critical.

- **Slope (Most Critical)**
- **Pebble Count (Most Critical)**
- **Bankfull Height (Critical)**
- **Thalweg Depth (Critical)**
- **Large Woody Debris Tally (Critical)**
- **Bankfull Width (Critical)**
- **Wetted Width**
- **Station Length**
- **Anthropogenic Disturbance**
- **Habitat Unit**

The quality of the data is principally dependent on the training of the field crew. The slope, bankfull height, and pebble counts are the most prone to error. There are several items to consider when applying the EMAP protocol. First, although the EMAP manual recommends a clinometer for measuring slope, a range finder can be very useful and reduces measurement error related to the use of a clinometer. In areas where all slopes are very low (<1%), a transit or hydrostatic level should be used. If the slope is very small, even a small measurement error can have a relatively large effect on the final result. Second, the bankfull height measurements are most accurate when the field crew has training in geomorphology. The USFS provides a DVD with instructions on identifying bankfull height.[3] Finally, the accuracy of the pebble count can be improved for single site assessments by using a sieve to precisely measure the size of each pebble.

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1 Peck et al 2003
2 Kaufmann et al 1999
3 Stream Systems Technology Center

Estimates of Mean and Variability

Data was analyzed using custom built spreadsheets for data entry and metric calculation. With the exception of the "Riffle and Glide Only Analysis" described below, all subsequent data analysis was carried out using the psurvey.analysis package developed by the EPA for the R statistical program. All data analyzed in this way was weighted according to its inclusion probability. Variances were calculated using the Neighborhood Based Variance (NBV) estimator developed by the EPA.[1] NBV is a more precise estimate of variance when there is a spatial pattern to data and it capitalizes on the spatial balance of the GRTS sample.

Reference Conditions

The watershed assessment division of the ODEQ has collected data from hundreds of minimally disturbed sites across the state using the EMAP protocol. This includes 19 sites within the north coast and unfortunately none within the Nestucca River watershed. To collect reference data a sample is generated which ideally covers all of the gradients in each ecoregion such as elevation and vegetation type. All reference sites are required to have minimal anthropogenic disturbance in the riparian zone and upland areas.[2] The ODEQ's approach explicitly includes natural disturbance regimes as it is assumed that the biota of an area evolved in conjunction with these regimes. The metric values found in sites with minimal anthropogenic disturbance are used to judge the quality of physical habitat in the areas assessed. The ODEQ's approach is described in detail in DEQ Technical Report S04-002.[3] The locations of all available north coast reference sites are listed in Table 2 below.

LOCATION DESCRIPTION
Little North Fork Wilson River at River Mile 1.5
Rock Creek at River Mile 1.5
Trout Creek at River Mile 0.2
Unnamed tributary entering Bernhardt Creek at River Mile 3.0
Haight Creek at River Mile 1.20
Company Creek at River Mile 0.76
Schroeder Creek at River Mile 2.27
Bob Creek at River Mile 1.0
Tributary to North Fork Wolf Creek at River Mile 0.45
Cummins Creek at River Mile 1.02
Boulder Creek at River Mile 4.69
Youngs Creek at River Mile 1.11
Big Creek at River Mile 0.79
Flynn Creek at River Mile 1.71
Clear Creek at River Mile 0.72 (North Fork Trask River)
Cerine Creek at River Mile 0.4 (Mill, Siletz, Yaquina)
Harliss Creek
Cummins Creek
Gilmore Creek Trail

Table 2. North Coast Reference Locations

1 Stevens & Olsen A
2 Stoddard et al
3 Drake 2004

Sediment Indicators

The RBS metric was developed specifically to address the effects of bedded sediments on wadeable stream channels. RBS is defined as the ratio of the observed mean substrate diameter to the predicted competence of the channel at bankfull.[1] Channel competence is calculated from field measurements of slope, hydraulic radius, and channel roughness. RBS is a unitless ratio of values, and is commonly expressed as log RBS or LRBS to compress the values and to normalize the variance. When the observed mean particle diameter is equal to the predicted diameter of the largest particle the system can move at bankfull (D_CBF), the RBS ratio is equal to 1. The observed mean particle diameter and the D_CBF are primarily dependent upon disturbance regimes, channel morphology, geology, and climate. For example, small channels with low gradients are expected to have a small mean particle diameter and are not expected to have enough stream power to move larger particles during a bankfull event. The expected RBS score in these circumstances would be similar to a larger channel with steep gradients. In other words, RBS controls for stream power. In a channel impaired by fine sediments, the RBS score would be less than 1. By logging the RBS value, the data is normalized so that parametric statistical methods can be applied.

Previous studies have shown that increases in sediment input result in a fining of the streambed by overwhelming the capacity of the water column to move sediments.[2] Decreases in an RBS score would be correlated with an increased sediment supply. In this way, RBS is a useful measure of sediment input as well as instream conditions. Extremely low values indicate over-sedimentation (e.g -4) whereas large values indicate armoring of the stream bed (e.g +2.) A strength of the RBS metric when compared with a straight pebble count is that it is not confounded by stream power. Therefore it is possible to directly compare large and small channels with differing gradients. A second strength is that RBS is a composite metric calculated from numerous independent observations. This significantly increases the signal to noise ratio and reduces inter-observer bias. An erroneous result is less likely to occur due to measurement error.

In addition to using the RBS metric, the percentage of instream bedded fine sediments (%SAFN) (<2 mm) was also evaluated This metric is a direct and intuitive measure of fine sediment impairment, although the natural state of the stream must be considered to determine that level of impairment. The measurements used to calculate the RBS metric are also used to determine %SAFN.

1 Kaufmann et al 2006
2 Cover et al 2006

Sediment Benchmarks & Logic of Evaluating Potential Impairment

A multi-test approach was taken to determine the presence and level of fine sediment impairment. The importance of a weight of evidence in judging impairment must be emphasized at this point as this is consistent with the ODEQ's approach to assigning benchmarks for judging impairment.[1] This criteria assumes that measured values falling within the interquartile range of the relevant reference data are considered to be in good condition. Values within the 5th and 25th percentile range are in fair condition, and values below the 5th percentile are in poor condition. Unfortunately there is a scarcity of reference data from the North Coast (N=15 for LRBS, N=19 for %SAFN) and none within the Nestucca River watershed. Therefore no single assay or test was relied on to judge impairment.

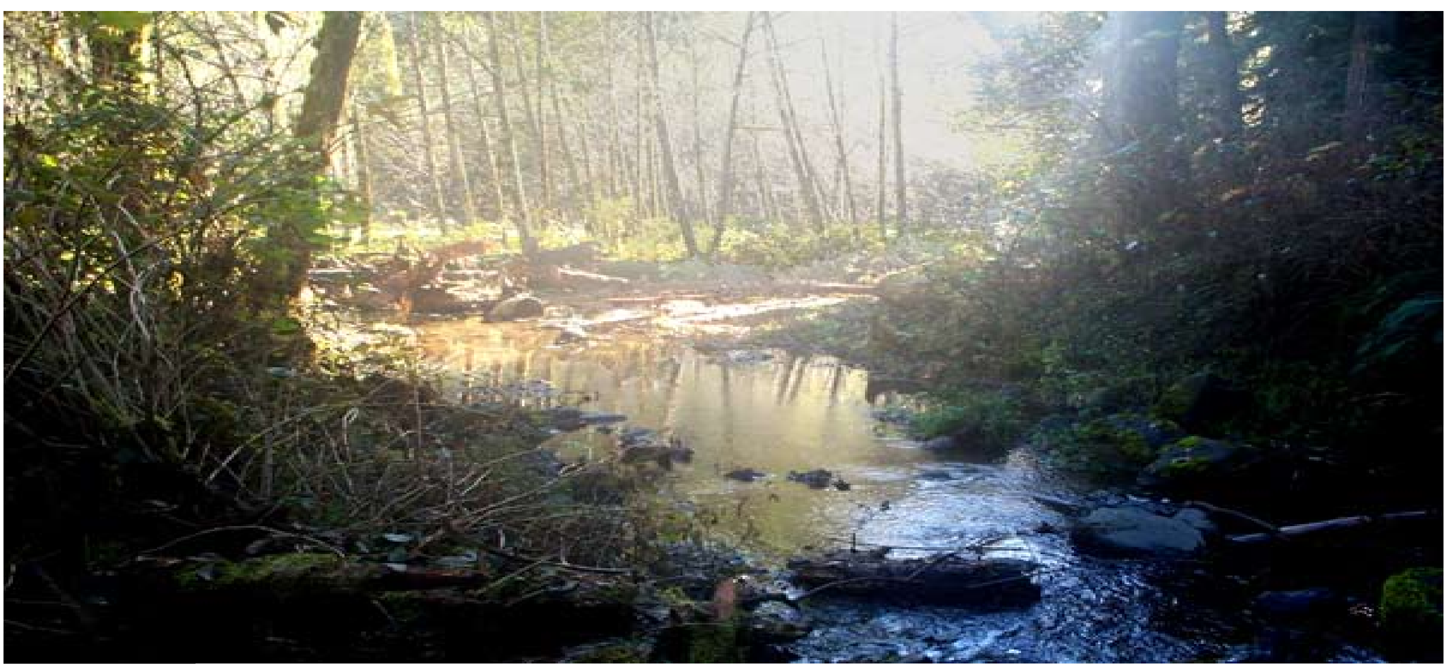
The four tests used to judge sediment impairment were;

1) Calculate the total percent sands and fines in riffles and glides only (%SAFN-Refer to Table 10 for results)

2) Calculate the percentage of sites that exceed the %SAFN and RBS benchmarks for impairment (Refer to Table 11 for results)

3) Use confidence intervals to look for a significant difference between the %SAFN and RBS benchmarks for impairment and the sample mean (Refer to Table 7 for results)

4) Use a Welch two sample t-test to compare the mean %SAFN and RBS values of the Nestucca River data to the reference data mean (Refer to Table 14 for results)



1 Drake 2006

For the first test, the %SAFN in riffles and glides only was evaluated using the methods subsequently described. This test directly addressed the language of the existing TMDL which requires less than 20% sands and fines in riffles and glides.

For the second test, the percentages of the sample which exceeded the 25th and 5th percentiles of the reference data for the LRBS & %SAFN metrics were calculated. Two approaches were used to generate a percentile score for the reference data. The calculated approach assumed a normal distribution and generated the percentile score using the mean and standard deviation. The empirical approach selected the actual data point closest to the desired percentile. For both metrics, preference was given to the approach that resulted in a reference score which was closer to the Nestucca River data. In this way, impairment was judged by the more stringent of the two approaches. The benchmarks used are listed in Table 3.

25th % Benchmarks for Judging Impairment	
LRBS (Empirical)	-1.17
%SAFN (Empirical)	35%
5th % Benchmarks for Judging Impairment	
LRBS (Calculated)	-2.35
%SAFN (Calculated)	57%

Table 3. ODEQ benchmarks for judging impairment.

For the third test, the 95% confidence intervals for the LRBS & %SAFN were used to look for significant differences between the measured mean values and the 25th percentile of the reference data. This is justified by the large sample size (~70) which makes it unnecessary to use the Student's t-distribution.

For the fourth test a two sample Welch t-test was used to compare the mean of the reference data to the the mean of the sample. The reference means and variance are presented in Table 4. The Welch t-test controls for differences in sample size and variance. In addition, it is robust when used on non-normal distributions. This is particularly true when the data is non-normal due to skewness and a two tailed test is used. With the exception of the correlation analysis, all of the hypothesis testing was two tailed.

Indicator	N	Mean	Std.Dev.	Standard Error
Log RBS	15	-0.8427	0.9229	0.2383
Percent Sands & Fines	19	25.4965	16.1771	3.7113
Residual Pool Depth (m^2/100)	15	12.0224	6.6883	1.7269
Wood Volume per Square Meter	19	0.0490	0.0846	0.0194
Width to Depth Ratio (m/m)	17	10.8000	3.3800	0.8500
Arcsin $\sqrt{p}$ Sands & Fines	19	0.0634	0.0216	0.0051

Table 4. ODEQ reference values for the North Coast.

Calculation of Relative Bed Stability

RBS has undergone significant changes since its development. This was in large part to satisfy critiques from the hydrology community that RBS was oversimplified.[1] Previously, RBS assumed a uniform Shield's parameter and used a simplified linear shear stress partitioning model based on residual pool depth and wood volume per m^2 of surface area. The old RBS formulation was inaccurate when used on streams with large hydraulic roughness values or low gradients. The 2007 formulation of RBS is significantly more robust and corrects for these problems.[2] Details of the calculations for both versions follow. The 2004 and 2005 datasets were also reanalyzed using the new formulation for comparison. All other analysis was done using the new formulation only.

PREVIOUS CALCULATION

RBS $= D_{gm}/D^*_{cbf}$

where

D_{gm} **= geometric mean diameter from systematic pebble counts**

D^*_{cbf} $= (0.604 * R\_STAR_{bf} * S^*)/\theta_c$ *or*

critical substrate diameter at bankfull flow averaged over reach and adjusted for shear stress reductions related to LWD and pool depth and frequency.

where

$\theta_c = .044$, **Shield's number for critical shear stress**

S = energy slope ≈ slope of reach water surface

$R\_STAR_{bf} = R_{bf} - Wd - d_{res}$

where

$R_{bf} \approx$ **0.5*(Mean Thalweg Depth + Mean Bankfull Height)** *or*

bankfull hydraulic radius

d_{res} **= residual pool depth**

Wd = wood volume divided by the surface area of the reach *or*

mean wood "depth" over the reach

1 Potyondy et al (2005)

2 Kaufmann et al (In preparation)

NEW CALCULATION

RBS = D_{gm}/D^*_{cbf}

where

D_{gm} = geometric mean diameter from systematic pebble counts

$D^*_{cbf} = (0.604*R_{bf}*S*(Cf_p/Cf_t)^{1/3})/\theta_c$ *or*
critical substrate diameter at bankfull flow averaged over reach and adjusted for shear stress reductions related to LWD and pool depth.

where

S = energy slope ≈ slope of reach water surface

$R_{bf} \approx 0.65*$(Mean Thalweg Depth + Mean Bankfull Height) *or*
Bankfull hydraulic radius

$Cf_p = f_p/8 = 1/8\ [\ 2.03\ \mathrm{Log}\ (12.2\ d_h/D_{gm})]^{-2}$

where

d_h = (Mean Thalweg Depth + Mean Bankfull Height) *or*
Hydraulic depth

$Cf_t = 1.21\ d_{res}^{1.08}(d_{res} + Wd)^{+0.638}\ d_{th}^{-3.3}$

where

d_{res} = residual pool depth in meters

d_{th} = R_BF/0.65 *or*
Bankfull thalweg height

Wd = wood volume divided by the surface area of the reach *or*
Mean wood "depth" over the reach

$\theta_c = 0.04\ Re_p^{-0.24}$ <u>when</u> $Re_p \leq 26$ <u>and</u> $0.5\ \{0.22Re_p^{-0.6} + 0.06(10^{-7.7\ Rep\string^-0.6})\}$ <u>when</u> $Re_p > 26$ *or*
Shield's number for critical shear stress

where

$Re_p = [(g*R\_BF*S)^{0.5}*D\_GM]/v$ *or*
Reynold's Particle Number

where

g = 9.81 m/s/s *or*
Acceleration due to gravity

v = 1.02 x 10-6 m^2/s at 20 C *or*
Kinematic viscosity of water

Habitat Complexity

Quantitative indicators of habitat complexity are generated as part of the RBS calculation. Three indicators were used in this study to assess habitat complexity; residual pool depth (RP100), width to depth ratio (W:D), and wood radius (RW). The aquatic habitat of many streams is degraded due to a lack of large woody debris (LWD) and channelization as a result of historic logging practices or active stream cleaning. These modifications serve to decrease the hydraulic roughness of the channel. Roughness elements trap fine sediments and decrease the competence of the channel to move sediments. It is theoretically possible to mask an increase in sediment input with an increased competence due to lack of hydraulic roughness. In this scenario fine sediment would not be considered a stressor, but elements critical to maintaining healthy aquatic ecosystems would be lacking. If those elements were restored, fine sediment could become a local stressor if the elevated sediment input was not corrected first. It is critical that hydraulic roughness be evaluated when interpreting data on sediment impairment.

RP100 – Residual pool depth can be conceptualized as what would be left over in a stream reach if all flow stopped. It is a measure of reach-scale bedform complexity and is directly proportional to pool frequency. Qualitative classifications of reaches into habitat units such as riffle, glide, or pool are flow and observer dependent. In contrast, residual pool depth is a flow-invariant metric and is a quantitative measure. It is therefore more suitable for use in sediment transport and regression analyses.

W:D – The width to depth ratio changes as a function of disturbance. In some instances it will increase with disturbance due to sustained bank erosion and elevated sediment inputs. Generally, this is caused by a decreased bedform complexity and degraded riparian vegetation. As a consequence, streams with a width to depth ratio greater than reference conditions could result in increased peak temperatures. In other instances, the width to depth ratio will decrease substantially as the channel down-cuts. This could be the result of channel confinement but geology determines to a large extent how the channel responds to disturbance. A decreased width to depth ratio could potentially indicate loss of overwintering fish habitat, increased flood potential, and loss of floodplain connectivity. The metric used in this study was the bankfull width divided by the bankfull height and was compared to the ODEQ reference values.

RW – The benefits and importance of large woody debris (LWD) is well established in the field of restoration biology.[1] Under the protocol used in this study, all wood inside the bankfull channel with a diameter greater than 10 centimeters and a length greater than 1.5 meters was tallied and assigned to a size class. These measurements were then converted to a statistic representing the total volume of wood inside the channel at bankfull height. This volume was divided by the surface area of the stream reach to give an estimate of wood volume per square meter. This controls for the absolute difference in wood volume between large and small channels.

1 Benda et al 2003

Effective Shade

In addition to the sediment TMDL, the Nestucca River watershed also has a temperature TMDL. To address this TMDL, a number of existing techniques were synthesized to develop a protocol for measuring and analyzing effective shade on BLM administered lands within the Nestucca River stream network. Although water quality standards for temperature are written in terms of a seven day moving average of daily maximums, all TMDLs in Oregon use effective shade as a surrogate for temperature. In order to measure compliance with a temperature TMDL, it is necessary to measure the effective shade within a stream network. A component of the Heat Source Model, the Shade-o-Lator, was used to calculate the expected effective shade for each site.[1] Originally developed at Oregon State University, the ODEQ maintains a modified version of the Heat Source Model.[2] Heat Source is a computational model used to develop temperature TMDLs. It uses channel morphology, vegetation, and incoming solar radiation data as well as known heating processes. Bankfull width and reach bearing measurements were used to model the expected shade for the 11 transects at each site. The model assumed that all data was taken on an August day in the Nestucca River watershed. The model also assumed that the bank was vegetated with 185 foot tall douglas fir (*Pseudotsuga menzeisii*) trees. The modeled shade value was subtracted from the measured shade value for each transect to determine how close the measured shade value was to the modeled shade value. The mean deviation of the 11 transects per site was calculated. By averaging these mean values over 30 sites, an estimate was generated of the deviation of the field measured effective shade from the modeled system potential value. The calculation resulted in a direct comparison with the existing TMDL target. This field protocol is consistent with the Oregon Watershed Enhancement Board (OWEB) Oregon Water Quality Monitoring Guidebook.[3] When combined with the aforementioned analytical protocol, this method could be used broadly for evaluating compliance with temperature TMDLs.

1 Boyd & Kasper 2003
2 ODEQ Heat Source Model 2006
3 OWEB 1999

Classification of Lithology

The area surrounding the sites used in the lithology assessment were evaluated in the field to assess the local lithology. This assessment was based on the criteria outlined in Table 5.[1]

Geology Map Unit Symbol	Rock Type or Formation	Rock or Deposit Description	Age-Epoch	Erodibility Rating*
Qal	Aluvial deposits	Unconsolidated, clay silt, sand and gravel alluvium deposited by water.	Holocene	2
Qf	Fluvial and estuarine deposits (Surficial deposits)	Unconsolidated, clay silt, sand and gravel alluvium deposited along rivers and streams.	Holocene	2
Qls	Landslide deposits (Surficial deposits)	Poorly sorted, unconsolidated material containing a wide range of particle sizes, commonly from clay to cobble- or boulder-size, and angular and/or subangular fragments with a clayey, silty, or sandy matrix.	Holocene and Pleistocene	2
Tbl	Tillamook Volcanics	Lower porphyritic basalt flows	Eocene, upper middle	1
Tbr	Tillamook Volcanics	Submarine basalt tuff and breccia	Eocene, upper middle	1
Ti	Tertiary Intrusive	Basalt sills	Eocene to Miocene	1
Tiab	Porphyritic balsalt (Intrusive)	Basalt sills	Eocene, late middle	1
Tidb	Diabase (Intrusive)	Diabase with smectite	Eocene, middle	1
Trsk	Trask River sandstone (Sedimentary)	Sandstone, siltstone and mudstone	Eocene, lower	2
Tsbr	Siletz River Volcanics	Basalt breccia	Eocene, lower	1
Tspb	Siletz River Volcanics	Pillow basalt	Eocene, lower	1
Tsr	Siletz River Volcanics	Pillow basalt, tuff breccia	Eocene, lower and middle	1
Tss	Sedimentary Rocks	Tuffaceous siltstone and shale	Eocene, upper and middle	2
Tsd	Sedimentary Rocks	Sedimentary rocks	Oligocene and upper Eocene	2
Ttv	Tillamook Volcanics	Basalt flows	Eocene, upper and middle	1
Ty	Yamhill Formation (Sedimentary)	Dark gray siltstone commonly with beds of tuff, sandstone, calcareous concretions, and carbonanceous fragments	Eocene, upper middle	2

Table 5. Geology Classifications Used

1=resistant 2=erodible

1 Wells et al 1995

Riffle & Glide Only Analysis

The riffle and glide analysis was an attempt to address the TMDL sediment target. The sediment TMDL target was defined as less than 20% sands and fines (%SAFN) in riffles and glides. This analysis was carried out by identifying pebble count cross sections in the data collected in a riffle or glide as noted under habitat unit. Using the 2005 data, an attempt was made to analyze each cross section as a separate data point. However it proved impossible to normalize the data generated from this method. Therefore the data was averaged within each reach, and then treated as a single data point. Even with this averaging, it still proved difficult to normalize the data. Ultimately a modified version of the arcsine transformation was applied to normalize the data.[1] This modified transformation can be seen below.

P'=ARCSIN(SQRT((X+(3/8))/(N+(3/4)))

For this analysis, the data was not weighted as the inclusion probabilities were very close between multi-density categories, 4.2 versus 4.7. In addition, the variable quality of the data from each site raises doubts about the applicability of weighting based on inclusion density. Finally, the neighborhood based variance algorithm was not used on the riffle and glide data. This was an attempt to provide the most conservative estimates of the calculated confidence intervals.

1 Zar 1999

Transformations

Two main transformations were used on the data. RBS was log transformed while the percentage of sands and fines was arcsine transformed. Because of the robustness of two sample Welch t-tests, only the most critical metrics in the dataset, LRBS and %SAFN, were normalized. Although data transformations are useful for calculating confidence intervals and employing parametric tests on non-normal data, they tend to introduce bias into the mean. Therefore it is often preferable to report means in terms of the original metric score rather than the transformed score. For example, Table 6 shows the mean RBS score generated from example raw RBS data and converted back using two transformations, Log (RBS) and Log (RBS +1). The latter transformation appears to be superior in terms of minimizing bias. The convenient property that LRBS < 0 when RBS < 1 is absent however.

RBS	Log (RBS)	Log (RBS +1)
0.22	0.15	0.20

Table 6. Effects of Log Transformations on LRBS Mean Values

Correlation

The correlation between the %SAFN metric and the LRBS metric was assessed using standard procedures to test the independence of the two metrics. These procedures included calculating a Pearson correlation coefficient (r), a coefficient of determination (r^2), and parametric testing for significance.[1] The statistical program R was used to perform this analysis. Additionally, a scatterplot was generated and was used to visually identify outliers. The outliers were removed and the analysis was performed again.

Monte Carlo Simulations

A Monte Carlo simulation was used to assess the effect of measurement error on the RBS metric. A single data matrix was developed containing all of the data from 2004 and 2005 (N=39 sites). Estimates of measurement error for each of the field measurements such as slope, D_GM, etc., have been developed by the EPA.[2] A simplifying assumption was made that the measurements represented the mean of the possible distribution of measurements. EPA derived error estimates were used to specify a distribution. The matrix was then permuted 1000 times to assess the effect of that error on the outcome of the population average and a single site. Finally, the size of the error was decreased by a factor of 100 to evaluate the potential effect of increasing the precision of the field protocol.

1 Zar 1999
2 Kaufmann et al 1999, Faustini & Kaufmann 2006

Results

The results of this study indicate that the portion of the Nestucca River stream network administered by the BLM is not impaired by fine sediment and is close to modeled system potential values for effective shade. When the mainstem Nestucca River was analyzed separately from the tributaries, it became apparent that the tributaries are below reference conditions for residual pool depth and that the mainstem Nestucca River is lacking LWD and has a greater than reference width to depth ratio. A complete summary of the results for the population, mainstem, and tributary metrics can be seen in tables 7, 8, and 9 below.

METRIC	N	MEAN	SD	LOWER 95% CB	UPPER 95% CB
LRBS	69	-0.770	0.465	-0.857	-0.682
OLD LRBS	39	-0.667	0.379	-0.762	-0.571
%SAFN	69	0.109	0.113	0.092	0.126
%GRAVELS	69	0.514	0.176	0.480	0.549
W:D (m/m)	69	10.201	4.056	9.377	11.025
RW (m)	69	0.046	0.052	0.036	0.055
RP100 (cm)	69	9.222	7.606	7.614	10.831
SHADE	29	0.858	0.127	0.807	0.908
ΔSHADE	29	-0.098	0.115	0.066	0.164

Table 7. Summary of Population Metrics

METRIC	N	MEAN	SD	LOWER 95% CB	UPPER 95% CB
LRBS	14	-0.484	0.432	-0.717	-0.252
%SAFN	14	0.115	0.062	0.084	0.147
%GRAVELS	14	0.378	0.097	0.329	0.427
W:D (m/m)	14	13.377	4.218	11.437	15.317
RW (m)	14	0.018	0.019	0.008	0.028
RP100 (cm)	14	18.726	9.040	14.011	23.441

Table 8. Summary of Mainstem Metrics

METRIC	N	MEAN	SD	LOWER 95% CB	UPPER 95% CB
LRBS	57	-0.834	0.450	-0.919	-0.749
%SAFN	57	0.106	0.122	0.088	0.125
%GRAVELS	57	0.550	0.174	0.510	0.591
W:D (m/m)	57	9.398	3.526	8.629	10.167
RW (m)	57	0.053	0.055	0.042	0.064
RP100 (cm)	57	6.710	4.362	5.805	7.614

Table 9. Summary of Tributary Metrics

Based on the criteria specified, none of these assays indicate impairment by fine sediment. The use of multiple indicators, tests, and stringent benchmarks supports this conclusion. The percentage of sands and fines in riffles and glides only (test 1) is presented in Table 10. None of the sites exceeded 20% sands and fines in riffles and glides only. This analysis was conducted on 33 sites collected in 2005. The number of sites exceeding the benchmarks for judging impairment (test 2) are presented in Table 11. The results of test three can be seen in Table 7 on the previous page. The results of all two sample t-testing (test 4) can be seen in Table 14 on the following page.

Mean %SAFN	8.2
Upper CB (95%)	10.1
Lower CB (95%)	6.5

Table 10. Percentage of Sands & Fines in Riffles and Glides Only

Number of Sites Exceeding the 25% LRBS(new) =	10/69 (14%)
Number of Sites Exceeding the 5th% LRBS(new) =	1/69 (1.4%)
Number of Sites Exceeding the 25% LRBS(old) =	4/39 (10.3%)
Number of Sites Exceeding the 5th% LRBS(old) =	0/39 (0%)
Number of Sites Exceeding the 25th% SAFN =	4/69 (5.8%)
Number of Sites Exceeding the 5th% SAFN =	2/69 (2.9%)

Table 11. Percentage of Sites which Exceed Benchmark Criteria

A scatterplot of the relationship between LRBS and %SAFN is shown in Illustration 1. Summary statistics for that correlation are presented in Table 12. There is significant correlation between these two metrics, accounting for 38% of the variance. Much of this correlation is driven by three outliers. When they are removed, the correlation drops a great deal. The results with outliers removed are presented in Illustration 2 and Table 13. For that reason, they should be considered semi-independent.

CORRELATION COEFFICIENT r	-0.62
DETERMINATION COEFFICIENT r^2	0.38
T VALUE	-6.40
DEGREES OF FREEDOM	67
1 SIDED P-VALUE	0.00

Table 12. Correlation Between LRBS and %SAFN with Outliers

CORRELATION COEFFICIENT r	-0.37
DETERMINATION COEFFICIENT r^2	0.14
T VALUE	-3.22
DEGREES OF FREEDOM	64
1 SIDED P-VALUE	0.0010

Table 13. Correlation Between LRBS and %SAFN without Outliers

METRIC	SUBPOPULATION	RESULT	SUBPOPULATION	P VALUE
LRBS	WATERSHED	N.S.	REFERENCE	P=0.7683
%SAFN	WATERSHED	<	REFERENCE	P=0.0002
W:D	WATERSHED	N.S.	REFERENCE	P=0.5338
RW	WATERSHED	N.S.	REFERENCE	P=0.8744
RP100	WATERSHED	N.S.*	REFERENCE	P=0.1668
RP100:DH	WATERSHED	N.S.*	REFERENCE	P=0.2054
LRBS	MAINSTEM	>	TRIBUTARIES	P=0.0141
LRBS	MAINSTEM	N.S.	RESIST_FIELD	P=0.3156
%SAFN	MAINSTEM	N.S.*	TRIBUTARIES	P=0.1336
W:D	MAINSTEM	>	TRIBUTARIES	P=0.0046
W:D	MAINSTEM	N.S.*	REFERENCE	P=0.0767
RW	MAINSTEM	<	TRIBUTARIES	P=0.0002
RW	MAINSTEM	N.S.*	REFERENCE	P=0.0684
RP100	MAINSTEM	>	TRIBUTARIES	P=0.0003
RP100	REFERENCE	>	TRIBUTARIES	P=0.0095
RP100:DH	MAINSTEM	N.S.	REFERENCE	P=0.7977
%GRAVELS	MAINSTEM	<	TRIBUTARIES	P<.0001
LRBS	CULVERTS	N.S.	WATERSHED	P=0.4449
%SAFN	CULVERTS	N.S.	WATERSHED	P=0.3948
W:D	CULVERTS	<	WATERSHED	P=0.0188
RW	CULVERTS	N.S.*	WATERSHED	P=0.1862
RP100	CULVERTS	<	WATERSHED	P=0.0147
RP100	CULVERTS	N.S.	TRIBUTARIES	P=0.3905
ΔSHADE	CULVERTS	>	WATERSHED	P=0.0056
LRBS	EROD_GIS	N.S.*	RESIST_GIS	P=0.3321
%SAFN	EROD_GIS	>	RESIST_GIS	P=0.0124
W:D	EROD_GIS	N.S.	RESIST_GIS	P=0.9974
RW	EROD_GIS	N.S.	RESIST_GIS	P=0.3410
RP100	EROD_GIS	>	RESIST_GIS	P=0.0369
ΔSHADE	EROD_GIS	N.S.	RESIST_GIS	P=0.5696
LRBS	EROD_FIELD	N.S.*	RESIST_FIELD	P=0.2234
%SAFN	EROD_FIELD	>	RESIST_FIELD	P=0.0132
W:D	EROD_FIELD	N.S.	RESIST_FIELD	P=0.6010
RW	EROD_FIELD	N.S.	RESIST_FIELD	P=0.5588
RP100	EROD_FIELD	>	RESIST_FIELD	P=0.0389
ΔSHADE	EROD_FIELD	N.S.	RESIST_FIELD	P=0.4044
N.S = Not Significant	* = Trending			

Table 14. Results of the two sample hypothesis tests performed - subpopulations defined in the glossary

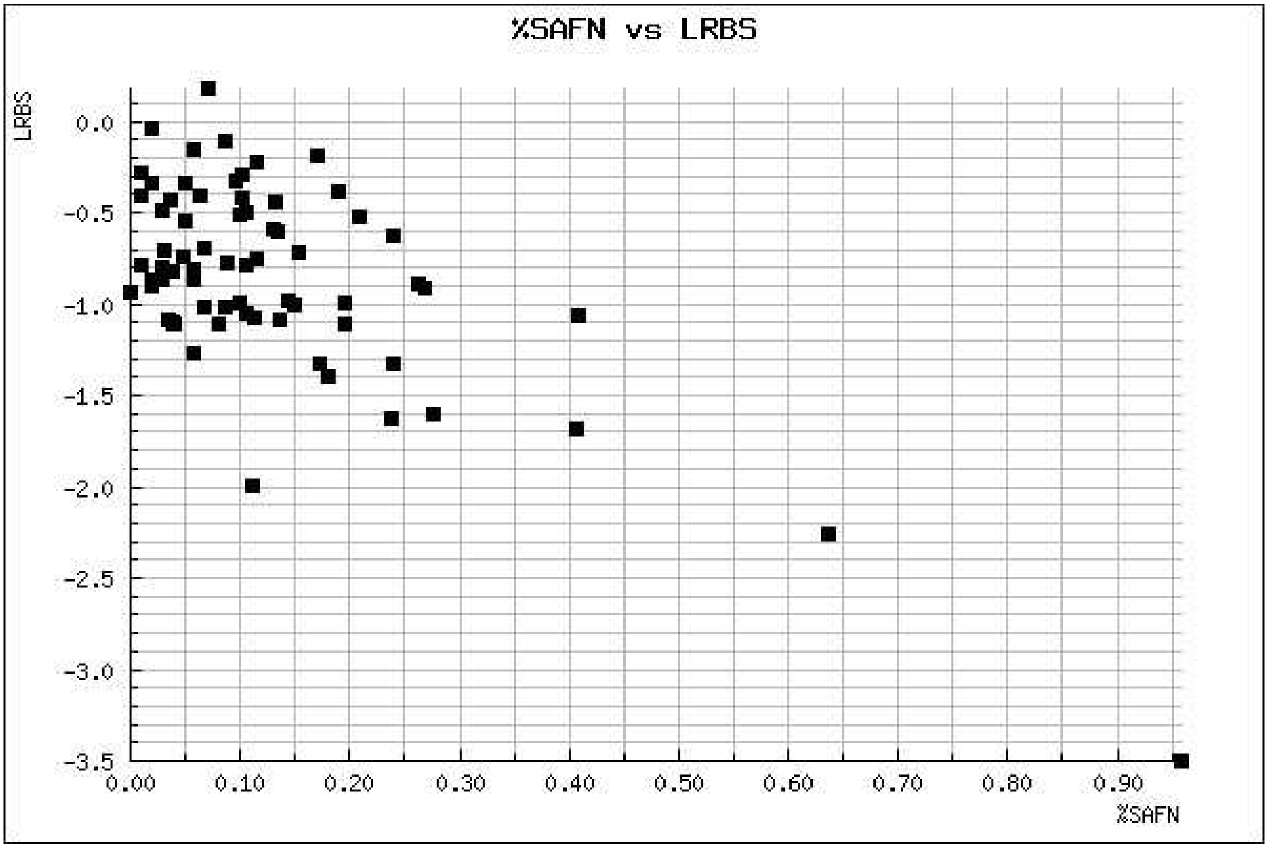


Illustration 1. Correlation between LRBS and %SANFN with outliers

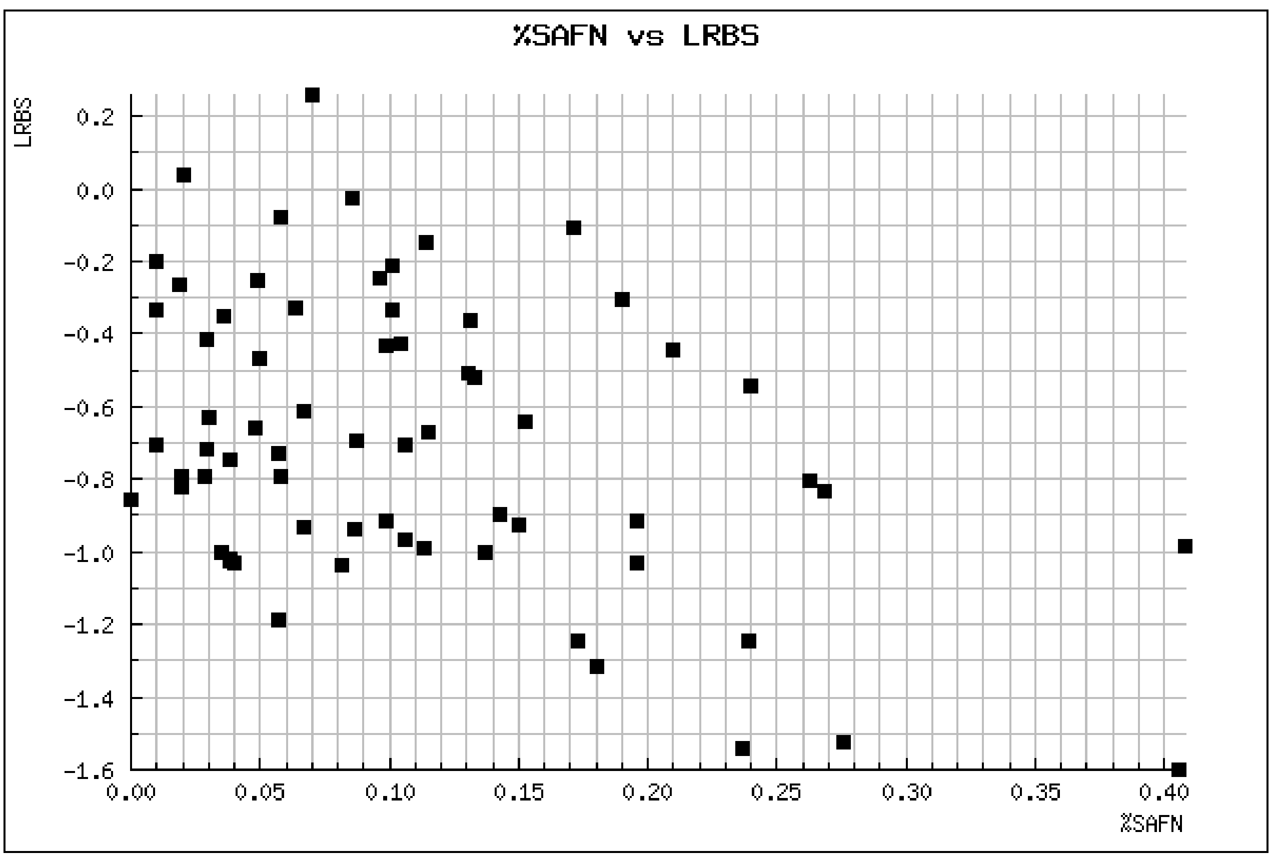


Illustration 2. Correlation between LRBS and %SANFN without outliers

Monte Carlo & Sample Size Considerations

The results of the Monte Carlo simulation are consistent with the values empirically determined by the EPA. When measured empirically, the standard deviation of the calculated LRBS metric when sites were revisited ranged from .35 to .44. This estimate is based on an earlier, less precise version of the protocol. The Monte Carlo model had a standard deviation of .35 for a single site. This indicates that the measurement error inherent in the protocol has been accurately modeled. Although the effect of measurement error is high for a single site, the effect on the full sample was small relative to the observed standard deviation of the sample. This indicates that measurement error plays a small role relative to sampling error. When measurement error was decreased by a factor of 100, the effect of error on the precision of both the population and the single site metrics decreased as well. Interestingly, the effect was much smaller than a factor of 100. Because measurement error is essentially random, error in one measurement such as slope is to a large degree canceled out by error in another such as mean particle size. This illustrates the value in using a multi-metric indicator like RBS. The results of the Monte Carlo simulation are presented in Table 15.

EMAP ERROR ESTIMATES	
STANDARD DEVIATION OF THE SAMPLE	0.407
POPULATION MEAN LRBS OVER 1000 SIMULATIONS	-0.784
POPULATION SD OF THE MEAN LRBS OVER 1000 SIMULATIONS	0.058
POPULATION COEFFICIENT OF VARIATION OF THE MEAN	7.44%
SINGLE SITE MEAN LRBS OVER 1000 SIMULATIONS	-0.881
SINGLE SITE SD OF THE MEAN LRBS OVER 1000 SIMULATIONS	0.353
SINGLE SITE COEFFICIENT OF VARIATION OF THE MEAN	40.05%
HIGH PRECISION ERROR ESTIMATES (1% EMAP)	
POPULATION MEAN LRBS OVER 1000 SIMULATIONS	-0.834
POPULATION SD OF THE MEAN LRBS OVER 1000 SIMULATIONS	0.012
POPULATION COEFFICIENT OF VARIATION OF THE MEAN	1.50%
SINGLE SITE MEAN LRBS OVER 1000 SIMULATIONS	-0.942
SINGLE SITE SD OF THE MEAN LRBS OVER 1000 SIMULATIONS	0.068
SINGLE SITE COEFFICIENT OF VARIATION OF THE MEAN	7.16%

Table 15. Monte Carlo Summary

The relationship between sample size and signal to noise is presented for a variety of estimated proportions in Table 16. In this case, proportion refers to the fraction of a given population which exceeds a given value. As indicated, the number of samples needed to characterize a population increases with increasing proportion. This has significant implications for evaluating impairment. For example if 20% (p=.2) of the sites in a given sample must exceed the benchmark to be considered impaired, then it is logical to use that proportion for determining sample size. If the actual percentage of impaired sites within the entire population is greater than twenty then the estimate will be less precise. This loss of precision however will be balanced by the increased total difference between the expected value of the sample and the 20% benchmark. If the actual percentage is less than 20, the estimate will be more powerful than expected. Based on this analysis, it is recommended that at least thirty sites be evaluated.

N	SE at P = .1	SE at P = .2	SE at P = .3	SE at P = .4	SE at P = .5
10	9.5%	12.6%	14.5%	15.5%	15.8%
20	6.7%	8.9%	10.2%	11.0%	11.2%
30	5.5%	7.3%	8.4%	8.9%	9.1%
40	4.7%	6.3%	7.2%	7.7%	7.9%
50	4.2%	5.7%	6.5%	6.9%	7.1%
60	3.9%	5.2%	5.9%	6.3%	6.5%
100	3.0%	4.0%	4.6%	4.9%	5.0%
150	2.4%	3.3%	3.7%	4.0%	4.1%
200	2.1%	2.8%	3.2%	3.5%	3.5%
500	1.3%	1.8%	2.0%	2.2%	2.2%
1000	0.9%	1.3%	1.4%	1.5%	1.6%

Table 16. Relationship between signal to noise ratio and sample size

A breakdown of the population by habitat unit is presented for researchers interested in comparing the data presented here to studies not based on the EMAP protocol. The traditional method of classifying channel segments by habitat units is subject to severe inter-observer and flow dependent bias. Residual pool depth was used in this study as the measure of pool frequency instead, as it is not subject to the same bias. This breakdown can be seen in Table 17 below.

HABITAT UNIT	PERCENTAGE
PLUNGE POOL	3.66%
LATERAL SCOUR POOL	12.24%
TRENCH POOL	2.81%
BACKWATER POOL	0.14%
IMPOUNDMENT POOL	1.41%
GLIDE	14.49%
RIFFLE	45.99%
RAPID	15.05%
CASCADE	4.22%

Table 17. Habitat Unit Breakdown

Cumulative distribution functions for all watershed metrics and for those sub-populations which exhibited significant differences are presented in appendix A, Figures 1 through 27. Cumulative distribution functions are an efficient way of conveying the distribution of the data.

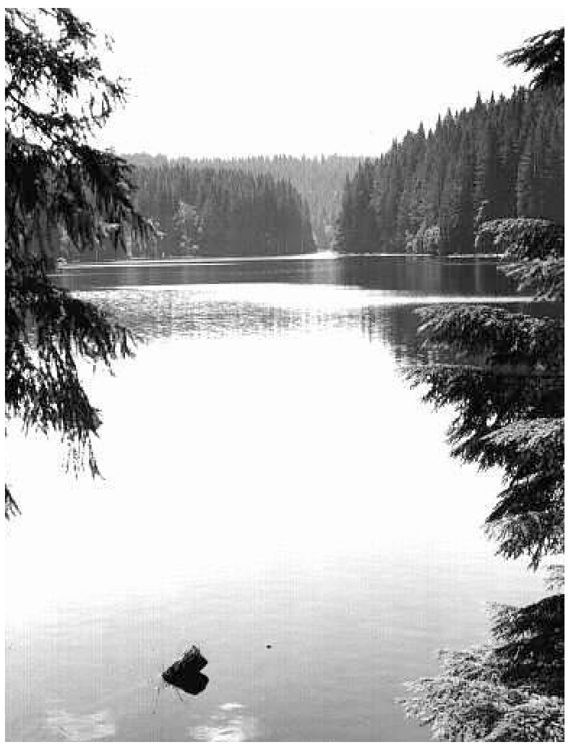
Discussion

Watershed Scale Indicators

The results of the four tests used in this study strongly indicate that the Nestucca River stream network administered by the BLM is not impaired by fine sediment. The first test indicated that the %SAFN in riffles and glides is significantly less than 20% (Table 10.) The second test indicated that less than 5% and 25% of the Nestucca River stream network sample exceeded the 5th and 25th percentiles of the reference data respectively (Table 11). Were the distributions identical, it would be predicted that 5% of the sites sampled would exceed the 5th percentile and 25% would exceed the 25th percentile. The third test indicated that the means of the LRBS and %SAFN metrics are both significantly below the 25th percentile of the existing reference data (Table 7). The fourth test indicated that the LRBS mean is not significantly different from the reference mean, and that the %SAFN mean is significantly less than the reference mean (Table 14). In summary, four separate analyses using two semi-independent indicators all are in agreement. In support of this conclusion, at a population scale, none of the metrics for evaluating habitat complexity were significantly different from reference conditions. However, the population average residual pool depth is numerically lower than the reference values, and this difference is close to significance. This may be due to the larger proportion of resistant lithology in the watershed. Regardless, the measured sediment scores cannot simply be explained as an artifact of decreased hydraulic roughness. Finally, the data suggests that a large proportion of the bed substrate consists of gravels (~50%).

Potential Sources of Fine Sediment within the Watershed

The failure of the Meadow Lake Dam (located above the study area) in 1962 had a profound effect on the hydrology of the river. The immediate effects of the flood and resulting debris torrent were the scoured channel, eroded roadbed, and the formation of terraces which are still visible. The long term effect of the dam failure has been the steady release of sediments into the stream network. A visual assessment conducted by BLM staff members concluded that Meadow Lake contributes sediments into the Nestucca River stream network. Large quantities of fine sediments were deposited on the bottom of Meadow Lake over its lifetime. These sediments are now chronically released, particularly during high water events.[1] The results of this study indicate that the system is capable of moving these fines out of the watershed.



Meadow Lake circa 1961

Following the Meadow Lake dam failure in 1962, there have been several channel altering events. These events have caused significant scour and loss of channel complexity in the main channel reaches. For example, one site in the study was located in a reach which had been scoured by a debris torrent during the 1996 flood. It is also one of the only sites with an LRBS score greater than zero. Many streams in the Nestucca River watershed were also actively cleared of instream wood prior to the 1980s. Finally, the Nestucca access road constrains the channel in many points, thus increasing the slope of the river. A portion of the road building was done by dynamiting the hillsides, the debris from which now lines much of the river bank. The large boulders generated by this process have essentially the same effect as rip-rap. Despite the many events which have served to simplify the watershed, at the most coarse scale, lack of roughness elements does not seem to be biasing the sediment indicators.

1 Nestucca Watershed Analysis 1994.

Effective Shade

The results of the shade assessment indicate that the portion of the Nestucca River stream network administered by the BLM is close to the modeled system potential effective shade. The measured mean effective shade was 85% and the modeled system potential effective shade was 95%. Although the measured shade is significantly less than the modeled shade by roughly 10%, this does not necessarily mean that the upper watershed stream network has a true excess of solar input. The Nestucca River watershed TMDL was one of the first TMDLs developed in Oregon and made a number of simplifying assumptions to facilitate the Heat Source modeling. Principally, it was assumed that the undisturbed state of the stream network was a climax ecosystem with a riparian community dominated by conifers of 185 feet. However all ecosystems exhibit a disturbance regime.[1] The ODEQ has recognized this point and has specifically incorporated a disturbance regime into the Willamette River TMDL released in 2006. It is recommended that any updates to the Nestucca River TMDL include a refinement of the assumptions of the shade modeling.

1 Nakamura et al 2003

Mainstem and Tributary Indicators

A closer examination of the data reveals that the mainstem Nestucca River in the upper watershed differs from its tributary streams in a number of metrics. The mainstem Nestucca River has a higher RBS score and is therefore significantly more stable than the rest of the stream network.[1] This is probably a result of the resistant volcanic geology of the mainstem. However there are two issues to consider when interpreting this result. The first is the difference between the ratio of resistant to erodible lithologies in the Nestucca River watershed and the ODEQ reference data. In the Nestucca River study area the ratio of resistant to erodible lithologies is approximately 8 to 5. The ODEQ reference data for the north coast has a ratio that is roughly 1 to 1. It was not possible to weight the proportions as details on the sampling of the reference data were not available. Given the alternatives, it was judged more important to keep the additional erodible reference data than to increase the variance and potentially bias the result by eliminating five erodible sites from the reference data. Additionally, it was the opinion of a BLM soils specialist that the resistant lithologies of the Nestucca River watershed are more erodible than in other areas.[2] Furthermore, the TMDL for the Nestucca Bay watershed does not differentiate between erodible and resistant lithologies in terms of %SAFN in riffles and glides.

Although the mainstem Nestucca River LRBS value differs from the tributaries, it is not different from the measured resistant LRBS value for the watershed. This illustrates the utility of conducting a lithology assessment as part of the sediment assessment protocol. Furthermore, it is apparent that the mainstem Nestucca River is more stable than the tributaries because of its resistant lithology. In contrast, the %SAFN of the mainstem is not significantly different from that of its tributaries. However, the mainstem Nestucca River does have significantly fewer gravels than the tributaries (33% vs. 55% - Table 14). The percentage of fine sediments should decrease as stream power increases, as is seen for the percentage of gravels. The lack of change in the percentage of sands and fines suggests that elevated levels of sands and fines may be entering the mainstem from Meadow Lake or other upstream sources. Further investigation would be necessary to clarify this issue.

1 Stable: Narrowly defined for the purpose of this document as having a larger RBS score.
2 Personal Communication Dennis Worrel 2006

The residual pool depth of the mainstem Nestucca River is greater than the contributing tributaries by a factor of almost three, and is significantly larger than the reference values. It is likely that a larger channel will have a larger absolute quantity of residual pool depth. To control for this, the residual pool depth divided by the hydraulic diameter (RP100:DH) was calculated as an alternate metric. Although this decreased the total magnitude of the difference, the same pattern remained between the mainstem Nestucca River and the tributaries. When this correction was applied to the reference data, the difference between the mainstem Nestucca River and the reference data disappeared but the difference between the tributaries and the reference data remained indicating that the tributaries have a significantly lower residual pool depth than the reference streams. Because the reference data is collected from minimally disturbed sites, it tends to include mostly smaller streams. This can introduce some bias into the results. It is recommended that this correction be applied to the residual pool depth metric when comparing channels of different sizes. The conclusion of these analyses is that the mainstem Nestucca River is within the range of reference values for residual pool depth but that the tributaries may fall outside the reference ranges.

A restoration project on Elk Creek can be seen in the photograph on the right.

The width to depth ratio of the mainstem Nestucca River is greater than the reference data suggesting that it has widened. This may be a result of the flood events which have perturbed the channel or may be a consequence of the proximity of the road and its deleterious effects on vegetation. The mainstem Nestucca River can be seen in the photograph above, on the left. The width to depth ratio is within the range of reference values in the tributary reaches.

Finally, the wood volume is lower in the mainstem Nestucca River than its tributaries or the reference data by a factor of two. The lack of large woody debris in the mainstem Nestucca River is apparently compensated for by the absolute increase in residual pool depth in terms of its effects on sediment transport. As the wood volume approaches reference levels, one would expect that the mean particle size would decrease, resulting in increased gravels.

Culverts

Although initially a random sample was drawn from 330 culverts in the Nestucca River watershed, only a small fraction of these were large enough to be included. Small culverts or culverts located immediately above a confluence were excluded from the sample. Out of the 330 culverts, 30 met this criteria and 12 of these 30 were sampled. This limits the applicability of the data to the larger population of culverts. The culvert subpopulation exhibited similar sediment scores to the rest of the watershed. Neither LRBS or %SAFN were significantly different from the population average. Effective shade was actually greater than the watershed average in reaches impacted by culverts. This may due to the presence of species such as salmon berry (*Rubus spectabilis*) and devils club (*Oplopanax horridus*) which readily colonize disturbed riparian areas such as those near culverts. In summary, the results indicate that the reaches modified by culverts did not reveal the contribution of excess fine sediments to the upper Nestucca River stream network. These results are only applicable to large culverts on land administered by the BLM and USFS. A summary of the culvert metrics can be seen in Table 18.

METRIC	N	MEAN	SD	LOWER 95% CB	UPPER 95% CB
LRBS	12	-0.584	0.792	-0.978	-0.190
%SAFN	12	0.162	0.210	0.070	0.253
%GRAVELS	12	0.319	0.185	0.224	0.414
W:D (m/m)	12	8.599	1.522	7.760	9.438
RW (m)	12	0.259	0.524	0.001	0.517
RP100 (cm)	12	5.682	3.538	4.384	6.979
SHADE	12	0.942	0.355	0.923	0.961
ΔSHADE	12	-0.030	0.032	-0.047	-0.013

Table 18. Summary of Culvert Metrics

Erodible vs. Resistant Lithologies

Under both classification approaches, the erodible sites had a greater %SAFN than resistant sites (25% vs 10%). Additionally, the LRBS scores of sites with erodible lithologies were numerically lower and therefore could be considered less stable. This result was only trending towards significance due to the relatively small sample size of the subpopulation. If the current values were extrapolated to a larger sample they would become significant. However it appears that local lithology has a greater impact on the percentage of fine sediments than it does on bed stability. It is possible that bed stability is driven more by the lithology of the contributing watershed whereas fine sediments are driven more by local lithologies. Furthermore, resistant sites exhibited significantly less residual pool depth. It is logical that a stream could not scour pools as easily in resistant lithologies as it could in erodible. Taken together, these findings support the known EPA and ODEQ results.[1]

Field truthing of the existing USGS geology maps revealed that many areas classified as erodible in fact reflected a local resistant lithology. Roughly half of the sites originally classified as erodible were reclassified. Interestingly this did not effect the outcome of the hypothesis testing. This suggests that the reclassified sites had metric values in between the two extremes. It is also apparent that streams in erodible watersheds scoured out the erodible sediments down to a more resistant bedrock.[2] Although the field truthing exhibited stronger quantitative trends, the GIS based classification was not qualitatively different. For that reason it appears that the existing GIS maps are adequate for management planning. Summaries of the erodible and resistant metrics can be seen in tables 19 and 20 below.

METRIC	N	MEAN	SD	LOWER 95% CB	UPPER 95% CB
LRBS	10	-0.942	0.608	-1.259	-0.625
%SAFN	10	0.249	0.177	0.157	0.341
%GRAVELS	10	0.491	0.139	0.407	0.574
W:D (m/m)	10	9.630	2.954	8.288	10.972
RW (m)	10	0.039	0.045	0.015	0.063
RP100 (cm)	10	11.656	4.915	8.733	14.580
SHADE	10	0.823	0.108	0.766	0.880
ΔSHADE	10	-0.126	0.091	-0.178	-0.074

Table 19. Summary of Field Classified Erodible Metrics

METRIC	N	MEAN	SD	LOWER 95% CB	UPPER 95% CB
LRBS	20	-0.657	0.523	-0.824	-0.490
%SAFN	20	0.113	0.140	0.068	0.157
%GRAVELS	20	0.457	0.206	0.369	0.544
W:D (m/m)	20	10.321	4.132	8.506	12.136
RW (m)	20	0.048	0.057	0.028	0.069
RP100 (cm)	20	7.226	5.682	4.925	9.528
SHADE	20	0.864	0.129	0.801	0.927
ΔSHADE	20	-0.093	0.118	-0.152	-0.033

Table 20. Summary of Field Classified Resistant Metrics

1 Kaufman and Hughes
2 Personal Communication, Dennis Worrel, BLM

Bear Creek

It was initially hypothesized that Bear Creek was a source of elevated sediment input and would exhibit a lower RBS score. When Bear Creek was analyzed individually it did not show results dissimilar from what was expected based on its overall lithology. However, the area is prone to large rotational slides that directly impinge on the channel. These slides may be source of sediment input. Due to the sporadic nature of these slides the degree to which they are impacting the system is uncertain. Summary statistics of the Bear Creek analysis can be seen below in Table 21.

METRIC	N	MEAN	SD	LOWER 95% CB	UPPER 95% CB
LRBS	8	-0.712	0.279	-0.914	-0.511
%SAFN	8	0.128	0.075	0.073	0.184
%GRAVELS	8	0.477	0.172	0.357	0.598
W:D (m/m)	8	12.595	3.959	10.011	15.178
RW (m)	8	0.041	0.050	0.012	0.070
RP100 (cm)	8	7.397	3.451	5.943	8.851

Table 21. Summary of Bear Creek Metrics

Old vs New RBS

The new RBS formulation was emphasized in this analysis due to the increased robustness of the metric. For example, under the old formulation, sites with very large wood volumes or residual pool depths resulted in meaningless values (e.g negative hydraulic radius scores). The new formulation corrects for these errors. In the case of the Nestucca River stream network, the new formulation consistently decreased the RBS scores. This is primarily due to a decrease in the Shield’s parameter. The changes did not qualitatively effect the results or the conclusions drawn.

The Effects of Measurement Error on Calculating Relative Bed Stability

To the extent that the assumptions used in the Monte Carlo model hold true, measurement error seems to have a small effect on the mean value of the LRBS metric for a reasonably large sample. However, this result is based on assumptions about the data which may not hold true in all cases. Error is more significant when evaluating a single site. The modifications to improve measurement precision discussed in the methods portion of this report should be applied in that case.

Limitations of the Current Protocol

The protocol as applied in the Nestucca River watershed has shown itself to be robust and efficient. There are, however, a number of potential limitations in its application. The statistical methods are particularly challenging for a practitioner without significant mathematical background. Results can be affected by a lack of understanding of the sampling methodology. Bias can be introduced if the site sampling plan is not adhered to rigorously. Even in cases where bias is avoided, deviation from the sampling plan can limit the general applicability of the results. These problems can be avoided with the oversight of a trained statistician familiar with the process. A second limitation is the requirement that all sampled streams be wadeable. In this study, almost all of the mainstem Nestucca River surveyed was wadeable. Where it was too deep to sample with the conventional protocol, dry suits and snorkel equipment was used to assess the condition of the stream bed. Theoretically this could be accomplished on very large channels.

The validity of the current protocol is highly dependent upon the accuracy, precision, and quantity of the reference data. Reference sites are explicitly selected on the basis of minimal disturbance. One consequence of this is that they do not necessarily represent the natural gradients present in the watershed. The vegetative community, lithology, and stream power may differ a great deal from reference conditions in a given watershed and there are fewer undisturbed sites in lower elevation reaches of many watersheds. Additionally, the reference data may lack sufficient randomness in the site selection. An alternate approach is recommended for developing benchmarks based on multiple linear regression. The logic of the approach is to apply multivariate regression to all of the available reference data to identify the controlling natural factors on bedded fine sediments. These factors would include climate, geology, and stream power as mentioned previously, and possibly many others. This process is analogous to an approach for generating the expected macro-invertebrate species composition for a given site under the River Invertebrate Prediction and Classification System (RIVPACS).[1] Once the sediment determinant model is built, it could be used to generate benchmarks for a specific watershed. This approach would also potentially solve the challenges of finding undisturbed sites in lower elevation reaches.

1 Hakwins 2004

Data Submission

In order to present the data in a format suitable for integration with the ODEQ's LASAR database, it is critical that all data be given a spatial address. Generally this takes the form of X and Y coordinates accompanied by spatial projection and transformation information. This can be easily obtained from the GIS layers created during the sampling phase. However, at the present time, the ODEQ has not explicitly outlined what actions will be taken following data submission. Until such time, it is recommended that the following items be submitted.

- **A single comma separated value (.csv) file with all of the relevant metrics for each site, xy coordinates, and design weights.**
- **A digital copy of the raw data in a spreadsheet compatible format.**
- **A report describing the results of the statistical analysis and its interpretation.**
- **GIS layers containing the sample frame and sites.**

The action taken upon submission will depend on the status of the water body and the outcome of the investigation. If the water body is not on the 303(d) list, and it is found to be impaired, this process should be sufficient to place it on the 303(d) list. If the water body is on the 303(d) list, does not have a TMDL in place, and is not found to be impaired, this process may be sufficient to petition for its removal from the 303(d) list. If a TMDL is in place for sediment this process moves the DMA toward compliance. If the water body is not found to be impaired it may eliminate the need to develop a WQRP.

Recommendations

- **This protocol be used for future water quality condition assessments.**
- **The dataset be evaluated for potentially suitable reference sites.**
- **The quantity of ODEQ reference data be increased to 30 sites per ecoregion III.**
- **At least 30 sites be evaluated during water quality assessments.**
- **A determinant model be developed to set benchmarks for judging impairment.**
- **Stream size be corrected for when evaluating RP100 independently.**
- **This dataset be included in future water quality condition assessments of the Nestucca River.**
- **This study be incorporated into updates of the Nestucca Bay Watershed TMDL.**
- **Updates to the Nestucca Bay Watershed TMDL refine the assumptions of shade modeling.**
- **Water quality assessments be linked to the biotic community.**
- **Large wood be classified as placed or natural.**
- **Large wood placement in the mainstem Nestucca River continue to be a priority.**
- **All stakeholders be included in the evaluation process.**

The protocol described in this document has been shown to be effective for assessing fine sediment impairment and instream shade in the Nestucca River stream network administered by the BLM. A rigorous analysis of the data has shown that the portion of the stream network assessed is not impaired by fine sediment. The recommended process for future assessments explicitly assumes a two stage approach to sampling. The first step is to assess the status of 30 sites throughout the entire portion of the stream network upstream of the reaches considered to be impaired. If both the LRBS and %SAFN metrics are significantly less than the benchmarks for judging impairment, the water body is not considered impaired. If either one of the metrics is not significantly different from the benchmarks, an additional round of sampling should be triggered to increase the statistical power of the analysis. The number of additional samples needed can be estimated from the variance of the first thirty sites. More sites would be needed if the variance were great than if the variance were small. If the two metrics provide contradictory results, macroinvertebrate sampling can be used to directly assess the biological status of the water body. The ODEQ has indicated that macroinvertebrate sampling can be included as an additional indicator.[1] If the sample and the benchmark (e.g 5th percentile of the reference data) for judging impairment are close to identical, it is important to err on the side of caution. In this case, the water body should be considered impaired. A follow up evaluation after five years is recommended to assess trends in this case. If both metrics exceed the benchmark, the water body is considered impaired. The rigor of this multi-metric assessment makes this process suitable for future water quality assessments.

Although the conclusions of this study were not compromised by the lack of reference data, this was the weakest area of analysis. The lack of reference data in other ecoregions could be an issue in future evaluations. The reference data should be increased to at least 30 sites per ecoregion III, the minimum number of sites recommended to generate statistically defensible conclusions.

1 Doug Drake, Personal Communication

This dataset should be evaluated for potentially suitable reference sites for the Oregon Coast Range ecoregion III. There were no reference sites within the Nestucca River watershed yet many of the sites evaluated could potentially meet the criteria for reference conditions. Furthermore, the natural gradients within each ecoregion are not always accurately represented. For instance, in the Nestucca River watershed there are fewer undisturbed lower elevation reaches than upland reaches. Studies conducted in ecoregions that vary greatly in both geomorphology and land use could be limited by the lack of representative reference data. A determinant model should be developed for use in areas where the reference data does not accurately represent every natural gradient. A determinant model could generate a predicted value for each site assessed.

When RP100 was calculated separately for the mainstem and the tributaries it was discovered that the tributaries had a lower RP100 value. Had the correction for hydraulic radius not been made it would have appeared that the mainstem Nestucca River had a greater residual pool depth than expected from the reference data. As indicated earlier, most of the reference data used in this study was collected from smaller streams. The correction used in this study adjusts for the confounding factor of hydraulic radius.

This study is the most comprehensive water quality assessment to date in the Nestucca River watershed. Data collected in this study should be used to update the existing TMDL for the watershed. Furthermore, the dataset should be included in any future water quality assessments of the Nestucca River watershed. This study has illustrated weaknesses in the assumptions as applied in the Nestucca Bay Watershed TMDL. Disturbance regimes should also be included in any updates to the Nestucca TMDL.

Water quality assessments are often motivated by their relationship to the biotic community but are rarely related directly to the status of the biotic community for legal and operational reasons. Ideally physical habitat and water quality should addressed in a holistic manner. There would be little reason to evaluate fine sediment were it not for the impact it has on the biotic community. An assessment such as this could be improved if it were guided by both the Clean Water Act and the Endangered Species Act. Although the stream network administered by the BLM is not impacted by fine sediments, the mainstem Nestucca River is significantly lacking large woody debris. Large wood placement should continue to be a priority in the watershed. A useful addition to the protocol would be to classify all instream wood as placed or natural. This would allow a DMA to track the effectiveness of their restoration efforts.

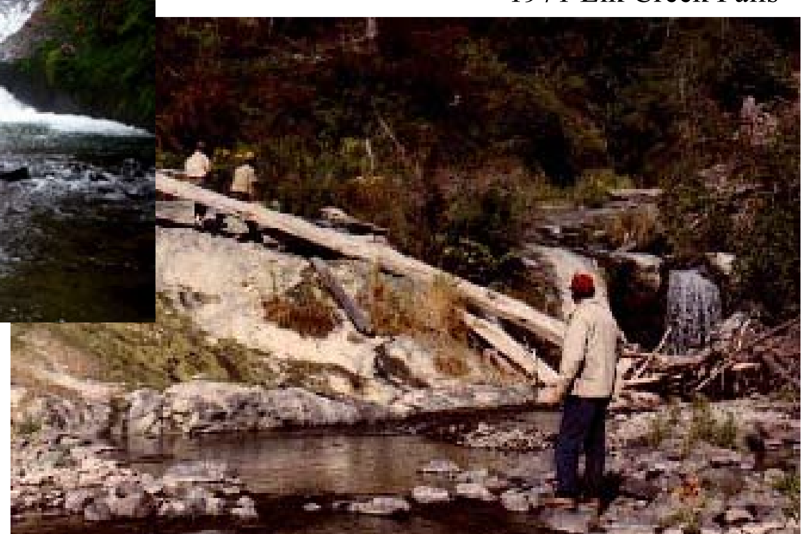
To be most cost effective, all stakeholders within the watershed should be included in the initial planning stages of an assessment project. TMDLs are developed at a watershed scale, and the statistical power of the analysis is dependent only on the sample size, not the population it is drawn from. In other words, if the question of interest is the status of the stream network as a whole, the assessment should take place in streams throughout the watershed. This approach has some significant consequences. With less than thirty sites, it is difficult to draw defensible conclusions about subpopulations within the watershed. Stakeholders with an interest in accurately characterizing a particular region of interest should consider increasing the sampling density within that region.

Conclusions

The results of this study indicate that the portion of the Nestucca River stream network administered by the BLM is not impaired by fine sediment. At a population scale it is within normal bounds for habitat complexity. However, the habitat quality of the mainstem Nestucca River is degraded by a lack of LWD, and is wider than expected. It appears that the mainstem Nestucca River has an elevated level of fine sediment input, possibly due to the presence of Meadow Lake or other upstream sources. The tributaries of the mainstem Nestucca River are lacking bedform roughness and pool volume. Additional inputs of large woody debris into the system may help to correct this problem. The measured effective shade of the study area is only slightly lower than the modeled system potential effective shade based on the TMDL. This difference may be an artifact of the assumptions of the TMDL, which have not been validated for this watershed. Properly sized culverts on large stream crossings do not seem to be contributing excess fine sediments to the system. Finally, stream reaches situated in erodible lithologies have significantly higher levels of fine sediments and somewhat less stable beds. While it is impossible to determine whether the initial 303(d) listing was accurate, it is apparent that the listing is no longer applicable for the current conditions of the Nestucca River stream network administered by the BLM in regards to fine sediment. This study satisfies a significant component of the BLM's responsibilities under the Nestucca River WQMP, the USFS/BLM protocol for addressing 303(d) listed waters, and the current MOA between the BLM and ODEQ.

2004 Elk Creek Falls

1971 Elk Creek Falls



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Appendix A - Cumulative Distribution Functions

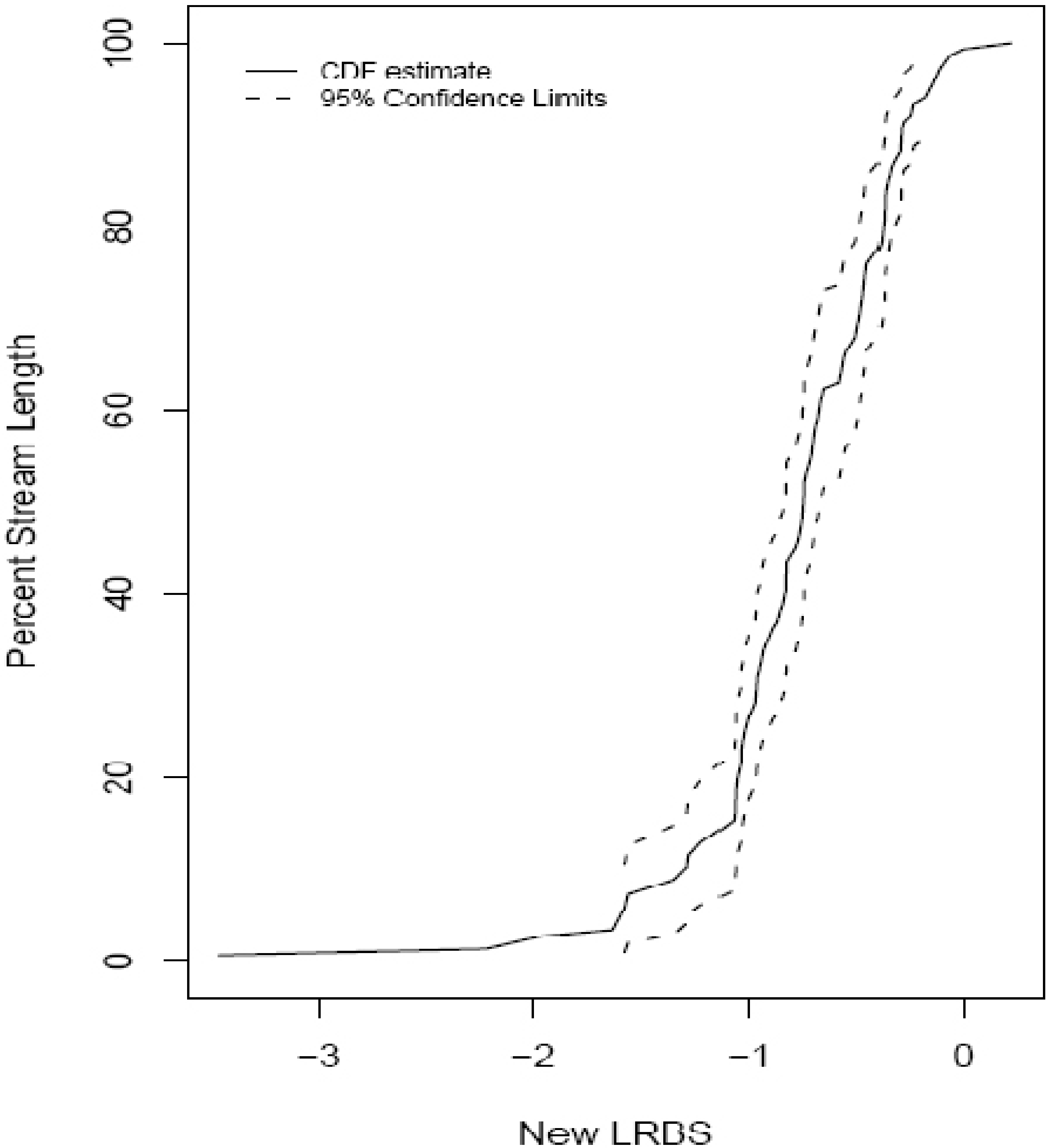


Figure 1. Watershed Log Relative Bed Stability Cumulative Distribution Function

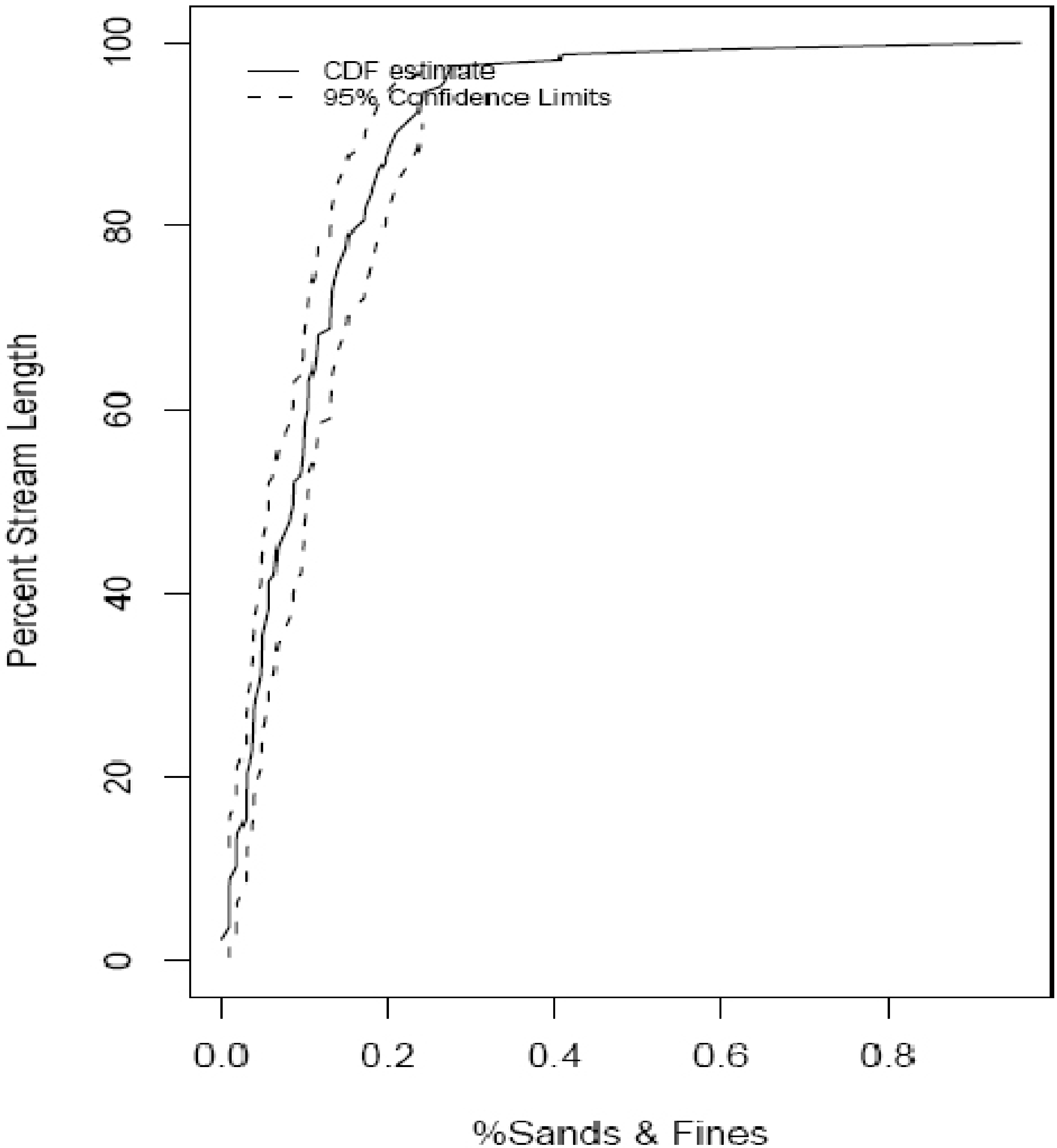


Figure 2. Watershed Percentage of Sands & Fines Cumulative Distribution Function

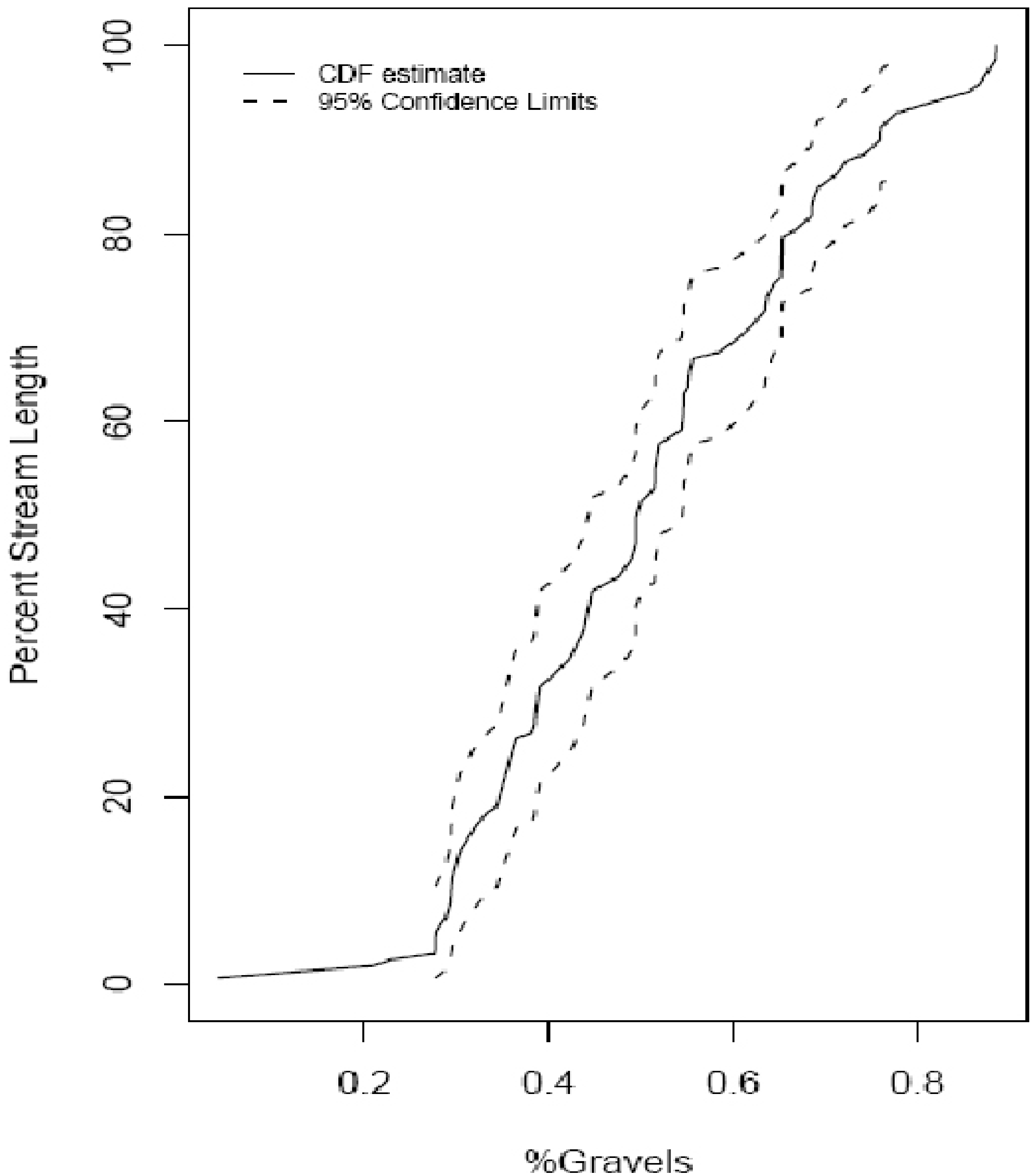


Figure 3. Watershed Percentage of Gravels Cumulative Distribution Function

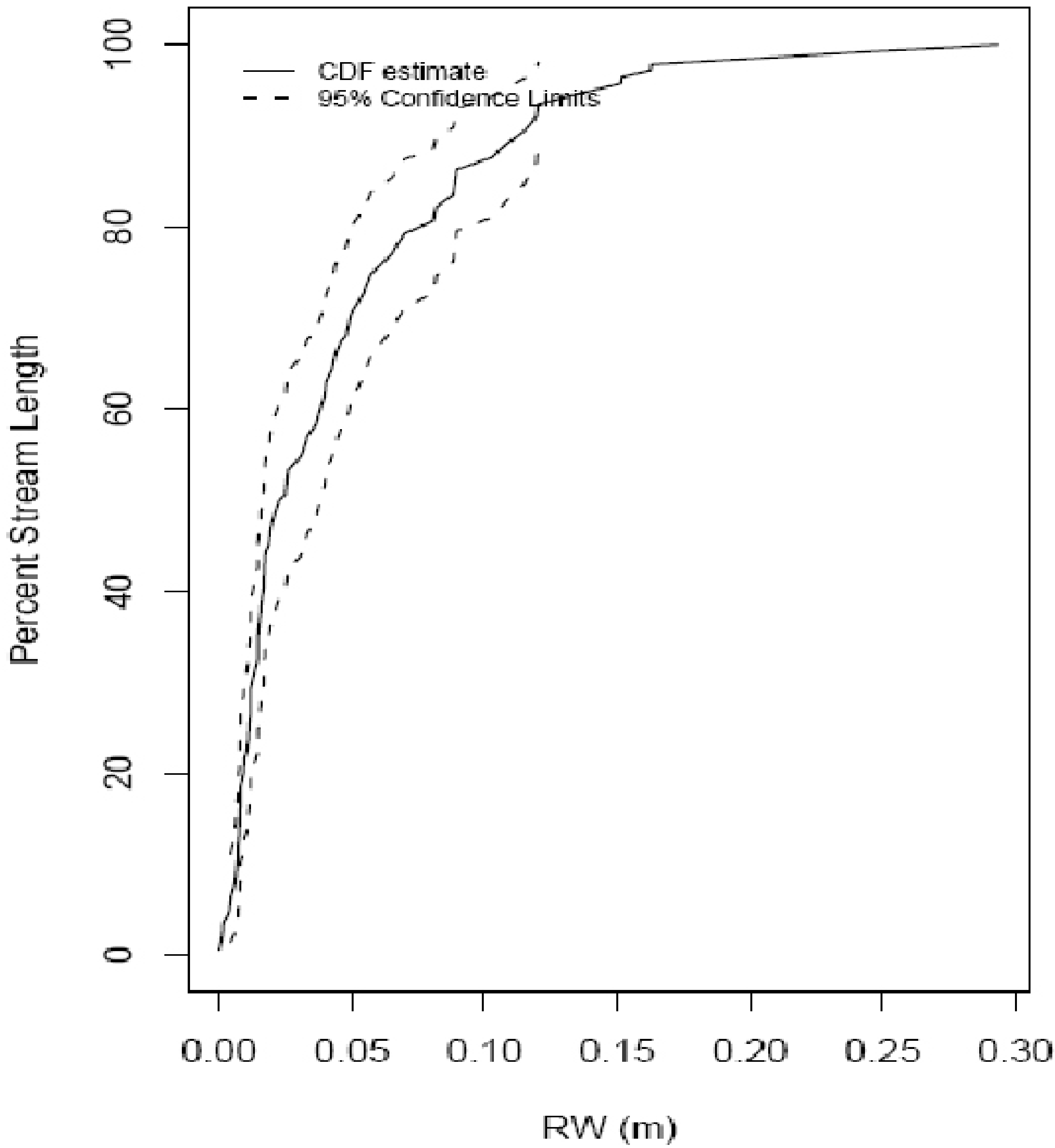


Figure 4. Watershed Wood Radius Cumulative Distribution Function

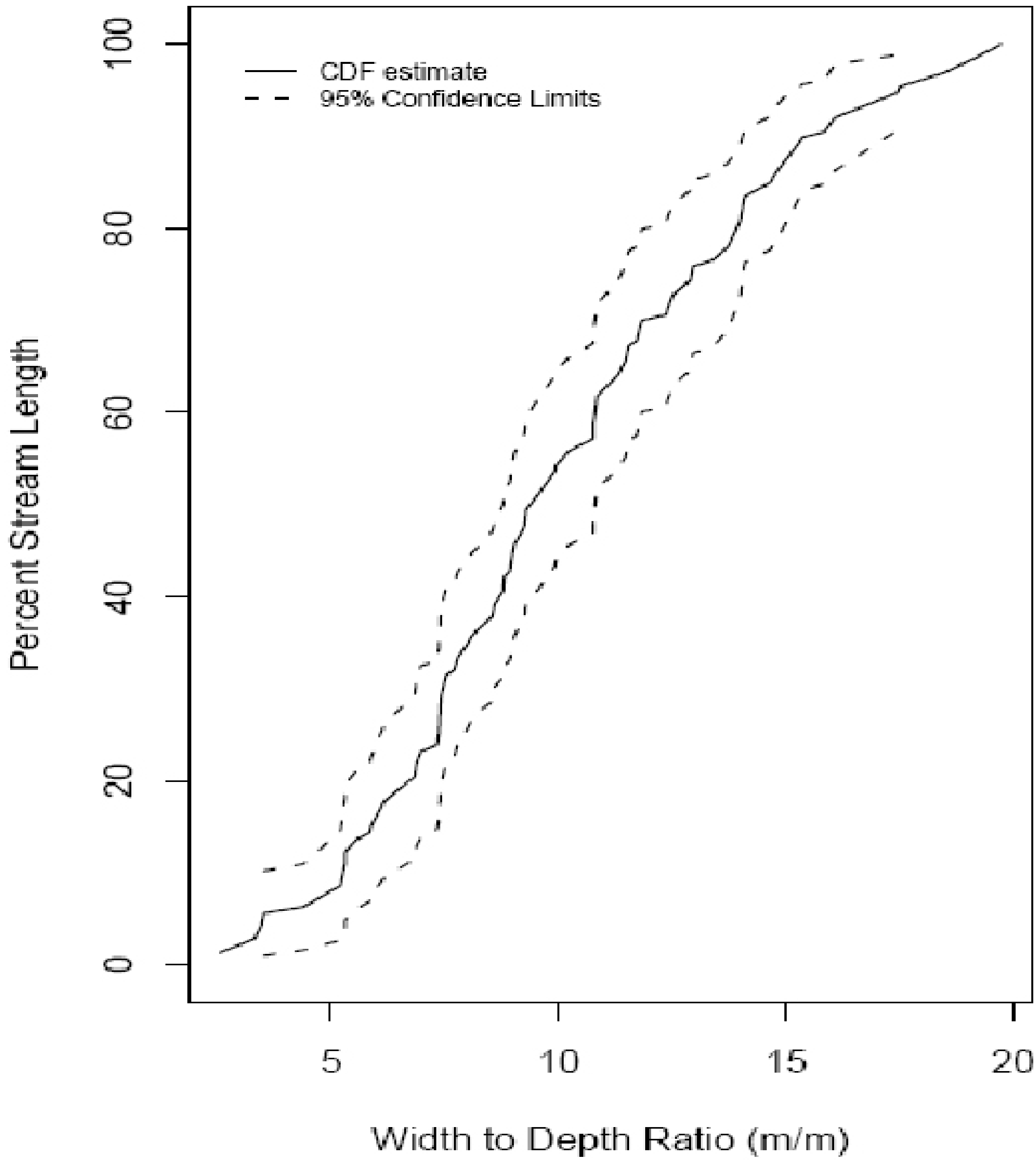


Figure 5. Watershed Width to Depth Ratio Cumulative Distribution Function

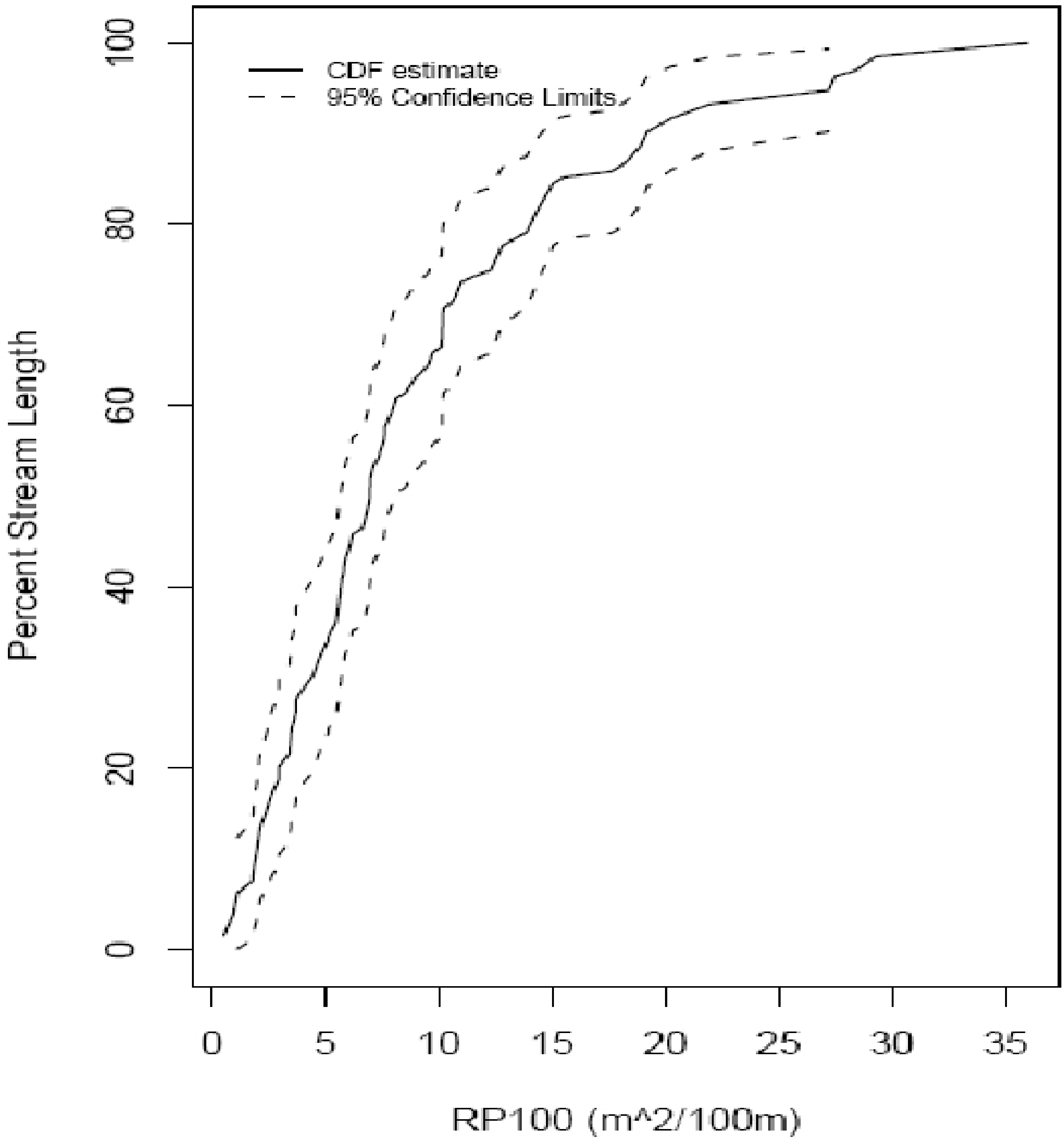
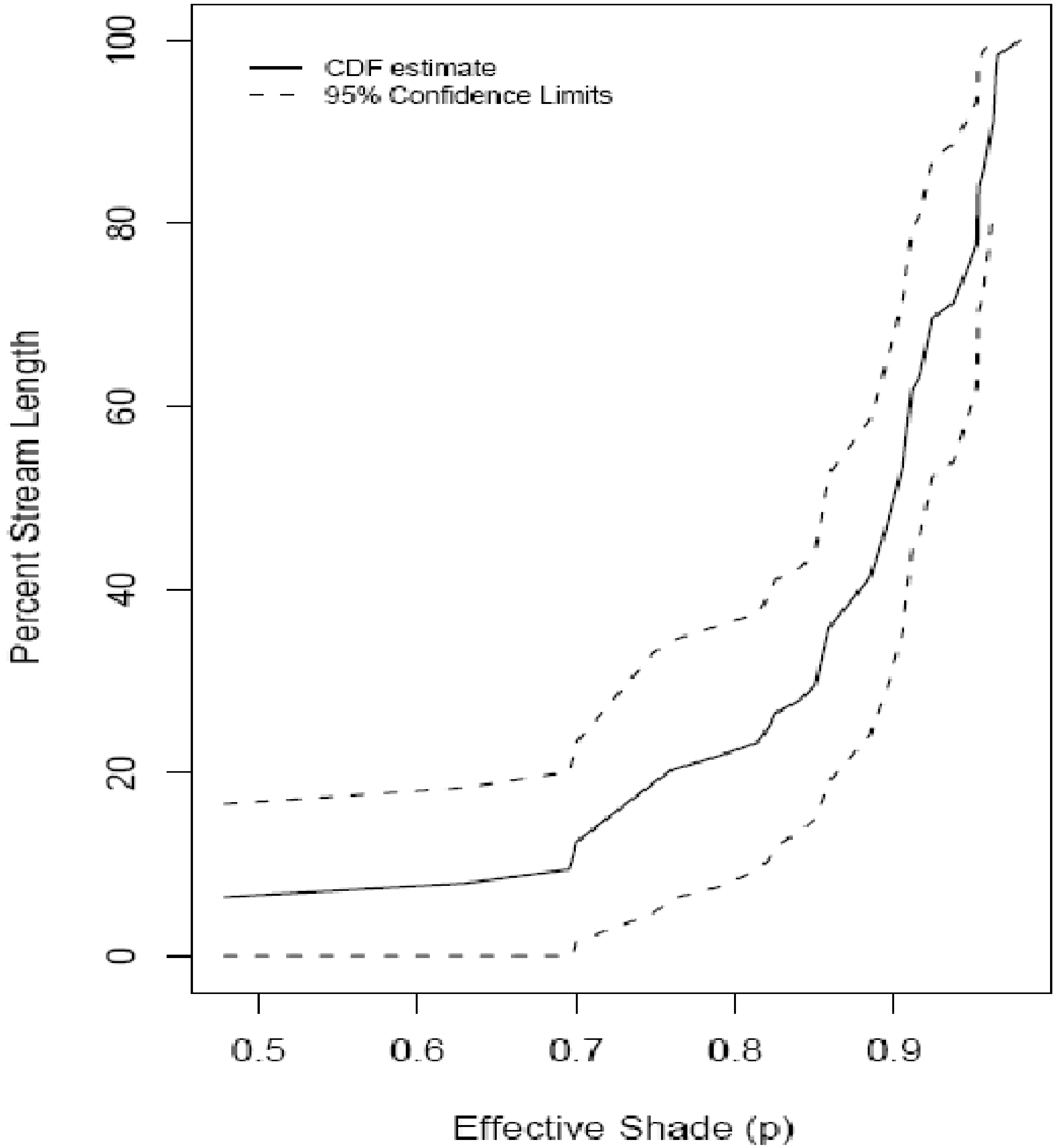


Figure 6. Watershed Residual Pool Depth Cumulative Distribution Function



<u>Figure 7. Watershed Effective Shade Cumulative Distribution Function</u>

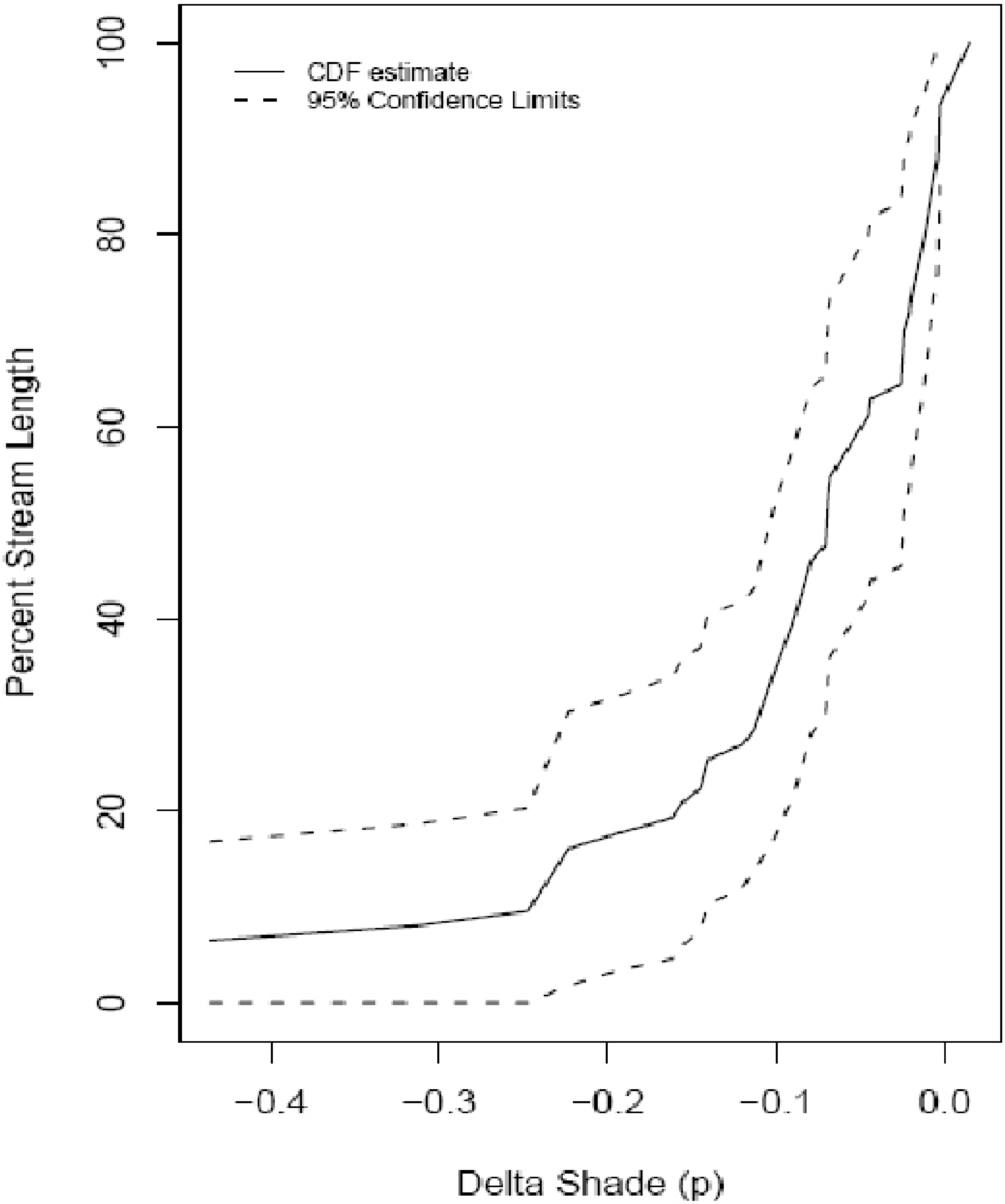


Figure 8. Watershed Delta Shade Cumulative Distribution Function

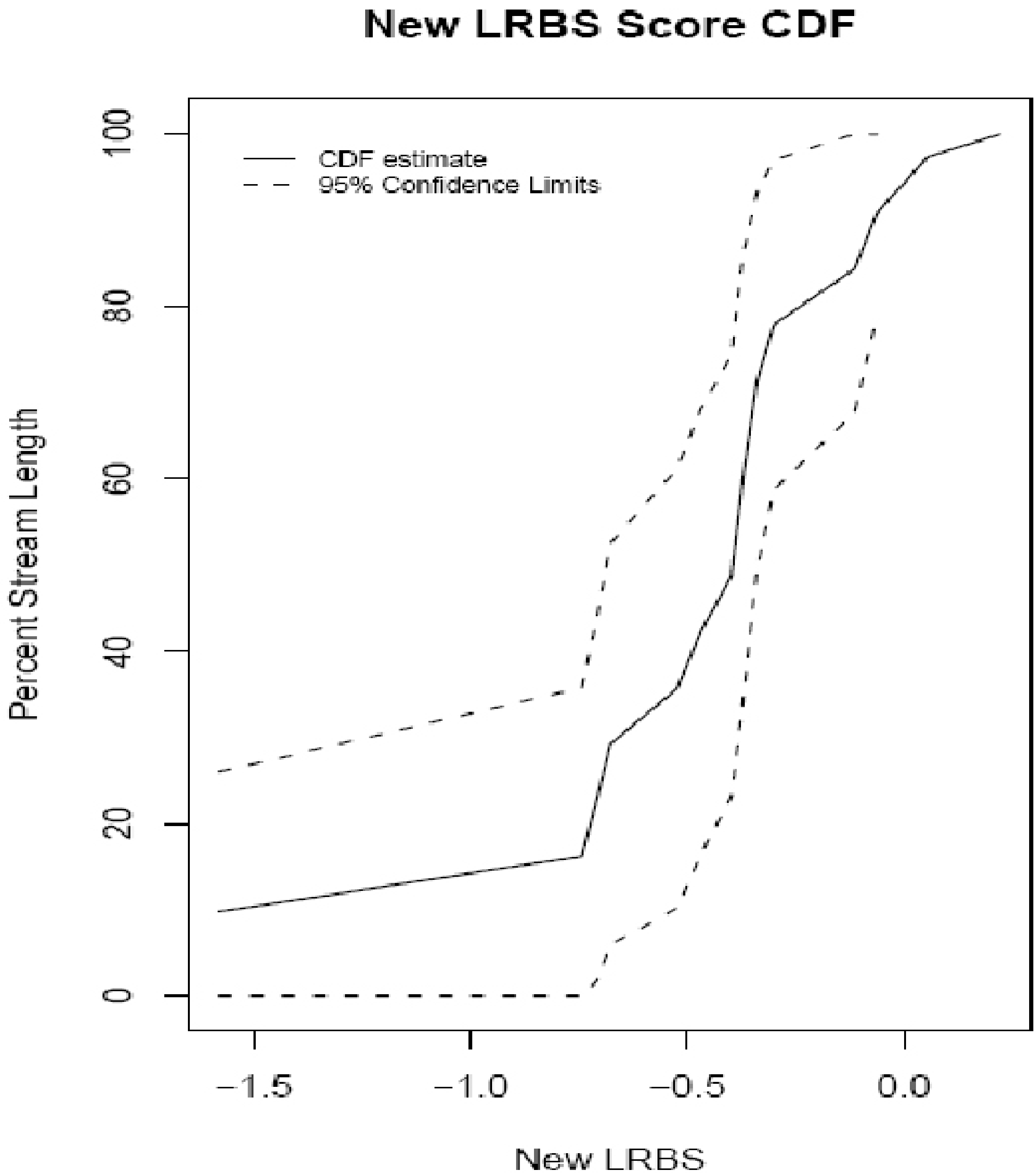


Figure 9. Mainstem Log Relative Bed Stability Cumulative Distribution Function

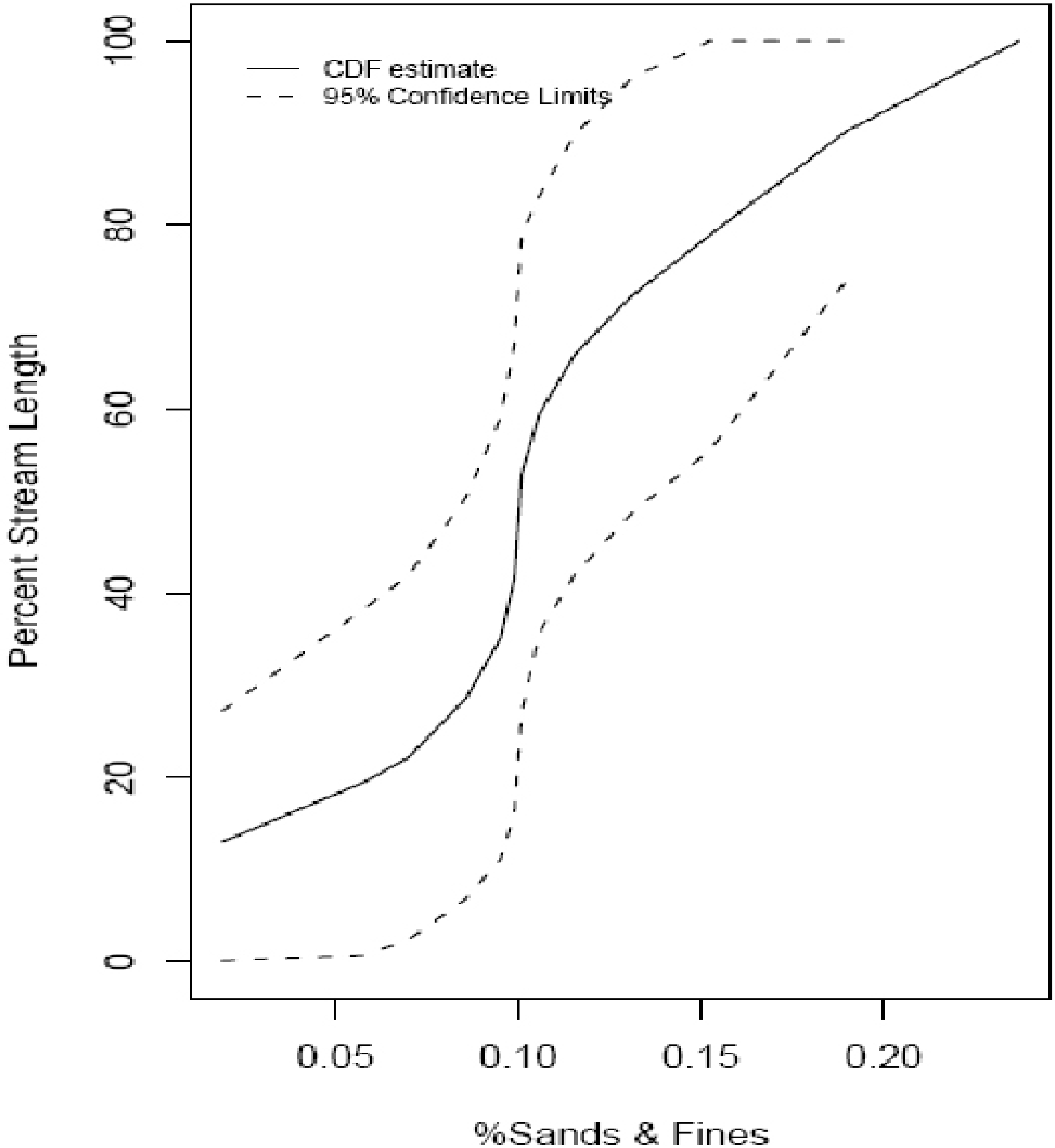


Figure 10. Mainstem Percentage of Sands & Fines Cumulative Distribution Function

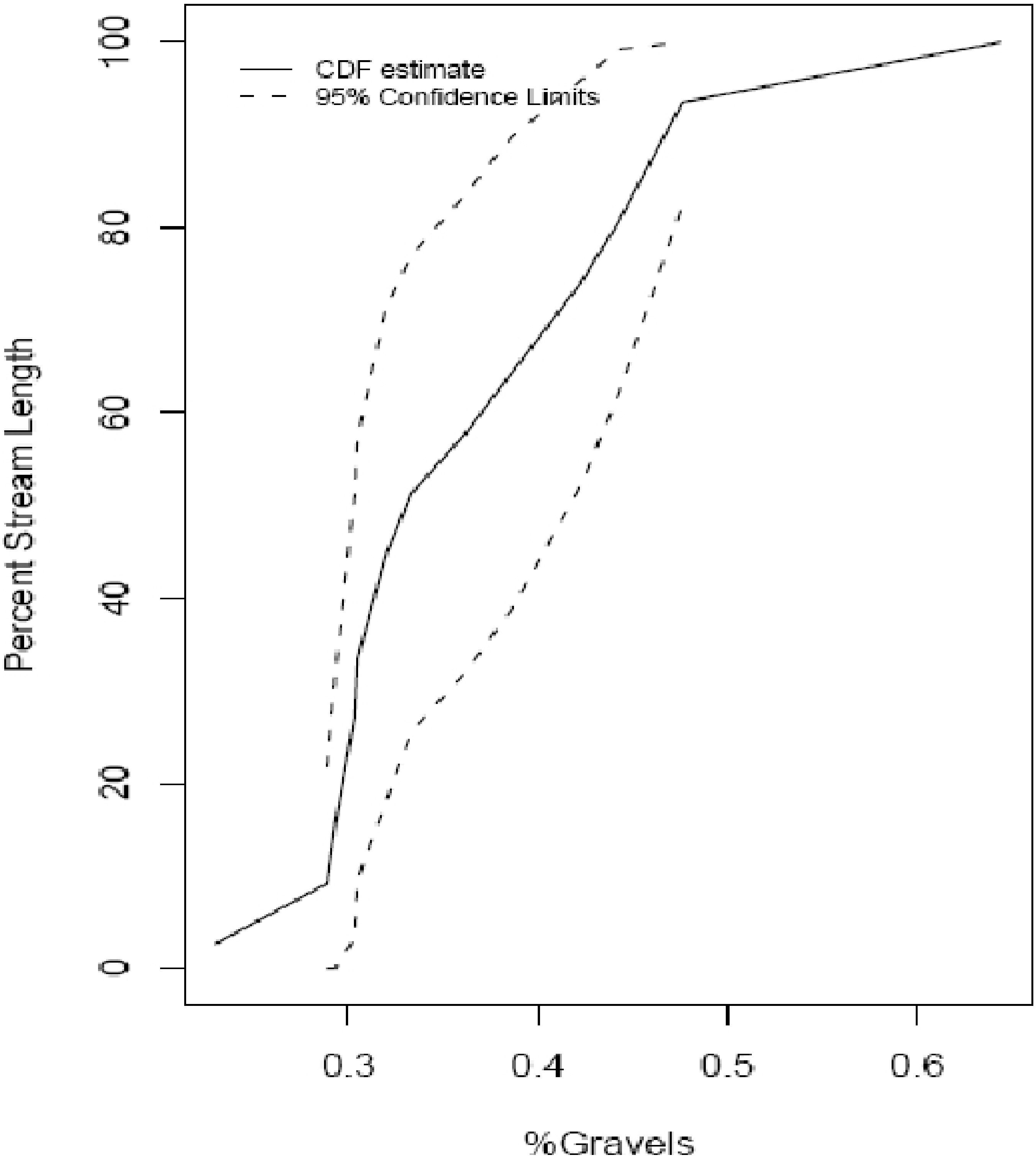


Figure 11. Mainstem Percentage of Gravels Cumulative Distribution Function

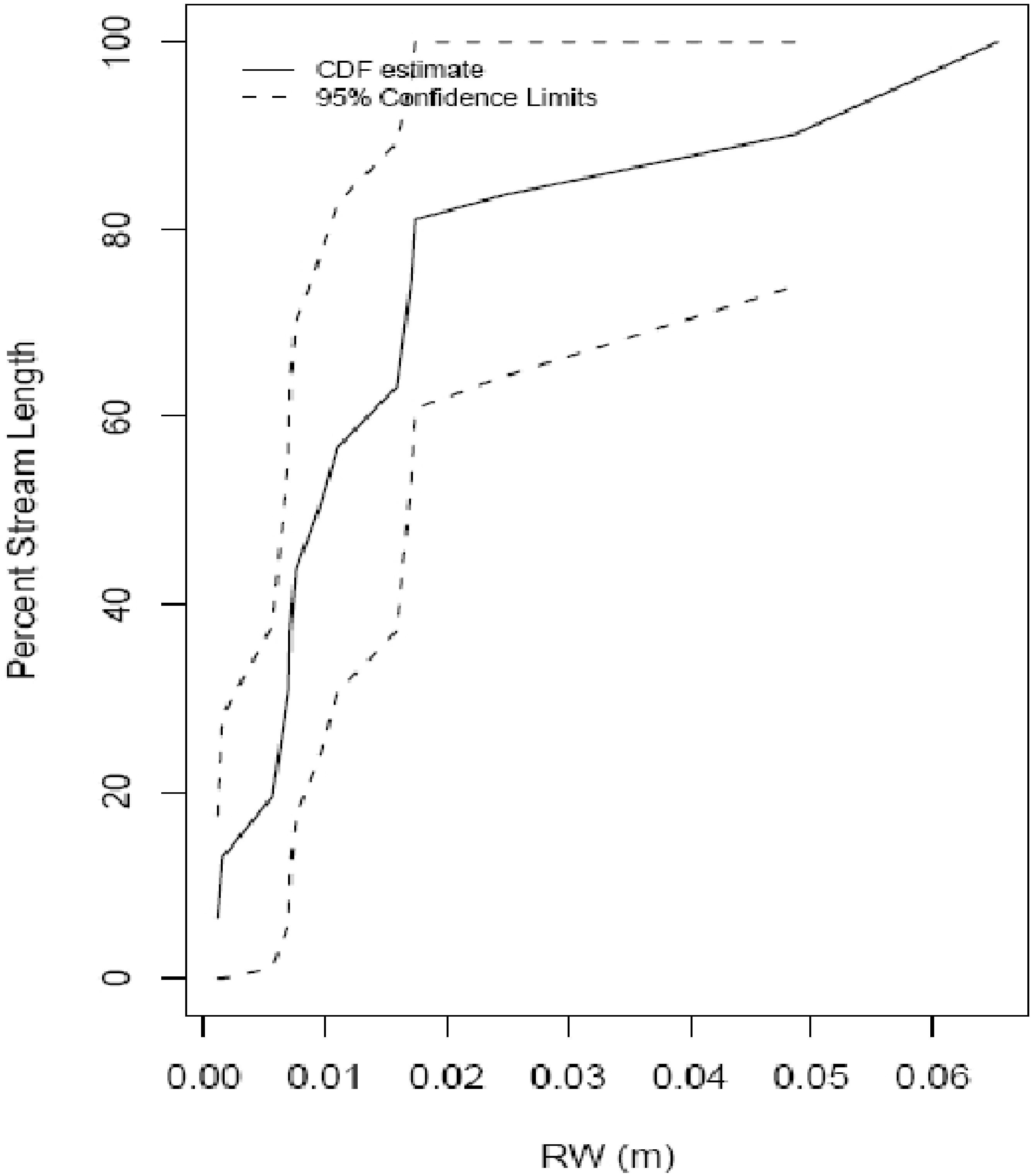


Figure 12. Mainstem Wood Radius Cumulative Distribution Function

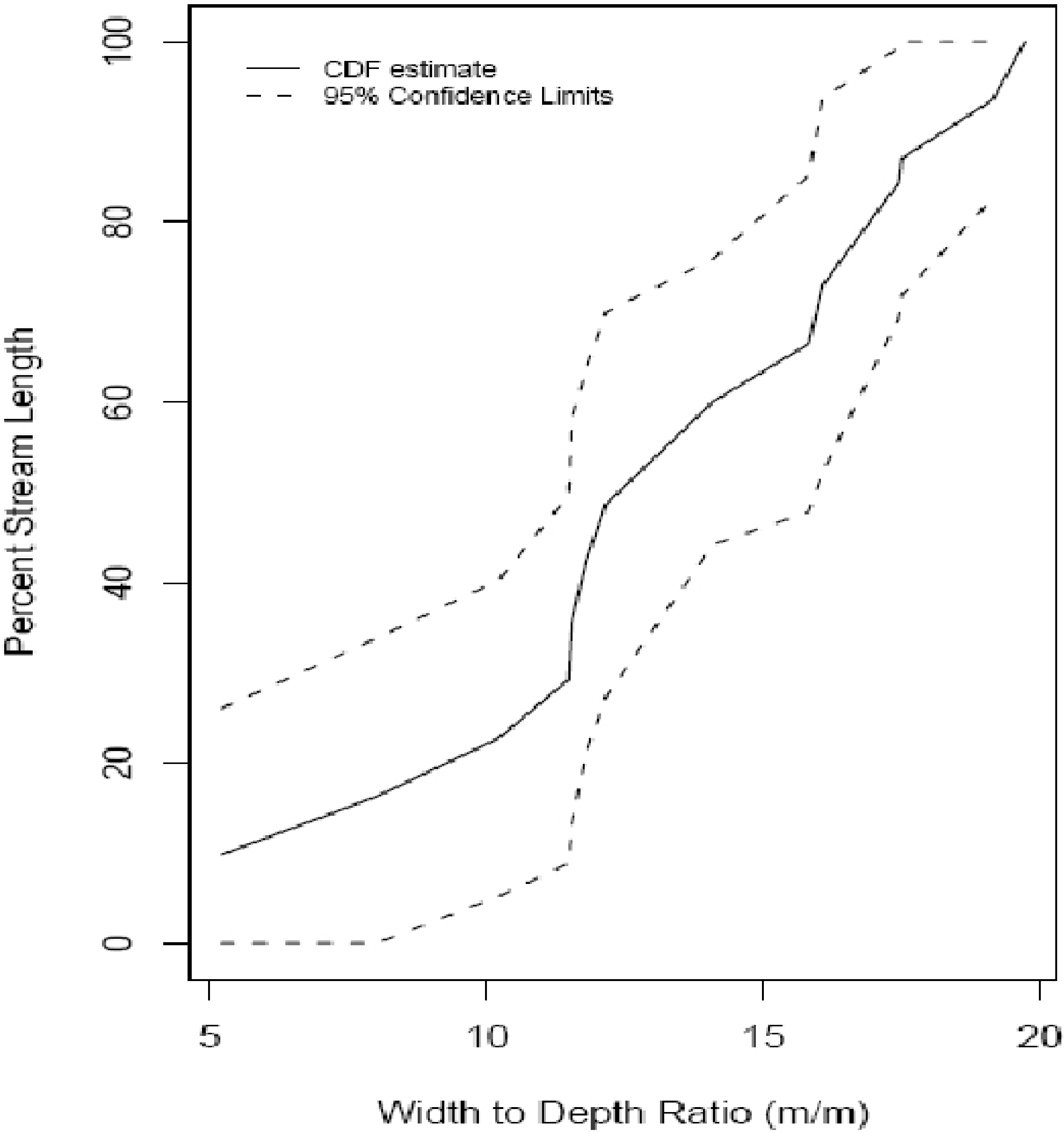


Figure 13. Mainstem Width to Depth Ratio Cumulative Distribution Function

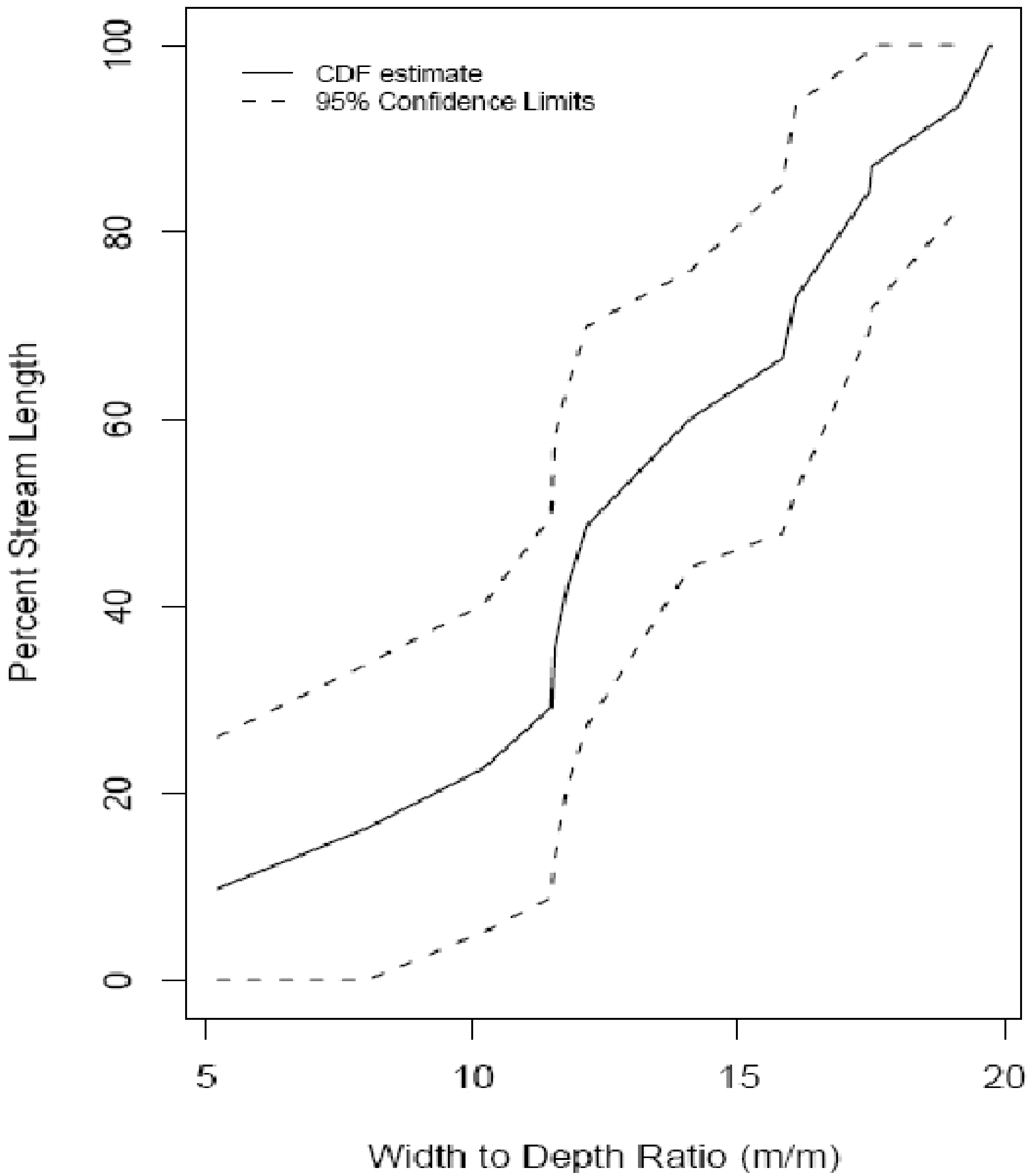


Figure 14. Mainstem Residual Pool Depth Cumulative Distribution Function

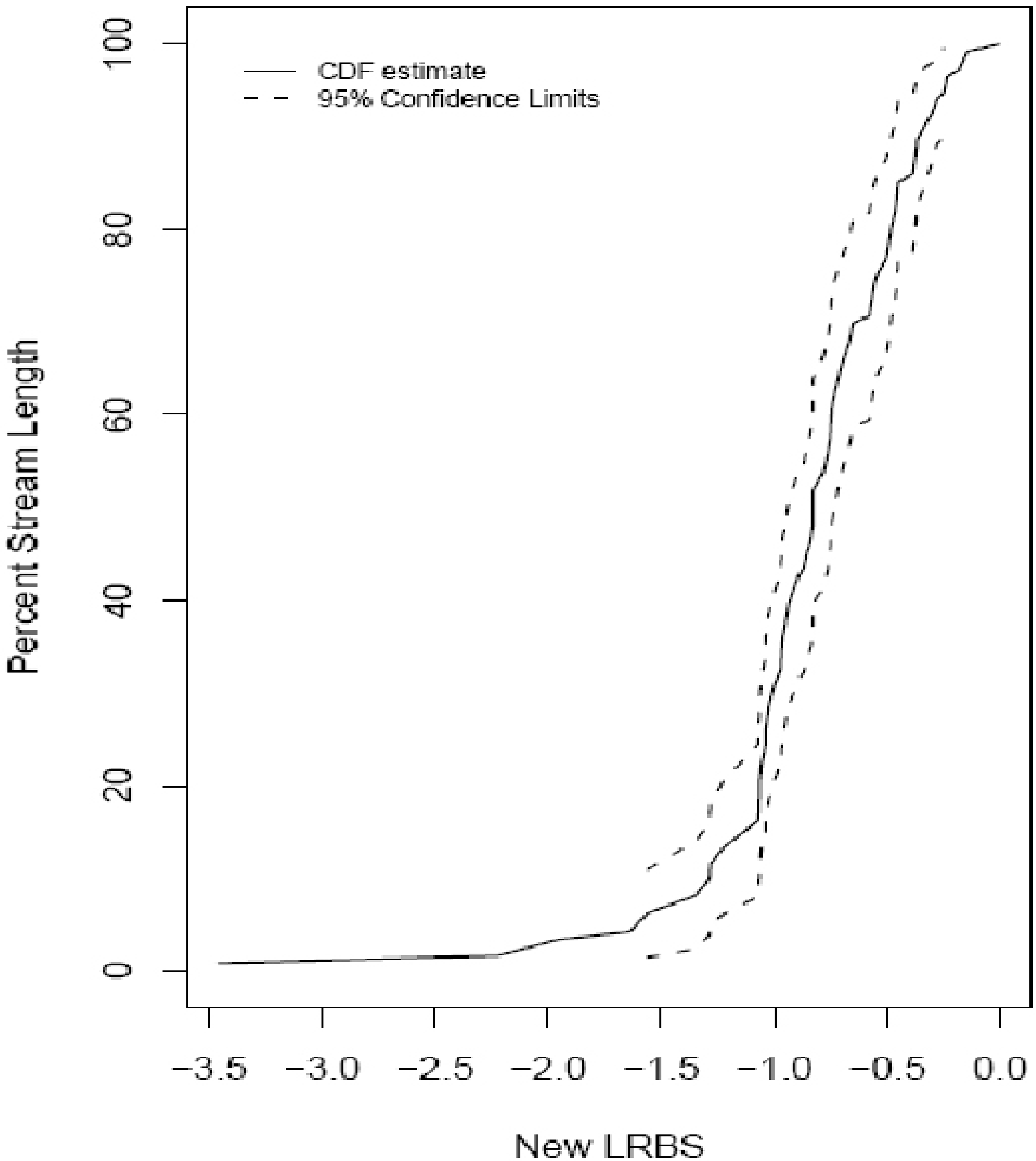


Figure 15. Tributaries Log Relative Bed Stability Cumulative Distribution Function

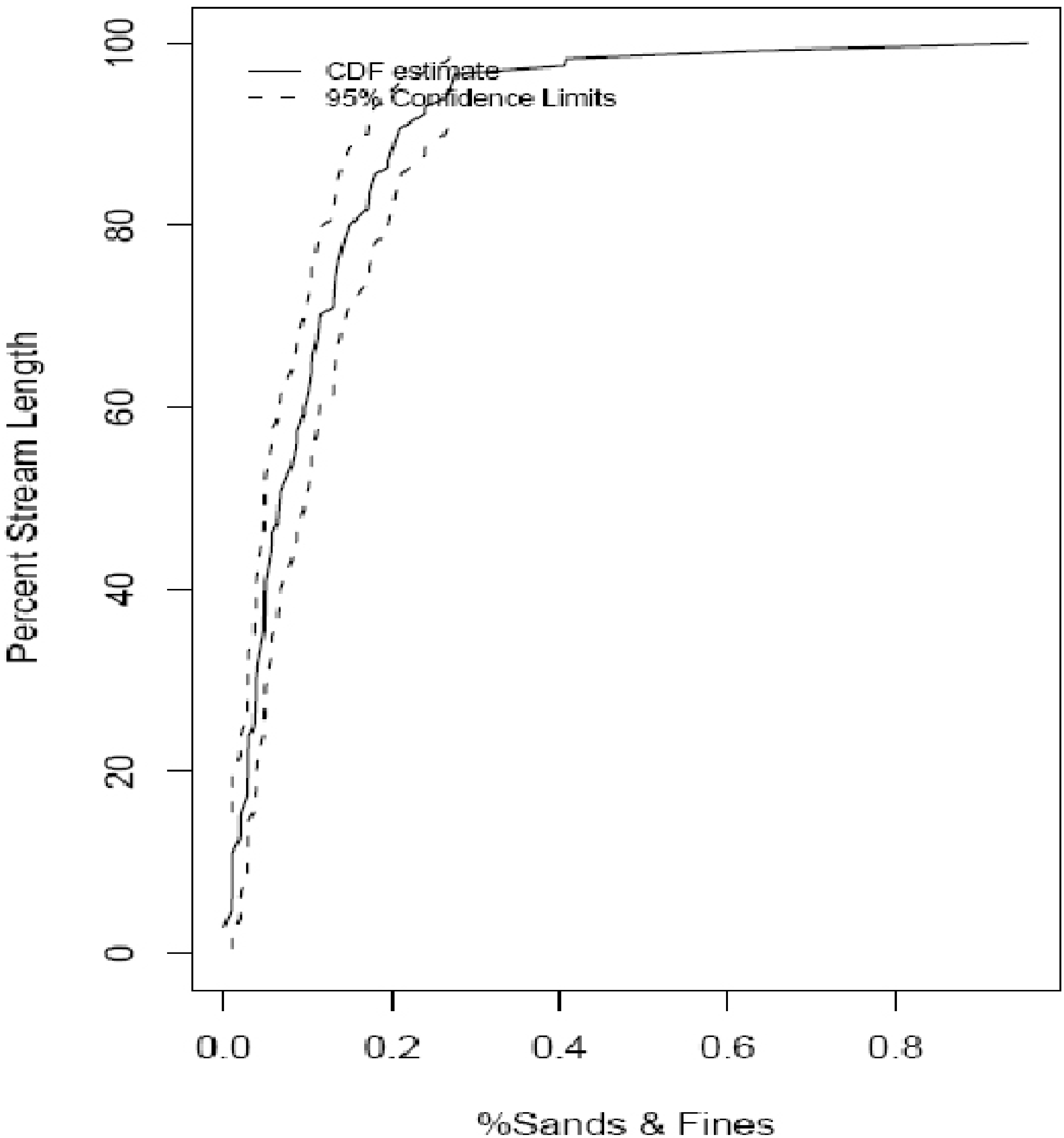


Figure 16. Tributaries Percentage of Sands & Fines Cumulative Distribution Function

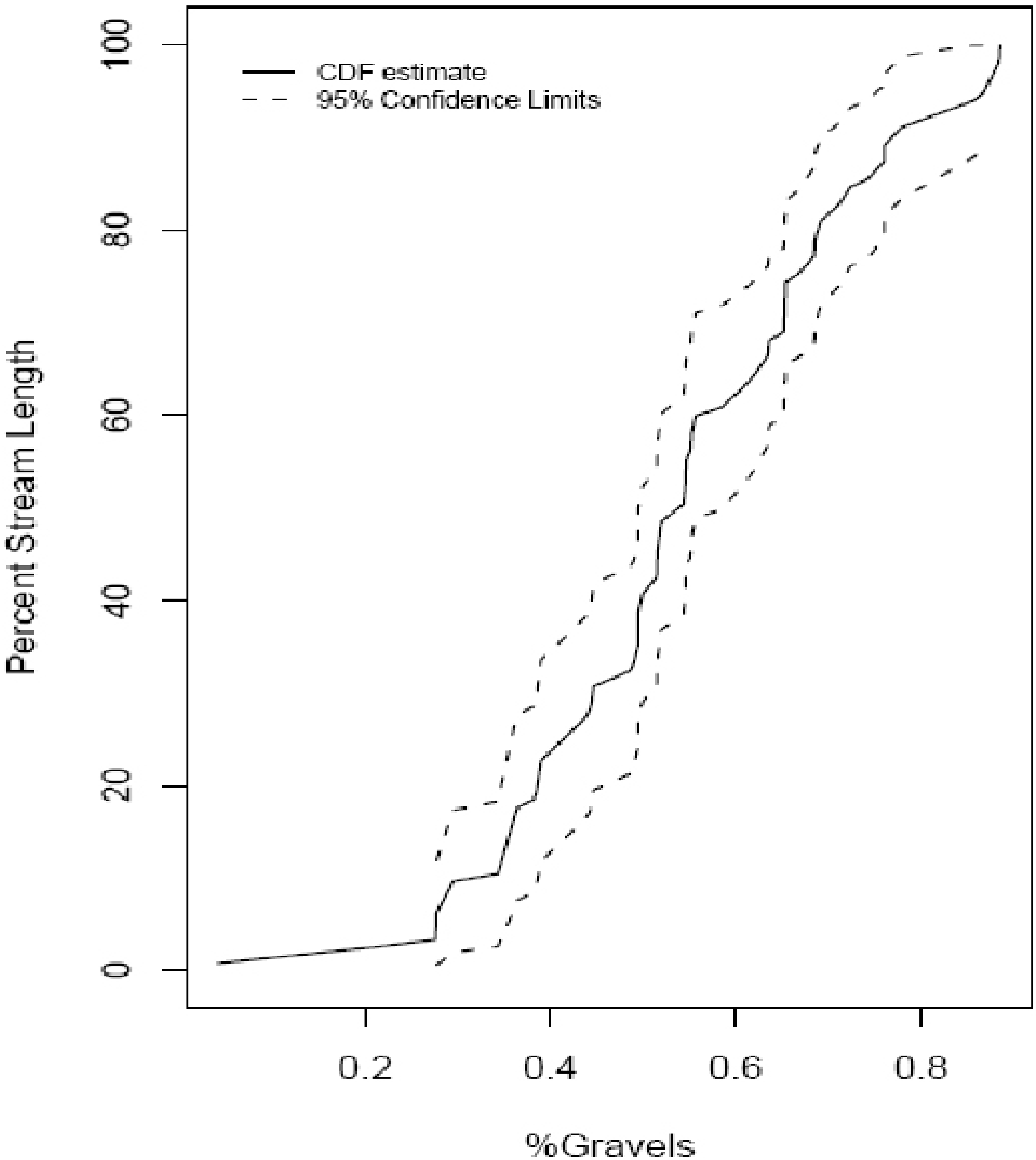


Figure 17. Tributaries Percentage of Gravels Cumulative Distribution Function

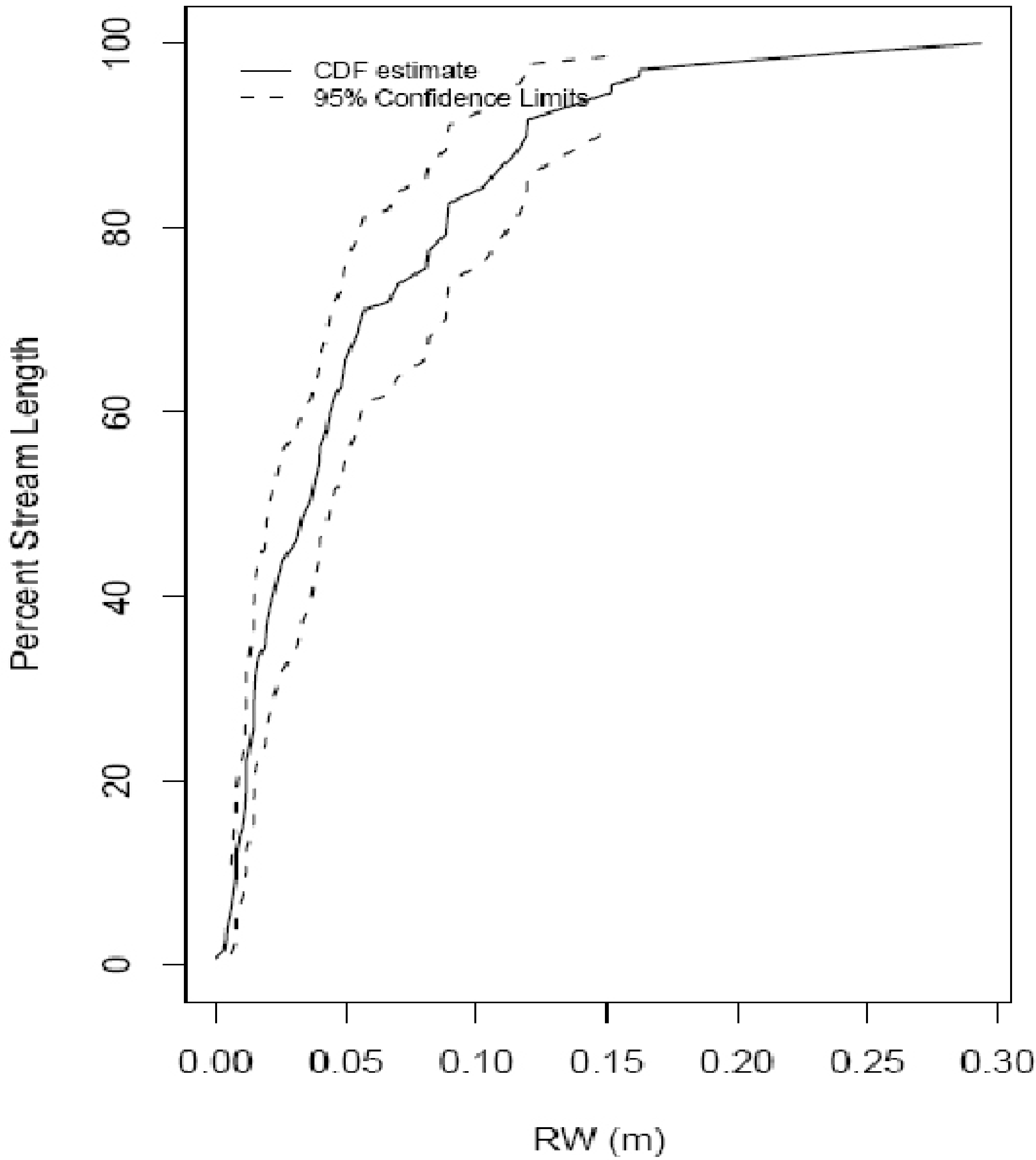


Figure 18. Tributaries Wood Radius Cumulative Distribution Function

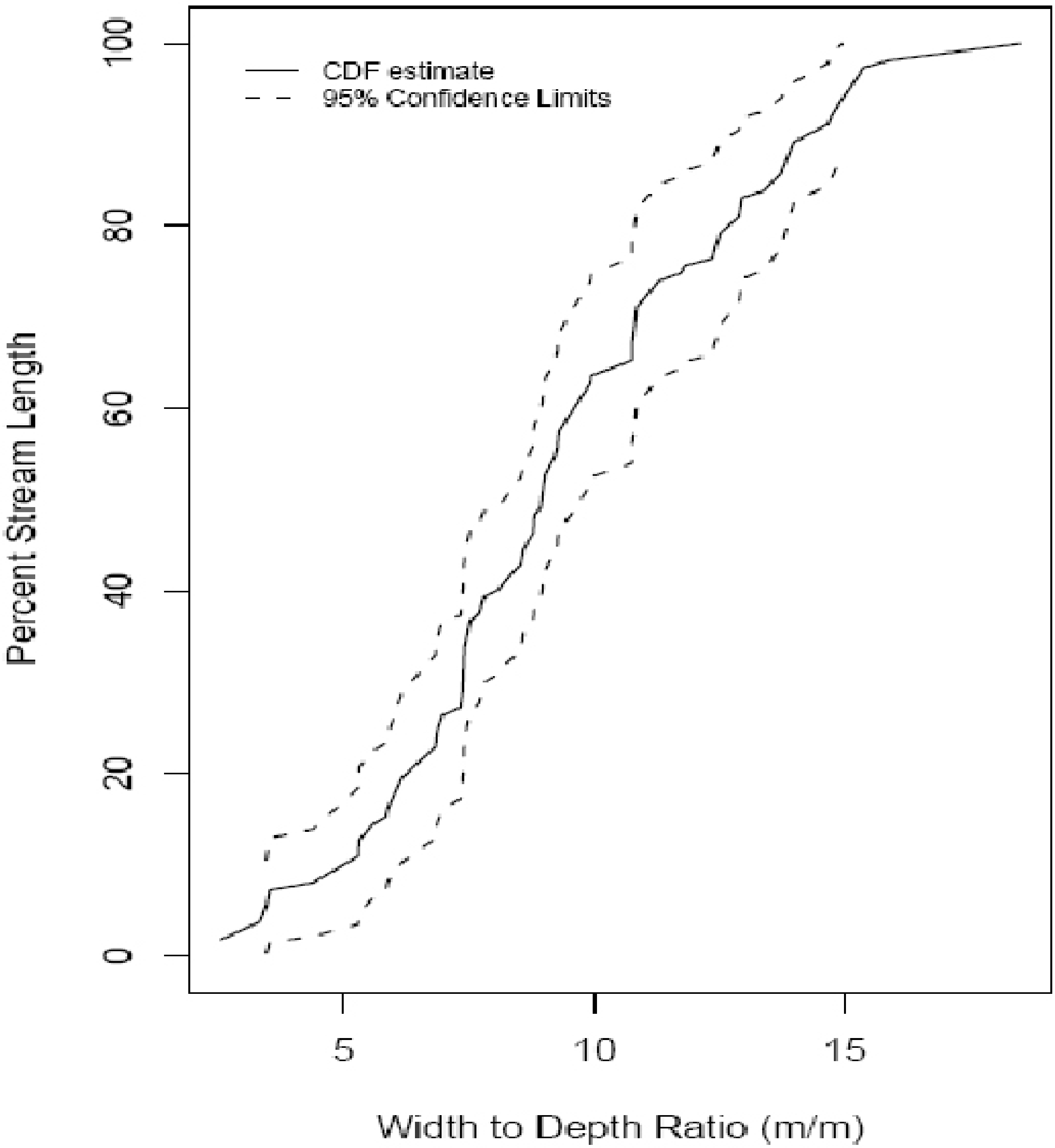


Figure 19. Tributaries Width to Depth Ratio Cumulative Distribution Function

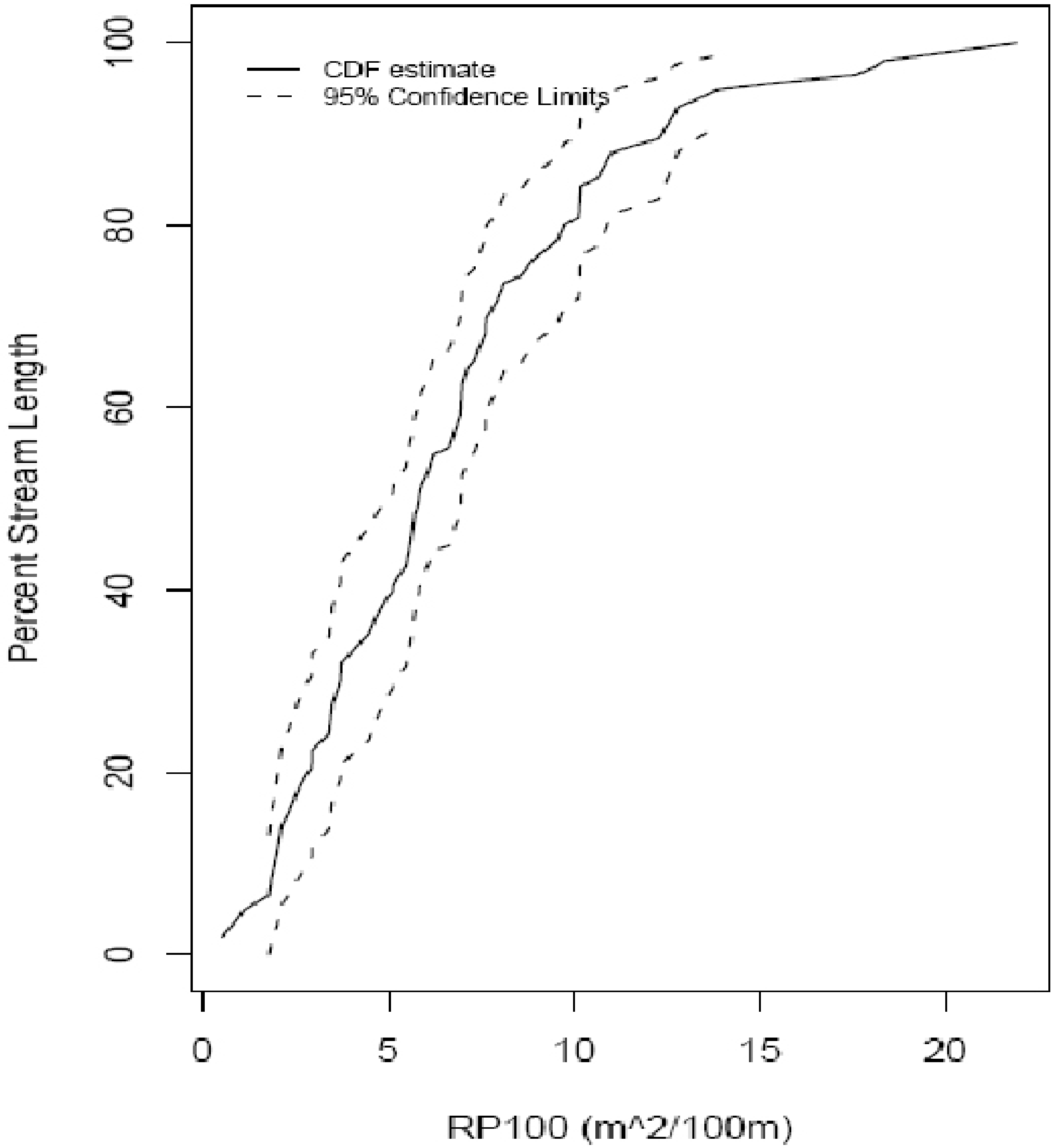


Figure 20. Tributaries Residual Pool Depth Cumulative Distribution Function

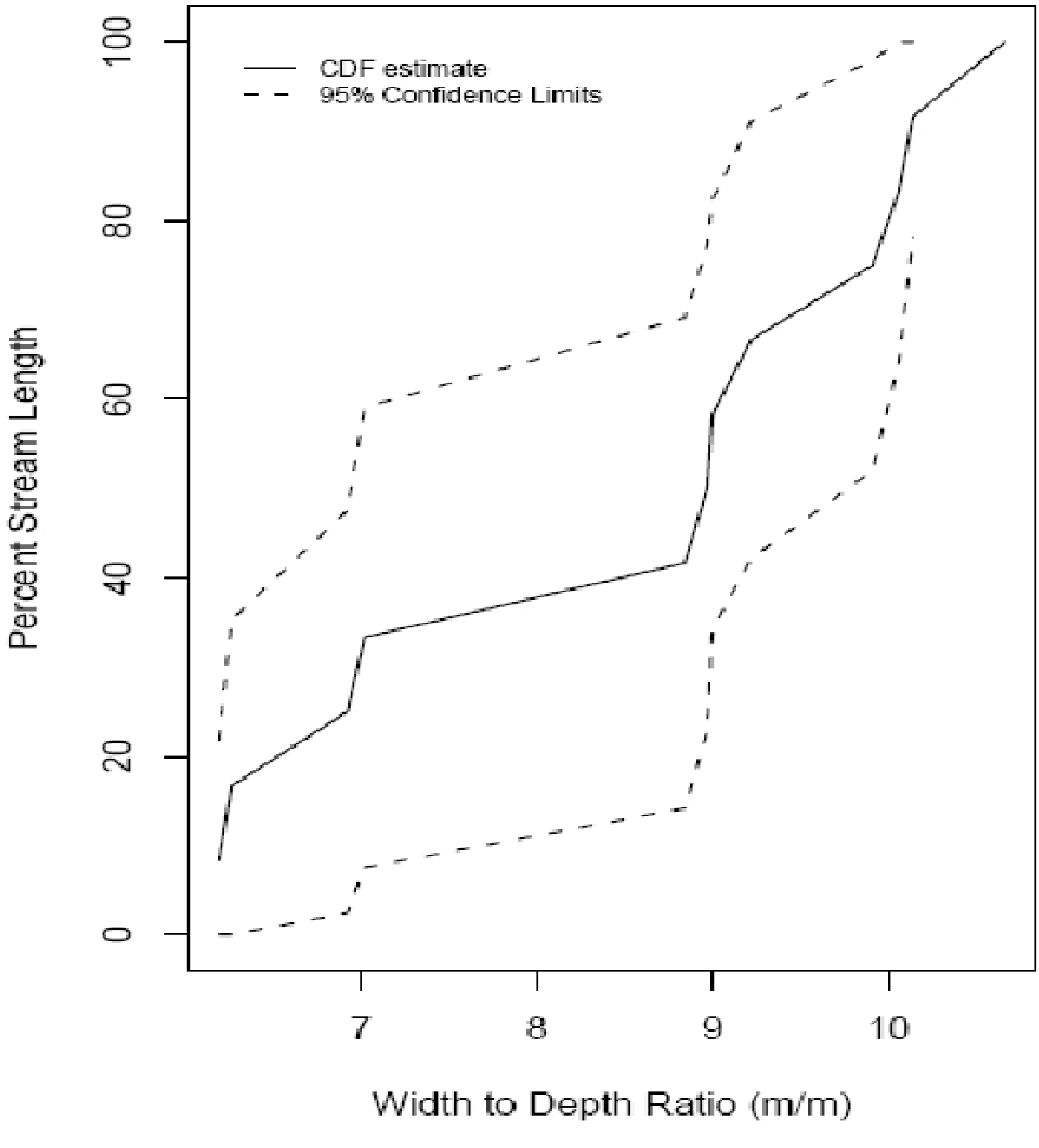


Figure 21. Culvert Width to Depth Ratio Cumulative Distribution Function

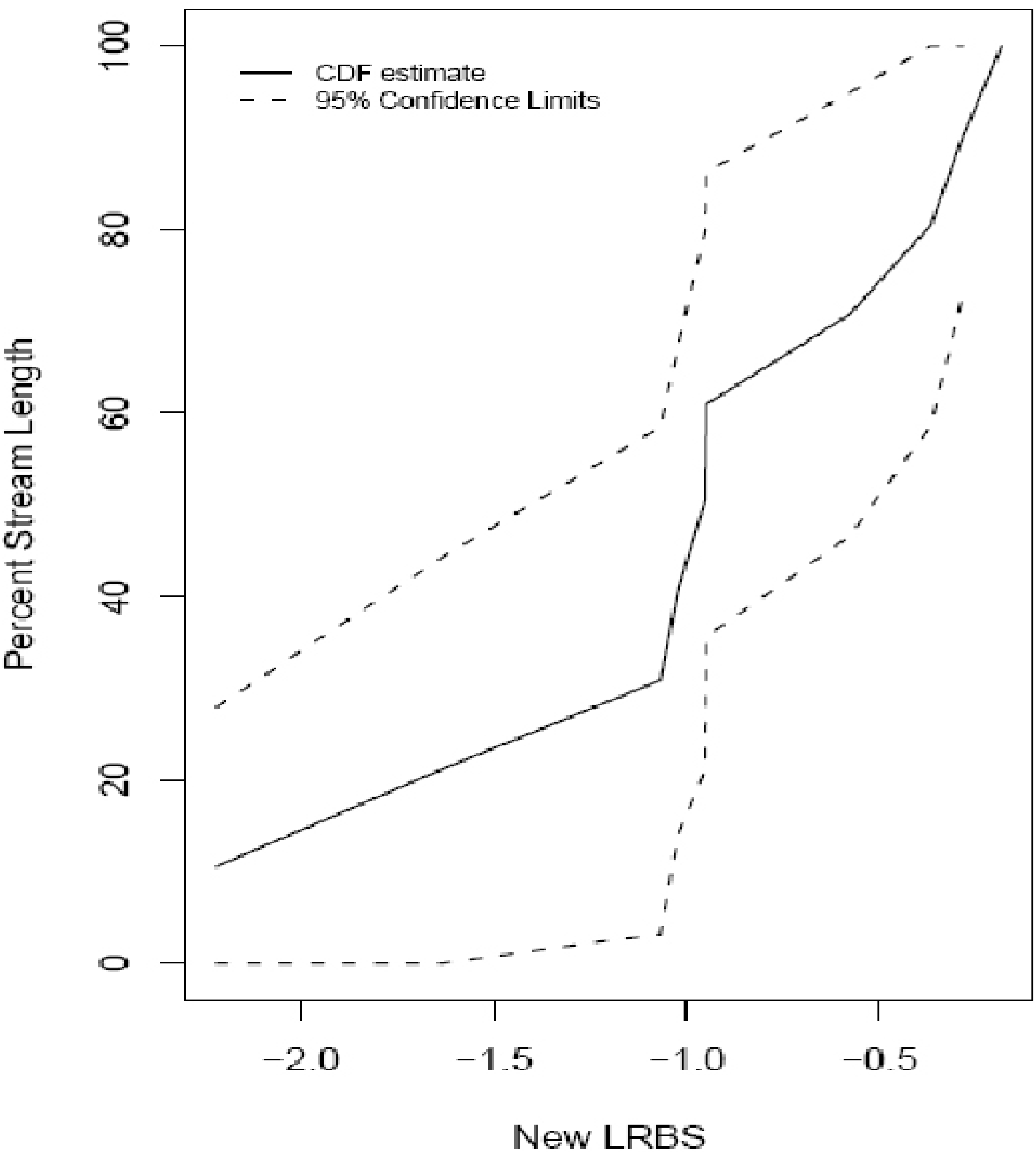


Figure 22. Field Classified Erodible Log Relative Bed Stability Cumulative Distribution Function

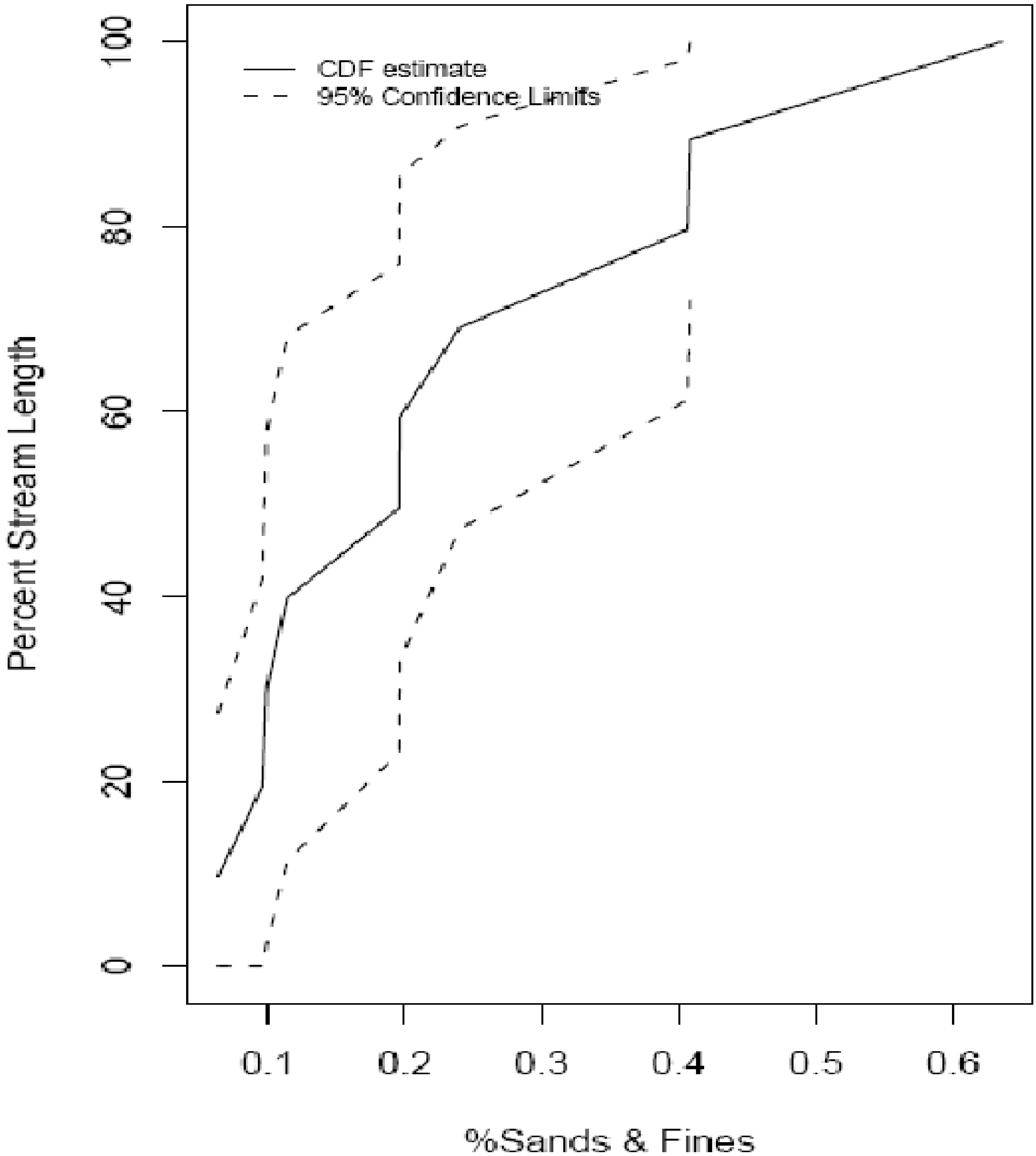


Figure 23. Field Classified Erodible Percentage of Sands & Fines Cumulative Distribution Function

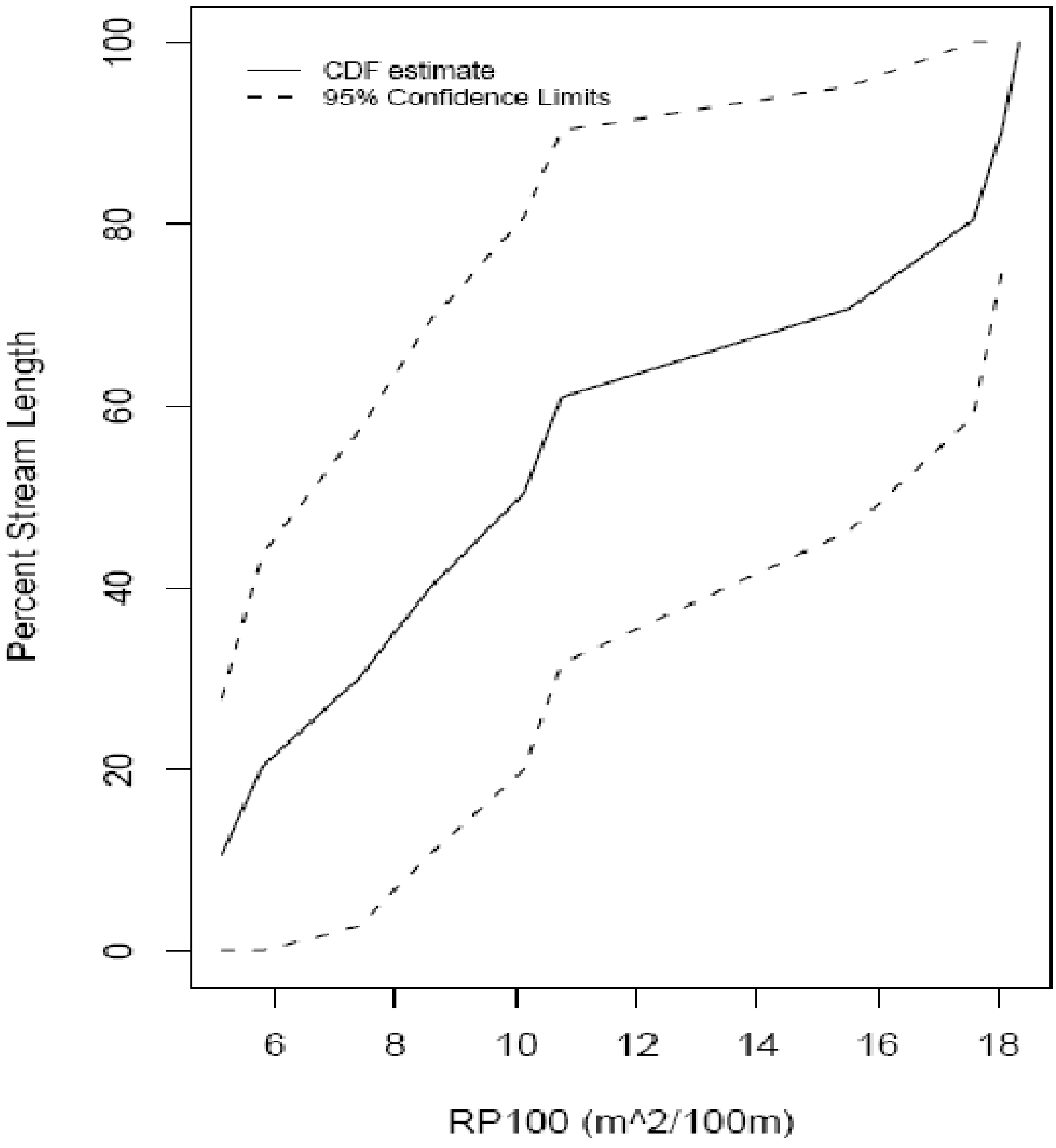


Figure 24. Field Classified Erodible Residual Pool Depth Cumulative Distribution Function

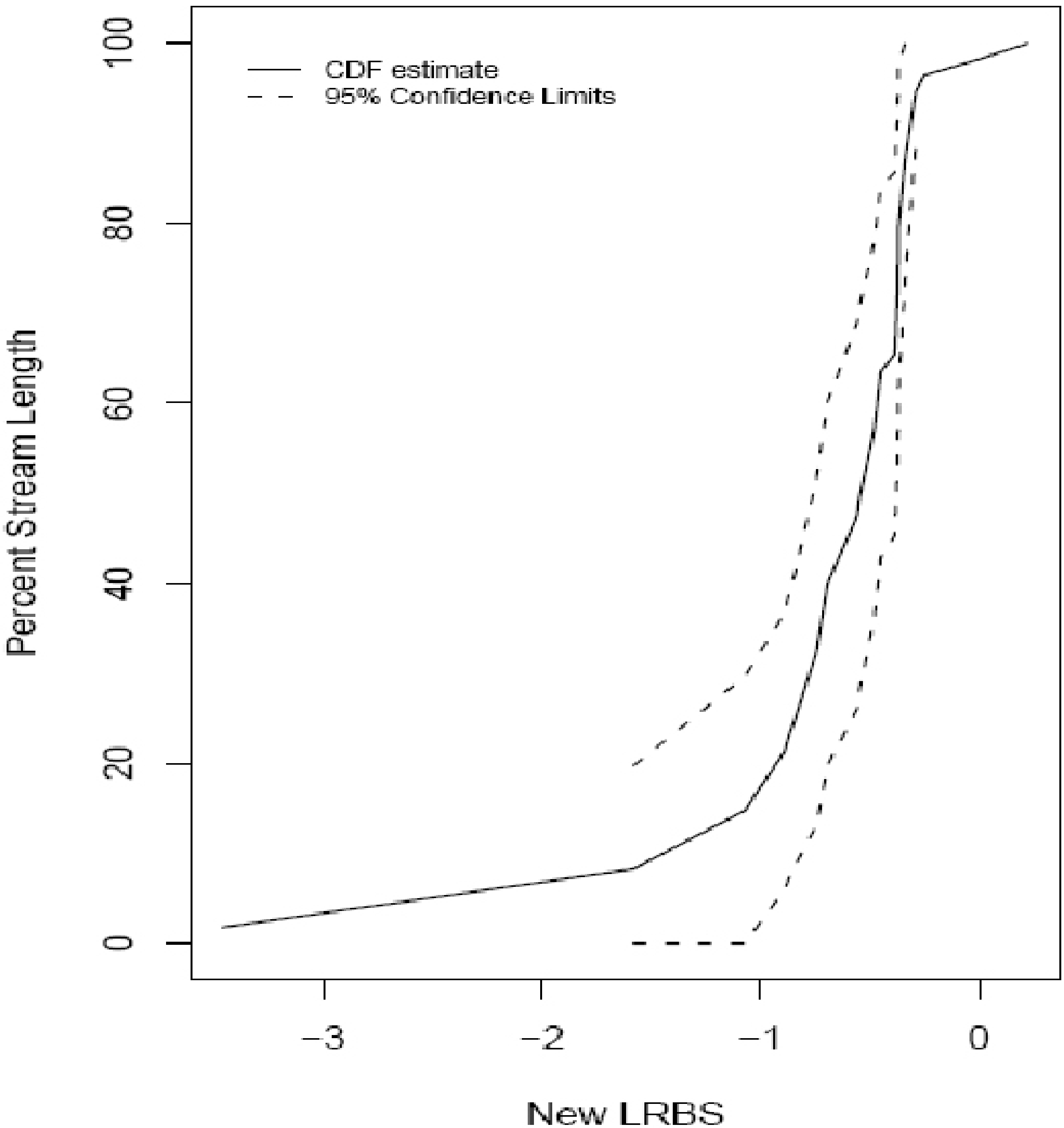


Figure 25. Field Classified Resistant Log Relative Bed Stability Cumulative Distribution Function

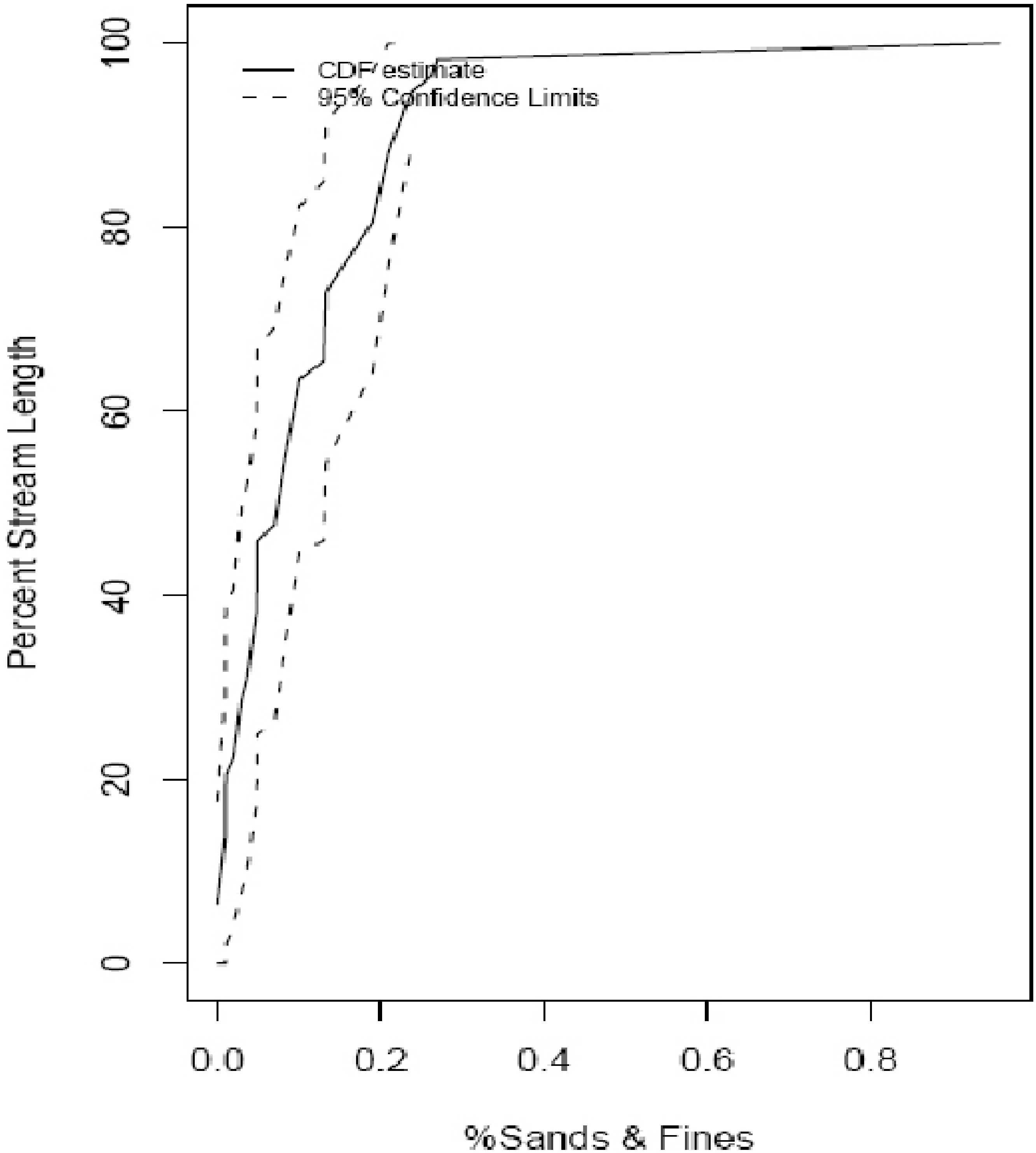


Figure 26. Field Classified Resistant Percentage of Sands & Fines Cumulative Distribution Function

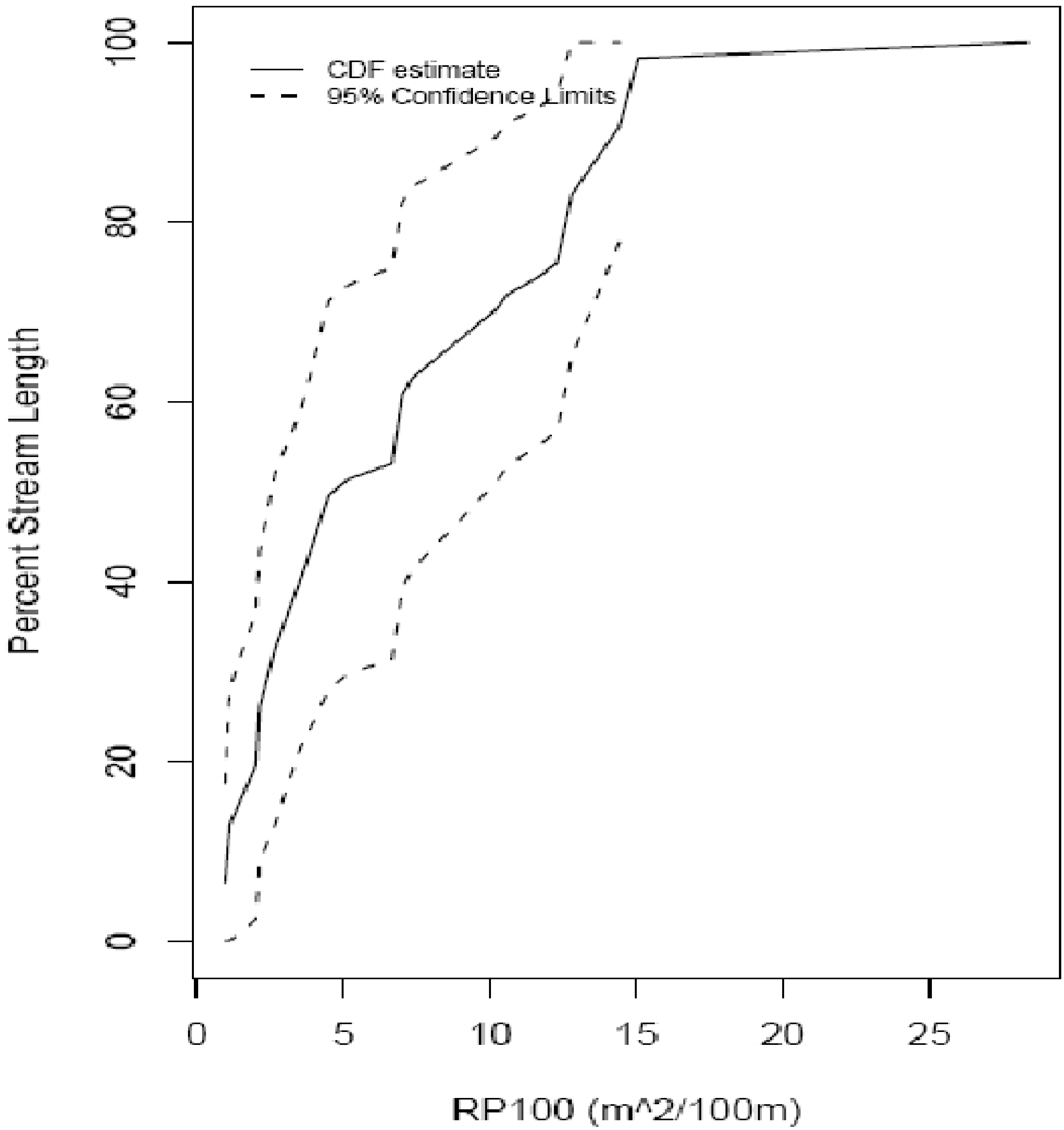


Figure 27. Field Classified Resistant Residual Pool Depth Cumulative Distribution Function

Appendix B - Guidelines for Land Managers in Assessing Water Quality Impairment by Fine Sediment

Executive Summary

The Federal Water Pollution Control Act also known as the Clean Water Act (CWA) established broad guidelines for protecting the quality of waters within the United States. A primary mechanism for addressing waters listed as impaired according to Section 303(d) of the CWA is the development of Total Maximum Daily Loads (TMDL.) A TMDL defines the maximum concentration of a pollutant that can be discharged into a water body without violating water quality standards. In the State of Oregon, the Oregon Department of Environmental Quality (ODEQ) has a responsibility for administering the CWA and does so through development and implementation of TMDLs and an associated Water Quality Management Plan (WQMP). In the role of a Designated Management Agency (DMA), the BLM assists the ODEQ in administering the CWA on federal lands. The BLM cooperates with the United States Forest Service (USFS), ODEQ, and the Environmental Protection Agency (EPA) in implementing the BLM and USFS 303(d) protocol for addressing impaired waters on Oregon's 303(d) list. Water Quality Restoration Plans (WQRP) that are developed according to the protocol guidelines detail actions for restoring or maintaining water quality.

The State of Oregon has been working to restore waters listed for temperature impairment since 1998 but until recently, the State was not focused on TMDL's for fine sediment. Recognizing an increased priority to address sediment as one of many water quality parameters requiring a TMDL, the EPA and ODEQ began evaluating a method based on the EPA's Environmental Monitoring & Assessment Program (EMAP) protocol. The Relative Bed Stability (RBS) metric is a component of the EMAP protocol and is the foundation of this methodology. The RBS metric accommodates comparison of channels of different size and gradient. The EMAP protocol utilizes a suite of customized statistical procedures that addresses the particular issues involved in monitoring and assessing aquatic habitat and resources.

An operational test of the modified EMAP protocol was completed in the Nestucca River Watershed in 2006. The lessons learned from the Nestucca River Stream Network Sediment and Physical Habitat study are presented here and will help to guide the ODEQ process for evaluating sediment impairment and developing water quality standards. Although this document is geared towards federal land managers, the information is also generally applicable to watershed councils, state and county agencies, and private landowners.

Background & Justification

> "It is the responsibility of the USFS and the BLM as Federal land management agencies through implementation of the Clean Water Act (CWA), to protect and restore the quality of public waters under their jurisdiction."[1]

> "BLM will manage BLM lands to protect, restore, and maintain water quality so that Federal and State water quality standards are met or exceeded to support beneficial uses, in accordance with applicable laws and regulations."[2]

The USFS and BLM protocol for addressing Section 303(d) listed waters was developed to provide a consistent approach for protecting and restoring water quality on lands administered by the federal government. The protocol provides a framework and outline for developing and implementing WQRPs, satisfying the BLM's responsibility as a DMA for implementing the CWA. The EPA estimates that roughly 40% of the nation's water bodies are impaired by fine sediment making it the leading water quality stressor.[3] Despite the need to address this problem, efforts to meet water quality standards for sediment have been hampered due to a lack of consistent, rigorous, and cost effective procedures for evaluation. Currently most 303(d) listings for sediment impairment are based on best professional judgment or limited data. Recognizing the need for improved procedures for listing impaired water bodies the EPA developed a set of indicators for evaluating the effects of suspended and bedded sediments on water quality. The ODEQ and the EPA are working to implement an approach for addressing fine sediment in Oregon. The Upper Nestucca Sediment and Physical Habitat Study was initiated in 2004 by the BLM's Salem District to contribute to that effort. This study evaluated the sediment listing for the Nestucca River watershed by isolating the parameters that were the basis for that listing. The results will contribute to conclusions regarding the validity and applicability of the RBS metric. The components of the protocol used in Oregon to assess fine sediment impairment are drawn directly from the EPA's EMAP protocol.

> "The Environmental Monitoring and Assessment Program (EMAP) is a research program to develop the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP's goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of current ecological condition and forecasts of future risks to our natural resources."[4]

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1 Forest Service and Bureau of Land Management Protocol for Addressing Clean Water Act Section 303(d) Listed Waters. (1999) Version 2

2 Memorandum of Agreement between United States Department of the Interior Bureau of Land Management and Oregon Department of Environmental Quality To Meet State and Federal Water Quality Rules and Regulations. (2001)

3 Framework for Developing Suspended and Bedded Sediments Water Quality Criteria. EPA-822-R- 06-001 (2006)

4 www.epa.gov/emap

An Overview of the Methodology

Evaluation of sediment is based on a statistical framework, the General Random Tessellation Stratified (GRTS) algorithm, that provides a process for the development of efficient sampling plans for surveys of streams, lakes, or forests.[1] The GRTS algorithm was developed by the EPA to support EMAP and is currently used by the ODEQ and the Oregon Department of Fish and Wildlife (ODFW) to select sites for habitat surveys. The GRTS algorithm is useful because it allows for generation of a spatially balanced, random sample. This is critical for accurately characterizing the condition of natural resources as site selection based on professional judgment can lead to biased results. Results from this study indicate the need for a minimum sample of 30 sites.

Field measurements should be taken during low flow conditions. For example in the Nestucca River these conditions occur in June-September. Topographic maps and aerial photographs are used to locate sites. It is important to attempt to visit each site contained in the original sample to avoid bias, however, due to a useful property of GRTS, it is generally acceptable to drop sites as a result of some barrier to access. A statistician should be consulted to verify that no systematic error has been introduced. Total reach length, based on wetted width multiplied by "40", is used to determine the total reach length necessary to adequately characterize linear variation in the channel at that site. Each sample reach is divided into ten equal segments so that a total of 11 transects would be sampled at each site (Illustration 3.)

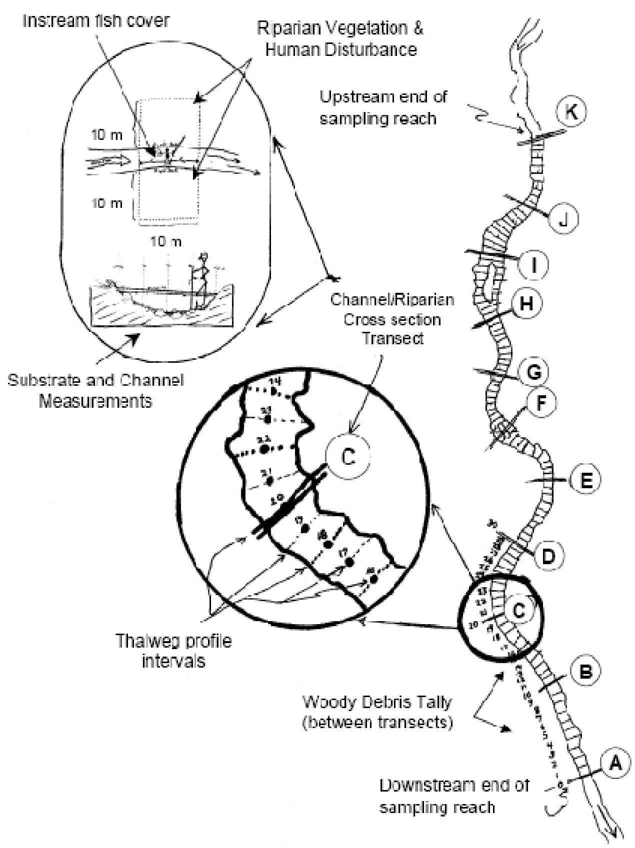

Illustration 3

1 Stevens, D. and Olsen, A. Spatially-Balanced Sampling of Natural Resources. Journal of the American Statistical Association, Vol. 99, No. 465 (2004)

The measurements taken at each site are condensed into a limited number of critical metrics used to characterize physical habitat. These include RBS, the total percentage of instream bedded sands and fines (%SAFN) (i.e. particles less than 2 mm), residual pool depth (RP100), and wood volume per square meter of surface area (RW). RBS and %SAFN are used to characterize the condition of the channel with respect to sediment. %SAFN is calculated based on a systematic pebble count collected along 21 cross sections per reach. Sediment samples are collected at 0, 25, 50, 75, and 100% of the wetted width along each transect and visually classified according to size (Illustration 4). A detailed discussion of the process and its adequacy for regional stream surveys can be found in Faustini & Kaufmann.[1]

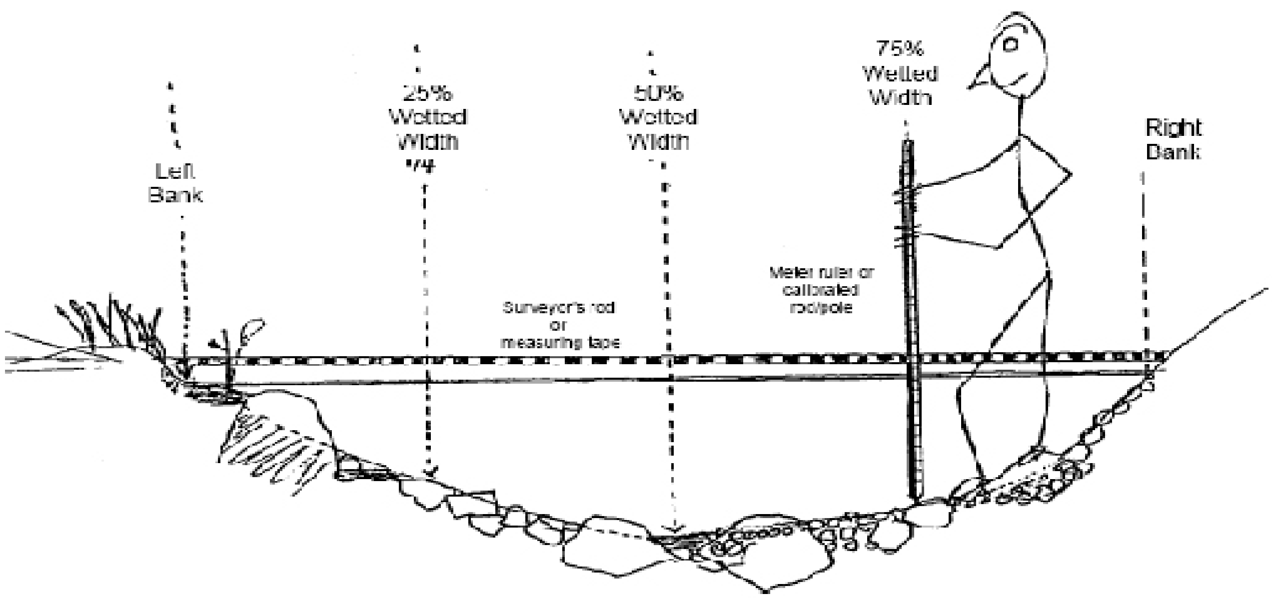

Illustration 4

1 Faustini, J.M. & Kaufmann, P.R. (A) Adequacy of Visually Classified Particle Count Statistics from Regional Stream Surveys. Journal of the American Water Resources Association (to be submitted to)

RBS is defined as the ratio of the mean instream particle size (D_GM) to the largest particle which the channel can move at bankfull (D_CBF). D_CBF is calculated using field measures of channel slope, hydraulic radius, and reach scale roughness. RBS is based on equations for calculating sediment transport. RBS is a unitless ratio and is expressed as a log of the ratio of values (e.g., log RBS or LRBS) to normalize the variance. When the observed D_GM is equal to the predicted D_CBF, RBS would be equal to 1 and LRBS would be equal to 0. The difference between an LRBS equal to 0 and an LRBS equal to 1 is a factor of 10. Interpretation of a 0 score is that the average size of the sediment entering the system is equal to the maximum size of the output from the system at bankfull flow. Extremely low RBS values indicate a high degree of sediment in the system whereas larger RBS values indicate a lesser degree of sediment in the system with greater potential for armoring of the stream bed.

The RBS method has two advantages over other metrics for evalutaing sedimentation. First, RBS controls for the effect of stream power on instream sediments thus making it possible to compare large and small streams throughout a stream network. Second, RBS is a composite metric calculated based on a number independent parameters so that it is robust to measurement error. This has been demonstrated based on field measurements and Monte Carlo simulations.[1] These two properties set RBS apart from other measures of sedimentation.

Hydraulic roughness should be given consideration when evaluating sediment impairment. Residual pool depth (RP100) and wood volume per square meter of channel surface (RW) provide measures of hydraulic roughness. RP100 can be conceptualized as what would be left over in a stream reach if all flow stopped. RP100 is a measure of reach-scale bedform complexity and is proportional to pool frequency. Large woody debris also contributes to hydraulic roughness and structures physical habitat. Using the EMAP method, all wood in the channel over 10 cm in diameter and 1.5 meters in length is evaluated and assigned to a size class to estimate the total volume of wood inside the channel at bankfull height. The volume is divided by the area of the stream reach (reach length X bankfull width) to derive an estimate of wood volume per square meter.

Measurements taken once per transect

- **Slope (Critical)**
- **Bankfull Height (Critical)**
- **Bankfull Width (Critical)**
- **Wetted Width**
- **Anthropogenic Disturbance**

Measurements taken more than once per transect

- **Pebble Count (Critical) 2/transect**
- **Thalweg Depth (Critical) 10/transect**
- **Large Woody Debris Tally (Critical) Continuous**
- **Habitat Unit 10/transect**

1 Mico, C. & Mico L. Sediment, Shade, and Complexity: Characterizing Ambient Water Quality and Physical Habitat in the Upper Nestucca. Technical Report Prepared for the BLM, Under Contract No. HAP064172. (2007)

All of the data gathered using the sediment assessment protocol is compared to reference data to determine the validity of 303(d) listing and the degree that a reach is impaired by fine sediments. The EMAP protocol is used by the ODEQ to develop reference data across Oregon. Reference data is collected from minimally disturbed riparian and upland sites in each ecoregion where natural parameters (e.g. elevation, vegetation type) reflective of natural disturbance regimes could be sampled from.[1] It is assumed that the biota of an area evolved in conjunction with natural disturbance regimes and that one could use the metric values found in sites with minimal anthropogenic disturbance to judge the quality of physical habitat in the areas considered for assessment.

Evaluation of impairment by fine sediments is based on a weight of evidence.[2] Ideally, this approach would entail collecting and analyzing as much data as possible in a variety of ways. In the Nestucca River watershed, numerous tests were conducted on the RBS and %SAFN metrics to evaluate impairment. For example, under one set of assumptions, a stream network may be considered impaired if 20% of the sites visited exceeded the 5th percentile of the condition derived from the reference site data. The conclusion is based on a comparison of the distributions. The weight of evidence approach is an informal attempt to minimize both false positives and negatives by requiring multiple analyses. This protocol minimizes operational costs as only one dataset is necessary to conduct multiple analyses. In general, when more evidence is brought to bear on a question, more support is garnered for the conclusion.

The process recommended herein assumes a two step sampling approach. The first step involves assessing the status of 30 sites in the areas upstream of the lower boundary of the reaches considered to be impaired. If the findings are within the range of reference conditions then the waterbody should not be considered impaired. If both the LRBS and %SAFN are significantly less than the benchmarks for impairment, the water body is not considered impaired. If the metrics are not significantly different from the benchmarks, an additional round of sampling is conducted to increase the statistical power of the analysis. The number of additional sites can be estimated based on the variance calculated for the results from the first thirty sites. If the variance is large then a greater number of sites will need to be added than if the variance is small. If the two metrics yield contradictory results, macroinvertebrate sampling can be used to directly assess the biological status of the water body. The ODEQ has indicated that macroinvertebrate sampling can be included as an additional indicator where necessary.[3] However, macroinvertebrate sampling should not be regarded as the fail safe for developing or verifying conclusions based on insufficient data or information. If the sample and the benchmark for judging impairment are nearly identical, a conservative conclusion that the water body is impaired should be drawn. In these cases, a follow up evaluation (e.g., 5 year interval) may be necessary to evaluate a trend. If both metrics are significantly greater than the benchmarks for impairment, the water body is considered impaired.

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1 Drake, D. Selecting Reference Condition Sites: An Approach for Biological Criteria an Watershed Assessment. ODEQ Technical Report WAS04-002 (2004)

2 Doug Drake, ODEQ, personal communication.

3 Doug Drake, ODEQ, personal communication.

If a water body is on the current 303(d) list and it is found to be impaired, results of the study should be sufficient to validate the listing. If a water body is on the 303(d) list, does not have a TMDL, and is not found to be impaired, the results are sufficient to petition for its removal from the list. If a TMDL is in place, the process does not revoke the TMDL, but satisfies the agency's responsibility as a DMA. The data and analysis generated during the assessment can be used as the basis for developing a WQRP.

Data and analytic results important to drawing conclusions about impairment includes:

- **A single comma separated value (.csv) file with all of the relevant metrics for each site, xy coordinates, and design weights.**
- **A digital copy of the raw data in spreadsheet compatible format.**
- **A report describing the results and interpretation of the statistical analysis.**
- **GIS layers containing the sample frame and sites.**

Conclusion

The modified EMAP protocol, specifically the RBS metric, was effective for drawing conclusions for BLM administered portions of the Nestucca River watershed that are listed for sediment impairment. The method as applied in the Nestucca River illustrated some challenges such as the effect of sample size on the ability to draw defensible conclusions about subpopulations within the watershed. Increased sampling density should improve the accuracy of results. Field sampling, data collection, and analysis require a significant degree of training and practice to master the methodologies. When properly applied, however, the EMAP protocol and RBS metric are appropriate for future sediment assessments.

Appendix C - Glossary of Terms

303(d) List: A list of all water quality impaired systems published on a biennial basis by each state and evaluated by the Environmental Protection Agency. The Department of Environment Quality is responsible for the list in Oregon.
Aquatic Conservation Strategy (ACS): A set of guidelines developed to restore and maintain the ecological health of watersheds and aquatic ecosystems contained within them on public lands. The strategy will protect salmon and steelhead habitat on federal lands managed by the Forest Service and the BLM within the range of the Pacific Ocean anadromy.
Arcsine Transformation: A common transformation used to normalize proportional data for subsequent parametric analyses. Mathematically, Xi is transformed to arcsine ($\sqrt{Xi}$).
Bankfull Discharge: Corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels.
Bankfull Height: The elevation of the channel at bankfull discharge, measured from the water surface at low flow. This height is determined empirically based on vegetation and channel morphology.
Bankfull Width: The width of the channel at bankfull discharge, determined empirically based on vegetation and channel morphology.
Bankfull Width to Depth Ratio (W:D): Defined as the bankfull width divided by the bankfull depth. It is a measure of bank condition, channelization, and floodplain connectivity.
Bedded Sediments: All sediments present on the surface of the channel bed.
Competence: The ability of a fluid medium, as a stream or the wind, to move and carry particulate matter, measured by the size or weight of the largest particle that can be transported.
Critical Bankfull Diameter (D_CBF): The largest diameter which the channel can transport at bankfull discharge, estimated using channel morphology and known sediment transport equations.
Comma Separated Value File (.csv file): A standard file format which can be read by many programs, including all common spreadsheet programs.
Delta Shade (Δshade): The difference between the effective shade measured using a Solar Pathfinder and the modeled shade generated using Heat Source.
Design Weight: The design weight represents the size of the target population which a given site represents. It is the inverse of the inclusion probability.
Effective Shade: Effective shade is defined as the fraction of incoming solar shortwave radiation above the vegetation and topography that is blocked from reaching the surface of the stream.
Environmental Monitoring and Assessment Program (EMAP): A nationwide EPA program designed to monitor water quality and provide technical resources for state and federal agencies to carry out their responsibilities under the Clean Water Act.
Erod_Field: Sites classified as having an erodible lithology based on a field assessment.
Erod_GIS: Sites classified as having an erodible lithology based on GIS coverage.

General Random Tessellation Stratified (GRTS): GRTS is a sampling algorithm developed by the EPA for use in EMAP. It generates random, spatially balanced samples and allows for dropped sites, frame errors, and subpopulations of unequal sizes.
Geometric Mean Particle Size (D_GM): A measure of central tendency. It is determined by a systematic pebble count and is defined as the square root of the product of the scores.
Heat Source Model: A computational model used by the ODEQ to develop temperature TMDLs. It uses data on channel morphology, vegetation, and incoming solar radiation data along with known heating processes to estimate the temperature under different conditions. It can also be used to calculate an expected shade value given a known aspect and channel width with assumed riparian vegetation
Hydraulic Diameter (DH): The mean bankfull height plus the mean thalweg depth of a reach.
Hydraulic Resistance (Cft): This is used along with the particle resistance to correct the bankfull hydraulic radius for large scale roughness due to bedform complexity and large woody debris.
Inclusion Probability: The inverse of the design weight. It represents the chance of a given site being included in the final sample.
Kinematic Viscosity of Water (v): Equal to 1.02 x 10-6 m2/s at 20 C
Late Successional Adaptive Management Area (LSA): A federal land designation which contains forests set aside from Matrix type logging, to be held in reserve for wildlife habitat. It differs from an LSR in that some logging may be undertaken to evaluate techniques for promoting the development of old growth habitat.
Late Successional Reserve (LSR): A federal land designation which contains forests set aside from Matrix type logging, to be held in reserve for wildlife habitat.
Log Transformation: A common transformation used to normalize logarithmically distributed data for subsequent parametric analyses. Mathematically Xi is transformed to log (Xi).
Median Particle Size (D_50): A measure of central tendency. The median is the middle of a distribution: half the scores are above the median and half are below the median. D_50 is determined by a systematic pebble count.
Modeled Shade: Determined using the Heat Source model. Field measurements of stream aspect and bankfull width are combined with assumptions about riparian vegetation under undisturbed conditions. It is equivalent to the system potential effective shade target set in the temperature TMDL.
Neighborhood Based Variance Estimator (NBV Estimator): Developed by the EPA for use in EMAP. It utilizes known spatial autocorrelation in natural resource data to provide more accurate estimates of sample and population variance.
Pebble Count: A procedure for evaluating the superficial composition of a channel bed. The general procedure is to measure and tally sediments by size at regularly spaced intervals across the channel. Under the EMAP protocol, samples are taken at 0, 25, 50, 75, and 100% of the wetted width at 21 cross sections per reach. Each sample is visually assigned to a size class. It is assumed that the sediments are log normally distributed within each size class.
Particle Resistance (Cfp): This is used along with the hydraulic resistance to correct the bankfull hydraulic radius for large scale roughness due to bedform complexity and large woody debris.
Percentage of Sands & Fines (%SAFN): The percentage of bedded sediments less than 2mm as determined by a systematic pebble count.
Percentage of Gravels (%Gravels): The percentage of bedded sediments greater than 2mm and less than 64 mm.

Radius at Bankfull (R_BF): The hydraulic radius at bankfull discharge. Rbf ≈ 0.65*(Mean Thalweg Depth + Mean Bankfull Height)
Relative Bed Stability (RBS): A unitless ratio of the geometric mean particle size to the critical bankfull diameter. Together with %SAFN it is the prime indicator of sediment impairment. RBS = Dgm/D*cbf = Dgm/((0.604*Rbf*S*(Cfp/Cft)1/3)/ θc)
Residual Pool Depth (RP100): Residual pool depth can be conceptualized as what would remain in a channel if all flow ceased. It is equal to the total longitudinal pool area per 100 meters of reach length. It is a flow invariant indicator of hydraulic roughness, bedform complexity, and pool frequency. It is calculated from a minimum of 100 systematic thalweg measurements.
Resist_Field: Sites classified as having a resistant lithology based on a field assessment.
Resist_GIS: Sites classified as having a resistant lithology based on GIS coverage.
Reynolds Particle Number (Rep): Rep = [(g*R_BF*S)0.5*D_GM]/v. It is used to calculate the Shield's Parameter for Critical Shear Stress.
Sample Frame: The original GIS layer which represents the population of interest. The frame is used by the GRTS algorithm to generate the sample.
Shield's Parameter for Critical Shear Stress (θc): θc = 0.04 Rep -0.24 when Rep<26 and 0.5 {0.22Rep-0.6 + 0.06(10-7.7 Rep^-0.6)} when Rep>26
Signal to Noise Ratio (S:N): An engineering term for the power ratio between a signal (meaningful information) and the background noise.
Slope (S): A unitless value equal to the change in elevation divided by the change in lateral position.
Solar Pathfinder^{tm}: A commercially available device for precisely measuring effective shade.
Stable: Narrowly defined for the purpose of this document as having a larger RBS score.
Thalweg Depth: The thalweg is considered in this document to be the deepest point in the channel when measured at low flow. The mean thalweg depth is calculated from a minimum of 100 systematic measurements throughout the reach.
Total Maximum Daily Load (TMDL): A calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. Water quality standards are set by States, Territories, and Tribes. They identify the uses for each waterbody, for example, drinking water supply, contact recreation (swimming), and aquatic life support (fishing), and the scientific criteria to support that use. A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The calculation must include a margin of safety to ensure that the waterbody can be used for the purposes the State has designated. The calculation must also account for seasonal variation in water quality. The Clean Water Act, section 303, establishes the water quality standards and TMDL programs.

Reprints can be downloaded from http://www.demeterdesign.net

Reprints can also be obtained by contacting the BLM Salem District office at;

1-503-375-5626

Acknowledgments

Thank you to Rosy Mazaika and Chester Novak for their critical support. Thank you to Trish Carroll for supporting RBS. Thank you to Russ Chapman for his field work, GIS assistance, and many other contributions, Darrin Neff for his wonderful photographs, field work, and commitment to fish, as well as Jamie Craig, Brandy Phillips, & Kirk Appleman for their excellent field work. Thank you to Dennis Worrel for doing too much to mention. Thank you to Doug Drake, Phil Kaufmann, Tony Olsen, Tom Kincaid, Ryan Michie, and York Johnson for invaluable technical assistance. Finally, thank you to Andy Pampush for believing in the project at a critical time.