Clear Creek
Stream Restoration
Restoration Plan
March 2002

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Stream Restoration
Hendersonville, NC

Clear Creek Restoration Design Report

Introduction

The North Carolina Wetlands Restoration Program (NCWRP) is sponsoring the restoration of Clear Creek in the French Broad River Basin. EcoLogic Associates, P.C. is the lead design firm contracted by the NCWRP to restore approximately 1300 linear feet of Clear Creek (Map 1). Problems in this stream reach include areas of tall, vertical, failing banks, beaver damage to vegetation, and planform and cross sectional geometry instabilities. This document summarizes the project's purpose, existing site conditions, assessment methodologies, and proposed restoration design. Supporting information is included in the attached appendices.

Design Goals

The design goals of the Clear Creek restoration project are as follows:

1. Improve water quality by reducing the sediment load generated by eroding banks;
2. Reestablish stable channel dimension, pattern, and profile to Clear Creek;
3. Restore a functioning floodplain;
4. Establish a riparian buffer of woody plant species, preferably native;
5. Enhance aquatic and terrestrial habitats in the stream corridor; and
6. Stabilize banks to safeguard a sanitary sewer line that runs parallel to Clear Creek along the left (south) side of the channel.

Design Procedure

Design procedures followed those outlined in *River Restoration and Natural Channel Design Course Handbook* (Rosgen, 1998.) Using this method, new dimension, pattern, and profile are designed for stability. Then shear stress and sediment transport capacity are calculated to ensure that the proposed design will effectively transport sediment without causing accelerated erosion or excessive deposition. The steps that lead to the design plan are as follows:

1. Conduct a watershed characterization for the project reach;
2. Survey a gage in the same hydrophysiographic region to verify field indicators associated with bankfull discharge;
3. Survey a reference reach in the same hydrophysiographic region;
4. Perform Level 2 and 3 classification and assessment of the project reach; and
5. Develop a design plan based on reference reach data, design goals, and existing site constraints.

Land Use

The Clear Creek restoration site has historically been used for pasture and more recently, hay production. Prior to January 1951, the date of the oldest aerial photograph available at the Henderson County NRCS Office, Clear Creek was straightened. Presumably, it was straightened for agricultural purposes and for construction of a sanitary sewer line, as the county was predominantly rural at that time. Successive aerial photographs show the construction of I-26 in 1965 and the progression of Clear Creek's evolution each decade for the last 50 years. A 1969 aerial photograph (NCDOT) shows Clear Creek flowing straight, wide and shallow, typical of an F stream type. The 1994 photograph shows that Clear Creek is trying to reestablish meanders. The flow area has narrowed and vegetated mid-channel bars have formed. (See photos 1 through 5).

The Clear Creek watershed consists primarily of woodland and agriculture with some highway businesses located along Route 64. Several orchards are located in the Clear Creek watershed, which extends to Bat Cave, NC.

Physical Setting

The Clear Creek restoration site is located in a relatively low slope mountain valley in Henderson County, NC. It is a fourth order tributary to Mud Creek in the French Broad River Basin. The restoration reach runs through a former overgrazed pasture between I-26 and Clear Creek Road. The watershed of this section of Clear Creek has a drainage area of approximately 44 square miles.

Clear Creek is listed as Class C waters, protected for secondary recreation, fishing, wildlife, fish and aquatic life propagation and survival, and agriculture. There are no restrictions on watershed development activities.

Soils around Clear Creek are primarily Codorus loam, transitioning to a Hayesville loam on the sloping hills to the north of the stream channel. Codorus loam is moderately well drained to somewhat poorly drained, moderately permeable, nearly level soils formed in micaceous alluvium. Hayesville loam is well drained, moderately permeable, gently sloping to moderately steep soils formed in residuum from granite, gneiss, and schist. (Henderson County Soil Survey, USDA SCS, 1980)

Existing Condition Survey

An existing condition survey of Clear Creek was conducted in December 2001. The pre-restoration stream length is 1315 linear feet from the riffle immediately downstream of the I-26 bridge to the sanitary sewer crossing immediately upstream of the Clear Creek Bridge. Based on the Rosgen stream classification system, this stream is a laterally unstable C4 (*Applied River Morphology,* D. Rosgen, 1996, p. 6-5) (See Appendix 2).

Station 0+00 of the survey started near the I-26 Bridge at the upstream limit of the restoration reach. Stationing increases in a downstream direction to the sanitary sewer crossing immediately upstream of the bridge at Clear Creek Road.

Channel Dimension

The cross-section dimensions, such as bankfull depth, width, and area, are typical for this stream type and drainage area (See Existing Condition Survey, Appendix 2). The bank height ratio (low bank height/max. bankfull depth) ranges from 1.3 near I-26 to 1.6 nearer Clear Creek Road. Ideally, when the stream has full access to its floodplain, this ratio equals 1. These ratios show that the channel has incised and carries more than bankfull flow before accessing its floodplain. This increases shear stress, particularly on the bare, upper banks, and accelerates bank erosion. The banks, comprised largely of sand and fine gravel, have bank height ratios ranging from moderately unstable to highly unstable.

Channel Pattern

Sinuosity, at 1.1, is low for a C stream type. The restoration reach is still quite straight. Several, vegetated mid-channel bars have formed, splitting flows. New meanders and floodplain benches are forming within the channel. However, meander wavelength, radius of curvature, and belt width are outside the range of stable C4 stream types.

Channel Profile

The upper riffle in the restoration reach is much steeper than the remainder of the restoration reach, and particle sizes found there are much larger than particles found in the remainder of the channel. This may be explained by the presence of I-26. The rock could have been a by-product of highway construction in the mid-1960's. Upstream of I-26, Clear Creek flows through agricultural fields.

Upstream of the study reach, the channel has a wider channel width, bank heights range from 4-6 feet above water surface, pools are relatively small but range from 3.5 to greater than 4 feet deep, and a thin layer of fines covering the gravel bottom is common. In the study reach, riffles and pools are poorly defined and occur at irregularly spaced intervals. The predominant particle size in the bed is gravel. (Existing Condition Survey, Appendix 2)

Riparian Corridor and Floodplain Assessment

This property is currently an open field; one small section on the northwest end was cut for hay this last season. The majority of the floodplain is treeless with occasional single specimens or clumps of small trees and shrubs in an infrequently mowed old field. There are mature large trees directly along the banks of the creek, along a line of an old straight channel and on uplands adjacent to the floodplain. Many of the woody species are pioneers of disturbed sites. The tulip trees, red maples and pines are now middle aged and surround the margins of the restoration. There are also significant amounts of weedy species typical of alluvial corridor sites. The restoration site includes riparian corridor, bottomland floodplain, and upland zones and related vegetation.

The floodplain along the restoration reach is comprised of alluvial soils covered in grass, mowed seasonally for hay. Historically, according to Bob Carter, Henderson County District Conservationist, the restoration site was used as pasture and was heavily overgrazed. This probably accounts for the lack of native, shrubby species and the presence of multiflora rose, which cows do not eat. Typical species found on the floodplain are Fescue (*Fetusca spp.),* mutiflora rose (*Rosa multiflora*), pokeweed (*Phytolacca americana*), and greenbriar (*Smilax spp.*) Woody vegetation is limited along the study length of Clear Creek. Where woody species are present, one can find river birch (*Betula nigra*), red maple (*Acer rubrum*), box elder (*Acer negundo*), tulip tree (*Liriodendron tulipifera*), pines (*Pinus spp.*), and tag alder (*Alnus serrulata*).

Since the stream is incised, several sections of bare, vertical banks are exposed. Materials eroded from these areas are transported downstream to Mud Creek since the stream has limited access to its floodplain. No riparian wetland systems were identified within this reach; however, wetland remnants occur within the outer edges of the floodplain as evidenced by persistent wetland vegetation including rushes (*Juncus sp*) and sedges (*Scirpus* sp, *Carex* sp). Approximately 3/4 of the length of the project reach lacks comprehensive, woody riparian plant cover.

Bankfull Verification

The North Carolina Rural Piedmont Regional Curve and a gage analysis of the Davidson River near Brevard in neighboring Transylvania County were used to verify the bankfull indicators identified in the field. The NC Rural Mountain Regional Curve estimates a 1.1-year return interval at that gage. We estimated a return interval closer to a 1.46-year return.

Based on NC rural regional curve regression equations, bankfull cross sectional area is estimated to be 286 sf on the mountain curve and 281 sf on the piedmont

curve (range 150 sf – 550 sf). The bankfull discharge estimate is based on cross-sectional geometry of a relatively stable riffle section in the upper portion of the Clear Creek study reach. Bankfull cross sectional area is calculated to be 222.6 square feet (sf). Bankfull discharge is estimated to be 1390 cfs. By continuity, bankfull velocity is calculated at 6.2 fps.

Reference Reach Analysis

Bent Creek, located in Bent Creek Experimental Forest, of the Pisgah National Forest in Buncombe County, is used in design as a C4 reference reach. Bent Creek is a gravel bed C stream type located in a valley that is sometimes confined on one side. Basin Creek, a C4 stream type in Wilkes County is also used as a reference reach. The drainage areas of Bent Creek and Basin Creek are smaller than that of Clear Creek. A summary of the Bent Creek data and Basin Creek data can be found on the Morphological Data sheet in Appendix 4.

Shear Stress, Velocity, and Sediment Transport

The flow associated with the critical shear stress for the proposed channel must be able to move the largest particle on the point bar. Entrainment calculations based on the riffle pebble count and a sieved bar sample are included in Appendix 3. Based on the equation $\tau_{ci} = 0.0834(d_i/d_{50})^{-0.872}$ (Andrews, 1984), the critical dimensionless shear stress for Clear Creek is 0.042. This value corresponds to a required mean bankfull depth of 4.5 feet to move the largest particle in the bar sample. Measured mean depth is 4.6 feet. Bankfull water surface slope required is .002 ft/ft, which is equal to the current bankfull slope of 0.002 ft/ft. Mean depth calculations indicate a slightly degrading stream, but the slope does not need to be adjusted.

Calculated bankfull shear stress is 0.12 pounds per square foot (psf). Based on the Shields diagram included in Appendix 3, bankfull discharge can move a particle 7.5 mm in diameter. The Shields diagram shows the relationship of grain diameter to critical shear stress for a combination of laboratory and field data.

Rosgen has added points to the Shields curve based on empirical data measured on natural rivers. These points indicate that the Shields curve tends to underestimate the competence of a river to move a particular particle size for critical shear stress values between 0.05 and 1.0 psf. Using this revised, empirically based curve, a shear stress of 0.12 psf corresponds to moving a particle closer to 25 mm in diameter.

Estimated channel velocities, based on four calculation methods for existing and proposed conditions, range from 6.1 to 9.0 feet per second (fps). The estimated velocity selected is 6.2 fps (based on continuity and u/u*) for existing and 5.0 fps for proposed conditions. This velocity was compared with velocities predicted by Figure 8.31 of *Stream Corridor Restoration Principals, Processes, and Practices*

(Federal Interagency Stream Restoration Workgroup, 1998.) The chart predicts basic velocities ranging from 4.0 to 6.5 fps depending on sediment load. This range supports the selected velocity estimate for the existing and proposed bankfull flow events.

A BEHI bank erosion prediction was calculated for the eroding meander bend at Station 9+65. Depending on the Stream Bank Erodibility curve used, the estimated soil loss in 500 feet of that section is 76 tons to nearly 162 tons of soil per year. This corresponds to 6.2 tons/foot/year (Colorado curve) to 13.1 tons/foot/year (Yellowstone curve) in a 500-foot section.

The stability inventory for the Level 3 assessment indicates that Clear Creek is a laterally unstable, C4 stream type, which can be restored to a stable C4. Problems arise due to high bank height ratio and high sediment supply, poor meander geometry, and irregularly spaced bed features. An additional problem is poorly defined pools and riffles. Therefore, the restoration design should focus on restoring stable meander geometry in the prior straightened reach, reducing the bank height ratio to 1 by creating bankfull benches and laying back banks so that woody vegetation can be established, and recreating stable bed forms at regular intervals. These measures will restore stability and diminish sediment loads caused by eroding banks delivered into the creek.

Natural Channel Design

Aerial photographs from 1951, 1965, 1969, 1970's, 1983, 1993 and 1994 provide a source of historical information on channel stability, modifications, and adjustment. Sometime prior to 1951 the channel was straightened, presumably to maximize agricultural production or facilitate construction of the sanitary sewer. In the 1969 aerial photo the channel appears to have degraded to an F stream type, wide and shallow. In 1994, mid channel bars are evident. Also in 1994, there are signs of meanders attempting to form within the eroded banks. Since 1994, mid-channel bars have evolved and relocated.

The proposed design aims to accelerate stream evolution to a stable C4. Current slope will be maintained and stable stream meanders will be added. Other goals of the design are to reduce bank height ratio, improve pools, and reestablish a woody riparian buffer along the length of the restoration reach.

Structures such as cross vanes and J-hook vanes will be used to control grade and near bank shear stress. Root wads will be used to protect the outside of meander bends. In the interest of reducing the bank height ratio, vertical banks will be laid back to create bankfull benches and to establish a more stable growing surface.

Tie-ins to existing streambed elevations will be done at the upper end at an existing riffle located at the property line near I-26. The downstream tie-in will be

above a sanitary sewer crossing upstream of the bridge over Clear Creek Road. The natural substrate of the stream will not be altered.

Sod mats, available on site, and riparian vegetation will be planted on the new banks and bankfull benches. Woody riparian vegetation, some of which can be harvested or transplanted on site, will help establish a healthy riparian buffer resistant to erosion.

Riparian Buffer Revegetation and Habitat Improvements

Many of the woody plant materials present on site can be harvested and used to revegetate the restored stream reach. Among the species that can be propagated or transplanted are black willow (*Salix nigra)*, box elder (*Acer negundo*), river birch (*Betula nigra*), silky dogwood (*Cornus amomum)*, and tag alder (*Alnus serrulata*).

Improved bed features, reduced sediment supply, and a revegetated riparian zone will improve habitat for muskellunge (*Esox masquinongy*), which is one of the goals of the French Broad River Basin Water Quality Improvement plan. It will also improve habitat for NC Natural Heritage Program listed creek-dwelling amphibians, fish and vascular plants. Some listed species include, but are not limited to, the Hellbender (*Cryptobranchus alleganiensis*), Southern zig-zag salamander (*Plethodon ventralis*), Mudpuppy (*Necturus maculosus*), Blueside darter (*Etheostoma jessiae*), Mooneye (*Hiodon tergisus*), sedges (*Caryx spp.*), and Gray's lily (*Lilium grayi*). A complete Natural Heritage species list is included at the end of the narrative as is a list of items that will help improve muskellunge habitat.

Utilities

The only utilities known to exist on site are an overhead power line and a sanitary sewer line. The sanitary sewer line parallels the left (south) side of the creek. Both utilities cross the stream just once near Clear Creek Road. At the overhead power line crossing, woody shrubs should be planted in the riparian zone instead of trees whose growth could interfere with the power line and require excessive pruning.

Monitoring and Evaluation Plan

EcoLogic Associates will perform physical monitoring of this site for one year after construction. After that time, a contractor to the WRP will perform monitoring. Permanent cross sections and photo points will be established and marked on the as-built drawings. An initial benthic macroinvertebrate sample was sent to Pennington and Associates, Inc laboratory for analysis. The 77 organisms found represented twenty-five taxa. The EPT index was 5; the biotic index was 6.27. Benthic survey results are included at the end of this report.

SPECIES	T.V.**	F.F.G.***	
MOLLUSCA			
Bivalvia			
Veneroida			
Corbiculidae			
Corbicula fluminea	6.12	FC	1
Gastropoda			
Mesogastropoda			
Pleuroceridae			
Elimia clavaeformis	*5	SC	1
Basommatophora			
Physidae			
Physella sp.	8.84	CG	1
Planorbidae	*6	SC	
Helisoma anceps	6.23	SC	1
ANNELIDA			
Oligochaeta	*10	CG	
Haplotaxida			
Lumbricidae		CG	5
ARTHROPODA			
Crustacea			
Decapoda			
Cambaridae			
Cambarus sp.	7.62	CG	1
Insecta			
Ephemeroptera			
Ephemerellidae			
Ephemerella sp.	*1	SC	1
Heptageniidae	*4	SC	
Stenonema modestum	5.5	SC	7
Odonata			
Aeshnidae	*3	P	
Boyeria vinosa	5.89	P	1
Coenagrionidae	*9	P	
Enallagma sp.	8.91	P	2
Gomphidae	*1	P	
Gomphus sp.	5.8	P	1
Erpetogomphus sp.	*1	P	2
Plecoptera			
Taeniopterygidae	*2	SH	
Taeniopteryx sp.	5.37	SH	1
Hemiptera			
Corixidae	9	PI	1
Megaloptera			
Corydalidae	*0	P	
Corydalus cornutus	5.16	P	1
Nigronia serricornis	4.95	P	2
Trichoptera			
Hydropsychidae	*4	FC	

Cheumatopsyche sp.	6.22	FC	23
Hydropsyche betteni gp.	7.78	FC	14
Diptera			
Chironomidae			
Cardiocladius obscurus	*5	P	1
Cricotopus sp.	*7	CG	1
Parametriocnemus lundbecki	3.65	CG	1
Rheotanytarsus sp.	5.89	FC	2
Simuliidae	*6	FC	
Simulium sp.	4	FC	1
Tipulidae	*3	SH	
Antocha sp.	4.25	CG	1
Tipula sp.	7.33	SH	4

TOTAL NO. OF ORGANISMS	77
TOTAL NO. OF TAXA	25
EPT INDEX	5
BIOTIC INDEX	6.27

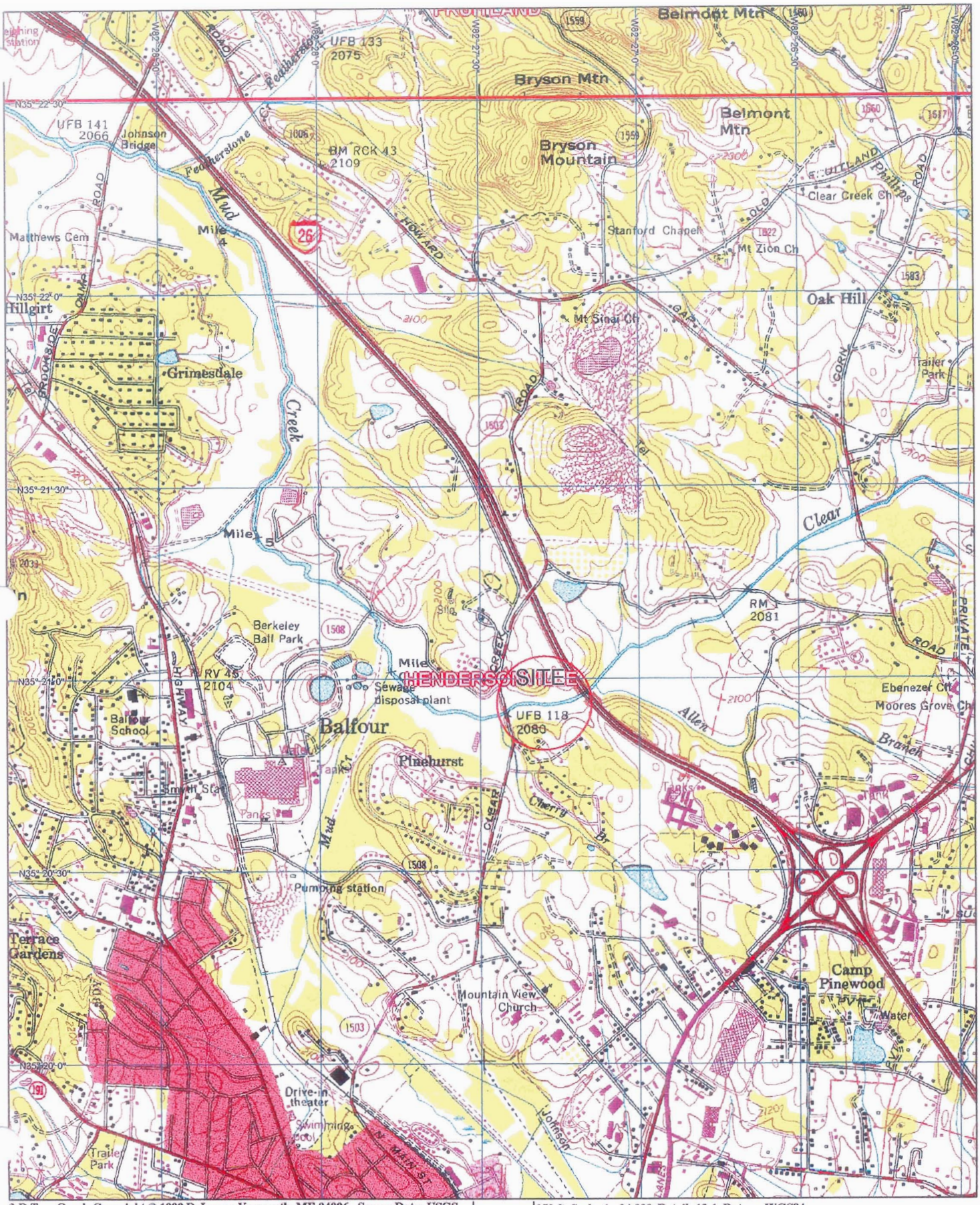
Cell: A69

Comment: *Hilsenhoff Tolerance Values used when North Carolina Tolerance Values are not available

**North Carolina Tolerance Values range from 0 for organisms very intolerant of organic wastes to 10 for organisms very tolerant of organic wastes

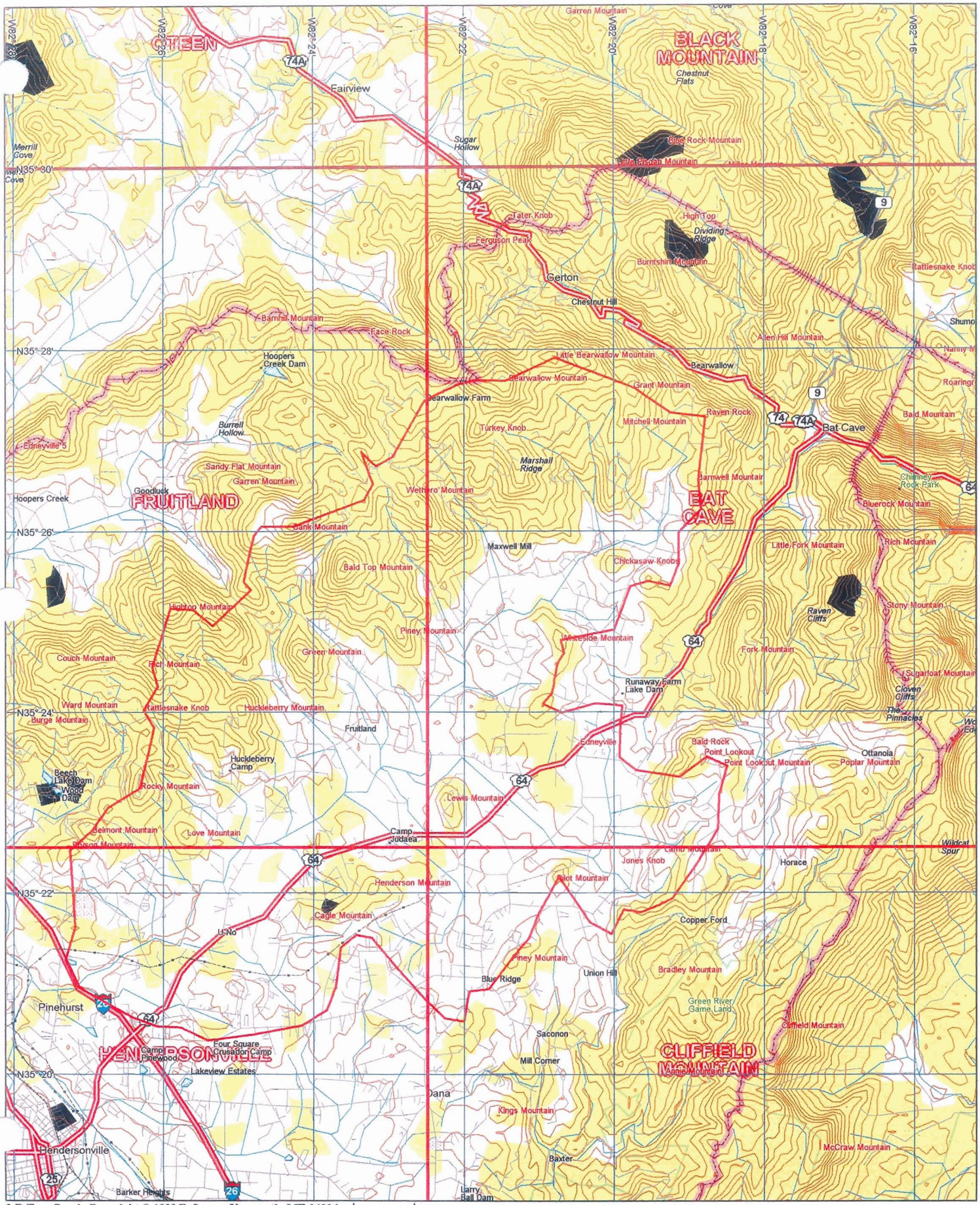
***F.F.G.-Functional Feeding Group: CG=Collector/Gatherer, FC=Filtering/Collectors, SC=Scrapers, SH=Shredders, P=Predators and PI=Piercer

Clear Creek Stream Restoration - Site Location Map



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS 950 ft Scale: 1 : 24,000 Detail: 13-1 Datum: WGS84

Clear Creek
Drainage Area to top of restoration reach = 44 sq.mi

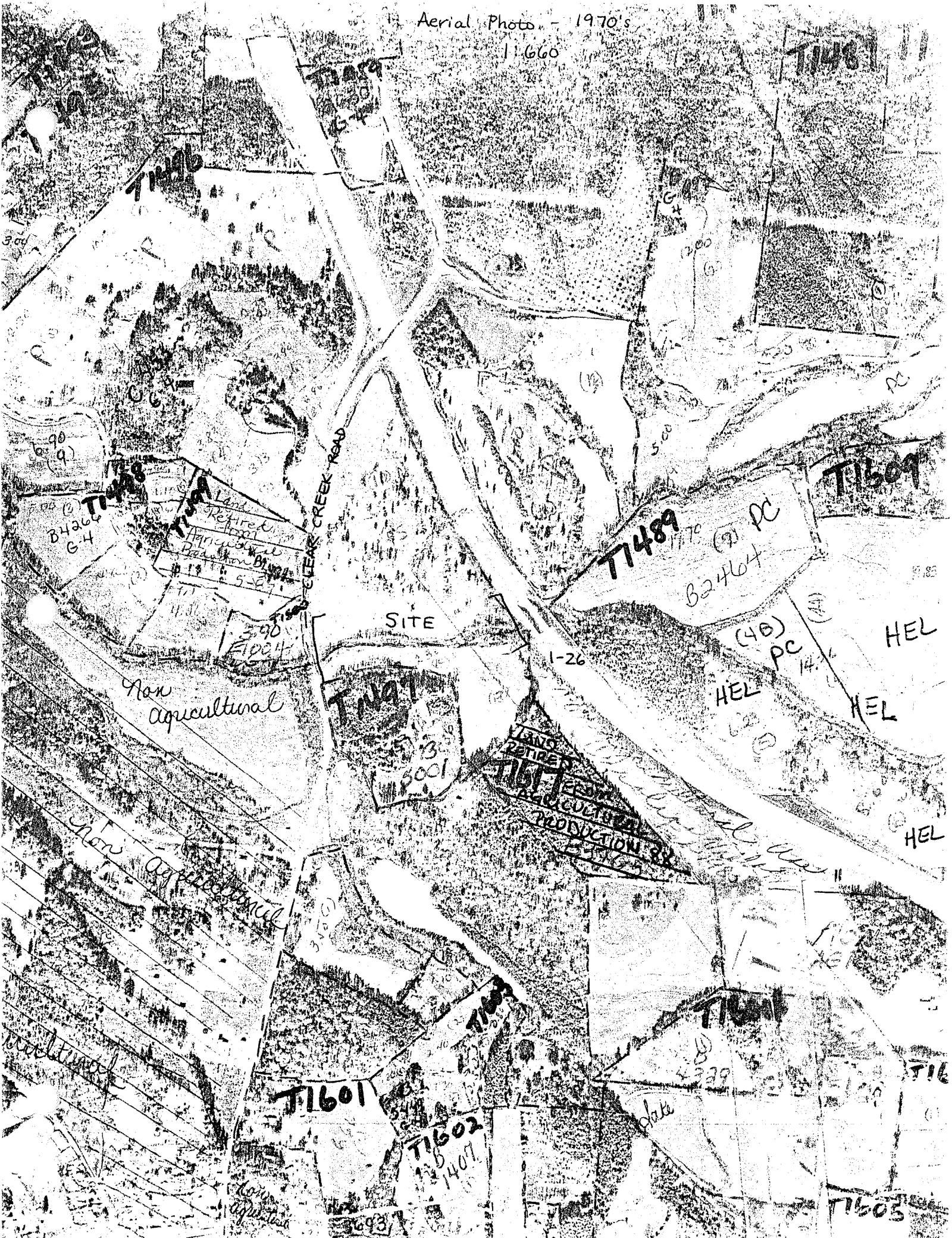


3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096
4000 ft Scale: 1 : 100,000 Detail: 11-0 Datum: WGS84


(Joins sheet 8)
(Joins sheet 11)
(Joins sheet 15)
595 000 FEET
960 000 FEET
Bryson Mountain
Belmont Mountain
Stoney Mountain
Balfour
Corn Mtn
HENDERSONVILLE
(county seat)
Mud Creek
Featherstone Cr
Phillips Branch
Clear Creek
Wolfpen Creek
Southern
Gulice Mountain
Britton Creek
Britton Cr
Cherrii Br
Allen Branch
SITE
5 000 4 000 3 000 2 000 1 000 0 5 000 Feet
1 .5 0 1 Kilometer
Scale - 1:20000


Aerial Photo - 1951
1:660
SITE
CLEAR CREEK ROAD


Aerial Photo - 1965
F8L
CLEAR CREEK ROAD
SITE
I-26
Construction


Aerial Photo - 1970's
1660
T1496
T1489
T1609
T1608
T1607
T1601
T1602
T1605
CLEAR CREEK ROAD
SITE
I-26
Non agricultural
Non Agricultural
Non agricultural
Land Retired from Agricultural Production
LAND RETIRED FROM AGRICULTURAL PRODUCTION
B4264
B2464
HEL
PC


Aerial Photo - 1983
1:1000
CLEAR CREEK RD
SITE
I-26
Aerial Photo - 1983
1:1000

Aerial Photo - 1993
1:660

RESTORATION REACH Summary Data

Stream Name: CLEAR CREEK (FRENCH BROAD RIVER BASIN)
Location: BETWEEN I-26 AND CLEAR CREEK ROAD, HENDERSON COUNTY, NC
Date: 12/12/2001
Crew: Louise Slate, Ken Bridle, John Vilas, Kelly Brannon
Stream Type: C4
Watershed Area: 44 sq. miles

Channel Dimensions

Max. Riffle Depth(drmax)(ft.):	6.0
Riffle Width(Wr)(ft.):	48.0
Riffle X-Sect. Area(Ar)(ft^2):	222.6
Riffle Mean Bankfull Depth(dmbkf):	4.6
Width/Depth ratio	10.4

Max. Pool Depth(dpmax)(ft.):	8.4
Pool Width(Wp)(ft.):	62.5
Pool X-Sect. Area(Ap)(ft.):	322.6

Width of Flood Prone Area (ft): 130-380 (narrower near I-26)
Entrenchment ratio: 2.7-3.6
Sinuosity: 1.09

Ratio: Max. Pool Depth/Max. Riffle Depth(dpmax/drmax):	1.4	
Ratio: Pool Width/Riffle Width(Wp/Wr):	1.3	
Ratio: Pool Area/Riffle Area(Ap/Ar):	1.4	
Ratio: Max. Pool Depth/Mean Bankfull Depth(dpmax/dbkf):	1.8	
Ratio: Lowest Bank Height/Max. Bankfull Depth(Bhlow/dmbkf):	1.3-1.6	
Streamflow: Estimated Mean Velocity(u) @ Bankfull Stage:	6.1	ft./sec.
Streamflow: Estimated Discharge(Q) @ Bankfull Stage:	1360	CFS

Channel Pattern

	Mean	Median	Min	Max	
Meander Wavelength(Lm):	230.0				ft.
Radius of Curvature(Rc):	68.5	57.0	40.0	120.0	ft.
Beltwidth(Wblt):	84		67	100	ft.
Meander Width Ratio(MWR=Wblt/Wbkf):	1.75				
RATIO: Radius of Curvature/Bankfull Width(Rc/Wbkf):	1.43	1.19	0.83	2.50	
RATIO: Meander Wavelength/Bankfull Width(Lm/Wbkf):	4.79				

Channel Profile

Valley Slope:	0.0044	ft./ft			
Water Surface Slope:	0.0020	ft./ft			
Riffle Slope:	0.0082	0.0065	0.0043	0.0138	ft./ft
Pool Slope:	0.00045		0.0003	0.0006	ft./ft
Run Slope:	0.0025				ft./ft
Glide Slope:					ft./ft
Riffle Length:	38.0	40.0	32.0	42.0	ft.
Pool Length:	75.0	85.0	33.0	130.0	ft.
Run Length:	47.6	25.0	24.0	126.0	ft.
Glide Length:	38.1	30.5	8.0	53.0	ft.
Riffle to Riffle Spacing:	414.5		199.0	630.0	ft.
Pool to Pool Spacing:	178.3	165.0	90.0	298.0	ft.
Riffle to Pool Spacing:	79.3	75.0	61.0	102.0	ft.
RATIO: Riffle Slope/ Water Surface Slope:	4.07	3.23	2.13	6.87	
RATIO: Pool Slope/Water Surface Slope:	0.223	0.000	0.127	0.310	
RATIO: Run Slope/Water Surface Slope:	1.241	0.000	0.000	0.000	
RATIO: Glide Slope/ Water Surface Slope:	0.000	0.000	0.000	0.000	
RATIO: Max. Riffle Depth/Mean Bankfull Depth:	1.31				
RATIO: Max.Pool Depth/Mean Bankfull Depth:	1.82				
RATIO: Max. Run Depth/Mean Bankfull Depth:	n/a				
RATIO: Max. Glide Depth/Mean Bankfull Depth:	n/a				
RATIO: Riffle Length/Bankfull Width:	0.79	0.83	0.67	0.88	
RATIO: Pool Length/Bankfull Width:	1.56	1.77	0.69	2.71	
RATIO: Run Length/Bankfull Width:	0.99	0.52	0.50	2.63	
RATIO: Glide Length/Bankfull Width:	0.79	0.64	0.17	1.10	
RATIO: Riffle to Riffle Spacing/Bankfull Width:	8.64	0.00	4.15	13.13	
RATIO: Pool to Pool Spacing/Bankfull Width:	3.71	3.44	1.88	6.21	
RATIO: Riffle to Pool Spacing/Bankfull Width:	1.65	1.56	1.27	2.13	

D84:	32	mm
dmbkf:	1402	mm
dmbkf/D84:	43.82	
u/u* :	12	*
Mannings 'n':	0.025	*

Channel Materials (particle size in mm)

D16 :	0.125
D35 :	0.5
D50 :	3.1
D84 :	20
D95 :	64

* Reference: Rosgen Reference Reach Field Book

Summary of Stability Condition Categories for the Level III Inventory

Stream: CLEAR CREEK			**Location:** HENDERSONVILLE (DS of I-26)			**Date:** 12-12-01	**Observers:** LS, KB
Level III Variables	Stream Type:	Flow Regime: P2	Stream Size: S-6	Stream Order:	Meander Pattern: M3	Depositional Pattern: B2/B8	Debris/Channel Blockage: D3/D10
	Riparian Vegetation: RV 10b	Current Compo/density: river birch, multiflora rose, fescue, pokeberry,	Potential Comp/density:		Altered Channel State: Prior straightened. Has incised, widened & is reestablishing flood plain at lower elevation		
Channel Dimension	Mean Bankfull Depth (ft): 4.6	Mean Bankfull Width (ft): 48	Width/Depth Ratio (ft): 10.35				
Channel Dimension Relationships	Existing Width/Depth Ratio(W/D_{ex}): 10.35	Reference Condition Width/Depth Ratio (W/D_{ref}): 15	(W/D_{ex})/(W/D_{ref}): 0.7	Circle: Excellent (Good) Fair Poor			

Channel Pattern		MWR	Lm/W_{bkf}	Rc/W_{bkf}	Arc Length/W_{bkf}	Arc Angle	Sinuosity
	Mean (Range)	1.6 (1.3 - 1.9)	4.3	1.3			

River Profile and Bed Features	Circle: (Riffle/Pool) Step/Pool Convergence/Divergence Dunes/antidunes/smooth bed						
	Max Bankfull Depth (ft):	Riffle 6.0	Pool 8.4	Depth Ratio (Max/Mean):	Riffle 1.3	Pool 1.6	Pool to Pool Spacing: 178.3
	Slope: Valley:	Average Bankfull: 0.002					

Channel Stability Rating	Pfankuch Rating: 114	Pfankuch Adjusted by Stream Type: POOR

Stream Channel Scour/Deposition Potential	Largest Particle - Bar Sample (mm): 41	τc_i: 0.042	Existing $Depth_{BKF}$: 4.6	Required $Depth_{BKF}$: 4.5	Existing $Slope_{BKF}$: 0.002	Required $Slope_{BKF}$: 0.002
	Circle: (Stable) Aggrading Degrading					

Vertical Stability	Bank Height Ratio: 1.3 to 1.6 (appears lower end)	Stable	(Moderately unstable)	Unstable	(Highly Unstable)	Width of Flood Prone Area (ft): 129	Entrenchment Ratio: 2.4

Bank Erosion Summary	Length of Bank Studied (ft): 500	Annual Streambank Erosion Rate (tons/yr): (162)	76	Curve Used: (Yellowstone) Colorado	Dominant BEHI: high/very high	Dominant NBS: very high

Stream Evolution Scenario	C → G → F → (C) → →	Existing Stream State (type): C4	Potential Stream State (type): C4

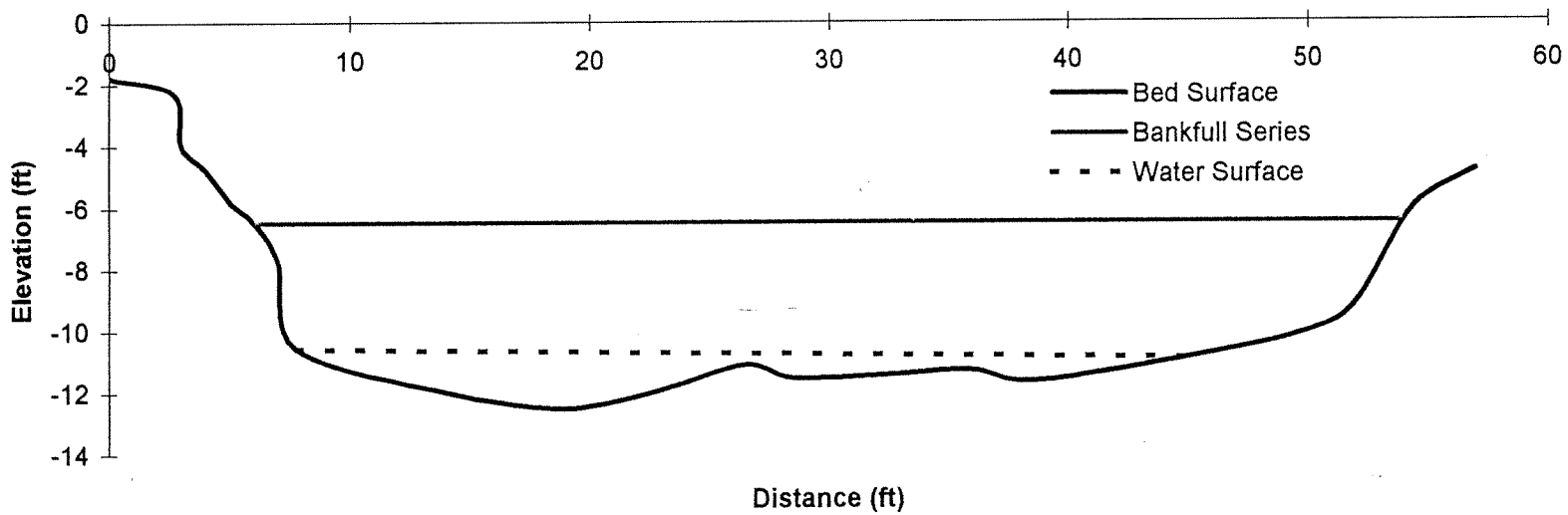
Sediment Supply	Circle: Extreme (Very High) High Moderate Low

Dimensionless Sediment Rating Curve:	Normal Above Normal (Excessive)

BHR = 1.3

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	STREAM:	Clear Creek Restoration Reach
							ID NUMBER:	Between I-26 and Clear Creek Road - Riffle
48.00	222.55	4.64	6.02	54.13	4.11	10.35	DATE	12/18/2001
37.20	37.59	1.01	1.88	42.72	0.88		Bankfull	
							Water Surface	

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	-1.78		32.0	-11.29
	2.7	-2.29		36.0	-11.66
	3.0	-3.97		38.5	-10.91
	4.0	-4.75	rew	45.0	-10.06
	5.0	-5.78		50.0	-9.14
lbf	6.0	-6.46		52.0	-6.44
	7.0	-7.73	rbf	54.0	-5.63
lew	7.8	-10.56		55.0	-4.82
		-11.97		57.0	-4.82
	14.0	-12.48			
	18.0	-12.44			
	20.0	-11.92			
	23.0	-11.11			
	26.5	-11.54			
	28.5	-11.46			

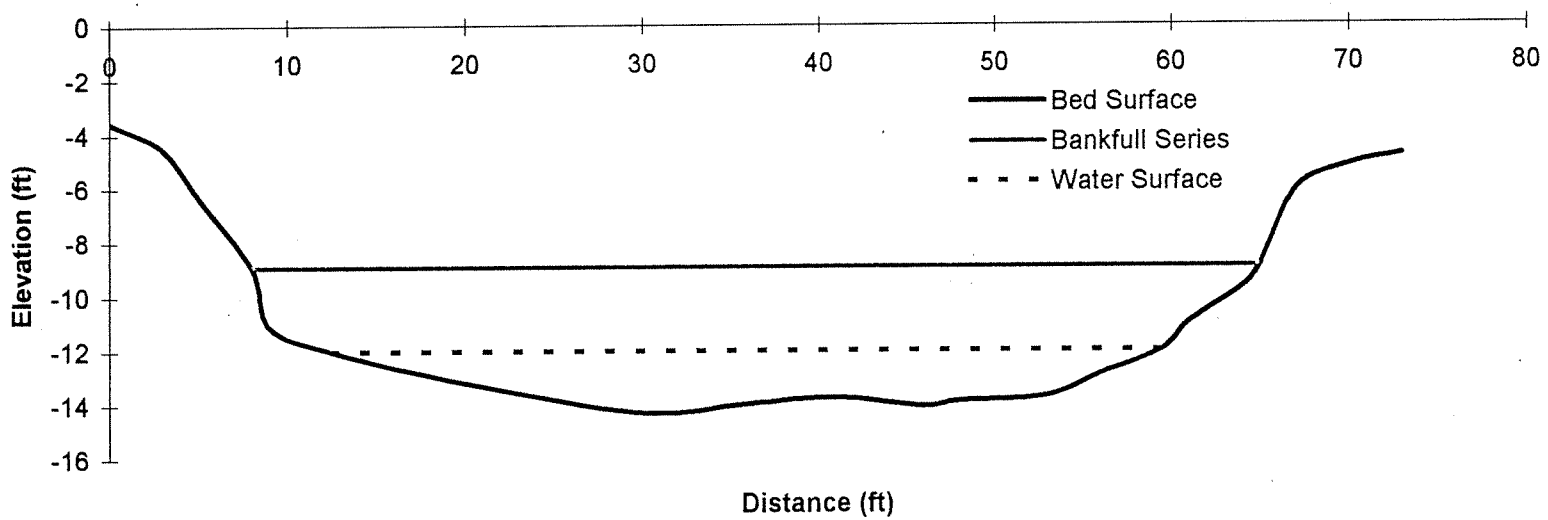


BHR = 1.5

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	
57.00	237.10	4.16	5.40	59.80	3.97	13.70	Bankfull
47.00	72.38	1.54	2.30	47.41	1.53		Water Surface

STREAM: Clear Creek
ID NUMBER: Run Cross Section
DATE 12/8/2001

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	-3.56		61.0	-11.00
	3.0	-4.50		64.0	-9.70
	5.0	-6.30	rbf	67.0	-8.90
lbf	8.0	-8.90		70.0	-6.10
	9.0	-11.10		73.0	-5.20
lew	12.5	-12.00			-4.80
	20.0	-13.20			
	30.0	-14.30			
	36.0	-14.00			
	41.0	-13.75			
	46.0	-14.10			
	48.0	-13.90			
	53.0	-13.70			
	56.0	-12.90			
rew	59.5	-12.00			

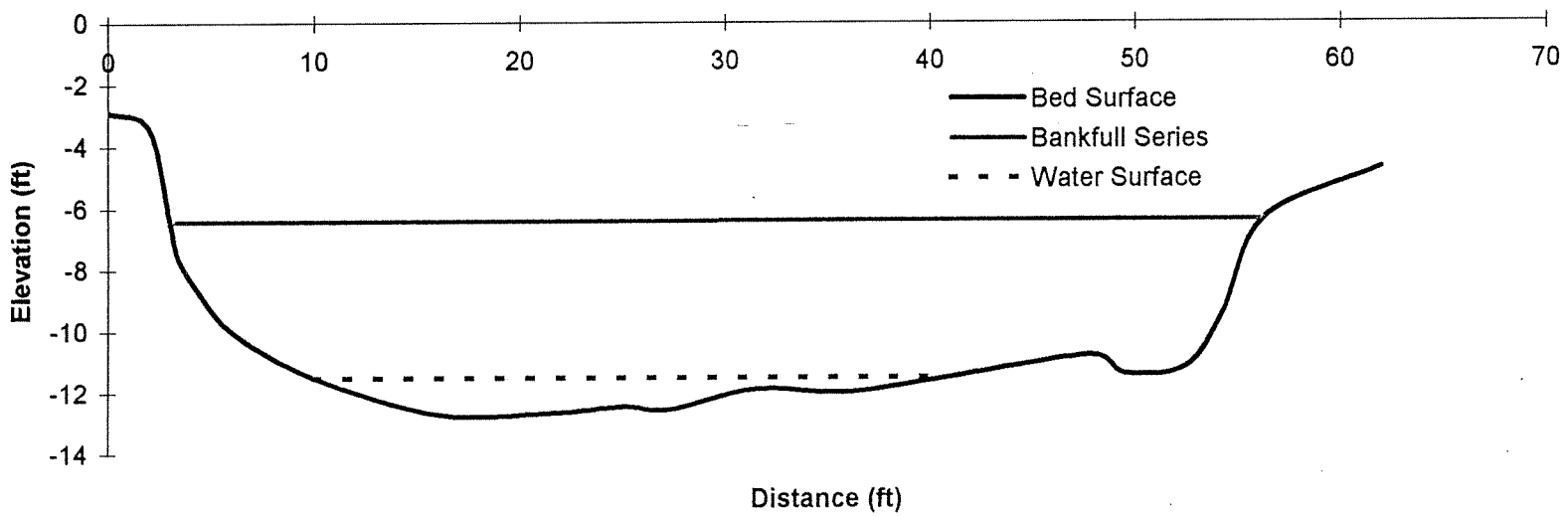


BHR = 1.92
(check this)

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	
53.30	269.89	5.06	6.31	58.14	4.64	10.53	Bankfull
31.00	22.33	0.72	1.20	31.20	0.72		Water Surface

STREAM: Clear Creek Restoration Reach
ID NUMBER: Glide Cross Section
DATE 12/12/2001

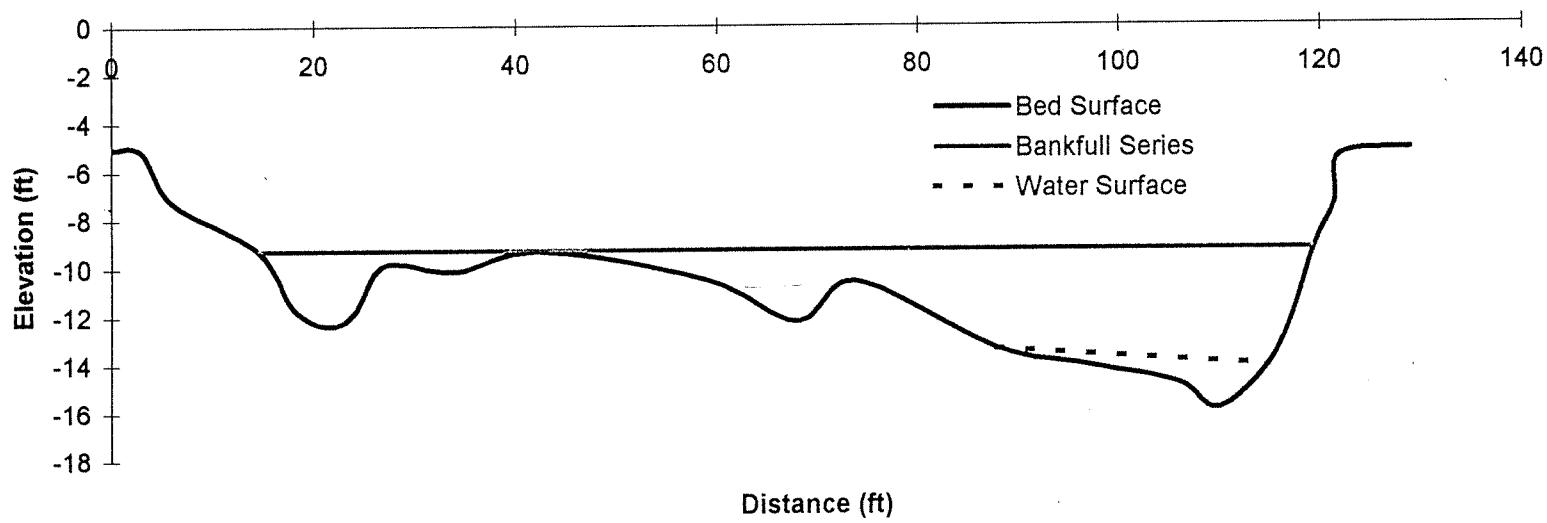
Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	-2.90		52.5	-11.40
	2.0	-3.40		54.3	-11.20
	3.4	-6.40	rbf	56.3	-9.45
	4.6	-7.60		62.0	-6.35
	6.2	-8.90			-4.70
lew	10.0	-10.10			
	16.0	-11.50			
	21.5	-12.70			
	25.0	-12.65			
	27.2	-12.45			
	31.5	-12.55			
	36.0	-11.90			
rew	41.0	-12.00			
	48.0	-11.50			
	49.5	-10.80			



BHR = 1.57

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	STREAM:	Clear Creek
							ID NUMBER:	pool cross section - BEHI
							DATE	1/8/2002
105.00	268.81	2.56	6.68	109.87	2.45	41.01	Bankfull	
27.00	23.15	0.86	2.44	27.53	0.84		Water Surface	

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	-5.05		106.0	-14.84
	3.0	-5.14		110.0	-15.94
	6.0	-7.26	rew	115.0	-14.10
lbf	14.5	-9.26		117.5	-11.87
	18.0	-11.64	rbf	121.5	-9.26
	21.4	-12.37		122.0	-7.36
	24.0	-11.84		129.0	-5.44
	27.0	-9.88			-5.14
	34.0	-10.15			
	42.5	-9.32			
	59.0	-10.52			
	68.0	-12.25			
	74.0	-10.60			
lew	88.0	-13.39			
	97.0	-14.10			

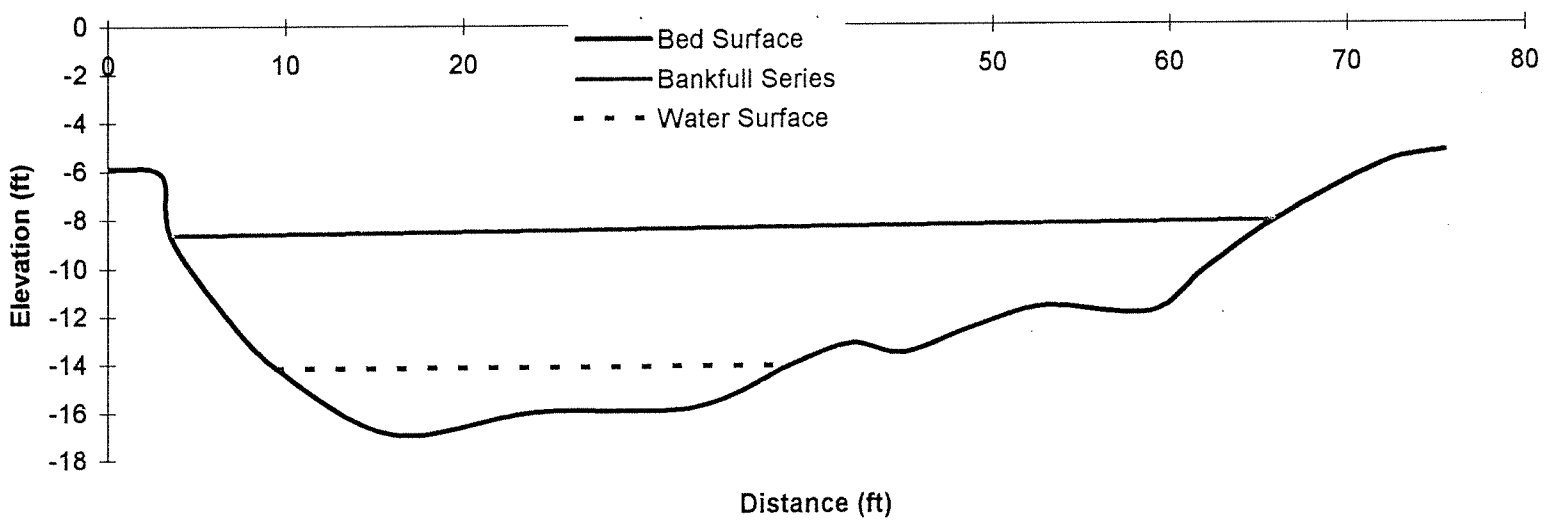


BHR FILE

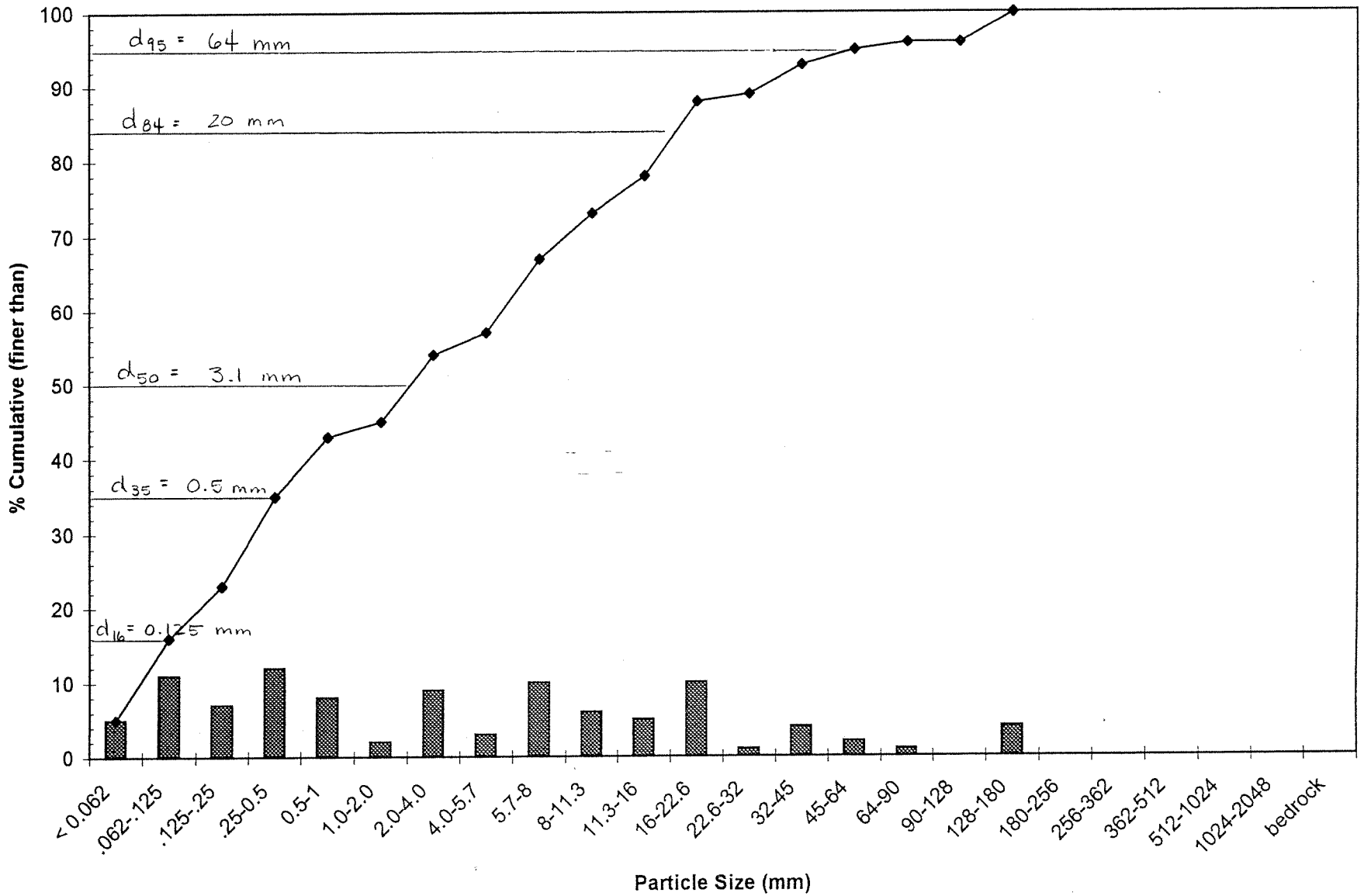
STREAM: Clear Creek
ID NUMBER: Pool X-sec
DATE 12-12-01

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	
62.50	322.61	5.16	8.35	66.93	4.82	12.11	Bankfull
29.00	48.30	1.67	2.76	29.88	1.62		Water Surface

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	-5.90	rbf	66.0	-8.10
	3.0	-6.10		72.0	-5.80
lbf	3.5	-8.60		75.5	-5.25
	6.2	-11.55			-5.25
lew	9.5	-14.15			
	16.0	-16.90			
	24.0	-16.00			
	33.0	-15.85			
rew	38.5	-14.10			
	42.0	-13.20			
	45.0	-13.60			
	49.0	-12.50			
	53.0	-11.65			
	59.0	-11.90			
	62.0	-10.15			

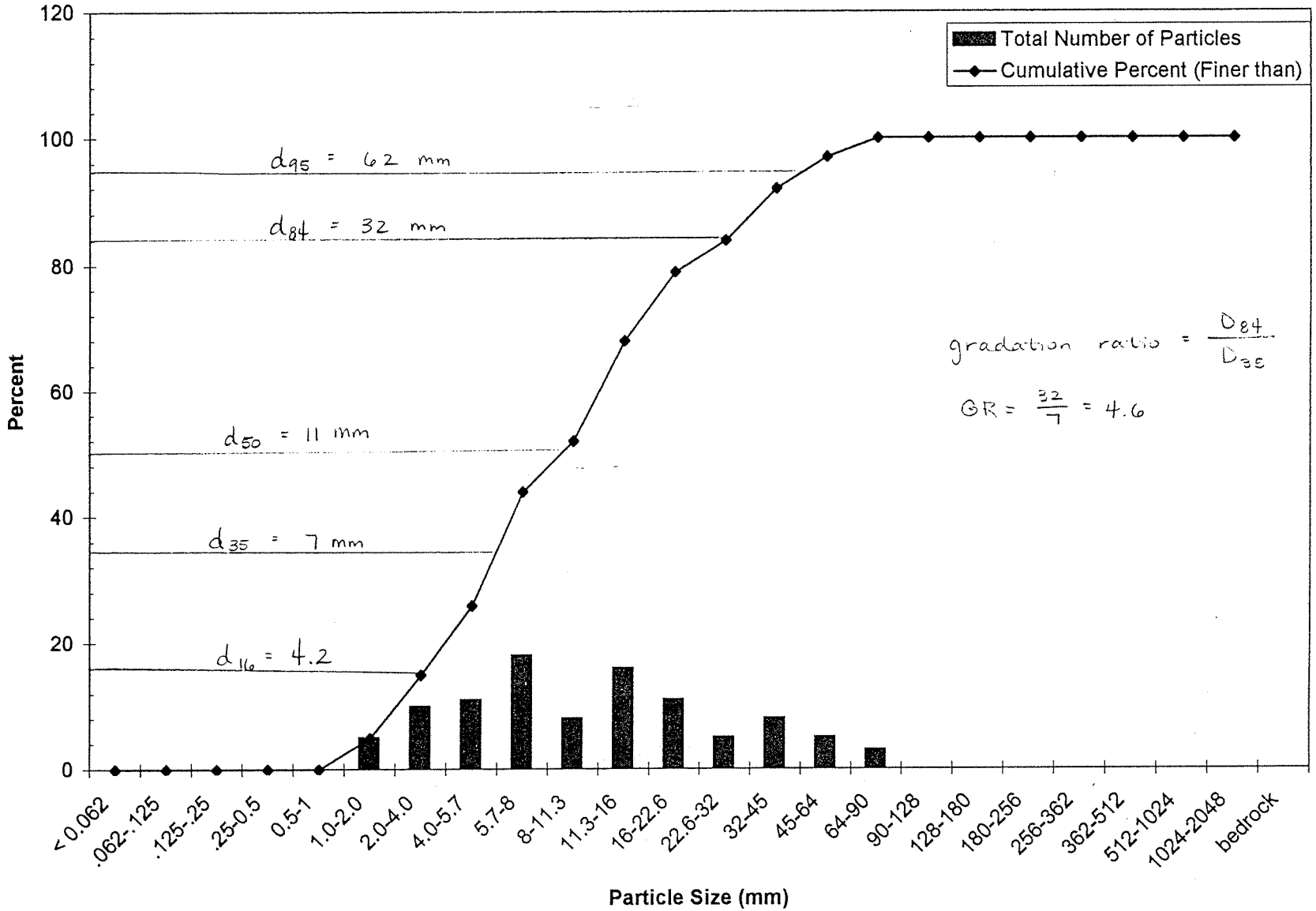


Clear Creek Classification Pebble Count

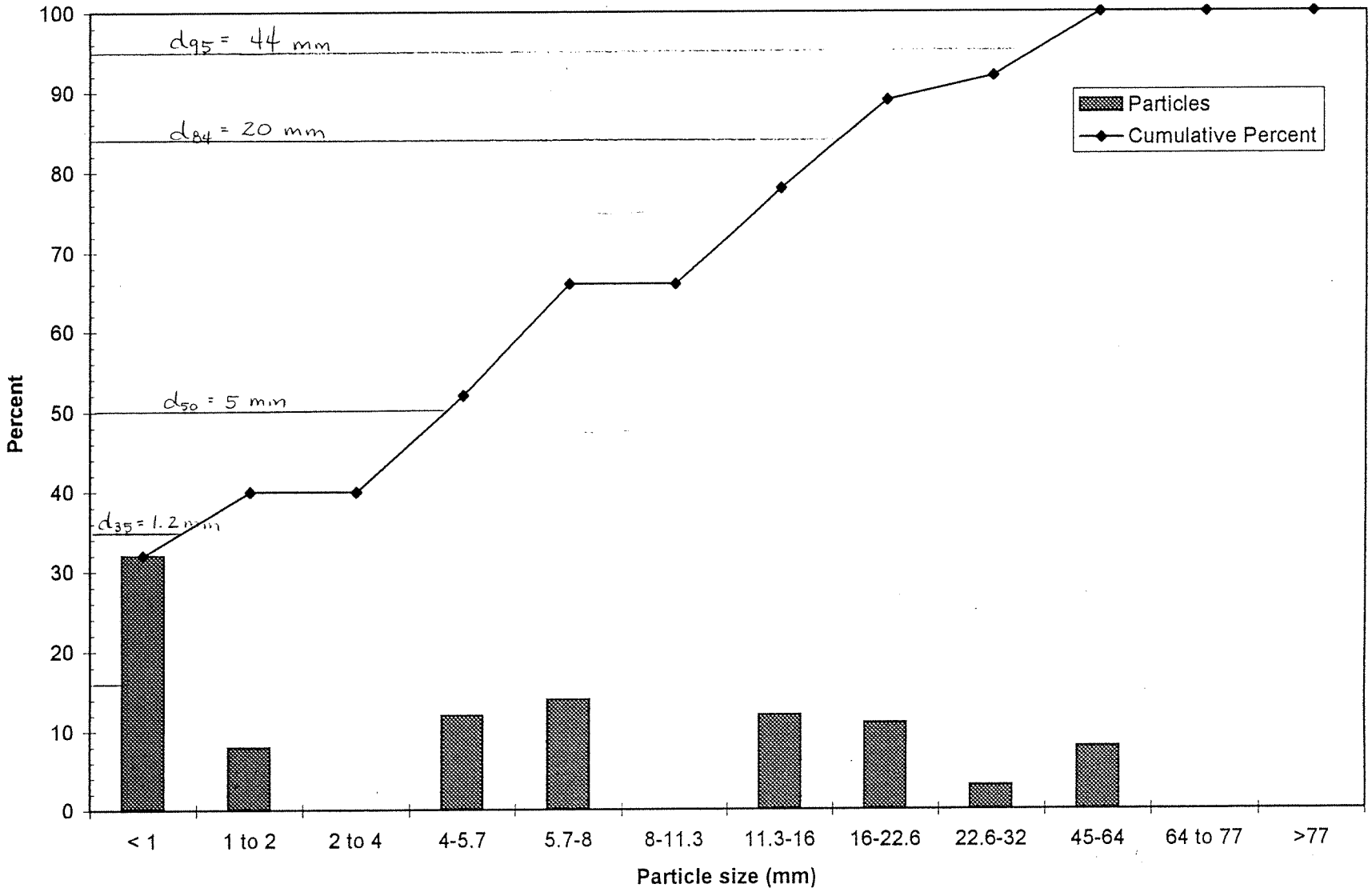


taken by 2nd mid-channel bar in downstream direction.

Riffle Pebble Count 1-8-2002



Clear Creek Subpavement Sample
1/8/2002



Velocity Comparison Form

Date 1-17-02 Team EcoLogic

Stream CLEAR CREEK Location HENDERSONVILLE

Input Variables			Output Variables		
Bankfull Cross Sectional Area (A_{BKF})	222.6	ft^2	Bankfull Mean Depth $D_{BKF} = (A_{BKF}/W_{BKF})$	4.6	ft
Bankfull Width (W_{BKF})	48.0	ft	Wetted Perimeter (WP) $(\sim(2*D_{BKF})+W_{BKF})$	54.1	ft
D84	32	mm	D84 (mm/304.8)	0.105	ft
Bankfull Slope	0.002	ft/ft	Hydraulic Radius (R) (A_{BKF}/WP)	4.1	ft
Gravity	32.2	ft/s^2	R/D84 (use D84 in FEET)	39.0	ft/ft

R/D84, u/u*, Mannings n		
u/u* (using R/D84: see Reference Reach Field Book: p188, River Field Book:p233)	11.7	ft/s/ ft/s
Mannings n: (Reference Reach Field Book: p189, River Field Book:p236)	0.026	$ft^{1/6}$
Velocity: from Manning's equation: $u=1.49R^{2/3}S^{1/2}/n$	6.6	ft/s

0.170696193842

u/u*=2.83+5.7logR/D84		
u*: $u^*=(gRS)^{0.5}$	0.51	ft/s
Velocity: $u=u^*(2.83+5.7\log R/D84)$	6.1	ft/s

Mannings n by Stream Type		
Stream Type	C4	
Mannings n: (Reference Reach Field Book: p187, River Field Book:p237)	0.019	$ft^{1/6}$
Velocity: from Manning's equation $u=1.49R^{2/3}S^{1/2}/n$	9.0	ft/s

Continuity Equation		
Q_{BKF} (cfs) from regional curve or stream gage calibration	1816	cfs
Velocity (u=Q/A or from stream gage hydraulic geometry)	8.2	ft/s

1840

Entrainment Calculation Form

Stream: Clear Creek	Reach: by 2nd island bar
Date: 1-9-02	Observers LS, KB - EcoLogic

Critical Dimensionless Shear Stress:

$$\tau c_i = 0.0834(d_i/d_{50})^{-0.872}$$

Value	Variable	Definition
11	d_i (mm)	D50 Bed Material (D50 from riffle pebble count)
5	d_{50} (mm)	Bar Sample D50 or Sub-pavement D50
0.042	τc_i	**Critical Dimensionless Shear Stress**

Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample:

$$d_r = (\tau c_i * 1.65 * D_i)/S_e$$

1.65 = submerged specific weight of sediment

Value	Variable	Definition
0.042	τc_i	Critical Dimensionless Shear Stress
0.13	D_i (feet)	Largest particle from bar sample
0.002	S_e (ft/ft)	Existing Bankfull Water Surface Slope
4.5	d_r (ft)	**Bankfull Mean Depth Required**
4.6	d_e (ft)	**Existing Bankfull Mean Depth (from riffle cross section)**

Circle: Stable (d_e/d_r =1) (1.02) Aggrading (d_e/d_r <1) Degrading (d_e/d_r >1)

Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample:

$$S_r = (\tau c_i * 1.65 * D_i)/d_e$$

1.65 = submerged specific weight of sediment

Value	Variable	Definition
0.042	τc_i	Critical Dimensionless Shear Stress
0.13	D_i (feet)	Largest particle from bar sample
4.6	d_e (ft)	Existing Bankfull Mean Depth (from riffle cross section)
0.002	S_r (ft/ft)	Bankfull Water Surface Slope Required

Circle: Stable (S_e/S_r =1) Aggrading (S_e/S_r <1) Degrading (S_e/S_r >1)

Sediment Transport Validation

41	Largest Particle in Bar Sample D_i (mm)
0.12	Bankfull Shear Stress $\tau_c = \gamma RS$ (lb/ft^2) (62.4)(4.1)(0.002) = 0.51 @ riffle; (62.4)(2.45)(0.002) = 0.31 @ BEHI
7.5 (orig) 25 (rev.)	Moveable particle size (mm) at bankfull shear stress (predicted by the Shields Diagram: Blue field book:p238, Red field book: p190)
0.17 (orig) 0.09 (rev)	Predicted shear stress required to initiate movement of D_i (mm) (see Shields Diagram: Blue field book:p238, Red field book: p190)

PFANKUCH CHANNEL STABILITY EVALUATION

Reach Location Clear Creek Date 12-12-01 Observers Ken Bridle, Kelly Brannon STREAM TYPE

catagory			EXCELLENT		GOOD		FAIR	
UPPER BANKS	1	Landform Slope	Bank Slope Gradient <30%	2	Bank slope gradient 30-40%.	4	Bank slope gradient 40-60%.	(6) 9
	2	Mass Wasting	No evidence of past or future mass wasting.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly year long.	
	3	Debris Jam Potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	(6)
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep dense soil binding root mass.	3	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	<50-70% density. Lower vigor and fewer species form a shallow, discontinuous root mass.	9
LOWER BANKS	5	Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7	1	Adequate. Bank overflows rare. W/D ratio 8-15.	(2)	Barely contains present peaks. Occasional overbank floods. W/D ratio 15 to 25.	3
	6	Bank Rock Content	65%+ with large angular boulders. 12"+ common	2	40-65%. Mostly small boulders to cobbles 6-12".	4	20-40% with most in the 3-6" diameter class.	6
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern without cutting or deposition. Stable bed.	2	Some present causing erosive cross currents and minor pool filling. Obstructions newer and less firm.	(4)	Moder. frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6
	8	Cutting	Little or none. Infreq. raw banks less than 6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12"	6	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident.	12
	9	Deposition	Little or no enlargement of channel or pt. bars	4	Some new bar increase, mostly from coarse gravel.	8	Moder. deposition of new gravel and course sand on old and some new bars.	12
BOTTOM	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges, surfaces smooth, flat.	(2)	Corners and edges well rounded in two dimensions.	3
	11	Brightness	Surfaces dull, dark or stained. Gen. not bright.	(1)	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, ie 35-65% mixture range.	3
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	(4)	Mostly loose assortment with no apparent overlap.	6
	13	Bottom Size Distribution	No size change evident. Stable mater. 80-100%.	4	Distribution shift light. Stable material 50-80%.	8	Moder. change in sizes. Stable materials 20-50%.	(12)
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	6	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	(18)
	15	Aquatic Vegetation	Abundant. Growth moss-like, dark green, perennial. In swift water too.	(1)	Common. Algal forms in low velocity and pool areas. Moss here too.	2	Present but spotty, mostly in backwater. Seasonal algal growth makes rocks slick.	3
			totals	2		12		66

Stream Width.....x avg. depth.....x mean velocity.....=Q .....cfs

Gauge Ht.....Reach Gradient.....Stream Order.....Sinuosity Ratio.....

Width Bf.....Depth Bf.....W/D Ratio.....Bf Dischrge (Q Bf).....

Drainage Area.....Valley Gradient.....Stream Length.....Valley Length.....

Sinuosity.....Entrenchment Ratio.....Length Meander (Lm).....Belt Width.....

Sediment Supply
Extreme.....
Very High.....
High..X..
Moderate..X..
Low.....

Stream Bed Stability
Aggrading.....
Degrading..X..
Stable.....

Width/
Normal
High.....
Very Hi

TOTAL SCORE for Reach E.....+ G.....+ F

Remarks.....

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6
GOOD	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85
FAIR	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-10
POOR	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	(111+)	111+	106+

Stream Type	DA3	DA4	DA5	DA6	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	G1	G2	G3	G4
GOOD	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-10
FAIR	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-12
POOR	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+

BEHI Variable Worksheet

Stream: Clear Creek	Cross Section:	Date: 12-12-01	Observers: Ken B., John V.

Bank Height/Max Depth Bankfull (C)

Highest Bank Height (ft)	9.32 A	Max Bankfull Depth (ft)	7.7 B	A/B	1.2 C

Root Depth/Bank Height (F)

Root Depth (ft)	3.8' D	Study Bank Height (ft)	6.72 E	D/E	0.57 F

Weighted Root Density (H)

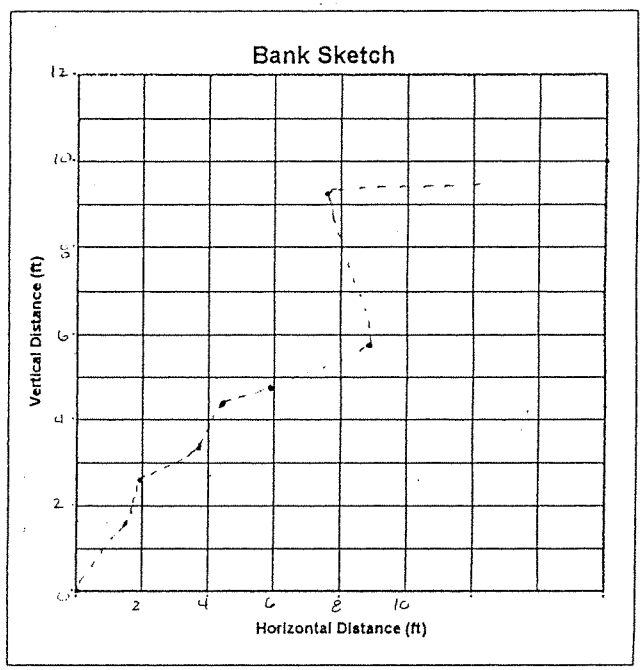
Root Density (%)	15% G	G*F	8.5 H

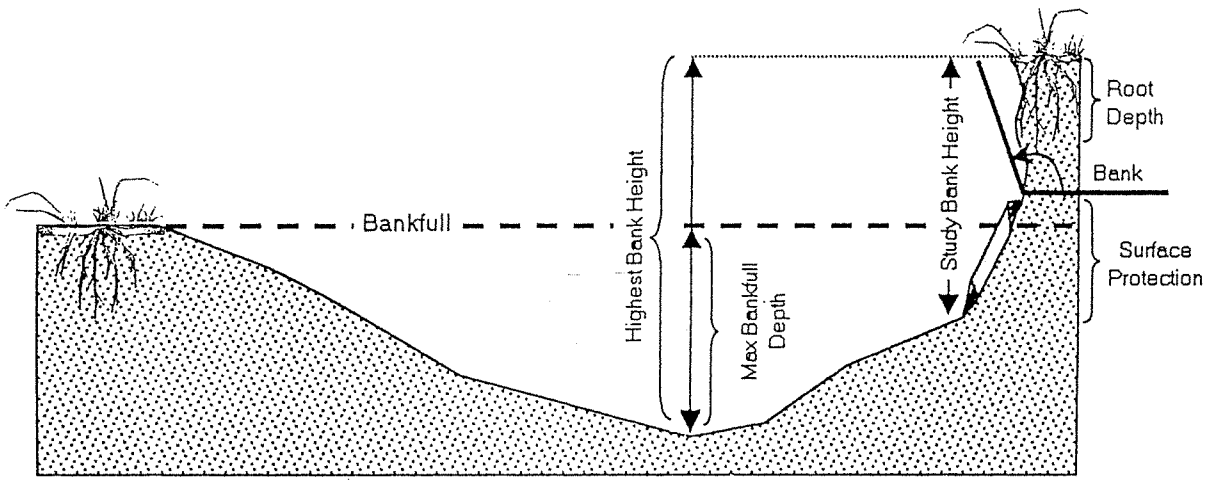
Bank Angle (I)

Bank Angle (Degrees)	110 I

Weighted Surface Protection (K)

Height of Bank Protection (ft)	3.1 J	J/E	0.46 K





Bank Erodibility Hazard Rating Guide

Stream Clear Creek Reach Date 12-12-01 Crew KB/JV

Bank Erosion Potential		Bank Height/ Bankfull Ht	Root Depth/ Bank Height	Root Density %	Bank Angle (Degrees)	Surface Protection%
Bank Height (ft): / Bankfull Height (ft):						
VERY LOW	Value	1.0-1.1	1.0-0.9	100-80	0-20	100-80
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9
	Choice	V: I:	V: I:	V: I:	V: I:	V: I:
LOW	Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9
	Choice	V: I:	V: 0.57 I: 3.6	V: I:	V: I:	V: I:
MODERATE	Value	(1.2)1.5	0.49-0.3	54-30	61-80	54-30
	Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9
	Choice	V: 1.2 I: 4.0	V: I:	V: I:	V: I:	V: 46 I: 4.6
HIGH	Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9
	Choice	V: I:	V: I:	V: 15 I: 7.9	V: I:	V: I:
VERY HIGH	Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10
	Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0
	Choice	V: I:	V: I:	V: I:	V: 110 I: 8.7	V: I:
EXTREME	Value	>2.8	<0.05	<5	>119	<10
	Index	10	10	10	10	10
	Choice	V: I:	V: I:	V: I:	V: I:	V: I:
V = value, I = index				SUB-TOTAL (Sum one index from each column)		28.8

Bank Material Description:

Bank Materials

Bedrock (Bedrock banks have very low bank erosion potential)

Boulders (Banks composed of boulders have low bank erosion potential)

Cobble (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)

Gravel (Add 5-10 points depending percentage of bank material that is composed of sand)

Sand (Add 10 points)

Silt Clay (+ 0: no adjustment)

BANK MATERIAL ADJUSTMENT: 10

Stratification Comments:

Stratification

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

STRATIFICATION ADJUSTMENT: —

VERY LOW	LOW	MODERATE	HIGH	VERY HIGH	EXTREME
5-9.5	10-19.5	20-29.5	30-39.5	40-45	46-50

Bank location description (circle one)

(Straight Reach) Outside of Bend

GRAND TOTAL BEHI RATING: 38.8

Bank Erosion Prediction

Stream	Cross Section	Date
CLEAR CREEK		1-9-02

Near Bank Stress Rating

Mean Shear Stress

Bankfull Hydraulic Radius (ft) R	0.96
Water Surface Facet Slope (ft/ft) S	0.0016
Shear Stress (lb/ft^2) $\tau = \gamma RS$ (γ=62.4lb/ft^3)	0.096

Near Bank Shear Stress

Bankfull Hydraulic Radius (ft) R (near bank 1/3)	4.2
Near Bank Water Surface Slope (ft/ft) S	0.0005
Shear Stress (lb/ft^2) τ near bank= γRS	0.131
Near Bank Stress/ Mean Shear Stress (τ near bank/τ)	1.37

Conversion of Numerical Indices to Adjective Ratings

Near Bank Stress Rating	Near Bank Stress/Mean Shear Stress
Very Low	<0.8
Low	0.8 - 1.05
Moderate	1.06 - 1.14
High	1.15 - 1.19
Very High	1.2 - 1.6
Extreme	>1.6
Near Bank Stress Rating	VERY HIGH

Stream Bank Erodibility Rating

BEHI Rating	Borderline HIGH / V. HIGH

Bank Erosion Prediction at Cross Section

A	B	C	D
Lateral Erosion at Cross Section (feet/year)	Bank Height (feet)	Length of Bank (feet)	Predicted Erosion $feet^3$
0.8 (Colorado) 1.7 (Yellowstone)	7.7	1 500'	3080 SF ≈ 76 tons 6545 SF ≈ 162 Tons

Circle graph used: (Colorado) Yellowstone

Column A: Use Stream Bank Erodibility Rating and Near Bank Stress Rating in conjunction with Figure 6-27 in Rosgen, 1996.

Column B: Study Bank Height (Use Cross Section Plot: top of bank - toe of bank)

Column C: Input 1 foot for point erosion @ cross section

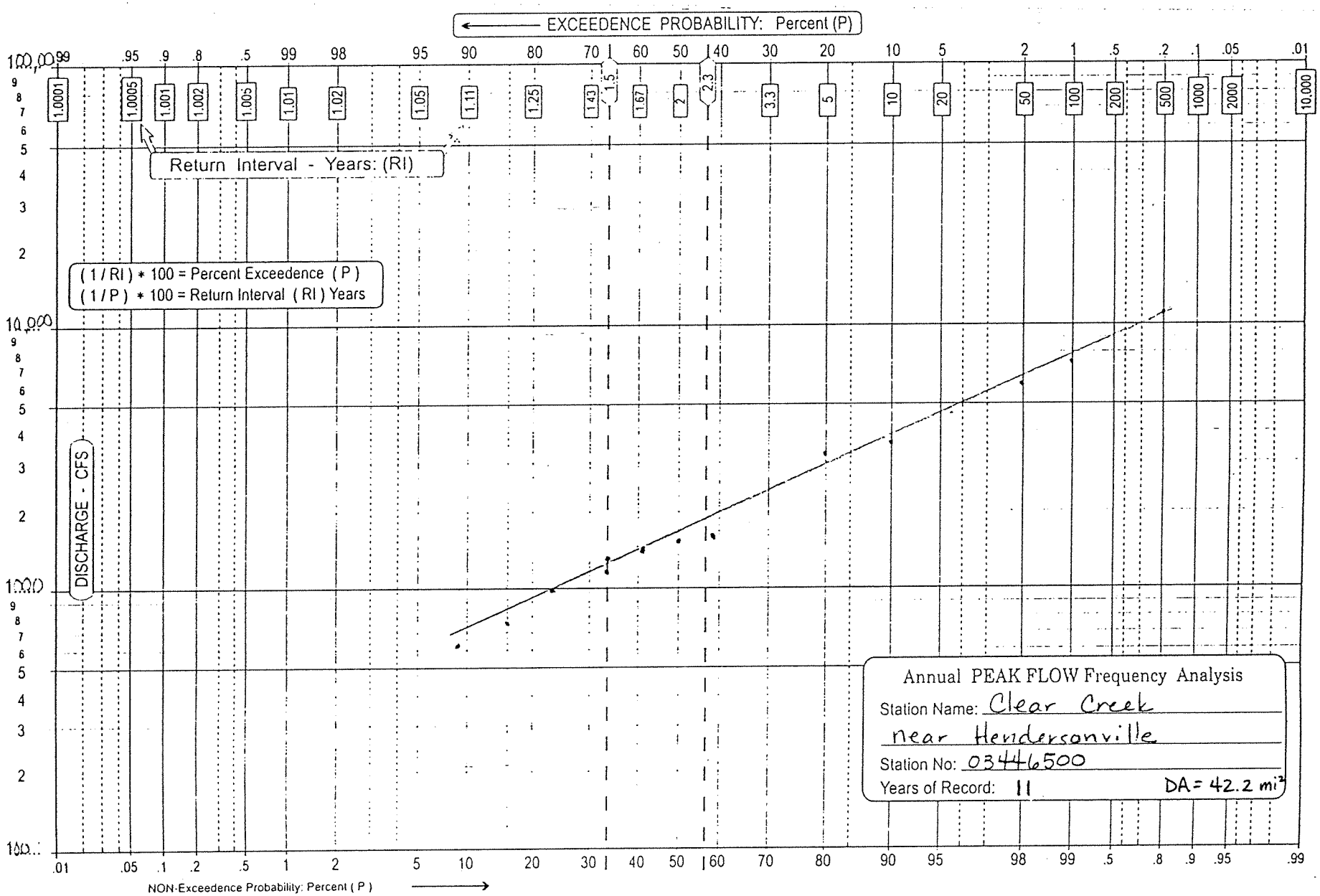
Column D: Columns A*B*C

Q_{bkf} = 1390 cfs

Q_2 = 1590 cfs
Q_5 = 3180 cfs
Q_{10} = 3425 cfs

Q_{25} = 4900 cfs
Q_{50} = 5850 cfs
Q_{100} = 7125 cfs

Flood frequency curve developed from gage data and the hydraulic model used to developed for the published FEMA Flood Insurance Study



Clear Creek Morphological Data

CLASSIFICATION DATA	Existing Channel	Reference Basin Creek	Reference Bent Creek	Proposed Channel
Rosgen Stream Type	C4	C4	C4	C4
Drainage Area (sq mi)	44	7.2	5.35	44
Bankfull Width (W_{bkf}) (ft)	53	33.2	32	60
Bankfull Mean Depth (d_{bkf}) (ft)	4.64	2.1	2.1	4.66
Bankfull Cross Sectional Area (A_{bkf}) (sf)	245.9	69.7	65.6	280.0
Width/Depth ratio (W_{bkf}/d_{bkf})	11.4	15.8	15.6	12.9
Maximum depth (d_{mbkf}) (ft)	7.7	2.5	3.1	7.1
Width of flood prone area (W_{fpa}) (ft)	129	85	150	200
Entrenchment ratio (ER)	2.4	2.6	4.7	3.3
Water surface slope (S) (ft/ft)	0.002	0.014	0.011	0.002
Sinuosity (stream length/valley length) (K)	1.09	1.02	1.2	1.17
DIMENSION DATA				
Pool Depth (ft)	5.8	3.1	2.4	10.7
Riffle Depth (ft)	4.6	2.1	2.1	4.7
Pool Width (ft)	69	40.6	23.5	100
Riffle Width (ft)	53	33.2	32	60
Pool XS Area (sf)	400.2	64.4	56.4	1071.8
Riffle XS area (sf)	245.9	69.7	65.6	279.6
Pool depth/mean riffle depth	1.3	1.5	1.2	2.3
Pool width/riffle width	1.3	1.2	0.7	1.7
Pool area/riffle area	1.6	0.9	0.9	3.8
Max pool depth/d_{bkf}	2.3	1.5	2.4	3.2
Low bankheight/max bankfull depth	1.6	1	1.1	1
Mean bankfull velocity (V) (fps)	5.7	5.5	4.6	5.0
Bankfull discharge (Q) (cfs)	1390	375	300	1390
PATTERN DATA				
Meander length (L_m) (ft)	230	350	339	630
Radius of curvature (Rc) (ft)	69	40.1-69.3	20.4	150-180
Belt width (W_{blt}) (ft)	67-100	59-75	50	150
Meander width ratio (W_{blt}/W_{bkf})	1.6	2.0	1.6	2.5
Radius of curvature/bankfull width	1.3	1.2-2.1	0.6	2.5 - 3
Meander length/bankfull width	4.3	10.5	10.6	10.5
PROFILE DATA				
Valley slope	0.0044	0.014	0.0225	0.0044
Average water surface slope	0.002	0.014	0.011	0.002
Riffle slope	0.008	0.021	0.034	0.003
Pool slope	0.00045	0.002	0.0018	0.0004
Pool to pool spacing	235-393	305	66.2	300-420
Pool length	87	17-53	26.5	96
Riffle slope/avg water surface slope	4.1	1.48	3.24	1.5
Pool slope/avg water surface slope	4.4	0.14	0.17	0.2
Run slope/avg water surface slope	1.25	0.22	1.31	0.8
Glide slope/avg water surface slope				
Run depth/d_{bkf}	1.2	1.05		1.90
Glide depth/d_{bkf}				1.55
Pool length/bankfull width	1.6	1.13	0.83	1.60
Pool to pool spacing/bankfull width	4.4-7.4	9.2	2.1	5.0-7.0
CHANNEL MATERIALS				
D16	0.125	0.17	1.8	0.125
D35	0.5	29	4.2	0.5
D50	3	58	12	3
D84	20	180	31	20
D95	64	300	126	64

Clear Creek avg slope = 0.002 d bkf= 4.6 ft

Proposed Longitudinal Profile d end riff = 4.7 ft

Henderson County d run = 8.85 ft

NC Wetlands Restoration Program d glide = 7.2 ft

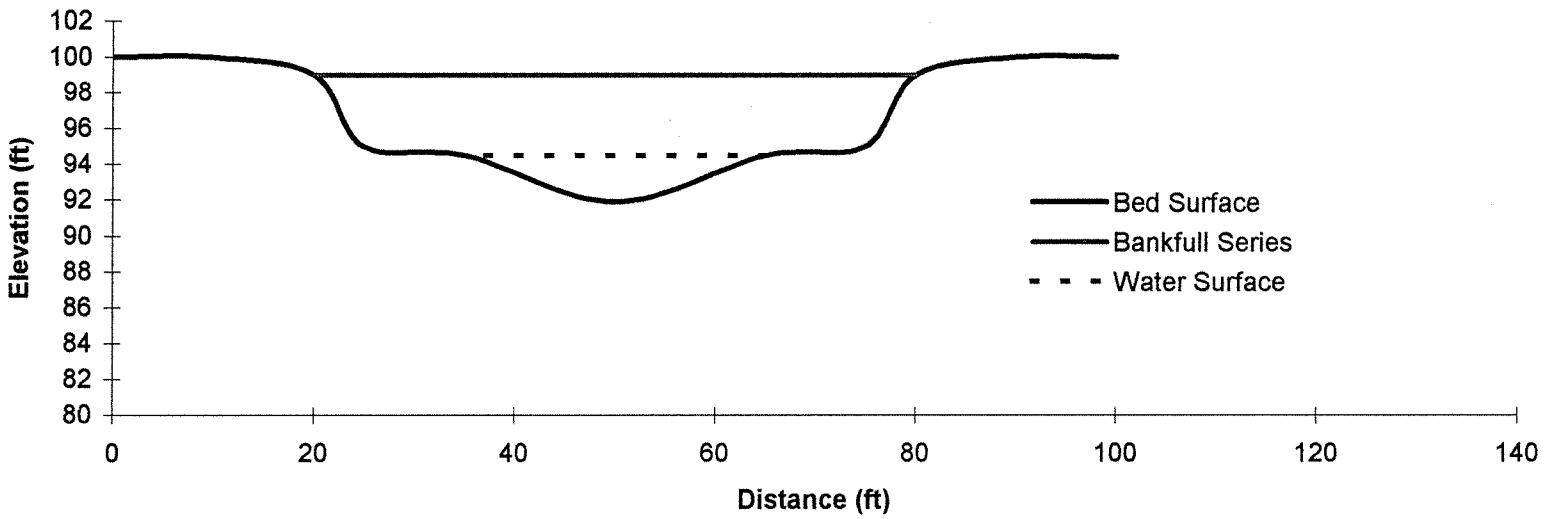
d max pool= 15.0 ft

d pool = 10.7 ft

Feature	Station	TW Elev	Baseflow EL	BKF EL	Slope	Length
begin riffle	0	2065.7	2067.40	2070.30	0.003	50
end riffle	50	2065.50	2067.25	2070.20	0.003	25
run/begin pool	75	2061.30	2067.18	2070.15	0.0016	50
max pool	125	2055.05	2067.10	2070.05	0.0004	75
pool	200	2059.20	2067.07	2069.90	0.0004	75
end pool/glide	275	2062.55	2067.04	2069.75	0.0011	75
begin riffle	350	2065.00	2066.96	2069.60	0.003	50
end riffle	400	2064.80	2066.81	2069.50	0.003	25
run/begin pool	425	2060.60	2066.73	2069.45	0.0016	50
max pool	475	2054.35	2066.65	2069.35	0.0004	75
pool	550	2058.50	2066.62	2069.20	0.0004	75
end pool/glide	625	2061.85	2066.59	2069.05	0.0011	75
begin riffle	700	2064.30	2066.51	2068.90	0.003	50
end riffle	750	2064.10	2066.36	2068.80	0.003	25
run/begin pool	775	2059.90	2066.29	2068.75	0.0016	50
max pool	825	2053.65	2066.21	2068.65	0.0004	75
pool	900	2057.80	2066.18	2068.50	0.0004	75
end pool/glide	975	2061.15	2066.15	2068.35	0.0011	75
begin riffle	1050	2063.60	2066.07	2068.20	0.003	50
end riffle	1100	2063.40	2065.92	2068.10	0.003	25
run/begin pool	1125	2059.20	2065.84	2068.05	0.0016	50
max pool	1175	2052.95	2065.76	2067.95	0.0004	75
pool	1250	2057.10	2065.73	2067.80	0.0004	75
end pool/glide	1325	2060.45	2065.70	2067.65	0.0011	75
begin riffle	1400	2062.90	2065.62	2067.50	0.003	

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	STREAM:	Clear Creek
							ID NUMBER:	Typical Riffle Section
-60.00	279.00	-4.65	7.10	63.28	4.41	12.90	DATE	2/11/2002
-30.00	39.80	-1.33	2.60	40.63	0.98		Bankfull	
							Water Surface	

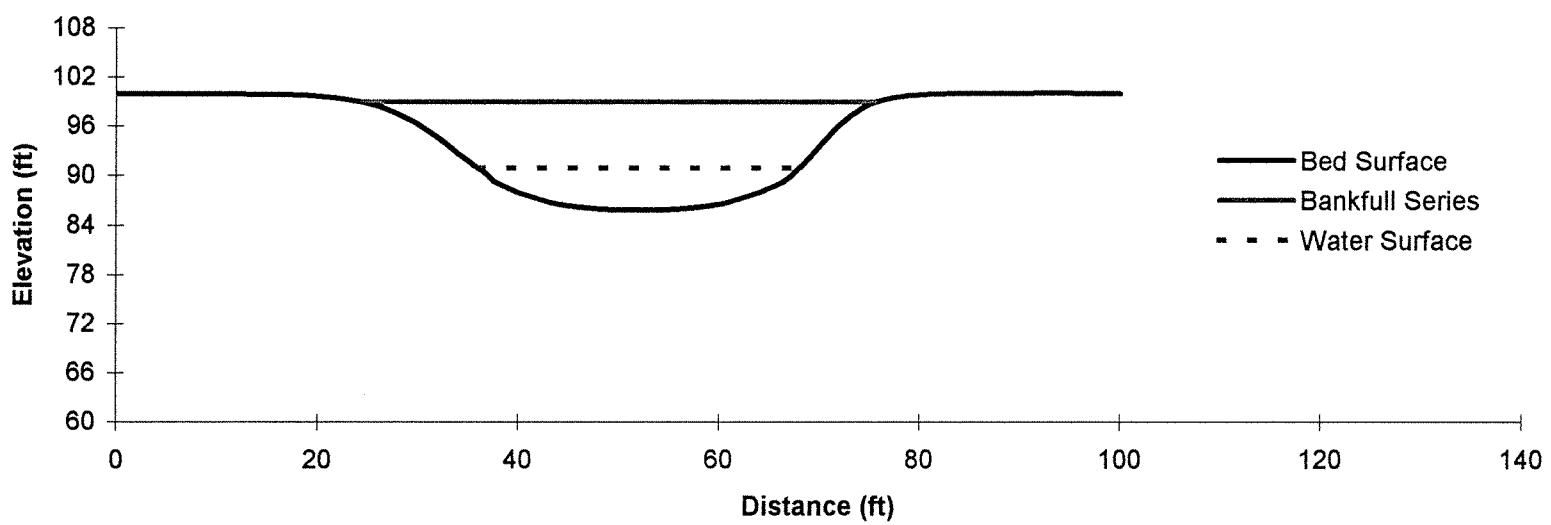
Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	100.00			
	10.0	100.00			
rbf	20.0	99.00			
	25.0	95.00			
rew	35.0	94.50			
	50.0	91.90			
lew	65.0	94.50			
	75.0	95.00			
lbf	80.0	99.00			
	90.0	100.00			
	100.0	100.00			



Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	
51.40	454.20	8.84	13.20	60.00	7.57	5.82	Bankfull
32.00	120.60	3.77	5.20	34.72	3.47		Water Surface

STREAM: Clear Creek
ID NUMBER: Typical run section
DATE 2/12/2002

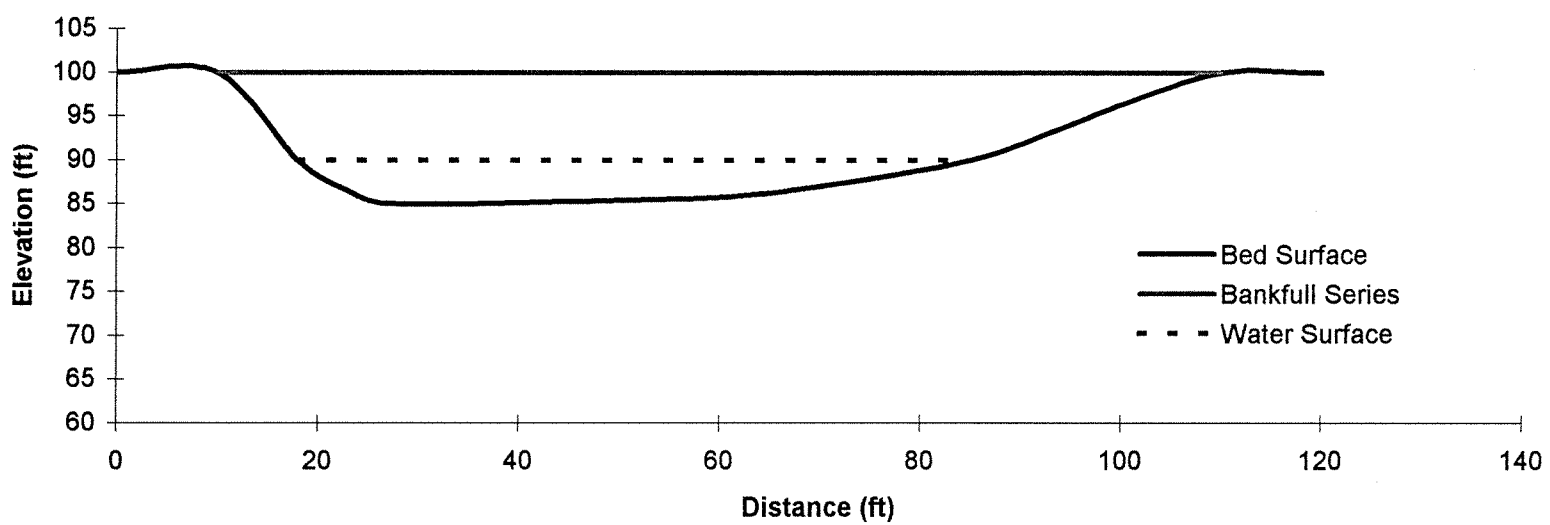
Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	100.00			
lbf	24.3	99.00			
lew	36.0	91.00			
	38.0	89.00			
	44.0	86.50			
	52.0	85.80			
	60.0	86.50			
	66.0	89.00			
rew	68.0	91.00			
rbf	75.7	99.00			
	90.0	100.00			
	100.0	100.00			



Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	
100.00	1073.38	10.73	15.00	129.86	8.27	9.32	Bankfull
67.00	240.25	3.59	5.00	73.76	3.26		Water Surface

STREAM: Clear Creek
ID NUMBER: Typical pool section
DATE 2/12/2002

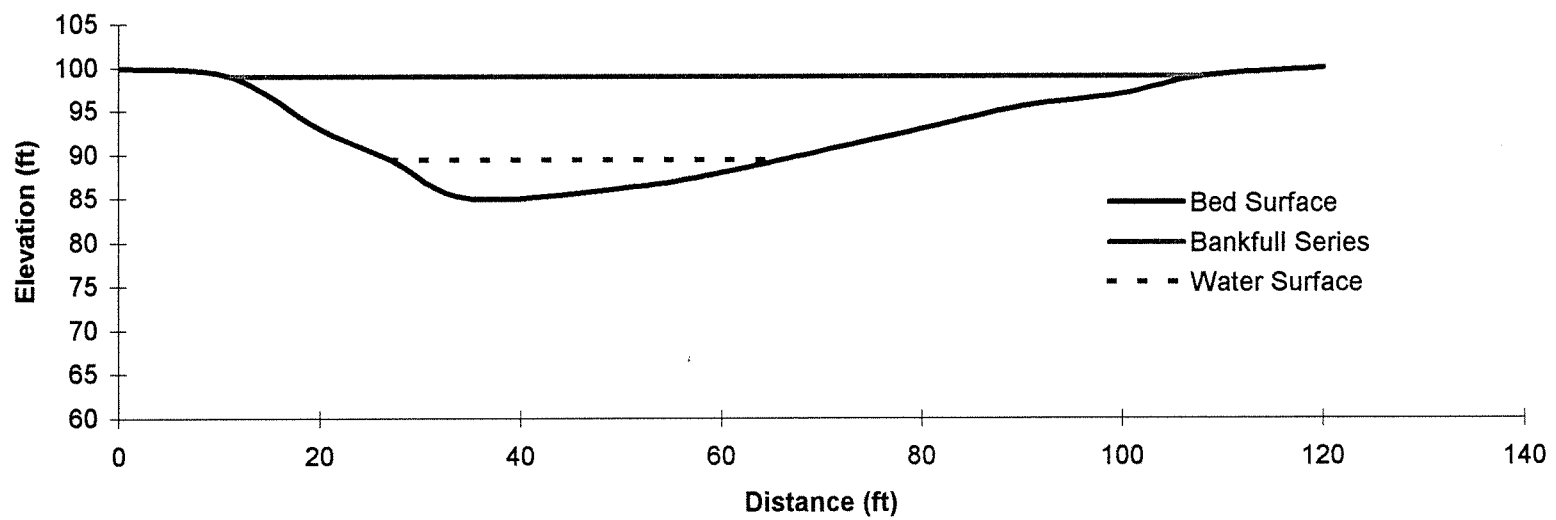
Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	100.00		120.0	100.00
lbf	10.0	100.00			
lew	18.0	90.00			
	23.0	86.50			
	27.0	85.00			
	45.0	85.25			
	50.0	85.35			
	60.0	85.75			
	70.0	87.00			
rew	85.0	90.00			
		94.00			
		96.25			
	95.0	100.00			
	100.0	100.00			
rbf	110.0	100.00			



Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	
97.00	747.50	7.71	14.00	102.31	7.31	12.59	Bankfull
39.00	104.25	2.67	4.50	40.57	2.57		Water Surface

STREAM: Clear Creek
ID NUMBER: Typical glide Section
DATE 2/12/2002

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	100.00			
lbf	11.0	99.00			
	20.0	93.00			
lew	27.0	89.50			
	35.0	85.00			
	52.0	86.50			
	60.0	88.00			
rew	66.0	89.50			
	80.0	93.00			
	90.0	95.50			
	100.0	97.00			
rbf	108.0	99.00			
	120.0	100.00			



Velocity Comparison Form

Class

Date Team EcoLogic

Stream CLEAR CREEK (PROPOSED) Location HENDERSONVILLE

Input Variables			Output Variables		
Bankfull Cross Sectional Area (A_{BKF})	280.0	ft^2	Bankfull Mean Depth $D_{BKF} = (A_{BKF}/W_{BKF})$	4.65	ft
Bankfull Width (W_{BKF})	60.0	ft	Wetted Perimeter (WP) $(\sim(2*D_{BKF})+W_{BKF})$	63.3	ft
D84	32	mm	D84 (mm/304.8)	0.105	ft
Bankfull Slope	0.002	ft/ft	Hydraulic Radius (R) (A_{BKF}/WP)	4.41	ft
Gravity	32.2	ft/s^2	R/D84 (use D84 in FEET)	42	ft/ft

R/D84, u/u*, Mannings n		
u/u* (using R/D84: see Reference Reach Field Book: p188, River Field Book:p233)	11.8	ft/s/ ft/s
Mannings n: (Reference Reach Field Book: p189, River Field Book:p236)	0.025	$ft^{1/6}$
Velocity: from Manning's equation: $u=1.49R^{2/3}S^{1/2}/n$	7.2	ft/s

u/u*=2.83+5.7logR/D84		
u*: $u^*=(gRS)^{0.5}$	0.53	ft/s
Velocity: $u=u^*(2.83+5.7\log R/D84)$	6.4	ft/s

Mannings n by Stream Type		
Stream Type	C4	
Mannings n: (Reference Reach Field Book: p187, River Field Book:p237)	0.019	$ft^{1/6}$
Velocity: from Manning's equation $u=1.49R^{2/3}S^{1/2}/n$	9.0	ft/s

Continuity Equation		
Q_{BKF} (cfs) from regional curve or stream gage calibration	1390	cfs
Velocity (u=Q/A or from stream gage hydraulic geometry)	5.0	ft/s

Streamside Vegetation Establishment Plan
Clear Creek, Henderson County

Draft 04Mar02

This site will require transplanting and reuse of on site woody and herbaceous plants and the addition of new planting material. The work will consist of preparing the planting areas, furnishing and placing transplants, sod mats, seed, live stakes, bareroot trees, mulch, fertilizer, soil amendments and anchored ground covering materials. These will be placed in the streambanks, floodplain, access areas and other areas disturbed by construction.

Seeding

Seedbed Preparation

On sites where equipment can be operated safely the seedbed shall be adequately loosened and smoothed. Foreign material and obstructions should be removed at this time. Disking and cultipacking or both may be necessary. On sites where equipment cannot access, the seedbed should be prepared by hand. All surfaces should be scarified to produce a surface where seed can stay in place until successful germination. If seeding is done immediately after construction, seedbed preparation may not be required except on compacted, polished or freshly cut areas.

Fertilizing

Evenly distribute lime and fertilizer over the area to be seeded. Uniformly mix the lime and fertilizer into the top 3 inches of soil. Apply lime and fertilizer according to soil test results or at the following rates

Lime	50-100 lbs./ 1000 sq. ft.	1-2 tons/ acre
Fertilizer (10-10-10)	9-12 lbs./ 1000 sq. ft.	400-500 lbs./ acre

Sod Mats

Strip and stockpile mats of existing desirable herbaceous vegetation. Insure that several inches of soil remains attached to the vegetation. The root systems should remain moist and protected from direct sunlight and drying winds while the vegetation is stockpiled. These mats will be placed on the bankfull benches and lower slopes of the banks and anchored in place with stakes. Native sedges and rushes are preferable for use as sod mats however, fescue and other sod-forming species are acceptable if they are found on site.

Seeding

Temporary Seeding

Used on recently graded or disturbed sites when erosion and sedimentation control is required and permanent vegetation cannot be established due to planting season or logistics. The use of temporary seedings may also be required to stabilize the site prior to

the establishment of native or other woody vegetation. Anchored mulch or erosion control fabrics will be needed to provide surface protection until any vegetation becomes established.

Fall and Winter Seeding		
Oats	2lbs. / 1000 sq. ft.	3 bu. / acre
Rye	3lbs. / 1000 sq. ft.	2.5 bu. / acre

Summer Seeding		
Sudangrass	1 lb. / 1000 sq. ft.	35-45 lbs. / acre
Browntop Millet	1 lb. / 1000 sq. ft.	30-40 lbs. / acre

Permanent Seeding

Use in combination with woody plantings and transplants on the upslope side of the riparian planting. Late spring and summer planting is ideal for native perennial warm season grasses. These grasses should be used when enhancing wildlife habitat is a goal of the riparian planting. Spring planted seed should be pre-treated with a cold, wet chill process to maximize germination. Fall plantings should be planted with a lightly sowed cool season annual grass and forb mixture to hold the soil. Fall plantings do not need the wet, chill pretreatment. Omit the fertilizer when planting native grasses. A mixture of at least three native grasses should be used. Competition from sod-forming grasses like fescue and bluegrass should be removed by either mechanically or chemically eliminating these before planting the native mixes.

Cool Season Fall or Spring Seedings

Orchardgrass	0.3 lbs. / 1000 sq. ft.	7 lbs. / acre
Big, Little or Broomsedge Bluestem	0.2 lbs. / 1000 sq. ft.	5 lbs. / acre
Eastern Gamma or Switchgrass	0.5 lbs. / 1000 sq. ft.	10 lbs. / acre

A mixture can be made with components at ½ the above rates. Mixtures should include three or more species. The addition of a legume like white clover (at 1/4 recommended rate) is advocated when planting a mixture.

Warm Season Summer Seedings

A warm season grass mix similar to the following is commercially available from several sources. Soil temperature must be above 55°F for proper germination. Seed germination can be further enhanced by pressing the seed into the seedbed using a roller.

Annual Ryegrass	40%
Big Bluestem	26%
Little Bluestem	14%
Indiangrass	14%
Switchgrass	6%

The recommended rate is 42 pounds of mix / acre.

Mulching

Mulching should be performed at the time of seed sowing or within 48 hours of that time. Weed free grain straw should be applied on seeded areas at a rate of 3 bales per 1000 square feet or 1.5 tons per acre. Mulch should be applied uniformly. Mulch should be anchored with a mulch crimper, asphalt tackifier, wet down with water or held in place with appropriate mulch netting.

Woody Plant Installation

Care and Handling

All planting stock should be treated in such a way as to promote the health and vigor of the plant material and reduce the stress of transplanting and reestablishment. Planting stock should be stored in a cool and moist environment and protected from direct sun and drying winds. Roots of bareroot stock shall be kept moist before and during planting operations. Containerized or potted stock shall be kept moist at all times. Live stakes should be planted while dormant, which may require refrigeration if the weather is warm. Damaged roots or shoots should be pruned appropriately during installation.

Transplants

Most woody species found along riparian corridors can be salvaged by transplanting. Native shrubs and small trees transplant well and will provide mature growth much faster than other planting material. Even the stumps of many large trees will resprout and survive proper transplantation. Care should be taken to mark the desirable transplants along the corridor prior to construction. These plants should be marked with paint or flagging. These plants are then excavated during the first phase of construction and placed in a safe location nearby. This site should be sheltered from the afternoon sun and winds. Periodic checks should be made to see that the soil around the roots remains moist, they can be watered as needed.

Care should be taken to get as much root ball as possible. It is also advisable to protect the stems or trunk during this digging and moving procedure. Single trunks should be temporarily wrapped with thick cloth or other padding if necessary to prevent damage to the cambium and bark. Multi-stemmed shrubs are often tied together to make them more easy to handle and less prone to damage. Once the plants have been lifted from their original position and set in the temporary location the tops should be trimmed. Depending on the size of the plant and the species one third to one half of the shoot mass should be removed.

Transplanted material should be placed in their final location as soon as possible or heeled into a temporary ditch outside of the construction zone until the planting site is complete. As with other woody plant material the transplants should be re-set so that the root collar is no deeper then the soil surface, the soil should be firmly compacted around the rootball and the plant should be watered by thorough soaking. No fertilizer should be added.

Planting

Plant rooted stock in a vertical position with the root collar just at the soil surface. The planting trench or hole must be deep enough and wide enough to permit the roots to spread out and down without a bending of the primary root structures. Care should be taken to prevent breaking or damaging the roots or "J" planting of tap root structures. Make sure that the roots are in contact with soil and no air pockets remain after the soil has been packed and firmed around the planting. Dormant plantings should be inserted to a depth that allows them to reach adequate soil moisture.

Species Selection

It is important to plant as much diversity as is available to enhance the wildlife value, aesthetics and resilience of the corridor and restoration. At a minimum a selection of 10-12 tree and shrub species should be selected that add to the species diversity that occurs naturally at this site. The density, effectiveness and ecological function of the woody plantings will be enhanced by combining canopy trees, understory trees and shrubs in a mixture that approximates a natural riparian forest type that would occur in an undisturbed site.

Bare-root and containerized woody species should be planted on the top of the bank along then length of the riparian corridor. Live stakes and transplanted material should be used on the lower banks and bankfull benches.

Tree Species Suitable for Clear Creek Restoration

Plant to Plant Spacing 9-9 feet 530 plants / acre initial stock density

Black Willow, Green Ash, Sugar Maple, Sycamore, American Chestnut, Hackberry, Sweet Birch, River Birch, Bitternut or Pignut Hickory, Persimmon, Black Walnut, Cucumber Magnolia, Black Gum, Sourwood, Shortleaf Pine, White Pine, Black Cherry, Scarlet Oak, Swamp Chestnut Oak, Red Oak, Black Locust, Basswood, Eastern Hemlock, American Elm, Pawpaw, American Holly

Shrub Species Suitable for Clear Creek Restoration

Plant to Plant Spacing 5-5 feet 1700 / acre initial stock density

Buttonbush, Hazelnut, Elderberry, Red Chokeberry, Silky Dogwood, Spicebush, Serviceberry, Hawthorne, Highbush Blueberry, Tag Alder, Witch Hazel, Sweet Shrub, Buttonbush, Sweet Pepperbush, Winterberry, Mountain Laurel, Blackhaw, Yellowroot

Target density of the planting at maturity is 320 trees per acre and 1200 shrubs per acre.

The use of tree shelters or bark wrap may be necessary at Clear Creek to prevent damage by the resident beaver and deer populations. These shelters can be used on the more valuable material and the most slow growing and hard to establish species. These shelters will also accelerate the growth of these woody plants so that they can withstand

this herbivore attack. Other anti-browsing chemical deterrents may also be needed to train these animals to avoid these plantings until they become established.

Live stakes

Live stakes and other cuttings should be dormant at the time of installation. They should be typically ½ to ¾ inch in diameter and 2-3 feet long. They should have a pointed end at the bottom to facilitate driving into the bank with a dead-blow hammer. Two thirds of the stake should be driven into the ground leaving less than 6 inches above the surface. The stakes will be planted on 3 foot spacing in staggered rows. The number and location of the live stake rows will be determined by the size and shape of the bank, location of transplants, sod mats and existing woody vegetation. A minimum of three rows starting at the foot of the bank and extending to the top of the bank with additional rows as needed. Damage from the hammering should be clipped off leaving a clean, smooth cut.

Live Stake Species suitable for Clear Creek Restoration

Black Willow
Streamco Willow
Silky Dogwood
Red-Osier Dogwood

The planting should include a mixture of the above species with no more than 40% of any one species and no less than 15% of the least common.

All trash should be removed from the site after planting and disposed of properly. Once all plantings are completely installed the site should be left as clean and as natural looking as possible.

Monitoring Plan for Clear Creek
Hendersonville, NC

Stream restoration in North Carolina requires physical and biological monitoring based on NC Division of Water Quality criteria. The monitoring period is five (5) years. This time is required to assess the stability of the restored channel and the survivability of the vegetation planted during the restoration. The monitoring should be done annually following the completion of construction. Reports should be sent to the USACE each year and NC DWQ on the first, third and fifth years.

The Monitoring Report should include the following items from new data collected each year.

The restoration of Clear Creek involves changes to dimension, pattern and profile. Benchmarks for permanent cross sections, photo points and the top of the restoration reach profile will be installed during construction. These benchmarks will be referenced during all following data collection monitoring visits. Use of benchmarks will allow all monitoring data to be comparable.

Stream Geomorphology
The minimum requirements of one cross section per 20 bankfull widths could be met with one cross section. The designers feel that there should be three cross sections to more adequately monitor the upper, middle and lower sections of the reach since the amount of channel relocation and in-situ vegetation differs across this range. These cross sections will be located in such a way as to capture the range of cross sectional geometry installed at this site. One section will be a riffle section in the middle of the project that will also be the site of monitoring pebble counts, benthic macro-invertebrate collections and channel geometry diagnostics like width-depth ratio, entrenchment ratio, bank height ratios and bankfull depth measurements. One riffle cross section will be at the top of the reach, which will also be a benthic macro-invertebrate collection site. The third cross section will be in one of the curves to measure stability of a pool.

The pattern of the as-built stream will be documented with measurements of sinuosity, meander width ratio, and radius of curvature on the newly constructed meanders.

A longitudinal profile will be run through the length of the restoration reach. This profile will measure the bed, water surface, and bankfull elevations with careful documentation of bed features. The resultant data should provide facet slopes of the riffles and pools and the spacing and length of the features documented.

The bed materials will be documented by conducting a pebble count at each reference location. The d50 and d84 of the riffles will be calculated and reported. A classification pebble count based on the proportional percentage of riffles and pools will also be conducted and reported.

Riparian Revegetation
Transects or sample blocks will be established for monitoring the riparian vegetation. The herbaceous sod mat transplants and new seedings will be assessed for establishment,

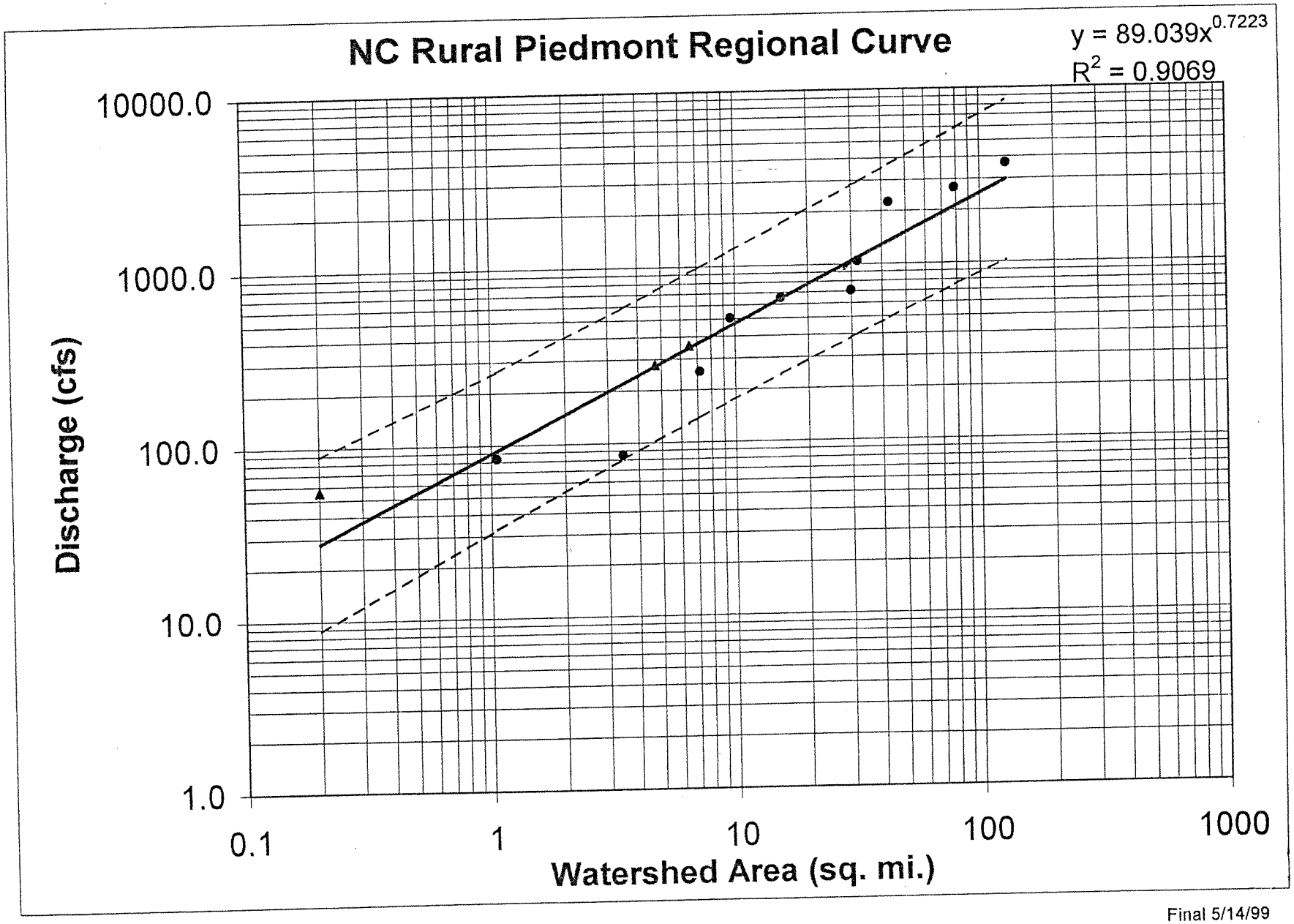
survivability and durability. The transplants and woody stems will be counted and assessed for survivability and to document attainment of the success criteria of 320 trees per acre after five years.

Benthos

Benthic macro-invertebrates will be collected as per the standard methods outlined in the Benthic Macroinvertibrate Monitoring Protocols for Compensatory Stream Restoration Projects Technical Guide. At least one member of the collecting team will be a NC-DWQ Certified Benthic Macroinvertibrate Collector. A NC-DWQ Certified Lab will identify the samples.

Photo Points

Photographs showing the banks and the channel with a scale included will document each permanent cross section. Photographs will also be taken of the in-stream structures, the vegetation on the banks and some longitudinal views of the restoration reach.


NC Rural Piedmont Regional Curve
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R^2 = 0.9069
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1000.0
100.0
10.0
1.0
Discharge (cfs)
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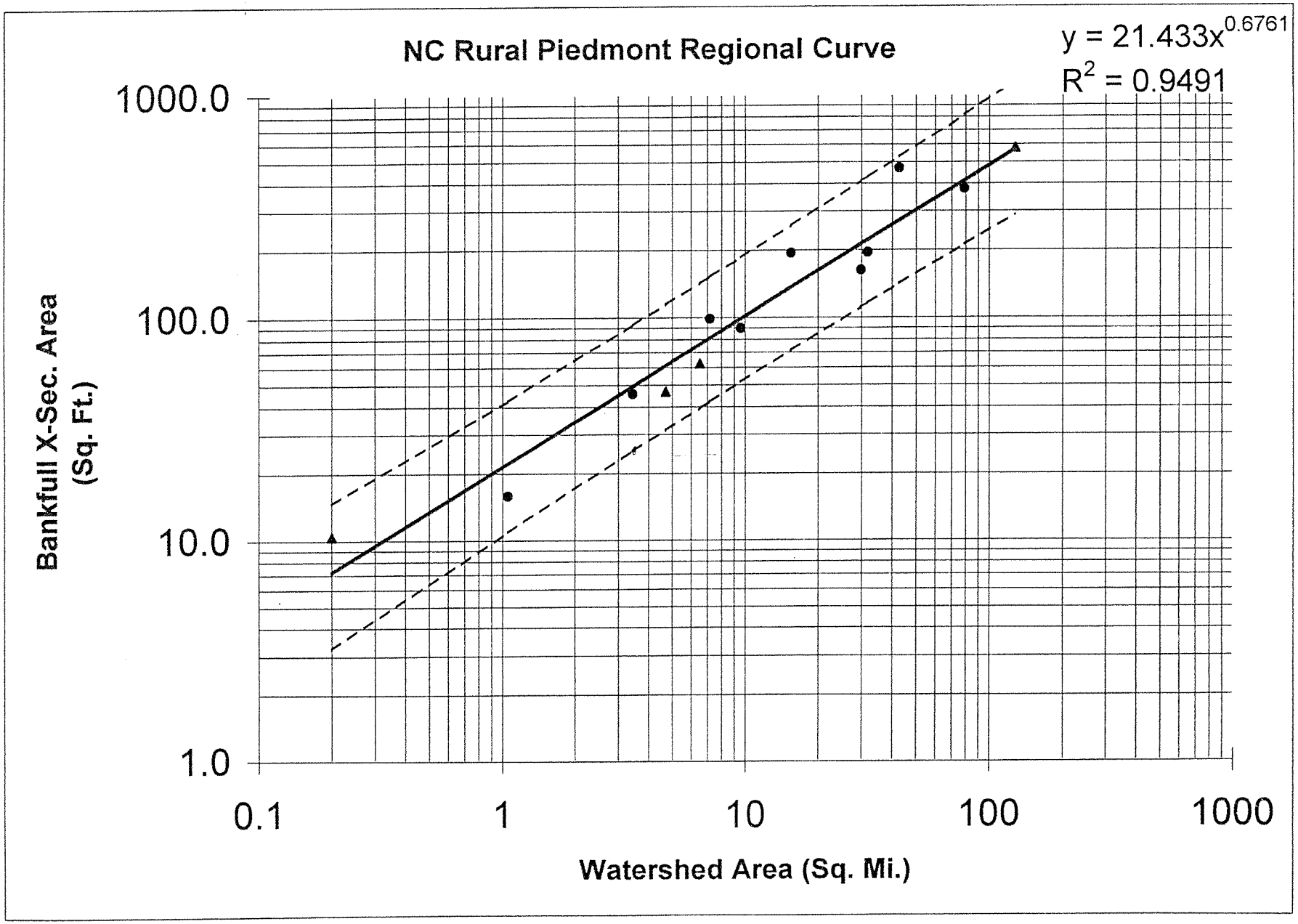
1
10
100
1000
Watershed Area (sq. mi.)

Final 5/14/99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R^2 = 0.9491
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100.0
10.0
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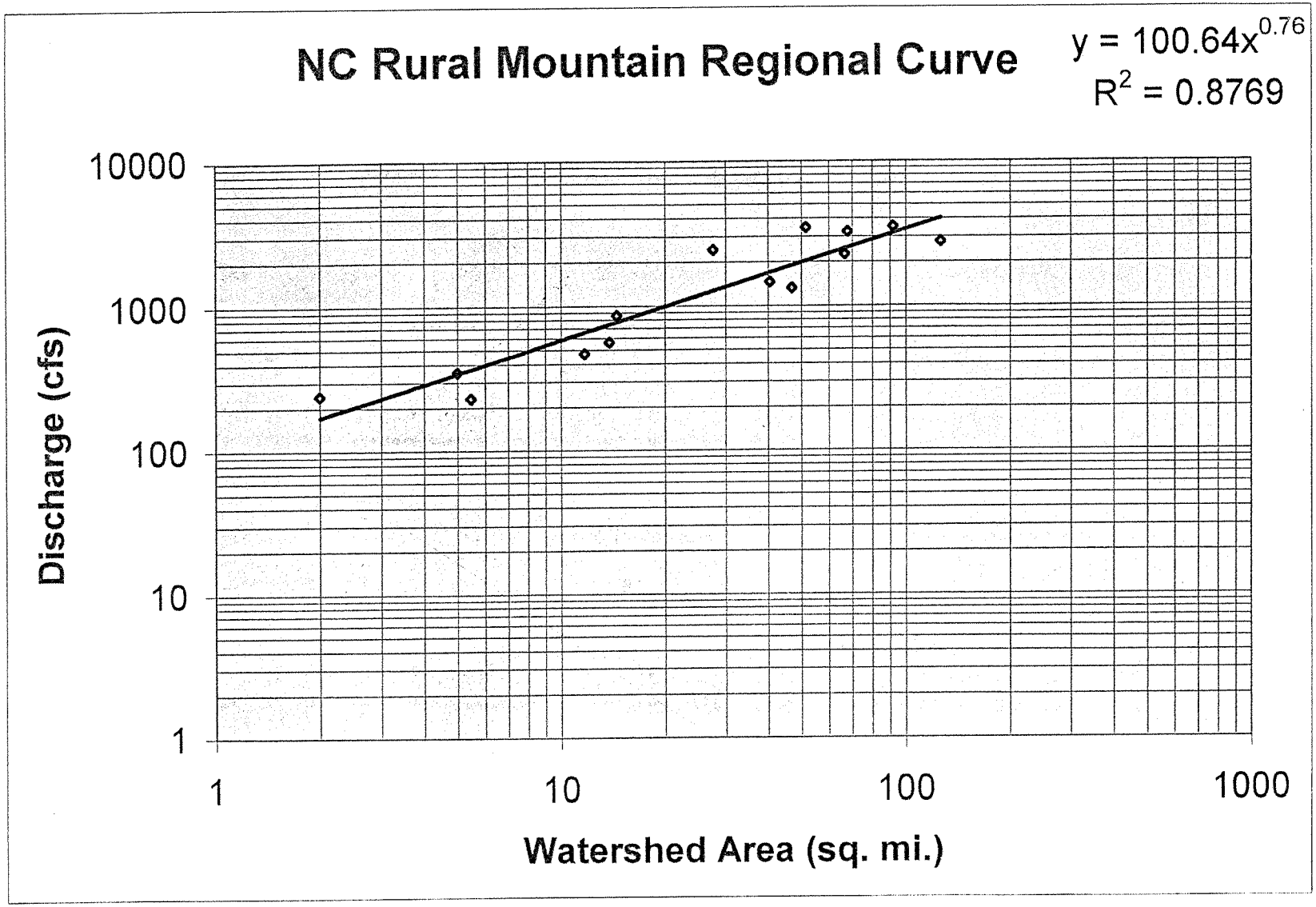
1
10
100
1000
Bankfull X-Sec. Area (Sq. Ft.)
Watershed Area (Sq. Mi.)

Final 5/14/99


NC Rural Mountain Regional Curve
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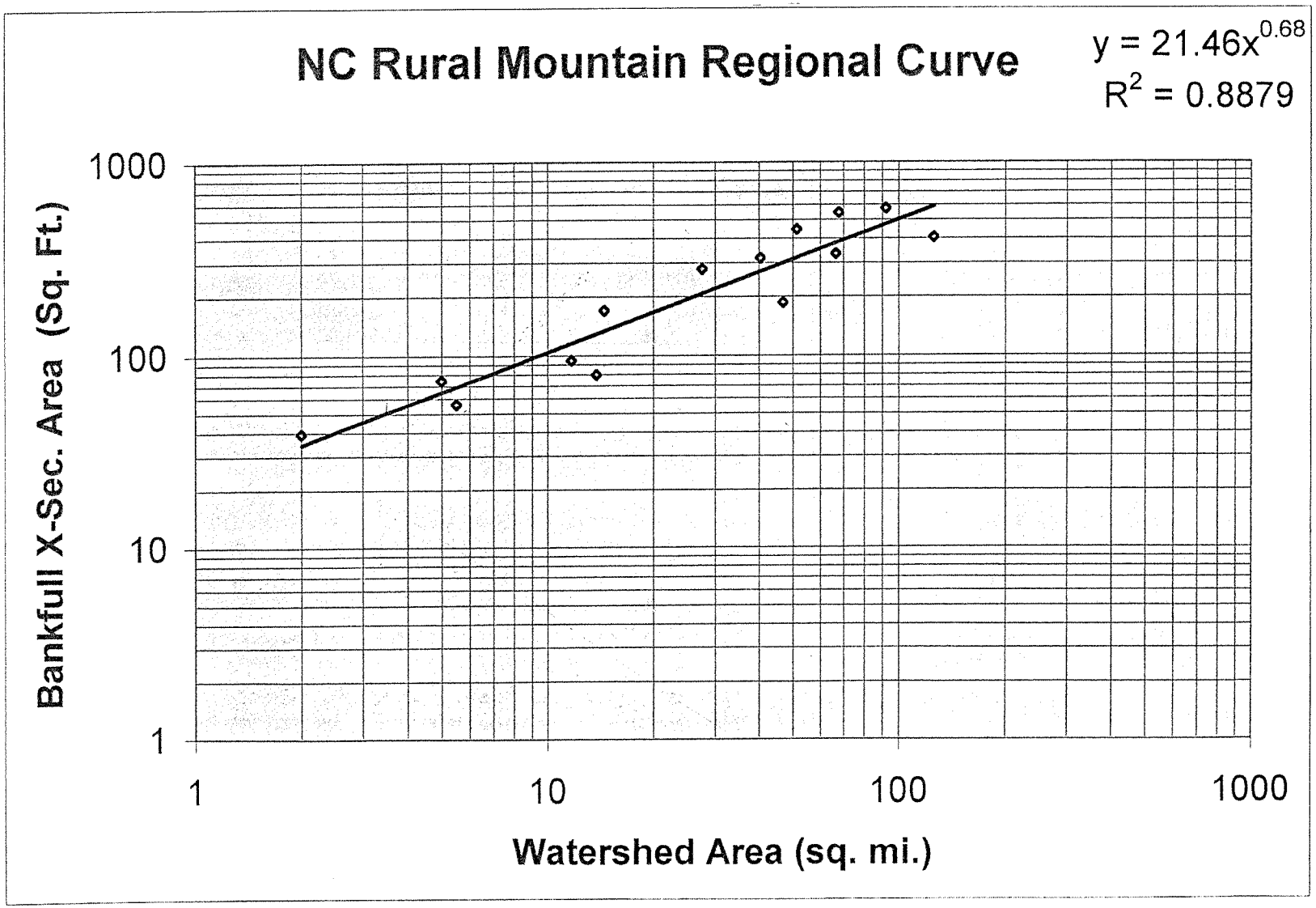
1000
100
10
1
1
10
100
1000
Watershed Area (sq. mi.)


NC Rural Mountain Regional Curve
y = 21.46x^0.68
R^2 = 0.8879
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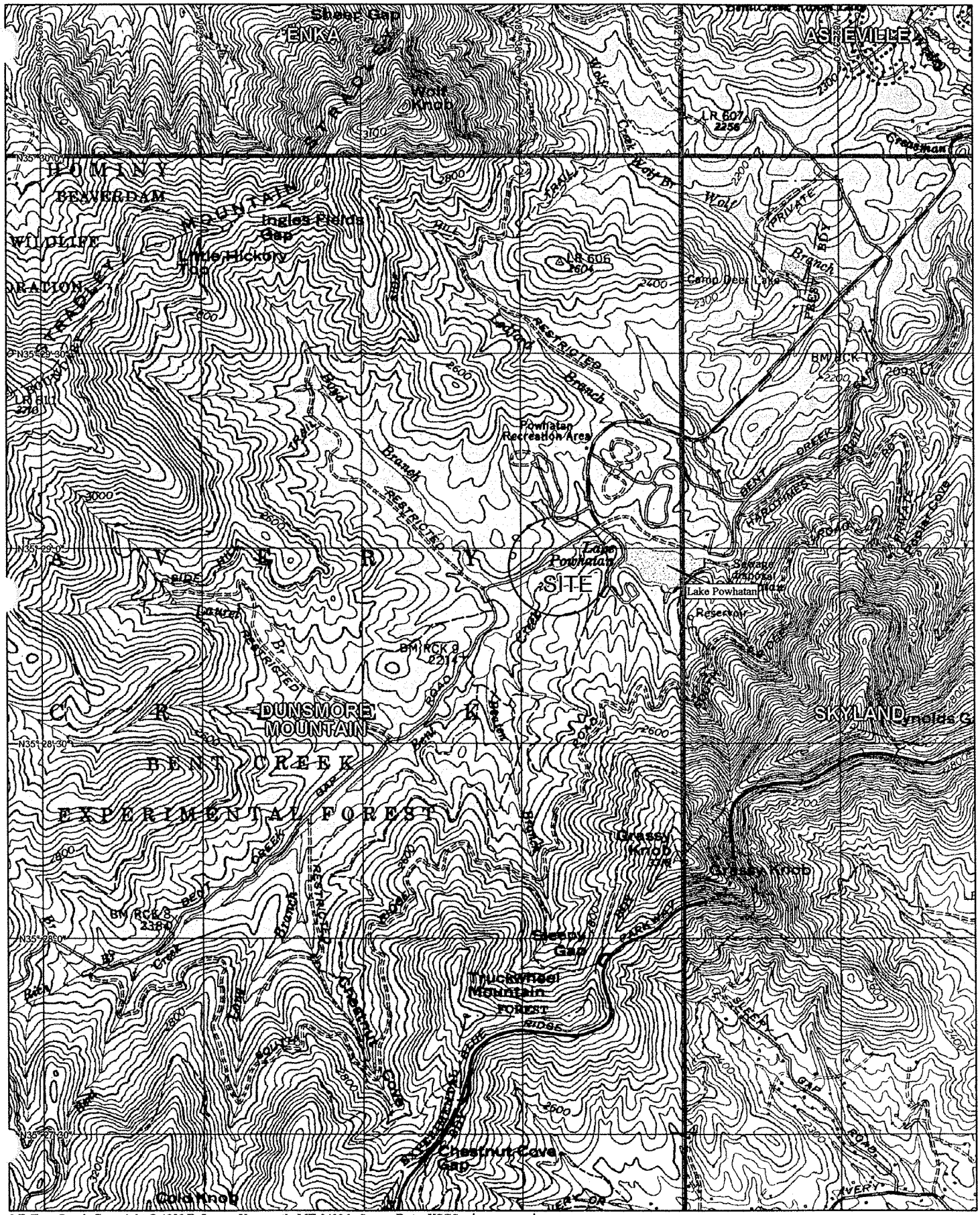
1000
100
10
1
1
10
100
1000
Watershed Area (sq. mi.)



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS 950 ft Scale: 1 : 24,000 Detail: 13-1 Datum: WGS84

SITE NAME: Bent Creek **DATE:** December 12, 2001

SIZE: 500 feet **QUADRANGLE:** Dunsmore MT

LOCATION: In the Bent Creek Experimental Forest southeast of Asheville, NC. The reach is 4500 feet upstream of Lake Powhatan, just below an old dam ruin. The site within a mile of the Blue Ridge Parkway which edges the valley on the south (Truckwheel Mt) and east (Grassy Knob). The reference reach can be reached by parking at the Hardtimes trail head and hiking upstream or parking along the road in a campsite just above the reach.

SITE SIGNIFICANCE: Type C Reference Reach

GENERAL DESCRIPTION: Bent Creek flows through the bottom of the valley that contains the Bent Creek Experimental Forest southwest of Asheville, NC. The valley contains many trails for hiking and mountain bike riding which appear to be heavily used. There is also a large campground near Lake Powhatan that is open during the summer season. Additionally there are year round camping facilities available along the road that follows along the north side of Bent Creek up to the headwaters of the valley at Truckwheel Mountain.

The reach runs through a Type 2 or 3 valley type with moderately steep, gentle, sloping valley that includes some alluvial deposites. At this point in the valley there are accessible floodplains on one or both sides of the creek, allowing the development of meander patterns and depositional features typical of a Type C stream. The end of the reach is constricted against a high bank on the right with a floodplain only on the left.

The valley contains a young to moderate age tree canopy dominated by tuilp tree, red maple, pines and hemlocks. The understory along the creek includes witch hazel, ironwood, rhododendrons, mountain laurel, greenbriar and dog hobble. Herbs along the creek include asters, seedbox, panicum grasses, violets, wiregrass, sedges, rushes mosses and liverworts.

REFERENCE REACH Summary Data

Stream Name: BENT CREEK (FRENCH BROAD RIVER BASIN)
Location: UPSTREAM OF LAKE POWHATAN, PISGAH NATIONAL FOREST, BUNCOMBE COUNTY, NC
Date: 12/18/2001
Crew: Louise Slate, Ken Bridle, Mark Taylor, Kelly Brannon
Stream Type: C4
Watershed Area: 5.35 sq. miles

Channel Dimensions

Max. Riffle Depth(drmax)(ft.):	3.0
Riffle Width(Wr)(ft.):	37.0
Riffle X-Sect. Area(Ar)(ft^2):	61.8
Riffle Mean Bankfull Depth(dmbkf):	1.7
Width/Depth ratio	22.2

Max. Pool Depth(dpmax)(ft.):	5.0
Pool Width(Wp)(ft.):	23.4
Pool X-Sect. Area(Ap)(ft.):	55.9

Ratio: Max. Pool Depth/Max. Riffle Depth(dpmax/drmax):	1.6	
Ratio: Pool Width/Riffle Width(Wp/Wr):	0.6	
Ratio: Pool Area/Riffle Area(Ap/Ar):	0.9	
Ratio: Max. Pool Depth/Mean Bankfull Depth(dpmax/dbkf):	3.0	
Ratio: Lowest Bank Height/Max. Bankfull Depth(Bhlow/dmbkf):	1.1	
Streamflow: Estimated Mean Velocity(u) @ Bankfull Stage:	5.8	ft./sec.
Streamflow: Estimated Discharge(Q) @ Bankfull Stage:	360	CFS

Channel Pattern

	Mean	Median	Min	Max	
Meander Wavelength(Lm):	92.0		76.0	108.0	ft.
Radius of Curvature(Rc):	20.4	20.4	17.6	23.1	ft.
Beltwidth(Wblt):	28				ft.
Meander Width Ratio(MWR=Wblt/Wbkf):	0.76		2.05	2.92	
RATIO: Radius of Curvature/Bankfull Width(Rc/Wbkf):	0.55	0.55	0.48	0.62	
RATIO: Meander Wavelength/Bankfull Width(Lm/Wbkf):	2.49				

Channel Profile

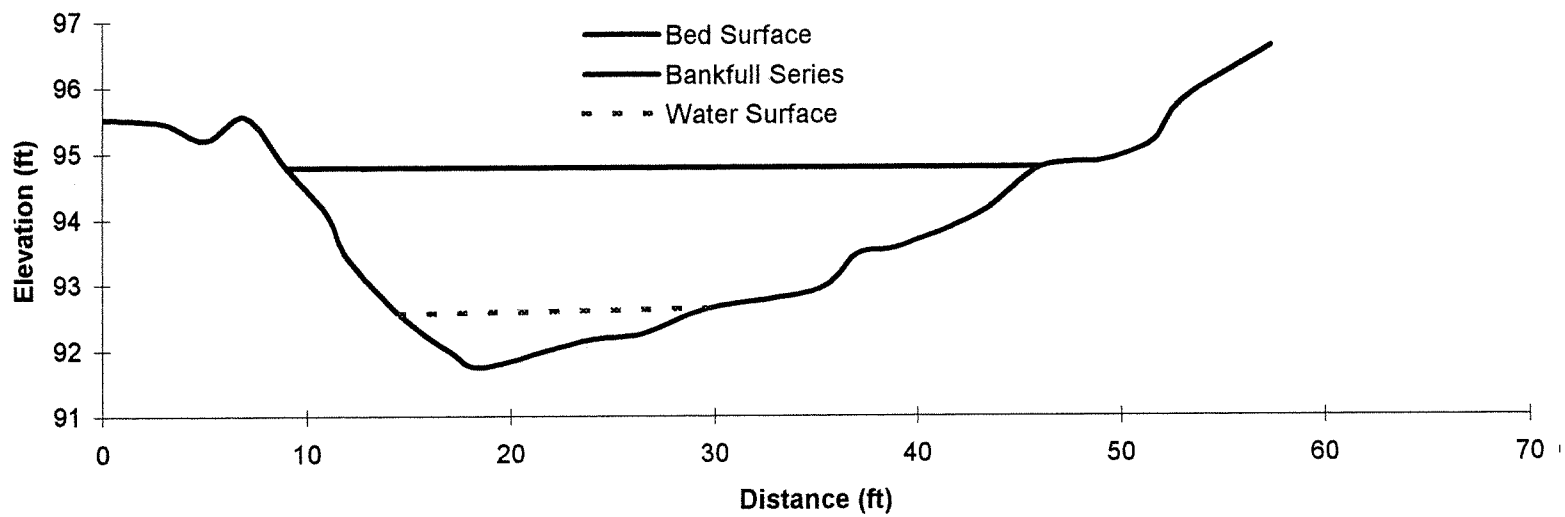
	mean	median					
			Valley Slope:	0.0225	ft./ft		
			Water Surface Slope:	0.0105	ft./ft		
			Riffle Slope:	0.0340	0.0286	0.0107	0.0680 ft./ft
			Pool Slope:	0.0018	0.0010	0.0003	0.0040 ft./ft
			Run Slope:	0.0138	0.0141	0.0100	0.0169 ft./ft
			Glide Slope:	0.0056	0.0060	0.0000	0.0111 ft./ft
r length/w bkf	0.41		Riffle Length:	15.0	15.0	10.0	19.0 ft.
pool l/ w bkf	0.72	0.45	Pool Length:	26.5	16.5	12.0	70.0 ft.
run l/w bkf	0.37	0.32	Run Length:	13.8	12.0	7.0	26.0 ft.
glide w/w bkf	0.39	0.43	Glide Length:	14.5	16.0	7.0	21.0 ft.
	1.78	1.73	Riffle to Riffle Spacing:	65.8	64.0	32.0	121.0 ft.
	1.79	1.70	Pool to Pool Spacing:	66.2	63.0	51.0	99.0 ft.
	0.97	0.81	Riffle to Pool Spacing:	36.0	30.0	17.0	63.0 ft.

RATIO: Riffle Slope/ Water Surface Slope:	3.24	2.72	1.02	6.48
RATIO: Pool Slope/Water Surface Slope:	0.17	0.10	0.03	0.38
RATIO: Run Slope/Water Surface Slope:	1.32	1.35	0.95	1.61
RATIO: Glide Slope/ Water Surface Slope:	0.53	0.57	0.00	1.06
RATIO: Max. Riffle Depth/Mean Bankfull Depth:	1.81			
RATIO: Max.Pool Depth/Mean Bankfull Depth:	2.98			
RATIO: Max. Run Depth/Mean Bankfull Depth:	n/a			
RATIO: Max. Glide Depth/Mean Bankfull Depth:	n/a			
RATIO: Riffle Length/Bankfull Width:	0.41	0.41	0.27	0.51
RATIO: Pool Length/Bankfull Width:	0.72	0.45	0.32	1.89
RATIO: Run Length/Bankfull Width:	0.37	0.32	0.19	0.70
RATIO: Glide Length/Bankfull Width:	0.39	0.43	0.19	0.57
RATIO: Riffle to Riffle Spacing/Bankfull Width:	1.78	1.73	0.86	3.27
RATIO: Pool to Pool Spacing/Bankfull Width:	1.79	1.70	1.38	2.68
RATIO: Riffle to Pool Spacing/Bankfull Width:	0.97	0.81	0.46	1.70

D84:	32	mm
dmbkf:	509	mm
dmbkf/D84:	15.91	
u/u* :	9.5	Reference: Rosgen Reference Reach Field Book
Mannings 'n':	0.029	"

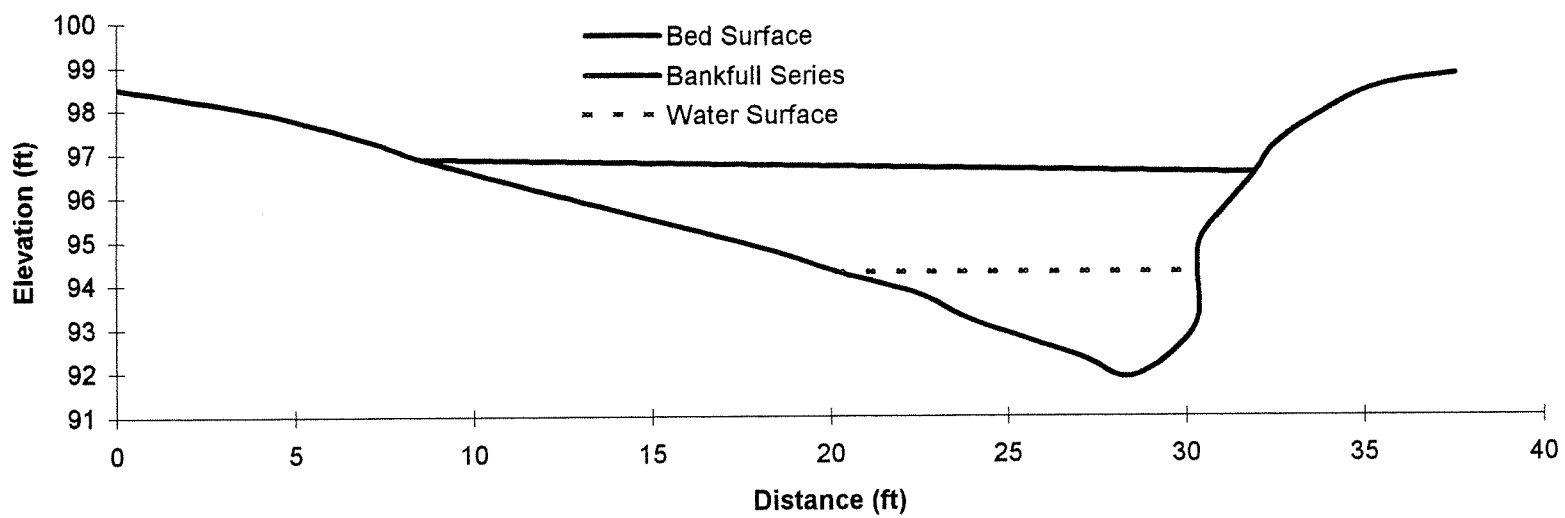
Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	STREAM:	Bent Creek
							ID NUMBER:	Upstream of Lake Powhatan
							DATE	12/18/2001
37.00	67.29	1.82	3.03	37.78	1.78	20.34	Bankfull	
15.20	6.52	0.43	0.82	15.32	0.43		Water Surface	

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	95.52		37.0	93.47
	3.0	95.45		39.0	93.58
	5.0	95.20		43.0	94.08
	7.0	95.55	rbf	46.0	94.78
lbf	9.0	94.78		49.0	94.88
	11.0	94.07		51.5	95.17
	12.0	93.42		53.0	95.80
lew	14.5	92.56		57.3	96.62
	17.0	91.99			
	18.5	91.75			
	22.0	92.02			
	24.0	92.18			
	26.5	92.26			
rew	29.7	92.64			
	35.0	92.93			

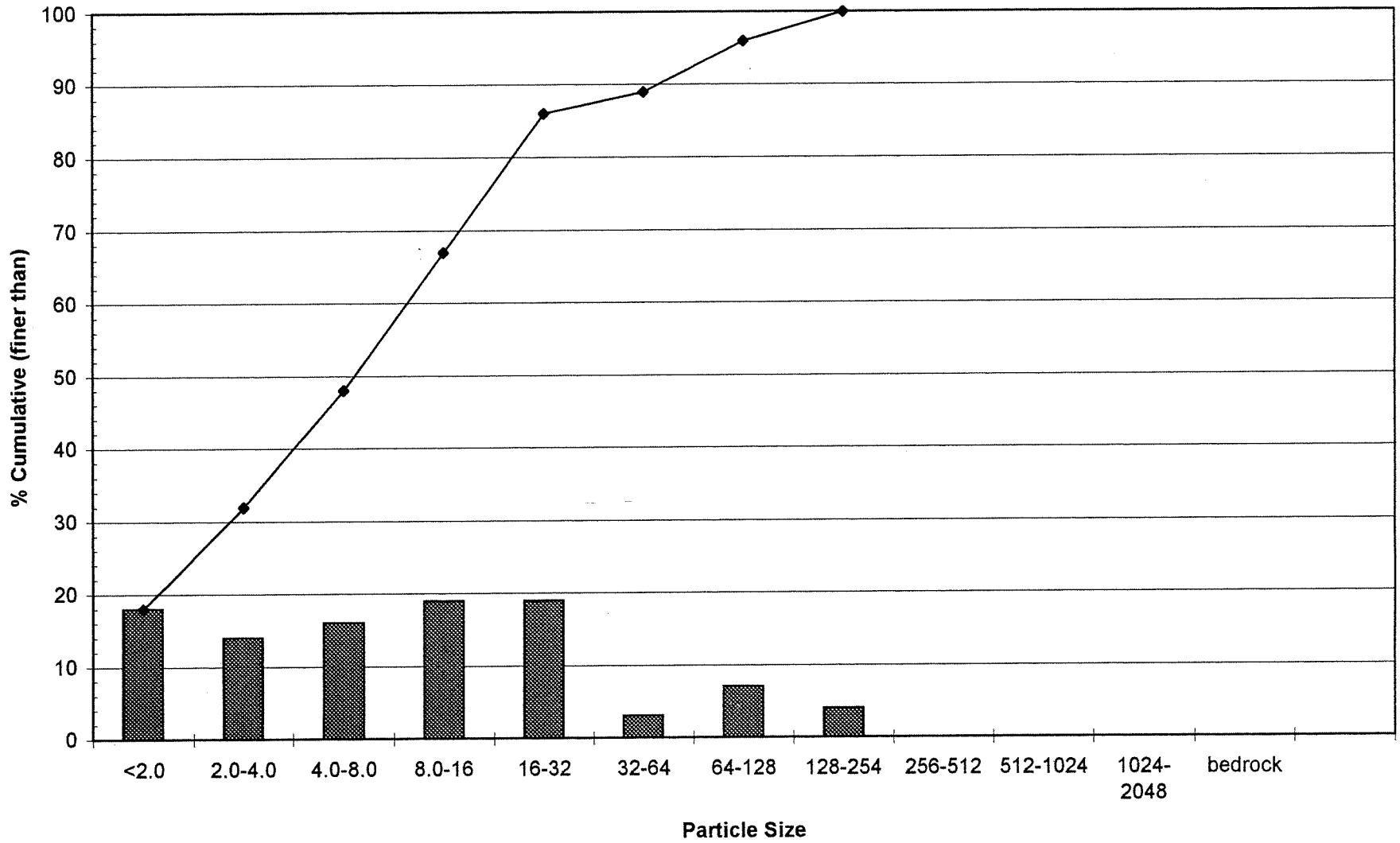


Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Width/Depth Ratio	STREAM:	Bent Creek
							ID NUMBER:	Pool Cross Section
							DATE	12/18/2001
23.40	54.36	2.32	4.96	26.84	2.03	10.07	Bankfull	
10.10	12.87	1.27	2.40	11.98	1.07		Water Surface	

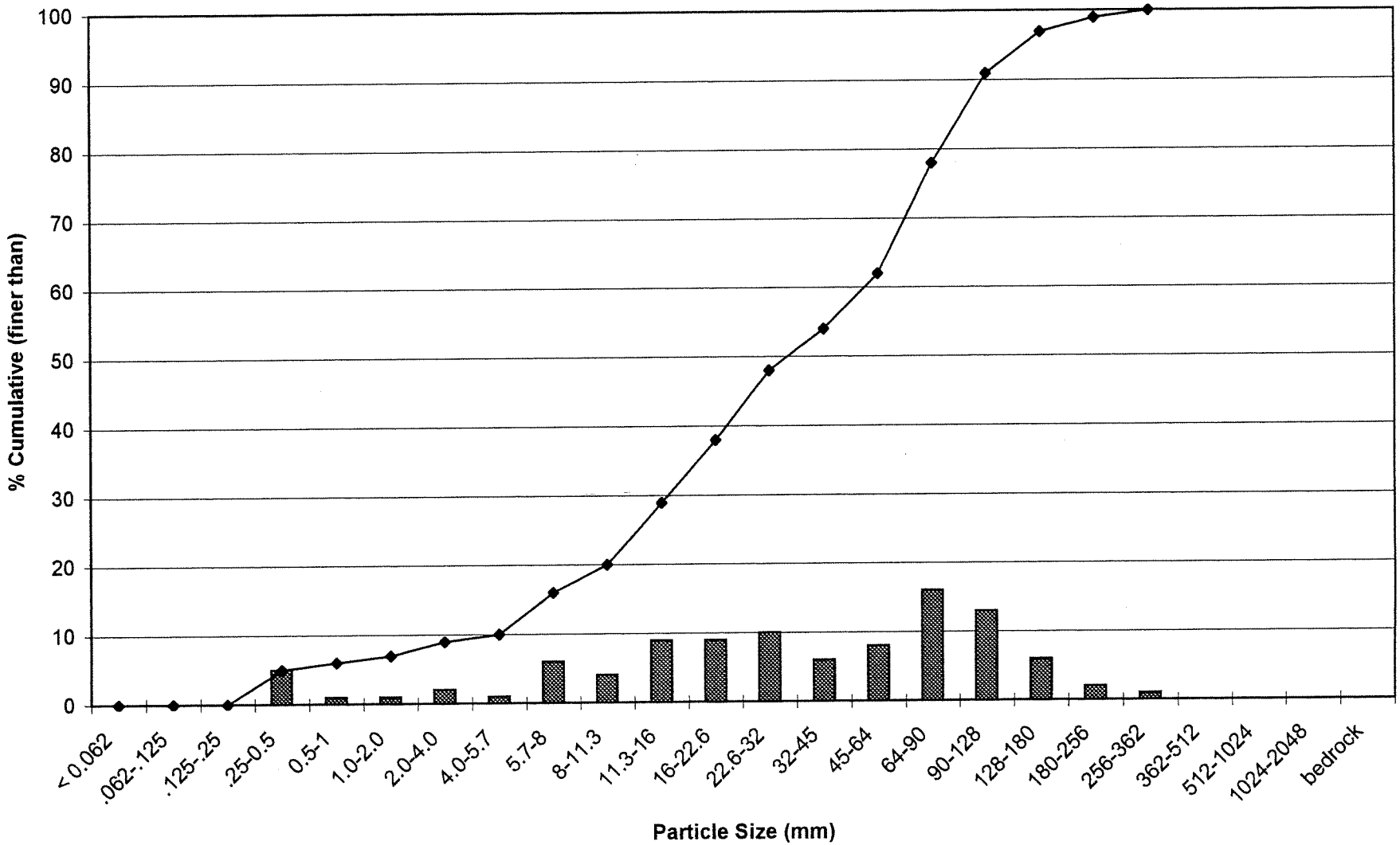
Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
	0.0	98.50		31.9	96.54
	4.0	97.95		32.5	97.22
	7.0	97.30		34.0	98.02
lbf	8.5	96.88		35.5	98.55
	12.0	96.12		37.5	98.80
	18.0	94.87			
lew	20.2	94.30			
	22.5	93.78			
	24.0	93.19			
	27.0	92.36			
	28.5	91.90			
	30.2	92.99			
rew	30.3	94.30			
	30.4	95.07			
rbf	31.2	95.88			



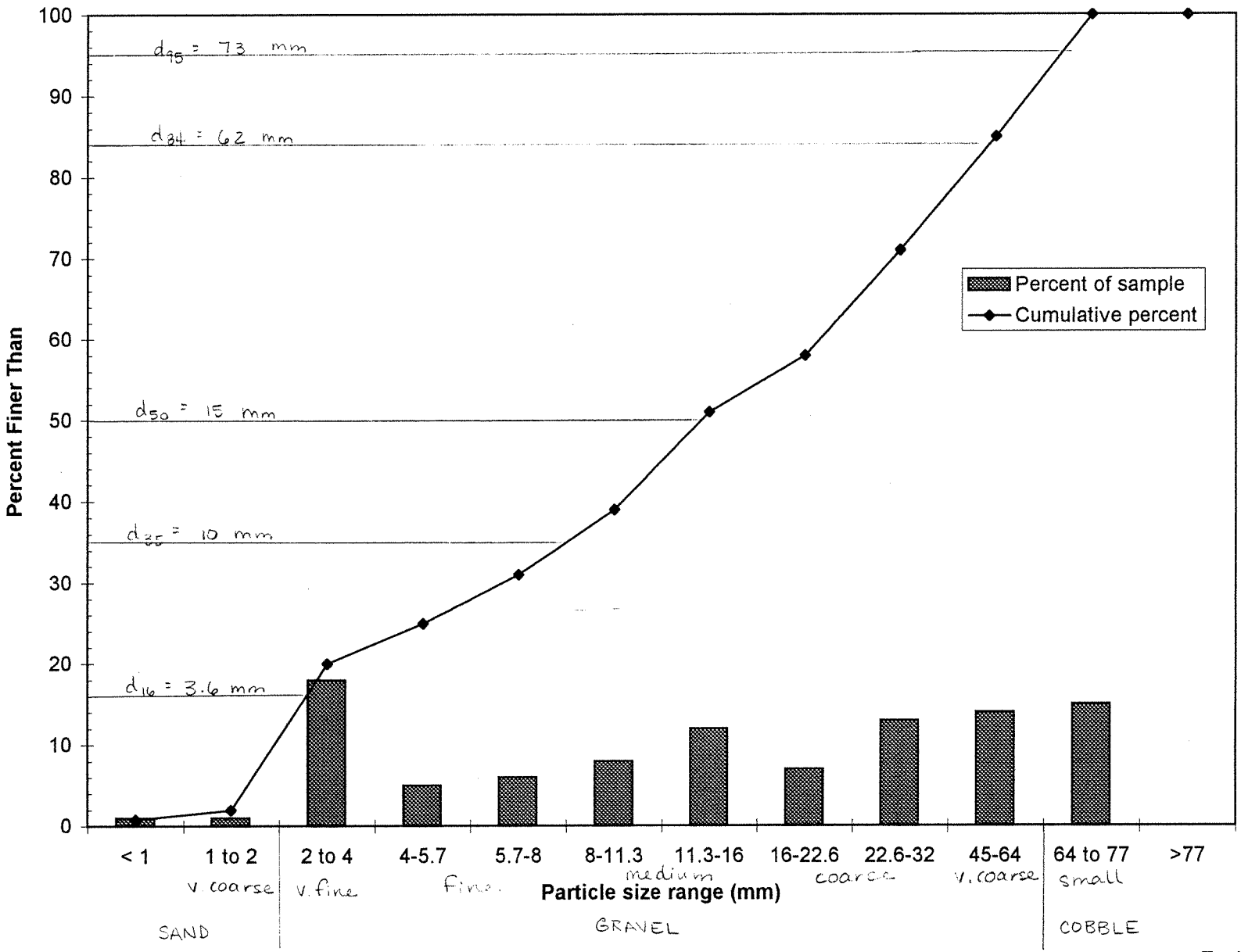
Bent Creek Classification Pebble Count



Bent Creek Riffle Pebble Count



Bent Creek Subpavement Sample



2/6/2002

EcoLogic Associates

Velocity Comparison Form

~~Class~~ Velocity range @ bankfull 5.4-6.4 fps

Date 2-6-02 Team EcoLogic

Stream Bent Creek Location US of Lake Powhatan

Input Variables			Output Variables		
Bankfull Cross Sectional Area (A_{BKF})	67.3	ft^2	Bankfull Mean Depth $D_{BKF} = (A_{BKF}/W_{BKF})$	1.8	ft
Bankfull Width (W_{BKF})	37	ft	Wetted Perimeter (WP) $(\simeq(2*D_{BKF})+W_{BKF})$	37.8	ft
D84	62	mm	D84 (mm/304.8)	0.203	ft
Bankfull Slope	0.0105	ft/ft	Hydraulic Radius (R) (A_{BKF}/WP)	1.78	ft
Gravity	32.2	ft/s^2	R/D84 (use D84 in FEET)	8.75	ft/ft

R/D84, u/u*, Mannings n		
u/u* (using R/D84: see Reference Reach Field Book: p188, River Field Book:p233)	8.2	ft/s/ ft/s
Mannings n: (Reference Reach Field Book: p189, River Field Book:p236)	0.031	$ft^{1/6}$
Velocity: from Manning's equation: $u=1.49R^{2/3}S^{1/2}/n$	7.2	ft/s

u/u*=2.83+5.7logR/D84		
u*: $u^*=(gRS)^{0.5}$	0.776	ft/s
Velocity: $u=u^*(2.83+5.7\log R/D84)$	6.4	ft/s

Mannings n by Stream Type		
Stream Type	C4	
Mannings n: (Reference Reach Field Book: p187, River Field Book:p237)	0.019	$ft^{1/6}$
Velocity: from Manning's equation $u=1.49R^{2/3}S^{1/2}/n$	11.8	ft/s

Continuity Equation		
Q_{BKF} (cfs) from NC rural mountain regional curve or stream gage calibration	365	cfs
Velocity (u=Q/A or from stream gage hydraulic geometry)	5.4	ft/s

PFANKUCH CHANNEL STABILITY EVALUATION

Reach Location Bent Creek, Buncombe Co. Date 12-18-01 Observers LS, KB, KB, MT STREAM TYPE C4

		catagory	EXCELLENT		GOOD		FAIR	
UPPER BANKS	1	Landform Slope	Bank Slope Gradient <30%	(2)	Bank slope gradient 30-40%.	4	Bank slope gradient 40-60%.	
	2	Mass Wasting	No evidence of past or future mass wasting.	3	Infrequent. Mostly healed over. Low future potential.	(6)	Frequent or large, causing sediment nearly year long.	
	3	Debris Jam Potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep dense soil binding root mass.	(3)	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	<50-70% density. Lower vigor and fewer species form a shallow, discontinuous root mass.	
LOWER BANKS	5	Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7	1	Adequate. Bank overflows rare. W/D ratio 8-15.	2	Barely contains present peaks. Occasional overbank floods. W/D ratio 15 to 25.	
	6	Bank Rock Content	65%+ with large angular boulders. 12"+ common	2	40-65%. Mostly small boulders to cobbles 6-12".	4	20-40% with most in the 3-6" diameter class.	
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern without cutting or deposition. Stable bed.	2	Some present causing erosive cross currents and minor pool filling. Obstructions newer and less firm.	(4)	Moder. frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	
	8	Cutting	Little or none. Infreq. raw banks less than 6".	(4)	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident.	
	9	Deposition	Little or no enlargement of channel or pt. bars	(4)	Some new bar increase, mostly from coarse gravel.	8	Moder. deposition of new gravel and course sand on old and some new bars.	
BOTTOM	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges, surfaces smooth, flat.	2	Corners and edges well rounded in two dimensions.	
	11	Brightness	Surfaces dull, dark or stained. Gen. not bright.	1	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright. ie 35-65% mixture range.	
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	(4)	Mostly loose assortment with no apparent overlap.	
	13	Bottom Size Distribution	No size change evident. Stable mater. 80-100%.	4	Distribution shift light. Stable material 50-80%.	(8)	Moder. change in sizes. Stable materials 20-50%.	
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	6	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	(12)	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	
	15	Aquatic Vegetation	Abundant. Growth moss-like, dark green, perennial. In swift water too.	1	Common. Algal forms in low velocity and pool areas. Moss here too.	(2)	Present but spotty, mostly in backwater. Seasonal algal growth makes rocks slick.	
			totals	13		38		

Stream Width.....x avg. depth.....x mean velocity.....=Q .....cfs

Gauge Ht.....Reach Gradient.....Stream Order.....Sinuosity Ratio.....

Width Bf.....Depth Bf.....W/D Ratio.....Bf Dischrge (Q Bf).....

Drainage Area.....Valley Gradient.....Stream Length.....Valley Length.....

Sinuosity.....Entrenchment Ratio.....Length Meander (Lm).....Belt Width.....

Sediment Supply
Extreme.....
Very High.....
High.....
Moderate.....
Low.....

Stream Bed Stability
Aggrading.....
Degrading.....
Stable.....

Wid
Nor
High
Very

TOTAL SCORE for Reach E.....+ G.....

Remarks.....

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C
GOOD	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60
FAIR	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-
POOR	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	10

Stream Type	DA3	DA4	DA5	DA6	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	G1	G2	G3	G
GOOD	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-
FAIR	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108
POOR	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	12