STREAM RESTORATION PLAN

RICHLAND CREEK, WAKE COUNTY, NC

Prepared for

NC Ecosystem Enhancement Program

Final - June 13, 2007

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Stream Restoration Plan for Richland Creek

Town of Wake Forest, Wake County, NC

1. Introduction:

The North Carolina Ecosystem Enhancement Program seeks to restore 2800 linear feet of Richland Creek, located in the Neuse River watershed in Wake County, North Carolina. Richland Creek is located in the Neuse River Basin. This document summarizes the project's purpose, existing site conditions, assessment methodologies, and proposed restoration design. Supporting information is included in the attached appendices.

2. Goals and Objectives:

1. Establish stable channel dimension, pattern, and profile;
2. Restore a functioning floodplain;
3. Enhance aquatic and terrestrial habitat in the stream corridor;
4. Provide a riparian management zone that is compatible with the surrounding uses (golf course and electrical transmission corridor) and yet retains the ecological function of the riparian zone; and
5. Improve water quality by reducing the sediment load generated by failing banks and by restoring a riparian buffer.

3. Location Information:

a. River basin: Neuse River. Richland Creek joins the Neuse River just below Falls Lake. The project reach is about five miles upstream from this confluence.
b. USGS 8-digit catalog number: 03020201 in subbasin 03-04-02
c. County: Wake County
d. Nearest Town: Wake Forest, NC. The reach is within Paschal Golf Course on the western edge of town.
e. Stream name and classification: Richland Creek (F4)
f. USGS quad sheet: Wake Forest quadrangle (See Map 3f)
g. Location map: See Map 3g

4. General Watershed Information:

a. **Drainage area:** Approximately 7.8 square miles.
b. **Dominant land use:** The restoration reach bisects a golf course; otherwise the watershed is urbanized to the east and rural/ residential to the west.

c. Relative distribution of land use:

The majority of the watershed, extending from Wake Forest, NC to northwest of Youngsville in Franklin County is rural. The upper watershed in Franklin County is comprised of farms including a small percentage of row crops (mainly corn and soybeans), with the predominant land use being pasture, hayfields and woodlands. The upper portion is about 45 percent forest, 45 percent agriculture and 10 percent residential/commercial. The lower portion of the watershed in Wake County is approximately 50 percent rural and 50 percent residential/ urban. The rural portion is split almost evenly between forest and active farmland. The farmland areas contain edge woodlots and forests, some of which are adjacent to grazing fields and are accessed by cattle and horses. The forested portions of the landscape are on steeper slopes, rocky soil areas and along stream corridors.

The Richland Creek watershed contains a high voltage electrical transmission corridor that parallels the creek along its entire length and crosses it several times. One of the crossings occurs in the upper 400 +/- feet of the proposed restoration reach.

d. Estimation of future land use change:

Recent development relating to the urban sprawl of Wake County has intensified the conversion of farmland in the Richland Creek watershed into residential and related commercial uses. At the time of our watershed survey, there were about five new housing developments being built on recently converted farmland within sight of the main channel of Richland Creek, upstream of the restoration reach. There are many other developments that have been or are being built, or are planned within the watershed. Additionally, several large farms are for sale and forestland is being timbered, with the strong potential to be converted to non-farm uses.

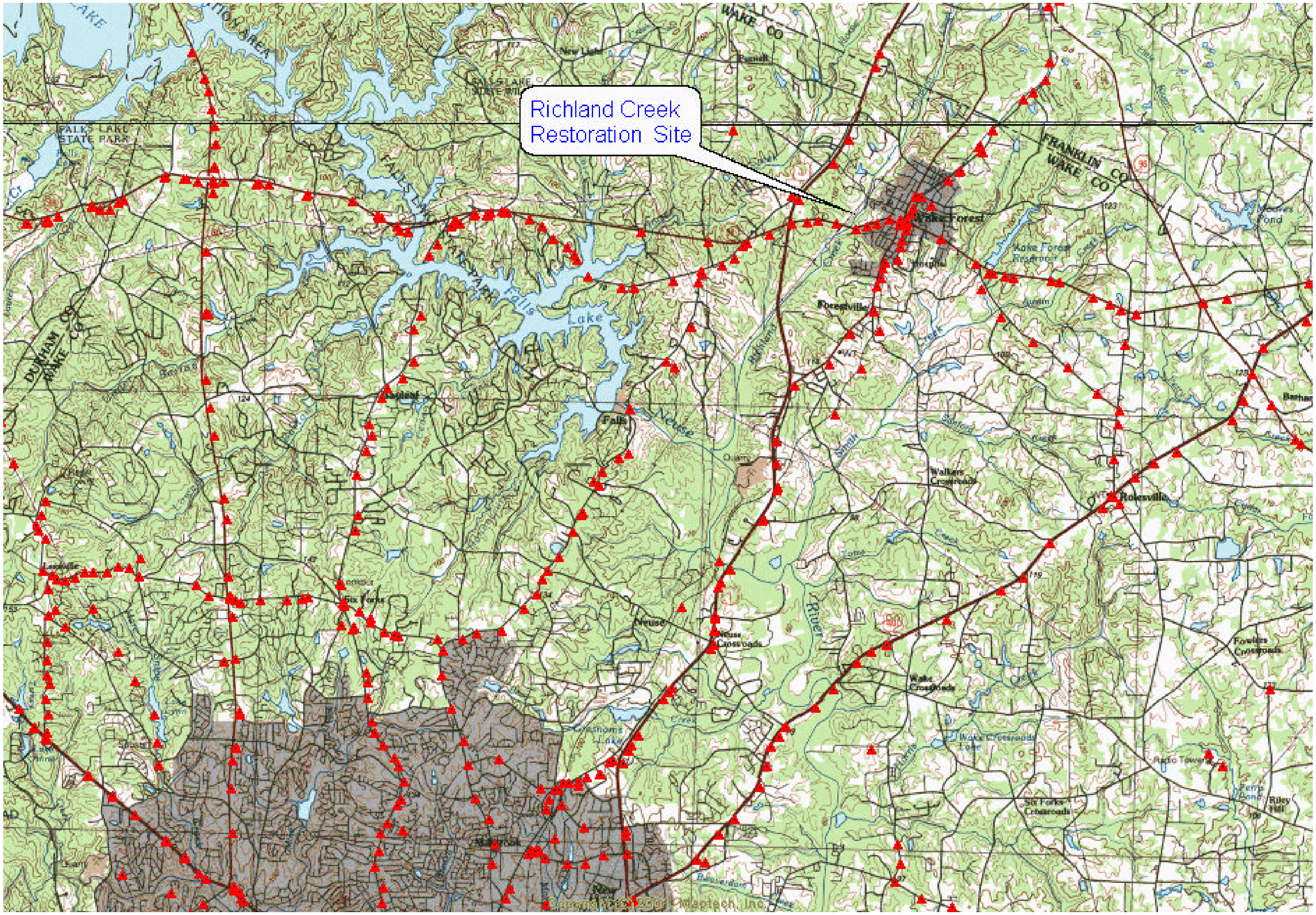
Given the recent history of land use in the Triangle area, it can be expected that land uses in this watershed will become increasingly converted to residential, commercial and other urban uses. This will likely result in increased levels of impervious surfaces, increased stormwater runoff, and declining water quality and impaired aquatic and riparian habitat throughout the watershed.

5. Description of Existing Conditions

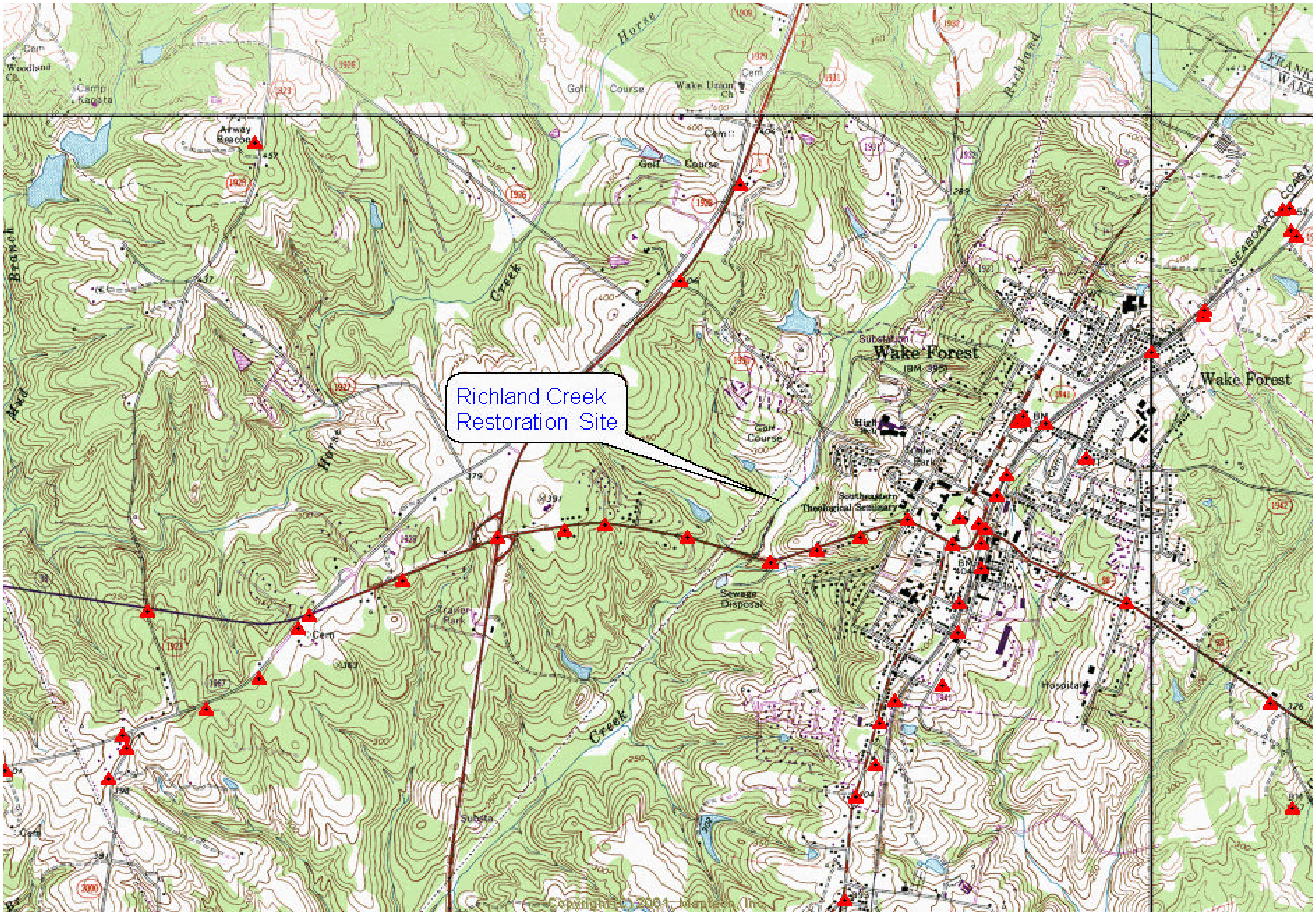
a. Existing hydrological features (See Aerial photo (1999)):

The existing stream reach is a highly modified channel with a long history of impact. The reach runs the length of Paschal Golf Course, which was first constructed in 1917. Development and management of the golf course involved straightening the creek channel and draining adjacent floodplains with ditches and buried tiles. Several ponds were also constructed on the floodplain over the years; the remnants of one still remains in the restoration corridor.

There are two small creeks that enter the restoration reach from the west. One of these creeks drains a small pond on the western edge of the golf course. This creek enters the



Map 3f General Location (from USGS Quadrangle "Wake Forest, NC")



Map 3g. Location Map

Richland Creek Paschal Golf Course Wake Forest, NC

N

0 25 50 100 150 200 Feet

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reach just inside the forested lower reach. The other creek enters from the west side at the lower end of the project near the Durham Road box culverts. Both of these creeks drain areas of 50 to 100 acres and can be easily integrated into the restoration plan.

There are several storm drains that enter the channel within the restoration reach. One of the storm drains enters the restoration reach after collecting stormwater from the student-housing complex east of the floodplain. Other storm drains collect stormwater from the golf course parking lot and the access road.

The lower reach is dramatically impacted by large trees that have fallen in the channel and/or large logs lodged in the channel causing local deposition and scour.

a. Soils (See Figure 5b and Table 5b):

The soils along the restoration corridor are relatively uniform throughout the reach based on the Soil Survey of Wake County. Richland Creek soils are predominately Chewacla Soils (Cm) which occur on 0 to 2 percent slopes. Chewacla soils have a surface layer of brown to dark grayish-brown sandy loam to silt loam 4 to 12 inches thick. Soil colors below the surface layer range from brown to dark grayish-brown, and the texture ranges from sandy loam or silt loam to clay. The total thickness of the series is from 34 inches to more than 72 inches. Infiltration is good and runoff is slow. Flooding hazard is high and the hazard of wetness is very severe.

Within the Richland Creek floodplain, two other soil classifications occur, Altavista and Madison.

Altavista (Afa) soils occur on 0 to 4 percent slopes. The soils are comprised of fine sandy loam located on low stream terraces. The surface layer is brownish-gray and light gray-brown fine sandy loam 3 to 15 inches thick. The subsoil is yellowish-brown to reddish-yellow and is 12 to 29 inches thick. Infiltration is good and runoff is slow to medium. Most of this soil type coincides with golf course fairways.

Madison (MdD2) occurs on 10 to 15 percent slopes. This series of Madison soils are an eroded sandy loam located on narrow side slopes bordering upland drainage ways. The surface layer is 3 to 7 inches thick of dark-brown to brown sandy loam, and in most cases it is comprised of a mixture of original surface soil and subsoils. The subsoil is a friable clay loam to clay, red to dark red that is 10 to 35 inches thick. Infiltration is fair and surface runoff is very rapid.

A shallow geotechnical exploration was conducted throughout the restoration corridor. The soils were found to generally match the mapped types (soil classification tests are available if needed). Analyses of samples collected along the corridor indicate the upper 2 feet is mostly loose to medium dense silty sand of either residual or alluvial derivation. Below this level to a depth of 3.5 to 5 feet, the soils are mostly residual, of medium density, and vary from silty sand to silty clay.

In some locations below the alluvial soils, dense saprolite of either clay or sand composition occurs. In several locations throughout the reach, bedrock or hard clay saprolite in the channel bottom functions as a grade control. Undisturbed residual soils are anticipated to have sufficient strength to form competent banks at slopes of 2(H) to 1(V) or steeper, but because the shallower soils are often alluvial and less dense, floodplain banks should be laid back to 3(H) to 1(V) where room allows.

In the central portion of the floodplain, the subsoil was saturated at a depth of approximately 3.5 feet, indicating the approximate surface of the water table.

b. Existing plant communities (See Figure 5c):
The existing plant communities throughout the reach are comprised of three different types. The three types are the result of different management practices applied to various areas of the restoration corridor.

The upper 400 feet of the reach lies within an electrical transmission corridor. The management of vegetation under the power lines includes seasonal cutting and mowing to maintain vegetation less than 12 feet tall. This results in a thick growth of tree resprouts, shrubs dominated by blackberry canes and aggressive vines like honeysuckle.

The middle section of the restoration reach (from Stations 400 to 1900 feet) is dominated by the developed golf course and is managed accordingly. With the exception of a few large specimen trees scattered along the creek corridor, the majority of woody vegetation has been removed from the stream banks and suppressed by herbicides and regular mowing. In most areas, turf grass exists right up to the tops of banks. Some areas have no vegetation as a result of bank failure creating vertical or undercut banks with exposed soils, or a thick mulch of grass clippings dumped on the banks from mowers used to maintain the course.

The lower section of the restoration reach (about 900 feet) has a forested bank on the right (west) side and a managed golf course link on the left (east) side. The forested side has many large and mature trees, subcanopy trees and shrubs along with thick vines and riparian herbs. The forested area is thickly invaded with invasive exotic species typical of creeks in urban areas of the Piedmont. The east bank is managed with mowed turf grass to the top of banks with few remaining woody plants.

The majority of vegetation in the Richland Creek riparian zone, as it flows through Paschal Golf Course, is mowed grass to the stream bank edge. Portions of the riparian buffer support multi-layered vegetation with canopy hardwoods, mostly in areas where the golf course is not maintained. Canopy and subcanopy trees include specimen loblolly pine (*Pinus taeda*), river birch (*Betula nigra*), boxelder (*Acer negundo*), and flowering dogwood (*Cornus florida*). Other trees noted include black willow (*Salix nigra*), sycamore (*Platanus occidentalis*), American ash (*Fraxinus americana*), water oak (*Quercus nigra*), sweet gum (*Liquidamber styraciflua*), red maple (*Acer rubrum*), black walnut (*Juglans nigra*), willow oak (*Quercus phellos*), redbud (*Cercis canadensis*), and swamp red oak (*Quercus shumardii*).

Richland Creek
Stream Restoration
Prepared for Ecosystem Enhancement Program
Soils Map

Drawing: 5-B
Revision: Review Comments
Number Date Description

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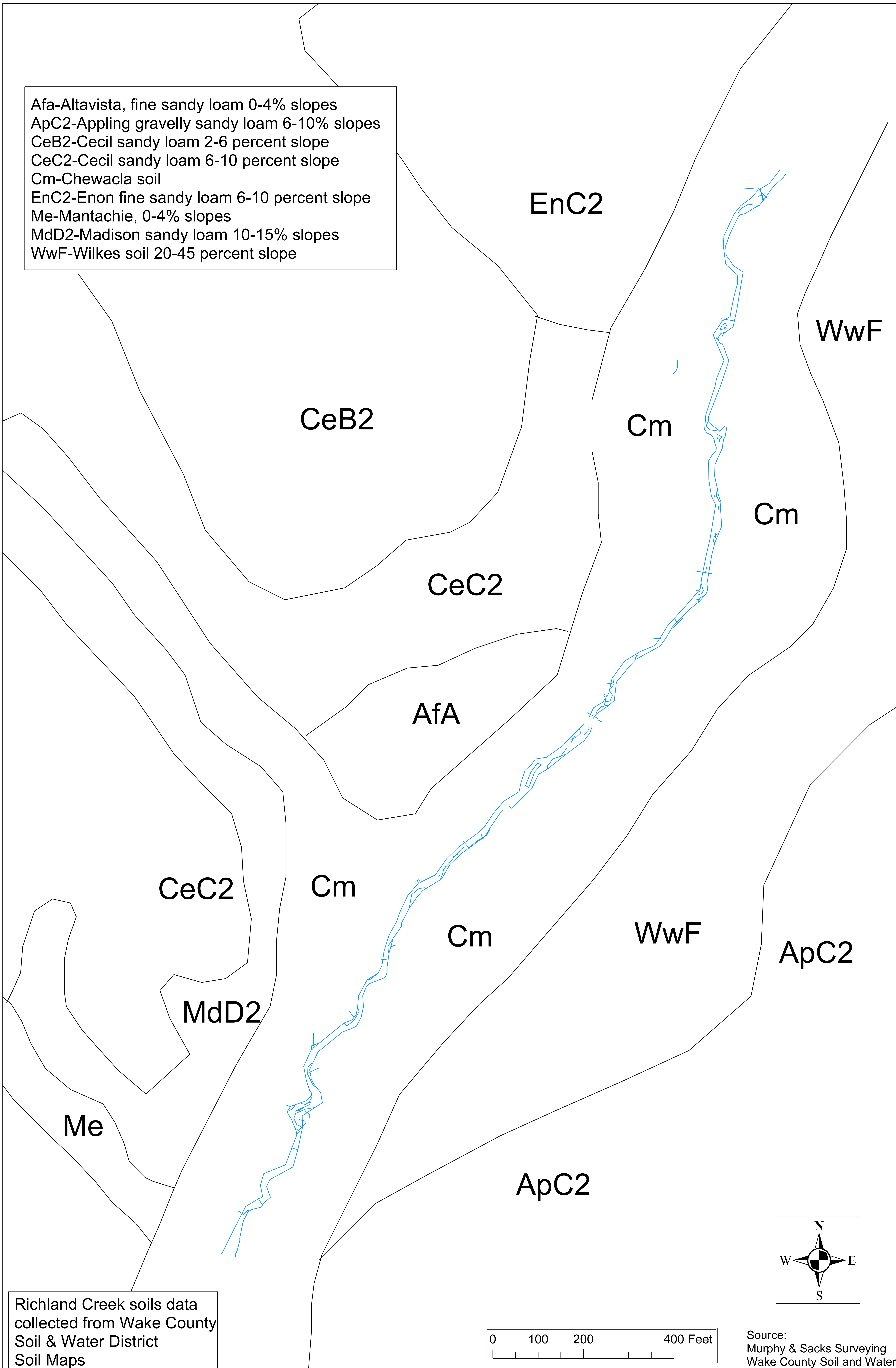

Source:
Murphy & Sacks Surveying
Wake County Soil and Water

Table 5b-1

SOIL BORING LOG

Richland Creek
Town of Wake Forest, Wake County, NC

Boring No.	Description
1	Stiff Clayey Silt (Residual) Augered into Rt. bank @ mid-height
2	Med. Dense Sandy Silt (Residual) Augered into Rt. bank @ mid-height
3	Hard Clay (Saprolite) Augered into stream bottom
4	0'-4' Firm Silty Sand (Alluvial or Residual) Augered on Rt. floodplain Wet @ 3.5', Water at 4.0'
5	Dense Silty Coarse-Med. Sand (Residual) Augered into Lt. bank toe
6	0'-2' Firm Silty Sand (Alluvial or Residual) Augered on Rt. floodplain 2'-4' Med. Dense Silty Sand with Gravel (Residual) Wet @ 3.0', Saturated at 4.0'
7	0'-2.5' Firm Silty Sand (Alluv. or Residual) Augered on Rt. floodplain 2.5'-4' Firm Clayey Sandy Silt (Residual) Wet @ 3.5'
8	0'-4' Firm Sandy Silty Clay (Residual) Augered on Rt. floodplain

NOTES:
1. Field exploration done on August 20, 2004
2. Golf course superintendent shared knowledge of past bedrock and/or boulder encounters on the east side of the stream, but none historically on the west side.

Table 5b-2

SUMMARY OF LABORATORY TEST DATA*

Richland Creek (Ecologic)

Boring Number	Sample Depth (feet)	Sample Type**	USCS Classification	Natural Moisture Content %	Atterberg Limits			Max. Dry Density (pcf)	Optimum Moisture Content (%)	Remolded Unit Weight (psf)		Bearing Ratio	Internal Friction Angle (degrees)		% Finer No. 200
					L.L	P.L.	P.I.			Dry	Wet		Total	Eff.	
2	0-2	Bulk													38
3	0-0	Bulk	CL		36	16	20								62
4	0-3	Bulk	SC		26	18	8								37
6	2-4	Bulk	SM		11	NP	NP								16
7B	2.5-4	Bulk													27
8	0-4	Bulk	CL		46	24	22								83

* Graphic Presentations of Results of Triaxial, Consolidation, CBR, Proctor, Grain Size and other tests follow this summary.

** SS=Split Spoon Sample (ASTM D-1586)
UD=Undisturbed Sample (ASTM D-1587)

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Job Number: ______
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Richland Creek
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Plant Communities

Drawing: 5-C
Revision:
Number Date Description

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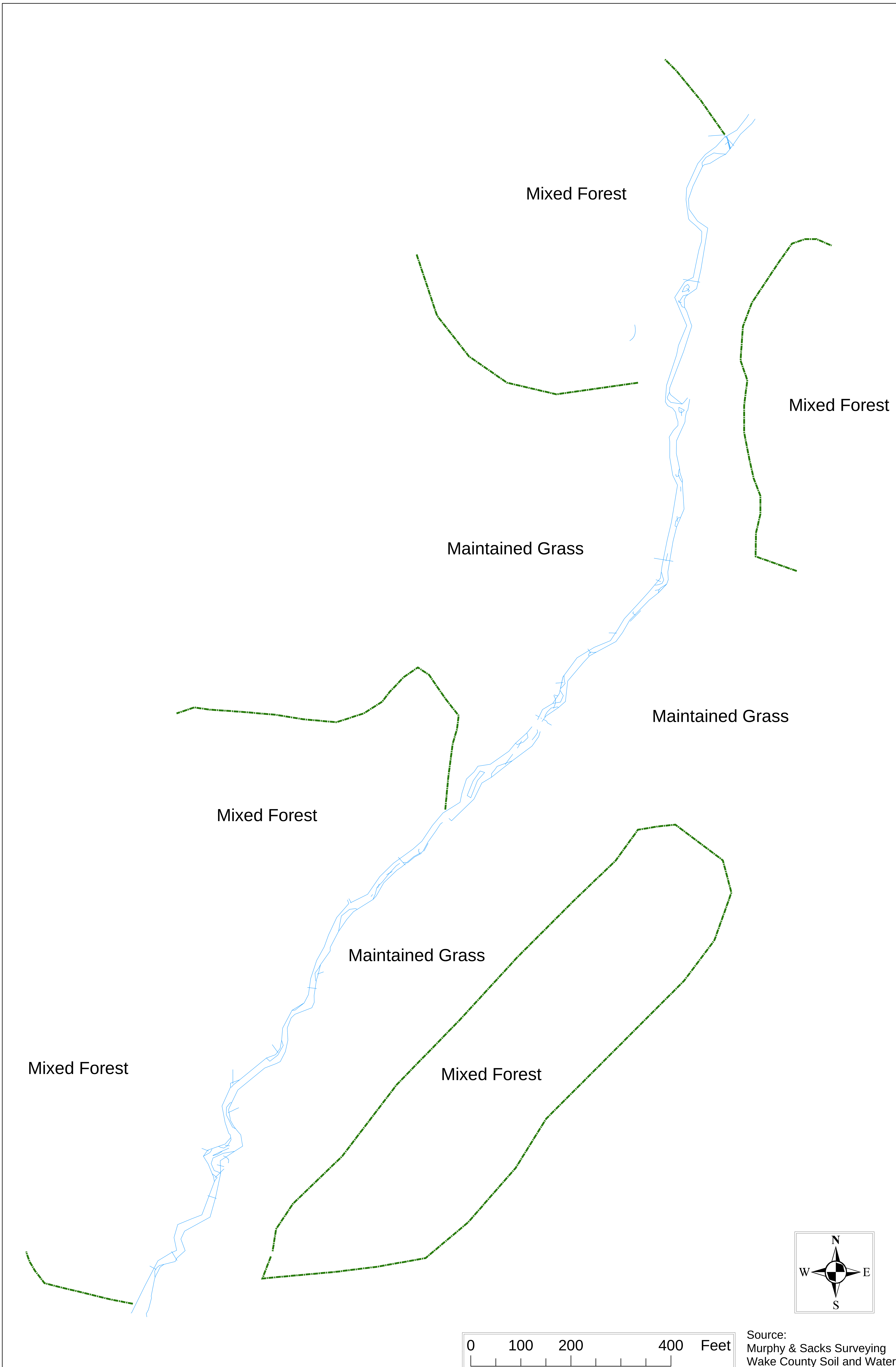


The gravel bars in the channel support numerous saplings of sycamore (*Platanus occidentalis*), and black willow (*Salix nigra*). Native riparian shrubs that occur on the site include silky dogwood (*Cornus amomum*), tag alder (*Alnus serrulata*), elderberry (*Sambucus canadensis*), and hazelnut (*Corylus americana*). A few non-native, invasive shrubs that were noted include privet (*Ligustrum sinensis*), multiflora rose (*Rosa multiflora*), and silverberry (*Eleagnus umbellate*).

The herb and vine layer includes a mix of native and non-native species. Aggressive spreading non-native species noted include Japanese grass (*Microstegium vimineum*), chickweed (*Stellaria media*), Japanese honeysuckle (*Lonicera japonica*), fescue (*Festuca* sp), and bittersweet (*Cardamine* sp.). Native wetland species noted in the riparian buffer include needle rush (*Juncus effusus* and other spp.), sedges (*Carex lurida, C. criniata*), wing stem (*Verbesina occidentalis*), grapes (*Vitis* spp), cat-tails (*Typha latifolia*), jewelweed (*Impatiens capensis*), sensitive fern (*Onoclea sensibilis*), and jumpseed (*Tovara virginiana*).

a. Threatened/endangered species

The North Carolina Natural Heritage Program lists three animal species, two vascular plants, two natural communities and one special habitat as significant in the Wake Forest quadrangle. Only one of these species is federally listed as a Federal Species of Concern and that is the Southeastern Myotis (a bat), which is only historically known and has not been observed in this area since 1979. Likewise, the Neuse River Waterdog is only known as a historic occurrence. The only currently known listed animal species is the Four-toed salamander (NC Special Concern) which lives in wetlands of a type that do not occur within the restoration reach corridor.

The two plant species listed for Wake Forest quadrangle also include one currently known species and one historic reference. The historic reference is to the Glade Milkvine, which occurs on mafic or calcareous soil types that do not occur within the Richland Creek restoration reach. Likewise, the Swamp Saxifrage, while known to occur in the area, requires wetland habitats that do not occur on the land surrounding the restoration reach.

The two listed natural community types include the Piedmont/Mountain Levee Forest and the Floodplain Pool, and the listed special habitat includes the Wading Bird Rookery, none of which occur in the area of the restoration reach.

b. Stream geometry and substrate

i. Level II classification

The stream channel within the restoration reach is a composite of two stream types. The upper reach is a C4 stream with more belt width and significantly larger point bars and deeper pools than most of the reach. The majority of the remaining reach is a F4 stream with little meander geometry, an entrenchment ratio of 1.4, a width-to-depth ratio of 11.6, and a sinuosity of 1.22. The bankfull width of the existing stream varies between 22 and 35 feet, with a corresponding depth range of 1.4 to 2.8 feet at bankfull.

This reach of Richland Creek was first identified as a candidate for stream restoration by Wake County NRCS District Conservationist Tom Hill. In April 2001, Tom and his staff installed bank pins in several sections of the creek in order to document the rate of bank failure. The failure and movement of the banks was evident in the morphology of increasing meander in several areas, and substantiated by the long-term observations of Mr. Bobby Kinton, Paschal Golf Course Superintendent.

The results of bank pin measurements indicated at least 70 tons/100 feet of soil loss into Richland Creek in the area where the bank pins were placed. Mr. Hill measured over 800 feet of severely eroded banks similar to the area with the bank pins. For the remainder of the reach, he estimated at least 15 tons/100 feet of soil loss over an additional 2000 feet. The measurements were taken from April to December 2001. The calculated total sediment loss over this period from the entire reach is 860 tons. This equates to an annual rate of soil loss of 1290 tons/ year for the project reach.

Our survey found two of the bank pins at one location still in place, which were measured. Compared to an earlier photo of the site from Tom Hill, we estimate the bank has receded an additional 18 inches at that location over 26 months. In other locations of bank pins, the pins are gone, presumably due to the bank having moved roughly 3 to 6 feet during the same period. BEHI analysis rates the overall reach as having a High erodibility hazard rating, with an estimate of soil loss in the reach exceeding 9000 cubic feet/year, or approximately 540 tons/year.

ii. Pavement/subpavement analysis

The existing condition of the stream reach through Paschal Golf Course, which exhibits a significant amount of bed and bank instability, limits the formation of well developed and stable riffle and bar features. Two riffles and two bars were sampled for particle size. The pavement and subpavement analysis indicates the D_{50} of the pavement is about 22 mm, while the D_{50} of the subpavement is 2.5 mm in a riffle in the well-defined C4 section. Near the low end of the reach in the F4 section, the riffle particles are smaller, with the D_{50} being 12 mm for pavement and 2.7 mm for subpavement. The largest particle from the pavement included a 61 mm, 339-gram rock, while the subpavement had a largest particle of 44 mm, 114 grams.

Given the proportion of riffle and subpavement D_{50}'s, the entrainment calculation indicates an aggrading channel bed. The Shields Diagram indicates the stream is competent to move the largest particles found in the system.

6. Stream Reference Studies

a. Classification of reference stream(s)

Two reference reaches were investigated for use in this restoration. An extended search was made to locate a reference reach close to the restoration reach, or at least in the eastern Piedmont. After discussions with colleagues who frequently work in the Raleigh area, we surveyed an unnamed tributary to Lake Wheeler, which classified as a C4 stream of reference quality. We deemed this reference suitable for use for project design. In addition, we consulted with KCI Associates, who is conducting stream restoration work just upstream from our project. KCI identified some short sections of Richland Creek near the Wake County line, which are of reference quality, and shared the data with us. The data is shown on the Morphological Data Table (Table 7b).

b. Reference dimension, pattern, and profile

The reference reaches represent drainage areas of 0.28 to 4.8 square miles. The bankfull cross-sectional areas of the reference reaches are 13.5 to 70 square feet. The bankfull depths are 1.0 to 2.3 feet. Bankfull widths are 12 to 32 feet. These data fall just above the Piedmont Rural Regional Curve published by the NCSU Steam Restoration Institute. The pattern data also has a wide range of values that result from the differences in drainage areas and differences in valley type and adjacent land use. Meander lengths are 50 to 200 feet, radii of curvature are 18 to 70 feet, and belt widths are 50 to 300 feet. Valley slopes are .0045 to .006, with average water surface slopes of 0.004 to 0.005.

c. Reference stream morphological table

The reference reach morphological table is attached as Table 7b. Reference reach data is included in the morphological table with existing and proposed channel geometry data.

d. Reference stream vegetative community

The reference reaches both occur in forested portions of their watersheds. The vegetative communities are successional forest communities typical of the disturbed landscape of Piedmont NC. These alluvial forests occur along main channels and smaller tributaries. The canopy is patchy as a result of past agricultural and modern development activity, and is composed of river birch, *Betula nigra*, sweet gum, *Liquidambar styraciflua*, tulip tree, *Liriodendron tulipifera*, sycamore, *Platanus occidentalis*, red maple, *Acer rubrum* and box elder, *Acer negundo*. The understory contains ironwood, *Carpinus caroliniana*, flowering dogwood, *Cornus florida*, American beech, *Fagus grandifolia*, tree-of-heaven, *Ailanthus altissima*, red oak, *Quercus rubra* and black cherry, *Prunus serotina*. Occasional areas of shrubs contain strawberry bush, *Euonymus americanus*, yellowroot, *Xanthorhiza simplicissima*, Chinese privet, *Ligustrum sinense*, multiflora rose, *Rosa multiflora*, elderberry, *Sambucus canadensis*, and tag alder, *Alnus serrulata*. A mixture of herbs inhabit the various habitats along these alluvial valleys including native impatiens, *Impatiens capensis*, false nettle, *Boehmeria cylindrica*, knotweed, *Polygonum punctatum*, sedges, *Carex spp*, soft rush, *Juncus effusus*, may apple, *Podophyllum peltatum*, Japanese grass, *Microstegium vimineum*, tearthumb, *Polygonum sagittatum*, and asters, *Aster spp*.

7. Stream Restoration Plan

a. Stream classification of restored site

We propose to create a restored stream with stable banks, improved bed morphology and enhanced aquatic habitat. The primary goal is to produce a stable dimension, pattern and profile that conveys channel-forming (bankfull) and lesser discharges efficiently, dissipates energy and moves sediment without significant degradation or aggradation, provides a floodplain (bankfull) bench to help contain flood flows, and minimizes impacts to the golf course and adjacent utility corridors, with a protected buffer that allows for revegetation of currently bare and failing banks and reforestation for long-term habitat and water quality improvements.

We propose to construct a C4 channel with increased meander geometry, consistent bankfull width, increased pool depth, steeper riffles, flatter pools and native riparian vegetation on the banks.

The most significant constraint on the site is the sanitary sewer line that parallels the entire length of the restoration reach along the eastern side. In some cases the current channel is less than 20 feet from the sewer centerline. This sewer line corridor, and its associated utility easement, is a significant constraint on the east side of the restoration corridor and will limit the meander geometry of the restored channel (belt width, etc.).

b. Morphological table:

The attached Table 7b shows existing conditions, proposed conditions and reference conditions.

Note on gage conditions: Despite an intensive search, we were unable to locate a gage station in the Wake County area that had both a long history of record and identifiable and usable bankfull indicators. When we inquired with the NC Ecosystem Enhancement Program and the NCSU Stream Restoration Institute, they acknowledged the problem and recommended some possible gages that later proved to be unsuitable or in a different ecoregion of the state.

The two methods used to verify bankfull stage at Richland Creek were: 1) regional hydraulic geometry relationships (regional curves), and 2) stage/discharge data from KCI for Richland Creek.

KCI was also unable to find a suitable gage in the area, but they installed a staff gage, flow meter and pressure transducer in Richland Creek to allow them to determine the stage/discharge relationships of the creek directly.

Monitoring of surface water fluctuations was undertaken to understand the hydrologic response of the watershed and to verify the proposed design discharges. Two (2) surface water-monitoring gauges, one (1) barometric logger (required for gauge calibration), and one (1) rain gauge were used to perform this monitoring. Three months of continuous

Table 7b Morphological Data Richland Creek, Wake County, NC

CLASSIFICATION DATA	Existing Channel	Reference Upper Richland Creek	Reference UT to Lake Wheeler	Proposed Channel
Rosgen Stream Type	F4/1	C4	C4	C4/1
Drainage Area (sq mi)	7.8	4.8	0.28	7.8
Bankfull Width (W_{bkf}) (ft)	22-35	28-32	9.2-13.5	33
Bankfull Mean Depth (d_{bkf}) (ft)	1.4-2.8	2.3-2.4	.9-1.1	2.6
Bankfull Cross Sectional Area (A_{bkf}) (sf)	48-72	67-75	6.5-13.8	85.0
Width/Depth ratio (W_{bkf}/d_{bkf})	12-13.8	12.2-13.3	10.5-12.3	12.1
Maximum depth (d_{mbkf}) (ft)	3.4-3.8	3.75	.9-1.6	3.4
Width of flood prone area (W_{fpa}) (ft)	28-60	>100	35-55+	100
Entrenchment ratio (ER)	1.7-1.9	3.1-3.6	3.8-4.1	3.0
Water surface slope (S) (ft/ft)	0.0028	0.004	0.0045	0.0028
Sinuosity (stream length/valley length) (K)	1.22	1.1	1.15-1.2	1.2
DIMENSION DATA				
Pool Depth (ft)	3.1	2.9	1.1-1.4	3.4
Riffle Depth (ft)	1.4-2.8	2.3-2.4	.9-1.6	2.6
Pool Width (ft)	49.6	26-35	9.0-11.1	36
Riffle Width (ft)	22-35	28-32	10-13.1	33
Pool XS Area (sf)	56.0	70-75	11.1-14.1	120.0
Riffle XS area (sf)	60.9	67-75	8.8-21.6	86.0
Pool depth/mean riffle depth	1.5	1.2-1.3	.9-1.3	1.3
Pool width/riffle width	1.7	.9-1.1	.7-1.6	1.1
Pool area/riffle area	0.9	.9-1.1	1.1	1.3
Max pool depth/d_{bkf}	2.0	1.9-2.0	2.0-2.5	2.1
Low bankheight/max bankfull depth	1.2	2-Jan	1-1.2	1
Mean bankfull velocity (V) (fps)	3.1-7.0	3.6-5.0	2.5-3.5	5.0
Bankfull discharge (Q) (cfs)	305-400	260-280	16-48	425
PATTERN DATA				
Meander length (L_m) (ft)	110-300	110-200	38-58	220-330
Radius of curvature (Rc) (ft)	32-98	37-70	16-32	80-100
Belt width (W_{blt}) (ft)	22-71	100-300	30-60	60-300
Meander width ratio (W_{blt}/W_{bkf})	1.59	9.3-10.7	1.2-4.4	9.0
Radius of curvature/bankfull width	1.34	1.1-2.1	2.5-3.5	2.4
Meander length/bankfull width	3.4-4.0	3.9-6.3	16-48	6.0-9.0
PROFILE DATA				
Valley slope	0.003	0.0045	0.005	0.003
Average water surface slope	0.0028	0.004	0.005	0.0028
Riffle slope	0.02-.037	.005-.009	.007-.03	0.0056
Pool slope	.0009-.0022	.000-0.025	000-.0022	0.00056
Pool to pool spacing	38-258	25-90	14-80	150-230
Pool length	23-96	25-May	8-22.0	41
Riffle slope/avg water surface slope	4.0	1.3-2.3	1.4-6.0	1.5-2.0
Pool slope/avg water surface slope	0.6	0.0-0.6	00.0-.44	0.5
Pool length/bankfull width	1.1	.2-.9	.49-1.6	1.20
Pool to pool spacing/bankfull width	3.5	.8-3.0	1.4-5.9	4.5
CHANNEL MATERIALS				
D16	1.5		0.76	
D35	7.3		1.5	
D50 riffle	12		5.4	>10
D84	35		21.8	
D95	49		36	
PAVEMENT			Bar	
D16	12		1.4	
D35	14		2-Jan	
D50	22.5		7	
D84	54		29	
D95	61		55	
Largest #1	61		61/13oz	
Largest #2	56		44/6oz	
SUBPAVEMENT				
D16	1.2			
D35	1.7			
D50	2.5			
D84	14			
D95	27			
Largest #1	58			
Largest #2	38			

recordings (June through September) were utilized in this study. In-situ gauging with a Doppler velocity meter was used to calibrate the discharge estimates from these instruments.

Stream stage data (water levels) were collected in the stream immediately up stream of the start of our restoration reach. Data was collected for three months (June through September) and water levels were correlated to an estimated discharge using a rating curve generated for the gauged section. Three significant flow events occurred during the monitoring period. On August 30th, Richland Creek in the vicinity of the gauge was discharging approximately 309 ft^3/s. August 13th and June 8th experienced flows exceeding 185 and 155 ft^3/s, respectively. The stage data collected during this period is useful in supporting/validating the bankfull identification from field indicators.

After these storm events a significant trend was apparent in the hydrograph and a stage/discharge relationship could be determined. This relationship was then plotted so that the discharge of known bankfull indicator elevations could be determined. These stage/discharge relationships were then adjusted for watershed area. This produced a sequence of bankfull discharges related to the watershed areas: 5.6 square miles = 320 cfs, 7.2 square miles = 400 cfs and 7.8 square miles = 425 cfs. Since the EEP restoration reach has the largest of these areas, we are using a design discharge of 425 cfs at bankfull. As expected, this level falls between the NC Rural Piedmont Regional Curve value of 390 cfs and the NC Urban Piedmont Regional Curve value of 770 cfs.

Figure 7b shows the stage/discharge relationship for Richland Creek from KCI.

c. Scaled plans (See Drawings 7C-1 and 7C-2)

d. Longitudinal profile (See Table 7d and Figure 7d)

The design longitudinal profile is attached in both table and chart form.

e. Sediment transport analysis (Tables 7e)

Entrainment calculations for the existing and proposed channels are attached.
The riffle pebble count D_{50} for both is 12 mm, and the bar/subpavement D_{50} for both is 2.5 mm. In addition, the largest particle from the bar/subpavement for both analyses is 58 mm. The only difference is the bankfull mean depth, which is deeper in the proposed channel. The entrainment calculations show the existing channel to be aggrading and the proposed channel to be stable.

f. Special features (Rock ramp fishway) (See Drawing 7F and Tables 7f)

(By Alan Schlindwein, PE, KCI Associates)

Rock ramps are essentially an analog of natural rock outcroppings. Within some watersheds, there are bedrock outcroppings that create steep and rough flow conditions in stream channels. Upstream and downstream of this natural feature, there may be normal alluvial stream channels. These outcropping features are so common, that they are habitat for some species and are used for spawning by fish like the Sturgeon. The difficultly in analog design is to create a stable channel bed and predictable flow system.

Because these rock ramp channels are so steep (the proposed gradient on Richland Creek is only 10% as steep as the proposed rock ramp) they must be built with boulders. These boulders will not be replaced by natural means, so they must be immobile. To complicate matters, the modeling of shallow flow on boulders is not well defined in the literature and the length of rock ramps are such that the flow must be broken by a pattern of exposed rock for migratory fish to pass. This pattern of exposed rocks is called, a boulder garden, and it creates flow conditions of refuge, turbulence and chutes. The created chute flow intensifies the stress on the channel bed well above the average flow of the rock ramp.

To model the resistance of the rock surface at shallow depths, Mussetter's relationship (1989) for the Darcey-Wiesbach friction factor is used. A Manning's "n" is derived and used in the flow equation to generate average flow conditions. The concentration of flow and shear around the boulders is taken from Shamloo et al (2002) and used to determine the critical shear stresses that the channel must resist. The pattern of stone in the boulder garden is taken from Acharya et al (2000). The stone sizes are calculated using Andrews (1994) critical shear stress equation.

The exposed stone in the boulder garden pattern must be just high enough to affect the shallow flows and must be wide enough to create the chute & wake flow pattern. In between the chutes and the wake is a region of von Karman vortex flow streets. These turbulent vortex streets are where larger fish swim up the rock ramps (Liao et al, 2003). To cross the chute, the fish use a swimming burst to reach the wake of the upstream boulder. At the top of the structure, the fish burst into the slow moving water of the natural stream channel. Because rock ramps resemble natural geological features so well, they are two-way migration paths, both upstream and downstream.

The cross section of the fishway is "V" shaped, which concentrates low flows into a small channel. The boulder garden is spaced such that large boulders border this narrow, low flow every 9 feet along the profile. At higher flows the central boulders will be washed out hydraulically, so lateral boulders are needed in shallower water to create the necessary flow conditions for fish passage. The horizontal spacing is 6 feet for each row of three exposed boulders. By providing multiple pathways up the structure, debris or ice can only temporarily block an individual pathway. Higher flows will wash trees and ice off of the rock ramp; in this way they are self-cleaning and low maintenance. These rock ramps are so steep, that sediments will not settle on these features and they will remain flush and well aerated.

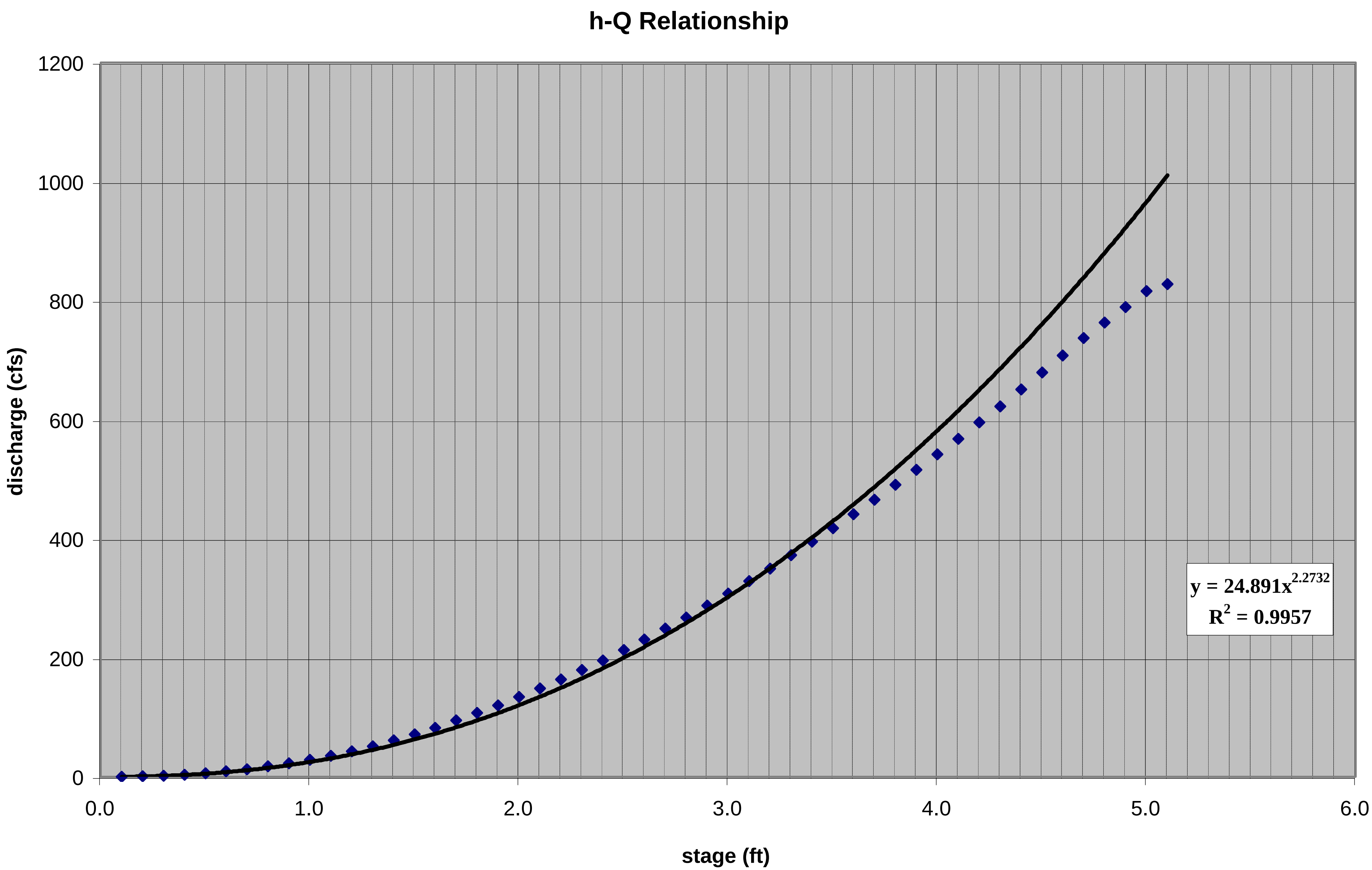
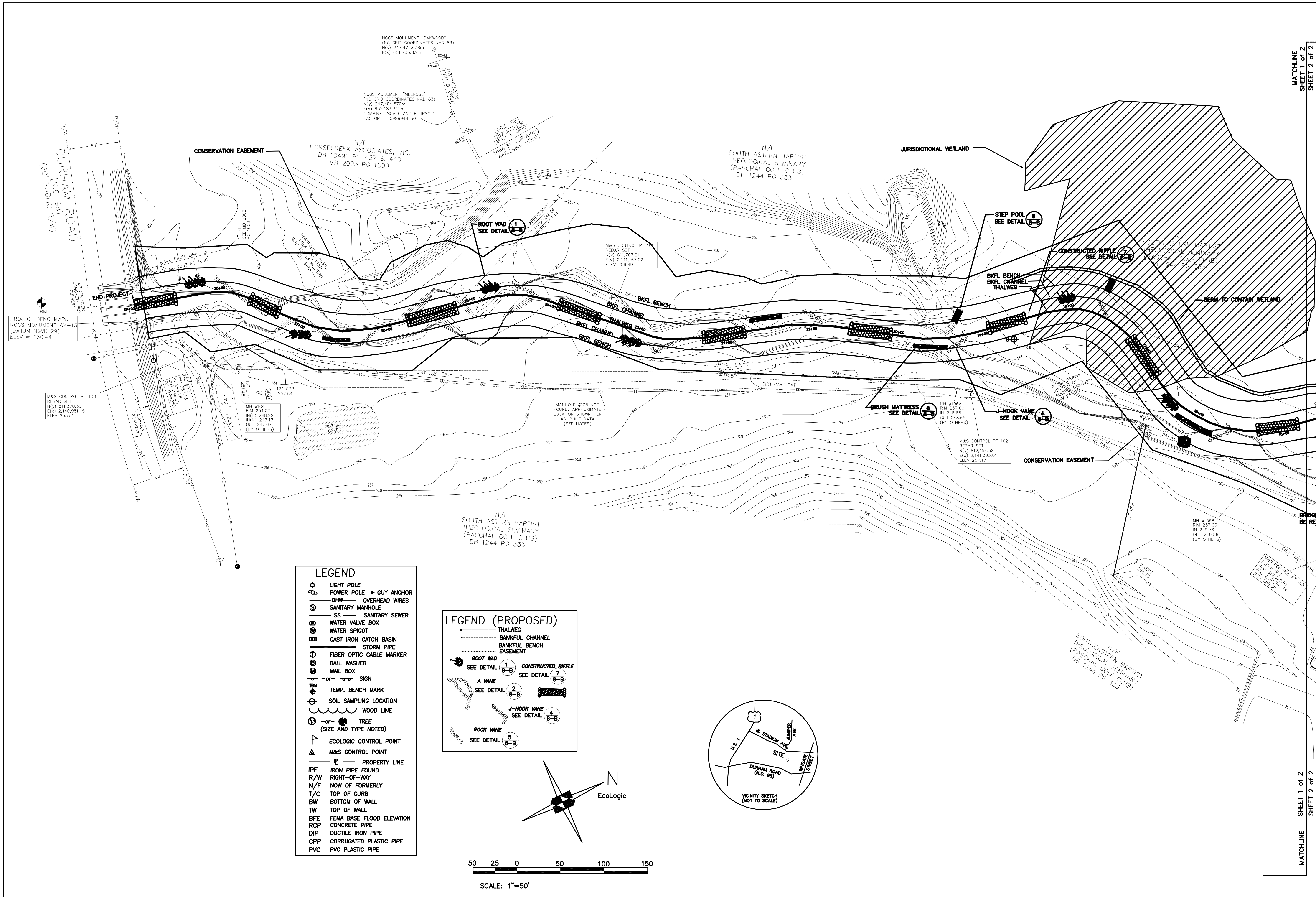


Figure 7b (from KCI Associates)



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PROJECT:

RICHLAND CREEK
STREAM RESTORATION
WAKE COUNTY, NC

PREPARED FOR:

NORTH CAROLINA
ECOSYSTEM ENHANCEMENT PROGRAM

NO.	DESCRIPTION	DATE
4	REDESIGN REISSUED	2/23/07
3	PLANFORM REVISED	7/17/06
2	WETLAND ADDED	3/28/05
1	REVIEW COMMENTS	1/31/05

REVISIONS

RESTORATION PLAN

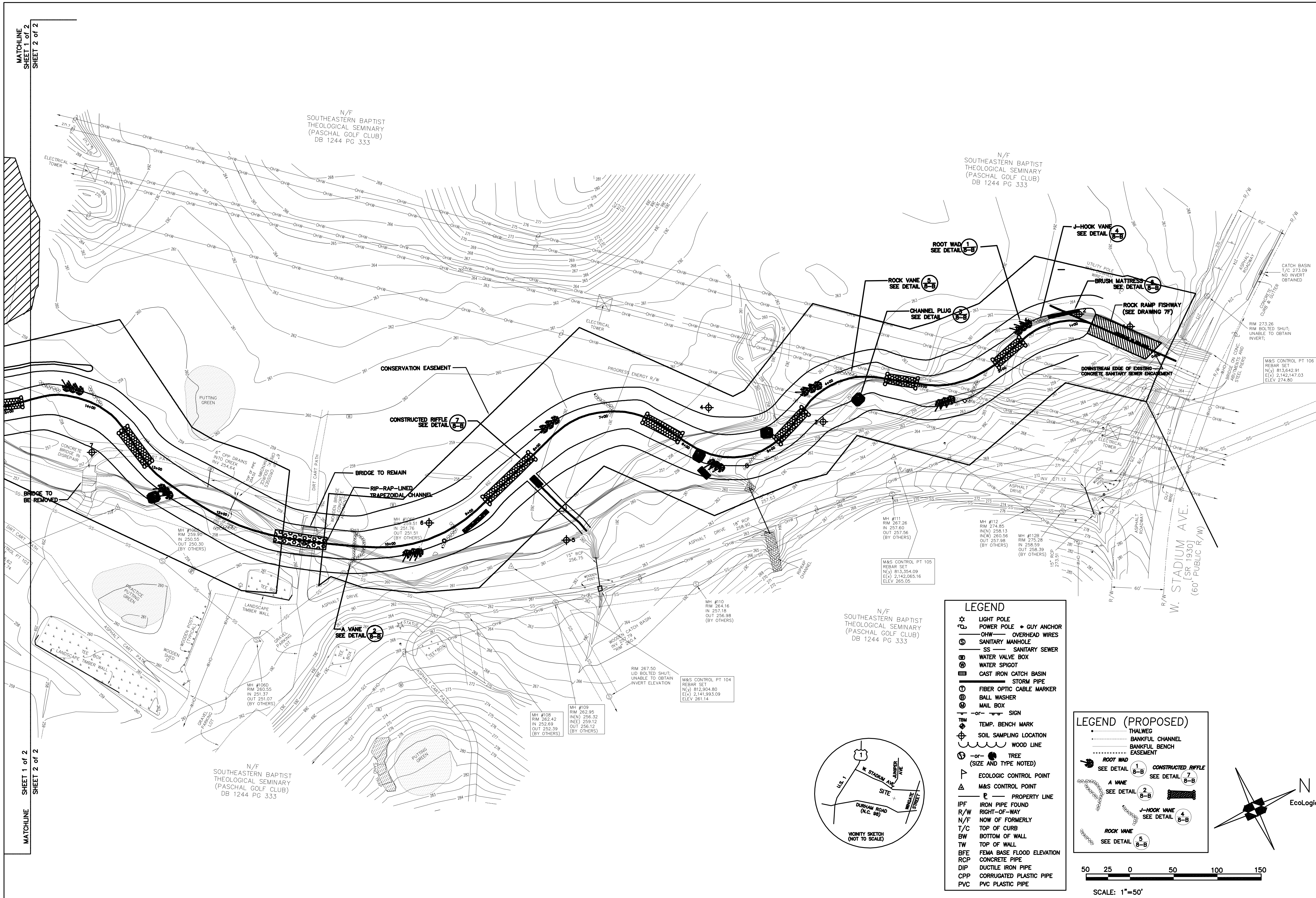
SCALE: 1" = 50'
DATE: 1/22/05
DRN. BY: KDH
CHECKED BY: MAT

PROJECT NO:
–

SHEET ____ OF ____

DRAWING

7C-1



LEGEND

- LIGHT POLE
- POWER POLE • GUY ANCHOR
- —OHW— OVERHEAD WIRES
- SANITARY MANHOLE
- — SS — SANITARY SEWER
- WATER VALVE BOX
- WATER SPIGOT
- CAST IRON CATCH BASIN
- STORM PIPE
- FIBER OPTIC CABLE MARKER
- BALL WASHER
- MAIL BOX
- —or— SIGN
- TBM TEMP. BENCH MARK
- SOIL SAMPLING LOCATION
- WOOD LINE
- —or— TREE (SIZE AND TYPE NOTED)
- ECOLOGIC CONTROL POINT
- M&S CONTROL POINT
- — ℄ — PROPERTY LINE

IPF	IRON PIPE FOUND
R/W	RIGHT-OF-WAY
N/F	NOW OF FORMERLY
T/C	TOP OF CURB
BW	BOTTOM OF WALL
TW	TOP OF WALL
BFE	FEMA BASE FLOOD ELEVATION
RCP	CONCRETE PIPE
DIP	DUCTILE IRON PIPE
CPP	CORRUGATED PLASTIC PIPE
PVC	PVC PLASTIC PIPE

LEGEND (PROPOSED)

- THALWEG
- BANKFUL CHANNEL
- BANKFUL BENCH
- EASEMENT
- ROOT WAD SEE DETAIL 1 8-B
- CONSTRUCTED RIFFLE SEE DETAIL 7 8-B
- A VANE SEE DETAIL 2 8-B
- J-HOOK VANE SEE DETAIL 4 8-B
- ROCK VANE SEE DETAIL 5 8-B

50 25 0 50 100 150

SCALE: 1"=50'

N EcoLogic

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REVISIONS

RESTORATION PLAN

SCALE: 1" = 50'
DATE: 1/22/05
DRN. BY: KDH
CHECKED BY: MAT

PROJECT NO: —

SHEET ____ OF ____

DRAWING

7C-2

Table 7d
Proposed Longitudinal Profile

Richland Creek		ws slope =	0.0028	d rif =	3.4	ft
Stream Restoration	Last 600'	ws slope =	0.0040	d run =	3.8	ft
Wake County, NC		ramp slope =	0.028	d pool =	5.6	ft
NC Ecosystem Enhancement Program				d glide =	4.3	ft
				d bkf =	2.6	ft

Station	Feature	BKF EL	TW Elev	Structure
0	Fish Ramp	NA	257.7	Fish Ramp
77	Fish Ramp	NA	255.6	Fish Ramp
91	Transition	260.2	255.2	
111	Pool	260.1	254.5	
130		260.1	255.1	J-Hook Vane
145	Glide	260.0	255.7	Root Wads
165	RiffleTop	260.0	256.6	Const. Riffle
199	RiffleBot	259.9	256.5	Const. Riffle
226	Run	259.8	256.0	Rock Vane
246	Pool	259.8	254.2	
280	Glide	259.7	255.4	Root Wads
300	RiffleTop	259.6	256.2	Const. Riffle
336	RiffleBot	259.5	256.1	Const. Riffle
365	Run	259.4	255.6	Rock Vane
387	Pool	259.4	253.8	
423	Glide	259.3	255.0	Root Wads
445	RiffleTop	259.2	255.8	Const. Riffle
486	RiffleBot	259.1	255.7	Const. Riffle
519	Run	259.0	255.2	Rock Vane
544	Pool	258.9	253.3	
560		258.9	253.9	Root Wads
585	Glide	258.8	254.5	
610	RiffleTop	258.7	255.3	Const. Riffle
659	RiffleBot	258.6	255.2	Const. Riffle
698	Run	258.5	254.7	J-Hook Vane
715	Pool	258.5	252.9	
776	Glide	258.3	254.0	Root Wads
805	RiffleTop	258.2	254.8	Const. Riffle
872	RiffleBot	258.0	254.6	Const. Riffle
926	Run	257.9	254.1	J-Hook Vane
966	Pool	257.8	252.2	
1034	Glide	257.6	253.3	A Vane
1065	Bridge B	257.5	253.6	Rip-Rap
1087	Bridge A	257.4	253.5	Rip-Rap
1103	Bridge A	257.4	253.5	Rip-Rap
1125	Bridge B	257.3	253.4	Rip-Rap
1178	Run	257.2	253.3	Rock Vane
1213	Pool	257.1	251.5	
1270	Glide	256.9	252.6	Root Wads
1305	RiffleTop	256.8	253.4	Const. Riffle
1349	RiffleBot	256.7	253.3	Const. Riffle
1384	Run	256.6	252.8	Rock Vane
1410	Pool	256.5	250.9	

Table 7d
Proposed Longitudinal Profile

1425		256.5	251.3	Root Wads
1440		256.4	251.7	Rock Vane
1454	Glide	256.4	252.1	
1480	RiffleTop	256.3	252.9	Const. Riffle
1528	RiffleBot	256.2	252.8	Const. Riffle
1566	Run	256.1	252.3	J-Hook Vane
1594	Pool	256.0	250.4	
1642	Glide	255.9	251.6	Root Wads
1670	RiffleTop	255.8	252.4	Const. Riffle
1716	RiffleBot	255.7	252.3	Const. Riffle
1753	Run	255.5	251.7	Rock Vane
1781	Pool	255.5	249.9	
1800		255.4	250.5	Root Wads
1827	Glide	255.3	251.0	
1855	RiffleTop	255.3	251.9	Const. Riffle
1894	RiffleBot	255.2	251.8	Const. Riffle
1925	Run	255.1	251.3	J-Hook Vane
1948	Pool	255.0	249.4	
1987	Glide	254.9	250.6	
2010	RiffleTop	254.8	251.4	Const. Riffle
2053	RiffleBot	254.7	251.3	Const. Riffle
2087	Run	254.6	250.8	Rock Vane
2112	Pool	254.5	248.9	
2155	Glide	254.4	250.1	
2180	RiffleTop	254.4	251.0	Const. Riffle
2223	RiffleBot	254.2	250.8	Const. Riffle
2257	Run	254.1	250.3	Rock Vane
2282	Pool	254.1	248.5	
2300		254.0	249.1	Root Wads
2325	Glide	253.9	249.6	
2350	RiffleTop	253.8	250.4	Const. Riffle
2393	RiffleBot	253.7	250.3	Const. Riffle
2427	Run	253.5	249.7	J-Hook Vane
2452	Pool	253.4	247.8	
2475		253.3	248.4	Root Wads
2495	Glide	253.3	249.0	
2520	RiffleTop	253.2	249.8	Const. Riffle
2573	RiffleBot	253.0	249.6	Const. Riffle
2615	Run	252.8	249.0	Rock Vane
2656	Pool	252.6	247.0	
2699	Glide	252.4	248.1	Root Wads
2730	RiffleTop	252.3	248.9	Const. Riffle
2761	RiffleBot	252.2	248.8	Const. Riffle
2786	Run	252.1	248.3	Rock Vane
2805	Pool	252.0	246.4	
2836	Glide	251.9	247.6	Root Wads
2855	RiffleTop	251.8	248.4	Const. Riffle
2900	RiffleBot	251.6	248.2	Const. Riffle

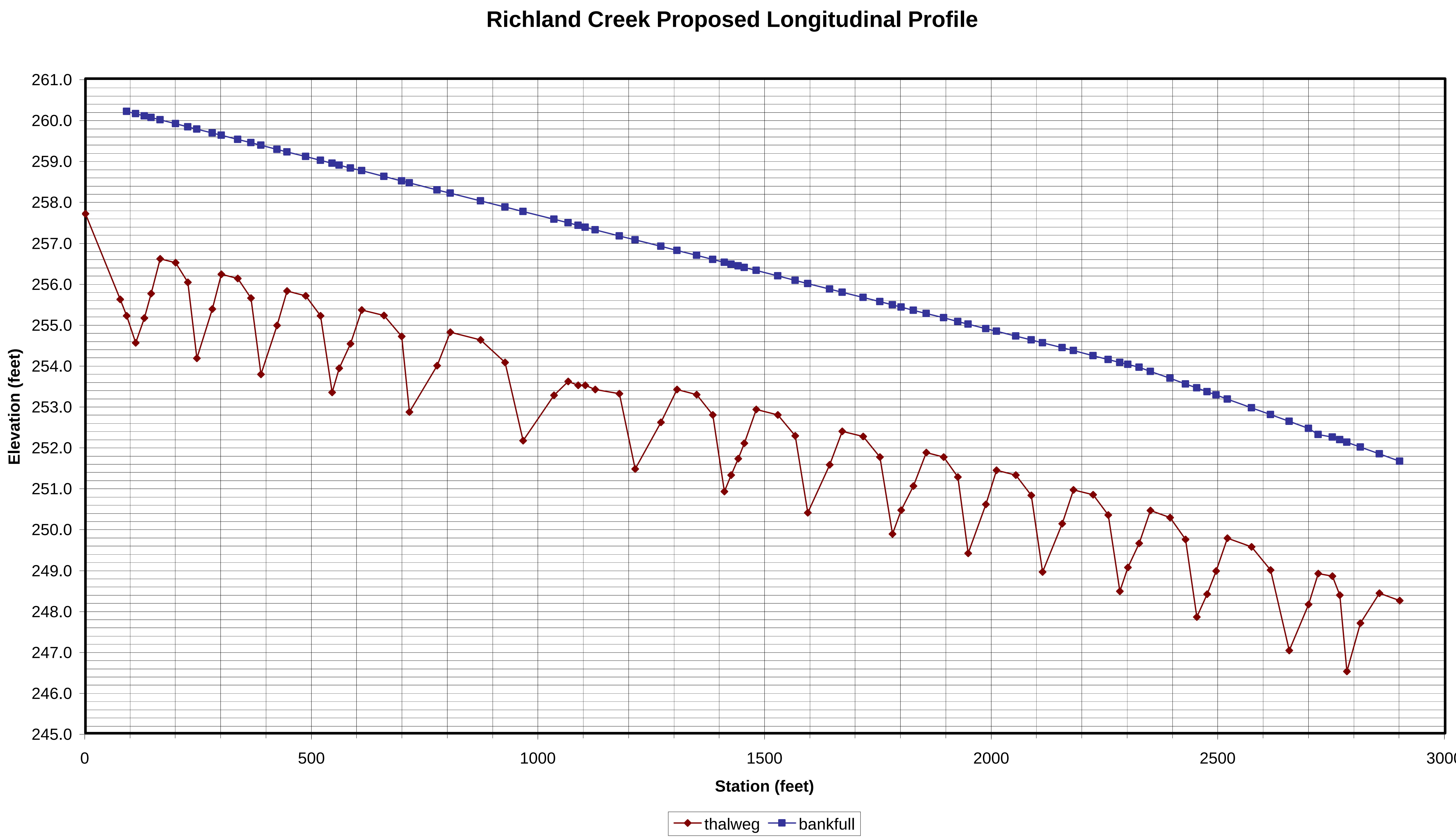

Richland Creek Proposed Longitudinal Profile
261.0
260.0
259.0
258.0
257.0
256.0
255.0
254.0
253.0
252.0
251.0
250.0
249.0
248.0
247.0
246.0
245.0
Elevation (feet)
0
500
1000
1500
2000
2500
3000
Station (feet)
thalweg
bankfull

Figure 7d

Table 7e (Existing)

ENTRAINMENT CALCULATION FORM

Stream:	Richland Creek, Existing	Reach:	Paschal Golf Course
Team:	Ken, Kyle, Moni	Date:	5/10/2004

Information Input Area

12	D_{50}	Riffle bed material D50 (mm)			
2.5	$\hat{D}_{50}$	Bar sample D50 (mm)			
58.0	D_i	Largest particle from bar sample (mm)	0.19	(feet)	304.8 mm/foot
0.003	S_e	Existing bankfull water surface slope (ft/ft)			
2.1	d_e	Existing bankfull mean depth (ft)			
2	R	Hydraulic Radius of Riffle Cross Section (ft)			
1.65	γ_s	Submerged specific weight of sediment			

Calculation of Critical Dimensionless Shear Stress

4.80	$D_{50}/\hat{D}_{50}$	If value is between 3-7	**Equation 1** will be used:	$\tau^*_{ci} = 0.0834(D_{50}/\hat{D}_{50})^{-0.872}$
4.83	D_i/D_{50}	If value is between 1.3-3.0	**Equation 2** will be used:	$\tau^*_{ci} = 0.0384(D_i/D_{50})^{-0.887}$
0.0212	τ^*_{ci}	Critical Dimensionless Shear Stress	**Equation used:**	**1**

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

2.38	d_r	Required bankfull mean depth (ft)	$d_r = \dfrac{\tau^*_{ci}\gamma_s D_i}{S_e}$		
0.88	d_e/d_r	$\dfrac{\text{Existing mean bankfull depth}}{\text{Required mean bankfull depth}}$	Stable ($d_e/d_r = 1$)	Aggrading ($d_e/d_r<1$)	Degrading ($d_e/d_r>1$)
aggrading	Vertical Stability of Stream				

Calculation of BKF Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample

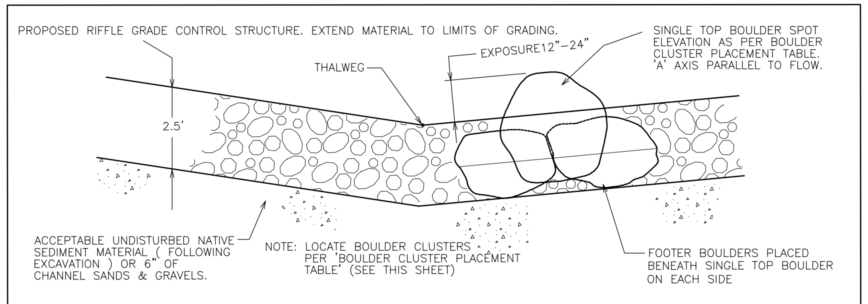
0.0032	S_r	Required bankfull water surface slope (ft)	$S_r = \dfrac{\tau^*_{ci}\gamma_s D_i}{d_e}$		
0.88	S_e/S_r	$\dfrac{\text{Existing water surface slope}}{\text{Required water surface slope}}$	Stable ($S_e/S_r = 1$)	Aggrading ($S_e/S_r < 1$)	Degrading ($S_e/S_r > 1$)
aggrading	Vertical Stability of Stream				

Sediment Transport Validation

0.35	Bankfull Shear Stress $\tau_c = \gamma RS$ (lb/ft2) γ = Density of water = 62.4 lbs/ft^3
20-80	Moveable particle size (mm) at bankfull shear stress (predicted by the Shields Diagram: Blue field book:p238, Red field book:p190)
.30-.90	Predicted shear stress required to initate movement of D_i (mm) (see Shields Diagram: Blue field book:p238, Red field book:p190)

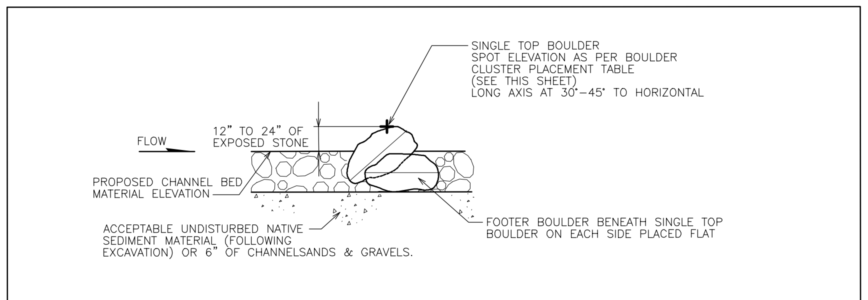
Table 7e (Proposed)

ENTRAINMENT CALCULATION FORM					
Stream:	Richland Creek, Proposed		Reach:	Paschal Golf Course	
Team:	Ken, Kyle		Date:	9/29/2004	
Information Input Area					
12	D_{50}	Riffle bed material D50 (mm)			
2.5	$\hat{D}_{50}$	Bar sample D50 (mm)			
58.0	D_i	Largest particle from bar sample (mm)	0.19	(feet)	304.8 mm/foot
0.003	S_e	Proposed bankfull water surface slope (ft/ft)			
2.5	d_e	Proposed bankfull mean depth (ft)			
2.3	R	Hydraulic Radius of Riffle Cross Section (ft)			
1.65	γ_s	Submerged specific weight of sediment			
Calculation of Critical Dimensionless Shear Stress					
4.80	$D_{50}/\hat{D}_{50}$	If value is between 3-7	**Equation 1** will be used: $\tau^*_{ci} = 0.0834(D_{50}/\hat{D}_{50})^{-0.872}$		
4.83	D_i/D_{50}	If value is between 1.3-3.0	**Equation 2** will be used: $\tau^*_{ci} = 0.0384(D_i/D_{50})^{-0.887}$		
0.0212	τ^*_{ci}	Critical Dimensionless Shear Stress	**Equation used:**		**1**
Calculation of Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
2.38	d_r	Required bankfull mean depth (ft)	$d_r = \dfrac{\tau^*_{ci}\gamma_s D_i}{S_e}$		
1.05	d_e/d_r	Existing mean bankfull depth / Required mean bankfull depth	Stable ($d_e/d_r = 1$)	Aggrading ($d_e/d_r<1$)	Degrading ($d_e/d_r>1$)
stable	Vertical Stability of Stream				
Calculation of BKF Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
0.0027	S_r	Required bankfull water surface slope (ft)	$S_r = \dfrac{\tau^*_{ci}\gamma_s D_i}{d_e}$		
1.05	S_e/S_r	Existing water surface slope / Required water surface slope	Stable ($S_e/S_r = 1$)	Aggrading ($S_e/S_r < 1$)	Degrading ($S_e/S_r > 1$)
stable	Vertical Stability of Stream				
Sediment Transport Validation					
0.40	Bankfull Shear Stress	$\tau_c = \gamma RS$ (lb/ft2)	γ = Density of water = 62.4 lbs/ft^3		
20-90	Moveable particle size (mm) at bankfull shear stress (predicted by the Shields Diagram: Blue field book:p238, Red field book:p190)				
.3-.9	Predicted shear stress required to initate movement of D_i (mm) (see Shields Diagram: Blue field book:p238, Red field book:p190)				



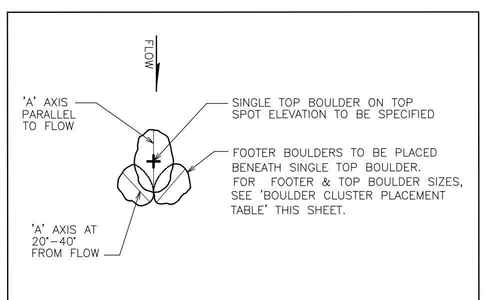
BOULDER CLUSTER : CROSS–SECTION

NOT TO SCALE



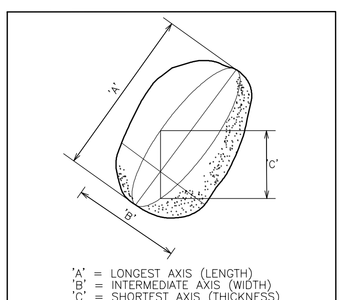
BOULDER CLUSTER : PROFILE

NOT TO SCALE



BOULDER CLUSTER : PLAN VIEW

NOT TO SCALE



BOULDER DETAIL

NOT TO SCALE

STATION	OFFSET	REFUGIA STONE WIDTH	EXPOSURE	ROW	THALWEG ELEV.	TOP OF REF. ROCK
(ft)	(ft)	(ft)	(ft)		(ft)	(ft)
49+70	4.5(R)	2	2	1	257.67	260.42
	1.5(R)	2	1			258.92
	1.5(L)	2	1			258.92
49+79	4.5(L)	2	2	2	257.42	260.17
	1.5(R)	2	1			258.67
	1.5(L)	2	1			258.67
49+88	4.5(R)	2	2	3	257.17	259.92
	1.5(R)	2	1			258.42
	1.5(L)	2	1			258.42
49+97	4.5(L)	2	2	4	256.91	259.66
	1.5(R)	2	1			258.16
	1.5(L)	2	1			258.16
50+06	4.5(R)	2	2	5	256.66	259.41
	1.5(R)	2	1			257.91
	1.5(L)	2	1			257.91
50+15	4.5(L)	2	2	6	256.41	259.16
	1.5(R)	2	1			257.66
	1.5(L)	2	1			257.66
50+24	4.5(R)	2	2	7	256.16	258.91
	1.5(R)	2	1			257.41
	1.5(L)	2	1			257.41

BOULDER CLUSTER PLACEMENT TABLE

NOTES:

OFFSETS ARE REFERENCED TO A DOWNSTREAM VIEW. (R)=OFFSET TO THE RIGHT, (L)=OFFSET TO THE LEFT.

STATION 49+68 EQUALS ECOLOGIC STATION 0+00 AND IS DOWNSTREAM EDGE OF CONCRETE SANITARY SEWER ENCASEMENT. ALL VERTICAL ELEVATIONS SHOWN ARE IN NAVD 88.

CHANNEL BED MATERIAL – GRADATION TABLE

% LESS THAN	STONE SIZE(NCDOT SEC.1042)
100	2.0 FT
40–50	1.6 FT (USE CLASS II)d_{50}
30–40	1.0 FT (USE CLASS I)
20–30	0.5 FT (USE CLASS B)d_{30}
10–20	0.25 FT (USE CLASS A)
0–10	0.125 (USE NO.57 STONE)

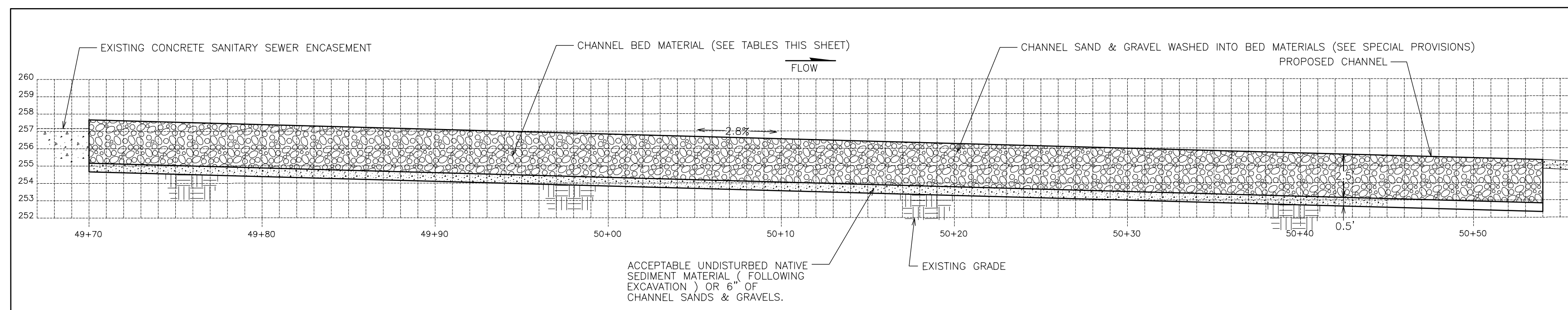
CHANNEL SAND & GRAVEL – GRADATION TABLE

% LESS THAN	SIEVE SIZE(mm EQUIVALENT)
100	2.5 IN (64mm)
95–100	1.25 IN (32mm)
88–100	5/8 IN (16mm)
62–96	5/16 IN (8mm)
40–77	#5 (4mm)
17–48	#10 (2mm)
0–35	#18 (1mm)

ACCEPTANCE CRITERIA FOR BOULDER

MINIMUM	MIDRANGE	MAXIMUM
24 INCHES	30 INCHES	36 INCHES

CHANNEL MATERIALS



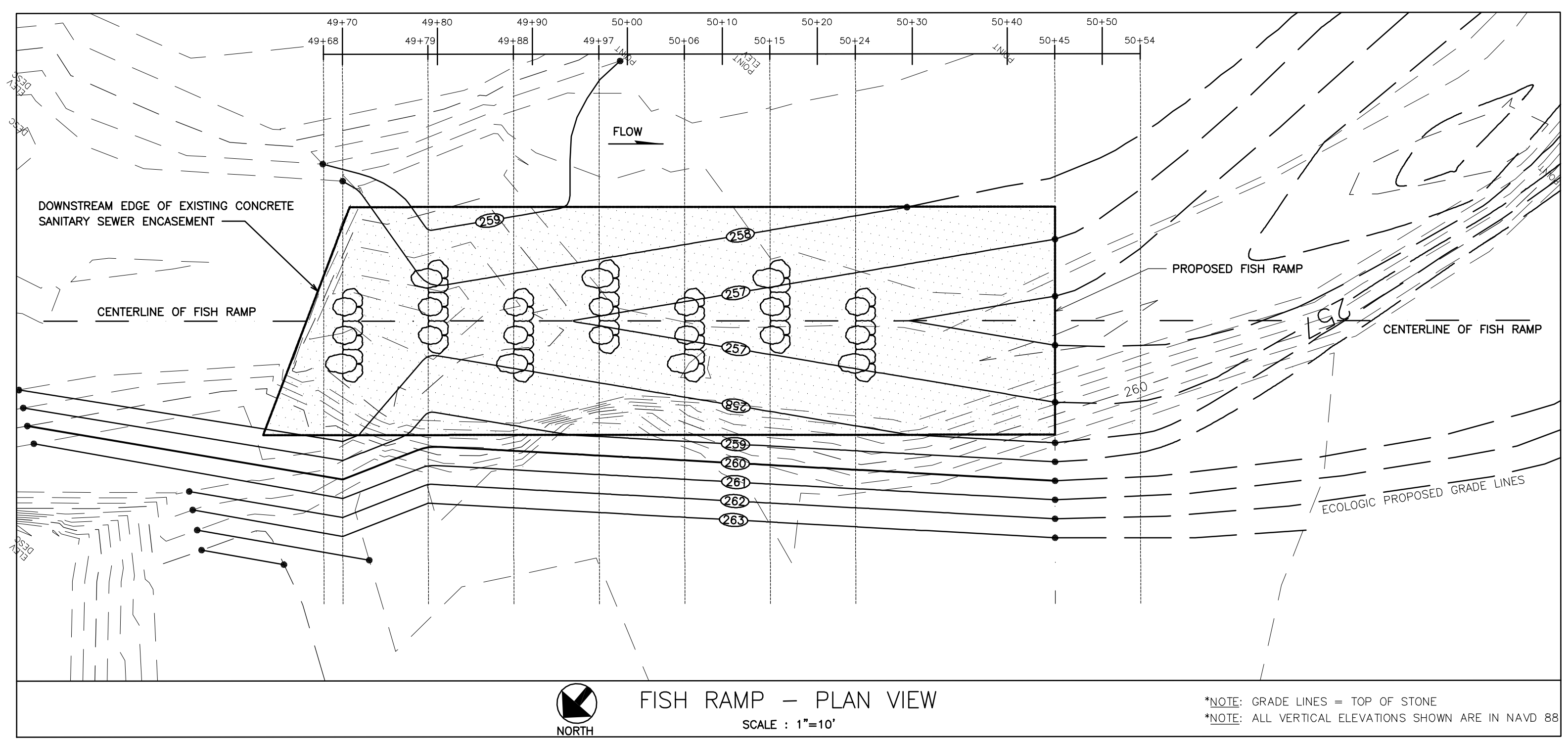
FISH RAMP – PROFILE VIEW

SCALE : 1"=5'

*NOTE: BOULDER CLUSTERS NOT SHOWN FOR CLARITY
*NOTE: ALL VERTICAL ELEVATIONS SHOWN ARE IN NAVD 88

NOTES:

STATION 49+68 EQUALS ECOLOGIC STATION 0+00 AND IS DOWNSTREAM EDGE OF CONCRETE SANITARY SEWER ENCASEMENT. ALL VERTICAL ELEVATIONS SHOWN ARE IN NAVD 88.



FISH RAMP – PLAN VIEW

SCALE : 1"=10'

*NOTE: GRADE LINES = TOP OF STONE
*NOTE: ALL VERTICAL ELEVATIONS SHOWN ARE IN NAVD 88

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PROJECT:
RICHLAND CREEK
STREAM RESTORATION
WAKE COUNTY, NC

PREPARED FOR:
NORTH CAROLINA
ECOSYSTEM ENHANCEMENT PROGRAM

NO.	DESCRIPTION	DATE

REVISIONS

ROCK RAMP FISHWAY

SCALE: N.T.S.
DATE: 2/23/07
DRN. BY: KCI
CHECKED BY: MAT

PROJECT NO:
–

SHEET OF

DRAWING

7F

Table 7f-1

Richland Creek
Wake Forest, NC

Rock Ramp Fishway Cross-Sections

Station	49+70		Station	50+00		Station	50+30		Station	50+45
Off Set	Elevation		Off Set	Elevation		Off Set	Elevation		Off Set	Elevation
(ft)	(ft)		(ft)	(ft)		(ft)	(ft)		(ft)	(ft)
-12	258.00		-12	258.83		-12	258.00		-12	257.58
-8	257.89		-7	258.00		-6	257.00		-8.5	257.00
-4	257.78		-1	257.00					-2.5	256.00
0	257.67		0	256.83		0	256.00		0	255.58
4	257.78		1	257.00					2.5	256.00
8	257.89		7	258.00		6	257.00		8.5	257.00
12	258.00		12	258.83		12	258.00		12	257.58

Table 7f-2

Richland Creek
Wake Forest, NC

Refugia Boulders - Boulder Garden Pattern

Station	Offset	Refugia Stone Size			Thalweg	Top of
		Width	Exposure	Row	Elevation	Ref Rock
(ft)	(ft)	(ft)	(ft)		(ft)	(ft)
4970	4.5	2	2			260.42
4970	1.5	2	1	1	257.67	258.92
4970	-1.5	2	1			258.92
4979	-4.5	2	2			260.17
4979	-1.5	2	1	2	257.42	258.67
4979	1.5	2	1			258.67
4988	4.5	2	2			259.92
4988	1.5	2	1	3	257.17	258.42
4988	-1.5	2	1			258.42
4997	-4.5	2	2			259.66
4997	-1.5	2	1	4	256.91	258.16
4997	1.5	2	1			258.16
5006	4.5	2	2			259.41
5006	1.5	2	1	5	256.66	257.91
5006	-1.5	2	1			257.91
5015	-4.5	2	2			259.16
5015	-1.5	2	1	6	256.41	257.66
5015	1.5	2	1			257.66
5024	4.5	2	2			258.91
5024	1.5	2	1	7	256.16	257.41
5024	-1.5	2	1			257.41

Table 7f-3

Richland Creek
Wake Forest, NC

Rock Ramp Hydraulics

							Rock Ramp Hydraulics			Boulder Garden Pattern													
	side slope	6			0.028	1.2	1.7	class 2 riprap						0.1			0.71						
								Mussetter	Manning's		max		Englsh Units			max			Andrews 95				
d	g	A	Wp	Rh	So	D50	D84	n	v	Q	shear	v	Q	d	CrestElev.	shear	D05	tau*c50	tau*c5	tau5	tau5/shear	tau50	tau50/shear
(m)	m/s2	(m2)	(m)	(m)	(m/m)	(m)	(m)		(m/s)	(m3/s)	(N/m2)	(fps)	(ft3/s)	(ft)	ft	(lbs/ft2)	(m)						
												0	0	0	258.7	0							
0.030488	9.81	0.005577	0.3709	0.015036	0.028	0.96	1.36	0.303386	0.033695	0.000188	0.008374	0.110519	0.006631	0.1	258.8	0.17472	0.568	0.0375	0.059263	0.544855	65.06	0.582714	69.58
0.060976	9.81	0.022308	0.7418	0.030073	0.028	0.96	1.36	0.247573	0.065515	0.001462	0.016749	0.21489	0.051573	0.2	258.9	0.34944					32.53		34.79
0.091463	9.81	0.050193	1.1127	0.045109	0.028	0.96	1.36	0.219814	0.096664	0.004852	0.025123	0.317059	0.171212	0.3	259	0.52416					21.69		23.19
0.121951	9.81	0.089233	1.483601	0.060146	0.028	0.96	1.36	0.202028	0.127385	0.011367	0.033498	0.417824	0.401111	0.4	259.1	0.69888					16.27		17.40
0.152439	9.81	0.139426	1.854501	0.075182	0.028	0.96	1.36	0.189229	0.157792	0.022	0.041872	0.517559	0.776337	0.5	259.2	0.8736					13.01		13.92
0.182927	9.81	0.200773	2.225401	0.090219	0.028	0.96	1.36	0.179375	0.187951	0.037736	0.050246	0.616479	1.331592	0.6	259.3	1.04832					10.84		11.60
0.213415	9.81	0.273275	2.596301	0.105255	0.028	0.96	1.36	0.171446	0.217905	0.059548	0.058621	0.714727	2.101294	0.7	259.4	1.22304					9.29		9.94
0.243902	9.81	0.35693	2.967201	0.120292	0.028	0.96	1.36	0.164861	0.247684	0.088406	0.066995	0.812404	3.119625	0.8	259.5	1.39776					8.13		8.70
0.27439	9.81	0.45174	3.338101	0.135328	0.028	0.96	1.36	0.159263	0.277312	0.125273	0.07537	0.909583	4.420568	0.9	259.6	1.57248					7.23		7.73
0.304878	9.81	0.557704	3.709002	0.150365	0.028	0.96	1.36	0.154417	0.306806	0.171107	0.083744	1.006323	6.037932	1	259.7	1.7472					6.51		6.96
0.335366	9.81	0.674822	4.079902	0.165401	0.028	0.96	1.36	0.15016	0.33618	0.226861	0.092118	1.10267	8.005373	1.1	259.8	1.92192	*** DESIGN DEPTH ***				5.91		6.33
0.365854	9.81	0.803093	4.450802	0.180438	0.028	0.96	1.36	0.146376	0.365445	0.293487	0.100493	1.19866	10.35641	1.2	259.9	2.09664					5.42		5.80
0.396341	9.81	0.942519	4.821702	0.195474	0.028	0.96	1.36	0.14298	0.394611	0.371929	0.108867	1.294325	13.12444	1.3	260	2.27136					5.00		5.35
0.426829	9.81	1.093099	5.192602	0.210511	0.028	0.96	1.36	0.139906	0.423686	0.463131	0.117241	1.389691	16.34274	1.4	260.1	2.44608					4.65		4.97
0.457317	9.81	1.254833	5.563502	0.225547	0.028	0.96	1.36	0.137103	0.452677	0.568034	0.125616	1.484779	20.04449	1.5	260.2	2.6208					4.34		4.64
0.487805	9.81	1.427722	5.934402	0.240584	0.028	0.96	1.36	0.134532	0.481588	0.687574	0.13399	1.57961	24.26278	1.6	260.3	2.79552					4.07		4.35
0.518293	9.81	1.611764	6.305303	0.25562	0.028	0.96	1.36	0.132161	0.510427	0.822687	0.142365	1.6742	29.03058	1.7	260.4	2.97024					3.83		4.09
0.54878	9.81	1.80696	6.676203	0.270657	0.028	0.96	1.36	0.129964	0.539196	0.974306	0.150739	1.768563	34.38081	1.8	260.5	3.14496					3.61		3.87
0.579268	9.81	2.013311	7.047103	0.285693	0.028	0.96	1.36	0.127919	0.5679	1.14336	0.159113	1.862713	40.3463	1.9	260.6	3.31968					3.42		3.66
0.609756	9.81	2.230815	7.418003	0.30073	0.028	0.96	1.36	0.126009	0.596543	1.330777	0.167488	1.956661	46.95981	2	260.7	3.4944					3.25		3.48
0.640244	9.81	2.459474	7.788903	0.315766	0.028	0.96	1.36	0.124219	0.625128	1.537485	0.175862	2.050419	54.254	2.1	260.8	3.66912					3.10		3.31
0.670732	9.81	2.699286	8.159803	0.330803	0.028	0.96	1.36	0.122536	0.653657	1.764407	0.184237	2.143995	62.26151	2.2	260.9	3.84384					2.96		3.16
0.70122	9.81	2.950253	8.530704	0.345839	0.028	0.96	1.36	0.120948	0.682133	2.012466	0.192611	2.237397	71.01489	2.3	261	4.01856					2.83		3.03
0.731707	9.81	3.212374	8.901604	0.360876	0.028	0.96	1.36	0.119448	0.710559	2.282582	0.200985	2.330635	80.54663	2.4	261.1	4.19328					2.71		2.90
0.762195	9.81	3.485648	9.272504	0.375912	0.028	0.96	1.36	0.118026	0.738937	2.575676	0.20936	2.423715	90.88916	2.5	261.2	4.368					2.60		2.78
0	9.81	0	0	#DIV/0!	0.028	0.96																	
0	9.81	0	0	#DIV/0!	0.028	0.96																	
0	9.81	0	0	#DIV/0!	0.028	0.96																	

References

Acharya, M., J.A. Kells, and C. Katopodis (2000) "Some Hydraulic Aspects of Nature-Like Fishways", *Proceedings for the Joint Conference on Water Resources Engineering and Water Resources Planning and Management*, Minneapolis, ASCE, Reston, VA.

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8. Typicals (Drawings 8-A and 8-B)

a. **Cross-sections** See Drawing 8-A

b. **Structures** See Drawing 8-B

9. Stream Riparian Planting Plan

a. **Electrical transmission corridor restrictions:**
Progress Energy requirements for planting beneath the three-phase, high voltage power lines are that plants not exceed 12 feet in height (personal communication: Mark Smith, Progress Energy Forester). At the time of correspondence, Mr. Smith stated no other requirements, but noted he would advise if he found any. As of this writing, no additional requirements have been provided.

A low-growing plant species list will be specified for use under the power lines. This includes species with height at maturity under the height limit and aggressive enough to compete with invasive vegetation to establish bank protection and riparian corridor wildlife habitat.

b. **Neuse River buffer requirements:**
The restoration reach is in the upper watershed of the Neuse River basin. As a result the restoration project is subject to buffer requirements that apply to streams in this basin. The regulations stipulate that the buffer shall have two zones: (1) an undisturbed forest zone beginning at the centerline of intermittent and perennial streams and extending

landward a distance of 30 feet on all sides of the waterbody, and (2) a vegetated zone beginning at the outer edge of Zone1 and extending an additional 20 feet. The combined width of Zones 1 and 2 shall be 50 feet.

c. Planting plan outline

The following sections outline the planting plan specifications:

1. Site Preparation

The planting plan includes the preservation of suitable existing vegetation, the reuse (transplanting) of suitable woody and herbaceous plants that must be disturbed, and the addition of new, native plant material. Site preparation will consist of preparing the planting areas, including the removal of undesirable vegetation, such as weedy, invasive or otherwise pest plants, and other plants that must be cleared to construct the restoration.

A serious effort shall be made to retain and protect existing native vegetation that is well rooted, healthy and appropriately sited alongside the impacted channel. In those areas, plants suitable for reuse shall be flagged by a representative of the Planting Plan Designer who is familiar with native riparian flora, then carefully extracted and stored by the Contractor for subsequent transplanting. Transplanting during channel shaping is preferred to limit the time the transplant is in transition.

Those areas of the site that become or have previously been compacted by construction equipment, trucks, etc. shall be ripped with a subsoiler, raked, and left in a rough, loose condition. Subsoil ripping should also occur on exposed banks and other denuded areas where trees are to be planted. The surface should be left rough for tree planting, with the orientation of any furrows being parallel to the stream and to the slope contours. Following this step, the surface shall be prepared for seeding using rubber-tired equipment or by hand to avoid re-compaction.

2. Soil Tests and Amendments

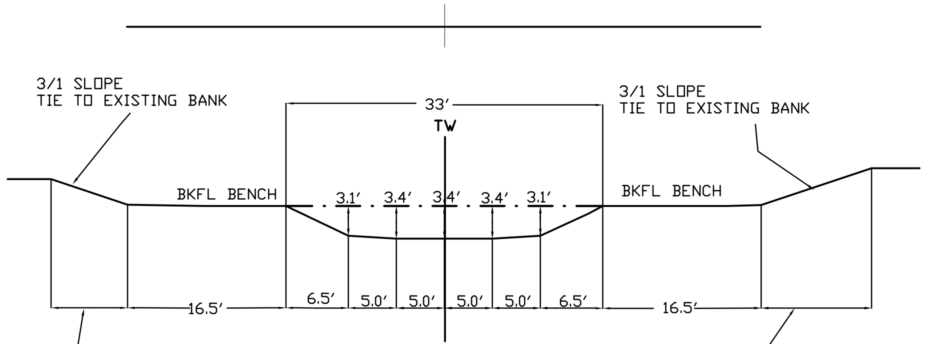
Soil in all planting areas shall be amended in accordance with test recommendations, and the rate of fertilization and lime application shall be in accordance with the test results. Soil sampling shall be performed utilizing sample methods recommended by the North Carolina Department of Agriculture and Consumer Services (NCDA&CS). The Planting Plan Designer is responsible for the soil sampling and adjusting the soil amendments according to the test results.

Soil amendment recommendations for native plant establishment:

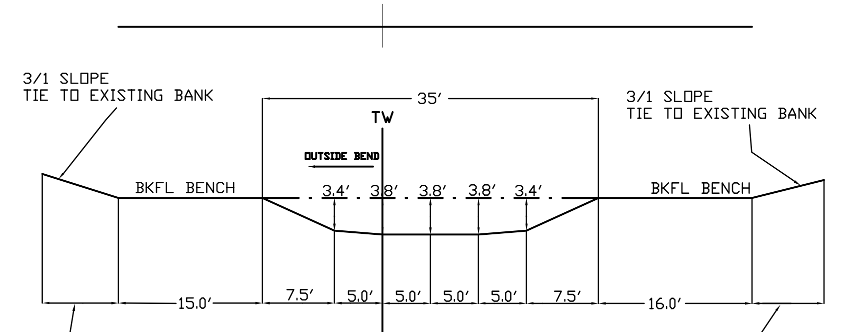
Lime	50-100 lbs./1000 sq. ft.	(1-2 tons/acre)
Fertilizer (4-24-24)	4-6 lbs./1000 sq. ft.	(200-250 lbs./acre)

Recommendations for grass establishment (also used on other areas disturbed during construction and planted with something other than native grasses)

Lime	50-100 lbs./1000 sq. ft.	(1-2 tons/acre)
Fertilizer (10-10-10)	8-12 lbs./1000 sq. ft.	(400-500 lbs./acre)

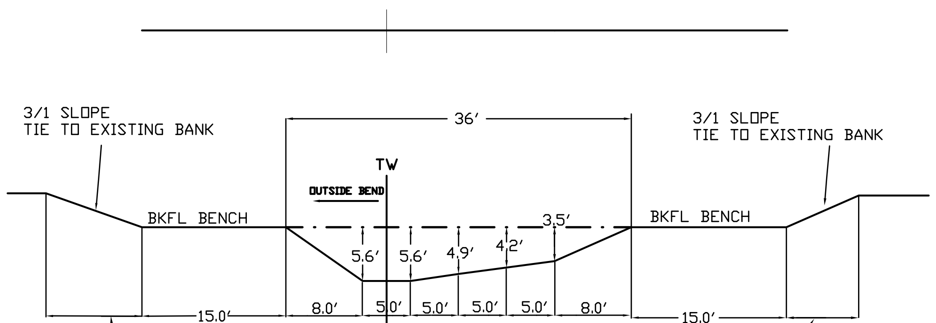


TYPICAL SECTION-RIFFLE

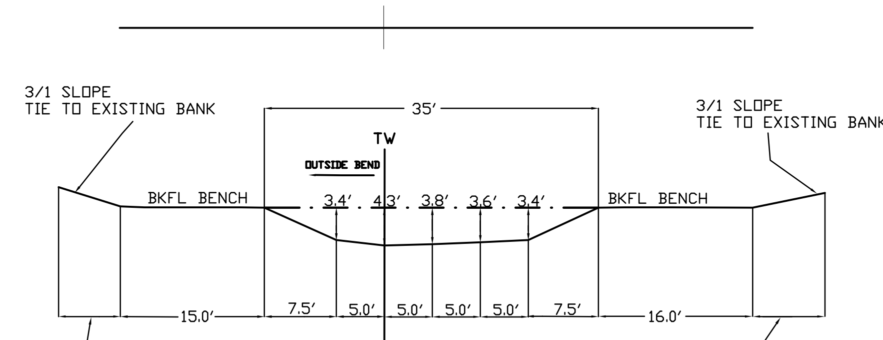


TYPICAL SECTION-RUN

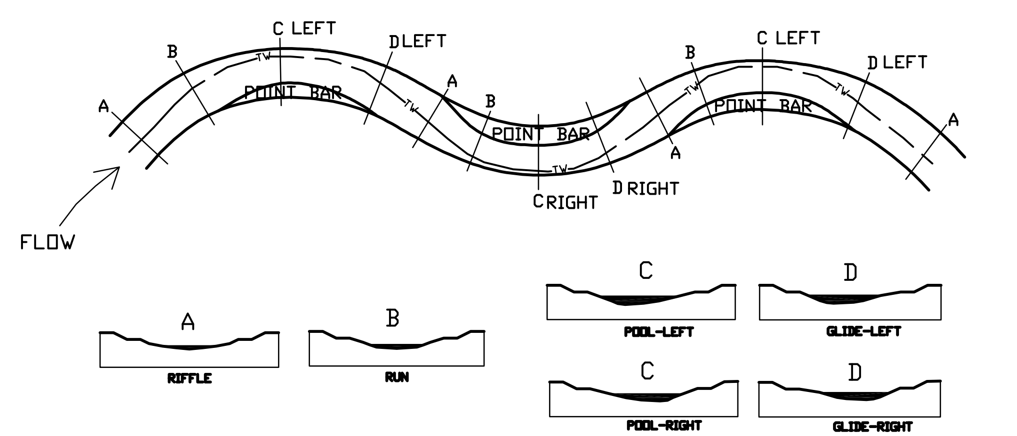
SCALE: 1"=10'



TYPICAL SECTION-POOL



TYPICAL SECTION-GLIDE



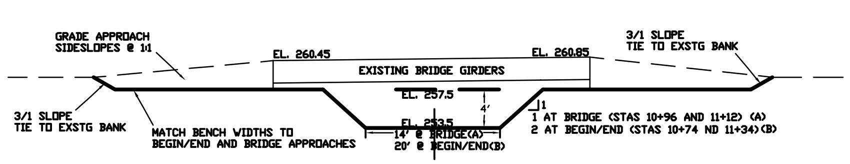
BED FEATURE SEQUENCE AND CROSS SECTIONS

SEE TYPICAL CROSS SECTIONS AND STATIONING FOR MORE DETAILS.

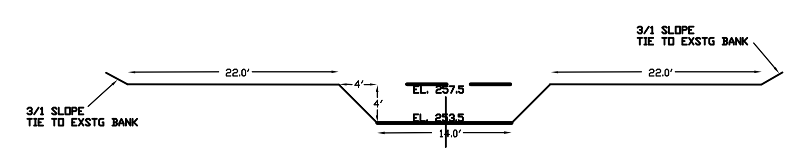
SCALE: 1"=10'

EXISTING

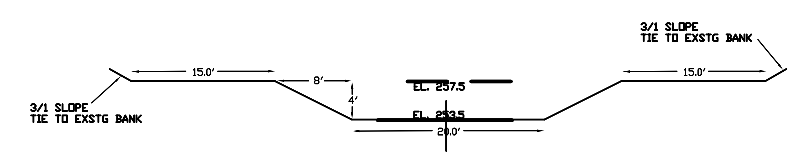
PROPOSED



CROSS SECTION AT BRIDGE CROSSING
(STAS 10+74 TO 11+34)



BRIDGE CROSS SECTION A



BRIDGE CROSS SECTION B

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PROJECT: RICHLAND CREEK STREAM RESTORATION WAKE COUNTY, NC

PREPARED FOR: NORTH CAROLINA ECOSYSTEM ENHANCEMENT PROGRAM

NO.	DESCRIPTION	DATE
1	REDESIGN ISSUED	2/23/07

REVISIONS

TYPICAL CROSS SECTIONS

SCALE: AS NOTED
DATE: 12/02/04
DRN. BY: KDH
CHECKED BY: MAT

PROJECT NO: –

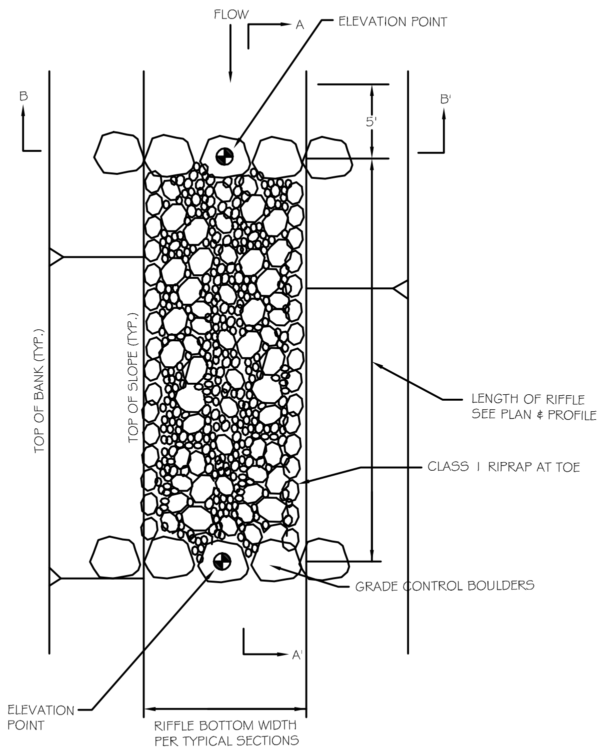
SHEET ____ OF ____

DRAWING

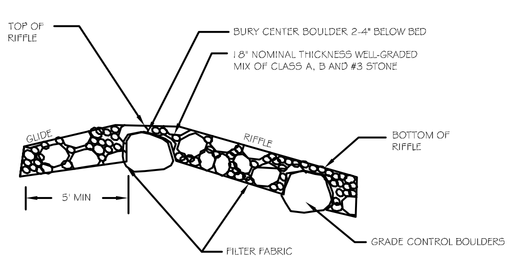
8A

CONSTRUCTED RIFFLE DETAIL 1

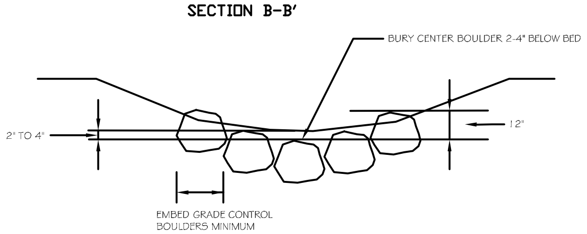
PLAN VIEW



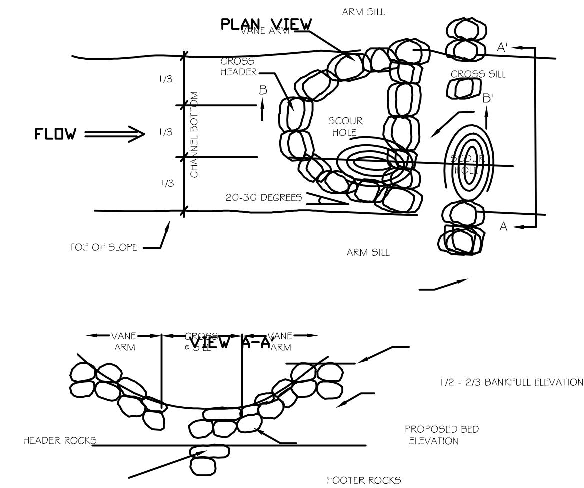
SECTION A-A'



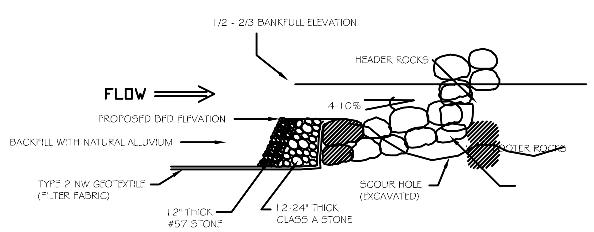
SECTION B-B'



A-VANE DETAIL 2



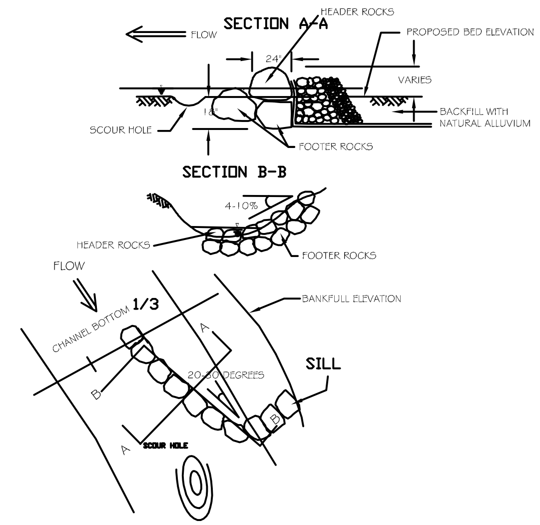
SECTION B-B'



A-VANE INSTALLATION NOTES

1. HEADER AND FOOTER ROCKS SHALL BE MIN 24" ALONG ANY AXIS. THE BOULDERS SHALL BE APPROVED BY THE ENGINEER PRIOR TO INSTALLATION OF THE STRUCTURE.
2. THE CROSS HEADER ROCKS SHALL BE PLACED SUCH THAT THE TOP ELEVATION IS AT THE PROPOSED BED ELEVATION.
3. GEOTEXTILE SHALL START AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWN TO THE BOTTOM OF THE FOOTER ROCKS, THEN UPSTREAM 10' +/- 1'.
4. BACKFILL BEHIND (UPSTREAM) OF THE FABRIC WITH CLASS A AND NO. 57 STONE FOLLOWED BY ALLUVIUM AS SHOWN.
5. ROCKS NOT ACCEPTABLE FOR USE IN OTHER STRUCTURES MAY BE UTILIZED TO FILL IN GAPS BETWEEN HEADER AND FOOTER ROCKS AS APPROVED BY THE ENGINEER.
6. STRUCTURE SLOPES AND ANGLES SHALL BE AS SHOWN UNLESS DIRECTED OTHERWISE BY THE ENGINEER.

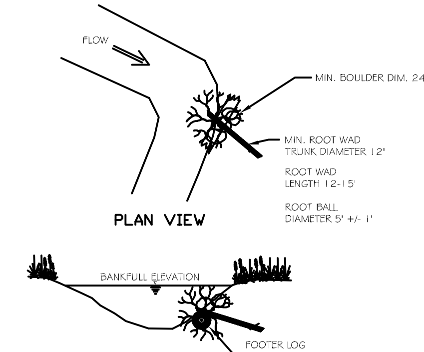
ROCK VANE DETAIL 3



ROCK VANE INSTALLATION NOTES

1. HEADER AND FOOTER ROCKS SHALL BE MIN 24" ALONG ANY AXIS. THE BOULDERS SHALL BE APPROVED BY THE ENGINEER PRIOR TO INSTALLATION OF THE STRUCTURE.
2. THE UPSTREAM HEADER ROCK SHALL BE PLACED SUCH THAT THE TOP ELEVATION IS AT THE PROPOSED BED ELEVATION.
3. GEOTEXTILE SHALL START AT THE TOP OF THE HEADER ROCKS AND EXTEND DOWN TO THE BOTTOM OF THE FOOTER ROCKS, THEN UPSTREAM 10' +/- 1'.
4. BACKFILL BEHIND (UPSTREAM) OF THE FABRIC WITH CLASS A AND NO. 57 STONE FOLLOWED BY ALLUVIUM AS SHOWN.
5. ROCKS NOT ACCEPTABLE FOR USE IN OTHER STRUCTURES MAY BE UTILIZED TO FILL IN GAPS BETWEEN HEADER AND FOOTER ROCKS AS APPROVED BY THE ENGINEER.
6. STRUCTURE SLOPES AND ANGLES SHALL BE AS SHOWN UNLESS DIRECTED OTHERWISE BY THE ENGINEER.

ROOT WAD DETAIL 4



ROOT WAD INSTALLATION

A TRENCH SHALL BE DUG ALONG THE TOE OF THE BANK TO A DEPTH OF THE DIAMETER OF THE FOOTER LOG. A PRUNED FOOTER LOG (DIA 10-24") SHALL BE PLACED AT THE TOE OF THE CHANNEL AND THE ROOT WAD (MIN. BASAL DIAMETER 12",LENGTH 10-12') SHALL BE PLACED DIRECTLY ABOVE IT. THE ROOT MASS SHALL BE ORIENTED IN SUCH A WAY THAT THE VELOCITY VECTORS OF THE WATER ARE ALIGNED WITH THE TRUNKS LOGITUDINAL AXIS AND WILL INTERSECT THE ROOT MASS AT A 90 DEGREE ANGLE. THERE SHALL BE NO VOID BEWEEN THE ROOT MASS AND THE BANK ON THE UPSTREAM SIDE OF THE CHANNEL. A BOULDER MAY BE PLACED ON THE DOWNSTREAM SIDE, ON TOP OF, AND ON THE UPSTREAM SIDE BETWEEN THE ROOT MASS AND THE BANK TO PROVIDE EROSION CONTROL AS DIRECTED BY THE ENGINEER. BOULDERS FOR THE ROOT WAD STRUCTURES SHALL BE LARGER THAN 0.66 TON (OR APPROX. 24"X24"X24") AS APPROVED BY THE ENGINEER.

THE PREFERRED METHOD FOR INSTALLATION OF A ROOT WAD IS TO DRIVE THE SHARPENED TRUNK OF THE ROOT WAD INTO THE STREAMBANK USING AN EXCAVATOR CONTAINING A HYDRAULIC THUMB. IF IT IS DEEMED NOT POSSIBLE TO DRIVE THE TRUNK INTO THE BANK, A TRENCH SHALL BE DUG IN THE BANK AND THE TRUNK SHALL BE PLACED IN THE TRENCH. THE TRENCH SHALL BE BACKFILLED AND COMPACTED.

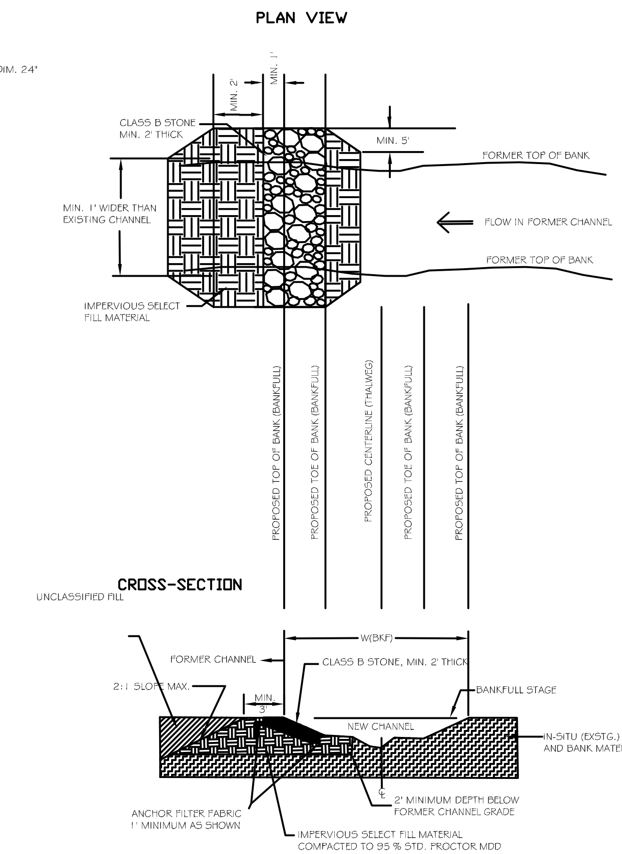
ALL DISTURBED OR FILL MATERIAL SHALL BE COMPACTED TO A DENSITY COMPARABLE TO THE ADJACENT UNDISTURBED MATERIAL UNLESS OTHERWISE APPROVED BY THE ENGINEER.

ALL MATERIALS FOR THIS STRUCTURE SHALL BE APPROVED BY THE ENGINEER PRIOR TO INSTALLATION.

STATIONING OF ROOT WADS SHALL BE AS SHOWN ON THE PLANS OR AS DIRECTED BY THE ENGINEER. THE ACTUAL NUMBER OF ROOT WADS NECESSARY WILL DEPEND ON THE SIZE OF THE ROOT FAN AND THE ACTUAL CONDITION OF THE SITE AT THE TIME OF CONSTRUCTION.

CHANNEL PLUG DETAIL 5

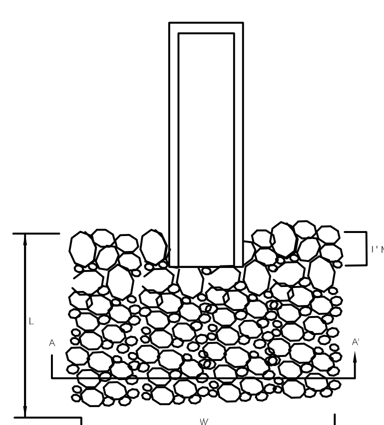
PLAN VIEW



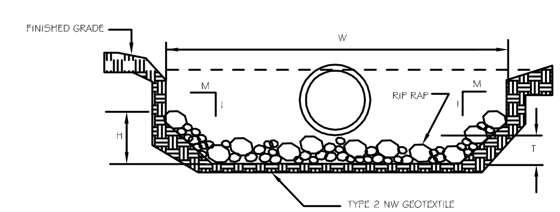
CHANNEL PLUG INSTALLATION

1. CHANNEL PLUGS TO BE LOCATED AS SHOWN ON THE PLANS AND AT OTHER LOCATIONS AS DIRECTED BY THE ENGINEER.
2. SIDE SLOPE THAT IS ADJACENT TO NEW CHANNEL NEEDS TO MATCH PROPOSED CROSS-SECTION IN THAT REGION.
3. KEY CHANNEL PLUG INTO BED AND BANK A MINIMUM OF 1 FOOT.

OUTLET PROTECTION DETAIL 6



PLAN VIEW



SECTION A-A'

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PROJECT: RICHLAND CREEK STREAM RESTORATION WAKE COUNTY, NC

PREPARED FOR: NORTH CAROLINA ECOSYSTEM ENHANCEMENT PROGRAM

NO.	DESCRIPTION	DATE
1	REVISIONS	8/13/07
1	DETAILS ADDED	2/22/07

REVISIONS

STRUCTURE DETAILS

SCALE: NO SCALE
DATE: 12/02/04
DRN. BY: KDH
CHECKED BY: MAT

PROJECT NO: –

SHEET ____ OF ____

DRAWING

8B

3. Temporary Seeding

Temporary seeding shall be required on all disturbed areas that are: a) associated with temporary erosion or sediment control measures or other temporary features (e.g., haul roads, diversions, sediment traps, stockpiles) that will not be removed within 7 calendar days, b) planned to receive permanent seeding but will remain exposed for more than 15 working days; or c) planned to receive permanent seeding that is out of season for the construction period. In all cases, the temporary ground cover must be established within 15 working days following completion of any phase of grading.

4. Permanent Seeding

Permanent ground cover shall be provided in all designated areas within 15 working days or 90 calendar days (30 calendar days on exposed slopes), whichever is shorter, following completion of construction of any portion of the work.

Use permanent seeding on channel banks that will receive channel lining, on the bankfull bench, on terrace side slopes, and upslope of the channel in the riparian buffer. A mixture of native grasses and herbs shall be used. Competing, sod-forming grasses like fescue and bluegrass should be removed by either mechanical or chemical methods before planting native mixes. Seeding shall occur before coir fiber mats or other channel linings are placed on the subgrade.

a. Seed Mixtures

The permanent seed mixture for the riparian corridor shall be approximately as follows:

Oat Grain, *Avena sativa* or Rye Grain, *Secale Cereale*	25%
Virginia Wild Ryegrass, *Elymus virginicus*	25%
Switchgrass, *Panicum virgatum* var. Carthage	25%
Showy native wildflower mix (Ernst Seed)	25%

5. Woody Plant Installation (Trees and Shrubs)

New woody plant material shall be installed in the restoration corridor as shown on the plans to enhance biodiversity, which improves both ecological function and aesthetics. This also allows the introduction of species that would not establish on their own and provides for site selection to enhance plant performance and restoration success. Planting stock may include containerized, bare root, or balled and burlaped trees and shrubs. Bare root seedlings shall be planted using a spade. Rooted plants shall be planted in holes sized to match the existing container or root ball.

The storage, handling, and planting of bare-root seedlings will follow the procedures outlined in the NC Division of Forest Resources' (NCFS) *Pocket Guide to Seedling Care and Planting Standards, 4th Edition,* which can be obtained at all NCFS county offices. Planting will not take place on 'Severe Days' as defined by the *Pocket Guide To Seedling Care and Planting Standards.*

All planting stock shall be handled in such a manner as to promote the health and vigor of the plant material and reduce the stress of transplanting and reestablishment. This means that all woody planting shall occur in the plant's dormant season, normally from November 15 to March 31. Planting stock shall be stored in a cool and moist environment and protected from direct sun and drying winds. Roots of bare root stock shall be kept moist before and during planting operations. Containerized or potted stock shall be kept moist at all times. Live stakes shall be prevented from drying and kept in a dormant condition, which may require daily moisture addition and refrigeration (below 40° F) if the weather is dry and warm. Damaged roots or shoots should be pruned appropriately before or during installation.

a. Species Selection
It is important to plant as much diversity as is available to enhance the wildlife value, aesthetics and resilience of the riparian corridor restoration. A minimum of six (6) tree and four (4) shrub species shall be selected to enhance the species diversity that occurs naturally at the 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 that would occur at an undisturbed site.

i. Tree Species Suitable for Richland Creek Restoration
Black Willow (*Salix nigra*), Green Ash (*Fraxinus pennsylvanica*), Sugar Maple (*Acer floridanum*), Sycamore (*Platanus occidentalis*), American Chestnut (*Castanea dentata*), Hackberry (*Celtis occidentalis*), River Birch (*Betula nigra*), Bitternut (*Carya cordiformis*) or Pignut Hickory (*Carya glabra*), Persimmon (*Diospyros virginiana*), Black Walnut (*Juglans nigra*), Black Gum (*Nyssa sylvatica*), Sourwood (*Oxydendrum arboreum*), Black Cherry (*Prunus serotina*), Red Oak (*Quercus rubra*), Water Oak (*Quercus nigra*), Black Locust (*Robinia psuedo-acacia*), American Elm (*Ulmus americana*), Pawpaw (*Asimina triloba*) Dogwood (*Cornus florida*), Redbud (*Cercis Canadensis*), American Holly (*Ilex opaca*) and Fringetree (*Chionanthus virginicus*).

ii. Shrub Species Suitable for Richland Creek Restoration
Buttonbush (*Cephalanthus occidentalis*), Hazelnut (*Corylus flavula*), Elderberry (*Sambucus Canadensis*), Red Chokeberry (*Aronia arbutifolia*), Silky Dogwood (*Cornus amomum*), Spicebush (*Lindera benzoin*), Serviceberry (*Amelanchier laevis*), Hawthorne (*Crategus punctata*), Highbush Blueberry (*Vaccinium constablaei*), Tag Alder (*Alnus serrulata*), Witch Hazel (*Hamamelis virginiana*), Sweet Shrub (*Calycanthus floridus*), Sweet Pepperbush (*Clethera acuminata*), Winterberry (*Ilex verticillata*), Mountain Laurel (*Kalmia latifolia*), Blackhaw (*Viburnum prunifolium*) and Yellowroot (*Xanthorhiza simplicissima*).

iii. Live Stake Species Suitable for Richland Creek Restoration
Black Willow, Silky Willow, Silky Dogwood, Buttonbush (requires pilot hole), and Elderberry (requires pilot hole).

iv. Recommended Species for Richland Creek Restoration
Based on observations of the natural riparian communities in the Wake County region, there are several plant species that are recommended. It can be assumed that Red Maple (*Acer rubrum*) and Tulip Tree (*Liriodendron tulipifera*) will establish themselves voluntarily in the restoration reach as they are well represented in the adjacent forests; thus, their use is discouraged.

The added woody plants may include Sycamore, Walnut, Red Oak, Hickory, Green Ash and Black Willow as eventual canopy species. Subcanopy species may include Dogwood, Redbud, American Holly, Fringetree and Sourwood. Shrub species may include Elderberry, Tag Alder, Highbush Blueberry, Silky Dogwood, Red Chokeberry, Buttonbush and Hawthorne.

This mixture will maximize the vertical diversity for wildlife, produce a wide range of fruit and seed types, and provide the human neighborhood with seasonal displays of flower, fruit and leaf color.

b. Planting Density (including transplants)

Trees	Spacing = 8 feet	680 plants/acre initial stock density
Shrubs	Spacing = 4 feet	1360 plants/acre initial stock density
Live Stakes	Spacing = 3 feet	4840 plants/acre initial stock density

Target density of plantings at maturity: 320 trees/acre and 1200 shrubs/acre.

c. Woody Plant Protection
The use of tree shelters, bark wrap, fencing or chemical deterrents may be necessary at Richland Creek to prevent damage by deer and beaver. The 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 the woody plants so that they can withstand herbivore attack. Anti-browsing chemical deterrents may also be needed to train the animals to avoid the plantings until they become established.

6. Invasive/Exotic Species Control
a. Removal of Exotic Grasses and Ground Cover
The work involves removal of exotic grasses that are located in non-wooded areas included in the proposed stream buffer through application of herbicide. Designer will identify location of grasses to be removed.

Any commercially available herbicide designated and suitable for extermination of grasses is allowable as long as it is labeled for use in riparian and wetland areas. The company performing the work in this section must have a commercial license as required by the North Carolina Pesticide Board. The work in this section must comply with the North Carolina Pesticide Law of 1971 and applicable federal laws including but not limited to purchase, transport, storage, application, and disposal of chemical herbicides.

b. Removal of Exotic Trees and Shrubs
The work involves removal and extermination of individual trees and shrubs through application of herbicide and hand excavation as identified by the Designer. This work does not include those exotic trees and shrubs that are excavated and removed as part of clearing and grubbing for site preparation.

Any commercially available herbicide designated and suitable for extermination of trees and shrubs is allowable as long as it is labeled for use in riparian and wetland areas. The company performing the work in this section must have a commercial license as required by the North Carolina Pesticide Board. The work in this section must comply with the North Carolina Pesticide Law of 1971 and applicable federal laws including but not limited to purchase, transport, storage, application, and disposal of chemical herbicides.

10. Stream Monitoring Plan

Stream restoration in North Carolina requires physical and biological monitoring based on NC Division of Water Quality criteria (Monitoring Level 1). 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 restoration of this 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 visits. Use of benchmarks will allow all monitoring data to be comparable.

a. Photo reference sites
Longitudinal and lateral photos showing the banks and the channel with a scale included will document the restored reach and each permanent cross-section. Photographs may also be taken of in-stream structures, plant survival plots, and any other noteworthy features. A map of the location and direction of each photograph shall be developed during the as-built survey. The same points should be included in subsequent monitoring visits as a minimum.

b. Plant survival
Plant survival will be monitored in accordance with EEP's most current version of vegetation monitoring guidance. Plots will be established during the as-built survey for monitoring riparian vegetation. Transplants and woody stems will be counted and assessed for survivability and attainment of the success criteria of 320 trees per acre after three years. Allowances for additional mortality with time provide a final criterion of

260 trees per acre through year five. Observations of vegetation loss or damage due to drought, disease or herbivore predation will also be noted.

c. Channel stability

Permanent cross-sections shall be established to 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 and channel geometry diagnostics like width-depth ratio, entrenchment ratio, bank height ratio and bankfull depth measurements. One additional riffle cross-section will be established and a third cross-section will be located in one of the curves to measure stability of a pool. The cross-section locations will be determined and permanently marked by the designer at the time of the as-built survey.

The bed materials will be documented by conducting a pebble count at each reference location. The d_{50} and d_{84} 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.

Observation of rock and log structures, root wads, erosion control matting, permanent erosion control measures, stream crossings, bridges and exclusion fencing will also be conducted to evaluate the stability and durability of these installations.

d. Biological indicators

If required, benthic macroinvertebrates may be collected using standard methods outlined in the Benthic Macroinvertibrate Monitoring Protocols for Compensatory Stream Restoration Projects technical guide.

11. Stream Success Criteria

The success of the stream restoration will be determined by how it achieves the general criteria outlined in Appendix II of the multi-agency workgroup document titled “Stream Mitigation Guidelines, April 2003” (Figure 11). Also important is how well it satisfies the landowner’s requirements for a stable, aesthetic creek channel.

Criteria for success include that the stream be vertically and horizontally stable, i.e., “minimal evidence of instability (down-cutting, deposition, bank erosion, increase in sands or finer substrate material)”. Furthermore, a stable stream channel should neither aggrade nor degrade substantially over time. Channel adjustments over time are a normal aspect of a dynamic stream. This is especially true of watersheds like Richland Creek’s, which are undergoing transformation from rural to increasingly urban land uses.

Appendix II. General criteria used to evaluate the success or failure of activities at mitigation sites and required remedial actions to be implemented should monitoring indicate failure of a component.

Mitigation Component	Success (requires no action)	Failure →	Action
(1.) <u>Photo Reference Sites</u> Longitudinal photos Lateral photos	No substantial* aggradation, degradation or bank erosion.	Substantial aggradation, degradation or bank erosion.	When substantial aggradation, degradation or bank erosion occurs, remedial actions will be planned, approved, and implemented.
(2.) <u>Plant Survival</u> Survival plots Stake counts Tree counts	$\geq$ 75% Coverage in Photo Plots Survival and growth of at least 320 trees/acre through year 3, then 10% mortality allowed in year 4 (288 trees/acre) and additional 10% mortality in year 5 for 260 trees/acre through year 5.	< 75% coverage in photo plots for herbaceous cover. Survival of less than 320 trees per acre through year 3 and then less than the success criteria for years 4 and 5.	Areas of less than 75% coverage will be re-seeded and or fertilized, live stakes and bare rooted trees will be planted to achieve desired densities.
(3.) <u>Channel Stability</u> Cross-sections Longitudinal profiles Pebble counts	Minimal evidence of instability (down-cutting, deposition, bank erosion, increase in sands or finer substrate material).	Substantial* evidence of instability.	When Substantial evidence of instability occurs, remedial actions will be planned, approved, and implemented.
(4.) <u>Biological Indicators</u> Invertebrate populations Fish populations	Population measurements remain the same or improve, and species composition indicates a positive trend.	Population measurements and species composition indicate a negative trend.	Reasons for failure will be evaluated and remedial action plans developed, approved, and implemented.

*Substantial or subjective determinations of success will be made by the mitigation sponsor and confirmed by COE and review agencies.
Monitoring Level 1 will include items 1, 2, and 3, and may include item 4 based on the project review.
Monitoring Level 2 will include items 1 and 2, and may include item 3 based on the project review.
Monitoring Level 3 will include only item 1.

Figure 11