R-2635C On-Site Mitigation
Wake County, North Carolina
Project No. 35520.1.1

Prepared for:
NC Department of Transportation
Natural Environment Unit
Parker Lincoln Building
2728 Capital Boulevard, Suite 240
Raleigh, NC 27604

Mitigation Plan
February 2007

Table of Contents

Page

1.0 Introduction **1**

2.0 Project Description **1**

3.0 General Watershed Information **1**

4.0 Existing Conditions **1**
4.1 Unnamed Tributary to Reedy Branch 1
4.2 Jurisdictional Wetlands 2
4.3 Existing Plant Communities 2
4.4 Threatened and Endangered Species 3

5.0 Natural Channel Design **3**
5.1 Reference Reach Analyses 3
5.2 Sediment Transport Analyses 4
5.2.1 Aggradation/ Degradation Analysis 4
5.2.2 Sediment Transport Summary 4
5.3 Proposed Design 4

6.0 Flood Analyses **5**

7.0 Stream Riparian Planting Plan **5**

8.0 Stream Monitoring Plan **5**

9.0 References **6**

Figures
Figure 1. Vicinity Map
Figure 2. Existing Watershed
Figure 3. Soils Map
Figure 4. Reference Reach Map

Tables
Table 1. Summary of Existing Cross Sections – Unnamed Tributary to Reedy Branch
Table 2. Federally Threatened and Endangered Species Potentially Occurring in Wake County

Appendices
Appendix A. Existing Cross Sections
Appendix B. Morphological Data
Appendix C. Particle Size Distribution Data
Appendix D. Entrainment Calculations
Appendix E. Velocity Calculations
Appendix F. Photos

1.0 Introduction

This Stream Restoration Plan addresses proposed improvements to be implemented by the North Carolina Department of Transportation (NCDOT) along an Unnamed Tributary (UT) to Reedy Branch in Wake County. The plan is being completed to provide on-site mitigation for unavoidable stream impacts associated with the construction Transportation Improvement Project (TIP) number R-2635C, or the Western Wake Freeway (I-540) in western Wake County, North Carolina. The project covers approximately 640 linear feet of the UT to Reedy Branch.

2.0 Project Description

The R-2635C mitigation site is situated approximately 2,300 feet downstream of US 64, immediately west of the Town of Apex (Figure 1). Land use along the floodplain is predominately wooded, aside from the perpendicular crossing of a gas line easement and a small portion of a horse pasture that extends from the adjacent upland area to the east. The existing channel appears relatively stable with moderately vegetated banks, exhibiting minimal bank erosion. The existing channel also exhibits a stable pattern and profile in the vicinity of the relocation. Restoration of the UT will involve the construction of a new channel with connectivity to the historic floodplain throughout the area. These efforts will utilize Priority Level II stream restoration principles to re-establish approximately 640 linear feet of stream channel upstream of the proposed roadway crossing. A protected riparian buffer will be established as part of the on-site mitigation requirements and a conservation easement will be established and fenced in its entirety to restrict access to the restored areas and the I-540 right-of-way. The R-2635C mitigation site will be held in perpetuity under the strictures of the NCDOT right-of-way.

3.0 General Watershed Information

03030002

The UT is situated .within the Cape Fear River Basin within the US Geological Survey (USGS) hydrological unit code (HUC) 030030002 and the NC Division of Water Quality (NCDWQ) sub-basin 03-06-05. Its drainage area at the mitigation site covers approximately 420 Acres (0.67 square miles). The overall watershed is relatively rural, dominated by low density residential areas and forest land. The land use in the watershed is actively developing with large scale developments currently under construction north of US 64. The mitigation site will be located in the existing floodplain associated with the UT to Reedy Branch. Elevations across the project site range from a high of 315 feet above mean sea level (msl) at the upper limit of the UT relocation to a low of 308.6 feet above msl at the culvert entrance, at the downstream end. The R-2635C mitigation site is within the Piedmont physiographic province; specifically, the Triassic Basin Ecoregion (Griffith et al., 2002). According to the Wake County Soil Survey, Wehadkee and Bibb soils underlie the project area (Figure 3). These soils are poorly drained and occur along floodplains, narrow upland draws and in depressions throughout the county (Cawthorn, 1970).

4.0 Existing Conditions

4.1 Unnamed Tributary to Reedy Branch

The headwaters of the UT to Reedy Branch are bounded to the north by SR 1601, to the east by NC 55, and to the west by SR 1163 (Kelly Road). The tributary flows in a southerly direction for approximately 0.9 miles before passing under US 64, then in a southwesterly direction for approximately 0.8 miles before passing under Kelly Road. It converges with Reedy Branch approximately 1.0 mile downstream of Kelly Road. As previously mentioned, the drainage area associated with the mitigation site covers

approximately 420 acres (Figure 2). The existing stream channel is located in its historical floodplain. The relatively young age of the hardwood species indicate the area may have been cleared in the past for agricultural purposes; however, the floodplain and stream have recovered with a well established buffer and a channel exhibiting only minimal amounts of erosion. Based on field reconnaissance, existing channel surveys, and sediment transport analysis, the current stream channel is slightly incised, though stable.

The existing UT channel flows approximately 1,200 linear feet within the limits of the R-2635C project area. The existing channel slope averages 0.0050 ft/ft. Existing profile information for the stream is presented in Appendix A. The UT to Reedy Branch classifies as a slightly incised E4 channel according to the Rosgen stream classification system (Rosgen, 1994). A summary of the cross section data used to determine these classifications can be found in Table 1 and existing cross section views are presented in Appendix B. Additional information, including existing pattern data for the stream, is shown with all the morphological data in Appendix C.

According to the modified Wolman Pebble Count procedure, the average d_{50} (50% of the sampled population is equal to or finer than the representative particle diameter) is approximately 6.3 mm, which falls within the gravel size category. The d_{50} for the wetted perimeter was approximately 11 mm. Pebble counts were taken at each cross section and a bar sample was taken immediately downstream of the project area. The particle size distribution data which includes the classification, wetted perimeter, and bar sample are presented in Appendix D.

Table 1. Summary of Existing Cross Sections –Unnamed Tributary to Reedy Branch

Cross Section	Station No.	Morph. Feature	Bankfull Area (ft^2)	Ent. Ratio*	W/D Ratio*	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Stream Class.*
1		Riffle	11.4	40.8	8.1	11.98	0.95	E4
2		Pool	16.5	N/A	N/A	12.3	1.34	--
3		Riffle	11.7	42.8	7.1	11.68	1.00	E4

*Notes: Ent. Ratio is "Entrenchment Ratio"
W/D Ratio is "Width/Depth Ratio"
Stream classification is only viable along riffle sections.

4.2 Jurisdictional Wetlands

Jurisdictional wetland determinations were performed using the three-parameter approach as prescribed in the 1987 *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory, 1987). A consulting firm hired by NCDOT performed wetland delineations between 1997 and 1998. A riverine wetland occurs adjacent to the existing UT to Reedy Branch. This wetland was determined to be a Palustrine Forested, Broad-leaved Deciduous wetland which is characterized by a dominance of hardwood deciduous species associated with bottomland hardwood forests. The forested classification denoted that the wetland is composed of vegetation that is 20 feet or taller (NCDOT, 2004). The proposed on-site mitigation will impact a small portion of this wetland area.

4.3 Existing Plant Communities

The vegetative communities found within the mitigation area can be characterized under one major grouping, the Mesic Mixed Hardwood Forest (Schafale and Weakley, 1990). Dominant species observed

included such canopy trees as water oak (*Quercus nigra*), tulip poplar (*Liriodendron tulipifera*), loblolly pine (*Pinus taeda*), red maple (*Acer rubrum*), white oak (*Quercus alba*), sweetgum (*Liquidambar styraciflua*) and American elm (*Ulmus americana*). Common understory and vine species included black willow (*Salix nigra*), black cherry (*Prunus serotina*), American holly (*Ilex opaca*), highbush blueberry (*Vaccinium corymbosum*), giant cane (*Arundinaria gigantea*), grape (*Vitis* sp.), cross vine (*Bignonia capreoata*), poison ivy (*Toxicodendron radicans*) and Japanese honeysuckle (*Lonicera japonica*). Herbaceous species were limited, based on the timing of the assessment (winter). Species such as microstegium (*Microstegium vimineum*) and smartweed (*Panicum* sp.) were easily identifiable; however, other species are also anticipated to be present during the growing season.

4.4 Threatened and Endangered Species

According to the US Fish and Wildlife Service (USFWS), three endangered and one threatened species are known to occur in Wake County. Information regarding these federally listed species is presented in Table 2.

Table 2. Federally Threatened and Endangered Species Potentially Occurring in Wake County

Common Name	Scientific Name	Federal Status*	Preferred Habitat	Habitat Present	Biological Conclusion
Red-cockaded woodpecker	*Picoides borealis*	E	Open park-like pine stands (live) w/ little undergrowth	No	May Affect – Not likely to Adversely Affect
Bald eagle	*Haliaeetus leucocephalus*	T	Mature forests near large bodies of water	Yes	No Effect
Michaux's sumac	*Rhus michauxii*	E	Sandhills, sandy forests, woodland and woodland edges	Yes	May Affect – Not likely to Adversely Affect
Dwarf wedge mussel	*Alasmidonta heterodon*	E	Stable silt-free streambed	No	No Effect

*Notes:
E denotes Endangered (a taxon is "in danger of extinction throughout all or a significant portion of its range."
T denotes Threatened (a taxon "likely to become Endangered within the foreseeable future throughout all or a significant portion of its range.")

5.0 Natural Channel Design

5.1 Reference Reach Analyses

One reference reach, noted as Southwest Prong Beaverdam Creek, has been identified for use on the R-2635C stream restoration site. This stream is situated within the Raleigh City Limits and was chosen as it represents a stable, urban, piedmont stream. The current watershed for UT to Reedy Branch is relatively rural; however, a significant portion of the watershed is currently under construction and is anticipated to urbanize rapidly. The UT to SW Prong Beaverdam Creek is located immediately upstream of the intersection of Lake Boone Trail and Runnymeade Road (Figure 4). This stream is characterized as a first order stream and classifies as an urban C5 stream type. Specific morphological data for this reference reach are given within the morphological table presented in Appendix C. Its watershed covers approximately 0.28 square miles (180 acres) and encompasses an older urban neighborhood in the City of

Raleigh. Common species located along the riparian zone of this stream include tag alder (*Alnus serrulata*), red maple, river birch (*Betula nigra*), sweetgum, flowering dogwood (*Cornus florida*), tulip poplar, giant cane, poison ivy, jewelweed (*Impatiens capensis*) and bamboo (*Phyllostachys aurea*).

5.2 Sediment Transport Analyses

Sediment plays a major role in the influence of channel stability and morphology (Rosgen, 1996). A stable stream has the capacity to move its sediment load without aggrading or degrading.

The critical dimensionless shear stress (τ^*_{ci}) is the measure of force required to initiate general movement of particles in a bed of a given composition. Based on the d_i of 11 mm and the bar sample d_{50} of 3.0 mm for the UT, the critical dimensionless shear stress was calculated to be approximately 0.0189 lbs/ft^2. Entrainment and velocity calculation sheets used for these analyses are presented in Appendices E and F, respectively.

The critical shear for the proposed channel has to be sufficient to move the D_{84} of the bed material. Based on the Shield's curve, particles ranging from 20 mm to 40 mm could be moved within the proposed UT channel, with an average moveable size of 22 mm. The largest particle found on depositional bars was 2.0 mm. The D_{84} and D_{100} of the UT are 18 mm and 36 mm, respectively. Therefore, the proposed design has sufficient shear stress to move the bedload associated the stream channel. The use of plan form, structures and vegetation will assist in maintaining the long term stability of the proposed channel.

5.2.1 Aggradation/Degradation Analysis

New channel construction associated with natural channel design projects generally includes the design and layout of a channel with increased length and sinuosity and reduced slope as compared with the existing channel. However, when relocating a relatively stable channel, meanders become gentler and slope will slightly increase. This is evident with the R-2635C mitigation site. The proposed design for the UT will result in a new channel slightly more slope (0.0055 ft/ft) than the existing channel (0.005 ft/ft). The proposed width/depth ratios were adjusted in conjunction with the slope to ensure that the proposed stream will transport its sediment over time without aggrading or degrading.

5.2.2 Sediment Transport Summary

Based on the calculations for competency, aggradation, degradation and capacity, bankfull conditions in the proposed UT design channel will entrain particles ranging from 20 to 40 mm. The D_{100} of the UT is 36 mm. The design channel is predicted to remain stable over time based on the establishment of proper dimension, pattern and profile and an active floodplain. The addition of riparian vegetation will further enhance the long term stability of the entire system.

5.3 Proposed Design

Design methodologies are based on natural channel design concepts outlined by Rosgen (1994, 1996 and 1998). These methodologies include existing and reference reach channel surveys, data interpretations and geomorphological comparisons of all channel features. Based on field observations and preliminary ideas, the project will attempt to implement Priority Level II Restoration. A new channel will be constructed with the appropriate dimension, pattern and profile for the stream's valley. The slope along the restored stream will be 0.0055 ft/ft. Bankfull cross sectional areas found in this portion of the project average 16.0 square feet for riffles and 22.5 square feet for pools (Appendix C). The proposed riffle area is slightly larger than the area associated with the existing channel. During field reconnaissance, a small depression was noted east of the stream that is below bankfull. The approximate area of flow for this

slough is 5 square feet. Once this is combined with the existing channel area, a total bankfull flow area is approximately 16 square feet. This matches the rural regional curves for the Piedmont of North Carolina.

6.0 Flood Analyses

The R-2635C mitigation site is not located within the Federal Emergency Management Association's (FEMA) 100-year flood boundary, (FEMA, 2006). The proposed culvert to be constructed at the downstream limit of the mitigation site will control flood elevations. The proposed stream relocation will not have an adverse affect on existing flood elevations.

7.0 Stream Riparian Planting Plan

The planting plan for the riparian and upland buffers of the R-2635C site will provide post-construction erosion control and riparian habitat enhancement. The planting plan will also attempt to blend existing vegetative communities into recently restored areas. Plantings in the buffer areas will include native species appropriate for the Piedmont physiographic province. Plants within the floodplain will be flood tolerant species, which can accommodate periodic flooding events throughout the year. A variety of trees will be planted to provide cover and habitat for wildlife as well as soil stabilization. The NCDOT Roadside Environmental Unit will develop the specific details and plant lists to be utilized on the R-2635C restoration site.

Trees with extensive, deep rooting systems will assist in stabilizing the banks in the long term. Colonization of local herbaceous vegetation will inevitably occur, which will provide additional soil stability. Tree species will be planted as bare root stock on random eight-foot centers at a frequency of 680 stems per acre. Planting stock will be culled to remove inferior specimens, so only healthy, viable stock will be planted at the R-2635C restoration site. Planting of species will utilize dormant plant stock and will be performed to the extent practicable between December 1st and March 15th.

8.0 Stream Monitoring Plan

Monitoring will determine the degree of success the mitigation project has achieved in meeting the objectives of providing proper channel functions and increased habitat quality. This monitoring data will provide the NCDOT and resource agencies with evidence that the goals of the R-2635C mitigation project have been achieved. Monitoring of the site will include an NCDOT Level 1 assessment of geomorphology and riparian vegetation at least once each year for a total of five years. The monitoring reports will include detailed analysis of the new stream and floodplain pertaining to channel stability, plant survivability, reference photos and locations as well as a description of any problems and recommendations for remedial measures. Vegetative assessment will include stake and tree counts and identification of any problem areas such as missing, damaged or dead plantings. Requirements state that 260 stems/acre must be viable for success after the five year monitoring period. In the event that success criteria are not met, remedial measures will be installed to achieve success, as directed by the NCDOT. The permittee shall submit the monitoring reports to the US Army Corps of Engineers, Raleigh Regulatory Field Office Project Manager, within sixty days after completing the monitoring.

9.0 References

Daniels, R.B., S.W. Buol, H.J. Kleiss, and C.A. Ditzler, 1999. Soil Systems of North Carolina. NC State University, Soil Science Department, Raleigh, NC.

Cawthorn, J.W., 1970. Soil Survey of Wake County, North Carolina. US Department of Agriculture, Soil Conservation Service, in Cooperation with the NC Agricultural Experiment Station.

Environmental Laboratory, 1987. Corps of Engineers Wetlands Delineation Manual; Technical Report Y-87-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Federal Emergency Management Association (FEMA), 2004. http://www.fema.org.

Griffith, G.E., J.M. Omernik, J.A. Comstock, M.P. Schafale, W.H. McNab, D.R. Lenant, T.F. MacPherson, J.B. Glover, and V.B. Shelburne, 2002. Ecoregions of North Carolina and South Carolina (color poster with map, descriptive text, summary tables, and photographs). Reston, VA, US Geological Survey (map scale 1:1,500,000).

Hey, Richard and Dave Rosgen, 1997. Fluvial Geomorphology for Engineers. Wildland Hydrology, Pagosa Springs, CO.

North Carolina Administrative Code (NCAC), 1999. Subchapter 1I - Forest Practice Guidelines Related to Water Quality, Section .0100. 15A NCAC 1I.0102. Raleigh, NC.

North Carolina Department of Environment and Natural Resources (NCDENR). 2004. Basinwide Information Management System. Available: http://h2o.enr.state.nc.us/bims/reports/basinsandwaterbodies/03-07-04.pdf.

North Carolina Department of Environment and Natural Resources (NCDENR), 2004a. North Carolina Water Quality Assessment and Impaired Waters List (2004 Integrated 305(b) and 303(d) Report). Prepared by the NC Department of Environment & Natural Resources, Division of Water Quality, Water Quality Section.

North Carolina Department of Environment and Natural Resources (NCDENR), 2002. Basinwide Assessment Report - Yadkin-Pee Dee River Basin. Prepared by the NC Department of Environment & Natural Resources, Division of Water Quality, Water Quality Section.

North Carolina Department of Transportation (NCDOT), 2002. U-2707 Environmental Assessment. Prepared be the NC Department of Transportation, Project Development and Environmental Analysis Branch.

North Carolina Division of Land Resources (NCDLR), 1985. Geologic map of North Carolina. NC Geological Survey, Raleigh, North Carolina.

North Carolina Natural Heritage Program (NCNHP), 2004. Protected Species listed for Yadkin County, NC. Available: http://www.ncnhp.org/

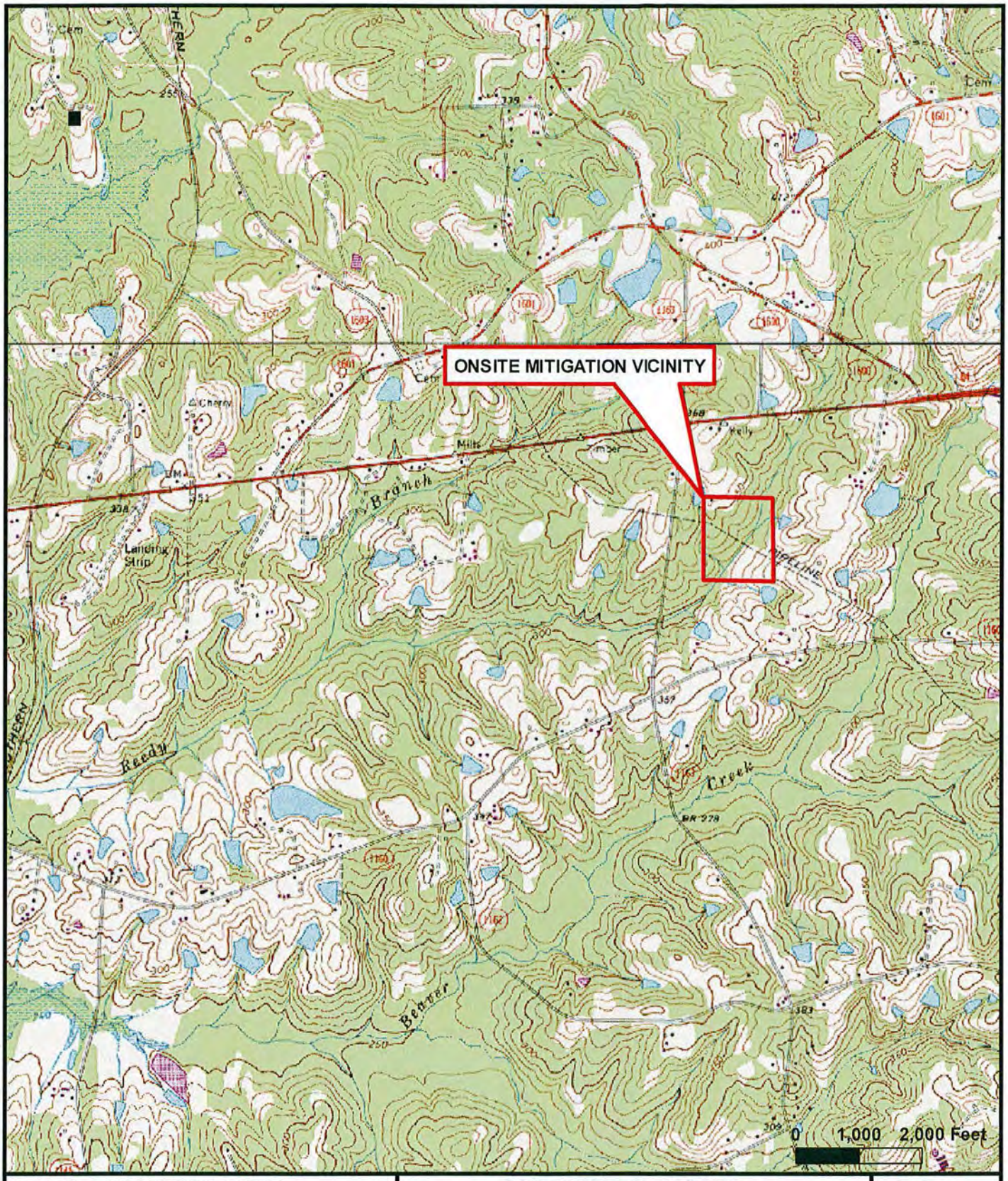
Rosgen, D.L., 1998. The Reference Reach – A Blueprint for Natural Channel Design. From Proceedings of the Wetlands and Restoration Conference, March 1998, Denver, CO. Wildland Hydrology, Pagosa Springs, CO.

Rosgen, D.L., 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Rosgen, D.L., 1994. A Classification of Natural Rivers. Catena, 22:169-199.

Schafale, M.P. and A.S. Weakley, 1990. Classification of the Natural Communities of North Carolina, Third Approximation. NC Natural Heritage Program, Division of Parks and Recreation, NC Department of Environment, Health and Natural Resources.

United States Fish and Wildlife Service (USFWS), 2006. Protected Species listed for Wake County, NC. Available: http://nc-es.fws.gov/es/countyfr.html



Prepared By: SUNGATE DESIGN GROUP, PA
915 Jones Franklin Road
Raleigh, NC 27606
(919)859-2243

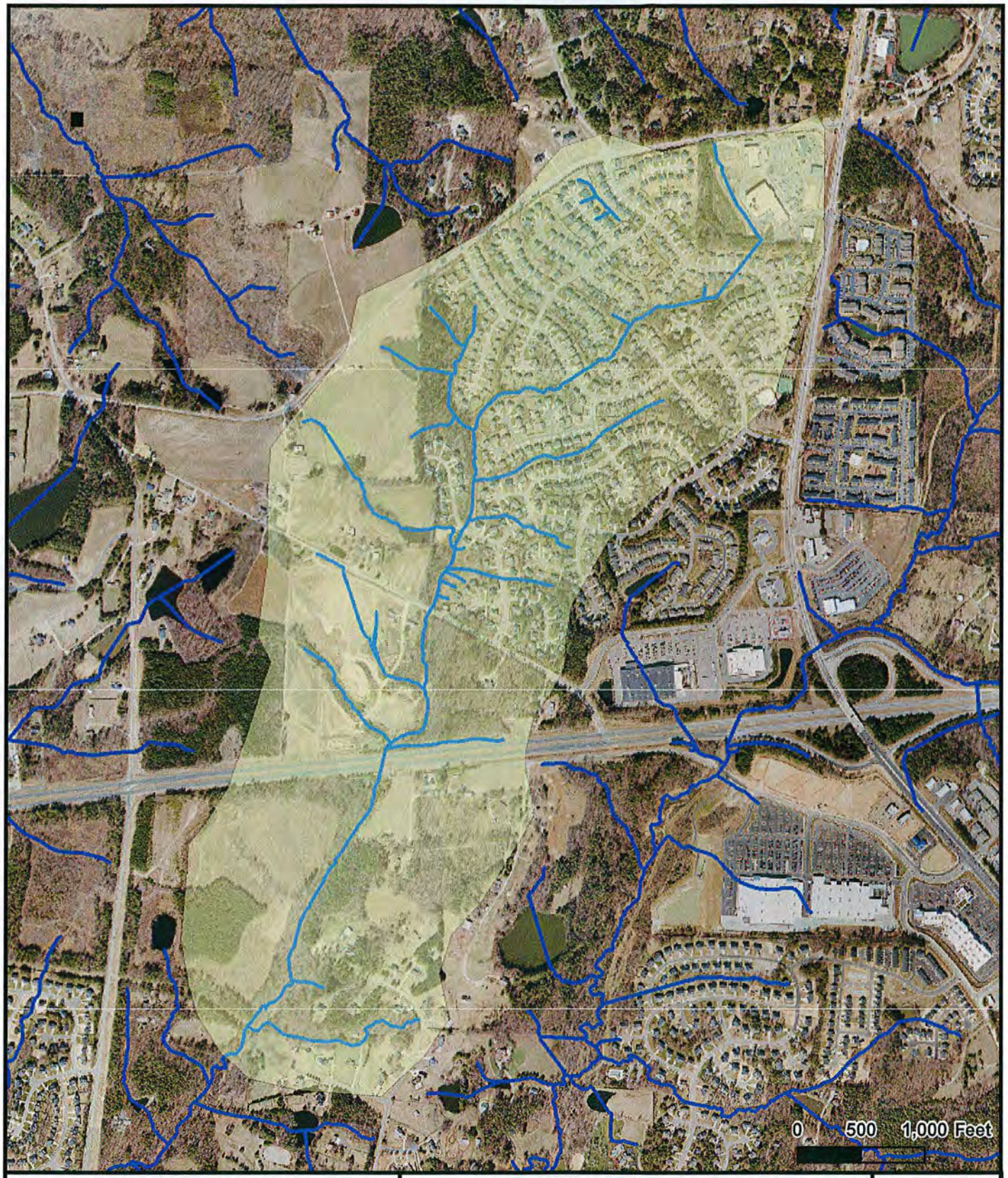
Prepared For: NC Department of Transportation
Natural Environment Unit
Parker Lincoln Building
2728 Capital Boulevard, Suite 240
Raleigh, NC 27604

R2635C Onsite Mitigation
Project #: 35520.1.1
Vicinity Map
Wake County, NC

January 12, 2007

Source: USGS Quadrangle Maps (New Hill and Green Level Quads)

FIGURE 1



Prepared By: SUNGATE DESIGN GROUP, PA
915 Jones Franklin Road
Raleigh, NC 27606
(919)859-2243

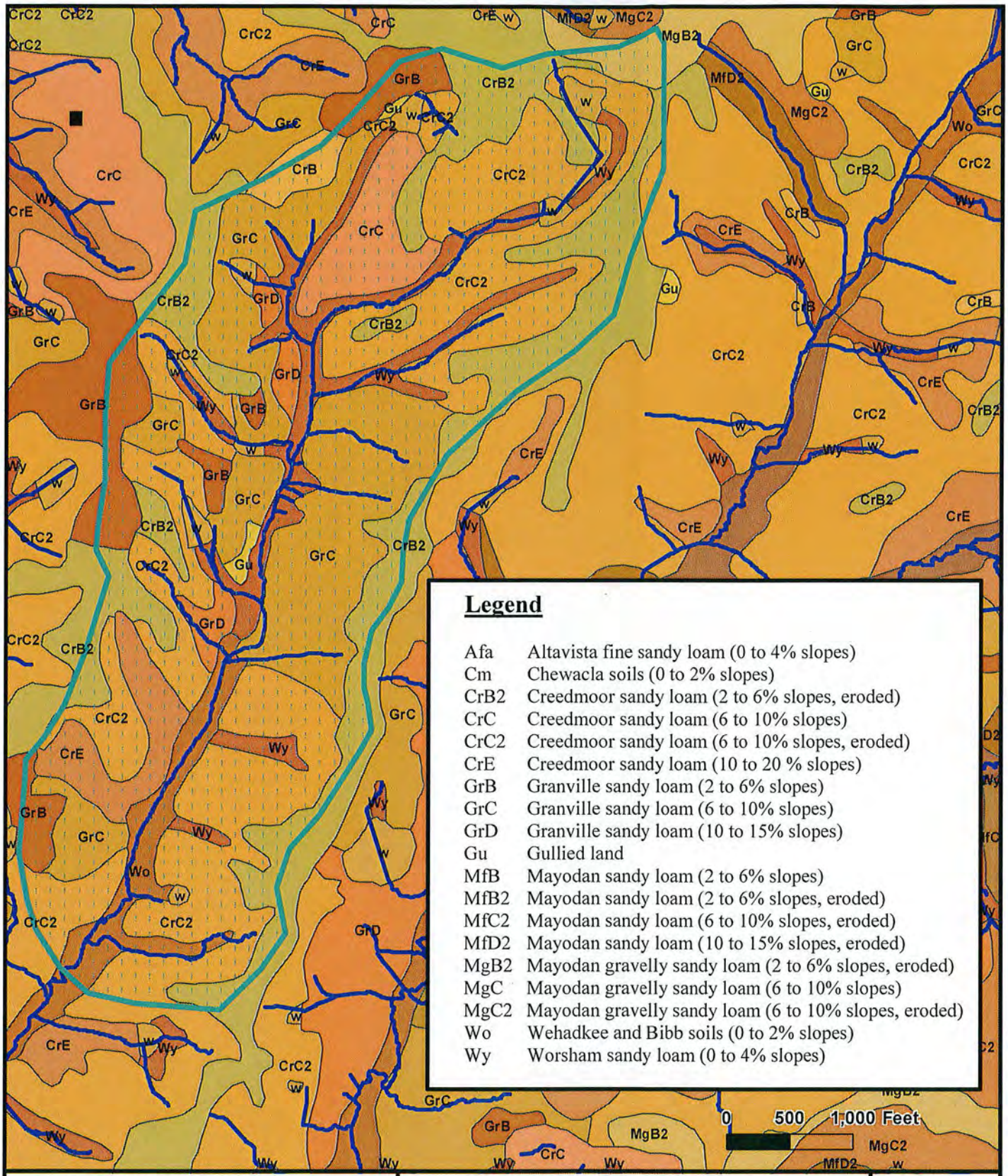
Prepared For: NC Department of Transportation
Natural Environment Unit
Parker Lincoln Building
2728 Capital Boulevard, Suite 240
Raleigh, NC 27604

R2635C Onsite Mitigation
Project #: 35520.1.1
Watershed Map
Wake County, NC

January 12, 2007

Source: USGS Quadrangle Maps (John H Kerr Dam and Middleburg)

FIGURE 2



Prepared By: SUNGATE DESIGN GROUP, PA
915 Jones Franklin Road
Raleigh, NC 27606
(919)859-2243

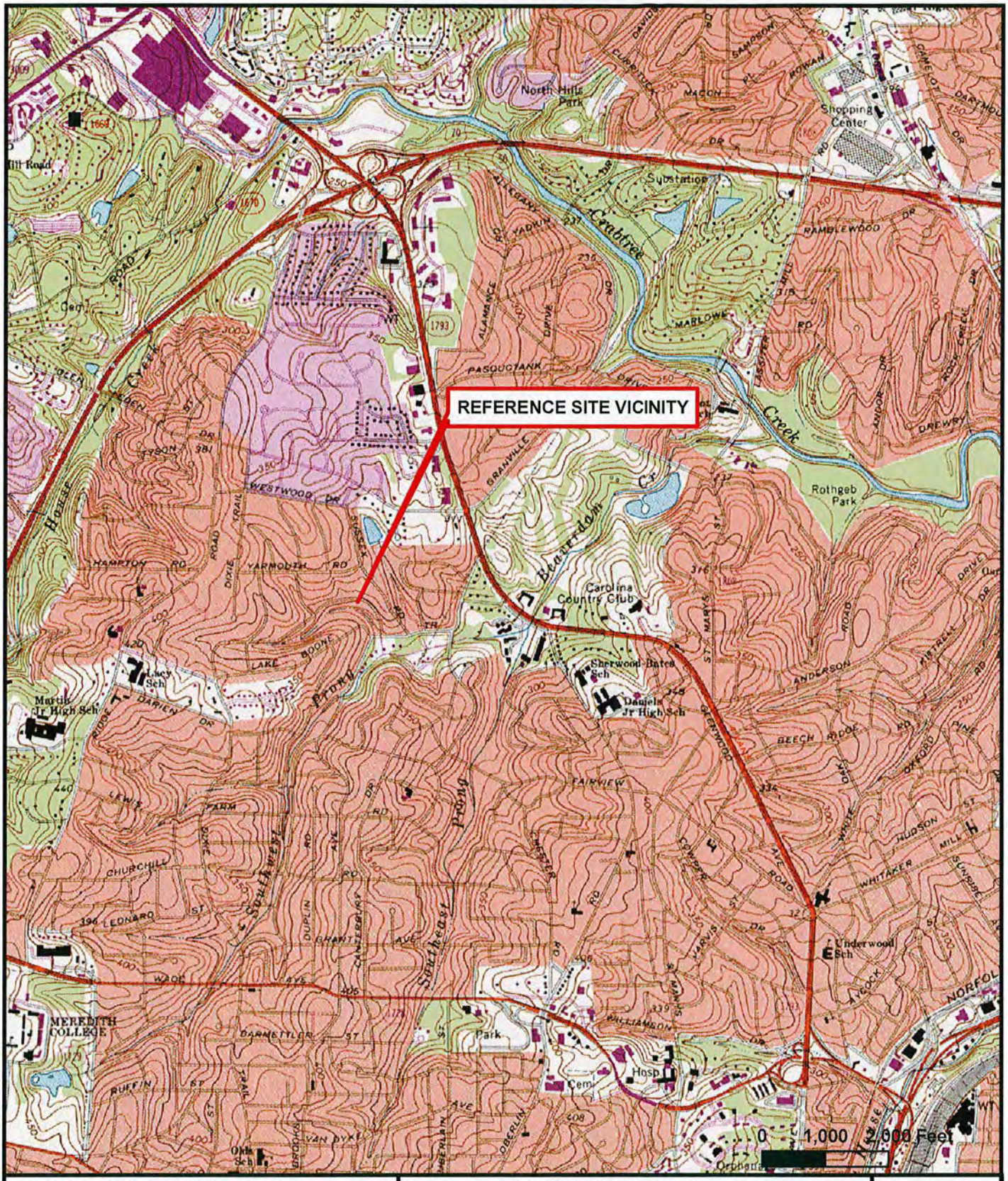
Prepared For: NC Department of Transportation
Natural Environment Unit
Parker Lincoln Building
2728 Capital Boulevard, Suite 240
Raleigh, NC 27604

R2635C Onsite Mitigation
Project #: 35520.1.1
Soil Survey Map
Wake County, NC

January 12, 2007

Source: USGS Quadrangle Maps (John H Kerr Dam and Middleburg)

FIGURE 3



Prepared By: SUNGATE DESIGN GROUP, PA
915 Jones Franklin Road
Raleigh, NC 27606
(919)859-2243

Prepared For: NC Department of Transportation
Natural Environment Unit
Parker Lincoln Building
2728 Capital Boulevard, Suite 240
Raleigh, NC 27604

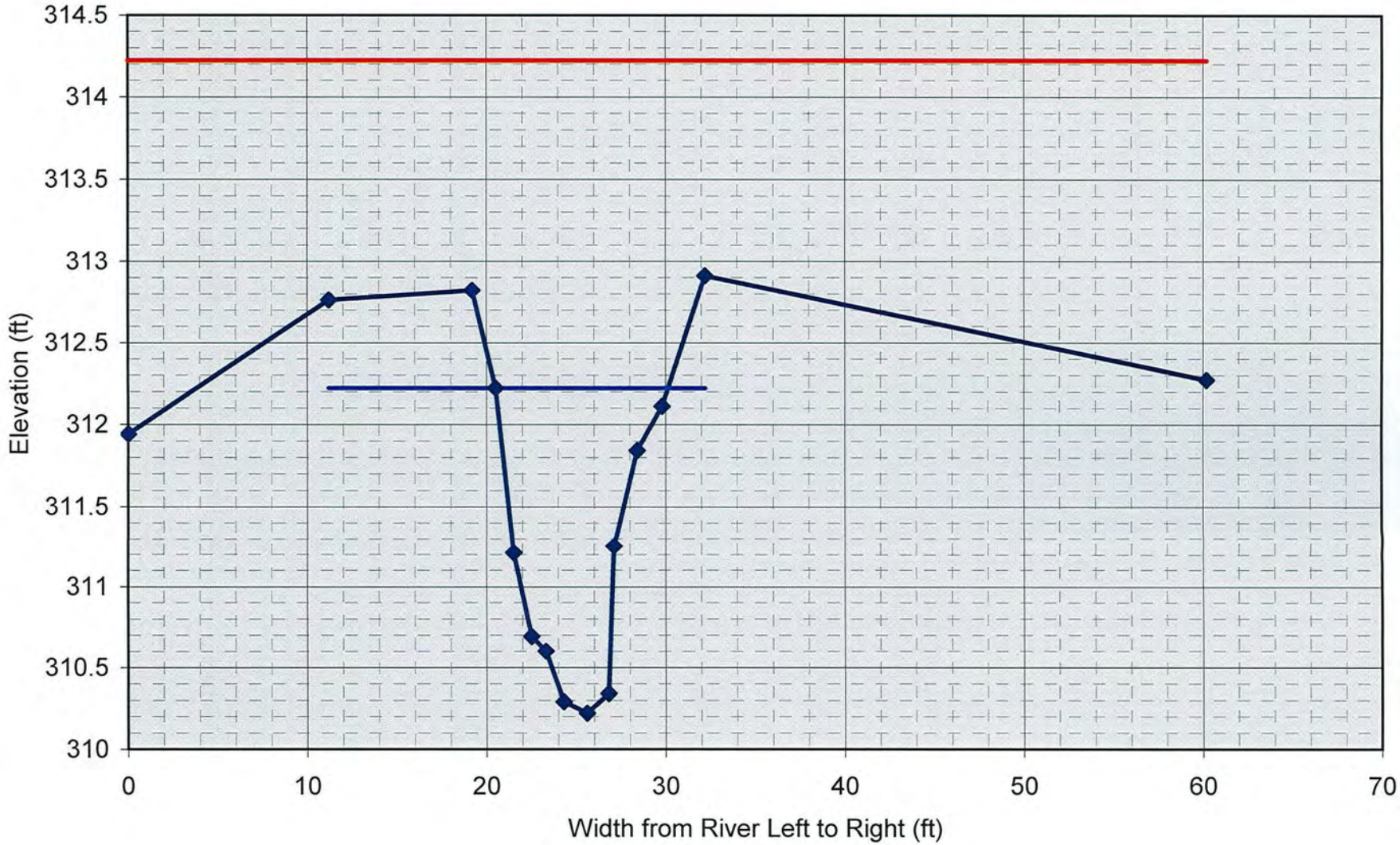
R2635C Onsite Mitigation
Project #: 35520.1.1
Reference Vicinity Map
Wake County, NC

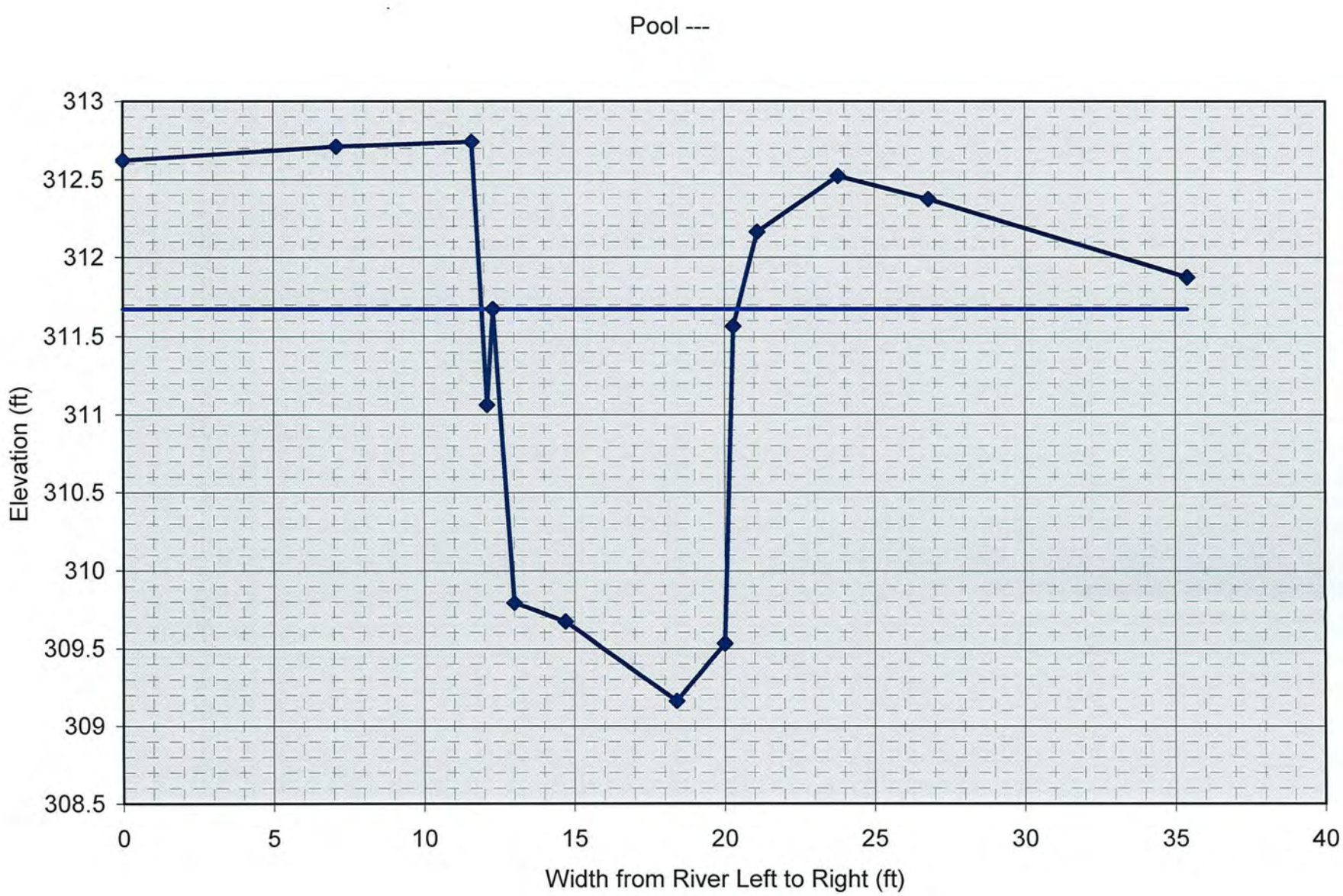
January 12, 2007

Source: USGS Quadrangle Maps (New Hill and Green Level Quads)

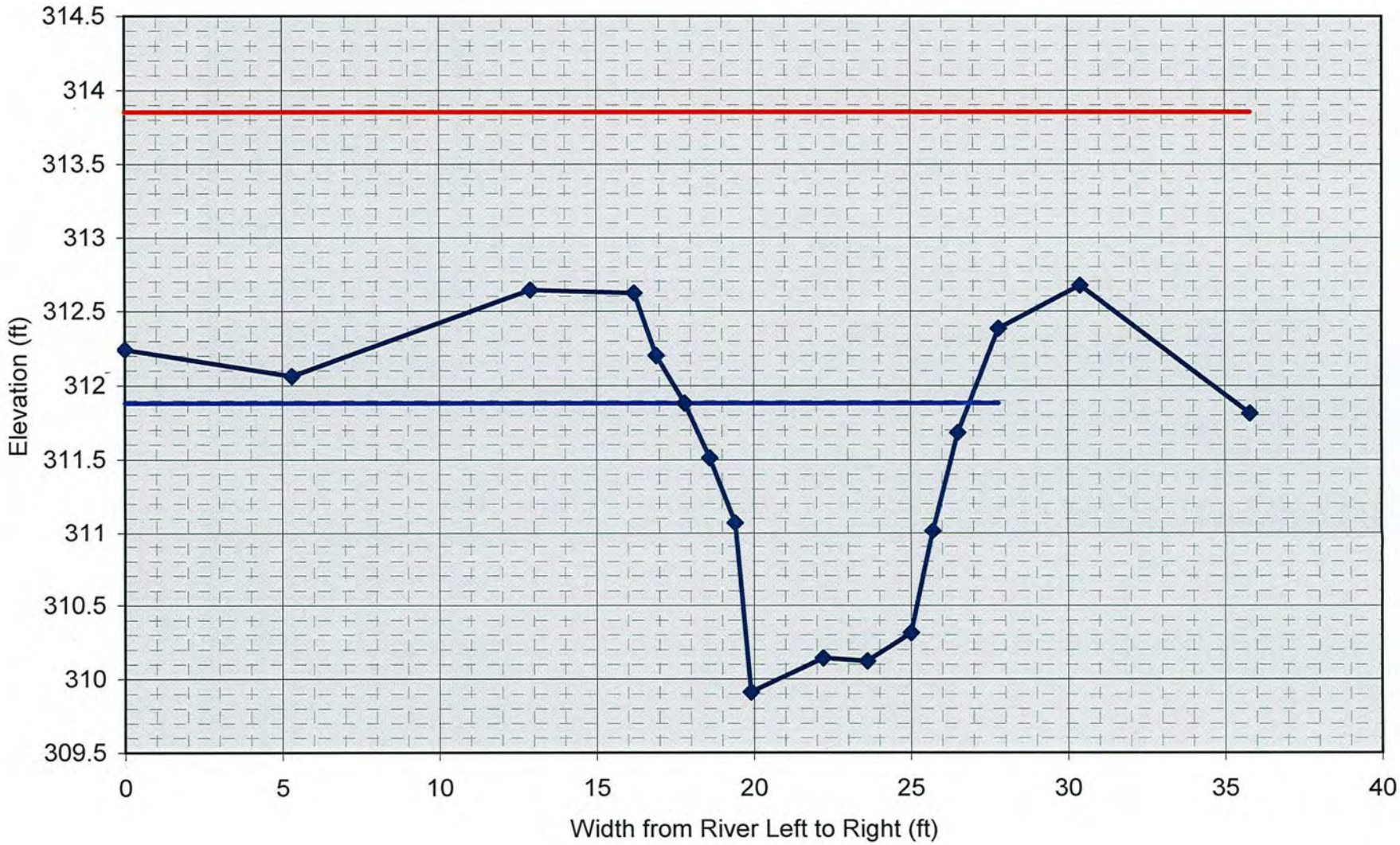
FIGURE 4

Riffle ---


314.5
314
313.5
313
312.5
312
311.5
311
310.5
310
Elevation (ft)
0
10
20
30
40
50
60
70
Width from River Left to Right (ft)


Pool ---
313
312.5
312
311.5
311
310.5
310
309.5
309
308.5
Elevation (ft)
0
5
10
15
20
25
30
35
40
Width from River Left to Right (ft)

Riffle ---


314.5
314
313.5
313
312.5
312
311.5
311
310.5
310
309.5
Elevation (ft)
0
5
10
15
20
25
30
35
40
Width from River Left to Right (ft)

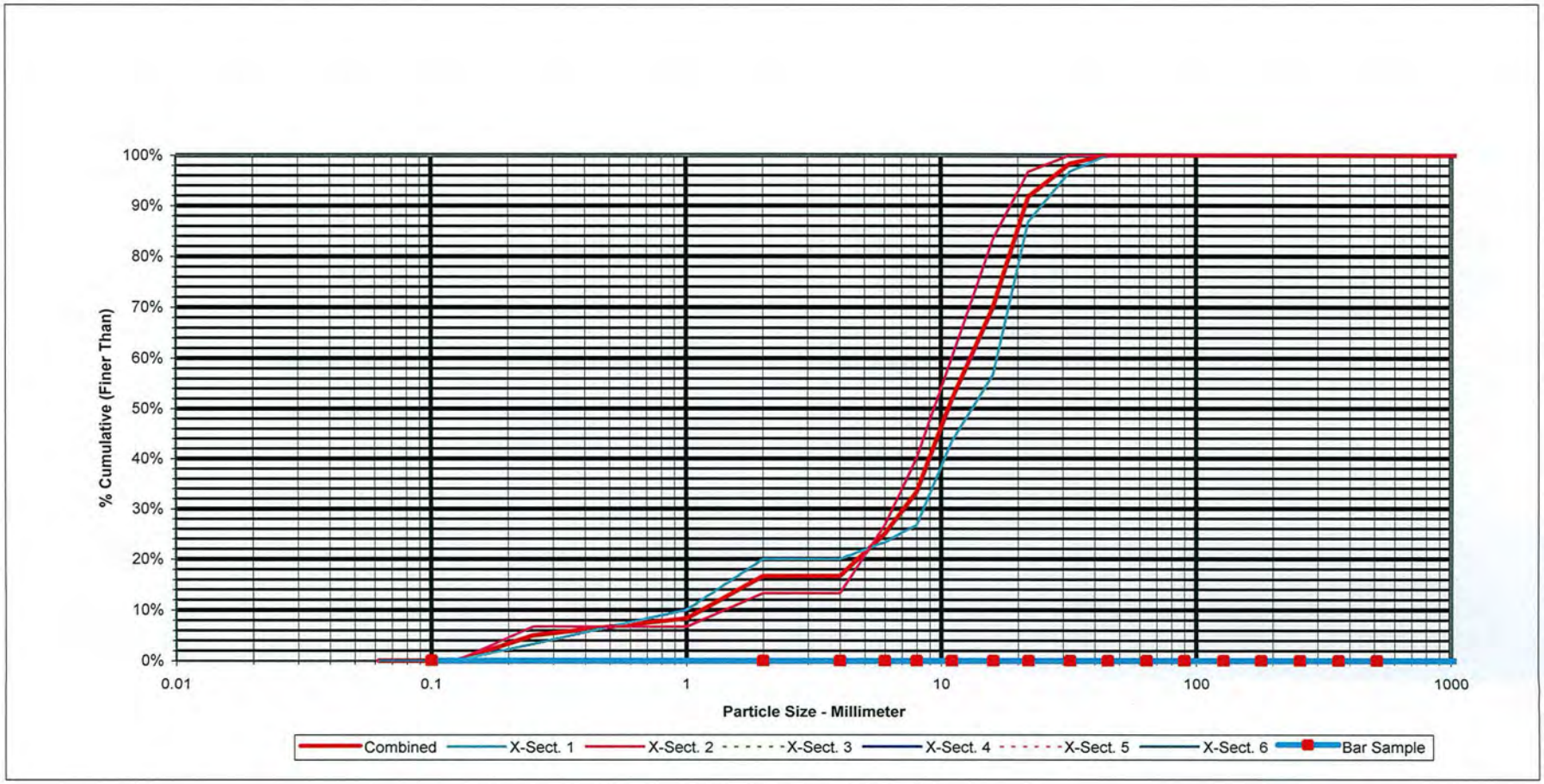
MORPHOLOGICAL CHARACTERISTICS OF THE EXISTING AND PROPOSED CHANNEL WITH GAGE STATION AND REFERENCE REACH DATA (Adapted from Rosgen, 1996)

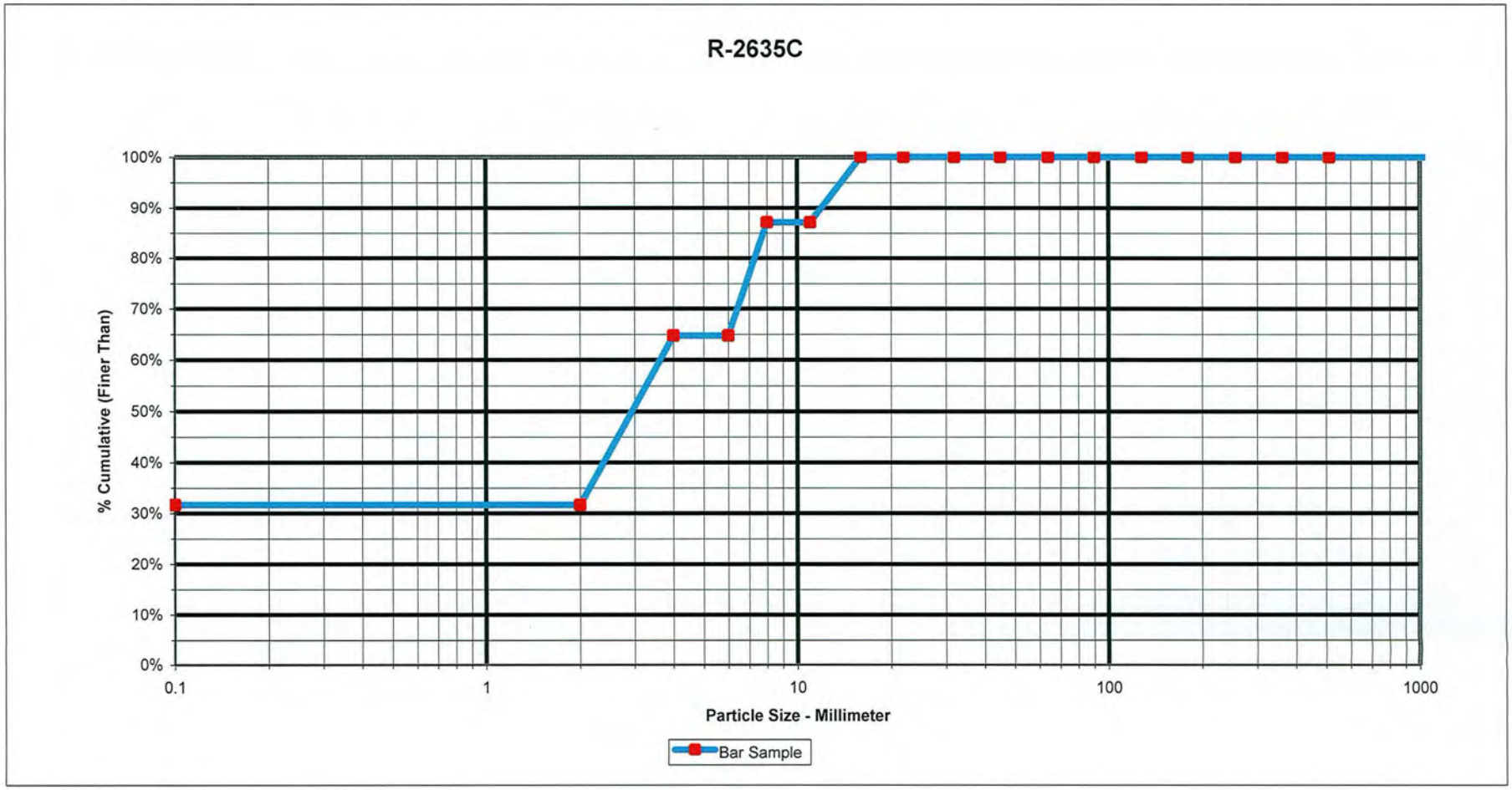
Restoration Site: R-2635C
USGS Gage Station: N/A
Reference Reach: UT to Beaverdam Creek
Surveyors: SDG
Date: 12/12/2006
Weather: Sunny - 60°

?

Variables		Existing Channel		Proposed Reach		Reference Reach
1. Stream Type		E4		C/E4		C5
2. Drainage Area (sq. mi)		0.67		0.67		0.28
3. Bankfull Width (Wbkf) ft	Mean:	9.4	Mean:	13.0	Mean:	11.8
	Minimum:	9.1	Minimum:		Minimum:	9.9
	Maximum:	9.6	Maximum:		Maximum:	14.1
4. Bankfull Mean Depth (dbkf) ft	Mean:	1.25	Mean:	1.2	Mean:	0.8
	Minimum:	1.19	Minimum:		Minimum:	0.7
	Maximum:	1.29	Maximum:		Maximum:	1.0
5. Width/Depth Ratio (Wbkf/dbkf)	Mean:	7.6	Mean:	10.8	Mean:	15.0
	Minimum:	7.1	Minimum:		Minimum:	
	Maximum:	8.1	Maximum:		Maximum:	
6. Bankfull Cross-Sectional Area (Abkf) sq ft	Mean:	11.6	Mean:	16.0	Mean:	9.4
	Minimum:	11.4	Minimum:		Minimum:	7.8
	Maximum:	11.7	Maximum:		Maximum:	10.5
7. Bankfull Mean Velocity (Vbkf) fps	Mean:	3.8	Mean:	4.3	Mean:	
	Minimum:	3.7	Minimum:		Minimum:	
	Maximum:	3.9	Maximum:		Maximum:	
8. Bankfull Discharge (Qbkf) cfs	Mean:	44.0	Mean:	68.8	Mean:	
	Minimum:	43.0	Minimum:		Minimum:	
	Maximum:	45.0	Maximum:		Maximum:	
9. Maximum Bankfull Depth (dmax) ft	Mean:	1.9	Mean:	1.8	Mean:	1.3
	Minimum:	1.7	Minimum:		Minimum:	1.0
	Maximum:	2.0	Maximum:		Maximum:	1.7
10. Width of Flood Prone Area (Wfpa) ft	Mean:	391.0	Mean:	85.0	Mean:	90.0
	Minimum:	390.0	Minimum:	110.0	Minimum:	
	Maximum:	392.0	Maximum:	60.0	Maximum:	
11. Entrenchment Ratio (Wfpa/Wbkf)	Mean:	41.6	Mean:	6.5	Mean:	7.6
	Minimum:	41.5	Minimum:	8.5	Minimum:	
	Maximum:	41.7	Maximum:	4.6	Maximum:	
12. Meander Length (Lm) ft	Mean:	119.0	Mean:	77.4	Mean:	71.0
	Minimum:	82.0	Minimum:	60.0	Minimum:	33.0
	Maximum:	164.0	Maximum:	95.0	Maximum:	144.0
13. Ratio of Meander Length to Bankfull Width (Lm/Wbkf)	Mean:	12.7	Mean:	6.0	Mean:	6.0
	Minimum:	8.7	Minimum:	4.6	Minimum:	2.8
	Maximum:	17.4	Maximum:	7.3	Maximum:	12.2
14. Radius of Curvature (Rc) ft	Mean:	17.6	Mean:	25.6	Mean:	18.0
	Minimum:	10.0	Minimum:	22.0	Minimum:	11.1
	Maximum:	32.0	Maximum:	34.0	Maximum:	38.0
15. Ratio of Radius of Curvature to Bankfull Width (Rc/Wbkf)	Mean:	1.9	Mean:	2.0	Mean:	1.5
	Minimum:	1.1	Minimum:	1.7	Minimum:	0.9
	Maximum:	3.4	Maximum:	2.6	Maximum:	3.2
16. Belt Width (Wblt) ft	Mean:	81.0	Mean:	36.3	Mean:	71.0
	Minimum:	44.0	Minimum:	28.0	Minimum:	30.0
	Maximum:	120.0	Maximum:	43.0	Maximum:	119.0
17. Meander Width Ratio (Wblt/Wbkf)	Mean:	8.6	Mean:	2.8	Mean:	6.0
	Minimum:	4.7	Minimum:	2.2	Minimum:	2.5
	Maximum:	12.8	Maximum:	3.3	Maximum:	10.1
18. Sinuosity (Stream length/valley distance) (K)	Mean:	1.5	Mean:	1.4	Mean:	2.2
	Minimum:		Minimum:		Minimum:	
	Maximum:		Maximum:		Maximum:	
19. Valley Slope (ft/ft)	Mean:	0.0075	Mean:	0.0074	Mean:	0.0300
	Minimum:		Minimum:		Minimum:	
	Maximum:		Maximum:		Maximum:	
20. Average Water Surface Slope for Reach (Savg)	Mean:	0.0050	Mean:	0.0055	Mean:	0.01300
	Minimum:		Minimum:		Minimum:	
	Maximum:		Maximum:		Maximum:	
21. Pool Slope (Spool) ft/ft	Mean:	0.0010	Mean:	0.0010	Mean:	0.0011
	Minimum:		Minimum:		Minimum:	0.0000
	Maximum:		Maximum:		Maximum:	0.0030
22. Ratio of Pool Slope to Average Slope (Spool/Savg)	Mean:	0.200	Mean:	0.182	Mean:	1.0
	Minimum:		Minimum:		Minimum:	0.0
	Maximum:		Maximum:		Maximum:	2.7
23. Maximum Pool Depth (dpool) ft	Mean:	2.5	Mean:	3.0	Mean:	2.4
	Minimum:		Minimum:		Minimum:	1.8
	Maximum:		Maximum:		Maximum:	2.9
24. Ratio of Maximum Pool Depth to Bankfull Mean Depth (dpool/dbkf)	Mean:	2.0	Mean:	2.4	Mean:	3.0
	Minimum:		Minimum:		Minimum:	2.3
	Maximum:		Maximum:		Maximum:	3.6
25. Pool Width (Wpool) ft	Mean:	8.5	Mean:	15.0	Mean:	9.9
	Minimum:		Minimum:		Minimum:	9.1
	Maximum:		Maximum:		Maximum:	10.5
26. Ratio of Pool Width to Bankfull Width (Wpool/Wbkf)	Mean:	0.9	Mean:	1.2	Mean:	0.8
	Minimum:		Minimum:		Minimum:	0.8
	Maximum:		Maximum:		Maximum:	0.9
27. Pool to Pool Spacing (p-p) ft	Mean:	N/A	Mean:	46.6	Mean:	36.5
	Minimum:		Minimum:	36.1	Minimum:	18.0
	Maximum:		Maximum:	58.7	Maximum:	58.0
28. Ratio of Pool-to-Pool Spacing to Bankfull Width (p-p/Wbkf)	Mean:	N/A	Mean:	3.6	Mean:	3.1
	Minimum:		Minimum:	2.8	Minimum:	1.5
	Maximum:		Maximum:	4.5	Maximum:	4.9

? .085
.0
.231


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Cumulative (Finer Than)
0.01
0.1
1
10
100
1000
Particle Size - Millimeter
Combined
X-Sect. 1
X-Sect. 2
X-Sect. 3
X-Sect. 4
X-Sect. 5
X-Sect. 6
Bar Sample


R-2635C
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Cumulative (Finer Than)
0.1
1
10
100
1000
Particle Size - Millimeter
Bar Sample

Entrainment Calculation Form

Project:	R-2635C	**Location:**	Wake County
Stream:	Reedy Branch	**Reach:**	Proposed
Date:	12/19/2006	**Observers:**	SDG

		Critical Dimensionless Shear Stress: Tci = 0.0834(di/d50)^-0.872				
Value	**Variable**	**Definition**				
11	di mm	D50 from	Riffle	or	Pavement*	*Choose
2	d50 mm	D50 from	Bar Sample	or	Sub Pavement*	*One*
0.0189	Tci	Critical Dimensionless Shear Stress				
		Bankfull Mean Depth Required for Entrainment of largest particle in Bar Sample: dr = (Tci*1.65*Di)/Se 1.65 = submerged specific weight of sediment				
16	mm	Largest Bar Sample Particle in mm				
0.05	Di ft	Largest Bar Sample Particle in ft				
0.0055	Se ft/ft	Bankfull Water Surface Slope				
0.30	dr ft	Bankfulll Mean Depth Required				
1.27	de ft	Bankfull Mean Depth (*From Rifffle Cross Section*)				
de/dr=	4.28	if = 1	<1		>1	
Choose one:		Stable	aggrading		Degrading	
		Bankfull Water Surface Slope Required for Entrainment of largest particle in Bar Sample: Sr = (Tci*1.65*Di)/de 1.65 = submerged specific weight of sediment				
0.05	Di ft	Largest Bar Sample Particle				
1.27	de ft	Bankfull Mean Depth (*From Rifffle Cross Section*)				
0.0013	Sr ft/ft	Bankfull Water Surface Slope Required				
Se/Sr=	4.28	if = 1	<1		>1	
Choose one:		Stable	aggrading		Degrading	
		Sediment Transport Validation - Bankfull Shear Stress Tc = yRS				
62.4	y lbs/cu ft	Density of water				
1.03	R=A/Wp					
16	A sq ft	Bankfull Cross-Sectional Area				
15.46	Wp	Wetted parameter				
0.0055	S ft/ft	Bankfull Water Surface Slope				
0.355188	Tc lb/sqr ft	Tc = yRS				
16	Di mm	Largest Bar Sample Particle (mm)				
22	mm*	Moveable Particle size (mm) at Bankfull Shear Stress predicted by the Sheilds diagram, Red field book: p.190; Blue: p.238				
0.28	lb/ft2	Predicted Shear Stress Required to move Di (lb/ft2) predicted by the Sheilds diagram, Red field book: p.190; Blue: p.238				

* Shear acceptable as largest particles found in stream were 26 and 36mm

Entrainment Calculation Form

Project:	R-2635C	**Location:**	Wake County
Stream:	Reedy Branch	**Reach:**	Existing
Date:	12/13/2006	**Observers:**	SDG

		Critical Dimensionless Shear Stress: Tci = 0.0834(di/d50)^-0.872
Value	**Variable**	**Definition**
11	di mm	D50 from Riffle or Pavement* — *Choose
2	d50 mm	D50 from Bar Sample or Sub Pavement* — *One*
0.0189	Tci	Critical Dimensionless Shear Stress
		Bankfull Mean Depth Required for Entrainment of largest particle in Bar Sample: dr = (Tci*1.65*Di)/Se 1.65 = submerged specific weight of sediment
16	mm	Largest Bar Sample Particle in mm
0.05	Di ft	Largest Bar Sample Particle in ft
0.0050	Se ft/ft	Bankfull Water Surface Slope
0.33	dr ft	Bankfulll Mean Depth Required
1.19	de ft	Bankfull Mean Depth (*From Rifffle Cross Section*)
de/dr=	3.64	if = 1 Stable; <1 aggrading; >1 Degrading
Choose one:		
		Bankfull Water Surface Slope Required for Entrainment of largest particle in Bar Sample: Sr = (Tci*1.65*Di)/de 1.65 = submerged specific weight of sediment
0.05	Di ft	Largest Bar Sample Particle
1.19	de ft	Bankfull Mean Depth (*From Rifffle Cross Section*)
0.0014	Sr ft/ft	Bankfull Water Surface Slope Required
Se/Sr=	3.64	if = 1 Stable; <1 aggrading; >1 Degrading
Choose one:		
		Sediment Transport Validation - Bankfull Shear Stress Tc = yRS
62.4	y lbs/cu ft	Density of water
0.95	R=A/Wp	
11.4	A sq ft	Bankfull Cross-Sectional Area
12	Wp	Wetted parameter
0.0050	S ft/ft	Bankfull Water Surface Slope
0.2964	Tc lb/sqr ft	Tc = yRS
16	Di mm	Largest Bar Sample Particle (mm)
18	mm	Moveable Particle size (mm) at Bankfull Shear Stress predicted by the Sheilds diagram, Red field book: p.190; Blue: p.238
0.28	lb/ft2	Predicted Shear Stress Required to move Di (lb/ft2) predicted by the Sheilds diagram, Red field book: p.190; Blue: p.238

Velocity Comparison Form

Project:	R-2635C	**Location:**	Wake County
Stream:	Reedy Branch	**Reach:**	Proposed
Date:	12/19/2006	**Observers:**	SDG

Input Variables		Output Variables	
Bankfull X-Sec Area (Abkf)	16 sq ft	Bankfull Mean Depth (Dbkf)	1.23 ft
Bankfull Width (Wbkf)	13 ft	Wetted Parameter (WP)	15.46 ft
D84 (Riffle or pavement)	20 mm	D84 (mm/304.8)	0.07 ft
Bankfull Slope (S)	0.0055 ft/ft	Hydraulic Radius (R)	1.03 ft
Gravitational Accleration (g)	32.2 ft/sq sec	Dbkf/D84 (use D84 in ft)	18.76 ft/ft
Bankfull Maximum Depth	1.5 ft.	R/D84 (use D84 in ft)	15.77 ft/ft

Dbkf/D84, u/u*, Mannings n		
u/u*	(Using Dbkf/D84 Red Book: p188; Blue p233)	10.1 ft/s/ft/s
Mannings n	(Red Book: p189; Blue :p236)	0.027
Velocity	(From Mannings' equation: u=1.4865 * (R^2/3)(S^1/2)/n)	4.18 ft/s

u/u*=2.83+5.7logR/D84		
u*	u* = (gRS)^.5	0.43 ft/s
Velocity:	u = u*(2.83+5.7log(R/D84))	4.13 ft/s

Mannings n by StreamType		
Stream type		E4
Mannings n	(Red Book: p187; Blue :p237)	0.032
Velocity	(From Mannings' equation: u=1.4865 * (R^2/3)(S^1/2)/n)	3.52 ft/s

Continuity Equation		
Qbkf	(cfs) original curve or stream gage hydraulic geometry	68.9 cfs
Velocity	(u=Q/A) or from stream gage hydraulic geometry	4.31 ft/s

Dr. Richard Hey Method		
Coefficient a	a = 11(R/dmax)^-0.314	12.47232184
Friction Factor - f	1/f^1/2 = 2.03 log (aR/(D84*3.5))	0.079262013
Velocity	(From D'Arcy Weisbach equation: u=(8*g*R S/f)^1/2)	4.30 ft/s

Velocity Comparison Form

Project:	R-2635C	**Location:**	Wake County
Stream:	Reedy Branch	**Reach:**	Existing
Date:	12/13/2006	**Observers:**	SDG

Input Variables		Output Variables	
Bankfull X-Sec Area (Abkf)	11.4 sq ft	Bankfull Mean Depth (Dbkf)	1.19 ft
Bankfull Width (Wbkf)	9.6 ft	Wetted Parameter (WP)	12 ft
D84 (Riffle or pavement)	20 mm	D84 (mm/304.8)	0.07 ft
Bankfull Slope (S)	0.005 ft/ft	Hydraulic Radius (R)	0.95 ft
Gravitational Accleration (g)	32.2 ft/sq sec	Dbkf/D84 (use D84 in ft)	18.14 ft/ft
Bankfull Maximum Depth	2 ft.	R/D84 (use D84 in ft)	14.48 ft/ft

Dbkf/D84, u/u*, Mannings n		
u/u*	(Using Dbkf/D84 Red Book: p188; Blue p233)	10 ft/s/ft/s
Mannings n	(Red Book: p189; Blue :p236)	0.027
Velocity	(From Mannings' equation: u=1.4865 * (R^2/3)(S^1/2)/n)	3.76 ft/s

u/u*=2.83+5.7logR/D84		
u*	u* = (gRS)^.5	0.39 ft/s
Velocity:	u = u*(2.83+5.7log(R/D84))	3.69 ft/s

Mannings n by StreamType		
Stream type		E4
Mannings n	(Red Book: p187; Blue :p237)	0.032
Velocity	(From Mannings' equation: u=1.4865 * (R^2/3)(S^1/2)/n)	3.17 ft/s

Continuity Equation		
Qbkf	(cfs) original curve or stream gage hydraulic geometry	cfs
Velocity	(u=Q/A) or from stream gage hydraulic geometry	0.00 ft/s

Dr. Richard Hey Method		
Coefficient a	a = 11(R/dmax)^-0.314	14.02300812
Friction Factor - f	1/f^1/2 = 2.03 log (aR/(D84*3.5))	0.07803079
Velocity	(From D'Arcy Weisbach equation: u=(8*g*R S/f)^1/2)	3.96 ft/s

Looking downstream over surveyed reach

Overview of riparian Area

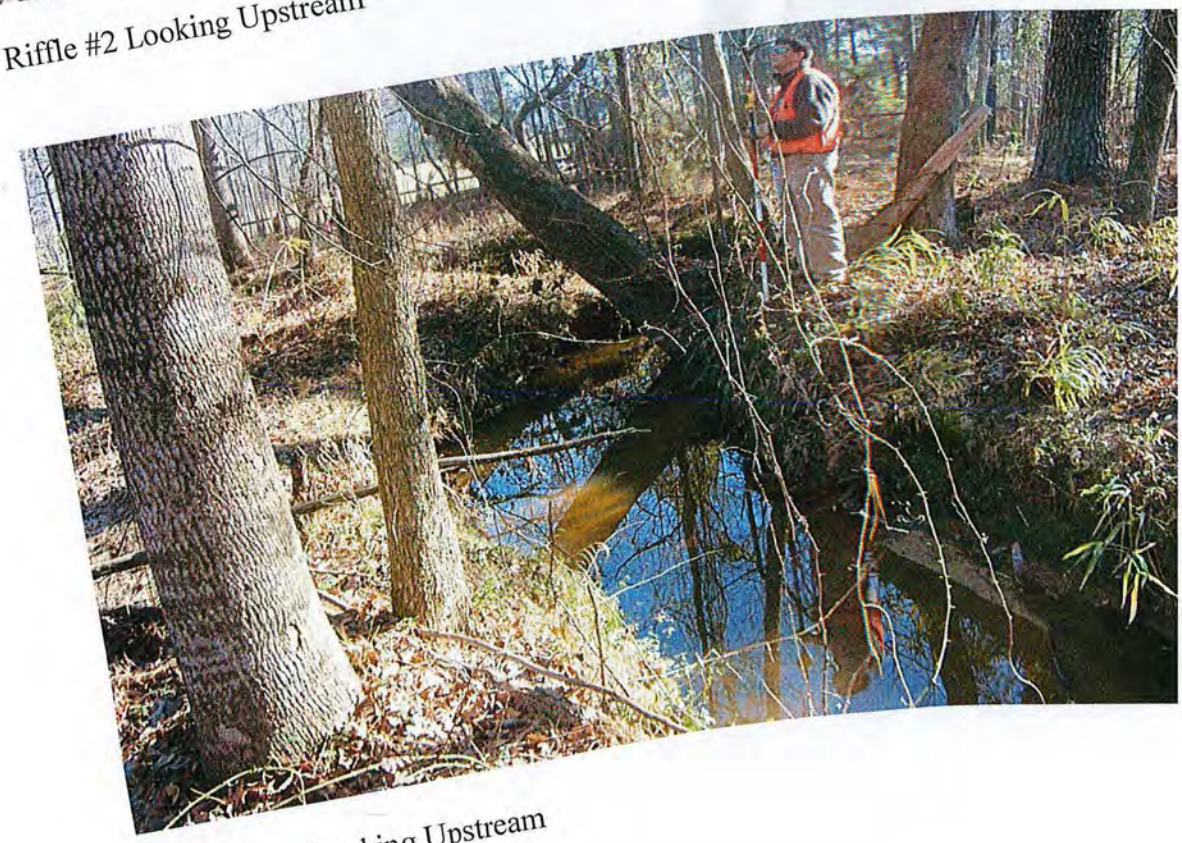
Overview #2 of Riparian Area

Riffle #1 Looking Downstream

Riffle #1 Looking Downstream

Riffle #2 Looking Upstream

Riffle #2 Looking Upstream



Pool Section Looking Upstream

Pool Section Looking Upstream

Wetland Area