Stream Restoration Report

Bushy Branch at Kentwood Park

ARCADIS

March 2002

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1. Introduction

1.1 Project Description

ARCADIS G&M of North Carolina, Inc. (ARCADIS) was retained by the North
Carolina Department of Environment and Natural Resources, Division of Water
Quality, Wetland Restoration Program (NCWRP) to complete this stream restoration
project utilizing natural channel design for Bushy Branch and its unnamed tributary
within the boundaries of Kentwood Park in Raleigh, North Carolina (Figure 1). Bushy
Branch at Kentwood Park was identified and targeted as a priority restoration area
during the development of the NCWRP's Basinwide Wetlands and Riparian
Restoration Plan for the Neuse River Watershed.

1.2 Purpose

The purpose of this report is to provide restoration designs as well as provide findings
of the field surveys along this segment of Bushy Branch and its unnamed tributary.

1.3 Methodology

Qualified biologists and engineers from ARCADIS conducted field surveys along the
project area in October and November of 2001. A topographical survey, using total
station surveying equipment, was conducted of the area to locate and identify features
and structures associated with Kentwood Park. The same equipment was used to
survey the stream features of Bushy Branch and its unnamed tributary. The stream
profile was surveyed by taking thalweg, water surface, bankfull and top of bank
measurements at the head of each feature (riffle, run, glide pool, max pool and step).
In some instances a bankfull indicator could not be identified at a feature. No bankfull
measurement was taken when this occurred. Also, the unnamed tributary was dry
during the surveys. Therefore, no water surface measurements were taken. Features
were identified by changes in the streambed. Bankfull measurements were taken
where an indicator was observed.

Cross sections measurements were taken at the same time the profile was surveyed.
The first cross section was measured at the head of a riffle to determine the bankfull
cross sectional area. This cross sectional area was compared to the regional curves
developed by North Carolina Stream Restoration Institute to confirm that bankfull was
correctly identified. The riffle cross section measurement was also used to classify the
stream according to the Rosgen classification system. Cross sections were also taken
at max pool, runs and glides.

Two reference reaches were also surveyed for the restoration project, one for each stream. The references reaches were surveyed with a level and survey rod.

2. Existing Site Conditions

2.1 Site Description and Land Use

Kentwood Park is owned by the City of Raleigh and is operated and maintained by its
Parks and Recreation Department. It is located in western Raleigh immediately south
of Kaplan Drive between Kent Road and Merwin Road (Figure 1). The park provides
a Frisbee golf course, baseball field, tennis courts and a playground for public uses.
Bushy Branch exhibits unstable banks primarily along the northeast corner of the park
as a result of pedestrian traffic associated with the Frisbee golf course. Downstream of
the Frisbee course, Bushy Branch appears more stable. The unnamed tributary exhibits
unstable banks from its source to its confluence with Bushy Branch.

Bushy Branch originates northwest of the I-440/Western Boulevard interchange and
flows to the southeast into Lake Raleigh at North Carolina State University's
Centennial Campus. Bushy Branch enters the northeast corner of the park property, as
it exits the culvert under Kaplan Drive, and flows southeastward approximately 900
feet along the western side of the park, paralleling the existing City of Raleigh sanitary
sewer easement. Two separate sanitary sewer crossings were observed along Bushy
Branch within the park, one above the streambed immediately downstream of Kaplan
Road culvert and one at the streambed approximately 400 feet downstream. Further
downstream, Bushy Branch continues southeastward under Gorman Street and into
Lake Raleigh, as noted above. The unnamed tributary, an intermittent stream,
originates at a storm drainage outlet immediately west of Kentwood Park and flows
eastward across the park to its confluence with Bushy Branch, about 400 feet
downstream of the Kaplan Drive culvert. Both of the streams are considered urban
type streams. The Bushy Branch watershed is urbanized and minimal future
development is anticipated.

2.2 Stream Classification

The existing streams were classified using the classification system and methodology
developed by Dave Rosgen of Wildland Hydrology, Inc. This method uses the
stream's pattern, profile, dimension, and substrate as parameters. The existing Bushy
Branch classified as a C-E4/1 stream type. The existing unnamed tributary to Bushy
Branch classified as a G4 stream type. All data is presented in Morphological
Characteristics Tables.

3. Stream Restoration Design

The proposed designs were based on bankfull cross sectional areas derived from the rural piedmont regional curves developed by the North Carolina Stream Restoration Institute. The urban piedmont regional curves are currently being revised. Also, bankfull cross sectional areas at the project site, as well as those at the reference reaches, were slightly higher than the rural piedmont regional curves but still within the 95% confidence interval.

Bushy Branch at Kentwood Park was determined to be an existing C-E4/1 stream exhibiting instability that is apparently attributed to excessive shear stress. The proposed design for Bushy Branch was developed using a stable C-E4/1 reference reach, an unnamed tributary to Lake Wheeler (Figure 2), and considering existing site constraints. The proposed design maintains the existing pattern and profile along Bushy Branch from the outlet of the existing reinforced concrete box culverts under Kaplan Drive for approximately 400 feet downstream. Along this reach, only the bankfull dimension of the stream will be adjusted as depicted on the proposed plans, profiles, and cross sections. Downstream of this point along the remainder of the Bushy Branch Project reach, the proposed dimension, pattern, and profile will be adjusted with the proposed stream tying back into the existing stream at the project terminus at station 20+50. This increase in sinuosity (and consequent increase in stream length) is necessitated to alleviate excessive shear stress, as discussed below. The proposed design along Bushy Branch consists of a combination of Priority Level 1-, 2-, and 3-like restoration. We have shown a proposed permanent easement at the southern end of the site where the existing stream is apparently not on the park property. This proposed easement should be located and obtained in order to permanently contain and protect the stream and its vegetated buffers.

Increasing stream length and reducing bankfull mean depth. The shear stress was reduced from 1.04 lbs/ft^2 to 0.75 lbs/ft^2. According to the Shields curve, this will entrain a 71 mm particle, the same size as the largest particle on the bar sample. Therefore, the proposed channel is not expected to aggrade or degrade. The critical minimum mean bankfull depth required to move the largest particle on the bar calculates to be 0.9 feet. The proposed bankfull mean depth of the new channel is 1.7 feet. The dimensionless shear stress calculation shows that the proposed minimum mean bankfull depth is deeper than what is required to entrain the largest particle. However, the presence of bedrock and the installation of grade control structures will prevent the stream from degrading.

A hydraulic analysis of the proposed stream restoration along Bushy Branch was prepared to determine whether the project would cause an increase in the 100-year flood elevation upstream of the project limits. The analysis was performed using the HEC-2 computer program from the U.S. Army Corps of Engineers. The City of Raleigh previously prepared a HEC-2 model of Bushy Branch in 1994, during a watershed study of the stream. The city model was obtained and used as the basis for the HEC-2 analysis prepared for this project.

The city model was updated with the 2001 ARCADIS field survey data within the project limits and used as the existing condition for comparison of the effects with the proposed stream restoration. The proposed stream cross section, pattern, and profile were used to prepare the proposed HEC-2 model. Comparison of results of the existing and proposed HEC-2 models indicated that no increase in the 100-year flood elevations will occur upstream of the project limits at Kaplan Drive.

The Unnamed Tributary to Bushy Branch at Kentwood Park was determined to be an existing G4 stream exhibiting instability that is apparently attributed to excessive shear stress. Using a stable B4/1 reference reach, an unnamed tributary to Mine Creek (Figure 3), and considering existing site constraints, the proposed design for the Unnamed Tributary to Bushy Branch was developed. This proposed step-pool-type system naturally fits the existing valley, allowing Priority Level 3 restoration (conversion from a G stream type to a B stream type). The proposed design maintains the existing pattern along the entire reach of the Unnamed Tributary. Due to the excessive shear stress and the inability to adequately increase sinuosity, the bankfull profile and dimension were modified as depicted on the proposed plans, profiles, and cross sections. The proposed profile was designed so that the stream was broken up into subreaches following the morphology of the step pool reference reach mentioned above. These subreaches have proposed average (or bankfull) water surface slopes which alleviate the excessive shear stress (see below). As shown on the proposed plans and profile, each of the subreaches is separated by steps established through the placement of boulder cross vanes.

The shear stress of the new channel calculates to be 0.8 lbs/ft^2. According to the Shields curve, this will entrain a 74 mm particle, the same size as the largest particle on the bar sample. The critical minimum mean bankfull depth required to move the largest particle on the bar calculates to be 0.5 feet. The proposed bankfull mean depth of the new channel is 0.6 feet. These calculations show the proposed channel is not expected to aggrade or degrade.

Permanent 50-foot vegetated buffers along both sides of the stream are proposed for Bushy Branch and the Unnamed Tributary. These buffers will consist of a combination of protection and maintenance of existing vegetation, vegetation transplants produced onsite during construction, and supplemental planting of other permanent native vegetation. Rootwads, boulder cross vanes, boulder vanes, and boulder j-hook vanes will be employed to help protect the adjusted bankfull dimension, pattern, and profile.

4. References

ARCADIS Geraghty & Miller, 2000, Stream Restoration Data Collection Report,
Kentwood Park, North Carolina.

Rosgen, D. L. and H. L. Silvey, 1998, Field Guide for Stream Classification. Wildland
Hydrology, Pagosa Springs, Colorado. 195 pp.

Rosgen, D. L., 1997, A Geomorphological Approach to Restoration of Incised Rivers.
Proceedings of the Conference on Management of Landscapes Disturbed by
Channel Incision. ISBN 0-937099-05-8.

Table 1

MORPHOLOGICAL CHARACTERISTICS OF THE EXISTING AND PROPOSED CHANNEL WITH GAGE STATION AND REFERENCE REACH DATA

(Adapted from Rosgen, 1996)

Restoration Site: Bushy Branch, Kentwood Park, Raleigh, NC
USGS Gage Station: 0208732885 "Marsh Creek NR New Hope, NC"
Reference Reach: UT Lake Wheeler (Swift Creek), Enchanted Oaks Subdivsion, Raleigh, NC

Variables	Existing Channel	Proposed Reach	Reference Reach	USGS Gage Station
1. Stream Type	C-E4/1	C-E4/1	C-E4/1	E
2. Drainage Area (sq. mi)	1.26 SQ MI	1.26 SQ MI	0.3 SQ MI	6.84 SQ MI
3. Bankfull Width (Wbkf) ft	Mean: 31 ft Range:25-36 ft	Mean: 24 ft Range: -	Mean: 11.5 ft Range: 11.0-12.5 ft	Mean: 36 ft Range: -
4. Bankfull Mean Depth (dbkf) ft	Mean: 2.0 ft Range: 1.8-2.1 ft	Mean: 1.7 ft Range: -	Mean: 1.1 ft Range: 0.9-1.2 ft	Mean: 3.8 ft Range: -
5. Width/Depth Ratio (Wbkf/dbkf)	Mean: 16 Range: 12-20	Mean: 14 Range: -	Mean: 11 Range: 9-14	Mean: 10 Range: -
6. Bankfull Cross-Sectional Area (Abkf) sq ft	Mean: 63 sf Range:51.5-69.8 sf	Mean: 40 sf Range: -	Mean: 12.2 sf Range: 11.2-12.8 sf	Mean: 135.8 sf Range: -
7. Bankfull Mean Velocity (Vbkf) fps	Mean: Range:	Mean: Range:	Mean: Range:	Mean: Range:
8. Bankfull Discharge, cfs (Qbkf)	Mean: Range:	Mean: Range:	Mean: Range:	Mean: 584.1 cfs Range: -
9. Maximum Bankfull Depth (dmax) ft	Mean: 2.9 ft Range:2.8-3.1 ft	Mean: 2.4 ft Range: 2.2-2.7 ft	Mean: 1.6 ft Range: 1.4-1.8 ft	Mean: 5.5 ft Range: -
10. Ratio of Low Bank Height to Max. Bankfull Depth (Bhlow/dmax)	Mean: Range:	Mean: Range:	Mean: 1.22 Range: 1.07-1.44	Mean: Range:
11. Width of Flood Prone Area (Wfpa) ft	Mean: 107 ft Range: 67-135 ft	Mean: - Range: 52 ft to >100 ft	Mean: 97 ft Range: 70-137 ft	Mean: 100 ft Range: -
12. Entrenchment Ratio (Wfpa/Wbkf)	Mean: 3.6 Range: 1.9-4.8	Mean: - Range: 2.2 to >6	Mean: 8.5 Range: 6.4-12.5	Mean: 2.2 Range: -
13. Meander Length (Lm) ft	Mean: 269 ft Range: 180-380 ft	Mean: 156 ft Range: 94-250 ft	Mean: 74 ft Range: 45-120 ft	Mean: Range:
14. Ratio of Meander Length to Bankfull Width (Lm/Wbkf)	Mean: 8.7 Range: 5.8-12.2	Mean: 6.5 Range: 3.9-10.4	Mean: 6.5 Range: 3.9-10.4	Mean: Range:
15. Raduis of Curvature (Rc) ft	Mean: 138 ft Range: 32-204 ft	Mean: 53 ft Range: 15-137 ft	Mean: 25 ft Range: 7-66 ft	Mean: Range:
16. Ratio of Radius of Curvature to Bankfull Width (Rc/Wbkf)	Mean: 4.4 Range: 1.0-6.6	Mean: 2.2 Range: 0.61-5.7	Mean: 2.2 Range: 0.61-5.7	Mean: Range:
17. Belt Width (Wblt) ft	Mean: 77 ft Range: 40-95 ft	Mean: 144 ft Range: 103-230 ft	Mean: 69 ft Range: 50-110 ft	Mean: Range:
18. Meander Width Ratio (Wblt/Wbkf)	Mean: 2.5 Range: 1.3-3.1	Mean: 6.0 Range: 4.3-9.6	Mean: 6.0 Range: 4.3-9.6	Mean: Range:
19. Sinuosity (Stream length/valley distance) (k)	Mean: 1.16 Range: n/a	Mean: 1.3 Range: 1.26-1.31	Mean: 1.57 Range: 1100 ft/700 ft	Mean: Range:
20. Valley Slope (ft/ft)	Mean: 0.0104 ft/ft Range: n/a	Mean: 0.0104 ft/ft Range: -	Mean: 0.01 ft/ft Range: n/a	Mean: Range:
21. Average Water Surface Slope or Bankful Slope for Reach (Sbkf or Savg)=(Svalley/k) ft / ft	Mean: 0.009 ft/ft Range: n/a	Mean: 0.008 ft/ft Range: 0.00793-0.00823 ft/ft	Mean: 0.006 ft/ft Range: n/a	Mean: Range:
22. Pool Slope (Spool) ft / ft	Mean: 0.004 ft/ft Range: 0-0.009 ft/ft	Mean: 0.00192 ft/ft Range: 0-0.00736 ft/ft	Mean: 0.0014 ft/ft Range: 0- 0.0055 ft/ft	Mean: Range:

MORPHOLOGICAL CHARACTERISTICS OF THE EXISTING AND PROPOSED CHANNEL WITH GAGE STATION AND REFERENCE REACH DATA

(Adapted from Rosgen, 1996)

Restoration Site: Bushy Branch, Kentwood Park, Raleigh, NC
USGS Gage Station: 0208732885 "Marsh Creek NR New Hope, NC"
Reference Reach: UT Lake Wheeler (Swift Creek), Enchanted Oaks Subdivsion, Raleigh, NC

Variables	Existing Channel	Proposed Reach	Reference Reach	USGS Gage Station
23. Ratio of Pool Slope to Average Slope (Spool/Sbkf)	Mean: 0.44 Range: 0-1.0	Mean: 0.24 Range: 0-0.92	Mean: 0.24 Range: 0-0.92	Mean: Range:
24. Maximum Pool Depth (dpool) ft	Mean: 4.1 ft Range: 3.7-4.3 ft	Mean: 4.3 ft Range: 3.4-5.8 ft	Mean: 2.7 ft Range: 2.2-3.7 ft	Mean: Range:
25. Ratio of Maximum Pool Depth to Bankfull Mean Depth (dpool/dbkf)	Mean: 2.0 Range: 1.9-2.2	Mean: 2.5 Range: 2.0-3.4	Mean: 2.5 Range: 2.0-3.4	Mean: Range:
26. Pool Width (Wpool) ft	Mean: 22.2 ft Range: 19.5-24.9 ft	Mean: 24 ft Range: 19-31 ft	Mean: 12.0 ft Range: 9.0-15.0 ft	Mean: Range:
27. Ratio of Pool Width to Bankfull Width (Wpool/Wbkf)	Mean: 0.72 Range: 0.63-0.80	Mean: 1.0 Range: 0.8-1.3	Mean: 1.0 Range: 0.8-1.3	Mean: Range:
28. Bankfull Cross-sectional Area at Pool (Apool) sq ft	Mean: 56.4 sf Range: 47.2-65.7 sf	Mean: 60 sf Range: 44-88 sf	Mean: 18.5 sf Range: 13.2-27.4 sf	Mean: Range:
29. Ratio of Pool Area to Bankfull Area (Apool/Abkf)	Mean: 0.90 Range: 0.75-1.04	Mean: 1.5 Range: 1.1-2.2	Mean: 1.5 Range: 1.1-2.2	Mean: Range:
30. Pool to Pool Spacing (p-p) ft	Mean: 111 ft Range: 46.9-140.8 ft	Mean: 120 ft Range: 46-310 ft	Mean: 57 ft Range: 22-148 ft	Mean: Range:
31. Ratio of Pool-to-Pool Spacing to Bankfull Width (p-p/Wbkf)	Mean: 3.6 Range: 1.5-4.5	Mean: 5.0 Range: 1.9-12.9	Mean: 5.0 Range: 1.9-12.9	Mean: Range:
32. Pool Length (Lp) ft	Mean: 34.3 ft Range: 16.0-60.1 ft	Mean: 62 ft Range: 24-233 ft	Mean: 30 ft Range: 11-112 ft	Mean: Range:
33. Ratio of Pool Length to Bankfull Width (Lp/Wbkf)	Mean: 1.11 Range: 0.52-1.94	Mean: 2.6 Range: 1.0-9.7	Mean: 2.6 Range: 1.0-9.7	Mean: Range:
34. Riffle Slope (Sriff) ft / ft	Mean: 0.016 ft/ft Range: 0.001-0.028 ft/ft	Mean: 0.0368 ft/ft Range: 0.0168-0.056 ft/ft	Mean: 0.028 ft/ft Range: 0.0125-0.0419 ft/ft	Mean: Range:
35. Ratio of Riffle Slope to Average Slope (Sriff/Sbkf)	Mean: 1.82 Range: 0.11-3.11	Mean: 4.6 Range: 2.1-7.0	Mean: 4.6 Range: 2.1-7.0	Mean: Range:
36. Maximum Riffle Depth (driff) ft	Mean: 2.9 ft Range: 2.3-3.5 ft	Mean: 2.4 ft Range: 2.2-2.7 ft	Mean: 1.6 ft Range: 1.4-1.8 ft	Mean: Range:
37. Ratio of Riffle Depth to Bankfull Mean Depth (driff/dbkf)	Mean: 1.5 Range: 1.1-1.8	Mean: 1.4 Range: 1.3-1.6	Mean: 1.4 Range: 1.3-1.6	Mean: Range:
38. Run Slope (Srun) ft / ft	Mean: 0.019 ft/ft Range: 0.005-0.029 ft/ft	Mean: 0.0176 ft/ft Range: 0.0036-0.0432 ft/ft	Mean: 0.013 ft/ft Range: 0.0025-0.0325 ft/ft	Mean: Range:
39. Ratio of Run Slope to Average Slope (Srun/Sbkf)	Mean: 2.08 Range: 0.56-3.22	Mean: 2.2 Range: 0.42-5.4	Mean: 2.2 Range: 0.42-5.4	Mean: Range:
40. Maximum Run Depth (drun) ft	Mean: 3.2 ft Range: 3.0-3.6 ft	Mean: 2.55 ft Range: 2.55 ft	Mean: 1.7 ft Range: 1.7 ft	Mean: Range:
41. Ratio of Run Depth to Bankfull Mean Depth (drun/dbkf)	Mean: 1.6 Range: 1.5-1.8	Mean: 1.5 Range: 1.5	Mean: 1.5 Range: 1.5	Mean: Range:
42. Slope of Glide (Sgl) ft / ft	Mean: 0.005 ft/ft Range: 0-0.029 ft/ft	Mean: 0.0054 ft/ft Range: 0-0.024 ft/ft	Mean: 0.004 ft/ft Range: 0-0.0183 ft/ft	Mean: Range:
43. Ratio of Glide Slope to Average Water Surface Slope (Sgl/Sws)	Mean: 0.58 Range: 0-3.22	Mean: 0.67 Range: 0-3.0	Mean: 0.67 Range: 0-3.0	Mean: Range:
44. Maximum Glide Depth (dgl) ft	Mean: 3.4 ft Range: 3.2-3.5 ft	Mean: 3.6 ft Range: 3.6-3.7 ft	Mean: 2.4 ft Range: 2.3-2.4 ft	Mean: Range:
45. Ratio of Glide Depth to Bankfull Mean Depth (dgl/dbkf)	Mean: 1.7 Range: 1.6-1.7	Mean: 2.1 Range: 2.1-2.2	Mean: 2.1 Range: 2.1-2.2	Mean: Range:

Materials:

MORPHOLOGICAL CHARACTERISTICS OF THE EXISTING AND PROPOSED CHANNEL WITH GAGE STATION AND REFERENCE REACH DATA

(Adapted from Rosgen, 1996)

Restoration Site: Bushy Branch, Kentwood Park, Raleigh, NC
USGS Gage Station: 0208732885 "Marsh Creek NR New Hope, NC"
Reference Reach: UT Lake Wheeler (Swift Creek), Enchanted Oaks Subdivsion, Raleigh, NC

Variables	Existing Channel	Proposed Reach	Reference Reach	USGS Gage Station
Particle Size Distribution of Channel Material (mm)				
D16	0.174	0.174	0.13	
D35	5.3	5.3	0.7	
D50	12	12	4	
D84	45	45	17	
D95	2074	2074	41	
Particle Size Distribution of Bar Material				
D16	0.239 0.275		0.239	0.335	
D35	1.7 3.3		1.7	2.5	
D50	4 7		4	5	
D84	30 23		30	15	
D95	66 38		66	26	
Largest Size Particle on Bar	71 40		71	38	

Sediment Transport:

Sediment Transport Validation (Based on Bankfull Shear Stress)	Existing 1.04 lb/sf	Proposed 0.75 lb/sf
Calculated value (mm) from curve	100	71
Value from Shields Curve (lb/ft2)	0.75	0.75
Critical dimensionless shear stress	0.019	0.019
Minimal mean dbkf (ft) calculated using critical dimensionless shear stress equations	0.8	0.9

Table 2

MORPHOLOGICAL CHARACTERISTICS OF THE EXISTING AND PROPOSED CHANNEL WITH GAGE STATION AND REFERENCE REACH DATA

(Adapted from Rosgen, 1996)

Restoration Site: UT Bushy Branch, Kentwood Park, Raleigh, NC
USGS Gage Station: 0208732885 "Marsh Creek NR New Hope, NC"
Reference Reach: UT Mine Creek, North Hills Drive, Raleigh, NC

Variables	Existing Channel	Proposed Reach	Reference Reach	USGS Gage Station
1. Stream Type	G4	B4/1	B4/1	E
2. Drainage Area (sq. mi)	0.06 sq mi	0.06 SQ. MI	0.17 sq mi	6.84 SQ MI
3. Bankfull Width (Wbkf) ft	Mean: 6.2 ft Range: 6-6.3 ft	Mean: 8.0 ft Range: -	Mean: 10.4 ft Range: 10.1-10.5 ft	Mean: 36 ft Range: -
4. Bankfull Mean Depth (dbkf) ft	Mean: 1.25 ft Range: 1.2-1.3 ft	Mean: 0.6 ft Range: -	Mean: 1.0 ft Range: 0.8-1.1 ft	Mean: 3.8 ft Range: -
5. Width/Depth Ratio (Wbkf/dbkf)	Mean: 5.0 Range: 5.0	Mean: 12 Range: -	Mean: 10.3 Range: 9-12	Mean: 10 Range: -
6. Bankfull Cross-Sectional Area (Abkf) sq ft	Mean: 7.7 sf Range: 7.3-8.0 sf	Mean: 5.0 sf Range: -	Mean: 10.1 sf Range: 8.9-10.9 sf	Mean: 135.8 sf Range: -
7. Bankfull Mean Velocity (Vbkf) fps	Mean: Range:	Mean: Range:	Mean: 4.9 fps Range: 4.5-5.6 fps	Mean: Range:
8. Bankfull Discharge, cfs (Qbkf)	Mean: Range:	Mean: Range:	Mean: 51.1 cfs Range: 45.5-56.6 cfs	Mean: 584.1 cfs Range: -
9. Maximum Bankfull Depth (dmax) ft	Mean: 1.7 ft Range: 1.6-1.8 ft	Mean: 1.0 ft Range: 0.9-1.0 ft	Mean: 1.6 ft Range: 1.5-1.7 ft	Mean: 5.5 ft Range: -
10. Ratio of Low Bank Height to Max. Bankfull Depth (Bhlow/dmax)	Mean: Range:	Mean: Range:	Mean: n/a Range: n/a	Mean: Range:
11. Width of Flood Prone Area (Wfpa) ft	Mean: 8.25 ft Range: 8.0-8.5 ft	Mean: - Range: 12 to 18 ft	Mean: 16.3 ft Range: 12.3-23.0 ft	Mean: 100 ft Range: -
12. Entrenchment Ratio (Wfpa/Wbkf)	Mean: 1.35 Range: 1.3-1.4	Mean: - Range: 1.5-2.2	Mean: 1.6 Range: 1.2-2.2	Mean: 2.2 Range: -
13. Meander Length (Lm) ft	Mean: 490 ft Range: 490 ft	Mean: 98 ft Range: -	Mean: 127 ft Range: n/a	Mean: Range:
14. Ratio of Meander Length to Bankfull Width (Lm/Wbkf)	Mean: 79 Range: 79	Mean: 12.2 Range: -	Mean: 12.2 Range: n/a	Mean: Range:
15. Raduis of Curvature (Rc) ft	Mean: 75 ft Range: 42-94 ft	Mean: 14 ft Range: 10-18 ft	Mean: 15.8 ft Range: 12.0-23.4 ft	Mean: Range:
16. Ratio of Radius of Curvature to Bankfull Width (Rc/Wbkf)	Mean: 12.1 Range: 6.8-15.2	Mean: 1.8 Range: 1.2-2.3	Mean: 1.8 Range: 1.2-2.3	Mean: Range:
17. Belt Width (Wblt) ft	Mean: 82 ft Range: 58-105 ft	Mean: 26 ft Range: 14-38 ft	Mean: 34 ft Range: 19-49 ft	Mean: Range:
18. Meander Width Ratio (Wblt/Wbkf)	Mean: 13.1 Range: 9.4-16.9	Mean: 3.3 Range: 1.8-4.7	Mean: 3.3 Range: 1.8-4.7	Mean: Range:
19. Sinuosity (Stream length/valley distance) (k)	Mean: 1.14 Range: n/a	Mean: 1.14 Range: -	Mean: 1.2 Range: n/a	Mean: Range:
20. Valley Slope (ft/ft)	Mean: 0.038 ft/ft Range: n/a	Mean: 0.038 ft/ft Range: -	Mean: 0.027 ft/ft Range:	n/a
21. Average Water Surface Slope or Bankful Slope for Reach (Sbkf or Savg)=(Svalley/k) ft / ft	Mean: 0.033 ft/ft Range: n/a	Mean: 0.024 ft/ft Range: -	Mean: 0.022 ft/ft Range: n/a	Mean: Range:
22. Pool Slope (Spool) ft / ft	Mean: - Range: -	Mean: 0.0024 ft/ft Range: 0-0.0048 ft/ft	Mean: 0.0014 ft/ft Range: 0-0.004 ft/ft	Mean: Range:

(Adapted from Rosgen, 1996)

Restoration Site: UT Bushy Branch, Kentwood Park, Raleigh, NC
USGS Gage Station: 0208732885 "Marsh Creek NR New Hope, NC"
Reference Reach: UT Mine Creek, North Hills Drive, Raleigh, NC

Variables	Existing Channel	Proposed Reach	Reference Reach	USGS Gage Station
23. Ratio of Pool Slope to Average Slope (Spool/Sbkf)	Mean: - Range: -	Mean: 0.1 Range: 0-0.2	Mean: 0.1 Range: 0-0.2	Mean: Range:
24. Maximum Pool Depth (dpool) ft	Mean: 2.0 ft Range: 2.0-2.1 ft	Mean: 1.2 ft Range: 1.0-1.4 ft	Mean: 2.0 ft Range: 1.7-2.3 ft	Mean: Range:
25. Ratio of Maximum Pool Depth to Bankfull Mean Depth (dpool/dbkf)	Mean: 1.64 Range: 1.60-1.68	Mean: 2.0 Range: 1.7-2.4	Mean: 2.0 Range: 1.7-2.4	Mean: Range:
26. Pool Width (Wpool) ft	Mean: 9.2 ft Range: 6.8-11.5 ft	Mean: 8 ft Range: 7.2-9.6 ft	Mean: 10.7 ft Range: 9.1-12.1 ft	Mean: Range:
27. Ratio of Pool Width to Bankfull Width (Wpool/Wbkf)	Mean: 1.5 Range: 1.1-1.8	Mean: 1.0 Range: 0.9-1.2	Mean: 1.0 Range: 0.9-1.2	Mean: Range:
28. Bankfull Cross-sectional Area at Pool (Apool) sq ft	Mean: 13.6 sf Range: 9.6-17.6 sf	Mean: 5.0 sf Range: 3.5-6.0 sf	Mean: 9.9 sf Range: 7.6-12.4 sf	Mean: Range:
29. Ratio of Pool Area to Bankfull Area (Apool/Abkf)	Mean: 1.8 Range: 1.2-2.3	Mean: 1.0 Range: 0.7-1.2	Mean: 1.0 Range: 0.7-1.2	Mean: Range:
30. Pool to Pool Spacing (p-p) ft	Mean: - Range: -	Mean: 25 ft Range: 21-33 ft	Mean: 32 ft Range: 27-43 ft	Mean: Range:
31. Ratio of Pool-to-Pool Spacing to Bankfull Width (p-p/Wbkf)	Mean: - Range: -	Mean: 3.1 Range: 2.6-4.1	Mean: 3.1 Range: 2.6-4.1	Mean: Range:
32. Pool Length (Lp) ft	Mean: - Range: -	Mean: 6.4 ft Range: 2.4-10.4 ft	Mean: 6.7 ft Range: 3.0-14.0 ft	Mean: Range:
33. Ratio of Pool Length to Bankfull Width (Lp/Wbkf)	Mean: - Range: -	Mean: 0.8 Range: 0.3-1.3	Mean: 0.8 Range: 0.3-1.3	Mean: Range:
34. Riffle Slope (Sriff) ft / ft	Mean: - Range: -	Mean: 0.034 ft/ft Range: 0.012-0.060 ft/ft	Mean: 0.0315 ft/ft Range: 0.01-0.055 ft/ft	Mean: Range:
35. Ratio of Riffle Slope to Average Slope (Sriff/Sbkf)	Mean: - Range: -	Mean: 1.4 Range: 0.5-2.5	Mean: 1.4 Range: 0.5-2.5	Mean: Range:
36. Maximum Riffle Depth (driff) ft	Mean: 1.8 ft Range: 1.6-1.9 ft	Mean: 1.0 ft Range: 0.9-1.0 ft	Mean: 1.6 ft Range: 1.5-1.7 ft	Mean: Range:
37. Ratio of Riffle Depth to Bankfull Mean Depth (driff/dbkf)	Mean: 1.4 Range: 1.3-1.5	Mean: 1.6 Range: 1.5-1.7	Mean: 1.6 Range: 1.5-1.7	Mean: Range:
38. Run Slope (Srun) ft / ft	Mean: - Range: -	Mean: 0.0024 ft/ft Range: 0-0.012 ft/ft	Mean: 0.003 ft/ft Range: 0-0.01 ft/ft	Mean: Range:
39. Ratio of Run Slope to Average Slope (Srun/Sbkf)	Mean: - Range: -	Mean: 0.1 Range: 0-0.5	Mean: 0.1 Range: 0-0.5	Mean: Range:
40. Maximum Run Depth (drun) ft	Mean: - Range: -	Mean: 0.9 ft Range: -	Mean: 1.5 ft Range: n/a	Mean: Range:
41. Ratio of Run Depth to Bankfull Mean Depth (drun/dbkf)	Mean: - Range: -	Mean: 1.5 Range: -	Mean: 1.5 Range: n/a	Mean: Range:
42. Slope of Glide (Sgl) ft / ft	Mean: - Range: -	Mean: 0.0072 ft/ft Range: 0-0.0216 ft/ft	Mean: 0.007 ft/ft Range: 0-0.02 ft/ft	Mean: Range:
43. Ratio of Glide Slope to Average Water Surface Slope (Sgl/Sws)	Mean: - Range: -	Mean: 0.3 Range: 0-0.9	Mean: 0.3 Range: 0-0.9	Mean: Range:
44. Maximum Glide Depth (dgl) ft	Mean: - Range: -	Mean: 1.0 ft Range: -	Mean: 1.6 ft Range: n/a	Mean: Range:
45. Ratio of Glide Depth to Bankfull Mean Depth (dgl/dbkf)	Mean: - Range: -	Mean: 1.6 Range: -	Mean: 1.6 Range: n/a	Mean: Range:
46. Step Slope (Sst)	Mean: - Range: -	Mean: 0.48 ft/ft Range: 0.175-0.785 ft/ft	Mean: 0.44 ft/ft Range: 0.16-0.72 ft/ft	Mean: Range:

(Adapted from Rosgen, 1996)

Restoration Site: UT Bushy Branch, Kentwood Park, Raleigh, NC
USGS Gage Station: 0208732885 "Marsh Creek NR New Hope, NC"
Reference Reach: UT Mine Creek, North Hills Drive, Raleigh, NC

Variables	Existing Channel	Proposed Reach	Reference Reach	USGS Gage Station
47. Ratio of Step Slope to Average Water Surface Slope (Sst/Savg)	Mean: - Range: -	Mean: 20 Range: 7.3-32.7	Mean: 20.0 Range: 7.3-32.7	Mean: Range:
48. Maximum Step Depth (dst)	Mean: - Range: -	Mean: 1.0 ft Range: -	Mean: 1.6 ft Range: n/a	Mean: Range:
49. Ratio of Step Depth to Bankfull Mean Depth (dst/dbkf)	Mean: - Range: -	Mean: 1.6 Range: -	Mean: 1.6 Range: n/a	Mean: Range:

Materials:				
Particle Size Distribution of Channel Material (mm)				
D16	0.098	0.098	0.04	
D35	7.1	7.1	1	
D50	12	12	11	
D84	29	29	176	
D95	42	42	2438	
Particle Size Distribution of Bar Material (Pavement/Subpavement) **See notes below**				
D16	0.7,0.1 / 6.5,0.2	6.5 , 0.2	21 / 0.5	
D35	5.3,0.7 / 15.0,1.8	15.0 , 1.8	44 / 3.5	
D50	10,3 / 22,7	22 , 7	55 / 7	
D84	19,15 / 47,28	47 , 28	80 / 34	
D95	22,24 / 76,40	76 , 40	91 / 68	
Largest Size Particle on Bar	30 / 74	74	84	

Sediment Transport:			
Sediment Transport Validation (Based on Bankfull Shear Stress)	**Existing** 2.47 LB/SF		**Proposed** **0.8** LB/SF
Calculated value (mm) from curve		350	74
Value from Shields Curve (lb/ft2)	0.4 / 0.75		0.8
Critical dimensionless shear stress	0.029 / 0.031		0.031
Minimal mean dbkf (ft) calculated using critical dimensionless shear stress equations	0.13 / 0.34		0.52

For existing UT Bushy Branch, 2 Pavement/Subpavement samples taken, Sample 1 taken upstream of existing culvert; Sample 2 taken downstream of existing culvert. Results from each shown above in the following format: Sample 1 Pavement,Sample 1 Subpavement / Sample 2 Pavement,Sample 2 Subpavement. Sediment Transport Results for existing UT Bushy Branch shown for both sample in same format. For Reference Reach, Pavement/Subpavement sample was also taken. Results were shown in the following format: Pavement / Subpavement
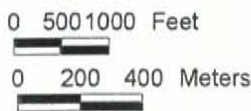
Wake County, NC

N

PROJECT LOCATION

Bushy Branch at Kentwood Park
Wake County, North Carolina

Figure No.

1

7.5 Minute Series
Topographic Quadrangle:
Lake Wheeler, NC

0 500 1000 Feet

0   200   400 Meters

Scale 1:24000

N.C. Wetlands
Restoration Program

ARCADIS G&M

P.O. Box 31388
Raleigh, NC 27622
(919) 782-5511

N

Wake County, NC

REFERENCE REACH
UT to Lake Wheeler
Wake County, North Carolina

Figure No.

2
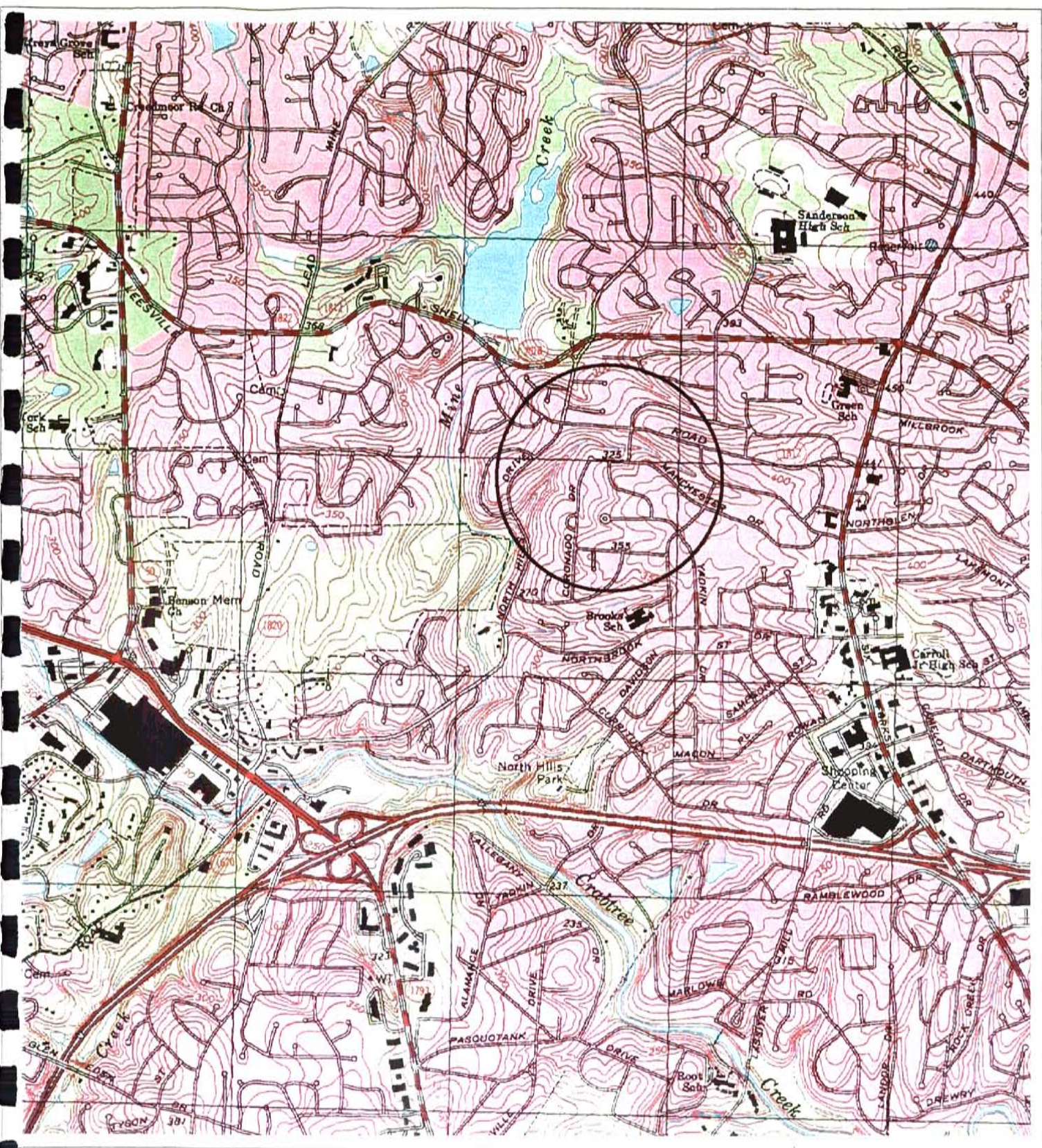
USGS

7.5 Minute Series
Topographic Quadrangle:
Raleigh West, NC

0   500 1000 Feet

0   200   400 Meters

Scale 1:24000

N.C. Wetlands
Restoration Program

ARCADIS G&M
P.O. Box 31388
Raleigh, NC 27622
(919) 782-5511

Wake County, NC

N

REFERENCE REACH
UT to Mine Creek
Wake County, North Carolina

Figure No.

3

Bushy Branch looking downstream. Frisbee golf course located to the right.

Bushy Branch looking downstream near confluence with unnamed tributary.

Bushy Branch five-foot high eroding bank.

Bushy Branch looking downstream. Note undercut trees on right.

Unnamed Tributary to Bushy Branch looking upstream near culvert outlet.

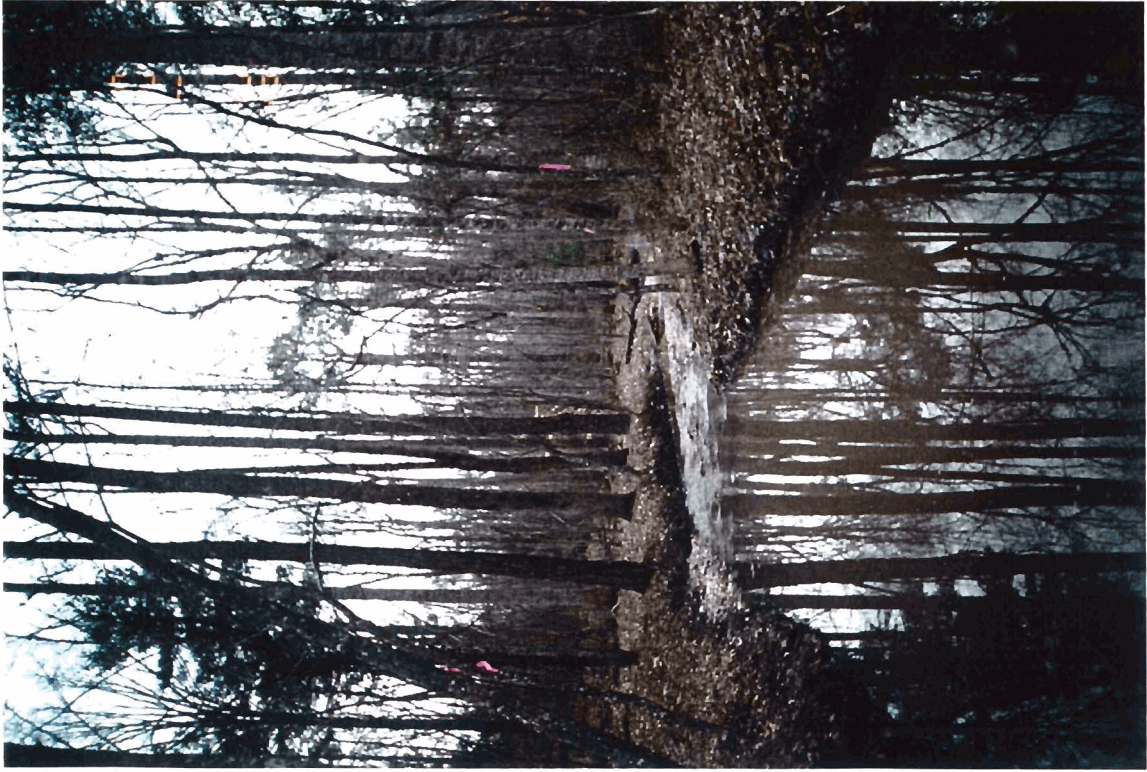Unnamed Tributary to Bushy Branch where Frisbee golf course crosses.

Unnamed Tributary to Bushy Branch eroding banks. Note lack of vegetation due to foot traffic.

Unnamed Tributary to Bushy Branch looking downstream at confluence with Bushy Branch. Frisbee golf course crosses at this location.
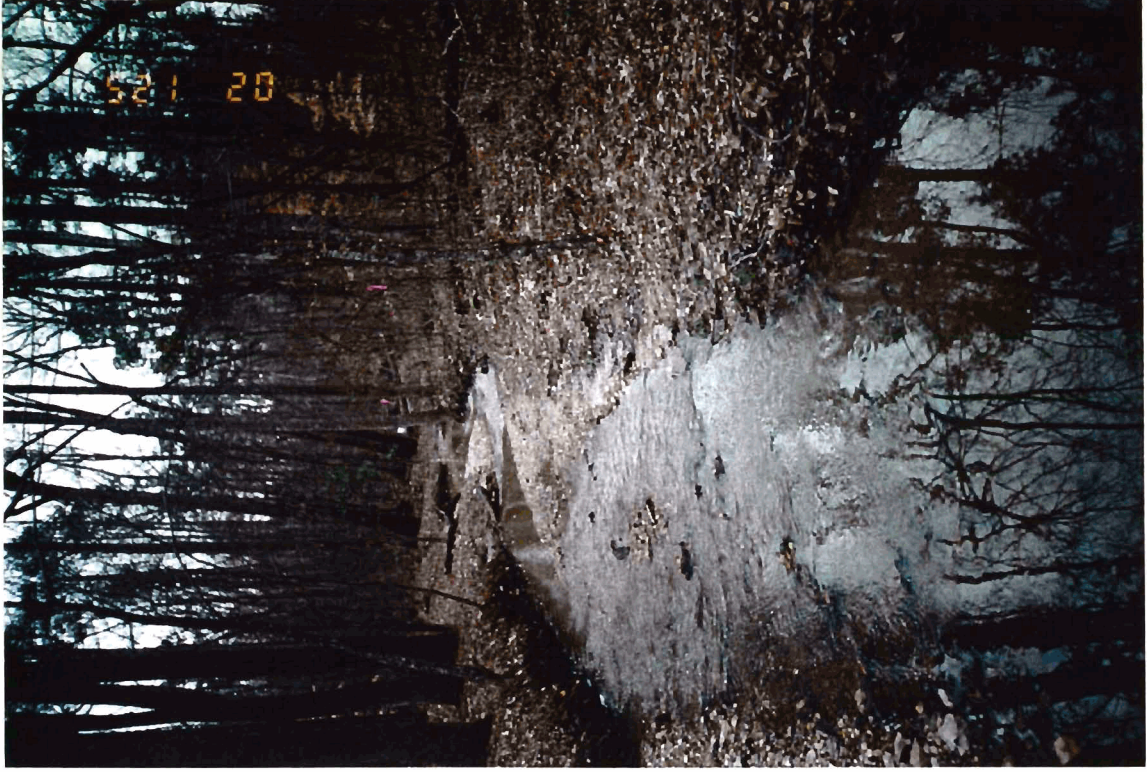
Reference Reach   Unnamed Tributary to Lake Wheeler

Reference Reach   Unnamed Tributary to Lake Wheeler

Reference Reach   Unnamed Tributary to Mine Creek

Reference Reach   Unnamed Tributary to Mine Creek