N.C. Wetlands Restoration Program
NCDENR DWQ

Brown Branch
Final Stream Restoration Report

February 2002

Biohabitats
Incorporated

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1.0 INTRODUCTION

In 2000 the North Carolina Department of Natural Resources (NCDENR) selected Brown Branch in the rural, Piedmont area of North Carolina as the setting for a demonstration stream restoration project. The project allows the rare opportunity to improve the channel form, function, and habitat of over a mile-long stream reach, with minimal constraints posed by adjacent infrastructure.

The restoration of Brown Branch was conceived as a demonstration project site to illustrate a range of stream restoration techniques effective in a rural setting. The site will showcase current stream restoration design methods and structures to interested environmental professionals and the community at large. Monitoring of the site will further allow reevaluation and improvements of techniques for future successful stream restoration in North Carolina.

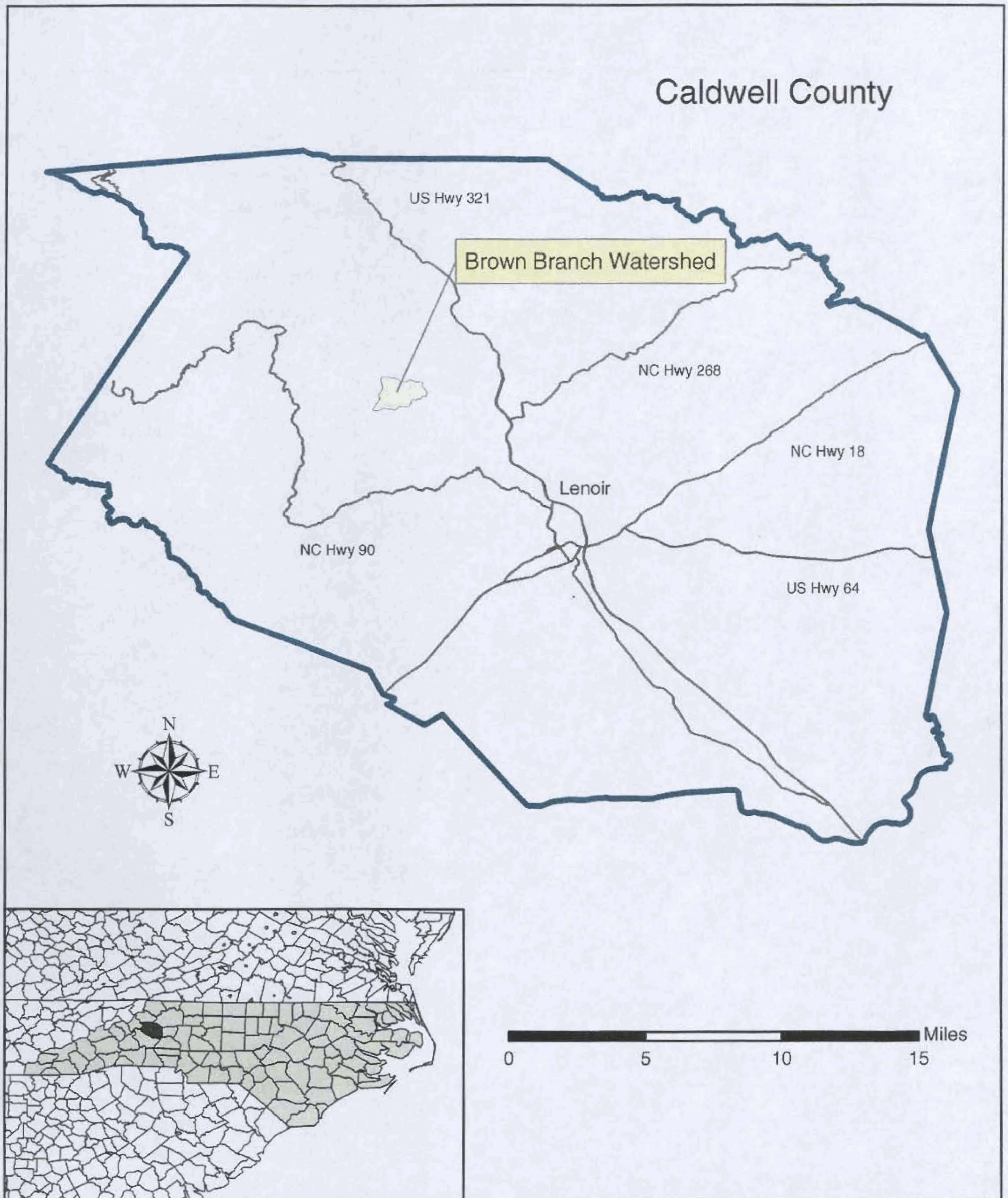
NCDENR secured the services of Biohabitats, Inc. to evaluate the study reach and develop an appropriate stream restoration design. The proposed design will restore a stable channel dimension, pattern, and profile for current watershed hydrologic conditions, will reestablish a riparian buffer, and reconnect the present incised channel to its floodplain.

This report outlines existing problems at the site, objectives of the project, the watershed setting, and the proposed approach to stream restoration. Ultimately, this document is intended to communicate the background and rationale for the restoration design of the river corridor.

2.0 PROJECT LOCATION

The Brown Branch stream restoration is located 3 miles northwest of Lenoir, North Carolina in the rural Mountain physiographic province (Figure 2.1). The study reach begins at the confluence of two first-order (at 1:24,000 scale) tributaries and follows the second-order channel downstream through a broad alluvial valley. The study reach ends approximately a mile downstream at the confluence of Brown Branch with Mulberry Creek. Mulberry Creek then flows southwest to the Johns River, which continues south to the Catawba River.

The Brown Branch watershed lies in the Upper Catawba, United States Geological Survey (USGS) Cataloging Unit 3050101 in the middle of Caldwell County. The Brown Branch watershed overlaps the Globe, Buffalo Cove, Collettsville, and Lenoir USGS 7.5-minute topographic quadrangles, with the study reach itself entirely on the Collettsville quadrangle.



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Brown Branch Stream Restoration, Caldwell County, North Carolina
Biohabitats Project No. 01015.01

Figure 2.1 Site Vicinity Map

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3.0 PROBLEM STATEMENT

A suite of physical conditions were identified as key problems associated with the form and function of the existing channel. These concerns are summarized below:

1. **Unstable channel configuration**
   a. Historical straightening of the channel has reduced flow resistance and increased shear stresses exerted along the channel margins.
   b. In some areas, vertical channel adjustment has been limited by the shallow depth to bedrock. Shear stresses have instead done "geomorphic work" on the more easily eroded channel banks, resulting in an overwidened channel condition.
   c. Field reconnaissance shows that meander bends with relatively low radii of curvature are currently unstable.
   d. Severe bank erosion has resulted from the existing unstable channel configuration, with many hotspots concentrated along the outsides of tight meander bends.

2. **Poor water quality**
   a. Rapid bank erosion is producing high sediment load in the channel.
   b. Entrained bank material is re-deposited downstream within the study reach or is transported to Mulberry Creek.

3. **Featureless bed**
   a. Sediment supplied by accelerated bank erosion is depositing more readily in the existing overwidened channel, thereby filling in many pool areas and inhibiting bedform development.
   b. The featureless bed is in part geologically driven by rapid breakdown of available metamorphic particles.

4. **Lack of riparian cover**
    a. Agricultural activities such as farming and grazing have kept the alluvial valley clear of non-herbaceous vegetation.
    b. Trees are particularly scarce along the (downstream) right bank and floodplain.

5. **Lack of large woody debris (LWD)**
    a. Upstream of the study reach, the forest canopy is continuous and large woody debris is delivered to and interacts with the bankfull channel. Pools are common in these areas.
    b. Along the study reach, the delivery of woody debris to the channel is extremely limited, and inhibits pool development.

6. **Poor habitat**
    a. Given the cumulative effects of the high sediment supply, overwidened channel condition, and little wood to induce turbulent eddies, in-stream habitat is poor.
    b. Riparian habitat is poor due to loss of channel connectivity with the floodplain (from historic channel ditching for agriculture) and the paucity of riparian vegetation. Highly dependent on the lateral exchanges between river and floodplain, biological productivity is impaired by the current channel configuration.

4.0 GOALS AND OBJECTIVES

The overarching goal of the project is to establish a stable planform, cross-sectional, and profile pattern to Brown Branch, with the premise that that geomorphic and habitat function will follow appropriate channel form. Specific objectives include the following:

1. **Reduce bank erosion.** Stream restoration will create a dynamically stable stream geomorphology such that the extent and severity of bank erosion will decrease and keep pace with sediment transport processes. The natural channel design will also reduce future maintenance needs, such as large-scale bank stabilization projects. However, it should be underscored that stream bank erosion is a natural process, and it should be expected to occur in high shear stress zones during flood events. In fact, in the absence of *any* sediment supplied from upstream and from within the study reach, some unwanted geomorphic change (e.g., extreme bed armoring and/or channel bed degradation) could then result.

2. **Improve water quality.** In reducing bank erosion, total suspended sediment will decrease and water quality will be improved. Increased connectivity between the channel and floodplain will allow deposition of suspended sediments in the form of natural alluvial levees.

3. **Enhance in-stream habitat**. The reconfiguration of the channel will enhance sediment transport processes in pools to promote deeper scour and greater hydraulic variability. Elements such as large woody debris and overhanging vegetation also will improve pool formation and provide shade and refuge to aquatic species. In addition, one would expect improved biological productivity due to greater input of leaf litter, and greater retention of organic matter and dissolved nutrients.

4. **Improve functional and aesthetic value of the riparian corridor.** Floodplain morphology will be designed to support both the riparian corridor and vernal pool wetlands. Where the riparian buffer is currently sparse to absent, riparian buffer

enhancement or establishment is proposed throughout the study area based on native plant communities endemic of the region. In depressions of abandoned existing channel and those created by regrading, the restoration design also includes areas with plant community adapted to vernal pool wetlands.

5. **Inspire educational opportunities and environmental appreciation.** Though a plan for environmental education is not expressly included in this part of the work effort, bringing community members to the site to learn about stream restoration techniques and benefits is an expected usage of this demonstration project. Both successful properties and unanticipated problems will provide heuristic examples to be applied in future stream restoration designs.

5.0 WATERSHED CONDITIONS

5.1 TOPOGRAPHY AND CLIMATE

Brown Branch is situated where the Piedmont geomorphic province meets the Mountain geomorphic province to the west. Elevations within the Brown Branch watershed range from approximately 1,200 to 2,120 feet. Drainage area to the site reach is approximately 0.74 and 1.26 mi^2 at the upstream and downstream ends, respectively.

Made mild by moist maritime air to the east, mountains to the west, and the broad scale of altitude (from about 1,000 to 6,000 feet above sea level), four discernible seasons are characteristic of the Caldwell County area. The average rainfall is 50 inches, of which over half usually falls between April and September (SCS, 1987). The greatest rainfall is likely in the humid month of July (4.8 inches average), when thunderstorms dominate. The yearly average temperature is about 58 degrees, with monthly averages of 77 degrees in July and 39 degrees in January.

5.2 BEDROCK GEOLOGY

Slopes of the Brown Branch watershed are underlain by the Wilson Creek Gneiss, which is granitic in composition (Reed, 1964). Bedrock outcrops are visible locally along the southeast valley wall adjacent to the stream. In several locations along the study reach, bedrock outcrops inhibit bed incision and southward channel migration, and establish a stable channel grade.

In the broad valley through which the study reach flows, the geologic substrate is floodplain alluvium derived from gneissic bedrock in the watershed. The bed material of Brown Branch is closely coupled with its gneiss source, which consists largely of minerals (micas) that break down rapidly. These weak minerals form weak, oblate gravels and finer sediment in Brown Branch. The more resistant major mineralogic component of the gneiss—quartz—tends to form rounded, whitish gravels that are more resistant to breakdown. Particles larger than gravel size are rare. As a result, there is no significant topographic variability in the channel profile in the form of alluvial steps, cobble ribs, or rock clusters. Instead, the bed of Brown Branch is somewhat featureless.

5.3 SOILS

The soils in the Brown Branch watershed occur in an orderly pattern related to geology, landforms, relief, climate, and natural vegetation of the area. Each soil type is associated with a particular part of the landscape. Figure 5.1 illustrates major soil associations in the Brown Branch watershed.

Along the study reach, there are two soil types present in a long narrow bands following the alluvial valley: Chewacla loam (Cm) and Conagree fine sandy loam (Co) (SCS, 1987). Both soil types are typical for floodplains along major stream in Caldwell County. As is the case at Brown Branch, the soil is cleared in most areas and used mostly for row crops, hay, or pasture. Where forested, dominant trees include yellow poplar (*Liriodendron tulipifera*), sycamore (*Platanus occidentalis*), red maple (*Acer rubrum*), black walnut (*Juglans nigra*), green ash (*Fraxinus pennsylvanica*), and river birch (*Betula nigra*). Understory plants include hazel alder (*Alnus rugosa*), black willow (*Salix nigra*), switchcane (*Arundinaria sp.*), greenbrier (*Smilax rotundifolia*), honeysuckle (*Lonicera japonica*), poison ivy (*Toxicondendron radicans*), box elder (*Acer negundo*) and grape (*Vitis sp.*).

The Chewacla loam follows the upper portion of the study reach, and consists of brown loam approximately 8 inches thick over yellowish brown loam extending to a depth of 44 inches (SCS, 1987). The depth to bedrock is generally greater than 60 inches. Chewacla loams are hydric (NRCS IIIw classification). The soil is somewhat poorly drained, and surface runoff is slow to ponded with occasional flooding. Seasonal wetness is the main limitation of land uses in the area.

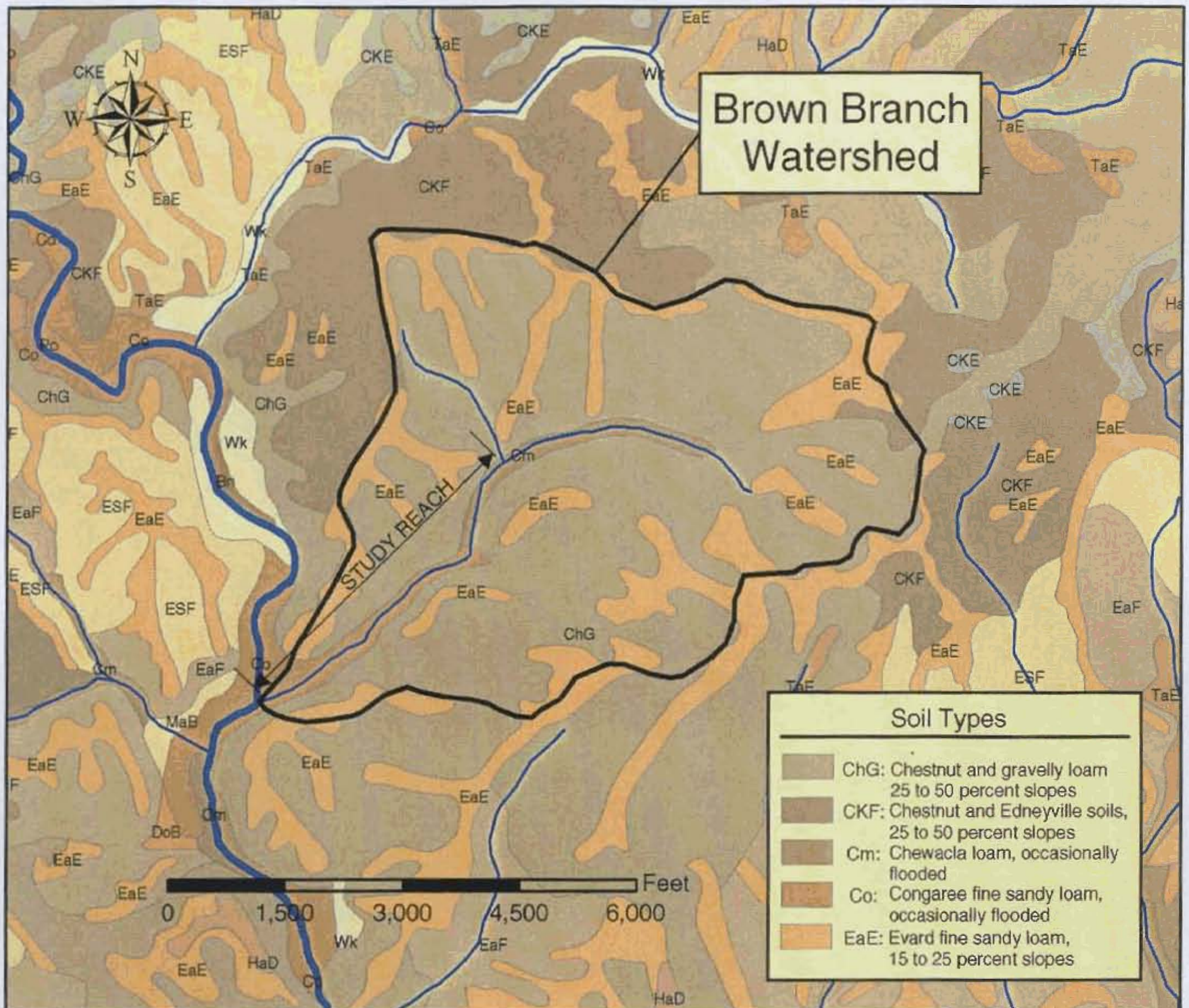
Along the downstream portion of the study reach, the floodplain soil switches to Congaree fine sandy loam. The surface layer of the Congaree soils is generally brown fine sandy loam 9 inches thick, with underlying dark yellowish brown fine sandy loam to a depth of 40 inches (SCS, 1987). The seasonal high water table is generally 2.5 to 4 feet below the surface. However, surface runoff from this unit is slow, and the soil is subject to occasional, brief flooding. Although not a hydric soil (NRCS IIw classification), Conagree loam does have some hydric properties that pose limitations to land uses.

The majority of the Brown Branch watershed—particularly side slopes (50 to 80 percent slopes)—consist of Chestnut gravelly loam (ChG). Typically the surface layer is dark yellowish brown gravelly loam and 6 inches thick. The subsoil to a depth of 72 inches is multicolored, partly weathered granitic gneiss. The soil is well drained, and surface runoff is rapid. In most areas, the soil is used as woodland. Conservation practices are needed to control erosion along logging access roads.

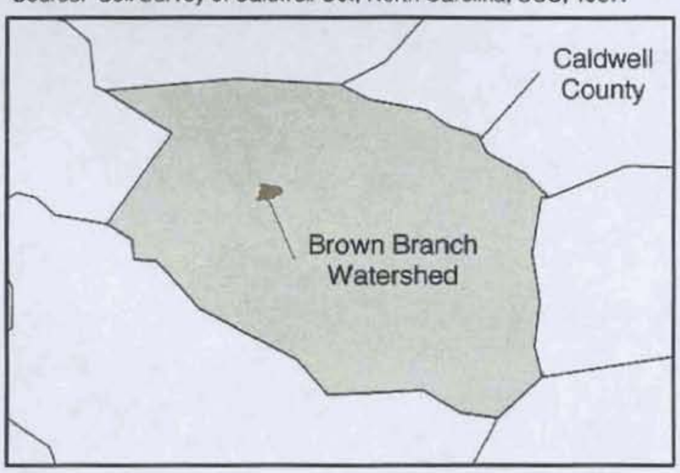
On ridge crests circumventing the Brown Branch watershed and the noses of major side valleys, the Evard fine sandy loam (EaE) predominates. The soil is well drained and tends to occur where slopes range from 15 to 25 percent. Typically, the surface layer is about 6 inches thick. It is grayish brown fine sandy loam in the upper part and yellowish brown fine sandy loam in the lower part. Surface runoff is rapid, and the hazard of erosion is severe in unvegetated, exposed areas. Along the mountain upland drainage divide, the Evard fine sandy loam intermingles with patches of Chestnut and Edneyville soils (CKG).

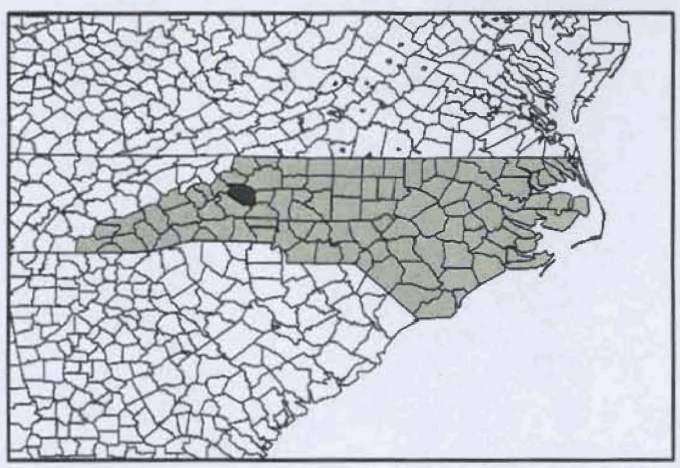
5.4 LAND USE

The upper Brown Branch watershed lies in the Grandfather Ranger District of the Pisgah National Forest and is managed by the U.S. Forest Service. It is likely that extensive logging occurred in the region at the turn of the century. However, geographic details are not readily available for review. The Grandfather Ranger District began under the Weeks Act with the purchase of an 8,100-acre tract in 1911. Now, the district covers over 189,000 acres. No details regarding land ownership and use prior to this time in the Brown Branch watershed are readily available.



Source: Soil Survey of Caldwell Co., North Carolina, SCS, 1987.





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Brown Branch Stream Restoration, Caldwell County, North Carolina
Biohabitats Project No. 01015.01

Figure 5.1 Study Reach Location and Soil Types in the Brown Branch Watershed

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Table 8.5 Brown Branch Existing and Proposed Channel Morphology versus Reference Reach Data

Parameters (variable, units)		Existing Channel, Representative Cross Section	Reference Reaches			Proposed Channel by Location*	
			Basin Creek	Joe's Creek	Richland Creek	U/S	D/S
General	Rosgen Stream Type	F4	C4	C4	C4	C4	C4
	Drainage Area (mi^2)	~1.0	7.2	6-7.6	1.0	1.26	0.74
	Estimated Bankfull Discharge (Q_{bkf}, cfs)	101	375	320	—	90	130
Riffle Dimensions	Bankfull Width (W_{bkf}, ft) **Mean** *(Range)*	**22.5** *(—)*	**33.2** *(29.5-36.9)*	**28.7** *(28.3-29.5)*	— *(16.2-16.7)*	**15.0** *(—)*	**17.5** *(—)*
	Bankfull Mean Depth (d_{bkf}, ft) **Mean** *(Range)*	**0.97** *(—)*	**2.1** *(1.9 - 2.2)*	**2.0** *(1.9-2.1)*	**0.9** *(—)*	**1.2** *(—)*	**1.4** *(—)*
	Bankfull Cross-sectional Area (A_{bkf}, ft^2) **Mean** *(Range)*	**21.93** *(—)*	**68.4** *(64.9-71.9)*	**58.1** *(55.0-61.1)*	**15.5** *(—)*	**18.1** *(—)*	**24.1** *(—)*
	Bankfull Maximum Depth (d_{max}, ft) **Mean** *(Range)*	**1.16** *(—)*	**3.1** *(3.0-3.2)*	**3.3** *(2.8-3.9)*	**1.5** *(—)*	**1.7** *(—)*	**1.85** *(—)*
	Width of Floodprone Area (ft)	30.7	—	—	—	≥50	≥ 60
	Facet slope **Mean** *(Range)*	**0.0091** *(—)*	**0.0208** *(—)*	**0.016** *(—)*	— *(—)*	**~0.02** *(0.01-0.03)*	**~0.02** *(0.01-0.03)*
Riffle Ratios	Bankfull Width/Depth Ratio (W_{bkf}/d_{bkf}, ft/ft), **Mean** *(Range)*	**23.1** *(—)*	**16.4** *(13.4-19.4)*	**14.2** *(13.5-14.9)*	— *(—)*	**12.5** *(—)*	**12.7** *(—)*
	Bankfull Width/Max Bankfull Depth **Mean** *(Range)*	**19.4** *(—)*	**10.71** *(9.22-12.3)*	**8.7** *(7.26-10.54)*	— *(—)*	**8.8** *(—)*	**9.5** *(—)*
	Bankfull Max Depth/Mean Bankfull Depth (d_{max}/d_{bkf}, ft/ft), **Mean** *(Range)*	**1.2** *(—)*	**1.51** *(1.36 - 1.68)*	**1.65** *(1.33 - 2.05)*	**1.67** *(—)*	**1.42** *(—)*	**1.34** *(—)*
	Entrenchment ratio (W_{fpa}/W_{bk}, ft/ft) **Mean** *(Range)*	**1.36** *(—)*	**8.9** *(—)*	**9.2** *(2.4 -15.9)*	— *(—)*	**≥3.3** *(—)*	**≥3.4** *(—)*
Planform Pattern Dimensions	Meander Length (Lm, ft) **Mean** *(Range)*	N/A	**350** *(—)*	**216.4** *(130 – 340)*	— *(90-94)*	— *(145-185)*	— *(175-220)*
	Ratio of Meander Length to Bankfull Width (L_m/W_{bkf}, ft/ft) **Mean** *(Range)*	— (—)	**10.5** *(—)*	**7.5** *(—)*	— *(5.4-5.8)*	— *(9.7-12.3)*	— *(10.0-12.6)*
	Belt Width (W_{bkf}, ft) **Mean** *(Range)*	— *(—)*	**64.7** *(59–75)*	**59** *(50–68)*	— *(25-40)*	— *(50-180)*	
	Radius of Curvature **Mean** *(Range)*	— *(—)*	**51.2** *(40.1–69.3)*	**11.6** *(9.3 -13.8)*	— *(14.3-26.1)*	— *(22-75)*	— *(26-90)*
Planform Pattern Ratios	Sinuosity (Stream Length/Valley Length, ft/ft)	1.1	—	—	—	1.2	
Longitudinal Profile	Valley Slope (S_{pool})	0.011	0.014	0.0089	0.0133	0.011	
	Pool Slope (S_{pool}, ft/ft)	N/A	0.0019	0.0	—	0.0	0.0
Pool Dimensions	Bankfull Width **Mean** *(Range)*	**N/A**	**50.3** *(35-68)*	**31.4** *(30.0-32.7)*	**11.1** *(—)*	**22.5** *(—)*	**26.0** *(—)*
	Maximum Pool Depth **Mean** *(Range)*	**N/A**	**4.8** *(4.1-5.2)*	**4.0** *(—)*	— *(—)*	**2.55** *(—)*	**2.80** *(—)*
	Pool to Pool Spacing (P-P, ft) **Mean** *(Range)*	**N/A**	**305** *(271–334)*	**109.1** *(27-35.3)*	— *(37.3-95.8)*	**130.5** *(38.9-422.6)*	
	Pool Area (A_p, ft^2)	N/A	109.6	74.6	20.1	27.5	37.9
Pool Ratios	Ratio of Pool to Pool Spacing (P-P/W bkf) **Mean** *(Range)*	N/A	**9.2** —	**5.4** —	—	**6.9** *(2.7-12.5)*	
	Ratio of pool depth to mean bankfull depth (d_{pool} ft)	N/A	**1.78** *(1.46-2.0)*	**1.78** *(1.6-2.0)*	— —	**2.24** —	**2.06** —

*U/S = Upstream half of study reach; D/S = Downstream half of study reach

N/A = not applicable

Within the lower half of the watershed along the study reach, land use in the last century has been agricultural. As such, Brown Branch has been ditched, straightened, and relocated to the southeast edge of the valley wall. Historical photographs available through the local NRCS office are not at a spatial and temporal resolution suitable to determine a more detailed history of adjacent land alterations and associated channel planform adjustments. However, the three available photographs dating back to 1940, and are summarized in Table 5.1 below.

Table 5.1 Observations from Historical Aerial Photographs

Date of Photograph	Quality, Scale*	General Observations (Stationing refers to that shown along the proposed channel.**)
1940	Good, Small	• Extensive ongoing agricultural activity in drainage valley. • Recent tillage evident downstream of STA 12+00. • Open fields maintained from STA 12+00 to 41+50. • Roadway evident along northwest perimeter of alluvial valley. • Channel locally evident along southeast perimeter of alluvial valley. • Recent alterations of streambanks evident at three locations. • No pond present, field at this location instead. • Upper elevations of watershed forested. • Many midchannel bars evident in Mulberry Creek.
1967	Poor, Small	• Conditions generally as in 1940, with the changes noted below. • Channel not visible through tree canopy of southeast perimeter. • No recent stream bank disturbances evident. • Unclear whether or not pond in place yet. • Few midchannel bars evident in Mulberry Creek.
1982	Good, Small	• Conditions generally as in 1967, with the changes noted below. • Tillage replaced by grazing downstream of STA 12+00. • Recent clearing and/or agricultural activity evident from STA 35+00 to 41+50. • Pond evident.

*Scale of photographs unknown, but on the order of 1:12,000.
**See Appendix A for stationing locations.

Today the alluvial valley surrounding the study reach is owned and operated by a 4H camp. Some grazing continues in this context, particularly in the downstream half of the study reach. Over the next few decades land use is expected to remain the same.

6.0 EXISTING CHANNEL CONDITIONS

6.1 STREAM GEOMORPHOLOGY

The Brown Branch study reach extends along one side of a cleared, broad alluvial valley surrounded by steep forested slopes. Since being ditched along the southeast side of the alluvial valley, Brown Branch has incised and become entrenched within the valley alluvium. The channel has low sinuosity (from straightening) and a low gradient (0.009 ft/ft) through the study area. Bed material is primarily sand and gravel. Following the Rosgen classification system (Rosgen, 1996), the majority of the existing channel classifies as an F4, which has poor recovery potential. (Conditions are somewhat variable, however, with minor segments portions of B_c, E, and C channel in cross-sectional dimension.) Owing to the lack of a buffer along the north side of the creek, riparian vegetation plays a minor role in streambank stability along much of Brown Branch. Instead, the channel has formed several tight, rapidly migrating meander bends in the exposed alluvium.

Appendix B includes a representative cross section and longitudinal profile of the existing channel. Three pebble counts were conducted in riffles in the upstream, mid-reach, and downstream portions of the study reach. The three pebble counts are nearly identical and were lumped to maximize sample size and more precisely identify index percentiles. When the three pebble counts are lumped together (325 particles total), the surface median grain size (D_{50}) is 19 mm and the D_{84} (size for which 84% of the grain size distribution is finer) is 43 mm.

6.2 EXISTING HYDROLOGICAL FEATURES

The drainage area to Brown Branch mostly consists of steep first-order streams draining to the alluvial valley. Once the stream reaches the valley, where historical agricultural practices have predominated, many of the tributaries are altered.

Some tributaries flowing from the right (northwest) side of the study reach have been ditched and straightened so that they travel directly to Brown Branch from the opposite valley wall. Others are piped from the roadway, under the alluvium, and discharge directly to Brown Branch. Most tributaries joining Brown Branch along the study reach are ephemeral, with the exception of the tributary at proposed STA 44+25.

Also prominent along the study reach is the large constructed pond northwest of the middle portion of the channel (STA 31+50 to 35+00, Appendix A). The pond receives runoff from a tributary and then releases overflow above an inlet elevation through a drainpipe to Brown Branch. The frequency of pond discharge is unknown, but is likely to have a negligible effect on stream hydrology.

6.3 EXISTING PLANT COMMUNITIES

6.3.1 Overview

Appendix C illustrates the vegetation types now present in the vicinity of the reference reach. The majority of the project area has been maintained in herbaceous growth though mowing and grazing practices. Looking downstream, the right side of the stream valley is a level to gently sloping floodplain used for grazing and recreational activities. Grazing dominates the use downstream of the horse stalls and pond. Upstream of the pond, recreation is the dominant use. Both of these uses require the area be maintained in short grass cover. Woody plants are common along the stream's riparian edge and occur sparsely in the floodplain in the area established for recreational use. Several small wetland areas are present in this area. Further upstream, in the vicinity of the confluence, the floodplain is dominated by taller old field growth. This area had not been mowed or grazed for a couple of years preceding the field work for this project. Small wetland areas are also present in this area. The right side of the stream is at the base of a steep forested slope. Upstream of the project boundary, the stream valley is in forest cover.

6.3.2 Characterization of Forest Area

The forest plant composition observed in and adjacent to the project area includes yellow birch (*Betula alleghaniensis*), tulip poplar (*Liriodendron tulipifera*), hemlock (*Tsuga* *canadensis*), beech (*Fagus grandifolia*), black gum (*Nyssa sylvatica*), sugar/rock maple (*Acer saccharum*), white pine (*Pinus strobus*), and magnolia (*Magnolia fraseri*), with a sub-canopy of flowering dogwood (*Cornus florida*), mountain laurel (*Kalmia latifolia*), and spicebush (*Lindera benzoin*). These species were dominant on the slopes adjacent to the floodplain.

In the more level floodplain portion of the project area, much of the project area is actively managed to maintain a non-forested condition as discussed above (Section 6.3.1). If the active management, consisting of grazing and mowing, were discontinued, the remainder of the project area would succeed to a forested condition.

6.3.3 Characterization of Floodplain Area

The mowed and grazed floodplain area included a variety of native and introduced grasses and forbs, including deer tongue (*Dichanthelium clandestinum*), soft rush (*Juncus effusus*), bamboo grass (*Microstegium vimineum*), panic grasses (*Panicum spp.*), little bluestem (*Schizachyrium scoparium*), and sedges (*Carex spp.*). The old field area in the vicinity of the confluence includes these species as well as wingstem (*Verbesina alternifolia*), brambles (*Rubus spp.*), dog-hobble (*Leucothoe racemosa*), and seedlings of the common trees from the adjacent slopes. Along the stream and throughout the floodplain, species of floodplain and riparian trees are present but not dominant. These species include river birch (*Betula nigra*), yellow birch, tulip poplar, sycamore (*Platanus occidentalis*), red maple (*Acer rubrum*), shellbark hickory (*Carya ovalis*), and green ash (*Fraxinus pennsylvanica*), with a sub-canopy of ironwood (*Carpinus caroliniana*), spicebush, dog-hobble, and smooth alder (*Alnus serrulata*).

In addition, several emergent wetlands areas were delineated in the floodplain (Appendix C). These are situated in areas maintained by mowing as well as in the old field area. As a result, the species present include many of the species listed above, as well as water pepper (*Polygonum piperoides*), hummock sedge (*Carex stricta*), and other unidentified sedges.

7.0 STREAM REFERENCE REACH SITES

7.1 REFERENCE REACH IDENTIFICATION

Because Lenoir lies in the Mountain physiographic province near its boundary to the east with the Piedmont province, a reference reach from either province could potentially be viable for application in the Brown Branch design. Biohabitats conducted an initial "cold" reference reach search in the Lenoir vicinity using USGS 7.5-minute topographic quadrangles. Approximately ten reaches were selected based on similar drainage area, valley morphology, slope, and land use. Each of these sites was too altered and unstable to represent reference conditions, or did not have suitable access.

Biohabitats then contacted individuals with the NCSU Stream Restoration Institute group and various County offices of the Natural Resources Conservation Service (NRCS) for potential reference reach sites in the area. Five Rosgen-classified C4 channels were identified for potential use: Basin Creek, Joes Creek, Richland Creek, Watauga River, and Mills River. In addition, two B_c4 channels were identified for possible use in the design of any straighter sections of Brown Branch. These sites are outlined in Table 7.1. Of the C4 channels, only the first three have drainage areas within the same order of magnitude as Brown Branch (<10 mi^2). As such, the Watauga and Mills River were not considered appropriate for comparison for use in detailed design. Furthermore, no data sets were made available to Biohabitats for these two rivers.

Data collected by agency personnel were made available for Basin, Joes, and Richland. Both Basin and Joes Creek were visited to verify their classification and suitability for use as reference reaches. Of the two, Basin Creek was found to be most appropriate based on more pristine conditions and similar forested land use. (Joes Creek appears somewhat incised in sections and lacks a wide riparian corridor.) Richland was not visited and lies considerably east of Lenoir. Although Basin Creek is the best reference reach, data from each of the three small basins is also included in this report for comparison with the range of parameters used in design of Brown Branch (see Table 8.5 for summary of data).

7.2 Reference Stream Vegetative Community

Given the few impacts to the riparian buffer upstream of the study reach, this upstream area was used as a reference vegetative community. The proposed plant community was developed based on field assessment of existing plant communities in the project area and in minimally modified areas immediately upstream of the project area. This plant community will develop into an assemblage of native plants capable of supporting natural ecosystem processes and native wildlife.

Table 7.1 Identified Reference Reaches

Reference Reach	Rosgen Stream Type	Drainage Area (mi^2)	County	Physiographic Province	Data Set Made Available	Detailed Location Info Made Available	Site Visit Conducted by Biohabitats
Basin Creek	C4	7.2	Wilkes	Mountain	Detailed, from Yadkinville NRCS	Yes	Yes
Joes Creek	C4	6.1	Caldwell	Mountain	Detailed, from Yadkinville NRCS	Yes	Yes
Richland Creek	C4	1.0	Moore	Piedmont	Abbreviated, from NCSU	No	No
Watauga River	C4	92.1	Watauga	Mountain	No	No	Yes
Mills River	C4	66.7	Henderson	Mountain	No	No	Yes
Catheys Creek	Bc4	11.7	Transylvania	Mountain	Abbreviated, from NCSU	Yes	Yes
Mitchell River	Bc4	6.5	Surry	Piedmont	No	No (also access was denied by landowner)	No

8.0 STREAM RESTORATION PLAN

8.1 General Approach

The approach to restoring Brown Branch is based on natural channel design principles, including the following:

- The preferred approach to implementation of goals will be the restoration of a natural, self-sustaining system that can adjust to changes in physical processes, with minimum human intervention.

- Restoration planning and design will be based on expected variability of physical processes, owing to hydrologic and sediment supply regimes.

- Restoration design will be rooted in *field-based* observations in the study watershed and stable reference reaches from the same or similar physiographic province, as well as current *quantitative* approaches and firsthand *experience* with other stream restoration projects.

- Restoration channel design will focus on identifying stable planform, profile, and cross-sectional geometries. Structural means also will be used to provide bank protection prior to full vegetation establishment, grade control at key locations, and enhance habitat variability within a reach. However, structures themselves are secondary to the natural channel design.

- Restoration design must seek to "do no harm" to those areas that are stable and clearly providing important ecological function. Instead, such areas should be preserved and incorporated into the broader restoration design. In this sense, the design is intended to work with rather than overprint nature.

- Restoration design will not "over-design." The design instead will include an appropriate range of channel conditions to mimic variability in nature—rather than strictly follow one design value for each parameter—so that, for example, meanders bends do not appear simply sinusoidal and planform features and geometry extend across the range of anticipated stable conditions.

8.2 STREAM GEOMORPHOLOGY

The proposed stream restoration design includes the establishment of a pool-riffle channel through the majority of the study reach. Pool-riffle channels have an undulating bed that defines a sequence of bars, pools, and riffles (Leopold *et al.*, 1964). This lateral bedform oscillation distinguishes pool-riffle channels from the other channel types. While riffles are the topographic cross-over from pool to bar, the term riffle is also loosely applied to the entire shallow channel area in this transition zone. Commonly, the transition from a riffle downstream into a pool is referred to as a run, and the transition from a pool downstream into a riffle is termed a glide.

In self-formed pool-riffle channels, pools are typically spaced about every 5-7 channel widths (Leopold *et al.*, 1964). Pool-riffle channels typically occur at moderate to low gradients and are generally unconfined with well established floodplains. Substrate size in pool-riffle channels can vary from sand to cobble, but is dominantly gravel-sized. In the Rosgen classification system, the stream would classify as a C4—a gravel-bedded, meandering, low-gradient, pool and riffle dominated—channel. Prior to human alteration, this is likely the stream type that Brown Branch once assumed.

8.3 DESIGN BANKFULL DISCHARGE

For the design, a bankfull discharge was first selected. Table 8.1 shows bankfull and two-year discharges predicted by various regression equations. The inclusion of the 2-year flow for comparison is based on the common assumption that for a stable alluvial channel, bankfull discharge is approximately equivalent to a flow between the 1- and 2-year discharges. Preliminary design discharges of 90 and 130 cfs were selected for the upstream and downstream portions of the study reach. (These values may need to be adjusted once the hydrologic model is finalized during the 90% design.)

Table 8.1 Predicted and Calculated Bankfull and 2-Year Discharge Values

Source	Bankfull Discharge (cfs)		2-Year Discharge (cfs)	
	Upstream	Downstream	Upstream	Downstream
Harmon *et al.*, year unspecified [1]	89.2	132.2	n/a	n/a
NCSU, Rural Mountain Table [2]	76.7	115.6	n/a	n/a
Harmon *et al.*, 1999 [3]	68.9	101.5	n/a	n/a
Jackson, 1976[4]	n/a	n/a	103.4	151.3
Biohabitats field-based calculation	101	n/a	n/a	n/a
Selected design discharge	**90**	**130**	**n/a**	**n/a**

n/a = not applicable or available
1 Includes data from 14 drainage areas between 2.0 and 126 mi^2. No confidence intervals shown on curves. R^2 is 0.97.
2 Table includes another variation of equations as in Harmon *et al.*, year unspecified, regression. No confidence intervals or R^2 included.
3 Includes data from 13 drainage areas between 0.2 and 128 mi^2. R^2 is 0.88.
4 Includes data from 257 sites with drainage areas greater than 0.5 mi^2.

8.4 Channel Cross-Sectional Dimension

The following section explains the development of average cross-sectional dimensions used in the design. (Actual values depicted in the grading plan may differ slightly to create variability). All typical dimensions discussed below are shown together in Appendix D for both riffle and pool cross sections. These dimensions are also contrasted with existing conditions and reference reach values in Table 8.5.

8.4.1 Riffle Bankfull Width

Design bankfull widths were selected after a review of several regression equations. First, a regression equation was established between the three small C4 reference reaches described in Section 7.1, such that:

Eqn. 1 $$\text{Bankfull Width} = 16.385\ (\text{Drainage Area})^{0.3359} \qquad (R^2 = 0.998)$$

where Bankfull Width is in feet and Drainage Area is in square miles. The regression is based on only three data points, and so the relationship should be considered approximate.

Table 8.2 compares the results from the regression with other similar regressions. These regressions are different in that they include a larger data set, a range of Rosgen channel types, and a broader range of contributing watershed area. Values were calculated for the upstream and downstream end of the study reach based on corresponding drainage areas.

Table 8.2 Comparison of Calculated Bankfull Widths

Regression	Brown Branch Upstream End of Study Reach	Brown Branch Downstream End of Study Reach	
	Predicted Value (ft)	Predicted Value (ft)	95% Confidence Interval (ft)
Basin, Joes, and Richland (Eqn. 1) Values used in Design	14.7	17.6	n/a
Harmon *et al.*, year unspecified [1]	17.5	21.2	n/a
NCSU, Rural Mountain Table [2]	16.7	20.4	n/a
Harmon *et al.*, 1999 [3]	10.2	12.9	7 – 30

n/a = not available

[1] Includes data from 14 drainage areas between 2.0 and 126 mi^2. No confidence intervals shown on curves. R^2 is 0.81.

[2] Table includes another variation of equations as in Harmon *et al.*, year unspecified, regression. No confidence intervals or R^2 included.

[3] Includes data from 13 drainage areas between 0.2 and 128 mi^2. R^2 is 0.81.

Existing bankfull widths observed at the site generally ranged between 20 and 25 feet, and were observed to be somewhat overwidened for the existing planform configuration. These field observations support the use of Equation 1 results, so that slightly smaller bankfull widths are used in the design than those existing. Based on its consistency with results from similar regional regressions and field observations, the preliminary design bankfull widths were selected following Equation 1.

8.4.2 Riffle Cross Section Dimensions

Typical cross sections were developed for the riffle and meander bend settings. Two sets of typicals were created—one for the upstream portion of the study reach, the other for the downstream portion.

Riffle cross sections were sized for the design bankfull discharges estimates described in Section 8.3 and bankfull widths selected in Section 8.4.1, while maintaining a shear stress that would mobilize larger particles present in the riffle grain size distribution. Entrenchment ratios and bankfull width-to-depth ratios appropriate to Rosgen C type channels were also maintained in the design.

8.4.3 Meander Cross Section Dimensions

Meander cross sections were sized using reference reach ratios from Basin Creek. The ratio of pool bankfull width to riffle bankfull width was set to that of Basin Creek (1.5), and is a typical value for stable, Rosgen C type meandering streams. The maximum pool depth to maximum riffle depth for Basin Creek is 1.5; this value was also used in the design and is known to be characteristic for streams of this type. Point bar slopes were maximized (9%-13%) in both the upstream and downstream design cross sections. This helps provide resistance to flows approaching and exceeding bankfull. Point bar slopes were not provided in the reference reach data sets. Our measurements of Piedmont C4 channels indicated that a range of 9 to 13% is appropriate.

8.5 PLANFORM DESIGN

The following section explains the development of average cross-sectional dimensions used in the design. Planform pattern was designed primarily based on reference reach data, particularly those for Basin Creek. However, professional judgment was in some cases necessary to be conservative in design and best promote stability. A range of values was also established for each parameter to mimic natural variability and accommodate any site constraints within the stable channel range. The proposed channel configuration is depicted in Appendix A. Design planform dimensions are also contrasted with existing conditions and reference reach values in Table 8.5.

8.5.1 Meander Wavelength

A range of meander wavelengths was established with guidance from the available meander length to bankfull width ratio for Basin Creek. This value was on the low end of those typically observed for Rosgen type C channels. As such, a design range was established to bracket the lower end of the range (Table 8.3). This range was applied throughout the study reach.

Table 8.3 Comparison of Meander Wavelength Ratios and Values

Source	Meander Wavelength/ Bankfull Width Ratio	Meander Wavelength (ft)	
		Upstream	Downstream
Basin Creek data set	10.5	----	----
Traditional range for C channels	11-14	----	----
Selected preliminary design range	10-12.5	145-185	175-220

8.5.2 Radius of Curvature

A range of radii of curvature was established with reference to the radius of curvature to bankfull width ratio available for Basin Creek. This value, 1.5, was at the low end of those generally considered stable in natural channel design.

Planform maps and field investigation helped to identify ten existing unstable bends along Brown Branch. The radii of curvature for these bends average approximately 35 ft. Given the average bankfull width of approximately 20 to 25 feet through the study reach, the radii of curvature for these bends are about 1.4 to 1.7 (Table 8.4). This provides further evidence that low radius of curvature values should be avoided at Brown Branch. However, in the proposed design other channel design parameters (vegetation, cross-sectional geometry, etc.) will improve the stability of such low radius of curvature bends. In light of this a range of 1.5 to 5.0 was established, with most values used in the design greater than 2.

8.5.3 Meander Belt Width

Values available for meander belt width to bankfull width ratios were found to be extremely low (1.9). For Brown Branch, belt width would scale to a range of 28 to 33 feet—in some cases less than the design radius of curvature. To maintain this belt width, the channel could not "wiggle" across the valley floor, but would be forced to follow the valley trend precisely.

Biohabitats' professional judgment is that the reference reach value is too low, and that this parameter does not provide any meaningful design guidance. Instead, a belt width of between 40 and 160 feet was used, as dependent on local constraints and the balance of other planform parameters. This higher range of meander belt width to bankfull width (2.3 to 10.9) provides additional variability to the planform channel design.

Table 8.4 Comparison of Radii of Curvature Ratios and Values

Source	Radius of Curvature/ Bankfull Width Ratio	Radius of Curvature (ft) Range (Majority)	
		Upstream	Downstream
Unstable bends of existing channel	1.4-1.7		
Basin Creek data set	1.5	----	----
Traditional range for C channels	>2	----	----
Selected preliminary design range	1.5-5.0	22-75 (30-60)	26-90 (35-70)

8.6 LONGITUDINAL PROFILE

The longitudinal profile was designed to follow the planform pattern of the proposed channel and the channel dimensions of typical cross sections. Riffle slopes were set to range from 1 to 3%, with the majority close to 2% in keeping with reference reach data. Glide and riffle slopes generally range from 6-12%, higher than those indicated in reference reach data sets which were deemed excessively low based on professional judgment. The profile was also developed to "tie" the channel into its existing configuration in those areas where channel conditions were stable and beneficial habitat is already present. At some locations a control structure, such as a cross vane, was used to drop the channel more abruptly to accommodate other design parameters. Appendix E shows the preliminary design profile developed following these guidelines.

Table 8.5 Brown Branch Existing and Proposed Channel Morphology versus Reference Reach Data

Parameters (variable, units)		Existing Channel, Representative Cross Section	Reference Reaches			Proposed Channel by Location*	
			Basin Creek	Joe's Creek	Richland Creek	U/S	D/S
General	Rosgen Stream Type	F4	C4	C4	C4	C4	C4
	Drainage Area (mi^2)	~1.0	7.2	6-7.6	1.0	1.26	0.74
	Estimated Bankfull Discharge (Q_{bkf}, cfs)	101	375	320	—	90	130
Riffle Dimensions	Bankfull Width (W_{bkf}, ft) **Mean** *(Range)*	**22.5** *(—)*	**33.2** *(29.5-36.9)*	**28.7** *(28.3-29.5)*	— *(16.2-16.7)*	**15.0** *(—)*	**17.5** *(—)*
	Bankfull Mean Depth (d_{bkf}, ft) **Mean** *(Range)*	**0.97** *(—)*	**2.1** *(1.9 - 2.2)*	**2.0** *(1.9-2.1)*	**0.9** *(—)*	**1.2** *(—)*	**1.4** *(—)*
	Bankfull Cross-sectional Area (A_{bkf}, ft^2) **Mean** *(Range)*	**21.93** *(—)*	**68.4** *(64.9-71.9)*	**58.1** *(55.0-61.1)*	**15.5** *(—)*	**18.1** *(—)*	**24.1** *(—)*
	Bankfull Maximum Depth (d_{max}, ft) **Mean** *(Range)*	**1.16** *(—)*	**3.1** *(3.0-3.2)*	**3.3** *(2.8-3.9)*	**1.5** *(—)*	**1.7** *(—)*	**1.85** *(—)*
	Width of Floodprone Area (ft)	30.7	—	—	—	≥50	≥ 60
	Facet slope **Mean** *(Range)*	**0.0091** *(—)*	**0.0208** *(—)*	**0.016** *(—)*	— *(—)*	**~0.02** *(0.01-0.03)*	**~0.02** *(0.01-0.03)*
Riffle Ratios	Bankfull Width/Depth Ratio (W_{bkf}/d_{bkf}, ft/ft), **Mean** *(Range)*	**23.1** *(—)*	**16.4** *(13.4-19.4)*	**14.2** *(13.5-14.9)*	— *(—)*	**12.5** *(—)*	**12.7** *(—)*
	Bankfull Width/Max Bankfull Depth **Mean** *(Range)*	**19.4** *(—)*	**10.71** *(9.22-12.3)*	**8.7** *(7.26-10.54)*	— *(—)*	**8.8** *(—)*	**9.5** *(—)*
	Bankfull Max Depth/Mean Bankfull Depth (d_{max}/d_{bkf}, ft/ft), **Mean** *(Range)*	**1.2** *(—)*	**1.51** *(1.36 - 1.68)*	**1.65** *(1.33 - 2.05)*	**1.67** *(—)*	**1.42** *(—)*	**1.34** *(—)*
	Entrenchment ratio (W_{fpa}/W_{bk}, ft/ft) **Mean** *(Range)*	**1.36** *(—)*	**8.9** *(—)*	**9.2** *(2.4 -15.9)*	— *(—)*	**≥3.3** *(—)*	**≥3.4** *(—)*
Planform Pattern Dimensions	Meander Length (Lm, ft) **Mean** *(Range)*	N/A	**350** *(—)*	**216.4** *(130 – 340)*	— *(90-94)*	— *(145-185)*	— *(175-220)*
	Ratio of Meander Length to Bankfull Width (L_m/W_{bkf}, ft/ft) **Mean** *(Range)*	— (—)	**10.5** *(—)*	**7.5** *(—)*	— *(5.4-5.8)*	— *(9.7-12.3)*	— *(10.0-12.6)*
	Belt Width (W_{bkf}, ft) **Mean** *(Range)*	— *(—)*	**64.7** *(59–75)*	**59** *(50–68)*	— *(25-40)*	— *(50-180)*	
	Radius of Curvature **Mean** *(Range)*	— *(—)*	**51.2** *(40.1–69.3)*	**11.6** *(9.3 -13.8)*	— *(14.3-26.1)*	— *(22-75)*	— *(26-90)*
Planform Pattern Ratios	Sinuosity (Stream Length/Valley Length, ft/ft)	1.1	—	—	—	1.2	
Longitudinal Profile	Valley Slope (S_{pool})	0.011	0.014	0.0089	0.0133	0.011	
	Pool Slope (S_{pool}, ft/ft)	N/A	0.0019	0.0	—	0.0	0.0
Pool Dimensions	Bankfull Width **Mean** *(Range)*	**N/A**	**50.3** *(35-68)*	**31.4** *(30.0-32.7)*	**11.1** *(—)*	**22.5** *(—)*	**26.0** *(—)*
	Maximum Pool Depth **Mean** *(Range)*	**N/A**	**4.8** *(4.1-5.2)*	**4.0** *(—)*	— *(—)*	**2.55** *(—)*	**2.80** *(—)*
	Pool to Pool Spacing (P-P, ft) **Mean** *(Range)*	**N/A**	**305** *(271–334)*	**109.1** *(27-35.3)*	— *(37.3-95.8)*	**130.5** *(38.9-422.6)*	
	Pool Area (A_p, ft^2)	N/A	109.6	74.6	20.1	27.5	37.9
Pool Ratios	Ratio of Pool to Pool Spacing (P-P/W bkf) **Mean** *(Range)*	N/A	**9.2** —	**5.4** —	—	**6.9** *(2.7-12.5)*	
	Ratio of pool depth to mean bankfull depth (d_{pool} ft)	N/A	**1.78** *(1.46-2.0)*	**1.78** *(1.6-2.0)*	— —	**2.24** —	**2.06** —

*U/S = Upstream half of study reach; D/S = Downstream half of study reach

N/A = not applicable

8.7 Floodplain Morphology

Where Brown Branch is being reconfigured, much of the existing adjacent floodplain will be disturbed during construction. Grading along the abandoned channel and along the proposed channel is necessary to accommodate the channel planform, cross-sectional, and profile design dimensions, and meet constraints posed by existing wetlands and portions of the channel to be left undisturbed. Within these bounds, however, there are many opportunities for grading a somewhat irregular floodplain to promote microhabitat diversity in the floodplain. It is intended that grading at Brown Branch will improve channel-floodplain connectivity, complement the physical function of the channel during flood events, and significantly enhance habitat beyond the channel banks.

Due to the high susceptibility to lateral and vertical shifts in broad alluvial valleys, low-gradient pool-riffle streams typically produce meander and depositional patterns superimposed on the floodplain surface(s). Grading along the proposed restoration design therefore will incorporate floodplain morphology appropriate to the setting, including 1) low gradient floodplain surfaces, and 2) elongated depressions below the floodplain surface, commonly where extended sections of the existing channel is to be abandoned. Planting zones associated with these two areas are described in Section 8.9. Locally, high points above the overall floodplain surface also will be included to preserve existing large trees or prevent development of meander chute cutoffs. Variable elevations will support a variety of plants adapted to a range of moisture conditions and enhance biological diversity of reptiles, breeding amphibians, forest-dwelling birds, and wetland dependant species.

8.8 Sediment Transport: Background and Calculations

Sediment transport is sufficiently complex that, before meaningful calculations can be done with respect any type of channel restoration, a review of available techniques, their assumptions, and their limitations is warranted. At Brown Branch, surface bed material is nonuniform (i.e. sand and gravel) and armored (i.e. the surface layer exposed to flow is coarser than the subsurface bed material). The proposed channel has a pool-riffle configuration. Therefore, sediment transport methods developed for nonuniform, armored gravel-bed, pool-riffle streams are most appropriate.

Gravel-bed pool-riffle streams exhibit characteristic sediment transport processes. Very rarely is the whole bed in motion and material eroded from one riffle typically is deposited on a proximal downstream riffle. In gravel-bed channels, the bankfull stage is the dominant discharge responsible for establishing channel morphology and accomplishing most sediment transport over an extended amount of time (Wolman and Miller, 1960; Andrews, 1980). Armored gravel-bed channels exhibit a near-bankfull threshold for general and significant bed surface mobility (Parker *et al.*, 1982; Jackson and Beschta, 1982; Andrews 1984). Significant sediment transport rates occurring following armor-mobilizing events are generally correlated with discharge, suggesting that bankfull sediment transport is limited by transport capacity, not sediment supply. Given these attributes of pool-riffle channels, the design of Brown Branch should allow for incipient motion of the *majority of the grain size distribution* (D_{50} minimum up through D_{84}) at the *bankfull* flow.

A simple model to serve as the basis of this calculation is that of Shields' (1936). Based on empirical data, Shields developed a curve to describe the dimensionless critical shear stress, τ^*_{ci} or Shield parameter, defined as:

$$\tau^*_{ci} = \tau_{ci} / (\rho_s - \rho)gD_i$$

where τ_{ci} is the Shield parameter or critical shear stress at incipient motion for the grain size of interest, D_i; g is the gravitational acceleration, and ρ_s and ρ are the sediment and fluid densities, respectively. Shields demonstrated that in fully rough flow (Reynolds numbers >489), as with gravel-bed rivers, dimensionless critical shear stress attains a constant value of 0.06 at this point. (Note the commonly quoted value of τ_{c50} equal to 0.06 for rough, turbulent flow in fact reflects only a *single* data point within the Shield's data set.) However, the experiment was based on nearly uniform grain sizes. Since gravel bed rivers like Brown Branch do not have uniform grain size distribution, interparticle effects and small bedforms add complexities to the relationship and require some adaptations of the model.

Since Shields' time, experimenters have attempted to develop more realistic values of τ_{c50} for use in poorly sorted gravel bed material. Studies of gravel-bed channels, in fact, demonstrate a dimensionless critical shear stress with a broad range from 0.030 to 0.086 (Buffington and Montgomery, 1993). In Table 8.6, we report τ_{c50} values from the literature particularly germane to Brown Branch.

Table 8.7 shows the likely incipient particle size of the upstream and downstream portions of the design channel based on the range and average of these τ^*ci values, relative to existing conditions. The sediment transport analysis shows that, as is desirable, there is a greater statistical likelihood that the upper portion of the grain size distribution (D_{50} through D_{84}) will be mobilized in the proposed design, without excessive shear to mobilize the entire grain size distribution. For the mean τ^*ci value, shear stress will increase in the proposed channel such that the D_{75} (33 mm) and D_{84} (43 mm) are mobilized more consistently during the bankfull flow (see boldface items in Table 8.7).

It is worth noting that the calculations simplify many aspects of sediment transport, and are really only a first-order approximation of the likely mobile grain-size distribution at bankfull discharge. Here it was assumed that the existing grain size distribution remains representative for sediment transport processes. In fact, in the restored condition, bed armoring may be expected to adjust sediment transport rates somewhat to any change in sediment supply in the pool-riffle channels (e.g., Dietrich *et al.*, 1989). However, the sediment transport results reported here are promising and are consistent with desirable sediment transport properties for restoration of Brown Branch. More detailed hydraulic calculations will be conducted using HEC-RAS in later design phases to quantify bankfull shear stresses along the proposed channel versus those predicted along the existing channel (and to guide placement of appropriate bank and bed protection where shear stresses exceed initial expectations).

Table 8.6 Dimensionless Critical Shear Stress (τ^*_{ci}) Measured in Natural Pool-Riffle Channels.

Study	Channel Type (Location)	Channel Conditions and Model Adjustments	D_{50} surface (mm)	σ_{gs} (φ)*	τ^*_{ci} (for D_{50})
Existing conditions at Brown Branch	Impacted pool-riffle with some braiding	n/a	19	1.4	n/a
Ashworth and Ferguson (1989)	Natural pool-riffle channel (Alt Dubhaig)	Variable sinuosity, sidewall correction implicit	~50	Not listed	0.072
Ashworth and Ferguson (1989)	Natural pool-riffle channel (River Feshie)	Mildly braided, sidewall correction implicit	~57.5	Not listed	0.054
Parker and Klingeman (1982)	Natural pool-riffle channel (Oak Creek)	No form drag or sidewall correction	54	1.09	0.035
Wathen *et al.* (1995)	Natural pool-riffle channel (Alt Dubhaig)	Variable sinuosity, no sidewall or form drag correction	21.3	~1.6	0.086
				Average value of τ^*_{ci}	**0.062**

*Measure of non-uniformity of sediment mixture, referred to as the graphic sorting coefficient. Defined by $(\varphi_{84} - \varphi_{16})/2$ where φ_{84} and φ_{16} are the 84th and 16th percentiles of the grain size distribution expressed in units of the phi ($\log_2$) scale.

Table 8.7 Results of Sediment Transport Calculations.

τ^*_{ci} (from Table 8.6)	Existing Conditions				Proposed Conditions: Upstream Portion of Study Reach				Proposed Conditions: Downstream Portion of Study Reach			
	Mean Depth (ft)	Shear Stress (lb/ft^2)	Incipient particle size (mm)	D_{50}, D_{75}, D_{84} mobile?	Mean Depth (ft)	Shear Stress (lb/ft^2)	Incipient particle size (mm)	D_{50}, D_{75}, D_{84} mobile?	Mean Depth (ft)	Shear Stress (lb/ft^2)	Incipient particle size (mm)	D_{50}, D_{75}, D_{84} mobile?
Min. (0.035)	1.0	0.55	46	Y, Y, Y	1.2	0.79	67	Y, Y, Y	1.4	0.91	77	Y, Y, Y
Mean (0.062)			26	Y, N, N			38	Y, Y, N			43	Y, Y, Y
Max. (0.086)			19	Y, N, N			27	Y, N, N			31	Y, N, N

8.9 PROPOSED PLANT COMMUNITIES

As described above, the existing floodplain and riparian plant communities are a product of anthropogenic factors (i.e. grazing and recreational uses). As a result of the proposed stream restoration efforts, the existing stream and floodplain plant communities will be modified (e.g., construction activities). (The design will protect and preserve existing emergent wetlands.) We propose to re-create forested floodplain plant communities in the areas disturbed during construction. In conjunction with floodplain morphology design (Section 8.7), at least two floodplain plant communities are proposed to be re-created in the project area, including a forested floodplain and small areas of wetland vernal pools.

The forested floodplain will occupy the majority of the project area; proposed species are shown in Table 8.8. Furthermore, these riparian woodland planting zones will be further developed into additional subcategories, including 1) mesic upper edge floodplain, 2) lower floodplain, and 3) large caliper lower floodplain (along meander bends for extra root cohesion). (Additional information on plant diversity, density, sizes, and spacing will be included in the planting plans later in the design process.)

The proposed vernal pool wetland areas are a cost-effective approach to creating a unique and valuable habitat feature in sections of the abandoned channel and other depressions resulting from the implementation of the stream restoration design. These wetland depressions will have a variable hydrologic regime, supporting a diverse plant and animal community, including amphibians, birds, and small mammals. As designed, these vernal pool wetlands are intended to support seasonal ponding (PFO1C) and the amphibian community.

Vernal pool wetlands will be situated in sections of the old stream channel to be abandoned as a result of the proposed stream restoration. These vernal pool habitats as proposed will have a woody canopy (i.e. shrubs and trees), around them, but have no woody plants installed in the bottom of the pool which is exposed to seasonal inundation. These portions of the pools will be stabilized with rye grass and planted with wetland-adapted herbaceous material (e.g., tussock sedge). Proposed wetland species are outlined in Table 8.9 and additional information on plant sizes, spacing, and numbers will be included in the planting plans. Wetland design areas also will be further developed during the design process to include some shrub scrub wetlands adjacent to vernal pools.

Table 8.8 Plant Communities Proposed along Forested Floodplain

Scientific Name	Common Name
Trees	
Carya cordiformis	Bitternut hickory
Fagus grandifolia	Beech
Juglans nigra	Black walnut
Liriodendron tulipifera	Tulip poplar
Pinus strobes	White pine
Tsuga Canadensis	Hemlock
Shrubs	
Amelanchier laevis	Allegheny serviceberry
Cornus florida	Flowering dogwood
Lindera benzoin	Spicebush
Viburnum prunifolium	Black haw
Grasses, Herbs, and Forbs	
Dichanthelium clandestinum	Deer-tongue grass
Elymus virginicus	Virginia wild rye
Lolium multiflorum	Annual rye
Panicum virgatum	Switchgrass

Table 8.9 Plant Communities Proposed along Vernal Pool Wetlands

Scientific Name	Common Name
Trees	
Acer rubrum	Red maple

Scientific Name	Common Name
Betula nigra	River birch
Platanus occidentalis	Sycamore
Populus deltoids	Cottonwood
Rhododendron maximum	Rosebay rhododendron
Salix nigra	Black willow
Shrubs	
Alnus serrulata	Smooth alder
Cornus alterniflora	Alternate leaved dogwood
Cornus amomum	Silky dogwood
Lindera benzoin	Spicebush
Grasses, Herbs, and Forbs	
Andropogon gerardii	Big bluestem
Carex stricta	Tussock sedge
Dichanthelium clandestinum	Deer-tongue grass
Elymus virginicus	Virginia wild rye
Iris versicolor	Blue flag
Juncus effuses	Softrush
Lolium multiflorum	Annual rye

8.10 IN-STREAM DESIGN ELEMENTS

8.10.1 Structural Elements

This concept design includes structural elements to provide extra protection to those areas subject to high shear stresses. These structures act to redirect flow and protect vulnerable outer meander bends.

Materials used in bank and bed protection structures will include those that enhance in-stream habitat and are perceived to be in keeping with natural aesthetics and natural channel materials already present in less disturbed portions of the site. These materials include large woody debris (LWD) interacting with the low flow and bankfull channel, and bedrock outcrops. Natural materials (wood and rock) and the features they form are mimicked with log bank protection, log vanes, root wads, and rock toe protection. Specifically, the following practices are proposed:

1. **Bank protection practices**
    1. Root wad revetments
    2. Rock toe protection

2. **Flow redirection**
    1. Log vanes
    2. J-rock and J-log vanes

3. **Grade control**
    1. Rock cross vanes
    2. Log cross vanes

More than any other structural element, LWD is emphasized throughout the restoration design. It is well documented that LWD provides significant habitat structure for fish and aquatic invertebrates, as well as storage of sediments and organic matter. Some studies have specifically noted these benefits in the broader vicinity of Brown Branch. Hilderbrand *et al.* (1998) placed LWD experimentally as a ramp angled upstream (similar to a single cross vane) in a third-order trout stream in the southwestern Virginian Appalachians with physical characteristics similar to Brown Branch (slope just under 1%, 16.4 foot bankfull width). LWD pieces longer than the average bankfull channel were found to be stable and induced significant adjacent scour. As has been found in studies of streams throughout the world, research in mountainous streams of North Carolina has shown a strong positive correlation between in-stream LWD loadings and both pool frequency and trout use in mature forests, relative to mid-successional forests (Flebbe and Dolloff, 1995; Flebbe, 1999). The use of extensive LWD at Brown Branch, therefore, is directed at maximizing pool frequency and encouraging use by trout species in keeping with project objectives.

Structures are distributed along the proposed stable channel planform layout not to "armor" the banks but to augment to initial stability of the natural channel design as vegetation growth occurs and the delivery of LWD increases. In time, it is intended that the riparian zone would maintain large woody debris recruitment rates firsthand and add to channel complexity. Furthermore, vegetation growth along the outsides of meander bends should secure erosion-prone banks as log structures decay over the longer term. Some bank treatments ("Bank Treatment" 1, 2, and 3 shown in Appendix A) will incorporate multiple structures in more complex arrangements.

At many locations, the design seeks to utilize natural bedrock outcrops for natural grade control and bank stabilization. In these locations, meanders are aligned so that bankfull flows will hit the bedrock, create scour, and then continue downstream. This approach allows for variety in physical features by exploiting existing conditions, and also reduces implementation costs by reducing the number of structures required to protect outside meander bends.

8.10.2 Soil Bioengineering Elements

Soil bioengineering, or non-structural means of stabilizing streambanks, are also proposed throughout the restoration project. Bank stabilization using soil bioengineering will include two main types: coir fiber logs and live branch layering.

Where live branch layering is proposed, the streambanks will be regraded to a stable angle and geometry and utilize vegetative planting and biodegradable materials to stabilize the streambank and prevent or reduce future streambank erosion. These practices are proposed where there is sufficient area available to regrade the streambank, sufficient sunlight to promote the growth of the live branches, and where the streambanks are not expected to be exposed to frequent erosive stream conditions.

Coir fiber logs will be used at the toe of banks in straighter sections of the stream, where some added bank protection is appropriate but more intensive structural methods would be unnecessary. Live branch layering is proposed above the coir fiber logs.

Soil bioengineering is also integrated with many of the structural treatments described in Section 8.10.2 and proposed along meander bends. For example, live branch layering is intermingled with log vanes and root wads for bank stability. In addition, the planting plan is integrated with structural and soil bioengineering elements to promote quick-growing, large rooted species along the apex of meander bends.

8.11 FLOODPLAIN DESIGN ELEMENTS

8.11.1 Wildlife Habitat Structures

Wildlife use snags, downed logs and brush piles for nesting, roosting, foraging, perching, cover, or territorial displays. These features are often referred to as wildlife habitat structures. Many applications of forestry practices have limited the number of snags and downed logs available for wildlife habitat. Maintenance procedures along developed areas also often prohibit the retention of brush piles. Wildlife dependent upon these features may experience loss of habitat and diminished use opportunities when these elements are lacking.

An ecosystem restoration project has added value if it tries to provide or retain some of these wildlife habitat structures. Within the Limit of Disturbance of this project, the incorporation of these elements provide habitat that may not be found until advanced stages of succession occur. Our approach exclusively uses onsite plant materials that would have otherwise been buried or removed from the site. The use of invasive plant species for these structures is prohibited in order to avoid the spread of seeds, fruits or the possibility of new growth from re-sprouting.

8.11.2 Wood Snags and Downed Logs

Snags are used for wildlife nesting, shelter and feeding sites. Tree cavities also form in the heart of trees from disease or limb loss and provide a place for nests of some birds including woodpeckers, owls, swallows and others. Snags also provide habitat requirements for cavity-dwelling amphibians, reptiles and mammals. The bare branches of snags serve as perches for hawks, vultures, eagles and other carnivorous birds. Snags are also attractive to insects that ultimately help to decompose the tree.

Fallen snags become logs and a new habitat element is created. Tiny soil organisms decompose the log and in turn are preyed upon by other organisms such as insects. Rotting logs provide a very moist environment and attract amphibians including salamanders and tree frogs. Downed logs also serve as important habitat for ground-dwelling mammals, birds and reptiles. Woody debris including logs can help prevent rapid runoff and erosion, and replenishes the soil. During decomposition of the log, nutrients are slowly released to the soil completing the cycle from which they came. Organic matter from the decomposition process adds to the structure and porosity of forest soils and provides conditions suited to future tree growth.

Woody debris elements, created from onsite salvaged trees include dead tree snags, dying tree snags, hinged snags, and downed logs. Wood snags are placed throughout the proposed woodland planting areas to provide important habitat elements. Dead tree snags consist of dead trees placed upright in the ground. They will be selected from trees within the limits of disturbance not marked for saving or protection. Dying snags consist of live trees left in place during construction that are expected to die due to excavation or filling. They will be left standing upon the completion of grading. Hinged snags are dying standing trees that are to be partially broken off and left in place. Hinged snags will be cut three-quarters of the way through the diameter of the tree and the top portion of the tree will be felled. The felled portion is either left as is, or up to one-half its mass is trimmed to provide material for brush piles, snags, and downed logs. Downed logs are felled trees salvaged from within the project limits of disturbance. As with snags, downed logs are also from trees not marked for saving or protection. Downed logs are to be partially buried in the ground so the log remains firmly in place.

8.11.3 Brush Piles

In addition to the large woody debris of snags and logs, brush piles of smaller-sized woody material are also proposed on the plans as habitat elements. Brush piles primarily provide cover, particularly winter cover, for rabbits, other small mammals (including rodents), birds (for roosting), and other animals. Brush piles will be created throughout woodland planting areas. They will consist of woody material one-quarter to six inches in diameter salvaged from the project site during construction. This material will include multi-branched woody debris with the leaves still attached. Brush piles will consist of woody debris stacked in an irregular pattern, and will be two to three feet high in the center, tapering to six to twelve inches along the edges.

9.0 SEDIMENT AND EROSION CONTROL PLAN

Given the proximity of the project to vulnerable aquatic environments, stringent sedimentation- and erosion-control measures will be implemented prior to ground disturbance and will be maintained throughout project construction. The North Carolina Natural Heritage Program is aware of the presence of a rare stonefly – *Diploperla morgani* – located in Mulberry Creek just below the confluence of Brown Branch. Impacts to Mulberry Creek therefore must be minimized or avoided.

9.1 PUMP AROUND

Because the work proposed for the project will be conducted in the stream channel, sediment controls will include a pump around that will divert clean water around the isolated work area to prevent excessive sediment from entering the stream during construction activities. This dewatering program will be implemented such that construction work does not affect water quality or aquatic resources within the creek. The pump around consists of an upstream sand dike which prevents stream water from entering the work area, and a sand bag dike at the lower limit of the work area to prevent sediments from entering the stream.

9.2 SLOPE STABILIZATION

All newly graded slopes will be stabilized with permanent seeding and matting at the end of each work day. Other sediment controls, such as silt fence will be used in areas where bank stabilization, and bank and floodplain grading are proposed.

9.3 PROTECTION OF EXTANT VEGETATION ADJACENT TO WORK AREA

Riparian woodland vegetation adjacent to the construction work area will be protected from inadvertent construction impacts by the placement of construction mesh fencing. The fencing will be in place prior to construction operations and grading at the site.

9.4 STABILIZED CONSTRUCTION ENTRANCE

There is an extended gravel road leading from (paved) Globe Mountain Road into the 4H Camp that should allow construction equipment sufficient distance to shed soil prior to entering the paved roadway. However, the contractor will place some additional gravel at the access points from the gravel road if conditions become muddy.

10.0 STREAM MONITORING PLAN

A technical monitoring plan is necessary to measure the success of the restoration plan. Technical monitoring will provide information needed to diagnose unforeseen problems resulting from changes in the environment, and the design and construction of the project. This information can then be used to develop restoration contingency plans, and facilitate the design and construction of future restoration projects with similar objectives and site conditions. The technical monitoring program should address and document pre-construction and initial post-construction conditions. The monitoring should be performed by a qualified firm with experience in designing and implementing stream restoration using a natural channel design approach.

Streams, by their nature, are dynamic systems which gradually adjust their cross section, profile, and planform with changing environmental conditions. Infrequent catastrophic events can also alter river form and course, though much more quickly. Meander bend cut offs and creation of oxbows are often the result of high magnitude flow events. Because rivers are dynamic systems which are subject to catastrophic events, evaluation of changes in the newly constructed channel must be taken in the context of the entire river system. To facilitate comparison between the relocated and natural channel, Biohabitats has developed a monitoring program which includes monumented cross sections upstream of and within the relocated channel. General observations of changes in natural morphology along with quantitative changes at the monumented cross sections will help indicate which channel changes deserved immediate attention.

Natural rivers are composed of areas of slow deep water (pools) and shallow fast moving reaches (riffles or glides). Pools are areas of bed scour (hence their greater than average depth), whereas glides and riffles are relatively shallow due to accumulated sediment. Sediment is also accumulated on the insides of meander bends, whereas the outside of a bend is typically a pool. Channel aggradation (bar formation) and/or degradation (bed and bank scour) all occur naturally as part of fluvial processes and one should not be overly concerned when they occur, especially in areas they are expected (i.e. degradation in meander bend pools and aggradation on inside point bars). Unexpected occurrence of channel bars and/or bed scour of the new channel may form after a storm event, but these changes are typically transient and may be reversed by next storm. These features will be noted during all scheduled monitoring to ascertain if they are temporary, static, or growing.

If the bar feature or bed degradation is not chronically increasing, then no action need be taken. If a bar is aggrading (growing) it could expand to the point where flows are directed into one or both banks causing erosion and possible bank failure. In this case the bar needs to be removed before bank failure occurs and the cause of the bar formation should be determined. Bar formation is often caused by debris jams or grade control structures. Debris jams will be removed along with the bar material and grade control structures will be modified to stop the accumulation of sediments. Bar formation can also be caused by an influx of larger than normal sediments Progression of bed scour could threatening the stability of the banks, log vanes, or rock weirs.

Streams may also change through catastrophic events such as floods. Large floods may cause local bank erosion and floodplain scour, and may even create oxbow wetlands by cutting off meander bends. It is important to evaluate the effects of infrequent, large-magnitude events on the newly constructed channel in the context of the entire river system. Changes in channel morphology (bank erosion, bed scour, bar formation) of the newly constructed channel must be compared to reaches upstream and downstream of the relocation. If a catastrophic event passes through the area and causes widespread bank erosion upstream and downstream of the relocated channel, then bank erosion within the relocated channel should be considered part of the natural process. Channel changes within the relocated channel which deviate from those in the natural channel will need to be addressed immediately.

Individual monitoring parameters are discussed below. Table 10.1 summarizes the frequency and content of monitoring recommended. The monitoring period should extend a minimum period of five years. In the event of a storm event exceeding bankfull flow during the first three monitoring years (as considered on a November to November basis) and not coinciding with a routine monitoring, an additional round of monitoring shall be undertaken within one week. The occurrence of a drought would also warrant additional monitoring of vegetation. In either instance, no more than one such additional monitoring round would be conducted in any November to November monitoring year.

10.1 Note Watershed Conditions

During each monitoring year, any major land use changes in the watershed will be noted to help interpret channel changes noted downstream during the monitoring period. For example, if extensive timber harvesting occurs in the upper watershed, one might expect changes in the hydrology and sediment supplied to the downstream channel unrelated to the stream restoration project.

10.2 Geomorphic Map

Using the construction as-built map of the restoration project, a qualified scientist will walk the length of the stream and note key geomorphic features. These features will the location of bedrock outcrops, bank erosion and/or slumping, significant and rapid erosion and deposition, channel flow pattern, and other important ongoing geomorphic processes, such as shallow subsurface piping and large woody debris racking. The map will provide a basis for interpretation of channel changes noted in other monitoring components and will guide maintenance measures required to preserve the structural and ecological integrity of the site. Observations along the entire stream corridor will be made to help identify land uses (e.g., livestock, bank trampling) that might jeopardize restoration measures, such as water quality, and therefore interfere with restoration objectives.

Geomorphic mapping will be conducted annually. In the event of a storm event exceeding bankfull flow during the first three monitoring years, an additional round of monitoring will be undertaken within one week.

10.3 Channel Cross Sections

Soon after construction, at least one permanent cross section will be established for every thousand feet of stream restoration. This equates to a minimum of 6 cross sections to document channel response and overall project success. An additional cross section will be established in a riffle section at least one hundred feet upstream of the limit of the project area for comparative purposes to observe any trends in channel change unrelated to the restoration project. Cross sections will be re-surveyed annually.

10.4 LONGITUDINAL PROFILE

In conjunction with the cross sections identified for monitoring above, the channel profile along the thalweg will be surveyed through the entire study reach. Survey points will be collected along the thalweg of the stream at all significant breaks in slope in addition to the deepest point in pools. Water surface elevations and bankfull elevations also shall be collected in conjunction with the longitudinal profile.

10.5 PHOTOGRAPHIC DOCUMENTATION

The overall performance of the stream restoration project, including vegetation growth, channel stability, and structure integrity, will be recorded at no fewer than twenty photographic documentation points. Rephotography at established photographic stations will ensure comparability. At least half of the photographic documentation points shall be established prior to construction activities, so that the restoration changes are more fully depicted.

If with time, a vantage may be obscured by vegetation, the vantage may be shifted slightly to document the salient features at that location. At minimum, photographs will be taken annually. In the event of a major storm event during the first three monitoring years or a drought during any one monitoring year, an additional round of photographic monitoring will be undertaken within one week of a flow event greater than bankfull.

10.6 INSPECTION OF STRUCTURE INTEGRITY

All bed and bank structures will be inspected regularly to assess their condition. At minimum, these inspections will occur biannually in the first two monitoring years and on an annual basis thereafter. Routine inspections of channel conditions will be conducted during low-water (non-flood) conditions to allow viewing of the structures, including such potential problems as displaced rock, settling and tilting, and undermining.

The performance of the structures also shall be monitored annually during a period of at least five years following construction. During the first three monitoring years additional inspections will be conducted within one week of a flow event exceeding bankfull. Recommendations for repair or removal of damaged structures will be made based on these observations.

10.7 Biological Indicators

Aquatic macroinvertebrates and fish are excellent "integrators" of water quality, flow stability, and habitat quality in that the number of species sampled at any one time must reflect the net temporal effect of these physical conditions—even though sampling itself occurs at a discrete time. Monitoring of these species will be conducted prior to and following construction, as well as within the same reference reach for physiochemical measurements. Biological parameters will be monitored annually in the five years following construction. The North Carolina Department of Water Quality will conduct monitoring of benthic macroinvertebrates, and the North Carolina Wildlife Resources Commission will monitor fishes.

10.8 Soil Bioengineering and Riparian Habitat

Many months may be required for plants to properly establish. Soil bioengineering and riparian habitat monitoring shall include surveys of the survival of planted material, including soil bioengineering and the broader riparian zone.

Vegetation will be monitored annually for a period of five years following installation. Plant survival shall be a minimum of 80% each year, for a period of three years. If survival rates fall below this level, remedial actions will be implemented in the following fall/winter (i.e. replanting). Follow-up inspections will focus on replacement of dead or dying plant materials and soil stabilization. In the event of a flow exceeding bankfull or an extended drought during a monitoring year, an additional round of monitoring will be undertaken.

10.9 Scour Chains and Bank Pins

To document precise changes in the bed at key points along the proposed channel alignment, scour chains and bed pins *may* be used at up to five key locations in the study reach. The equipment would be installed immediately following construction to capture subsequent changes. In the event of a flow exceeding bankfull in a monitoring year, an additional round of monitoring would be conducted.

10.10 Contingency Plan

Table 10.2 outlines contingency measures to address stream channel problems that may arise after construction.

Table 10.1 Proposed Monitoring Schedule

Monitoring Parameter	Preconstruction Documentation	Post-Construction Documentation	Routine Monitoring					Contingency Monitoring	
								Post-Flood Monitoring	Drought Monitoring
			Nov. 2002	Nov. 2003	Nov. 2004	Nov. 2005	Nov. 2006	Annually	Annually
Watershed Conditions		X	X	X	X	X	X		
Geomorphic Map		X	X	X	X	X	X	X	
Cross Sections		I, X	X	X	X	X	X		
Longitudinal Profile	■	X	X	X	X	X	X		
Photographs	I	X	X	X	X	X	X	X	X
Structures		X	X	X	X	X	X	X	
Riparian	■	X	X	X	X	X	X	X	X
Scour & Pins (proposed)		I, X	X	X	X	X	X	X	

X = Measurement proposed
I = Installation
■ = Data already available

Table 10.2 Stream Restoration Contingency Plan

Parameter	Concern	Contingency Plan	Timeframe*
Profile	Headcut progresses past grade control device	▪ Divert flow away from work area or pump around ▪ Stabilize head cut with large rocks (min. 30" dia.)	Immediate
	Severe scour at downstream end of vortex rock weir footers threatening stability of weir	▪ Divert flow away from work area or pump around ▪ Place large rock (min. 30" dia.) in scour hole without excavating ▪ Push rock down if necessary to make flush with channel	Monthly
Cross Section	Severe scour around root wad or log vane threatening stability of structure	▪ Divert flow away from work area or pump around ▪ Place large rock (min. 30" dia.) at base of scour ▪ Fill scour area with clean fill ▪ Plant with bankers willow and red-osier dogwood (1' - 2' cont.)	Monthly
Planform	Bank erosion in vicinity of root wads, log vanes, or vortex rock weirs	▪ Place top soil in eroded area and compact ▪ Seed with permanent seed mixture and stabilize with biodegradable matting ▪ Plant with bankers willow and red-osier dogwood (1' - 2' cont.) on outer edge of eroded area	Monthly
	Debris jam or beaver dam obstructing/ redirecting flow	▪ Remove any obstruction that form within the first five years	Monthly
Soil Bio-engineering	Section of soil bioengineering not growing	▪ Determine reason for failure. ▪ If failure was due to insufficient light, and shade tolerant species were used, remove the dead cuttings and plant containerized stock of shade tolerant shrubs such as red-osier dogwood, silky dogwood, arrow wood, and blackhaw. ▪ If failure was due to use of dead cuttings, improper installation, or disease, remove the dead cuttings and replace with live cuttings during the proper season	Seasonally
	Section of soil bioengineering and bank removed by high flow	▪ Add topsoil as necessary to restore bank ▪ Replace soil bioengineering during the proper season and	Seasonally
Construction	(Super) silt fence damaged	▪ Repair (super) silt fencing to meet specifications	Immediate
	Temporary stream crossing damaged or blown out	▪ Recover debris from old stream crossing ▪ Rebuild new stream crossing	Immediate
	Flooding of new channel before completion	▪ Pump water out of new channel ▪ Repair channel to previous condition	Immediate
	Erosion of berm separating new and existing channel	▪ Divert flow from new channel construction ▪ Pump water out of new channel ▪ Repair channel to previous condition	Immediate

*Timeframe is as follows: Immediate (1-7 days), Monthly (within 1 month), Seasonal (within 6 months).

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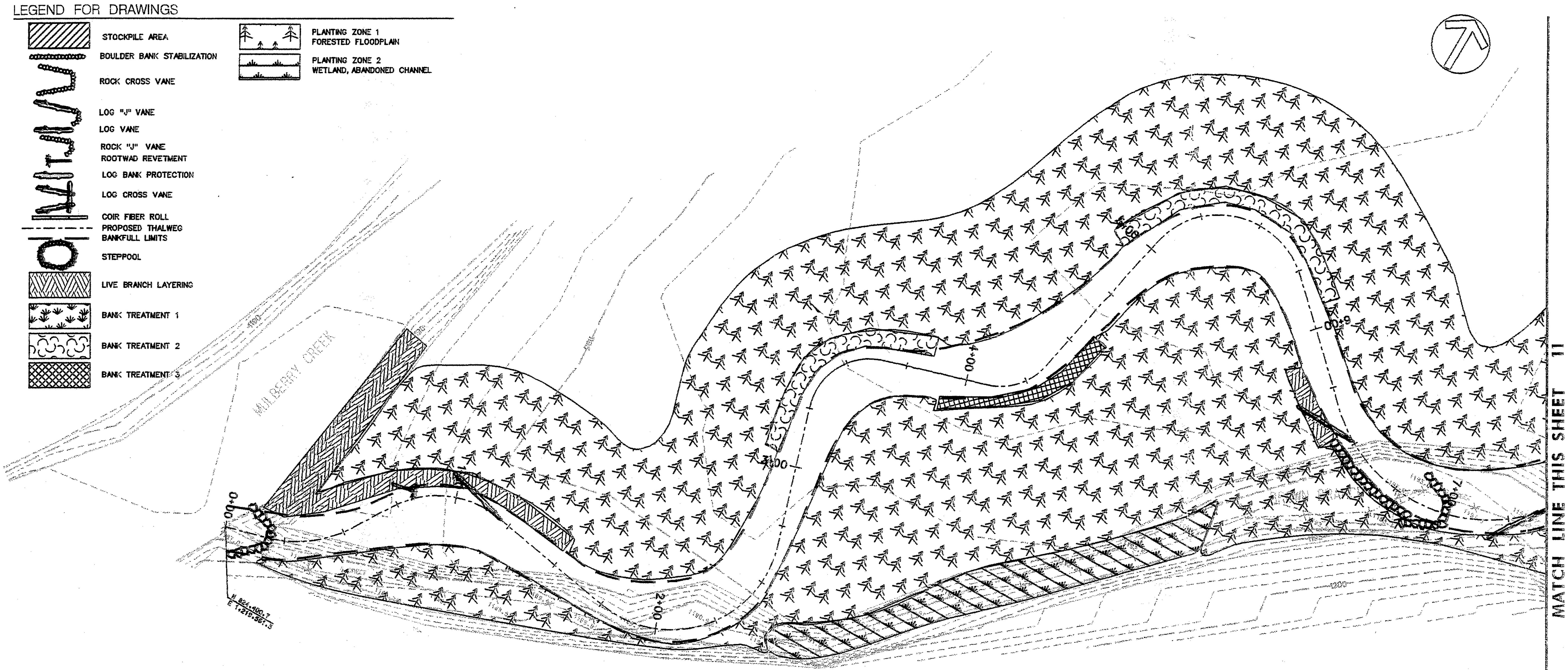
APPENDIX A

EXISTING VERSUS PROPOSED CHANNEL ALIGNMENT WITH PROPOSED STRUCTURES AND PLANTING PLAN



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REVISION		
DATE	BY	DESCRIPTION

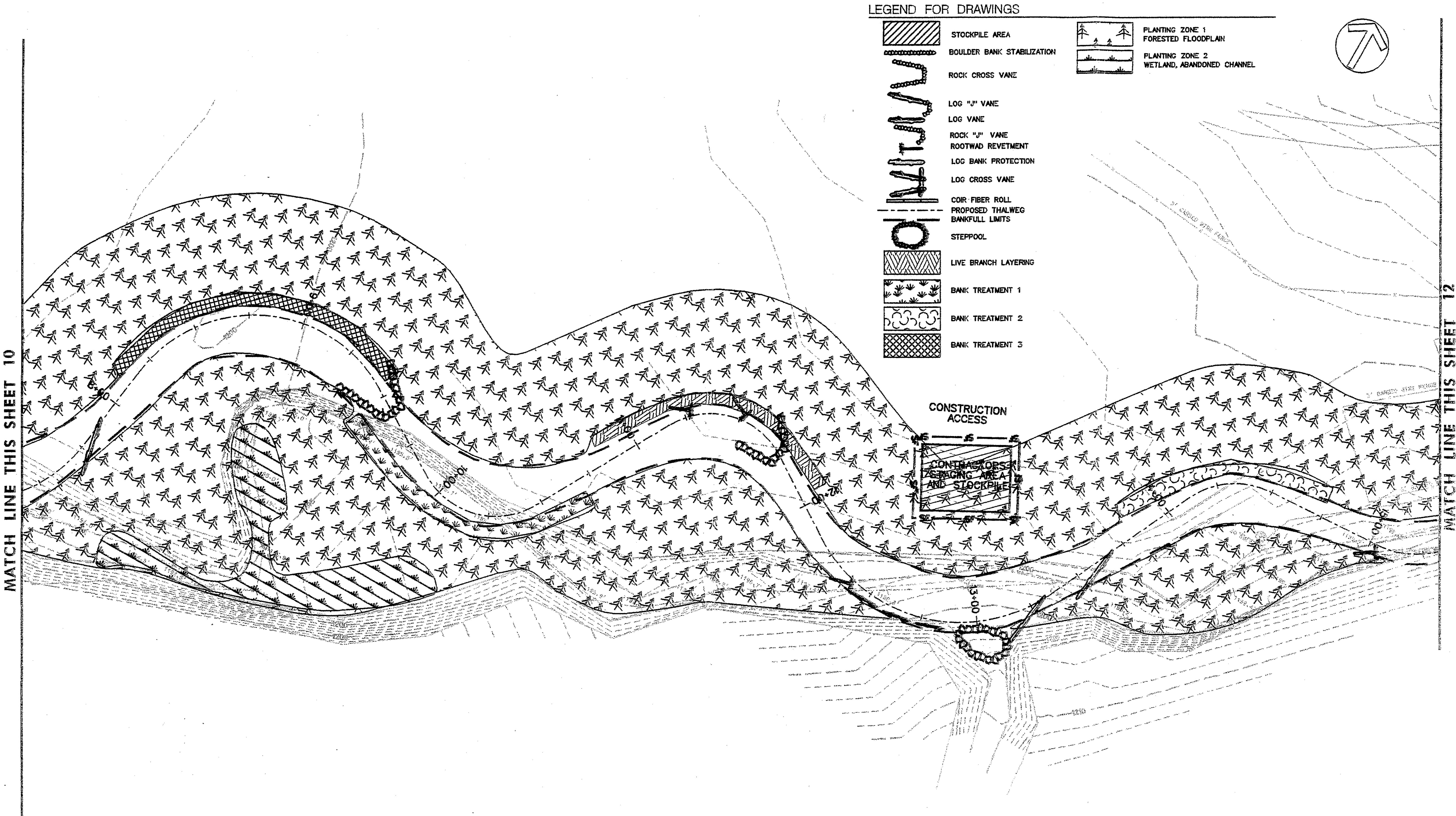
DATE: 1/24/02
DESIGNED: EMM
DRAWN: TLS
CHECKED: JKB

Biohabitats, Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659

BROWN BRANCH
STREAM RESTORATION

RESTORATION PLAN

SCALE: 1" = 20'-0"
CONTRACT N



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15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659

BROWN BRANCH STREAM RESTORATION

RESTORATION PLAN

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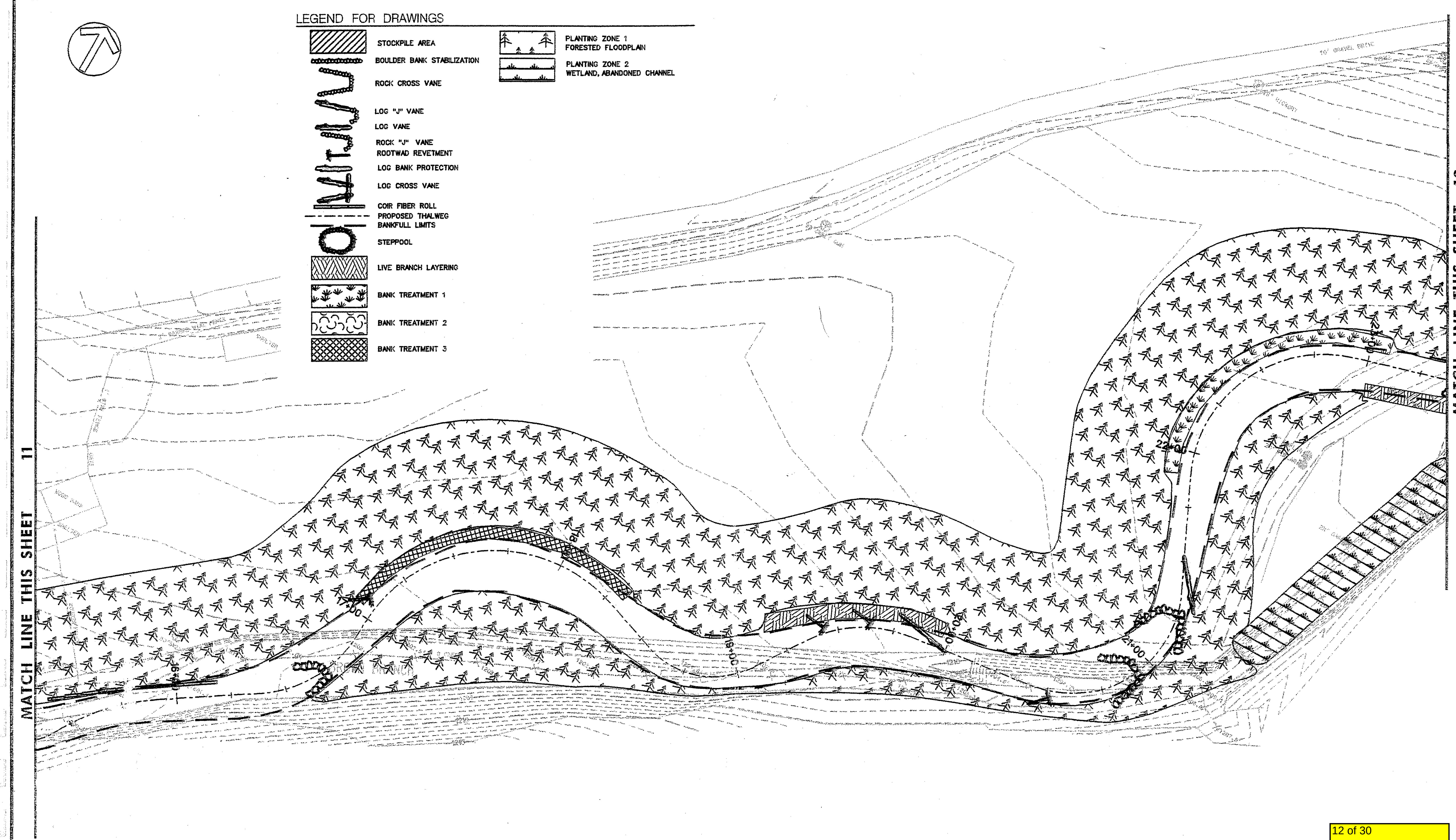

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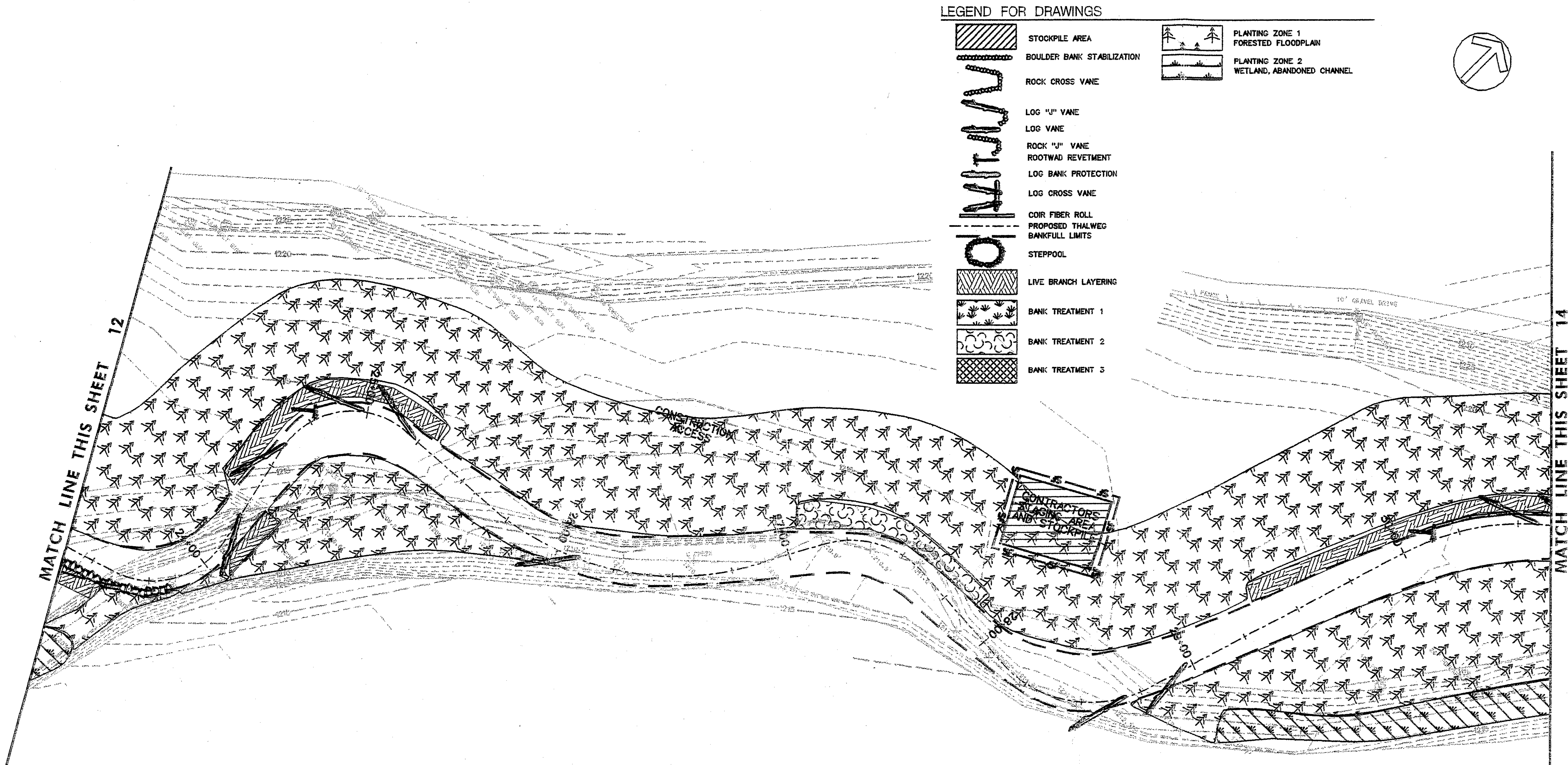
DRAWN: TLS
CHECKED: JKB

Biohabitats, Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659

BROWN BRANCH
STREAM RESTORATION

RESTORATION
PLAN

SCALE
1" - 20'
CONTRACT



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DRAWN: TLS
CHECKED: JKB
APPROVED:

Biohabitats, Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659

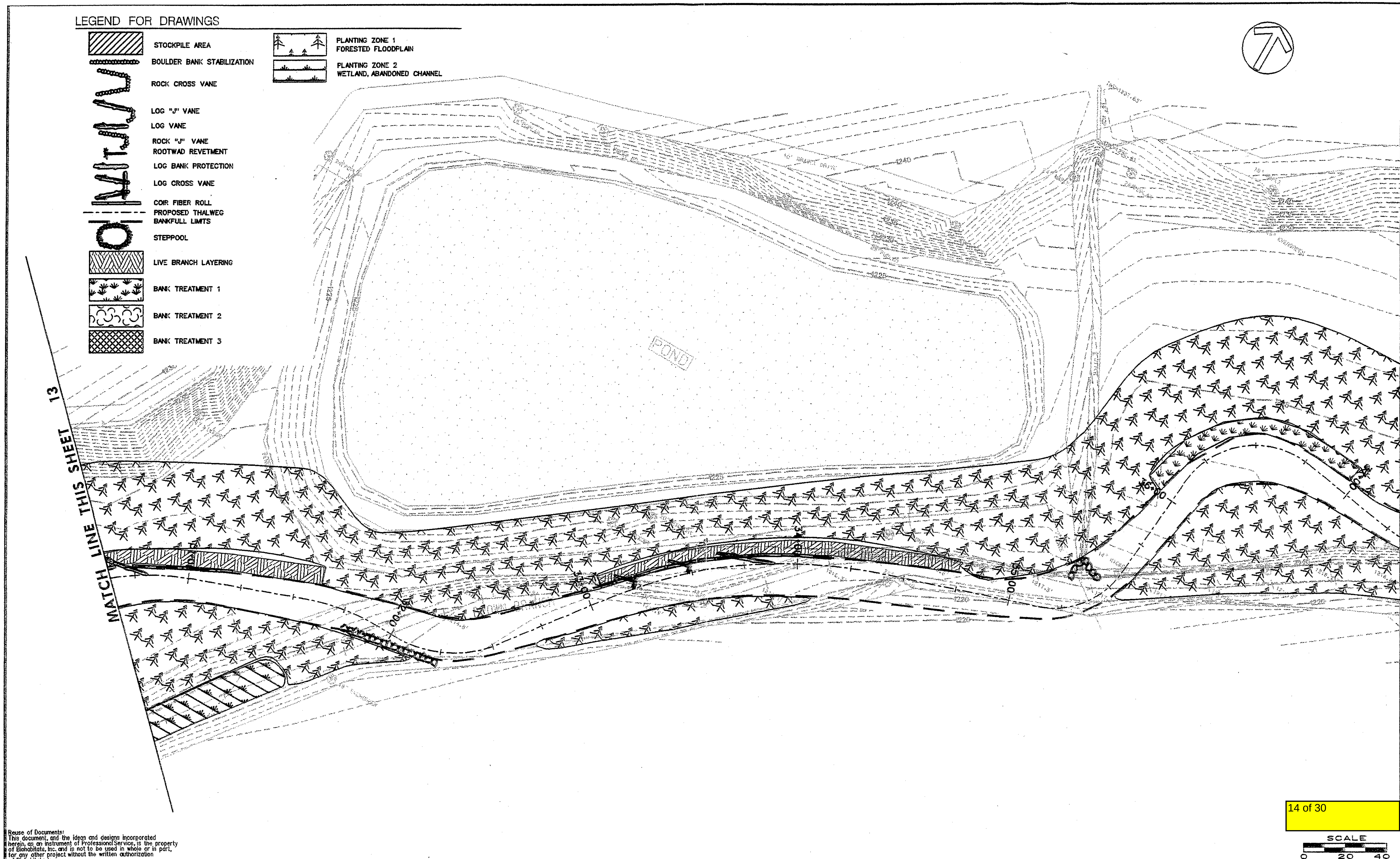
BROWN BRANCH STREAM RESTORATION

RESTORATION PLAN

SCALE: 1" = 20'-0

CONTRACT

SHEET



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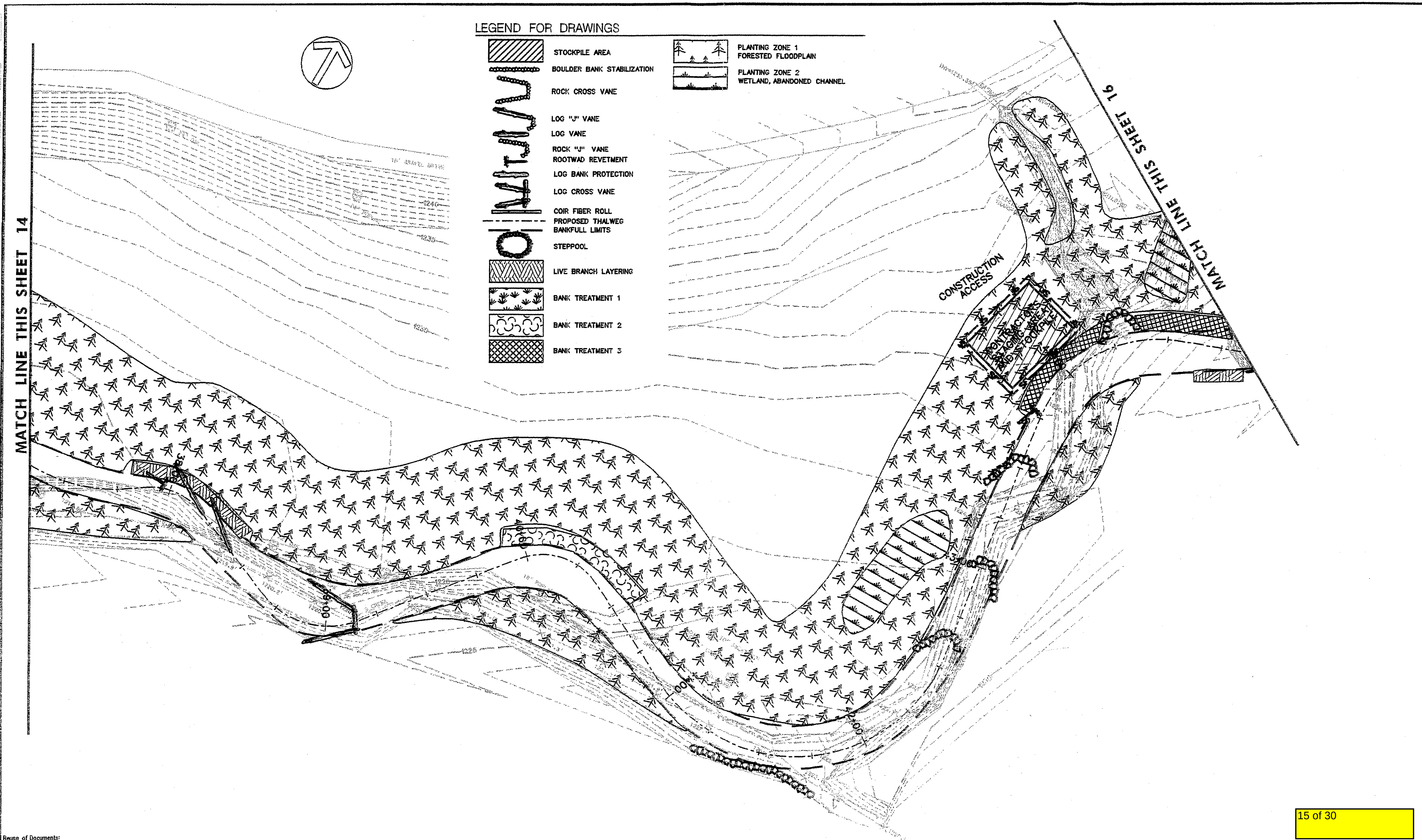
DRAWN: TLS
CHECKED: JKB

Biohabitats, Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659

BROWN BRANCH
STREAM RESTORATION

RESTORATION PLAN

SCALE 1" - 20
CONTRAC



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DATE	BY	DESCRIPTION

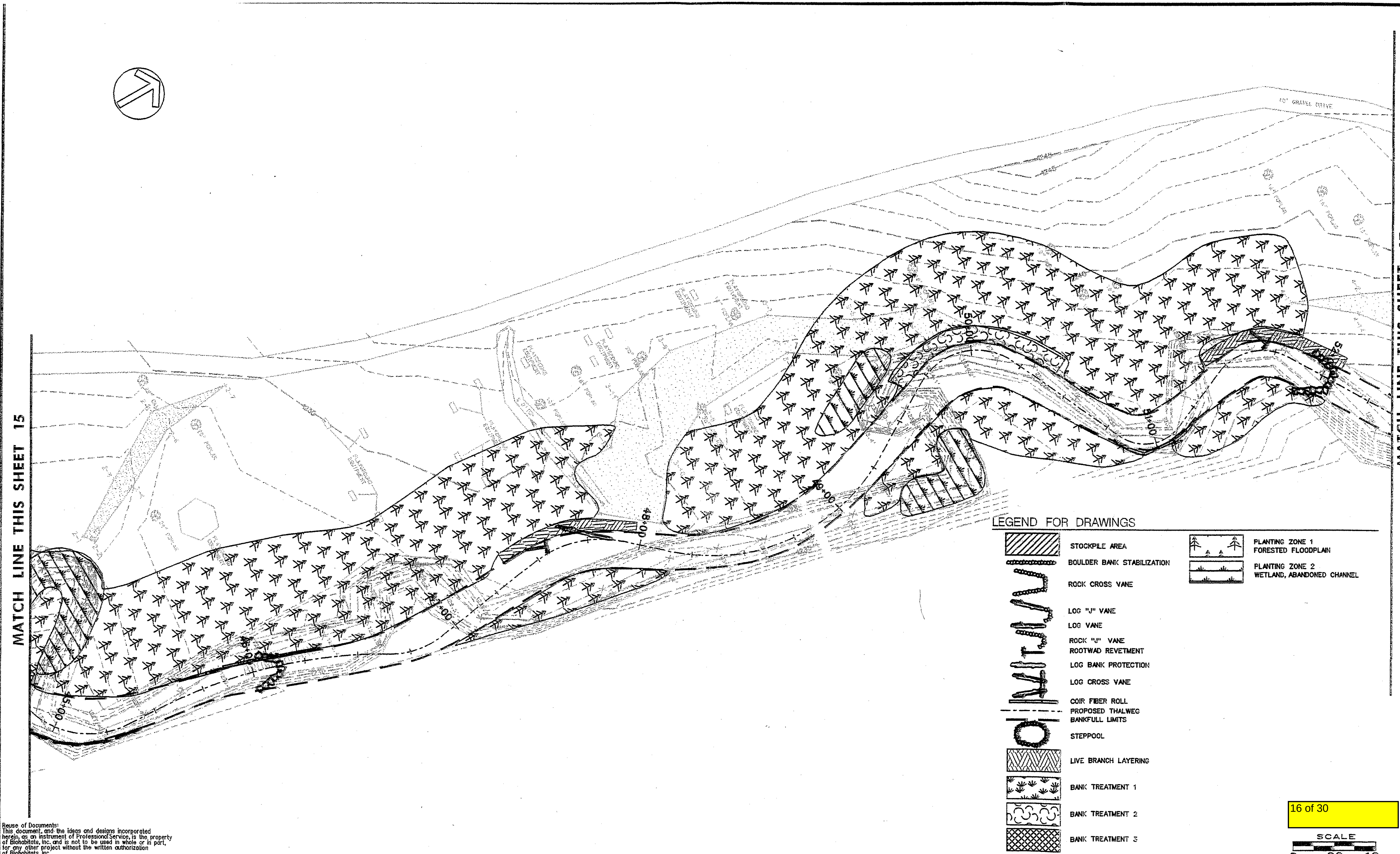
DATE: 1/24/02
DESIGNED: EMM
DRAWN: TLS
CHECKED: JKB

Biohabitats, Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659

BROWN BRANCH STREAM RESTORATION

RESTORATION PLAN

SCALE: 1" = 20'-0"
CONTRACT NO



16 of 30

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DATE	BY	DESCRIPTION

DATE: 1/24/02
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Timonium, Maryland 21093
Phone: 410-337-3659

BROWN BRANCH STREAM RESTORATION

RESTORATION PLAN

SCALE: 1" = 20'-0"
CONTRACT

LEGEND FOR DRAWINGS

- STOCKPILE AREA
- BOULDER BANK STABILIZATION
- ROCK CROSS VANE
- LOG "J" VANE
- LOG VANE
- ROCK "J" VANE
- ROOTWAD REVETMENT
- LOG BANK PROTECTION
- LOG CROSS VANE
- COIR FIBER ROLL
- PROPOSED THALWEG
- BANKFULL LIMITS
- STEPPOOL
- LIVE BRANCH LAYERING
- BANK TREATMENT 1
- BANK TREATMENT 2
- BANK TREATMENT 3
- PLANTING ZONE 1 FORESTED FLOODPLAIN
- PLANTING ZONE 2 WETLAND, ABANDONED CHANNEL

17 of 30

SCALE
0 20 40

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BROWN BRANCH STREAM RESTORATION

RESTORATION PLAN

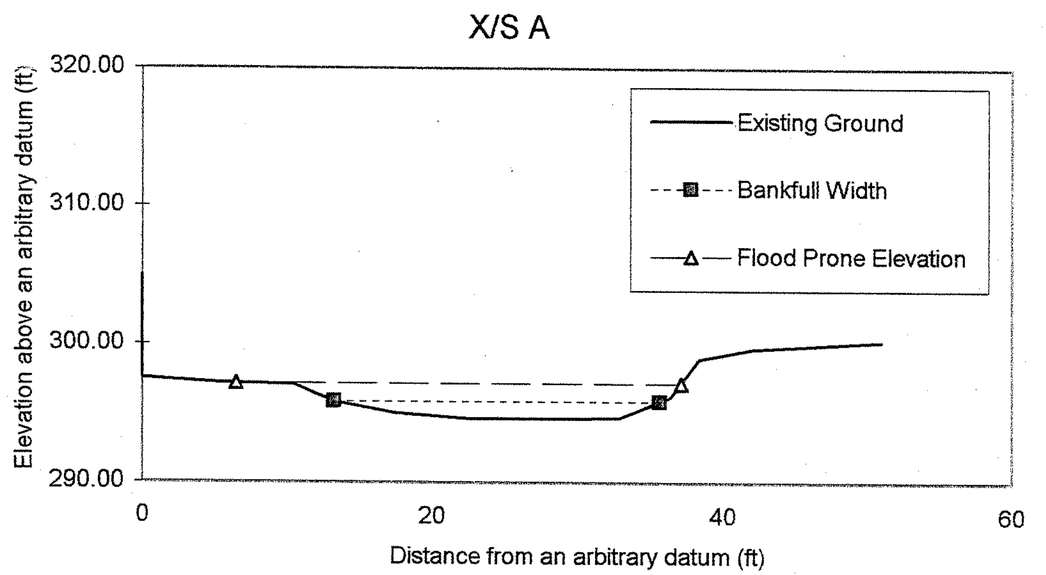
SCALE: 1" = 20'-0
CONTRACT N
SHEET

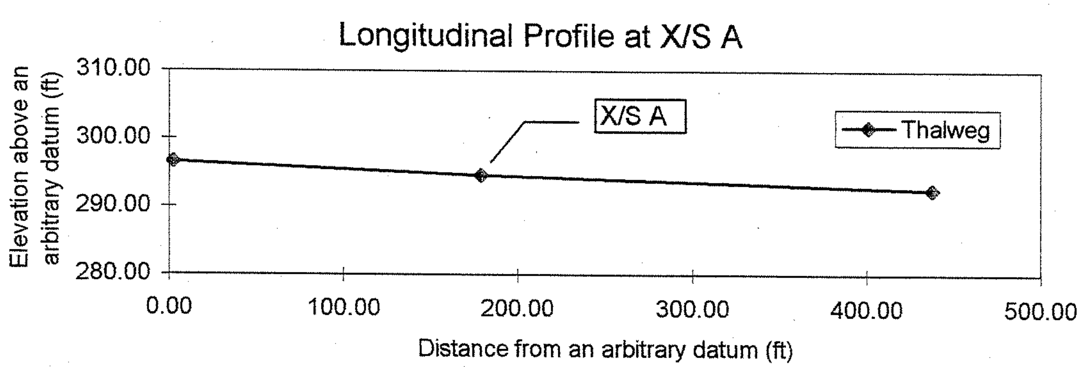
APPENDIX B

REPRESENTATIVE EXISTING CHANNEL CROSS SECTION AND LUMPED PEBBLE COUNT

Existing Cross Section and Channel Profile
Brown Branch

Biohabitats





Rosgen Stream Type Classification		
Entrenchment	1.36	
Width:Depth	23.09	
Sinousity	~1	
Slope	0.0091	
D50	21	(mm)
Stream Type	F4	

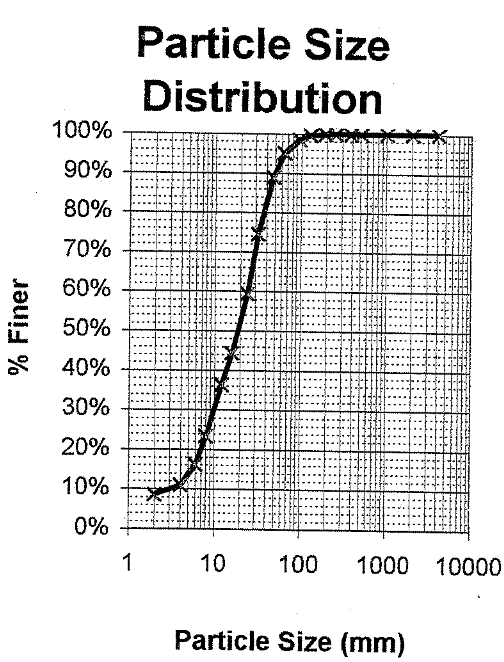
Flow Calculations		
Bankfull Width	22.50	(ft)
Bankfull Depth	0.97	(ft)
Area	21.93	(ft^2)
Manning's n	0.0300	
Velocity	4.62	(ft/s)
Discharge	101.28	(cfs)
Shear Stress	0.55	(lb/ft^2)

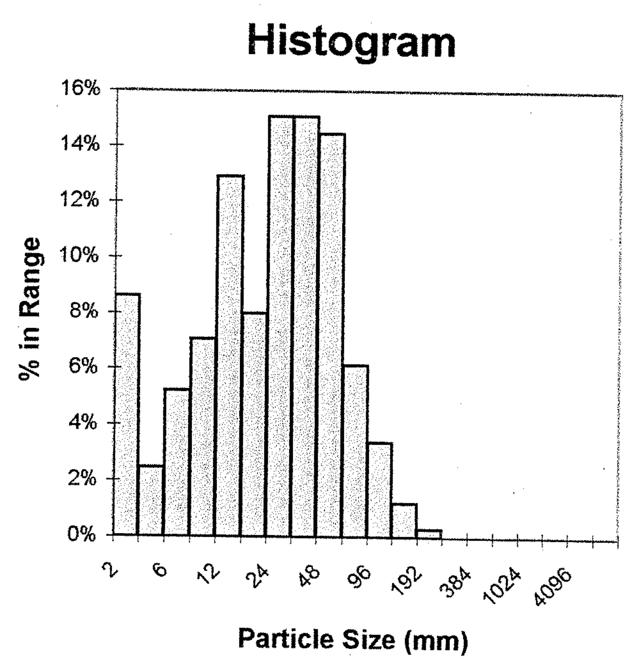
Biohabitats Project Number:	01015.01	
Surveyed:	July 18, 2001	By: VS/EMM

Pebble Count Data Sheet	**Project Name:** Brown Branch
In-stream, riffle only	**Project No:** 01015.01
	Date of Sample: 11/15/2001

Biohabitats

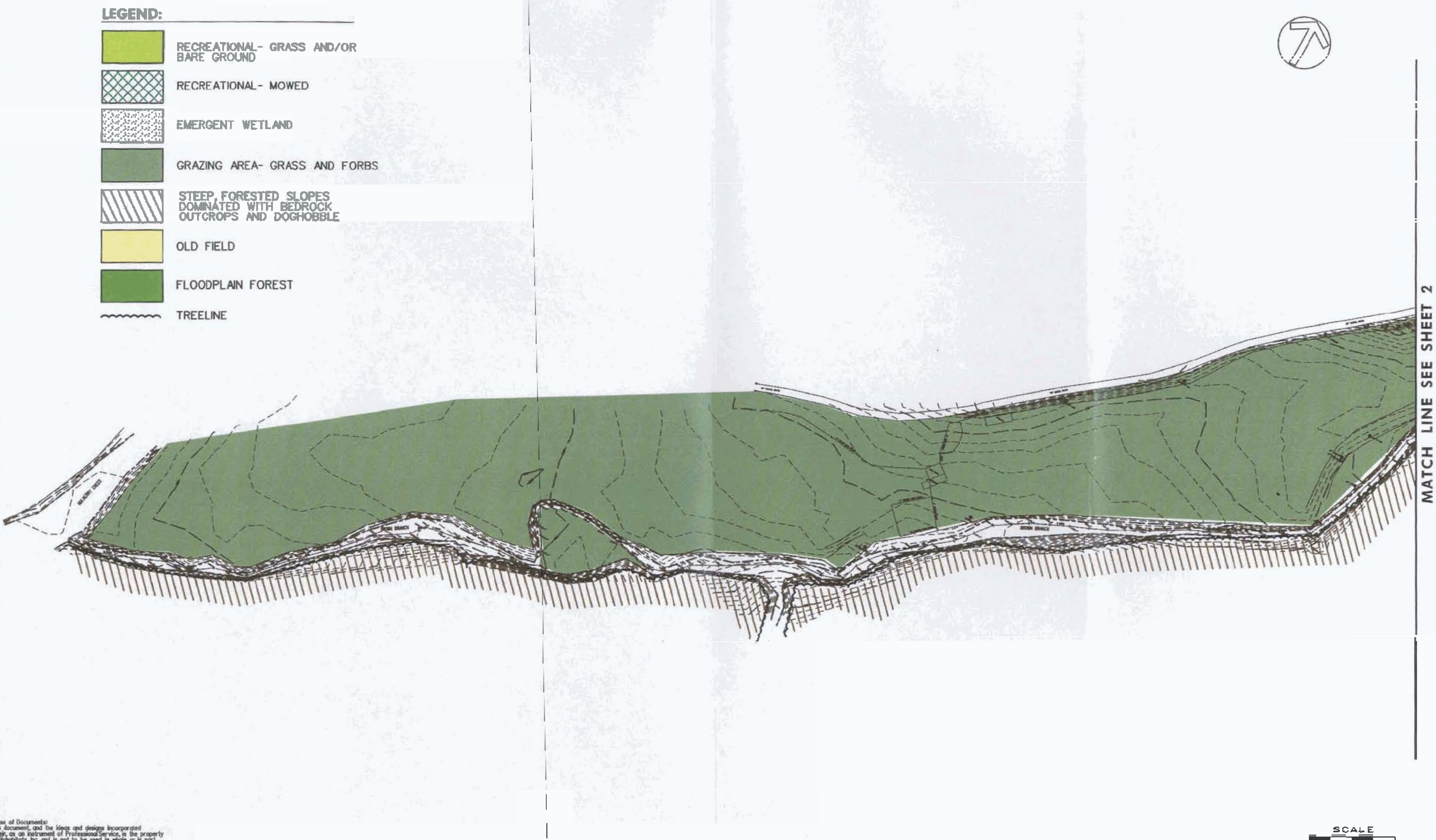
	Particle Size (mm)	Total #	% in Range	% Cumulative
Sand and Silt	< 2	28	9%	9%
Gravels	2 - 4	8	2%	11%
	4 - 6	17	5%	16%
	6 - 8	23	7%	23%
	8 - 12	42	13%	36%
	12 - 16	26	8%	44%
	16 - 24	49	15%	59%
	24 - 32	49	15%	74%
	32 - 48	47	14%	89%
	48 - 64	20	6%	95%
Cobbles	64 - 96	11	3%	98%
	96 - 128	4	1%	100%
	128 - 192	1	0%	100%
	192 - 256	0	0%	100%
Boulders	256 - 384	0	0%	100%
	384 - 512	0	0%	100%
	512 - 1024	0	0%	100%
	1024 - 2048	0	0%	100%
	2048 - 4096	0	0%	100%
Bedrock		0	0%	100%
	TOTALS:	325	100%	





APPENDIX C

EXISTING VEGETATION



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Biohabitats Project No.

Biohabitats, Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659
Fax: 410-583-5678

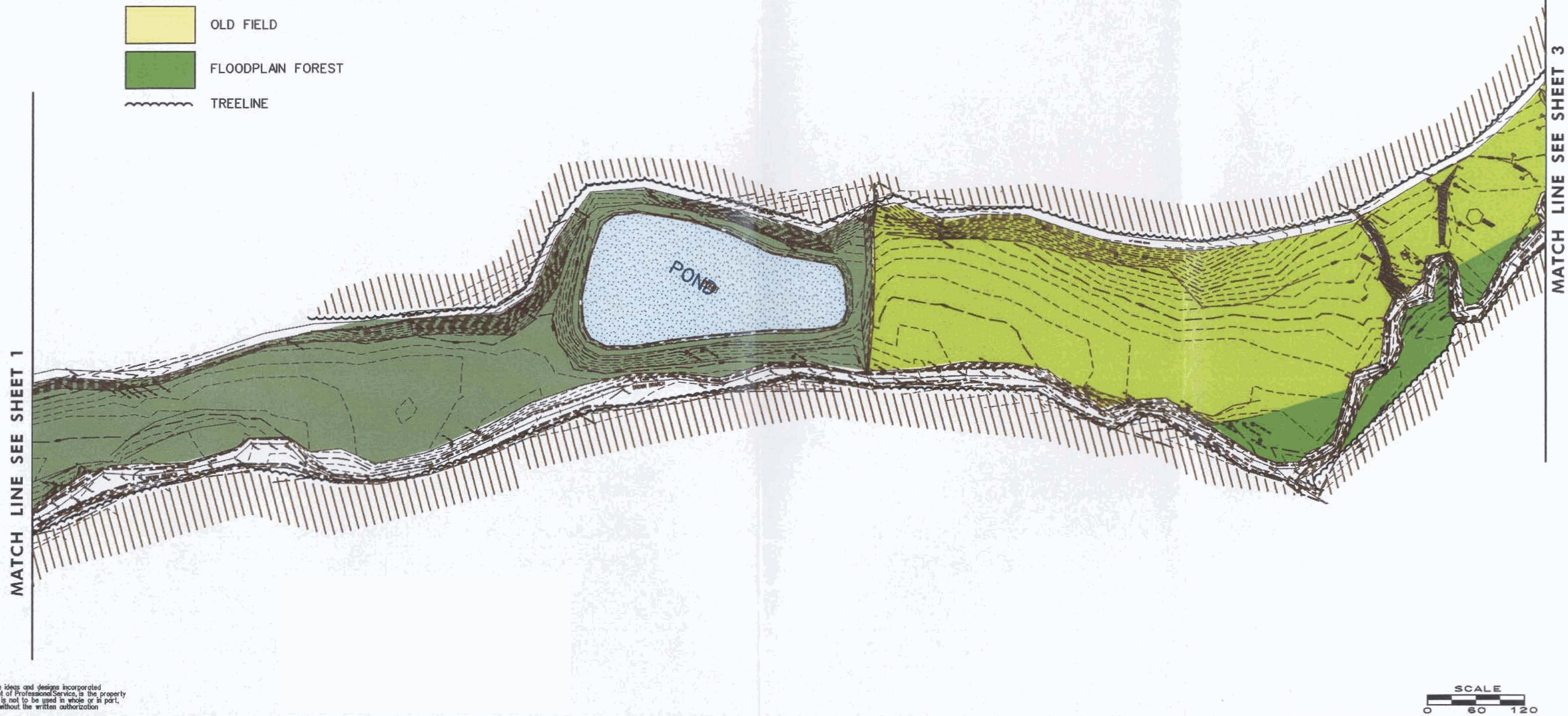
BROWN BRANCH STREAM RESTORATION

EXISTING VEGETATION

SCALE: 1" = 60'-0"
CONTRACT NO.
SHEET

LEGEND:

- RECREATIONAL- GRASS AND/OR BARE GROUND
- RECREATIONAL- MOWED
- EMERGENT WETLAND
- GRAZING AREA- GRASS AND FORBS
- STEEP, FORESTED SLOPES DOMINATED WITH BEDROCK OUTCROPS AND DOGHOBBLE
- OLD FIELD
- FLOODPLAIN FOREST
- TREELINE



REVISION		
DATE	BY	DESCRIPTION

DATE: 1/24/02
DESIGNED: EMM
DRAWN: TLS
CHECKED: JKB
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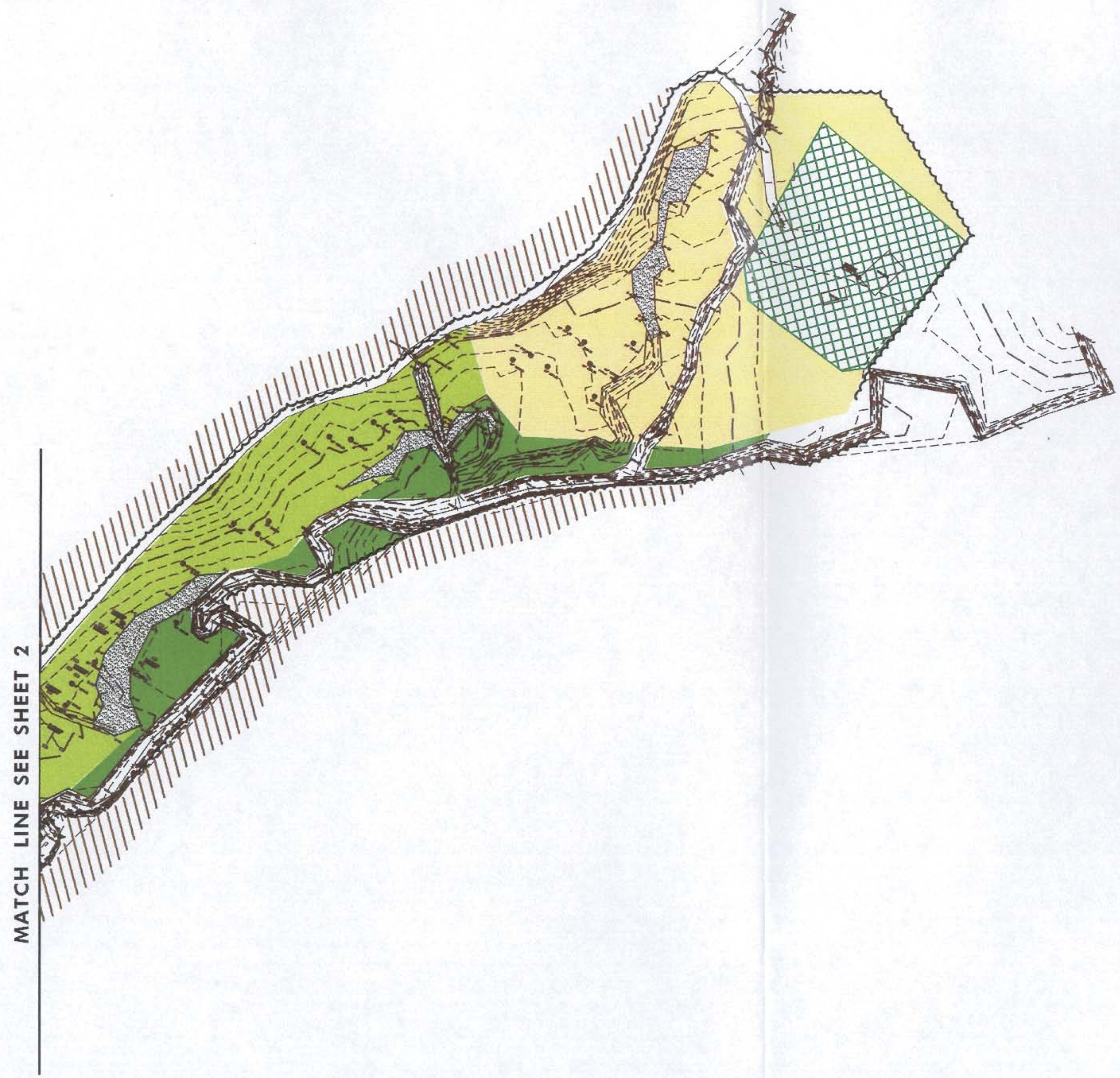
BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

EXISTING VEGETATION

SCALE: 1" = 60'-0"
CONTRACT NO.
SHEET 2 OF 30



LEGEND:

- RECREATIONAL- GRASS AND/OR BARE GROUND
- RECREATIONAL- MOWED
- EMERGENT WETLAND
- GRAZING AREA- GRASS AND FORBS
- STEEP, FORESTED SLOPES DOMINATED WITH BEDROCK OUTCROPS AND DOGHOBBLE
- OLD FIELD
- FLOODPLAIN FOREST
- TREELINE

SCALE

0 60 120

REVISION		
DATE	BY	DESCRIPTION

DATE: 1/24/02
DESIGNED: EMM
DRAWN: TLS
CHECKED: JKB
APPROVED:

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BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

EXISTING VEGETATION

SCALE: 1" = 60'-0"

CONTRACT NO.

SHEET 3 OF 30

APPENDIX D

TYPICAL PROPOSED CROSS SECTIONS

Project Name:	Brown Branch Stream Restoration
Biohabitats Project No. :	01015.01
Date:	December 10, 2001
Prepared by:	EMM
Cross Section Type:	Proposed Typical Riffle Cross Section

Stream Design Worksheet, Typical Riffle

Upstream half of study reach

Biohabitats

Input Variables		Units
Mannings "n" of channel =	0.035	
Mannings "n" of floodplain =	0.1	
Equivalent "n" for flood flows =	0.04	
Channel Slope =	0.01	(ft/ft)
Design B.F. Discharge =	90	(cfs)
Bankfull Elevation =	9.5	(ft)
Floodprone Elevation =	11.20	(ft)
Bankfull Width =	15	(ft)
Floodprone Width =	50	(ft)

Cross Section Points: Feature	Relative Distance (ft)	Relative Elevation (ft)	Bankfull Channel Calculations: Cross Section Area (ft^2)	Bankfull Channel Calculations: Wetted Perimeter (ft)		Floodprone Channel Calculations: Cross Section Area (ft^2)		Floodprone Channel Calculations: Wetted Perimeter (ft)
Floodprone	-25	11.20				0		0.00
	-25	11.20			lA.fp	14.875	lP.fp	17.58
Bankfull	-7.5	9.50	2.625	3.81		8.575		3.81
	-4	8.00	6.4	4.00		13.2		4.00
Max Depth	0	7.80	6.4	4.00		13.2		4.00
	4	8.00	2.625	3.81		8.575		3.81
Bankfull	7.5	9.50			rA.fp	14.875	rP.fp	17.58
	25	11.20				0		0.00
Floodprone	25	11.20	Total Area = 18.05	Total WP = 15.63	Total Area =	73.3	Total WP =	50.79

Calculated Variables		Units
Bankfull Cross Section Area =	18.1	(ft^2)
Bankfull Wetted Perimeter =	15.6	(ft)
Bankfull Hydraulic Radius =	1.16	(ft)
Bankfull Discharge =	89	(cfs)
Floodprone Cross Setion Area =	73.3	(ft^2)
Floodprone Wetted Perimeter =	51	(ft)
Floodprone Hydraulic Radius =	1.44	(ft)
Floodprone Discharge =	378	(cfs)
Bankfull Average Depth =	1.20	(ft)
Bankfull W/D Ratio =	12.5	(ft/ft)
Bankfull Entrenchment Ratio =	3.3	[ft/ft]
Bankfull Shear Stress =	0.79	(lb/ft^2)
D84=	52	(mm)
Bankfull Max Depth=	1.70	(ft)

Relevant Equations

Continuity Equation:

$$Q = V \times A$$

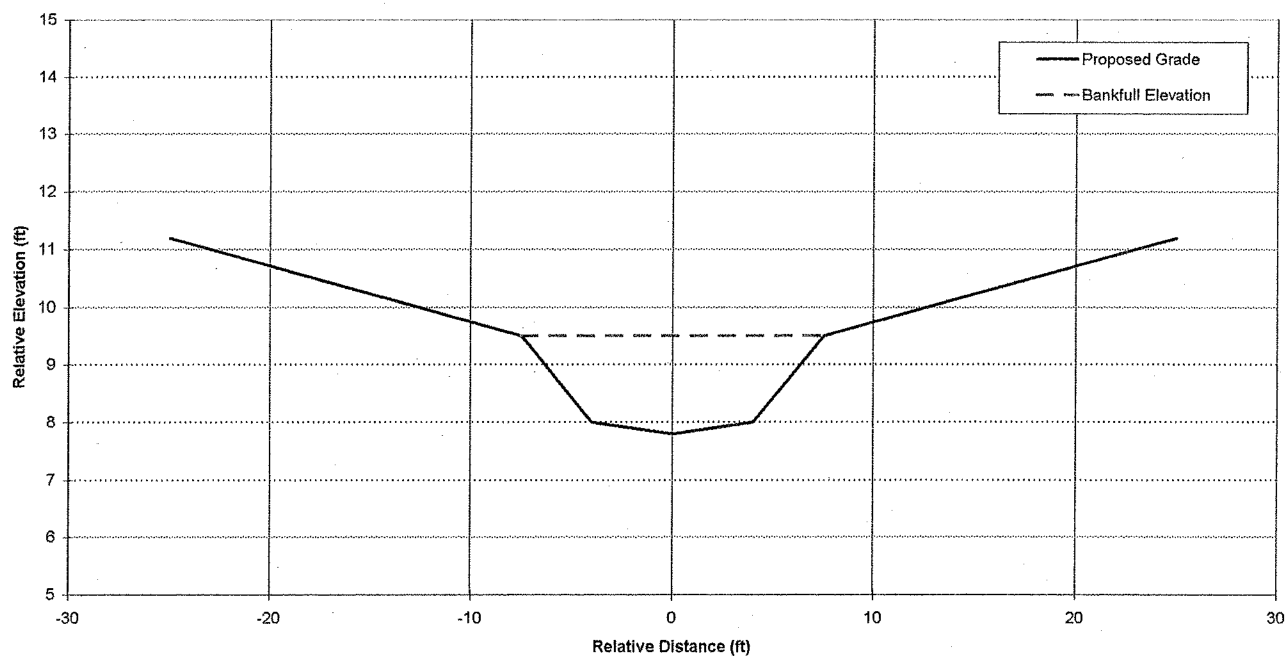
Manning's Equation (English units):

$$Q = 1.49\frac{A}{n}(R)^{\frac{2}{3}}(S)^{\frac{1}{2}}$$

Shear Stress Equation:

$$\tau_o = \rho g R S$$

Typical Riffle Cross Section (Upstream)



Project Name:	**Brown Branch Stream Restoration**
Biohabitats Project No.:	01015.01
Date:	December 10, 2001
Prepared by:	EMM
Cross Section Type:	Proposed Typical Left Meander Cross Section

Stream Design Worksheet, Typical Pool
Upstream half of study reach

Biohabitats Incorporated

Meander/Riffle Max Depth Ratio (ft/ft) =	1.5
Meander Depth (ft) =	2.55
Meander Bankfull Width (ft) =	22.50
Bar Slope (%) =	10.0
Outer Bank Slope (H:1Z) =	0.6

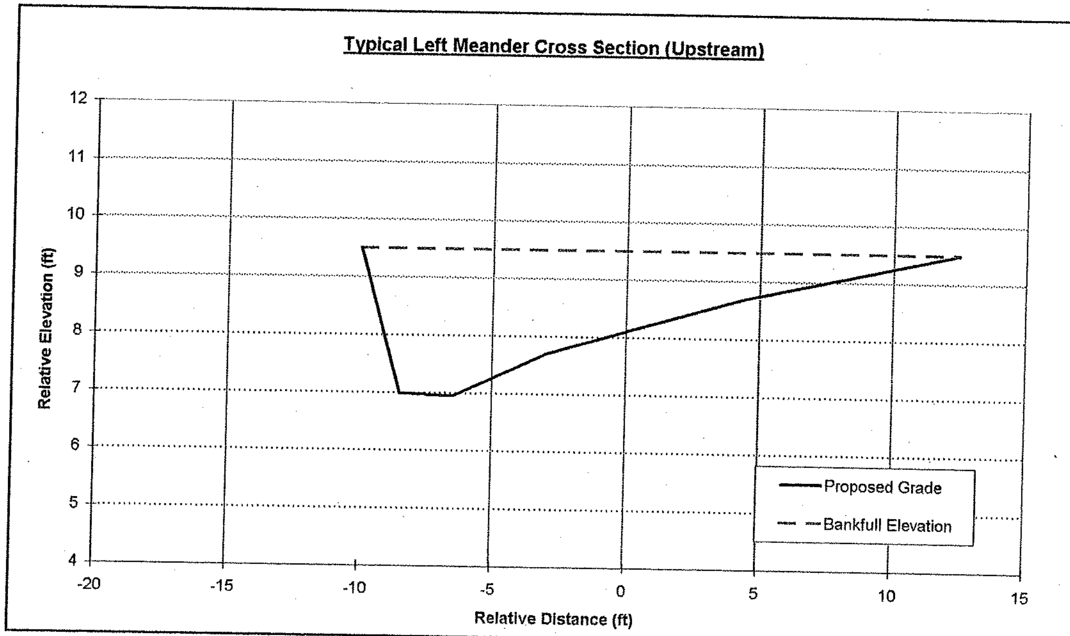
Input Meander Channel Dimensions

Feature	Relative Distance (ft)	Relative Elevation (ft)
Top of Bank		
Floodprone Left		
Top of Bank at Bankfull	-10.00	9.50
Pool	-8.50	7.00
Max Depth	-6.50	6.95
Bar Toe	-3.00	7.70
DSR Baseflow	0.00	8.10
Bar	4.50	8.70
Bankfull Right	12.50	9.50
Floodprone Right		
Top of Bank		

Output of Meander Geometry

Relative Distance (ft)	Relative Depth (ft)	Wetted Perimeter (ft)	Area (ft^2)
1.5	2.5	2.92	1.88
2	2.6	2.00	5.05
3.5	1.8	3.58	7.61
3	1.4	3.03	4.80
4.5	0.8	4.54	4.95
8	0.0	8.04	3.20

	Wetted Perimeter (ft)	Area (ft^2)
Total	24.10	27.49
	Hydraulic Radius (ft)	
	1.14	



Graphing Parameters

Bankfull Distance (ft)	Bankfull Elevation (ft)	Floodprone Distance (ft)	Floodprone Elevation (ft)
-10.00	9.50		
12.50	9.50		

Project Name:	Brown Branch Stream Restoration
Biohabitats Project No.:	01015.01
Date:	December 10, 2001
Prepared by:	EMM
Cross Section Type:	Proposed Typical Riffle Cross Section

Stream Design Worksheet, Typical Riffle

Downstream half of study reach

Input Variables		Units
Mannings "n" of channel =	0.035	
Mannings "n" of floodplain =	0.1	
Equivalent "n" for flood flows =	0.04	
Channel Slope =	0.01	(ft/ft)
Design B.F. Discharge =	130	(cfs)
Bankfull Elevation =	9.5	(ft)
Floodprone Elevation =	11.35	(ft)
Bankfull Width =	17.5	(ft)
Floodprone Width =	60	(ft)

Cross Section Points			Bankfull Channel Calculations				Floodprone Channel Calculations			
Feature	Relative Distance (ft)	Relative Elevation (ft)	Cross Section Area (ft^2)		Wetted Perimeter (ft)		Cross Section Area (ft^2)		Wetted Perimeter (ft)	
Floodprone	-30	11.35						0		0.00
	-30	11.35					lA.fp	19.65625	lP.fp	21.33
Bankfull	-8.75	9.50		3.5		4.37		10.9		4.37
	-4.75	7.75		8.55		4.75		17.3375		4.75
Max Depth	0	7.65		8.55		4.75		17.3375		4.75
	4.75	7.75		3.5		4.37		10.9		4.37
Bankfull	8.75	9.50					rA.fp	19.65625	rP.fp	21.33
	30	11.35						0		0.00
Floodprone	30	11.35	Total Area =	24.1	Total WP =	18.23	Total Area =	95.7875	Total WP =	60.89

Calculated Variables		Units
Bankfull Cross Section Area =	24.1	(ft^2)
Bankfull Wetted Perimeter =	18.2	(ft)
Bankfull Hydraulic Radius =	1.32	(ft)
Bankfull Discharge =	**130**	**(cfs)**
Floodprone Cross Setion Area =	95.8	(ft^2)
Floodprone Wetted Perimeter =	61	(ft)
Floodprone Hydraulic Radius =	1.57	(ft)
Floodprone Discharge =	530	(cfs)
Bankfull Average Depth =	1.38	(ft)
Bankfull W/D Ratio =	12.7	(ft/ft)
Bankfull Entrenchment Ratio =	3.4	[ft/ft]
Bankfull Shear Stress =	0.91	(lb/ft^2)
D_{84}=	60	(mm)
Bankfull Max Depth=	1.85	(ft)

Relevant Equations

Continuity Equation:

$$Q = V \times A$$

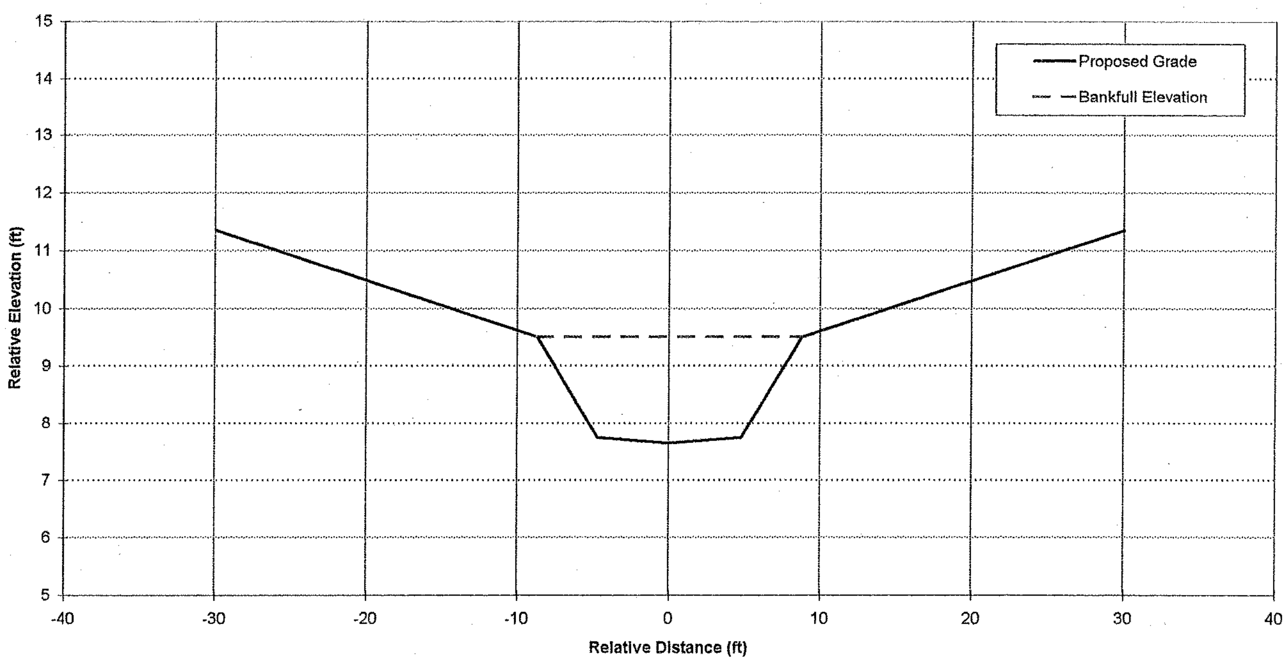
Manning's Equation (English units):

$$Q = 1.49\frac{A}{n}(R)^{\frac{2}{3}}(S)^{\frac{1}{2}}$$

Shear Stress Equation:

$$\tau_o = \rho g R S$$

Typical Riffle Cross Section (Downstream)



Project Name: Brown Branch Stream Restoration
Biohabitats Project No. : 01015.01
Date: December 10, 2001
Prepared by: EMM
Cross Section Type: Proposed Typical Left Meander Cross Section

Stream Design Worksheet, Typical Pool

Downstream half of study reach

Biohabitats

Meander/Riffle Max Depth Ratio (ft/ft) =	1.6
Meander Depth (ft) =	2.80
Meander Bankfull Width (ft) =	26.0
Bar Slope (%) =	9.0
Outer Bank Slope (H:1Z) =	0.6

Input Meander Channel Dimensions

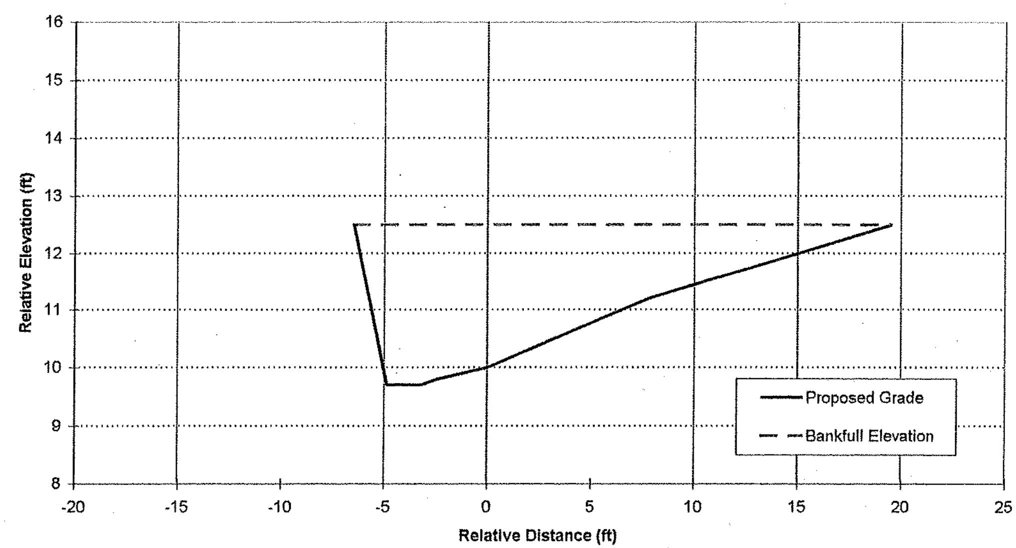
Feature	Relative Distance (ft)	Relative Elevation (ft)
Top of Bank		
Floodprone Left		
Top of Bank at Bankfull	-6.50	12.50
Pool	-4.90	9.70
Max Depth	-3.25	9.70
Bar Toe	-2.45	9.80
DSR Baseflow	0.00	10.00
Bar	7.80	11.20
Bankfull Right	19.50	12.50
Floodprone Right		
Top of Bank		

Output of Meander Geometry

Relative Distance (ft)	Relative Depth (ft)	Wetted Perimeter (ft)	Area (ft^2)
1.6	2.8	3.22	2.24
1.65	2.8	1.65	4.62
0.8	2.7	0.81	2.20
2.45	2.5	2.46	6.37
7.8	1.3	7.89	14.82
11.7	0.0	11.77	7.61

	Wetted Perimeter (ft)	Area (ft^2)
Total	27.80	37.86
	Hydraulic Radius (ft)	
	1.36	

Typical Left Meander Cross Section (Downstream)

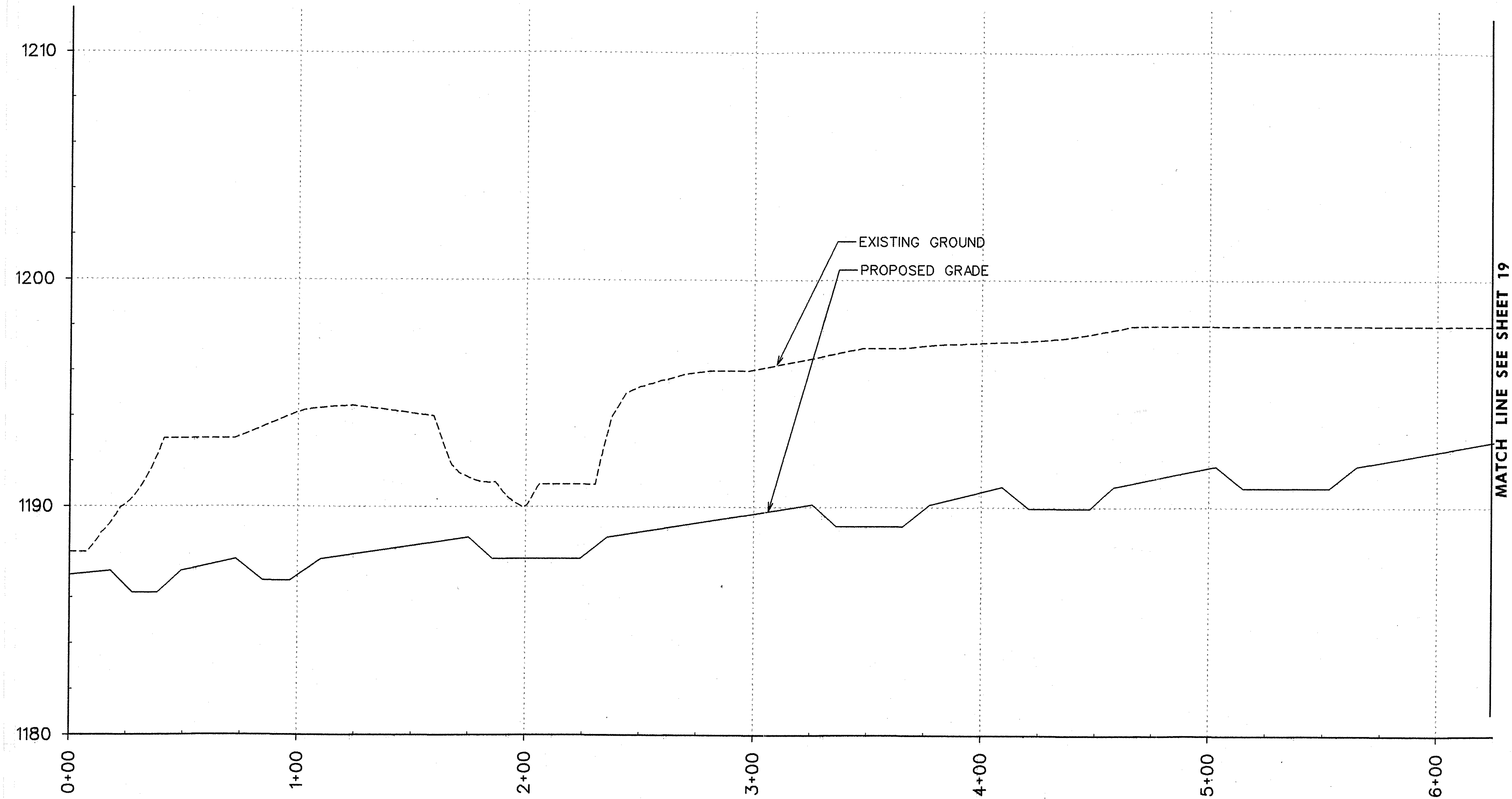


Graphing Parameters

Bankfull Distance (ft)	Bankfull Elevation (ft)	Floodprone Distance (ft)	Floodprone Elevation (ft)
-6.50	12.50		
19.50	12.50		

APPENDIX E

EXISTING AND PROPOSED PROFILE ALONG PROPOSED ALIGNMENT



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APPROVED:
Biohabitats Project No. 01015.01

Biohabitats, Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659
Fax: 410-583-5678
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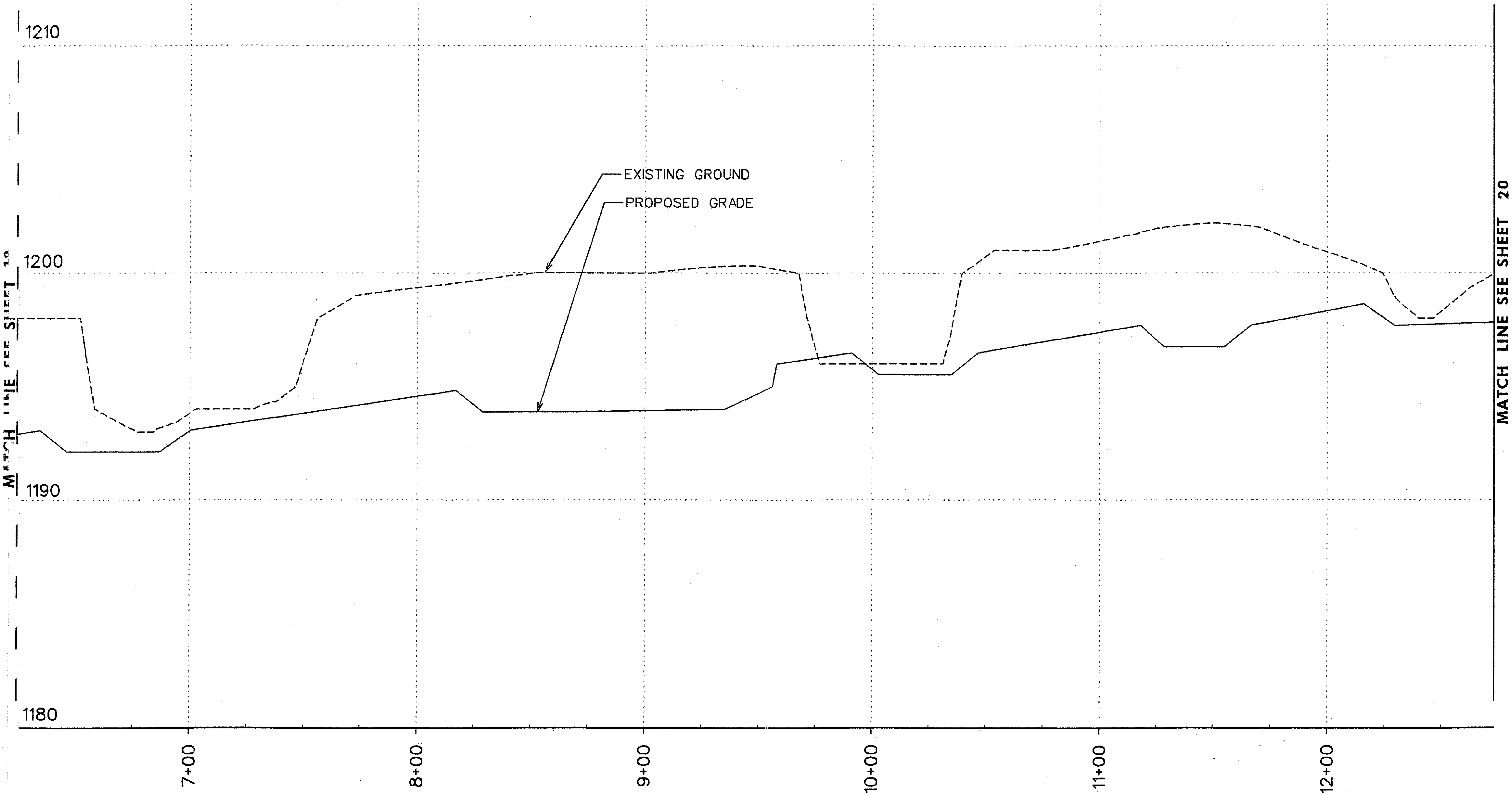
BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

PROFILE

SCALE: AS SHOWN
CONTRACT NO.
SHEET 18 OF 30



REVISION		
DATE	BY	DESCRIPTION

DATE: 1/24/02
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01015.01

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15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659
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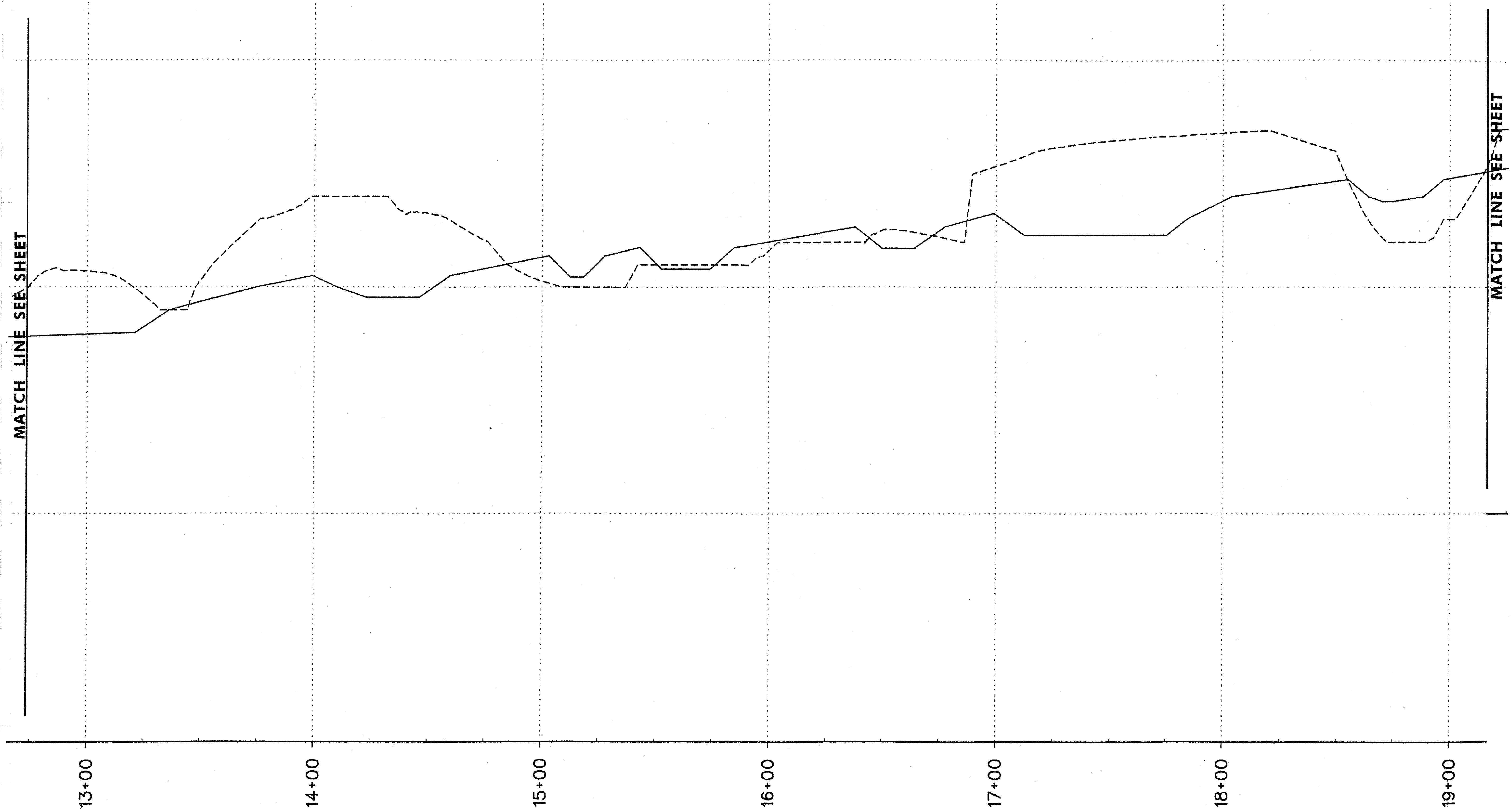
BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

PROFILE

SCALE: AS SHOWN
CONTRACT NO.
SHEET 19 OF 30



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Timonium, Maryland 21093
Phone: 410-337-3659
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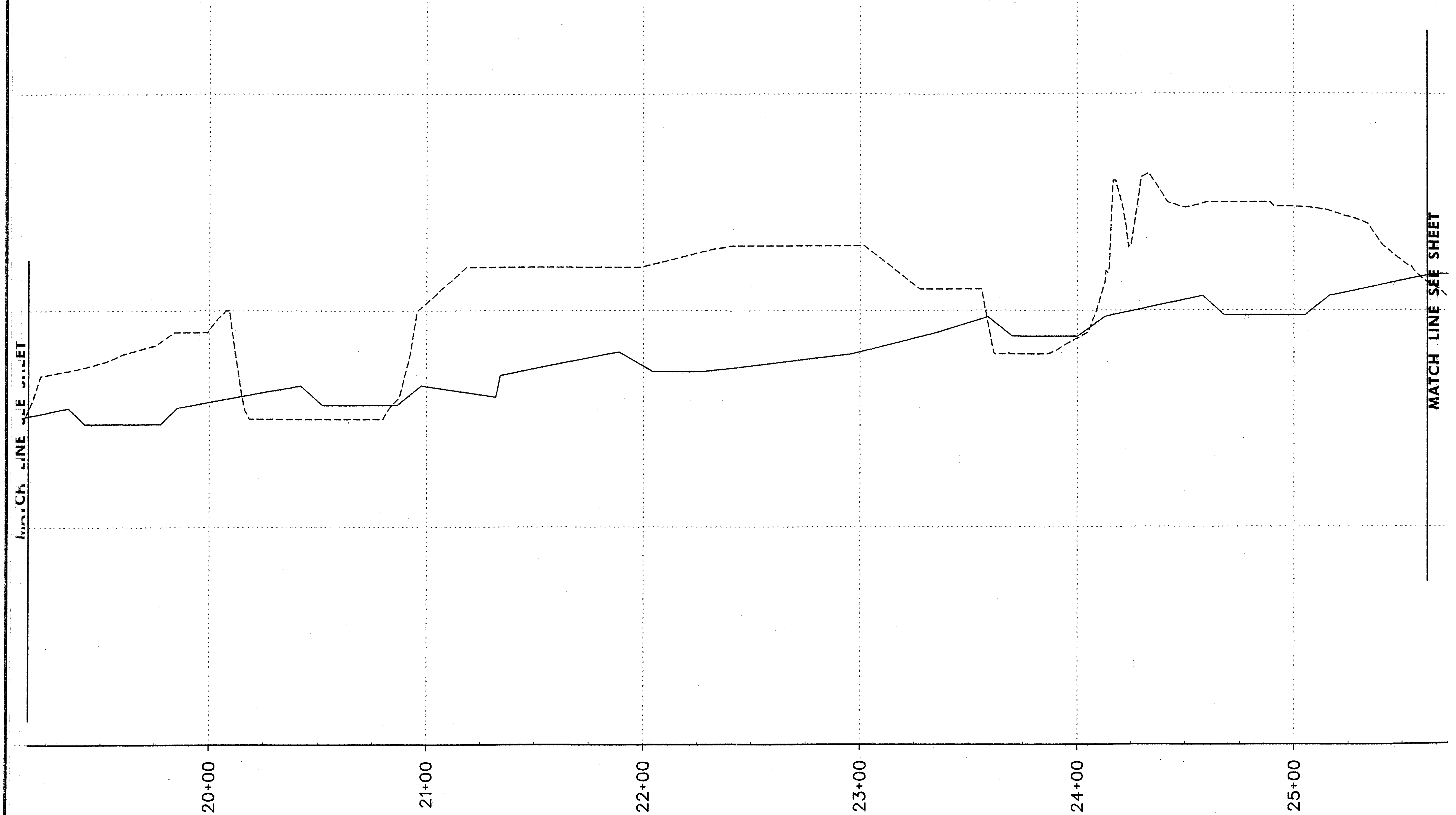
BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

PROFILE

SCALE: AS SHOWN
CONTRACT NO.
SHEET ? OF 30



REVISION		
DATE	BY	DESCRIPTION

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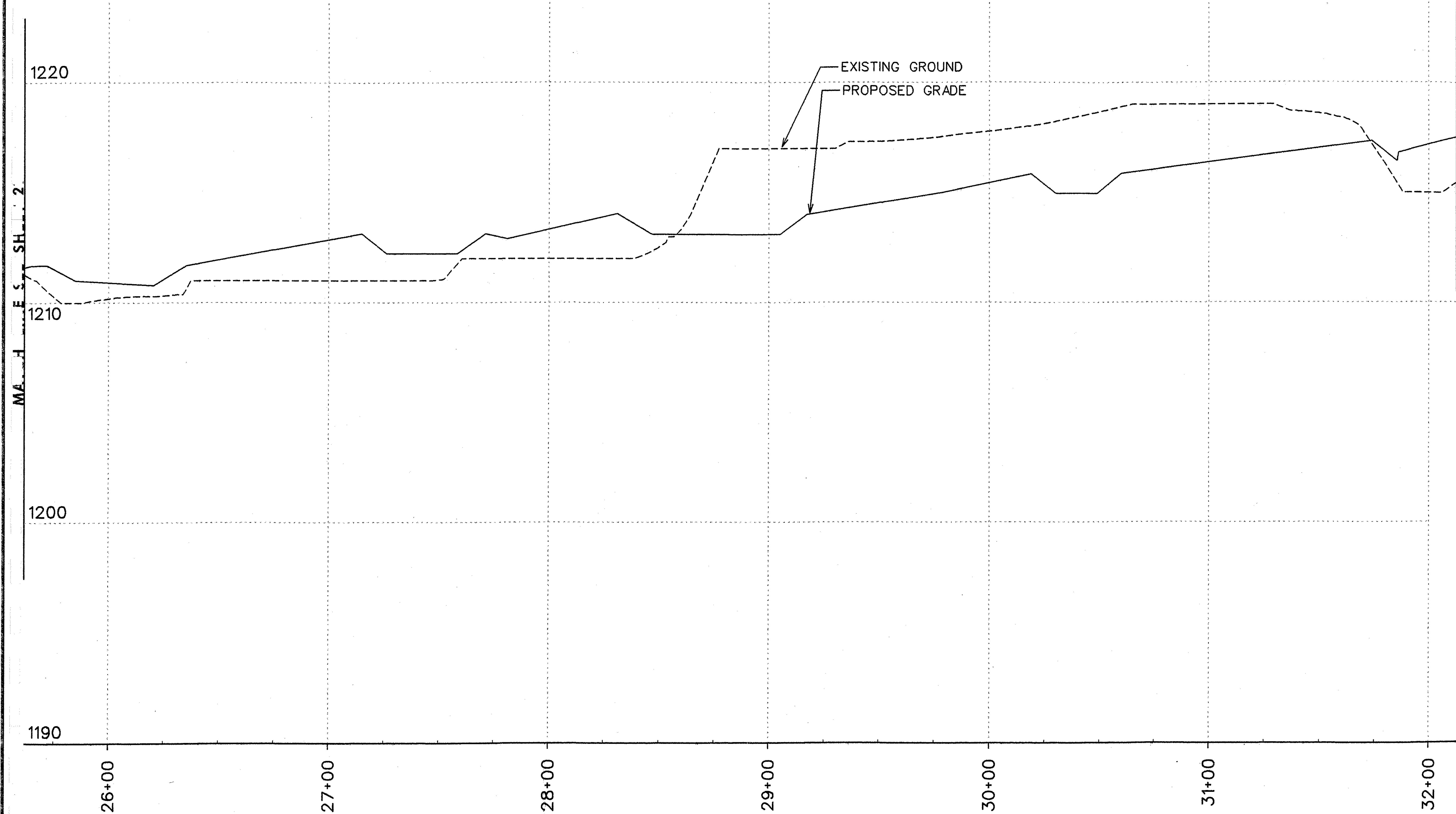
BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

PROFILE

SCALE: AS SHOWN
CONTRACT NO.
SHEET ? OF 30



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DATE	BY	DESCRIPTION

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Phone: 410-337-3659
Fax: 410-583-5678

BROWN BRANCH STREAM RESTORATION

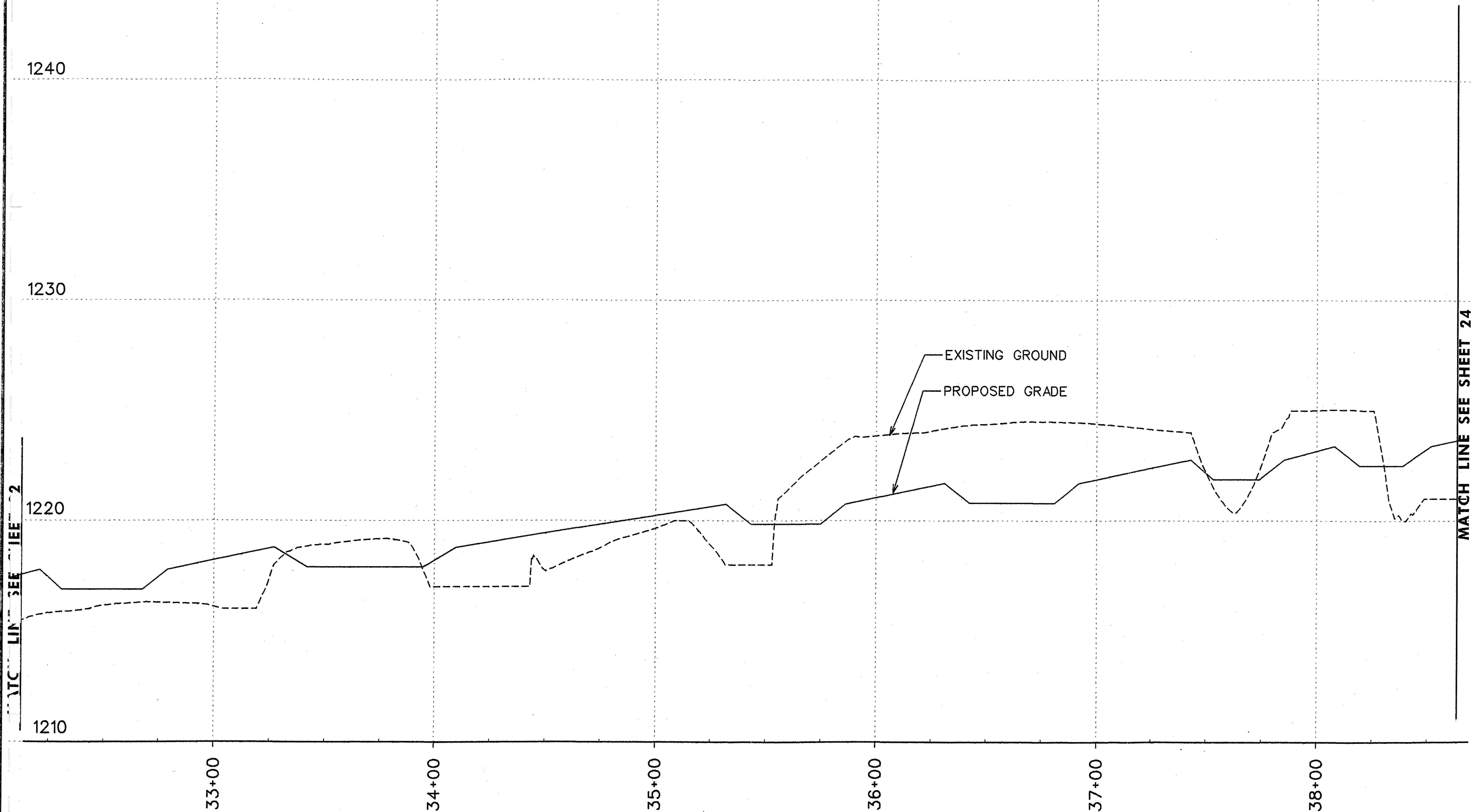
MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

PROFILE

SCALE: AS SHOWN

CONTRACT NO.

SHEET 22 OF 30



REVISION		
DATE	BY	DESCRIPTION

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15 West Aylesbury Road
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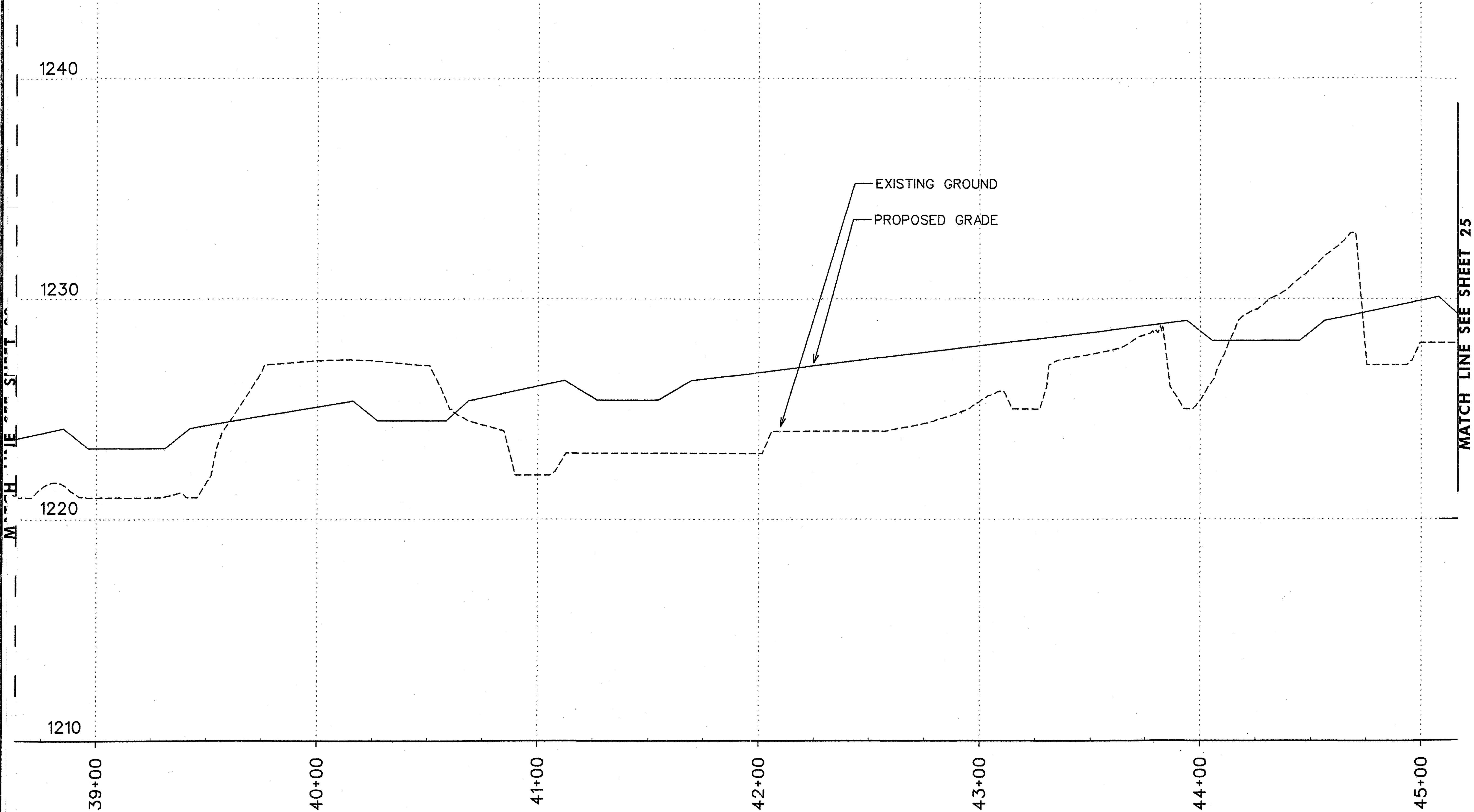
BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

PROFILE

SCALE: AS SHOWN
CONTRACT NO.
SHEET 23 OF 30



REVISION		
DATE	BY	DESCRIPTION

DATE: 1/24/02
DESIGNED: EMM
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CHECKED: JKB
APPROVED:
Biohabitats Project No.

Biohabitats,Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659
Fax: 410-583-5678

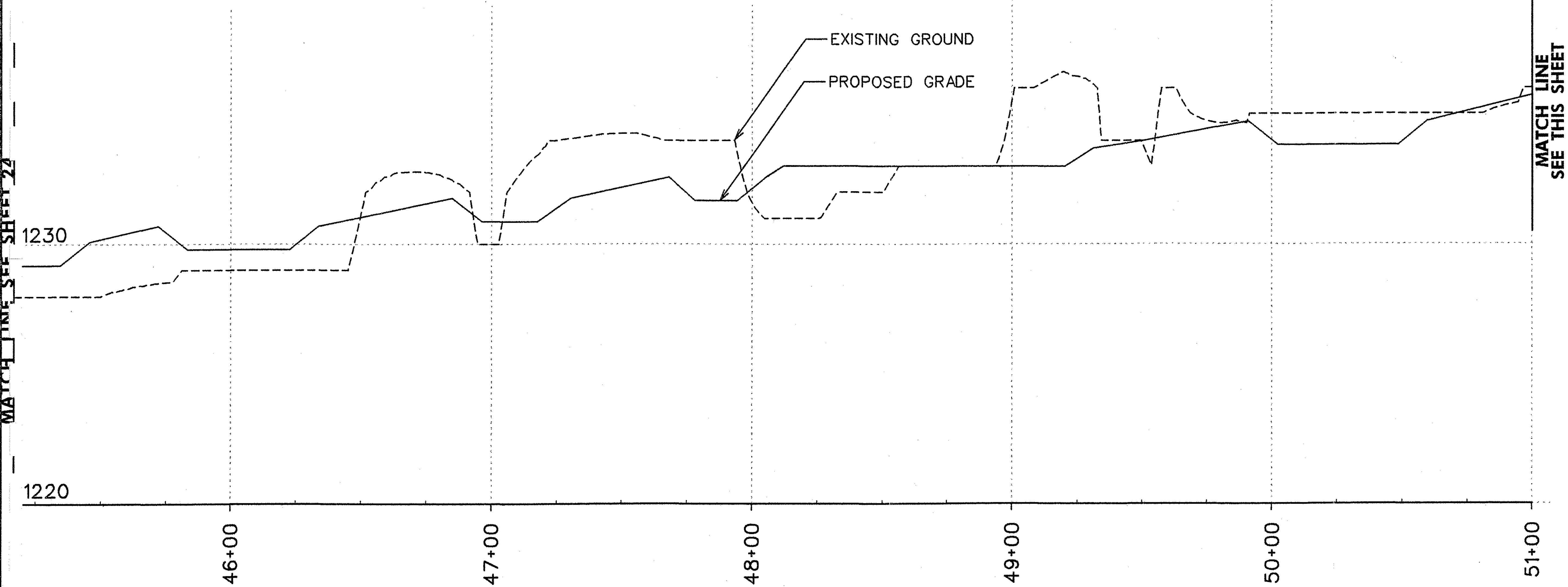
BROWN BRANCH STREAM RESTORATION

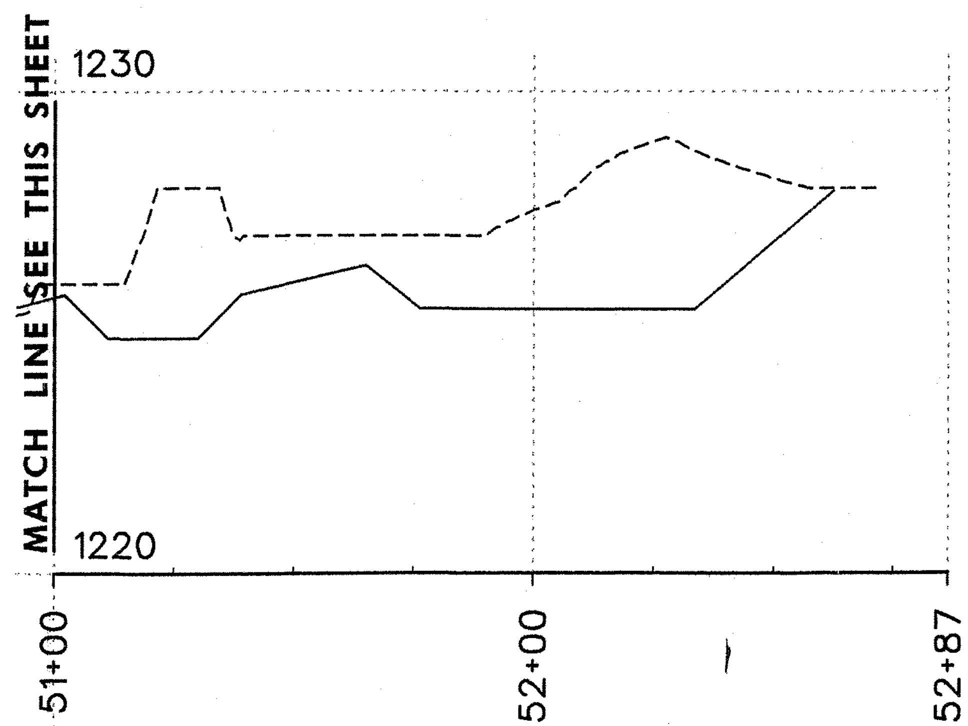
MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

PROFILE

SCALE: AS SHOWN

CONTRACT NO.





REVISION		
DATE	BY	DESCRIPTION

DATE: 1/24/02
DESIGNED: EMM
DRAWN: TLS
CHECKED: JKB
APPROVED:
Biohabitats Project No. 01015.01

Biohabitats, Inc.
15 West Aylesbury Road
Timonium, Maryland 21093
Phone: 410-337-3659
Fax: 410-583-5678
• Fostering Ecological Stewardship •

BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

PROFILE

SCALE: AS SHOWN
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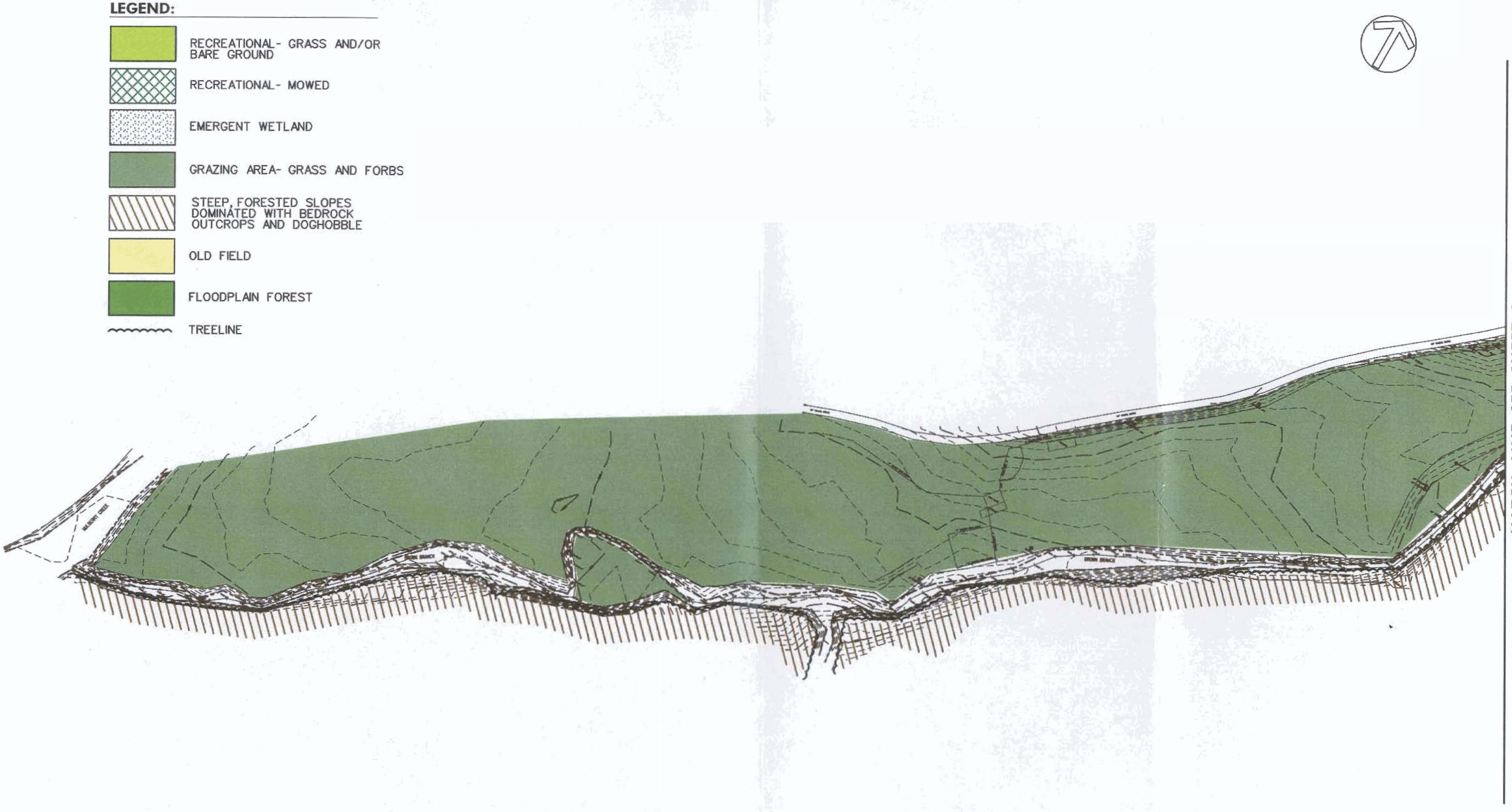
SHEET 25 OF 30

LEGEND:

- RECREATIONAL- GRASS AND/OR BARE GROUND
- RECREATIONAL- MOWED
- EMERGENT WETLAND
- GRAZING AREA- GRASS AND FORBS
- STEEP, FORESTED SLOPES DOMINATED WITH BEDROCK OUTCROPS AND DOGHOBBLE
- OLD FIELD
- FLOODPLAIN FOREST
- TREELINE



REVISION		
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BROWN BRANCH STREAM RESTORATION

MULBERRY TOWNSHIP CALDWELL COUNTY NORTH CAROLINA

EXISTING VEGETATION

SCALE: 1" = 60'-0"

CONTRACT NO.

SHEET 1 OF 30