South Muddy Creek Stream Restoration
McDowell County, North Carolina

NCDENR Contract D07032S

SCO Project No. 050666701

South Muddy Creek

South Fork Hoppers Creek

Prepared For

Ecosystem Enhancement Program
NC Department of Environment and Natural Resources
2090 US 70 Highway
Swannanoa, NC 28778

FINAL Restoration Plan
Submission Date: January 2008

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Report Prepared for

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EXECUTIVE SUMMARY

The Ecosystem Enhancement Program (EEP) proposes to restore, enhance, and preserve 7,499 linear feet (LF) of stream in the South Muddy Creek watershed in McDowell County, NC. The project includes work at two sites: 2,842 LF of South Muddy Creek at Sain Road and 4,657 LF of South Fork Hoppers Creek and three tributaries at the Landis Farm. The sites are located within the Muddy Creek LWP, identified by the Muddy Creek Partnership. A wetland area adjacent to South Fork Hoppers Creek will also be enhanced and restored. The project sites are located on agricultural tracts in the rural foothills near Marion, NC, as shown in Figure 1.1.

A summary of goals and objectives for each site part of this restoration project are as follows:

- South Muddy Creek Site
  - South Muddy Creek was historically straightened for agricultural purposes. The channel is currently incised and disconnected from the floodplain. Shear stress forces on the bed and banks have caused erosion. The goals for this project site are to restore the channel to geomorphically stable conditions, restore connectivity to a floodplain, improve water quality in the watershed, and improve aquatic and terrestrial habitat. A wide floodplain bench will be excavated and a new channel with stable dimension and pattern will be constructed. The channel will access the floodplain during bankfull or larger storm events, increasing hydrologic connections between the creek and floodplain and alleviating erosive shear stresses. Bedform diversity and varied structures will be incorporated into the design to provide a variety of aquatic habitats. The floodplain will be treated for invasive species and planted with a native riparian buffer to improve terrestrial habitat. Together, the increased infiltration provided through floodplain access and a healthy riparian community, combined with the elimination of excessive sedimentation from erosion, will improve water quality in the South Muddy Creek watershed.

- South Fork Hoppers Creek Site
  - The South Fork Hoppers Creek site has historically operated as a farm, and the majority of the site is currently in pasture. Channels throughout the site have been impacted by livestock and are incised and eroding. As the stream incised, the water table dropped, dewatering floodplain wetlands. The goals for the project site are to create geomorphically stable channels, restore connectivity to the floodplain, restore wetlands in a Piedmont/Low Mountain Alluvial forest, increase water quality, and improved aquatic and terrestrial habitat. To accomplish these goals, a combination of restoration and enhancement will be used. Restoration and enhancement will stabilize the eroding channel. Areas where Priority 1 restoration is used will result in increased connectivity with the floodplain and will restore historic floodplain wetlands. Both restoration and enhancement activities will diversify the bedform to improve aquatic habitat, and native revegetation of the floodplain will improve terrestrial habitat. Existing floodplain wetlands will be enhanced, and floodplain wetlands will be restored, where feasible. Removal of cattle and pigs, increased floodplain infiltration, and reduced sedimentation will improve water quality in the South Muddy Creek watershed. Additionally, the South Fork Creek watershed is threatened by nearby rapid development, so early natural resource protection in areas such as these is of critical importance.

Table ES.1 Restoration Plan Overview
South Muddy Creek Restoration Plan

Project Feature	Project Site	Existing Condition	Design Condition	Approach
South Muddy Creek	Sain Road	2,593 LF	2,842 LF	Rosgen Priority 2 Restoration
South Fork Hoppers Creek	Landis Farm	1,350 LF	1,244 LF	Rosgen Priority 1 Restoration
UT1- Reach A	Landis Farm	782 LF	782 LF	Preservation
UT1- Reach B	Landis Farm	970 LF	1,169 LF	Rosgen Priority 1 Restoration
UT2- Reach A	Landis Farm	366 LF	362 LF	Enhancement II
UT2- Reach B	Landis Farm	802 LF	802 LF	Enhancement II
UT3	Landis Farm	298 LF	298 LF	Preservation
Total Stream		**7,161 LF**	**7,499 LF**	
Wetland 1	Landis Farm	0.33 acre	0.33 acre	Enhancement
			1.29 acre	Restoration

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 INTRODUCTION, GOALS, AND LOCATION

1.1 Project Description

The North Carolina Ecosystem Enhancement Program (EEP) proposes to restore, enhance, and preserve 7,499 linear feet (LF) of stream in McDowell County, NC. The South Muddy Creek Stream Restoration project includes two project sites: the South Muddy Creek site located off of Sain Road and the South Fork Hoppers Creek site located off of Landis Lane. Figure 1.1 illustrates site locations. The streams proposed for restoration include approximately 2,593 LF of existing stream length along South Muddy Creek as shown in Figure 1.2 and 4,568 LF of existing stream length along South Fork Hoppers Creek and associated tributaries as shown in Figure 1.3. This project will also include the enhancement of up to 0.33 acre of riverine wetlands and the restoration of up to 1.29 acres of riverine wetlands. This project represents a unique opportunity to restore portions of the South Muddy Creek watershed as a part of the greater South Muddy Creek Watershed Initiative.

1.2 Goals

This project has been selected by EEP because the project sites are degraded and have high potential for restoration and enhancement of both streams and wetlands. The channels proposed for restoration are incised and have actively eroding banks. These reaches are disconnected from their historic floodplains and will continue to undergo bank erosion and degradation until a new floodplain forms at a lower elevation. The stream incision has caused the water table level to drop at Landis Farm, thus causing the riverine wetlands associated with the historic floodplain to shrink and lose function. Both project sites have been maintained for agricultural purposes. At both the South Muddy Creek and the Landis Farm site, fields are maintained up to the edge of the channel, preventing valuable riparian species from moving in to stabilize the banks. At the Landis site, cattle and pigs have free access to the stream channel. Bank instability from hoof shear is common, as is animal waste in the channel and riparian zone. The stream and riparian habitat values are impaired from agricultural encroachment, sediment loading into the stream, and the spread of invasive species within the riparian zone. In addition to agricultural encroachment, the South Fork Hoppers Creek watershed is threatened by development. Adjacent watersheds are rapidly developing, and protecting natural resources within the South Fork Hoppers Creek watershed is essential now before development endangers them.

The goals for the restoration project are as follows:

- Create geomorphically stable conditions for the streams on the project site.
- Enhance and restore wetland functions.
- Improve and restore hydrologic connections between creek and floodplain.
- Improve the water quality in the South Muddy Creek watershed.
- Improve aquatic and terrestrial habitat along the project corridor.
- Restore wetlands within a Piedmont/Low Mountain Alluvial Forest (Schaflale and Weakley, 1990).

To accomplish these goals, we recommend the following:

- Restore the existing incised, eroding, and channelized streams by creating stable channels with access to a floodplain.
- Restore wetland hydrology on the South Fork Hoppers site by providing a Rosgen Priority 1 stream restoration approach to raise the water table near to the existing floodplain.
- Improve water quality by establishing buffers for nutrient removal from runoff, by stabilizing stream banks to reduce bank erosion and sediment contribution to creek flows, and by fencing out livestock.
- Improve in-stream habitat by providing a more diverse bedform with riffles and pools, creating deeper pools and areas of water re-aeration, providing woody debris for habitat, and reducing bank erosion.

- Improve terrestrial habitat by planting riparian areas and wetland areas with native plant species.
- Establish native stream bank and floodplain vegetation in a permanent conservation easement to increase storm water runoff filtering capacity, improve bank stability, provide shading to decrease water temperature and provide cover, and improve wildlife habitat.

1.3 Directions to the Project Site

The South Muddy Creek Restoration project includes work at two sites: South Muddy Creek at Sain Road and South Fork Hoppers Creek and its tributaries at Landis Farm. Both project sites are near Marion, NC, as shown in Figure 1.1. The latitude and longitude at the center of each site are provided in Table 1.1

Table 1.1 Latitude and Longitude of Project Sites
South Muddy Creek Restoration Plan

Project Site	Latitude	Longitude
South Muddy Creek at Sain Road	35˚ 37' 31.33" N	81˚ 51' 29.47" W
South Fork Hoppers Creek at Landis Farm	35˚ 34' 38.18" N	81˚ 52' 45.82" W

1.3.1 Directions to South Muddy Creek

The South Muddy Creek stream restoration site is located approximately nine miles southeast of Marion in McDowell County, North Carolina, as shown in Figure 1.1.

Driving directions to the project site are as follows.

- From I-40, take State Route 226 South (I-40 exit 86).
- Continue approximately 10 miles south.
    - Turn left onto Trinity Church Loop.
    - Turn left onto Dysartville Road. Continue approximately 1 mile.
    - Turn left onto Sain Road (this road is an unpaved road). Continue approximately 0.5 mile to the bridge at South Muddy Creek.

1.3.2 Directions to South Fork Hoppers Creek

The South Fork Hoppers Creek stream and wetlands restoration site is located approximately 10 miles southeast of Marion in McDowell County, North Carolina, as shown in Figure 1.1.

Driving directions to the project site are as follows.

- From I-40, take State Route 226 South (I-40 exit 86).
- Continue approximately 10 miles south.
    - Turn right onto Landis Lane. Continue approximately 1 mile. Bear right at a fork in the road to stay on Landis Lane. Continue approximately 2 miles.
    - Landis Farm will be on the left, at sharp curve to the right.

1.4 USGS Hydrologic Unit Code and NCDWQ River Basin Designations

The South Muddy Creek Stream Restoration project is located in the Catawba River Basin. The site lies within the NCDWQ sub-basin 03-08-30 and hydrologic unit 03050101040020. Figure 1.1 depicts the basin boundaries and HUC’s for the project reach.

2.0 WATERSHED CHARACTERIZATION

2.1 Watershed Delineation

Table 2.1 displays the drainage areas for the stream reaches within the project boundaries. Figures 2.1 and 2.2 depict the drainage areas for each project reach.

Table 2.1 Drainage Areas By Reach
South Muddy Creek Restoration Plan

Reach	Acres	Square Miles
South Muddy Creek	12,032.0	18.8
South Fork Hoppers Creek	332.8	0.52
UT1A – UT of South Fork Hoppers Creek	48.6	0.06
UT1B – UT of South Fork Hoppers Creek	35.2	0.08
UT2A – UT of South Fork Hoppers Creek	25.6	0.04
UT2B – UT of South Fork Hoppers Creek	44.8	0.07
UT3 – UT of South Fork Hoppers Creek	12.0	0.02

2.2 Surface Water Classification/ Water Quality

NCDWQ designates surface water classifications for water bodies such as streams, rivers, and lakes which define the best uses to be protected within these waters (e.g., swimming, fishing, and drinking water supply). These classifications are associated with water quality standards that govern those uses. All surface waters in North Carolina must meet the minimum standards for fishable/swimmable waters (Class C). The other classifications provide additional levels of protection for primary water contact recreation (Class B) and drinking water supplies (WS). Class C waters are protected for secondary recreation, fishing, wildlife, fish and aquatic life propagation and survival, agriculture, and other uses. Classifications and their associated protection standards may also be designated to protect the free-flowing nature of a stream or other special characteristics.

Both South Muddy Creek and South Fork Hoppers Creek are classified by the NCDWQ as Class C waters (DWQ Index No. 11-32-2 and 11-32-2-9-1, respectively). Based on North Carolina's tributary rule, the tributaries would also be considered Class "C" waters. South Muddy Creek has seen improving water quality in the past monitoring cycle as demonstrated by the benthic macroinvertebrate Use Support rating increase from 'supporting but threatened' in 1998 to 'supporting' in 2004. However, the Catawba River Sub-basin Plan (NCDENR, 2004) continues to identify the Muddy Creek watershed as impacted by excessive sediment loads and notes that this watershed is a prime candidate for restoration and enhancements.

2.3 Physiography, Geology and Soils

South Muddy Creek and South Fork Hoppers Creek lie within the Piedmont physiographic province. Medina et al.'s *Physiography of North Carolina* map (2004) describes the Piedmont province as

> …consist(ing) of generally rolling, well-rounded hills and ridges with a few hundred feet of elevation difference between the hills and valleys. Elevations in the Piedmont range from 300 to 600 feet above sea level near its border with the Coastal Plain to 1,500 feet at the foot of the Blue Ridge. Resistant knobs and hills, called monadnocks, which occur in the Piedmont Province, include the Sauratown, South, and Uwharrie Mountains.

Within the Piedmont physiographic province, the South Muddy Creek and South Fork Hoppers Creek sites lie within the Inner Piedmont Belt, which is comprised mainly of thinly layered mica and biotite gneiss. The geology within the South Muddy Creek is mapped as migmatitic granitoid gneiss that is described as medium- to coarse-grained, gray, thickly layered gneissic biotite granite to quartz diorite. The South Fork Hoppers Creek site is mostly underlain by migmatitic granitoid gneiss with lesser amounts of schist, quartzite, and inequigranular biotite gneiss mapped along or close to the western edge of the South Fork Hoppers Creek site in the vicinity of UT2 (Goldsmith, 1988).

The soils surrounding the South Muddy and South Fork Hoppers sites are primarily Hayesville clay loam, Hayesville-Evard Complex, and Iotla sandy loam. Within the South Muddy Creek project boundary, Iotla sandy loam dominates with a small portion of the site consisting of Evard-Cowee complex (Figure 2.3). Iotla sandy loams are very deep, somewhat poorly drained soils. Permeability is moderately rapid and shrink-swell potential is low with the potential for occasional flooding. Evard-Cowee complex soils form in residuum from granite, schist, and gneiss. Evard soils are very deep and well drained. Permeability is moderate and shrink-swell potential is low. Cowee soils are moderately deep and well drained. Soft bedrock is within a depth of 20 to 40 inches. Permeability is moderate and shrink-swell potential is low.

The soils within the South Fork Hoppers Creek site boundaries are dominated by Iotla sandy loams with small portions of Evard-Cowee, Hayesville loam, and Hayesville clay loam (Figure 2.4). Hayesville loams are strongly sloping, very deep, and well drained soils on uplands. They formed in residuum from granite, gneiss, and schist. Permeability is moderate and shrink-swell potential is low. Hayesville clay loams are strongly sloping, very deep, well drained, eroded soils on uplands. They also form the in residuum from granite, gneiss, and schist. Permeability is moderate and shrink-swell potential is low.

2.4 Historic Land Use and Development Trends

The South Muddy Creek watershed is predominately forested, supporting some isolated rural residential housing, chicken farms, agricultural lands, nurseries, and several small rural residential developments. The majority of residences located within the watershed appear to have been built in the mid- to late twentieth century and there is no evidence of rapid future development. Table 2.2 presents the land use percentages within the South Muddy Creek watershed upstream of the project location. In the early 1960's the McDowell County Natural Resources Conservation Service (NRCS) constructed a flood control structure within South Muddy Creek approximately three miles upstream from the project boundary. This structure controls flows from approximately 12.4 square miles of the watershed and is located on privately-owned land and is maintained by the NRCS (for further information, see Section 3.3).

Within the project boundary, the land surrounding the South Muddy Creek site has been used predominantly for crop cultivation. A small percentage of land near the upstream and downstream extents of the project boundary is forested. Figure 1.2 depicts the agricultural area surrounding the project.

The South Fork Hoppers Creek watershed is predominately forested. Isolated rural residential houses, a chicken farm, and agricultural lands are located along Joe Branch Road, a road which follows the ridgeline of the watershed. Within the overall South Fork Hoppers Creek watershed, UT1 drains predominately forested land in addition to three newly constructed residential homes located at the upstream extent of the watershed. UT2 drains predominately forested land and a small fallow field. Table 2.2 presents the land use percentages within the South Fork Hoppers Creek site watershed upstream of the project location.

Within the project boundary, the dominant land use surrounding South Fork Hoppers Creek, UT1, and UT2 is agricultural pasture with some forested land at the upstream extents of UT1, UT2 and UT3. The development trend within the watershed appears to be slow residential growth with no impending threat of large scale residential subdivisions, commercial development, or industrial development; however, adjacent watersheds are seeing rapid residential growth. The proximity of rapid development highlights the importance of natural resource protection in the South Fork Hoppers Creek watershed.

Table 2.2 Watershed Land Use South Muddy Creek Restoration Plan		
South Muddy Creek Site Watershed Land Use		
Land Use Category	**Area (acres)**	**Percent Area**
Deciduous Forest	7,982	66.4
Pasture/Hay	1,267	10.5
Evergreen Forest	1,182	9.8
Shrub/Scrub	634	5.3
Developed Open Space	434	3.6
Grassland/Herbaceous	204	1.7
Mixed Forest	143	1.2
Cultivated Crops	70	0.6
Woody Wetlands	65	0.5
Barren Land (Rock/Sand/Clay)	29	0.2
Open Water	10	0.1
Developed Low Intensity	10	0.1
South Fork Hoppers Creek Site Watershed Land Use		
Land Use Category	**Area (acres)**	**Percent Area**
Deciduous Forest	195	59.7
Pasture/Hay	50	15.3
Shrub/Scrub	38	11.6
Grassland/Herbaceous	22	6.7
Developed Open Space	12	3.5
Cultivated Crops	5	1.5
Evergreen Forest	4	1.1
Barren Land (Rock/Sand/Clay)	2	0.6

2.5 Endangered/Threatened Species

Some populations of plants and animals are declining because of either natural forces or their inability to compete for resources with the encroachment of humans. The North Carolina Natural Heritage Program (NHP) and United States Fish and Wildlife Service (USFWS) lists of rare and protected animal and plant species contain five federally listed species known to exist in McDowell County (USFWS, 2006 and NCNHP, 2001).

Legal protection for federally listed species, Threatened (T) or Endangered (E) status, is conferred by the Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1534). This act makes illegal the killing, harming, harassing, or removing of any federally listed animal species from the wild; plants are similarly protected but only on federal lands. Section 7 of this act requires federal agencies to ensure that actions they fund or authorize do not jeopardize any federally listed species.

Organisms that are listed as Endangered (E), Threatened (T), or Special Concern (SC) on the NHP list of Rare Plant and Animal Species are afforded state protection under the State Endangered Species Act and the North Carolina Plant Protection and Conservation Act of 1979.

Species that the NHP and USFWS list under federal protection for McDowell County as of February 6, 2007, are listed in Table 2.3. A brief description of the characteristics and habitat requirements of the federally protected species is included in the following section, along with a conclusion regarding potential project impacts.

Table 2.3 Species of Federal and State Status in McDowell County, NC
South Muddy Creek Restoration Plan

Family	Scientific Name	Common Name	Federal Status	State Status	Habitat Present / Biological Conclusion
Vertebrates					
Sciuridae	*Glaucomys sabrinus coloratus*	Carolina Northern Flying Squirrel	E	E	No/No Effect
Emydidae	*Glyptemys muhlenbergii*	Bog Turtle	T	T	No on South Muddy Creek site/ No Effect Suitable Habitat on South Fork Hoppers Creek site/ Not Likely To Affect
Accipitridae	*Haliaeetus leucocephalus*	Bald Eagle	T	T	No/No Effect
Vascular Plants					
Cistaceae	*Hudsonia montana*	Mountain golden heather	T	E	No/No Effect
Orchidaceae	*Isotria medeoloides*	Small whorled pogonia	T	E	Suitable Habitat/No Effect

Note:
E An Endangered species is one whose continued existence as a viable component of the state's flora or fauna is determined to be in jeopardy.
T Threatened

2.5.1 Site Evaluation Methodology

A pedestrian survey of the project area was conducted in January 2007 for the species listed in Table 2.3. A second survey was conducted in May 2007 for the small whorled pogonia during its blooming season. No federal protected species were observed in or adjacent to the project area during the field surveys.

2.5.2 Federally-Protected Species

2.5.2.1 Vertebrates

***Glaucomys sabrinus coloratus* (Carolina Northern Flying Squirrel)**
Federal Status: Endangered
Animal Family: Sciuridae
Federally Listed: July 1, 1985

The northern flying squirrel is a small, nocturnal mammal that inhabits the high elevation ecotone between coniferous and northern hardwood forest. This high elevation habitat usually occurs above 5,500 feet of elevation. These squirrels are 10 to 12 inches long and weigh 3 to 5 ounces. Adults are gray with a light brown to reddish cast on their backs and light gray to white or buff undersides. The broad tails and folds of skin between the wrist and ankles form wing-like surfaces that enable these animals to glide downward from tree to tree or tree to ground. These mammals eat a wide variety of foods such as lichens, mushrooms, seeds, nuts, insects, and fruit. These squirrels nest in tree cavities such as woodpecker holes and usually produce one litter in the early spring.

The highest elevation on the South Muddy Creek restoration site is approximately 1,170 feet above Mean Sea Level (MSL), well below the location of the hardwood forest to coniferous forest ecotone preferred by this species. Appropriate habitat for these squirrels is not available in the study area. A search of the NHP database of rare species and unique habitats conducted in January 2007 shows no occurrences of this species in the project areas; it is therefore concluded that this project will not impact this species.

The highest elevation on the South Fork Hoppers restoration site is approximately 1,320 feet above Mean Sea Level (MSL), well below the location of the hardwood forest to coniferous forest ecotone preferred by this species. Appropriate habitat for these squirrels is not available in the study area. A search of the NHP database of rare species and unique habitats conducted in January 2007 shows no occurrences of this species in the project areas; it is therefore concluded that this project will not impact this species.

Glyptemys muhlenbergii (Bog turtle)
Federal Status: Threatened Due to Similar Appearance
Animal Family: Emydidae
Federally Listed: November 4, 1997

Bog turtles are small (3 to 4.5 inches) turtles with a weakly-keeled carapace (upper shell) that ranges from light brown to ebony in color. The species is readily distinguished from other turtles by a large, conspicuous bright orange to yellow blotch on each side of its head. Mating occurs from late April to early June. Eggs hatch in late July to early September.

Bog turtles are semi-aquatic and are only infrequently active above their muddy habitats during specific times of year and temperature ranges. They can be found during the mating season from June to July and at other times from April to October when the humidity is high, such as after a rain event, and when temperatures are in the seventies. Bog turtle habitat consists of bogs, swamps, marshy meadows, and other wet environments, specifically those that have soft, muddy bottoms. Its habitat usually contains an abundance of grassy or mossy cover. The turtles depend on a mosaic of microhabitats for foraging, nesting, basking, hibernation, and shelter (USFWS, 2000). "Unfragmented riparian systems that allow for the natural creation of open habitat are needed to compensate for ecological succession" (USFWS, 2000). Beaver, deer, and cattle may be instrumental in maintaining the essential open-canopy wetlands (USFWS, 2000).

The bog turtle is not nearly as rare as once thought, though it is still uncommon and adversely affected by continual habitat destruction and over-collection. The southern populations of bog turtles (in VA, TN, NC, SC, and GA) are listed as threatened due to similar appearance to northern bog turtles that are listed as threatened.

No suitable habitat exists for the bog turtle in the South Muddy Creek project area. The North Carolina Natural Heritage Program (NHP) database of rare species and unique habitats, checked in January 2007, indicates no records of occurrences in the study area. No bog turtles were observed or recorded in or near the study area, and the suitable habitat that exists within the project area is marginal. Therefore, it is anticipated that project construction will not affect the bog turtle.

The NHP files indicate a known population of bog turtles (first recorded in May 1993) approximately 3.5 miles southeast of the South Fork Hoppers Creek project area in a marshy meadow or degraded Southern Appalachian bog ("Vein Mountain Meadow Bog") adjacent to Second Broad River and SR 1781 in McDowell County approximately 0.5 mile (0.8 kilometer) south of SR 1802 junction.

Extremely marginal bog turtle habitat exists within the South Fork Hoppers Creek project area. One small wetland was identified and only portions of this wetland could be considered suitable habitat for the bog turtle. The entire wetland is located within an actively grazed field which has been disturbed and trampled, and the substrate at the time of the survey was thought to be marginal habitat for the bog turtle. Again, the bog turtle is listed as a result of similarity of appearance and populations are not in decline in the southeast region. We believe that restoration efforts are not likely to affect this species.

Haliaeetus leucocephalus (Bald eagle)
Federal Status: Threatened (Proposed for Delisting)
Animal Family: Accipitridae
Federally Listed: March 11, 1967; Proposed for Delisting: July 6, 1999

Bald eagles are large raptors, 32-43 inches (81-109 centimeters) long, with a white head, white tail, yellow bill, yellow eyes and feet. The lower section of the leg has no feathers. Wingspread is about 7 feet (2.1 meters). The characteristic plumage of adults is dark brown to black with young birds completely dark brown. Juveniles have a dark bill, pale markings on the belly, tail, and under the wings and do not develop the white head and tail until 5-6 years old (North Carolina Natural Heritage Program (NHP), 2001).

Bald eagles in the Southeast frequently build their nests in the transition zone between forest and marsh or open water. Nests are cone-shaped, 6-8 feet (1.8-2.4 meters) from top to bottom, and 6 feet (1.8 meters) or more in diameter. They are typically constructed of sticks lined with a combination of leaves, grasses, and Spanish moss. Nests are built in dominant live pines or cypress trees that provide a good view and clear flight path, usually less than 0.5 miles (0.8 kilometer) from open water. Winter roosts are usually in dominant trees, similar to nesting trees, but may be somewhat farther from water. In North Carolina, nest building takes place in December and January, with egg laying (clutch of 1-3 eggs) in February and hatching in March. Bald eagles are opportunistic feeders consuming a variety of living prey and carrion. Up to 80% of their diet is fish; self caught, scavenged, or robbed from osprey. They may also take various small mammals and birds, especially those weakened by injury or disease (NHP, 2001).

No suitable nesting or legitimate foraging habitat exists within either the South Muddy Creek or the South Fork Hoppers Creek site. Pine trees large enough to support bald eagle nests were not found in potential restoration areas, and were very limited in areas outside of the potential restoration areas. The North Carolina Natural Heritage Program (NHP) database of rare species and unique habitats, checked in January 2007, indicates no records of occurrences in the study area. No bald eagle nests or individuals were observed or recorded in or near the study area, and no potential habitat exists near either project area. Therefore, it is anticipated that project construction will have no effect on the bald eagle.

2.5.2.2 Vascular Plants

Hudsonia montana (Mountain golden heather)
Federal Status: Threatened
Plant family: Cistaceae
Federally Listed: October 20, 1980

Mountain golden heather is a low, needle-leaved shrub with yellow flowers and long-stalked fruit capsules. It usually grows in clumps of 4 to 8 inches across and about 6 inches high and sometimes is seen in larger patches of a foot or two across. The plants have the general aspect of a big moss or a low juniper, but their branching is more open, their leaves are about 0.25 inches long, and the plant is often somewhat yellow-green in color, especially in shade. The leaves from previous years persist scale-like on the older branches. The flowers appear in early or mid-June, and are yellow, nearly an inch across, with five blunt-tipped petals and 20 to 30 stamens. The fruit capsules are on 0.5-inch stalks, roundish, and with three projecting points at the tips. These fruits often persist after opening, and may be seen at any time of the year. Mountain golden heather begins flowering in about its third year, and roots vegetatively at the edges once they form well-rounded clumps, after perhaps 10 years. Large, well-rooted clones may become fragmented into separate, self-maintaining plants. The majority of the existing plants appear to have developed in this manner (USFWS, 2002).

This plant is found only in Burke and McDowell Counties, North Carolina, at elevations of 2,800 to 4,000 feet. Originally discovered on Table Rock Mountain in 1816, mountain golden heather has since been found at several other sites in Linville Gorge and on Woods Mountain. All sites are on public land within the Pisgah National Forest. Mountain golden heather is known from several localities within its range with the total number of plants possibly numbering 2,000 to 2,500. Monitoring is needed to determine if the plant's abundance may be cyclic (USFWS, 2002).

Mountain golden heather grows on exposed quartzite ledges in an ecotone between bare rock and leiophyllum dominated heath balds that merge into pine/oak forest. The plant persists for some time in the partial shade of pines, but it appears less healthy than in open areas.

No potential habitat exists at either the South Muddy Creek or the South Fork Hoppers Creek site for the mountain golden heather. The known populations are found in elevations well above the project area elevations. Also no heath balds are present within either project area. A search of the NHP database of rare species and unique habitats, conducted in January 2007, shows no occurrences of this species in the project area. Therefore, no impacts to this species are anticipated during the project construction.

Isotria medeoloides (Small whorled pogonia)
Federal Status: Threatened
Plant Family: Orchidaceae
Federally Listed: September 9, 1982

Small whorled pogonia is a small perennial member of the Orchidaceae. These plants arise from long slender roots with hollow stems terminating in a whorl of five or six light green leaves. The single flower is approximately one inch long, with yellowish-green to white petals and three longer green sepals. This orchid blooms in late spring from mid-May to mid-June. Populations of this plant are reported to have extended periods of dormancy and to bloom sporadically. This small spring ephemeral orchid is not observable outside of the spring growing season. When not in flower, young plants of Indian cucumber-root (*Medeola virginiana*) also resemble small whorled pogonia. However, the hollow stout stem of *Isotria* will separate it from the genus *Medeola*, which has a solid, more slender stem (USFWS, 1996).

Small whorled pogonia may occur in young as well as maturing forests, but typically grows in open, dry deciduous woods and areas along streams with acidic soil. It also grows in rich, mesic woods in association with white pine and rhododendron (Russo, 2000).

A search of the NHP database of rare species and unique habitats, conducted in January 2007, shows no occurrences of this species in either project area. Habitat does exist for the small whorled pogonia within the South Muddy Creek project area. The wooded bottomland hardwood forest area in the northeast portion of the project would be considered habitat for the small whorled pogonia.

Suitable habitat also is present within the South Fork Hoppers for the small whorled pogonia. The forested areas along UT1 and UT2 would be considered habitat for the small whorled pogonia.

An intensive field survey was conducted on May 21, 2007, during the species blooming season, to determine the presence of small whorled pogonia in the project area. No species were observed at either site within the project boundaries during the field survey; therefore no impacts to this species are anticipated during project construction.

2.5.3 USFWS Concurrence

The USFWS was notified of the project via letter on January 18, 2007, on March 7, 2007 regarding the results of the initial pedestrian survey, and again on May 24, 2007 regarding the second pedestrian survey. Baker Engineering has not received any comments from the USFWS at this point in time.

2.6 Cultural Resources

A letter was sent to the North Carolina State Historic Preservation Office (SHPO) on January 18, 2007, requesting review and comment for the potential of cultural resources in the vicinity of the project. Baker Engineering received a letter dated March 6, 2007, from SHPO recommending an archaeological survey of the site.

Due to the project's location within the aboriginal territory of the Cherokee people, a letter was also sent to the Eastern Band of Cherokee Indians Tribal Historic Preservation Office (THPO) on January 18, 2007, requesting their comment and review on the project. THPO responded with a letter dated March 19, 2007, requesting an archaeological survey of the site.

EEP has instructed Baker Engineering to continue with the project; EEP will reconcile SHPO and THPO responses.

2.7 Potential Constraints

Baker assessed the South Muddy Creek Restoration project site in regards to potential fatal flaws and site constraints. No fatal flaws have been identified during project design development.

2.7.1 Environmental Screening

An Environmental Data Resources, Inc (EDR) Radius Map Report that identifies and maps real or potential hazardous environmental sites within the distance required by the American Society of Testing and Materials Transaction Screening Process (ASTM E1528) was prepared for the site on January 22, 2007. Based on the EDR report, there are no known or potential hazardous waste sites within or adjacent to the project area. During field data collection, there was no evidence of any potential hazardous environmental sites in the proposed project area.

2.7.2 Utilities and Easements

Due to the project's remote rural location, utilities and easements are minimal. An overhead utility line parallels Sain Road, crossing South Muddy Creek approximately 50 feet downstream of the Sain Road bridge. No other utilities are present within the project boundaries. The Rutherford EMC electric cooperative will be contacted once a final design alignment is prepared for the South Muddy Creek site. We anticipate that one pole and guy wire will need to be moved and re-installed away from the stream's top of bank.

2.7.3 Property Ownership and Site Access

The land involved in the South Muddy Creek site is currently owned by Mr. Romulus Duncan and Mr. Larry Randolph. The land involved in the South Fork Hoppers Creek site is currently owned by Mr.

Steve Melton. EEP has informed Baker Engineering that the conservation easement for the South Muddy Creek site is being pursued, and the conservation easement option for the South Fork Hoppers Creek site is in the process of being renewed. As a result of shifting the creek alignments during restoration, portions of the existing South Fork Hoppers Creek and UT1B are located outside the proposed conservation easement. A temporary construction easement will be used to fill the existing channels after construction of the new meandering channels.

2.7.4 Hydrological Trespass and FEMA Flood Mapping

A Rosgen Priority 1 restoration is not feasible on the South Muddy Creek site, largely due to hydrologic trespass issues. The creek is too deeply incised to re-connect with its original floodplain without causing flooding upstream of the project boundary. A Rosgen Priority 2 restoration approach is feasible which will leave the channel at its existing elevation but will excavate bankfull benches to alleviate shear stress. Because additional conveyance area will be supplied by the excavated benches, we do not anticipate that the restored reach will flood more frequently or to greater extents than the existing condition.

Panel 200 of the FEMA Flood Insurance Rate Map (FIRM) for McDowell County, NC (Community Number 37111) indicates that the South Muddy Creek site is located in Zone A of the regulatory floodplain. Figure 2.5 illustrates the FEMA mapping at the South Muddy Creek site.

Zone A is the flood insurance rate zone that corresponds to the 1-percent annual chance flood; this floodplain area is determined in the Flood Insurance Study by approximate methods of analysis. Because detailed hydraulic analyses are not performed for such areas, no Base Flood Elevations (BFE) or depths are shown within this zone. Based on communication with the McDowell County local floodplain administrator, no formal submittal will be required to document grading in the floodplain. A copy of this correspondence is included in Appendix 7.

The State of NC is currently preparing updated mapping for the state; base flood elevations will be established for this area once the updated maps are adopted. EEP may be required to complete a Letter of Map Revision following construction of the project at this site. Mapping available from the NC Flood Mapping Program indicates that this site on South Muddy will have a Zone AE flood designation, indicating that base flood elevations are being developed for this site. The Flood Mapping Program indicates that maps in this area are post-preliminary but are not yet effective.

Baker Engineering plans to pursue a Rosgen Priority 1 restoration on the South Fork Hoppers Creek mainstem. A transition zone will be required at the upstream project limits to gradually tie the channel back into its floodplain. The length of the transition zone will be designed to avoid hydrologic trespass onto the upstream property.

The topography of UT1B supports a Rosgen Priority 1 restoration design without creating the potential for hydrologic trespass. There is low potential for offsite backwater effects upstream of UT1B because the Priority 1 design stops 782 LF short of the project boundary. The reach upstream of UT1B, UT1A, is slated for preservation. Restoring connectivity between the streambed and its floodplain will cause the floodplain adjacent to the restored reaches to flood more frequently and to greater extents than that of the existing condition. The flooding may extend outside of the proposed conservation easement boundaries.

FIRM Panel 200 for McDowell County indicates that there is no regulatory floodplain associated with the project on South Fork Hoppers Creek. No formal submittals will be required to document grading in the floodplain for this site. Figure 2.6 illustrates the currently effective FEMA mapping near the South Fork Hoppers Creek site. Mapping available from the NC Flood Mapping Program indicates that this site on South Fork Hoppers Creek will remain unmapped.

3.0 PROJECT SITE STREAMS (EXISTING CONDITIONS)

3.1 Existing Channel Geomorphic Characterization and Classification

South Muddy Creek is a perennial channel and a USGS blue-line stream. On February 7, 2007, onsite perennial and intermittent stream calls were made at the South Fork Hoppers Creek site following the scoring criteria from the North Carolina Division of Water Quality. South Fork Hoppers Creek, UT1, UT2, and UT3 were identified as perennial streams. Stream classification forms are included in Appendix 3.

Baker Engineering performed representative longitudinal and cross-section surveys of the stream reaches to assess the current condition and overall stability of the channels. Baker Engineering also performed pebble counts and collected substrate samples to characterize stream sediments. Figures 3.1 and 3.2 illustrate the locations of cross-section surveys on the South Muddy Creek site and the South Fork Hoppers Creek site, respectively. The following sections of this report summarize the survey results for the stream reaches proposed for work. A photo log of the sites is included in Appendix 1.

3.1.1 South Muddy Creek

The South Muddy Creek site is depicted in Figure 1.2 and is comprised of one reach. South Muddy Creek flows through a broad, alluvial floodplain characteristic of a Rosgen Valley Type VIII. Alluvial terraces typically present in a Valley Type VIII were not observed along South Muddy Creek; however historic agricultural manipulation of the floodplain in the form of filling, grading, and plowing has likely altered the topography of the area. The overall valley slope is 0.0017 feet per foot (ft/ft).

Within the project limits, South Muddy Creek was historically straightened to maximize available agricultural land. South Muddy runs against the steep, forested right valley wall for the first 300 LF. The channel is slightly sinuous and has defined riffle-pool sequences. Depositional features such as point bars are common in this upper section of the channel. South Muddy Creek departs from the valley wall and the channel is straight throughout the rest of the project area. Moderate riffle-pool sequences are present, however few depositional features were observed. A log debris jam, downstream of Sain Road bridge, has created backwater that extends 1,000 LF upstream. The baseflow water surface slope through the backwatered area is 0.0006 ft/ft. Below the debris jam, riffles and pools are well-defined. The overall channel slope is 0.0016 ft/ft.

Cross sections were surveyed at five riffle sections and four pools to characterize the channel. The channel has a low width-to-depth ratio, is incised as evidenced by bank height ratios of 2.4 to 3.2, and does not have access to a floodplain at bankfull stage. A reach-wide pebble count classified the overall channel materials as fine gravel. Within the project limits, South Muddy Creek is classified as a Rosgen stream type G4c. This channel type is commonly seen in Valley Type VIII throughout the Piedmont where agricultural activities have directly impacted the channel and riparian zone, resulting in an unstable system. One cross section, X1A, was noted as atypical of the rest of the reach. This cross section, located at the head of the project, has channel dimensions more typical of an F4 channel with a width-to-depth ratio is 26.9. This suggests that the first few hundred feet of the project reach are a transition zone between a different channel type upstream and the G4c channel type observed downstream.

Table 3.1 summarizes the geomorphic parameters of South Muddy Creek.

Table 3.1 Existing Geomorphic Characteristics of South Muddy Creek South Muddy Creek Restoration Plan	**South Muddy Creek**			
	Min	**Max**	**Avg**	**n***
1. Stream Type	G4c			
2. Drainage Area – mi^2	18.8			
3. Bankfull Width (w_{bkf}) – ft	24.1	51.2	32.3	5
4. Bankfull Mean Depth (d_{bkf}) – ft	1.9	3.0	2.7	5
5. Width/Depth Ratio (w/d ratio)	8.1	26.9	12.9	5
6. Cross-sectional Area (A_{bkf}) – ft^2	72.8	97.2	83.8	5
7. Bankfull Max Depth (d_{mbkf}) - ft	3.3	4.0	3.6	5
8. d_{mbkf} / d_{bkf} ratio	1.2	1.7	1.4	5
9. Low Bank Height to d_{mbkf} ratio	2.4	3.2	2.8	5+
10. Floodprone Area Width (w_{fpa}) – ft	29.6	72.7	44.8	5
11. Entrenchment Ratio (ER)	1.1	1.7	1.4	5
12. Meander length (L_m) – ft	No feature - straightened			
13. Ratio of meander length to bankfull width (L_m/w_{bkf})	No feature - straightened			
14. Radius of curvature (R_c) – ft	No feature - straightened			
15. Ratio of radius of curvature to bankfull width (R_c / w_{bkf})	No feature - straightened			
16. Belt width (w_{blt}) – ft	No feature - straightened			
17. Meander Width Ratio (w_{blt}/W_{bkf})	No feature - straightened			
18. Sinuosity (K) stream length / valley length	1.06			
19. Valley Slope -ft/ft	0.0017			
20. Average Channel Slope (S_{bkf}) -ft/ft	0.0016			
21. Pool Slope (s_{pool}) -ft/ft	0.0000	0.0003	0.0001	6
22. Ratio of Pool Slope to Average Slope (S_{pool} / S_{bkf})	0.0	0.2	0.1	6
23. Maximum Pool Depth (d_{pool}) – ft	3.8	5.8	4.8	4
24. Ratio of Pool Depth to Average Bankfull Depth (d_{pool}/d_{bkf})	1.4	2.1	1.8	4
25. Pool Width (w_{pool}) – ft	28.1	39.9	32.3	4
26. Ratio of Pool Width-to-Bankfull Width (w_{pool} / w_{bkf})	0.9	1.2	1.0	4
27. Pool Area (A_{pool}) – ft^2	85.9	103.7	96.2	4
28. Ratio of Pool Area to Bankfull Area (A_{pool}/A_{bkf})	1.0	1.2	1.1	4
29. Pool-to-Pool Spacing (p-p) – ft	80.0	240.0	163.0	4
30. Ratio of Pool-to-Pool Spacing to Bankfull Width (p-p/w_{bkf})	2.5	7.4	5.0	4
31. Riffle Slope (s_{riffle}) -ft/ft	0.0025	0.0061	0.0043	3
32. Ratio of Riffle Slope to Average Slope (s_{riffle}/ s_{bkf})	1.6	3.8	2.7	3

Table 3.1 Existing Geomorphic Characteristics of South Muddy Creek South Muddy Creek Restoration Plan	**South Muddy Creek**			
	Min	**Max**	**Avg**	**n***
Channel Materials (Particle Size Index – d_{50})	Fine Gravel			
d_{16} - mm	<0.06			
d_{35} - mm	0.2			
d_{50} - mm	4			
d_{84} – mm	25			
d_{95} - mm	44			
n* – This column represents the number of data points used where a range or mean is specified.				

The South Muddy Creek reach is located approximately 2.6 miles downstream from an in-line flood control structure. This structure (referred to hereafter as the impoundment) is located on private land in McDowell County and is operated by the NRCS. The impoundment was built in the early 1960's in response to downstream flooding and is well maintained and functional today. The riser structure is designed to pass the base flow from the 12.4 square mile watershed, retaining water during flows higher than baseflow conditions. Because of the size of the impoundment, Baker Engineering studied the impoundment's effect on bankfull geometry and discharge. Please refer to Section 3.3.1 for detailed information.

3.1.2 South Fork Hoppers Creek - Mainstem

The mainstem of South Fork Hoppers Creek is depicted in Figure 1.3 and is comprised of one 1,350 LF reach. The overall valley slope is 0.0115 ft/ft and the overall channel slope is 0.0101 ft/ft. The area has a history of pasture and general agricultural usage. Cattle are allowed to graze on the banks and access the channels. The streams on the project site have been channelized and riparian vegetation has been cleared in most locations. Both the left and right banks of the channel are eroded and the channel is incised. Much of the mainstem was straightened for agricultural purposes, which resulted in a vertically and horizontally unstable channel.

The mainstem of South Fork Hoppers Creek has channel dimensions typical of an E stream type in the Rosgen classification system, but the stream is incised and lacks access to the floodplain. This reach functions as a G5c. Table 3.2 summarizes the geomorphic parameters of the mainstem of South Fork Hoppers Creek and the two unnamed tributaries.

3.1.3 UT1A

UT1A begins at the southern property line of the Landis Farm and continues approximately 782 LF downstream to a pasture clearing. This reach has extremely well-vegetated banks and a mature forested floodplain. Due to the stable conditions of the floodplain, this reach is proposed for preservation only. No geomorphic data were collected on this reach.

3.1.4 UT1B

UT1B begins just upstream of the southern edge of a pasture clearing and continues 970 LF downstream to South Fork Hoppers Creek. The channel has an overall valley slope of 0.023 ft/ft and a channel slope of 0.019 ft/ft. The channel has been straightened for agricultural purposes and subsequently incised and widened in an attempt to recreate a floodplain at a lower elevation. This channel has a bank height ratio of approximately 2 in most areas and does not have access to the historic floodplain during bankfull events. The floodplain is currently grazed and both the left and right banks show signs of recent bank erosion due to cattle access.

The channel has an extremely low width-to-depth ratio and is classified as an incised E5 Rosgen stream type. Table 3.2 summarizes the geomorphic parameters of UT1B.

3.1.5 UT2A

UT2A begins at the northwestern property line and continues 366 LF to the downstream end of the pig pen and the upstream end of a pasture clearing. The channel has an overall valley slope of 0.034 ft/ft and an overall channel slope of 0.030 ft/ft. UT2A is incised with a low width-to-depth ratio and is classified as a G5 channel. Mature woody vegetation is established on the top of banks of the channel; however shear banks are present throughout the reach. A 15 foot headcut has formed in a wet weather ditch near the upstream terminus of this reach. Frequent access by pigs within the pig pen area has caused mass erosion on the left and right banks and has destroyed bed and bank definition. Upstream of the property boundary, two large headcuts continue to erode the headwaters of UT2. Table 3.2 summarizes the geomorphic parameters of UT2A.

3.1.6 UT2B

UT2B begins at the top of the pasture clearing and continues 802 LF to the confluence with South Fork Hoppers Creek. On the downstream portion of the channel, the creek centerline serves as the property line for approximately 317 LF to the confluence with South Fork Hoppers Creek. UT2B is marked by a distinct change in valley and channel slope from UT2A; UT2B has an overall valley slope of 0.023 ft/ft and a channel slope of 0.019 ft/ft. UT2B has been maintained for agricultural purposes. This channel is incised and is disconnected from the historic floodplain. Bankfull bench features are beginning to form throughout much of the reach. UT2B has a very low width-to-depth ratio and currently functions as G5c. Table 3.2 summarizes the geomorphic parameters of UT2B.

3.1.7 UT3

UT3 is a headwater tributary to South Fork Hoppers Creek. Within the project limits, UT3 is approximately 298 LF in length and has a drainage area of 0.02 square miles. This channel is located in the southeast corner of the site and is slated for preservation only. A geomorphic assessment was not performed on this reach.

Table 3.2 Existing Geomorphic Characteristics of South Fork Hoppers Creek and Unnamed Tributaries South Muddy Creek Restoration Plan	South Fork Mainstem				UT1B				UT2A				UT2B			
	Min	**Max**	**Avg**	**n***	**Min**	**Max**	**Avg**	**n***	**Min**	**Max**	**Avg**	**n***	**Min**	**Max**	**Avg**	**n***
1. Stream Type	G5c				E5				G5				G5c			
2. Drainage Area – mi^2	0.52				0.08				0.04				0.07			
3. Bankfull Width (w_{bkf}) – ft	7.4	14.4	10.5	3	3.4	5.7	4.6	2	5.9			1	5.5	6.2	5.7	2
4. Bankfull Mean Depth (d_{bkf}) – ft	1.0	1.6	1.2	3	0.6	1.0	0.8	2	1.1			1	0.9	1.1	1.0	2
5. Width/Depth Ratio (w/d ratio)	6.1	14.4	9.3	3	3.4	9.5	6.5	2	5.4			1	5.0	6.2	5.6	2
6. Cross-sectional Area (A_{bkf}) – ft^2	7.4	15.6	12.5	3	3.4	3.5	3.5	2	6.1			1	5.4	6.1	5.8	2
7. Bankfull Max Depth (d_{mbkf}) - ft	1.7	2.0	1.9	3	1.3	1.6	1.4	2	1.4			1	1.3	1.5	1.4	2
8. d_{mbkf} / d_{bkf} ratio	1.2	1.9	1.6	3	1.4	2.1	1.8	2	1.3			1	1.4	1.4	1.4	2
9. Low Bank Height to d_{mbkf} ratio	1.3	2.6	2.2	5+	1.1	4.5	2.0	5+	2.7	7.1	5.2	5+	1.0	3.9	2.2	5+
10. Floodprone Area Width (w_{fpa}) – feet	16.8	33.0	26.2	3	9.8	92.5	51.1	2	7.9			1	9.6	15.0	12.3	2
11. Entrenchment Ratio (ER)	2.0	3.4	2.6	3	2.9	16.2	9.5	2	1.4			1	1.7	2.7	2.2	2
12. Meander length (L_m) – ft	No well-defined features - Straightened				No well-defined features Straightened				Limited pattern due to narrow valley				No well-defined features Straightened			
13. Ratio of meander length to bankfull width (L_m/w_{bkf})	No well-defined features - Straightened				No well-defined features Straightened				Limited pattern due to narrow valley				No well-defined features Straightened			
14. Radius of curvature (R_c) – ft	No well-defined features - Straightened				No well-defined features Straightened				Limited pattern due to narrow valley				No well-defined features Straightened			
15. Ratio of radius of curvature to bankfull width (R_c / w_{bkf})	No well-defined features - Straightened				No well-defined features Straightened				Limited pattern due to narrow valley				No well-defined features Straightened			
16. Belt width (w_{blt}) – ft	No well-defined features - Straightened				No well-defined features Straightened				Limited pattern due to narrow valley				No well-defined features Straightened			
17. Meander Width Ratio (w_{blt}/W_{bkf})	No well-defined features - Straightened				No well-defined features Straightened				Limited pattern due to narrow valley				No well-defined features Straightened			
18. Sinuosity (K) stream length / valley length	1.14				1.18				1.14				1.22			
19. Valley Slope -ft/ft	0.0115				0.0228				0.0344				0.0230			
20. Average Channel Slope (S_{bkf}) -ft/ft	0.0101				0.0193				0.0302				0.0189			

Table 3.2 Existing Geomorphic Characteristics of South Fork Hoppers Creek and Unnamed Tributaries South Muddy Creek Restoration Plan	**South Fork Mainstem**				**UT1B**				**UT2A**				**UT2B**			
	Min	**Max**	**Avg**	**n***	**Min**	**Max**	**Avg**	**n***	**Min**	**Max**	**Avg**	**n***	**Min**	**Max**	**Avg**	**n***
21. Pool Slope (s_{pool}) -ft/ft	0.000	0.004	0.001	17	0.000	0.005	0.002	11	0.000	0.012	0.004	9	0.000	0.014	0.007	9
22. Ratio of Pool Slope to Average Slope (S_{pool} / S_{bkf})	0.0	0.4	0.1	17	0.0	0.3	0.1	11	0.0	0.4	0.1	9	0.0	0.7	0.4	9
23. Maximum Pool Depth (d_{pool}) – ft	2.1	2.4	2.2	3	1.3	1.6	1.5	2	2.6			1	1.7	1.9	1.8	2
24. Ratio of Pool Depth to Average Bankfull Depth (d_{pool}/d_{bkf})	1.8	2.0	1.8	3	1.6	2.0	1.8	2	2.4			1	1.7	1.9	1.8	2
25. Pool Width (w_{pool}) – ft	7.7	14.0	10.2	3	4.0	7.7	5.9	2	5.0			1	6.2	12.4	9.3	2
26. Ratio of Pool Width to Bankfull Width (w_{pool} / w_{bkf})	0.7	1.3	1.0	3	0.9	1.7	1.3	2	0.8			1	1.1	2.2	1.6	2
27. Pool Area (A_{pool}) – ft^2	11.6	14.8	13.2	3	3.4	4.3	3.9	2	9.4			1	5.9	8.7	7.3	2
28. Ratio of Pool Area to Bankfull Area (A_{pool}/A_{bkf})	0.9	1.2	1.1	3	1.0	1.2	1.1	2	1.5			1	1.0	1.5	1.3	2
29. Pool-to-Pool Spacing (p-p) – ft	27	161	66	14	14	110	52	9	14	48	31	8	15	127	64	10
30. Ratio of Pool-to-Pool Spacing to Bankfull Width ($p\text{-}p/w_{bkf}$)	2.6	15.3	6.3	14	3.0	23.9	11.3	9	2.4	8.1	5.3	8	2.6	22.3	11.2	10
31. Riffle Slope (s_{riffle}) -ft/ft	0.015	0.035	0.025	15	0.033	0.564	0.127	19	0.029	0.345	0.123	11	0.028	0.113	0.057	7
32. Ratio of Riffle Slope to Average Slope (s_{riffle}/ s_{bkf})	1.5	3.5	2.5	15	1.7	29.2	6.6	19	1.0	11.4	4.1	11	1.5	6.0	3.0	7
Channel Materials (Particle Size Index – d_{50})	Coarse sand				Medium sand				Coarse sand							
d_{16} - mm	0.20				0.17				0.14							
d_{35} - mm	0.38				0.33				0.35							
d_{50} - mm	0.69				0.46				0.60							
d_{84} – mm	26				22				23							
d_{95} - mm	67				56				59							

* n – This column represents the number of data points used where a range or mean is specified.

3.2 Channel Stability Assessment

A naturally stable stream must be able to transport the sediment load supplied by its watershed while maintaining dimension, pattern, and profile over time so that it does not degrade or aggrade (Rosgen, 1994). Stable streams migrate across alluvial landscapes slowly, over long periods, while maintaining their form and function. Instability occurs when scouring causes the channel to incise (degrade) or excessive deposition causes the channel bed to rise (aggrade). A generalized relationship of stream stability was proposed by Lane (1955) that states the product of sediment load and sediment size is proportional to the product of stream slope and discharge, or stream power. A change in any one of these variables causes a rapid physical adjustment in the stream channel.

3.2.1 Channel Evolution Process

A common sequence of physical adjustments has been observed in many streams following disturbance. This adjustment process is often referred to as channel evolution. Disturbance can result from channelization, increase in runoff due to build-out in the watershed, removal of streamside vegetation, and other changes that negatively affect stream stability. All of these disturbances occur in both urban and rural environments. Several models have been used to describe this process of physical adjustment for a stream. The Simon Channel Evolution Model (1989) characterizes evolution in six steps, including:

1. Sinuous, pre-modified
2. Channelized
3. Degradation
4. Degradation and widening
5. Aggradation and widening
6. Quasi-equilibrium.

Figure 3.3 illustrates the six steps of the Simon Channel Evolution Model.

The channel evolution process is initiated once a stable, well-vegetated stream that interacts frequently with its floodplain is disturbed. Disturbance commonly results in an increase in stream power that causes degradation, often referred to as channel incision (Lane, 1955). Incision eventually leads to over-steepening of the banks and, when critical bank heights are exceeded, the banks begin to fail and mass wasting of soil and rock leads to channel widening. Incision and widening continue moving upstream in the form of a head-cut. Eventually the mass wasting slows, and the stream begins to aggrade. A new, low-flow channel begins to form in the sediment deposits. By the end of the evolutionary process, a stable stream with dimension, pattern, and profile similar to those of undisturbed channels forms in the deposited alluvium. The new channel is at a lower elevation than its original form, with a new floodplain constructed of alluvial material (FISRWG, 1998).

3.2.2 South Muddy Creek Site- Channel Stability Discussion

South Muddy Creek is a perennial, channelized stream with a flow regime dominated by stormwater runoff from a watershed that is approximately 78% forested, 11% agricultural, 4% developed, and approximately 7% mixed grasslands and open space. A flood control structure upstream impacts the flow regime by decreasing peak flows as described in Section 3.3.1. South Muddy Creek is incised and vertically unstable as evidenced by the bank height ratios of 2.4 to 3.2. The channel is laterally constrained and has an entrenchment ratio of 1.1 to 1.7. Table 3.3 summarizes the geomorphic values associated with channel stability.

Table 3.3 Stability Indicators – South Muddy Creek Site South Muddy Creek Restoration Plan					
Parameter	**South Muddy Creek**				
	X1A	**X1**	**X3**	**X8**	**X9**
Stream Type	G4c → F4	G4c	G4c	G4c	G4c
Riparian Vegetation	Mature forested buffer 3 to 5 feet wide on the left bank, followed by cropland. Mature forested valley wall on right bank.	Mature forested buffer 3 to 5 feet wide on the left bank, followed by cropland. Mature forested valley wall on right bank.	Mature forested buffer 3 to 5 feet on both banks, followed by cropland.	Mature forested buffer on left bank. Mature forested buffer 3 to 5 feet wide on right bank followed by pasture and patches of forest.	Mature forested buffer on left bank. Mature forested buffer 3 to 5 feet wide on right bank followed by ornamental horticulture.
Channel Dimension					
Bankfull Area (SF)	97.2	89.6	81.5	77.7	72.8
Width/Depth Ratio	26.9	10.9	9.8	8.6	8.1
Channel Pattern					
Meander Width Ratio	N/A	N/A	N/A	N/A	N/A
Sinuosity	1.06	1.06	1.06	1.06	1.06
Vertical Stability					
Bank Height Ratio (BHR)	3.2	2.6	2.9	2.4	2.8
Entrenchment Ratio (ER)	1.4	1.7	1.4	1.1	1.2
Evolution Scenario	E-Gc-F-C-E	E-Gc-F-C-E	E-Gc-F-C-E	E-Gc-F-C-E	E-Gc-F-C-E
Simon Evolution Stage[2]	IV	V	IV	III	III

Notes:
1. N/A: Meander Width Ratio not measured because channel has been straightened.
2. Simon Channel Evolution; see Figure 3.3.

3.2.2.1 Bank Pin Study

Equinox Environmental has established three bank pin study sites within the South Muddy Creek site to monitor bank erosion. Bank pins were installed on June 29, 2001, and monitored on September 15, 2003. Raw data were supplied to Baker. Table 3.4 presents a summary of linear feet of lateral bank erosion occurring per year at each study site. These data suggest that, within the project limits, South Muddy Creek experiences between 3 to 7 inches of lateral bank erosion per year, with localized erosion up to 1.2 feet per year. This rapid erosion rate corresponds to tall, steep, and unvegetated banks observed throughout the project area.

Table 3.4 Bank Pin Study – South Muddy Creek Site **South Muddy Creek Restoration Plan**		
Bank Pin Study Site	Range of of localized Erosion/Year/Site in feet	Average of Erosion/Year/Site in feet
BP 28	**0.0-1.2**	**0.58**
BP 29	**0.0-1.1**	**0.47**
BP 30	**0.0-0.6**	**0.28**

3.2.3 South Fork Hoppers Creek Site- Channel Stability Discussion

The following section discusses channel stability on the South Fork Hoppers Creek site, including the project reaches slated for improvement on South Fork Hoppers Creek, UT1, and UT2. Table 3.5 summarizes the geomorphic parameters related to channel stability.

Table 3.5 Stability Indicators – South Fork Hoppers Creek Site South Muddy Creek Restoration Plan				
Parameter	**Stream Reach**			
	South Fork Hoppers Creek	**UT1B**	**UT2A**	**UT2B**
Stream Type	G5c	E5	G5	G5c
Riparian Vegetation	Fescue pasture with narrow (average 5-foot wide) buffer of alder.	Fescue pasture with narrow (average 5-foot wide) buffer of alder.	Mature forest; no understory. Roots do not penetrate to lower banks.	Primarily fescue pasture; forested right bank near downstream end of reach.
Channel Dimension				
Bankfull Area (SF)	7.4 – 14.4	3.4 – 3.5	6.1	5.5 – 6.2
Width/Depth Ratio	6.1 – 14.4	3.4 – 9.5	5.4	5.0 – 6.2
Channel Pattern				
Meander Width Ratio	N/A- channel has been straightened	N/A- channel has been straightened	N/A- narrow, steep valley does not allow for pattern	N/A- narrow, steep valley does not allow for pattern
Sinuosity	1.14	1.18	1.14	1.22
Vertical Stability				
Bank Height Ratio (BHR)	1.3 – 2.6	1.1 – 4.5	2.7 – 7.1	1.0 – 3.9
Entrenchment Ratio (ER)	2.0 – 3.4	2.9 – 16.2	1.3	1.7 – 2.7
Evolution Scenario	E -Gc-F-C-E	E -Gc-F-C-E	B-G-Fb-B	B-G-Fb-B
Simon Evolution Stage	III to IV	III	III	III to IV

3.2.3.1 South Fork Hoppers Creek

The South Fork Hoppers Creek channel within the project area is a perennial, channelized stream with a flow regime dominated by stormwater runoff from a forested and agricultural watershed. The channel has historically been straightened to maximize productive agricultural land. A narrow five-foot wide woody buffer is present at the top of the bank, primarily composed of alder (*Alnus serrulata*). Beyond this narrow buffer the reach is surrounded by actively-grazed pastureland with fescue (*Festuca elatior*) as the dominant vegetation. Cattle have full access to the channel and continuously trample the banks, causing bank erosion. One severe bend has formed at the downstream end of the reach, at the old road crossing and primary cattle crossing location. This sharp bend is the only pattern feature for the reach and is the reason for a sinuosity measurement of 1.08.

The stream has become vertically incised as evidenced by bank height ratios in the 1.5 to 2.5 range. The channel has remained fairly narrow; width-to-depth ratios were calculated in the 6.0 to 7.5 range for two surveyed cross-sections and at 14.4 for the upstream-most cross-section. With respect to Simon's channel evolution model, this reach is approximately at Stage III to IV: it has been channelized, is incising, and is widening.

3.2.3.2 UT1B

The UT1B channel flows through an active cattle grazing area. The headwaters of this watershed have seen recent residential development; based on landowner observations, bankfull events have occurred at a more frequent recurrence interval over the past three to five years. A narrow five-foot wide buffer is present at top of bank, primarily composed of alder (*Alnus serrulata*). Beyond this narrow buffer, the reach is surrounded by actively-grazed pastureland, with fescue (*Festuca elatior*) as the dominant vegetation.

Like the South Fork Hoppers reach, the channel has been straightened and woody vegetation has been managed to maximize productive agricultural land. The stream is located slightly right of the lowest point of the valley, indicating that the stream has been relocated from where it would naturally flow. The lower 200 LF of the reach, from the 24" CMP culvert crossing to the confluence with South Fork Hoppers, has down cut to meet the lowered grade of South Fork Hoppers Creek. The culvert provides vertical grade control for the upper portion of this reach, but the lower portion of the reach will continue to incise as South Fork Hoppers continues to degrade. Bank height ratios at the survey cross section were measured as 1.4 and 2.5 for the UT1B project reach. With respect to Simon's channel evolution model, this reach is approximately at Stage III: it has been channelized and is incising.

3.2.3.3 UT2A

UT2A is a small, steep channel located in a narrow valley. The average channel slope exceeds 3%. The stream banks and valley walls are steep, sparsely-vegetated clay embankments. The surrounding area is steep and forested, but few tree roots penetrate to the lower stream banks. The channel does not have access to a floodprone area. It is unlikely that the channel has been straightened; the lack of pattern appears to be a function of the narrow valley and steep slopes. The lower portion of UT2A flows through a pen where hogs are kept. The hogs have full access to the creek and for 100 LF, the system is severely over-wide, trampled, and lacks a distinct low-flow channel. This area is devoid of vegetation.

With respect to Simon's channel evolution model, this reach is approximately at Stage III: it has been impacted by livestock and is incising due to lack of vertical grade control. The channel likely began as a B channel, due to steep grade and narrow valley. Now that it is incised, the reach appears to be functioning like a G. We predict that left unchecked, the channel would continue to incise, then widen slightly, then re-form as a B at a lower elevation.

3.2.3.4 UT2B

UT2B flows from the pig pen area down to the confluence with South Fork Hoppers Creek. The valley widens through this reach and the channel slope decreases to less than 2%. Banks continue to be steep and sparsely vegetated. The channel is incised, as evidenced by bank height ratios of 3.5 and 3.9 at the surveyed cross-section locations. The channel is in a transition zone, is incising to meet the grade of South Fork Hoppers Creek, and has begun to widen. The channel is in Stage III to IV of Simon's evolution model. Like UT2A, due to the narrow, steep valley, we predict that this channel started as a B channel. The reach has incised and begun to widen. It is functioning as a G channel but is moving toward an F channel.

3.3 Bankfull Verification

Baker Engineering used several methods to verify the bankfull stage and corresponding discharge of the restoration reaches of the South Muddy Creek Restoration project. Bankfull stage was identified during the existing condition survey using geomorphic indicators. Estimates of discharge were made by using survey data, mathematical equations, hydrologic and hydraulic modeling, and regional relationships. Gage station data were used to further verify the findings. Each method reinforces the ultimate conclusion of a bankfull discharge.

3.3.1 South Muddy Creek

3.3.1.1 Bankfull Area

Bankfull stage throughout the reach was identified in the field; indicators included a break in slope, a flat depositional feature, and a consistent scour line. Surveyed riffle cross sections with bankfull indicators were plotted on the North Carolina Regional Curve (Harman et al, 1999) as shown in Figure 3.4. The bankfull cross sectional areas for South Muddy Creek plotted below the regional curve. This is likely caused by the reduction in flow from the upstream impoundment.

In order to verify the impoundment's impacts on the downstream channel Baker Engineering conducted a site visit on April 13, 2007 to the structure to assess the condition of the dam and spillway as well as the condition of South Muddy Creek upstream and downstream of the dam. The structure was functioning well and effectively passed the baseflow of the stream. A channel cross section was surveyed upstream of the impoundment, above backwater effects, as well as immediately downstream of the impoundment. Bankfull features for both cross sections were identified by consistent sand deposition on flats with established vegetation. Table 3.6 below details the geomorphic parameters obtained from the cross sections. The location of the cross-sections is shown in Figure 3.5

Table 3.6 Existing Geomorphic Characteristics of South Muddy Creek Upstream and Downstream of the Impoundment South Muddy Creek Restoration Plan	**South Muddy Creek**	
	Upstream of Impoundment	**Downstream of Impoundment**
1. Stream Type	E	G
2. Drainage Area – mi^2	12.0	12.4
3. Bankfull Width (w_{bkf}) – ft	27.8	21.0
4. Bankfull Mean Depth (d_{bkf}) – ft	3.7	2.0
5. Width/Depth Ratio (w/d ratio)	7.5	10.5
6. Cross-sectional Area (A_{bkf}) – ft^2	102.4	41.1

Table 3.6 Existing Geomorphic Characteristics of South Muddy Creek Upstream and Downstream of the Impoundment South Muddy Creek Restoration Plan	**South Muddy Creek**	
	Upstream of Impoundment	**Downstream of Impoundment**
7. Bankfull Max Depth (d_{mbkf}) - ft	4.6	2.3
8. d_{mbkf} / d_{bkf} ratio	1.2	1.2
9. Low Bank Height to d_{mbkf} ratio	1.0	3.0
10. Floodprone Area Width (w_{fpa}) – feet	(>100.0)*	26.5
11. Entrenchment Ratio (ER)	(>3.6)	1.3
* Floodprone Area Width was not collected for the *Above* cross section because the channel was completely connected to a wide, historic floodplain. ** Only one cross section was taken for each reach		

Bankfull cross sectional areas below the impoundment were slightly less than one half the cross sectional area observed upstream. This significant decrease in bankfull area verified the impoundment's effect on bankfull discharge and consequently cross sectional area. Computer models were developed from observations and measurements obtained from site visits in order to gain a more thorough understanding of the hydrology and hydraulics.

3.3.1.2 Bankfull Discharge

Preliminary Modeling

Preliminary modeling was performed to determine the impact of the impoundment on the proposed South Muddy Creek restoration reach. The as-built plans for the impoundment, dated July 31, 1961, were obtained from NRCS. An existing conditions HydroCAD model was developed using as-built pond information, typical cross sections, and basic watershed information retrieved from aerials and topographic maps. An SCS Type II 24-hour rainfall distribution was used for the hydrology analysis. Baker Engineering adjusted the rainfall amount to bring the watershed discharges near the North Carolina Piedmont Regional Curve's prediction. The model was then analyzed at the bankfull stage. Table 3.7 shows the model results compared to regional curve predictions.

Table 3.7 Existing HydroCAD Model Results South Muddy Creek Restoration Plan	**Drainage Area (square miles)**	**Regional Curve Discharge Prediction (cfs)**	**HydroCAD Model Discharge Prediction (cfs)**
Watershed above the impoundment	12.4	546	548
Channel below the impoundment	**12.4**	**546**	**65**
Watershed below the impoundment	6.4	339	339
Restoration reach	18.8	736	376

The volume of storage in the pond is approximately 210 acre-feet (ac-ft) at the crest of the primary riser and 5,232 ac-ft at the crest of the emergency spillway. Storage is extensive, and the 30-inch outlet structure limits pond outflow. During a modeled bankfull event in the watershed of 548 cfs, peak discharge from the pond is limited to 65 cfs. This decreases the downstream discharges at the South Muddy Creek restoration site to almost one half the predicted bankfull discharge. Analysis confirmed that the impoundment decreased bankfull flows, and therefore will have an impact on bankfull cross sectional areas as well.

A preliminary HEC-RAS model was created for the restoration reach. Survey data were incorporated into the model. A steady state hydraulic analysis was performed for existing channel dimensions with both the regional curve discharges and the HydroCAD model results. Modeled bankfull water surface elevations for the HydroCAD predicted discharges followed bankfull field indicators. This RAS model further verified field bankfull determinations.

In addition to creating a HydroCAD and HEC-RAS model to determine bankfull flows, Manning's equation was used to calculate discharge for the existing riffle cross sections. Manning's roughness coefficients were selected based on channel materials, channel type, and by using friction factor/relative roughness relationships for each cross section. The estimated discharges were then compared to that calculated through computer modeling. The insight gained from the field identified bankfull indicators, the Manning's discharge estimation methods, and the models further confirmed that the discharge value at the South Muddy Creek site is significantly less than that predicted by the regional curve.

Table 3.8 summarizes the design discharge calculations at South Muddy Creek.

Table 3.8 South Muddy Creek Bankfull Discharge Determination
South Muddy Creek Restoration Plan

Stream	Cross Section	DA (square miles)	Q, Rural Regional Curve (cfs)	Q, Manning's Formula		Q, Friction Factor/Relative Roughness	Q, HydroCAD (cfs)	Design Q (cfs)
				Roughness Coefficient	"n" from Stream Type			
South Muddy Creek	**X1A**	**18.8**	**736**	**314**	**257**	**318**	**376**	**400**
	X1	**18.8**	**736**	**331**	**291**	**338**	**376**	**400**
	X3	**18.8**	**736**	**346**	**222**	**387**	**376**	**400**
	X8	**18.8**	**736**	**311**	**221**	**308**	**376**	**400**
	X9	**18.8**	**736**	**243**	**205**	**248**	**376**	**400**

As a final verification of these discharges, the NC USGS rural regression equation was used to estimate the 1.25-, 1.5- and 1.75-year discharge. The generally accepted recurrence interval of a bankfull event is between 1 and 2 years, and often between approximately 1.25 and 1.5 years. Because of the known impact of the dam on the downstream discharge, the 1.25-, 1.5- and 1.75-year storm events were calculated independently for the watershed above the pond and below the pond. These storm events were processed through the HydroCAD model to determine the amount of flow received by the study reach during these return interval storms. Results are represented in Table 3.9 below. These results indicate that the estimated bankfull discharge of 400 cfs falls within the expected recurrence interval for bankfull events.

Table 3.9 USGS Regression Estimations at the South Muddy Impoundment **South Muddy Creek Restoration Plan**				
Watershed	DA (square miles)	1.25-Year Storm	1.5-Year Storm	1.75-Year Storm
Above Dam	**12.4**	**501**	**611**	**705**
Below Dam to South Muddy Creek Restoration Reach	**6.4**	**305**	**378**	**440**
Pond Outflow – HydroCAD (cfs)	**12.4**	**64**	**67**	**70**
South Muddy Creek Restoration Reach – HydroCAD (cfs)	18.8	344	418	480
Corresponding Rainfall in HydroCAD (in)		**1.60**	**1.69**	**1.76**

3.3.2 South Fork Hoppers Creek

3.3.2.1 Bankfull Area

At the South Fork Hoppers Creek site, the bankfull stages on the mainstem channel and the UT channels were identified in the field; the indicators included a break in slope on a flat, depositional feature and a high scour line. These indicators were consistent with other NC rural Piedmont streams. Bankfull data for the project reach was then compared with the NC Piedmont regional curve in Figure 3.4. The bankfull cross sectional areas consistently plotted slightly below the regional curve, however all were within the 95% confidence interval.

Gage Analysis

In order to verify that the Piedmont regional curve is appropriate to use in this region, we assessed the continuing stability on one USGS gage that was surveyed during the development of the regional curve, and surveyed cross sections and a longitudinal profile at a second USGS gauging station in January 2004. The Norwood Creek gage (USGS Gage 0214253830), which was surveyed for the NC Piedmont rural regional curve, is located about 50 miles east-northeast of the South Fork Hoppers Creek site. The second gage, on Jacob Fork (USGS Gage 02143040), is located approximately 15 miles to the east of the project site, and has 42 years of peak annual discharge record. The gage locations are illustrated in Figure 3.6. Appendix 6 contains the Jacob Fork survey information, 9-207 gage data analysis, stage-discharge rating table, and the log Pearson discharge analysis. The reader is directed to Harman et al. (1999) for information related to the Norwood Creek gage analysis.

The Norwood site is located in the same 8-digit HUC as the project site (03050101). The Jacob Fork gage is located in the adjacent 8-digit HUC (03050102). Drainage area is 7.2 square miles at the Norwood Creek gage site and 25.7 square miles at the Jacob Fork site. Both creeks have small drainage areas in comparison to most active USGS gages, supporting the low end of the regional curve as applicable to this region.

The top of bank was a very consistent bankfull indicator at the Norwood Creek site. Sandy deposition and wrack lines in the floodplain indicated that the creek overtops its banks on a frequent basis. A visual assessment of the gage site indicated that the creek has maintained a stable dimension, pattern, and profile since it was surveyed for the regional curve development. Because of this observed stability on the site, the information obtained from the survey during the regional curve development was used to verify drainage area versus bankfull cross-sectional area and discharge relationships for this watershed. The average bankfull cross-sectional area for Norwood Creek is 99 SF. The bankfull discharge is estimated to be 254 cfs.

Bankfull indicators at the Jacob Fork site consisted of a scour line and depositional features that were typically observed approximately 4.5 feet above water surface at the time of the survey. The stream has experienced some incision in the past and has abandoned a relic floodplain and created a new one at a lower elevation. Sandy deposition and wrack lines in the active floodplain indicated that the creek overtops its banks on a frequent basis. The thalweg, water surface, bankfull, and top of bank were surveyed for 850 LF through the gage and compared to the stage at the bankfull indicator (estimated based on a trend line through all the surveyed bankfull indicators) to the stage-discharge table listed for the gage. From the stage-discharge relationship, we estimated that the recurrence interval for the discharge of Jacob Fork related to the bankfull stage to be about 1.23 years. A log Pearson analysis was performed on the 42 years of available peak annual flow data. The bankfull recurrence interval for the rural Piedmont region is normally 1.09 to 1.8 years, with an average return interval of 1.4 years (Harman et al., 1999). The Jacob Fork return interval is within the range of data used to develop the NC Piedmont rural regional curve.

The average bankfull cross-sectional area for Jacob Fork (290 SF) plots slightly above the regression line on the NC Piedmont regional curve (Harman et al., 1999), as illustrated in Figure 3.4, which is typical of streams that are partially incised. Bankfull discharge was estimated, as discussed above, by comparing the stage at the bankfull indicator (estimated based on a trend line through all bankfull indicators) to the stage-discharge table listed for the gage. The bankfull discharge for Jacob Fork is approximately 1,140 cfs. The bankfull discharge was cross-referenced with the regional curve, as shown in Figure 3.4. The discharge plotted within the range of other data points used to develop the curve.

These gage analyses indicate that bankfull stage was correctly identified at the project site and that the NC Piedmont regional curve is applicable to these gage sites located near the South Fork Hoppers Creek site.

3.3.2.2 Bankfull Discharge

Several estimation methods were employed to verify bankfull discharge on South Fork Hoppers and the associated tributaries.

Bankfull discharges were calculated at riffle cross sections surveyed for the project using Manning's equation. Manning's roughness coefficients were selected based on channel materials, channel type, and by using friction factor/relative roughness of each cross section. Calculated discharges ranged from 31 cfs to 75 cfs on the mainstem, from 12 to 18 cfs on UT1, and from 23 to 35 cfs on UT2. Variations in flow estimates are attributable to the increasing drainage area and variations of channel dimension.

For further verification of these discharges, the NC USGS rural regression equation was used to estimate the 1.25-, 1.5-, 1.75-, and 2-year discharges. The generally accepted recurrence interval of a bankfull event is between 1 and 2 years, and often between approximately 1.25 and 1.5 years. The bankfull discharges calculated using Manning's equation fall in the 1- to 2-year discharges predicted by the regression equation. These results indicate that the estimated bankfull discharge range falls within the expected recurrence interval for bankfull events.

The USGS gauging station analyses performed at Norwood Creek and Jacob Fork indicated that the regional curve provides a reliable estimation of discharge based on drainage area within the region. Regional curve estimations were within the range of Manning's results and between the 1- and 2-year storm events. The insight gained from the comparison of all employed methods helped determine the design discharge values. Bankfull discharge for each reach was plotted on the regional curve, as shown on Figure 3.4.

Table 3.10 summarizes the design discharge by reach.

Table 3.10 South Fork Hoppers Creek Site Bankfull Discharge Determination

South Muddy Creek Restoration Plan

Stream	Cross Section	DA (square miles)	Q, Rural Piedmont Regional Curve (cfs)	Q, Manning's Equation (cfs)		Q, Friction Factor/Relative Roughness (cfs)	Q, Regression Equations (cfs)			Design Q (cfs)
				Roughness Coefficient	"n" from Stream Type		1.25-year	1.5-year	1.75-year	
South Fork Hoppers	X5	0.52	55.6	71.2	52.5	73.3	45.8	60.6	73.1	50
	X7	0.52	55.6	31.2	24.6	31.0	45.8	60.6	73.1	50
	X10	0.52	55.6	75.2	69.3	66.9	45.8	60.6	73.1	50
UT1B	X2	0.08	13.9	11.7	15.5	17.1	10.4	14.8	18.4	14
	X4	0.08	13.9	18.4	13.5	44.7	10.4	14.8	18.4	14
UT2A	X11	0.04	8.8	35.0	35.0	30.6	6.3	9.2	11.6	8
UT2B	X14	0.07	13.1	30.4	28.0	29.2	9.8	13.9	17.4	12
	X16	0.07	13.1	31.6	23.3	31.8	9.8	13.9	17.4	12

3.4 Vegetation and Habitat Descriptions

The habitat within and adjacent to the proposed South Muddy Creek site consists of Piedmont/Low Mountain Alluvial Forest, Northern Hardwood Forest, and agricultural fields as described by Schafale and Weakley (1990). The majority of the riparian buffer within the South Muddy Creek project area is very disturbed with the exception of two wooded areas at the northeastern and southwestern edges of the project area.

The habitat within and adjacent to the proposed South Fork Hopper Creek site consists of Piedmont/Low Mountain Alluvial Forest, Northern Hardwood Forest, and fallow agricultural fields as described by Schafale and Weakley (1990). The riparian areas ranged from relatively disturbed to very disturbed.

3.4.1 Piedmont/Low Mountain Alluvial Forest

Within the South Muddy Creek site, the Piedmont/Low Mountain Alluvial Forest areas cover approximately 30 percent of the project area and are located in the northeast and southwest portions of the site. Within these areas, the forested riparian stream buffer varies, but is generally greater than 50 feet in width. Canopy species consists of a mixture of bottomland and mesophytic trees including American sycamore (*Platanus occidentalis*), yellow poplar (*Liriodendron tulipifera*), river birch (*Betula nigra*), white ash (*Fraxinus americana*), red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), black cherry (*Prunus serotina*), and American beech (*Fagus grandifolia*). Understory trees and shrubs include box elder (*Acer negundo*), red maple, spicebush (*Lindera benzoin*), black cherry, Chinese privet (*Ligustrum sinense*), flowering dogwood (*Cornus florida*), and American holly (*Ilex opaca*). Herbaceous and vine species consist of blackberry (*Rubus* spp.), raspberry (*Rubus occidentalis*), Indian strawberry (*Duchesnea indica*), violets (*Viola spp.*), Japanese honeysuckle (*Lonicera japonica*), poison ivy (*Toxicodendron radicans*), giant cane grass (*Arundinaria gigantea*), greenbrier (*Smilax* spp.), and multiflora rose (*Rosa multiflora*).

The South Muddy Creek riparian buffer adjacent to the agricultural fields ranges from 5 to 10 feet in width and is sparse at best in many places. Species found within this limited riparian buffer zone in the agricultural fields area are similar to those found within the forested area as previously described with the addition of black willow (*Salix nigra*) and alder (*Alnus serrulata*).

Within the South Fork Hoppers Creek project area the Piedmont/Low Mountain Alluvial Forest ecological community composes the riparian stream buffer, which is limited to narrow corridors of 5 to 10 feet in width along the majority of the stream banks. Species found within this limited riparian buffer zone adjacent to the agricultural fields include red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), river birch (*Betula nigra*), yellow poplar (*Liriodendron tulipifera*), alder (*Alnus serrulata*), grape (*Vitis* spp.), multiflora rose (*Rosa multiflora*), Japanese honeysuckle (*Lonicera japonica*), Chinese privet (*Ligustrum sinense*), Virginia pine (*Pinus virginiana*), and red cedar (*Juniperus virginiana*). It should be noted that along the banks of UT2 and South Fork Hoppers Creek, alder is the predominant species and can be considered a viable species to transplant during project implementation.

3.4.2 Northern Hardwood Forest

Within the South Muddy Creek site the Northern Hardwood Forest community covers approximately 1 percent of the area and is located on slopes at the southwestern edge of the site. Canopy species include red cedar (*Juniperus virginiana*), yellow poplar (*Liriodendron tulipifera*), hemlock (*Tsuga canadensis*), black cherry (*Prunus serotina*), Virginia pine (*Pinus virginiana*), and river birch (*Betula nigra*). Understory, shrub, and herbaceous species include ironwood (*Carpinus caroliniana*), black cherry, dog hobble (*Leucothoe editorum*), sourwood (*Oxydendrum arboretum*), and Christmas fern (*Polystichum acrostichoides*).

Within the South Fork Hoppers Creek site the Northern Hardwood Forest habitat type is found at the upstream ends of both UT1 and UT2 and comprises approximately 15 percent of the project area. This habitat type is primarily found along steeper grades and higher elevations within the project area. Overstory species composition consisted of red cedar (*Juniperus virginiana*), sourwood (*Oxydendrum arboreum*), hemlock (*Tsuga canadensis*), red maple (*Acer rubrum*), yellow poplar (*Liriodendron tulipifera*), American beech (*Fagus americana*), pignut hickory (*Carya tomentosa*), southern red oak (*Quercus falcata*), white pine (*Pinus strobus*), Virginia pine (*Pinus virginiana*), and white oak (*Quercus alba*). Understory, shrub and herbaceous species consist of sourwood, Chinese privet (*Ligustrum sinense*), American holly (*Ilex opaca*), mountain laurel (*Kalmia latifolia*), rhododendron (*Rhododendron maximum*), alder (*Alnus serrulata*), poison ivy (*Toxicodendron radicans*), Christmas fern (*Polystichum acrostichoides*), and ground cedar (*Lycopodium obscurum*).

3.4.3 Agricultural Fields

Within the South Muddy Creek site agricultural is the most dominant community and covers approximately 70 percent of the project area. The fields have been used for various agricultural purposes including grazing, hay production, cultivating landscaping trees and shrubs, and crop production. Otherwise, vegetation within these fields primarily consists of herbaceous species, with a few shrub species, including red maple (*Acer rubrum*), sedges (*Carex* spp.), soft rush (*Juncus effusus*), asters (*Aster* spp.), beggars tick (*Bidens frondosa*), blackberry (*Rubus* spp.), multiflora rose (*Rosa multiflora*), fescue (*Festuca elatior*) and little bluestem (*Schizachyrium scoparium*).

Within the South Fork Hoppers Creek site the agricultural community is also the most dominant and covers approximately 85 percent of the project area. The fields have been used for grazing and hay production. Vegetation within these fields primarily consists of herbaceous species, with a few shrub species, including Chinese privet (*Ligustrum sinense*), sedges (*Carex* spp.), soft rush (*Juncus effusus*), asters (*Aster* spp.), beggars tick (*Bidens frondosa*), blackberry (*Rubus* spp.), multiflora rose (*Rosa multiflora*), fescue (*Festuca elatior*) and little bluestem (*Schizachyrium scoparium*).

4.0 REFERENCE STREAMS SUMMARY

Reference reach surveys are valuable tools to river designers. Reference reaches are stable rivers within a specific valley type (Rosgen, 1998). Their morphology dimension, pattern, and profile can be used as a template for design of a stable stream in a similar valley type with similar bed material. In order to extract the morphological relationships observed in a stable system, dimensionless ratios are developed from the surveyed reference reach. These ratios can be applied to a stream design to allow the designer to 'mimic' the natural, stable form of the target channel type.

While reference reaches can be used as an aid in designing channel dimension, pattern, and profile, there are limitations. The pattern for most reference reach quality streams is controlled by large trees and other woody vegetation. Therefore, the pattern is not "free to form" based on fluvial processes, but instead is formed by the vegetation. Parameters such as radius of curvature are especially affected by vegetation control, often resulting in very tight bends. Therefore, pattern ratios observed in reference reaches are often adjusted in the design criteria to create more conservative designs that are less likely to erode after construction, before the permanent vegetation is established.

Assigning an appropriate stream type for the corresponding valley type was considered conceptually prior to selecting reference reach streams. South Muddy Creek, South Fork Hoppers Creek, and UT1B all have valley types that would support C/E channel types. Because South Muddy Creek has a large drainage area, it was determined that more conservative design ratios would be used. Therefore, C type reference reaches were researched for the South Muddy Creek design. On the South Fork Hoppers Creek site, drainage areas are much smaller, and therefore it was determined that some more aggressive ratios would be incorporated into the design. Therefore, E type reference reaches were researched for the designs at the South Fork Hoppers site.

Two reference reach databases were consulted for potential design parameters. Four reference reach datasets were selected from the databases: a survey of Morgan Creek (Doll, 1999) and Barnes Creek (Clinton, 1998) for the South Muddy design and Sal's Branch (Clinton, 1998) and Spencer Creek (Clinton, 1998) for the South Fork Hoppers Creek and UTs designs. The geomorphic survey summaries are included in Table 4.1. The location of these reference reaches is included on Figure 3.6.

Table 4.1 Reference Reach Geomorphic Parameters
South Muddy Creek Restoration Plan

	South Muddy Creek Site						South Fork Hoppers Creek Site					
	Morgan Creek			Barnes Creek			Sal's Branch			Spencer Creek Downstream		
	Min	Max	n*	Min	Max	n*	Min	Max	n*	Min	Max	n*
1. Stream Type	C4			C4			E4			E4		
2. Drainage Area – square miles	8.4			23.0			0.20			1.0		
3. Bankfull Width (w_{bkf}) – feet	33.2	33.5	2	60.7	69.0	2	8.7		1	10.7		1
4. Bankfull Mean Depth (d_{bkf}) – feet	2.3	2.4	2	2.9	3.8	2	1.2		1	1.6		1
5. Width/Depth Ratio (w/d ratio)	14.1	14.7	2	16.0	23.8	2	7.3		1	5.7		1
6. Cross-sectional Area (A_{bkf}) – SF	75.1	79.8	2	288.0	199.0	2	10.4		1	17.8		1
7. Bankfull Mean Velocity (v_{bkf}) - fps	7.0			Not Available			Not Available			5.4		
8. Bankfull Discharge (Q_{bkf}) – cfs	524			Not Available			Not Available			97		
9. Bankfull Max Depth (d_{mbkf}) - feet	2.8	2.9	2	3.9	5.2	2	2.4		1	2.1		1
10. d_{mbkf} / d_{bkf} ratio	1.2	1.2	2	Not Available			2.6		1	1.3		1
11. Low Bank Height to d_{mbkf} Ratio	1.0		2	Not Available			1.2		1	1.0		1
12. Floodprone Area Width (w_{fpa}) – feet	77.5	86.8	2	219.0	220.0	2	163.0		1	60.0		1
13. Entrenchment Ratio (ER)	2.3	2.6	2	3.2	3.6	2	18.7		1	5.5		1
14. Meander length (L_m) – feet	Not Available			Not Available			38.0	45.0	3	46.0	48.0	2
15. Ratio of meander length to bankfull width (L_m/w_{bkf})	Not Available			Not Available			4.4	5.2	3	4.1	4.4	2
16. Radius of curvature (R_c) – feet	Not Available			Not Available			13.1	29.6	4	10.9	14.6	5
17. Ratio of radius of curvature to bankfull width (R_c / w_{bkf})	Not Available			Not Available			1.5	3.4	4	1.3	1.4	5
18. Belt width (w_{blt}) – feet	Not Available			Not Available			10.0	16.0	4	38.3	40.8	2
19. Meander Width Ratio (w_{blt}/W_{bkf})	Not Available			Not Available			1.2	1.8	4	3.4	3.6	2
20. Sinuosity (K) Stream Length/ Valley Distance	Not Available			Not Available			1.19			2.3		
21. Valley Slope – feet per foot	Not Available			Not Available			0.0115			0.0109		
22. Channel Slope ($s_{channel}$) – feet per foot	0.0070			0.0039			0.0109			0.0047		
23. Pool Slope (s_{pool}) – feet per foot	0.0001		1	0.0		1	0.0		4	0.0007		2
24. Ratio of Pool Slope to Average Slope (s_{pool} / $s_{channel}$)	0.01		1	0.0		1	0.0		4	0.2		2
25. Maximum Pool Depth (d_{pool}) – feet	4.1		1	6.8		1	3.1		1	3.3		1
26. Ratio of Pool Depth to Average Bankfull Depth (d_{pool}/d_{bkf})	1.8		1	2.0		1	2.6		1	2.1		1
27. Pool Width (w_{pool}) – feet	25.9		1	48.5		1	5.6		1	17.5		1
28. Ratio of Pool Width to Bankfull Width (w_{pool} / w_{bkf})	0.8		1	0.8		1	0.64		1	1.6		1
29. Pool Area (A_{pool}) – square feet	88.9		1	133.1		1	10.3		1	24.5		1
30. Ratio of Pool Area to Bankfull Area (A_{pool}/A_{bkf})	1.2		1	0.6		1	0.99		1	1.4		1
31. Pool-to-Pool Spacing – feet	46.0	277.0	2	Not Available			35.5	47	3	71.0		5
32. Ratio of Pool-to-Pool Spacing to Bankfull Width ($p\text{-}p/w_{bkf}$)	4.4	8.3	2	Not Available			4.1	5.4	3	6.6		5

Table 4.1 Reference Reach Geomorphic Parameters
South Muddy Creek Restoration Plan

	South Muddy Creek Site						South Fork Hoppers Creek Site					
	Morgan Creek			Barnes Creek			Sal's Branch			Spencer Creek Downstream		
	Min	Max	n*	Min	Max	n*	Min	Max	n*	Min	Max	n*
33. Riffle Slope [4] (s_{riffle}) – feet per foot	0.014	0.024	2	0.021	0.030	2	0.027	0.04	4	0.013		2
34. Ratio of Riffle Slope to Average Slope (s_{riffle}/ s_{bkf})	2.0	3.4	2	5.3	7.7	2	2.5	3.7	4	1.4		2
Particle Size Distribution of Riffle Material												
Material (d_{50})	Very Fine Gravel			Gravel			Medium Gravel			Medium Gravel		
d_{16} – mm	Not Available			0.4			4.8			<0.062		
d_{35} – mm	1.2			11			Not Available			3		
d_{50} – mm	3			60			9.5			8.8		
d_{84} – mm	77			512			30			42		
d_{95} – mm	800			>2048			Not Available			90		

* n – This column represents the number of data points used where a range or mean is specified.

5.0 PROJECT SITE WETLANDS (EXISTING CONDITIONS)

This section discusses the existing jurisdictional wetlands on site, the ambient climactic conditions, hydrological characterization, and soil characterization.

5.1 Jurisdictional Wetlands

Onsite surveys of the project areas were conducted on January 30 and 31, 2007, to identify potential USACE jurisdictional wetland locations (JD Action number is 2007-1174). Wetland presence was determined by evaluating existing hydrology, soils, and hydrophytic vegetation (where appropriate) within the project reaches. No wetlands were identified within the project area of the South Muddy Creek site. One jurisdictional wetland was identified within the South Fork Hoppers Creek project area. The USACE Routine Wetland Determination Data form for this wetland is included in Appendix 2. The location of the wetland identified within the project area is shown on Figure 3.2.

Wetland 1 is an emergent, toe-of-slope/floodplain wetland that is located adjacent to South Fork Hoppers Creek. This wetland is 0.33 acres in size and has been impacted by agricultural activities. Vegetation within this wetland is dominated by herbaceous species with no woody species identified. Vegetation primarily consists of soft rush (*Juncus effusus*) and fescue (*Festuca elatior*). Soils are sandy loams and are very dark grayish browns with slight yellowish red mottles in color. Wetland hydrology indicators include saturation in the wettest portions. This wetland appears to gain the majority of its water input through groundwater seepage from the adjacent slope. This wetland will only sustain impacts associated with enhancement activities.

5.2 Climatic Conditions

McDowell County has an average annual rainfall of 53.97 inches (NRCS, 1995) and a growing season that is 222 days long, beginning on March 28 and ending on November 4. Baker Engineering collected rainfall data for the monitoring period from the nearest automated weather station, located in Marion, approximately 9 miles northwest of the project site (Marion, NC UCAN: 14204, COOP: 315340). Monthly precipitation amounts from January 2006 through May 2007 are compared with McDowell County NRCS WETS table long term average monthly rainfall, in Table 5.1. These data indicate that over the entire period, total rainfall was slightly above normal, which is attributed to a particularly wet November and December.

Table 5.1 South Fork Hoppers Creek Site Precipitation Summary
South Muddy Creek Restoration Plan

Month-Year	Observed Precipitation (in)	WETS Table Average Monthly Precipitation (in)	Deviation of Observed from Average (in)
January-06	2.89	4.23	-1.34
February-06	2.0	5.46	-3.46
March-06	0.89	4.43	-3.54
April-06	3.87	4.41	-0.54
May-06	0.96	5.40	-4.44
June-06	4.18	4.70	-0.52
July-06	3.41	4.28	-0.87
August-06	5.52	4.24	1.28
September-06	7.15	4.48	2.67
October-06	2.72	3.95	-1.23

Table 5.1 South Fork Hoppers Creek Site Precipitation Summary South Muddy Creek Restoration Plan			
Month-Year	**Observed Precipitation (in)**	**WETS Table Average Monthly Precipitation (in)**	**Deviation of Observed from Average (in)**
November-06	10.47	4.43	6.04
December-06	17.52	3.96	13.56
January-07	1.37	4.23	-2.86
February-07	3.58	5.46	-1.88
March-07	8.88	4.43	4.45
April-07	3.66	4.41	-0.75
May-07	1.86	5.40	-3.54
Total	**80.93**	**77.90**	**3.03**

5.3 Water Table Hydrology

Ditching and channelization has occurred throughout the site. During conversion of the site, stream channels and wetland systems through the site were channelized and ditched to improve drainage. There is some evidence of land leveling but it does not appear that significant fill was placed within the wetland boundary.

Baker Engineering began collecting water table data from the field on the south side of South Fork Hoppers Creek from two automated gages in April 2007. Data collection is expected to continue at least through the 2007 growing season. Two automated gages were installed at the locations shown in Figure 3.2. Automated Gage 1 (AW1) is located adjacent to the existing wetland between the wetland boundary and the creek channel. Automated Gage 2 (AW2) is located just west of the existing wetland area. The automated Ecotone pressure transducer gages were installed to a depth of 40 inches, and were programmed to record water table levels every 12 hours. A wetland must have 12 consecutive days (5% of the growing season) of ground saturation (water table within 12 inches of ground surface) based on the WETS table for McDowell County (Marion, NC 5340) to meet minimum wetland hydrology criteria set forth in the *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory, 1987).

The data from the two automated gages on the site are provided in Appendix 5. Precipitation data collected during the monitoring period (April-07 through May-07) indicate that lower than average rainfall occurred. Both gages exhibited rapid increases in water table elevation following rainfall events, with the water table dropping relatively quickly following the rainfall events. Both gages are located within approximately 30 to 40 feet of the existing incised creek channel, which is approximately 3 to 4 feet deep. Therefore, the rapid decrease in the water table following rainfall events is most likely due to the drainage effect of the nearby stream. The area around AW2 has a lower average water table elevation than the location of AW1 adjacent to the existing wetland area. It is likely that water table levels are higher at the location of AW1 due to additional water inputs that are supplied by the adjacent wetland. During the period of monitoring, both gage AW1 or AW2 exhibited hydrologic conditions much drier than would be expected for a jurisdictional wetland. Gage data will continue to be collected and recorded, since the drought conditions hindered the existing condition wetlands assessment.

5.4 Hydrologic Modeling

To further investigate the current hydrologic status of the site and provide a means for evaluating proposed restoration plans, Baker Engineering developed hydrologic models to simulate site hydrology. DRAINMOD (version 5.1) was used to develop hydrologic simulation models to represent conditions at a variety of locations across the proposed restoration area. DRAINMOD was identified as an approved hydrologic tool for assessing wetland hydrology by the NRCS (1997). For more information on DRAINMOD and its application to high water table soils, the reader is referred to Skaggs (1980).

Model parameters were selected based on field measurements and professional judgment of site conditions. Rainfall and air temperature information were collected from the Marion automated weather station. Rainfall data points that were missing from the Marion station data set were replaced with points from nearby weather stations at Morganton (KMRN Morganton/ Lenoir Airport) and Rutherford airport (KRQD – Rutherford County Airport).

Measured field parameters were entered into the model, and initial model simulations were compared with observed data collected from the monitoring gages. To calibrate the model, parameters not measured in the field were adjusted within the limits typically encountered under similar soil and geomorphic conditions until model simulations most closely matched observed gage data.

Trends in the observed data were well represented by the model simulations; however, it should be noted that a limited amount of observed data was available for comparison. It is important to note that DRAINMOD uses simplifying assumptions in the estimation of water table depths. It should also be noted that DRAINMOD does not allow the modeling of groundwater and seepage inputs which will be important to the hydrology of the South Fork Hoppers Creek system, as evidenced by the existing wetland area that is fed by hillslope seepage. When applied to a site such as the South Fork Hoppers Creek system with complex hydrologic processes, the model can be used to assess overall trends and relationships but is unlikely to offer exact predictions of water table hydrology

DRAINMOD computes daily water balance information and outputs summaries that describe the loss pathways for rainfall over the model simulation period. Table 5.2 summarizes the average annual amount of rainfall, infiltration, drainage, run-off, and evapotranspiration estimated for the existing condition of the project area, based on 45-year simulations. The average amounts for the simulated area, as well as the minimum and maximum values, are presented in the table for gage AW1. Water balance sums were similar for gage AW2. Infiltration represents the amount of water that percolates into the soil and is lost via drainage or runoff. Drainage is the loss of infiltrated water that travels through the soil profile and is discharged to drainage ditches or underlying aquifers. Runoff is water that flows overland and reaches drainage ditches before infiltration. Evapotranspiration is water that is lost through direct evaporation of water from the soil or through the transpiration of plants.

From the data provided, it is clear that a significant amount of the rainfall on the site is lost to evapo-transpiration, which is typical for farm fields in the Southeastern US. Drainage is the largest loss pathway for water under the existing farm conditions, primarily due to the soil profile and incised condition of South Fork Hoppers Creek through the project site. Restoration of the site will involve raising the bottom elevation of the stream and increasing the amount of surface storage available to pond water. In this way, the respective amounts of drainage and run-off are decreased, and the excess water allows the water table to remain higher throughout the year, thus restoring wetland hydrology.

Table 5.2 Existing Conditions Water Balance Data (Gage AW1)
South Muddy Creek Restoration Plan

Hydrologic Parameter	Annual Amount over 45-Year Simulation Period (cm of water)	Annual Amount over 45-Year Simulation Period (% of average rainfall)
Precipitation	136.5 (84.5 to 201.2)	100
Drainage	68.5 (37.2 to 102.3)	50.2 (27.2 to 74.9)
Runoff	12.0 (0.0 to 34.5)	8.8 (0.0 to 25.3)
Evapotranspiration	58.6 (36.6 to 70.4)	42.9 (26.8 to 51.6)

5.5 Hydric Soils

The project soils are mapped as Iotla sandy loam according to the McDowell County Soil Survey. The Iotla soil series is on the hydric B list for McDowell County. The soil survey indicates that these areas contain hydric inclusions. The Iotla series is described as a nearly level, somewhat poorly-drained soil on flood plains adjacent to streams. Permeability is moderately rapid, and surface runoff is slow. The seasonal high water table is at a depth of 1.5 to 3.5 feet from November through April. The Iotla series is mapped for the entire wetland restoration project area. A description of other, non-hydric soils on the upland areas of the project site is provided in Section 2.3, and a soils map for the site is provided as Figure 2.4.

6.0 REFERENCE WETLANDS SUMMARY

An existing wetland and stream system that is similar to the system to be restored was identified for a past EEP project, the South Fork Hoppers Creek Restoration Project. This site is located within one mile of the current South Fork Hoppers Creek site and falls within the same climatic, physiographic, and ecological region as the proposed restoration site. The same reference wetland data used for the past project will be used for this current project. Figure 3.6 illustrates the location of the site.

The reference site is located on two adjacent parcels on Connelly Street near the Town of Glen Alpine, approximately 11 miles northeast of the South Fork Hoppers Creek restoration site. The stream associated with the wetland system is an unnamed tributary to Little Silver Creek. The reference site is most similar to a "Piedmont/ Low Mountain Alluvial Forest" as described by Schafale and Weakley (1990). These systems exist on river and stream floodplains. Hydrology of these systems is palustrine which are intermittently or seasonally flooded. Flows tend to be highly variable, with occasional flooding.

The site classifies as a wetland, utilizing criteria identified in the USACE 1987 Wetlands Delineation Manual. These criteria include the FAC Neutral Test, oxidized root channels, and local soil survey data. Climatic conditions of the reference site are the same as those described for the project site.

The reference site has experienced disturbances in the past, primarily due to its proximity to Connelly Street, Interstate 40, and a maintained power line easement. The disturbance is most evident in the existing vegetation. An extensive search of the area surrounding the South Fork Hoppers Creek site was conducted and no undisturbed sites were located. The hydrology of the reference site does not appear to be disturbed. Two automatic water level recorders were previously installed in the reference site to monitor the hydrology. Soils, hydrology, and vegetation of the site are described in the sections that follow. A wetland data form is included in Appendix 4.

6.1.1 Soils

Arkaqua is the primary series mapped on the reference site. The Arkaqua series consists of somewhat poorly drained soils that formed in loamy alluvium along nearly level floodplains and creeks. The soils of the reference site were investigated, and onsite soil samples were taken. Soils within the proposed reference wetland area exhibited hydric indicators, specifically a depleted matrix with a value of 4 and chroma of 1 with redox concentrations. Soil texture within the profiles ranged from clay loam to sandy clay loam.

6.1.2 Hydrology

The hydrology of the wetland varies across the site due to relative changes in topography and soil conditions. These conditions are typical of an alluvial forest system. The site hydrology is controlled primarily by groundwater discharge, overland flow, and overbank flooding captured in depressional areas. Standing surface water has been observed during both site visits which have been conducted.

This hydrologic regime matches closely with the anticipated hydrologic conditions of the restoration site. There is a small stream which flows through the reference site that is not incised and floods regularly. Hydrology of the site is also fed from groundwater discharge and hillslope seepage, similar to the conditions observed on the restoration site.

6.1.3 Vegetation

The canopy of the system is dominated by various bottomland species. The reference site is comprised of greater than 83% facultative and wetter species and therefore, meets the hydrophytic vegetation requirement. Vegetation within the reference wetland area primarily consists of red maple (*Acer rubrum*), sycamore (*Platanus occidentalis*), privet (*Ligustrum sinense*), American holly (*Ilex opaca*), tag alder (*Alnus serrulata*), elderberry (*Sambucus canadensis*), Christmas fern (*Polystichum acrostichoides*), and honeysuckle (*Lonicera japonica*).

7.0 PROJECT SITE STREAM RESTORATION PLAN

An overall watershed management approach was used in developing the stream restoration designs on the South Muddy Creek project sites. The designs take into consideration site constraints, watershed land uses, hydrologic controls, and reference conditions specific to each reach.

These project sites are appropriate candidates for restoration because the streams currently fall short of their hydraulic and ecological potential. Nearly all of the channel reaches are incised and sediment transport competency analyses indicate that the channels are prone to further degradation. Bed and bank erosion will continue to contribute sediment to the areas downstream of the project sites and to the widening of the streams. Bedform diversity is moderate throughout the project reaches and historic land use has degraded both the ecological and biological function of the streams and riparian areas. Restoration can help to stabilize the channels, halt incision and widening, significantly diminish bank erosion, and restore riparian habitat.

7.1 Restoration Project Goals and Objectives

The primary restoration goal is to create natural, geomorphically stable stream types within the proper valley type. The next goal is to improve and restore hydrologic connections between the streams and their floodplains. The final goals are to improve water quality and aquatic and terrestrial habitat throughout the project areas. In brief, these design objectives will be achieved by providing stable channels using natural channel design with bankfull floodplain access wherever possible. In-stream habitat will be enhanced by creating a riffle-pool sequence and structure placement. Terrestrial habitat will be enhanced through selection of appropriate riparian vegetation for planting along the project corridor. By providing the channel access to a floodplain, the benefits of flood attenuation, increased groundwater infiltration, and alleviation of bank stress and erosion will work together to improve water quality in the South Muddy Creek watershed.

7.2 Design Criteria Selection for Stream Restoration

Selection of a general restoration approach is the first step in selecting design criteria at the South Muddy Creek Restoration project sites. The approach was based on the reach's potential for restoration, as determined during the site assessment. The design philosophy for project streams is to use conservative values for the design ratios and to allow the stream to evolve to values exhibited by reference reaches with mature bottomland hardwood forests. This evolution will occur over time with flooding and the establishment of permanent vegetation.

Design criteria were selected based on the bankfull discharge, bankfull cross sectional area determination, range of the reference data, evaluation of past project performance, and professional judgment. Design criteria refinements were made to accommodate the existing valley morphology, to avoid encroachment of the valley wall, and to minimize unnecessary disturbance of the existing riparian forest. The proposed stream types for the project are summarized in Table 7.1.

Table 7.1 Project Design Stream Types
South Muddy Creek Restoration Plan

Stream	Proposed Stream Type	Rationale
South Muddy Creek	C4	Rosgen Priority 2 restoration will be used to increase sinuosity, riffle-pool development, and reestablish connection with a floodplain. Native re-vegetation throughout the project will improve habitat and stabilize the banks.
South Fork Hoppers Creek	C5	Rosgen Priority 1 restoration will increase sinuosity, riffle-pool development, and reestablish connection with the historic floodplain. Native re-vegetation will improve habitat and stabilize the banks.

Table 7.1 Project Design Stream Types South Muddy Creek Restoration Plan		
Stream	**Proposed Stream Type**	**Rationale**
UT1A	B	Preservation.
UT1B	C5	Rosgen Priority 1 restoration will increase sinuosity, riffle-pool development, and reestablish connection with the floodplain. Native re-vegetation will improve habitat and stabilize the banks.
UT2A	G5/B5	Enhancement will help to stabilize the channel and banks to decrease further incision and bank erosion. Rosgen Priority 1 restoration will be used through the pig pen to reconnect the channel with the natural floodplain and to enhance bed diversity. The steep, confined valley limits the feasibility of further work.
UT2B	G5c	Enhancement will help to stabilize the channel and banks to decrease further incision and bank erosion. The steep, confined valley limits the feasibility of further work. For the downstream portion of the reach, the creek serves as the property line and work will be limited to stabilization to improve stability on the left bank.
UT3	B	Preservation.

7.3 Design Parameters

The primary objective of the stream restoration effort is to design and construct a stream with stable dimension, pattern, and profile that has access to a floodplain at the bankfull stage when feasible. The proposed design for the South Muddy Creek site is illustrated in Figure 7.1 and the proposed design for the South Fork Hoppers site is illustrated in Figure 7.2.

The design rationale and design parameters for the design reaches are presented below.

Dimension

Throughout the proposed design, the bankfull dimensions were adjusted to convey the design discharges and reduce velocities and boundary shear stress. The selected design parameters also eliminate incision and restore access to a floodplain. A value at the low to medium range of width-to-depth ratios was chosen for C-type channels. These values allow the constructed channels to evolve into typical E-type morphology over time. Due to the lack of established vegetation after construction, low width-depth ratio E-type channels are difficult to construct and highly vulnerability to bank erosion immediately following construction. A bank height ratio (BHR) of 1.0 was incorporated into the design to develop a channel that would allow bankfull and greater flow events access to the floodplain. Typical cross sections are shown on the plan sheets. Additionally, each channel cross section was designed in conjunction with the channel slope to ensure sediment transport competency and capacity.

Pattern

The proposed channel alignment is designed to increase sinuosity in order to decrease the average channel slope and improve bedform diversity. A reduction in slope will reduce the likelihood of future incision. Meander width ratios throughout the project range from 3.0 to 8.4 times the bankfull width. Higher meander width ratios are incorporated into the designs to allow for lateral dissipation of energy through appropriate pool to pool spacing and riffles that across the floodplain. In areas where the valley is narrow, the meander width ratio necessarily decreases. In these areas, energy is dissipated through step pools bedforms. Radii of curvature have been designed throughout the project to fall into the range of approximately 2.0 to 4.0 times the channel's proposed bankfull width. Radii up to 6.1 times the bankfull width are used at the downstream extent of South Fork Hoppers in order to gradually reconnect the proposed channel with the existing channel.

Profile/Bedform

Bedform will be diversified throughout the project reaches through facet development (riffle, run, pool, glide, and step-pool) mimicking those characteristics of the reference reaches. Channel slopes have been designed to allow for proper sediment transport capacity and competency and have been kept in the appropriate range for the proposed channel type.

Riffle slopes throughout the design reaches are typically between 1.4 and 4.0 times the average slope of the channel. The maximum pool depth is proposed to be constructed from the meander curve apex to a point one-third of the distance along the profile from the apex to the head of the next downstream riffle, or two-thirds of the distance along the profile from the tail of riffle to the downstream head of riffle. (Copeland et al., 2001). The longitudinal profile was optimized in conjunction with structure placement for aquatic habitat.

7.4 Design Reaches

7.4.1 South Muddy Creek

This reach is designed as a Rosgen C4. The existing floodplain is to be excavated down to the existing bankfull elevation and the new channel alignment will meander across the wide floodplain.

A Rosgen Priority 2 restoration approach was determined to be the highest level of restoration that could be achieved on South Muddy Creek given site constraints. The current stream banks are approximately ten feet high, and reconnection of the channel to the historic floodplain (Rosgen Priority 1) could not be achieved without creating backwater conditions on adjoining properties. The new channel also needs to rejoin the existing stream channel approximately two thirds down the length of the restoration reach in order to pass under the Sain Road bridge. In light of these constraints, a new floodplain and meandering channel will be excavated at the existing bankfull elevation. The channel will straighten for approximately 60 LF upstream and downstream of the Sain Road bridge crossing. Two small drainage ditches will be tied into the constructed channel at the tails of pools. Table 7.2 summarizes the design parameters for this reach.

A variety of in-stream structures will be installed in this reach including angled log step pools, log vanes and log j-hook vanes that will serve to provide vertical grade control and improve habitat quality. Geolifts, brush mattresses (if constructed during the dormant season), and root wads will serve to protect the stream bank and to provide habitat. See Section 7.6 for information on use of structures. Cut materials from the floodplain and channel excavations will be used to backfill the original channel.

A vegetated buffer will be installed on both sides of the stream for a minimum width of 30 feet from top of bank to protect the restored channel. Fencing will be placed along the easement boundary on both banks to restrict cattle from entering the channel. A ford crossing will be established at Station 23+00 to allow access to both sides of the creek upstream of Sain Road bridge. Figure 7.1 illustrates the proposed restoration and conservation easement.

7.4.2 South Fork Hoppers Creek

Rosgen Priority 1 restoration, which includes relocation of the channel onto the historic floodplain, is the selected restoration method for this channel. The upstream 400 LF of South Fork Hoppers Creek has been designed as a meandering channel with minimal slope to transition to a Priority 1 restoration as quickly as possible. A minimum average slope of 0.004 feet/foot was calculated as the critical slope required to avoid aggradation in the reach. This minimum average slope was adopted for the transition reach. Riffles are steeper than the average slope, but range from 1.2 to 1.5 times average slope rather than the 2.0 to 3.0 times average slope used for the remainder of the reach.

This transition zone allows the stream to re-connect with the existing floodplain elevation near the upstream extent of the existing wetland area. Therefore, no grading will be required in the existing wetland area, and wetland hydrology will be enhanced by raising the water table adjacent to the stream and increasing overbank flood events.

Two riffle cross sections were designed for this reach; one for the length of the channel above the confluence of South Fork Hoppers with UT1 (Reach 1) and one for below (Reach 2). Reach 1 was designed as a C/E channel. The width-to-depth ratio is at the small end of a C-channel (13.2) but not less than 12 to classify as an E-channel. Sinuosity is low (approximately 1.2), which is the minimum for a meandering stream. The goal is to set up a stable channel that can narrow to an E dimension over time as vegetation is established along the banks. Angled log step pools and constructed riffles will be used to hold grade, protect banks and create bedform diversity. Below the confluence, Reach 2 was designed as a C channel with a steeper channel slope than Reach 1. A cross section with a higher width to depth ratio was selected to lower the potential for degradation and to ease the transition between the proposed and the existing channel. Constructed riffles will be used where necessary to protect against degradation.

Minimal floodplain grading will be required to achieve bank height ratios of 1.0 for the proposed channel. A 30 foot planted buffer will be installed to protect the restored channel. Fencing will be placed along the easement to restrict cattle from entering the channel. One ford crossing is located near Station 19+00 for access to pastures on both sides of the stream. Figure 7.2 shows the proposed stream approach and a recommended easement for the project.

7.4.3 UT1A

UT1A flows through a mature forest. The stream is geomorphically stable and exhibits well defined riffle-pool sequences. This reach will be preserved in its current condition. A conservation easement will be placed 30 feet to 100 feet off the right and left stream banks. The exact easement width within this range will be determined by EEP at a later date.

7.4.4 UT1B

As with the mainstem reach, a Rosgen Priority 1 restoration is the selected approach for this channel. This channel will be constructed as a meandering channel with proper dimension, pattern and profile. The proposed channel will be moved closer to the existing forested area on the existing left bank to the lowest part of the valley. A bankfull bench will be constructed on the right bank for the first 100 LF of the reach. Where the proposed alignment encroaches upon the transverse valley slope, a floodplain will be excavated. Structures, including brush mattresses, constructed riffles and angled log step pools will be used to increase habitat diversity.

A conservation easement will be placed on both sides of the stream to protect the restored channel. The easement will average 30 feet from the outside meander bend top of bank. Fencing will be placed along the right bank easement to restrict cattle access. One ford crossing is located near Station 18+70 for access to pastures on both sides of the stream.

7.4.5 UT2A

Enhancement Level II, beginning at the upstream project boundary and extending downstream to the pasture, is proposed for this channel. The proposed work will be considered a combination of Rosgen Priority 2, 3, and 4 approaches. The banks along the reach are steep with localized erosion. Bank erosion will be repaired where construction access is feasible. The channel will be reestablished as a step pool channel through the pig pen, and the surrounding landscape will be planted with live stakes and shade tolerant vegetation. A conservation easement will be placed on both sides of the stream to protect the enhanced channel. Fencing will be placed along the easement to restrict pig access.

Although outside the conservation easement, the severely eroded drainage ditch that joins the channel near the upstream extent was identified as a large source of sediment. This ditch will be graded to a stable slope and stabilized with shade tolerant vegetation.

7.4.6 UT2B

Enhancement Level II will be implemented on this reach. The pattern and profile of this reach are fair; however bank erosion was noted throughout the reach. Bank grading and planting will improve stability along this reach. For the downstream 317 LF of UT2B, the creek centerline represents the property line. The left bank only will be graded to a 3:1 slope and planted for stabilization. A conservation easement will be placed on the Landis Farm-owned bank(s) of the stream to protect the restored channel. A permanent ford crossing will be established at the existing location. Fencing will be placed along the easement boundary to restrict cattle from entering the channel.

7.4.7 UT3

UT3 flows through a mature forest in a steep valley. The stream is geomorphically stable and exhibits well defined riffle-pool sequences. This reach will be preserved in its current condition. A conservation easement will be placed 30 feet to 100 feet off the right and left stream banks. The exact easement width within this range will be determined by EEP as the project continues.

Table 7.2 Existing and Proposed Geomorphic Characteristics
South Muddy Creek Restoration Plan

	South Muddy Creek						South Fork Hoppers Creek - Reach 1						South Fork Hoppers Creek-Reach 2						UT1B						UT2B					
	Existing			Proposed			Existing			Proposed			Existing			Proposed			Existing			Proposed			Existing			Proposed		
	Min	**Max**	**n***	**Min**	**Max**	**n***	**Min**	**Max**	**n***	**Min**	**Max**	**n***	**Min**	**Max**	**n***	**Min**	**Max**	**n***	**Min**	**Max**	**n***	**Min**	**Max**	**n***	**Min**	**Max**	**n***	**Min**	**Max**	**n***
1. Stream Type	G4c		-	C4		-	G5c		-	C5		-	G5c		-	C5		-	E5		-	C5		-	G5c		-	B5c		-
2. Drainage Area – mi^2	18.80		-	18.8		-	0.52		-	0.52		-	0.52			0.52		-	0.08		-	0.08		-	0.07		-	0.07		-
3. Bankfull Width (w_{bkf}) – ft	24.1	51.2	5	43.2		1	7.4	14.4	3	13.2		1	7.4	14.4	3	14.2		1	3.4	5.7	2	7.0		1	5.5	6.2	2	6.5		1
4. Bankfull Mean Depth (d_{bkf}) – ft	1.9	3.0	5	3.0		1	1.0	1.6	3	1.0		1	1.0	1.6	3	0.9		1	0.6	1.0	2	0.5		1	0.9	1.1	2	0.4		1
5. Width/Depth Ratio (w/d ratio)	8.1	26.9	5	14.4		1	6.1	14.4	3	13.2		1	6.1	14.4	3	15.8		1	3.4	9.5	2	13.8		1	5.0	6.2	2	15.0		1
6. Cross-sectional Area (A_{bkf}) – ft^2	72.8	97.2	5	128.5		1	7.4	15.6	3	13.8		1	7.4	15.6	3	12.7		1	3.4	3.5	2	3.6		1	5.4	6.1	2	2.8		1
7. Bankfull Mean Velocity (v_{bkf}) - ft/sec	4.1	5.5	5	3.1		1	3.2	6.8	3	3.6		1	3.2	6.8	3	3.9		1	4.0	4.1	2	4.2		1	2.0	2.2	2	4.3		1
8. Bankfull Discharge (Q_{bkf}) – ft^3/sec	400.0		-	400		-	50		3	50		1	50		3	50		-	14		-	14		-	12		-	12		1
9. Bankfull Max Depth (d_{mbkf}) - ft	3.3	4.0	5	4.2		1	1.7	2.0	3	1.3		1	1.7	2.0	3	1.2		1	1.3	1.6	2	0.8		1	1.3	1.5	2	0.5		1
10. d_{mbkf} / d_{bkf} ratio	1.2	1.7	5	1.4		1	1.2	1.9	3	1.3		1	1.2	1.9	3	1.3		1	1.4	2.1	2	16		1	1.4	1.4	2	1.2		1
11. Low Bank Height to d_{mbkf} ratio	2.4	3.2	5+	1.0		1	1.3	2.6	5+	1.0		1	1.3	2.6	5+	1.0		1	1.1	4.5	5+	1.0		1	1.0	3.9	5+	1.0		1
12. Floodprone Area Width (w_{fpa}) – feet	29.6	72.7	5	210+		10	16.8	33.0	3	50+		8	16.8	33.0	3	50+		2	9.8	92.5	2	30+		16	9.6	15.0	2	10.0	22.0	5
13. Entrenchment Ratio (ER)	1.1	1.7	5	4.9+		10	2.0	3.4	3	3.8+		8	2.0	3.4	3	3.8+		2	2.9	16.2	2	4.3+		16	1.7	2.7	2	1.5	3.4	5
14. Meander length (L_m) – ft	Straightened		-	345	506	6	Straightened		-	130	177	6	Straightened		-	179	313	1	Straightened		-	58	134	13	Straightened		-	Not Applicable		-
15. Ratio of meander length to bankfull width (L_m/w_{bkf})	Straightened		-	8.0	11.7	6	Straightened		-	9.8	13.4	6	Straightened		-	12.6	22.0	1	Straightened		-	8.3	19.1	13	Straightened		-	Not Applicable		-
16. Radius of curvature (R_c) – ft	Straightened		-	84	138	9	Straightened		-	37	53	8	Straightened		-	45	87	3	Straightened		-	14	24	16	Straightened		-	Not Applicable		-
17. Ratio of radius of curvature to bankfull width (R_c / w_{bkf})	Straightened		-	1.9	3.2	9	Straightened		-	2.8	4.0	8	Straightened		-	3.2	6.1	3	Straightened		-	2.0	3.4	16	Straightened		-	Not Applicable		-
18. Belt width (w_{blt}) – ft	Straightened		-	128	209	9	Straightened		-	54	78	8	Straightened		-	62	62	3	Straightened		-	32	59	16	Straightened		-	Not Applicable		-
19. Meander Width Ratio (w_{blt}/W_{bkf})	Straightened		-	3.0	4.8	9	Straightened		-	4.1	5.9	8	Straightened		-	4.4	4.4	3	Straightened		-	4.6	8.4	16	Straightened		-	Not Applicable		-
20. Sinuosity (K) stream length / valley length	1.1		-	1.2		-	1.14		-	1.2		-	1.14		-	1.1		-	1.18		-	1.6		-	1.22		-	1.0		-
21. Valley Slope	0.0017		-	0.002		-	0.0115		-	0.0095		-	0.0115		-	0.0017		-	0.0228		-	0.0228		-	0.0230		-	0.0293		-
22. Average Channel Slope (S_{bkf})	0.0016		-	0.0017		-	0.0101		-	0.0077		-	0.0101		-	0.0016		-	0.0193		-	0.0144		-	0.0189		-	0.0293		-
23. Pool Slope (s_{pool})	0.0000	0.0003	6	0.0	0.005	11	0.0	0.004	17	0.0	0.0018	8	0.0	0.004	17	0.0011	0.0018	3	0.0000	0.0050	11	0.0	0.0028	16	0.0	0.0143	9	0.0	0.0089	5
24. Ratio of Pool Slope to Average Slope (S_{pool} / S_{bkf})	0.0	0.2	6	0.0	0.3	11	0.0	0.4	17	0.0	0.2	8	0.0	0.4	17	0.07	0.1	3	0.0	0.3	11	0.0	0.2	16	0.0	0.8	9	0.0	0.3	5
25. Maximum Pool Depth (d_{pool}) – ft	3.8	5.8	4	6.2	10.3	11	2.1	2.4	3	2.0		9	2.1	2.4	3	2.5	2.7	3	1.3	1.6	2	1.0	2.0	16	1.7	1.9	2	1.8		1
26. Ratio of Pool Depth to Average Bankfull Depth (d_{pool}/d_{bkf})	1.4	2.1	4	2.1	3.4	11	1.8	2.0	3	2.0		9	1.8	2.0	3	2.8	3.0	3	1.6	2.0	2	2.0	4.0	16	1.7	1.9	2	4.5		1
27. Pool Width (w_{pool}) – ft	28.1	39.9	4	46.0		1	7.7	14.0	3	15		1	7.7	14.0	3	15.0		1	4.0	7.7	2	9.3		1	6.2	12.4	2	8.0		1
28. Ratio of Pool Width to Bankfull Width (w_{pool} / w_{bkf})	0.9	1.2	4	1.1		1	0.7	1.3	3	1.1		1	0.7	1.3	3	1.1		1	0.9	1.7	2	1.3		1	1.1	2.2	2	1.2		1
29. Pool Area (A_{pool}) – ft^2	85.9	103.7	4	168	177	11	11.6	14.8	3	19		1	11.6	14.8	3	19.0		1	3.4	4.3	2	6.9		1	5.9	8.7	2	4.5		1
30. Ratio of Pool Area to Bankfull Area (A_{pool}/A_{bkf})	1.0	1.2	4	1.3	1.4	11	0.9	1.2	3	1.4		1	0.9	1.2	3	1.5		1	1.0	1.2	2	1.9		1	1.0	1.5	2	2.0		1
31. Pool-to-Pool Spacing (p-p) – ft	80.0	240.0	4	154	327	10	27.0	161.0	14	82	118	7	27.0	161.0	14	138	176	2	14.0	110.0	9	42	105	15	15.0	127.0	10	19.0	25.0	4
32. Ratio of Pool-to-Pool Spacing to Bankfull Width ($p\text{-}p/w_{bkf}$)	2.5	7.4	4	3.6	7.6	10	2.6	15.3	14	6.2	8.9	7	2.6	15.3	14	9.7	12.4	2	3.0	23.9	9	6.0	15.0	15	2.6	22.3	10	2.9	3.8	4
33. Riffle Slope (s_{riffle})	0.0025	0.0061	3	0.0034	0.0054	7	0.0150	0.0350	15	0.0130	0.0305	6	0.0150	0.0350	15	0.0275	0.033	3	0.033	0.564	19	0.0198	0.0371	12	0.0281	0.113	7	0.039	0.052	5
34. Ratio of Riffle Slope to Average Slope (s_{riffle}/s_{bkf})	1.6	3.8	3	2.0	3.2	7	1.5	3.5	15	1.7	4.0	6	1.5	3.5	15	1.7	2.1	3	1.7	29.2	19	1.4	3.5	12	1.5	6.0	7	1.3	1.8	5

7.5 Sediment Transport

7.5.1 Methodology

The purpose of sediment transport analysis is to check whether the stream restoration design can be expected to create a stable channel that does not aggrade or degrade over time, but adjust within its stable limits. The overriding assumption is that the project reaches designed as C and E type channels should be transporting all the sediment delivered from upstream sources, thereby being considered a "transport" reach.

Sediment transport competency is measured in terms of the relationship between critical and actual depth at a given slope, and occurs when the critical depth produces enough shear stress to move the largest (d_{100}) subpavement particle. Stream restoration designs must be tested to ensure that the new channel dimensions (in particular, the design bankfull mean depth) create a stream that has the ability to move its sediment load without aggrading or degrading over long periods of time. Sediment transport is assessed through two measures: sediment transport competency and sediment transport capacity. Competency is the ability of a stream to move particles of a given size and is a measurement of force, often expressed as units of pounds per square foot (lbs/ft^2). Sediment transport capacity is the ability of a stream to move a quantity of sediment and is a measurement of stream power per area, often expressed in units of watts/square meter.

The total volume of sediment transported through a cross-section consists of bedload plus suspended load fractions. Suspended load is normally composed of fine sand, silt, and clay particles transported in the water column. Bedload is generally composed of larger particles, such as course sand, gravels, and cobbles, which are transported by rolling, sliding, or hopping (saltation) along the bed.

Project reaches were separated for sediment transport analyses based on median particle size and channel slope and dimension. Because the riffle materials were coarse sands to gravels for each of the project reaches, both competency and capacity were checked.

7.5.1.1 Competency Analysis

Median substrate size has an important influence on the mobility of particles in stream beds. Critical dimensionless shear stress (τ_{ci}) is the measure of force required to initiate general movement of particles in a bed of a given composition. At shear stresses exceeding this critical value, essentially all grain sizes are transported at rates in proportion to their presence in the bed (Wohl, 2000). Critical dimensionless shear stress can be calculated for gravel-bed stream reaches using surface and subsurface particle samples from a stable, representative riffle in the reach (Andrews, 1983). The following equations are used to determine the critical dimensionless shear stress required to mobilize and transport the largest particle from the bar sample (or subpavement sample) (Rosgen, 2001a).

a) Calculate the ratio d_{50}/ds_{50}

where: d_{50} = median diameter of the riffle bed (from 100 count in riffle or pavement sample)
ds_{50} = median diameter of the bar sample (or subpavement)

If the ratio d_{50}/ds_{50} is between the values of 3.0 and 7.0, then calculate the critical dimensionless shear stress using Equation 1.

$$\tau_{ci} = 0.0834(d_{50}/ds_{50})^{-0.872}$$ **(Equation 1)**

b) If the ratio d_{50}/ds_{50} is not between the values of 3.0 and 7.0, then calculate the ratio of D_i/d_{50}

where: D_i = largest particle from the bar sample (or subpavement)
d_{50} = median diameter of the riffle bed (from 100 count in the riffle or pavement sample)

If the ratio D_i/d_{50} is between the values of 1.3 and 3.0, then calculate the critical dimensionless shear stress using Equation 2.

$$\tau_{ci} = 0.0384(D_i/d_{50})^{-0.887}$$ **(Equation 2)**

7.5.1.2 Aggradational Analysis

The aggradation analysis is based on calculations of the required depth and slope needed to transport large sediment particles, in this case defined as the largest particle of the riffle subpavement sample. Required depth can be compared with the existing/design mean riffle depth, and required slope can be compared to the existing and design slopes to verify that the stream has sufficient competency to move large particles (and thus prevent thalweg aggradation). The required depth and slope are calculated by:

$$d_r = \frac{1.65\tau_{ci}D_i}{S_e}$$ **(Equation 3)**

$$s_r = \frac{1.65\tau_{ci}D_i}{d_e}$$ **(Equation 4)**

where: d_r = required bankfull mean depth (ft)
d_e= design bankfull mean depth (ft)
1.65 = sediment density (submerged specific weight)
= density of sediment (2.65) – density of water (1.0)
τ_{ci} = critical dimensionless shear stress
D_i = largest particle from bar sample (or subpavement) (ft)
s_r = required bankfull water surface slope (ft/ft)
S_e = design bankfull water surface slope (ft/ft)

The aggradation analysis is used to assess both existing and design conditions; for example, if the calculated value for the existing critical depth is significantly larger than the measured maximum bankfull depth, this indicates that the stream is aggrading. Alternately, if the proposed design depth significantly differs from the calculated critical depth, and the analysis is deemed appropriate for the site conditions, the design dimensions should be revised accordingly.

7.5.1.3 Competency Analysis using Shields Curve

As a complement to the required depth and slope calculations, boundary shear stresses for a design riffle cross-section can be compared with a modified Shields curve to predict sediment transport competency. The shear stress placed on the sediment particles is the force that entrains and moves the particles and is given by:

$$\tau = \gamma Rs$$ **(Equation 5)**

where: τ = shear stress (lb/ft^2)
γ = specific gravity of water (62.4 lb/ft^3)
R = hydraulic radius (ft)
s = average channel slope (ft/ft)

The boundary shear stress can be estimated for the design cross-section and plotted on a critical shear stress curve, as shown in Figure 7.3. The particle size that CO curve predicts will be moved is compared to the D_i of the site subpavement. The CO curve is used rather than the Leopold et al curves because data collected from NC more closely matches this relationship. The CO curve predicts whether the design conditions will have enough shear stress to move a particle larger than the largest subpavement particle found in the creek and prevent aggradation.

7.5.1.4 Degradation Analysis

A degradation analysis is performed in order to assess whether the design cross-sections will result in scour and bed downcutting. The potential for degradation may be evaluated by examining the upper competency limits for design cross-sections and by reviewing existing and design grade control at the site. The calculated shear stress discussed in Section 7.5.1.3 can be used to describe the upper competency limits for the design channel. The calculated shear stress is compared to the CO curve, as illustrated in Figure 7.3, to determine the largest particle size that stress value will move. This value should be comparable to the D_{84} to D_{95} values from the reach-wide pebble count.

7.5.1.5 Sediment Transport Capacity

For sand bed streams, sediment transport capacity is much more important than competency. Sediment transport capacity refers to the ability of a stream to move a mass of sediment past a cross-section per unit of time in pounds/second or tons/year. Sediment transport capacity can be assessed directly using actual monitored data from bankfull events if a sediment transport rating curve has been developed for the project site. Since this curve development is extremely difficult, other empirical relationships are used to assess sediment transport capacity. The most common capacity equation is stream power. Stream power can be calculated a number of ways, but the most common is:

$$\omega = QS/W_{bkf}$$

(Equation 6)

where: w = mean stream power (W/m^2)
γ = specific weight of water 9,810 N/m^3); $\gamma = \rho g$, where ρ is the density of the water-sediment mixture (1,000 kg/m^3) and g is the acceleration due to gravity 9.81 m/s^2)
Q = bankfull discharge (m^3/s)
S = design channel slope (m/m)
Wbkf = bankfull channel width (m)
Note: 1 ft-lb/sec/ft^2 = 14.56 W/m^2

Equation 6 describes the ability of the stream to accomplish work, i.e., move sediment. Calculated stream power values are compared to reference and published values. If deviations from known stable values for similar stream types and slopes are observed, the design should be reassessed to confirm that sediment will be adequately transported through the system without containing excess energy in the channel.

7.5.2 South Muddy Creek Sediment Transport Analysis

Table 7.3 summarizes the existing sediment competence calculations for South Muddy Creek. Cross section X1A has an existing depth of 1.9 ft and slope of 0.0016 ft/ft. The existing conditions are in excess of the depth (1.3 ft) and slope (0.0009) required to move the D100 of the subpavement . This portion of the channel is therefore capable of moving a much larger particle size than the D100 and is degradational. The first 500 LF of the project are a transition zone between the G4c stream type downstream and the F channel upstream.

Cross Section X1 has an existing depth and slope less than the critical depth and slope required to move the D100. This indicates that this portion of the channel is aggradational and is not adequately transporting the sediment supplied to it. The presence of a lateral sand bar at this location supports this analysis. Cross Section X3 has an existing depth and slope in great excess of the critical depth and slope required to move the D100. This portion of the channel is highly degradational and is classified as a Rosgen G4c.

Cross Section X8 and X9 were analyzed using a steeper channel slope than the upstream cross sections because the reach is below the backwater effects of the debris jam. A slope of 0.0020 ft/ft was used to calculate sediment transport rates. Both Cross Section X8 and X9 have greater depth than the critical values required to move the D100. This portion of the channel is highly degradational and is classified as a Rosgen G4c.

Capacity, measured by unit stream power, steadily increases in the downstream direction. This corresponds to the observed transition from an F type channel at the upstream boundary to a Gc type channel downstream. F channels are aggradational due to higher width-to-depth ratios and lower velocities while Gc channels are degradational due to lower width-to-depth ratios and generally higher velocities.

Table 7.3 Existing Boundary Shear Stresses and Stream Power – South Muddy Creek
South Muddy Creek Restoration Plan

Parameter	X1A	X1	X3	X8	X9
Bankfull Discharge, Q (cfs)	400	400	400	400	400
Bankfull Area (square feet)	97.2	89.6	81.5	77.7	72.8
Mean Bankfull Velocity (fps)	4.1	4.5	4.9	5.1	5.5
Bankfull Width, W (feet)	51.2	31.5	28.5	25.8	24.3
Bankfull Mean Depth, D (feet)	**1.9**	**2.9**	**2.9**	**3.0**	**3.0**
Width to Depth Ratio, w/d (feet/ foot)	26.9	10.9	9.8	8.6	8.1
Wetted Perimeter (feet)	55.0	37.3	34.3	31.8	30.3
Hydraulic Radius, R (feet)	1.8	2.4	2.4	2.4	2.4
Channel Slope (feet/ foot)	**0.0016**	**0.0016**	**0.0016**	**0.0020**	**0.0020**
Boundary Shear Stress, τ (lbs/ft^2)	0.180	0.240	0.240	0.300	0.300
Subpavement D_{100} (mm)	33	80	18	51	65
Largest Moveable Particle (mm) per Shield's Curve (Rosgen Curve)	30-70	40-90	40-90	45-95	45-95
Critical Depth (feet)	**1.3**	**4.2**	**0.6**	**2.0**	**2.5**
Critical Slope (feet/ foot)	**0.0009**	**0.0030**	**0.0004**	**0.0013**	**0.0023**
Unit Stream Power (Watts/ sq meter)	**10.8**	**15.6**	**17.1**	**22.5**	**24.0**

Table 7.4 summarizes the proposed channel dimensions and critical depths and slopes for the proposed conditions. The proposed South Muddy Creek design has a depth and slope similar to the critical values, and is estimated to be competent to move the supplied sediment load without aggrading or degrading. Unit stream power for the proposed reach falls between values calculated at X1A and X1, corresponding to the capacity value between an aggradational and a degradational channel. As an added measure to protect against degradation, grade control structures and constructed riffles will be used.

Table 7.4 Proposed Boundary Shear Stresses and Stream Power – South Muddy Creek South Muddy Creek Restoration Plan	
Parameter	**South Muddy Creek**
Bankfull Discharge, Q (cfs)	400.0
Bankfull Area (square feet)	128.5
Mean Bankfull Velocity (fps)	3.1
Bankfull Width, W (feet)	43.2
Bankfull Mean Depth, D (feet)	**3.0**
Width-to-Depth Ratio, w/d (feet/ foot)	14.4
Wetted Perimeter (feet)	49.2
Hydraulic Radius, R (feet)	2.6
Channel Slope (feet/ foot)	**0.0017**
Boundary Shear Stress, τ (lbs/ft^2)	0.28
Subpavement D_{100} (mm)	51.0
Largest Moveable Particle (mm) per CO Curve	45-90
Critical Depth (feet)	**2.4**
Critical Slope (feet/ foot)	**0.0013**
Unit Stream Power (Watts/ sq meter)	**12.6**

7.5.2.1 South Fork Hoppers Creek Sediment Transport Analysis

Table 7.5 summarizes the existing sediment transport calculations for South Fork Hoppers Creek and UT1B, which are the two reaches on the Landis Farm site slated for restoration. The analysis of the existing cross sections on South Fork Hoppers Creek indicates that the channel has the competence to move a larger particle size than that found in the channel substrate. The critical depth and critical slope are higher than needed for transport equilibrium. It should be noted that the data used to develop these relationships came from much larger rivers and are not directly applicable to these streams. Therefore, this analysis is only used as a guide, rather than a final determination of channel size and slope. Unit stream power is in the 27.6 to 48.2 Watts per square meter (W/m^2) range. The average stream power for stable streams in a study by Bledsoe is 30 W/m^2 for the 2-year storm event (2002). The 1.5-year recurrence interval event in the Bledsoe channels is estimated to create stream power in the 20 W/m^2 range. The bankfull discharges for all reaches on the South Fork Hoppers site are near the 1.5 year return interval (see Table 3.10) and therefore 20 W/m^2 was determined to be the required unit stream power to avoid aggradation. The analysis of existing cross sections on South Fork Hoppers Creek indicates that the channel has more sediment competency and capacity than needed for a stable stream.

The analysis of the existing cross sections on UT1B indicates that the channel has the competence to move a larger particle size than that found in the channel substrate. The critical depth and critical slope are higher than needed for transport equilibrium. Unit stream power is in the 34.5 to 45.5 W/m^2 range. The analysis of existing cross sections on UT1B indicates that the channel has more sediment competency and capacity than needed for a stable stream.

Table 7.5 Existing Boundary Shear Stresses and Stream Power – South Fork Hoppers Creek and UT1B
South Muddy Creek Restoration Plan

Parameter	South Fork Cross Section X5	South Fork Cross Section X7	South Fork Cross Section X10	UT1B Cross Section X2	UT1B Cross Section X4
Bankfull Discharge, Q (cfs)	50	50	50	14	14
Bankfull Area (square feet)	14.5	7.4	15.6	3.4	3.5
Mean Bankfull Velocity (cfs)	3.4	6.8	3.2	4.1	4.0
Bankfull Width, W (feet)	14.4	7.4	9.7	3.4	5.7
Bankfull Mean Depth, D (feet)	**1.0**	**1.0**	**1.6**	**1.0**	**0.6**
Width-to-Depth Ratio, w/d (feet/ foot)	14.4	7.4	6.1	3.4	9.4
Wetted Perimeter (feet)	16.4	9.4	12.9	5.4	6.9
Hydraulic Radius, R (feet)	0.9	0.8	1.2	0.6	0.5
Channel Slope (feet/ foot)	**0.0101**	**0.0101**	**0.0101**	**0.0193**	**0.0193**
Boundary Shear Stress, τ (lbs/ft^2)	0.56	0.50	0.76	0.77	0.61
Subpavement D_{100} (mm)	28	25	42	64	16
Largest Moveable Particle (mm) per Shield's Curve (Rosgen Curve)	60-180	60-180	65-200	65-200	60-180
Critical Depth (feet)	**0.4**	**0.3**	**0.6**	**0.3**	**0.04**
Critical Slope (feet/ foot)	**0.0040**	**0.0033**	**0.0041**	**0.0053**	**0.0003**
Unit Stream Power (Watts/ sq meter)	**27.9**	**48.8**	**35.6**	**45.5**	**34.5**

N/A: sediment ratio values were not in correct range to allow for use of critical depth and critical slope equations.

Table 7.6 summarizes the proposed channel dimensions and critical depths and slopes given the proposed conditions. The proposed South Fork Hoppers Creek Reach 1 design has a depth and slope slightly higher than the critical design values. The design depth and slope will still have the competency to move particles equal to or larger than the largest subpavement particle sampled in the channel. Stream power will decrease to approximately 22.9 W/m^2, which is lower than existing conditions and near the estimated stable value of 20 W/m^2 (Bledsoe, 2002). While the design conditions are an improvement over the existing conditions, the sediment transport analysis indicates that degradation is a design consideration. In order to protect against degradation, structures such as constructed riffles and angled log step pools will be installed. These features will control vertical stability so that the channel will not degrade. The South Fork Hoppers Creek Reach 2 design has a unit stream power comparable to the existing conditions, therefore all riffles throughout this reach will be constructed to protect against degradation. This will also serve to provide grade control and protect against headcuts that could migrate upstream due to downstream channel instability.

The proposed UT1B design results in a design depth and slope very close to the critical depth and slope indicated by sediment transport calculations. According to the CO curve, the channel will be able to move a particle within the same size class as the largest particle sampled. Shear stress is significantly decreased in the design channel. The design stream power will also be decreased to 22.8 W/m^2, much closer to the estimated stable value of 20 W/m^2 (Bledsoe 2002). These results indicate that the design channel should possess the competency and capacity to move its sediment load without excessive aggradation or degradation. As with South Fork Hoppers Creek, grade control structures will be used to maintain vertical stability on the reach.

Table 7.6 Proposed Boundary Shear Stresses and Stream Power – South Fork Hoppers Creek and UT1B
South Muddy Creek Restoration Plan

Parameter	South Fork Hoppers Creek – Reach 1	South Fork Hoppers Creek – Reach 2	UT1B
Bankfull Discharge, Q (cfs)	50	50	14
Bankfull Area (square feet)	13.8	12.7	3.6
Mean Bankfull Velocity (cfs)	3.6	3.9	3.9
Bankfull Width, W (feet)	13.2	14.2	7.0
Bankfull Mean Depth, D (feet)	**1.0**	**0.9**	**0.5**
Width-to-Depth Ratio, w/d (feet/ foot)	13.2	15.8	13.8
Wetted Perimeter (feet)	15.3	16.0	8.0
Hydraulic Radius, R (feet)	0.9	0.8	0.4
Channel Slope (feet/ foot)	**0.0077**	**0.0155**	**0.0144**
Boundary Shear Stress, τ (lbs/ft^2)	0.43	0.77	0.40
Subpavement D_{100} (mm)	25-42	25-42	16-64
Largest Moveable Particle (mm) per Shield's Curve (Rosgen)	50-100	80-175	11-20
Critical Depth (feet)	**0.4-0.8**	**0.2-0.4**	**0.4**
Critical Slope (feet/ foot)	**0.0032-0.0062**	**0.0037-0.0072**	**0.0106**
Unit Stream Power (Watts/ sq meter)	**22.9**	**44.0**	**22.8**

7.6 In-Stream Structures

A variety of in-stream structures are proposed for the South Muddy Creek restoration project. Structures such as root wads, constructed riffles, angled log step pools, geolifts, and brush mattresses will be used to stabilize the newly-restored streams. Wood structures will dominate because of the materials observed in the existing systems. A substantial amount of wood will be generated through the construction of the project at the South Muddy Creek site; less will be generated at the South Fork Hoppers Creek site. Table 7.7 summarizes the use of in-stream structures at the site.

Table 7.7 Proposed In-Stream Structure Types and Locations South Muddy Creek Restoration Plan	
Structure Type	**Location**
Root Wad	Outside bank of smaller radius meander bends.
Brush Mattress	Outside bank of meander bends that are located offline of the existing channel.
Geolifts	Outside bank of meander bends that intercept the existing channel
Log J-Hook Vane	In meander bends to help turn water, encourage scour pool development, and increase available habitat.
Log Vane	In meander bends to turn water.
Cover Log	In pools to provide habitat features.
Angled Log Step Pool	In steeper riffles to provide grade control, diversify the thalweg path, and to provide micro-pool habitat.

Root Wad

Root wads are placed at the toe of the stream bank in the outside of meander bends for the creation of habitat and for stream bank protection. Root wads include the root mass or root ball of a tree plus a portion of the trunk. They are used to armor a stream bank by deflecting stream flows away from the bank. In addition to stream bank protection, they provide structural support to the stream bank and habitat for fish and other aquatic animals. They also serve as a food source for aquatic insects. Root wads will be placed throughout South Muddy Creek and South Fork Hoppers Creek.

Brush Mattress

Brush mattresses are placed on bank slopes on the outside of meander bends for stream bank protection. Layers of live, woody cuttings are wired together and staked into the bank. Brush mattresses help to establish vegetation on the bank to secure the soil. Once the vegetation is established, the cover also provides habitat for fish and macroinvertebrates. Depending on availability of suitable vegetation onsite, brush mattresses may be used interchangeably with alder and willow transplants, at the discretion of the onsite engineer.

Log J-Hook Vane

Log J-hook vanes are used to protect the stream bank and encourage pool scour and habitat diversity. The length of the vane arm can span one half to two thirds the bankfull channel width. J-hooks are located either upstream or downstream along a meander bend and function to redirect the flow energies away from the bank, keep the thalweg in the center of the channel, and protect the stream bank. Boulders placed in the “J” portion of the structure produce lateral and vertical flow diversity at low flows. At bankfull flows, the boulders serve as energy dissipation features, adding to the overall bed roughness and providing local downstream eddy microhabitat. This structure will be placed in meander bends to help turn the water. A J-hook vane will also be included at the end of South Muddy Creek restoration reach to center the thalweg as the proposed channel rejoins the existing channel.

Log Vane

A log vane is used to protect the stream bank. The length of a single vane structure can span one-half to two-thirds the bankfull channel width. Vanes are located either upstream or downstream along a meander bend and function to initiate or complete the redirecting of flow energies resulting in reduced near bank shear stress and alignment maintenance. Vanes are located just downstream of the point where the stream flow intercepts the bank at acute angles. Log vanes are proposed on South Muddy Creek.

Cover Log

A cover log is placed in the outside of a meander bend to provide habitat in the pool area. The log is buried into the outside bank of the meander bend; the opposite end extends through the deepest part of the pool and may be buried in the inside of the meander bend, in the bottom of the point bar. The placement of the cover log near the bottom of the bank slope on the outside of the bend encourages scour in the pool. This increased scour provides a deeper pool for bedform variability. Cover logs will be used on all reaches.

Angled Log Step Pool

Angled log step pools consist of a header log and a footer log placed in the bed of the stream channel, perpendicular to stream flow. The logs extend into the stream banks on both sides of the structure to prevent erosion and bypassing of the structure. The logs are installed flush with the channel bottom upstream of the log. The footer log is placed to the depth of scour expected, to prevent the structure from being undermined. The logs are placed at alternating angles to the bank to diversify the low flow path and allow micro pool habitats to form between steps. This structure provides bedform diversity, maintains the channel profile, and provides pool and cover habitat. Angled log step pools will be used in steeper riffles on all reaches throughout the project sites.

7.7 Soil Restoration

7.7.1 Narrative & Soil Preparation and Amendment

Soil composition is vitally important to the success of newly planted riparian vegetation. Technical specifications will require the contractor to perform pre-construction soil tests to determine the existing soil composition. Soil amendments necessary to support the growth of proposed herbaceous and woody riparian species shall be added prior to planting.

8.0 PROJECT WETLAND AND VEGETATION RESTORATION PLAN

This section discusses the design criteria selected for potential wetland restoration on the South Muddy Creek project sites.

8.1 Restoration of Wetland Hydrology

The existing agricultural fields across the site are currently drained by the channelized and incised condition of South Fork Hoppers Creek. To restore wetland hydrology to the site the stream will be restored and the old channel will be fully to partially filled. When complete filling of the stream is not possible, channel plugs will be constructed using compacted earth along the length of the abandoned channel at roughly 50-foot intervals. Channel plugs will also be used in locations where the restored stream channel will cross the existing stream channel. In these locations, the existing stream will be plugged for at least 50 feet on both sides of the restored channel to prevent drainage losses and channel avulsion.

Surface flows from the adjacent hillslopes will be diverted into the restored wetland area where topography allows. Overland flow will be diverted over the floodplain area, where it will be intercepted by wetland micro topography (surface storage areas) and allowed to infiltrate into the soil column, maintaining a higher water table.

Grading activities will focus primarily on creating microtopography within the wetland boundary and adjusting surface flow patterns to improve hydrologic inputs to the site. Site grading will also remove any historic drain tiles, field crowns, surface drains, or swales that were imposed during conversion of the land for agriculture. Surface roughening will be the final step of the grading operations to maximize surface storage potential at the site.

The topography of the restored site will be patterned after natural floodplain wetland reference sites and will include the restoration of minor depressions and tip mounds (microtopography) that promote diversity of hydrologic conditions and habitats common to natural wetland areas. These techniques will be instrumental to the restoration of site hydrology by promoting surface ponding and infiltration, decreasing drainage capacity, and imposing higher water table conditions across the restoration site. Microtopography contributes to the properties of forest soils and to the diversity and patterns of plant communities (Lutz, 1940; Stephens, 1956; Bratton, 1976; Ehrnfeld, 1995). Microtopography will be established after floodplain areas have been restored to design grades.

8.2 Hydrologic Modeling Analyses

The DRAINMOD simulations that were developed to evaluate the current hydrologic status of the restoration site were modified to estimate the hydrologic conditions of the site under the proposed restoration practices. Model parameters that describe the depth of stream and topographic surface storage were changed to values representative of the described restoration practices; for example, drain depths were reduced to represent average water levels in the restored, meandering channel. Surface storage parameters were increased, within a range of two to three centimeters, to represent soil scarification practices and grading. Input files that describe cropping conditions were changed to represent forested conditions.

Several model scenarios were simulated to evaluate the restored hydrologic conditions for the restoration areas. Hydrologic simulations were run at 25, 75, and 150 feet from the proposed stream channel. These three simulations indicate a range of hydrologic conditions that will be imposed across the restored site. The simulation at 75 feet can be assumed to represent average conditions across the site, with the majority of the restored acreage on the site being represented by this hydrologic scenario. The remaining two scenarios represent areas of increased and decreased wetness, such as low-lying, depressional areas, or areas of higher elevation near the edge of the site, respectively. It is important to note that the hydrology of the targeted restored wetland system is highly variable across a given site, supporting the ecological and functional diversity that makes these systems so valuable. Forty-five year simulations were run following the procedures described in Section 5.4, and DRAINMOD input files are provided in Appendix 8.

A water balance for average restored conditions (75 feet from the proposed stream channel) is presented in Table 8.1. The proposed water balance illustrates a decrease in runoff and drainage, resulting in more water infiltrating into the soil profile, allowing the water table to remain higher throughout the year and thus restoring wetland hydrology.

Table 8.1 Proposed Conditions Water Balance Data
South Muddy Creek Restoration Plan

Hydrologic Parameter	Annual Amount over 45-Year Simulation Period (cm of water)	Annual Amount over 45-Year Simulation Period (% of average rainfall)
Precipitation	136.5 (84.5 to 201.2)	100
Drainage	36.2 (8.8 to 64.0)	26.5 (6.4 to 46.9)
Runoff	30.4 (4.5 to 68.4)	22.3 (3.3 to 50.1)
Evapotranspiration	69.8 (50.8 to 83.9)	51.1 (37.2 to 61.5)

The results of the simulations indicate that hydrologic conditions imposed across the restored site will vary from location to location, depending on the distance from the restored stream channel or center of wetland area and topographic variability. The simulations for the wetland area show that the 25-foot scenario is influenced most by the drainage effect of the stream channel and is, therefore, predicted to experience drier conditions than the 75- and 150-foot scenarios. In locations near the stream channel, hydrology will primarily be controlled by the baseflow water level in the restored stream and overbank flooding. In areas farther from the restored stream, the drainage effect becomes less significant, and evapotranspiration and runoff are the primary water loss pathways. Hydrology of these areas will be restored by the restoration of an overbank flooding regime and by topographic manipulations imposed to increase surface storage and infiltration of water on the site.

These modeled scenarios provide an indication of the hydrologic conditions that are expected across the restored site. The data indicate that the areas closest to the stream and the edges of the wetland will typically exhibit wetland hydrology for a smaller percentage of the growing season than the depressional areas further from the restored channel. Under average conditions, wetland hydrology will occur for approximately 6-12% of the growing season across the restored wetland site. Since no wetland system is homogeneous throughout, hydrology will vary across the restored site. Factors that will affect hydrology in any particular location include seepage inputs and outputs, degree of ponding, frequency of stream flooding events, local soil and subsoil conditions, runoff, and run-on.

8.3 Natural Plant Community Restoration

Native riparian and wetland vegetation will be established in the restored stream buffer and wetland areas. Also, areas of invasive kudzu on the South Muddy Creek site will be managed so as not to threaten the newly-established native plants within the conservation easement.

8.3.1 Stream Buffer and Wetland Vegetation

Bare-root trees, live stakes, and permanent seeding will be planted within designated areas of the conservation easement. A minimum 30-foot buffer will be established along all restored stream reaches. In general, bare-root vegetation will be planted at a target density of 680 stems per acre, or an 8 foot by 8 foot grid. Planting of bare-root trees and live stakes will be conducted during the dormant season.

Species selection for re-vegetation of the site will generally follow those suggested by Schafale and Weakley (1990) and tolerances cited in the US Army Corps of Engineers Wetland Research Program (USACE WRP) Technical Note VN-RS-4.1 (USACE WRP, 1997). Selected species for hardwood re-vegetation are presented in Table 8.2. Species selection may change due to availability at the time of planting.

Tree species selected for wetland and stream restoration areas will be generally weak to tolerant of flooding. Weakly tolerant species are able to survive and grow in areas where the soil is saturated or flooded for relatively short periods of time. Moderately tolerant species are able to survive in soils that are saturated or flooded for several months during the growing season. Flood tolerant species are able to survive on sites in which the soil is saturated or flooded for extended periods during the growing season (USACE, 1997).

Observations will be made during construction of the site regarding the relative wetness of areas to be planted. Planting zones will be determined based on these observations, and planted species will be matched according to their wetness tolerance and the anticipated wetness of the planting area.

Once trees are transported to the site, they will be planted within two days. Soils across the site will be sufficiently disked and loosened prior to planting. Trees will be planted by manual labor using a dibble bar, mattock, planting bar, or other approved method. Planting holes for the trees will be sufficiently deep to allow the roots to spread out and down without "J-rooting." Soil will be loosely compacted around trees once they have been planted to avoid drying out.

Live stakes will be installed randomly two to three feet apart using triangular spacing or at a density of 160 to 360 stakes per 1,000 square feet along the stream banks between the toe of the stream bank and bankfull elevation. Site variations may require slightly different spacing.

Table 8.2 Proposed Floodplain and Wetland Vegetation
South Muddy Creek Restoration Plan

Common Name	Scientific Name	Percent Planted by Species
Upper Slope Floodplain Areas		
Sugarberry	*Celtis laevigata*	10%
Persimmon	*Diospyros virginiana*	15%
Green ash	*Fraxinus pennsylvanica*	20%
Tulip poplar	*Liriodendron tulipifera*	15%
Sycamore	*Platanus occidentalis*	10%
Swamp chestnut oak	*Quercus michauxii*	15%
Southern red oak	*Quercus rubra*	15%
Floodplain Buffer		
River birch	*Betula nigra*	10%
Sugarberry	*Celtis laevigata*	5%
Persimmon	*Diospyros virginiana*	10%
Green ash	*Fraxinus pennsylvanica*	15%
Black walnut	*Juglans nigra*	5%
Tulip poplar	*Liriodendron tulipifera*	15%
Blackgum	*Nyssa sylvatica*	5%
Sycamore	*Platanus occidentalis*	20%
Swamp chestnut oak	*Quercus michauxii*	8%
Willow oak	*Quercus phellos*	7%
Stream Banks- Live Stakes		
Silky dogwood	*Cornus amomum*	40%
Ninebark	*Physocarpus opulifolius*	15%
Silky willow	*Salix sericea*	30%

Table 8.2 Proposed Floodplain and Wetland Vegetation South Muddy Creek Restoration Plan		
Common Name	**Scientific Name**	**Percent Planted by Species**
Elderberry	*Sambucus canadensis*	15%
Wetland Enhancement and Restoration Areas		
River birch	*Betula nigra*	15%
Persimmon	*Diospyros virginiana*	10%
Green ash	*Fraxinus pennsylvanica*	17%
Black walnut	*Juglans nigra*	13%
Blackgum	*Nyssa sylvatica*	10%
Sycamore	*Platanus occidentalis*	20%
Willow oak	*Quercus phellos*	10%
Black willow	*Salix nigra*	5%

Permanent seed mixtures will be applied to all disturbed areas of the project site. Table 8.3 lists the species, mixtures, and application rates which will be used. Species selection may change due to availability at the time of planting. The permanent seed mixture specified for floodplain areas will be applied to all disturbed areas outside the banks of the restored stream channel and is intended to provide rapid growth of herbaceous ground cover and biological habitat value. The species provided are deep-rooted and have been shown to proliferate along restored stream channels, providing long-term stability.

Mixtures will also include temporary seeding (rye grain or browntop millet). Temporary seeding will be applied to all disturbed areas of the site that are susceptible to erosion. These areas include constructed stream banks, access roads, side slopes, and spoil piles. If temporary seeding is applied from November through April, rye grain will be used and applied at a rate of 130 pounds per acre. If applied from May through October, temporary seeding will consist of browntop millet, applied at a rate of 45 pounds per acre.

Table 8.3 Proposed Riparian Seed Mixture South Muddy Creek Restoration Plan		
Common Name	**Scientific Name**	**Percent of Mixture**
Red top	*Agrostis alba*	5%
Virginia wildrye	*Elymus virginicus*	10%
Switchgrass	*Panicum virgatum*	15%
Gamma grass	*Tripsicum dactyloides*	15%
Smartweed	*Polygonum pennsylvanicum*	5%
Little bluestem	*Schizachyrium scoparium*	5%
Soft rush	*Juncus effusus*	5%
Beggars tick	*Biden frondosa* (or *aristosa)*	10%
Lance-leaf coreopsis	*Coreopsis lanceolata*	10%
Deertongue	*Dichathelium clandestinum*	10%
Big bluestem	*Andropogon gerardii*	5%
Indian grass	*Sorgastrum nutans*	5%

8.3.2 Invasive Species Removal

The South Muddy Creek site has an extensive infestation of kudzu on the right bank upstream and downstream of Sain Road. Much of this area will be excavated during construction of the Priority 2 floodplain bench. The surrounding areas will be treated and should continue to be monitored so that the kudzu does not threaten the newly-planted riparian vegetation. Stripped kudzu material will need to be burned or disposed off-site.

Isolated invasive plants, such as mimosa and multiflora rose, will also be removed during grading activities.

8.4 Additional Site Improvements

At the Landis Farm site, unstable areas contributing sediment to South Fork Hoppers Creek will be addressed. An unpaved farm road has become compacted so that vegetation is unable to grow and storm water becomes concentrated flow on this low topographic feature and carries sediment into the creek from the road. A ditch also enters South Fork Hoppers Creek near the old road location. The ditch is vertically unstable with a 4-foot head cut migrating upstream and causing extensive erosion. Both of these features will be addressed in final design, likely by filling with extra soil and planting to create a more stable area.

A wet weather ditch carries runoff through the woods at the southern edge of the site and onto the field adjacent to the existing wetland. This surface flow path will be protected and stabilized with a rock crossing at an existing farm road crossing.

9.0 PERFORMANCE CRITERIA

Specific success criteria components are presented below. Baker Engineering will set up baseline as-built records; EEP will continue monitoring for five years following construction.

9.1 Stream Monitoring

Channel stability and vegetation survival will be monitored on the project site. Post-restoration monitoring will be conducted for five years following the completion of construction to document project success.

Geomorphic monitoring of restored stream reaches will be conducted for five years to evaluate the effectiveness of the restoration practices. Monitored stream parameters include stream dimension (cross sections), pattern (longitudinal survey), profile (profile survey), and photographic documentation. The methods used and any related success criteria are described below for each parameter.

9.1.1 Bankfull Events

The occurrence of bankfull events within the monitoring period will be documented by the use of a crest gage and photographs. One crest gage will be installed on the South Muddy Creek site and one crest gage will be installed at the South Fork Hoppers Creek site on the floodplain within 10 feet of the restored channel. The crest gage will record the highest watermark between site visits, and the gage will be checked each time there is a site visit to determine if a bankfull event has occurred. Photographs will be used to document the occurrence of debris lines and sediment deposition on the floodplain during monitoring site visits.

Two bankfull flow events in separate years must be documented within the five-year monitoring period. Otherwise, the stream monitoring will continue until two bankfull events have been documented in separate years.

9.1.2 Cross Sections

Two riffle and two pool cross-sections will be established on the South Muddy Creek site. Six cross-sections will be installed at the South Fork Hoppers Creek site: one riffle and one pool on South Fork Hoppers Creek, on UT1B, and on UT2. Each cross-section will be marked on both banks with permanent pins to establish the exact transect used. A common benchmark will be used for cross sections and consistently used to facilitate easy comparison of year-to-year data. The annual cross-section survey will include points measured at all breaks in slope, including top of bank, bankfull, inner berm, edge of water, and thalweg, if the features are present. Riffle cross sections will be classified using the Rosgen Stream Classification System.

There should be little change in as-built cross sections. If changes do take place, they should be evaluated to determine if they represent a movement toward a more unstable condition (e.g., down-cutting or erosion) or a movement toward increased stability (e.g., settling, vegetative changes, deposition along the banks, or decrease in width/depth ratio). Cross sections will be classified using the Rosgen Stream Classification System, and all monitored cross sections should fall within the quantitative parameters defined for channels of the design stream type.

9.1.3 Longitudinal Profile

A longitudinal profile will be surveyed immediately after construction and once every year thereafter for the duration of the five-year monitoring period. The restored channels at South Muddy Creek, South Fork Hoppers Creek, UT1B, and UT2 will be surveyed and included in monitoring. At least 3,000 feet of channel will be surveyed each year for the longitudinal survey. Measurements will include thalweg, water surface, right and left edge of channel, and right and left top of bank. Each of these measurements will be taken at the head of each feature (e.g., riffle, pool) and at the maximum pool depth. The survey will be tied to a permanent benchmark to facilitate comparison of data year-to-year.

The longitudinal profiles should show that the bedform features are remaining stable; i.e., they are not aggrading or degrading. The pools should remain deep, with flat water surface slopes, and the riffles should remain steeper and shallower than the pools. Bedform observed should be consistent with those observed for channels of the design stream type.

9.1.4 Bed Material Analyses

A reach-wide pebble count will be conducted for each restored reach (South Muddy Creek, South Fork Hoppers Creek, UT1B, and UT2. Pebble counts will be conducted immediately after construction and at a two-year interval thereafter at the time the longitudinal surveys are performed (years three and five) throughout the five year monitoring period. Pebble count data will be plotted on semi-log paper and compared with data from pervious years.

9.1.5 Photo Reference Sites

Photographs will be used to visually document restoration success. Reference stations will be photographed before construction and continued annually for at least five years following construction. Photographs will be taken from a height of approximately five to six feet. Permanent markers will be established to ensure that the same locations (and view directions) on the site are monitored in each monitoring period.

Lateral reference photos. Reference photo transects will be taken at each permanent cross-section. Photographs will be taken of both banks at each cross-section. The survey tape will be centered in the photographs of the bank. The water line will be located in the lower edge of the frame, and as much of the bank as possible will be included in each photo. Photographers should make an effort to consistently maintain the same area in each photo over time.

Photographs will be used to evaluate channel aggradation or degradation, bank erosion, success of riparian vegetation, and effectiveness of erosion control measures subjectively. Lateral photos should not indicate excessive erosion or continuing degradation of the banks. A series of photos over time should indicate successive maturation of riparian vegetation.

9.2 Storm Water BMP Monitoring and Success Criteria

No storm water BMPs are proposed at the South Muddy Creek stream restoration project.

9.3 Wetland Monitoring

Groundwater monitoring stations will be installed in the wetland restoration area to document hydrologic conditions of the restored site. Four automated groundwater monitoring stations will be installed. Groundwater monitoring stations will follow the USACE standard methods found in WRP Technical Notes ERDC TN-WRAP-00-02 (July 2000).

In order to determine if the rainfall is normal for the given year, rainfall amounts will be tallied using data obtained from the Marion automated weather station, located approximately 12 miles northwest of the project site.

The monitoring data should show that the site has been saturated within 12 inches of the soil surface for at least 9% of the growing season, and that the site has exhibited an increased frequency of flooding. These criteria are based on the modeling analysis presented in Section 8.2.

The restored site will be compared to reference site data. In addition, the restored site's hydrology will be compared to pre-restoration conditions, both in terms of groundwater and frequency of overbank events.

9.4 Vegetation Monitoring

Successful restoration of the vegetation on a site is dependent upon hydrologic restoration, active planting of preferred canopy species, and volunteer regeneration of the native plant community. In order to determine if the criteria are achieved, vegetation monitoring quadrats will be installed across the restoration site for woody tree species monitoring. Twelve quadrats will be installed on the South Muddy Creek site and twelve quadrats will be installed on the South Fork Hoppers Creek site (consisting of 11 plots for stream restoration monitoring and 1 plot for wetland restoration and enhancement monitoring). The size of individual quadrats will be 10 meters by 10 meters. Vegetation monitoring will occur in spring, after leaf-out has occurred. Individual quadrat data will be provided and will include diameter and height measurements. Individual seedlings may be marked to ensure that they can be found in succeeding monitoring years. Mortality will be determined from the difference between the previous year's living, planted seedlings and the current year's living, planted seedlings.

At the end of the first growing season, species composition and survival will be evaluated. For each subsequent year, until the final success criteria are achieved, the restored site will be evaluated between July and November.

Specific and measurable success criteria for plant density on the project site will be based on the recommendations found in the WRP Technical Note (USACE, 1997) and past project experience.

The interim measure of vegetative success for the site will be the survival of at least 320, 3-year old, planted trees per acre at the end of year three of the monitoring period. The final vegetative success criteria will be the survival of 260, 5-year old, planted trees per acre at the end of year five of the monitoring period. While measuring species density is the current accepted methodology for evaluating vegetation success on restoration projects, species density alone may be inadequate for assessing plant community health. For this reason, the vegetation monitoring plan will incorporate the evaluation of additional plant community indices to assess overall vegetative success.

9.5 Maintenance Issues

Maintenance requirements vary from site to site and are generally driven by the following conditions:

- Projects without established, woody floodplain vegetation are more susceptible to erosion from floods than those with a mature, hardwood forest.
- Wet weather during construction can make accurate channel and floodplain excavations difficult.
- Extreme and/or frequent flooding can cause floodplain and channel erosion.
- Extreme hot, cold, wet, or dry weather during and after construction can limit vegetation growth, particularly temporary and permanent seed.
- The presence and aggressiveness of invasive species can affect the extent to which a native buffer can be established.

Maintenance issues and recommended remediation measures will be detailed and documented in the as-built and monitoring reports. The conditions listed above and any other factors that may have necessitated maintenance will be discussed.

9.6 Schedule/Reporting

Annual monitoring reports containing the information defined herein will be submitted to EEP by December 31 of the year during which the monitoring was conducted. Project success criteria must be met by the fifth monitoring year, or monitoring will continue until all success criteria are met.

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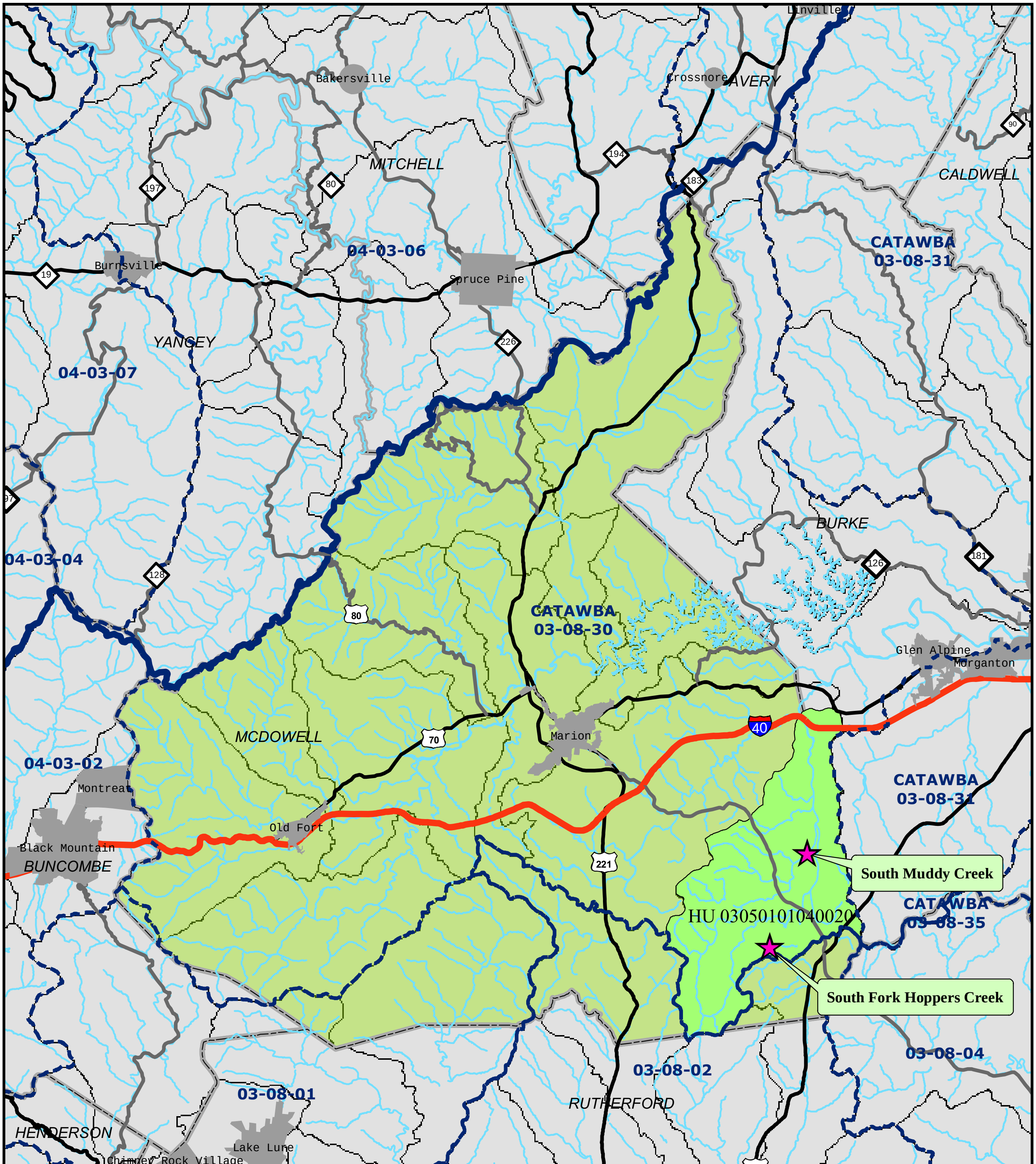

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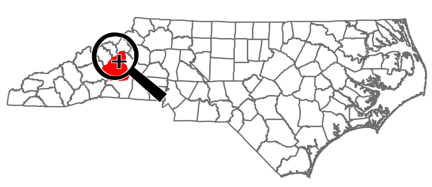


LEGEND:

NCDWQ Sub-basin

Counties

USGS Hydrologic Unit

0 2.5 5 Miles

Figure 1.1: Project Vicinity Map
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC

LEGEND:

Proposed Conservation Easement

Project Reach

Property Boundaries

Streams

Topographic Lines

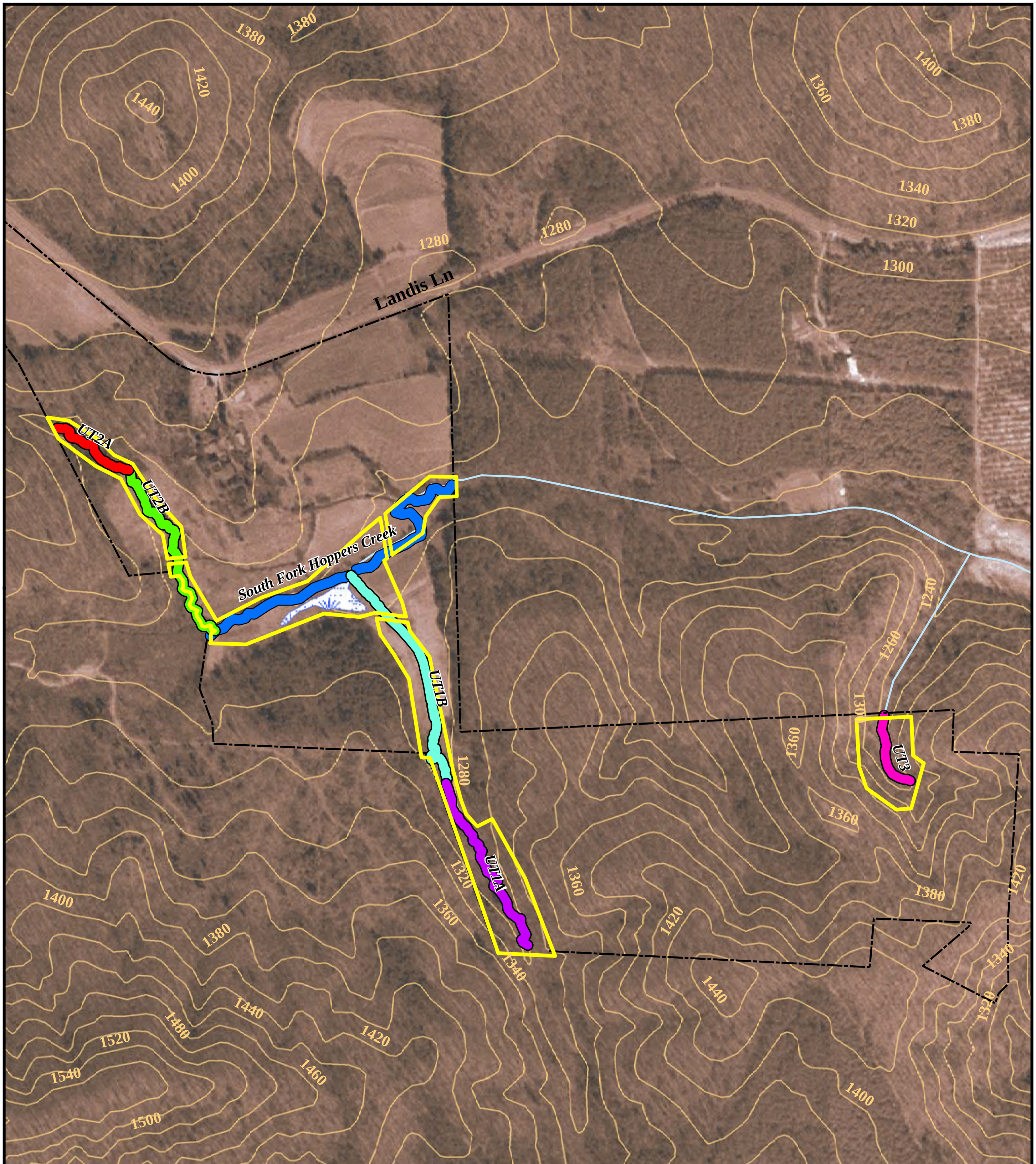
0 150 300 Feet

N

Ecosystem Enhancement PROGRAM

Figure 1.2: South Muddy Creek Reach Location Map
South Muddy Creek Stream Restoration Project
EEP Project D07032S
McDowell County, NC

Baker



LEGEND:

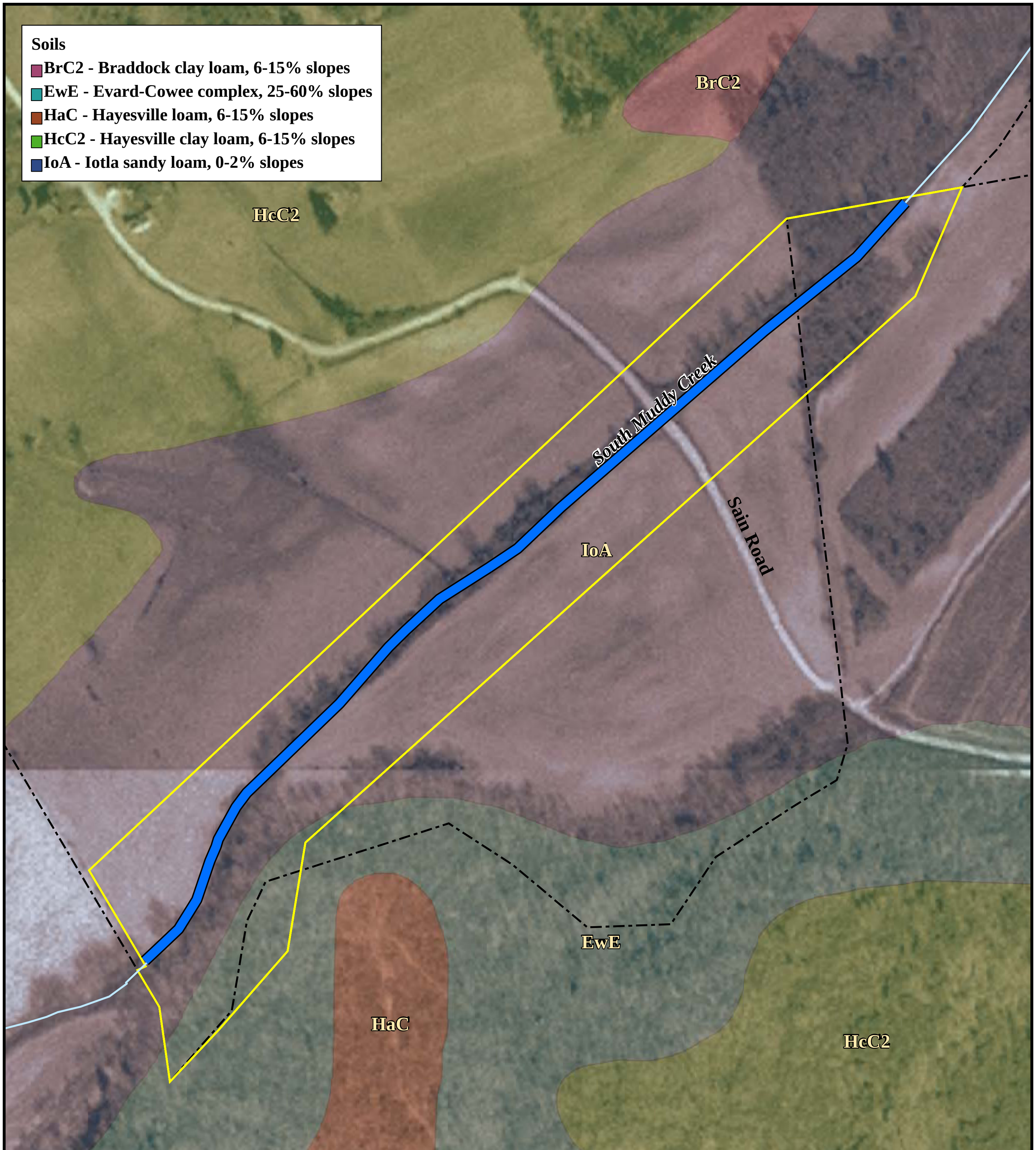
- Streams
- Approximate Property Boundary
- Final Conservation Easement
- Topographic Lines
- Existing Wetland
- UT1A
- UT1B
- UT2A
- UT2B
- South Fork Hoppers Creek
- UT3

0 250 500 Feet

Figure 1.3: South Fork Hoppers Creek Reach and Wetland Location Map
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC

Ecosystem Enhancement PROGRAM

Baker

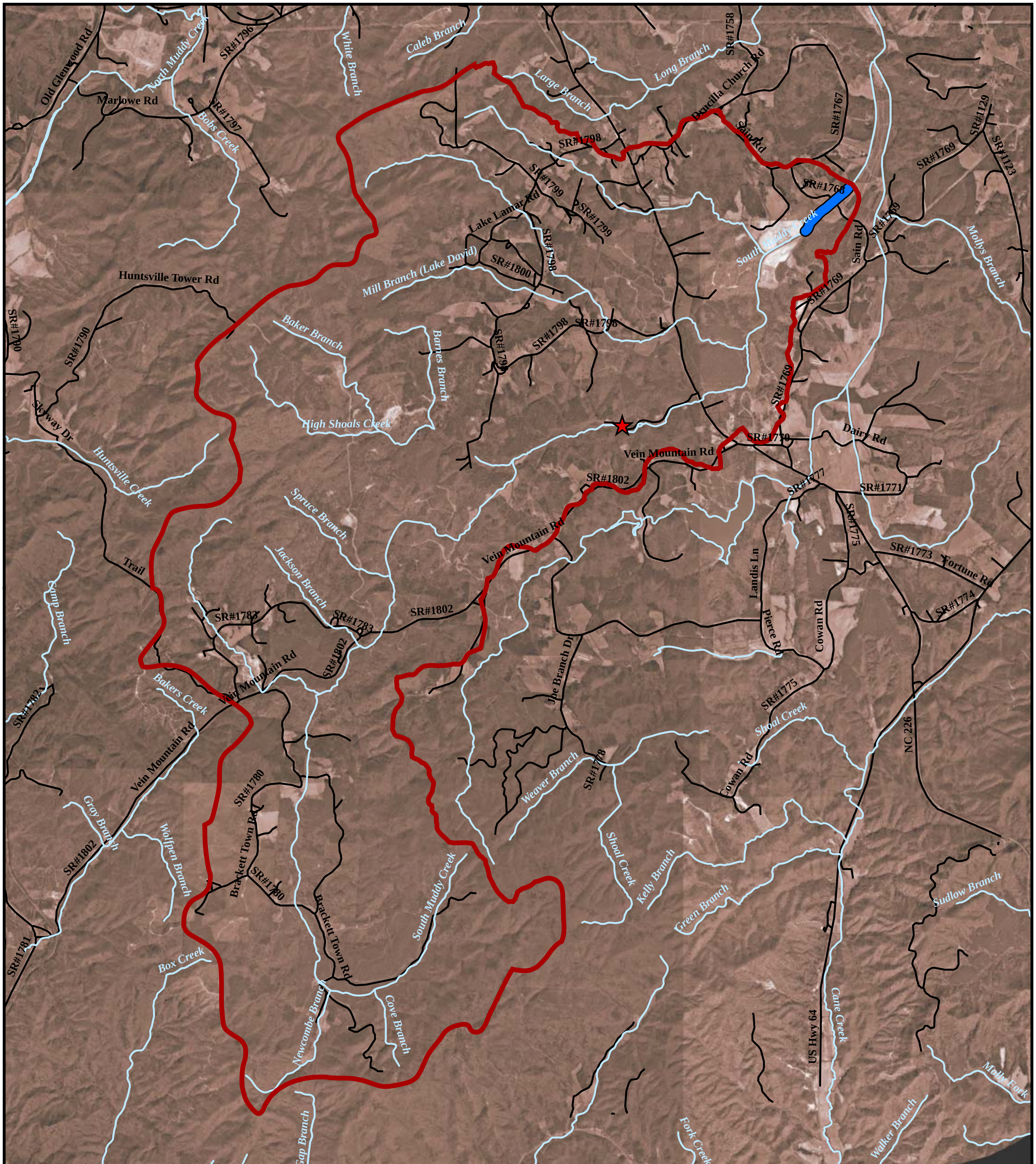


LEGEND:

- Project Reach
- Streams
- Proposed Conservation Easement
- Property Boundaries

0 150 300 Feet

Figure 2.3: South Muddy Creek
Site Soils Map
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC



LEGEND:

Project Reach

Drainage Areas

NRCS In-line flood constrol structure (Impoundment)

0 0.5 1 Miles

Streams

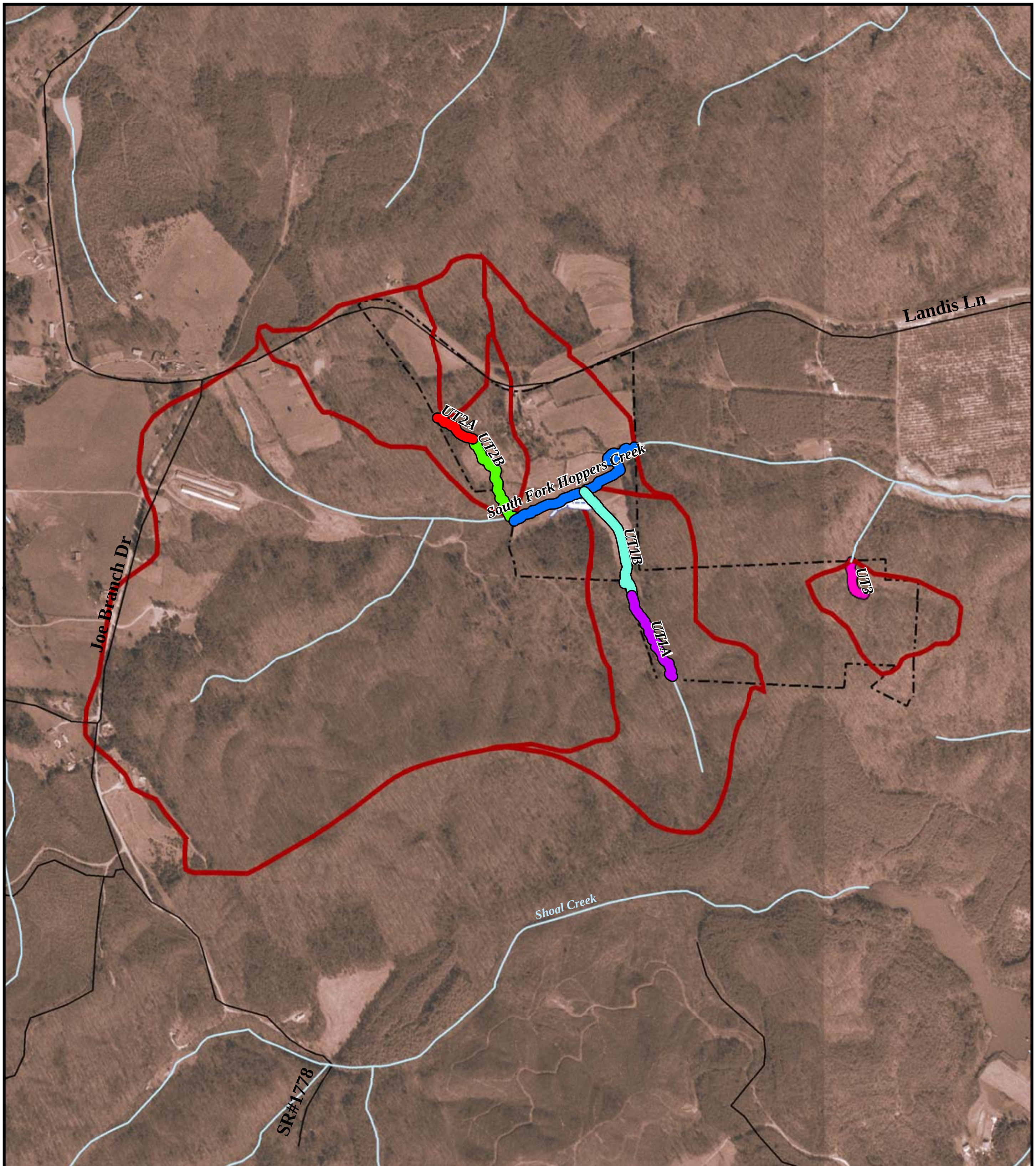
Roads

N

Figure 2.1: South Muddy Creek Watershed Map & Impoundment Location
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC

Ecosystem Enhancement PROGRAM

Baker



Ecosystem Enhancement PROGRAM

LEGEND:

Streams

Approximate Property Boundary

Drainage Areas

Existing Wetland

0 500 1,000 Feet

Project Reaches

South Fork Hoppers Main

UT1A

UT1B

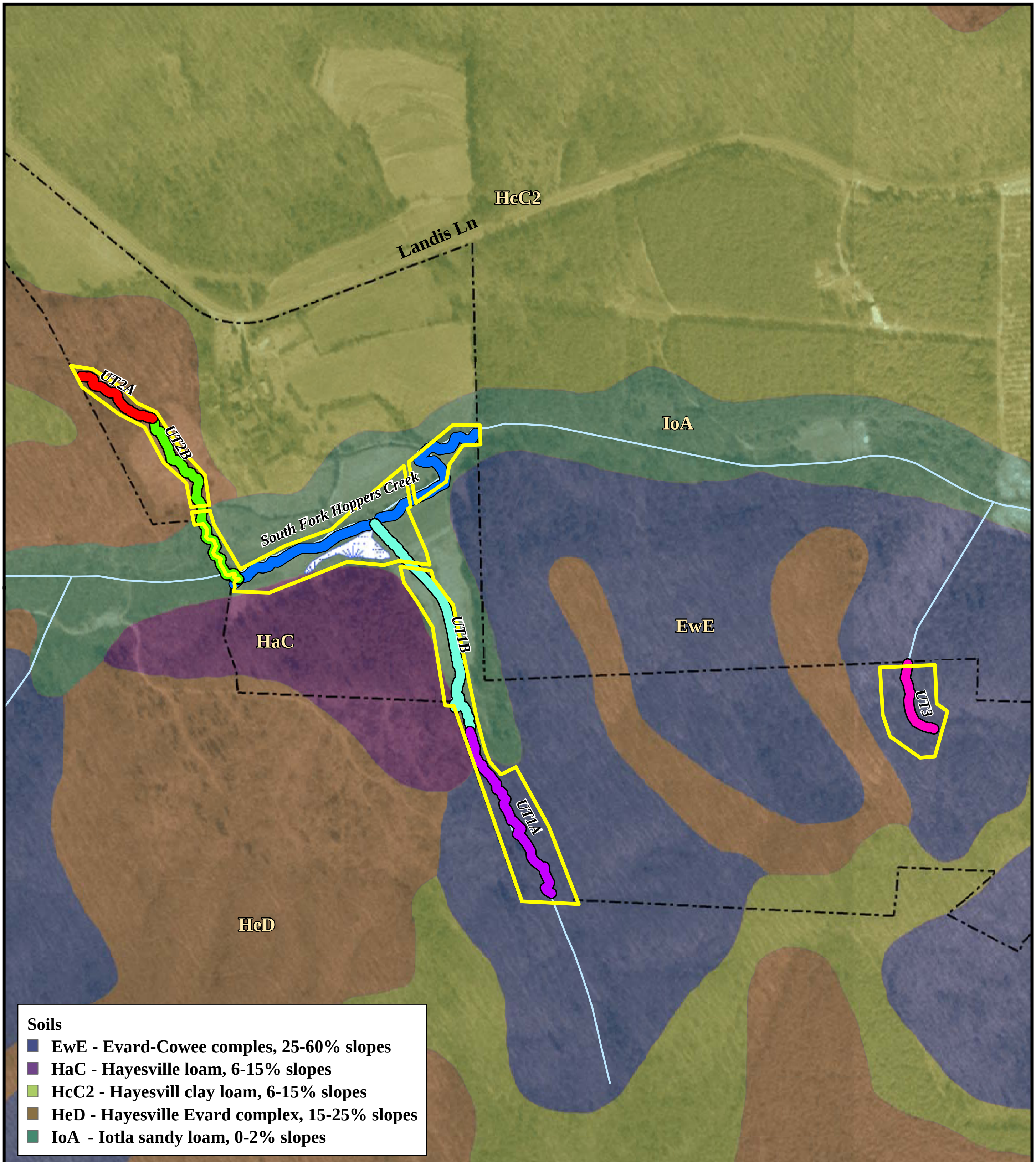
UT2A

UT2B

UT3

Figure 2.2: South Fork Hoppers Creek Watershed Map
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC

Baker



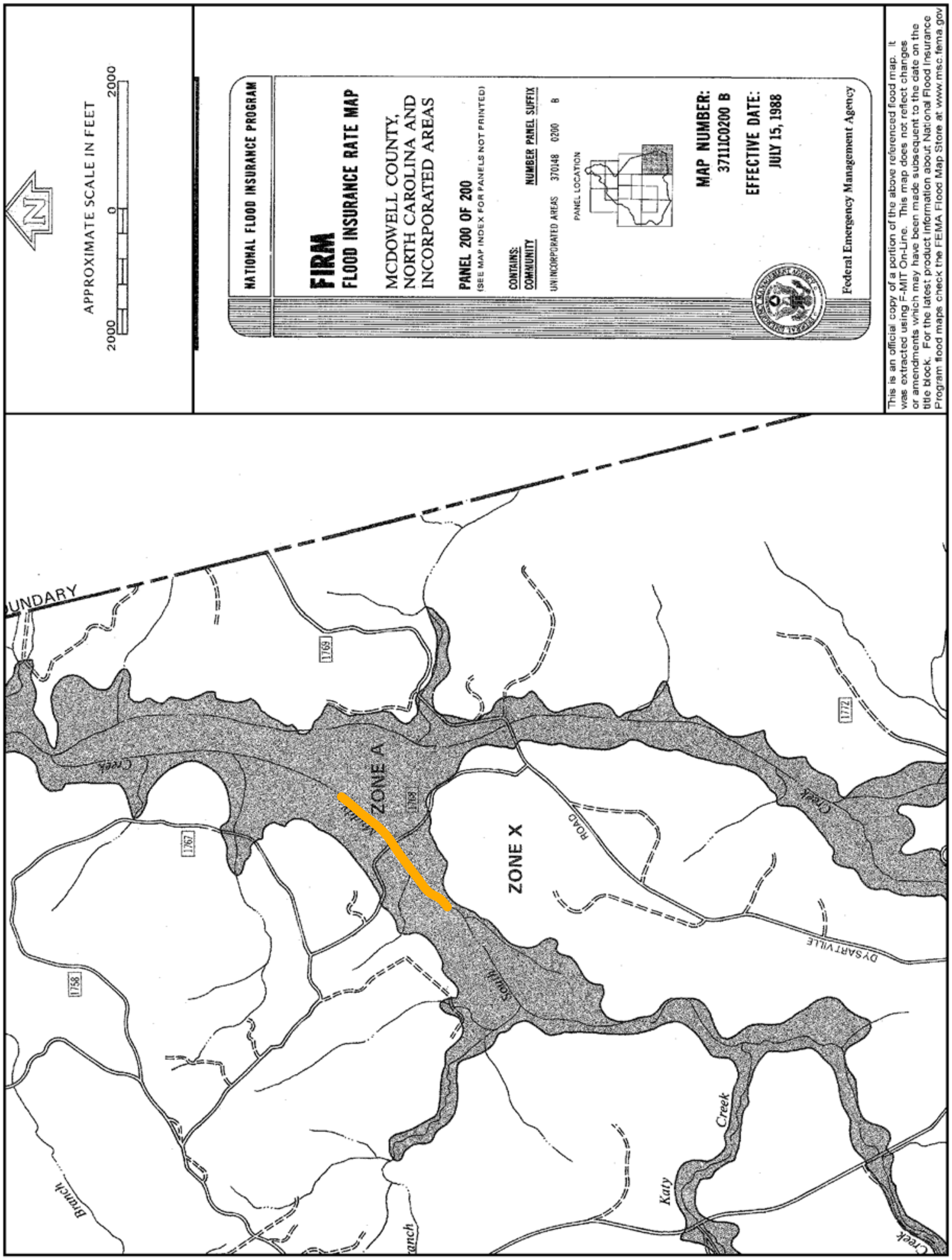
Ecosystem Enhancement PROGRAM

LEGEND:

- Streams
- Approximate Property Boundary
- Final Conservation Easement
- Existing Wetland
- South Fork Hoppers Creek
- UT1A
- UT1B
- UT2A
- UT2B
- UT3

Figure 2.4: South Fork Hoppers Creek Site Soils Map
South Muddy Creek Stream Restoration Project
EEP Project D07032S
McDowell County, NC

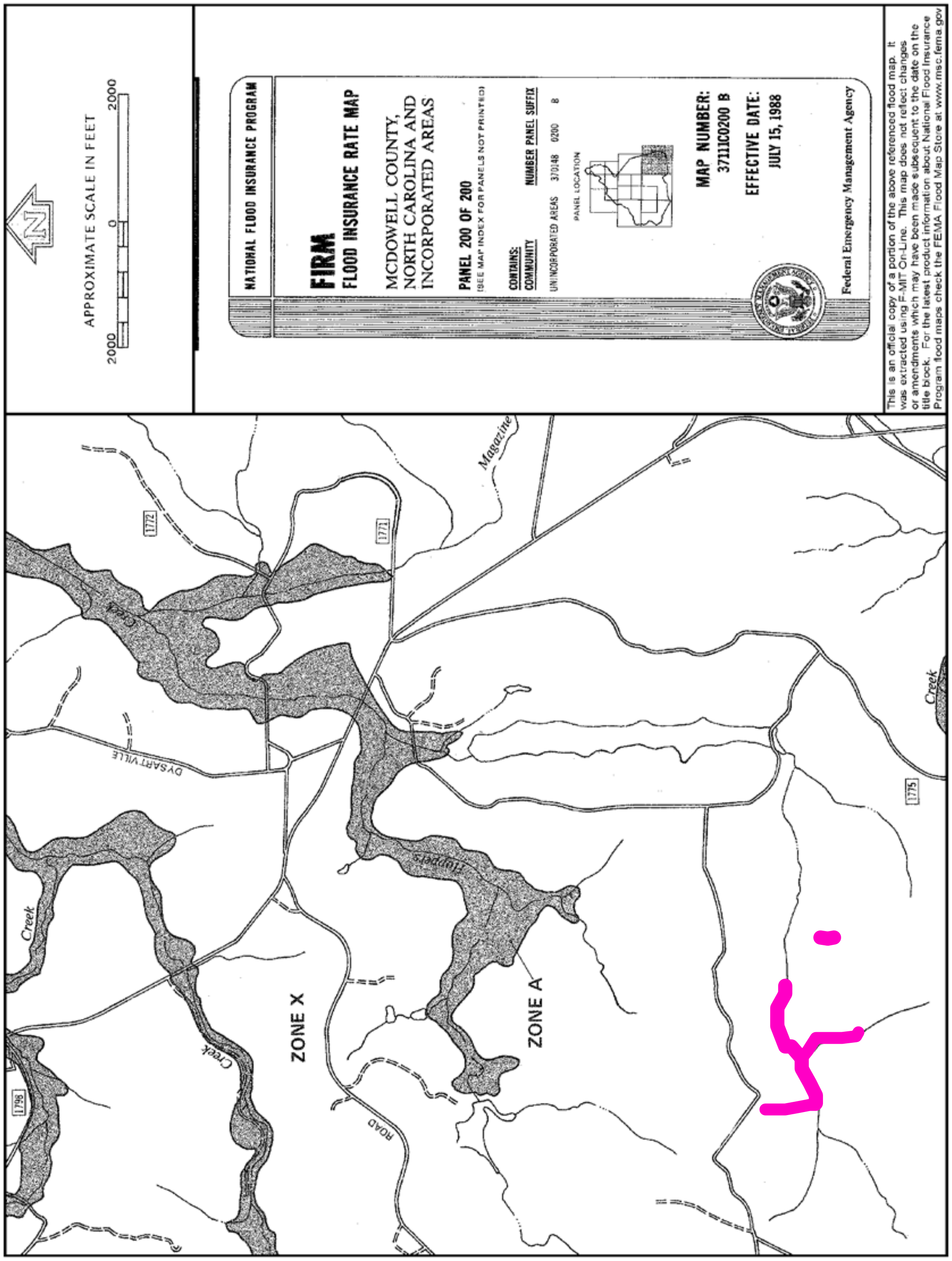
Baker



LEGEND:

South Muddy Creek Project Reach

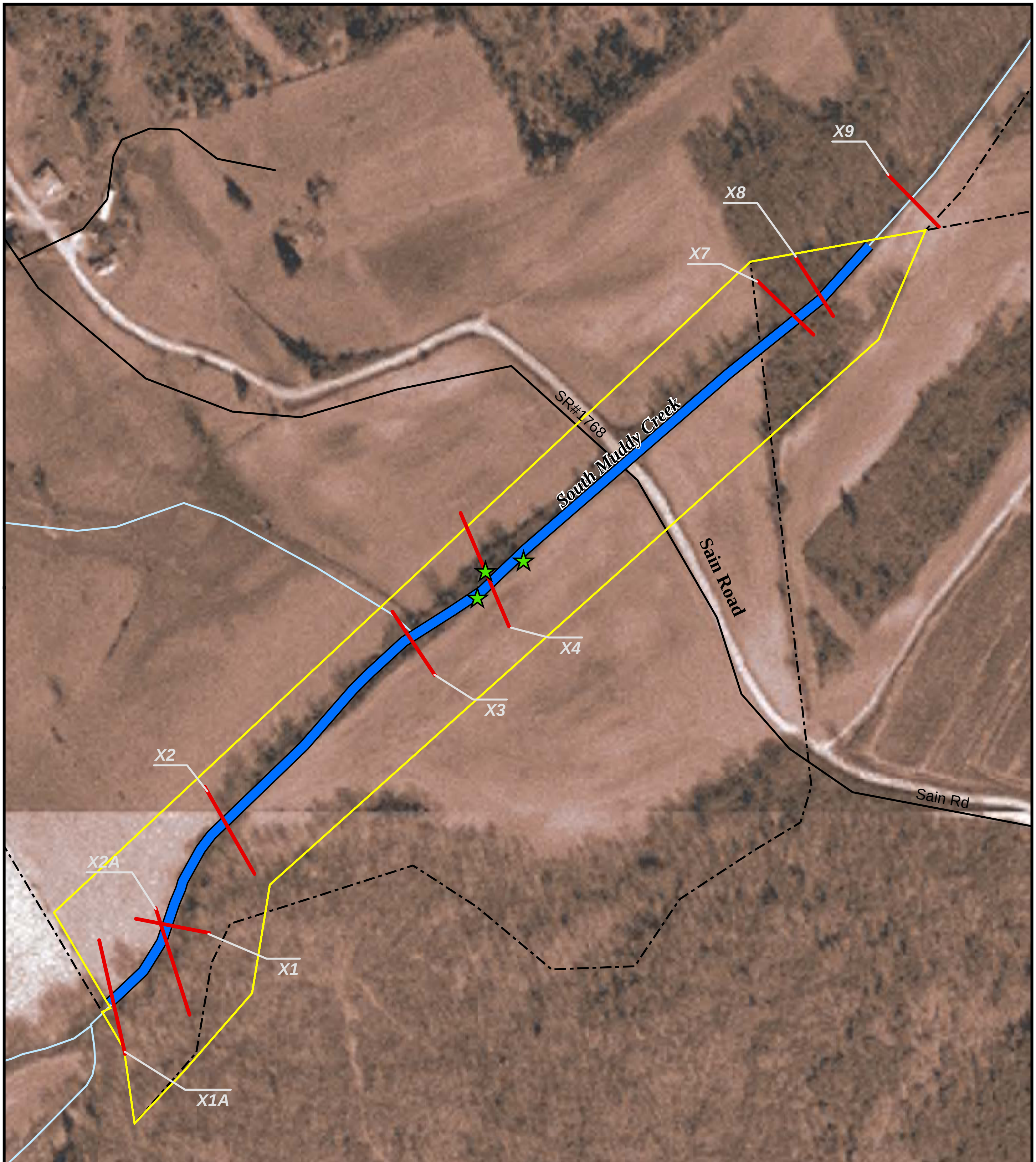
Figure 2.5 South Muddy Creek FEMA Map
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC



LEGEND:

South Fork Hoppers Creek Project Reaches

Figure 2.6 South Fork Hoppers Creek FEMA Map
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC

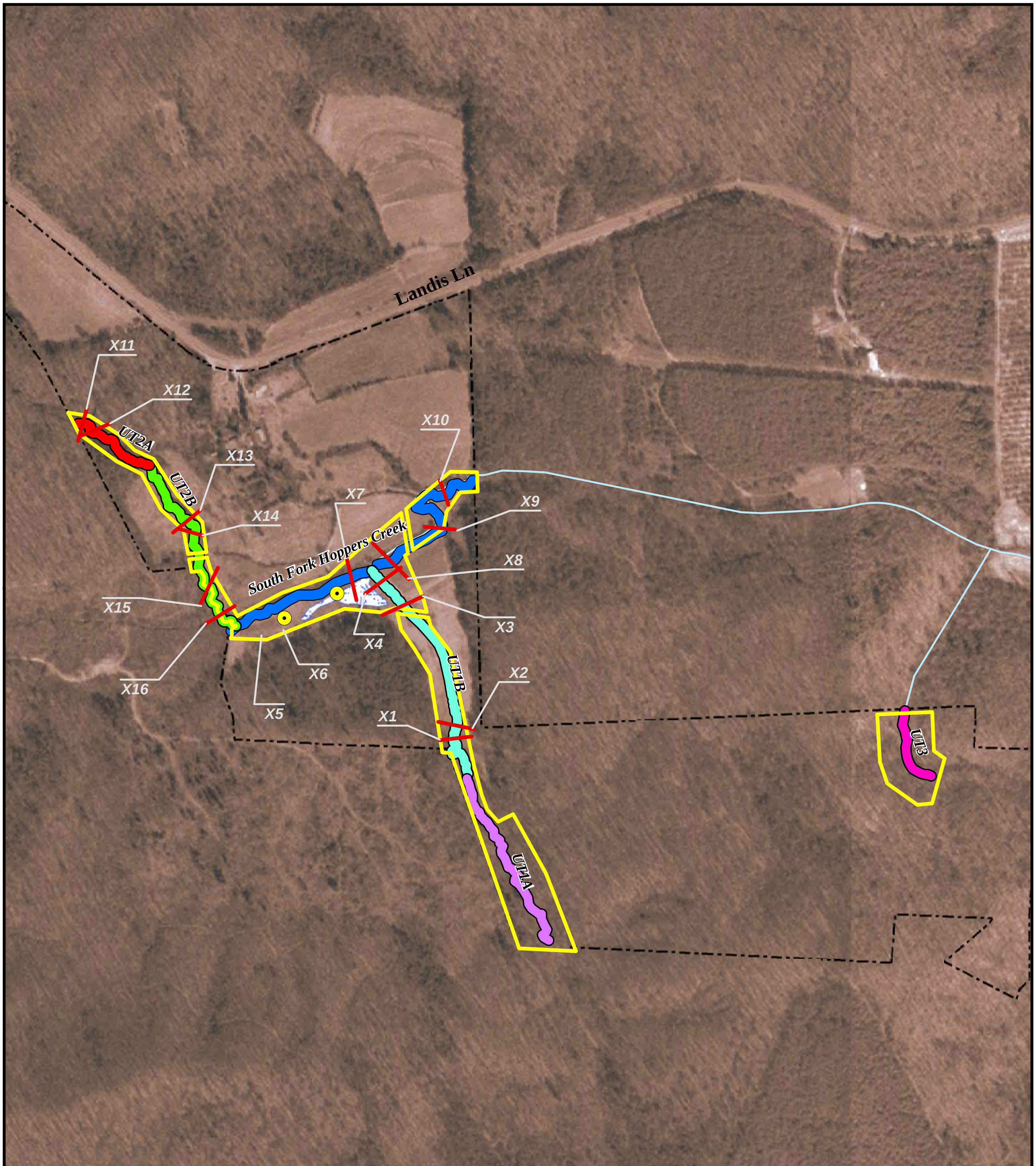


LEGEND:

	Project Reach		Property Boundaries
	Streams		Proposed Conservation Easement
	Cross-Section		Bank Pins-By Others

0 150 300 Feet

Figure 3.1: South Muddy Creek Existing Conditions Cross-Sections Map
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC

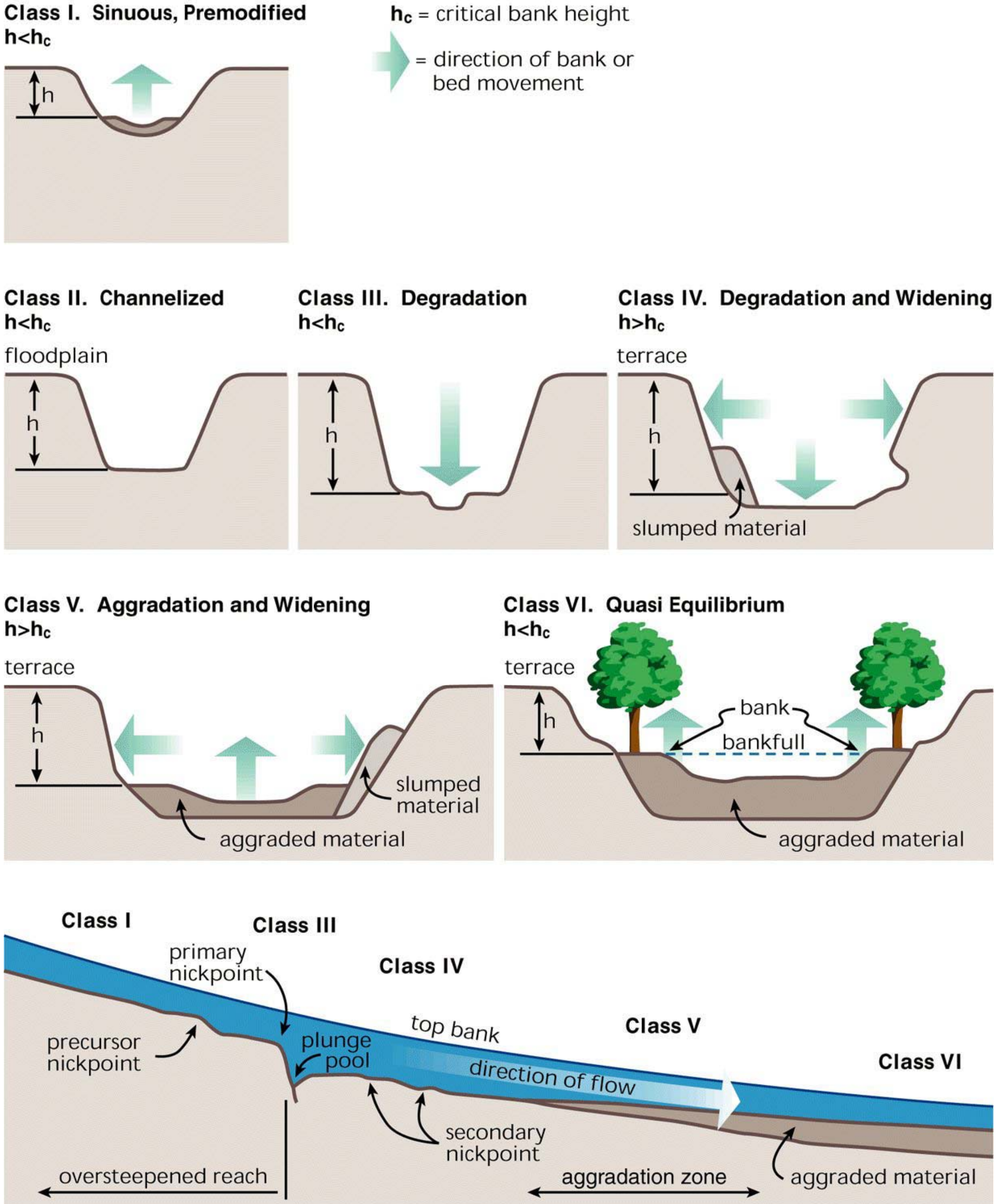


LEGEND:

	Streams		South Fork Hoppers Creek
	Approximate Property Boundary		UT1A
	Cross-Section		UT1B
	Final Conservation Easement		UT2A
	Wetland Gages		UT2B
	Existing Wetland		UT3

0 250 500 Feet

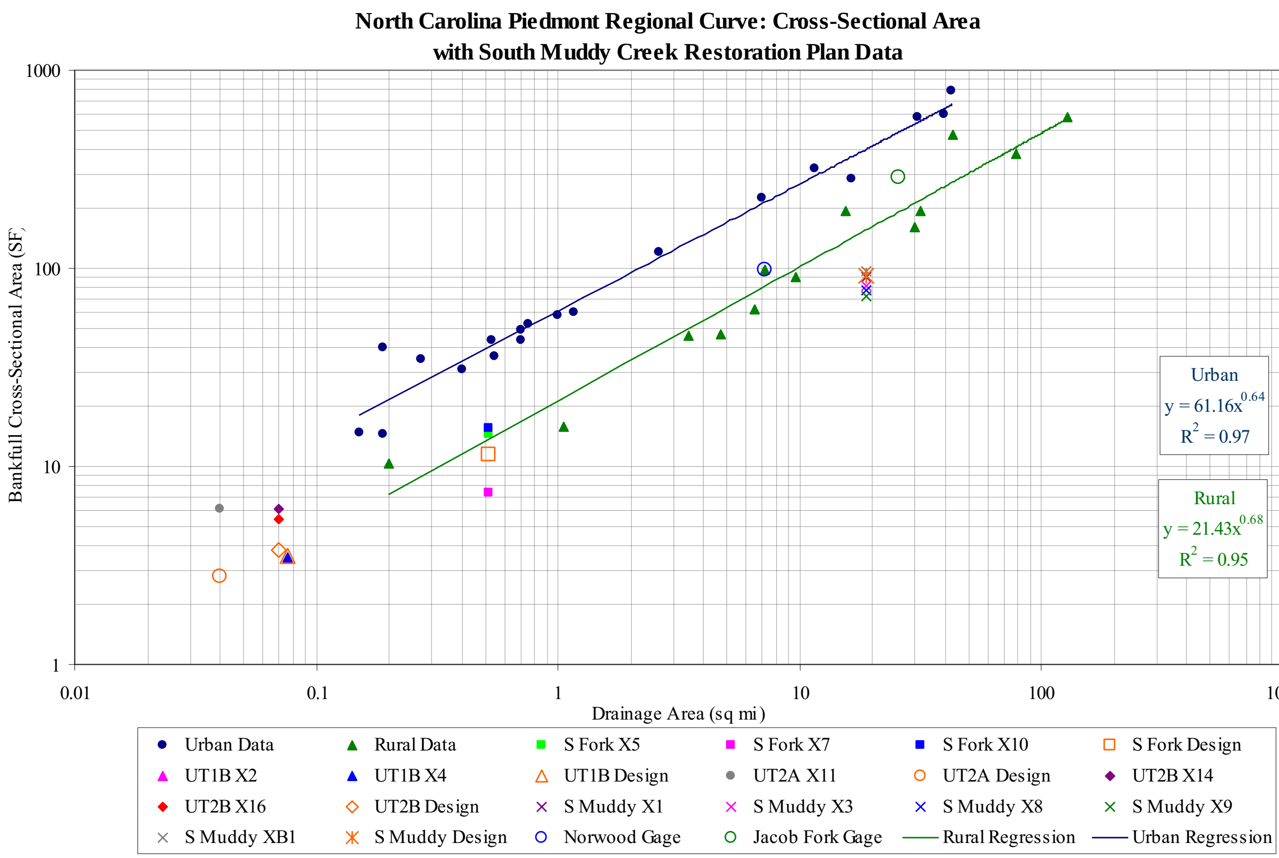
Figure 3.2: South Fork Hoppers Creek Existing Conditions Cross-Sections Map
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County, NC

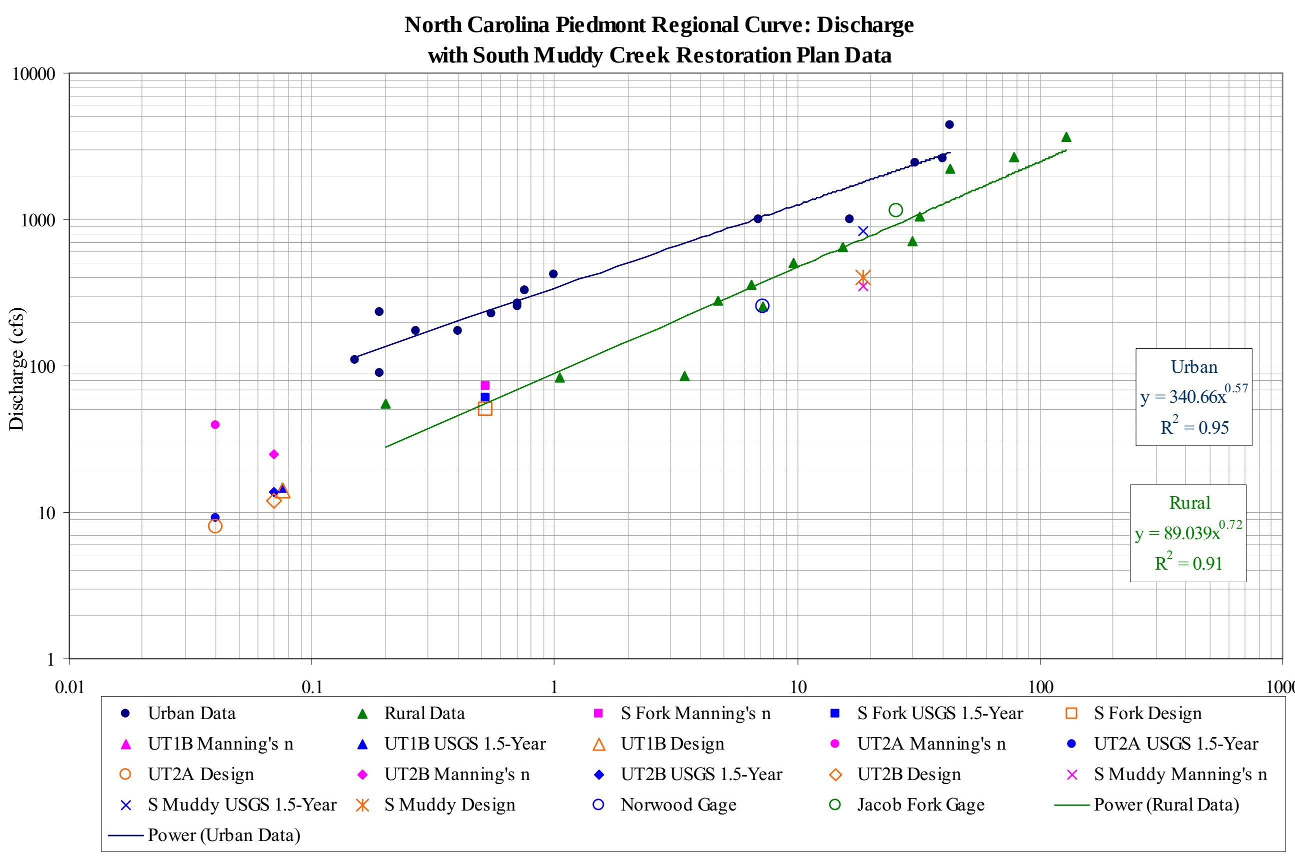


Source: Simon, 1989; US Army Corps of Engineers, 1990.
Fig. 7.14 -- Channel evolution model..
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US).

Figure 3.3
Simon Channel Evolution Model
South Muddy Creek Stream Restoration Plan
EEP Project D07032S
McDowell County, NC

Source: Simon, 1989





Note: Project data were not considered in regional curve development.

Figure 3.4
NC Piedmont Regional Curves with Project Reach Data
South Muddy Creek Stream Restoration Plan
EEP Project D07032S
McDowell County, NC

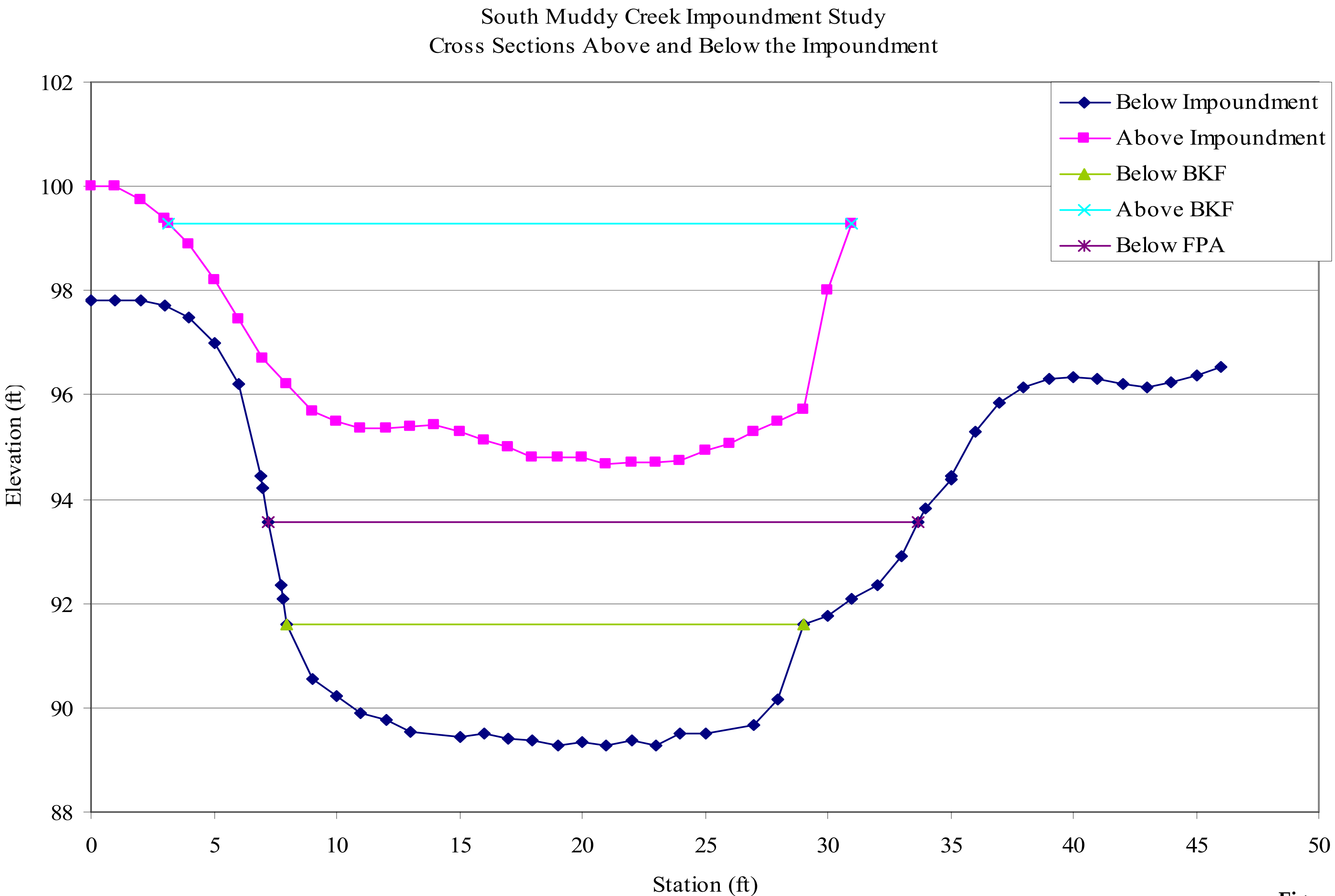
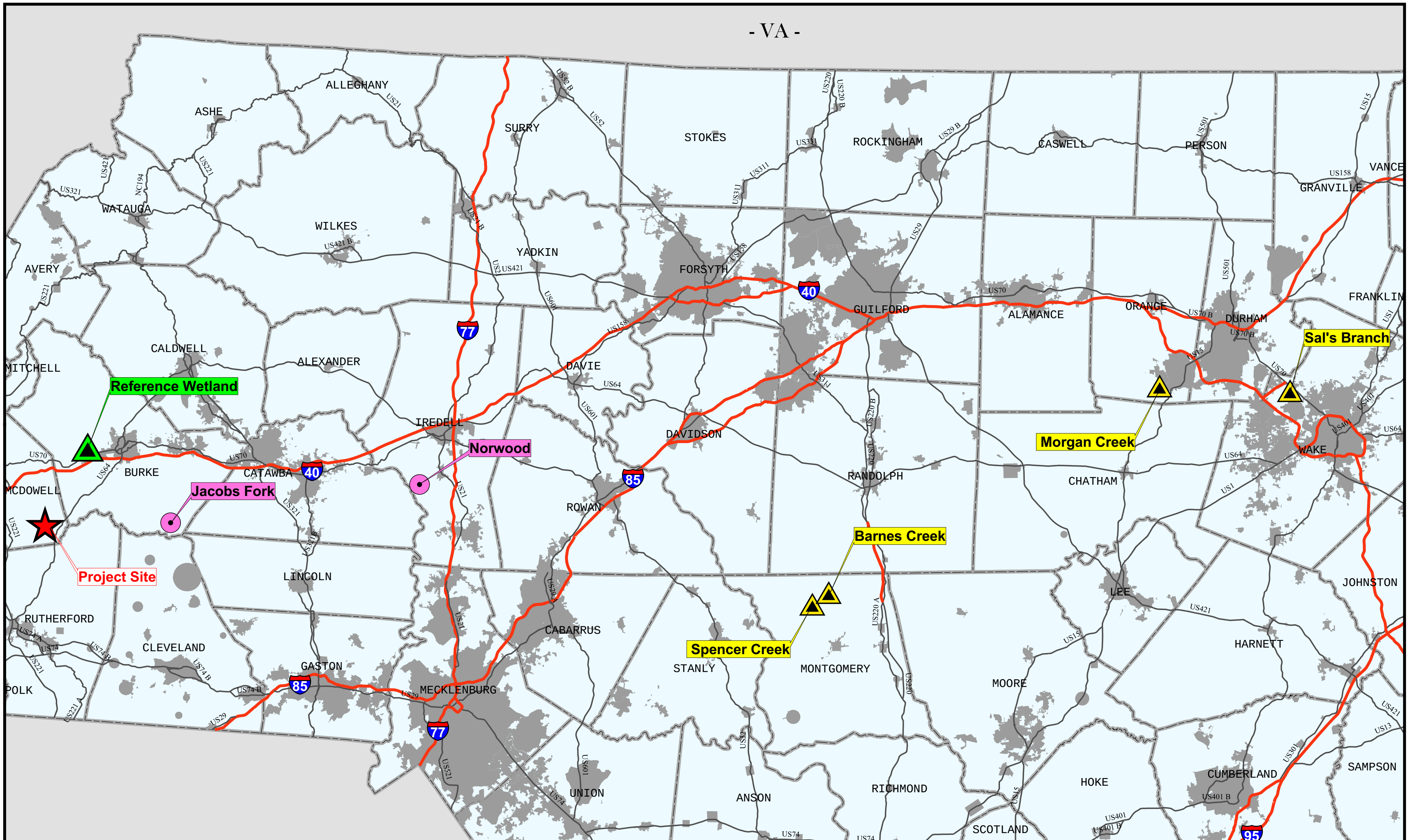


Figure 3.5
South Muddy Creek Impoundment Study
South Muddy Creek Stream Restoration Plan
EEP Project D07032S
McDowell County, NC



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LEGEND

- Reference Reach Sites
- Wetland Reference Sites
- Bankfull Reference Site Gage Locations
- Counties
- Municipal Boundaries

0 12.5 25 Miles

Figure 3.6: Gage Stations, Reference Reach, and Reference Wetland Locations
South Muddy Creek
Stream Restoration Project
EEP Project D07032S
McDowell County

Ecosystem Enhancement PROGRAM

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LEGEND:

- Proposed Restoration Design
- Proposed Conservation Easement
- Property Boundaries
- Streams

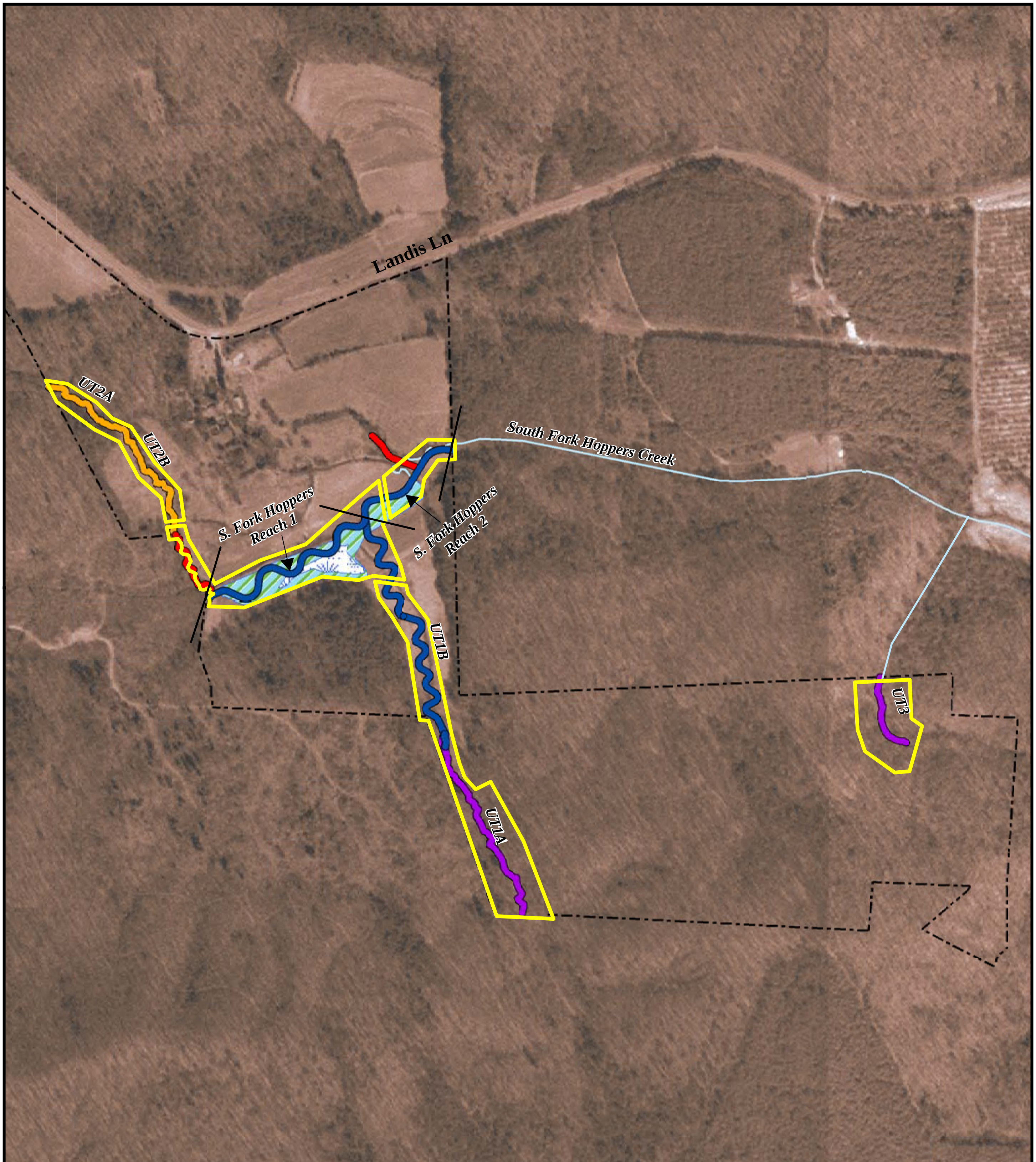
0 150 300 Feet

N

Figure 7.1: South Muddy Creek Proposed Restoration Design
South Muddy Creek Stream Restoration Project
EEP Project D07032S
McDowell County, NC

Ecosystem Enhancement PROGRAM

Baker



LEGEND:

- Streams
- Approximate Property Boundary
- Final Conservation Easement
- Wetland Restoration
- Wetland Enhancement

Proposed Design

- Restoration
- Enhancement Level II
- Stabilization
- Preservation

0 250 500 Feet

Figure 7.2: South Fork Hoppers Creek Proposed Restoration Design
South Muddy Creek Stream Restoration Project
EEP Project D07032S
McDowell County, NC

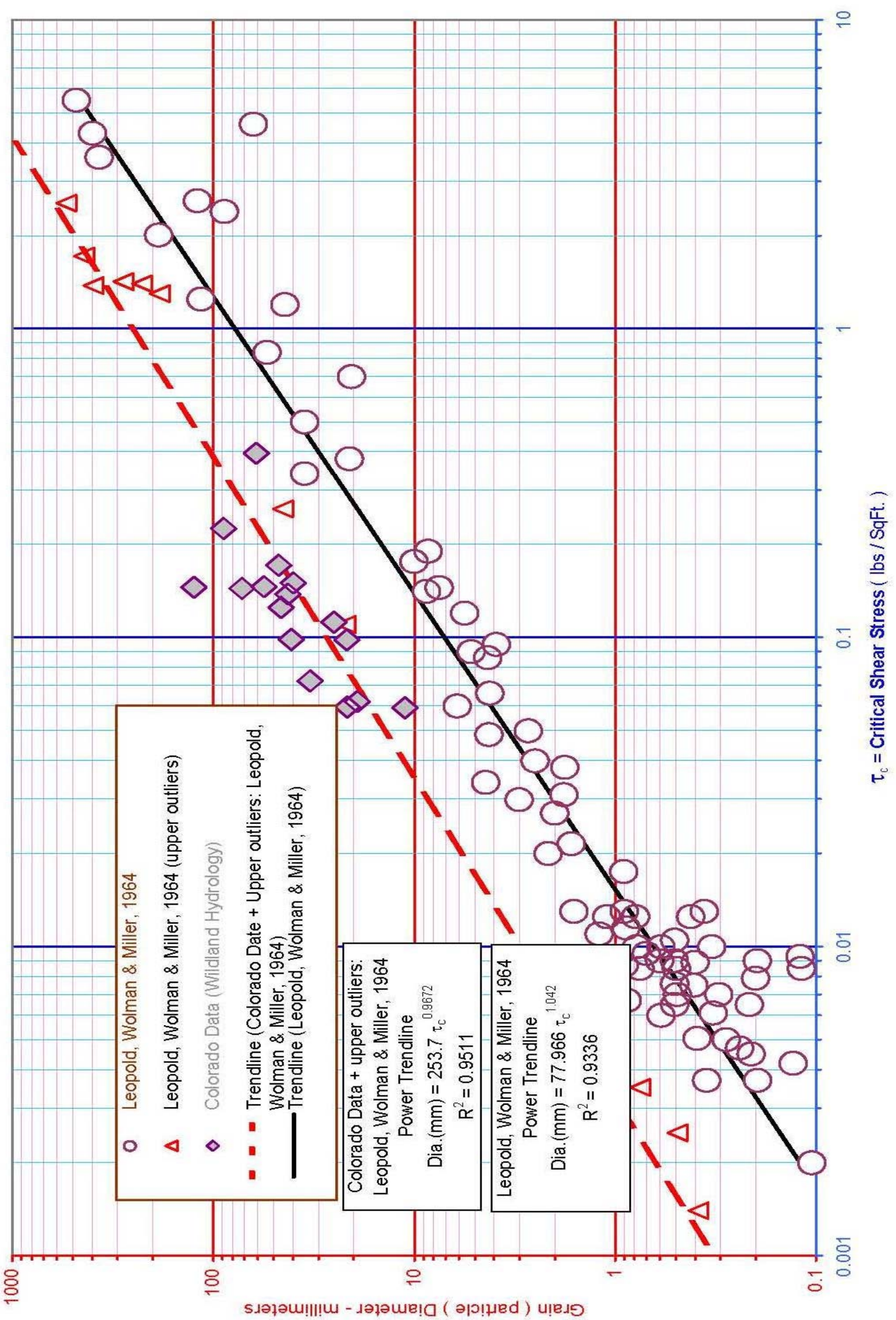


Figure 7.3
Shield's Curve Modified with Colorado Data
South Muddy Creek Stream Restoration Plan
EEP Project D07032S
McDowell County, NC

Click on the Desired Link Below

Appendices