August 8, 2013

Technical Review Committee
C/O Kelly Ibrahim, Chair

BMP Request

Dear Ms. Ibrahim:

The Albemarle Soil & Water Conservation District is requesting the creation of BMP's to better utilize NCACSP and CCAP funding, and to compliment the implementation of the Little River Water Quality Improvement and River Protection Initiative.

Little River is rated as impaired by the NCDENR, and the EPA 303d List. The Little River Water Quality Improvement and River Protection Initiative is essentially a watershed scale, water quality improvement plan to address the water quality and river protection issues associated with Little River.

Several new BMP's are being requested to compliment this effort:

- Riparian Herbaceous Cover (Buffers) for Drainage Systems
- Wetland Filters for Drainage Systems
- Rock Weir (Water Control Structure)

Currently, no BMPs are available in the NCACSP or CCAP to address these needs; however, all components needed for these BMP's are available, and the existing cost-share levels for individual components are adequate.

These BMP's have been developed, perfected, and utilized in the Albemarle SWCD over the past 20 years to address water quality problems associated with drainage waters. Attached is a reference, "Management Alternatives to Enhance Water Quality and Ecological Function of Channelized Streams and Drainage Canals" . This reference substantiates the development, application, and water quality improvement effectiveness of these proposed BMP's.

Respectfully,

Fenton Eure III, Chairman, Albemarle SWCD ____

Wetland Filters for Drainage Systems (Constructed Wetland)

Definition/Purpose:

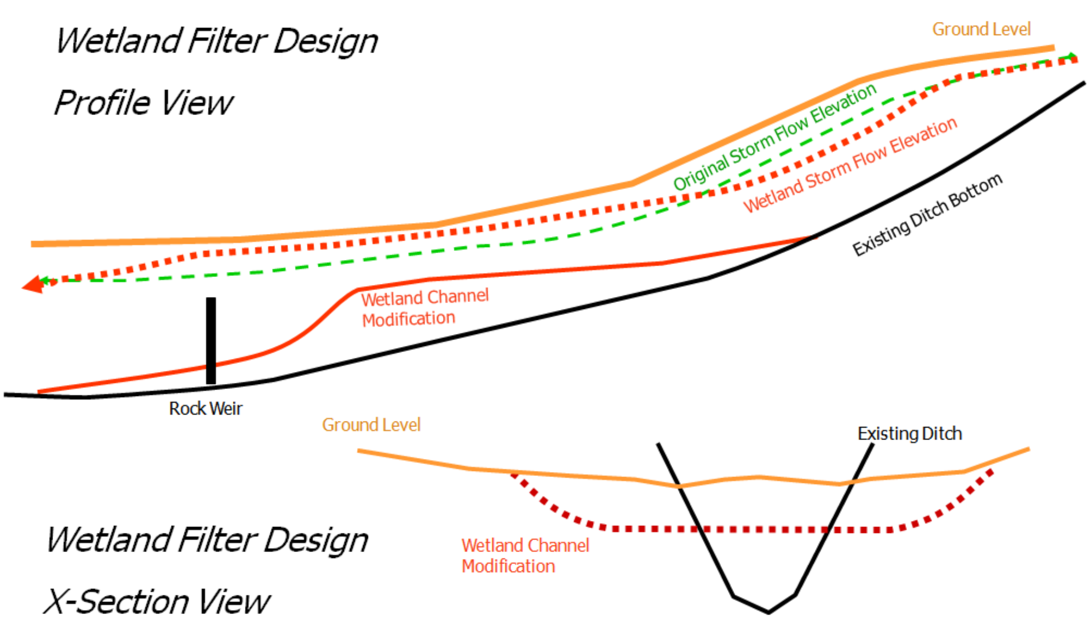
A wetland constructed within an existing drainage system to reduce the concentration of targeted pollutants (nitrogen, phosphorus, sediment) in drainage waters from runoff or subsurface flows before reaching creeks or streams in an effort to address watershed and regional water quality issues.

Policies:

1. Wetland filters within existing drainage systems are intended to address the water quality issues associated with uncontrolled and unfiltered drainage systems that carry water borne pollutants nitrogen, phosphorus, and sediment) directly to creeks, streams, and rivers.

2. Wetland filters will be planted with four or more species of trees and emergent vegetation (Refer to attached Wetland Plant List). These species must emulate the indigenous wetland vegetation within the watershed. Initial planting will be at a spacing of one plant per 10 square feet. Wetland plants can be transferred from sources within the watershed (dug and replanted), or purchased from a nursery source.
3. For future maintenance, the concentration and type of wetland plants found is expected to change with seasonal and environmental conditions. Any natural occurring density, variance, or spatial distribution of population is acceptable for wetland specifications.

4. **Wetland Filter Design**



Wetland Filter Design Considerations:

- Watershed scale modeling (utilizing HEC-RAS, etc) will be performed to determine weir configurations that reflect upstream drainage considerations.
- Maintain stagnant water levels 0.5 to 1.5 feet deep in the wetland area.

5. Wetland filters must be complimented with water control structures (usually Rock Weirs).

6. BMP life expectancy 10 years.

Cost Share Components Needed for Wetland Filter For Drainage Systems (Constructed Wetland)

Wetland Filter For Drainage Systems (Constructed Wetland)						
Existing Program List	Component	Unit Type	Unit Cost	Maximum Cost Share	Minimum Cost Share	Cost Type
NCACSP	Excav. w/spoil remove	CuYd	$ 2.20			Average
NCACSP	Grading-light (1-3 in)	Acre	$ 1,700.00			Average
NCACSP	Vegetation-bag lime, seed & fert	Acre	$ 700.00			Average
NCACSP	Vegetation-establish, hydroseed	Acre	$ 1,700.00			Average
NCACSP	Vegetation-mulch, small grain straw	Acre	$ 550.00			Average
CCAP	Wetland Plants Installed	Each	$ 2.30			Average
NCACSP	Vegetation-Bare Root Seedlings	Each	$ 1.80			Average

Wetland Plants List - Wetland Filters for Drainage Systems
Suggested Plantings*

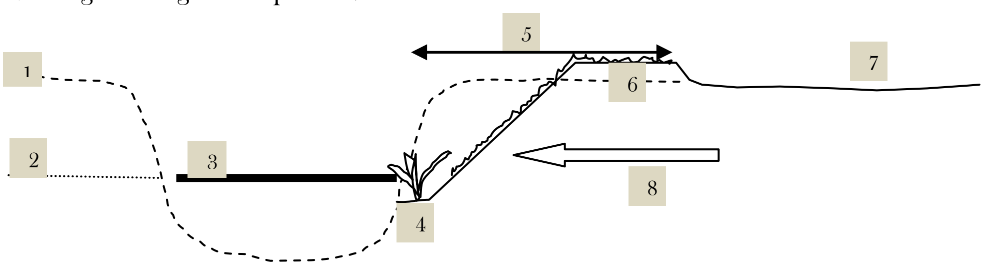
• Arrow arum	Peltandra virginica
• Broad leaf arrowhead	Sagittaria spp.
• Southern blue flag,	Iris virginica
• Cattail	Typha latifolia
• Lizard's tail	Saururus cernuus
• Pickerelweed	Pontederia cordata
• Spatterdock	Nuphar advena
• Bulrush	Scirpus spp.
• Sawgrass	Cladium mariscus jamaicense
• Sedge	Carex Carex spp.
• Spike Rush	Eleocharis spp.
• Black needle rush	Juncus roemerianus
• Rush	Juncus spp.
• Giant Cane	Arundinaria gigantean
• Giant Cordgrass	Spartina cynosuroides
• Salt Meadow Cordgrass	Salt Meadow Spartina patens
• Smooth Cordgrass	Spartina alterniflora
• Rice Cutgrass	Leersia oryzoides
• Black gum	Nyssa sylvatica
• Swamp black gum	Nyssa biflora
• Water tupelo	Nyssa aquatica
• Bald Cypress	Taxodium distichum

*(Recommended species for Wetland Filters for Drainage Systems. Plantings should reflect the indigenous plants within the watershed)

Riparian Herbaceous Cover (Buffer) for Drainage Systems

Definition /Purpose:

To intercept subsurface drainage, reduce ditch bank erosion from surface water over bank flow, maintain and stabilize ditch banks, and expose drainage water flowing in ditches to wetland biology for water quality improvement. These riparian herbaceous cover buffers are to be used in conjunction with water control structures to establish consistent ditch water levels for exposure to wetland biology and to force subsurface drainage through the riparian buffers.

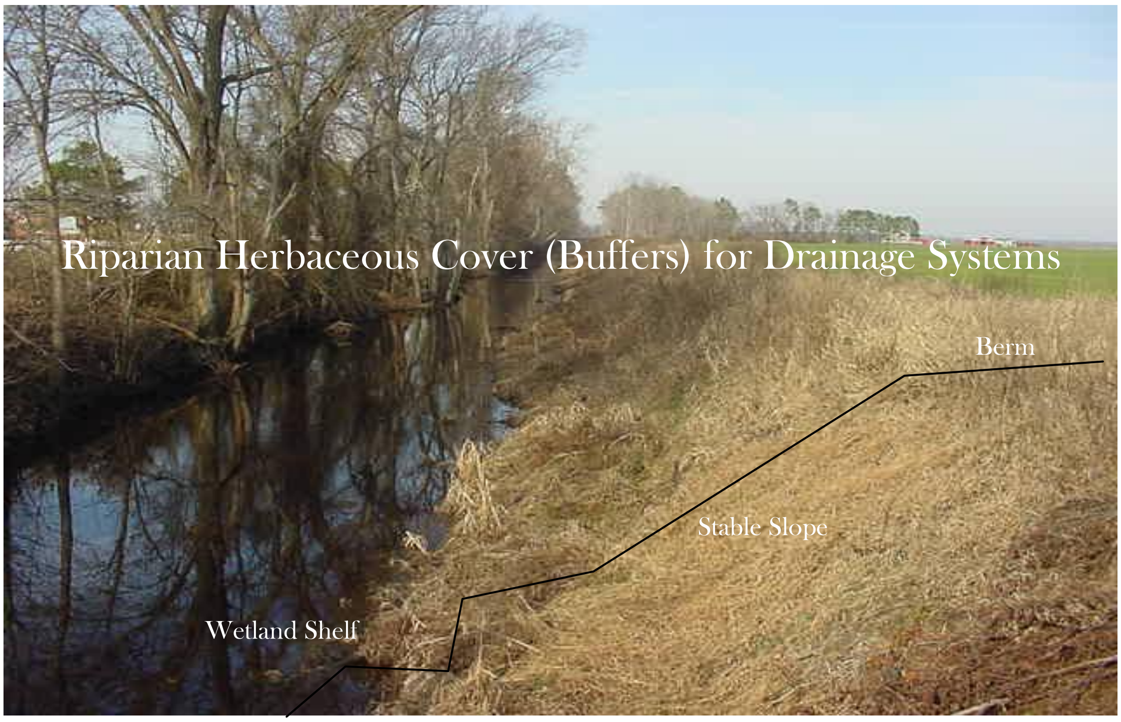


1. Existing Main Canal or Outlet Ditch
2. Existing field ditches elevation (2.5 to 3.0 ft below ground level) entering drainage Main or Canal.
3. Water level controlled at elevation of existing outlet field ditches or 2.5 to 3.0 ft below ground level.
4. Wetland shelf (1 ft wide) to support emergent wetland vegetation; six inches below level of water control. Exposes flowing ditch water to wetland biology.
5. Riparian herbaceous cover buffer must be at least 2.5 times the ditch width, but not more than 35 ft measured from the wetland shelf to the berm area. (Reference NRCS RIPARIAN HERBACEOUS COVER 390)
6. Berm (0.5 to 1.0 ft above ground level) to prevent surface water overflow. Land shaping and grading required. Drop pipes may be needed.
7. Land shaping and grading area for spoil disposal (area determined to spread spoil 3 inches deep).
8. Water quality improvement impacts realized by subsurface drainage water forced through vegetative buffer, and ditch flow interaction with riparian vegetation.

Policies:

1. At least four species of wetland plants will be initially utilized (Refer to Suggested Wetland Plants List attached). Any variety of wetland plants can be use provided they reflect the indigenous species found within the watershed. Initial wetland plantings should be approximately on five-foot spacings. For future maintenance, the concentration and type of wetland plants found is expected to change with seasonal and environmental conditions. Any natural occurring density, variance, or spatial distribution of population is acceptable for wetland specifications.
2. Riparian herbaceous cover buffer must be at least 2.5 times the ditch width, but not more than 35 ft measured from the wetland shelf to the berm area. (Reference: NRCS RIPARIAN HERBACEOUS COVER 390)
3. Water control (preferably a rock weir) is required to compliment this BMP (Reference: STRUCTURE FOR WATER CONTROL 587).

4. Excavated spoil for slope stabilization is to be spread on the adjacent farm fields. Land shaping and grading is required to divert surface water from flowing over ditch banks (Reference: LAND SMOOTHING 466). Drop pipes may be needed.
5. Ditch slope to be established in grasses and shrubs compatible with stabilization requirements and management strategy (Reference: Critical Area Planting 342).
6. Minimum life of BMP (10 years).



Average Cost Components Needed for Riparian Herbaceous Cover (Buffer) for Drainage Systems

(All items are available in current NCACSP, and CCAP cost list).

Existing Program List	Component	Unit Type	Unit Cost	Maximum Cost Share	Minimum Cost Share	Cost Type
NCACSP	Excav. w/spoil remove	CuYd	$ 2.20			Average
NCACSP	Grading-light (1-3 in)	Acre	$ 1,700.00			Average
NCACSP	Vegetation-bag lime, seed & fert	Acre	$ 700.00			Average
NCACSP	Vegetation-establish, hydroseed	Acre	$ 1,700.00			Average
NCACSP	Vegetation-mulch, small grain straw	Acre	$ 550.00			Average
CCAP	Wetland Plants Installed	Each	$ 2.30			Average

Wetland Plants List
Suggested Species for Wetland Shelf
Riparian Herbaceous Cover (Buffer) for Drainage Systems

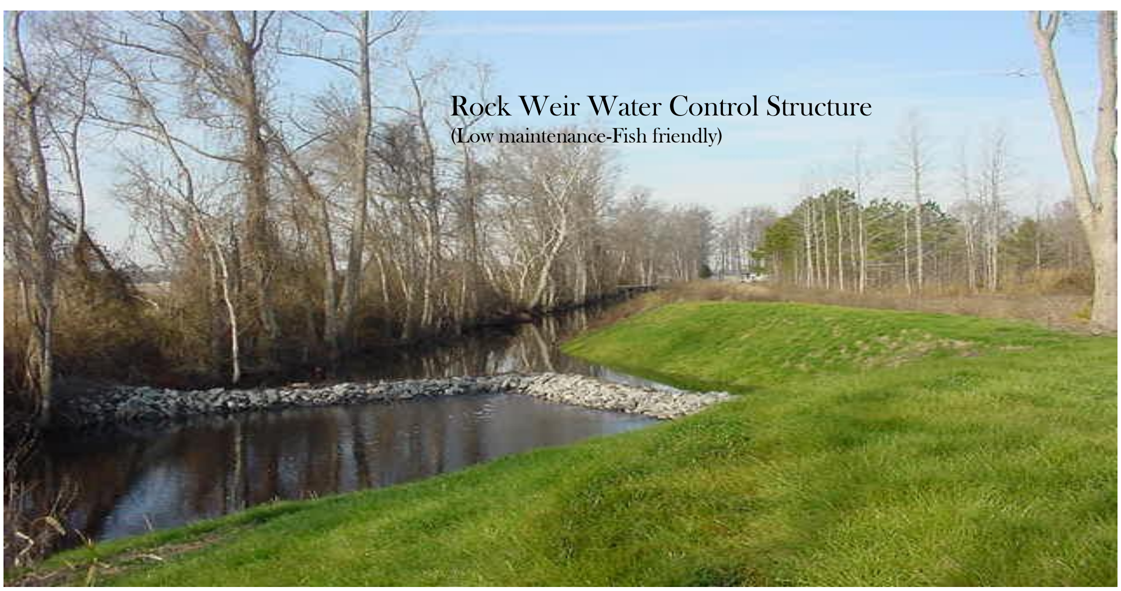
Arrow arum	Peltandra virginica
Broad leaf arrowhead	Sagittaria spp.
Southern blue flag,	Iris virginica
Cattail	Typha latifolia
Lizard's tail	Saururus cernuus
Pickerelweed	Pontederia cordata
Spatterdock	Nuphar advena
Bulrush	Scirpus spp.
Sawgrass	Cladium mariscus jamaicense
Sedge	Carex Carex spp.
Spike Rush	Eleocharis spp.
Black needle rush	Juncus roemerianus
Rush	Juncus spp.
Giant Cane	Arundinaria gigantean
Giant Cordgrass	Spartina cynosuroides
Salt Meadow Cordgrass	Salt Meadow Spartina patens
Smooth Cordgrass	Spartina alterniflora
Rice Cutgrass	Leersia oryzoides

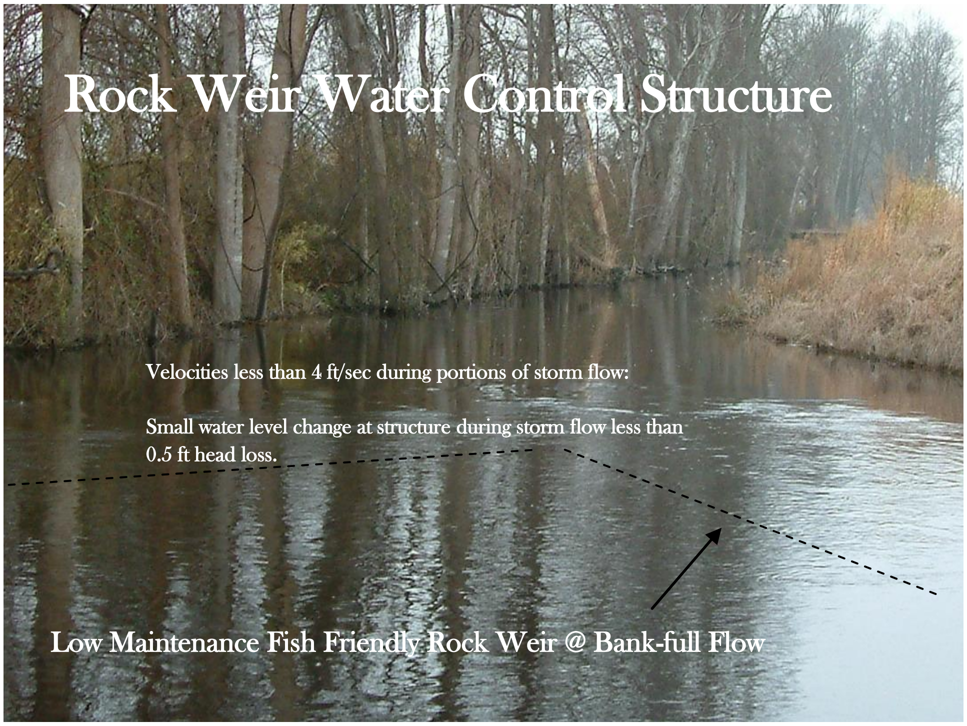
Rock Weir (Water Control Structure)

Definition/Purpose:

A water control structure that is low maintenance, fish friendly, and improves water quality on a watershed scale. This structure reduces total subsurface and surface water drainage volumes; improves anadromous fish habitat access to headwater areas defined by drainage systems; and establishes static water levels needed to support wetland shelves associated with Riparian Herbaceous Cover (Buffers) for Drainage Systems , and Wetland Filters for Drainage Systems. (Reference ACSP Water Control Structure BMP) (Reference: Structure for Water Control 582).

- Addresses water quality and excessive drainage issues associated with main drainage outlets that pierce the surficial aquifer. Generally these structures are used on drainage outlets that range from 4 to 10 feet deep
- Requires no adjustment or maintenance of storm water flow level.
- Fish friendly:
    1. Some areas of the weir will contain slopes of 3% or less;
    2. Drainage flow velocities over the weir will be less than 4 ft/sec during some portions of the drainage discharge.
- Works in conjunction with upstream drainage systems:
    1. Water control occurs at elevations below upstream drainage outlets, generally 3.0 feet below upstream ground levels.
    2. Storm drainage events pass over the structure without significantly impeding upstream surface and subsurface drainage flow rates, or significantly altering upstream surface water profiles.





Policies

1. Utilize applicable structural and management considerations found in ACSP Water Control Structure specifications.
2. Ditch water levels will controlled at elevations that do not interfere with upstream subsurface water table control, or surface water and storm water drainage flows (Generally 3.0 feet below upstream field elevations).
3. Watershed scale modeling (utilizing HEC-RAS, etc) will be performed to determine weir configurations that reflect upstream drainage considerations.
4. BMP life 10 yrs.

Cost-Share Components Needed for Rock Weir Water Control Structure

(All components available in NCACSP)

Existing Program List	Component	Unit Type	Unit Cost	Maximum Cost Share	Minimum Cost Share	Cost Type
NCACSP	Excav. w/spoil remove	CuYd	$ 2.20			Average
NCACSP	Stone-Boulders	Ton	$ 77.00			Average
NCACSP	Stone-gravel	Ton	$ 31.00			Average
NCACSP	Stone-riprap	CuYd	$ 33.00			Average
NCACSP	Filter Cloth-geotextile fabric	SqYd	$ 2.25			Average
NCACSP	Grading-light (1-3 in)	Acre	$ 1,700.00			Average
NCACSP	Vegetation-bag lime, seed & fert	Acre	$ 700.00			Average
NCACSP	Vegetation-establish, hydroseed	Acre	$ 1,700.00			Average
NCACSP	Vegetation-mulch, small grain straw	Acre	$ 550.00			Average

Management Alternatives to Enhance Water Quality and Ecological Function of Channelized Streams and Drainage Canals

R.O. Evans **K.L. Bass** **M.R. Burchell**
R.D. Hinson **R. Johnson** **M. Doxey**

Abstract

Drainage practices in humid regions historically focused on straightening and deepening natural channels to increase their hydraulic capacity and minimize upstream flooding. In most cases, traditional channel improvements disassociated the channel from the natural floodplain, especially for smaller storms, degrading water quality and ecological functions associated with the riparian floodplain. Pilot studies were implemented to demonstrate and evaluate alternative channel management strategies and design geometries to identify alternatives that would enhance water quality functions while maintaining the necessary drainage function. Channel alternatives included: establishment of in stream and riparian wetlands, lowering of the floodplain to reconnect the channel with the floodplain, redesign of channels using natural channel design principles, and establishment of conservation easements to encourage establishment of perennial riparian buffer vegetation. This paper summarizes several projects that were implemented between 1994 to 2006 to provide better management of drainage water in order to enhance water quality and other ecological functions in large drainage canals. Hydrology and water quality were monitored from one to three years at each site. In addition, plant communities and macro-invertebrates were monitored at three sites. Nitrogen transport was reduced by 20-40% with in-stream wetlands. Reconnecting the channel with the floodplain dampened the hydrograph peak and reduced the “out-of-floodplain” risks outside the project area. The alternative practices were more expensive and resulted in two to three times more land area being taken out of production compared to conventional drainage practices. However, the benefits were improved water quality, lower peak outflow rates, and enhanced habitat for wildlife. It is concluded that there are environmentally friendly alternatives to traditional practices of frequently cleaning and mowing trapezoidal ditch channels to achieve drainage requirements.

The authors are Robert O. Evans, Professor, Kris L. Bass, Extension Associate, and Mike R. Burchell, Extension Assistant Professor, Department of Biological and Agricultural Engineering, North Carolina State University; R. Dwane Hinson, District Conservation, USDA Natural Resources Conservation Service; Rodney Johnson, retired Albemarle RC & D Coordinator, USDA-NRCS; and Mike Doxey, District Technician, Currituck Soil and Water Conservation District.

Portions of this paper were presented and printed in the Proceedings of the 2004 ASABE Specialty Conference “Self-Sustaining Solutions for Streams, Wetlands, and Watersheds”, St Paul, Minnesota, USA; and in the Proceedings of the 19th ICID Congress “Improving Water and Land Management for Increasing Efficiency in Irrigated Agriculture”, Beijing China, 2005.

Early Drainage in Eastern North Carolina

Settlers migrated to North Carolina from Jamestown, Va. and established one of the first permanent settlements along the Chowan River in 1626. The explorations from Jamestown to eastern North Carolina required travel around or through the Dismal Swamp. As early as 1728, William Byrd surveyed the Dismal Swamp and saw the opportunity to drain it noting that the swamp was higher in elevation than the surrounding land (Boyd, 1929). In 1763, George Washington along with five associates formed the "Adventurers for Draining the Great Dismal Swamp" (also know as the Dismal Swamp Canal Company) and obtained 16,188 ha with the intention of draining them. They dug one 7.5 km canal to Lake Drummond known as the Washington Ditch (Brown, 1970). The Dismal Swamp canal was proposed in 1784 to provide navigation from the Chesapeake Bay to the Albemarle Sound. Construction began in 1793 and was completed in 1805 (Brown, 1970).

While the Dismal Swamp Canal was dug primarily to provide navigation, it had a profound effect on water movement through and subsequent drainage of the Dismal Swamp in southeastern Virginia and northeastern North Carolina. The natural overland flow through the swamp was generally from northwest to southeast. The spoil material from the canal placed along one side of the channel formed a dyke that effectively blocked the natural overland flow. As a result, lands to the west of the canal became wetter while lands to the east became drier (Ruffin, 1861). With the construction of additional ditches, the lands to the east were soon extensively cultivated. Edmond Ruffin traveling the area in 1836 described an extensive parallel ditch drainage system (Ruffin, 1861) that is still widely utilized today along the Atlantic Coast.

There are now few un-channelized streams remaining in the lower and middle coastal plain regions of the Atlantic and Gulf States. In most cases, traditional channel improvements have disassociated the channel from the natural floodplain degrading riparian floodplain water quality and ecological functions. Woody riparian vegetation along the sides of the streams have been removed and ditch banks are routinely mowed to provide access for periodic clean-out and removal of silt. In many channelized streams, most storm flows are confined predominately to the main channel. The riparian floodplain that once routinely remained soaked or inundated during the winter and spring for months at a time now only flood during large storms (storms greater than 3 to 5 year recurrence interval). In bypassing the floodplain, there is less opportunity for potential pollutants in the drainage water to be filtered and assimilated. While wetness is still a concern to landowners, intensive drainage systems sometimes remove more water than necessary especially on sandy soils during drier periods, leading to over drainage (Doty et al., 1982).

Early Attempts to Address Agricultural Drainage Water Quality

Controlled drainage has become a management practice implemented in eastern North Carolina to address the issue of over drainage and agricultural drainage water quality. Controlled drainage involves the use of some type of adjustable, flow-retarding structure placed in the drainage outlet that allows the water level in the outlet to be artificially set. Many types of structures can be used depending on the layout of the drainage system (Evans and Skaggs., 1985; Evans et al., 1992; Evans 2003). When properly managed, controlled drainage has been documented to reduce the transport of nitrogen in agricultural drainage waters by as much as 40% (Evans et al., 1995; Fausey et al, 2004). In 1985, controlled drainage was adopted as a Best Management Practice (BMP) by North Carolina and as such qualified for cost share assistance to landowners under the North Carolina Agricultural Cost-Share Program administered by the N.C. Division of Soil and Water Conservation (Evans and Skaggs, 2004). Since 1985, approximately 3500 water control structures have been implemented on about 120,000 ha across eastern North Carolina. The practice of controlled drainage is now being promoted by the Agricultural Drainage Management Systems Task Force – a multi state, multi agency work group – as a practical means to reduce the transport of nitrogen originating in the upper Mississippi Valley from getting into waterways and contributing further to the hypoxic zone in the Gulf of Mexico (ADMS, 2003).

The rate of implementation of controlled drainage peaked in North Carolina at about 10,000/year in 1991 (Evans and Skaggs, 2004). A resurgence in public concern and interest in water quality arose in the early 1990s following several major fish kills in the lower Neuse River and Albemarle/Pamilco Sound Estuary. Controlled drainage was one of several practices recommended for agricultural lands to address this problem; however, significant increase in controlled drainage implementation did not occur. As a result, the authors began to ponder if other practices could be used in addition to or in conjunction with controlled drainage to more effectively reduce the transport of nutrients, especially nitrogen, in agricultural drainage.

Drainage Canal Alternatives

Pilot studies were begun in 1994 to demonstrate and evaluate alternative management strategies and channel design geometries that might enhance water quality and ecological functions while maintaining the necessary drainage function. Channel alternatives included establishment of in stream and riparian wetlands, lowering of the floodplain to reconnect the channel with the floodplain (priority II restoration), redesign of channels using natural channel design principles to reconnect the channel with the natural floodplain (priority I restoration), and establishment of conservation easements to eliminate traditional ditch bank mowing and facilitate establishment of perennial riparian vegetation. Restoration of riparian wetlands and buffers were implemented and evaluated at some locations. It is beyond the scope of this paper to provide detailed descriptions of each project including methodology used to monitor and evaluate each practice's effectiveness to address water quality and ecological goals. Instead, only general observations that address project characteristics and performance are presented herein. The reader is directed to original publications for detailed project descriptions, explanation of monitoring methodology, and scientific analysis and results (Bass and Evans, 2000; Dukes and Evans, 2003, 2006; Dukes et al., 2002, 2003; Jia et al., 2006; Shelby et al., 2005; Smeltz, 2004; Tweedy and Evans, 2001; Wright et al., 2006).

Maintenance of the pre project high flow drainage capacity was a design requirement on all projects. That is, the capacity of each channel (flow, Q) under high flow conditions (bankfull) could not be reduced below what it was prior to the project. HEC-RAS was used to evaluate the impact of the channel alternatives and/or design parameters on the water surface profile before and after the implementation of each project. The hydraulic design procedure involved evaluating the existing condition for each channel using HEC-RAS and determining bankfull flow, Q. The HEC-RAS analysis was then repeated incorporating the channel alternative (weir, in-stream wetland, floodplain, etc.) and the water surface profile re-computed and compared to the pre-project condition. Appropriate channel dimension, for example cross sectional area, was adjusted (sized) in HEC-RAS until the new water surface profile for the pre-project bankfull Q was within an acceptable range. No increase in the water surface profile was considered acceptable within urban watersheds while about a 50 mm (2 inch) rise in the water surface profile was considered acceptable for agricultural watersheds. Practical applications of this design rationale are discussed for several of the following projects.

Tull's Creek Project – Currituck County

The first drainage alternative project was initiated in the Tull's creek watershed in Currituck County in 1995. The project involved a one mile reach of the main canal system draining approximately 80 ha of cropland. One reach of the canal (450 m) was managed in the traditional "free" drainage mode, a second reach was managed in the "controlled" drainage mode, and the third reach was planted with a variety of wetland plants (Fig 1) to provide a combination in-stream wetland/controlled drainage system. Approximately 4500 plants were planted in the wetland section. Based on visual observations made during September, 1996, over 90 percent of all species except cattail survived. Annual re-growth of wetland vegetation was excellent throughout the evaluation period (1997 – 1999). The outlet of each reach was instrumented to continuously measure outflow (Fig 2). Grab samples were collected monthly to evaluate treatment effects on water quality. In general, nitrogen concentrations were higher while phosphorus concentrations were lower with drainage control both with and without the addition of wetland plants. Total flow, phosphorus and sediment transport were significantly lower with both controlled drainage treatments. The addition of plants did not appear to provide an additional water quality benefit other than an improvement in water clarity over drainage control alone. Habitat benefits may have been enhanced by the plants; but, habitat benefits were not evaluated. This initial project demonstrated that it was possible to maintain wetland plants in drainage ditches without frequent mowing or adversely impacting the drainage performance of the ditch.

Liza's Bottom – Chowan County, Town of Edenton

The Edenton urban project, initiated in 1997, involved construction to lower the old floodplain along approximately 400 m of stream known as Liza's Bottom and create approximately 1 ha of in-stream wetlands. The stream carries drainage waters from agricultural lands and runoff from commercial and urban sources such as a solid waste transfer site and a former farm supply facility. The channel was initially channelized prior to 1900 and routinely cleaned out thereafter such that the riparian floodplain was rarely functional. A 1 ha wetland was constructed in April-May, 1997. The wetland was built by excavating the existing hydraulically dysfunctional floodplain down to the stream base-flow level and raising the stream bottom (Fig 3). The soils found in the floodplain and used for the wetland substrate were variable, with some reduced and high in organic matter and others clayey in content. Islands were built in the interior to minimize transportation of cut/fill material and create a more sinuous flow path. A low head, wooden bulkhead was installed at the outlet to maintain water depths of 0.1m to 0.5m (6-18"). The wetland bottom was graded for a mixture of shallow and deeper pool areas. Native plants were used in the wetland and transplanted on a 1m x 1m spacing. The wetland intercepts drainage waters from approximately 240 hectares of surrounding watershed. One hundred and sixty hectares are attributed to agricultural and natural forested area, sixty ha to urban area, and twenty ha to intensive commercial areas. The resulting watershed/wetland area ratio is 100:1, which is less than half the minimum size typically recommended in the literature (Scheuler, 1992).

The wetland was instrumented to continuously measure inflow and outflow (Fig 4). Flow measurements were made at the two main inlet streams (E2 and E3) and at the wetland outlet (E1) using continuous water level recorders. Stage measurements were combined with weirs and calibrated discharge curves to generate a continuous mass flow record. A comparison between predicted drainage and runoff from the watershed and measured wetland outflow volumes lead to the conclusion that the overall flows observed were reasonable for use with concentration data to predict nutrient mass transport (Bass, 2000). Water quality samples were taken over time and at various flow stages. Background water samples were acquired from January 1996 until construction began in May, 1997. After planting, grab samples were taken on bi-weekly intervals. Automatic water samplers were utilized at the two main inlets and at the outlet. Over 1000 samples were acquired during the monitoring period.

During base flow conditions, attenuation within the Liza Bottom constructed wetland was approximately 7 days with no significant attenuation during large storm flows. Prior to wetland construction, there were no changes in ammonium (NH_4-N) concentrations between up and downstream monitoring locations while nitrate showed a 40% decrease indicating some nitrate was likely being removed along the stream by denitrification. Over the four-year monitoring period which ended December, 2000, NO_3-N concentrations were reduced by 60%, NH_4-N by

30%, and TKN by 9.5% resulting in a flow-weighted total nitrogen reduction of 20% . Yearly and seasonal means indicated that significant improvements in NO_3-N and NH_4-N concentrations can be achieved with relatively small wetlands. Initially, total- and ortho- phosphorus concentrations were unchanged by the wetland. However, by the end of year 2, phosphorus concentrations began to increase. During the last two years of monitoring, there was a net increase in phosphorus discharge from the wetland of 55%. This project, located near the county high school, provided living labs for both biology and physical science classes.

Table 1. Overall nutrient reductions on concentration and mass basis, Edenton wetland

	NO_3-N	NH_4-N	TKN	TN	TP	OP
Concentration basis	60%	30%	9.5%	20%	-55%	-55%
Mass basis	55%	16%	6%	18%	-50%	-50%

Guinea Mill Watershed – Currituck County

Currituck County is one of the fastest growing counties in North Carolina resulting largely from urban sprawl originating in Tidewater Virginia. The Guinea Mill watershed project (approximately 2,000 ha) was initiated in 1999 to address drainage and water quality issues arising from rapid urbanization of a predominately rural county (Fig 5). Over half the watershed is projected to be converted from farmland to residential by 2010. Drainage systems that were generally adequate for agricultural land uses are not adequate for residential development (Fig 6).

As part of the Guinea Mill project, a tax-supported Water Management Service District, one of the first in North Carolina, was formed by the Currituck County commissioners. The purpose of the Service District is to generate revenue to assure the future maintenance and persistence of the project components. Under N.C. Statue, a Service District operates similar to a Drainage District in terms of establishment, taxation and governance. The advantage of a Service District is the ability to incorporate multiple objectives in the charter whereas a Drainage District by State Statue has one objective, that being drainage or flood protection. Under Drainage District law, penalties can be assessed for activities such as addition of weirs or structures to control flow.

This constraint has prevented the installation of water control structures within Drainage District right-of-ways for the purpose of providing controlled drainage. In the case of a Service District, it become the responsibility of the leadership to determine on a case by case basis what activities achieve the overall goals of the District. For example, a Service District can have an objective of providing flood protection but at the same time allow installation of a water control structure to enhance water quality. It if is deemed that water quality is more important to the District than drainage, drainage can be compromised for the benefit of water quality.

There are 289 parcel owners within the Guinea Mill Watershed with the majority in eight (8) major subdivisions. Permanent conservation easements involving 20 ha along both sides of the canal were purchased and are managed by the county utilizing an advisory board comprised of five landowners in the watershed. The advisory Board is charged with the duty of investigating, studying and making recommendations to the Board of Commissioners pertaining to the construction, enlargement, improvement, maintenance, operation and regulation of the Service District. A county ordinance was established requiring all new subdivisions and any landowners encroaching on the easement and canal to submit a plan for that encroachment (i.e., culvert, drainage swale, etc) to the Service District prior to installation.

Guinea Mill Canal dissects the watershed and runs the entire length of approximately 13 km (Fig 7). The fourteen kilometers of riparian buffers were established along the Guinea Mill Canal. Where farming use to occur next to the stream bank (Fig 8), buffers are established with vegetation maintained 0.3 to 1 m high (Fig 9). In-stream constructed wetlands (Fig 9) were installed on 3.4 ha within the Guinea Mill Canal. In the wetland section, the canal was widened from 10 to 20 m. The widened channel section increased the cross sectional area of the channel to offset the increased flow resistance resulting from the wetland plants. Two in-stream wetland cells were constructed one approximately 2 km and the second about 1 km in length. The wetland cells were planted with a variety of wetland plants on a 1 m by 1 m spacing.

A rock weir water control structure was installed to enhance hydrologic function at low flows. The rock weir (1 m high by 1.2 m top width by 21 m length) was located just downstream of a 15 ha hardwood swamp (Fig 10). The hydrology of the swamp had been significantly altered by channelization of Guinea Mill Canal. The rock weir raised the base flow elevation by approximately 1 m, restoring some hydrologic function to the riparian swamp (Fig 11). In addition, scour pools formed downstream of the rock weirs which enhanced aquatic habitat. As in previous examples, the channel was widened in the vicinity of the rock weirs to offset the reduction in flow depth resulting from the weir. Annual inspections of all conservation easements are made by the Advisory Board and the Currituck SWCD Board with their respective reports submitted to the County commissioners.

Newland Watershed Project – Pasquotank County

A similar tax supported Service District project was initiated in the Newland Watershed in Pasquotank County in 1998. The watershed Service District encompasses approximately 7,000 ha. The US Hwy158 Canal and Sheppard Ditch are the primary outlets for the southeastern section of the Dismal Swamp Wildlife Refuge. In recent years, landowners downstream of the refuge have been subjected to flooding resulting from failure and overtopping of the refuge dyke.

This project involved development of a conceptual water management plan for the refuge that balanced the water management needs of the refuge with the drainage and water quality needs of the downstream landowners and citizens. Debris was cleared and snagged in the upper Pasquotank River which is the outlet for both the 158 and Sheppard Ditch canals. Both canals were excavated to stabilize stream banks. The ditch bottoms were excavated to create a ledge for establishment of 2.6 acres of in stream constructed wetlands (Figs 12 and 13).

Five associated rock weir water control structures (Figs 14 and 15) were installed to enhance base flow hydrology and ecological function. At the rock weirs, the channel is widened to maintain the same cross sectional area as existed prior to the project so that the channel capacity will not be reduced at high flows. Vegetative buffers were established along 4.2 km of the 158 Canal and 3.6 m on Sheppard Ditch. Annual inspections are made by the Advisory Board and the Pasquotank SWCD Board with their respective reports submitted to the County commissioners.

Edenton Airport and Industrial Park – Chowan County

The Edenton Airport and Industrial Park restoration and enhancement project in Chowan County was initiated in 2000. As part of the construction and development of the Edenton Army Base in the 1930's, the lower stream reach of the watershed was channelized with the spoil deposited in the adjacent floodplain and a short circuit cutoff constructed that shortened the flow path of drainage water to the Albemarle Sound by more than a kilometer. This project involved three hydrologic enhancements. The first involved restoration of stream and riparian floodplain functions in the lower stream segment. Spoil piles were removed to restore some hydrologic functions to the floodplain (Fig 16). Re-growth maples were replaced with cypress and mixed bottomland hardwood species. At several locations, the straightened, channelized stream was re-routed back through its original floodplain (Fig 17).

The second hydrologic enhancement involved construction of a 300 m reach of stream and riparian floodplain. Final design consisted of an 250 m stream/wetland valley with floodplain width varying from 7 to 10 m. The stream was designed to meander within the wetland valley (Fig 18). The stream/wetland system was designed to be from 0.5 to 1.5 below original grade. Lastly a series of 3 storm water wetlands were constructed between the constructed and restored stream reaches (Fig 19).

Water quality monitoring showed mean pollutant concentrations for all sampling locations were lower than most urban or agricultural watersheds. The relatively undeveloped status of the watershed was most likely a causative factor for the low concentrations. Concentrations of ammonium-N were frequently higher downstream of large areas of open water within the restored reach (Smith and Evans, 2004). The existence of open water was likely attractive to waterfowl and other wildlife species which deposited fecal matter within the restored reach. Inlet and outlet pollutants concentration at the constructed wetland cell were similar for all constituents except nitrate-N. A 71% reduction in nitrate-N concentration was observed. Both total nitrogen and total phosphorus concentrations were observed to decrease thru the created stream reach. Wetland processes were likely the primarily cause of this water quality improvement. Additionally sediment concentrations were lower at the created stream reach than at upstream sampling locations. It appears that the constructed wetland cell in the downstream extent of the created stream/floodplain reach effectively reduced both nutrients and sediment transport.

Golf Course Stream and Wetlands – Chowan County

An innovative approach was initiated in 2003 to manage poor drainage and stormwater (Fig 20) at the Chowan Golf Course. Existing drainage ditches (Fig 21) were redesigned utilizing natural channel design concepts along with HEC-RAS hydrologic analysis and interconnected to a network of twelve constructed stormwater wetlands (Fig 22 and 23) ranging in size from 0.1 to 2 ha. On this project, the ratio of watershed area to wetland area is 10:1. All stormwater conveyance channels and wetlands are protected by a permanent conservation easement under the control of the County Commissioners.

Nutrient and water management plans are being developed for the golf course. Once the management plans are adopted, modifications will require the approval of the County Commissioners. The wetland system is designed to treat and retain the first two inches of runoff which is recycled back onto the course through irrigation resulting in a nearly “closed” system except for very large events. The hydrologic and water quality performance of this system is being evaluated. Stormwater retention durations in the wetlands has ranged from 3 to 30 days depending on storm size and the watershed to wetland area ratio. After three growing season, there has been no adverse effect on wetland plants from large fluctuations (0.3-0.5 m) in water table levels resulting from the large range in stormwater retention time. Nitrogen concentrations spiked briefly following heavy fertilization to establish the fairways which were being established at the same time the wetlands were establishing. As a result, the immature wetlands did not have the capacity to assimilate the initial pulse of N in the runoff. After the initial growing season (establishment phase), nitrate and ammonium concentrations exiting the wetlands have been near detection levels.

Core Creek Stream and Wetland Restoration/Creation – Craven County

The Core Creek project consisted of relocation of an unnamed channelized stream within the Core Creek watershed that had been significantly impacted by cattle access (Fig 24). The degraded stream was a G5 class (Rosgen classification system) channelized stream with severe bank erosion and degraded water quality. The new channel was designed using a combination of analog, empirical, and analytical design techniques (COE, 1995; Shields et al., 2003). The relocated E5 channel was constructed using priority II methodology in March, 2005. Priority II involves lowering the floodplain (stream valley) elevation to an appropriate level based on stream bank elevation compared to Priority I which involves raising the streambed to match the existing floodplain (stream valley) elevation.

The constructed stream consisted of a uniform dimensional section, meandering pattern, and 0.1% slope (Fig 25). A 30 to 40 m wide stream valley was constructed by stockpiling 150 mm of topsoil then removing 0.5 to 0.6 m of subsoil. The topsoil was then redistributed across the valley followed by construction of a 3.5 m (top width) by 0.5 m deep E5 channel with an average sinuosity of 1.3 (Fig 26). Log vanes were used to hold grade and root wads to armor banks. Flow hydraulics and design structures controlled riffle/pool formation (Fig 27).

Prior to construction, background monitoring showed there was no significant difference in upstream and downstream nitrogen concentrations (upstream and downstream of the planned construction reach). Phosphorus concentrations and fecal coliform levels downstream were significantly higher than upstream. Macro-invertebrate sampling indicated that the quality of the stream was severely stressed.

Since construction, periodic cross section measurements indicate the re-located stream dimension, pattern and profile were well designed to meet expected channel hydraulics and regional geomorphology (Lindow et al., 2007). Bank mass wasting and slumping occurred during and immediately following construction. This was due to geotechnical instability caused by a pressurized sand layer at the streambed elevation. This area stabilized as soon as bank vegetation became established. Water quality monitoring and evaluation since construction is ongoing. Initial macro-invertebrate monitoring indicate improvement in aquatic habitat compared to the original channel. The stream and associated floodplain appear to be stable and have the capacity to transmit greater flood volumes than the original trapezoidal channel without a floodplain.

Summary

Pilot studies were demonstrated and evaluated to investigate alternative channel design geometries and management to encourage water quality and ecological functions while maintaining the necessary drainage function. Channel alternatives included establishment of in-stream wetlands, lowering of the floodplain to reconnect the channel with the floodplain, redesign of channels using natural channel design principles to reconnect the channel with the natural floodplain, and establishment of conservation easements to eliminate traditional ditch bank mowing to encourage establishment of perennial riparian vegetation. Results to date indicate that alternatives exist that can be used to address drainage, water quality and ecological functions more effectively than have been achieved in the past with conventional trapezoidal drainage canals. Of course, all of the alternatives evaluated are more costly than conventional drainage canals required to achieve just the drainage function. The project costs in these studies ranged from a low of about $40/linear foot of channel to $140/linear foot of channel. Increased costs were associated with the initial costs of additional earth work required to either widen channels or create artificial floodplains and the larger land areas being taken out of production. These projects accomplish the first step in the evaluation process which is to demonstrate technical feasibility. The added costs are not justified by increased drainage benefits to the landowner. Therefore, it becomes incumbent on society to put a value on the water quality and ecological functions achieved to determine if public funds should be used to help landowners offset the costs of achieving the additional water quality and ecological functions.

The projects discussed herein were supported by a combination of grants from the North Carolina Clean Water Management Trust Fund, N.C. Department of Environment and Natural Resources 319(h) Program; N.C. Agricultural Cost Share Program, N.C. Conservation Reserve and Enhancement Program, and USDA Farm Bill along with local government and landowner in- kind contributions.

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Figure 1. In-stream wetland reach of Tulls Creek project.

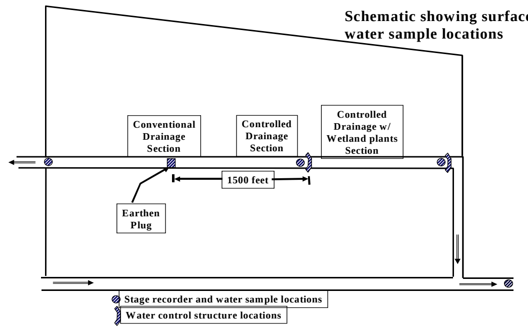

Figure 2. Schematic of water management treatments and sample locations.

Figure 3. Constructed in-stream wetland, Edenton, N.C. construction was completed May,

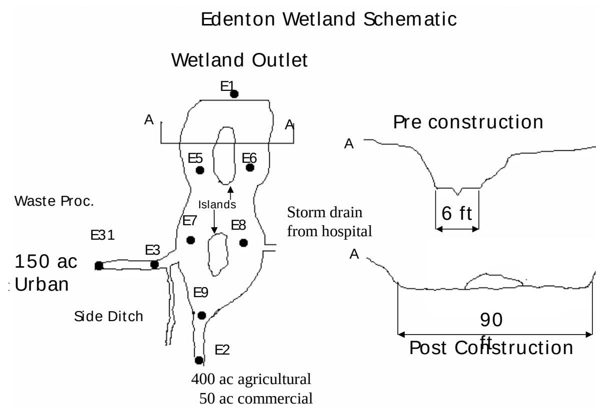

Figure 4. Schematic of monitoring locations at Edenton in-stream wetland.

Figure 5. Residential development is rapidly displacing agricultural crop fields in Currituck County.

Figure 6. Agricultural drainage is often inadequate after urbanization.

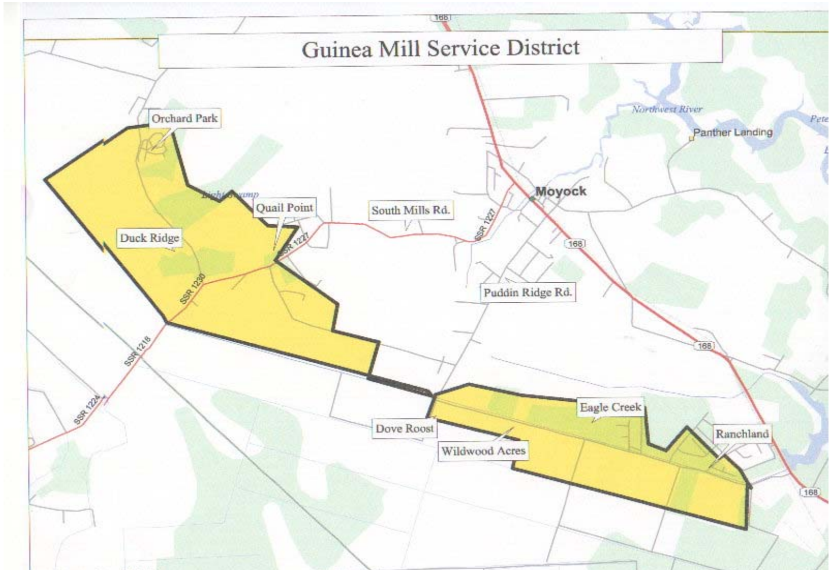

Figure 7. Shaded area represents guinea Mill Water Management Service district.

Figure 8. Upstream section of Guinea Mill with neither buffers or in-stream wetlands.

Figure 9. Lower section of Guinea Mill after installation of riparian buffer and instream wetland. Note path was moved away from canal bank.

Figure 10. Rock weir soon after installation.

Figure 11. Rock weir raises upstream water level at base flow enhancing hydrologic function of upstream swamp.

Figure 12. Section of Shepard Ditch showing bank shaping, wetland ledge and rock weir soon after installation.

Figure 13. Section of Shepard Ditch during dry period after establishment of wetland plants on constructed ledge (right bank).

Figure 14. One of five rock weirs installed to elevate the water level at base flow and enhance hydrologic function.

Figure 15. Vegetative buffers were established along ditch banks and the channel was widened to maintain capacity at the rock structures.

Figure 16. Restored swamp and floodplain reach of Edenton airport project.

Figure 17. View of lower floodplain after third growing season.

Figure 18. Constructed stream and floodplain of small headwater stream.

Figure 19. Constructed stormwater wetland in series in drainage system.

Figure 20. Poor drainage and ponding at Chowan Golf Club prior to project.

Figure 21. Typical drainage ditch on Chowan Golf course prior to stream project.

Figure 22. Constructed stream channel with riparian floodplain after construction.

Figure 23. Constructed stream and wetland one month after planting.

Figure 24. Cattle in Core Creek tributary stream prior to restoration.

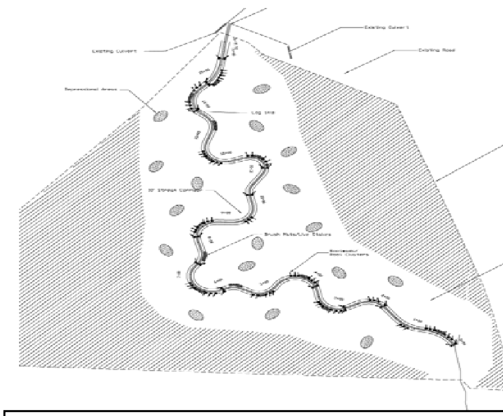

Figure 25. Schematic of Core Creek natural channel design.

Figure 26. Core Creek relocated stream just after construction.

Figure 27. Core Creek relocated stream one year after construction.