The Effectiveness of Vegetated Drainage Swales in Nutrient Management

By

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Abstract

Excessive nutrient runoff to the surface waters of the United States through stormwater has been identified by the Environmental Protection Agency as one of the largest current contributors of water pollution. Stormwater that runs off of the land surface with no identifiable origin is known as Nonpoint Source Pollution (NPS). NPS Pollution control is typically performed from either a Structural or Non-structural best management practice (BMP). Nonstructural BMPs, also known as Passive BMPs, often are less costly, quicker to design and easier to install and maintain. One of the more common passive stormwater BMPs are vegetated swales.

The vegetated swale has traditionally been used solely as a primary conveyance device for NPS stormwater. Because the cost and installation of swales is reasonable, the view of swales in recent years has shifted from simply a stormwater conveyance system to a possible effective pollution removal BMP. The general pollution control from these established passive systems are thought to rely on a number of factors. Because one of the primary factors influencing pollutant removal in an open channel drainage swale may be the swale's soil medium, the relationship soil media has with dissolved nutrient pollution warrants investigation.

Site tests were conducted in Gaston County to determine the effect that a soil's medium would have on nutrient absorption within vegetated swale. A solution mixture was released in four separate channels, whose soil was composed of either clay or sand. Samples were then collected within these channels at fifty foot intervals. When tested at a private lab it was determined that nutrients in the released solution did show varying degrees of nutrient reduction. Although solution samples showed reductions at least 37% for N and 24% for P, the different soil media being examined provided no substantive difference in the removal of nutrients.

Biography

Danon Lawson has lived in a variety of areas within the United States. It was witnessing the challenges each region faces in managing their unique natural resources that lead him to a heightened interest in the sciences behind proper natural resource management. With this growing interest, Danon studied diverse habitats and proper management techniques in the Southern Appalachian Mountains, where he achieved his Bachelors of Science from Western Carolina University in 1997.

Danon has worked for Gaston County's Natural Resources Department, also known as the Gaston Soil and Water Conservation District, since July 2000 and is currently the Conservation Programs Administrator for the department. He is currently a certified floodplain manager, CPESC (Certified Professional in Erosion and Sediment Control), and CESSWI (Certified Erosion, Sediment, and Stormwater Inspector). In 2010, Danon enrolled in the Masters of Environmental Assessment Program at NC State University in order to further his passion for studying natural sciences and how humans can better manage their resources. With this knowledge Danon aspires to help solve problems and better care for the resources entrusted to each of us.

Acknowledgements

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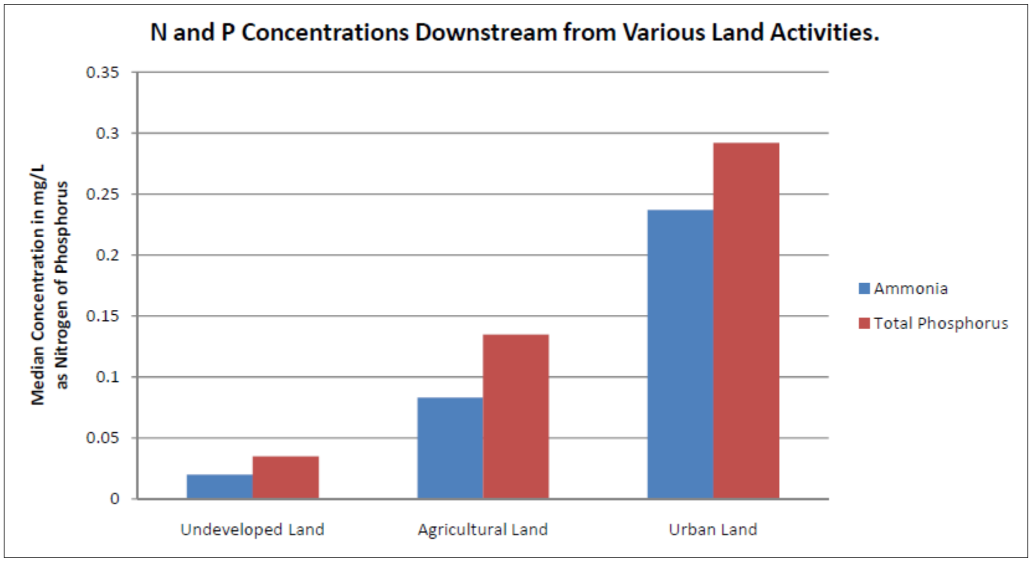
Introduction

Nutrient pollution, specifically pollution from nitrogen and phosphorus, is recognized by the US Environmental Protection Agency as one of the most costly, challenging and widespread forms of pollution in US water supplies (EPA; 2012). The impacts of nutrient pollution are diverse and widespread, affecting surface waters, through eutrophication, as well as groundwater through leaching. This type of contamination can have lasting effects on not only environmental health, but also human health. Human health problems such as the blood disease Methemoglobinemia (“Blue Baby Syndrome”) in infants exposed to high nitrogen levels in ingested water can result in severe cardiac problems and even death (DeBaun; Frei-Jones; et al 2011). Further health risks may also result from exposure to noxious forms of rapidly grown algal blooms that contain cyanobacteria as well as toxic plankton in the phylum dinoflagellata and heterokontophyta (World Health Organization; 2012). These harmful algal blooms can grow as a result of high concentrations of dissolved nutrients in surface waters and often contain human hepatotoxins and neurotoxins. The neurotoxin domoic acid, which, when bioaccumulated in shellfish, can cause amnesic shellfish poisoning (ASP) and can then lead to permanent short term memory loss, is one such example (Washington State; DEH 2012).

The introduction of nutrient pollution into a system is often traced to either point or non point source (NPS) pollution. Point source pollution is classified as pollution whose discharge source is easily identified by an individual location. When considering dissolved nutrients, however, of particular concern is the surface and ground water pollution that has diffuse origins and is commonly called nonpoint source pollution. As a result of the distributive nature of non point source pollution over large areas, sedimentation, total suspended solids (TSS), metals and dissolved nutrients are known to be the primary pollutants. The majority of uncontrolled nutrient pollution stems from non-point sources and can occur from a number of both rural and urban land uses.

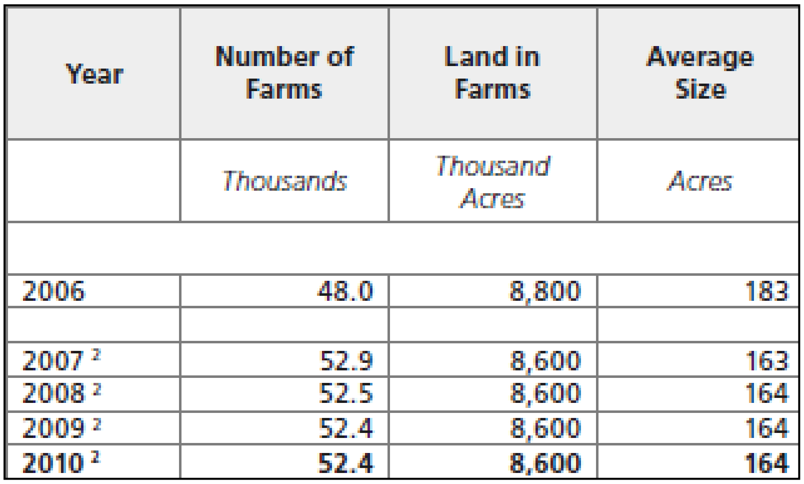
Figure 1 gives a graphical illustration of how the nutrients are distributed nationwide based on land use.



[*Figure 1*: Ammonia and phosphorus concentrations are highest downstream from urban areas. Nationally, 92% Nitrogen and 76% Phosphorous has been recognized as from non-point source contributors. (USGS - 1996)]

The Challenge of Land Use

While there is not as much available farmland in the Southern Piedmont as there once was, the number of smaller and more diverse farms is on the rise. Table 1 shows the increase in farms statewide, yet a decrease in acreage per farm. [Note: Table 1 shows the most current data for the last five years. While the trend in farm number and acreage size continues, the data reflected in the table shows a slowing of the trend. This is primarily a result of national economic conditions due to the US housing recession, as the purchase and establishment of small farmland in North Carolina between 2006 and 2007 began to slow.]

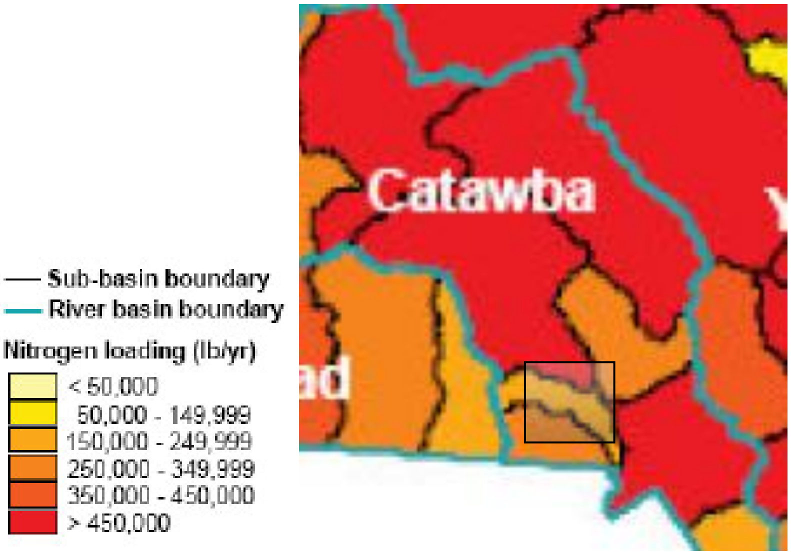


Year	Number of Farms	Land in Farms	Average Size
	Thousands	*Thousand Acres*	*Acres*
2006	48.0	8,800	183
2007 [2]	52.9	8,600	163
2008 [2]	52.5	8,600	164
2009 [2]	52.4	8,600	164
2010 [2]	**52.4**	**8,600**	**164**

(Table 1: Number of farms and land in farms in the State of North Carolina, from the 2010 North Carolina Agricultural Statistics, North Carolina Department of Agriculture)

Many of these farms are utilizing the land for different and often times more nontraditional practices. In addition to a wider array of agricultural practices, producers also contend with increased production pressure on smaller tracts of land. Combining nontraditional agriculture with greater pressure can set the stage for quite a spatial challenge for nutrient pollution control. It is, therefore, now more important than ever to consider proper nutrient best management practices that are easily installed and maintained in smaller spaces. Agricultural communities are revisiting the old technology of swale construction in smaller spaces to better understand the relationship between water runoff, dissolved nutrients and their relationship to neighboring surface water (Kara, et al; 2008).

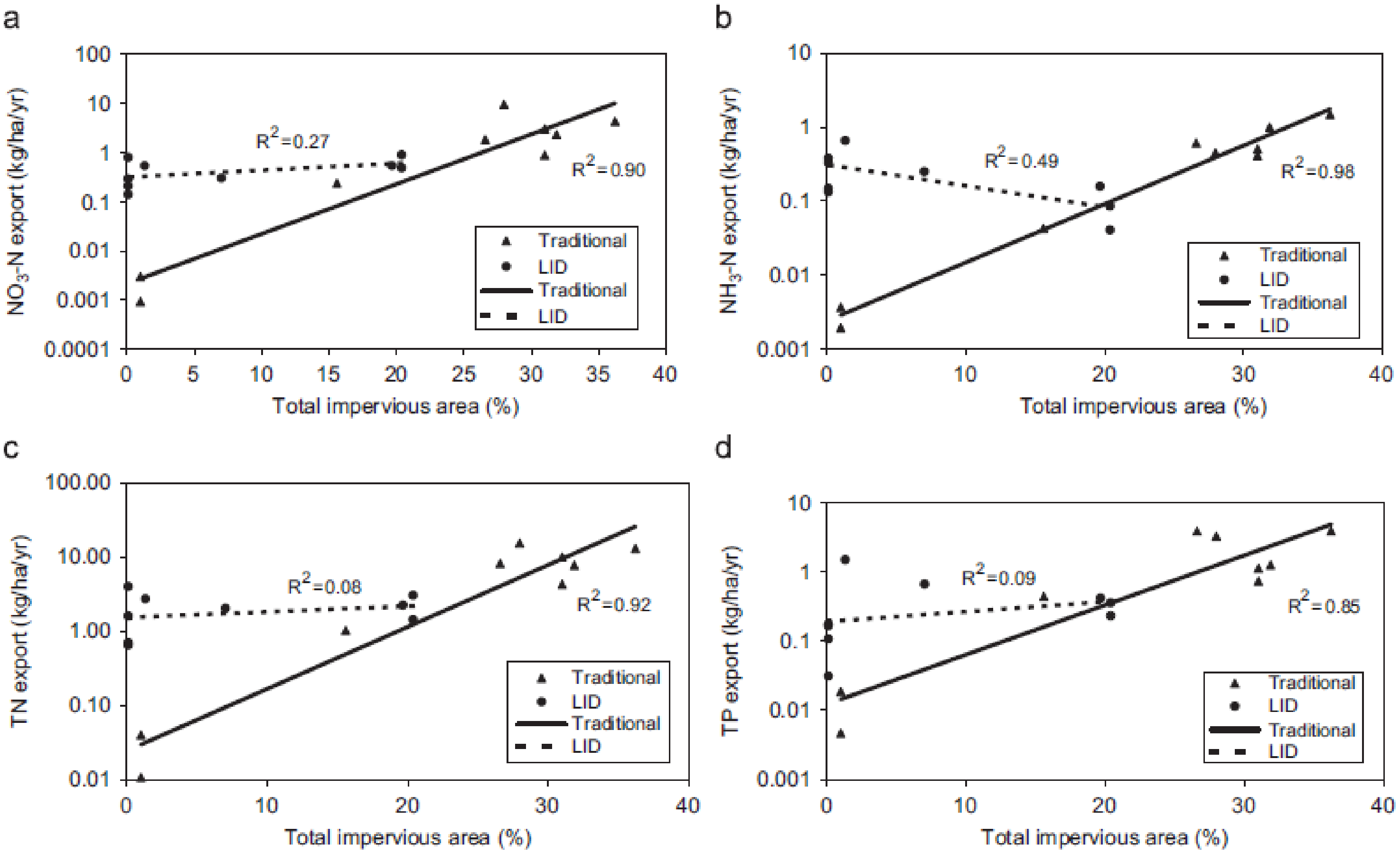
Urbanization within the Southern Piedmont continues to increase as available land is converted from its previous uses of production agricultural and forest land. This increase in urbanization and impervious surfaces consequently increases the quantity of stormwater runoff. Grassed lined ditches continue the role they have historically played as a stormwater conveyance in urban development. With the total amount of farmland dwindling and being replaced by development , which in turn increases nutrient stormwater pollution in some of the more urban surface water bodies, a better understanding of how pollutants are conducted in these grassed channel systems becomes critical. Urban pressure is a primary source of increased nutrient pollution to surface water with activities such as commercial lawn applications of fertilizer, installation of new fertilized sod, pet waste, increased automotive activity and construction practices. The nutrient residue from each of these activities is carried to neighboring surface water from various impervious surfaces such as roadways, parking lots and roof tops.



(*Figure* 2: Cumulative potential nitrogen loading in lb/yr along the lower Catawba river in the Southern Piedmont of NC, The outlined area shows the location within Gaston County where the vegetated ditch study took place; Data Source NCDWQ Catawba River Basin Plan; 2010)

Within the last ten years, enhancement of stormwater regulations to include the presence of EPA Phase II stormwater rules has mandated communities to consider and engage greater improvement in their designs for managing post construction stormwater. Because land development continues in urban areas, and government regulations are navigating changes in stormwater pollution control, innovative and conservation land planning is gradually becoming a logical trend in some urban areas within the Piedmont of North Carolina. Here, the appropriate use of land and pollution control of water resources are integrated to satisfy multiple government mandated facets of modern development. (Deitz and Clausen; 2007)

In addition to conservation considerations, reduced development costs associated with natural stormwater treatment systems has become a selling point for alternative land development such as Low Impact Development (LID). LID satisfies the goal of integrating stormwater best management practices within the development process to create an ascetically pleasing community, and one that follows post construction stormwater pollutant control regulations in a cost-effective manner. The pollution management goals of LID are accomplished by using biological methods of BMP designs.



(*Figure* 3: Depicted nutrient export from both traditional and LID subdivisions; Source – Dietz; Clausen 2007)

Low Impact Development, however, has yet to be embraced universally by all communities. Developing areas that are hesitant to accept LID in community planning often times encourage or even require traditional curb and gutter development as part of the planning standard. With hesitancy toward LID, traditional development continues to be the most popular tactic in the realm of community design in much of Southern Piedmont of North Carolina. However, as they continue to be utilized as stormwater conveyance devices, vegetated swales persist in playing an important component of traditional designs. Stormwater drainage sites often occur between properties and near parking areas within a traditionally constructed subdivision. Because this type of system is where stormwater first interacts with any type of conveyance practice, any treatment that could occur within even a small system would benefit the overall pollutant removal process.

Large agricultural operations giving way to an increase in smaller agriculture with more diverse practices, an increase in urban development and federal mandates placed on construction and smaller municipalities are all excellent reasons to examine vegetated swales as a viable source of pollution control. Assessment of the swale design and particularly the soil media that they are composed of will be important for improving information regarding the swales implementation and treatment capabilities. Understanding how nutrients interact with established channels based on common soil media found in the Southern Piedmont of North Carolina can assist in proper planning of agricultural operations as well as future LID and traditional development design within this region and may serve as an example to other portions of the state and country of how soil media influences the treatment of non-point source stormwater.

Currently, the principle recognized treatment utilized in reducing nutrient pollution from NPS pollution include intensively managed and engineered Best Management Practices (BMPs), commonly found in urban settings, such as dry stormwater detention ponds, wet retention ponds, and bioswales. More passive management systems also are found in agricultural and rural environments. These BMPs can include land that is terraced to reduce erosion and nutrient runoff, and riparian buffers along laucistrine or riverine systems.

One passive BMP that has recently been studied for inclusion in nonpoint source pollution reduction is the vegetated swale. Vegetated swales are known by a number of different names, including grassed waterways, open conveyance channels, and stormwater diversion ditches. Whatever the name, however, the purpose of these open vegetated channels has historically remained the same. To channelize and remove stormwater in a manner that will allow the land in question to reach its maximum potential. That potential can be in the form of agriculture, rural open space, residential development or commercial and industrial real estate. With such an important role of moving stormwater from areas of high to areas of low concentration, it is not surprising that in recent years vegetated swales have been considered as a viable alternative for stormwater treatment in both urban and rural settings.

Nonpoint source pollution is notorious for being difficult to manage, due to the large and variable runoff area that pollutant laden stormwater flows over. In fact, often times the first structure that this type of pollution comes into contact with is the vegetated swale. In an effort to create an affordable, low maintenance, treatment process, while harnessing existing technology, vegetated swales have therefore been viewed as a tool to viably reduce some of the principle pollution from nonpoint source stormwater. A natural choice for initial potential pollution reduction, vegetated swales have been the subject of a number of stormwater pollution control studies. These studies have shown varying degrees of effectiveness in the treatment of diverse pollution in the stormwater, resulting in a debate over the use of vegetated swales as a proper stormwater management practice.

Those opposing the use of swales as a stormwater treatment BMP, cite research that suggests that vegetated swales conveying stormwater are not effective at properly reducing nonpoint source stormwater pollution to any substantial degree. With this in mind, alternative methods are recommended to diminish pollution in stormwater runoff (Novotny and Olem, 1994). One such treatment practice is the bioswale, a stormwater BMP that is similar in appearance to a vegetated ditch, but is specifically designed to treat non-point source polluted stormwater prior to its entry into surface water. Many of the existing vegetated swales and general principles behind the function of this practice have therefore warranted the conversion or creation of bioswales (Mazer et al; 2001). The term bioswale refers to a vegetated channel that has both homogeneous soil media and an area that slows water to a minimal velocity where infiltration through the soil is the primary treatment of the stormwater. Bioswales should therefore not be confused with the subject of vegetated swales (stormwater conveyance systems) that were installed and intended for stormwater transport that is currently under discussion.

Countering the argument against swales as a valid stormwater treatment BMP, are claims that traditional vegetated stormwater swales do aid significantly in controlling various forms of pollutant run off. Vegetated swales and filter strips have been noted to effectively remove sediment from urban stormwater runoff as well as total suspended solids, heavy metals. (Deletic and Fletcher 2005).

With the focus on controlling and studying the removal rates of such highly prioritized pollutants as sediment, total suspended solids, and metals, it comes as no surprise that nutrient pollution control using vegetated swales has also been studied. The effectiveness of the nonpoint source nutrient runoff treatment using vegetated swales was show to fluctuate based on the data collected from various field reports. One study of vegetated swales pointed to nutrient uptake in Florida ranging from 25%-30% nutrient removal of total Phosphorus (P) and lower level removal of total Nitrogen (TN) reduction ranging from -7% to 11% (Yousef et al. 1987) While in 2006, it was reported that nitrogen and phosphorous concentrations remained generally unchanged (Barrett et al, 2006). Finally reports of TN reduction of 45% were published by Roseen et al. 2009. Despite the conflicting reports and philosophies over the effectiveness of vegetated swales, their passive method of water conveyance continues to be of great interest when discussing dissolved nutrient pollution control methods of nonpoint source pollution.

The variability documented regarding nutrient removal from a vegetative swale illustrates the complexity of this passive best management practice. Factors that may contribute to the variable results previously recorded may be due to a number of reasons. One reason for this variability would be the channel's design. Because the initial purpose of a vegetative swale is to convey water in a manner that relocates concentrations in a non-erosive manner, the channel slopes and carrying capacity are large factors. A typical and ideal vegetative swale slope is between 1 and 2%, and should not exceed 5% with shallow slopes. The low flow velocities and increased retention of such a slope would help rates of infiltration (Collins et, al 2010). In addition, the establishment of vegetation from the time a swale is created not only plays a role in stabilizing the channel from concentrated water flow but also increases the ability of capturing any TSS matter. The suspended solids often are sources of non-dissolved nutrients. Even with the TSS removal, however, the vegetative capability of dissolved nutrient uptake through plant attenuation in a channel with steady storm flow conditions has not been shown to be very effective (G. Mazer et al; 2001).

A final aspect that can influence the movement of pollutants in a vegetated swale is the soil medium that composes the structure of the channel. While total suspended solids are typically inhibited by vegetation, as previously mentioned, it is the soil medium that is thought to responsible for metal and dissolved nutrient uptake. Some research has shown that nutrient loss in water (specifically N and P) can be mathematically estimated in soil profile water movement models in non-concentrated flow surfaces. These model principles parallel field assessments that showed elapsed travel time due to swale length increased infiltration and reduced nutrients due to settling (Yu et al, 2001). This infiltration rate is directly related to the physical, biological and chemical components within the soil media. Complexities such as vegetation type, soil saturation, soil composition, microbial activity, duration of water flow and temperature, however, all play a role in determining how the nutrients are up taken and their interaction within the media.(Jiao et al; 2004.) The complex relationship that soil has within the created swale produces a number of questions about not only how pollution is controlled in a vegetated channel, but also how the properties of the soil within the swale influence that control.

Regional differences in conditions in soil media can also create additional variability in how pollutants and the transporting stormwater interact within a swale. It is for this reason, that it is crucial to understand some of the localized factors when considering vegetated swales for pollution removal.

Because soil types can change within a channel, it is important to better understand how pollutant interaction occurs within the soils of a particular a region. In the southern Piedmont of North Carolina, soil diversity can be greater than in many other parts of the state. Positioned between the rocky clay rich soils of the southern Appalachian Mountains in the western part of the state, and the sandy soils of the coast in the eastern part of the state, the Piedmont has a blend of sandy and clay laden soils. Along with these soils, the Piedmont of NC is also host to the most common soil in the state of NC, Cecil Clay soil. Because of such diversity in soil media, understanding if there is a difference in infiltration rates, and general soil chemistry will help provide a better guide to where and how a vegetated channel can be effective for dissolved nutrient removal. With the shift from traditional agriculture and development practices to more innovative and productive techniques in land and stormwater management, this information can help aid in better passive technology for nutrient pollution control.

Therefore, field tests were conducted in Gaston County North Carolina to determine both the effectiveness of nutrient reduction from passive swales, as well as the role that soil media plays, if any, in this BMP. This information may help in gaining a more complete understanding of the complexities of nutrient management in a region with diverse soil media.

Methods

The following field tests were conducted in Gaston County NC on March 15 and March 16, 2012 at the Dallas Park and at the Dallas location of Gaston College.

Part 1: **Selecting the field sites:**

In order to determine accurate representation of how nutrient laden water responds to soils and vegetation in roadside ditches, two dissimilar soils had to be selected for comparison basis. The site selection also included ditches that were not newly established, but were representative of actual conditions of long term establishment and management. Management for vegetated swales includes practices of regular mowing and pesticide treatment. Although each swale in question is vegetated, management practices did not include intentional fertilization of any of the ditches as they are used as primary stormwater conveyances. Site selection with such long term establishment and management is important in that an established ditch represents actual in situ conditions of long term future planning for water treatment. Each open drainage ditch was specifically selected with an outlet into an open field or BMP detention area to prevent off site contamination of surface water.

To ensure that the soil media was the primary focus, certain criteria were established for ditch site selection. The criteria for selecting ditch locations were as follows:

1.) **Dissimilar soils** – Two ditch-line soil types, one predominately sandy and the other predominately clayey, were selected to perform field examinations. To ensure proper representation for each soil type, and to better understand how nutrients respond to the two soil types in an accurate manner, a total of four test sites were selected (two from each soil type). The primary area of study was in the center of Gaston County at the Dallas Park. The Dallas Park was a large enough area to select three of the four ditches for the study. Two of these ditches were a predominantly clayey soil (Cecil complex; very common in the Southern Piedmont of North Carolina). The third ditch location in the Dallas Park contained a common sandy soil in Gaston County (Appling Sandy Loam). Because the development of the Dallas Park was completed in the 1970's it served as an excellent example of well established and developed representative ditches. The final representative ditch was at the property neighboring the Dallas Park, Gaston College. Here the same sandy soil type (Appling Sandy Loam) was used to show representation of the sandy soils common in North Carolina's southern Piedmont. This ditch line was established in the 1980's, and although more recently developed than the Dallas Park, this vegetated swale had been adequately established to serve as a representative location.

2.) **Slope and distance of ditch-line** – in order to have consistency among swales, the slope and distance for each location was considered when each site was being selected for the study.

The distance for each test location was 200 linear feet. The slope for each ditch was 2%, not only a common representative slope gradient in the Piedmont for conveying water, but also recommended as a standard for vegetated swale designs.

3.) **Vegetation** – Each ditch was well vegetated (complete vegetative cover of fescue, clover, and other broadleaf plants)

4.) **Channel width** - The average width of the four ditches tested was 3 feet. (While it is impossible to hold a 3 foot uniform width throughout the entire 200 feet of each swale, the channel width for each location retained an average of 3 feet in width and did not appear to influence the travel time of the solution.)

Part 2: **Preparing the solution**

In order to determine the nutrient uptake of water in the ditches, a known quantity of solution had to be mixed and distributed in the ditches. The following description is the method and quantity of solution made and the method of distribution.

1.) **The solution** – A known quantity of nitrogen and phosphorous was used and dispensed from a 320 gallon holding tank. One hundred times the maximum amount of nitrogen and phosphorous permitted in surface waters by the USEPA (1000 mg/L and 10 mg/L respectively) was added to the tank full of water.

a. **The nutrients used** - soluble nitrogen (Urea Nitrate 46-0-0) and partially soluble phosphorous (Triple Superphosphate 0-45-0) fertilizers [the solubility of P in triple super phosphate is in excess of 90%. The quantity used for urea nitrate was 2630g and for Triple

Superphosphate was 30g. (that equates to 1,209,800 mg of N in 1211 L of water and 13,500 mg of P in 1211L of water [estimating 90% P availability] –This equaled 999 mg/L of **N** and 10 mg/L of **P**)

2.) **Solution holding tank and distribution:** The solution tank used for each of the test sites has a 320 gallon (1211 L) capacity, and was filled to the capacity mark at each fill up. The valve at the base of the tank was 1.5 inches and using gravity released the water at an average of 55 GPM.

The volume of water held and released in the tank was equivalent to a "first flush" condition, or one inch of water, from a 513 square foot area. The first inch of runoff is considered the amount that has the highest concentration of nutrients flushed from an impervious surface. This volume of water is much smaller than the area that the ditch was designed for; however because the quantity and slopes were consistent, the volume and traveled time remained relatively equal to ensuring that the solution was distributed over the same vegetated surface area with the only difference being the media.

Part 3: **Running Nutrient Rich Solution Tests**

1.) **Tank and slope set up** – Using the gravity head pressure from the 320 gallon tank located in the back of a pickup truck (where the valve location was 3 ½ feet from the ground) the nutrient water was released at a slight incline directing the hose down the 2% sloped ditch-line.

2.) **Water Travel**- each ditch was well vegetated, which contributed to a relatively high amount of friction in the channel. Therefore, the vegetation significantly retarded the flow of water, and the travel time. Despite the rapid release of 55 gallons per minute, the water traveled down the 2% slope at an average time for each collection site recorded.

3.) **Infiltration rates -** Infiltration rates are based on the following equation. {[Volume 1 (in^3) – Volume 2 (in^3)] / 2400 (inches)]} * 12 = in^3 solution loss per ft (Where Volume 1 is taken at the point of release and volume 2 is taken at the final sample location - The volume for each point was taken utilizing the formula for ½ of an elliptical cylinder volume with 1 inch of channel length.) The infiltration rate is critical to understanding the quantity of water that has been taken upwithin the channel. This measurement is used to show the influence of the soil media on nutrient uptake based solely on a quantity basis. The measurements for infiltration rate are based on the assumption that the channel is uniform. While perfect uniformity in any channel is not likely in any situation, the development of these vegetated swales were preformed in such a similar manner that the slopes, channel structure, and vegetation are all quite similar. The primary difference between these channels is the soil media, such that the change in volume represents actual field conditions.

4.) **Porosity and Bulk Density of the soils** – Samples of the soil were extracted from each of the ditches, weighed and oven dried in a 105 C oven for 24 hours and weighed again to determine the bulk density of the soil. [That is the mass of a unit volume of bulk soil determined using the following formula: (**Mass of oven dried soils / bulk volume of the soil**).]

The porosity was determined by first crushing the soil peds into a fine dust using a hammer and refilling the solution containers. Each sample was weighed to make sure that only the structure changed and nothing was lost in the process of pulverizing the soil. Water was then administered to each soil sample to the upper lip of the container to ensure all of the space in the container was occupied. The volume of water for each sample was recorded. The soils porosity was figured using the following equation: (**Total Volume of water / Total Volume**). The bulk density of the soil is important as it shows the volume of the soil and as well as the shrink-swell potential. Porosity, or the volume of bulk soils not occupied by solids, also plays an important role in showing the infiltration capability of each of the soils being examined.

Part 4: **Sampling Methods**

1.) **Depth to wetting/soil sample collection**. - When taking the soil samples, each was taken at the depth to wetting. By the time the water receded, the average depth to wetting on both soil types was 6 inches. Therefore, each soil plug taken was 6 inches in depth. Locations of soil sampling was just downflow of each of the solution collection devices (every 50 feet), the only exception to this was the initial soil sample taken 25 feet from the point of release.

2.) **Water collection/solution collection** – Solution samples were taken every 50' from the point of solution release. Plastic solution collection bottles were inserted in to the soil at just below the soil depth, collecting the solution at various stages of the channel. In addition, a control sample was taken at the time of release from the end of the flex tank orifice to ensure that the solution quantities were correct.

3.) **Sample Packaging and Lab Testing** - Collected samples were packaged and sent to Waters Ag Laboratories in Owensboro, KY on Saturday March 17, 2012. Soil samples from each site were packed into the Waters Ag soil collection bags, and the solution was sealed in a 16 ml solution container. Waters Ag Laboratories determined the nutrient content (for both Nitrate Nitrogen, and Phosphorus) in 23 solution samples and the Phosphorous content in soil for the first 6 inches of 25 samples of swales soil media.

Results and Discussion

Treatment Solution: According to Waters Ag Lab results the treatment solution for each of these locations was significantly less than was predicted in the mixture. Upon contacting the lab, the staff concurred that the change in solution from Urea was due in part to the fact that, highly soluble in water, Urea Nitrate can convert to NH_4 through hydrolysis thus reducing the quantity of expected nitrate. This assessment was confirmed, although to a much lesser degree, by research preformed in a joint effort between Montana State University and Washington State University (Jones; Koenig; et al.; 2007). As a consequence of a lower concentration starting solution than was initially anticipated, the final readings are also at lower concnetrations. The variation in anticipated and actual control amounts, however, does not have a significant impact on the final results of the field tests, as the solution amount taken at the last collection station is important relative to the original solution.

Field Test Results

The information shown below reflects the soil media characteristics and response to the nutrient solution for each vegetated swale as recorded in the field. While the media is dynamic and subject to change within the 200 linear foot area, the components listed for each sample represents a snapshot of the soil media at each location. These components are recorded to provide a visualization of actual field conditions between soil types of the Southern Piedmont.

Soil and Water Content and Infiltration Quantity by Volume Volume

Swale	1	2	3	4
Dry Bulk Density	1.15 g/cm^3	1.08 g/cm^3	1.00 g/cm^3	1.26 g/cm^3
Particle Density	1.37 g/cm^3	1.22 g/cm^3	1.35 g/cm^3	1.43 g/cm^3
Water Content (Field)	183 ml	85 ml	109 ml	110 ml
Water Content (Saturation)	187 ml	217 ml	172 ml	189 ml
Volume of Water Infiltrated	897.04 L	957.61 L	1211 L	1040.87 L

(Table 2: Swales 1 and 2 contain soils with Cecil Urban Clay media; Swales 3 and 4 contain Appling Sandy Clay media)

In addition to these in situ soil properties, the soil media results based on porosity, percent soil saturation at field condition, percent total volume of the solution infiltrated and the nutrient loss lab results from Waters Lab in Owensboro KY, have been incorporated in the following table:

Soil Media Characteristics and Treatment Effectiveness

Swale	Porosity	% Saturated (at time tested)	% of Total Vol Infiltrated	% **Nitrate** Removed	% **P** Removed
1	12%	98%	74%	37%	29%
2	11%	39%	79%	82%	50%
3	26%	63%	100%	100%	100%
4	16%	60%	86%	42%	24%

(Table 3: Swales 1 and 2 contain soils with Cecil Urban Clay media; Swales 3 and 4 contain Appling Sandy Clay media)

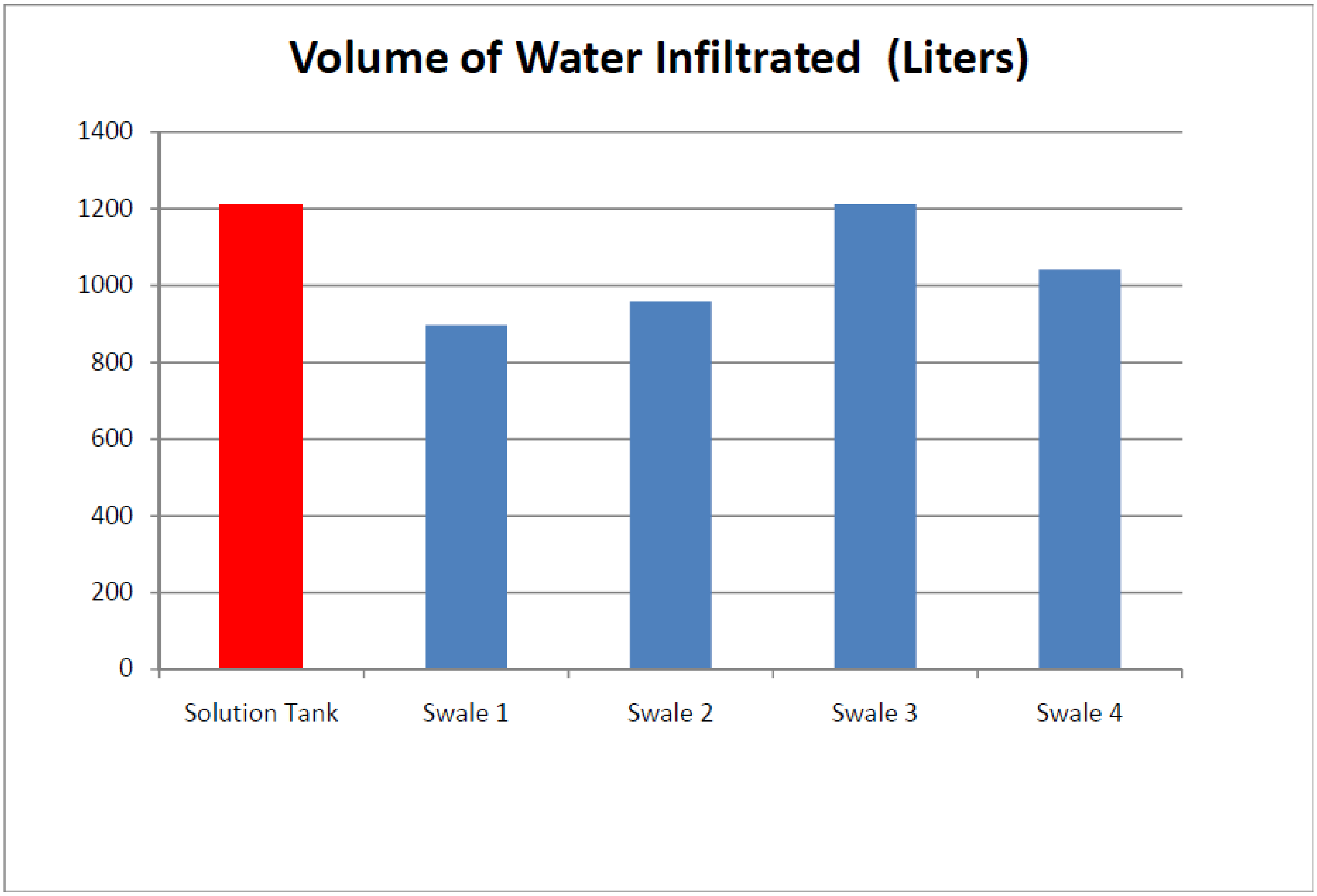
Table 3 provides an illustration of what the in situ porosity, water content and nutrient removal was during this field study. Furthermore, the percentage of nutrient removal and infiltration, depicted in the table, may provide a basis for future studies of similar soil conditions.

Analysis of the results:

I. Physical components of the soil in each channel (Bulk density, porosity and infiltration)

Each channel had specific physical components, examined in the field study, which had some bearing on the final quantities of nutrients in the solution. The soils' bulk density, porosity and infiltration were the primary physical components in the soil media that were examined to determine the impact the interaction nutrients and stormwater have with the soil's media. Because of the variability of these physical components they represent the fundamental difference between traditionally established vegetated stormwater swales and stormwater Bioswales that are specifically designed with stormwater management in mind. In Bioswales media, a uniformed homogeneous soil of higher infiltration rates is intentionally incorporated in the channel design. The water enters the swale and is detained to increase stormwater settling, while infiltration occurs. The traditional swales, however, do not add any additional media and utilize only the soil that is on site. Herein lies the primary reason that traditional channels are not recognized for management of nutrients.

In the field tests performed in Gaston County, the traits of bulk density and porosity were both examined. The infiltration of water is the byproduct of these two soil characteristics, as well as the channel design. A graphical illustration of the infiltration results is depicted below, showing the infiltration of field measured volumes within the first 200 ft. While the channel is influenced by many factors, including vegetation and any irregularity in the constant structure, the primary difference between each vegetated swale was the soil media.



(*Figure* 4: Infiltration rates of each swale as calculated in the field.)

This figure shows the starting solution tank in red and represents the 320 gal (1211 L) administered to each channel. Aside from the previously noted vegetation and channel irregularity, some influencing factors should also be noted on this chart. 1.) The primary difference between swale one and swale two (the two Cecil clay swales) may have to do with the time of day. In swale one, the administration of the solution was performed in the morning, when the water content in the soil was higher. The data in Table 2 shows that the moisture content in the soil is almost twice that of the same soil type in the afternoon. Likewise the difference between swale 3 and swale 4 was due to an irregularity in the third swale channel that was not noted until the water was released. Consequently, the entire volume of water was infiltrated in the 3rd swale before it reached the 4th sampler. Such anomalies in the field work have been noted here to better illustrate the tremendous variability within an established channel, and possibly why there is such variability in previous field studies.

The purpose of identifying infiltration rates is important, as it shows the volume of water lost over time. Between the clay soils of swale 1 and 2, and the sandy soils of swales 3 and 4 there is only a moderate difference. The time of travel for the solution was equal regardless of the media and was recorded as follows:

From 0' to 50' – Travel time 5 minutes
From 50'-100' - Travel time 9 minutes
From 100' – 150' Travel time 9 minutes
From 150' – 200' Travel time 11 minutes for sites 1, 2, and 4 (site 3 never had water reach the collection device, due to back ponding from heavy vegetation at the last station resulting in greater infiltration.)

The infiltration rates, however, deviated by about 10%. The sandy soils infiltrated only marginally more water at an equal rate of flow. Although the 3rd channel infiltrated 100% before it reached the 4th collection point, this increased infiltration rate was confirmed by taking measurements at the 3rd collection point.

This marginal difference may be explained by field conditions and times of day as well as the porosity of the soil media, as the bulk densities are very similar. Regardless, the volume lost to infiltration plays a role in better understanding how swales can manage pollutant rich stormwater.

II. Chemical Components of the soil in each channel (pH)

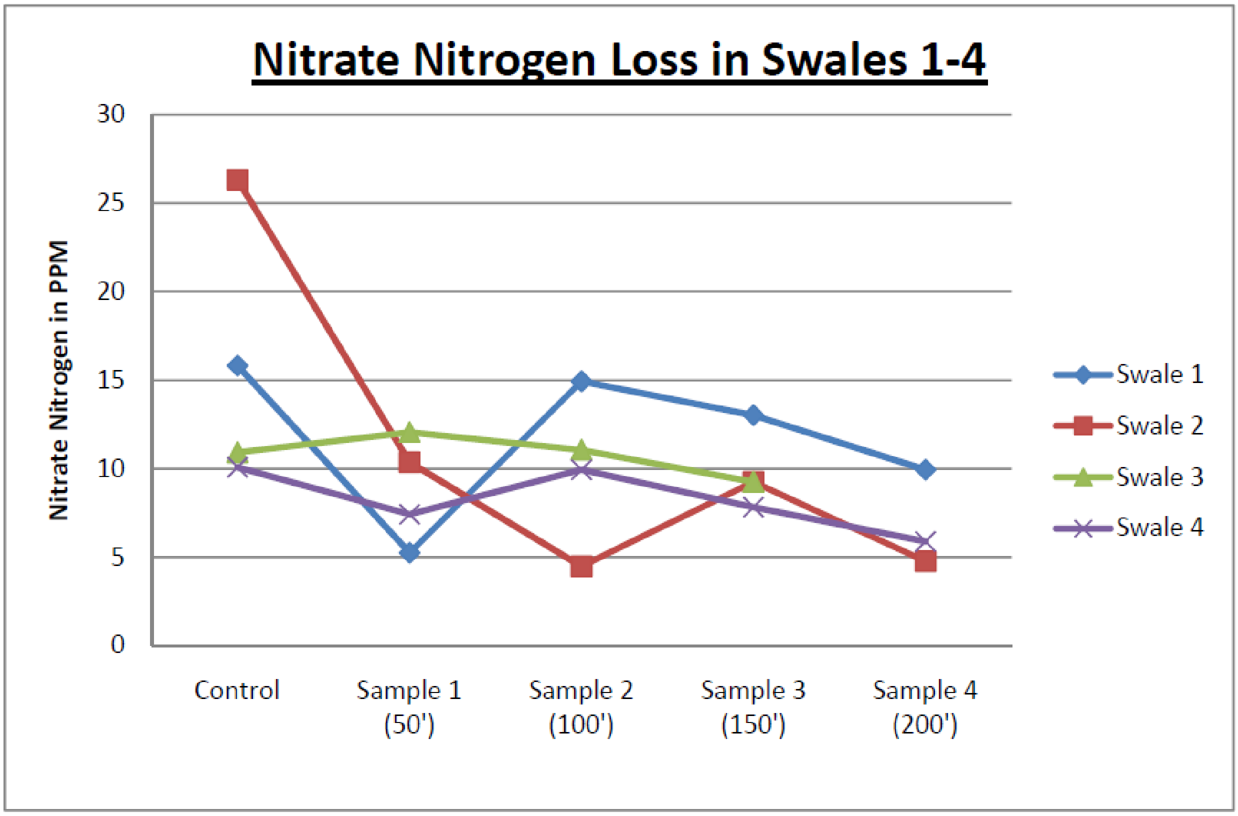
Each channel also has specific chemistry which can influence the ability to absorb dissolved nutrients. The pH of the soil impacts the ability of the soil to absorb Phosphorus. If the soil is too basic (greater than pH of 7) the Phosphorus will fix to Ca and become unavailable for plant uptake, thereby increasing the likelihood of nutrient runoff. In soils that are acidic (pH of 5.5 or less) the Phosphorus will fix to Al and again become amorphous Al or Fe phosphates that will typically become unavailable for plant uptake. (Busman; Lamb; et al. 2009)

Of the 20 soil samples collected, the average pH of the soil samples remained between 5.5 and 6.6. Thus, each channel was chemically able to retain the Phosphorus through vegetation. The influence of the pH chemistry can be clearly seen in the ratings of phosphorus in the soil samples collected on site. Out of the 20 samples, only one soil sample showed a high phosphorous content. The other 19 were ranked as either low or medium content.

The pH of the soil in channels plays a significant role as phosphorus pollution is closely associated with the phosphorus content in suspended solids and soil solution. Both contributing factors are directly impacted by the overall pH. Therefore, as phosphorous is added to the soil, the chemistry is adequate to allow any additional phosphorus to be attenuated in the vegetated swale, and eventually up taken by the vegetation.

III. Nutrient Loss Based on soil media

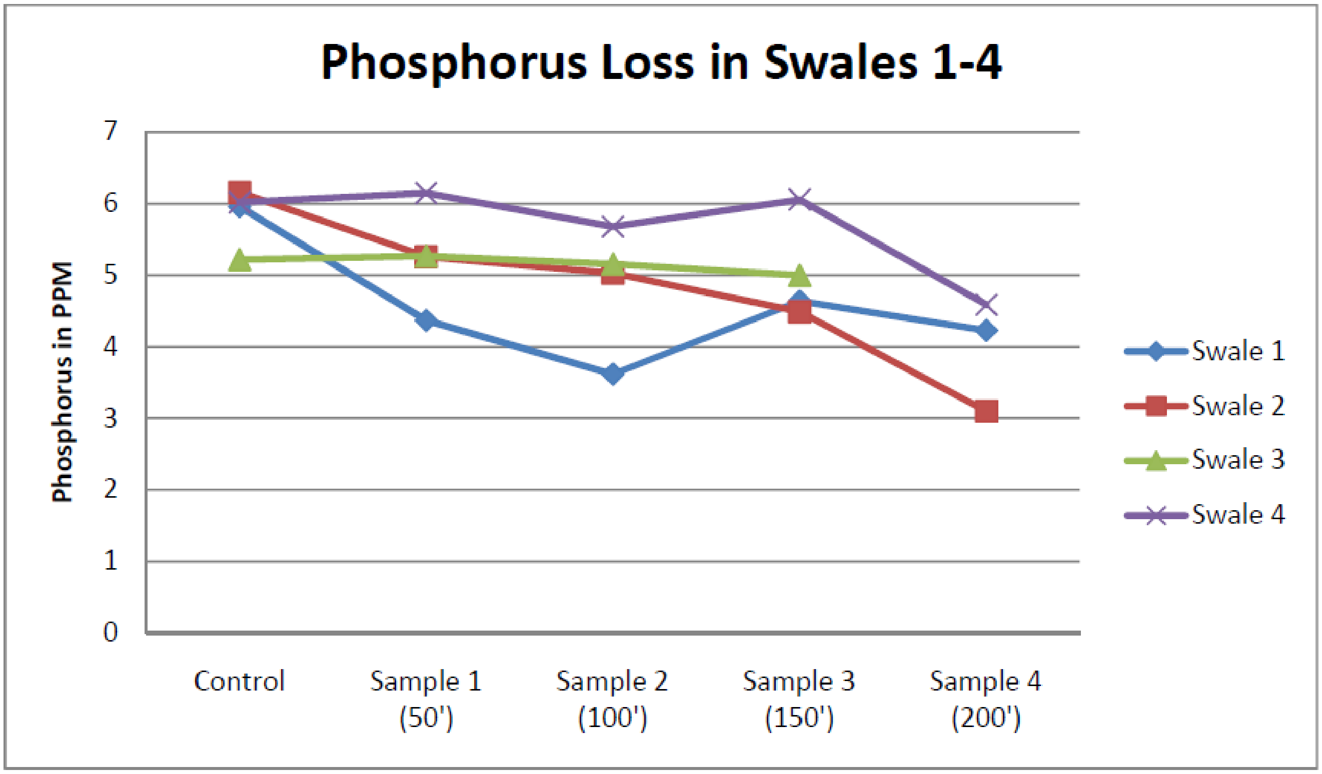
The following graph shows the nitrogen loss from point 0 (release) to point 4 (200’) illustrating the lab results for each of the channels.



(*Figure* 5: Field tests of samples at fifty foot intervals from the starting solution, and the nitrogen content tested at each location.)

As illustrated in the chart, a noticeable reduction took place in each of the samples. Swales 1 and 2 are the clay swales and show more efficient nitrogen reduction than swales 3 and 4. The graph also helps to depict the volatility of nitrogen, as the nitrogen cycle is complex and can exhibit variability in field conditions. Overall, however, each swale shows a certain level of nitrogen removal regardless of soil type. As representative soil types of the Southern Piedmont of North Carolina, a combined average of about 44% reduction of nitrogen was assessed, regardless of media.

The lab results for phosphorus loss in swales are depicted in the next graph. Here the variability in sample readings is not as great as with nitrogen due to the fact that phosphorous in general is a much more stable component within the soil.



(*Figure* 6: Field tests of samples at fifty foot intervals from the starting solution, and the Phosphorus content tested at each location

Again, the loss of phosphorous nutrients is evident in each channel; however the swales representing variable soil media show no significant difference in how the phosphorous is lost. As an example, the loss of phosphorus in Swale 1, a Cecil clay soil media type, actually is very similar to the loss of phosphorus in swale 4, a sandy media channel. An average phosphorous loss of 27% was found for the four soil types regardless of the media.

Conclusion

An established vegetated swale can be classified as a stormwater conveyance ditch that has both a stable channel design and vegetation with a healthy root system. Swales that are established have long been used primarily as stormwater transportation systems with little or no understanding of the treatment potential outside of sediment and erosion control. Because swales are both economically installed and maintained for stormwater management, they are a natural point of interest when considering the treatment of stormwater.

The testing that was conducted for this review was performed specifically in established stormwater ditches, in order to provide a clear illustration of what to expect when considering the treatment of dissolved nutrients in stormwater and how continued treatment may occur for ditches that are newly created. Due to the chemical dynamics involved, dissolved nutrients in stormwater respond differently when interacting with the various components of an established vegetated swale versus one that is newly formed.

One component within a swale that plays a critical role in treatment of stormwater is the soil media. The physical, chemical and biological aspects of soil media can influence the removal rate and capability of the dissolved nutrients. Of particular interest in this area is the treatment of both phosphorous and nitrogen in established vegetated swales. Because phosphorous can attenuate in the soil, the effectiveness of swales in the treatment of this nutrient over long periods of time becomes an important factor when considering established vegetated swales as a passive BMP. The results of the field study shows that established ditches that are exposed to a presence of phosphorus rich runoff, will continue to show removal even after years of use as a conveyance system. In conjunction with this phosphorous treatment, the established vegetated channels found in the Southern Piedmont of North Carolina appear to also provide a measure of treatment for nitrogen as well. Overall, the value that an established vegetated swale can provide stormwater treatment should not be overlooked.

In summary, the role of the media appears to play a small role in the nutrient uptake and removal based on the field test data. While the infiltration rates of the stormwater in each soil did account for a marginal difference due to a steady movement of solution down slope, where sandy soil media had a slightly higher rate of infiltration, differences occurring from soil media types seem to end there. Based on the field tests, the type of soil media did not provide substantive difference when considering the percentage of nutrient removal rate for either Nitrogen or Phosphorus. Based on these data, it is likely that the treatment variability that occurs among the established vegetated swales is due to other factors.

While the principle focus of this study was the influence of the soil media on dissolved nutrients, the results recorded from these field tests represent a certain snapshot of treatment based on time and location. There are a number of variables that can influence the outcome of treatment which require further study of vegetated swales under a variety of conditions. Ultimately, further studies in established swales examining vegetation and uneven channel surfaces would be a prudent next step in evaluating what components are influential in established swale nutrient reduction. Overall, the potential that vegetated drainage swales offer for stormwater pollutant reduction is significant. While established vegetated drainage swales are not likely to reduce dissolved nutrients by 100%, regardless of the conditions, their treatment as part of a larger stormwater system should not be overlooked. The benefits of these systems should continue to be examined and incorporated as Low Impact Development and non-traditional agriculture increase throughout the Southern Piedmont. Additional research of this passive Best Management Practice may serve as an example for other areas of the state or nation facing similar nutrient pollution challenges.

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