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Evaluation and Implementation of BMPs for NCDOT's Highway and Industrial Facilities

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16. Abstract

This research has provided NCDOT with (1) scientific observations to validate the pollutant removal performance of selected structural BMPs, (2) a database management option for BMP monitoring and non-monitoring sites, (3) pollution prevention plans for vehicular maintenance facilities, and (4) treatment options for borrow pit wastewaters. An intensive monitoring program was conducted to characterize and examine the pollutant removal performance of three highway BMP types (grass filter strip, filtration swale, and grassed shoulder). A Stormwater Data Management System was developed for storage and retrieval of BMP site characterization data that are obtained during BMP site inspection. Suggestions were provided to the development of pollution prevention plans for vehicular maintenance facilities. Treatment technologies for borrow pit wastewater have been presented including the development of pump capacity curves for proper sizing and operation of stilling basins, a spreadsheet calculator for performing cost analysis for the polymer injection treatment system, and chemical/physical treatment alternatives.

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Executive Summary

Under the mandate of NPDES stormwater permit, NCDOT has launched a series of research programs to examine the most effective ways to reduce the impacts of highway runoff on surface water quality. Currently, the permit has included nine main components to address illicit discharge detection and elimination, post construction controls, encroachment, construction controls, industrial facilities, education and involvement, research, and total maximum daily loads.

This research attempts to provide NCDOT with (1) scientific observations to validate the pollutant removal performance of selected structural BMPs, (2) a database management option for BMP monitoring and non-monitoring sites, (3) pollution prevention plans for vehicular maintenance facilities, and (4) treatment options for borrow pit wastewaters.

Three structural BMPs were monitored over a period of three to six months. The grass filter strip that was installed in Clayton, North Carolina, was able to achieve TSS removals of 56-94% based on concentration reduction and 68-97% removal based on mass load reduction. The regulatory requirement of 85% TSS removal is within the range of the estimated long-term TSS removal of 78%-88% achievable by this filter strip. It is conceivable that TSS removal performance may be affected by the prevailing rainfall distribution in a particular year. Consequently, state agencies need to consider the range of performance variance as justifications to the fluctuation of treatment performance that could have been influenced by annual rainfall patterns. Computer simulation using the VFSMOD computer model has revealed that maintaining grass growth in good conditions with regard to density and grass spacing is critical for achieving high sediment removal. Depending on the particle size distribution of influent sediment, a majority of sediment removal can be typically achieved within the first thirty-three feet (ten meters) of a filter strip.

The second monitored BMP was a filtration swale installed in Troy, North Carolina. This swale has achieved TSS reductions between 56% and 100% based on a mass load reduction. Turbidity levels were approximately 50% below inflow levels. The filtration swale appeared to attenuate runoff peak flows rather successfully with peak outflows lagging inflow discharges by one to five hours. The performance of the filtration swale as a nutrient trap was variable. The BMP treatment train (filtration swale + grassed swale) appeared to retain the dominant form of nitrogen in precipitation (NH_4-N) relatively effectively. However, the retention of NO_3-N appeared to be almost entirely attributable to hydrologic retention and therefore was variable.

The third BMP site was the W.T. Harris Blvd. grassed shoulder in Charlotte, North Carolina. This grassed shoulder could achieve TSS reductions averaging 40% based on concentration differences between overland runoff at the road edge and samples obtained at the end of the shoulder slope. It is recommended that active turf management be employed on pre-existing grassed shoulders and swales and efforts be made on newly

constructed roadways to increase the infiltration capacities of these surfaces at least in the Piedmont and Blue Ridge regions of the state.

Recommendations were made for disposal, recycling, reuse, and/or on-site collection and treatment of wash water from vehicular and equipment maintenance facilities within MS4 and at remote sites. Environmental power washing could be a feasible option to reduce the amount of wash water generation. A combined use of catch basin insert with specialized pollutant removal media and bioretention treatment or other manufactured BMPs could accomplish the treatment goals but further research and field demonstration will be needed.

In an effort to improve the operation of stilling basins treating borrow pit wastewater, a set of pump capacity curves have been developed to provide design alternatives for determining stilling basin capacity, based on the anticipating pumping rates and turbidity reduction goal rather than following the general rule of 1,800 ft^3/ac. These curves can also serve as a guide for operators to adjust the pumping rates for an existing basin when a surge of high turbidity is forthcoming. Further research is needed to validate the reliability of these pump capacity curves. Additional research has revealed the potential use of ferric chloride and Alchlor®-AC coagulants, roughing filters, and low cost filtration materials for turbidity reduction. The turbidity reduction matrix developed by NCDOT has included a variety of treatment options; however, continued updates of this matrix will help incorporate emerging innovative and low-cost treatment alternatives. Finally, a polymer-injection-system calculator was developed to assist cost analysis for different treatment schemes including treating 100% of the borrow pit wastewater by polymers without the use of stilling basins, or partially treating the waste stream with conjunctive use of stilling basins.

The research has also resulted in the development of a database for managing stormwater BMP characterization data in the form of Microsoft Access. This database was developed to facilitate the storage of inspection data at monitored or non-monitored BMP sites and the retrieval of data files with the use of a numerical index corresponding to NCDOT's fourteen divisions across the state.

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1. Introduction

It has been reported that the 99,600 miles of North Carolina's federal, state and local government maintained roads, streets and highways are approximately equivalent to 320,000 acres of paved area (http://h2o.enr.state.nc.us/nps/What_is_NPS/roads.htm). This acreage of paved area is about one percent of the state's land or roughly the size of an average county in North Carolina. Increased storm water runoff from paved road surfaces can lead to erosion in receiving streams and discharge of various pollutants to nearby surface waters.

In 1998, North Carolina Department of Transportation (NCDOT) became the first state agency to receive a state-issued statewide National Pollutant Discharge Elimination System (NPDES) stormwater permit. Under the mandate of this permit, NCDOT has launched a series of research programs to acquire information about the most effective ways to reduce the impacts of highway runoff on surface water quality. Currently, the permit has included nine main components to address illicit discharge detection and elimination, post construction controls, encroachment, construction controls, industrial facilities, education and involvement, research, and total maximum daily loads (TMDL).

In 2001, NCDOT initiated a series of pilot studies to test the pollutant removal performance of a variety of structural best management practices (BMPs). Structural BMPs that have been installed to control highway runoff at each of the agency's fourteen divisions include bioretention basin, filtration swale, stormwater wetland, dry detention basin, water quality hazardous spill basin, level spreader, and grass filter strip (see Chapter 3 for additional BMP types). BMP options implemented at industrial facilities include stormwater wetland in Wilson County; dry detention basin in Alexander County; and inlet control, erosion control, housekeeping, and gravel versus asphalt pad in Orange County. The use of stilling basins and other treatment technologies is being assessed for turbidity reduction related to borrow pit operations. Without a doubt, the implementation of these BMP retrofit programs requires an enormous effort of engineering design, installation, field monitoring, synthesis of literature information, analysis of monitoring data, and final assessment of BMP performance and effectiveness.

A research team from the University of North Carolina at Charlotte (UNC Charlotte) has engaged in a number of projects to assist NCDOT in partial compliance of the NPDES permit requirements. Major projects completed by UNC Charlotte researchers include:

- Characterization and Pollutant Loading Estimation for Highway Runoff (Wu et al. 1997)
- Sampling and Testing of Stormwater Runoff from North Carolina Highways-HWY 99-6 (Wu and Allan 2001)
- GIS Coverages for North Carolina Highways and Sensitive Waters-HWY 0712 (Wu, 2000)

- A GIS-methodology for Predicting North Carolina Highway Runoff Pollutant Loadings-HWY 2003-17 (Allan and Wu, 2005).

In 2002, NCDOT awarded another research contract to UNC Charlotte researchers (HWY 2003-19). The primary goals of this project, as documented in this report, are to provide NCDOT with (1) scientific observations to validate the pollutant removal performance of selected structural BMPs, (2) a database management option for BMP monitoring and non-monitoring sites, (3) pollution prevention plans for vehicular maintenance facilities, and (4) treatment options for borrow pit wastewaters. The scope of work was divided into five project tasks as given below. Technical memorandums for each project task or subtask had been regularly submitted throughout the course of research.

Task A: Highway structural BMP Review and Assessment

A.1 Visit selected BMP sites to collect site characterization data

A.2 Assemble site characterization data for subsequent data storage and retrieval

A.3 Assess BMP selection methodology

A.4 Review BMP performance including proprietary or manufactured BMPs

Task B: Highway BMP Site Characterization

B.1 Establish a BMP database using Microsoft Access for non-monitoring sites

B.2 Assemble pertinent site characterization data and monitoring results for inclusion in the National Stormwater BMP Database

Task C: BMP site monitoring

C.1 Implement synoptic sampling along major flow paths of a grass filter strip (GFS)

C.2 Implement synoptic sampling along major flow paths of a filtration swale (FS)

C.3 Implement synoptic sampling along major flow paths of roadside grassed shoulder

Task D: Pollution prevention plans for vehicular maintenance facilities

D.1 Perform literature review to summarize treatment processes

D.2 Report on pollution prevention plans from selected states

Task E: Treatment processes for borrow pit wastewaters

E.1 Establish treatment matrix considering effectiveness, cost and limitations

E.2 Develop a spreadsheet calculator for the polymer injection treatment option

E.3 Develop "pump capacity curves" for sizing stilling basins

This report presents research findings for each project task. It is divided into ten chapters and includes four appendixes. Review and synthesis of literature information pertaining to BMP selection methodology (A.3) are described in Chapter 2. BMP characterization and performance assessment (A.2, A.4) are included in Chapter 3. Field monitoring results of three different BMP types (C.1, C.2, C.3) are provided in Chapters 4, 5, and 6, respectively. Data management options and submission to the National Stormwater BMP Database (A.1, A.2, B.1, B.2) are described in Chapter 7. Chapters 8 and 9 detail the pollutant prevention plans for vehicular maintenance facilities and treatment options for borrow pit wastewaters (D, E), respectively. Concluding remarks and recommendations are given in Chapter 10.

2. BMP Selection Methodology

Best management practices are methods, measures, or practices employed to provide structural controls or non-structural approaches for managing water quality problems resulting from nonpoint sources pollution (NPS). Structural BMPs are typically constructed facilities designed to function unattended during a storm and to provide passive treatment at the occurrence of wet-weather flows (Urbonas, 2000). The Associated General Contractors of America provides a list of Internet addresses for access to state BMP manuals (Appendix 1). The U.S. Environmental Protection Agency (USEPA) has released a report titled "National Menu of Best Management Practices for Storm Water Phase II" with links to various sources of generic and proprietary BMPs (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cfm).

In light of the enormous information available in the literature, this chapter attempts to synthesize the published literature and to develop a BMP selection methodology that is relevant to North Carolina applications.

2.1 Review of Federal and State Methodologies

2.1.1 USEPA

BMP selection is a complex process due to the existence of a number of competing factors that must be addressed when selecting an individual BMP or a combination of BMPs comprising a treatment train (USEPA, 1999). In addition to site-specific application requirements, other factors to be considered may include cost, local regulations, aesthetics, design experience, and competing receiving water considerations such as temperature and nutrient levels. The list of competing factors include drainage area, land uses, average rainfall frequency, duration and intensity, runoff volume and flow rates, soil types, site slopes, availability of land, future development and land use in watershed, depth to groundwater table, availability of supplemental water to support vegetative BMPs, susceptibility of freezing, safety and community acceptance, maintenance accessibility, and periodic and long-term maintenance and/or rehabilitation needs. The USEPA report did not discuss the selection methodology in any greater detail but suggested several reference materials for readers to pursue additional reading of the subject matter.

2.1.2 NCHRP

The National Cooperative Highway Research Program (NCHRP) has compiled a list of conceptual BMP selection factors for the management of runoff from surface transportation facilities (TRB, 2001). Although each of these factors appears to be relevant, NCHRP has not elaborated a procedure to render technical guidance for process selection. These conceptual factors are aesthetics, costs, design criteria, erosion and sediment control, effectiveness, efficiency, innovation, level of service, nutrient management, pollutant removal, remediation, requirements, and site constraints. One of the conceptual factors, i.e. the nutrient management, is a very important factor when implementing BMPs for highways located within a nutrient sensitive watershed, such as the Neuse River watershed in North Carolina.

2.1.3 FHA

The Federal Highway Administration released a planning-level review of the applicability and use of new and more traditional BMPs in ultra-urban areas (USDOT, 2000). An ultra-urban setting may be defined as a drainage area of more than 50% imperviousness with less than one acre of land available for BMP implementation. In many cases, runoff from state highways is likely treated and controlled on lands that are adjacent to or within the right-of-way (ROW). One of the limiting factors affecting the construction of management facilities within or adjacent to ROW is lack of land availability. Therefore, BMP types applicable to ultra-urban environment could be potential BMP candidates for highway runoff management.

Once a state-DOT has established the respective responsibility of pollutant contribution to the total storm water system within the local jurisdiction, a state-DOT can then proceed with determining the runoff volume and constituents associated with highway runoff, assessing the potential impacts, and implementing a series of structural and nonstructural measures to minimize these impacts. A three-step decision-making process has been suggested to apply both quantitative and qualitative criteria for sequentially screening BMP alternatives. The selection methodology outlined by FHA is reproduced in Figure 2.1.

Step 1: A sequential elimination is initially initiated to eliminate non-applicable options based on a predefined set of criteria (Scoping).

Step 2: A comparative analysis is employed to derive feasible management alternatives based on site characteristics, BMP effectiveness, and compatibility and complementary performance (Evaluation).

Step3: Additional analysis is performed to finalize management alternatives to redefine the list of BMPs and/or BMP combinations (Final Selection).

2.1.4 State of Maryland

The Maryland Stormwater Design Manual outlines a process for selecting the best BMPs for a development site and provides guidance on factors to be considered for BMP placement (MDDOE, 2000). These selection factors are not specific for highway runoff but may serve as reference if they can be properly adopted to highway runoff management.

<u>Watershed factors</u>: critical area, cold water watershed, sensitive watershed, aquifer protection area, water supply reservoir, or shellfish and/or beach protection zone.

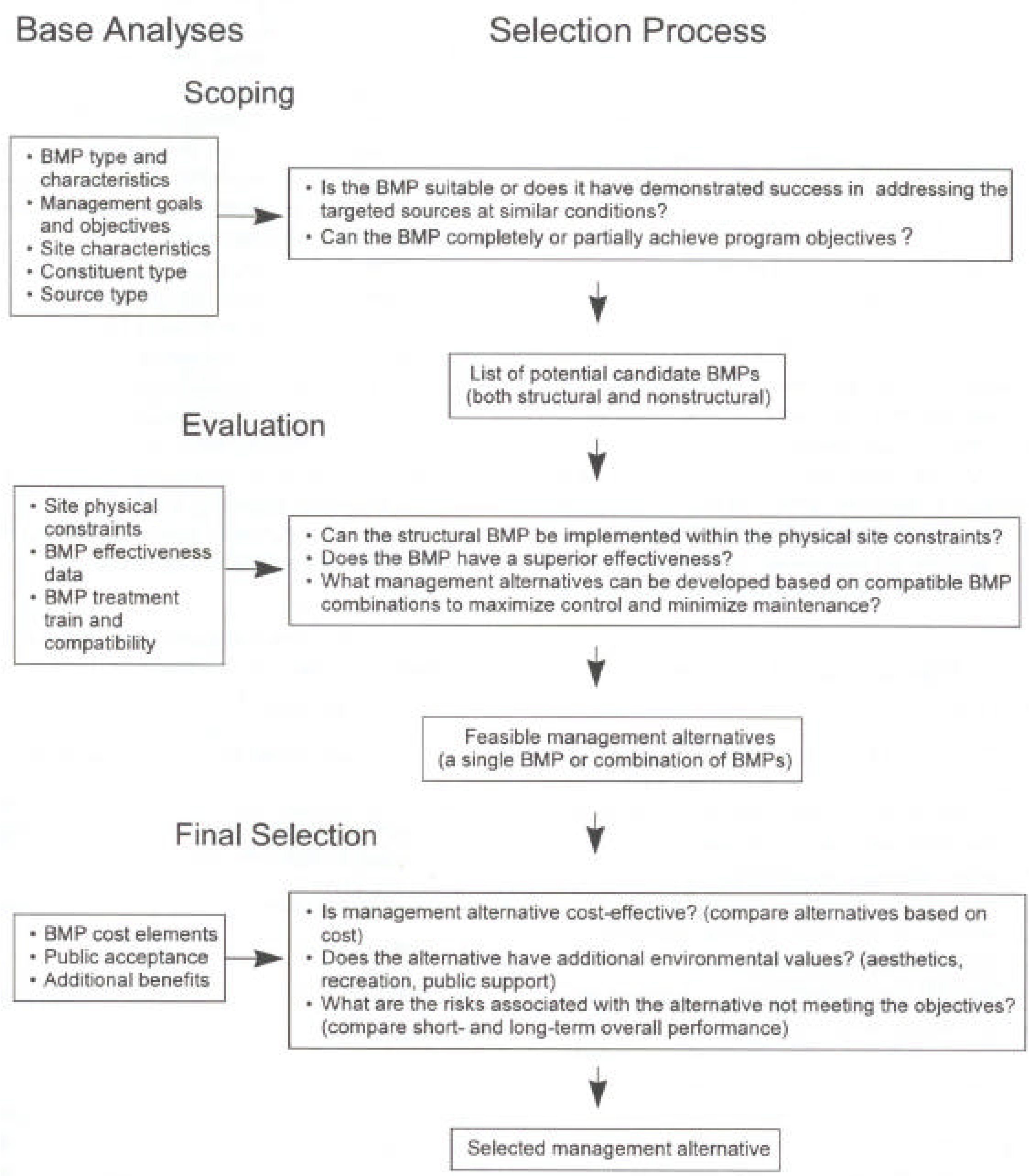


Figure 2.1 Key Steps of a BMP Selection Process (USDOT 2000)

Terrain factors: design constraint imposed by local terrain or underlying geology.

Stormwater treatment suitability: five sizing rules including water quality volume (WQ_v), recharge volume (Re_v), channel protection storage volume (CP_v), overbank flood protection volume (Q_p), and extreme flood volume (Q_f) requirements; safety concerns; adequate space; and ability to accept hotspot runoff.

Physical feasibility factors: soils, water table, drainage area, slope or head conditions.

Community and environmental factors: maintenance, habitat, community acceptance, cost and others.

Locational and permitting factors: locating the BMP system at a site to fully comply with local, state and federal regulations.

2.1.5 State of California

The Storm Water Quality Handbook released by the California Department of Transportation (Caltrans, 2003a) provides guidance for contractors and Caltrans staff through the process of preparing the Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Conrtol Program (WPCP). This document sets the essential elements and data reporting templates for the submision of SWPPPs and WPCPs.

In a second docment, Caltrans (2003b) describes three major components of a BMP selection process. The decision process for selecting treatment BMPs at specific sites is reproduced in Figure 2.2.

Identification of pollutants of concern

- Water quality standards
- TMDLs and 303(d) lists
- Basin Plans
- Standard Urban Storm Water Mitigation Plans
- Applicable Treatment BMPs

Determination of BMP placement and use considerations

- Site-specific conditions
- Availability of right-of-way
- Hydrology
- Water quality flow (WQF) versus water quality volume (WQV)

Application of approved BMPs including

- Pollution prevention BMPs (preservation of existing vegetation, concentrated flow conveyance, slope/surface portion etc.)

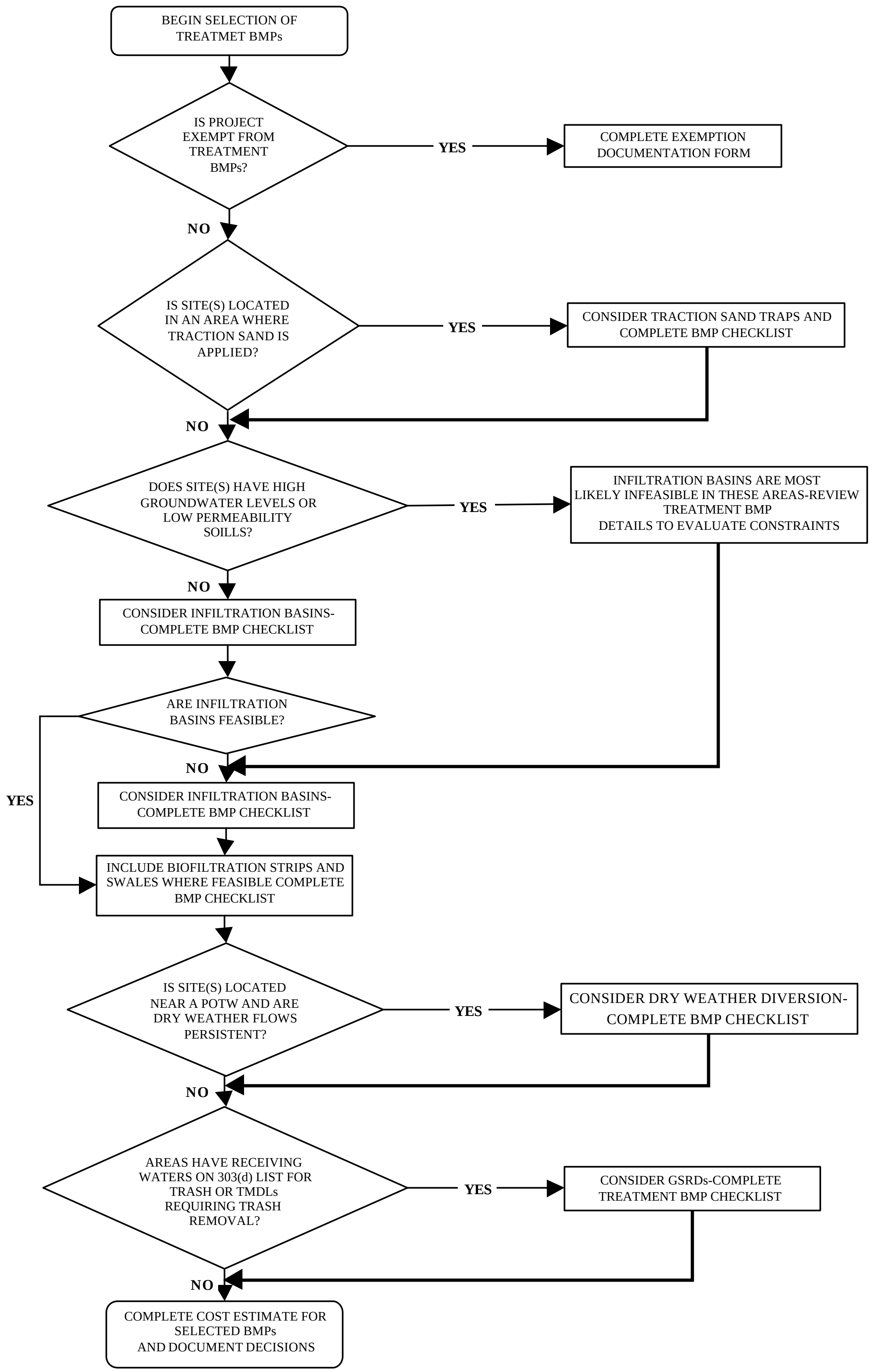


Figure 2.2 Selection Process for Treatment BMPs (Caltrans 2003b)

- Treatment BMPs (permanent treatment devices and facilities)
- Construction site BMPs (temporary soil stabilization and sediment control, non-storm water management, and waste management)
- Maintenance BMPs (litter pickup,waste management, street sweeping etc)

2.1.6 Washington State

The Washington State Department of Transportation (WADOT, 2004) has published a comprehensive "Highwy Runoff Manual" for both Western and Eastern Wasington. Five major aspects of BMP selection are included in this report:

Part I : Applicable minimum requirements and project specific considerations
Part II: Source Control BMPs
Part III: Runoff Treatment and Flow Control Requirements for Drainage Basins (miminimum requirements 5 and 6)
Part IV: Flow Control BMPs (Figure 5.3.1 or 5.3.4 in WADOT Manual)
Part V: Runoff Treatment BMPs (Figure 5.3.2 or 5.3.5 in WADOT Manual

The applicable minimum requirements included in Part I of the manual are summarized below:

Requirement 1 for Stormwater Planning: construction stormwater pollution planning and permanent stormwater control planning.

Requirement 2 for Construction Stormwater Pollution Prevention: TESC (Temporary Erosion and Sediment Control) Plans and SPCC (Spill Prevention, Control and Countermeaures) planning.

Requirement 3 for Source Control of Pollutants: operational BMPs (preventive maintenance procedures, spill prevention and cleanup, inspection of potential sources) and structural BMPs (vegetation for temporary and permanent erosion control, separation of contaminated runoff from clean runoff, street sweeping).

Requirement 4 for Maintaining the Natural Drainage System: preserving and utilizing the natural drainage systems to the fullest extent, and preventing erosion at and downstream of the discharge location.

Requirement 5 for Runoff Treatment: reducing pollutant loads and concentrations in stormwater runoff to maintain the beneficial use of receiving waters. When site conditions are appropriate, infiltration is considered the most effective BMP for runoff treatment. Treatment excemptions may be negated by requirement set forth in a TMDL or a water clean-up plan. Four treatment targets are set for basic treatment (80% TSS), enhanced treatment (greater removal of dissolved metals), oil control, and phosphorus control (50% TP).

Requirement 6 for Flow Control: applying to newly created impervious surface, converted pervious surfaces, and replaced impervious surface.

Requirement 7 for Wetlands Protection: maintaining the wetland's hydrologic conditions, hydrophytic vegetation, and subsurface characteristics.

Requirement 8 for Incorporating Watershed-Based/Basin Planning into Stormwater Management: promoting development of watershed-based resource plans for implementing comprehensive water resources protection measures.

Requirement 9 for Operation and Maintenance: achieving appropriate preventive maintenance and peformance checks, and assuring stormeater control facilities are adequately maintained and properly operated.

2.2 Proposed Methodology

Upon reviewing various selection methodologies presented in the literature, UNC Charlotte researchers thereby propose a "five-step" BMP selection methodology relevant to North Carolina conditions (Figure 2.3). This methodology has incorporated those important factors cited in the literature and, in addition, a number of unique features derived from North Carolina research experiences.

Step 1: Identify permit compliance and renewal requirements, and resources available for program implementation (e.g. TMDL and 303(d) list).

Step 2: Develop a BMP suitability matrix for the Mountain, Coastal and Piedmont regions (e.g. Table 2.1). This suitability matrix should include conventional, ultra-urban and proprietary BMPs.

Step 3: Establish a performance database in electronic format (Chapter 7), and assessment guidelines such as the ultra-urban BMP methodology or other appropriate approaches (e.g. www.bmpdatabase.org).

Step 4: Use GIS-methodologies for outfall prioritization, site characterization and cumulative frequency analysis for roadway conditions, and statistical pollutant loading estimation in order to rank sites for BMP needs (see Allan and Wu 2005).

Step 5: Perform comparative analysis of cost effectiveness and compatibility assessment to meet permit requirements for each BMP treatment unit/train, and to develop placement strategy for overall watershed protection objectives (e.g. USDOT 2000; Caltrans 2003b).

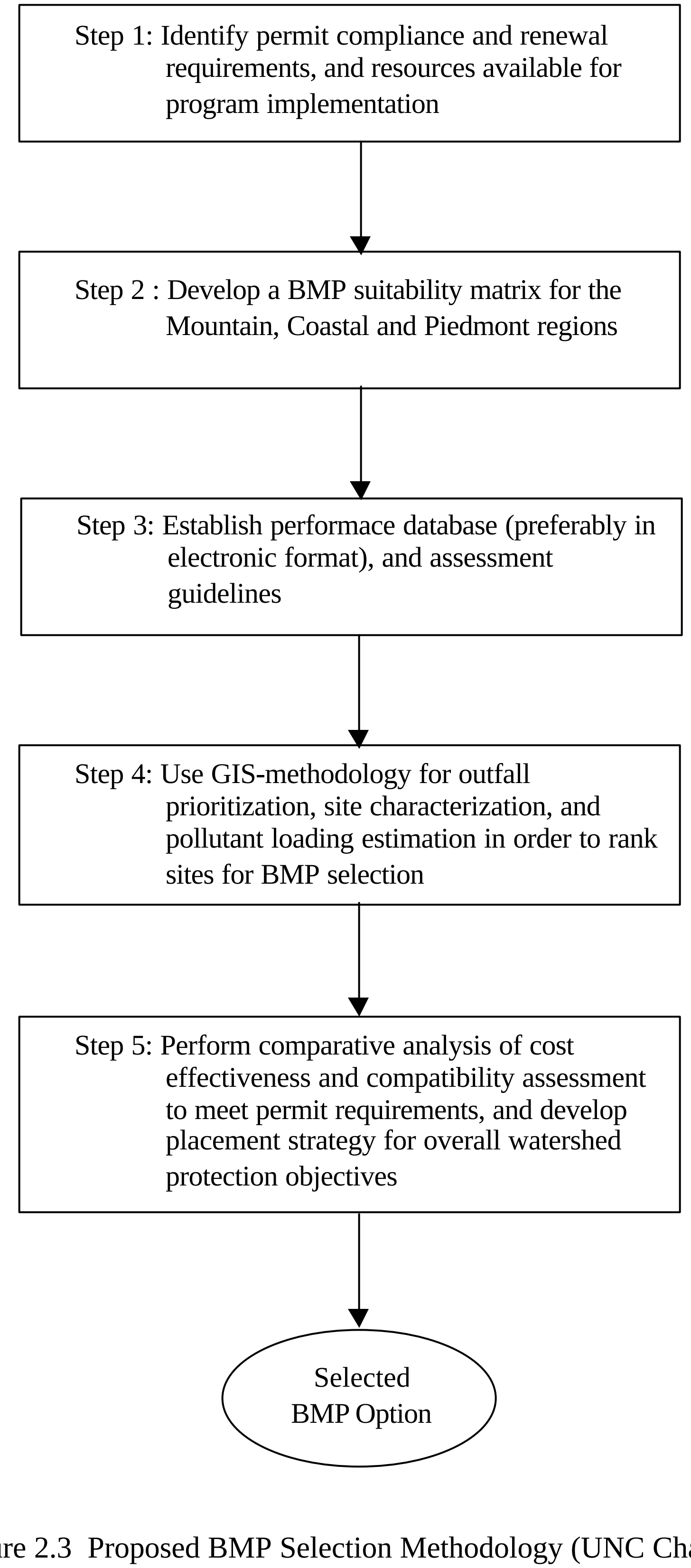


Figure 2.3 Proposed BMP Selection Methodology (UNC Charlotte)

Table 2.1 Treatment Suitability Matrix for Stormwater BMPs

BMP Category	BMP List	Hydrology		Water Quality Benefits		
		Rate Control	Volume Reduction	TSS	P&N	Fecal Coliform
Retention	Wet Pond	H	L	P	S	S
	Extended Retention Pond	H	L	P	S	S
	Wet Vaults	M	L	P	S	M
	Dry Pond	H	L	S	M	M
Detention	Oversized Pipes	H	L	M	M	M
	Oil/Grit Separator	L	L	S	M	M
	Dry Swale	M	L	P	S	M
	On-lot Infiltration	M	H	P	P	S
Infiltration	Infiltration Basin	M	H	P	P	S
	Infiltration Trench	M	H	P	P	S
	Stormwater Wetland	H	M	P	S	P
Wetland	Wet Swale	L	L	P	S	M
	Surface Sand Filters	L	L	P	S	S
Filtration	Underground Filters	L	L	P	S	S
	Bioretention	M	M	P	P	S
	Filter Strips	M	M	S	M	M

(MCES 2000) For hydrology: H = high, M = medium, L = low
For water quality: P = primary, S = secondary, M = minor

The following example can be used to illustrate the selection of a final list of candidate BMPs. The assumptions are nutrient sensitive watershed, impermeable soil, and adequate resources. The filtration swale located in Division 8 (see Chapter 6 for site information) is a good example for this application.

Step 1: The water-quality of concern has been identified to be "nutrient sensitive" and adequate financial resources are available for BMP implementation.

Step 2: From Table 2.1, it appears that the infiltration treatment category is most appropriate for nutrient control, followed by retention, wetlands or certain types of filters. Modification of soil permeability and provision of an underdrain will be needed for infiltration treatment due to the presence of impermeable soil.

Step 3: Review of literature to determine anticipated treatment performance based on case studies that have been reported in the National Stormwater BMP Database or other information sources.

Step 4: The most critical locations for placement and installation of BMP options will be assessed. This can be accomplished by site visits and negotiation with state water quality officials, in conjunction with the use the GIS-based prioritization and characterization methodology (e.g. Allan and Wu, 2005)

Step 5: Finally, information gathered from steps 1, 2, 3 and 4 will be used to perform cost-benefit analysis from a short list of potential BMP options including the filtration swale.

3. Assessment of BMP Performance

This chapter reviews BMP characterization and pollutant removal performance pertaining to structural BMPs. It also provides an assessment of those structural BMPs that have been installed at NCDOT's fourteen divisions according to criteria relating characterization to pollutant removal performance. Source information for propriety or manufactured BMPs is included in Appendix 2.

3.1 BMP Characterization

The primary goal of performing a BMP characterization is to provide scientific justifications defining the inter-relationships between water quality improvement needs and the unit processes required for treating stormwater runoff. Such knowledge is not only helpful for BMP design, but also useful for supporting the BMP selection methodology described in Chapter 2. Major processes associated with pollutant removal from stormwater include:

- Settling – gravitational separation of particulates from stormwater under either quiescent or dynamic flow conditions (e.g. detention ponds).
- Filtration – physical straining of pollutants as stormwater passes through a filter media (e.g. sand).
- Infiltration – permeable base designed to convey stormwater to underlying soils (e.g. porous pavement, infiltration trenches).
- Hydrodynamic separation – engineered system to accelerate separation of particulate matters from stormwater under dynamic conditions (swirl technology, air flotation).
- Bioremediation – biologically based processes including biological uptake, biotransformation, biodegradation, biosorption, and/or immobilization (e.g. bioretention, wetlands).
- Chemical treatment – use of chemical agents, polymer aids, and/or natural materials to promote flocculation, deactivation or oxidation of pollutants.
- Adsorption – use of natural or manufactured media for capturing pollutants from the water column.

Huber et al. (2005) categorized structural BMPs by fundamental processes and sub-classified according to the underlying unit processes (Table 3.1). Additional information pertaining to BMP characterization is available elsewhere (Shoemaker et al. 2000). It is conceivable that BMP characterization can be the starting point to relate water-quality improvement needs and the underlying treatment principles. These relationships will allow design engineers to incorporate as many treatment principles as possible into a BMP treatment unit or treatment train. Once a unit process has been determined, the type of pollutants that can be removed by such a unit process can be identified to ascertain if the goal of water quality improvement has been properly met.

Table 3.1 Structural BMPs Categorized by Fundamental Unit Processes

Fundamental Process	Unit Processes	Example BMP Types
Hydrological Controls	Peak Attenuation	Extended detention basins Retention detention ponds
	Volume Reduction	Infiltration basins Porous pavement Dry swale
Physical Processes	Density Separation	Oil-water separator Swales with check dams Retention/detention ponds Extended detention basins
	Size Separation	Media filters Vortex separators Infiltration/exfiltration trenches and basins
	Sorption/Filtration	Biofilters Bioretention systems Catch basin inserts
Biological Processes	Nutrient Assimilation	Bioretention systems Biofilters
	Uptake and Storage	Biofilters Bioretention systems
	Microbially Mediated Transformation	Wet swales Bioretention systems
Chemical Processes	Flocculation/Precipitation Ion Exchange	Detention/retention ponds Subsurface wetlands
Advanced Treatment Processes	High Rate Filtration Nanofiltration/Membranes Chemical Disinfection Aeration/Gas Stripping Chemical Oxidation Reduction	Advanced processes require highly controlled conditions and are more akin to municipal treatment than to conventional stormwater treatment.

(Huber et al. 2005)

As an example, the characterization scheme presented in Table 3.1 was applied to NCDOT's BMP installations in order to identify the underlying unit treatment processes that provide the removal of targeted pollutants, as shown in Table 3.2.

Table 3.2 Identification of Unit Processes and Removal of Primary Pollutants for NC Highway BMP Installations

DOT Division	Retrofit BMPs	Unit Processes Identified	Primary Pollutants Removed
1	Bioretention Swale	Filtration, Infiltration	TSS
2	Bioretention Basin	Infiltration, Bioremediation	TSS, Nutrients
3	Extended Dry Detention Basin	Settling	TSS
4	Level Spreader/Grass Filter Strip	Filtration, Infiltration	TSS
5	Extended Detention Basin	Settling	TSS, Nutrients, Coliforms
6	Grade Control with Grass Swale	Filtration	TSS
7	Proprietary BMP	Hydrodynamic Separation	TSS
8	Filtration Swale	Infiltration, Filtration	TSS
9	Water Quality Hazard Spill Basin	Settling	Withholding chemical spills
10	Bioretention Basin	Infiltration, Bioremediation	TSS, Nutrients
11	Bioretention Basin	Infiltration, Bioremediation	TSS, Nutrients
12	Bioretention Basin	Infiltration, Bioremediation	TSS, Nutrients
13	Grassed Swale with Curb Cut	Filtration	TSS
14	Catch Basin Inserts	Filtration	Depends upon media used

3.2 BMP Performance

An effective BMP design must include features that would attenuate runoff volume, improve transport of runoff flow, and enhance the remoal of runoff pollutants. The retrofit program must also include a maintenance plan, evaluation of secondary impacts likely to occur due to BMP intervention/installation (Schueler et al. 1992), and post auditing of sustainable performance. Appropriate BMP selection will depend on the constituents to be removed. Pollutant capturing principles can range from simple physical retention or infiltration to adsorption with or without biological treatment (Tshirintzis and Hamid 1997; Finley et al. 1993; Yousef et al. 1987).

Novotny and Olem (1994) have noted that in many cases, removal of priority pollutants depends on partition between solid and dissolved forms, biodegradability, and volatility of chemical constituent. The most effective removal mechanisms may employ organic constituents such as vegetation or peat that absorb or degrade the pollutants of concern. Removal of volatile pollutants can be accomplished in highly aerated environment such as overland sheet-flow systems. Mitigated wetlands were found to reduce not only peak flow (in excess of 40%), but also result in removals of 90% for total suspended solids (TSS), 65% for chemical oxygen demand (COD), 70% for total phosphorus (TP) and orthophosphorus (OP), and 50% for zinc (Yu et al., 1998).

Pollutant removal performance for various BMP types is summarized in Table 3.3. The performance data as presented in Table 3.3 should be viewed as the benchmark performance to aid BMP selection. Some of the data might not be related to highway runoff studies. However, the data could be useful for initial screening purposes when applying the BMP selection process outlined in Chapter 2.

Table 3.3 Pollutant Removal Effectiveness (%)

BMP	TSS	TP	TN	NO_3-N	Metals	Bacteria	Oil & Grease
Infiltration Trench	75-99	50-75	45-70	NA	75-99	7-98	NA
Bioretention	75	50	50	NA	75-80	NA	NA
Detention Ponds	46-98	20-94	28-50	24-89	NA	NA	NA
Wetlands	65	25	20	NA	35-65	NA	NA
Vegetated Swales	30-90	20-85	0-50	NA	0-90	NA	75
Vegetated Filter Strip	27-70	20-40	20-40	NA	2-80	NA	NA
Catch Basin Inserts	NA	NA	NA	NA	NA	NA	=90
Biofilters (StormTreat)	95	89	NA	NA	65-98	83	NA

(USDOT 2000) NA = not available

A data management tool is available to allow Internet access of BMP performance data (www.bmpdatabase.org) via the International Stormwater Best Management Practices Database Project (Strecker et al. 2004). There are currently over 170 structural BMP entries in the database including grass swales (32), detention basins (24), hydrodynamic devices (17), media filters (30), percolation trench/wells (1), porous pavement (5), retention ponds (33), wetland basins (15), and wetland channels (14). Six data entries are from North Carolina researchers including one case study of wet detention pond performance conducted by the UNC Charlotte researcher (Wu 2000).

In summary, the assessment of BMP performance should include the analysis of both water quantity and water quality considerations. Design standards should account for the hydrologic losses that may occur with some BMP types and to encourage the use of these BMP types. Continuous computer simulation can be used to ascertain if the hydraulic functionality of BMPs could be sustained over an extended period of time. The anticipated performance of BMPs should be carefully examined with regard to pollutants-of-concern. If the management goal requires a mix of pollutants-of-concern in stormwater, then a multiple, sequential BMP treatment train would be most effective.

4. BMP Monitoring - Grass Filter Strip

This chapter presents the results of a field monitoring program designed to investigate the pollutant removal mechanisms and effectiveness of grass filter strips (GFS). The monitored site (I-40/NC-42 GFS) is located near I-40 and adjacent to NC highway 42 in Clayton, North Carolina. Contributing drainage areas include a five-lane asphalt roadway and a grassy area alongside of the highway. The treatment train consists of a riprap lined ditch, a flow diversion box, a level spreader, the grass filter strip, and an outflow ditch.

In addition, pertinent design information of grass filter strips was reviewed along with computer simulation to examine the sensitivity of design parameters. Monitoring results obtained have been accepted for inclusion into the National Stormwater BMP Database (see Chapter 7).

4.1 Background

In contrast to grass swales, which are shallow, grass-lined, typically flat-bottomed channels, grass or vegetative filter strips require no flow through channels and consist of moderately sloped grass areas to receive runoff as overland sheet flow (Barrett et al. 1998). Sediment deposition occurs along the flowpath of a grass filter strip with simultaneous removal of other pollutants that are attached on the settled particulate matters (Dillaha et al. 1989)

Vegetative treatment practices can be conveniently installed along a highway segment. Mowing and trimming are the only maintenance needs. They can also serve as an effective means for erosion control. However, filter strip treatment systems are typically limited to locations where the source area is at least 300 to 400 ft (preferably 1,000 ft or more) from the nearest creek, stream or lake. Filter strips can be effective only if the runoff enters as sheet flow. This sheet flow requirement limits the use of grass filter strips to relatively small, smoothly graded drainage areas unless a level spreader can be provided at the upstream edge of the strip. Recommended design criteria for slope and suggested Manning's coefficients for different vegetaton coverages are given in Tables 4.1 and 4.2, respectively. Factors affecting the performance of grass filter strips include flow rate; sediment characteristics; slope along the flow path; length of the strip; type, stiffness, height, and density of vegetation; infiltration rate; mass of litter; degree of channelization; antecedent weather conditions; previously accumulated sediment; and dust fallout (Deletic 2001).

A simple expression in the form of $L = 100S^{0.5}/n$ has been propsoed for determining the required strip length (L, ft), given strip slope (S) and Maninig's coefficient (n) (NJDEP 2003). For example, given S = 6% and n = 0.35, the calculated strip length would be 70 ft. A minimum length of 20 ft is suggested regardless of any combinations of slope and Manning's value. The length requirement equation is applicable for coarse soils such as sand. For other types of soils such as silts or clays, the calculated length must be multipled by a length correction factor (Table 4.3).

Although length is one of the primary factors affecting sediment trapping efficiency, excessive length is unnecessary. Sediment removal efficiency was found to vary from 50% to 98 % as flow length increased from 8 ft (2.44 m) to 64 ft (19.52 m) This length of 64 ft is equivalent to a filter strip of 6% slope and n = 0.35 as calculated above. Almost all of the aggregates larger than 40 µm in diameter can be captured with the first 16 ft (5 m) of the filter strip (Gharabaghi et al. 2000)

Table 4.1 Criteria for Slope of Filter Strip

Filter Strip Soil Type	Hydrologic Soil Group	Maximum Filter Strip Slope (ft/ft)	
		Dense Grass, Sod and Bermuda Grass	Woods with Dense Underbrush
Sand	A	0.07	0.05
Sandy Loam	A	0.08	0.07
Loam, Silt Loam	B	0.08	0.08
Sandy Clay Loam	C	0.08	0.08
Clay Loam, Silty Clay, Clay	D	0.08	0.08

NJDEP (2003)

Table 4.2 Manning's Roughness Coefficients (n)

Surface Cover on Filter Strip	Manning's roughness (n)
Dense grass	0.25
Sod	0.35
Meadow or created woods with dense vegetation and duff layer	0.35
Natural woods with dense vegetation and duff Layer	0.40

NJDEP (2003)

Table 4.3 Filter Strip Length Correction Factors

Filter Strip Soil Type	Hydrologic Soil Group	Filter Strip Length Correction Factor
Sand	A	1.0
Sandy Loam	A	1.1
Loam, Silt Loam	B	1.3
Sandy Clay Loam	C	1.5
Clay Loam, Silty Clay, Clay	D	1.8

NJDEP (2003)

TSS reduction by filter strips depends mainly on the initial amount of solids present in runoff. An 18% reduction of solids was reported when the initial concentration of solids was less than 30 mg/L. However, when the initial concentration was above 200 mg/L, the solids removal could reach 62% to 82% (Ghate et al. 1997).

Grass filter strips perform better when treating sediment and nutrients that are adsorbed/attached to sediment, while trapping of dissolved nutrients and other materials are less efficient. In some cases, an increase in nutrient release has been observed (Dillaha et al. 1989). Should an inflow travel through a grassy swale before reaching the filter strip, the observed removal efficiency for the filter strip alone could greatly understate the potential improvement. This is because the influent concentrations to the filter strip had been reduced by the grassy swale (Barrett et al. 1998).

Filter strips are capable of removing suspended solids, as well as nutrients, and organics provided the flow within the strip is low to moderate. Removal capabilities could be a function of the geometry of the filter strip and the contributing watershed area. The NJ Stormwater Manual (NJDEP 2003) provides a quick means of estimating TSS removal efficiency given the depth of flow on the filter strip and the watershed's time-of-concentration, Figure 4.1. For example, assuming a flow depth of 0.25 inch and a travel time of 10 minutes, an estimated TSS removal efficiency of 77% can be found from Figure 4.1. Most of all, the effectiveness of a grass filter strip depends heavily upon maintaining sheet flow across the grass surface, which can be accomplished by a level spreader and by careful maintenance of the grass surface.

4.2 Field Monitoring

An experimental grass filter strip of 24 ft (7.3 m) wide by 55 ft (16.7 m) long has been installed adjacent to NC highway 42 in Clayton, North Carolina (Figures 4.2). The highway segment that was monitored is a five-lane asphalt section with a posted speed limit of 45 mi/h (73 km/h) and an average daily traffic count of more than 30,000 vehicles per day. The contributing drainage from the highway to the filter strip includes the impervious roadway section (49%) and a pervious roadside grassy area (51%). The combined drainage area is approximately 0.86 acres (3,500 m^2). The predominant soil in this area is hydrologic soil group B.

The entire treatment train consists of a riprap lined ditch, a flow diversion box, a level spreader, the experimental filter strip, and an outflow ditch The filter strip has a 4-6% slope along its flow path. Runoff originated from the monitored highway segment drains into a 212 ft^3 (6 m^3) diversion box, followed by a 6-inch (15 cm) diameter, 26 ft (8 m) long underground pipe that empties into a 24 ft (7.3 m) wide level spreader before flowing into the filter strip. A gravel layer of about 1.5-ft deep was installed underneath the level spreader and extended to about the first 1/3-length of the filter strip. This gravel layer provides drainage to empty the level spreader after each storm event and temporary storage of infiltrating runoff from the filter strip during a runoff event. Refer to Figures 4.3, and 4.4 for site layout and cross-sectional profile of the monitored area.

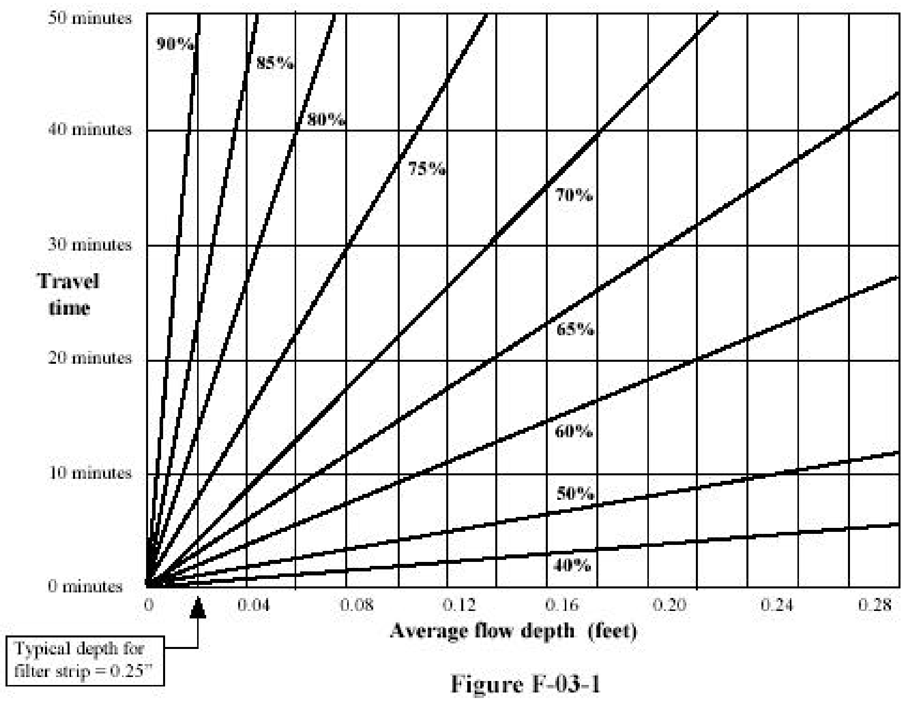


Figure 4.1 TSS Removal % as Functions of Travel Time and Average Flow Depth (NJDEP 2003)

A tipping bucket raingage was installed at the site to collection rainfall information. Two Sigma 900 automatic samplers were used to collect flow-proportional composite samples from the inflow and outflow of the filter strip. Inflow samples were taken inside a concrete flow-control box installed on the sidewall of the level spreader. Outflow samples were taken inside the outflow channel upstream of a 120^o V-notch weir. Three sample-collection troughs were laid inside and along the flow path of the strip. The opening of each trough is 1.5 by 2.0 inches (3.8 by 5.1 cm) and was positioned flush with ground level. The inlet of each trough was positioned at 3.7 ft (4.2 m), 27.5 ft (8.4 m), and 41.2 ft (12.5 m), respectively, downstream from the level spreader or the filter strip inlet. Each trough ran the length of the filter strip and extended into a 10 L sampling bottle at the downstream end and outside of the filter strip. Openings of the troughs were adjusted to minimize overfilling of each of the collection bottles. The trough-captured samples can be considered as flow-driven, continuous composite samples, representing water quality composition taken at different flow lengths within the filter strip.

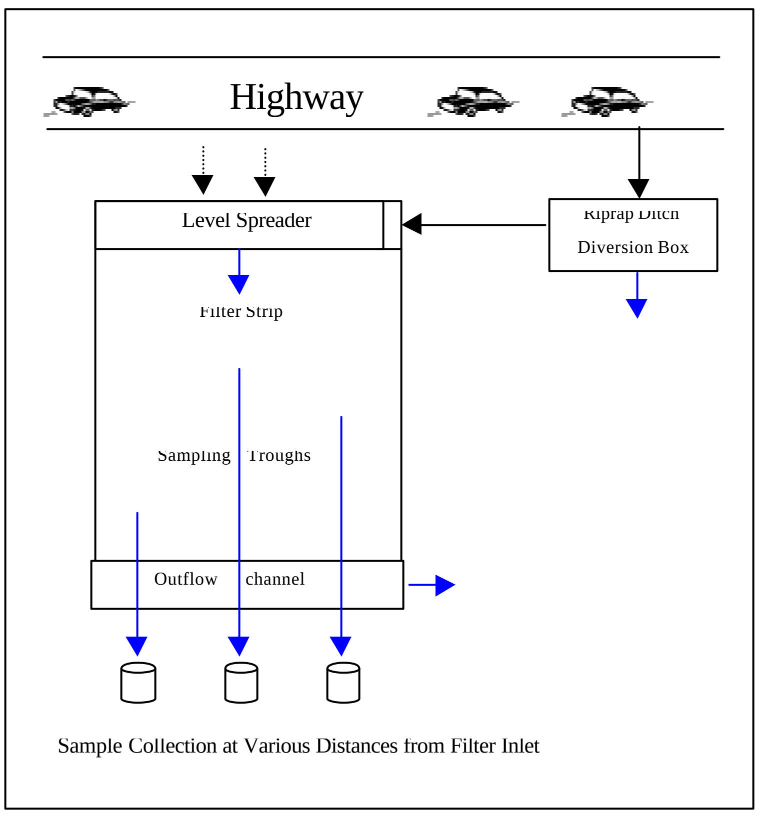


Figure 4.2 Plan View Showing Sampling Equipment, Level Spreader and Filter Strip at the I-40/NC-42 GFS Site

Figure 4.3 Outflow Collection at the I-40/NC-42 GFS Site

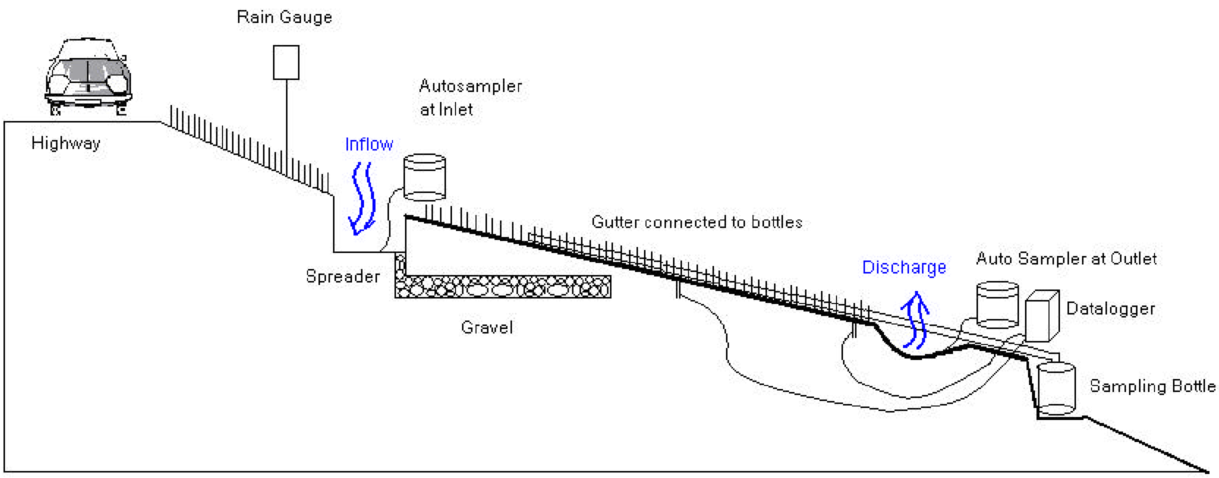


Figure 4.4 Cross-Sectional Profile of the Grass Filter Strip

4.3 Monitoring Results

A total of nine storm events have been monitored, as shown in Table 4.4 and Figure 4.5. The total rainfall amount for each of these monitored events ranged from 0.22 to 1.98 inches, with a mean of 0.81 inches and a standard deviation of 0.55 inches. Approximately 67% (1.3 inches) of the total rainfall (1.98 inches) for the 05-01-2004 event occurred within the first 24 hours of a 2-day period. The same amount of rainfall (1.29 inches) for the 06-04-2004 event occurred only within a 5-hr duration. Since this research was not for the purpose of NPDES reporting requirements, the distribution of monitored events appears to adequately represent the practical range of rainfall amounts occurring within the study area. Three out of the nine events had incomplete flow data and/or rainfall records.

Table 4.4 Summary of Monitored Storm Events

Date	Precipitation (inches)	Event Duration (hrs)
03-31-2004	0.40	9.7
04-11-2004	0.92	41.8
04-26-2004	0.30	8.6
05-01-2004	1.98	49.5
05-30-2004	0.95	3.5
06-04-2004	1.29	5.0
06-23-2004	0.22	1.2
06-26-2004	0.61	30.3
06-29-2004	0.58	1.1

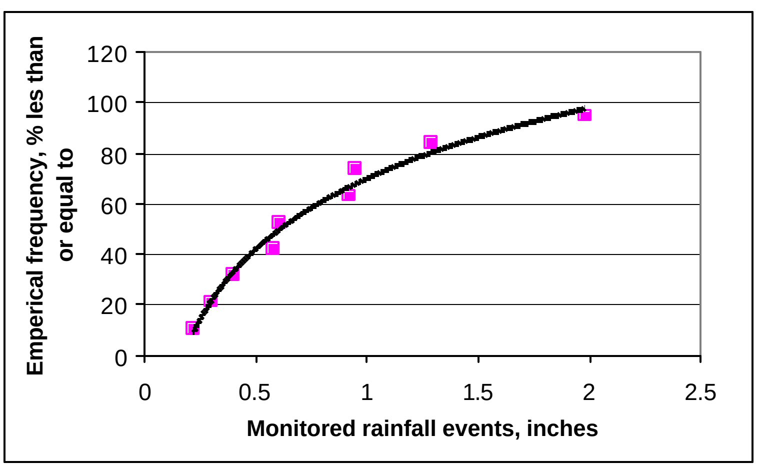


Figure 4.5 Observed Cumulative Frequency of Monitored Storm Events

4.3.1 Hydrologic Performance

Peak Flow Reduction: This was obtained by comparing the peak flows of the inflow to and outflow from the grass filter strip. Peak flow reductions were found to vary from as high as 90% for small rainfall events to around 15% for large rainfall events. Peak flow reductions as a function of rainfall amounts is shown in Figure 4.6.

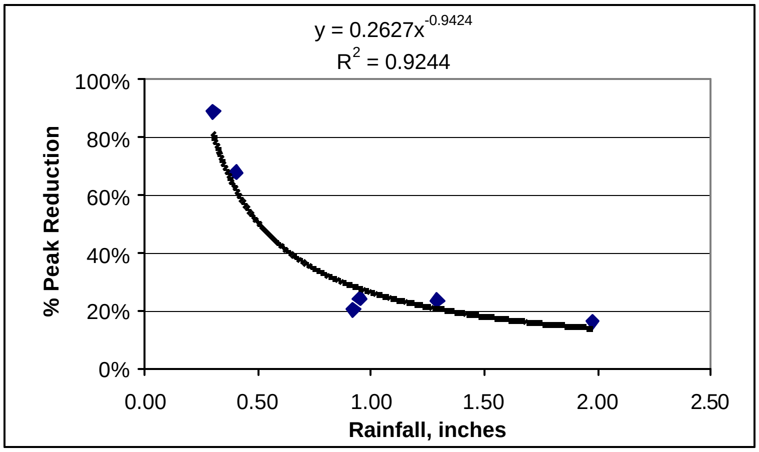


Figure 4.6 General Trend of Peak Flow Reductions

Runoff Volume Reduction: Ratios of cumulative outflow-to-inflow volume from the filter strip could provide a measure of the potential of water retention by filter strip. The general trend as displayed in Figure 4.7 indicates that depending on the magnitude of the rainfall events, approximately 10-40% of inflow volumes were lost as a result of infiltration. This is equivalent to about 60-90% of inflow that runs off from the filter strip.

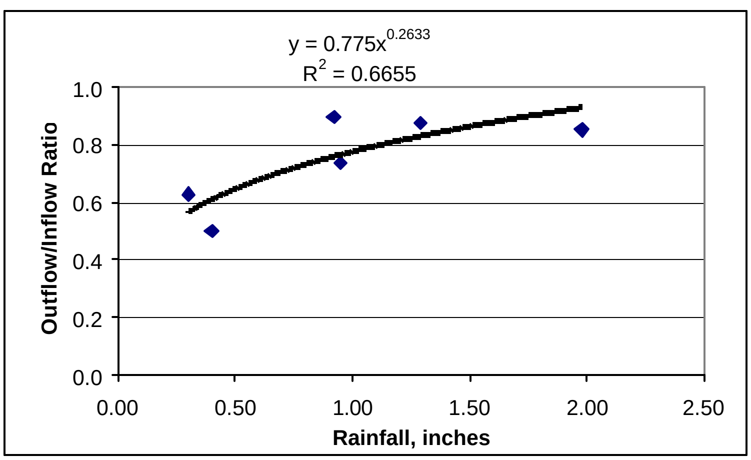


Figure 4.7 General Trend of Outflow-to-Inflow Ratios

The ratio of infiltration-to-inflow volume is another measure of water retention and a useful indicator for the reduction of the exporting soluble pollutants. The infiltrated volume was obtained by taking the difference between inflow and outflow volumes adjusted for direct precipitation on the filter strip. The infiltration loss (infiltration-to-inflow volume) is observed to be inversely proportional to rainfall amounts, as shown in Figure 4.8.

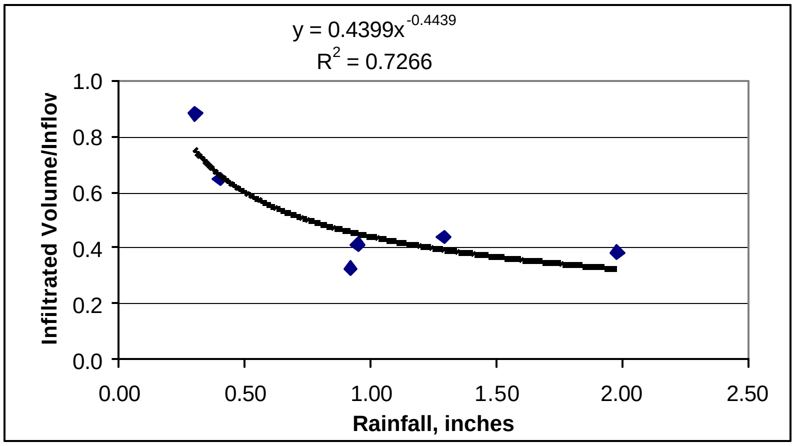


Figure 4.8 General Trend of Infiltration-to-Inflow Volume Ratios

Infiltration Analysis: The infiltration analysis was performed using storm data collected from the March 31, 2004 event, as shown in Figures 4.9, 4.10 and 4.11. The differences between inflow and outflow volumes, which represent the cumulative infiltration, were then calculated, as shown in Figure 4.12. Finally, the incremental infiltration rates were developed and fitted by the Horton Infiltration Model (Figure 4.13).

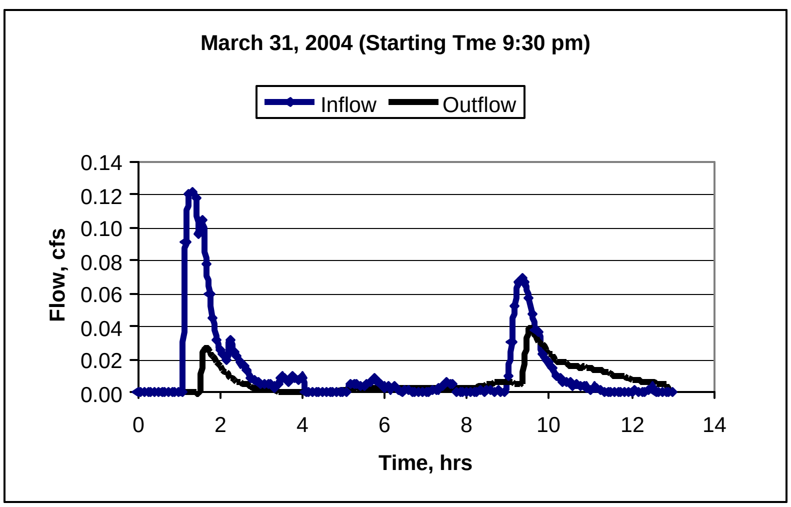


Figure 4.9 Inflow and Outflow Hydrographs

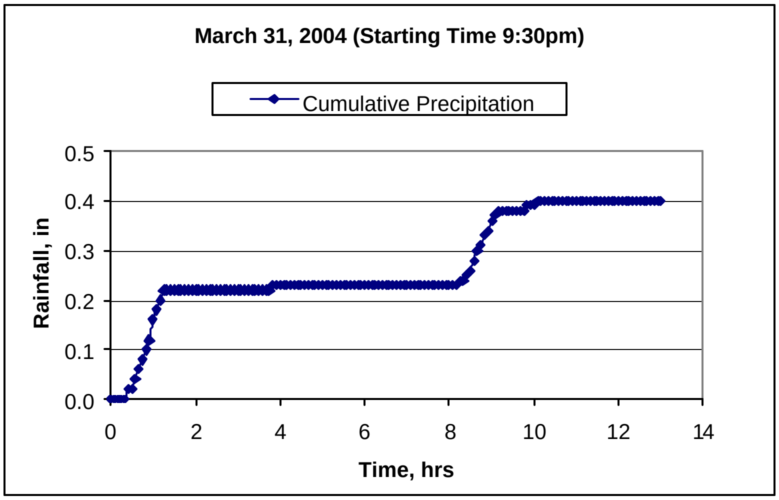


Figure 4.10 Cumulative Rainfall Volume

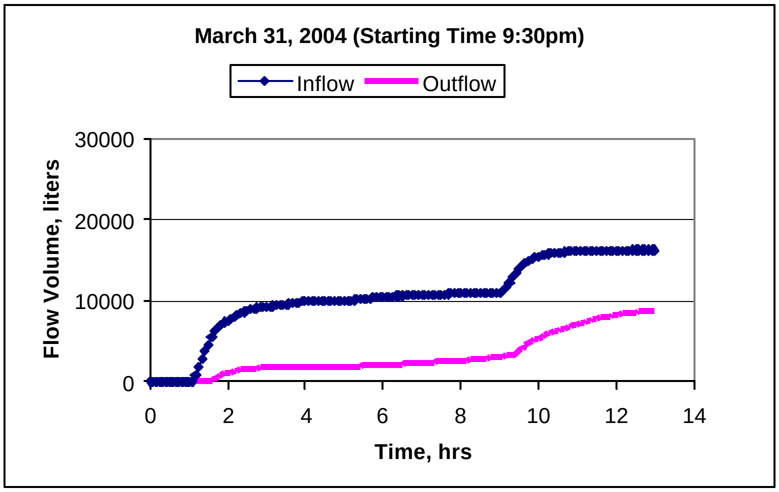


Figure 4.11 Cumulative Inflow and Outflow Volumes

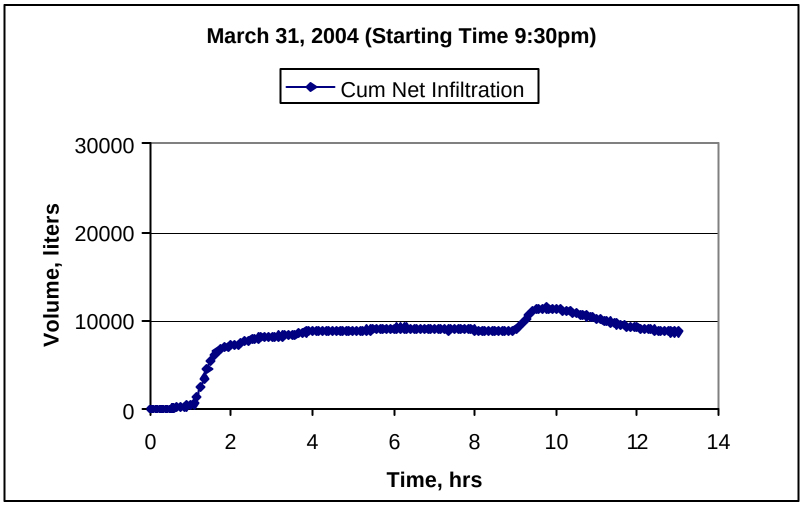


Figure 4.12 Cumulative Infiltration Volumes

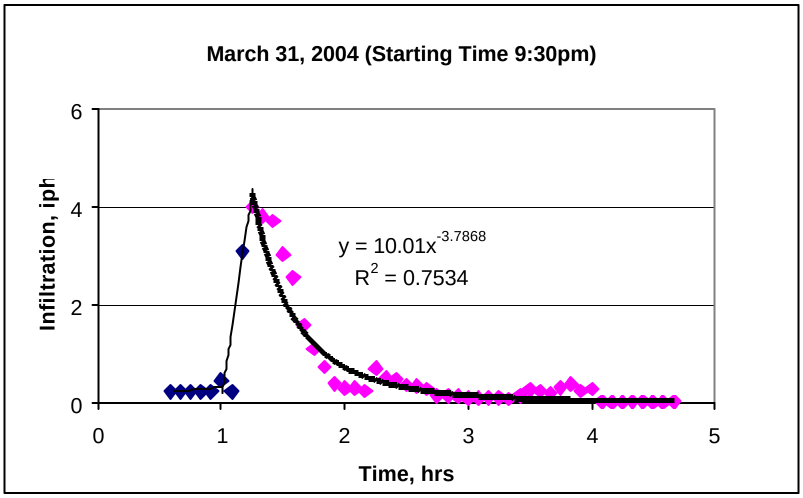


Figure 4.13 Infiltration Rate Analysis

The right portion of the incremental infiltration curve (Figure 4.13) can be fitted by the Horton Infiltration Model:

$$f(t) = f_c + (f_o - f_c)e^{-Kt}$$

Where

$f(t)$ = infiltration rate, iph (in/hr)
f_c = ultimate infiltration rate, iph
f_o = initial infiltration rate, iph
K = rate constant, hr^{-1}

Taking f_o = 4.01 iph and f_c = 0.05 iph from Figure 4.13, the rate constant K was determine to be 2.2 hr^{-1} which is typical for bluegrass turf.

4.3.2 Pollutant Removal Performance

Monitoring data for total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), dissolved organic carbon (DOC), ortho-phosphate (PO_4-P), and nitrate (NO_3-N) are summarized in Tables 4.5, 4.6, 4.7, 4.8, 4.9 and 4.10, respectively. See chapter 7 for methods of laboratory analysis.

The filter strip has achieved TSS removals of 56-94% based on concentration reduction and 68-97% removal based on mass load reduction. The outflow TSS concentration averaged 5.4 ± 2.2 mg/L which apparently represents the residual concentration achievable by this treatment device. The inflow TSS concentration averaged 32 mg/L but exhibited a standard deviation of 31 mg/L or a coefficient of variation equal to almost 100%. This fluctuation of inflow TSS concentrations was due, in part, to the presence of a riprap ditch upstream of the filter strip, which serves as a sediment trap for coarse particulate matters. This is evident from the fact that six out of nine TSS concentrations delivered from the riprap ditch to the filter strip were below 20 mg/L. Storm events of one inch or greater were responsible for delivering higher TSS in runoff and/or re-suspension of the settled sediment in the riprap ditch, resulting in TSS concentrations in the range of 50-110 mg/L being delivered to the filter strip. Therefore, it is important to account for the removal effectiveness of each treatment unit/device comprising the entire treatment train, rather than focusing on the isolated performance of the filter strip itself. It is also important to use the mass-load-ratio to report removal efficiency when infiltration loss cannot be practically neglected.

Table 4.5 Summary of TSS Monitoring Data

Date (1)	Rain, in (2)	Inflow TSS, mg/L (3)	Outflow TSS, mg/L (4)	TSS Conc. Reduction, % (5)	Runoff Ratio (6)	TSS Mass Removal, % (7)
03/31/04	0.40	18.7	8.1	56.5	0.50	78.3
04/11/04	0.92	19.1	5.6	70.7	0.90	73.8
04/26/04	0.30	16.5	5.9	64.4	0.63	77.7
05/01/04	1.98	52.9	5.1	90.3	0.85	91.8
05/30/04	0.95	13.2	5.8	56.4	0.74	67.9
06/04/04	1.29	107.4	8.4	92.2	0.87	93.2
06/23/04	0.22	16.8	1.0	94.1	0.52	96.9
06/26/04	0.61	14.3	4.9	65.7	0.68	76.7
06/29/04	0.58	26.5	4.1	84.5	0.67	89.6
Average	0.81	31.7	5.4	75.0	0.71	82.9
STD	0.56	30.9	2.2	15.4	0.15	10.1

Column (1) – Dates for monitored storm events
Column (2) – Recorded total event rainfalls
Column (3) – Measured inflow pollutant concentrations as composite samples
Column (4) – Measured outflow pollutant concentrations as composite samples
Column (5) – Pollutant reduction calculated based on inflow and outflow concentrations
Column (6) – Observed runoff coefficients
Column (7) – Pollutant removal calculated based on mass removal ratios
[Column (3) – Column (6)*Column (4)]/[Column (3)]*100

The average removal, based on concentration reduction, for TN was 7 ± 19%. It is noted that the average inflow TN concentration of 1.51 ± 0.89 mg-N/L was only slightly greater than the average outflow TN concentration of 1.37 ± 0.78 mg-N/L. The filter strip could have been considered to perform quite unsatisfactorily for TN reduction if the removal efficiency were based on concentration reduction. However, the average removal based on mass load reduction was 34 ± 12%. As stated earlier, it is more appropriate to use mass-load-ratio in reporting removal efficiency when infiltration loss could not be practically neglected. The same argument also applies to the interpretation of removal efficiencies for TP, DOC and NO_3-N, rendering mass load reductions of 16%, 24% and 22%, respectively.

The removal of PO_4-P could not be reliably concluded from the current data. The sampling period was from late spring to early summer time with possible release of P that had been accumulated due to decayed vegetation and/or spring fertilization. The average effluent PO_4-P concentration of 0.15 mg/L is about 5 times greater than the influent concentrations. According to Wu and Allan (2001), the average PO_4-P from North Carolina highway runoff was found to be 0.12 mg/L (varied from 0.06-0.25 mg/L).

Using this concentration as inflow to the treatment train, the overall reduction efficiency (mass load reduction) would have been 11% [(0.12 – 0.15*0.71)/0.12*100]. The reduction and potential release of PO_4-P may vary seasonally; therefore, it is necessary to collect water samples for an extended period of time to account for seasonal variability when assessing the PO_4-P removal performance from any vegetative treatment systems.

Table 4.6 Summary of TN Monitoring Data

Date (1)	Rain, in (2)	Inflow TN, mg/L (3)	Outflow TN, mg/L (4)	TN Conc. Reduction, % (5)	Runoff Ratio (6)	TN Mass Removal, % (7)
03/31/04	0.40	1.32	1.67	-26.5	0.50	36.7
04/11/04	0.92	2.07	1.29	37.7	0.90	44.2
04/26/04	0.30	3.44	3.05	11.3	0.63	44.6
05/01/04	1.98	0.81	0.65	19.8	0.85	31.7
05/30/04	0.95	1.61	1.66	-3.1	0.74	24.2
06/04/04	1.29	1.00	1.04	-4.0	0.87	9.1
06/23/04	0.22				0.52	
06/26/04	0.61	0.92	0.87	5.4	0.68	35.7
06/29/04	0.58	0.90	0.73	18.9	0.67	45.5
Average	0.81	1.51	1.37	7.4	0.71	33.9
STD	0.56	0.89	0.78	19.3	0.15	12.4

Column (1) – Dates for monitored storm events
Column (2) – Recorded total event rainfalls
Column (3) – Measured inflow pollutant concentrations as composite samples
Column (4) – Measured outflow pollutant concentrations as composite samples
Column (5) – Pollutant reduction calculated based on inflow and outflow concentrations
Column (6) – Observed runoff coefficients
Column (7) – Pollutant removal calculated based on mass removal ratios
[Column (3) – Column (6)*Column (4)]/[Column (3)]*100

Table 4.7 Summary of TP Monitoring Data

Date (1)	Rain, in (2)	Inflow TP, mg/L (3)	Outflow TP mg/L (4)	TP Conc. Reduction, % (5)	Runoff Ratio (6)	TP Mass Removal, % (7)
03/31/04	0.40	0.12	0.25	-100.0	0.50	0.0
04/11/04	0.92	0.22	0.17	27.3	0.90	34.9
04/26/04	0.30	0.31	0.20	35.5	0.63	59.7
05/01/04	1.98	0.23	0.18	21.7	0.85	33.4
05/30/04	0.95	0.15	0.39	-160.4	0.74	-91.5
06/04/04	1.29	0.30	0.36	-17.2	0.87	-2.4
06/23/04	0.22				0.52	
06/26/04	0.61	0.28	0.24	15.4	0.68	42.4
06/29/04	0.58	0.24	0.17	26.7	0.67	52.4
Average	0.81	0.23	0.24	-18.6	0.71	16.1
STD	0.56	0.07	0.09	72.5	0.15	48.9

See Table 4.6 footnotes for explanations.

Table 4.8 Summary of DOC Monitoring Data

Date (1)	Rain in (2)	Inflow DOC mg/L (3)	Outflow DOC mg/L (4)	DOC Conc. Reduction, % (5)	Runoff Ratio (6)	DOC Mass Removal, % (7)
03/31/04	0.40	12.4	17.1	-37.4	0.50	31.3
04/11/04	0.92	13.9	12.9	6.9	0.90	16.6
04/26/04	0.30	31.3	29.8	5.0	0.63	40.6
05/01/04	1.98	9.7	9.2	5.8	0.85	19.8
05/30/04	0.95	10.9	14.7	-34.8	0.74	0.9
06/04/04	1.29	9.2	10.9	-18.2	0.87	-3.3
06/23/04	0.22				0.52	
06/26/04	0.61	10.1	10.6	-4.5	0.68	28.9
06/29/04	0.58	13.4	9.1	32.3	0.67	54.5
Average	0.81	13.9	14.3	-5.6	0.71	23.7
STD	0.56	7.3	6.8	23.5	0.15	19.4

Column (1) – Dates for monitored storm events
Column (2) – Recorded total event rainfalls
Column (3) – Measured inflow pollutant concentrations as composite samples
Column (4) – Measured outflow pollutant concentrations as composite samples
Column (5) – Pollutant reduction calculated based on inflow and outflow concentrations
Column (6) – Observed runoff coefficients
Column (7) – Pollutant removal calculated based on mass removal ratios
[Column (3) – Column (6)*Column (4)]/[Column (3)]*100

Table 4.9 Summary of PO_4-P Monitoring Data

Date (1)	Rain, in (2)	Inflow PO_4-P, mg/L (3)	Outflow PO_4-P, mg/L (4)	PO_4-P Conc. Reduction, % (5)	Runoff Ratio (6)	PO_4-P Mass Removal % (7)
03/31/04	0.40					
04/11/04	0.92	0.044	0.039	11.1	0.90	20.4
04/26/04	0.30	0.091	0.150	-64.3	0.63	-2.7
05/01/04	1.98	0.039	0.039	0.0	0.85	14.9
05/30/04	0.95	0.036	0.173	-381.8	0.74	-254.3
06/04/04	1.29	0.062	0.163	-163.2	0.87	-130.0
06/23/04	0.22				0.52	
06/26/04	0.61	0.121	0.101	16.2	0.68	43.0
06/29/04	0.58	0.010	0.065	-566.7	0.67	-347.6
Average	0.81	0.055	0.150	-164.1	0.71	-93.77
STD	0.56	0.036	0.141	227.1	0.15	154.6

See Table 4.8 footnotes for explanations.

Table 4.10 Summary of NO_3-N Monitoring Data

Date (1)	Rain, in (2)	Inflow NO_3-N, mg/L (3)	Outflow NO_3-N, mg/L (4)	NO_3-N Conc. Reduction, % (5)	Runoff Ratio (6)	NO_3-N Mass Removal, % (7)
03/31/04	0.40				0.50	
04/11/04	0.92	0.064	0.056	12.3	0.90	21.4
04/26/04	0.30	0.221	0.187	15.3	0.63	47.1
05/01/04	1.98	0.061	0.034	52.7	0.85	52.7
05/30/04	0.95	0.303	0.239	41.8	0.74	41.8
06/04/04	1.29	0.086	0.081	17.2	0.87	17.2
06/23/04	0.22				0.52	
06/26/04	0.61	0.025	0.052	-109.1	0.68	-42.3
06/29/04	0.58	0.025	0.029	-18.2	0.67	20.7
Average	0.81	0.112	0.097	- 4.2	0.71	22.3
STD	0.56	0.107	0.083	49.9	0.15	31.9

Column (1) – Dates for monitored storm events
Column (2) – Recorded total event rainfalls
Column (3) – Measured inflow pollutant concentrations as composite samples
Column (4) – Measured outflow pollutant concentrations as composite samples
Column (5) – Pollutant reduction calculated based on inflow and outflow concentrations
Column (6) – Observed runoff coefficients
Column (7) – Pollutant removal calculated based on mass removal ratios
[Column (3) – Column (6)*Column (4)]/[Column (3)]*100

4.3.3 Predicting Long-Term TSS Removal

This section presents a statistical approach for predicting the annual long-term TSS removal efficiency that is achievable by a grass filter strip (GFS). The short-term TSS monitoring data was extrapolated to serve as the basis of prediction. This procedure can be justified based on the facts that, unlike other water quality parameters, TSS removal performance is less subject to seasonable variations in biological uptake or release, and the short-term monitoring data adequately covered the practical range (0.2 to 1.98 inches) of storm events occurring at the study area (Figure 4.5). The information of long-term TSS removal for storm events up to one inch is needed for NPDES monitoring requirements.

The first step of analysis was to define the distribution of rainfall events ranging from 0.2 to 1.0 inch. A typical annual rainfall distribution in the Piedmont area consists of 60% and 87% of the storm events with rainfall amounts = 0.5 inch and =1.0 inch, respectively. This distribution was normalized between 0% and 100% for rainfall amounts of 0.0 to 1.0 inch. Additional annual rainfall patterns were synthesized to account for variations of the annual rainfall distribution in wet and dry years. Using the 0.5-inch event at 60% chance of occurrence as the pivot point, additional annual rainfall patterns were synthesized to represent the occurrence of the 0.5-inch event at 81% and 70% chances, and at 50% chance of a linearly even distribution, as shown in Figure 4.14.

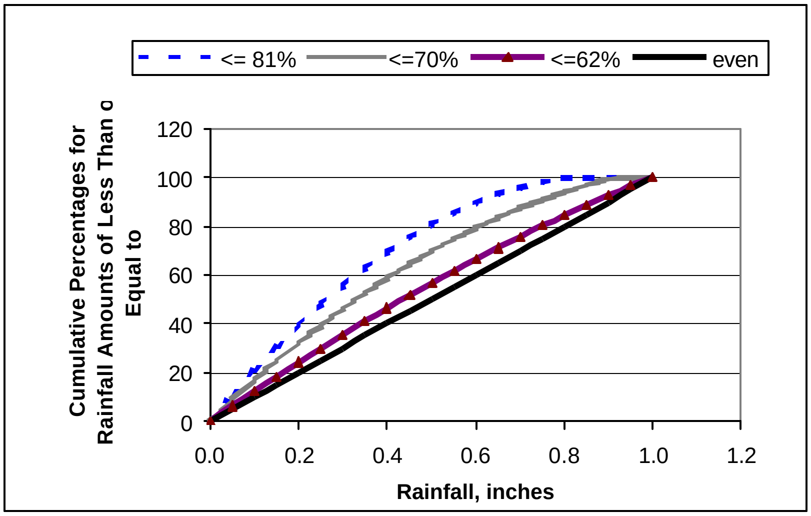


Figure 4.14 Rainfall Distributions for Long-Term TSS Removal Calculations

The annual rainfall patterns as displayed in Figure 4.14 are as follows:

- 81% events of 0.5 inch or less
- 70% events of 0.5 inch or less
- 62% events of 0.5 inch or less
- 50% events of 0.5 inch or less (even distribution)

The next step was to plot the relationship between TSS removal and rainfall amounts in the range of 0.2 to 1.0 inch, as shown in Figure 4.15. This generalized trend was applied to the rainfall distributions (Figure 4.14). The annual or long-term TSS removals were then calculated as shown in Table 4.11. The long-term removals for TN, TP and DOC were calculated in a similar way and results are also included in Table 4.11.

Judging from the range of long-term TSS removal (78%-88%), the experimental filter strip by itself may or may not meet the 85% TSS removal requirement depending on the prevailing rainfall distribution in a particular year. However, the overall TSS removal performance including sediment trappings by the riprap ditch and the level spreader would, without a doubt, exceed the 85% removal requirement.

There is a 10% range of the long-term TSS removal efficiency (78% - 88%) as a result of the assumed rainfall distribution. Similar ranges of performance variance for TN, TP and DOC are 7%, 10% and 17%, respectively. State agencies should consider the range of performance variance as justifications to the fluctuation of treatment performance that could have been influenced by annual rainfall patterns.

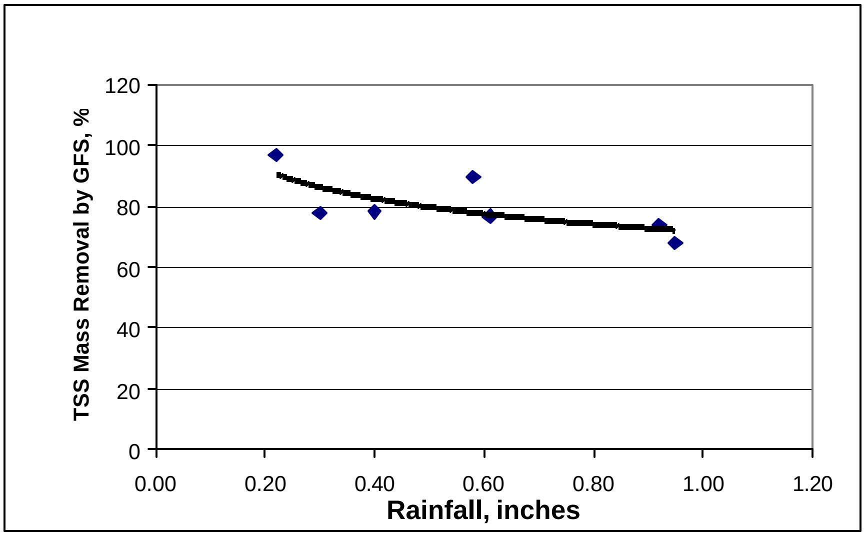


Figure 4.15 Generalized TSS removal Trends

Table 4.11 Prediction of Annual, Long-Term Mass-Load of Pollutant Removals by I-40/NC-42 Grass Filter Strip

		Assumed Rainfall Distributions		
Parameters	Even	62%	70%	81%
TSS	78	83	86	88
TN	41	44	46	48
TP	44	48	52	54
DOC	29	34	40	46

4.4 Computer Simulation

This part of the research was to examine the influence of physical factors such as soil properties (saturated hydraulic conductivity and initial water content), vegetative coverage (grass spacing), pollutant characteristics (mean particle size, d_{50}), and structural dimensions (strip length) on filter strip performance. Both field data and computer simulations were used to quantify the incremental effects of each of the above parameters on sediment removal.

4.4.1 VFSMOD Computer Model

Suwandono et al (1999) described a Vegetative Filter Strip Model (VFSMOD) for the simulation of water movement and sediment transport within a filter strip. VFSMOD consists of a number of modules including the use of (i) a time-dependent Green-Ampt infiltration module for calculating the water balance in the soil surface, (ii) a kinematic wave overland flow module for determining flow depths and rates on the infiltrating soil surface, and (iii) a sediment filtration module for simulating transport and deposition of the incoming sediment along the strip. VFSMOD is capable of handling changes in flow due to sediment deposition, complex storm patterns, and varying surface conditions (slope and vegetation) along the filter strip (Munoz-Carpena et al. 1999). Required input parameters for each sub-model are described below.

The hydrology sub-model: The hydrologic sub-model simulates the processes of overland flow and infiltration. Input parameters for this sub-model are given in Table 4.12. The length, width and slope of the experimental filter strip were obtained from field measurements. The Manning's roughness coefficient was estimated from visual observation of field conditions (Chow 1959; NJDEP 2003). The saturated hydraulic conductivity was determined in the field using infiltration rings. The saturated water content was based on laboratory analysis of soil cores that were removed from several locations within the filter strip.

Table 4.12 Input Parameters for the Hydrology Sub-model

Symbol	Description	Values	Units
VL	Length of the Filter Strip	16.7	m
FWIDTH	Width of Filter Strip	7.3	m
NPROP	Number of Segments with Different Surface Properties	1	
Manning's n	Manning's Roughness for Each Segment	0.24	$s/m^{1/3}$
S	Slope at Each Segment	0.04	
K_s	Saturated Hydraulic Conductivity	$4.5\times10\text{-}6$	m/s
θs	Saturated Water Content	0.4	m^3/m^3
θ_i	Initial Water Content	0.1	m^3/m^3

The sediment sub-model: Input parameters for the sediment sub-model are given in Table 4.13. Data for grass spacing and height were estimated from field observations. Incoming sediment characteristics, including mean sediment particle size, density, and porosity of deposited sediment, were estimated from literature sources (Sartor and Boyd 1972; Shaheen 1975; Sansalone et al. 1998). Although several of these parameters were derived from literature values, it is expected that the sensitivity analysis performed on these parameters would extend the data range to acceptable field values.

Table 4.13 Input Parameters for the Sediment Sub-model

Symbol	Description	Values	Units
Ss	Spacing of the Filter Media Elements (grass)	2	cm
H	Filter Media Height (grass)	20	cm
d_{50}	Mean Sediment Particle Size	0.0008	cm
ρ_s	Sediment Particle Density	2.65	g/cm^3
P	Porosity of Deposited Sediment	0.434	

4.4.2 Simulation Results

The VFSMOD model was tested against the sediment concentration profile along the filter strip and verified by a portion of the runoff hydrograph obtained from the May 1, 2004 storm event. Figures 4.16 and 4.17 indicate that the VFSMOD model can be reasonably tested against field observed data. Additional model testing can be found from Han et al. (2005).

Sensitivity analysis was also performed to study the effects of individual process variable exerting on filter strip performance. A base-condition of the simulation was established using the input parameters of the I-40/NC-42 grass filter strip as given in Tables 4.12 and 4.13. The hydrologic input was the SCS type II storm with 6-hr duration and 1-inch (25 mm) rainfall volume. The incoming sediment concentration was set at 100 mg/L.

Physical factors: It can be seen from Figure 4.18 that increasing the initial water content by a factor of 3.5 would only decrease the infiltration loss by less than 5%. Figure 4.19 indicates that increasing the hydraulic conductivity by a factor of 4 would result in an increase of an overall infiltration loss by about 7% at the end of the filter strip. Hydraulic conductivity values adopted in the simulation are representative of soil types ranging from silt-loam to sandy-loam. In other words, uncertainties encountered in estimating both soil hydraulic conductivity and initial water content that are within field values would amount to ±10% to 12% over- or under-estimates of infiltration volume calculations. TSS removal totals are essentially unaffected by the variations of these two hydrologic parameters. Both figures indicate that a filter strip with 10 m length could trap over 80% of the incoming sediment.

Vegetative coverage: Grass spacing is another parameter that could have pronounced influence on TSS removal. Figure 4.20 shows approximately 20% decrease in TSS removal when grass spacing increases from 2 to 7 cm. According to Haan et al. (1994), the sediment trapping efficiency is proportional to an exponent of the Reynold's number, which, in turn, is a function of grass spacing. The change in TSS removal performance can be estimated from a regression equation derived from Figure 4.20 in the form of $T_s = 100*\exp(-0.05*S_s)$. Where T_s is the sediment trapping efficiency (%), S_s is spacing of the filter media elements in cm. This regression equation was based on a simulated filter strip of 55 ft (17.6 m) and an incoming sediment particle size (d_{50}) of 8 um.

Regular maintenance is very important to keep the filter strip in good operating conditions. Filter strips should be inspected regularly for gully erosion, density of vegetation, and damage due to pedestrian or vehicular traffic. Maintaining a dense vegetative coverage could increase the flow resistance of the filter strip, which helps reduce the flow velocity, enhance particle settling, and prevent re-suspension of small particles.

Particle size: Figure 4.21 displays the relationship between TSS removal and particle sizes. The filter strip is very efficient in removing sediment particles of greater than 8 μm. Sediment with particle size less than 2 μm tends to pass the filter strip with the outflow runoff. The sediment trapping efficiency can be estimated by using the following simple exponential equation, $T_s = 100*\exp[-6*(1/d_{50})^2]$, that applies to a 55-ft (16.7 m) filter strip with a grass spacing of 2 cm.

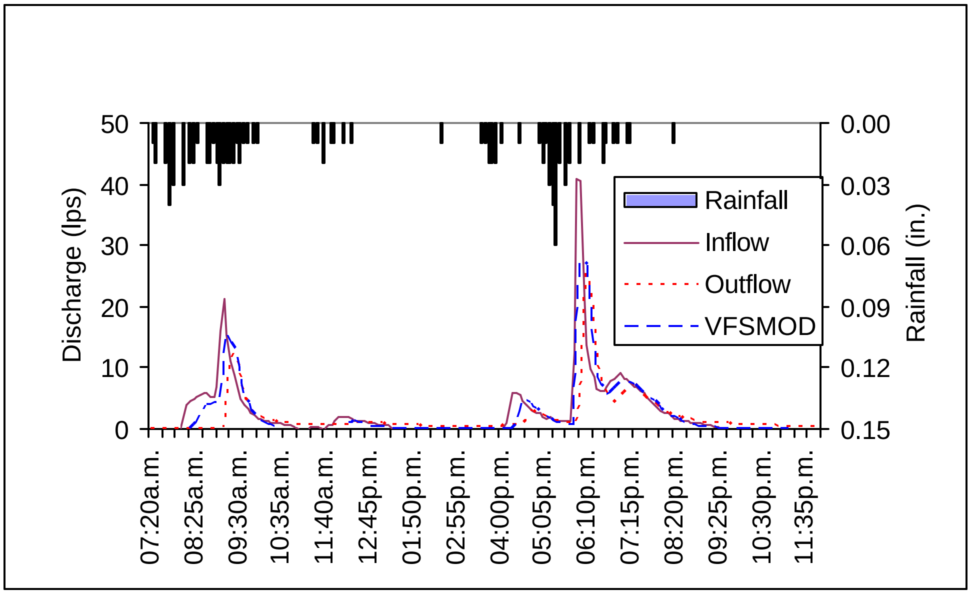


Figure 4.16 Hydrographs for the 5-1-04 Storm Event

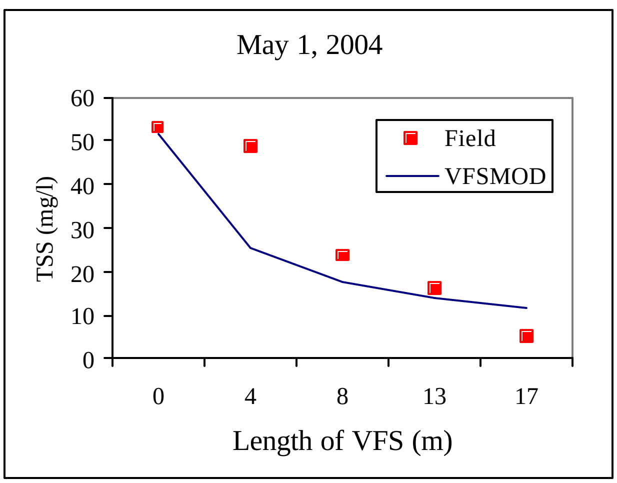
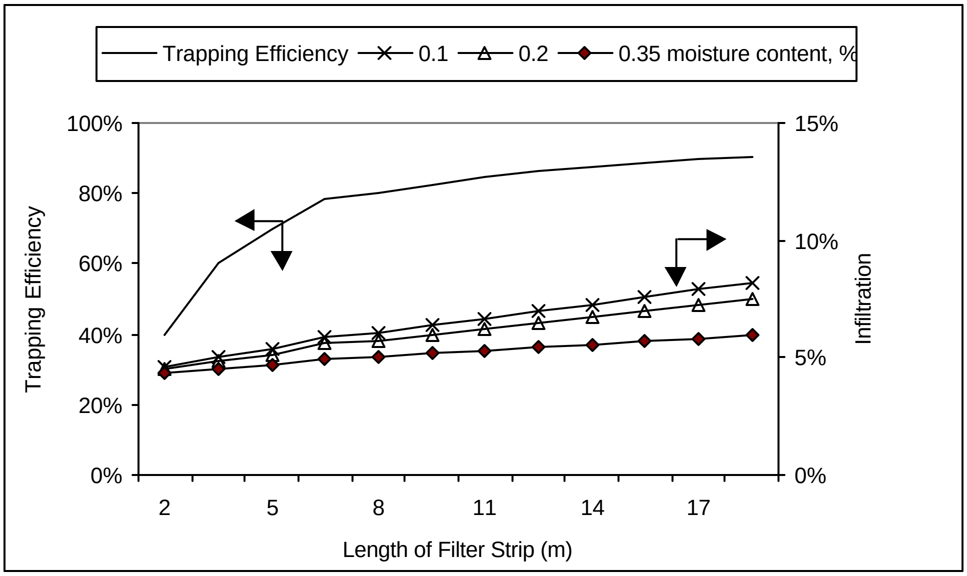
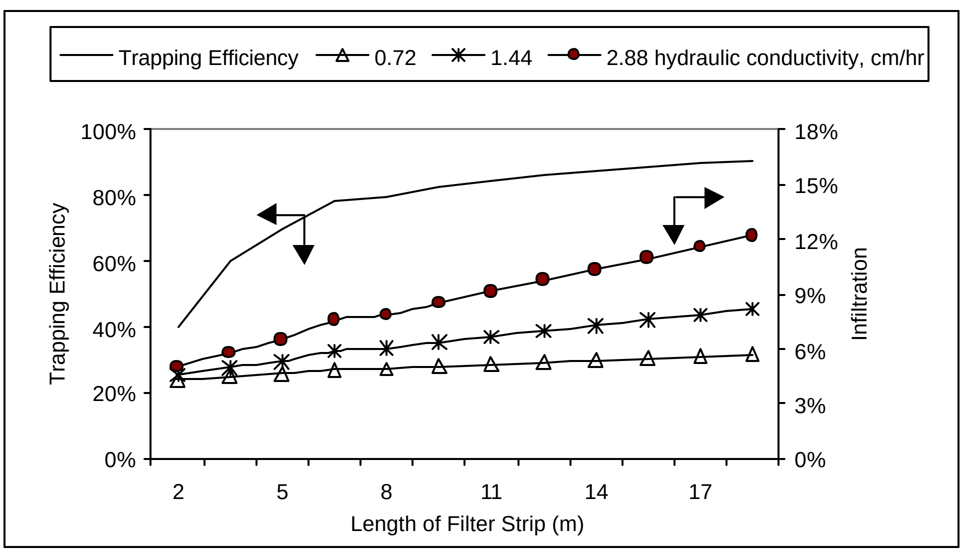


Figure 4.17 Sediment Removal Simulated by VFSMOD



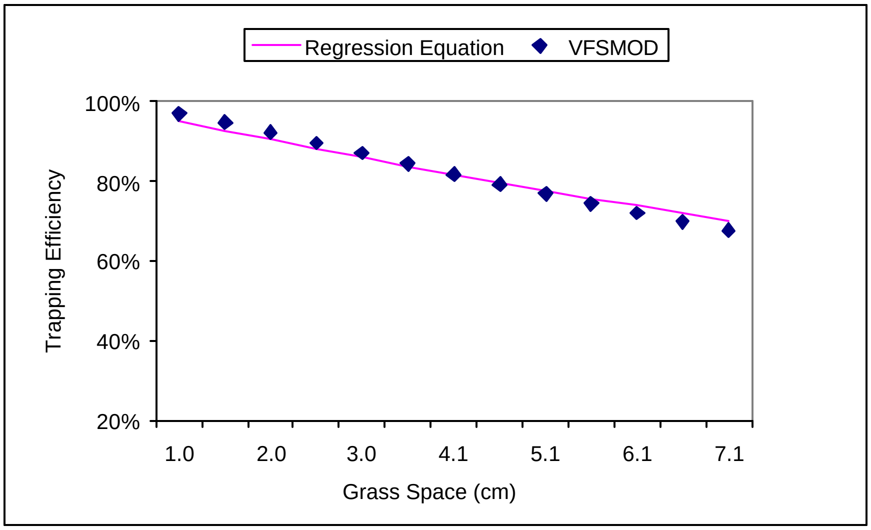
(d_{50} = 8 μm, VKS = 1.44 cm/hr, Grass Spacing = 2 cm)

Figure 4.18 Effect of Initial Water Content on Trapping Efficiency and Infiltration



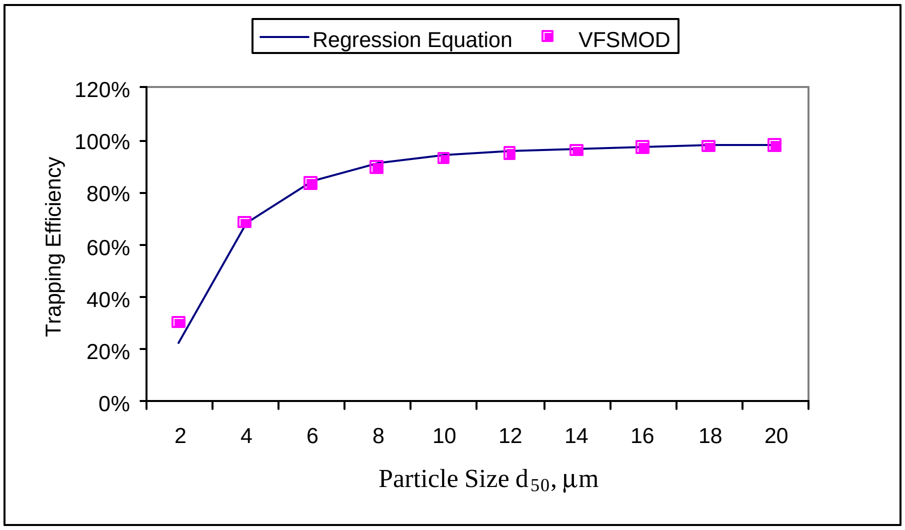
(d_{50} = 8 μm, Initial Water Content = 0.1%, Grass Spacing = 2cm)

Figure 4.19 Effect of Soil Saturated Hydraulic Conductivity on Trapping Efficiency and Infiltration



(d_{50} = 8 μm, Length = 16.7 m)

Figure 4.20 Effect of Grass Spacing on TSS Trapping Efficiency



(Grass Spacing = 2 cm, Length = 17.6 m)

Figure 4.21 Effect of Particle Size (d_{50}) on TSS Trapping Efficiency

In summary, VFSMOD can be used to simulate the settling of suspended sediment along a grass filter strip. However, simulation results must be carefully reviewed in light of the underlying assumptions and model limitations. The simulation of sediment removal was not sensitive to the variations in hydraulic conductivity and initial water content. These soil properties are particularly important for the simulation of water infiltration and the removal of soluble pollutants. Simulated results obtained can be summarized as follows.

- TSS reduction along the filter strip follows an exponentially increasing removal pattern. The majority of sediment removal can be achieved within the first 33 ft (10 m) of a filter strip.

- Uncertainties encountered in estimating both soil hydraulic conductivity and initial water content could amount to ± 10% to 12% over- or under-estimates of infiltration volume calculations.

- Vegetative filter strips are very effective in capturing aggregates larger than 8 μm. Fine particles with diameter less than 2 μm are relatively difficult to be removed by grass filter strips. The reduction of fine particles in runoff relies mainly on infiltration losses across filter strip.

- Grass spacing significantly affects sediment removal efficiency. Thus, the selection of plants should be based on their compatibility with local climate conditions, soils, and topography and their ability to tolerate urban stresses from pollutants, variable soil moisture and water levels. The performance of a grass filter strip may fluctuate with seasons if the growth conditions of vegetation coverage follow distinct seasonal patterns.

5. BMP Monitoring – Filtration Swale

5.1 Introduction and Site Description

This chapter summarizes the hydrologic and water quality data collected from the Filtration Swale (FS) BMP located in NCDOT Division 8 near Troy, NC at the junction of NC 24/7 and NC 109. Site photos are presented in Figure 5.1 and a schematic diagram of the site is given in Figure 5.2.

a) View of Filtration Swale looking towards the swale outlet from NC 24/7. The riprap-lined forebay is in the foreground and NC 109 appears on the left.

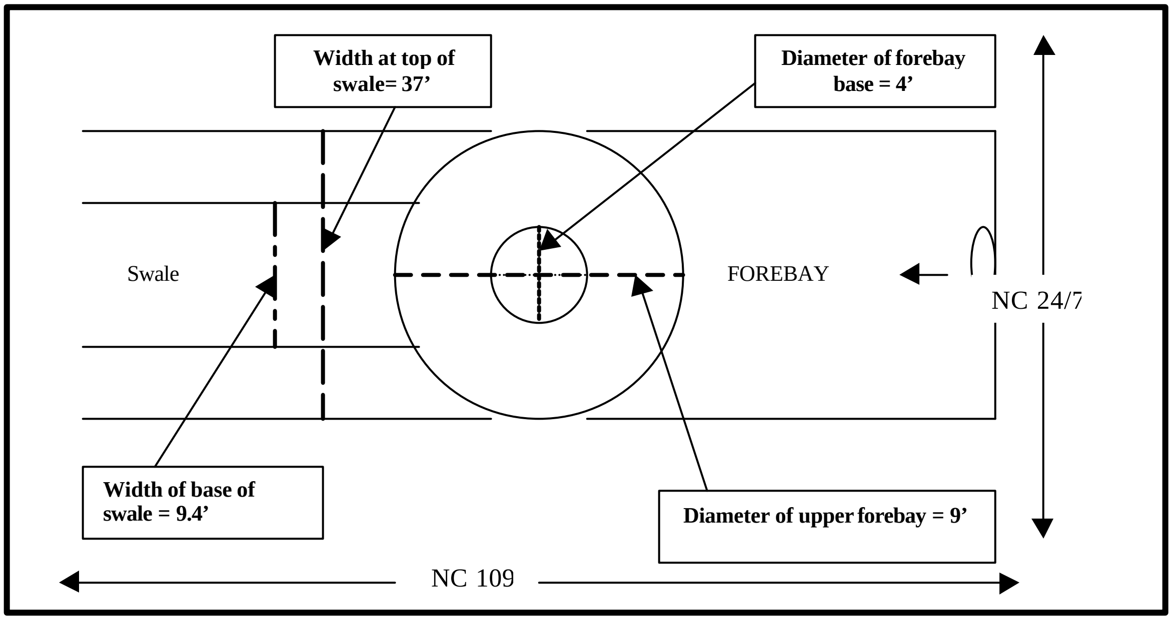
b) View of Filtration Swale outlet weir. The instrumentation enclosure housing the autosampler / flow meter is on the right side of the image and NC 109 appears on the left.

c) View of Filtration Swale 18" inlet culverts and riprap lined forebay. The culvert on the right is non functional. NC 24/7 appears at the top of the image.

d) View of Filtration Swale outlet weir. A 6" perforated pipe drains the crushed rock storage reservoir beneath the swale and exits at the base of the outlet weir. NC 109 appears to the right in the image.

Figure 5.1 Division 8 Filtration Swale Site Photos

1. PLAN VIEW



2. SIDE VIEW

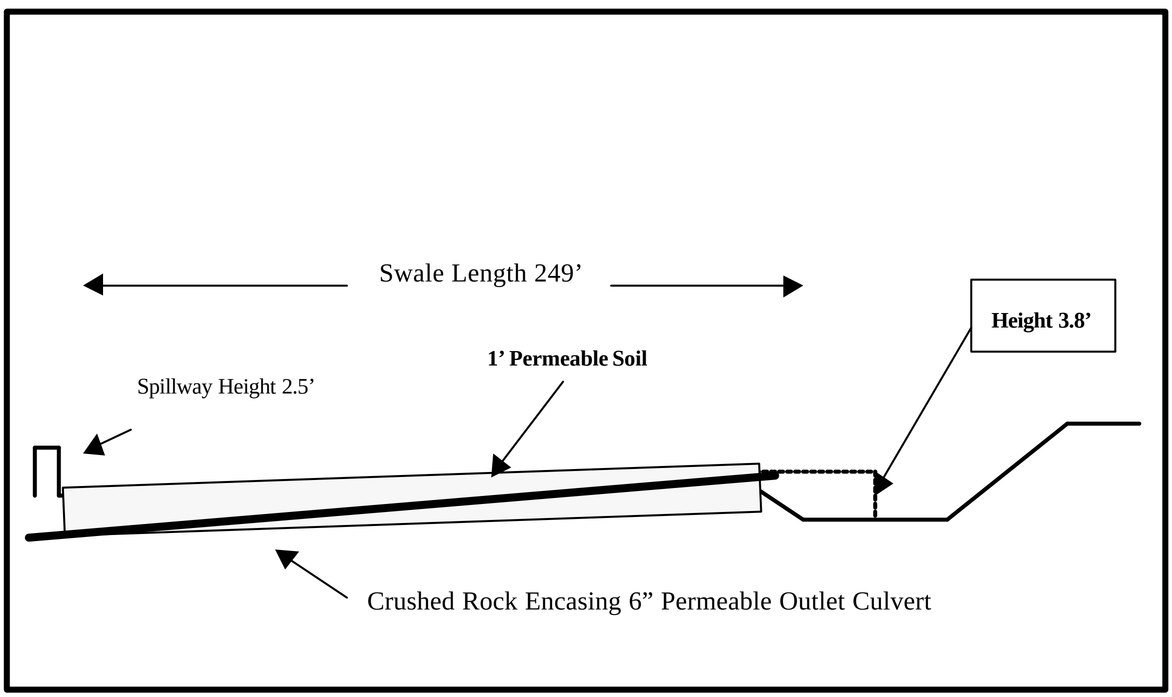


Figure 5.2 Division 8 Filtration Swale Dimensions

The FS collects surface drainage from a total of 108,306 ft^2 (10,062 m^2) of land surface of which 44% is impervious. The BMP is designed to act as a dry infiltration basin. Runoff from a 469 ft (143 m) length of the eastbound lane of NC 24/7 drains directly into a 16.4 ft (5m) wide grassed swale, which is drained by a drop culvert. Runoff from this section of NC 24/7 drains into the forebay of the FS via an 18” (0.46 m) concrete culvert. Sixty-six feet (20 m) of the westbound lane of NC 24/7 drains directly into a 16.4 ft (5 m) wide grassed swale that also empties directly into the FS forebay. Drainage from the junction of NC 24/7 and NC 109 and 262 ft (80 m) of the southbound lane of NC 109 drains directly across a 10 ft (3 m) wide grassed shoulder and into the FS.

The FS riprap lined forebay is designed to settle large particulates and dampen inflow energy to reduce erosion within the structure. Water must rise a total of 3.8 ft (1.17 m) from the bottom of the forebay to enter the FS. The total length of the FS is 249 ft (76m) with a surface slope of 0.008. The vertical structure of the FS consists of a vegetated soil layer approximately 1 ft (0.3 m) deep overlying a permeable geotextile material that overlays a bed of crushed rock of variable thickness. Imbedded within the crushed rock is a perforated 6” (0.15 m) culvert, which drains the structure. A rectangular outlet weir controls surface drainage from the structure with an emergency spillway at 2.5 ft (0.77 m) above the surface of the swale at its outlet.

During the January to December, 2005, monitoring period inflow and/or outflow samples were collected from fifteen precipitation events. Of these precipitation events, samples and discharge were successfully collected at both the outflow and inflow of the treatment BMP from rain events occurring on February 27, March 8, March 31, October 6 and November 27. Hydrologic data has been collected for forty-two rain events including those where water quality data has been collected.

5.2 Methodology

Field Sampling and Monitoring: One 18” inflow culvert and the 6” outflow culvert were monitored with SIGA Max900 autosamplers. The second inflow culvert at this site was not instrumented as its inlet appeared to have been paved over. The inflow sampler collected water samples on a timed basis, with more intensive sampling during the first period of the runoff event and then on a half hourly basis thereafter. The outflow sampler collected a composite runoff sample on a flow proportional basis. Rainfall was collected with a tipping bucket recording rain gage and was logged by the inflow sampler. Water levels in the forebay and within the underlying rock fill were measured continuously with two Druc pressure transducers and were logged with a Campbell Scientific, CR10x data logger. Soil moisture data was continuously recorded with a CS616 reflectometry probe.

Air temperature and relative humidity was recorded with a Vaisala HMP45C sensor and incoming solar radiation is measured with a Li-Cor silicon pyranometer. Soil moisture, air temperature, relative humidity and solar radiation data will be used to construct a more detailed water balances of the FS and will be analyzed in a UNC

Charlotte graduate student thesis currently in progress. Flooding double ring infiltrometers were used to determine infiltration capacities of the swale soils.

Laboratory Analyses: Water samples were retrieved from the field within twenty four to forty eight hours of collection and transferred to UNC Charlotte for analysis. Upon arrival turbidity and specific conductance are measured on unfiltered water samples. An unfiltered sub sample was poured off and frozen for later analysis of total phosphorus. The remaining sample is vacuum filtered and the total suspended sediment content was determined from the volume of water filtered and the dry residue weight remaining on the filter paper. The filtrate was then frozen for subsequent analysis. Ammonium (NH_4-N), nitrate (NO_3-N), and ortho phosphorus (ortho-P) were measured on a Dionex DX 500 ion chromatograph (IC) system using either a CS12a or AS14 analytical column for cation and anion determinations, respectively. Total nitrogen (TN) and dissolved organic carbon (DOC) were measured after thermo-combustion on a Shimadzu TOC-V system with a TN module. Total phosphorus was measured colormetrically on both filtered and unfiltered samples after a heated acid/persulphate digestion. With the above analytical procedure the two dissolved inorganic nitrogen species NO_3-N and NH_4-N are directly measured and dissolved organic nitrogen can be estimated as the difference of TN – (NO_3-N + NH_4-N). Our analytical scheme directly measures ortho phosphate. Particulate bound phosphorus can be estimated from the difference of $TP_{(unfiltered)} - TP_{(filtered)}$. The colloidal unreactive fraction of phosphorus is determined as the difference between $TP_{(filtered)}$ and ortho-P. The detection limit for ortho-P in the Dionex was approximately 0.15 mg/L. Where the concentrations of the dissolved total fraction were less than this, we report the ortho-P concentration as less than 0.15 mg/L.

Water Balance Analysis: In order to account for runoff inputs not entering the FS from the forebay culvert we have used the water level data recorded from the forebay and within the FS swale itself to adjust recorded flow rates at the inflow and outflow culverts to known storage changes within the BMP. Elevation and BMP dimensions were determined from an intensive field topographic level survey and used to construct stage/volume curves for both the forebay and the FS itself. A porosity value of 0.4 was used when accounting for changing water volumes within the crushed rock reservoir underlying the BMP (Freeze and Cherry 1979). Water retention within the BMP was determined as the difference in storage change from the beginning of the runoff event until the cessation of runoff from the outlet culvert. When rain events occurred on the FS with water still draining from a previous event, the event duration was determined by the return of water levels to those measured prior to the event. No hydrologic retention was attributed to these events.

5.3 Results

Hydrology: Infiltration capacities measured for the FS soils ranged from 4.7 to 7.1 in/hr (0.12 to 0.18 m/hr). The forebay water level record for the entire 2005 monitoring period is presented in Figure 5.3.

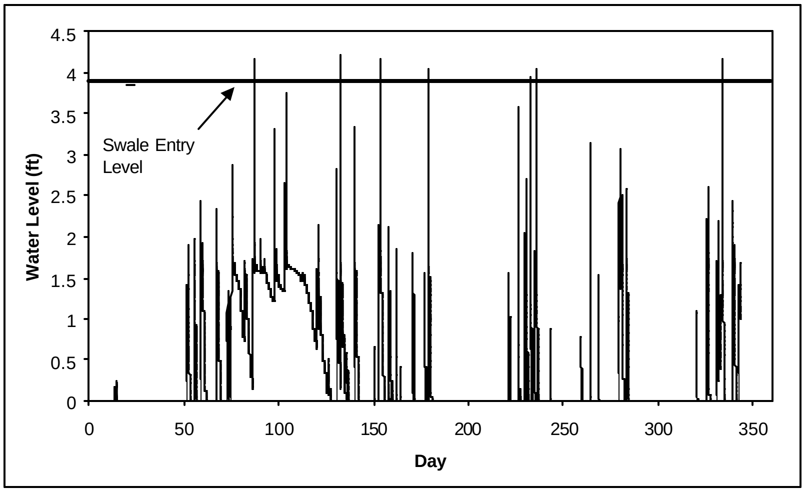


Figure 5.3 2005 Division 8 Filtration Swale Water Level

Water filled the forebay and entered the FS at least seven times during the 2005 monitoring period but the water level was always well below the spillway outlet. Water level data are missing from Days 19 to 48 and 181 to 214 so it is possible water may have also flooded into the FS during these periods. The maximum depth of flooding within the FS was approximately 4” on day 132. Water levels generally drained to zero in one to three days after each precipitation event except for the day 75 to 127 period where the forebay continuously remained at least partially filled. The most likely explanation for this period of inundation is that evaporation rates were low enough during this period to allow water to accumulate given the precipitation frequency and magnitude during this time period.

The cumulative precipitation, inflow and outflow hydrographs and water levels recorded for events where water quality data was collected for both the inflow and outflow of the FS is presented in Figures 5.4-5.8.

The water quality analyses of bulk precipitation, inflow and outflow samples are presented in Tables 5.1, 5.2 and 5.3, respectively. A total of 127 water quality samples were collected from the Division 8 BMP during the twelve-month monitoring period. Each of the inflow samples reported in Table 5.2 is a calculated composite of up to twenty-four sequential samples collected during each event.

The bottom elevation of the swale water level well was approximately 12.6” (32 cm) above the forebay base elevation. The water table response in the forebay and swale were generally synchronous with a maximum of a 15 minute time lag between the two water levels (Figures. 5.4-5.8). Surprisingly, despite the close coupling between the swale and forebay water level responses there is a significant time lag between the peak inflow and outflow responses. Under dry antecedent moisture conditions the basin time lag was approximately 3.5 hours (Figures 5.4 and 5.5). Under wet conditions this lag declined to approximately 55 minutes (Figure 5.6). The total runoff volume retained within the FS for the events depicted above varied between 0 ft^3 (Figure 5.6) and 400 ft^3

(11.3 m^3) of water (Figure 5.4). The calculation of runoff retention within the FS is determined by the antecedent moisture conditions within the FS prior to the runoff event but also by the accuracy of the post built site survey and porosity chosen to represent the storage volume within the crushed rock reservoir underlying the BMP.

Water Quality: Water quality data for bulk precipitation and inflow and outflow runoff are presented in Tables 5.1, 5.2 and 5.3, respectively. The net retention or export of selected water quality parameters is presented in Table 5.4. Box and Whisker Plots summarizing the data in Tables 5.1 to 5.3 are presented in Figures 5.9 to 5.20. Analysis of the water quality data collected at the Division 8 site should be tempered by the relatively small size and the unbalanced seasonality of the sample collection at this site. Atmospheric nitrogen deposition appears to be dominated by inputs of the inorganic species NH_4-N and NO_3-N (Table 5.1). In most precipitation samples NH_4-N concentrations were over 2x greater than NO_3-N concentrations. We have not calculated an organic N fraction for the Bulk Precipitation samples at this site, as there appears to have been an incomplete oxidation and combustion of the high NH_4-N levels with the Shimadzu TN system. The result is that the sum of the inorganic fraction often exceeds that of the TN measured. This does not seem to be an issue in the FS inflow and outflow samples where the NH_4-N levels were much lower. Atmospheric phosphorus inputs at this site appear to be equally divided between particulate and dissolved fractions.

Table 5.1 Division 8 Bulk Precipitation

	Depth (Inches)	Turbidity NTU	Conductivity µS	TSS mg/L	NH_4-N mg/L	NO_3-N mg/L	TN mg/L	ortho-P mg/L	TP_F mg/L	TP mg/L	DUP mg/L	Part. P mg/L	DOC mg/L
02/25/05	0.43	1.82	16.9	7.2	1.17	0.47	0.853		0.09	0.21		0.12	2.20
02/27/05	0.60			31.1	0.00	0.17	0.290	<0.15	0.08	0.26		0.18	1.10
03/08/05	0.82			9.2	1.69	0.26	0.501	<0.15		0.28		0.28	1.88
03/16/05	1.44			37.4	1.15	0.25	0.464	<0.16	0.08	0.09		0.01	1.39
03/22/05	1.17			34.4	0.12	0.61	1.353	0	0.08	0.51	0.08	0.43	1.92
03/27/05	1.34				1.67	0.24	0.856	0	0.08	0.22	0.08	0.14	1.44
04/12/05	2.87			112.4	0.84	0.4	0.782	0.15	0.25				4.02
05/20/05	0.44	2.31	25.3	6.0									
06/01/05	2.91		25.3	98.0			0.654						6.48
10/07/05	1.83	1.64	9	1.2	0.31	0.08	0.159	0.16	0.16	0.16	0	0.00	1.35
Average		1.9	19.1	37.4	0.87	0.31	0.7	0.08	0.12	0.25	0.05	0.17	2.42
STD		0.35	7.83	40.85	0.67	0.17	0.36	0.09	0.07	0.13	0.05	0.15	1.75

DUP is dissolved unreactive phosphorus = TP_F - ortho-P TP_F is TP (filtered)
Part. P is particulate phosphorus = TP – TP_F.
Blanks are missing values.

Ammonium levels appear to decline in surface runoff inputs to the FS while NO_3-N concentrations remained relatively constant and the organically complexed fraction increased over atmospheric inputs (Tables 5.1 and 5.2). Total phosphorus concentrations in surface runoff increased significantly over atmospheric deposition with the DUP (dissolved unnreactive) and Part. P (particulate fractions) both increasing. As could be expected inflow runoff TSS concentrations and DOC concentrations both increased significantly over those measured in Bulk Precipitation samples. The DOC analysis is a non-specific test for the presence of organic carbon. Carbon containing compounds that could be expected to contribute to the DOC total include both natural compounds such as tannins and organic acids released from decomposing vegetation and anthropogenic compounds such as oil and grease and combustion products. Declines in DOC concentration in the FS outflow may therefore represent declines in the concentration of these anthropogenic compounds and/ or naturally occurring humic substances.

Turbidity levels, TSS, NH_4-N and DOC concentrations all appeared to decline in the Division 8 FS in relation to surface water inputs (Tables 5.2 and 5.3, Figures 5.9, 5.11, 5.12 and 5.13). Conductivity, organic N, ortho-P, DUP and TP all appeared to increase in concentration over inflow concentrations (Figures 5.10, 5.15, 5.17, 5.18 and 5.20). Nitrate, TN and Part P. concentrations appear to be similar between surface water inflow and outflow from the FS (Figures 5.14, 5.16 and 5.19). The settling of particulates in the FS forebay in conjunction with the infiltration of surface runoff through the vegetated soil cover and underlying gravel layer appears to effectively clarify runoff and retains particulates at this site. During the 2005 monitoring period approximately 8" (20 cm) of particulates had accumulated at the base of the FS forebay (Allan field observation). There appears to be significant retention of NH_4-N within the FS either through biotic (vegetative uptake) or inorganic retention (cation exchange). Despite the apparent retention of NH_4-N within the FS TN concentrations did not appear to decline as a result of increased concentrations of organically complexed N in outflow waters. The source of the organic N within the FS is likely decomposing vegetative and microbial matter. The relatively unchanged NO_3-N concentrations in inflow and outflow waters suggest that vegetative uptake and denitrification within the FS is relatively unimportant. Perhaps surprisingly TP appeared to increase in FS outflow waters over inflow waters. The DUP and ortho P fraction both appeared to increase in concentration after runoff passed through the FS. It is quite possible that dissolved P concentrations are influenced by adsorption/desorption reactions within the FS. A graduate student at UNC Charlotte will be conducting a series of batch experiments to determine the potential for phosphorus release or uptake by soils and sediments within this BMP during 2006. DOC concentration appeared to decline by approximately 30% over inflow concentration, which may represent the retention of anthropogenic and/or natural carbon containing compounds within the FS.

Table 5.2 Filtration Swale Inflow Samples

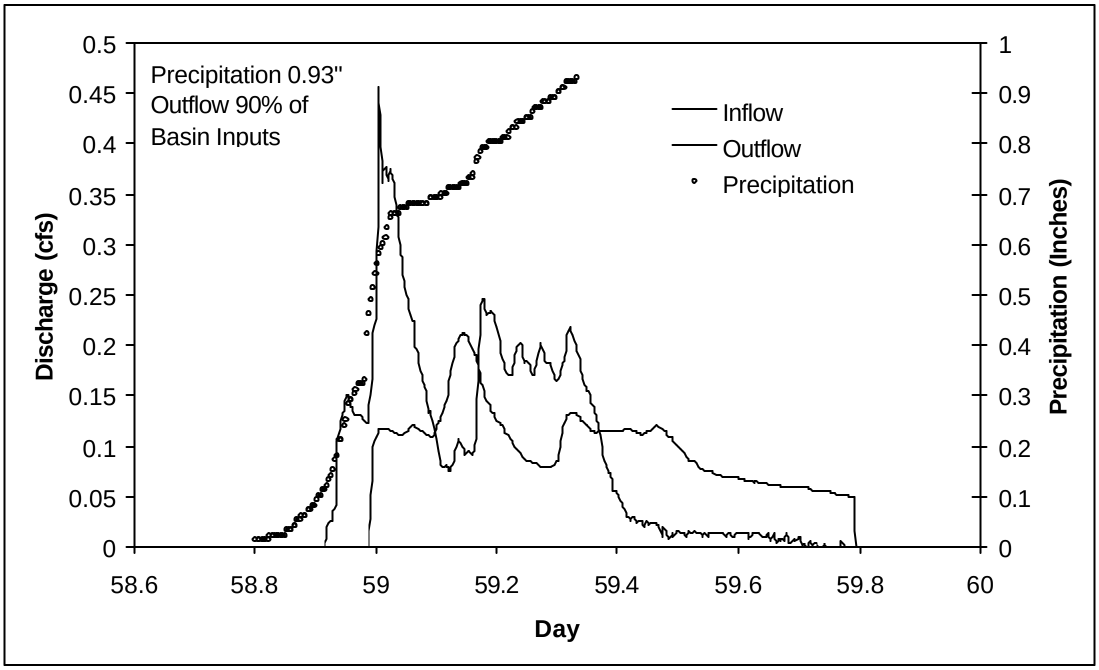
	Turbidity NTU	Conductivity µS	TSS mg/L	NH_4-N mg/L	NO_3-N mg/L	TN mg/L	Org-N mg/L	ortho-P mg/L	TP_F mg/L	TP mg/L	DUP mg/L	Part. P mg/L	DOC mg/L
02/27/05	41.9	55.8	15.3	0.00	0.49	1.576	1.086		0.51	0.63		0.12	5.36
03/08/05	108.6	54.1	132.8	0.31	0.57	1.130	0.253	0.00	0.25	0.72	0.25	0.47	8.17
03/16/05	84.0	34.7	71.0	0.30	0.26	0.824	0.264	0.16	0.40	0.49	0.24	0.09	7.86
03/27/05	168.0	43.1	590.7	0.04	0.38	1.064	0.646	0.17	0.23	1.63	0.06	1.40	8.55
03/31/05	40.3	49.4	468.3	0.47	0.15	0.611	0.000	0.20	0.37		0.17		9.56
04/12/05	17.7	38.7	14.8	0.34	0.04	0.630	0.250	0.15	0.27	0.49	0.12	0.21	19.41
06/01/05		184.4	27.6			1.820							22.24
06/10/05	64.6	56.9		0.18	1.67	1.885	0.038	0.25	0.96	1.11	0.71	0.15	10.24
09/26/05	2.2	89.0	7.7	1.07	0.05	0.643	0.000	0.20	0.50	0.54	0.30	0.04	13.24
10/06/05	39.9	34.9		0.00	0.29	0.574	0.284	0.18	0.36	0.53	0.18	0.17	9.89
11/27/05	4.9	73.25	14.5	1.76	0.34	2.006	0.000	0.35	0.93	0.38	0.58		10.85
Average	57.2	64.9	149.2	0.45	0.42	1.160	0.282	0.18	0.48	0.72	0.29	0.33	11.40
STD	51.5	42.9	221.4	0.56	0.47	0.563	0.346	0.09	0.23	0.40	0.22	0.45	5.10

Org-N = TN – NH_4-N + NO_3-N.
DUP is dissolved unreactive phosphorus = TP_F - ortho-P.
Part. P is particulate phosphorus = TP - TP_F. TP_F is TP (filtered)
Blanks are missing values.
Inflow concentrations for the 10/6/05 precipitation event were determined from a forebay sample during the event as the inflow auto sampler failed to collect samples during this precipitation event.

Table 5.3 Filtration Swale Outflow Samples

	Turbidity NTU	Conductivity µS	TSS mg/L	NH_4-N mg/L	NO_3-N mg/L	TN mg/L	Org-N mg/L	ortho-P mg/L	TP_F mg/L	TP mg/L	DUP mg/L	Part. P mg/L	DOC mg/L
02/24/05	55.8	56.0	20.8	0.00	0.49	0.87	0.379	1.22	0.88	1.12		0.24	9.84
02/27/05	24.2	51.4	8.0	0.06	0.17	1.11	0.880	0.15	1.15	1.59	1.00	0.44	7.52
03/08/05	45.3	44.0	17.5	0.00	0.12	0.53	0.408	0.24	0.64	0.73	0.40	0.09	7.98
03/24/05	7.2	95.0	4.5	0.00	0.76	3.98	3.216	0.33	0.96	1.27	0.63	0.31	7.83
03/31/05	19.2	69.1	14.9	0.00	0.63	0.90	0.271	0.20	0.44		0.24		5.96
05/05/05	25.8	104.1	43.9	0.25									
10/06/05	34.1	57.1	37.9	0.25	0.50	0.79	0.041	0.30	0.78	1.01	0.48	0.23	10.44
12/05/05	11.7	39.4	4.4	0.00	0.10	0.38	0.283	0.18	0.27	0.29	0.09	0.02	5.04
Average	27.9	64.5	19.0	0.07	0.40	1.22	0.78	0.37	0.73	1.00	0.47	0.22	7.80
STD	16.5	23.5	14.8	0.11	0.27	1.24	1.10	0.38	0.30	0.45	0.32	0.15	1.92

Org-N = TN – NH_4-N + NO_3-N.
DUP is dissolved unreactive phosphorus = TP_F - ortho-P.
Part. P is particulate phosphorus = TP - TP_F. TP_F is TP (filtered)
Blanks are missing values.



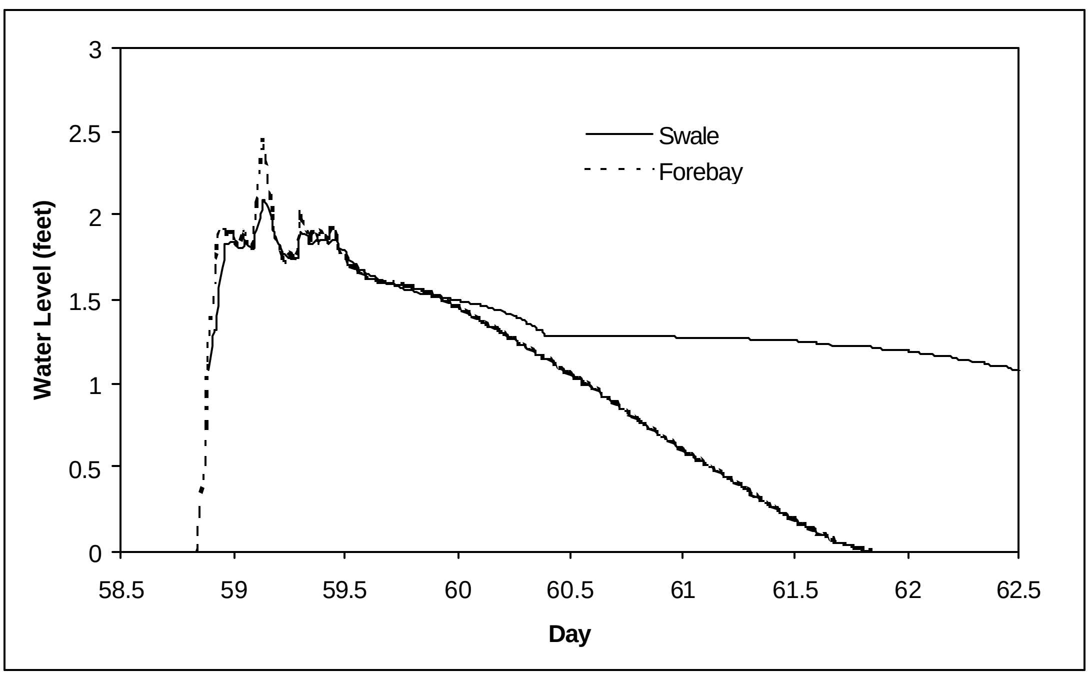
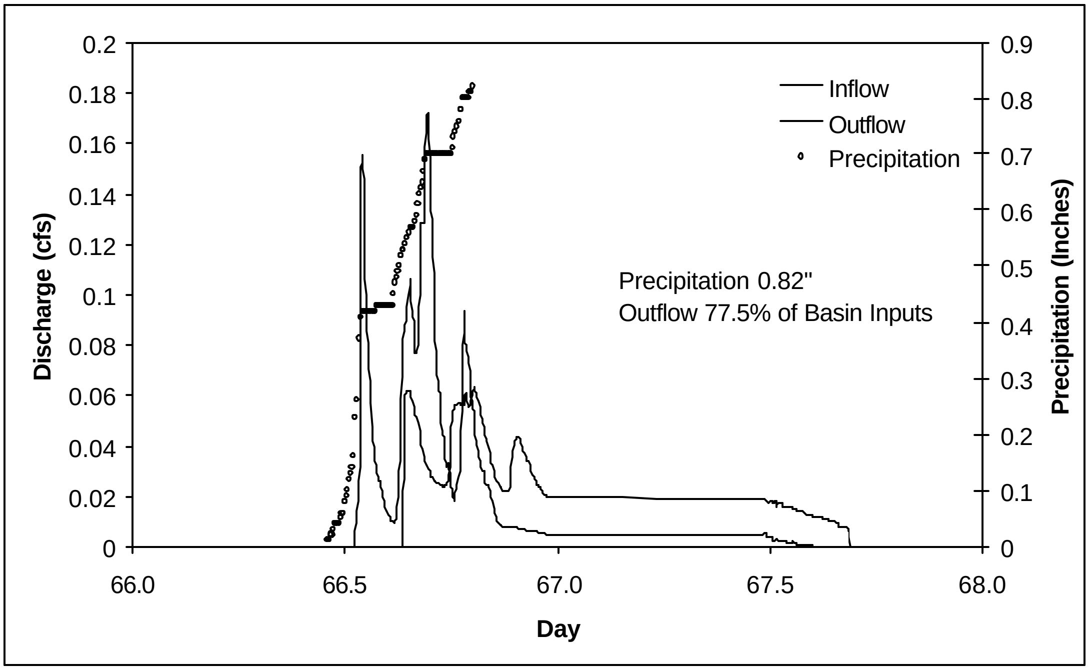


Figure 5.4 Division 8 Filtration Swale Inflow and Outflow Hydrographs and Water Levels February 27 to March 3, 2005.



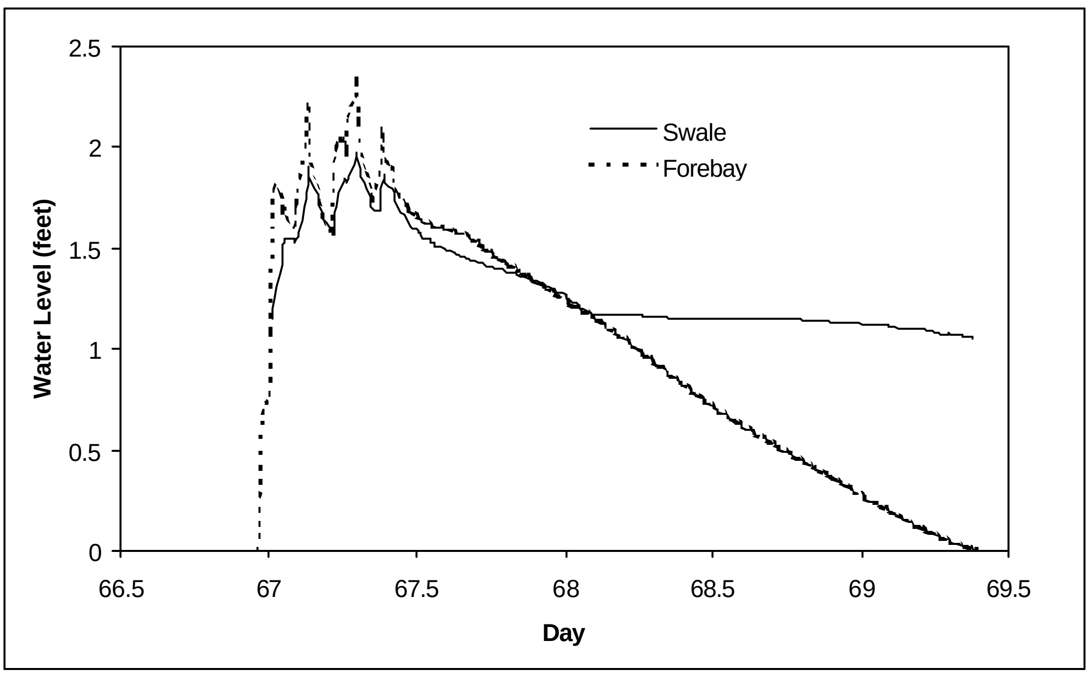
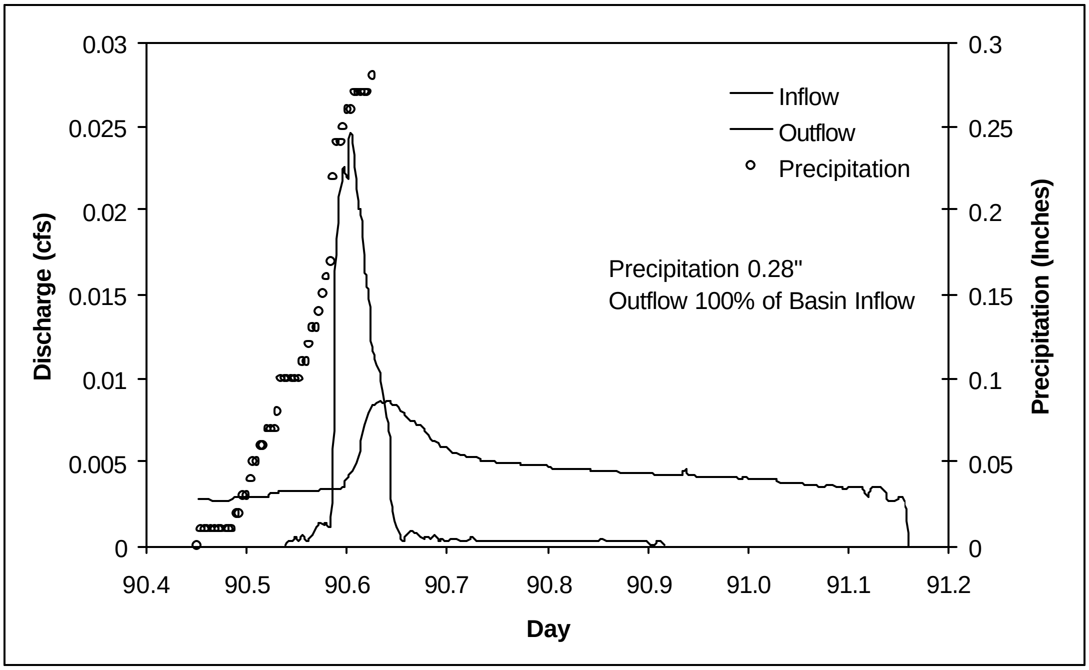


Figure 5.5 Division 8 Filtration Swale Inflow and Outflow Hydrographs and Water Levels March 7 to March 10, 2005



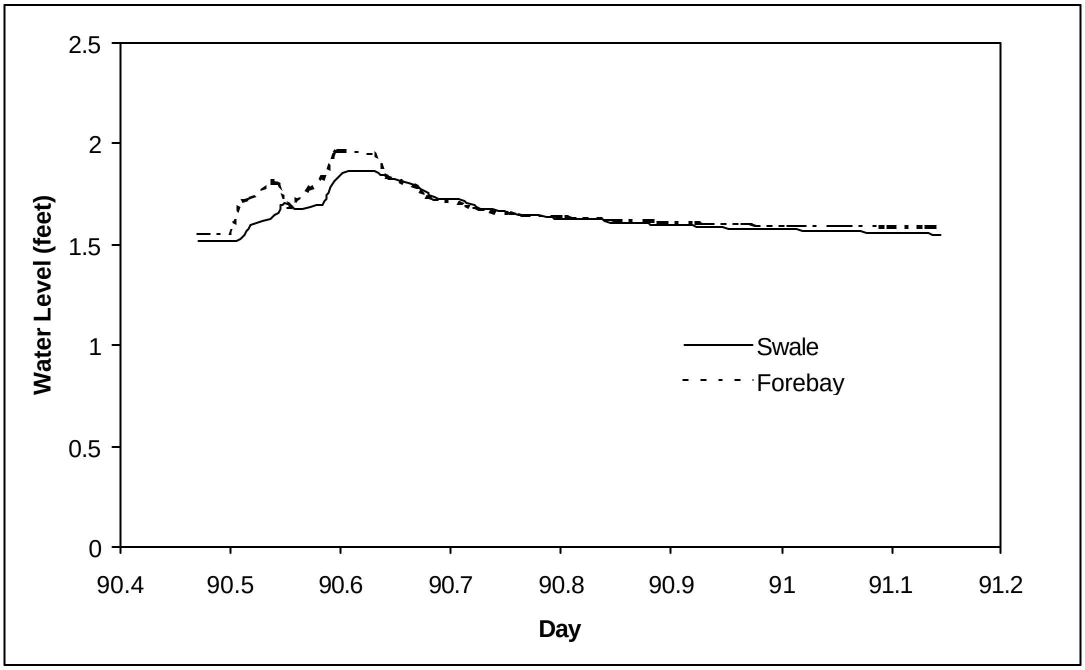
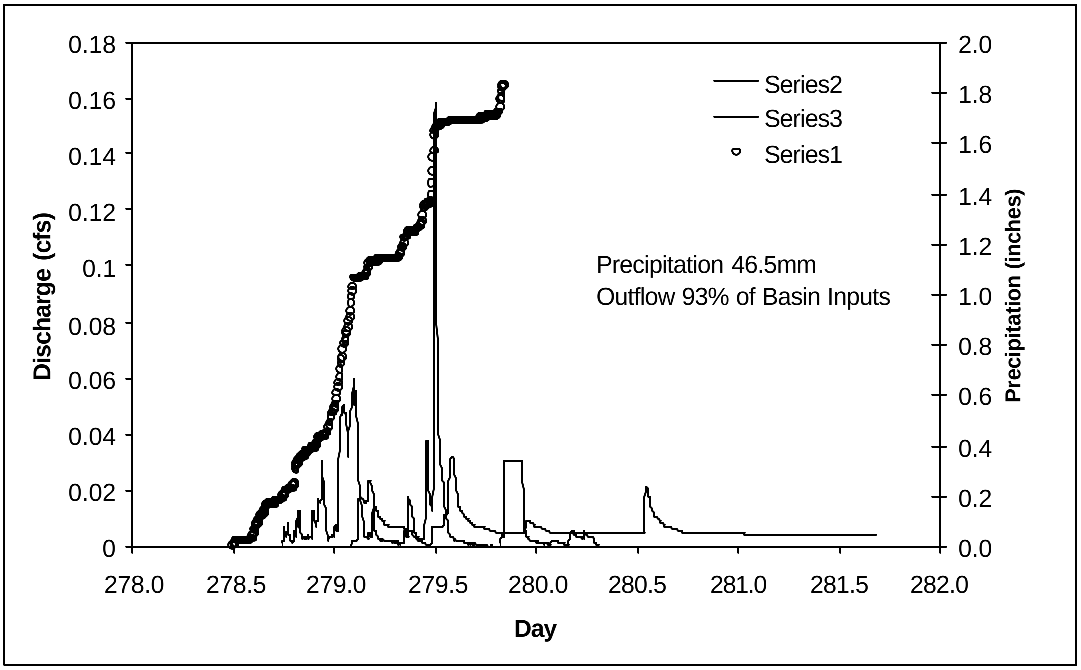


Figure 5.6 Division 8 Filtration Swale Inflow and Outflow Hydrographs and Water Levels March 31 to April 1, 2005



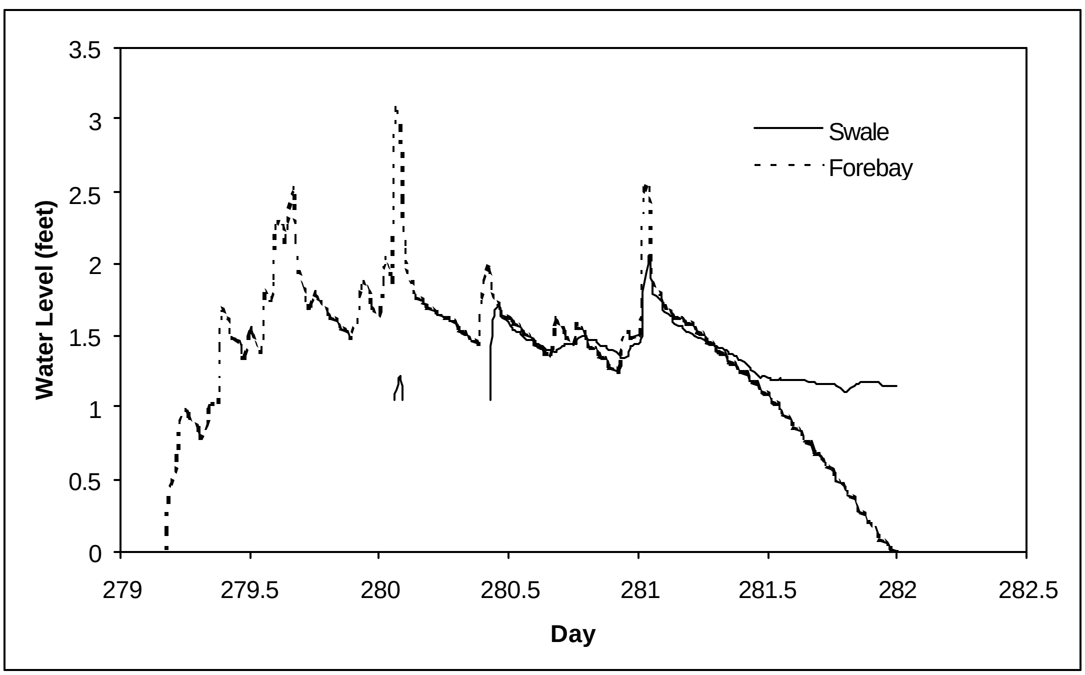
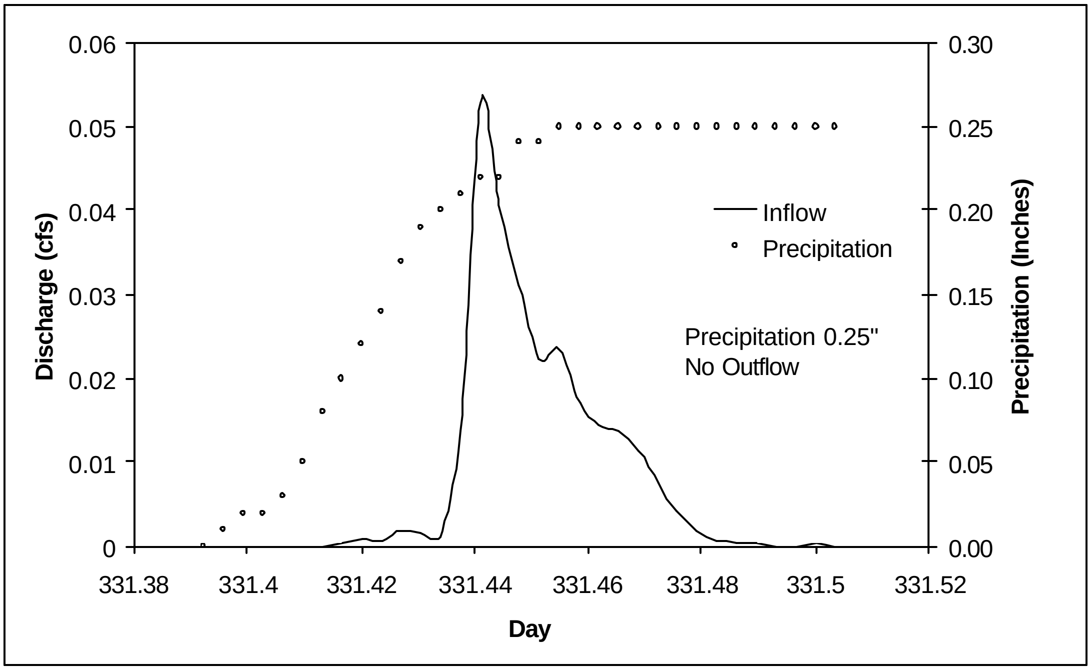


Figure 5.7 Division 8 Filtration Swale Inflow and Outflow Hydrographs and Water Levels October 5 to October 9, 2005



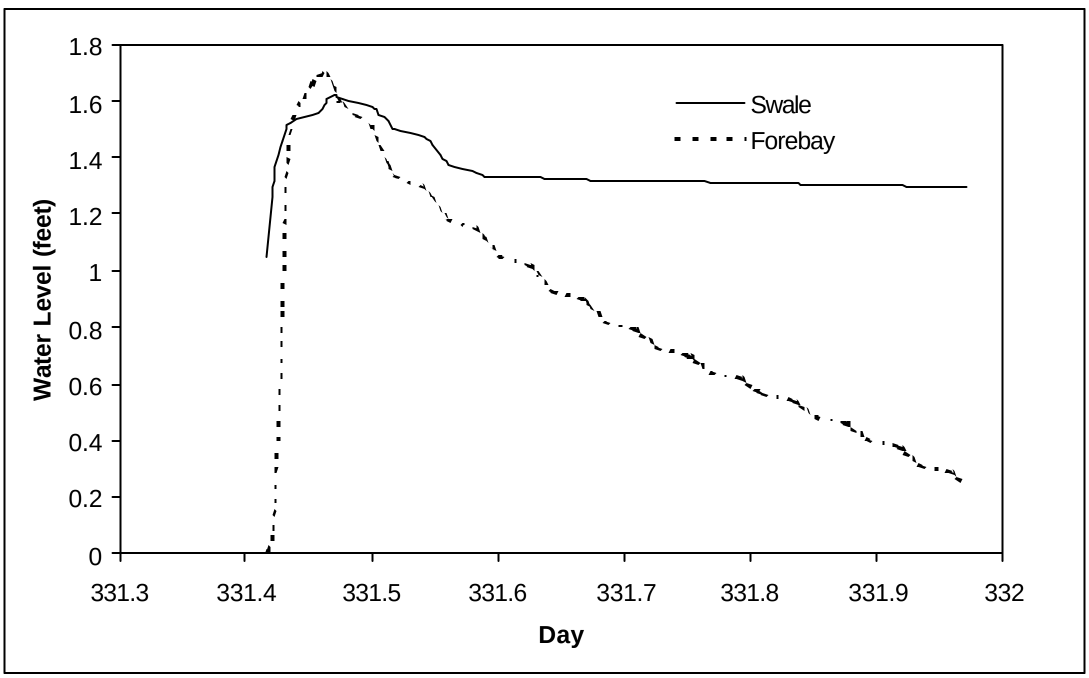


Figure 5.8 Division 8 Filtration Swale Inflow and Outflow Hydrographs and Water Levels November 27, 2005

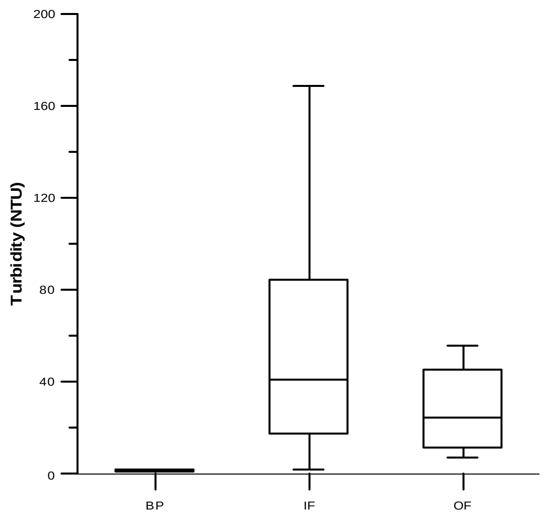


Figure 5.9 Turbidity

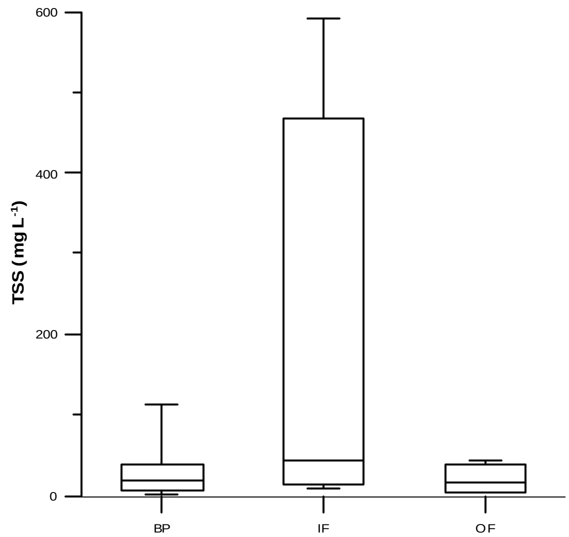


Figure 5.11 Total Suspended Solids

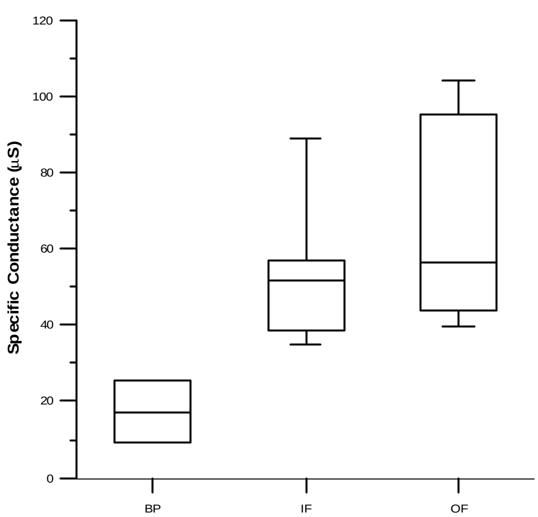


Figure 5.10 Specific Conductance

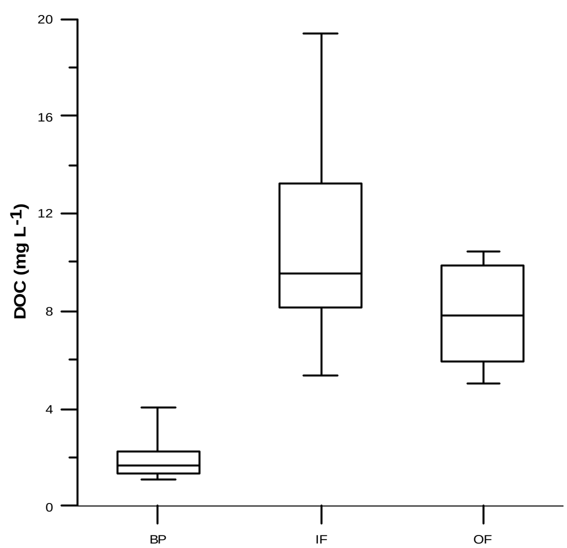


Figure 5.12 Dissolved Organic Carbon

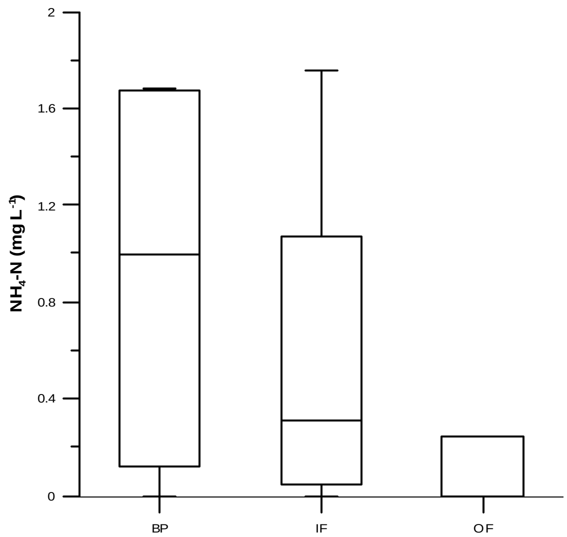


Figure 5.13 Ammonium

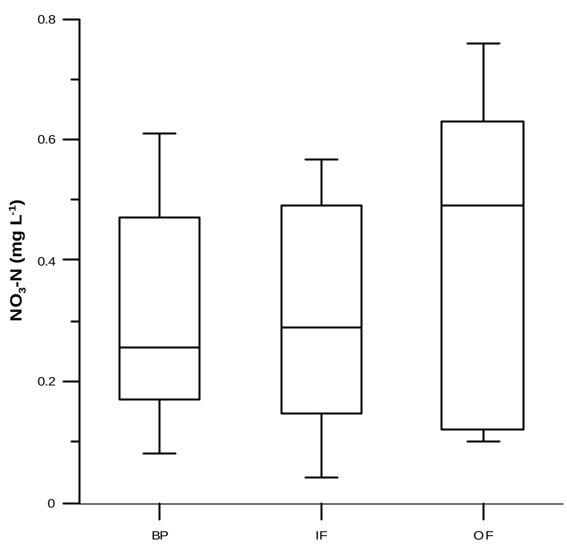


Figure 5.14 Nitrate

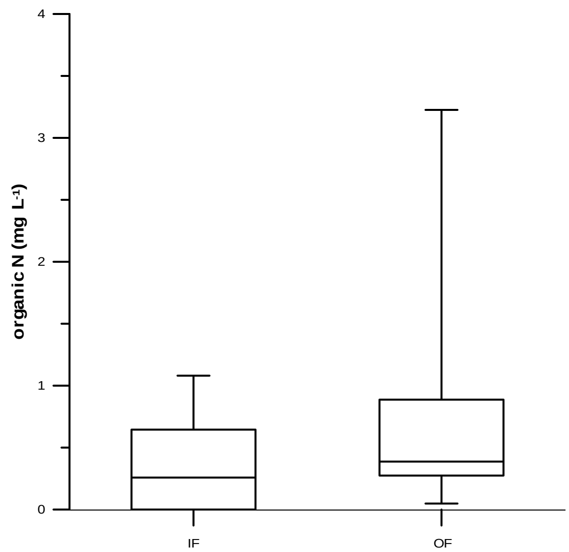


Figure 5.15 Organic Nitrogen

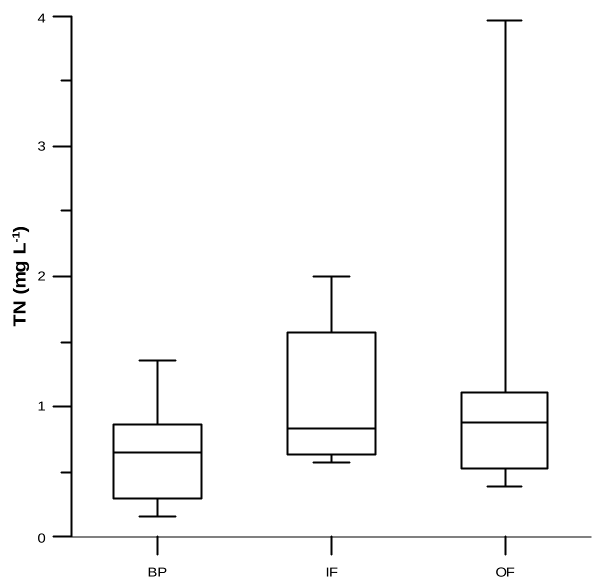


Figure 5.16 Total Nitrogen

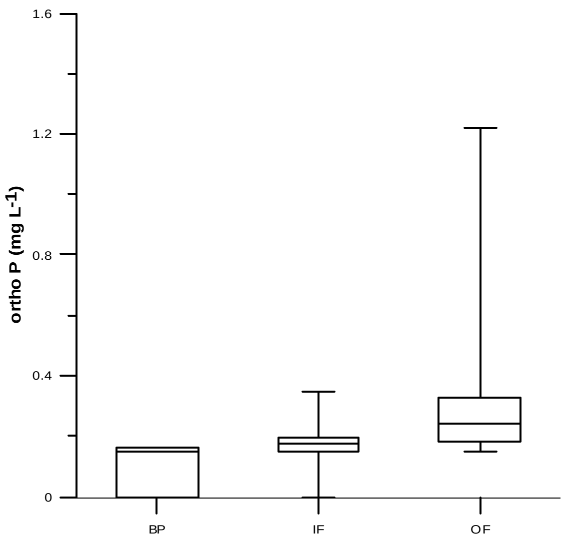


Figure 5.17 ortho Phosphorus

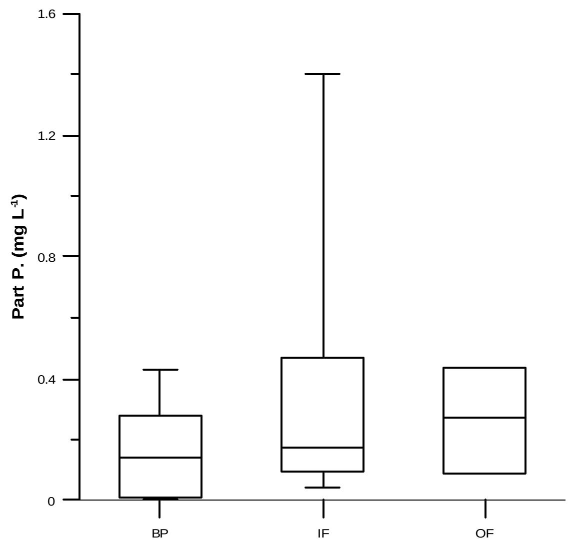


Figure 5.19 Particulate Phosphorus

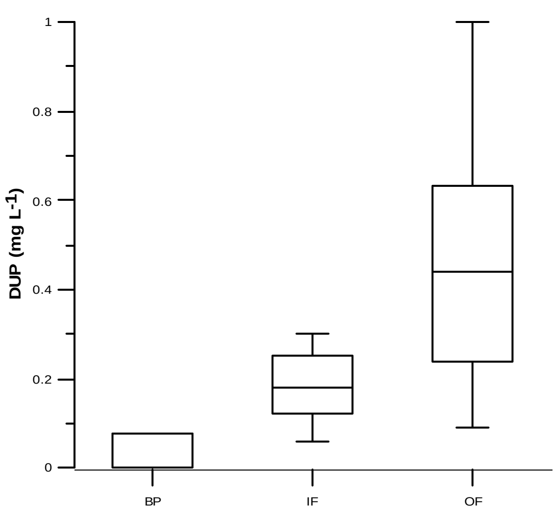


Figure 5.18 Dissolved Unreactive Phosphorus

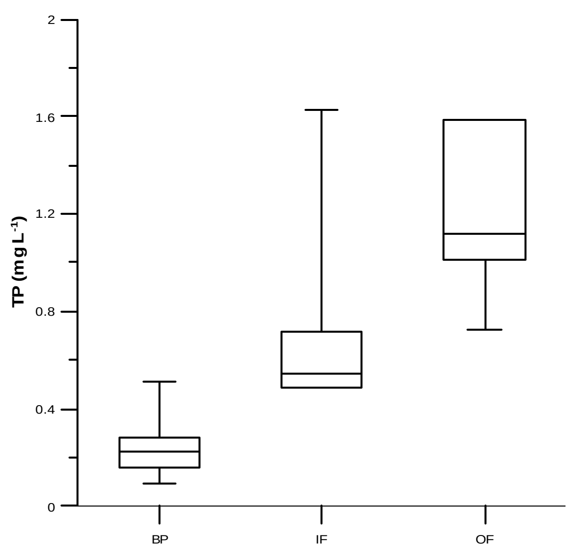


Figure 5.20 Total Phosphorus

The net retention of most nutrients and DOC for the runoff events examined in Table 5.4 is extremely variable. The only consistent trends exhibited are the net retention of TSS in all storms and the net export of DUP and ortho P for those events that generated an outflow from the FS. The FS BMP at the Division 8 site appears to be effective at reducing downstream loadings of TSS and NH_4-N but displays little impact in reducing either NO_3-N or TN levels in highway stormwater runoff. The FS appears to be a net source of TP to downstream waters. Both the DUP and ortho-P fraction appear to be elevated in outflow waters in relation to stormwater inputs. At this point it is unclear what the source of dissolved phosphorus is within the infiltration swale. The most likely in basin source of P is from the desorption of particulate bound phosphorus from deposited runoff sediments and/or desorption from swale soils. Nutrient retention within the FS will be maximized under dry antecedent conditions for small precipitation events when available water storage is highest. The maximum runoff storage retained for the events examined to date was approximately 530 ft^3 ($15 m^3$) of water. Under wet antecedent conditions runoff yields near 100% were observed for precipitation events as small as 0.28” (7 mm). Under these conditions potential nutrient retention through runoff reduction will be minimal.

Table 5.4 Filtration Swale Water Quality Treatment

	Hydrologic Retention % of inflow	TSS %R	NH_4-N %R	NO_3-N %R	TN %R	organic N %R	ortho-P %R	TP_F %R	TP %R	DUP %R	Part. P %R	DOC %R
02/27/05	10.0	52.6	-100.0	68.8	36.4	27.1		-102.9	-127.1		-230.0	-26.2
03/08/05	22.5	88.5	100.0	81.5	59.1	-41.3	-100.0	-122.4	11.3	-39.0	83.2	14.6
03/31/05	0.0	96.8	100.0	-331.2	-47.4	100.0	-2.4	-19.9		-39.9		37.6
10/06/05	7.0		-100.0	-60.3	-27.6	86.6	-55.0	-101.5	-77.2	-148.0	-25.8	1.8
11/27/05	100.0	100	100	100	100	100	100	100	100	100	100	100

Positive values indicate a net retention while negative values represent a net export. Both are expressed as a percentage of the total input.
Blanks are missing values.

6. BMP Monitoring - Grassed Shoulder

This chapter summarizes the water quality data sampled from the grassed shoulder and swale that collects runoff from NC-29 immediately north of its junction with W.T. Harris Blvd in Charlotte, NC. Surface flow samples from the grassed shoulder have been collected for eight rain events. Of these eight events five events: July 31, August 8, September 17, October 6 and November 29 generated coincident road surface runoff and overland flow runoff samples from the grassed swale (Table 6.2). Events on February 14, April 22, June 28 and July 4 generated samples from the grassed swale only. Water quality and hydrologic data has also been collected for twelve rain events for runoff from the Highway 29 bridge deck located immediately south of the Highway 29 grassed swale sampling location. This data will be analyzed as part of a UNC Charlotte graduate student thesis during the spring and summer semesters of 2006. Two of the bridge deck sampling events (April 22 and October 6) were coincident with samples collected from the grassed swale site.

6.1 Methodology

Field Sampling and Monitoring: Water draining from the Hwy 29 bridge deck is collected in a 12” drainage culvert that empties into a 90^{o} v-notch weir that is monitored with a SIGA Max900 auto sampler. The bridge deck sampler collects sequential water samples on a timed basis. Rainfall is collected with a tipping bucket recording rain gage and is logged by the bridge deck auto sampler. Stormwater draining directly from the Highway 29 road surface is collected in a 2” perforated PVC pipe that parallels the road surface for approximately 8’ (Figures 6.1 and 6.2). The pipe then turns at a right angle and drains into a collecting bottle. Runoff draining from the road surface and moving through the grassed shoulder as overland flow is collected along two transects oriented perpendicular to the road surface. Overland flow is intercepted by plastic fencing installed perpendicular to the slope and ending in plastic collecting vessels installed below ground level. The first transect (Slope 1) is 29 ft (8.8 m) in length and has a slope of 0.3. The second transect (Slope 2) is 27.2 ft (8.3 m) in length and has a slope of 0.07. Samples are collected at 9.5 ft, (2.9 m), 18.4 ft (5.6 m) and 29 ft (8.8 m) from the road surface for transect S1 and 9.5 ft (2.9 m), 17.7 ft (5.4 m) and 27.2 ft (8.3 m) from the road surface for transect S2. Samplers were offset from one another so as to not interfere with collectors located further down slope along the grassed swale. Flooding double ring infiltrometers were used to determine infiltration capacities of the road shoulder soils.

Laboratory Analyses: Water samples are collected from the field within forty-eight hours of collection and transferred to UNC Charlotte for analysis. Upon arrival turbidity and specific conductance are measured on unfiltered water samples. An unfiltered sub sample is poured off and frozen for later analysis of total phosphorus. The remaining sample is vacuum filtered and the total suspended sediment content is determined from the volume of water filtered and the dry residue weight remaining on the filter paper. The filtrate is then frozen for subsequent analysis. Ammonium (NH_4-N), nitrate (NO_3-N), and ortho-phosphorus (orth-P) are measured on a Dionex 500 ion chromatograph (IC) system using either a CS12a or AS14 analytical column for cation and anion determinations, respectively. Total nitrogen (TN) and dissolved organic carbon are measured after thermo-combustion on a Shimadzu TOC-V system equipped with a TN module. Total phosphorus is measured colormetrically on both filtered and unfiltered samples after a hot acid/persulphate digestion. With the above analytical procedure the two dissolved inorganic forms NO_3-N and NH_4-N of nitrogen are directly measured and organic nitrogen can be estimated as the difference of TN – (NO_3-N + NH_4-N). Our analytical scheme directly measures ortho P. Particulate bound phosphorus can be estimated from the difference of $TP_{(unfiltered)} - TP_{(filtered)}$. The colloidal unreactive fraction of phosphorus is determined as the difference between $TP_{(filtered)}$ and ortho-P. Turbidity and specific conductance measurements were not made on samples where sample volume was a consideration in the completion of the analysis of other higher priority water quality constituents.

a) Monitoring site facing W.T. Harris Blvd and the northbound on ramp to W.T. Harris Blvd. The S2 (low slope) monitoring transect is near the junction of the two roadways. Drainage from the enclosed basin is through a drop culvert obscured by the shrub in the middle of the image.

b) Close up view of S1 (steep slope) monitoring transect. Collectors are obscured by the vegetation but are marked by the light colored stakes. W.T. Harris Blvd. is to the left in the image.

Figure 6.1 Site Photos of W.T. Harris Grassed Shoulder Monitoring Site

6.2 Results

The measured infiltration capacities for the road shoulder soils at the highway 29 site were extremely low with a mean of 0.2 $\pm$ 0.2 in/hr (0.5 $\pm$ 0.5 cm/hr), n = 7. In areas of low infiltration capacity overland flow could be generated by relatively low rainfall intensities. In these same areas there would be little opportunity for infiltration and hydraulic retention of overland flow generated from the impervious portions of the Highway 29 road corridor. From field observations it appeared that for the most part, stormwater runoff from the Highway 29 road surface traveled in discrete surface flow lines rather than as widespread overland sheet flow. Wheel ruts and other microtopographic features appeared to be primarily responsible for the rapid development of concentrated flow at this site. The occurrence of concentrated flow within a few feet of the roadside would further limit the potential for infiltration loss at this site.

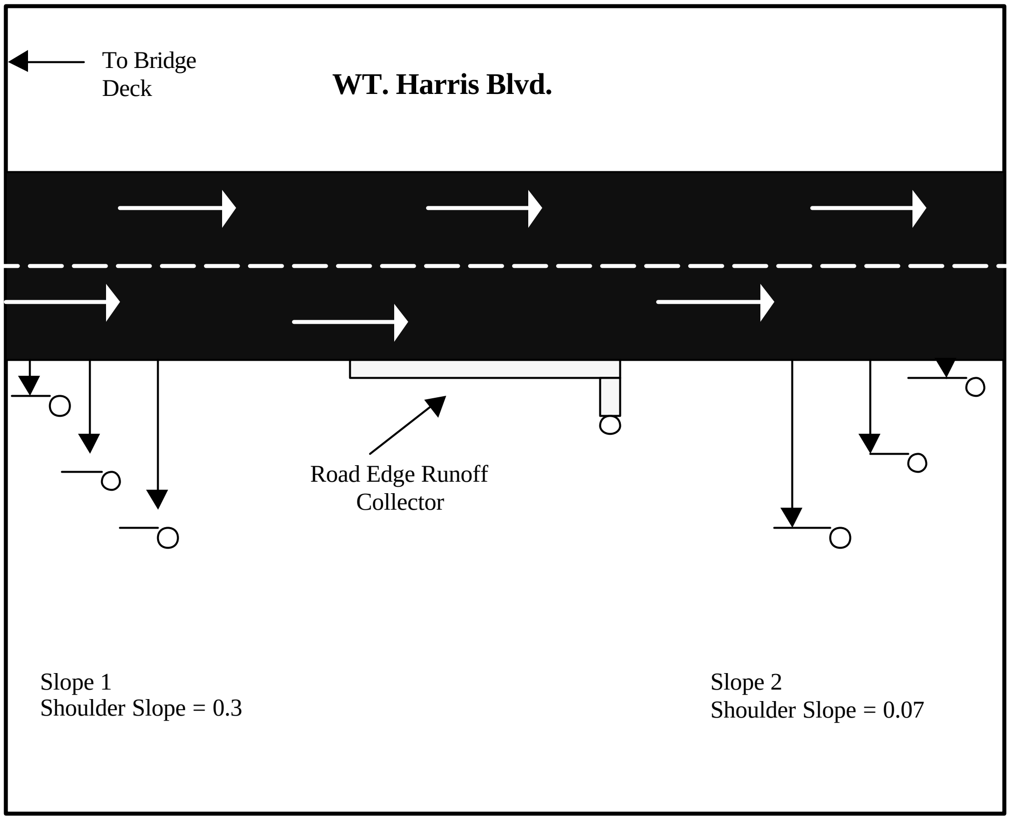


Figure 6.2 Schematic of W.T. Harris Blvd. Grassed Shoulder Sampling Design

Approximately 290 water quality samples were collected from the Highway 29 site. The water quality analyses of bulk precipitation and the overland flow samples collected from the grassed shoulder during the study period are presented in Tables 6.1 and 6.2, respectively. Water quality trends for samples collected within the grassed filter strip are presented in Figures 6.3 to 6.11. Water quality trends are depicted separately for Slope 1 (steep transect) and Slope 2 (low gradient transect). Water quality trends for organic N, DUP and Part. P are not depicted owing to the low frequency of their detection and missing analyses necessary to calculate these constituents.

TSS, specific conductance, ortho-P, TP and DOC concentrations in Bulk Precipitation were much higher at the urban Highway 29 location in comparison to the more rural Division 8 site (Tables 5.1 and 6.1). Inorganic N species in Bulk Precipitation (NH_4-N and NO_3-N) were significantly higher at the rural site and may reflect agricultural sources in the area.

When examining Figures 6.3 to 6.11, it is apparent that overland flow concentrations varied significantly between events for almost every water quality constituent. Except for TSS the concentration range for overland flow was higher for the steeper slope transect (1) in comparison to the low slope transect (2). In many instances there appeared to be no consistent trend in the runoff concentrations as overland flow moved through the grassed shoulder. Often concentrations of the mid sample along each transect were either significantly higher or lower than either the initial or final sample in the same transect. In order to simplify the examination of the Highway 29 water quality data we have calculated the ratio of the concentration of the lowest sample from each transect to that of the initial sample collected directly from the edge of the pavement. Edge-of-pavement samples were collected for five runoff events and are presented in Tables 6.3 and 6.5. Ratios greater than one indicate an increase in concentration while ratios less than one indicate a decrease in concentration as water moved from the road surface through the grassed shoulder. As the infiltration losses are expected to be relatively insignificant at this site the ratios calculated in Tables 6.3-6.6 likely reflect the overall net retention or export of material from the grassed shoulder at this site. In Tables 6.4 and 6.6 the ratio of the final sample to that of the initial sample collected within the grassed shoulder are calculated. These calculation were performed to examine those events where shoulder but not roadside samples were collected and to specifically examine changes in runoff concentration along the grassed shoulder for each transect.

Water quality constituents can be divided into three separate groups in terms of their net retention or release from the Highway 29 grassed shoulder. TSS was the only constituent that exhibited a net retention at both transects for the majority of the runoff events. A second group of constituents including specific conductance, NH_4-N, TN, ortho-P, TP and DOC displayed increasing concentrations in all or most of the events sampled. Turbidity levels and NO_3-N concentrations appeared to be equally likely to increase or decrease in concentration as runoff drained across the grassed shoulder. However, turbidity almost always decreased and NO_3-N decreased for the slope 1 transect and the opposite trends were observed for the low slope transect 2. Decreasing concentrations of TSS reflect both sedimentation and the physical “combing” action of vegetation in retaining particulates within the grassed shoulder. Increases in concentration reflect the dissolution of salts and desorption of solutes from particulates and/or soils within the grassed shoulder. Readily soluble material is contributed from direct atmospheric dryfall as well as atmospheric and vehicle source material that is deflated by wind and vehicles from the road surface and deposited along the road edge during intrastorm periods. Significant amounts of readily soluble material may also be contained on the surfaces of particulates stored from previous runoff events.

An examination of nutrient retention within the Highway 29 grassed shoulder reveals that water quality constituents could be divided into two broad categories. The first category includes water quality constituents that always or almost always-increased in concentration as runoff moved through the grassed shoulder. These constituents included turbidity, conductivity, TN, ortho-P, TP and DOC. A second group, including TSS, NH_4-N and NO_3-N displayed variable retention or net export, depending upon the event examined. It is perhaps surprising that TSS concentrations actually increased in four of seven events for runoff moving through the low slope transect 2 (Table 6.6). However, at least two of the apparent increases in TSS are the result of minor increases in TSS over low initial concentrations (7/31/05 and 8/8/05, Table 6.2). The magnitude of increase in net export for all water quality constituents (except TSS) was higher for Transect 1 as compared to Transect 2 (Tables 6.3-6.6). In some instances the difference could be attributed to a single sample (e.g. turbidity) while for other constituents (e.g. specific conductance) general differences in net retention exist between sites.

Table 6.1 Highway 29 Bulk Precipitation Chemistry

	Depth (inches)	Turbidity NTU	Conductivity µS	TSS mg/L	NH_4-N mg/L	NO_3-N mg/L	TN mg/L	ortho-P mg/L	TP(Filtered) mg/L	Part. P. mg/L	TP mg/L	DOC mg/L
02/15/05	0.29	5.8	22.0		0.00	0.02	1.555	0.00		0.26	0.26	4.66
02/22/05	0.57	120.0	15.8	21.4	1.27	0.29	0.875	1.12	0.06	0.34	0.40	3.43
03/01/05	1.03	1.4	11.8	20.7	1.04	0.27	0.675	1.14	0.06	1.34	1.40	2.03
03/08/05	0.68			196.6	0.23	0.01		0.00	0.08			
03/16/05	0.79			50.5	0.00	0.25	0.801	0.00	0.06	0.49	0.55	2.38
03/22/05	0.92		13.2	167.5	1.06	0.29	0.749	0.16	0.12	0.50	0.62	2.43
03/27/05	1.41			8.4	1.33	0.17	0.761	0.17			0.20	1.71
04/12/05	3.07					0.36	0.675	0.19	0.20	0.18	0.38	3.73
04/22/05	0.31			181.1	0.51	0.05	1.085	0.71	2.37			17.77
05/20/05	0.41		170.3	1613.6	0.00	0.50	1.184	0.23	0.41	1.38	1.79	14.39
06/02/05	2.40	5.4	25.6	104.4	0.12		0.126		1.25	0.65	1.90	17.08
09/17/05	0.11	2.9	52.2		2.07	1.10	1.484	0.18	0.50		0.31	6.34
09/25/05					0.48	0.00	0.447	1.45	3.06			16.47
10/06/05	4.98	1.5	20.0	11.8	0.00	0.18	0.072	1.66	0.81	0.29	1.10	3.58
11/21/05	1.54	4.7	56.9	25.1	0.00	0.04	0.282	0.64	2.10			11.08
Average		20.2	43.1	218.3	0.58	0.25	0.769	0.55	0.85	0.60	0.81	7.65
STD		44.0	50.4	468.4	0.66	0.29	0.453	0.58	1.03	0.45	0.63	6.25

Part. P is particulate phosphorus. TP – TP (filtered).
Blanks are missing values.

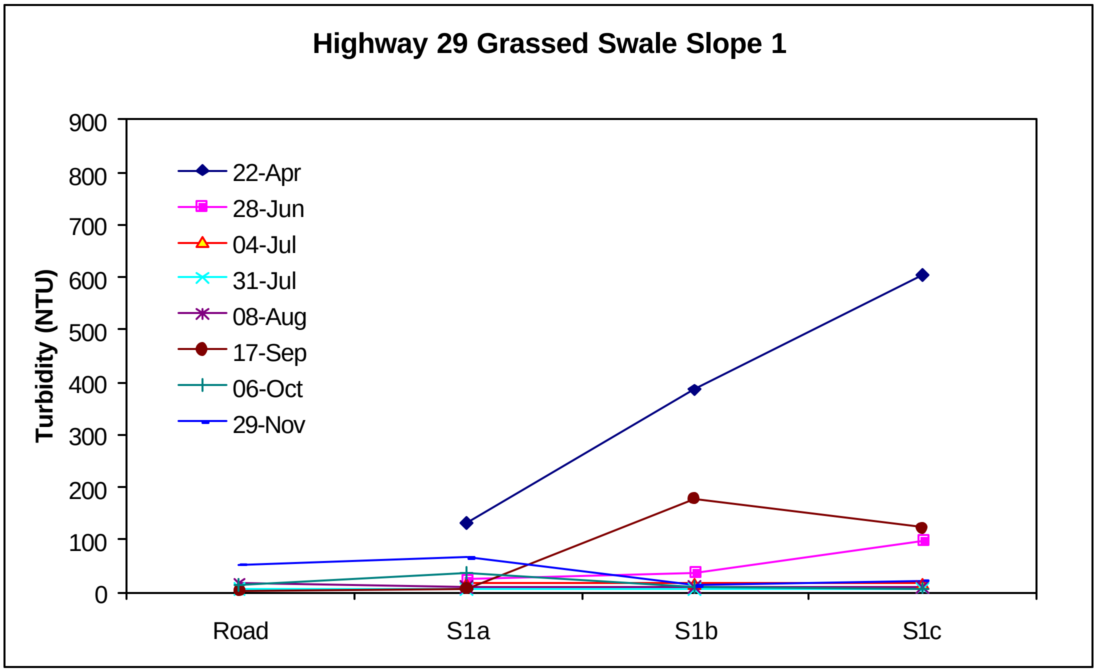
Table 6.2 Highway 29 Road Surface Grass Shoulder Overland Flow Samples

	Depth (mm)	Turbidity NTU	Conductivity µS	TSS mg/L	NH_4-N mg/L	NO_3-N mg/L	organic N mg/L	TN mg/L	ortho-P mg/L	DUP mg/L	Part. P mg/L	TP(Filtered) mg/L	TP mg/L	DOC mg/L
04/22/05														
	Road													
	S1a	131.0	57.6	905.6	1.68	0.41		1.685	1.13		0.99	0.31	1.30	17.44
	S1b	386.0	50.3	1377.3	1.74	0.27		1.431	1.12		2.28	0.34	2.62	16.80
	S1c	605.0	105.1	546.3	0.89	0.50	0.00	1.390	0.00		1.74	0.30	2.04	15.15
	S2a	852.0	74.9	2133.3	1.32	0.56		1.560	1.12		2.23	0.21	2.44	15.10
	S2b	53.1	424.0	95.5	0.00	1.25	2.68	3.933	1.20		0.75	0.87	1.62	34.22
	S2c	253.0	45.6	416.8	1.88	0.36		1.580	1.12		0.81	0.27	1.08	16.28
06/28/05														
	Road													
	S1a	25.4	26.7	234.6	1.54	0.27		1.283	1.87		0.75	0.98	1.73	9.45
	S1b	38.2	40.2	56.1	1.62	0.80	0.62	3.049	2.90		7.71	0.52	8.23	19.54
	S1c	98.0	165.5	29.5	0.72								4.35	
	S2a	194.0		668.1	10.27	0.10	2.19	12.560	2.27	1.36	3.33	3.63	6.96	16.67
	S2b	199.0	82.0	254.6	2.62	0.08		2.443	0.48	1.00	0.82	1.49	2.31	18.07
	S2c	49.6	149.3	1191.0	10.11	0.43	3.28	13.828	2.38	0.65	3.27	3.03	6.31	33.99
07/04/05														
	Road													
	S1a	15.7	22.3	12.5	0.50	0.38		0.725	0.25	0.01	0.01	0.26	0.27	4.81
	S1b	17.5	21.1	9.5	0.51	0.61	0.47	1.584	0.38	0.01	0.08	0.40	0.48	12.82
	S1c	16.5	19.6	15.2	1.41	0.44	1.28	3.127	1.08		0.16	0.92	1.07	28.65
	S2a	110.0	66.2	254.9	1.06	0.29	0.09	1.442	0.64	0.29	0.50	0.94	1.43	12.56
	S2b	156.0	68.0	106.7	0.27	0.20	1.68	2.148	0.31	0.39	0.44	0.70	1.14	29.97
	S2c	161.0	69.0	88.9	1.47	0.20	1.39	3.056	1.53		0.51	1.31	1.81	35.56

Table 6.2 Highway 29 Road Surface Grass Shoulder Overland Flow Samples (cont'd)

	Depth (mm)	Turbidity NTU	Conductivity µS	TSS mg/L	NH_4-N mg/L	NO_3-N mg/L	organic N mg/L	TN mg/L	ortho-P mg/L	DUP mg/L	Part. P mg/L	TP(Filtered) mg/L	TP mg/L	DOC mg/L
07/31/05														
	Road	5.3	34.9	6.2	0.83	0.17		0.742	0.17	0.16	0.00	0.33	0.33	7.33
	S1a	5.1	68.3	7.7	0.30	0.82	0.80	1.920	0.24	0.56		0.80	0.64	13.94
	S1b	5.6	84.9	15.2	0.59	0.19	0.73	1.503	0.33	0.97	0.72	1.30	2.02	14.99
	S1c	7.9	126.9	6.1	0.52	0.05	0.96	1.533	0.23	0.62	0.01	0.85	0.86	15.12
	S2a	4.8	75.1	8.4	0.37	0.07	1.14	1.576	0.28	0.48	0.02	0.76	0.78	15.50
	S2b	5.0	86.5	6.3	0.84	0.22	2.33	3.392	0.17	0.43	0.15	0.60	0.75	40.29
	S2c	13.5	97.1	18.4	0.82	0.16	0.35	1.331	0.58	1.92		2.50	1.11	19.06
04/22/05														
	Road	16.6	17.3	40.6	0.65	0.16		0.554	0.22	0.38		0.60	0.36	6.00
	S1a	10.9	54.3	27.1	0.93	0.62		1.468	0.30	0.40	0.15	0.70	0.85	8.86
	S1b	11.6	126.6	14.2	1.01	1.64	0.97	3.613	0.31	0.69		1.00	0.91	21.94
	S1c	10.6	340.0	13.6	1.85	11.62	0.23	13.700	0.52	1.48	0.05	2.00	2.05	29.36
	S2a	17.4	51.5	11.4	0.70	0.09	0.19	0.978	0.25	0.85		1.10	0.70	11.27
	S2b	16.2	89.0	9.0	0.74	0.05	1.13	1.923	0.22	0.38	0.06	0.60	0.66	25.34
	S2c	17.2	77.5	23.9	0.68	0.05	0.91	1.638	0.41	0.99	0.05	1.40	1.45	22.41
04/22/05														
	Road	2.3	49.2		0.51	0.24	2.73	3.477	0.30	0.60	0.03	0.90	0.93	52.37
	S1a	4.8	153.9		1.04	7.39		7.583	0.65	1.89	0.46	2.54	3.00	11.18
	S1b	179.0	1040.0	613.8	14.32	0.14	13.41	27.870	3.07	17.38	0.30	20.45	20.75	55.47
	S1c	124.0	710.0	250.3	9.81	0.05	7.50	17.360	7.75	22.17		29.92	21.30	59.77
	S2a	6.6	200.0	54.7	1.37	0.62	1.38	3.373	2.07	5.11	1.07	7.18	8.25	30.52
	S2b	9.0	199.6	51.4	0.61	34.69		3.604	5.67	1.33	0.26	7.00	7.26	30.86
	S2c	11.6	400.0										20.72	
10/06/05														
	Road	15.0	29.5	447.5	0.52	0.16		0.37	0.21	0.31	1.18	0.52	1.70	7.05
	S1a	38.9	70.8	347.4	0.58	0.51		0.95	0.55	1.33	0.43	1.88	2.31	11.47
	S1b	12.1	220.0	109.2	0.95	7.19		5.64	0.54	1.34		1.88		22.44
	S1c	9.5	344.0	76.6	4.86	16.44		12.33	1.65	0.07	0.57	1.72	2.29	29.76
	S2a	7.6	136.8	100.6	2.02	0.43		1.92	1.31	3.45		4.76	2.57	20.17
	S2b	9.8	149.7	140.9	2.75	0.10		2.11	1.88	4.80		6.68		24.32
	S2c	9.5	121.7	72.8	0.85	0.14	0.50	1.49	2.03	5.13	0.08	7.16	7.24	28.68
11/29/05														
	Road	52.5	40.6	417.7	1.06	0.21		0.755	0.16		2.46	0.12	2.58	5.35
	S1a	65.9	61.7	270.3	1.86	0.46		1.838	0.38	0.90		1.28		9.56
	S1b	14.4	103.5	49.1	1.26	0.93	0.47	2.658	0.31	0.65	0.24	0.96	1.20	18.60
	S1c	20.7	128.1	77.3	0.43	0.25	1.97	2.654	0.21	0.51	0.13	0.72	0.85	28.97
	S2a	98.4	108.1	380.5	1.62	0.45	0.37	2.435	0.41	1.11	0.95	1.52	2.47	21.13
	S2b	49.7	80.9	86.1	0.96	0.36	0.42	1.746	0.33	0.87	0.11	1.20	1.31	19.60
	S2c	69.1	117.3	277.8	1.41	0.04	1.67	3.115	0.68	2.52		3.20	1.90	44.07

Organic N = TN – NH_4-N + NO_3-N.
D UP is dissolved unreactive phosphorus. TP (filtered)- ortho-P.
Part. P is particulate phosphorus. TP – TP (filtered).
Blanks are missing values or in the case of organic N, DUP and Part. P values are not calculated where the resultant concentration is a negative value. In these instances it was assumed the uncertainties in the chemical analyses used to determine TN, NH_4-N, NO_3-N and TP were greater than the concentrations of these water quality constituents.



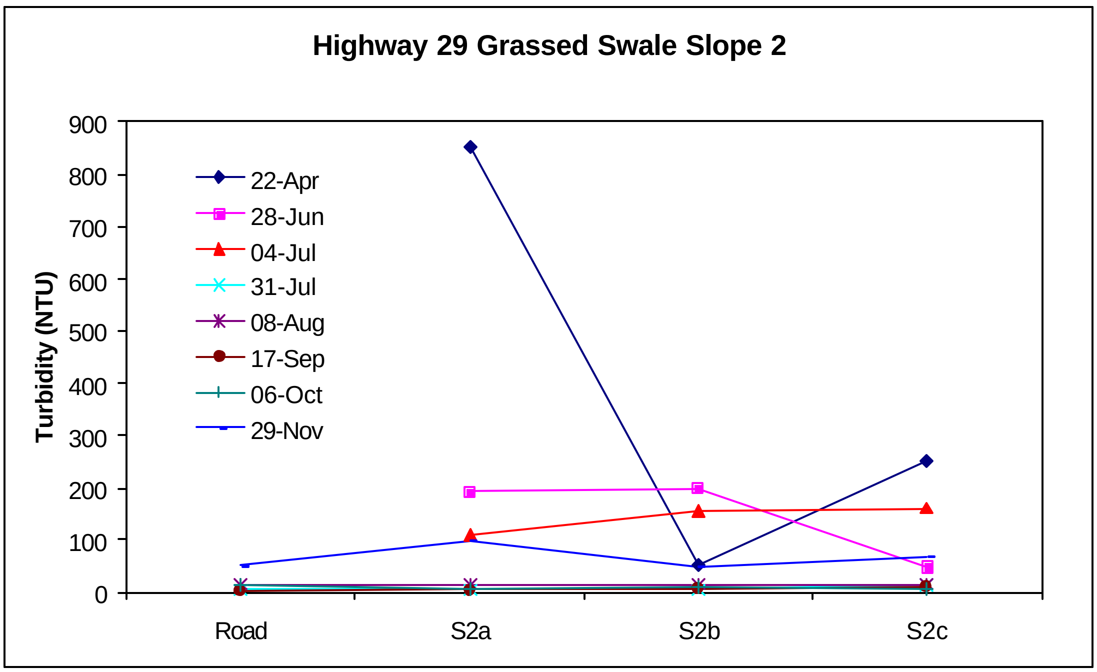
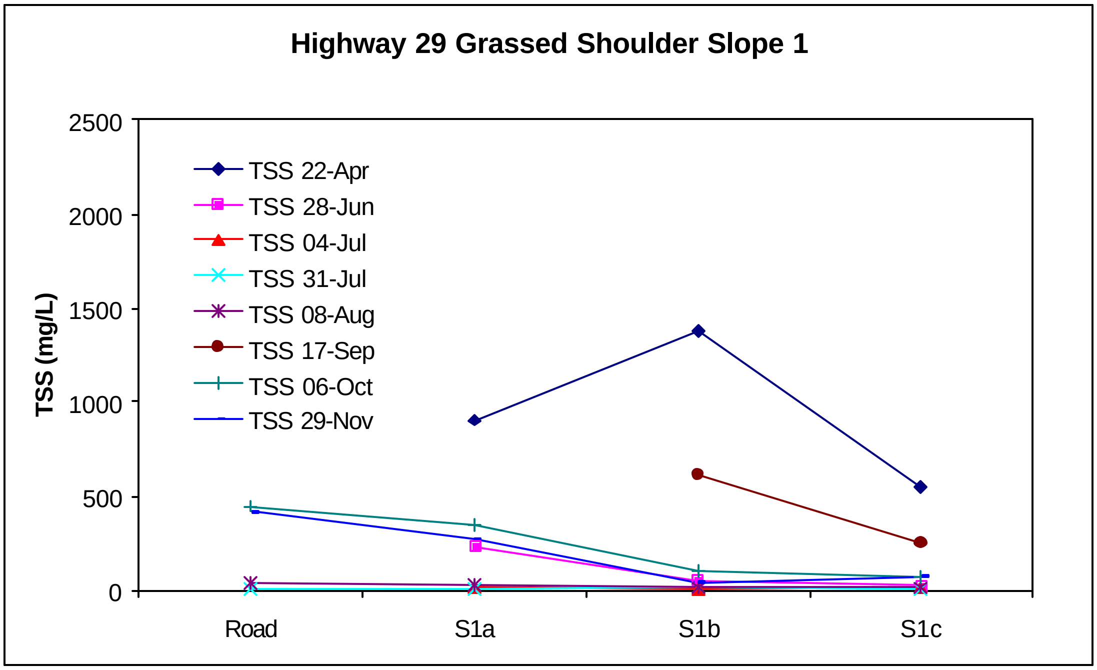


Figure 6.3 Overland Flow Turbidity



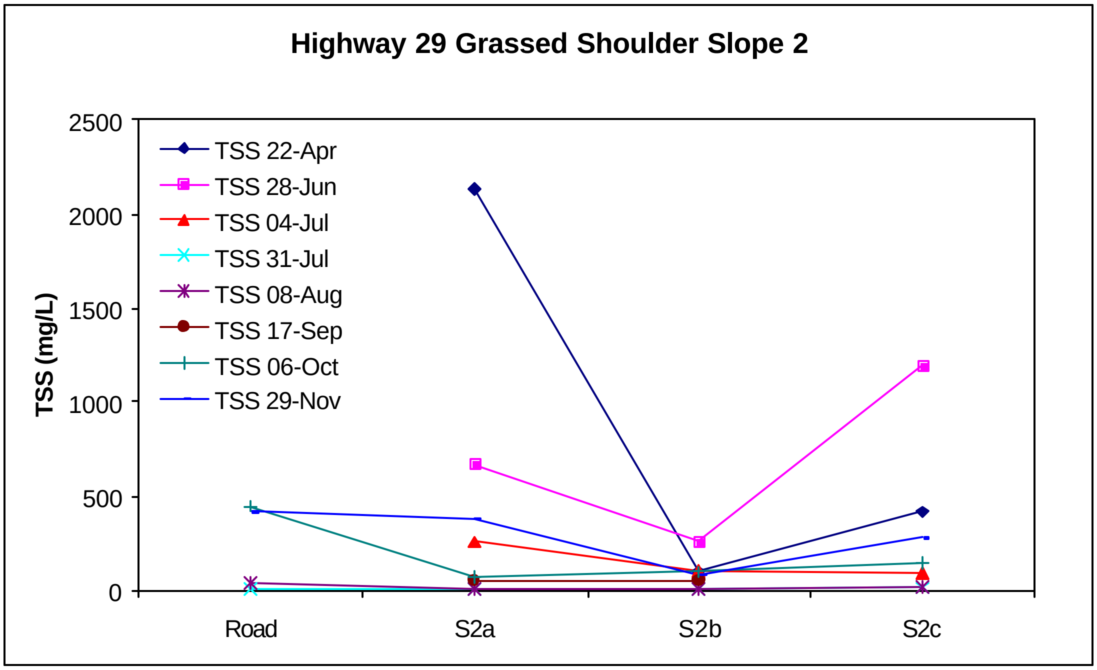
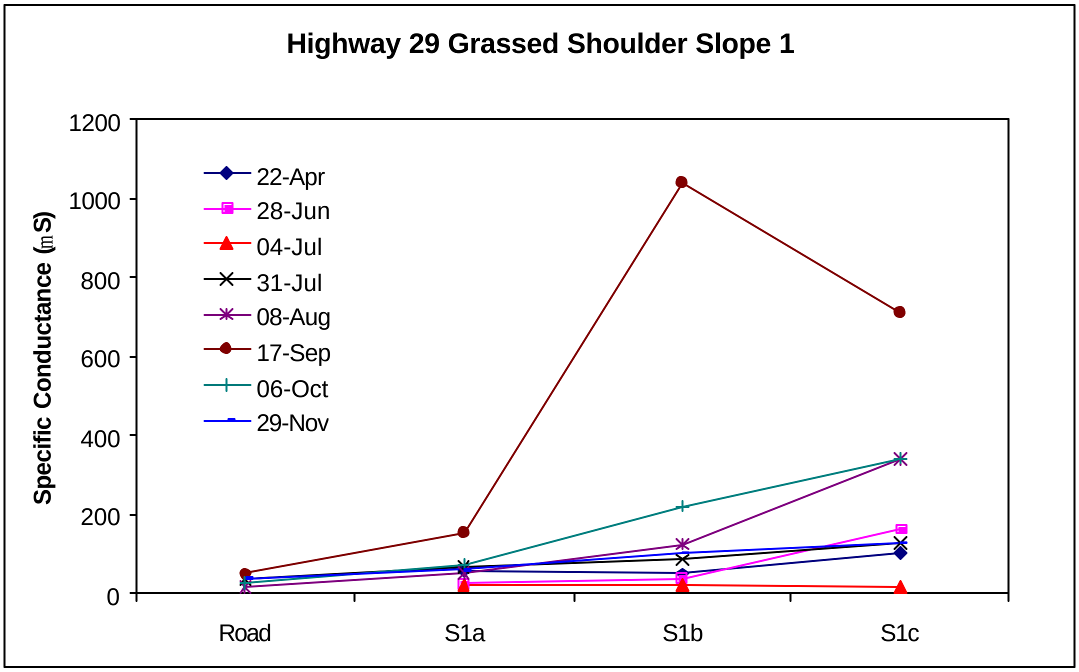


Figure 6.4 Overland Flow Total Suspended Solids



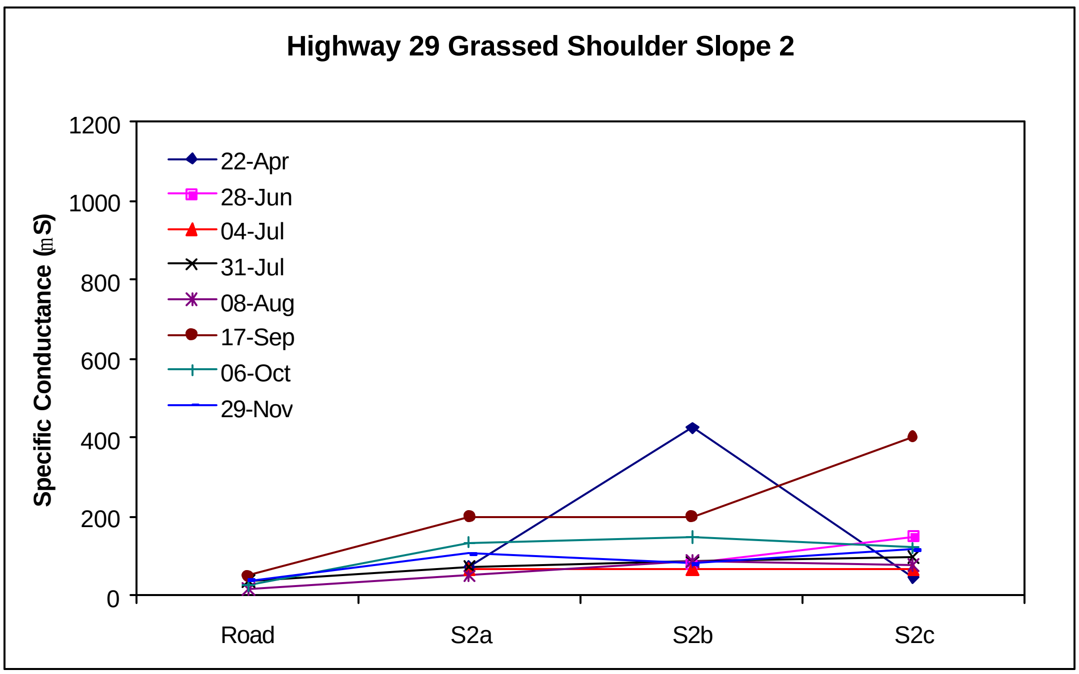
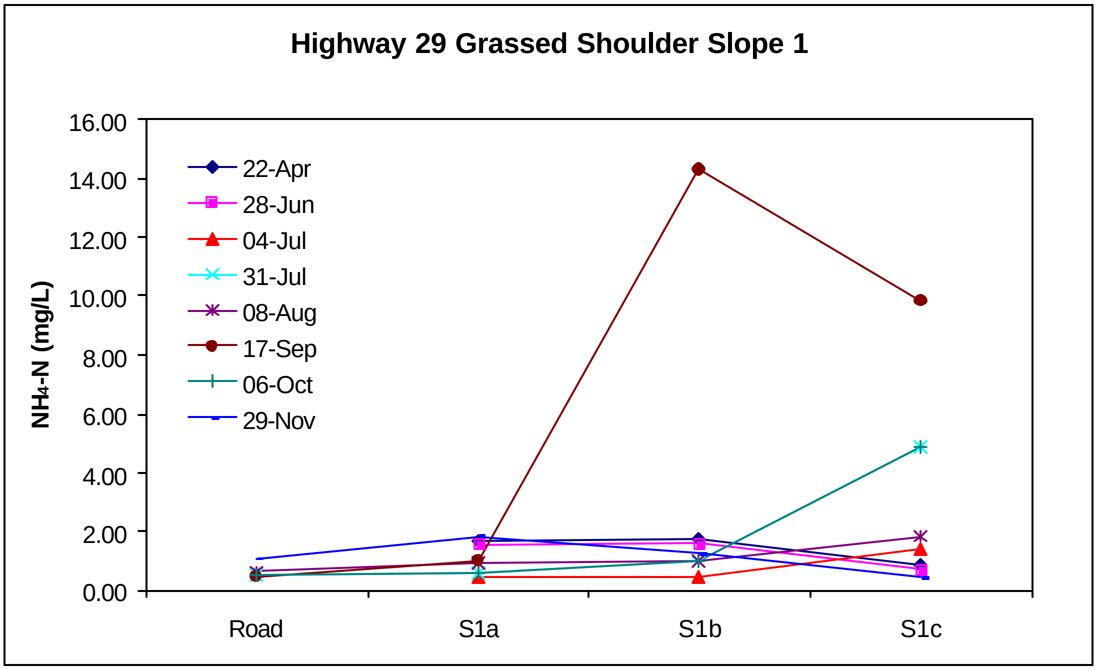


Figure 6.5 Overland Flow Specific Conductance



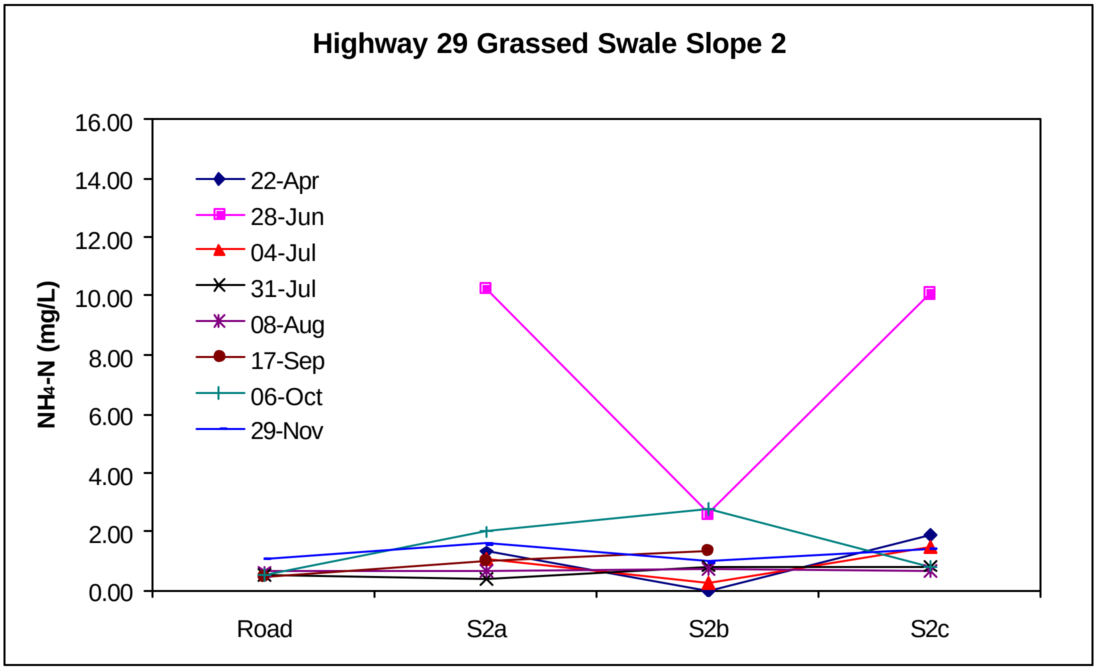
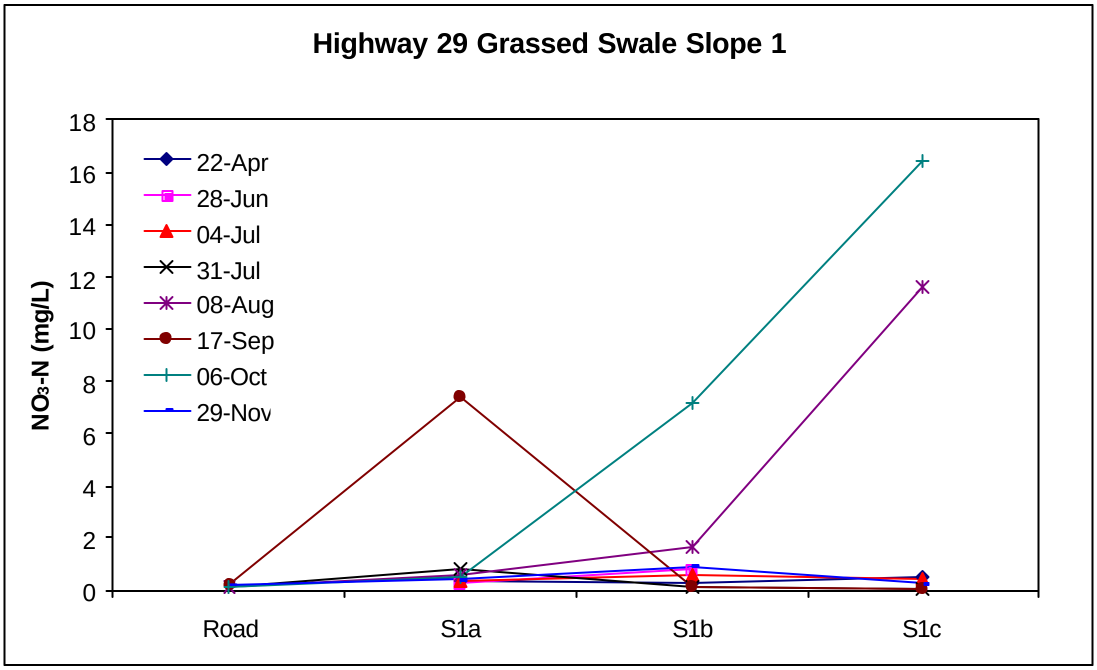


Figure 6.6 Overland Flow Ammonium



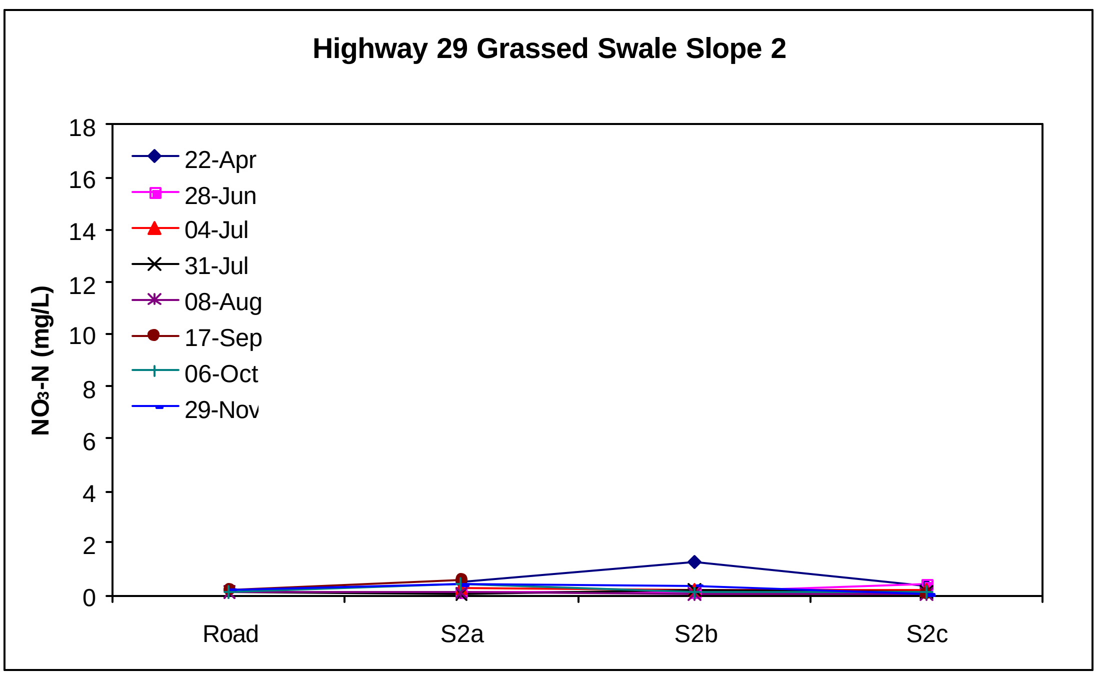
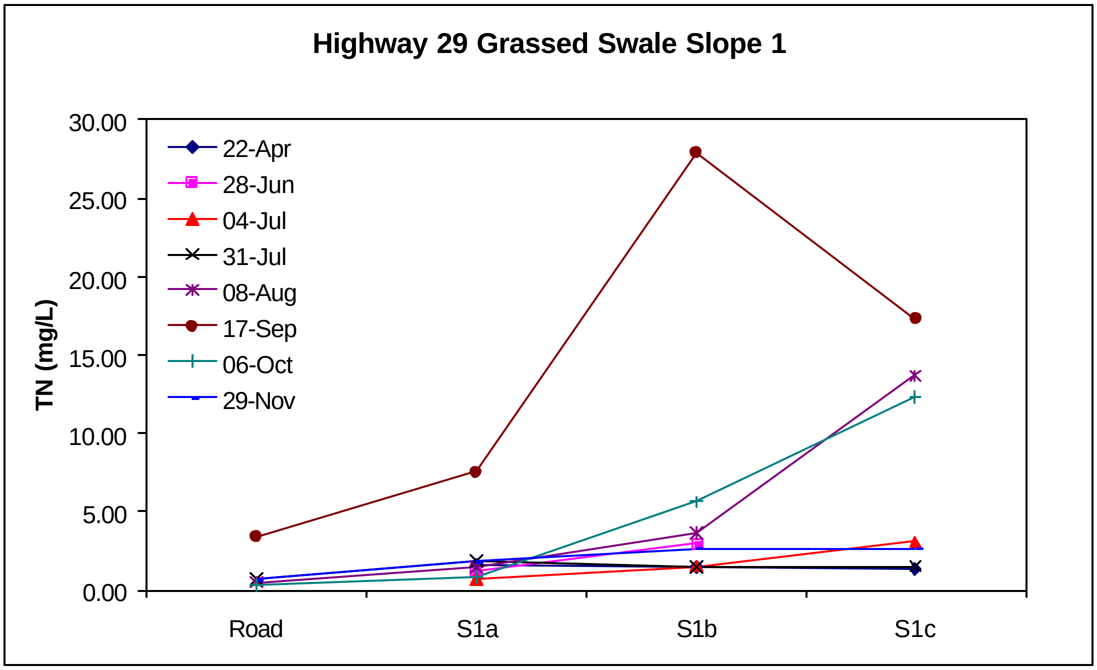


Figure 6.7 Overland Flow Nitrate



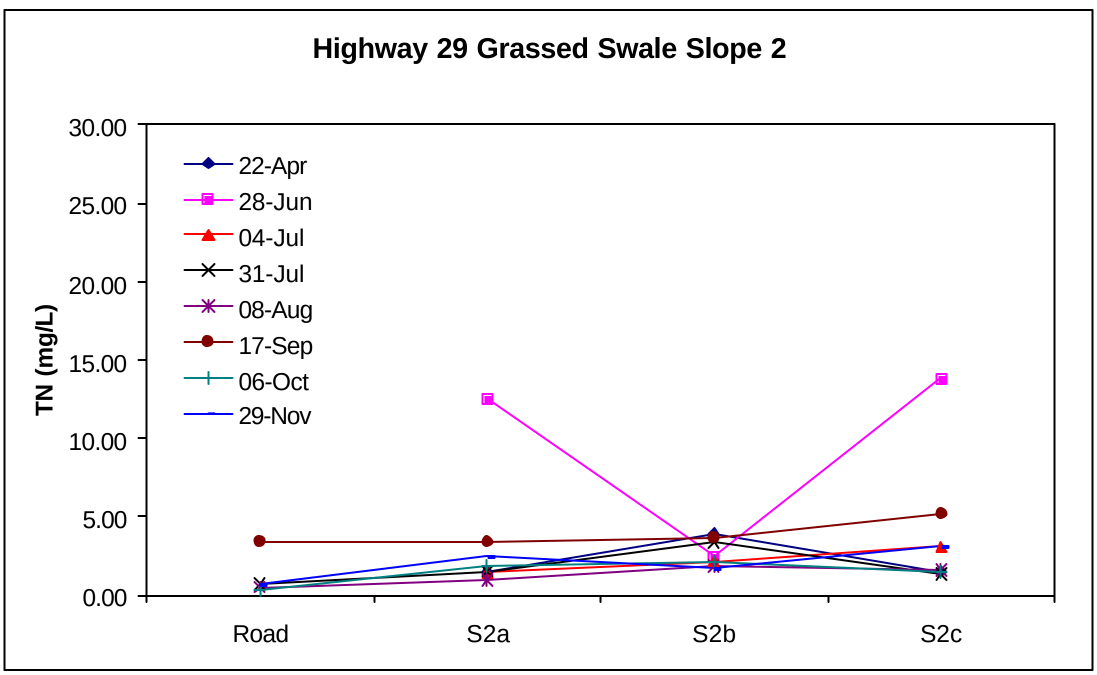
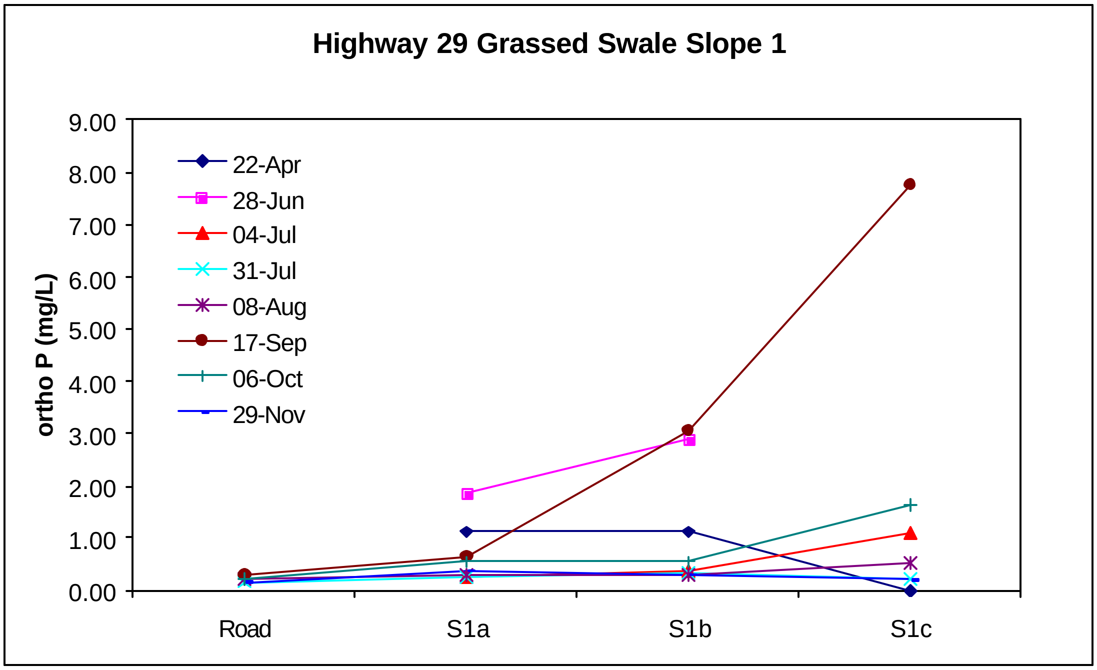


Figure 6.8 Overland Flow Total Nitrogen



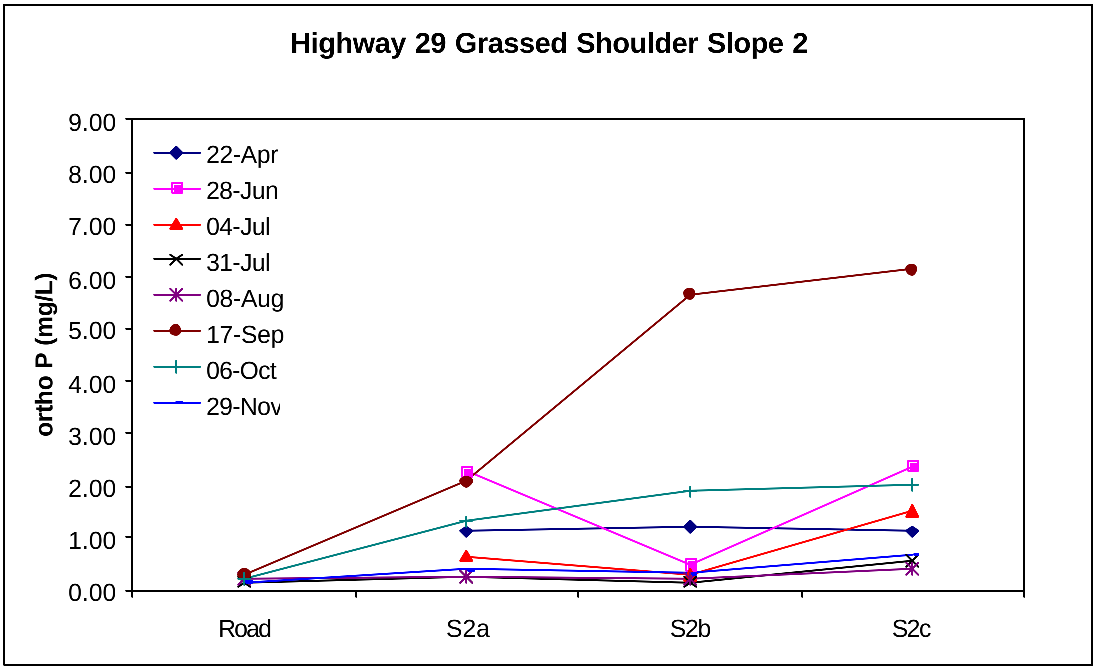
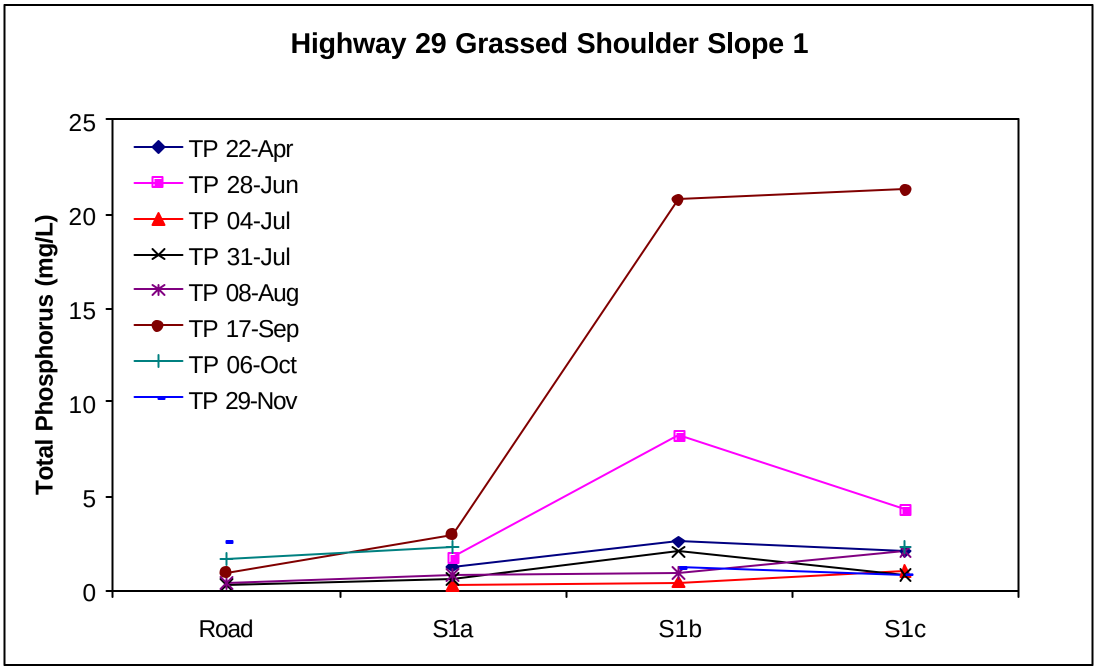


Figure 6.9 Overland Flow ortho Phosphorus



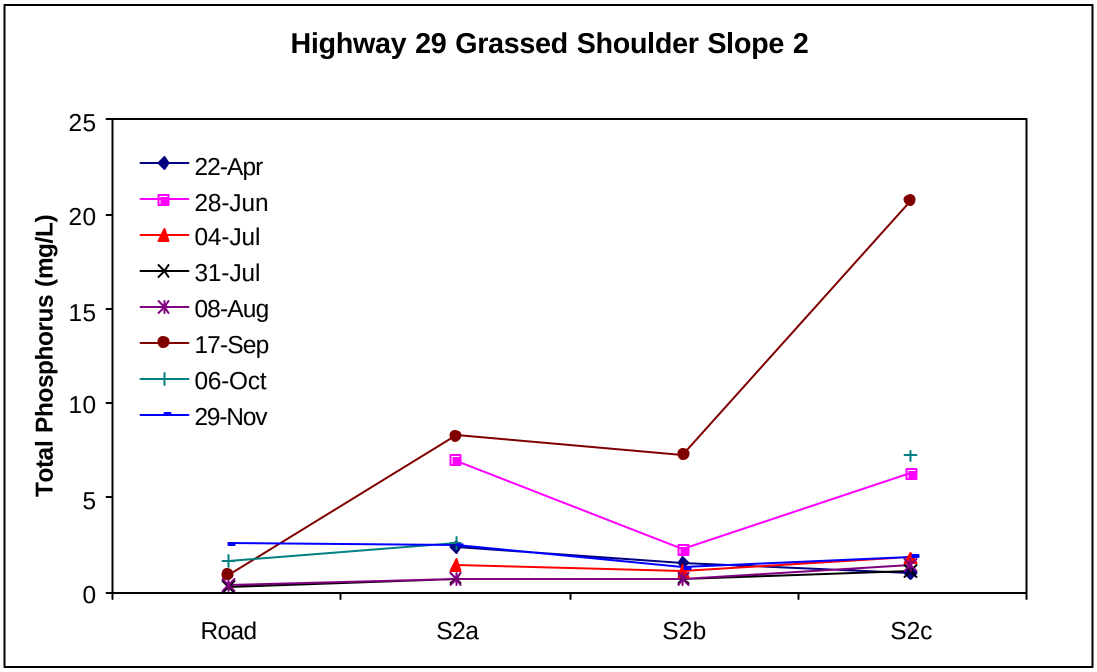
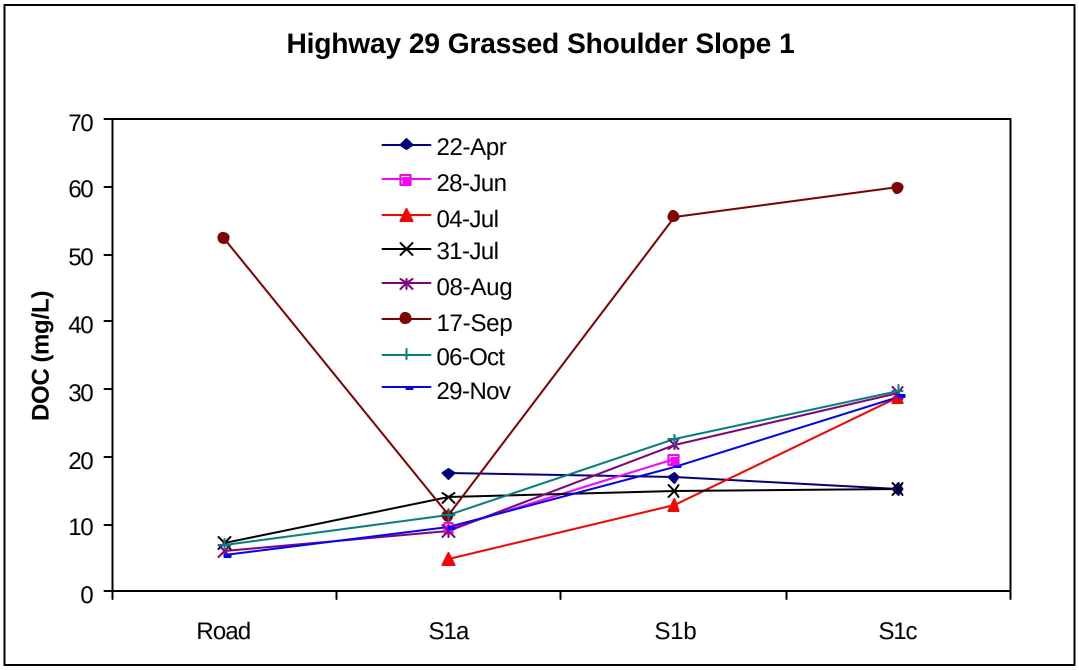


Figure 6.10 Overland Flow Total Phosphorus



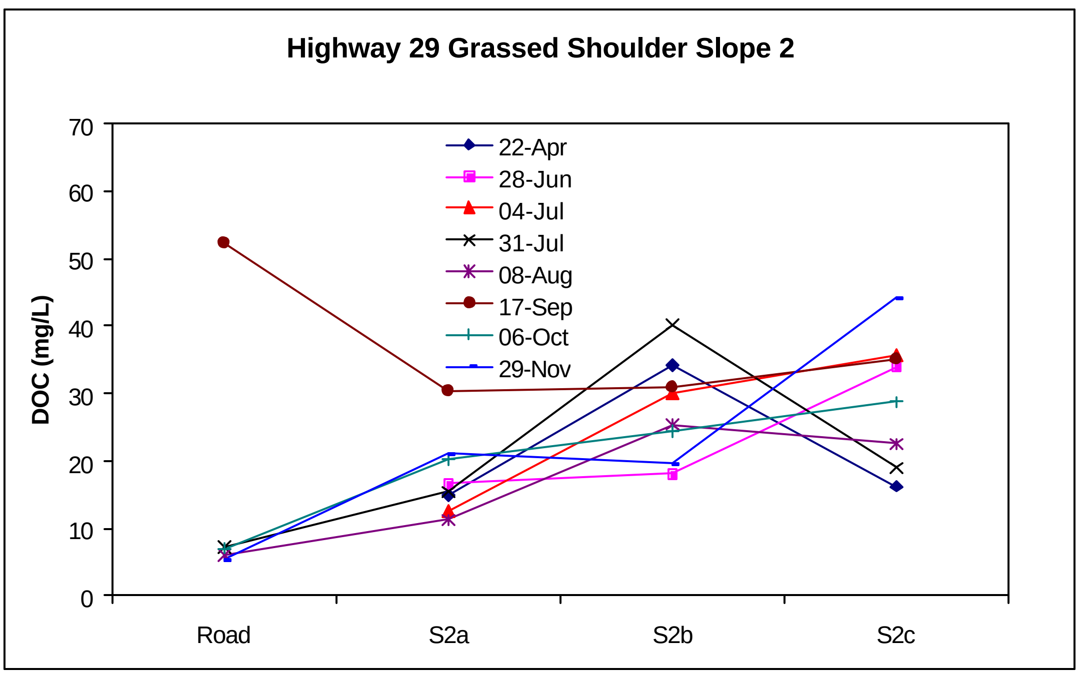


Figure 6.11 Overland Flow Dissolved Organic Carbon

Table 6.3 Ratio of Terminal Grassed Shoulder Sample to Road Concentration, Slope 1

	Turbidity	TSS	Conductivity	NH_4-N	NO_3-N	TN	ortho-P	TP	DOC
07/31/05	1.5	1.0	3.6	9.4	0.3	2.1	1.4	2.6	2.1
08/08/05	0.6	0.3	19.7	2.8	72.6	24.7	2.4	5.7	4.9
09/17/05	0.5		14.4	19.3	0.2	5.0	25.8	22.9	1.1
10/16/05	0.6	0.2	11.7	9.4	102.8	33.0	7.9	1.3	4.2
11/29/05	0.4	0.2	3.2	0.4	1.2	3.5	1.3	0.3	5.4
Average	0.7	0.4	10.5	8.3	35.4	13.7	7.7	6.6	3.5
STD	0.4	0.4	7.1	7.3	48.9	14.2	10.5	9.3	1.9

Table 6.4 Ratio of Terminal Grassed Shoulder Sample to First Sample Concentration, Slope 1

	Turbidity	TSS	Conductivity	NH_4-N	NO_3-N	TN	ortho-P	TP	DOC
04/22/05	4.6	0.6	1.8	0.5	1.2	0.8	0.0	1.6	0.9
06/28/05	3.9	0.1	6.2	0.5				2.5	
07/04/05	1.1	1.2	0.9	2.8	1.1	4.3	4.4	3.9	6.0
07/31/05	1.5	0.8	1.9	8.3	0.1	0.8	1.0	1.3	1.1
08/08/05	1.0	0.5	6.3	2.0	18.7	1.6	1.7	2.4	3.3
09/17/05	25.6		4.6	9.4	0.0	2.3	11.9	7.1	5.3
10/06/05	0.2	0.2	4.9	8.3	32.2	13.0	3.0	0.6	2.6
11/29/05	0.3	0.3	2.1	0.2	0.5	1.4	0.6		3.0
Average	4.8	0.5	3.6	4.0	7.7	3.5	3.2	2.8	3.2
STD	8.6	0.4	2.1	4.0	12.8	4.4	4.1	2.2	1.9

Table 6.5 Ratio of Terminal Grassed Shoulder Sample to Road Concentration, Slope 2

	Turbidity	TSS	Conductivity	NH_4-N	NO_3-N	TN	ortho-P	TP	DOC
07/31/05	2.5	3.0	2.8	1.6	2.3	1.8	3.4	3.4	2.6
08/08/05	1.0	0.6	4.5	1.0	0.3	3.0	1.9	4.0	3.7
09/17/05	5.0		8.1		0.21	1.5	20.4	22.3	0.7
10/16/05	0.6	0.3	4.1	1.6	0.9	4.0	9.7	4.3	4.1
11/29/05	1.3	0.7	2.9	1.3	0.2	4.1	4.3	0.7	8.2
Average	2.1	1.1	4.5	1.4	0.8	2.9	7.9	6.9	3.9
STD	1.8	1.2	2.2	0.3	0.9	1.2	7.6	8.7	2.8

Table 6.6 Ratio of Terminal Grassed Shoulder Sample to First Sample Concentration, Slope 2

	Turbidity	TSS	Conductivity	NH_4-N	NO_3-N	TN	ortho-P	TP	DOC
04/22/05	0.3	0.2	0.6	1.4	0.6	1.0	1.0	0.4	1.1
06/28/05	0.3	1.8		1.0	4.3	1.1	1.0	0.9	2.0
07/04/05	1.5	0.3	1.0	1.4	0.7	2.1	2.4	1.3	2.8
07/31/05	2.8	2.2	1.3	1.0	0.3	3.0	1.9	1.4	1.2
08/08/05	1.0	2.1	1.5	1.0	0.6	1.7	1.6	2.1	2.0
09/17/05	1.8		2.0		0.1	1.5	3.0	2.5	1.1
10/06/05	1.3	1.8	0.9	0.4	0.3	0.8	1.5	2.8	1.4
11/29/05	0.7	0.7	1.1	0.9	0.1	1.3	1.7	0.8	2.1
Average	1.2	1.3	1.2	1.0	0.9	1.6	1.8	1.5	1.7
STD	0.8	0.9	0.5	0.3	1.4	0.7	0.7	0.9	0.6

In summary the grassed shoulder at the Highway 29 site appears to be somewhat effective at removing TSS from road source stormwater runoff. Removal efficiency was on average 40% of pavement runoff inputs to the grassed shoulder. The grassed shoulders appeared to be ineffective in retaining NH_4-N, TN, ortho-P, TP and DOC with concentrations in overland runoff increasing significantly over those measured in pavement-edge runoff. Sources of material that could be mobilized from the road shoulder include particulates, aerosols and evaporates contributed by atmospheric deposition and material mechanically removed from the road surface by wind and vehicular motions which is deposited within the road corridor. In addition to these sources it is possible that desorption of nutrients could occur from road shoulder soils as well as from previously deposited runoff sediments. In part, these results may be somewhat site specific as this site is “dwonstream” from the Highway 29 bridge deck. Deicing mateials are preferentially applied to bridge decks and the material may serve as a source of nutrients and ions wtithin the grassed shoulder during growing season runoff events. Turbidity levels and NO_3-N concentrations displayed both increases and decreases in comparison to pavement runoff and varied by event. Infiltration capacities at the Highway 29 site were extremely low, averaging 0.2 in/hr (0.5 cm/hr). The low infiltration capacities in conjunction with microtopographic features that encourage concentrated rather than sheet flow minimize the opportunity for runoff retention and water quality treatment at this site. It is recommended that active turf management (plugging) be carried out at such sites to enhance infiltration. Increased *in situ* infiltration in roadside shoulders and swales would reduce stormwater runoff volumes and enhance turf health, both of which could be expected to increase sediment deposition and increase nutrient retention in road corridors.

7. BMP Data Management and Reporting

This section of the report explains the data entry format required by the National Stormwater BMP Database. It also presents the development of a Stormwater Data Management System (SDMS) for organizing highway BMP site-characterization data that is obtainable by performing a field inspection. Some of the data entries in the Stormwater Data Management System are compatible with the National Stormwater BMP Database.

7.1 Data Reporting for Monitored Highway BMP Sites

The National Stormwater BMP Database has been in development since 1994 under a USEPA grant with the Urban Water Resources Research Council of ASCE. The Database was initiated to provide a unified basis for data reporting, data evaluation, monitoring strategies, and assessment of factors affecting BMP performance. The Database and its guidance manual can be accessed at www.bmpdatabase.org. As of August 2004, the Database has included more than 170 structural BMPs, as summarized below.

o Biofilter (Grass Swales)	32
o Detention Basin	24
o Hydrodynamic Device	17
o Media Filter	30
o Percolation Trench/Well	1
o Porous Pavement	5
o Retention Pond	33
o Wetland Basin	15
o Wetland Channel	14

Data requirements for this Database have included three levels of data entry: required, essential and nice-to-have. The required, essential and/or nice-to-have information are available for each of following data categories:

1. General Site Information
2. Sponsorship
3. Watershed Information
4. Structure Information
5. Monitoring Information
6. Instrument Information
7. Cost Information
8. Precipitation Information
9. Runoff Information
10. Water Quality Information
11. Design Information

There is no minimum requirement for the number of monitored storm events, although a reasonable number of storm events may be needed for obtaining meaningful statistics of the monitoring results. Data maintenance is under the supervision of individuals from Wright Water Engineers, Inc. in Denver, Colorado. On-line data submissions can be implemented at the aforementioned web address. Technical experts from Wright Waters Engineers will help analyze the data for pollutant removal performance.

As an example, the relevant data collected from the I-40/NC-42 GFS site in Clayton, North Carolina, has been submitted to this Database. The completed data entry template is shown in Table 7.1. Table 7.2 summarizes water quality data entry in spreadsheet format.

7.2 Data Entry Template for Non-monitored Highway BMP Sites

A Stormwater Management Data System was developed to facilitate the storage of inspection data at monitored or non-monitored BMP sites and the retrieval of data files with the use of a numerical index corresponding to NCDOT's fourteen divisions across the state. The data entry template can be used to compile critical information that relates the facility to the surrounding environmental conditions, verify if the facility was built as originally designed, identify potential malfunctioning problems, and estimate its pollutant removal performance. Table 7.3 presents the essential information included in this SDMS application. The data entry template can also be used to gather information from potential sites for field monitoring or post-auditing of monitored highway BMP sites. The electronic data files are in the form of Microsoft Access (provided in a separate CD) and contain the characterization data of the following BMP sites that were visited during the course of this research.

1. Grass Filter Strip/Level Spreader on I-40/NC-42 (Division 4)
2. Bioretention at Swannanoa River on I-40/US-70 (Division 12)
3. Filtration Swale on US-17 in New Bern (Division 2)
4. Bioretention at I-40 Rest Area in Warsaw (Division 3)
5. Bioretention on I-40 at Rest Area EBL before the Catawba River near Exit 138 (Division 12)
6. Filtration Swale near Troy at NC 24/27 and NC 109 (Division 8)
7. Grassed shoulder at W.T. Harris/NC 29 in Charlotte (Division 10)

Table 7.1 Data Entry for the USEPA National Stormwater BMP Database
(I-40/NC-42 GFS Site)

1. General Information (Table 7.1)

Data Entry Priority Level: 1 = Required, 2 = Essential but nor required, and 3 = Nice to have

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	BMP Test Site Name	1	I-40/NC-42 GFS	
2	City	1	Clayton	
3	County	3	Johnston	
4	State	1	NC	
5	Zip Code	1	27529	
6	Country	1	US	
7	Time Zone	3	EST	
8	USGS Quadrangle Map	3	Edmondson Quadrangle	
9	Principal Meridian	3		
10	Range	3		
11	Township	3		
12	Section	3		
13	Quarter-Quarter-Quarter section	3		
14	Latitude	2	35º36’21.7”	GPS recorded at outlet
15	Longitude	2	78º33’52.6”	GPS recorded at outlet
16	Altitude	1	310 feet	Edmondson Quadrangle
17	Hydrologic Unit Code	2	03020201	http://cfpub.epa.gov/surf/huc.cfm?huc_code=03020201
18	EPA Reach Code	2	073	http://www.epa.gov/OST/BASINS

2. Sponsor (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Agency Type	3	Mr. Matt Lauffer,	
2	Address	3	NCDOT, Raleigh, NC	

3. Watershed Information (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Subject Watershed Name	1	Upper Neuse	http://www.epa.gov/surf/
2	Total Watershed Area	1	0.86 ac	Survey and NCDOT map
3	Total Length of Watershed	3	454 ft	Hwy 292 ft + Ditch 162 ft
4	Total Length of Grass-Lined Channel	3	123 ft	
5	Total Watershed Area Disturbed	3		
6	Percent (%) Irrigated Lawn and/or Agriculture	3		
7	Percent (%) Total	1	48.9	

	Impervious Area in Watershed			
8	Percent (%) of Total Impervious Area (above) Hydraulically Connected	2	100	
9	Percent (%) of Watershed Served by Storm Sewers	3		
10	Storm Sewer Design Return Period (yrs)	3		
11	Average Watershed Slope	3	0.06	
12	Average Runoff Coefficient	3	0.8	
13	NRCS Hydrologic Soil	3	C	
14	Soil Type	3		
15	Type of Vegetation	3	Grass	
16	Regional Climate Station in the United States	1	7069	Selected from data entry software for Raleigh-Durham
17	Land Use Information	1	48.9% Highway + 51.1% Vegetation	Drainage area from the highway and adjacent grass area.
18	Settling Velocity Distributions	3		
19	Comments	3		Grassed-open channel, diversion box, level spreader, grass filter strip, and outflow channel.
	Roads, Streets and Alleys in Watershed			
1	Total Paved Roadway Area	3	0.42 Acre	
2	Total Length Curb/Gutter on Paved Roads	3	292 ft	
3	Total Unpaved Roadway Area	3		
4	Total Length Curb/Gutter on Unpaved Roads	3		
5	% Paved Roads Draining to Grass Swales/Ditches	3		
6	% Unpaved Roads Draining to Grass Swales/Ditches	3		
7	Type of Pavement on Roads, Streets and Alleys	3	Asphalt	
8	Parking Lots in Watershed	3		
9	Total Paved Parking Lot Area	3		
10	Total Length Curb/Gutter on Paved Lots	3		
11	Total Unpaved Parking Lot	3		
12	Total Length Curb/Gutter on Unpaved Lots	3		
13	% Paved Lot Area Draining to Grass Swales	3		
14	% Unpaved Lot Area Draining to Grass Swales	3		
15	Type of Pavement in Parking Lots	3		

4. Structure Information (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	What date was the BMP facility put into service?	1	1/1/04	
2	How many separate inflow points does the facility have?	1	1	
3	Is the BMP designed to bypass or overflow when full?	1	Bypass	
4	Describe the type and frequency of maintenance, if any	2		
5	What was the last date that the facility was rehabilitated, if any?	2		
6	Describe the type of rehabilitation, if any	2		
7	Describe the type and design of each BMP outlet	2	Rectangle inlet weir, and V-Notch outlet weir	
8	BMP Drawing	1	See Attached File	

5. Monitoring Information (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Station	1	GFS inlet	GFS outlet
2	Identify Upstream BMP	1	Dry Channel Level Spreader	Grass Filter Strip
3	Identify Relationship to upstream BMP	1	Outflow	Outflow
4	Identify Downstream BMP	1	Grass Filter Strip	
5	Identify Relationship to Downstream BMP	1	Inflow	

6. Instrumentation Information (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Select monitoring station where instrument is located	1	GFS inlet and outlet	
2	What date was the instrument installed?	2	3/6/2004	
3	What type of instrument is in place?	2	Sigma 900 Max Auto Sampler	
4	What type of monitoring is conducted?	2	Composite Samples, Flow, Precipitation	
5	What type of control	2	Rectangle Weir at	

	structure is in place, if any?		inlet, V-notch weir at outlet	
6	Additional Comments	3		

7. Cost Information (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Monitoring Year	3	GFS inlet Dry Channel	GFS outlet Grass Filter Strip
2	Comments	3	Level Spreader	
3	Fixed Monitoring Station Costs	3	Outflow	Outflow
4	Temporary Monitoring Station Costs	3	Grass Filter Strip	
5	Year of Cost Basis	3	Inflow	
6	Equipment Costs	3		
7	Maintenance Costs	3		
8	Sampling Costs	3		
9	Laboratory Costs	3		

8. Precipitation Information (repeat for each storm event) (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Select Monitoring Station for Event	1	Inlet and Outlet*	
2	Start Date	2		
3	Start Time	2		
4	End Date	2		
5	End Time	2		
6	Total Storm Precipitation	2		
7	Peak One Hour prcip. Rate	2		

*Data provided in accompanied Excel files

9. Runoff Information (repeat for each storm event) (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Monitoring Station	1	Inlet and outlet*	
2	Select the type of flow	1	Highway Runoff	
3	If storm runoff, select the related precipitation event, if available.	2		
4	Flow Start Date	1		
5	Flow Start Time	2		
6	Flow End Date	2		
8	Flow End Time	2		
9	Total Storm Flow Volume into or from BMP	1		
10	Peak Storm Flow Rate into or from BMP	2		
11	Total Bypass Volume, if any	1		

12	Peak Bypass Flow Rate, if any	2		
13	Dry Weather Base Flow Rate	1		

*Data provided in accompanied Excel files

10. Water Quality Information (repeat for each storm event) (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Select Monitoring Station Where Data Collected	1	Inlet and Outlet*	
2	Select Related Flow Event	1		
3	Date Water Quality Sample Collected	1		
4	Time Water Quality Sample Collected	2		
5	What medium does the instrument monitor?	1	Surface Runoff/flow	
6	What types of sample are collected?	2	Composite	
7	Provide the Number of Samples, If Composite	2		
8	Describe Quality Assurance/Quality Control Measures in Place for the Sampling Event	2		
9	Additional Comments	3		
10	Water Quality Parameter (STORET)	1		
11	Value	1		
12	Unit	1		
13	Qualifier	1		
14	Analysis Method	2		

*Data provided in accompanied Excel files

11. Design Information (Table 7.1)

	Date Element	Priority Level	Data Entry	Data Acquisition Method
1	Grass Strip Length	1	55 ft	
2	Grass Strip Slope	1	0.06	
3	Flow Depth during 2-Year Storm	1	0.22 ft	
4	2-Year Peak Flow Velocity	1	0.62 ft/s	
5	Describe Grass Species and Densities	1	Indigene, 2 cm	
6	Is Strip Irrigated?	1	No	
7	Estimated Manning's n During 2-Year Flow	3	0.25	
8	Depth to Groundwater or Impermeable Layer	3		
9	Measured Saturated	3	0.05 in/hr	

	Infiltration Rate, if Known		
10	NRCS Hydrologic Soil Group	2	B
	Grass Filter Strip Construction Cost Estimates		
11	Year of Cost Estimate	3	
	Construction Costs:		
12	Excavation Costs	3	
13	Structural Control Devices Costs	3	
14	Vegetation and Landscaping Costs	3	
15	Engineering and Overhead Costs	3	
16	Land Costs or Values	3	
	Rehabilitative Costs:		
17	Average Annual Sediment Removal Costs	3	
18	Average Annual Revegetation Costs	3	

Table 7.2 Water Quality Data Entry (National Stormwater BMP Database)

Precip. Event	Total Precip. in	Starting Date	Outflow/Inflow Ratio, RC	WQ Parameter	Inlet mg/L	Outlet mg/L	CR % Rem.	MR % Rem.
1	0.40	3/31/2004	0.50	TSS	18.7	8.1	56.52	78.25
2	0.92	4/11/2004	0.90	TSS	19.1	5.6	70.79	73.83
3	0.30	4/26/2004	0.63	TSS	16.6	5.9	64.35	77.72
4	1.98	05/1/2004	0.85	TSS	52.9	5.1	90.31	91.75
5	0.95	5/30/2004	0.74	TSS	13.2	5.8	56.37	67.92
6	1.29	06/4/2004	0.87	TSS	107.4	8.4	92.18	93.16
7	0.22	6/23/2004	0.52	TSS	16.8	1.0	94.05	96.90
8	0.61	6/26/2004	0.68	TSS	14.3	4.9	65.73	76.68
9	0.58	6/29/2004	0.67	TSS	26.5	4.1	84.53	89.61
	CR = removal based on concentration, MR = mass removal					avg =	74.98	82.87

WQ Parameter	Inlet mg/L	Outlet mg/L	CR % Rem.	MR % Rem.	WQ Parameter	Inlet mg/L	Outlet mg/L	CR % Rem.	MR % Rem.
TN	1.32	1.67	-26.52	36.72	TP	0.124	0.248	-100.00	-0.04
TN	2.07	1.29	37.68	44.17	TP	0.220	0.160	27.27	34.85
TN	3.44	3.05	11.34	44.58	TP	0.310	0.200	35.48	59.67
TN	0.81	0.65	19.75	31.70	TP	0.230	0.180	21.74	33.39
TN	1.61	1.66	-3.11	24.19	TP	0.149	0.388	-160.40	-91.48
TN	1.00	1.04	-4.00	9.10	TP	0.303	0.355	-17.16	-2.40
TN					TP				
TN	0.92	0.87	5.43	35.66	TP	0.279	0.236	15.41	42.44
TN	0.90	0.73	18.89	45.54	TP	0.240	0.170	29.17	52.44
		avg =	7.43	33.96			avg =	-18.56	16.11

WQ Parameter	Inlet mg/L	Outlet mg/L	CR % Rem.	MR % Rem.	WQ Parameter	Inlet mg/L	Outlet mg/L	CR % Rem.	MR % Rem.
DOC	12.43	17.08	-37.41	31.27	NO_3-N				
DOC	13.90	12.93	6.94	16.64	NO_3-N	0.064	0.056	12.28	21.42
DOC	31.31	29.75	4.98	40.61	NO_3-N	0.221	0.187	15.31	47.06
DOC	9.71	9.15	5.77	19.79	NO_3-N	0.061	0.034	44.44	52.71
DOC	10.92	14.72	-34.80	0.88	NO_3-N	0.303	0.239	20.90	41.83
DOC	9.21	10.89	-18.24	-3.34	NO_3-N	0.086	0.081	5.26	17.20
DOC					NO_3-N				
DOC	10.11	10.57	-4.55	28.86	NO_3-N	0.025	0.052	-109.09	-42.27
DOC	13.39	9.07	32.26	54.52	NO_3-N	0.025	0.029	-18.18	20.65
		avg =	-5.63	23.65			avg =	-4.15	22.66

Table 7.2 Water Quality Data Entry (National Database) – continued

WQ Parameter	Inlet mg/L	Outlet mg/L	CR % Rem.	MR % Rem.
PO_4-P	0.044	0.039	11.11	20.37
PO_4-P	0.091	0.150	-64.29	-2.69
PO_4-P	0.039	0.039	0.00	14.89
PO_4-P	0.036	0.173	-381.82	-254.29
PO_4-P	0.062	0.163	-163.16	-130.00
PO_4-P	0.036	0.473		
PO_4-P	0.121	0.101	16.22	42.99
PO_4-P	0.010	0.065	-566.67	-347.63
		avg =	-164.09	-93.77

WQ Parameter	STORET Number	Unit	Qualifier	Analytical Method	QA/QC
TSS	80154	MG/L	A	2540(D)	2 duplicates
TN	600	MG/L-N	A		3 duplicates
TP	665	MG/L-P	*	4500-P(E)	
DOC	680	MG/L-C	A	5310(B)	3 duplicates
NO_3-N	620	MG/L-N	*	4100(B)	
PO_4-P	671	MG/L-P	*	4100(B)	

* Only one sample was analyzed (No duplicate)

Note: Inlet samples are composite samples entering the Grass Filter Strip
Outlet samples are composite samples leaving the Grass Filter Strip
CR = Concentration Ratio for Removal Efficiency, (Cin-Cout)/Cin*100
MR = Mass Ratio for Removal Efficiency, (Cin-Cout*RC)/Cin*100
For storm of 6/23/2004, only TSS sample was available.

Laboratory Procedures

For TN, we used Shimadzu scientific instruments, Inc. Model TNM-1, combustion decomposition with chemiluminescence detection.
For DOC, we used Shimadzu scientific instruments, Inc. Model TOC-V, combustion catalytic oxidation method.
For NO_3-N and PO_4-P, we used Dionex Corporation Ion Chromatograph Model DX 500.

Table 7.3 Data Entry Template (Stormwater Data Management System, UNC Charlotte)

Data Element	Data Acquisition
1. Site Location	
Name of Facility	
State plane coordinates or GPS at Facility Outlet	GPS measurement
City, County, State, Zip Code, Country, Altitude	To be identified
Physiographic Region	To be identified
USGS Quadrangle Map Name	
Highway Section Serviced by BMP	Verify during visit
Approx. Roadway ADT Draining to Facility	Measure during visit
Drainage Area	Verify during visit
Percent Imperviousness	Verify during visit
Roadway Type	Verify during visit
2. River Basin	
River Basin ***(Subject Watershed Name)***	http://www.epa.gov/surf/
NRCS HSG (Soils)	Check soil maps
User-support of Receiving Water	Check DQW web info
DOQQ	Check DOQQ map
TMDLs	Check DWQ web info/impairments
Stream Classification	Check DWQ info
Annual Precipitation, P10 or greater	Check USGS info
Regional Climate Station	Check Data Entry Software
Land Use Information	Check land use maps
3. Facility Functionality	
BMP Drawing	Request copy from NCDOT
Facility Type (e.g. VFS)	Enter BMP type
Describe the Entire Treatment Train	Verify during visit
Vegetation Establishment	Observe during visit
What date was the BMP facility put into service?	Ask NCDOT
How many separate inflow points?	Verify during visit
Is the BMP designed to bypass/overflow when full?	Verify during visit
4. Field Observations	
Erosion	Observe during visit
Clogging	Observe during visit
Vegetation Growth	Observe during visit
Excessive Water Accumulation	Observe during visit
Other Concerns	Observed during visit
5. Pollutant Removal Performance	
Performance Data from Literature	Include 2-3 major references
Pictures from Site Visit	Obtain during visit
Assessment of Potential Benefits	Drawing conclusions
Other Observations/Remarks	Note during visit
6. Design Information (specific for BMP type)	
(The following is for Grass Filter Strip)	
Grass Strip Length	Verify during visit
Grass Strip Slope	Verify during visit
Flow Depth During 2-year Storm	To be computed
2-year Peak Flow Velocity	To be computed
Describe Grass Species and Densities	Observe during visit
Is Strip Irrigated?	Observed during visit
Measured Saturated Infiltration Rate	Measure during visit, if possible
Depth to Groundwater or Impermeable Layer	Measure during visit, if possible

* Terms in ***blue*** are similar information required by the National Stormwater Database

8. Industrial facilities

The need for washing/cleaning operations is important from both safety and equipment maintenance needs. The second phase of the NPDES requirements that was issued to NCDOT includes the evaluation of pollution prevention (PP) alternatives and implementation of BMP pilot studies at all of the agency's industrial facilities. These requirements have impacted the operation of NCDOT's one-hundred-fifteen industrial facilities across the state.

According to Part II of the NCDOT NPDES Stormwater Permit for vehicle and equipment cleaning areas, a PP plan must describe measures that prevent or minimize contamination of the stormwater runoff from all areas used for vehicle and equipment cleaning. The facility shall consider performing all cleaning operations indoors, covering the cleaning operation, ensuring that all wash water drains to the sanitary sewer system (i.e., not the stormwater drainage system, unless permitted by another NPDES general or individual permit), collecting the stormwater runoff from the cleaning area and providing treatment or recycling, or other equipment measures. If a sanitary sewer connection is not available to the facility and cleaning operations take place outdoors, the cleaning operations shall take place on grassed or graveled areas to prevent point source discharges of the wash water into storm drains or surface waters. Where cleaning operations cannot be performed as described above and when operations are performed in the vicinity of a storm drainage collection system, the drain is to be covered with a portable drain cover during cleaning activities. Any excessive ponded water shall be removed and properly handled by pumping to a sanitary sewer prior to removing the drain cover. Detergents used outdoors shall be biodegradable and the pH adjusted to be in the range of 6 to 9 standard units. The point source discharge of vehicle and equipment wash waters, including tank cleaning operations, are not authorized by this permit and must be covered under a separate NPDES general or individual permit or discharged to a sanitary sewer in accordance with applicable industrial pretreatment requirements.

This chapter of the report provides NCDOT with relevant information and action plans developed by transportation agencies across the country. It is anticipated that a systematic evaluation of the types, methods, and solutions can be properly practiced to formulate an effective pollution prevent plan/policy. The following sections document pollution prevention activities pertaining to truck/equipment wash/maintenance facilities undertaken by Federal, non-NC State Agencies and commercial services.

8.1 Federal Regulatory Review

Under the provisions of CFR 122.26 (b)(14)(i)-(xi), industrial facilities belonging to one of the eleven categories of "Stormwater Discharges Associated with Industrial Activity" that discharge stormwater to a municipal separate storm sewer system (MS4) or directly to waters of the United States shall require authorization under a NPDES industrial stormwater permit (http://cfpub.epa.gov/npdes/stormwater/indust.cfm).

If an industrial facility has a Standard Industrial Classification (SIC) code or meets the narrative description listed in these eleven categories, the facility operator must determine if the facility is eligible for coverage under a general or an individual NPDES industrial stormwater permit. In some cases, a facility operator may be eligible for a conditional/temporary exclusion from permitting requirements. (http://cfpub.epa.gov/npdes/stormwater/swcats.cfm).

The Storm Water Phase II Rule allows operators of industrial facilities in any of the eleven categories of "Stormwater Discharges Associated with Industrial Activity" (except construction activities, which are addressed under the construction component of the NPDES Storm Water Program) have the opportunity to certify to a condition of "no exposure" and as long as the condition of "no exposure" exists at a certified facility, the operator is excluded from NPDES industrial storm water permit requirements.

Transportation facilities are listed as category viii and are classified by SIC codes which include vehicle maintenance shops, equipment cleaning operations, or airport deicing operations, as shown below.

SIC Code

40	Railroad transportation
41	Local and interurban passenger transit
42	Trucking and warehousing (except 4221-25, see (xi))
43	US postal service
44	Water transportation
45	Transportation by air
46	Petroleum bulk stations and terminals

Only those portions of the facility that are either involved in vehicle maintenance (including vehicle rehabilitation, mechanical repairs, painting, fueling, and lubrication), equipment cleaning operations, airport deicing operations, or which are otherwise identified under categories (i)-(vii) or (ix)-(xi) are associated with industrial activity, will require permit coverage.

Mr. Brent Larsen of EPA Region 6 was contacted to clarify certain NPDES issues pertaining to regulatory perspectives and on-site management of vehicular wash water. Mr. Larsen's comments, which were in response to industrial inquires, have been posted on a website (http://www.dcs1.com/del/delpg5/epabmp96.html). His remarks are summarized below.

(A) Discharge of vehicle wash waters to a Water of the United States, even if via a separate storm sewer system, does legally require a National Pollutant Discharge Elimination System (NPDES) permit. In addition, section 402(p) of the Clean Water Act requires NPDES permits for the discharge of Storm Water Associated with Industrial Activity. The definition of "the discharge of Storm Water Associated with Industrial Activity" within 40 CFR 122.26 (b) (14) includes post offices, certain motor freight, most manufacturing facilities, etc.

(B) The facility operator is typically required to address storm water runoff from vehicle maintenance (including washing) areas at these facilities. There is a difference between the actual wash water which has required a waste water NPDES permit since 1972, and the storm water runoff from the areas where the vehicle washing occurs which has required a storm water NPDES permit since October 1992.

(C) Since an NPDES permit is only required for a point source discharge of pollutants, several scenarios where a waste water permit would not be required may include:

- If a “dry” wash method is used and no waste water is generated, there is no discharge that would require a permit.
- If wash water is collected and recycled for reuse, there would be no point source discharge at the wash site and therefore no need for a permit. The wash water could be collected in many ways, including commercially-available portable devices similar to a child’s inflatable swimming pool that a vehicle is driven onto and then washed; blocking the storm drains with specialized plugs or simple plastic and sandbag-type devices; use of a wash rack with drains to a storage vault; etc. This type of process is commercially available within the power washer industry.
- If wash water is collected and disposed of into a sanitary sewer (e.g. wash rack plumbed to sanitary or water collected and dumped into sanitary sewer system on site), there would be no point source discharge at the wash site and therefore no need for a permit.
- If wash water is collected and taken off site to a public or private waste water treatment plant, or discharged off site to the sanitary sewer system, no permit would be needed. Note that the public or private waste water treatment plant would need to have its own NPDES discharge permit.
- If wash water is collected and applied to the land (e.g. for irrigation, etc.) or otherwise allowed to evaporate (e.g. an evaporation pond) without ever being discharged, there would be no need for a permit. Note that the land application of the wash water could, in certain circumstances, trigger the need for a storm water discharge permit for the application site.

(D) A waste water permit would only be required if

- Wash water is allowed to run off the property and into a conveyance, including a storm water drain, leading to a Water of the United States, or
- Wash water is collected and transported off site, where it is then discharged.

(E) The party taking waste water off-site, and not the facility operator, would be responsible for proper disposal of the wash water removed from the site.

(F) Disposal into a sanitary sewer would require permission from the local city or wastewater authority and compliance with any applicable industrial pretreatment requirements. Illegal dumping of waste water could result in fines from the local municipality, the State, and/or the Environmental Protection Agency.

(G) Any facility with "Storm Water Associated with Industrial Activities" would still need to obtain a storm water permit for the areas where any vehicle maintenance, including washing, fueling, or mechanical repair, occurs. However, this would be the case regardless of the vehicle wash method used, unless the all storm water from these areas was also captured and prevented from discharging.

(H) There are alternatives to obtaining a NPDES permit, and several of these options (such as contracting mobile pressure washers) offer opportunities for pollution prevention.

8.2 Storm Water Pollution Prevention Plan (SWPPP)

8.2.1 Guidance Document

The USEPA has published a guidance document pertaining to developing and implementing a Storm Water Pollutant Plan for industrial facilities (USEAP 1992). The document provides guidance on SWPPP requirements for industrial (non-construction) activity under the NPDES Storm Water Program. It includes steps to develop a pollution prevention plan, general descriptions of activity and site-specific BMPs, a set of worksheets and checklists, and an example of a PP plan. Section 3.4 of this document summarizes BMPs for vehicle and equipment washing. Vehicle wash water is considered to be a process wastewater and needs to be covered by an NPDES permit. Generalized BMPs are recommended as follows.

- Use phosphate-free biodegradable detergents
- Designate a specific area when performing the washing of vehicles or equipment over an open ground (the specific area should be bermed to collect the wastewater and graded to direct the wash water to a treatment facility.)
- Consider filtering and recycling wash water (if recycling is not practical, the wastewater can be discharged to the sanitary sewer with due consideration for pretreatment requirements.)

The USEPA has recommended several major components to be included in a PP plan:

(A) Planning and Organization

- Form a PP Team
- Review Pertinent Plan

(B) Assessment

- Develop Site Map
- Inventory and Describe Exposed Materials
- List Significant Spills and Leaks
- Test for Non-Storm Water Discharges
- Evaluation of Monitoring Data
- Summarize Pollutant Sources and Risks

(C) BMP Identification

- Baseline BMPs
- Select Activity and Site-Specific BMPs

(D) Implementation

- Implement BMPs
- Train Employees

(E) Evaluation and Monitoring

- Conduct Annual Site Inspection/BMP Evaluation
- Conduct Recordkeeping and Reporting
- Review and Revise Plan

(F) General Requirements

- Deadlines
- Signature Requirements
- Plan Location and Public Access
- Required Plan Modification

(G) Specific Requirements

- Discharge Through MS4s
- Salt Storage Piles
- EPCRA Section 313 Facilities

8.2.2 Sample SWPPP

The USEPA has released a sample SWPPP for a trucking terminal. The trucking terminal consists of a truck/trail storage area, a truck loading area where truck-cleaning operations take place, a maintenance garage, a storage warehouse, a fueling station, and an office building. The facility falls under a SIC code of 4231. Passive treatment BMPs were included with a goal to remove 80% of all storm water pollutants. The following summarizes some of the BMPs developed in this SWPPP.

(http://www.epa.gov/reg3wapd/stormwater/pdfs/transportation.pdf).

- Inspection of entering vehicles for leaks and place drip pans under the detected leaks.
- Absorbent oil socks are placed on storm inlets as a secondary preventive measure.
- Truck storage areas will be paved and curbed to better contain leaking fluids.
- Make available an emergency fuel spill/clean-up kit.

- Contract a vendor to remove oily sludge and solvent from parts cleaning to be in compliance with the RCRA standards for a Large Quantity Generator.
- Use high-pressure spray to reduce the quantity of wash water.
- Collect all wastewater from the cleaning operations into 55-gal drums for off-site disposal.
- Install a sand filtration system or in-ground oil-water separator to treat the cleaning wastewater.
- Cover the fueling station with a new roof and curb its perimeter.
- The loading area will be paved and sloped to contain all spill fluids.
- A new fluid storage building and covered loading dock will be built.

8.3 Review of State Approaches

8.3.1 State of California

The California Department of Transportation (Caltrans) publishes a series of bimonthly bulletin on "Maintenance Storm Water Pollution Prevention Bulletin". Several of the previously published bulletins are of particular interest: (http://www.dot.ca.gov/hq/env/stormwater/publicat/maintain/index.htm)

- Vol. 5, Issue 2, September 2002, reviews BMPs to prevent pollutant discharges from a maintenance facility
- Vol. 1, issue 5, June 1998, discusses the common vehicle and equipment washing practices and implementation of appropriate BMPs for pre-wash, exterior wash and pressure washing.

Pre-Wash and Rising Operations

- Pre-wash or rinse vehicles only to remove accumulated sediment and prohibit the use of detergents or pressure washing of engines or undercarriages.
- Do not use solvents to clean vehicles at any time.
- Provide a designated paved area away from hazardous material or waste storage area to prevent potential contamination of overspray or runoff.
- If possible, berm or slope the area to prevent run-on and run-off of wash water onto the yard and direct drainage to a sump to allow sediment to settle prior to discharge.
- If space permits, make the area large enough to accommodate bigger vehicles such as sweepers and truck beds.
- If a sump cannot be provided, use a sediment trap such as straw bales, gravel bags or A.C. berms that will allow sediment and debris to settle prior to discharge.

- Make sure that rinse water does not drain across the facility where it can pick up oils and debris prior to discharge.

Pressure Washing Operations

- Use an approved wash rack that is sloped to contain and drain wash water and constructed to prevent run-on and run-off.
- Use phosphate-free, biodegradable detergents when available.
- Discharge wash water to a sanitary sewer, a dead-end sump, or a recycle system.
- Collect water and sediment from sumps and dispose off properly.
- Comply with local agency pre-treatment and monitoring requirements for wash water discharged to the sanitary sewer and install oil-water separators, rain sensors or canopies when required.

Caltrans has also published "The Caltrans Stormwater Quality Handbooks" which consist of several guidance manuals that are specific for water pollution control during construction including:
(http://www.dot.ca.gov/hq/construc/stormwater/CSBMPM_303_Final.pdf):

- Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Control Program (WPCP) Preparation Manuals.
- Construction Site Best Management Practices Manual (BMP Manual)
- Project Planning Design Guide

The BMP Manual provides several guidelines for vehicle and equipment cleaning (NS-8, Figure 8.1), as summarized below:

- Vehicle and equipment wash water shall be contained for percolation or evaporative drying away from storm drain inlets or watercourses and shall not be discharged within the highway right-of-way. Apply sediment control BMPs if applicable.
- For outside cleaning operations, the cleaning area must locate away from storm drain inlets, drainage facilities, or watercourses; must be paved with concrete or asphalt and bermed to contain wash waters and to prevent run-on and run-off; and must configure with a sump to allow collection and disposal of wash water. The wash water shall not be discharged to storm drains or watercourses.
- When cleaning with water, high-pressure sprays may be considered and use positive shutoff valve to minimize water usage. Facility water racks shall discharge to a sanitary sewer, recycle system or other approved discharge systems and shall not discharge to the storm drainage system or watercourse.

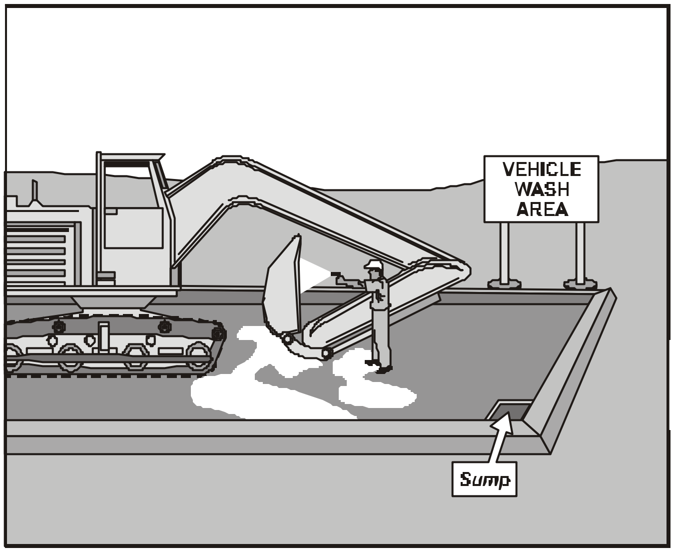


Figure 8.1 Vehicle and Equipment Cleaning (NS-8)

8.3.2 City of Franklin, Tennessee

The City of Franklin, Tennessee, has developed a Storm Water Management Manual to assist concerned individuals to comply with the guideline set forth by NPDES Phase II Rule (http://www.franklin-gov.com/bpm.aspx). The manual provides guidance for BMP selection, design and implementation. It takes a fact-sheet approach to allow easy access and expedient use. Readers are referred to the city's website for a copy of pollution prevention guidelines for vehicle and equipment cleaning (ICP-03/ICP-12).

8.3.3 Pierce County, Washington State

The Pierce County's Stormwater Pollution Prevention Manual provides guidelines to help businesses, homeowners and public agencies to implement BMPs in order to prevent pollutants from contaminating stormwater runoff and entering receiving waters. This manual contains a section (A1) summarizing guidelines for cleaning and washing activities.
(http://www.co.pierce.wa.us/pc/services/home/environ/water/swm/sppman/a1.htm)

8.4 Sample NPDES Permit from South Carolina

The Department of Health and Environmental Control, South Carolina, has issued a NPDES general permit for vehicle wash water discharges covering the period of April 1, 1996 to March 31, 2001 (10). Section B (Eligibility) of this permit is reproduced below. (http://www.dcs1.com/del/delpg5/scnpdes1.html)

1. This permit may cover all new and existing point source discharges to waters of South Carolina, as identified in this section below, except for discharges identified under paragraph II.B.3.

a. Types of wastewater permitted: This permit authorizes the discharge of 10,000 gallons per day or less of wastewater from the following types of operations as further specified in this permit:

- Commercial, fixed, exterior, vehicle washing facilities (CFEVWF) which discharge to a waterway or the land.
- Fixed exterior, vehicle washes on the vehicle owner's property which discharge to a waterway or the land.
- Mobile washing of vehicle exteriors on the property of a vehicle owner which discharges to a waterway or the land. The mobile washer, not the property owner, has coverage in this case.
- Construction equipment washing which discharges to a waterway or the land. Erosion control facilities and/or other measures shall be utilized at all sites. Sites which are covered by NPDES General Permit SCR100000 ("Storm Water Discharges from Construction Activities that are Classified as 'Associated with Industrial Activity' by EPA Regulation") must use these facilities to meet the requirements of construction-related stormwater permit coverage. These activities shall be incorporated into the Stormwater Pollution Prevention Plan required by that permit.
- Wash water that is 100% recycled - no discharges.

b. A discharger covered under this permit who intends to increase the discharge of any of the types of wastewater permitted hereunder to a flow rate greater than is authorized under this permit must apply for and obtain an individual permit for such discharge before increasing the flow rate.

2. This permit may authorize vehicle wash water discharges that are mixed with other discharges provided that the other discharges are in compliance with the terms, including applicable NOI or application requirements, of a different NPDES general permit or individual permit authorizing such discharges.

3. Limitations on Coverage. The following vehicle wash water discharges are not authorized by this permit:

   a. Vehicle wash water discharges that are mixed with other types of wastewater unless those wastewater discharges are in compliance with a different NPDES permit;

   b. Vehicle wash water discharges that are subject to an existing NPDES individual or general permit; are located at a facility where an NPDES permit has been terminated or denied; or which are issued a permit in accordance with paragraph V. M. (Requirements for Individual or Alternative General Permits) of this permit. Such discharges may be authorized under this permit after an existing permit expires or is cancelled;

c. Pressure washing or steam cleaning of engines or parts is prohibited under this General Permit. These activities require an individual NPDES permit and construction permit be obtained.

d. Vehicle washing using chemicals of any type or detergents which are not readily biodegradable (Note that mild acidic cleansers may be used if readily biodegradable but may cause pH violations);

e. Vehicle wash water discharges that the Department has determined to be or which may reasonably be expected to be contributing to a violation of a water quality standard;

f. Vehicle wash water discharges that would adversely effect a listed endangered or threatened species or its critical habitat;

g. Wash water that is discharged to a permitted public sewer, sanitary sewer, septic tank, or tile field. Other permits may apply for these discharges, and;

h. Wash water discharges which are categorically limited such as lead battery transport truck wash water (40 CFR 461).

8.5 Environmental Power Washing and Commercial Services

8.5.1 Power Washing

Environmental Power Washing is pressure washing with no off property discharge and discharging the wash water to a sanitary sewer. The preferred entry point to the Municipal Sanitary Sewer System (POTW) is a sand trap, or a grease trap. Other possible points of entry may be slop sinks, mop sinks, sanitary sewer clean outs, commodes, inside floor drains, etc. Washing with a recycling system on a portable vinyl pad is the most expensive way; this needs to be the option of last resort. Recycling systems do not typically remove total dissolved solids, heavy metals, detergents, herbicides, insecticides, or pesticides. Hence the longer the wash with recycled water, the harder it is to get something clean and one has to rinse with fresh water. Often times, washing items in place then capturing the wash water is a less expensive option. (http://www.dcs1.com/del/delpg5/rept507.html)

Common water control devices may include: recycling system; pretreatment or sewer discharge systems; limited recycling systems; wash pits (portable vinyl wash pads), vacuum sludge filtering systems; wet weather vacuums, sump pumps; drain covers; portable dams; vacuum booms; oil absorbent pads, booms, pillows, and tubes; plastic sheeting; filter tubs; buckets; pans; and squeegees. Sometime it is possible to use the terrain and natural drainage and catch the water at a low spot to accomplish “no off property discharge”. It is also possible to use a wet/dry vacuum and vacuum up the water before off property discharge. A lot of contractors have used evaporation effectively enough that they can wash for several hours and only have to recover less than 55 gallons of wash water.

Recommended PP practices for the Mobile Power Wash Industry have been documented for the Greater Kansas City Metropolitan Area. Guidelines pertaining to transportation-related washing or detailing are summarized below:
(http://www.dcs1.com/del/delpg5/KCbmp97.html)

1. Fleet Washing [Exterior washing to remove mainly dirt with soap]:

   - Capture the wash water using wash pads, temporary seals over storm sewer, or permanent wash station with no outlet.
   - Dispose of wash water through proper sanitary sewer access point.
   - If a permanent wash station is utilized, the wash water may be left for evaporation.
   - Wash area cleaning protocol needs to be followed.

2. Engine/Equipment Degreasing; Auto/truck drive train cleaning, engine degreasing, airplane cleaning, including landing gear [with or without soap]:

   - If solvents used are considered hazardous waste under RCRA, then the wash water may be required to be contained and handled as hazardous waste. Disposal to the POTW is subject to review and approval prior to discharge.
   - If no solvents are used, wash water must be contained and treated, if required, prior to discharging to a proper sanitary sewer access point. Types of treatment may include oil/water separators and coalescers. Contact the Control Authority serving your area for additional information concerning regulations.

The following is a list of equipment suppliers for washing collection, cleaning and disposal systems.

(1) GOTO http://www.dcs1.com/del/delpg7/ for power wash equipment and an example is shown below.


Stationary Hot High Pressure Washers, 1,000 to 3,000 PSI, $2,750.00 to $4,550.00

(2) GOTO http://www.dcs1.com/del/delpg4/ for wash water collection materials.

- ✓ Complies with state and federal wastewater laws
- ✓ Works with your existing pressue-washer equipment
- ✓ Simple and easy to maintain
- ✓ Field proven for thousands of hours by contract cleaners
- ✓ Easy set-up and storage
- ✓ Made of super-durable "Truck-tarp" fabric

Standard Sizes:

- o 75 foot by 20 foot (Tractor-Trailer) 220 lbs....................................$1,195.00
- o 50 foot by 20 foot (Buses, Trucks, Vans) 145 lbs...........................$ 795.00
- o 30 foot by 20 foot (Cars, Service Trucks, Pick-ups) 90 lbs.............$ 490.00

Vinyl Laminated Nylon Ground Covers

- o 75 foot by 13.5 foot (Tractor-Trailer) $760.00
- o 50 foot by 13.5 foot (Buses, Trucks, Vans) $506.00

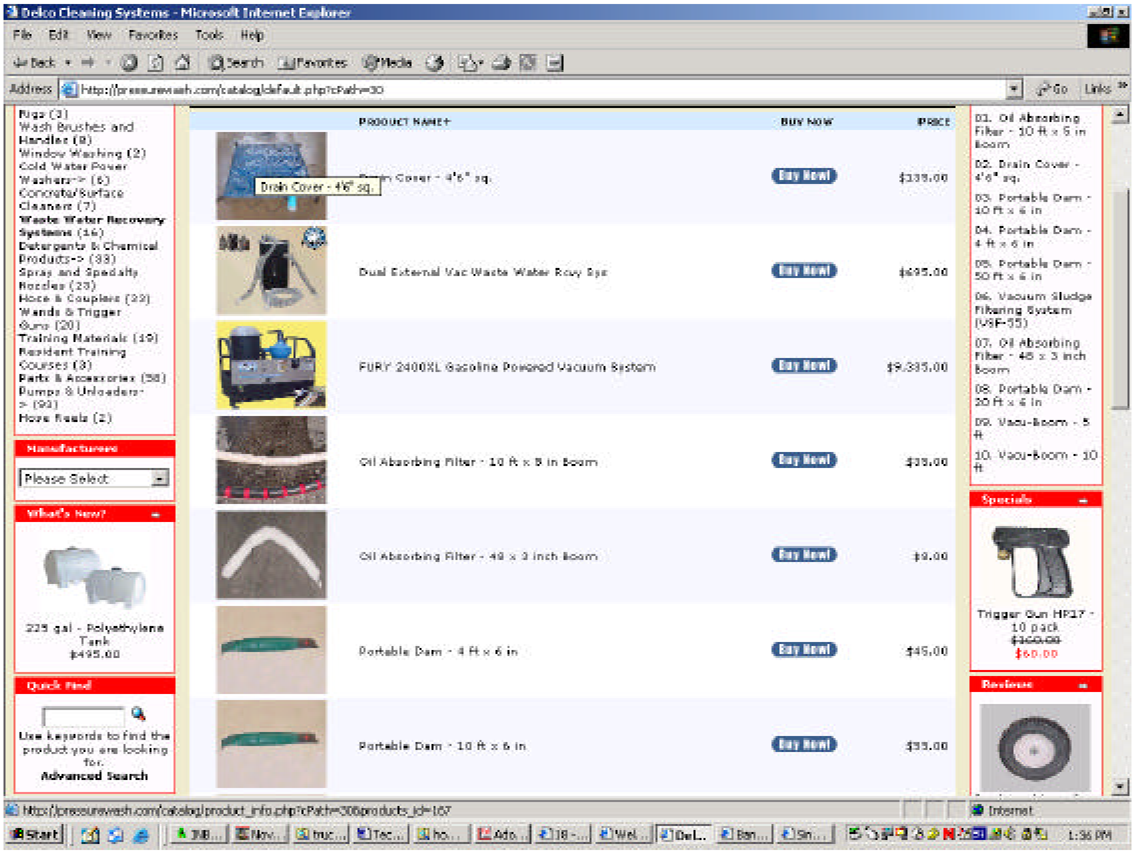
Berms can be made of 2 x 4s, flexible corrugated sewer pipe, or 3 inch PVC pipe cut in 1/2 length wise. Berms not included.

Specifications:

- o Material: 18 oz. Vinyl-Coated Polyester.
- o Hems: Lockstitch sewn with two rows of #207 UV-treated bonded polyester thread
- o Seams: 1" rotary hot-air welded
- o Tensile Strength: 450 by 400 lbs.

- Abrasion Resistance: 250 cycles
- Temperature Range: Minus 65 degrees to 200 degrees
- Webbing: 1.5" (breaking strength approx. 2,500 lbs.)
- All tarps are $0.85 per square foot. Custom sizes available.

(3) GOTO http://pressurewash.com/catalog/ for wastewater recovery systems.

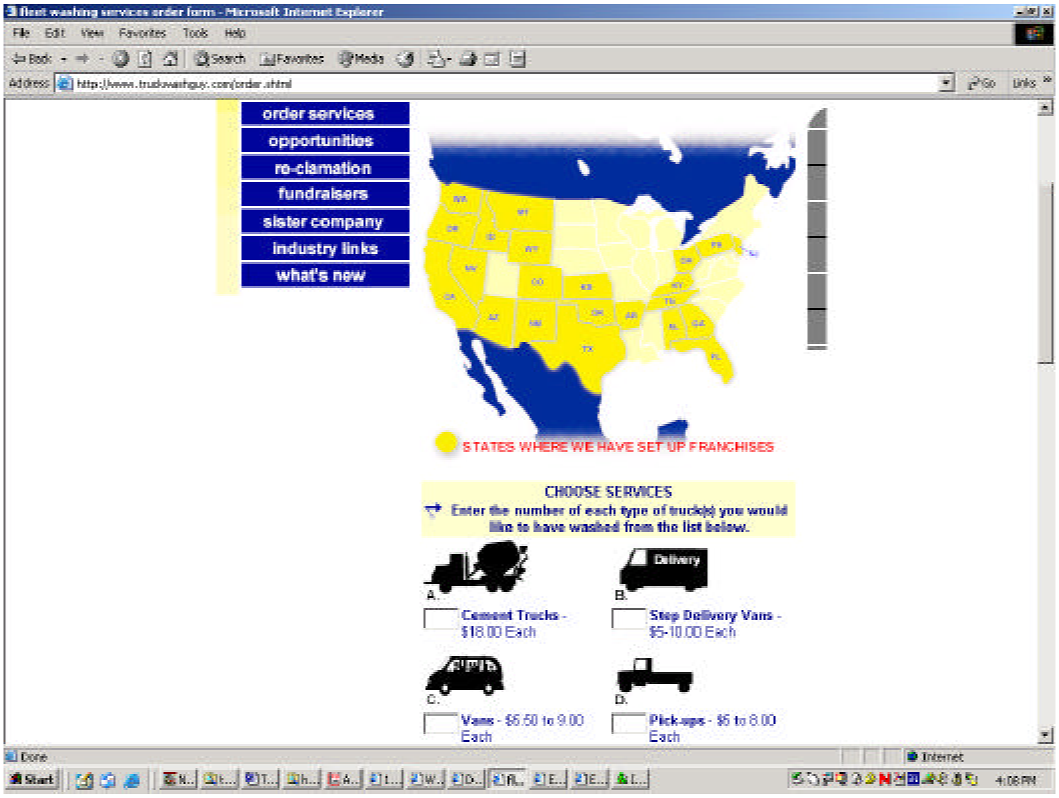


(4) GOTO http://epsiusa.com/ for recycling system.

(5) GOTO http://www.ikeca.com/chap18proc/index.html for slide presentation of the Environmental Power Washing Systems and other information.

8.5.2 Commercial Services

The Truck Wash Guys® provides mobile fleet truck washing for private fleets and leasing companies, on-site in truck yards and at customer locations. This is just one of the few examples of commercial services. No commercial services have been identified for North Carolina at the time this report was submitted. (http://www.truckwashguy.com)



8.6 Concluding Remarks

The following items are recommended for consideration when developing a PP plan/policy for NCDOT's truck/equipment wash/maintenance facilities. A summary diagram for all possible PP options is shown in Figure 8.2.

- Clarification of regulatory requirements pertaining to *waste water* versus *storm water* NPDES (refer to Section 8.1)

- Review of the preventive measures and wash water minimization techniques that are outlined by Caltrans, City of Franklin, Tennessee; Pierce County, Washington State; or the USEPA's example of SWPPP, etc.

- The discharge of wash water from facilities within MS4 may consider:

  a. Connection to existing sanitary sewers,
  b. Off-site disposal offered by contracting vendors,
  c. On-site recycling and reuse, and/or
  d. On-site collection.

- The discharge of wash water from remote facilities may consider:

  a. On-site recycling and reuse,
  b. On-site collection,
  c. On-site treatment such as evaporative methods (e.g. evaporation pond, bioretention), and/or
  d. On-site infiltration measures.

- A general permit coverage approach such as the South Carolina permit (refer to Section 4) may be explored.

- Use of Environmental Power Washing is a possible option.

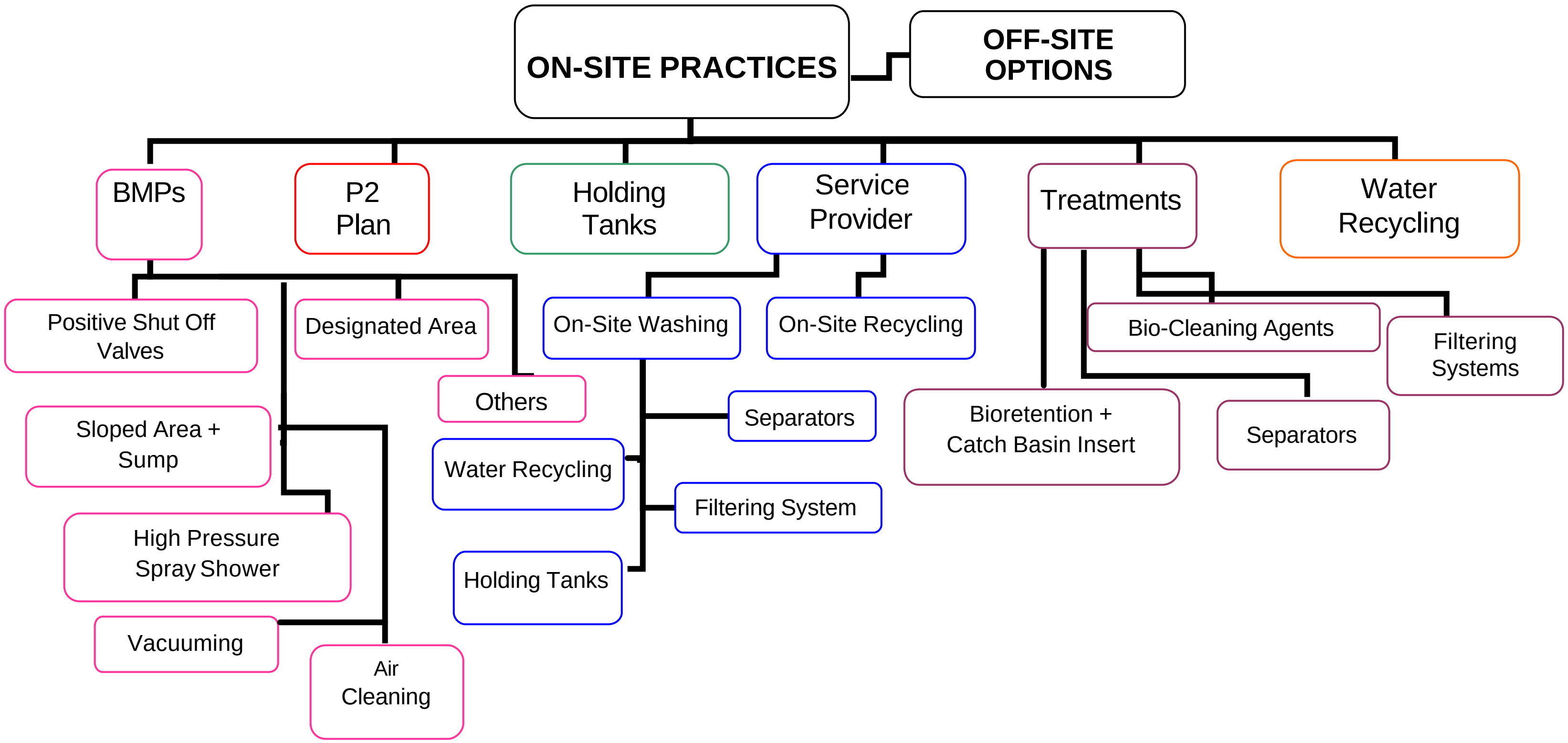


Figure 8.2 Wash Water Management Options (UNC Charlotte)

9. Borrow Pit Wastewater

Borrow pits are areas where soils are being excavated to provide fill dirts for the foundation of a building or roadbed. Excavation typically leaves a shallow to moderately deep hole in the ground. One of the concerns confronting by NCDOT for borrow pits located in the northeastern part of the state is the accumulation of water inside the pit area due to high water table and direct rainfall (Figure 9.1). The accumulated water or borrow pit wastewater must be continuously pumped out of the pit, treated and discharged to a receiving stream. This discharge must meet the current regulatory requirement of turbidity compliance (50 NTU). Stilling basins have been the most common practice used to provide sedimentation of coarse to fine particles for turbidity reduction. Other treatment options are also being explored by NCDOT for turbidity reduction. A list of these options has been documented in the form of a "turbidity reduction matrix' which is included in Appendix 3 of this report. The goals of our research were to provide technical guidance for improving the operation of stilling basins, and the proper use of chemical coagulation and polymer injection treatment systems.

9.1 Stilling Basins

Stilling basins have been widely used to retain and treat borrow pit wastewaters. The general rule-of-thumb for sizing a stilling basin has been adopted from the requirement of 1,800 ft^3/ac originally used by the surface mining industry and, subsequently, for sediment and erosion control. Past experience derived from the mining industry has shown that this sizing requirement could be as effective as sizing capacities of lesser or greater capacities when dealing with TSS removal. As seen from Figure 9.2, sediment basins with capacities of 900 ft^3/ac or 4,261 ft^3/ac could perform equally well when compared to the 1,838 ft^3/ac basin. (USEPA 1980)

Figure 9.1 Water Accumulation inside a Borrow Pit

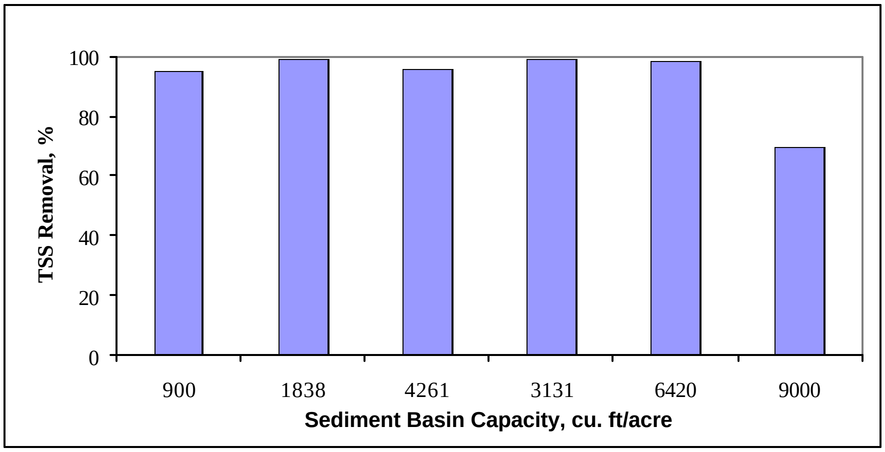


Figure 9.2 Performance of Sediment Basins for TSS Removal (USEPA 1980)

Turbidity is a measure of water clarity and an indicator of the quantity of suspended solids in the water. The main contributors to turbid (murky) water are clay, silt, fine organic matter and microscopic organisms, predominantly living algae. The major problem with turbid water is that the matter it contains can remain in suspension for a long time. Removing the suspended solids has not, in many cases, guaranteed the simultaneous removal of turbidity to below acceptable levels. This is particularly evident when examining data collected from several stilling basins located in the northeastern part of North Carolina. All of the 10 stilling basins investigated exhibit a wide range of basin capacity (ft^3/ac) and are capable of providing effluent turbidity of less than 50 NTU under normal operating conditions. However, the treated effluent may occasionally exceed the allowable limit of 50 NTU when there is a surge of influent turbidity level, regardless of the basin capacity. There is a lack of correlation between the peaking factor, which is measured as observed effluent peak turbidity to long-term average effluent turbidity, and the basin capacity in cubic feet of basin volume to the acreage of borrow pit surface area. A peaking factor as high as 3.7 has been observed from this dataset, as shown in Figure 9.3

The dynamic nature of influent turbidity can be best illustrated by examining a dataset collected from the Davis Pit Stilling Basin for the period of 8/20/2004 – 8/26/2004. The Davis Pit Stilling Basin has a total capacity of 1,851 ft^3/ac and is partitioned into two flow-through smaller basins connected in series. As seen from Figure 9.4, this two-stage stilling basin effectively controls the final discharge to below 50 NTU when the peak influent turbidity was about 80 NTU or less. The turbidity peaks between inflow and outflow in the first-stage basin appear to be separated by about 40-50 hours, which is equivalent to the approximate detention time available for settling of turbidity-induced fine particles in this basin. Consequently, when there is a surge of inflow turbidity the operator will have to adjust the pumping rate to provide adequate detention time. It is also noted that a two-stage basin would perform better than one large basin that may incur more short-circuiting and contain dead volumes.

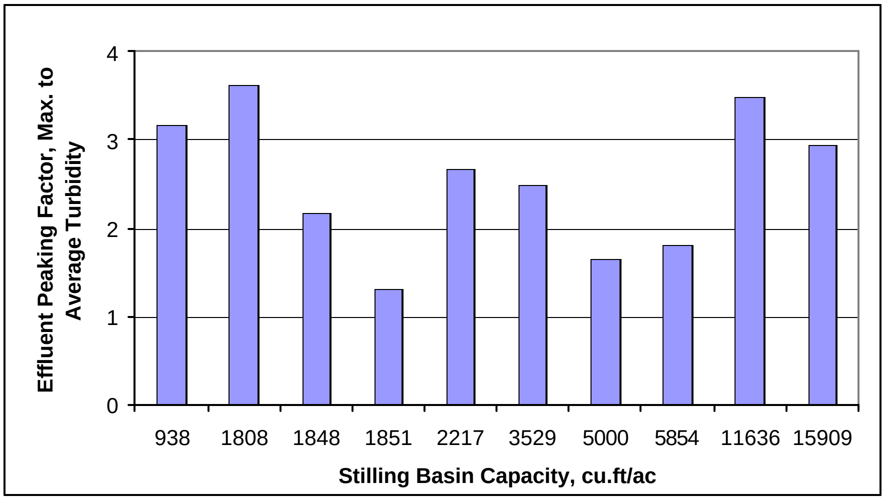


Figure 9.3 Turbidity Peaking Factor versus Stilling Basin Capacity (NC Field Data)

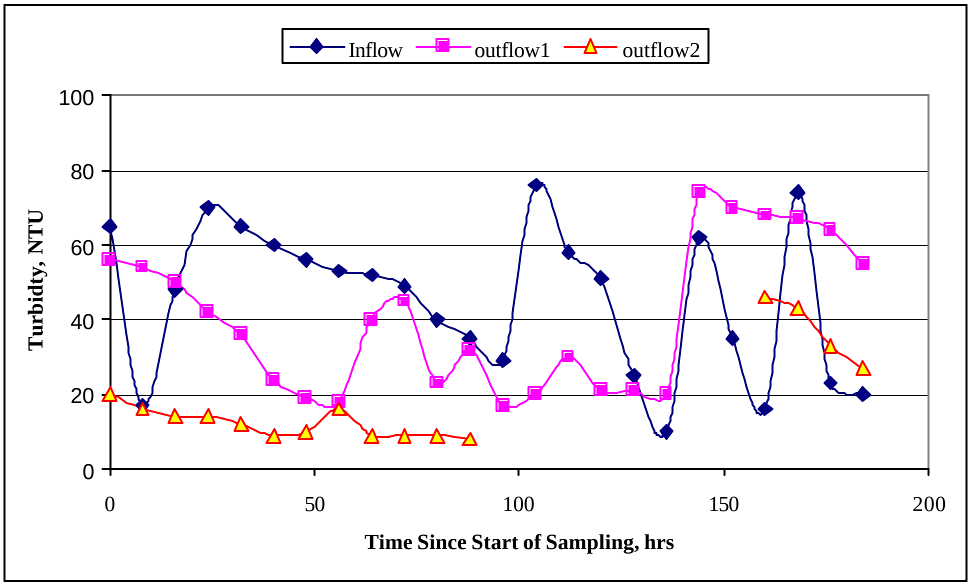


Figure 9.4 Monitoring Data For Davis Pit Stilling Basin (NC Field Data)

9.1.1 Pump Capacity Curves

It is essential to develop operational guidelines (e.g. pump capacity curves) for the reduction of turbidity during steady conditions, as well as during the period of turbidity surges. The goal of research was to investigate the pump capacity relationships in order to achieve a desirable level of turbidity reduction for stilling basins treating borrow pit wastewater. The scope of research involved the collection of field turbidity data from a borrow pit site to form the basis for determining the turbidity reduction rate constant. A complete-mixed, quasi-steady state flow model was used to derive the relationships between pumping rates and effluent turbidity levels for a given sizing requirement.

Two sets of settling data were employed to derive the turbidity reduction rate constants. The first dataset was a series of settled turbidity data in the range of 60-1250 NTU (McLaughlin 2002). This dataset was further divided into two subsets (>300 NTU and 300-100 NTU). The second dataset was obtained by measuring turbidity readings of water samples that were taken from the stilling basin at Davis Pit during the period without pumping. This dataset has a turbidity range of 29-70 NTU. Quiescent conditions are likely to be established inside the stilling basin during the period without pumping, and the occurrence of gravity settling inside the stilling basin may be similar to conducting laboratory batch settling tests.

The turbidity reduction rate constant is evaluated as a first-order reaction:

$$dC/dt = - Kt \qquad (1)$$

Where C = turbidity, K = turbidity reduction rate constant, hr^{-1}, and t = time, hr. This equation can be integrated to yield:

$$C/C_o = e^{-Kt} \qquad (2)$$

C_o is the initial turbidity of the batch test. Equation (2) is then applied to turbidity data to derive the respective rate constants, as shown below and in Figures 9.5, 9.6 and 9.7.

$$K = 1.4946\ hr^{-1} \quad \text{for} \quad \text{Turbidity} > 300\ \text{NTU} \qquad (3)$$

$$K = 0.0720\ hr^{-1} \quad \text{for} \quad \text{Turbidity} < 300 \text{ but} > 100\ \text{NTU} \qquad (4)$$

$$K = 0.0111\ hr^{-1} \quad \text{for} \quad \text{Turbidity} < 100\ \text{NTU} \qquad (5)$$

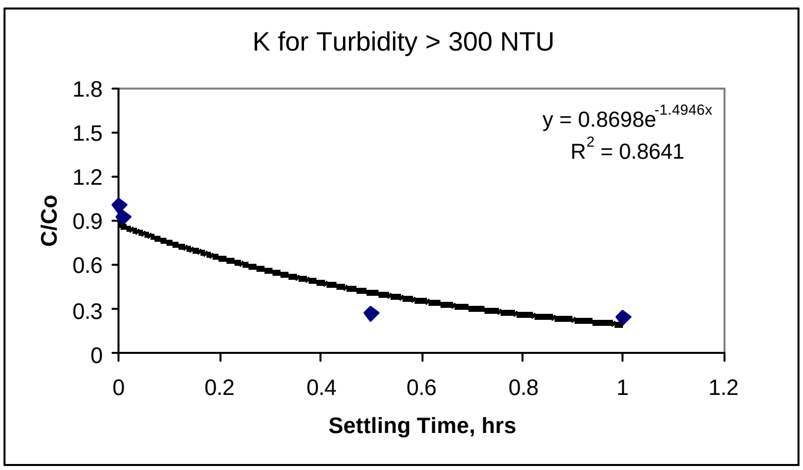


Figure 9.5 Determination of Turbidity Reduction Rate Constant

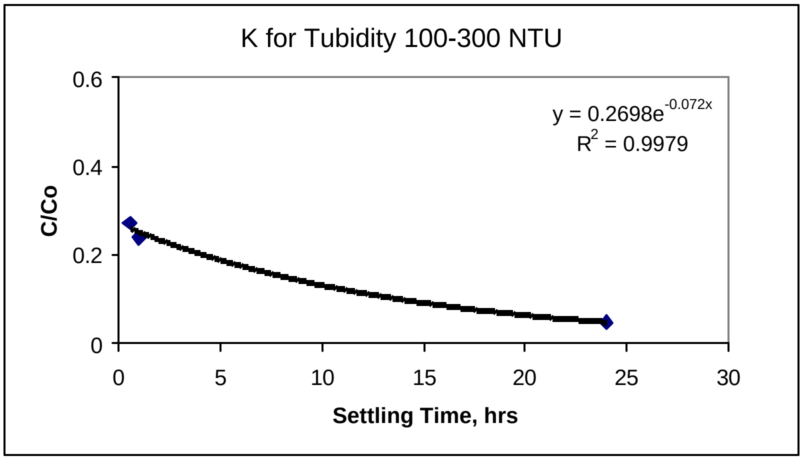


Figure 9.6 Determination of Turbidity Reduction Rate Constant

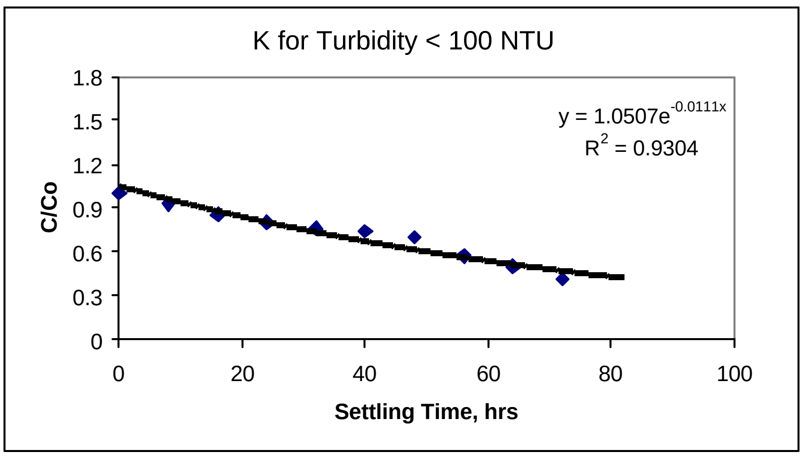


Figure 9.7 Determination of Turbidity Reduction Rate Constant

The pump capacity relationships can be derived using a complete-mixed basin receiving constant inflow and operating at quasi-steady state conditions. The solution of the mass balance equation with settling is solved to yield:

$$C = (Q*C_{in}/V)/(Q/V + 24*K) \qquad (6)$$

Where Q = pumping rate, gpd or MGD; V = volume of stilling basin, gallons or MG; and C_{in} = inflow turbidity, NTU. The reciprocal of Q/V is the average detention time. Figure 9.8 displays the reduction of turbidity as a function of detention time for different inflow turbidities.

Relationships between unit pumping rate, UPR, (gpd per acre of borrow pit area), and detention time, t_d, (hr) are plotted in Figure 9.9. Mathematically, these relationships can be written as:

For sizing rule of 3,600 ft^3/ac: $UPR = 215{,}436 * t_d^{-1}$ (7)
For sizing rule of 1,800 ft^3/ac: $UPR = 323{,}158 * t_d^{-1}$ (8)
For sizing rule of 1,200 ft^3/ac: $UPR = 646{,}317 * t_d^{-1}$ (9)

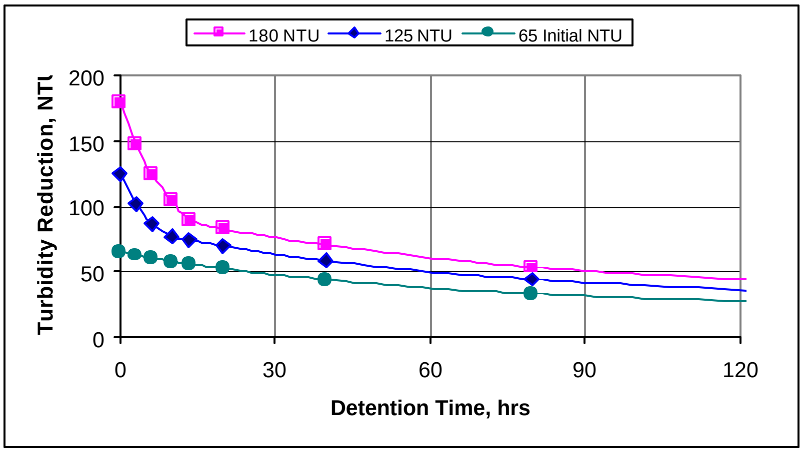


Figure 9.8 Turbidity Reduction According to Equation (6)

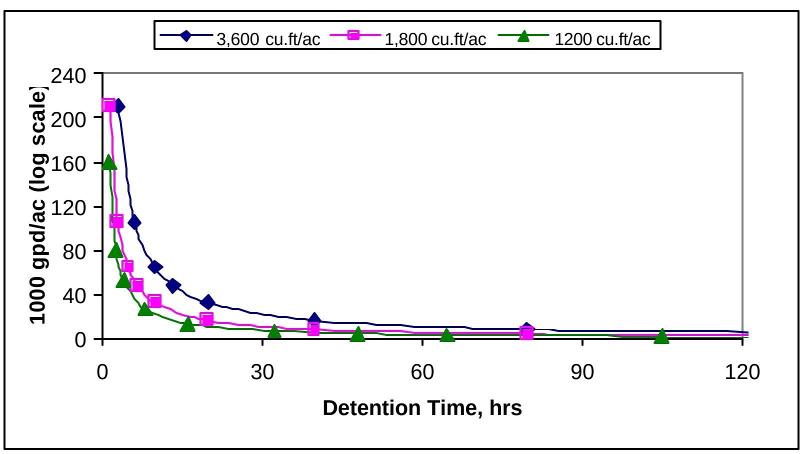


Figure 9.9 Pump Capacity Curves for Different Sizing Rules

9.1.2 Application of Pump Capacity Curves

An example is given to illustrate how to use these pump capacity curves to achieve a targeted turbidity reduction. It is required to determine the respective pumping rates from a borrow pit when the stilling basin is sized according to 1,200 ft^3/ac and 1,800 ft^3/ac and the inflow turbidity concentrations are 85, 65 and 55 NTU. The borrow pit has a surface area of 20 acres. The solution procedures are given below and computational results are shown in Table 9.1. Computational Procedures are as follows:

Step 1: Use Figure 9.8 or Equation (6) to determine the required t_d (V/Q) to achieve a discharge turbidity of 50 NTU.

Step 2: Use Figure 9.9 or Equations (8) and (9) to determine the design pumping rate gpd/ac and convert to gpd and MGD.

Note that Scenario 4 is identical to conditions found in the Norman Pit (20 acres, 1,851 ft^3/ac, 0.65 MGD, average 50 NTU, and peak 65 NTU). If the pumping rate can be operated at 0.43 MGD (Scenario 2) instead of 0.65 MGD, then the stilling basin for the Norman Pit can be sized at 1,200 ft^3/ac.

Table 9.1 Sizing of Stilling Basin According to Alternative Sizing Rules

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Borrow Pit Surface area, acres	20	20	20	20
Sizing Rule, ft^3/ac	1,200	1,200	1,800	1,800
Required Stilling Basin Volume, ft^3	24,000	24,000	36,000	36,000
Assumed Inflow NTU	65	55	65	55
t_d needed, hrs (step 1)	25	10	25	10
Allowable Pumping, gpd/ac (step 2)	8,618	21,544	12,926	32,316
Allowable Pumping, gpd	172,351	430,878	258,526	646,316
Allowable Pumping, MGD	0.17	0.43	0.26	0.65

In summary,

- Pump capacity curves have been derived based on a limited amount of settling data and the stilling basin is considered ideal, i.e. well mixed, no short-circuiting, and no dead volume.

- A safety factor of 5-15% may be appropriate to account for non-ideal flow conditions in the stilling basin.

- When a series of ponds can be designed for the same capacity requirement, the performance of ponds-in-series will approach ideal flow conditions.

- The pump capacity curves could provide design alternatives for basin capacity (ft^3/ac) that may be different than the 1800 ft^3/ac rule, based on the anticipating pumping rates and turbidity reduction goal. They can also guide field operators to adjust the pumping operation when a surge of high turbidity is anticipated

9.2 Chemical Coagulation

Applications and limitations of chemical coagulation/flocculation for turbidity removal are reviewed. The information provided is intended to be supplemental to the "Turbidity Reduction Matrix" developed by NCDOT. Additional information for commercially available alum compound and ferric chloride are also addressed.

9.2.1 Chemical Coagulants

Literature dealing with chemical coagulation is mostly available from the drinking water treatment industry, e.g. the American Water Works Association. On the contrary, there is very limited published data for turbidity removal from borrow pit wastewaters using chemical coagulants. Turbidity removal from surface mining wastewaters using alum and lime has been reported (US EPA, 1980), as shown in Table 9.2.

Table 9.2 Percent Turbidity Reduction Using Alum and Lime Treatment of Surface Mining Wastewater

	West Virginia, %	Kentucky, %
Alum for TSS removal	84	64
Alum for turbidity removal	84	80
Lime for TSS removal	94	60
Lime for turbidity removal	96	83

(USEPA, 1980)

While the operation of drinking water treatment facilities in the United States requires sophisticated instrumentation, it must be recognized that the USEPA regulations on drinking water are very stringent. For instance, USEPA currently requires that 95% of drinking water samples be less than or equal to 0.3 NTU, whereas turbidity up to 50 NTU is acceptable for borrow pit effluent. The lower turbidity standards associated with borrow pit discharges allows for much flexibility in the sizing, operation and control of borrow pit treatment facilities. The opportunity to apply rudimentary (though fundamentally sound) treatment techniques that are common in less technologically advanced applications could bring about viable options for treating borrow pit wastewaters. Roughing filters typically do not produce 0.3 NTU, but they are used successfully for drinking water treatment in a number of countries around the world. Roughing filters could be used in conjunction with smaller stilling basins or even in place of stilling basins.

Proper coagulation is necessary to achieve improved solids removal efficiencies and/or to facilitate the design of smaller stilling basins. Optimum coagulation is very important for financial reasons in facilities that are treating hundreds of millions of gallons of water each day, and optimum coagulation is also important for meeting the USEPA turbidity regulations and safeguarding public health. Neither of these concerns applies to borrow pit wastewaters, which render the coagulation process much simpler and easier to design and control. Consequently, the knowledge gained from drinking water treatment may be re-configured to borrow pit wastewater treatment. Table 9.3 provides a general guidance for the application of alum- and iron-based coagulants, as well as lime and gypsum. (http://www.agric.nsw.gov.au/reader/water-quality-supply/ac2-turbidity.htm)

Table 9.3 Drinking Water Treatment using Chemical Coagulants

Chemicals	Typical Dose (mg/L)	Comments
Alum (aluminum sulfate)	50-75	Most effective between pH 6.8 and 7.5 Will increase water acidity slightly Floc formation is slow in acidic water Takes 2 and 24 hours to flocculate and settle into a stable sludge Do not use if water pH is less than 5.5 due to likely release of toxic levels of dissolved aluminum May violate effluent limitation of sulfate
Ferric alum (crude alum with iron impurities)	50-75	Effective over a wider pH range of 5.5 to 8.5 Will increase water acidity slightly Floc formation is slow in acidic water Takes 2 and 24 hours to flocculate and settle into a stable sludge Do not use if water pH is less than 5.5 due to likely release of toxic levels of dissolved aluminum
Ferric sulfate	Up to 250	pH greater then 5 is required or it may lower oxygen levels
Ferric chloride	Up to 300	pH greater than 5 is required or it may lower oxygen levels May be corrosive
Gypsum (calcium sulfate)	50 to 300	Little pH change Slight increase in salinity Needs to be spread evenly across water surface Can cause scum deposits in equipment Takes 36 to 72 hours to flocculate and settle
Lime (calcium hydroxide)	Up to 300	Increase in pH Slight increase in salinity Usually contains insoluble impurities and requires constant stirring due to being sparingly soluble in water
Poly-aluminum chloride	-	Cost is about three times of common coagulants but it may be similar in cost when treating turbid waters

9.2.2 Commercially Available Alum Compounds

Aluminum and iron-based coagulants form metal hydroxides when they coagulate. In effect they are fully hydrolyzed to become 100% hydroxylated, releasing a hydrogen ion for each hydroxyl group (OH^-) acquired. This in turns leads to a fall in the pH of the water being treated as it becomes more acidic.

The commercially available ALCHLOR®-AC is a concentrated, high basicity polyaluminium chloride solution $[Al_2(OH)_5Cl]$. Since it is already 83% hydroxylated (while alum sulfate has near-zero hydroxylation), the magnitude of pH drop is significantly lower. The equations below depict this effect in terms of the overall hydrolysis reaction of each coagulant:

Alum sulfate: $2Al^{3+} + 6H_2O$? $2Al(OH)_3 + 6H^+$

Alchlor®-AC: $[Al_2(OH)_5]^+ + H_2O$? $2Al(OH)_3 + H^+$

Alchlor®-AC has been shown to exhibit improved performance over alum at equivalent dose rates in terms of removal of color, turbidity, particle count or organic matter. It costs approximately A$0.90/kg (US$0.70/kg). This may allow the use of lower dose rates, leading to lower sludge volumes and other environmental benefits. (http://www.hardman.com.au/Alchlor-ac.htm)

9.2.3 Ferric Chloride

Ferric chloride reacts in water with hydroxide alkalinity to form various hydrolysis products that incorporate $Fe(OH)_3$. These compounds possess high cationic charge which allows them to neutralize the electrostatic charges found on colloidal compounds and also to bind to negatively charged particles, including the ferric hydroxide itself. (http://www.pvschemicals.com/techMSDS/PotableTech.doc)

The hydrolysis products from ferric chloride, nominally ferric hydroxide, are different from those of sulfate based ferric sulfate and aluminum sulfate (alum). The aggregates or floc particles of ferric hydroxide are physically more discrete and dense and have a higher cationic charge density. In contrast, the floc aggregates of ferric sulfate and aluminum sulfate tend to be less discrete and “fluffy” or cloud like, this apparently due to differences in the types of bonding of the hydrolysis products. These differences translate into characteristics and abilities for ferric chloride that set it far apart from the sulfate based coagulants. In typical plant situations one can expect to use about 30% less ferric chloride than aluminum sulfate (on a dry weight basis) to achieve similar results.

Ferric Chloride forms a more discrete and dense floc that promotes faster sedimentation in general and specifically, better sedimentation in cold water. This dense floc has more available cationic charge that allows higher reactivity with colloidal solids. The high ratio of cationic charge to total mass also makes the ferric chloride hydrolysis products more reactive and adsorptive with emulsified and semi-emulsified organic matter; such as oils, fats, and other natural and synthetic organic matter.

The high density of the ferric hydroxide floc leads to another important benefit for the treatment plant. The settled sludge volume of the ferric (chloride) hydroxide ranges typically from 1/3 to 2/3 that of sulfate based coagulants. Additionally, the sludge developed through the use of ferric chloride is generally much easier for dewatering.

One of the other characteristics of ferric chloride is its ability to form floc over a very wide pH range as is demonstrated in Figures 9.10 and 9.11. It is seen from Figure 9.10, the ferric chloride coagulation diagram has a much broader coagulant dose range (2.7 to 270 mg/L) and pH range (approximately 6.0 to 10.0) for effective "sweep coagulation". The application of ferric chloride instead of aluminum sulfate offers increased flexibility in operation and design, and relieves any concern over violation of the 250 mg/L sulfate regulation Ferric chloride, ferric sulfuate and aluminum are very similar in cost (e.g. a 55-gal drum $FeCl_3$ costs US$165.00).

These figures also show the very low solubility of ferric hydroxide compared to aluminum hydroxide. The combination of these properties allow ferric chloride to function over a very wide pH range with little fear of carry over into down stream processes due to post precipitation. This ends up being very important for operations looking to flocculate at higher pH's and alkalinity's while controlling corrosivity factors in the water. Additionally, the low end of the pH range becomes especially important to enhanced coagulation processes.

In summary,

- Alum coagulation has a narrow range of coagulant does (e.g. 20-60 mg/L) and coagulated water pH (6.8-8.3).

- Ferric chloride has a much broader coagulant dose range (3-270 mg/L) and pH range (approximately 6.0-10.0) for effective "sweep coagulation". The use of ferric chloride instead of aluminum sulfate offers increased flexibility in operation and relieves any concern over violation of the 250-ppm sulfate regulation.

- Typically it would require approximately 11.4 times more gypsum than alum or ferric chloride on a molar basis. Also, the does of gypsum could be critical and highly variable between locations depending on the iron and particle concentrations naturally present in the water.

- ALCHLOR®-AC could be an alternate source of coagulant and its application to treating borrow pit wastewater needs further research and investigation.

- It is recommended to consider the use of roughing filters and inexpensive filter materials for turbidity removal to achieve less than 50 NTU and a laboratory/pilot study will be needed.

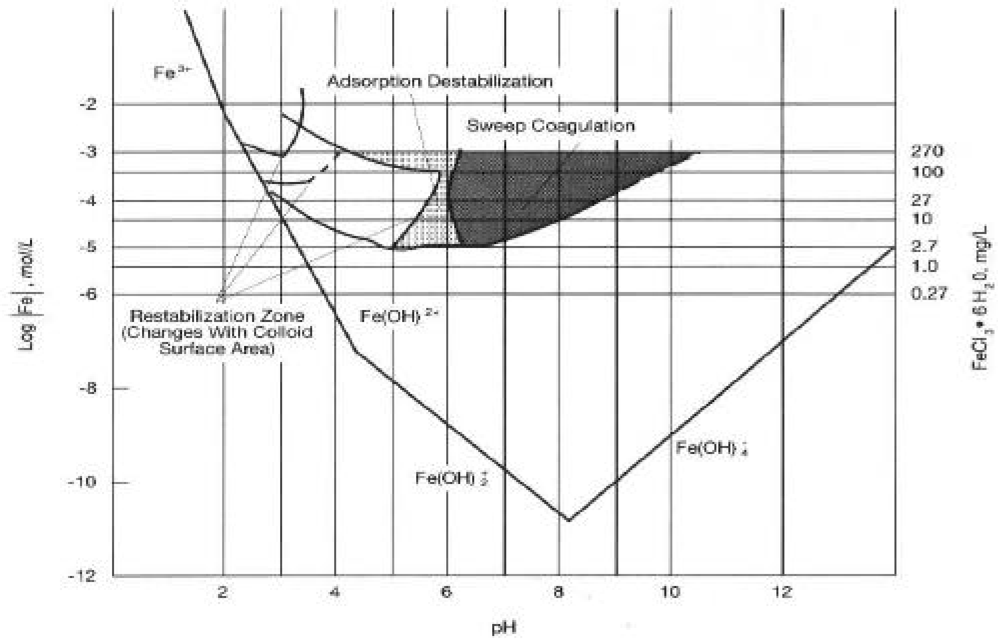


Figure 9.10 Ferric Chloride Solubility Chart (Johnson and Amirtharajah, 1983)

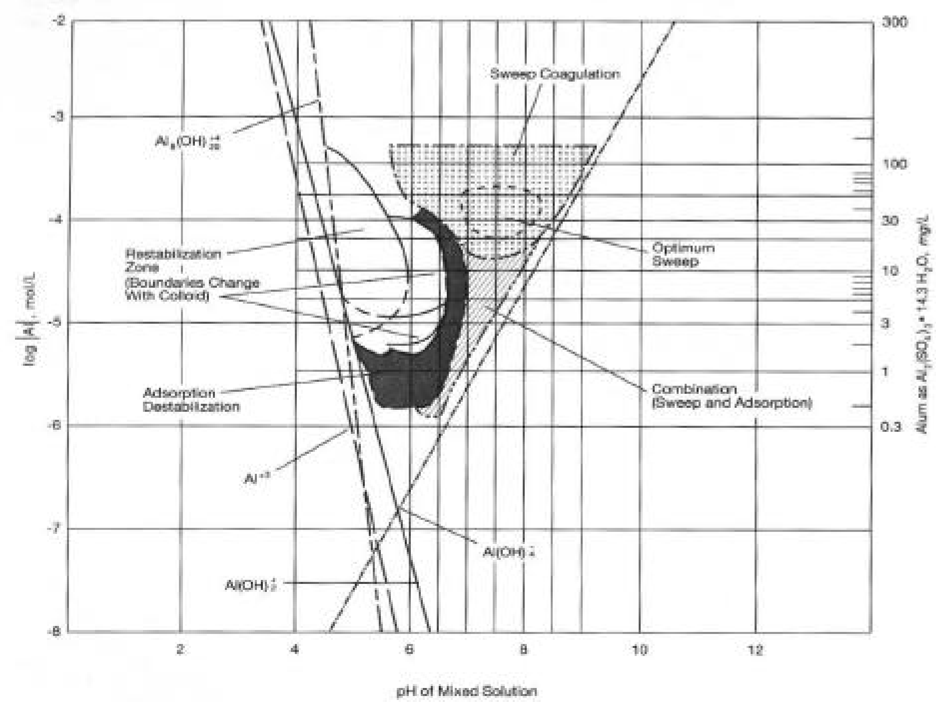


Figure 9.11 Aluminum Sulfate Solubility Chart (Amirtharajah and Mills, 1996)

- o Consider the use of smaller stilling basins with coagulation (chemical or polymer coagulants), equipped with baffles and other means for floc separation/removal.

- o Consider the use of mobile treatment units that can be economically built by university students/researchers.

9.3 Polymer Injection Treatment System

The system provides injection of anionic polymer solution to the wastewater, which allows flocculation to occur, followed by filtration using either a filter bag or other means of sedimentation.

This section of the report presents a review of the chemistry of the ionic polymers, laboratory tests performed by NCSU researchers, and the potential use of sequential addition of polycationic and polyanionic polymers as a means to promote the occurrence of patching and bridging mechanisms. A portion of the experimental data presented by the NCSU researchers was further analyzed to demonstrate that the flocculation mechanism using polyanionic polymer could be attributed to cation-bridging effects. The general trend revealed from these observations can be used to guide the selection of the types of anionic polymers. In addition, the specific information of a commercial polymer injection system and its field-test performance is presented together with the development of a polymer injection system (PIS) calculator for quick estimation of treatment costs associated with different treatment scenarios.

9.3.1 Chemistry of Polyacrylamide

Polyacrylamide or PAM is a water-soluble polymer derived by the polymerization of acrylamide. PAMs can be synthesized in the form of cationic, nonionic or anionic polymer with molecular weights typically ranging between 0.1 mg/mol to 15 mg/mol. Anionic PAMs are more effective for flocculation and stabilization of soil particles than nonionic polymers. The toxicities of cationic PAMs are in the 1 mg/L range while those for anionic PAMs are 100-1000 times greater, which provides a good safety margin for typical applications.

The charge density in anionic PAMs varies in proportional to the percentage of OH^- group substituted for NH_2 groups on the polymer. Negatively charged PAM can be attracted to negatively charged clay surfaces, rather than being repulsed from the clay surfaces, through a phenomenon known as cation-bridging (Laird 1997) Cation-bridging occurs in aqueous solution in such a way that the anionic groups of the polymer interact with an exchangeable cation of the soil through a water molecule to yield an "outer-sphere" complex.

9.3.2 NCSU Research

McLaughlin (2002) performed a series of screening tests for eleven PAMs and thirteen sediment sources from construction sites across North Carolina. One of the anionic products, the Superfloc A-100, was found to rank among the top three flocculants for 10 of 13 sediment sources. Some PAMs were found equally effective but at different doses that could be as slow as 0.075 mg/l. The differences between PAMs in reducing turbidity were clearest shortly after mixing the PAM and soil (20 sec). These turbidity differences were usually maintained 30-60 minutes after mixing, but allowing the soil/water mix to settle for 24 hours reduced or eliminated the differences.

Although the anionic PAMs used in the McLaughlin's study were obtained from various commercial sources, they can be broadly categorized according to their molecular charge densities. The sediment sources investigated have also been characterized by their sodium adsorption ratio (SAR), pH, and other properties. If the phenomenon of cation-bridging does play an important role affecting the performance of anionic PAMs, a general trend might be expected when correlating the SAR ratio versus charge density of the anionic PAMs. Such a trend can be obtained by plotting the charge density of those top performance PAMs versus the SAR ratios of the respective sediment sources. The general trend as displayed in Figure 9.12 appears to support the theory of cation-bridging mechanism and provide a general guide for selecting anionic PAMs to treat sediment sources of differing SAR's.

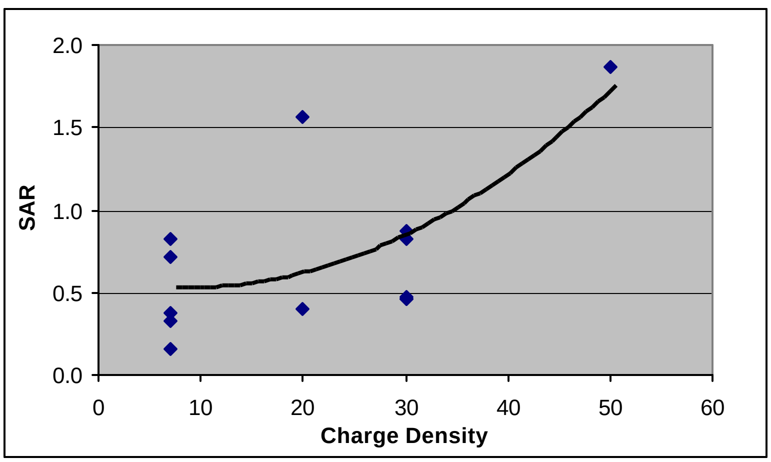


Figure 9.12 Relationship Between Charge Density of Top Performance Anionic PAMs and SAR Ratio

9.3.3 Sequential Addition of Polycations and Polyanions

Petzold et al. (2003) investigated the use of highly charged polycation poly(diallyll-dimethyl-ammoniumchloride), or PDADMAC, in combination with different high molecular weight polyanions of the PAM type as flocculants for clay suspension and natural wastewaters from gravel pits. The flocculation mechanism was influenced by the sequence of polymeric addition. The most effective way was initial addition of polycation followed by polyanion, resulting in the occurrence of patching and bridging mechanisms. Further research of this application for treating borrow pit wastewaters is recommended.

9.3.4 Polymer Injection System (GeoSpec, Inc.)

The “Flocculator, Storm Water Treatment System” is a method of removing sediment laden storm water from construction sites. The “System” works by injecting a specific amount of polymer solution (GeoFoc™) to a known rate of storm water discharge and then filtering the flocculated sediment through a filter bag (FlocBag™). A general schematic of the treatment train is shown in Figure 9.13. Suggested treatment procedures are described below.

A. Water Sample: A 20 oz. minimum sample of dirty storm water from the site is sent to independent laboratory for a proper analysis.

    1. Analysis will specify the type of polymer to be used.

    2. Analysis will specify the percentage of solution to be mixed.

    3. Analysis will specify the injection rate of polymer (gallons per hour) to the amount of storm water discharge (gallons per minute).

B. The Flocculator: The injection system will by sized according to the rate of storm water discharge.

    1. Flocculator-500 will treat up to 500 gallons per minute of storm water discharge.

    2. Flocculator-1,000 will treat up to 1,000 gallons per minute of storm water discharge.

    3. Higher rates of discharge will be handled on an individual basis. Higher rates require a more detailed analysis of the construction site.

C. Method of Discharge: The sediment laden storm water may be discharged through the Flocculator system in two (2) ways.

    1. Pumping application (detail 1): The Flocculators solution feed tube can be easily adapted to a standard trash pump.

    2. Gravity feed application (detail 2): The Flocculator solution feed tube can be easily adapted to the discharge pipe coming from a retention pond or settling basin.

        a. A gate valve should be attached to the discharge pipe.
        b. An automatic flow detection switch is available to be attached to the Flocculator.

D. Method of Filtration: A specific filter bag (FlocBag™) will be deployed to accept storm water after it has been treated by the Flocculator System. The specific deployment of filter bags will be site specific based on available area and amount of storm water discharge.

1. Standard FlogBags™ are 10'x 15' or 7.5' x 15'. Each bag has two openings to allow multiple bags to be joined together (see detail 3) to accommodate larger discharge.

2. Special FlocBags™ can be made upon request to accommodate unique size or discharge requirements.

E. E. Flocculant: GeoFloc™ is soil specific anionic, water-soluble, co-polymer (polyacrylamide), that when mixed into a specific solution is injected into a specific amount of storm water. When injected into turbid storm water it flocculates fine particles and colloidal clays in the water. Independent laboratory testing should be used to specify exact amounts of flocculant.

System Performance

The following summarizes two field applications of the polymer injection system, per information provided by Mr. Frank Milchuck of GeoSpec, Inc. The first application is for a NCDOT's borrow pit location in Plymouth, NC (Figure 9.14). The treatment system has been in continuous operation for about 8 months with the following specifics.

A. 6" Thompson pump discharge rate at 1,500 gpm

B. Flocculator injection at a rate of 30 gph of a 0.12% anionic polymer solution

C. Beginning turbidity ranges from 300 to 800 NTU

D. Discharge turbidity ranges from 25 to 45 NTU

E. Filtration method is a lined basin with coir baffles and a flashboard riser for discharge (it ran for 6 months before the coir baffles needed to be replaced)

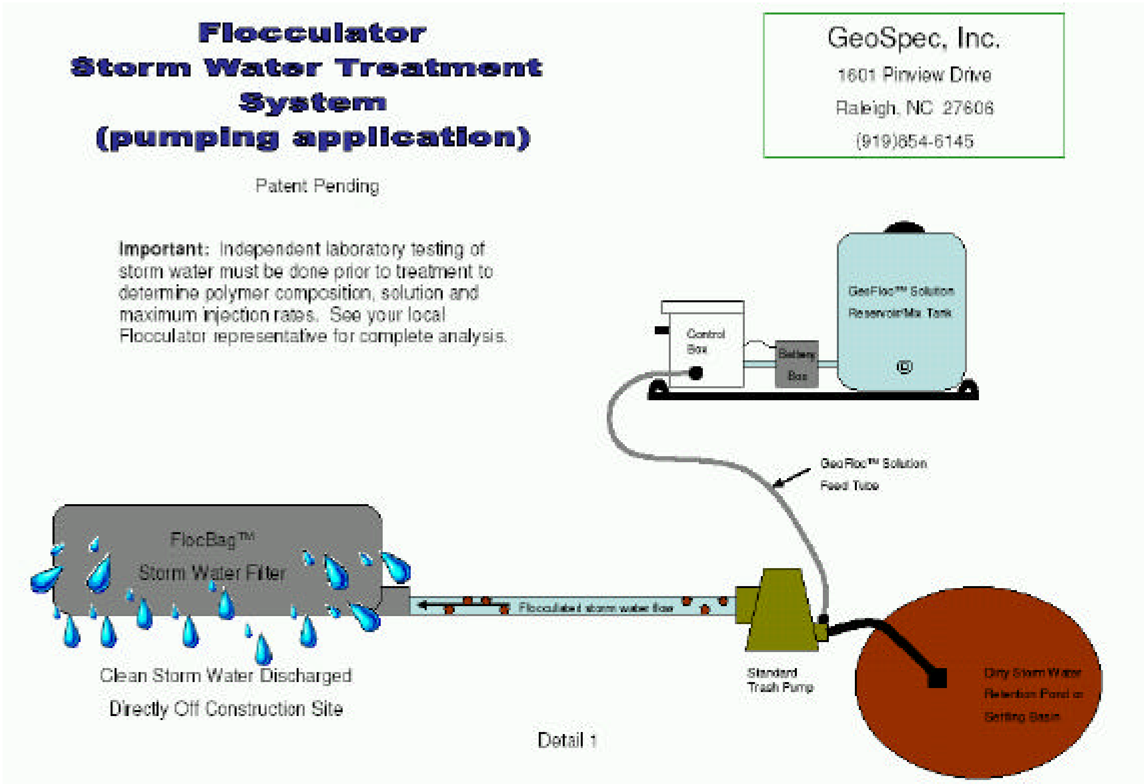


Figure 9.13 Schematic of the Polymer Injection System (with pumps)

The second application was for the treatment of muddy waters resulting from a culvert repair operation (Figure 9.14). The treatment rate was at 200 gpm with the addition of 0.12% anionic polymer solution at a rate of 5 gph. The influent turbidity was very high (approx. 1100 NTU). With the replacement of the 10'x15' filter bag every 12 hours of pumping, the effluent turbidity was around 25-75 NTU. If the cleanest possible water were treated, the bags would last longer. However, if the pump suction head is sucking up mud, the bag will not last as long.

9.3.5 Development of System Cost Calculator

The UNCC research team has developed a spreadsheet calculator to help estimate the weekly operating cost of the polymer injection system (PIS). A copy of the PIS calculator is attached as Appendix 4 of this report. The basic performance and cost data used to develop this PIS calculator were provided by the vendor, as shown below:

Polymer injection, gallons per hour:	10
Polymer solution, %:	0.5
Polymer cost, $/10 gph:	1.0
Filter bag, $/bag:	125
System cost (approx.), $:	7,500

Figure 9.14 Treatment of Borrow Pit Wastewater

The PIS calculator allows users to compare operating costs associated with different treatment scenarios:

Scenario 1: Full Treatment of Borrow Pit Wastewater (without stilling basin)

Scenario 2: Partial Treatment of Borrow Pit Wastewater (the treated effluent is mixed with stilling basin effluent for discharge)

Scenario 3: Full or Partial Treatment of Stilling Basin Effluent

Scenario 4: Partial Treatment of Borrow Pit Wastewater (The treated effluent is mixed with untreated borrow pit wastewater for discharge without a stilling basin.)

For example, treatment costs associated with treating 500 gpm (influent turbidity of 150 NTU) for each treatment scenario meeting effluent discharge of less than 50 NTU have been calculated by the PIS calculator, as follows:

Scenario 1: $543/week for Scenario 1 when treating 100% borrow pit wastewater without the use of a stilling basin

Scenario 2: $395/week for Scenario 2 when treating 73% borrow pit wastewater.

Scenario 3: $504/week for Scenario 3 when 73% of effluent from stilling basin assuming 50% turbidity removal achievable by the stilling basin.

Scenario 4: $480/week for Scenario 4 when treating 88% of the borrow pit wastewater without the use of a stilling basin.

10. Conclusions and Recommendations

The primary goals of this research were to provide NCDOT with (1) scientific observations to validate the pollutant removal performance of selected structural BMPs, (2) a database management option for BMP monitoring and non-monitoring sites, (3) pollution prevention plans for vehicular maintenance facilities, and (4) treatment options for borrow pit wastewaters. An intensive monitoring program has been conducted to characterize and examine the pollutant removal performance of three highway BMP types (grass filter strip, filtration swale, and grassed shoulder). A Stormwater Data Management System was developed for storage and retrieval of BMP site characterization data that are obtained during BMP site inspection. Suggestions were provided to the development of pollution prevention plans for vehicular maintenance facilities. Treatment technologies for borrow pit wastewater have been reviewed including the development of pump capacity curves for the operation of stilling basins. A spreadsheet version for polymer injection system cost calculations was also formulated.

The following conclusions/recommendations are pertaining to the pollutant removal performance of three monitored highway BMP types:

Grass filter strip:

1. The filter strip has achieved TSS removals of 56-94% based on concentration reduction and 68-97% removal based on mass load reduction. The outflow TSS concentration averaged 5.4 ± 2.2 mg/L which apparently represents the residual concentration achievable by this treatment device.

2. It is important to account for the removal effectiveness of each treatment unit/device comprising the entire treatment train, rather than focusing on the isolated performance of the filter strip itself. It is also important to use the mass-load-ratio to report removal efficiency when infiltration loss cannot be practically neglected.

3. The regulatory requirement of 85% TSS removal is within the range of the estimated long-term TSS removal of 78%-88% achievable by the filter strip. TSS removal performance could be affected by the prevailing rainfall distribution in a particular year.

4. Computer simulations using VFSMOD computer model have revealed that maintaining grass growth in good conditions with regard to density and grass spacing is important for sediment removal; and depending on particle sizes of the inflow sediment, a majority of sediment removal can be achieved within the first thirty-three feet (ten meters) of a filter strip.

5. The majority of the infiltration losses may occur early during a particular runoff event as water was observed to enter the crushed rock reservoir underlying the filter strip by flowing down the downstream face of the level

spreader as flow was initiated. During this early period of runoff no overland flow through the filter strip was observed. Overland flow through the filter strip appeared to be initiated once storage in the underlying crushed rock reservoir was filled. The crushed rock reservoir apparently helps enhance infiltration of flow over the filter strip.

6. The estimated long-term mass removals for TN and TP are 41%-48% and 44%-54%, respectively. However, a monitoring program that lasts an extended period is needed to valid these removal performances due to the short-term effort (March to June) of the current monitoring study.

Filtration Swale:

1. The filtration swale achieved TSS reductions between 56% and 100% based on a mass load reduction. The 100% removal was achieved for a 0.25" runoff event where no outflow occurred from the FS. TSS concentrations in FS outflow waters averaged 19.0 $\pm$ 14.8 mg/L. Turbidity levels appeared to be approximately 50% below inflow levels. The water quality data obtained from the Division 8 FS should not be viewed as comprehensive owing to the limited amount of complete storms sampled during this study.

2. Hydrologic retention was extremely variable with this BMP. During the March 2005 period little or no hydrologic retention was measured as storage appeared to be full prior to most events. Rain events as small as 0.25" displayed 100% runoff yield within a few hours of the beginning of rainfall. Later during the growing season under dry antecedent conditions events of similar magnitude generated little or no runoff from the infiltration swale.

3. The FS swale appeared to attenuate runoff peak flows rather successfully with peak outflow discharges lagging inflow discharges by one to five hours. This time lag occurred despite an almost instantaneous response to runoff exhibited by in-swale water levels. A possible explanation for this could be related to the geotextile fabric used in the BMP construction. The fabric was visually observed to effectively 'dam' water within the soil profile. This may explain the delayed outflow response as the drainage culvert was wrapped in this same material.

4. The FS appeared to be sized correctly for the area it drained with all highway runoff during the study period infiltrating through the FS before being discharged. The maximum flooding depth measured was approximately 4" during the period of observation, which was about two feet below the spillway outlet elevation.

5. The performance of the FS as a nutrient trap was variable. The FS BMP treatment train (FS + grassed swale) appeared to retain the dominant form of nitrogen in precipitation (NH_4-N) relatively effectively. However, the

retention of NO_3-N appeared to be almost entirely attributable to hydrologic retention and therefore was variable. Our limited data suggest that the FS may be relatively ineffective in retaining N as the retention may be balanced by an increase in the net export of organically complexed N as determined from TN measurements. Perhaps surprisingly there appeared to be a net export of P from the FS. The net export was comprised largely by the release of both ortho-P and dissolved unreactive phosphorus. The source of this internally released P is currently under investigation. Potential sources of internally released P include: desorption from FS soils and desorption from previously detained road source sediments.

Grass Shoulder:

1. The W.T. Harris Blvd. grassed shoulder achieved TSS reductions averaging 40% based on concentration differences between overland flow runoff at the road edge and samples obtained at the end of the shoulder slope. These values are similar to those reported for similar studies with more extensive data sets than that collected for the current study.

2. Directly measured infiltration rates for the W.T. Harris Blvd site were extremely low averaging 0.2 $\pm$ 0.2 in/hr. Given the relative impermeability of this site, there is almost no opportunity for significant infiltration abstractions in all but the smallest and lowest of intensity rain events. It is recommended that active turf management be employed on pre-existing grassed shoulders and swales and efforts be made on newly constructed roadways to increase the infiltration capacities of these surfaces at least in the Piedmont and Blue Ridge regions of the state.

3. Observations made during runoff events and during equipment maintenance and installation indicate that sheet flow was extremely limited in areal extent and concentrated flow began almost at the road edge as micro topographic features channeled overland flow into discrete flow paths. This rapid generation of concentrated flow further minimized the opportunity for infiltration losses and minimized water-substrate contact reducing the potential for TSS retention. It is unclear how this channeling of flow might be reduced on road shoulders as most of the microtopographic variation was introduced by post construction vehicle traffic. Post construction efforts to increase infiltration are likely the best way to maximize infiltration losses to help counteract the generation of concentrated flow.

4. The Grassed Shoulder at the W.T. Harris site was relatively ineffective in terms of nutrient retention or turbidity reduction. In many instances significant increases in concentration were observed as runoff moved from the road edge through the grassed shoulder. Sources of material that could be mobilized from the road shoulder include particulates and aerosols contributed by atmospheric deposition within the road corridor and material mechanically

removed from the road surface by wind and vehicular motions. In addition to these sources it is possible that desorption of nutrients could occur from road shoulder soils as well as from previously deposited runoff sediments. As per the previous discussion for hydrologic retention the most practical means to reduce nutrient export from roadside shoulders similar to the study site would appear to be to enhance the infiltration capacity of soils in the near road region.

The following conclusions/recommendations are provided for the BMP data reporting and management options:

1. Field monitoring data obtained from the I-40/NC-42 grass filter strip site has been accepted for inclusion in the National Stormwater BMP Database. Currently, the Database has included more than 170 entries for grass swale (biofilter), detention basin, hydrodynamic device, media filter, percolation trench/well, porous pavement, retention pond, wet basin, and wetland channel.

2. Non-monitoring data obtained from field inspection needs to be organized and saved. A database, the Stormwater Data Management System, in the form of Microsoft Access has been developed for this purpose. Some of the data entries are common to the National Stormwater BMP Database. Data retrieval can be accomplished by entering a division number of any one of the NCDOT's fourteen divisions across the state.

The following conclusions/recommendations are suggestions for pollution prevention plans for vehicular maintenance facilities:

1. The discharge of wash water from facilities within MS4 may consider the connection to existing sanitary sewers, off-site disposal offered by contracting vendors, on-site recycling and reuse, and/or on-site collection

2. The discharge of wash water from remote facilities may consider on-site recycling and reuse, on-site collection, on-site treatment such as evaporative methods (e.g. evaporation pond, bioretention), and/or on-site infiltration measures.

3. Use of Environmental Power Washing could be a feasible option.

4. It is recommended to perform a pilot test of using catch basin insert in combination with bioretention for remote facilities. Some of the proprietary or manufactured BMPs (Appendix 2) can be considered for applications at remote facilities and facilities within MS4.

The following conclusions/recommendations are addressed to the turbidity control of borrow pit wastewaters:

1. Pump capacities curves have been developed to provide design alternatives for determining stilling basin capacity that could be deviated from the 1,800 ft^3/ac rule, based on the anticipating pumping rates and turbidity reduction goal. Conversely, these curves can be used as a guide to adjust the pumping rates for an existing basin when a surge of high turbidity is forthcoming.

2. Additional research is needed to further validate and test the reliability of these pump capacity curves using computer simulation of transient flow conditions and field monitoring for data collection. The current estimates should be used with caution and a safety factor of 5-15% is recommended.

3. Ferric chloride and ALCHLOR®-AC are potential chemical coagulants for treating borrow pit wastewaters. Research is needed to test the effectiveness of these chemical coagulants. Ferric chloride has a much broader coagulant dose range (3-270 mg/L) and pH range (approximately 6.0-10.0) for effective “sweep coagulation”. The use of ferric chloride instead of aluminum sulfate offers increased flexibility in operation and relieves any concern over violation of the 250-ppm sulfate regulation. Alchlor®-AC has been shown to exhibit improved performance over alum at equivalent dose rates in terms of removal of color, turbidity, particle count or organic matter. This may allow the use of lower dose rates, leading to lower sludge volumes and other environmental benefits.

4. Use of roughing filters and low-cost filtration materials are recommended for additional research. Past research has shown the effectiveness of using roughing filters and low-cost filter media for turbidity reduction in developing countries.

5. The turbidity reduction matrix (Appendix 3) provides useful guide for a variety of treatment technologies for borrow pit wastewaters. Continued updates of this matrix will help incorporate other innovative and low-cost treatment options.

6. The polymer-injection-system cost calculator (Appendix 4) can be used to perform cost analysis for different treatment schemes including treating 100% of the borrow pit wastewater without stilling basins, and partially treating the waste stream with the use of stilling basins.

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Appendix 1 State BMP Manuals

(Associated General Contractors of America)

Alabama

Alabama Department of Environmental Management—BMP Manuals ($2 - $20)
http://www.adem.state.al.us/EnviroProtect/Water/Surface/ SurfaceOth/surwatot.htm

California

California Storm Water BMP Construction Handbook ($12)
BMP Handbook for San Diego County ($90)
http://www.swrcb.ca.gov/stormwtr/index.html
Los Angeles Storm Water Program Publications
http://www.lastormwater.org (click "publications")

Connecticut

2002 Guidelines for Soil Erosion and Sediment Control ($90)
http://www.whereeverythingis.com/depstore/StoreFront.bok (click "Guidelines & Technical Manuals")

Delaware

Delaware Erosion and Sediment Control Handbook ($30)
Delaware Conservation Design for Storm Water Management Guidance Manual ($25)
http://www.dnrec.state.de.us/dnrec2000/divisions/soil/ stormwater/stormwater.htm

Florida

Florida Development Manual: A Guide to Sound Land and Water Management
To order, e-mail patricia.sanzone@dep.state.fl.us or greg.knecht@dep.state.fl.us
Non-Point Source Management Best Management Practices, Public Information, and Environmental Education Resources
http://www.dep.state.fl.us/water/stormwater/pubs.htm

Georgia

Georgia Storm Water Management Manual
http://www.atlantaregional.com/water/waterquality/ stormwatertaskforce.html

Idaho

Catalog of Storm Water BMPs for Idaho Cities & Counties
http://www2.state.id.us/deq/water/stormwater_catalog/ index.asp

Indiana

Handbook for Erosion Control in Developing Areas ($25)
http://www.in.gov/idem/water/publications/forms.html

Iowa

Storm Water Management for Construction Activities—
General Permit No. 2: A Brief Guide to Developing Pollution Prevention Plans & BMPs
http://www.state.ia.us/government/dnr/organiza/epd/ wastewtr/wwapps/npdes.htm#storm

Louisiana

State Of Louisiana Nonpoint Source Pollution Management Program - Construction
http://nonpoint.deq.state.la.us/manage10.html

Maine

Storm Water Management for Maine: BMPs
http://janus.state.me.us/dep/blwq/stormwtr/material.htm#bmp
Maine Department of Transportation Office of Environmental Services BMP Manual
http://www.state.me.us/mdot/mainhtml/contractor.htm

Maryland

Maryland Storm Water Design Manual, Volumes I & II ($25)
http://www.mde.state.md.us/environment/wma/stormwater manual/

Massachusetts
Storm Water Management—
Volume I: Storm Water Policy Handbook
Volume II: Storm Water Technical Handbook
http://www.state.ma.us/dep/brp/ww/stormwat.htm
Michigan
DEQ Index of BMPs/Individual BMPs
http://www.michigan.gov/deq/1,1607,7-135-3313_3682_3714-13186--,00.html
Minnesota
Protecting Water Quality in Urban Areas: A Manual ($40)
http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html
Urban Small Sites Best Management Practice Manual ($7.50 CD-ROM/ $40 Hardcopy)
http://www.metrocouncil.org/environment/watershed/bmp/manual.htm
Missouri
Protecting Water Quality: A Construction Site Water Quality Field Guide
http://www.dnr.state.mo.us/wpscd/wpcp/wpcp-guide.htm
Montana
Montana Department of Water Quality – Storm Water Program – BMPs and Erosion Control Plans
http://www.deq.state.mt.us/pcd/wpb/erosion.htm
New Hampshire
Storm Water Management and Erosion and Sediment Control for Urban and Developing Areas in New Hampshire (No Code Number $25.00)
Best Management Practice for Urban Storm Water Runoff. (R-WSPCD-95-3 $5.00)
Managing Storm Water as a Valuable Resource. (Available Online No Charge)
http://www.des.state.nh.us/desguid.htm
New Jersey
Revised Manual for New Jersey: BMPs for Control of Nonpoint Source Pollution from Storm Water
http://www.state.nj.us/dep/watershedmgt/bmpmanual.htm
New York
New York Storm Water Management Toolbox
http://www.dec.state.ny.us/website/dow/toolbox.htm
North Carolina
NCDENR BMP and Site Planning Manuals & Fact Sheets
http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm
NCDENR Publications List, Including: Erosion, Sediment Control Planning & Design Manual ($65) Erosion and Sediment Control Field Manual ($13) Sediment Control Inspector's Guide ($20) Erosion & Sediment Control Practices: Video Modules ($15)
http://www.dlr.enr.state.nc.us/eropubs.html
North Dakota
A Guide to Temporary Erosion-Control Measures for
Contractors, Designers and Inspectors
http://www.health.state.nd.us/ndhd/environ/wq/storm/ permits/construction.htm
Ohio
Storm Water Program – Factsheets, Forms, & Check Lists
http://www.epa.state.oh.us/dsw/storm/
Oregon
BMPs & Storm Water Pollution Control Plan
http://www.deq.state.or.us/wq/wqpermit/wqpermit.htm

Pennsylvania
Handbook of BMPs for Developing Areas ($25)
http://www.pacd.org/products/bmp/bmp_handbook.htm
South Carolina
NPDES Storm Water Program Home Page
http://www.scdhec.net/water/html/swnpdes.html NPDES Storm Water Program – Construction Program http://www.scdhec.net/water/html/swn_conprog.html Sediment, Erosion, & Storm Water Management Home Page
http://www.scdhec.net/water/html/erfmain.html
Tennessee
Tennessee Erosion and Sediment Control Handbook
http://www.state.tn.us/environment/wpc/ Knoxville BMP Manual
http://www.ci.knoxville.tn.us/engineering/bmp_manual/
Texas
Texas Nonpoint Sourcebook – Interactive BMP Selector
http://www.txnpsbook.org/SiteMap.htm Storm Water Quality BMPs for Construction Activities – North Central Texas
http://www.dfwstormwater.com/runoff.html
Utah
UPDES Storm Water Home Page
http://www.deq.state.ut.us/EQWQ/updes/stormwater.htm
Storm Water Utility – BMP's http://www.ci.west-valley.ut.us/pworks/storm%20water %20utility/bmp3.htm
Virginia
Maintaining Your BMPs: A Guidebook for Private Owners and Operators in Northern Virginia Northern Virginia BMP Handbook: A Guide to Planning and Designing BMPs in Northern Virginia
http://www.novaregion.org/enviser.htm
Washington
Final Draft of Storm Water Manual for Western Washington
http://www.ecy.wa.gov/programs/wq/stormwater/manual.htm l#copies
Washington State Department of Transportation – Highway
Runoff Manual http://www.wsdot.wa.gov/fasc/engineeringpublications/librar y.htm
King County Storm Water Pollution Control Manual
http://dnr.metrokc.gov/wlr/Dss/Spcm.htm
Wisconsin
Wisconsin Nonpoint Source Publications
http://www.dnr.state.wi.us/org/water/wm/nps/pubs.htm
Wyoming
NPDES Storm Water Permits Program Home Page
http://deq.state.wy.us/wqd/Storm.htm Urban BMP's for Nonpoint Source Pollution
http://deq.state.wy.us/wqd/watershed/92171.pdf

U.S. EPA BMP MANUALS

Storm Water Management for Construction Activities: Developing Pollution Prevention Plans and BestManagement Practices
http://cfpub.epa.gov/npdes/stormwater/cgplarge.cfm? program_id=6
NPDES Storm Water Publications Library
http://cfpub.epa.gov/npdes/pubs.cfm?program_id=6
EPA Region 6 Storm Water Forms and Documents
http://www.epa.gov/Region06/6en/w/formsw.htm

Appendix 2 List of Proprietary or Manufactured BMPs

	Product Name	Descriptions
1	Abtech Oars Passive Skimmer	Catch basin insert for removal of HC (also effective for bacteria inactivation)
2	Abtech Oars Ultra-Urban Filter	Prevent oil, grease, trash and sediment from entering the storm drain system
3	ADS Retention/Detention Filter	Subsurface retention/detention system
4	Aqua-Filter Stormwater Filtration System	Aqua-Swirl™ concentrator + filtration chamber for fine sediment and soluble/insoluble pollutants
5	Aqua-Guard Catch Basin Insert	Catch basin insert for removal of course sediment, trash/debris, and pollutants (oil, nutrients and metals)
6	Aqua-Swirl Concentrator	Combining gravitational and hydrodynamic drag forces for solids to settle and capturing of free-floating oil and debris
7	Baysaver	Gravitational separation for sediment, free floating oils, trash and debris
8	Contactor & Recharger	Subsurface on-site piping for absorption and infiltration
9	Continuous Deflective Separation Unit	Remove gross pollutants and overcome the clogging, reduced efficiency and capacity problems w/ direction filtration
10	Downstream Defender	Based on Vortex technology to augment gravitational forces to maximize solids/liquids separation
11	Howland Swale	Siltation trap + pretreatment mash with specialized plants + vegetated storage chamber

12	Filtrexx Ditch Chexx	Help to slow water flow, create ponding, settling and filtering of settleable solids in channel flow
13	Filtrexx InletSoxx	Offer physical/chemical/biological filtration for construction sites
14	Filtrexx SiltSoxx	Trap sediment by filtering the water passing thru the berm, allowing ponding, and settling of solids
15	Inceptor	Patented PolyDak filter for catching basin/inlet for HC, PCBs, lead, copper, zinc, Cr VI, and other heavy metals
16	Kleerwater Oil Water Separator	Separate free-floating oils and greases from water mixtures
17	Microgen Storm Water Aeration System	Quickly raise DO levels in stormwater pinds, lakes and estuaries after a storm
18	Netting TrashTrap	Use disposable mesh nets to capture and remove floatables from stormwater and CSO
19	SNOUT Oil-Debris Separator	Remove floatables, oil and grease, and sediment in catch basins and other water quality improvement structures
20	ETV Stormceptor	Remove oil, sediment and other urban stormwater pollutants
21	StormFilter	Based on mechanical filtration, ion exchange, and adsorption, to remove TSS, soluble metals, soluble P, NO_3 and oil/grease
22	StormTreat	Use sedimentation chambers and constructed wetland to treat first flush and more
23	Stormvault	Patented stormwater mitigation system is a capture and hold design to remove pollutants and slowly releases the effluent

24	StreamGuard Exert II	Geotextile-covered, rigid plastic shell installed on top of a catch basin to prevent sediment from entering
25	StreamGuard Catch Basin Insert	StreamGuard^{TM} polymer for absorption of HCs, and capture sediment and debris
26	StreamGuard Passive Skimmer	Use HC absorbing polymer to float in the sump or catch basins
27	TurboTank Mobile Water Treatment Unit	Transportable water treatment plant to remove suspended solids
28	Ultra-DrainGuard Oil & Sediment Model	Catch basin insert to filter sediment, oil and debris
29	Vortechs Stormwater Treatment System	Remove and retain sand, HC-laden sediments, metals, petroleum-based liquids, and other floatable and settleable debris
30	V2B1 Stormwater Treatment System	Treatment of stormwater using swirl sedimentation technology
31	http://www.psinternational.com	PS International Oil and Water Separator
32	http://www.crystalstream.com/	Crystal Stream Technologies - inflow passes fine mesh and continues around baffles slowing and spreading the flow to separate oil
33	http://www.foxenviro.com.au/	FOX systems include catch basin applications, oil/water separator, diversion systems etc.

Appendix 3 NCDOT Turbidity Reduction Matrix for Borrow Pits

(This matrix was prepared by Dr. Bob Holman of NCDOT.

Additional comments were inserted in "italic font" by UNC Charlotte researchers)

Method	**Description**	**Advantages**	**Disadvantages**	**Costs**	**Comments**
Stilling (sediment) Basin – Standard BMP	These are small sediment basins with baffles that can be constructed of stone or sediment control fence. Flashboard riser can also be used to control the water level.	Basins are easy to build and maintain. They provide further treatment before pit water is discharged to the environment on a continuous basis.	Basins are only 96-72% effective at removing suspended solids under normal conditions. If turbidity (>50 NTU) is encountered, then additional BMPs may be needed. These types of basins alone are ineffective at removing fine or colloidal particles.	$24,000/basin (basin size determined by pump capacity & size of particles to be removed)	Outlet water should be drawn from the surface. Basin sized according to 1800 cu.ft per disturbed acre. *Use pump-capacity-curves to assist the operation of variable pumping rates and for different sizing rules (UNC Charlotte).*
1. Silt Bag	Pit water is pumped through a water permeable bag resting on a bed of stone to increase bag discharge area. PAM can also be introduced in the pump system for enhanced sediment removal.	Easy to install and remove bag. Effective at removing large size particles. Only a small footprint is required.	Silt bag is limited to certain flow rate and bag does not remove fine or colloidal particles unless a PAM treatment is also used.	$650/setup	Addition of PAM may cause floc to seal bag.
2. Aluminum Sulfate (Alum)	A granular coagulant material added by spreader to pit water to settle suspended material. Maximum rate is 25 lb per	Inexpensive and easy to apply. Works well on clay particles. PAM can also be used when re-suspension problem	A toxicity (TOX) test is required because of a potential in pH shift. Also a background test for the amount of iron and aluminum	TOX test costly $1,325/treatment.	PH needs to be above 5.5 to avoid toxic level of aluminum. May need time for pH adjustment.

	1,000 cu. ft of water to keep below 250 ppm sulfate.	occurs.	present in the pit water should be conducted. May take 1-2 days to clear water.		
3. Gypsum	A powder coagulant material added by spreader to put water to settle out suspended material. Maximum rate is 25 lb per 1,000 cu. ft to keep below 250 ppm sulfate.	Easy to spread and takes around two days to clear the water column before surface pumping	Requires much larger quantities of material (100 times) that of alum and a toxicity test. Can resuspend in large pit on windy days.	TOX test costly, $2,000/treatment	Also can produce pH swings.
4.Polyacrylamide (PAMs)	A broad range of flocculants in liquids, power, and solid forms to chemically bind sediment particles together and settle out.	Works very well under many conditions. Does not affect pH and is non-toxic to aquatic organisms.	Needs oversight for setup and water test for best products and equipment match. May not work on some clay materials.	$2/1,000 cu. ft treated. *Use PSI calculator for different treatment schemes and treatment cost analysis (UNC Charlotte).*	Keep below 250 ppm sulfate
5. Well Point Pumping (Bank Filtration)	Pit is dewatered by a series of shallow wells surrounding the pit at approximately 20' intervals.	Water can be directly discharged to the environment without TOX testing.	Rainwater is a problem and can create turbid waters in the pit. Must be treated before being discharged to the environment usually with flocculant because drawdown of pit exceeds filtering capacity of soil.	Setup and run pump $18,400/month for 2000 linear ft.	If iron levels are high the discharge must pass rough a stilling basin. *Need additional field testing and computer modeling of drawdown (UNC Charlotte).*
6. Land Application Irrigation	Water from pit is pumped out to irrigate agricultural crops	Ideally, pit water is used by agricultural crops and there is no discharge.	If pit water is not applied the correct volumes, runoff might occur. Also, there is a limited distance from the pit that irrigation pipe can be extended.	Run extra pumps and cost to land application. Cost not known.	

7. Impoundment (Detention)	Large detention basin used for storage, evaporation, and sedimentation of pumped water from the pit.	There would be a long, slow term release from this basin after material has settled out and discharged through an outflow pipe.	In some areas, land for impoundment may be hard to find due to the size of the basin and location issues. Very fine material will not settle in some cases.	Problem if land is limited. $1,000/month.	Storm event often resuspends settle particles.
8. Cell Mining	The borrow pit is divided into individual cells and water is pumped out of one cell into another so a cell can be mined dry.	There is no immediate discharge from the pit.	Extra movement of discharge water from one cell to another within the pit. Wastewater from the pit will have to be discharged sometime during the active life of the pit.	Cost is unknown.	
9. Sand Filtration	Water from the pit is passed through a floc sock and into a 4 chamber sand media filter for the treatment.	Treated water can be discharged directly to the environment.	The rental rate for this equipment is very costly. May want to consider buying equipment and moving system around to different problem site.	Rent high cost $47,500/month based on site conditions.	Proper pump rate and prefiltration must place and monitored closely.
10. Wet Mining	Material from pit is moved wet and placed on higher ground to drain before being moved to job site.	There is no discharge from the pit.	Material from pit is handled twice, land needed for stockpiling materials, and time needed for pile to dry.	Double normal handling costs (unknown).	

Note:

1) Chart arranged from the least (1.) to the more effective BMP method (10.) for turbidity reduction. Goal is for pit water to be discharging at or below the 500 NTU level.(Water quality Standard for 401 Certification, DWQ)

2) Many of these turbidity reduction techniques can be combined to provide further treatment such as silt bags combined with PAM.

Appendix 4 Polymer Injection Treatment System (PIS) Calculator

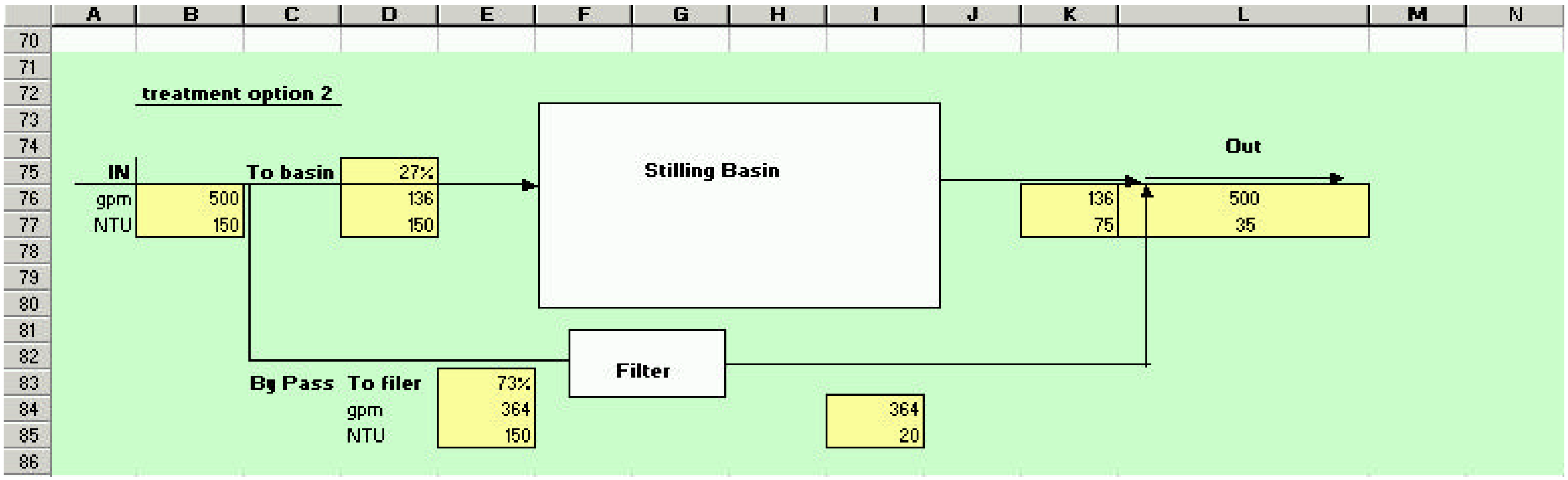
	A	B	C	D	E	F	G	H	I	J	K	L	M
1				**Appendix C. Polymer Injection System Cost Calculator**									
2													
3	**Basic Specifications (vendor info - do not change):**												
4													
5					polymer	# bag/8-hr	$ per bag		Flow			Gal of Stormwater Treated	
6			gph	gpd	$/10 gph	per week	Unlined	Lined	gpm	gpd		Per Bag per 8-hr period	
7	Polymer injection:		10	240	1							per week	
8	Injection bags (filter):					1	125	175					
9	Stormwater flow:								500	720000		1680000	
10													
11		The filtering process can typically reduce turbidity from +/- 100-140 to less than 20 NTU											
12													
13													
14	**Treatment Option 1: Direct Filtering (no Stilling Basin)**												
15													
16	Enter the daily pumping rate (gpm):						500		**you only need to enter data to cells with blue highlights.**				
17													
18	Enter the number of 8-hr period for daily pumping:						3						
19													
20	Type of filter bags (enter "1" for unlined or "2" for lined):						1						
21													
22	**Results:**												
23	Polymer Injection Rate: (gph)						10		**Results are displayed in cells with yellow highlights.**				
24	Polymer cost per day: ($)						24						
25	Stormwater treated per day: (Gal)						720000						
26	# of bags of needed per week:						3						
27													
28	Weekly operating costs based on the specified flow rates:												
29													
30		Polymer, $/wk :		168									
31													
32		Filter bag, $/wk:		375									
33													
34		total, $/wk:		**$543**									
35													

Treatment Option 2: Filtering the Bypass Portion Prior to Stilling Basin

Enter the Pumping Flow Rate (gpm):	500
Enter the turbidity of inflow (NTU):	150
Enter the turbidity of the regulated discharge (NTU):	35
Enter the turbidity of the stilling pond effluent (NTU):	75
Enter the turbidity of the filtered water (NTU):	20
Enter the number of 8-hr period for daily pumping	3
Type of filter bags (enter "1" for unlined or "2" for lined):	1
% of the bypass flow:	27%
Pumping flow rate to filter (gpm):	364
Polymer Injection Rate: (gph)	7.27
Polymer Cost Per Day: ($)	17.45
Flow rate to stilling pond (gpm):	136.36
Stormwater Filtered Per Day: (Gal)	523636
Total amount of water (treated+bypass) per day: (Gal)	720000
# of Bag of Consumption Per Week:	2.2

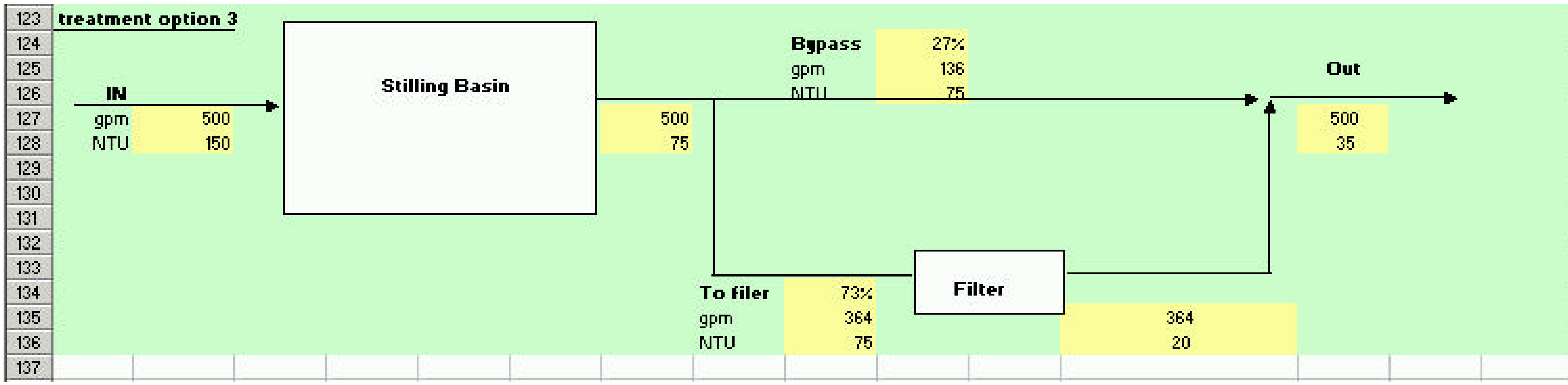
Weekly operating costs based on the specified flow rates:

Polymer, $/wk :	122
Filter bag, $/wk:	273
total, $/wk:	**$395**



treatment option 2
IN
gpm
NTU
500
150
To basin
27%
136
150
Stilling Basin
136
75
Out
500
35
Filter
By Pass
To filer
gpm
NTU
73%
364
150
364
20

89	**Treatment Option 3: Filtering the Effluent Portion of the Stilling Basin**	
90		
91	Enter the Pumping Flow Rate (gpm):	500
92		
93	Enter the turbidity of inflow (NTU):	150
94		
95	Enter the turbidity of the regulated discharge (NTU):	35
96		
97	Enter the turbidity of the stilling pond effluent (NTU):	75
98		
99	Enter the turbidity of the filtered water (NTU):	20
100		
101	Enter the number of 8-hr period for daily pumping	3
102		
103	Type of filter bags (enter "1" for unlined or "2" for lined):	1
104		
105	% of the bypass flow:	27%
106	Pumping flow rate to filter (gpm):	364
107	Polymer Injection Rate: (gph)	7.27
108	Polymer Cost Per Day: ($)	17.45
109	Stormwater Filtered Per Day: (Gal)	523636
110	Total amount of water (treated+bypass) per day: (Gal)	720000
111	# of Bag of Consumption Per Week:	2.2
112		
113	Weekly operating costs based on the specified flow rates:	
114		
115	Polymer, $/wk :	122
116		
117	Filter bag, $/wk:	382
118		
119	total, $/wk:	**$504**
120		

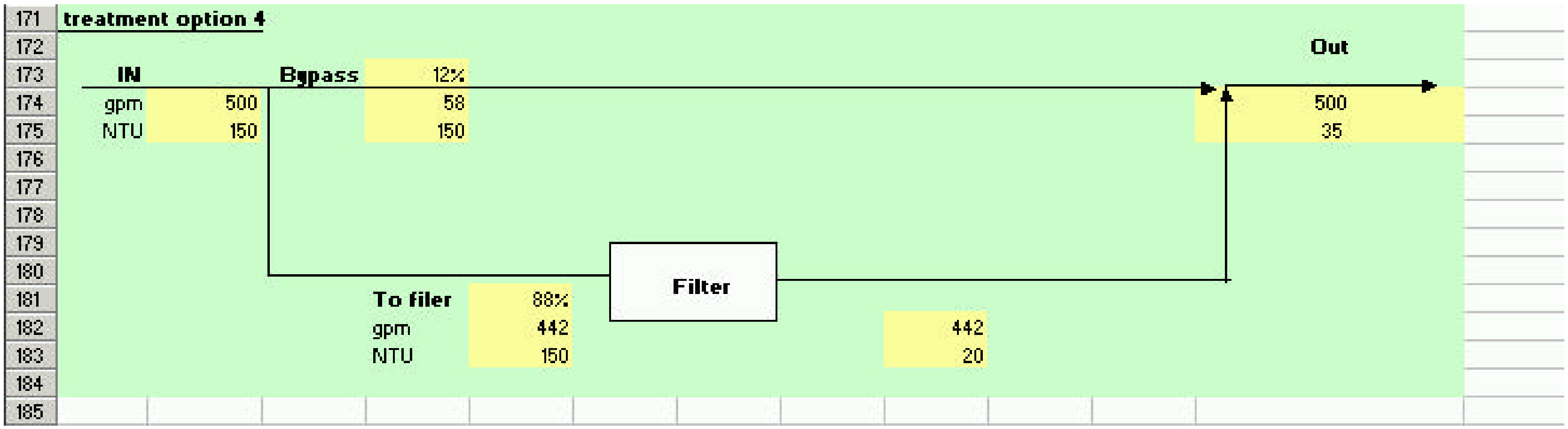

123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
treatment option 3
IN
gpm 500
NTU 150
Stilling Basin
500
75
Bypass 27%
gpm 136
NTU 75
Out
500
35
Filter
To filer 73%
gpm 364
NTU 75
364
20

Treatment Option 4: Filtering with Bypass and without stilling basin

Enter the Pumping Flow Rate (gpm):	500
Enter the turbidity of inflow (NTU):	150
Enter the turbidity of the regulated discharge (NTU):	35
Enter the turbidity of the filtered water (NTU):	20
Enter the number of 8-hr period for daily pumping	3
Type of filter bags (enter "1" for unlined or "2" for lined):	1
% of the bypass flow:	0.12
Pumping flow rate to filter (gpm):	442
Polymer Injection Rate: (gph)	8.85
Polymer Cost Per Day: ($)	21.23
Pumping flow rate to stilling pond (gpm):	57.69
Stormwater Filtered Per Day: (Gal)	636923
Total amount of water (treated+bypass) per day: (Gal)	720000
# of Bag of Consumption Per Week:	2.7

Weekly operating costs based on the specified flow rates:

Polymer, $/wk :	149
Filter bag, $/wk:	332
total, $/wk:	**$480**


171 treatment option 4
172 Out
173 IN Bypass 12%
174 gpm 500 58 500
175 NTU 150 150 35
176
177
178
179
180 Filter
181 To filer 88%
182 gpm 442 442
183 NTU 150 20
184
185