Final Report

Evaluation of Nutrient Loading Rates and Effectiveness of Roadside Vegetative Connectivity for Managing Runoff from Secondary Roadways

Prepared By

Jy S. Wu, Ph.D., P.E.
Department of Civil and Environmental Engineering

Craig J. Allan, Ph.D.
Department of Geography and Earth Sciences

9201 University City Blvd.
University of North Carolina at Charlotte
Charlotte, NC 28223

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Abstract

This report documents research findings regarding the implementation of a storm water monitoring program to characterize pollutant constituent concentrations and nutrient loading rates originated from three secondary roads in the Piedmont region of North Carolina. Hydrologic and water quality data were collected for 26-30 storm events from two paired sites at each of the three monitoring locations. These secondary roads carry an average traffic volume of 590-2,600 vehicles per day in both directions. It was found that event mean concentrations for most pollutant constituents are substantially lower than those of the NC Piedmont primary roads. The export of total nitrogen was estimated to be 3-5% of that from a typical development site. The paired-site monitoring strategy has provided a common database to evaluate the effectiveness of existing roadside vegetation that serves as a natural best management practice for the attenuation of pollutant constituents in secondary roadway runoff. Water quality benefits and the likely cost savings associated with roadside vegetative treatment should be included in a comprehensive highway runoff management program.

Disclaimer

The contents of this report reflect the views of the authors and not necessarily the views of the University. The authors are responsible for the accuracy of the data presented herein. The contents also do not necessarily reflect the official views or policies of the North Carolina Department of Transportation or the Federal Highway Administration at the time of publication. This report does not constitute a standard, specification, or regulation.

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Executive Summary

Secondary roads are the backbone of the nation's rural transportation network. These transportation arteries carry small-to-moderate traffic flows from surrounding residential, farming, business and industrial land uses to principal county routes and primary highway systems. It is known that secondary roads are connected or interconnected to grassed strips and vegetated ditches on their right-of-ways, which functions as a natural best management practice for pollutant attenuation. Water quality benefits and the likely cost savings associated with the inherent and environmental-friendly vegetative treatment should be included in a comprehensive highway runoff management program.

This research has implemented a storm water monitoring program to characterize pollutant constituent concentrations and nutrient loading rates originated from roadway segments on three secondary roads in the Piedmont region of North Carolina. These secondary roads carry an average traffic volume of 590-2,600 vehicles per day in both directions. Hydrologic and water quality data were collected for 26-30 storm events from two paired sites at each of the three monitoring locations. The paired-site monitoring strategy has provided a common database to evaluate the effectiveness of existing roadside vegetation for the attenuation of pollutant constituents in secondary roadway runoff. The following conclusions and recommendations can be drawn from this NCDOT-funded project.

- Event mean concentrations (EMCs) for storm runoff from secondary roads connected to vegetated roadside ditch are 15 mg/L TSS, 0.08 mg/L NO_3-N, 0.02 mg/L PO_4-N, 0.03 mg/L NH_4-N, 0.49 mg/L TN, 0.07 mg/L TP (filtered) and 0.13 mg/L TP (unfiltered). These EMCs are substantially lower than those of the NC Piedmont primary roads and the national highway runoff characterization data for rural roads.
- Annual pollutant loads derived from secondary roadway runoff connected to vegetated roadside ditch are 11 lb/ac-yr TSS, 0.05 lb/ac-yr NO_3-N, 0.02 lb/ac-yr PO_4-P, 0.02 lb/ac-yr NH_4-N, 0.35 lb/ac-yr TN, 0.06 lb/ac-yr TP (filtered) and 0.09 lb/ac-yr TP (unfiltered). Particularly, TN export was estimated for secondary roads to be 3-5% of that from a typical development site.
- Pollutant credits attributed to vegetative treatment based on EMC reductions are 53% TSS, 65% NO_3-N, 88% NH_4-N, and 25% for TN; with essentially no credits for phosphorus species including PO_4-N and TP.

- Pollutant credits attributed to vegetative treatment based on annual loads (lb/ac-yr) are 95% NH_4-N, 87% NO_3-N, 77% TSS, 67% TN, 59% TP (filtered), 50% PO_4-N, and 33% TP (unfiltered).
- Data presented in this report for assessment of vegetative treatment effectiveness and characterization of secondary roadway runoff are based on site-averaged performance. Due consideration must be given to account for the statistical uncertainty of these averaged values.
- Research is needed to include pollutant credits provided by roadside vegetative treatment into a comprehensive TMDL modeling study on watershed scale. This is particularly important for watersheds, such as the Jordan Lake Watershed, comprised of a large percentage of secondary roads.
- Research is needed to evaluate pollutant removal mechanisms occurring in vegetated ditches including criteria required to maximize the adjoining filter strip and/or optimize the performance along the ditch.
- Research is needed to develop vegetative management practices with due consideration of water quality enhancement offered by vegetative treatment.
- Coordination among agencies is needed to minimize near-site construction activities leading to elevated sediment discharged into roadside ditches and to avoid utility work along the roadside ditch causing periodic disruption of the established vegetation.
- Finally, vegetated roadside ditches may play a significant role to alleviate or even eliminate the need of structural best management practices for secondary roads, if they are properly constructed and maintained.

Table of Contents

List of Tables

List of Figures

1. Introduction

North Carolina Department of Transportation (NCDOT) has conducted a variety of collaborative research projects to quantify pollutant loads from the agency's permitted activities, enhance or improve existing storm water management and control practices, and develop new technologies to meet future permit requirements. These efforts are guided by the state-issued statewide NPDES storm water permit. The University of North Carolina at Charlotte, led by a research team from the Departments of Civil and Environmental Engineering and Geography and Earth Sciences, has engaged in technical assistance to characterize pollutant loadings from various highway types across the state (Wu et al., 1998; Wu and Allan, 2001), developed a GIS-methodology for storm water outfall inventory and prioritization (HWY-0712) and pollutant loading assessment (Allan and Wu, 2004), evaluated structural best management practices (BMPs) for highways and industrial facilities operated by NCDOT (Wu and Allan, 2006), and studied the effectiveness of manufactured or proprietary storm water BMPs (Allan and Wu, 2009).

Numerous studies on pollutant loading rates as a function of land use have produced a wide range of literature values with observed variability influenced by regional and site specific characteristics such as rainfall, soil type, and relative percentage of impervious area (Driscoll et al., 1990). Few studies have identified nutrient loading rates from secondary roads, and of these, only a fraction of that data is applicable to North Carolina conditions. Secondary roads constitute the backbone of the nation's rural transportation network and include county roads, subdivision streets and collector roads. These transportation arteries carry small-to-moderate traffic flows from surrounding residential, farming, business and industrial land uses to principal county routes and primary highway systems including state highways and interstates. As an example, within one of the project sites examined in this report, the Jordan Lake watershed, secondary roads comprise more than 77% or 3,059 out of 3,938 miles of the total roadway mileage.

Secondary roads typically include a 50-foot right-of-way for maintenance access and future road improvement needs. Wherever feasible, a 32-foot road width including side ditches and adequate drainage are required. Because of their vegetated cover and the presence of soils of variable permeability, these ditches might be considered as an existing BMP type similar to vegetative filter strips or other vegetative control measures that have been employed to mitigate the impact of roadway runoff (Han et al., 2005). The potential of water quality benefits and the likely cost savings associated with roadside vegetative treatment may have been inadvertently neglected from a comprehensive highway runoff management program.

This research was aimed at developing a scientifically defensible database to quantify the pollutant-loading rates (TSS and nutrients) of storm runoff from secondary roads, and quantifying the water quality benefits associated with the passage of highway runoff through vegetated roadside ditches that are inherently part of the secondary road network. This report presents research findings regarding the implementation of a storm water monitoring program conducted at three paired-site locations in Chatham and Lincoln counties of North Carolina. It includes a literature review for vegetative control (Chapter 2), site characteristics and monitoring methodology (Chapter 3), monitoring results for each study site (Chapters 4, 5 and 6), overall removal performance as compared to removal credits of 20% TN and 20% TP that have been suggested by the NC Division of Water Quality (Chapter 7), and concluding remarks and recommendations (Chapter 8).

2. Literature Review

This chapter presents a critical review of highway runoff characterization and methodology for predicting event mean concentrations and pollutant loads at highway runoff sites. It also includes a discussion on design practices and pollutant removal performance of vegetated roadside ditches.

2.1 Characterization of Highway Runoff

Studies on characterization of highway runoff have been limited to single-site or multiple-site monitoring of highway segments. Nevertheless, these results have contributed to a better understanding of environmental factors affecting highway runoff quality and the potential impacts of highway runoff on receiving streams.

Hoffman et al., (1985) monitored highway runoff for hydrocarbons, metals and solids from Interstate 95 in Rhode Island. The export of solids and other pollutants from highway runoff was estimated to be responsible for more than 50% of the annual pollutant loads delivered to the receiving stream. Loading factors of significant importance were identified as highway drainage area and traffic volume.

Irish et al. (1998) employed storm runoff data from an Expressway in Austin, Texas, to develop regression models for predicting pollutant loads. The study has found that the pollutant load for each constituent was dependent on a unique subset of identified variables, providing some insight of the interrelationship between process variables and pollutant loads.

Another characterization study was conducted on three highway segments typical of urban, semi-urban, and rural settings in the Piedmont region of North Carolina (Wu et al., 1998). Runoff from the urban bridge deck site was found to carry total suspended solids that are relatively higher than typical urban highways, whereas nitrogen and phosphorus loadings are similar to agricultural runoff. Long-term pollutant loadings were developed to compare highway runoff with other categories of nonpoint sources.

Kayhanian et al. (2003) reported that most of the highway runoff constituents are influenced by annual average daily traffic and factors associated with watershed characteristics and pollutant build-up and wash-off. This California study has shown that the accumulation of pollutant on highways was influenced by antecedent dry period, drainage area, maximum rainfall intensity and land use.

Han et al. (2006) monitored three highway sites in Los Angeles during wet seasons to derive event mean concentrations, partial event mean concentrations, and mass first flush factors. The study could not establish good correlations between total suspended solids and most other conventional pollutants, and between monitored pollutants and storm characteristics except dry antecedent dry days. Los Angeles has an annual average rainfall of 15 inches, which might have contributed to contradiction of pollutant loading correlations reported in the literature.

Li et al. (2008) revealed a strong relationship between antecedent dry periods and pollutant concentrations based on highway runoff data collected at College Station, Texas. However, similar observations were not supported by the runoff data from the Austin highways. The College Station data appears to provide a different inside to the pollutant buildup and removal processes on highway runoff.

Two significant characterization studies have been conducted on state-wide basis, providing estimates of EMCs and pollutant loads for state-owned highway systems that require storm water permits.

A state-wide characterization study in California includes monitoring of thirty four highway sites during 2000-2003 (Kayhanian et al, 2007). A total of 635 storm events were collected over a wide range of annual traffic (2,100-328,000 ADT), surrounding land use (rural, commercial, residential, and agricultural), average annual rainfall (9-40 inches for different parts of the state), and highway types (inter-state and state highways). EMCs for key constituents obtained from the Californian study are summarized in Table 2.1.

Another state-wide highway runoff study was performed in North Carolina during the period of 1999-2000 (Wu and Allan, 2001). A total of 237 storm events were sampled at ten highway sites in the Piedmont (6 sites), Mountains (2 sites) and Coastal (2 sites) regions. Site conditions include land use (urban, rural, commercial and residential), drainage areas (0.15-13.46 acres), and impervious cover (22-100%). Annual rainfall totals during the monitoring period were 36, 37 and 65 inches, respectively, for the Mountains, Piedmont and Coastal regions. EMCs for key constituents obtained from the NC study are given in Table 2.2.

Table 2. 1 Summary of Selected EMCs from the California State-wide Study

	Non-urban Highways*	Urban Highways Low*	Urban Highways High*	Average for Entire Dataset	Medium for Entire Dataset
TSS, mg/L	70	76	159	113	59
NO_3-N, mg/L	0.6	0.8	1.6	1.07	0.6
TKN, mg/L	1.5	2.1	2.5	2.06	1.4
Ortho-P, mg/L	0.1	0.1	0.1	0.11	0.06
TP, mg/L	0.2	0.3	0.3	0.29	0.18

*Non-urban = < 30,000 AADT; Urban Highway Low = 30,000-100,000 AADT;
Urban Highway = > 100,000 AADT

Table 2. 2 Summary of Selected EMCs from the North Carolina State-wide Study

	Piedmont	Mountains	Coastal	Average for Entire Dataset	Medium for Entire Dataset
TSS, mg/L	8-139	20-60	20-210	70	37
NO_3-N, mg/L	0.31-0.84	0.30-0.33	0.15-0.36	0.48 (0.54)*	0.40
TKN, mg/L	1.10-2.40	1.10-1.20	0.80-3.00	1.59	1.37
Ortho-P, mg/L	0.09-0.24	0.06-0.13	0.05-0.32	0.15	0.12
TP, mg/L	0.24-0.35	0.13-0.20	0.09-0.69	0.27	0.21

*Number in parenthesis is for sum of NO_3-N + NO_2-N

With regards to developing predictive equations, the California study has provided a set of equations for most pollutant constituent and several of these equations are shown below:

$$\text{Ln (TSS EMC)} = 4.28 - 0.124\beta_1 + 0.102\beta_2 - 0.099\beta_3 + 4.934\beta_5$$

$$\text{Ln (NO}_3\text{-N EMC)} = 1.30 - 0.417\beta_1 + 0.092\beta_2 - 0.090\beta_3 + 2.870\beta_5$$

$$\text{Ln (TKN EMC)} = 1.70 - 0.343\beta_1 + 0.102\beta_2 - 0.128\beta_3 + 1.535\beta_5$$

$$\text{Ln (TP EMC)} = - 1.20 - 0.143\beta_1 + 0.128\beta_2 - 0.051\beta_3 + 0.900\beta_5$$

Where, β_1 = total event rainfall, mm
β_2 = antecedent dry periods, days
β_3 = (seasonal cumulative rainfall)$^{1/3}$, mm
β_5 = annual average daily traffic, AADTx10^{-6} vehicles/day

Note that β_4 representing the size of drainage area was not included in the above predictive equations for TSS, NO_3-N, TKN and TP. Site and event parameters (e.g. β_1, β_2, β_3 and β_5) were found to have significant influence on EMCs, as well as other factors of surrounding land use and geographic regions. The study concluded that the characteristics of highway runoff in California are generally similar to other states such as Texas and North Carolina, and the national highway runoff studies (Driscoll et al., 1999).

On the other hand, the North Carolina study has developed TN export functions for the following conditions:

For all 10 sites: $TN = 0.2880 + 2.09\times10^{-3} (ADT) + 0.0913 (Imp)$

Excluding one Piedmont site that was subject to on-site erosion:

$$TN = -1.06 + 0.0066\times10^{-3} (ADT) + 0.1098 (Imp)$$

Because the correlation coefficients for ADT are relatively small, ADT was removed from the above two equations, resulting in the following simplified TN export functions:

For Piedmont and Mountains regions: $TN = 0.8912\, e^{0.0256\, Imp}$

For Coastal regions: $TN = 3.9860\, e^{0.0091\, Imp}$

Where, TN = lb/ac-yr
ADT = vehicles/day (9,300-78,800)
Imp = imperviousness, % (22-100)

2.2 Vegetative Treatment for Highway Runoff

Grass swales or vegetated ditches and filter strips are inherently part of most roadway drainage network and may provide on-site treatment for highway runoff. Vegetated swales or ditches are designed to meet water quality and flow-based design storms; whereas drainage channels are constructed to handle a specific peak flow rate with limited pollutant removal. The treatment processes occurring in vegetated swales and filter strips are complex and involve hydraulic, physical (infiltration, deposition and filtration) and biochemical (denitrification, biostorage and degradation) components.

In reality, a vegetated roadside ditch not only carries flow in its longitudinal direction, but also receives lateral inflow of roadway runoff that passes through its side slopes before joining the ditch flow. The grassed side slopes may, in effect, function as a filter strip whose pollutant removal capacity depends on the slope, vegetation establishment and other conditions. Consequently, pollutant removal performance of vegetated ditches could be viewed as a combined effect of treatment processes encountering in the longitudinal and perpendicular flow paths.

Vegetative treatment has been recognized by regulatory agencies as best management practices for storm water runoff. Barrett et al. (2006) conducted a study to document the water quality benefits of vegetated side slopes typically of common rural highway cross sections in Texas. Significant removal of certain pollutants was found to occur over the width of vegetated filter strips, often within the first four meters from the edge of the pavement. The study also includes a survey of state DOT practices using vegetated roadsides for the treatment of storm runoff, as summarized below:

Agency	Agency Comments
Florida DOT	Vegetation is recognized for its importance in reducing roadside erosion.
Maryland DOT	Vegetated roadside is part of an overall strategy in reducing nonpoint source pollution and has researched with different slopes at existing roadways.
Minnesota DOT	Vegetated roadsides, bio-swales, bio-retention ditches, and infiltration ditches are useful tools in reducing nonpoint source pollution. The “switch grass” (Panicum Virgatum) that is common to the prairie states has been found to be extremely effective in phosphorus removal.
New York DOT	Te state has established vegetated roadsides as part of the overall roadway design.
Utah DOT	The state has researched on the effectiveness of vegetative roadsides for runoff treatment
Washington DOT	The state considers biofiltration swales as an effective means of treating roadway runoff and has published a maintenance manual for vegetated facilities.

Deletic and Fletcher (2006) performed experimental research on vegetated swale and filter strip for the removal of TSS, TN and TP; and verification of a water and sediment transport model (TRAVA). Artificial inflow was provided at the upstream portion of the grass swale with no lateral flow. The swale was found to achieve 69%, 46% and 56% removals of total loads for TSS, TP, and TN, respectively. TSS removal performance for the field strip (7.8% slope and 6.2 m long) exhibited an exponential decay with the majority of large particles being trapped within the first part of the strip. Only a small percentage of particles of less than 5.8 μm was retained along the entire length. Table 2.3 reproduces the summary statistics of vegetative treatment performance as reported by Deletic and Fletcher (2006). The statistics was compiled from published data by Barrett et al (1998), Bren et al. (1997), Dillaha et al. (1989), Kercher et al. (1983), Magette et al. (1989) and Walsh et al. (1997).

Table 2. 3 Summary Statistics of Vegetated Swale Performance*

	TSS Removal, %	TP Removal, %	TN Removal, %
Number of Studies**	(18)	(20)	(13)
Mean	72	52	45
Medium	76	55	50
10th Percentile	50	35	18
90th Percentile	93	73	70

*Deletic and Fletcher (2006)
**Numbers in parenthesis are for the number of studies used to compile the statistics

More recently, Storey et al. (2009) surveyed design practices and water quality benefits for rural roadside storm water treatment using vegetated buffers, filter strips and grass swale, and proposed design guidelines for effective treatment of rural highways. Relevant to our project is the use of grass swale or vegetated ditch and, therefore, the recommended design criteria for grass swales as given by Storey et al. (2009) are summarized in Table 2.4. Readers are referred to the source of publication for recommended design criteria related to filter strips and vegetative buffers.

2.3 Summary

Literature data clearly supports the beneficial use of vegetated treatment for highway runoff. Most of these studies are relevant to urban and rural highways although few studies referred to daily traffic counts that are compatible with secondary roads. Literature pertaining to characterization and utilization of vegetative treatment for secondary roadway runoff is almost non-existent. It is noted that the recommended design criteria for grass swale or vegetated ditch by Storey et al. (2009) were revised from existing practices. Further research is needed to evaluate the water quality benefits associated with these criteria.

Table 2. 4 Recommended Design Criteria for Grass Swales*

Design Parameter	Recommended Criteria
Design Storm	2 year with 10-year capacity
Longitudinal slope	2-6% (1% minimum and 10% maximum)
Side Slope	33% maximum
Bottom width	2 to 8 ft
Length with check dam	Provision of a hydraulic residence time of 9 minutes
Length without check dam	Minimum of 100-ft continuous swale before discharge
Cross section	V-shape to maximize the adjoining filter strip length and increase performance capabilities
Contributing drainage area	1% of swale surface area
Flow type	Concentrated flow
Flow depth	4 to 6 inches or 2/3 of grass height
Flow velocity	1-5 feet per second
Vegetation density	90% (80% minimum)
Vegetation type	Selection based on soil type, inundation tolerance, filtering capabilities, typical mowing height and design flow velocities
Soil type	Preferred NRCS soil types of A, B, or C with minimum 0.27 inches per hour infiltration
Depth of water table	2 feet minimum
Depth of bed rock	3 feet minimum

*Storey et al. (2009)

3. Methodology and Procedures

3.1 Research Objectives

State-owned primary roads usually receive higher priority than secondary roads for structural BMP installations. However, secondary roads are mostly connected or interconnected to grassed strips and ditches. The inherent and environmental-friendly benefits of vegetative coverage that exists in the right-of-ways of secondary roads should be carefully taken into consideration. It is important to understand and be able to quantify the inherent benefits and, ultimately, integrate their performance into a cost effective storm water BMP management strategy.

The scope of this NCDOT-funded project was to implement a comprehensive monitoring program that would provide hydrologic and water quality data for deriving nutrient loading rates from selected secondary roadways in North Carolina, particularly in the Jordan Lake watershed. The data will expand the previous highway runoff dataset collected by Wu and Allan (2001) and extend the agency's ability to evaluate pollutant loading rates for a wider range of road conditions than at present.

Monitoring results were also employed to assess the pollutant-loading reduction potential of existing vegetative coverage alongside of selected secondary roads. Hydrologic connectivity analysis was performed to study the movement of roadway runoff through grassed shoulders and ditches, allowing an assessment of the effectiveness of pervious vegetated surfaces in removing roadway source pollutants.

3.2 Site Selection

The Jordan Lake watershed encompasses a total drainage area of 1,686 square miles and includes most of the urban areas of Durham, Chapel Hill, Cary, Burlington, Greensboro and several other small communities. The total maximum daily load (TMDL) plan that was developed for this watershed requires 35% and 5% reductions of total nitrogen (TN) and total phosphorus (TP), respectively, along the Upper New Hope Arm of the lake above SR 1008. Additional 8% and 5% reductions in TN and TP, respectively, were indicated for the Haw River Arm. These reductions are equally borne through reductions in both point and nonpoint pollutant sources (NC DENR, 2007). The Upper New Hope Arm was included on the 2002-303(d) list and the Lower New Hope Arm and the Haw River Arm were placed on the 2006-303(d) list of impaired waters.

Because of the large percentage of secondary road mileage (3,059 out of 3,938 miles or 77% of the total roadway mileage) and the recommended nutrient reductions in the Jordan Lake watershed, the research was directed to conduct a field monitoring program at two secondary roads within this watershed area. A third location was selected near the university campus in Charlotte for immediate response to sample collection after short-duration storm events. This near-Charlotte site was chosen based on the range of traffic volumes encountered at the Jordan Lake sites. Roadway characteristics of the three study sites are summarized in Table 3.1

Table 3. 1 Characteristics of Selected Secondary Roads

Secondary Road	Site Name Abbreviation	Site Location City, County	ADT Vehicles/day*
SR 1943	JLS	Pittsboro, Chatham	590
SR 1717	JLN	Chapel Hill, Chatham	2,600
SR 1360	MIL	Ironton, Lincoln	1,400

* Average daily traffic (ADT) including both driving directions was taken in the vicinity of the respective monitoring locations over a 7-day period in October 2008.

3.3. Monitoring Strategy

A paired-site sampling strategy was implemented. Storm runoff originated from one section of the roadway drains naturally into a vegetated ditch where runoff flow and samples are collected. Runoff from another section of the same roadway is intercepted and sampled at the roadside edge. Storm data from these paired sites, i.e. roadside edge versus outflow from the vegetated ditch, were employed to derive pollutant loads from secondary roads and to assess the pollutant removal performance of the vegetated ditch.

3.3.1 Site Preparations

A selected segment on each of the three secondary roads was re-configured by installing a curved curb along the roadway edge to intercept surface runoff and divert it into a weir-box device (Figures 3.1 and 3.2). Runoff flows into the rear portion of this structure and leaves the front portion through a 60^o weir. A bubbler-style water level sensor was employed to continuously record the water level above the weir notch.

Figure 3. 1 Flow Collection and Sampling Weir-Box Configuration

Figure 3. 2 Installation of a Weir-Box Device

Upstream of this weir-box monitoring site, runoff flows naturally through the grassy shoulder strip into a drainage ditch (Figure 3.3). A bubbler flow meter was installed on the bottom of the adjacent drainage ditch for water level measurements. Two ISCO automatic samplers were installed at each paired-site location for collecting water samples of surface runoff from the weir box (weir samples) and runoff receiving vegetative treatment (ditch samples), respectively. Table 3.2 summarizes the physical characteristics of each monitoring site.

Figure 3. 3 Typical Setup of a Paired-Site Monitoring Location

3.3.2 Storm Criteria

Fifteen to twenty (15-20) eligible storms were required to be monitored at each site. There are two paired sites at each monitoring location. At least half of the eligible storms were to include concurrent hydrologic and water quality data of the same storm at the paired sites, e.g. JLS-W and JLS-D. Eligible storms are monitored events that incur sample collection from at least 70% of either the runoff duration or, in some cases, the amount of total rainfall. In addition, storm events were expected to be associated with rainfall amounts of greater than 0.2 inches to less than 1.5 inches.

Table 3. 2 Characteristics of Paired-site Monitoring Locations on Three North Carolina Secondary Roads

Site Name*	Latitude and Longitude	Secondary Roads	Nearby Address	Drainage Area (ft^2)	Paved Area (% Imp)	Side/Ditch Slope	Ditch Length/Width (ft)
JLS-W	35°42’20.98”N 79°06’08.48”W	SR 1943	3388 Hanks Chapel Rd, Pittsboro, NC 27312	1,042	100		
JLS-D	Same as above	SR 1943	Same as above	15,696	65.4	0.142/0.022	462/12
JLN-W	35°48’56.89”N 75°03’21.59”W	SR 1717	1416 Jack Bennett Rd, Chapel Hill, NC 27517	1,125	100		
JLN-D	Same as above	SR 1717	Same as above	23,027** 48,352**	46.5 37.3	0.137/0.039	1071/12
MIL-W	35°26’34.67”N 81°06’26.40”W	SR 1360	1398 Brevard Place Rd, Ironton, NC 28080	1,291	100		
MIL-D	Same as above	SR 1360	Same as above	10,343	47.9	0.172/0.049	315/17

*JLS-W = Jordan Lake South weir sampling site, JLS-D = Jordan Lake North ditch sampling site, JLN-W = Jordan Lake North weir sampling site, JLN-D = Jordan Lake North ditch sampling site, MIL-W = Mt. Island Lake weir sampling site, and MIL-D = Mt. Island Lake ditch sampling site.

** The first number is for the combined roadway segment and vegetated ditch areas, and the second number includes additional off-site drainage that is above the site with runoff overflowing into the ditch area.

Storms ranging from 0.2 to 1.0 inches represent approximately 60-80% of rainfall events that typically occur in the Piedmont region. The majority of pollutant loadings can be accounted for with storms of 1.0" or less, or from the first 0.5-1.0 inch of larger storms. When the TMDL model is taken into consideration, it would be necessary to collect few storms of greater than 1.0 inch for use in basin-wide TMDL assessment.

The study included special effort to manually re-stock and re-start the automatic samplers to continue the sampling process for long-duration and large storm events. This was due to the limited number of sampling bottles (12 or 24 bottles) available for each programmed run. These bottles must be replaced at the end of one sampling sequence, sometimes in the middle of a long-duration storm event. Typically, a minimum of 72 hours is required to elapse between two consecutive events for deriving event-based pollutant loads. However, an elapse time between 10-72 hours was used in this study when comparing pollutant loads from the same storm at the paired-site monitoring location.

3.3.3 Sample Handling and Testing

Rainfall amounts were recorded at each paired site using recording (tipping bucket) and non-recording (standard) raingages and compared with the multiple precipitation estimates (MPE) provided by the NC State Climatic Office. Bulk precipitation samples were collected to account for atmospheric inputs before and during each event. Each bulk precipitation sampler consists of a 5-gallon plastic bucket with removable plastic liners suspended at 2.5 meters above the ground surface. Precipitation samples were analyzed for water quality constituents similar to runoff samples.

Water samples were collected by ISCO samplers on fixed time intervals, i.e. 15-20 or 30 minutes for short- or long-duration storms. Individual samples were manually combined after hydrograph inspection to yield flow-weighted composite samples over the course of the runoff period. These composite water-quality samples were analyzed at the Environmental Research Laboratories at UNC Charlotte. Key water quality constituents analyzed include total suspended solids (TSS), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), chloride (Cl^-), ortho-phosphate phosphorus (PO_4-P), total nitrogen (TN) and total phosphorus (TP).

Water samples were retrieved from the field within twenty four to forty eight hours of collection. Upon arriving at the UNC Charlotte laboratories, turbidity and specific conductance are measured on unfiltered water samples. An unfiltered sub-sample was poured off and frozen for later analysis of TN and TP. The remaining sample was vacuum filtered and the TSS content was determined from the volume of water filtered and the dry residue weight remaining on the filter paper. The filtrate was analyzed for NH_4-N, NO_3-N, and PO_4-N using a Dionex DX 500 ion chromatograph system with either a CS12A or AS14 analytical column for cation and anion determinations, respectively. TN was measured after thermo-combustion on a Shimadzu TOC-V system with a TN module. TP was measured colormetrically on both filtered and unfiltered samples after a heated acid/persulfate digestion. Blank and duplicate samples were included for QA/QC control.

3.3.4 Hydrologic Connectivity

One of the challenging aspects of this project was to determine the hydrologic connectivity between vegetative coverage and roadway drainage. Hydrologic connectivity refers to the degree in which a drainage area is directly connected or unconnected to its ultimate discharge point. Impervious areas directly connected to discharge points would exert an immediate impact on stream flow and water quality; whereas runoff from an unconnected or partially connected impervious area would be reduced with simultaneous attenuation of pollutant loads. A procedure was implemented using the Excel spreadsheet program to quantify the effects of hydrologic connectivity between roadway drainage and vegetated ditch, as given below:

1) Develop a runoff hydrograph for the roadway segment (see section 3.3.5 below).
2) Convert the runoff flow rates to volumetric discharges (□t* Q, t is time in seconds and Q is flow rate in ft^3/s).
3) Divide the volumetric discharge by roadway drainage area to obtain flow depths as inches.
4) Combine flow depths from step (3) and rainfall depths falling onto the ditch at each time step (□t) to yield total inflow depths for the vegetated ditch.
5) Apply an acceptable procedure to account for abstraction losses within the vegetated area (e.g. curve number technique).
6) Rescale the resulting depths to the entire drainage area including roadway segment and the vegetated ditch.
7) Compare the rescaled depths with the volumetric discharges estimated from a rating cure at the ditch sampling point.
8) Perform channel routing to obtain outflow hydrograph, if needed.

3.3.5 Flow Determinations

During the initial stage of this research, a water truck was employed to supply runoff flow on roadway segments at each monitoring location. Simultaneous measurements of water depths in the weir-box device or at the drainage ditch versus flow rates were conducted. Flow leaving the weir box was directed to a plastic bag over a short time interval. The amount of water in the plastic bag was then poured into a graduated cylinder to determine its volume, which was divided by the collection time to estimate the corresponding flow rate. This process was repeated for a range of inflow rates by adjusting the rate of water release from the water truck. In the case of ditch flow, a floating object was allowed to follow the flowing water and the time of travel over a given distance was recorded. Flow rates were obtained by multiplying the velocity of travel after certain adjustments to the respective cross-sectional areas. Water levels recorded by the automatic samplers were also simultaneously taken to develop correlations of the recorded depths versus field tested depths for subsequent calculations. Consequently, the following generalized equations have been developed for converting recorded flow depths to flow rates.

Weir Flow Equation:

$$Q = \alpha(H \square \eta)^{\beta}$$

Where Q is flow rate, α and β are equation coefficients, H is water depth recorded by automatic sampler, and h is the event-based adjustment height prior to the occurrence of runoff through the weir box.

Ditch Flow Equation:

$$Q = VA$$

In which V is flow velocity that is calculated either by Manning's equation or a regression equation in the form of $V = a(H - h)^{b}$, A is the cross-sectional area related to the flow depth, "a" and "b" are equation coefficients, and "h" is an event-based adjustment depth before the occurrence of ditch flow.

4. Jordan Lake South Monitoring Site

This chapter summarizes the hydrologic and water quality data collected at the Jordan Lake South (JLS) monitoring station. This paired-site sampling location is near 3388 Hanks Chapel Road on SR 1943 in Pittsboro, N.C. Thirty eligible storm events have been successfully monitored during the period of October 2007 to April 2009. Of this total, twenty four storms include concurrent data relevant to surface runoff drained directly from the roadway segment to a weir box device and, at a second site, runoff was intercepted and passed through a roadside ditch. This paired-site monitoring strategy provides a consistent database to characterize surface runoff from secondary roads and to assess the pollutant removal performance of the vegetated roadside ditch area.

4.1 Site Characterization

The Hanks Chapel Road on SR 1943 is a two-lane paved road carrying an average daily traffic count of 590 vehicles in both directions. Sampling equipment and roadway drainage at this paired–site monitoring station are shown in Figures 4.1 and 4.2, respectively. At the weir sampling site, surface runoff drains directly from a 1,042 ft^2 roadway segment into a weir-box device as described in Chapter 3. This monitoring site has a 100% impervious cover and is designated as JLS-W. Surface runoff originated from another roadway segment of 10,260 ft^2, located immediately above JLS-W, flows laterally into a 5,436 ft^2 vegetated roadside ditch area. This JLS-D drainage site has a total area of 15,696 ft^2 with 65% impervious cover. The ditch area has a side slope of 14.2% and a channel slope of 2.2%. The vegetated roadside ditch area functions naturally as a water quality management practice for the incoming roadway runoff.

4.2 Hydrology

Thirty eligible storm events were monitored during the period of October 2007 to April 2009, as summarized in Table 4.1. Twenty four events contain concurrent hydrologic and water quality data of the same storm. The number of eligible storms exceeded the minimum requirement of 15-20 events with at least half of which having to include concurrent hydrologic and water quality data at both measurement sites.

Figure 4. 1 JLS Paired-Site Monitoring Sites

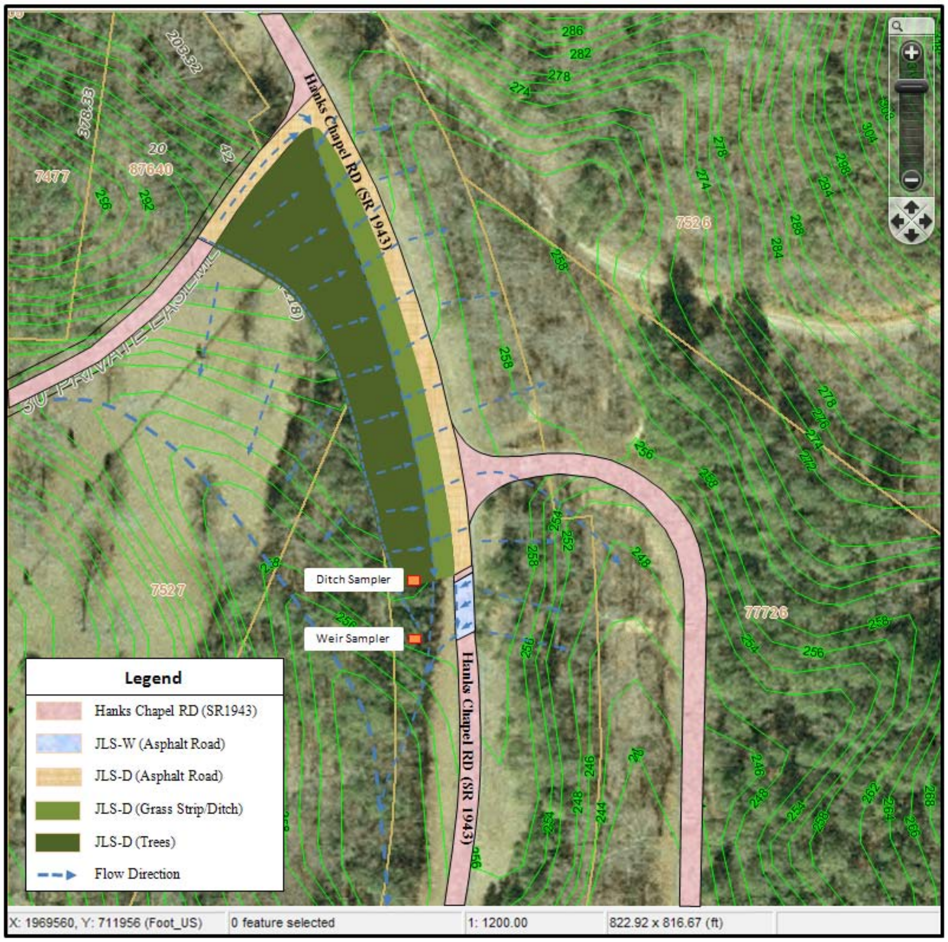

Figure 4. 2 Plan View of JLS Monitoring Station

Table 4. 1 Summary of Rainfall and Runoff Relationships at JLS

# Storm	Date	Rainfall (inches)	Duration (hrs)	Runoff Coefficient	
				JLS-W	JLS-D
1	10/26/07	0.84	8	0.648	0.538
2*	12/15/07	1.15	9	0.818	0.502
3*	01/17/08	0.55	8	0.599	0.207
4**	02/01/08	0.75	10	0.734	0.344
5	02/12/08	1.00	12	0.849	0.481
6	02/18/08	0.30	2	0.672	0.112
7	03/04/08	0.94	12	0.717	0.205
8	03/15/08	0.95	3	0.883	0.488
9**	04/27/08	1.08	4	0.652	0.392
10	05/18/08	0.44	2	0.749	0.204
11	05/20/08	0.52	2	0.654	0.152
12	07/04/08	0.44	3	0.536	0.131
13	07/05/08	0.67	7	0.645	0.382
14	07/06/08	1.26	7	0.825	0.532
15	07/18/08	0.53	1	0.502	0.220
16	07/23/08	0.38	3	0.688	0.179
17	07/27/08	0.24	2	0.577	0.112
18*	08/13/08	0.28	7	0.351	0.043
19	08/26/08	2.73	19	0.784	0.508
20	09/10/08	0.73	3	0.646	0.472
21	09/16/08	0.98	6	0.796	0.454
22	10/17/08	0.60	9	0.822	0.393
23	11/03/08	0.65	11	0.846	0.349
24	11/24/08	0.30	8	0.199	0.190
25**	12/20/09	1.28	12	0.831	0.572
26	12/25/08	0.28	5	0.405	0.028
27	01/28/09	0.27	2	0.680	0.284
28	02/28/09	0.57	13	0.669	0.239
29	04/06/09	0.20	4	0.511	0.100
30	04/10/09	0.41	9	0.685	0.259
Average		0.73	6.9	0.672	0.313

*Ditch samples only ** Weir samples only

4.2.1 Precipitation

As seen from Table 4.1, the average rainfall amount and duration for these thirty eligible storms are 0.73 inches and 6.9 hrs, respectively. Rainfall data was obtained from a tipping bucket (recording) raingage and a standard (non-recording) raingage. An attempt was made to compare raingage data to radar-based precipitation estimates derived from NWS WSR-88D Doppler Radar after proper calibration with the routinely available hourly surface gages. This is known as Multi-sensor Precipitation Estimates, or MPE. Figure 4.3 compares MPE estimates to recording raingage measurements of daily rainfall totals for storm events monitored at JLS during the period of October 2007 to May 2009. Excellent agreement is obtained between the recording raingage data and MPE estimates, which provides validation of rainfall data collection at this and the other monitoring locations. Few exceptions to the agreement between recording and MPE data are shown in Figure 4.4 with explanations as given below.

For storm cases 1, 2 and 6 (Figure 4.4), the recording raingage did not function properly and provided only partial data for the entire event. Since the daily totals agreed well between the non-recording gage and MPE values, rainfall totals were adjusted for the recording raingage according to the non-recording gage data. For storm cases 3, 4, 5, 7 and 8, MPE values are either lower or higher than both recording and standard raingage data. Since similar measurements were obtained for both raingage data at the site, coupled with the fact that runoff flow responded proportionally to rainfall data, the gage data are considered acceptable as most of these storms are highly localized. It is noted that MPE recorded 4.13 inches on 2008-03-15 19:00:00 rather than 0.413 inches, which possibly could have been a data entry error.

4.2.2 Flow Hydraulics

A flow-depth relationship was established during the controlled water truck field experiment as $Q\ (\text{cfs}) = 0.94(H)^{2.0207}$. Where Q is the weir flow, cfs, and H is water depth, ft, above the weir notch. This relationship matches reasonably well with flows calculated by the 60° weir equation of $Q = 1.443\ (\text{depth})^{2.5}$. Both equations tend to over-estimate the amount of runoff for most of the collected storms. Consequently, several well-defined storms were selected for calibration based on runoff volume requirements as determined by the curve number technique, resulting in an adjusted field equation of $Q = 0.458\ (H)^{1.9507}$. This equation provides reasonable runoff volume estimates for most storms. Flow-depth relationships for these three equations are shown in Figure 4.5.

Flows in the ditch were determined by the Manning's equation using recorded water depths and the channel geometry (Figure 4.6). The hydrologic connectivity method described in Chapter 3 was employed to determine the appropriate Manning's coefficient, based on runoff volume balance. It was found that a Manning's coefficient of 0.53 provides acceptable results for most storm events.

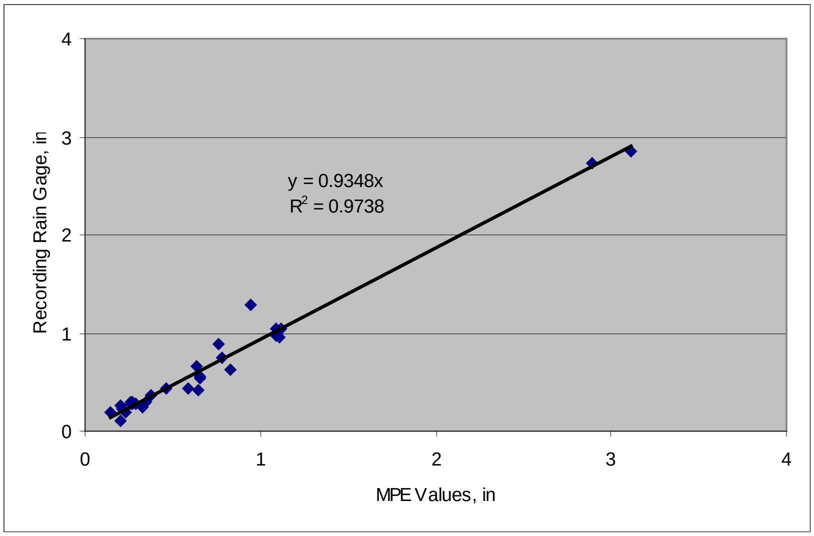

Figure 4. 3 Comparing Recording Gage and MPE Estimates at JLS

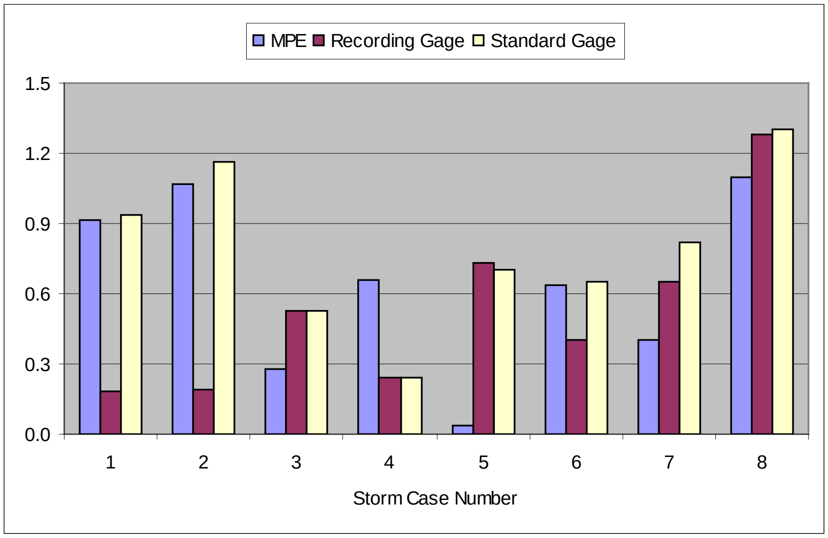

Figure 4. 4 Inconsistent Rain Gage and MPE Data at JLS

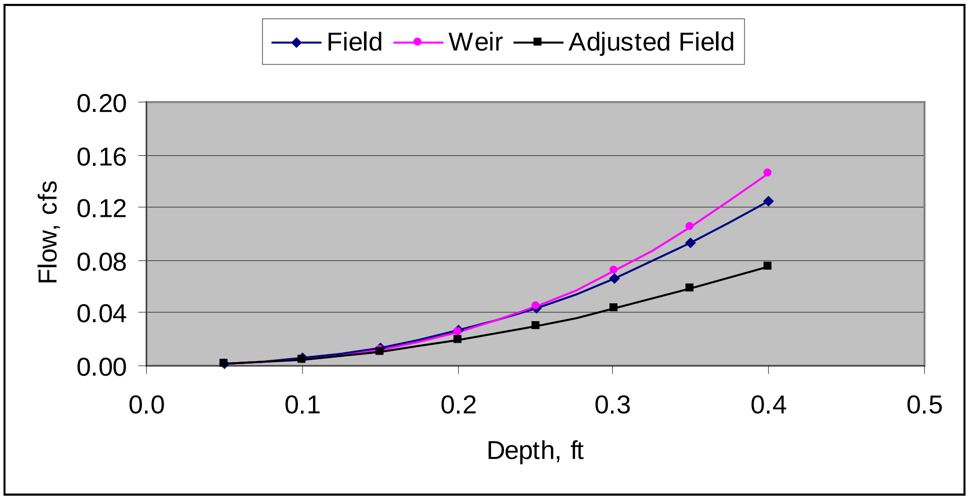

Figure 4. 5 Flow-depth relationships at JLS-W Site

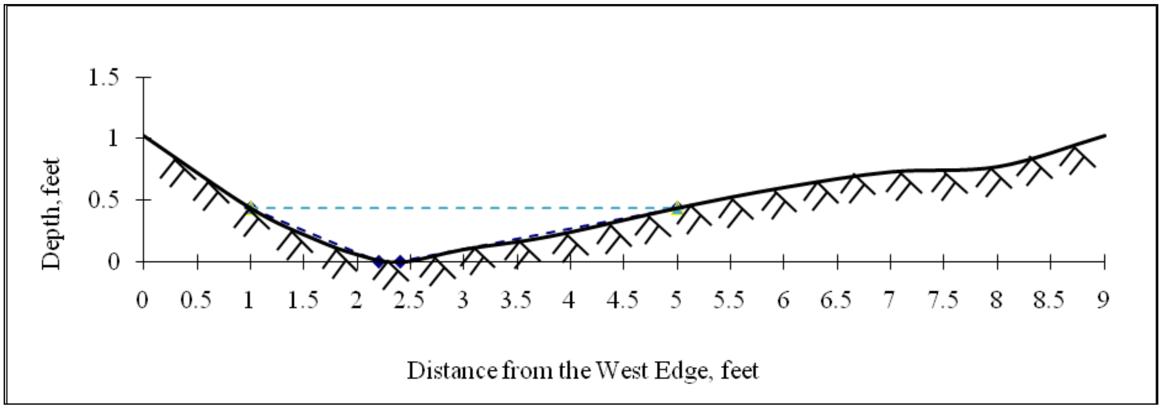

Figure 4. 6 Cross-sectional View of JLS Ditch

4.2.3 Rainfall and Runoff Relationships

Runoff-to-rainfall ratios, defined as runoff divided by rainfall depths, are plotted against rainfall depths in Figures 4.7 and 4.8 for JLS-W and JLS-D sites, respectively. The general trends as displayed in these figures indicate that depending on the magnitude of rainfall, approximately 44%-90% and 9%-67% of rainfall within the range of 0.20-1.50 inches/event runs off at the JLS-W or JLS-D site, respectively.

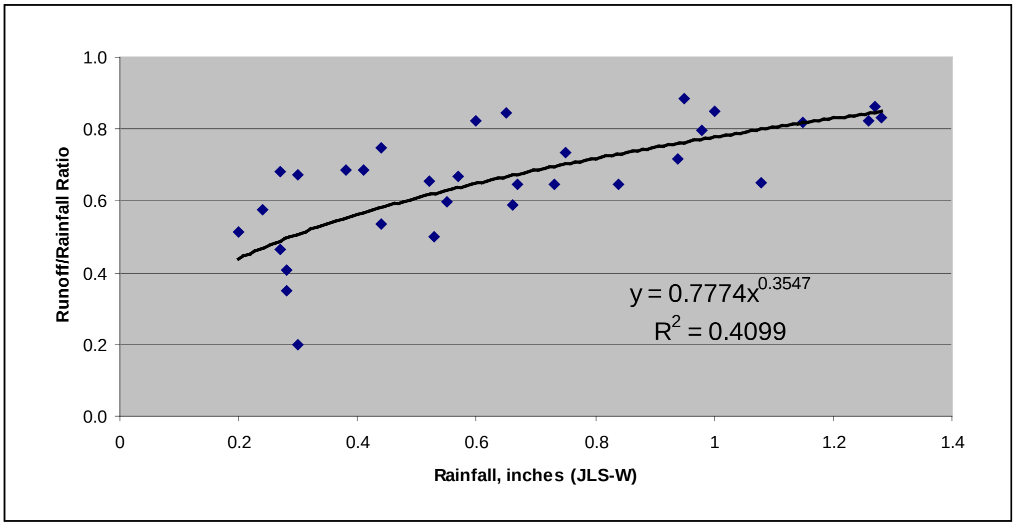

Figure 4. 7 Rainfall-Runoff Relationship at JLS-W site

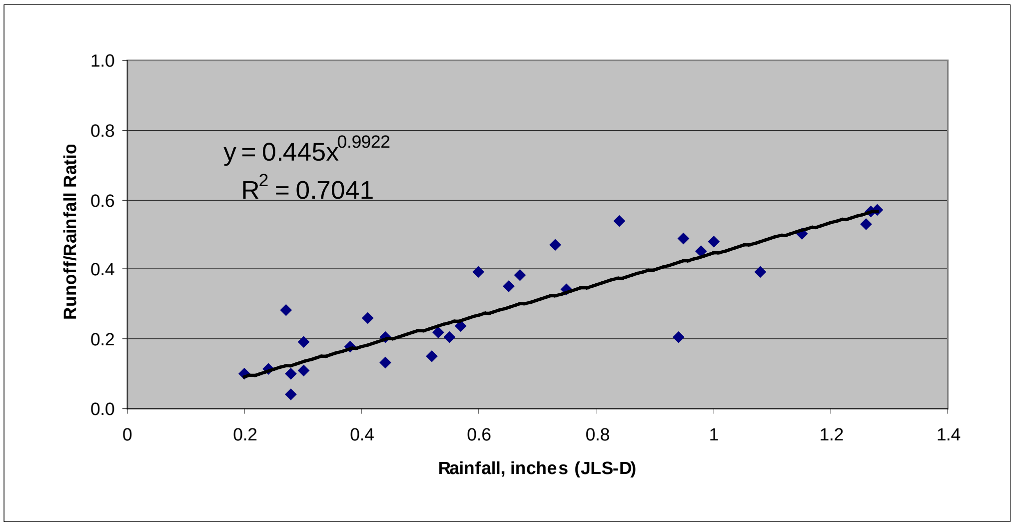

Figure 4.8 Rainfall-Runoff Relationship at JLS-D site

4.3 Event Mean Concentrations

Composite samples were analyzed for each storm event. These concentrations are referred to as event mean concentrations (EMCs) because they represent the flow-weighted average concentration over a storm event. Appendix A provides the EMCs for pollutant constituents that were analyzed at each monitoring location. Whenever the sample concentration is below its detection limit, the sample concentration is reported as its equivalent detection limit. Site-averaged EMCs are calculated as the arithmetic mean of event EMCs at a given monitoring site. Table 4.2 presents these site-averaged EMCs of key constituents for the JLS paired monitoring sites. For comparison purpose, Table 4.2 also includes EMC data of the Piedmont highway sites (CLT-1, CLT-2, US-74, WIN, GAR, MON) reported by Wu and Allan (2001), and the national dataset for urban and rural highway runoff (Driscoll et al., 1999).

Note than rainfall events monitored in this study include 25% less than 0.40 inches, 50% less than 0.60 inches, and 75% below 0.90 inches. Therefore, the site-averaged EMCs given in Table 4.2 can be considered representative of sample means at the monitoring location.

Table 4. 2 Site-averaged EMCs for the JLS Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS (mg/L)	NO_3-N (mg/L)	PO_4-P (mg/L)	NH_4-N (mg/L)	TN* (mg/L)	TP_{fil} (mg/L)	TP_{unfil} (mg/L)
JLS-W	0.6	0.02	100	35	0.23	0.02	0.26	0.63	0.05	0.12
JLS-D	0.6	0.36	65	14	0.07	0.02	0.03	0.50	0.06	0.13
% Reduction				60	70	0	89	21	-	-
CLT-1	50.2	0.37	100	135	0.83	0.09	1.05	3.23		0.24
CLT-2	33.4	0.57	61	86	0.61	0.21	0.97	2.81		0.35
US-74	9.3	0.86	50	8	0.31	0.24	0.11	1.61		0.31
WIN	52.2	2.16	48	15	0.54	0.16	0.13	1.82		0.25
GAR	78.8	3.46	33	11	0.84	0.14	0.13	1.94		0.20
MON	9.4	13.46	22	139	0.51	0.12	0.28	2.01		0.26
25 Percentile**	17.9	0.44	37	9	0.41	0.11	0.11	1.67		0.22
Site Average**	44.8	1.06	58	51	0.63	0.17	0.48	2.28		0.27
Urban***	> 30			142	0.76	0.40		2.59		
Rural***	< 30			41	0.46	0.16		1.33		

* TN for the Piedmont sites are obtained as TKN + NO_3-N

** Excluding MON site data due to erosion and site disturbance

***National database as site-median EMC concentrations (Driscoll et al., 1999)

4.3.1 Site-averaged TSS EMCs

A site-averaged TSS EMC of 35 mg/L was obtained for surface runoff at JLS-W. This concentration is 15% below the average rural-highway value of 41 mg/L, 31% lower than the averaged Piedmont site data of 51 mg/L, and 74% less than the bridge deck data of 135 mg/L (CLT-1). Both JLS-W and CLT-1 sites are 100% impervious; however, ADT at JLS-W is only 2% of that recorded at CLT-1.

JLS-D has a site-averaged TSS of 14 mg/L that is 66% below the average rural-highway data and 73% below the averaged Piedmont site data. When compared TSS data at this paired-site location, the averaged TSS concentration was reduced from 35 mg/L to 14 mg/L. This is equivalent to a 60% reduction of site-averaged TSS EMC due to the passage of roadway runoff through the vegetated roadside ditch area.

4.3.2 Site-averaged TN and TP EMCs

Total nitrogen is not an EPA parameter but has recently been used by state agencies to regulate nitrogen discharges from storm runoff. It is determined by oxidizing nitrogen containing compounds to nitrate. Thus, nitrate concentration must be subtracted from the TN value in order to compare it to the commonly reported total Kjeldahl nitrogen (TKN) data. TKN is the sum of organic nitrogen, ammonia and ammonium present in water samples. For comparison purpose, TNs of the Piedmont highway data were derived by adding nitrate-N to the TKN data. All forms of phosphorus are converted to its orthophosphate in the TP procedure used in this study and results are compatible to the total Kjeldahl phosphorus analysis.

The site-averaged TN concentration was reduced from 0.63 mg/L (JLN-W) to 0.50 mg/L (JLS-D), resulting in an overall EMC reduction credit of 21%. This result is encouraging and supports the hypothesis of incorporating roadside vegetation for TN management. Also, TN EMCs observed at this secondary road are substantially lower than those major/primary Piedmont roads by 75% on the average.

Site-average TP (unfiltered) concentrations of 0.12-0.13 mg/L at both JLS sites are 52%-56% lower than the Piedmont site average of 0.27 mg/L. The filtered TP concentration is about 45% of the unfiltered TP EMCs. There was essentially no reduction in TP EMCs at this paired-site monitoring location. The level of TP concentrations remained low and was approaching the equilibrium concentrations that are unlikely to be further attenuated by the vegetative treatment process (Wu and Allan, 2006).

4.3.3 Inorganic N and P Constituents

Ammonia data was reported as NH_3-N in the Piedmont study, which is based on the conversion of NH_4-N to NH_3-N according to the following equilibrium equation:

$NH_3 + H^+ <==> NH_4^+$

However, the method of analysis for ammonia by ion chromatograph employed in the current study involves the determination of its ionic species of NH_4^+ present in a water sample. If the water chemistry favors a shift of its equilibrium to NH_3, then the amount of NH_4^+ that is detectable could be reduced accordingly.

Ammonium-N EMC from roadway surface runoff of 0.26 mg/L at JLS-W is 46% lower than the averaged Piedmont concentration of 0.48 mg/L. The site averaged NH_4-N of 0.03 mg/L at JLS-D is substantially lower (94%) than the averaged Piedmont data of 0.48 mg/L. An eighty nine percent (89%) reduction of NH_4-N EMC is observed at this paired-site location.

Nitrate-N EMCs from roadway surface runoff of 0.23 mg/L at JLS-W is 64% less than the averaged Piedmont data of 0.63 mg/L. The site averaged NO_3-N of 0.07 mg/L at JLS-D is 89% lower than the averaged Piedmont data of 0.63 mg/L. A seventy percent (70%) reduction of NO_3-N EMC is obtained at this paired site location.

Phosphate-P EMC is 0.02 mg/L at both JLS sites. Its concentration is unlikely reduced at this paired site location as concentrations are approaching soil equilibrium concentrations that are unlikely to be further attenuated by the vegetative treatment process.

4.4 Pollutant Loading Rates

4.4.1 Unit Event Load

Unit event load, mg/m^2 or lb/ac, provides a means of comparing pollutant exporting potential among highway runoff sites. It also provides a basis to calculate the annual loads. Unit event load is calculated by the following expression.

$$\text{Unit event load} = EMC * Vr \div A = EMC * R * 25.40$$

Where Vr = total runoff volume per storm event

A = total drainage area

R = direct runoff or rainfall excess, inches

25.40 = conversion to mg/m^2 when R is in inches and EMC in mg/L

Table 4.3 presents the site-averaged unit event loads for the JLS paired sites, together with previously reported data from several Piedmont sites. Appendix B includes the unit event loads for each monitoring site. By comparing site-averaged unit event loads at the JLS paired-site location, the percentages of unit load reductions, due to the presence of vegetated roadside ditch, are 93% for NH_4-N, 87% for NO_3-N, 71% for TSS, 43% for TN, 42% for TP (unfiltered), and 33% for TP (filtered). The export of pollutants at JLS-D is significantly less than the averaged Piedmont data by 84%, 81% and 74%, respectively, for TSS, TN and TP.

Table 4. 3 Site-averaged Unit Event Load for the JLS Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS (mg/m^2)	NO_3-N (mg/m^2)	PO_4-P (mg/m^2)	NH_4-N (mg/m^2)	TN* (mg/m^2)	TP_{fil} (mg/m^2)	TP_{unfil} (mg/m^2)
JLS-W	0.6	0.02	100	314	2.50	0.21	2.72	6.58	0.55	1.18
JLS-D	0.6	0.36	65	91	0.33	0.17	0.18	3.78	0.37	0.68
Reduction				71%	87%	19%	93%	43%	33%	42%
CLT-1	50.2	0.37	100	1,619	8.37	1.23	10.67	34.14		3.10
CLT-2	33.4	0.57	61	876	6.06	2.54	8.50	28.76		4.07
US-74	9.3	0.86	50	138	1.52	2.35	1.19	14.33		3.13
WIN	52.2	2.16	48	64	1.42	0.89	0.50	7.01		1.27
GAR	78.8	3.46	33	92	4.16	0.93	0.93	12.67		1.45
MON	9.4	13.46	22	881	1.34	0.42	0.70	7.88		1.23

*TNs for the Piedmont sites are obtained as TKN + NO_3-N

4.4.2 Annual Pollutant Load

Storm water loads can be expressed on a continuous and uniform basis encompassing both dry and wet weather periods. This is accomplished by normalizing the unit event load over the respective runoff duration and multiplied it by the ratio of average storm duration to the average time between storms. The annual storm pollutant load is used to compare with the continuous discharge of point sources for pollutant load allocation or watershed planning and management activities. The procedure of calculation for annual pollutant load is similar to that employed by Wu and Allan (2001) in their Piedmont highway runoff study.

Site-averaged annual pollutant loads obtained for the JLS monitoring sites are given in Table 4.4, including the respective data of the Piedmont highway runoff and of the national urban runoff. Annual loads of TSS, TN and TP for the JLS-D site are 91%, 87% and 84% below the averaged values of the Piedmont sites.

Table 4. 4 Site-averaged Annual Pollutant Loads for the JLS Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS (lb/ac-yr)	NO_3-N (lb/ac-yr)	PO_4-P (lb/ac-yr)	NH_4-N (lb/ac-yr)	TN* (lb/ac-yr)	TP_{fil} (lb/ac-yr)	TP_{unfil} (lb/ac-yr)
JLS-W	0.6	0.02	100	53	0.42	0.04	0.46	1.11	0.09	0.20
JLS-D	0.6	0.36	65	12	0.04	0.02	0.02	0.48	0.05	0.09
Piedmont Site Averages	9.3-78.8	0.37-3.46	22-100	138	0.98	0.35	1.03	4.20		0.57
National**				280-10,580	0.71-7.14		0.92-4.10	2.19-35.64		0.54-7.33

*TNs for the Piedmont sites are obtained as TKN + NO_3-N

** Driscoll et al., (1999)

4.5 Vegetative Treatment Performance

Vegetated roadside ditches associated with secondary road networks potentially offer a variable treatment effectiveness for most pollutants of concern. Table 4.5 presents EMC attenuations and annual load reductions by comparing constituent data at the paired monitoring sites.

Vegetative treatment at this JLS location has resulted in EMC attenuation of 89% for NH_4-N, 70% for NO_3-N, 60% for TSS, 21% for TN, and essentially no attenuation for PO_4-N and TP. Annual pollutant loads are reduced in the order of 96% (NH_4-N), 91% (NO_3-N), 77% (TSS), 57% (TN), 55 % (TP-unfiltered), 50% (PO_4-P), and 44% (TP-filtered). Load reduction may be due to the loss of pollutant constituents via infiltration and/or biosorption, which greatly enhances the reduction of pollutant export on a mass-discharge basis. The load reduction in P export would appear to be entirely related to infiltration losses as EMC's were not different between ditch and roadway monitoring sites.

According to Schuler (1987), TN export from a development site at 65% imperviousness is estimated to be 11 lb/ac-yr (based on EMC's of 1.4 mg/L and 2.6 mg/L of TN for pervious and impervious surfaces, respectively). TN export in surface runoff from the JLS-W secondary road is 1.11 lb/ac-yr, as shown in Table 4.5. After vegetative treatment, it was reduced to 0.48 lb/ac-yr or 4.4% of the expected export at a typical development site.

Table 4. 5 Summary of Performance Data at the JLS Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS	NO_3-N	PO_4-P	NH_4-N	TN*	TP_{fil}	TP_{unfil}
							EMC, mg/L			
JLS-W	0.6	0.02	100	35	0.23	0.02	0.26	0.63	0.05	0.12
JLS-D	0.6	0.36	65	14	0.07	0.02	0.03	0.50	0.06	0.13
EMC attenuation				60%	70%	0 %	89%	21%	0 %	0 %
							Annual Load, lb/ac-yr			
JLS-W				53	0.42	0.04	0.46	1.11	0.09	0.20
JLS-D				12	0.04	0.02	0.02	0.48	0.05	0.09
Load Reduction				77%	91%	50%	96%	57%	44%	55%

4.6 Bulk Precipitation

Figure 4.9 displays the ratios of event-averaged bulk precipitation concentrations to site-averaged EMCs at JLS-W. At least 20% of TSS in roadway surface runoff may be due to atmospheric input and over 60% of other pollutant constituents can be attributed to atmospheric inputs. These observations indicate the importance of atmospheric contributions to roadway surface runoff. However, caution must be employed in the interpretation of these results as some of the inputs measured as bulk precipitation may be attributed to re-suspension from the road surface.

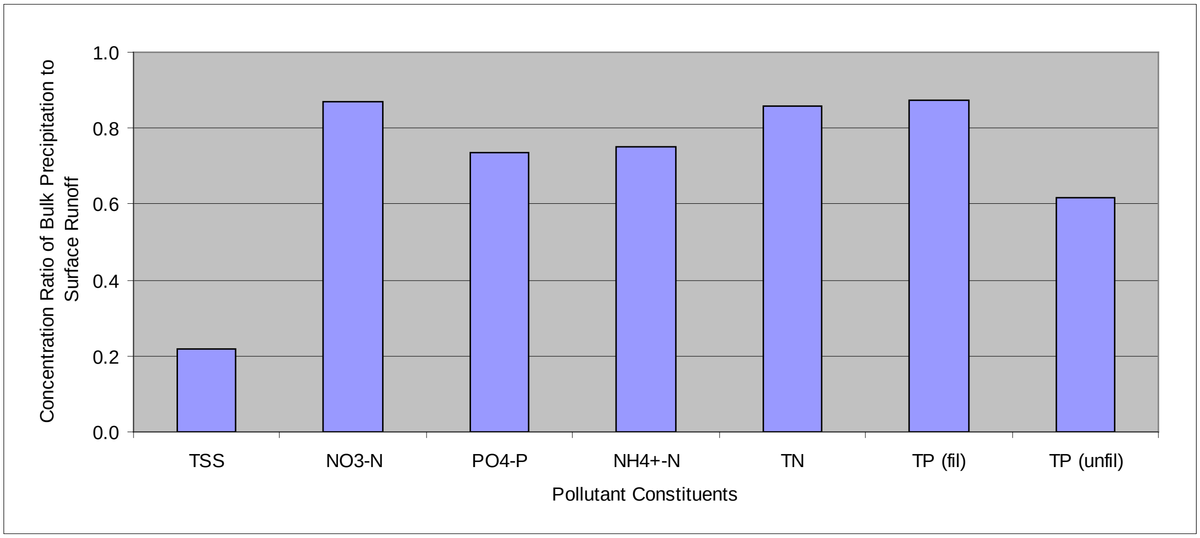

Figure 4. 9 Comparison of Bulk Precipitation to Roadway Surface Runoff at JLS

4.7 Summary

- Thirty eligible storm events were monitored at the Jordan Lake South paired sites. Concurrent roadway and water quality data were collected for twenty four storm events at both JLS-W and JLS-D sites.
- Runoff ratios varied in the range of 44-90% and 9-67% for rainfall events ranging from 0.20-1.50 inches at the JLS-W impervious site and the JLS-D vegetated runoff site, respectively.
- The site-averaged TSS EMC of 14 mg/L for roadway runoff at JLS-D is 66% below the rural highway value reported in the national database and 73% lower than the averaged data for the Piedmont region.
- The site-averaged TN EMC of 0.50 mg/L for roadway runoff at JLS-D is 62% below the rural highway value reported in the national database and 78% lower than the averaged data for the NC Piedmont region.
- Site-averaged TP EMCs of 0.12-0.13 mg/L are 52%-56% lower than the Piedmont site average concentration of 0.27 mg/L. The low concentrations appear to approach the residual limit and are unlikely to be further attenuated by the vegetative treatment process.

- The presence of vegetated roadside ditch at the JLS-D site has resulted in EMC attenuation for NH_4-N (89%), NO_3-N (70%), TSS (60%), and TN (21%). EMCs for PO_4-N and TP remained essentially the same.
- Reductions in annual pollutant loads were achieved for NH_4-N (96%), NO_3-N (91%), TSS (77%), TN (57%), TP-unfiltered (55%), PO_4-P (50%), and TP-filtered (44%). These reductions can be viewed as pollutant credits resulting from the presence of vegetated ditch along secondary roads.
- TN export in roadway surface runoff from this JLS secondary road is 1.11 lb/ac-yr, which is about 10 times less than that of a typical development site. After vegetative treatment, it was reduced to 0.48 lb/ac-yr or 4.4% of the expected export at a development site.

5. Mountain Island Lake Monitoring Sites

This chapter summarizes the hydrologic and water quality data collected at the Mountain Island Lake (MIL) monitoring station. This paired-site sampling location is near 1398 Brevard Place on SR 1360 in Ironton, N.C. Twenty six eligible storm events have been successfully monitored during the period of October 2007 to February 2009. Of this total, twenty three storms include concurrent data for surface runoff drained directly from the roadway segment to a weir box device and, at a second site, runoff was intercepted and passed through a roadside ditch. This paired-site monitoring strategy provides a consistent database to characterize surface runoff from secondary roads and to assess the pollutant removal performance of the vegetated roadside ditch area. Three additional events were monitored from March to May of 2009 in which road construction occurred at the upper portion of the monitored roadway segment, resulting in elevated TSS concentrations at both paired sites.

5.1 Site Characterization

The Brevard Place Road on SR 1360 is a two-lane asphalt paved road carrying an average daily traffic count of 1,400 vehicles in both directions. Sampling equipment and roadway drainage at this paired–site monitoring station are shown in Figures 5.1 and 5.2, respectively. At the weir sampling site, surface runoff drains directly from a 1,291 ft^2 roadway segment into a weir-box device as described in Chapter 3. This monitoring site has a 100% impervious cover and is designated as MIL-W. Surface runoff originated from another roadway segment of 4,959 ft^2, located immediately above MIL-W, flows laterally into a 5,384 ft^2 vegetated roadside ditch area. This MIL-D drainage site has a total area of 10,343 ft^2 with 48% impervious cover. The ditch has a side slope of 17.2% and a channel slope of 4.9%. The vegetated roadside ditch area functions naturally as a water quality management practice for the incoming roadway runoff.

5.2 Hydrology

Table 5.1 provides a summary of the twenty six eligible storms collected during the period of October 2007 to February 2009. Twenty three eligible storms include concurrent hydrologic and water quality data from the same storm at the paired MIL-W and MIL-D sites. The number of eligible storms exceeded the minimum requirement of 15-20 events with at least half of which having to include concurrent hydrologic and water quality data for the same storm. Storm #22 of 2.6 inches includes a number of sub-storms occurring within thirty three hours.

5.2.1 Precipitation

The average rainfall and duration, excluding storm no. 27-29 that were monitored during the time of site disturbance, are 0.53 inches and 5.9 hrs, respectively, as shown in Table 5.1. Rainfall data was obtained from a tipping bucket (recording) raingage and a standard (non-recording) raingage. The tipping bucket was directly connected to an automatic sampler and installed on the inner right-of-way of the monitored road segment, which was located unavoidably close to roadside trees due to space limitations and safety considerations. The standard rain gage was installed at approximately 540 feet away from the tipping bucket in open space to minimize the influence of tree canopy. Event-based rainfall totals recorded by the tipping bucket raingage is about 15%, on the average, less than that collected by the standard raingage (Figure 5.3). Rainfall totals for several storm events were adjusted to match the standard raingage data.

Figure 5. 1 MIL Paired Monitoring Sites

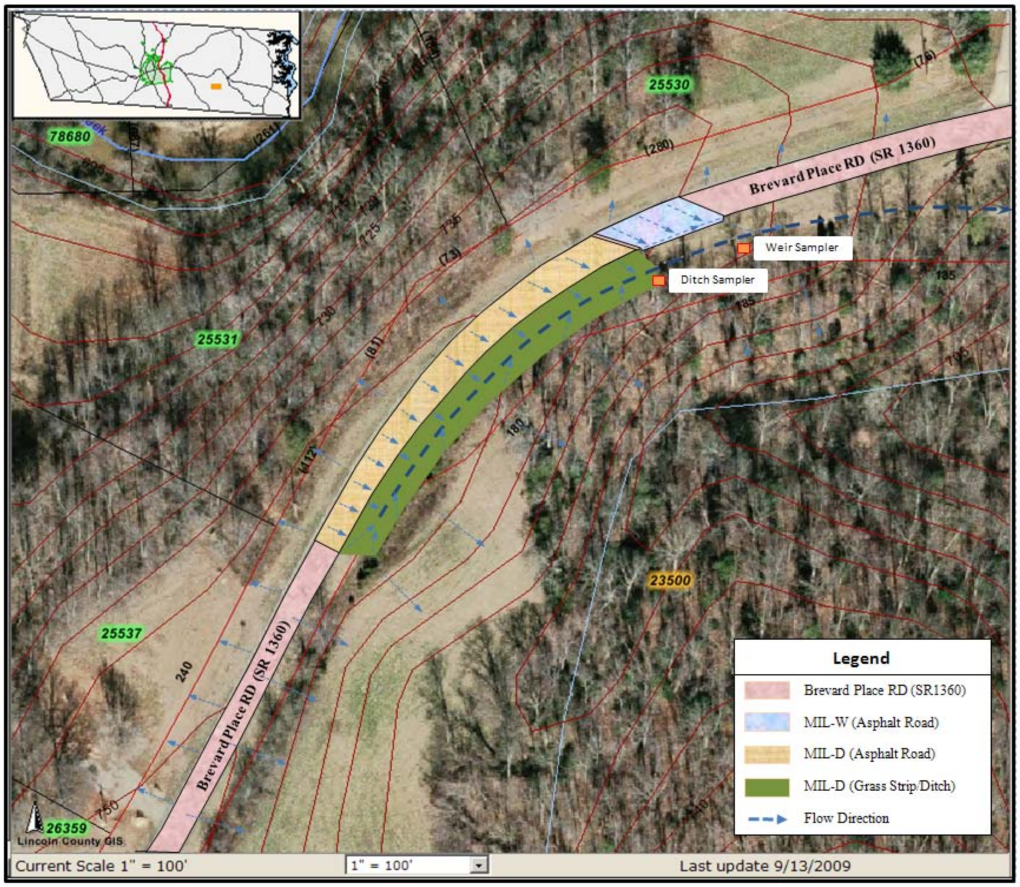

Figure 5. 2 Plan View of MIL Monitoring Station

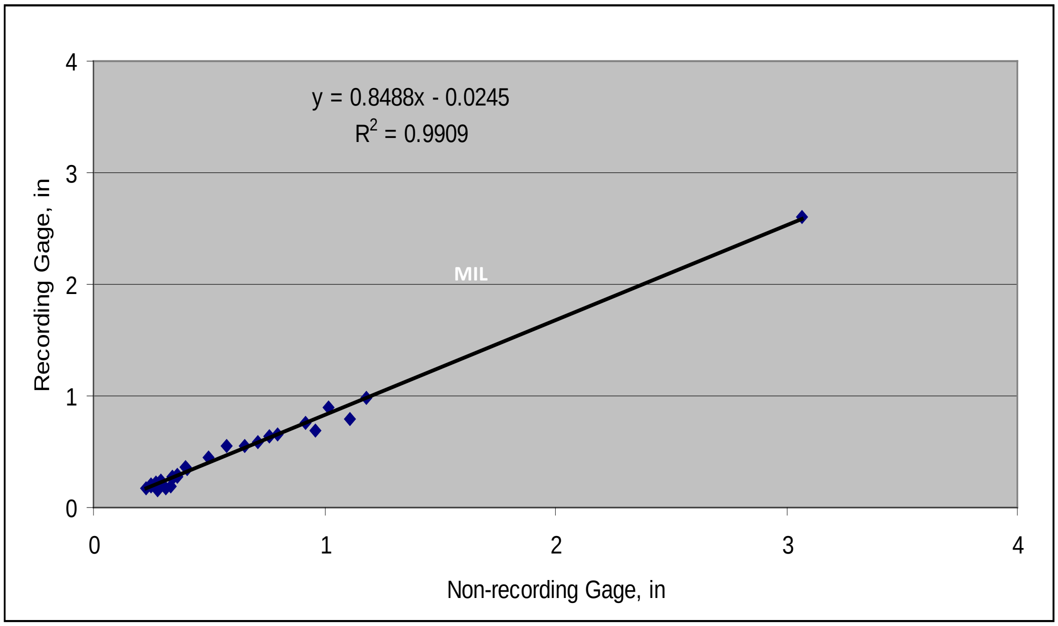

Figure 5. 3 Comparing Recording and Non-recording Raingage Data at MIL Station

Table 5. 1 Summary of Rainfall and Runoff Relationships at MIL

# Storm	Date	Rainfall (inches)	Duration (hrs)	Runoff Coefficient	
				MIL-W	MIL-D
1	10/24/07	0.41	5	0.565	0.059
2	11/15/07	0.27	2	0.565	0.039
3*	11/25/07	0.25	1	0.400	-
4	01/10/08	0.29	2	0.463	0.146
5	01/31/08	0.44	4	0.584	0.168
6	02/13/08	0.22	6	0.820	0.032
7	02/17/08	0.28	3	0.637	0.140
8	03/04/08	0.57	3	0.767	0.211
9	03/07/08	0.64	7	0.666	0.265
10	03/15/08	0.64	4	0.668	0.194
11	03/19/08	0.55	3	0.709	0.202
12	04/26/08	0.65	2	0.430	0.230
13	05/15/08	0.28	9	0.479	0.048
14*	07/04/08	0.34	2	0.683	0.068
15	07/05/08	0.34	2	0.399	0.065
16	07/08/08	0.36	2	0.535	0.122
17	07/22/08	0.80	2	0.679	0.260
18*	07/28/08	0.25	3	0.573	0.009
19	10/08/08	0.90	8	0.873	0.388
20	10/17/08	0.35	11	0.711	0.092
21	11/24/08	0.23	8	0.562	0.014
22	12/10/08	2.60	33	0.918	0.676
23	12/24/08	0.36	8	0.544	0.050
24	01/28/09	0.32	2	0.491	0.075
25	02/18/09	0.58	6	0.780	0.289
26	02/28/09	0.72	16	0.833	0.363
27	03/25/09**	0.38			
28	03/28/09**	0.75			
29	05/16/09**	0.40			
Average		0.53	5.9	0.628	0.168

*Weir samples only **Events subject to road construction impacts

5.2.2 Flow Hydraulics

The hydraulic test on August 22, 2007, using a water truck to supply flow through the weir box has resulted in a depth-flow relationship of $Q = 13.52(H)^{2.3572}$. Where Q is the flow, cfs, and H is water depth, ft, over the weir notch. This relationship yields flow estimates that are significantly higher than that calculated by the 60^o-weir equation. For reasons as mentioned in Chapter 4, several well-defined storms were selected for calibration based on runoff volume balance as determined by the curve number technique and adjustments of the flow depths recorded by the auto sampler. This has resulted in an equation of $Q = 20.562\ (H' - \alpha)^{2.8519}$ for calculating flows from the weir box. In this equation, H' equals to 0.3844H - 0.0678, H is the recorded level where the bubbler module is fixed, and α is an event-based correction factor ranging from 0.027 to 0.048 ft. The correction factor was determined based on the duration, intensity, initial water level, and the time since the previous event.

Flow hydraulics along the roadside ditch was determined by the following equations.

$$A = 6.0465\ (H - \beta)^2$$

$$v = 6.68\ (H - \beta)^{1.67} \quad \text{or} \quad v = 5.11\ (H - \beta)^{1.67}$$

$$Q = Av = 40.4\ (H - \beta)^{3.67} \quad \text{or} \quad Q = 30.9\ (H - \beta)^{3.67}$$

Where H is the flow depth in feet on the ditch as recorded by the auto sampler; β is an event-based correction factor, ranging from 0 to 0.05 ft, determined mainly on the subsidence of the bubbler module on the ditch; and coefficients 6.68 and 5.11 or 40.4 and 30.9 are for winter or summer seasons, respectively. Flow calculations by these equations were compared to the Manning's equation. To do this, the hydrologic connectivity method described in Chapter 3 was employed to determine the appropriate Manning's coefficient, based on runoff volume balance. It was found that a Manning's coefficient in the range of 0.24 to 0.33 provides acceptable results for most storm events. The channel geometry of the vegetated ditch at the MIL monitoring station is shown in Figure 5.4.

5.2.3 Rainfall and Runoff Relationships

Runoff-to-rainfall ratios, defined as runoff divided by rainfall depths, are plotted against rainfall depths in Figures 5.5 and 5.6, respectively, for MIL-W and MIL-D sites, respectively. The general trend as displayed in these figures indicates that depending on the magnitude of rainfall, approximately 50%-80% and 2-50% of rainfall within the range of 0.20-1.50 inches per event runs off at the MIL-W and MIL-D sites, respectively.

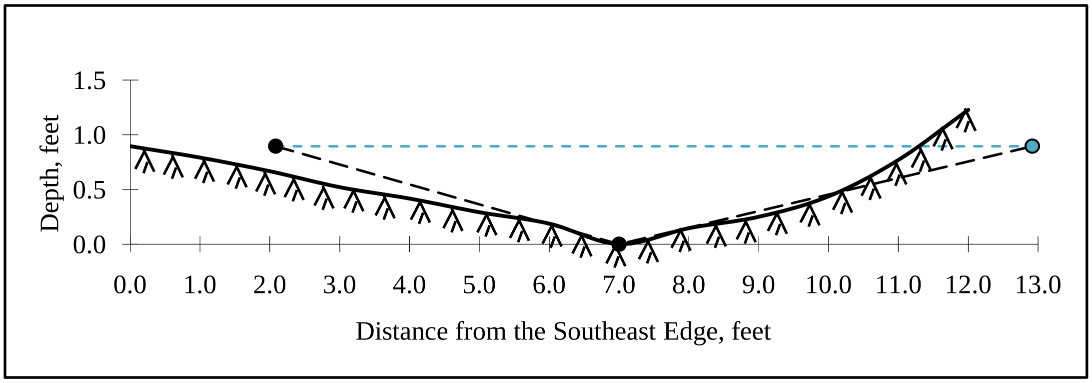

Figure 5. 4 Cross-sectional View of the MIL Ditch

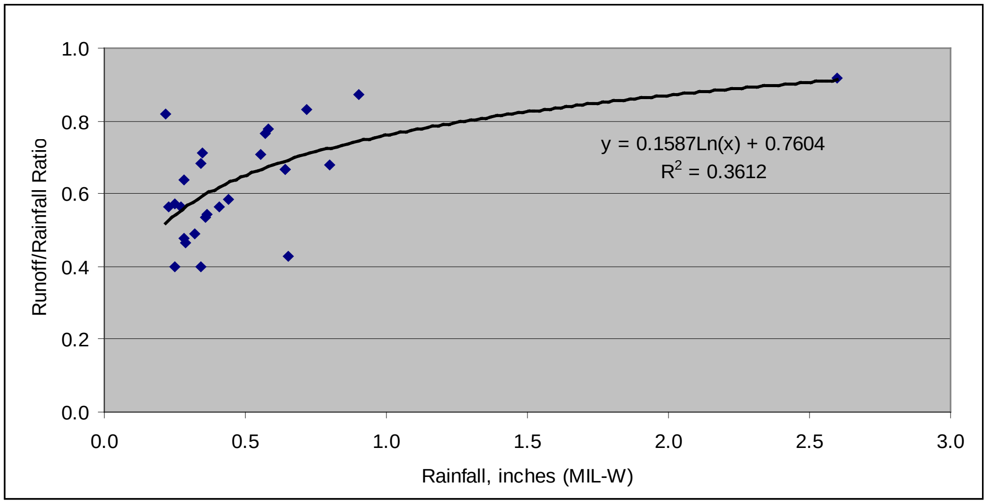

Figure 5. 5 Rainfall-Runoff Relationship at MIL-W Site

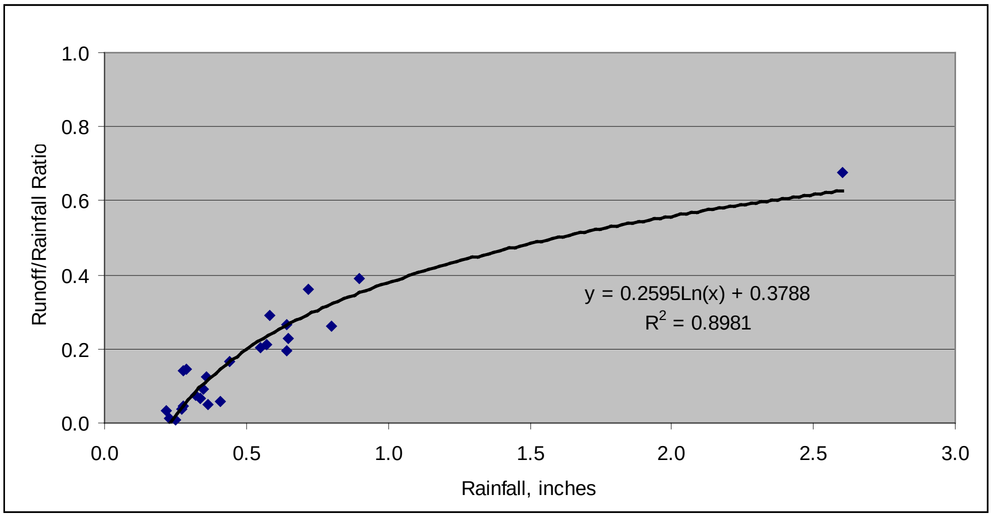

Figure 5. 6 Rainfall-Runoff Relationship at MIL-D Site

5.3 Event Mean Concentrations

Composite samples were analyzed for each storm event. These concentrations are referred to as event mean concentrations (EMCs) because they represent the flow-weighted average concentration over a storm event. Appendix A provides the EMCs for pollutant constituents that were analyzed at each monitoring location. Whenever the sample concentration is below its detection limit, the sample concentration is reported as its equivalent detection limit. Site-averaged EMCs are calculated as the arithmetic mean of event EMCs at a given monitoring site. Table 5.2 presents these site-averaged EMCs of key pollutant constituents for the MIL paired sites. For comparison purpose, Table 5.2 also includes EMC data of the NC Piedmont sites (CLT-1, CLT-2, US-74, WIN, GAR, MON) as reported by Wu and Allan (2001), and the national dataset for urban and rural highway runoff (Driscoll et al., 1999). TSS EMCs for storm events 27-29 (Table 5.1) were in the order of 700-1200 mg/L and excluded from site-averaged EMCs calculations.

5.3.1 Site-averaged TSS EMCs

A site-averaged TSS EMC of 28 mg/L was obtained for surface runoff at MIL-W. This concentration is 32% below the average rural-highway value of 41 mg/L, 45% lower than the averaged Piedmont site data of 51 mg/L, and 79% less than the bridge deck data of 135 mg/L (CLT-1). Both MIL-W and CLT-1 sites are 100% impervious; however, ADT at JLS-W is only 3% of that recorded at CLT-1.

MIL-D has a site-averaged TSS of 16 mg/L that is significantly below the average rural-highway data by 61% and the averaged Piedmont site data by 69%. When compared TSS data at this paired-site location, the averaged TSS concentration was reduced from 28 mg/L to 16 mg/L. This is equivalent to a 43% reduction of site-averaged TSS EMC due to the passage of roadway runoff through the vegetated roadside ditch area.

5.3.2 Site-averaged TN and TP EMCs

Site-averaged TN concentrations at the MIL-D (0.56 mg/L) and MIL-W (0.55 mg/L) sites are not significantly different from each other. TN EMCs observed at this secondary road are substantially lower than those major/primary Piedmont roads by 76 %, on the average.

Table 5. 2 Site-averaged EMCs for the MIL Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS (mg/L)	NO_3-N (mg/L)	PO_4-P (mg/L)	NH_4-N (mg/L)	TN* (mg/L)	TP_{fil} (mg/L)	TP_{unfil} (mg/L)
MIL-W	1.4	0.03	100	28	0.22	0.02	0.17	0.55	0.06	0.13
MIL-D	1.4	0.24	48	16	0.09	0.02	0.03	0.56	0.07	0.12
% Reduction				43	59	0	82	-	-	8
CLT-1	50.2	0.37	100	135	0.83	0.09	1.05	3.23		0.24
CLT-2	33.4	0.57	61	86	0.61	0.21	0.97	2.81		0.35
US-74	9.3	0.86	50	8	0.31	0.24	0.11	1.61		0.31
WIN	52.2	2.16	48	15	0.54	0.16	0.13	1.82		0.25
GAR	78.8	3.46	33	11	0.84	0.14	0.13	1.94		0.20
MON	9.4	13.46	22	139	0.51	0.12	0.28	2.01		0.26
25 Percentile**	17.9	0.44	37	9	0.41	0.11	0.11	1.67		0.22
Site Average**	44.8	1.06	58	51	0.63	0.17	0.48	2.28		0.27
Urban***	> 30			142	0.76	0.40		2.59		
Rural***	< 30			41	0.46	0.16		1.33		

* TN for the Piedmont sites are obtained as TKN + NO_3-N

** Excluding MON site data

***National database reported as site-median EMC concentrations (Driscoll et al., 1999)

Site-average TP (unfiltered) concentrations of 0.12-0.13 mg/L at both MIL sites are 52%-56% lower than the Piedmont site average of 0.27 mg/L. A small reduction of 8% was obtained for TP (unfiltered) between these paired sites. The filtered TP concentration is about 45% of the unfiltered TP EMCs. There was essentially no reduction of TP (filtered) EMCs at this paired-site monitoring location.

5.3.3 Inorganic N and P Constituents

Ammonium-N EMC from roadway surface runoff of 0.17 mg/L at MIL-W is 65% lower than the averaged Piedmont concentration of 0.48 mg/L. The site averaged NH_4-N of 0.03 mg/L at MIL-D is substantially lower (94%) than the averaged NC Piedmont data of 0.48 mg/L. An eighty two percent (82%) reduction of NH_4-N EMC is observed at this paired-site location.

Nitrate-nitrogen EMCs of 0.22 mg/L from roadway surface runoff at MIL-W is 65% less than the averaged Piedmont data of 0.63 mg/L. The site averaged NO_3-N of 0.09 mg/L at MIL-D is 86% lower than the averaged Piedmont data of 0.63 mg/L. A fifty nine percent (59%) reduction of NO_3-N is obtained at this paired site location.

Phosphate-P EMC is 0.02 mg/L at both MIL sites. Its concentration is unlikely reduced at this paired-site location due to runoff concentrations roughly in equilibrium with the P content of surface soils.

5.4 Pollutant Loading Rates

5.4.1 Unit Event Load

The calculation of unit event load, mg/m^2 or lb/ac, is based on the methodology as described in Chapter 4. Table 5.3 presents the site-averaged unit event loads for the MIL paired sites, together with previously reported data from the Piedmont sites. By comparing site-averaged unit event loads at the MIL paired-site location, the percentages of unit load reductions, due to the presence of vegetated roadside ditch, are 94% for NH_4-N, 90% for NO_3-N, 76% for TSS, 62% for TN, 56% for TP (unfiltered), and 49% for TP (filtered). The export of pollutant at MIL-D is significantly less than the averaged NC Piedmont data by 90%, 91% and 80% for TSS, TN and TP, respectively.

5.4.2 Annual Pollutant Load

The procedure of calculation for annual pollutant load is similar to that employed by Wu and Allan (2001), as described in Chapter 4. The annual storm pollutant load can be used to compare with the continuous discharge of point sources for pollutant load allocation or watershed planning and management activities. Site-averaged annual pollutant loads obtained for the MIL monitoring sites are given in Table 5.4, together with the NC Piedmont highway runoff data and the national urban runoff data. Annual loads of TSS, TN and TP for the MIL-D site are 93%, 93% and 84%, respectively, below the averaged values of the respective NC Piedmont data.

5.5 Vegetative Treatment Performance

Vegetated roadside ditches associated with secondary road networks could offer a range of treatment effectiveness to most pollutants of concern. Table 5.5 presents EMC attenuations and annual load reductions by comparing pollutant constituent data at the paired monitoring sites.

Table 5. 3 Site-averaged Unit Event Load for the MIL Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS (mg/m^2)	NO_3-N (mg/m^2)	PO_4-P (mg/m^2)	NH_4-N (mg/m^2)	TN* (mg/m^2)	TP_{fil} (mg/m^2)	TP_{unfil} (mg/m^2)
MIL-W	1.4	0.03	100	237	1.63	0.27	1.40	4.53	0.67	1.17
MIL-D	1.4	0.24	48	56	0.16	0.06	0.09	1.72	0.34	0.51
Reduction				76%	90%	78%	94%	62%	49%	56%
CLT-1	50.2	0.37	100	1,619	8.37	1.23	10.67	34.14		3.10
CLT-2	33.4	0.57	61	876	6.06	2.54	8.50	28.76		4.07
US-74	9.3	0.86	50	138	1.52	2.35	1.19	14.33		3.13
WIN	52.2	2.16	48	64	1.42	0.89	0.50	7.01		1.27
GAR	78.8	3.46	33	92	4.16	0.93	0.93	12.67		1.45
MON	9.4	13.46	22	881	1.34	0.42	0.70	7.88		1.23

*TNs for the Piedmont sites are obtained as TKN + NO_3-N

Table 5. 4 Site-averaged Annual Pollutant Loads for the MIL Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS (lb/ac-yr)	NO_3-N (lb/ac-yr)	PO_4-P (lb/ac-yr)	NH_4-N (lb/ac-yr)	TN* (lb/ac-yr)	TP_{fil} (lb/ac-yr)	TP_{unfil} (lb/ac-yr)
MIL-W	1.4	0.03	100	40	0.28	0.05	0.23	0.76	0.11	0.20
MIL-D	1.4	0.24	48	10	0.03	0.01	0.02	0.29	0.06	0.09
Piedmont Site Averages	9.3-78.8	0.37-3.46	22-100	138	0.98	0.35	1.03	4.20		0.57
National**				280-10,580	0.71-7.14		0.92-4.10	2.19-35.64		4.07

*TNs for the Piedmont sites are obtained as TKN + NO3-N
** Driscoll et al., (1999)

Vegetative treatment at this MIL location has resulted in EMC attenuation of 82% for NH_4-N, 59% for NO_3-N, 43% for TSS, 8% for TP (unfiltered), and essentially no attenuation for TN, PO_4-N and TP (filtered). Annual pollutant loads are reduced in the order of 91% (NH_4-N), 89% (NO_3-N), 80% (PO_4-P), 75% (TSS), 62% (TN), 55 % (TP-unfiltered), and 45% (TP-filtered). Load reduction may be due to the loss of pollutant constituents via infiltration and/or biosorption, which greatly enhances the reduction of pollutant export on a mass-discharge basis.

According to Schuler (1987), TN export from a development site at 65% imperviousness would be approximately 11 lb/ac-yr (based on 1.4 mg/L and 2.6 mg/L of TN for pervious and impervious surfaces, respectively). TN export in surface runoff from this MIL-W secondary road is 0.76 lb/ac-yr, as seen from Table 5.5. After vegetative treatment, it was reduced to 0.29 lb/ac-yr or 2.6% of the expected export from a typical development site.

Table 5. 5 Performance of Vegetative Treatment at the MIL Monitoring Location

Sampling Location	TSS	NO_3-N	PO_4-P	NH_4-N	TN*	TP_{fil}	TP_{unfil}
				EMC, mg/L			
MIL-W	28	0.22	0.02	0.17	0.55	0.06	0.13
MIL-D	16	0.09	0.02	0.03	0.56	0.07	0.12
Reduction	43%	59%	0 %	82%	0 %	0 %	8 %
				Annual Load, lb/ac-yr			
MIL-W	40	0.28	0.05	0.23	0.76	0.11	0.20
MIL-D	10	0.03	0.01	0.02	0.29	0.06	0.09
Reduction	75%	89%	80%	91%	62%	45%	55%

5.6 Bulk Precipitation

Figure 5.7 displays the ratios of event-averaged bulk precipitation concentrations to site-averaged EMCs at MIL-W. At least 16% of TSS in roadway surface runoff may be due to atmospheric input. Atmospheric inputs appear to account for over 60% each of the other pollutant constituents. These observations may indicate the importance of atmospheric contribution to roadway surface runoff. However, caution must be used in the interpretation of these results as some of the materials captured by the bulk collector may have originated from the road surface.

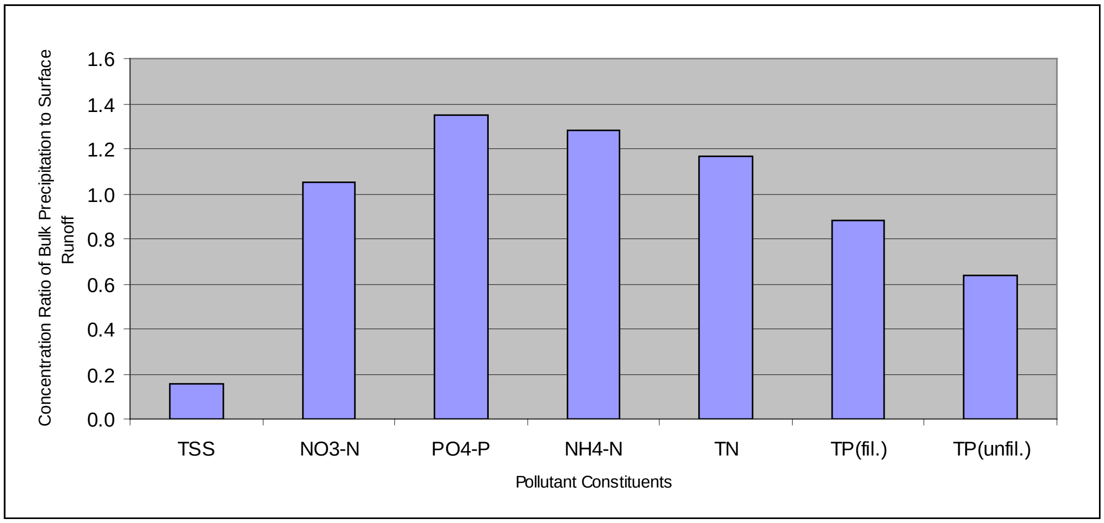

Figure 5. 7 Comparison of Bulk Precipitation to Roadway Surface Runoff at MIL

5.7 Summary

- Twenty six eligible storm events were monitored at the Mountain Island Lake paired sites. Concurrent roadway and water quality data were collected for twenty three storm events at the paired sites of MIL-W and MIL-D.
- Runoff ratios varied in the range of 50-80% and 2-50% for rainfall events ranging from 0.20-1.50 inches at the MIL-W impervious site and the MIL-D vegetated runoff site, respectively.
- The site-averaged TSS EMC of 16 mg/L for roadway runoff at MIL-D is 61% lower than the rural highway value reported in the national database and 67% lower than the averaged highway runoff data for the NC Piedmont region.
- The site-averaged TN EMC of 0.56 mg/L for roadway runoff at MIL-D is 58% below the rural highway value reported in the national database and 75% lower than the averaged highway runoff data for the NC Piedmont region.
- Site averaged TP EMCs of 0.12-0.13 mg/L are 52%-56% lower than the Piedmont site averaged concentration of 0.27 mg/L. There was a small reduction of 8% of TP EMC as a result of the vegetative treatment process.
- The presence of vegetated roadside ditch at this MIL location has resulted in EMC attenuation for NH_4-N (82%), NO_3-N (59%), TSS (43%), and TP (8%). EMCs for TN, PO_4-N and TP (filtered) remained essentially the same.

- The observed reductions in annual pollutant loads due to vegetative treatment are better for soluble constituents such as NH_4-N (91%), NO_3-N (90%) and PO_4-P (80%); followed by particulate associated constituents like TSS (75%), TN (62%), and unfiltered TP (55%). These reductions can be viewed as pollutant credits attributed to the presence of vegetated ditch along secondary roads.
- TN export in surface runoff from this MIL-W secondary road is 0.76 lb/ac-yr, which is about 3.3% of that for a typical development site. After vegetative treatment, it was reduced to 0.29 lb/ac-yr or 2.6% of the expected export from a typical development site.

6. Jordan Lake North Monitoring Sites

This chapter summarizes the hydrologic and water quality data collected at the Jordan Lake north (JLN) monitoring station. This paired-site sampling location is near 1416 Jack Bennett Road on SR 1717 in Chapel Hill, N.C. Twenty-six eligible storm events have been successfully monitored during the period of October 2007 to May 2009. Of these storms, eighteen storm events include concurrent data for surface runoff drained directly from the roadway segment to a weir box device and, at a second site, runoff was intercepted and passed through a roadside ditch. This paired-site monitoring strategy provides a consistent database to characterize surface runoff from secondary roads and to assess the pollutant removal performance of the vegetated roadside ditch area.

This monitoring location has experienced numerous site disturbances due to road resurfacing, road construction, and installation of telephone cables. The paired-site data has provided a basis to characterize surface runoff from secondary road but, more interestingly, to observe the impact of road construction and maintenance activities that would inadvertently change the water quality of roadway runoff.

6.1 Site Characterization

The Jack Bennett Road on SR 1717 is a two-lane paved road carrying an average daily traffic count of 2,600 vehicles in both directions. Sampling equipment and roadway drainage at this paired–site monitoring station are shown in Figures 6.1 and 6.2, respectively. At the weir sampling site, surface runoff drains directly from a 1,125 ft^2 roadway segment into the weir-box device as described in Chapter 3. This monitoring site has a 100% impervious cover and is designated as JLN-W. Surface runoff originated from another roadway segment of 10,710 ft^2, located immediately above JLN-W, flows laterally into a 12,317 ft^2 vegetated roadside ditch area. This JLN-D drainage site has a total area of 113,906 ft^2 including an upstream area of mixed land-use, resulting in an overall 47% impervious cover. The ditch has a side slope of 13.7% and a channel slope of 3.9%. The vegetated roadside ditch area functions naturally as a storm water quality management practice for the incoming roadway runoff.

Figure 6. 1 JLN Paired Monitoring Sites

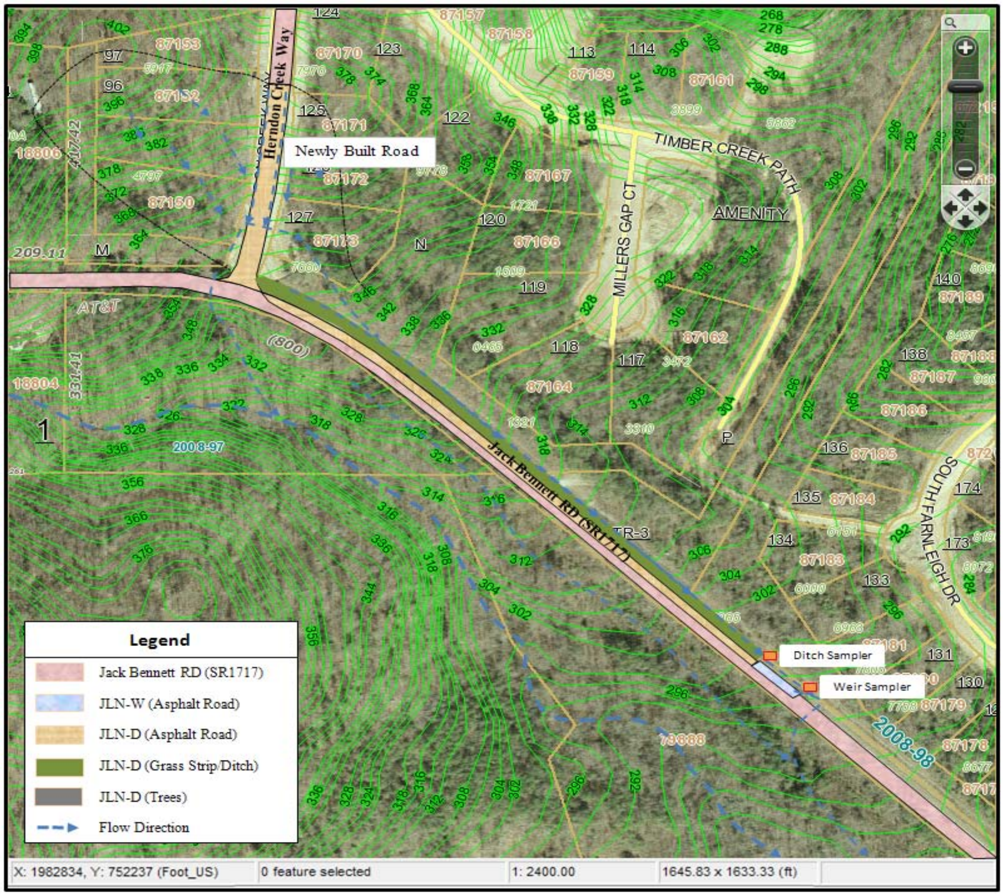

Figure 6. 2 Plan View of JLN Monitoring Station

Both the JLN-W and JLN-D sites have experienced numerous site disturbance throughout the monitoring period. In April of 2007, resurfacing was performed on Jack Bennett road including the monitored road segments, which resulted in elevated road surface and the grassed right-of-way was rotor tilled. Later in August of 2007, new telephone cables were installed along the bottom of the vegetated ditch. The ditch area near the sampling location was reshaped and the sampling strainer was damaged (Figure 6.3a). Starting from November of 2007 to June of 2008, a new road (Herndon Creek Way) was constructed to the north of the sampling site with muddy runoff draining directly to the ditch monitoring area (Figure 6.3b). In early June of 2008, the newly installed telephone cable was replaced or new cables were added to the right-of-way (Figure 3.c). These disturbances have potentially increased on-site infiltration and significantly increased ditch erosion.

6.2 Hydrology

Twenty six eligible storm events were monitored at JLN paired sites during the period of October 2007 to May 2009, as listed in Table 6.1. Eighteen events contain concurrent hydrological and water quality data of the same storm at the paired JLN-W and JLN-D sites. The number of eligible storms exceeded the minimum requirement of 15-20 events with at least half of which having to include concurrent hydrologic and water quality data of the same storm at the paired sites.

6.2.1 Precipitation

As seen from Table 6.1, the average rainfall and duration are 0.71 inches and 7.0 hrs, respectively. Rainfall data at the JLN monitoring location was obtained from a tipping bucket (recording) raingage and a standard (non-recording) raingage. The tipping bucket was installed on the inner right-of-way of the monitored road segment and directly connected to an automatic sampler. The standard rain gage was mounted at just 25 feet away from the tipping bucket raingage. Both were located between the ditch sampler and the weir sampler and not impacted by adjacent trees. The amounts of rainfall recorded by the tipping bucket matched very well with those collected by the standard raingage. On the average, the amounts of rainfall recorded by the tipping bucket are just 3% less than those collected by the standard rain gage (Figure 6.4).

a) Disturbance Due to Telephone Cable Setting (08/2007)

b) Disturbance Due to Road Construction (11/2007-06/2008)

c) Disturbance Due to Telephone Cable Setting (06/2008)

Figure 6. 3 Construction Disturbance at JLN Sites

Table 6. 1 Summary of Rainfall and Runoff Relationships at JLN

# Storm	Date	Rainfall (inches)	Duration (hrs)	Runoff Coefficient	
				JLN-W	JLN-D
1*	11/15/07	0.31	6	0.677	0.065
2**	12/16/07	0.95	17	0.842	0.323
3**	01/17/08	0.61	10	0.710	0.241
4	02/02/08	0.77	8	0.821	0.285
5	02/14/08	0.96	13	0.802	0.337
6	02/18/08	0.42	6	0.651	0.229
7*	02/22/08	0.26	4	0.481	0.174
8	03/04/08	1.13	6	0.838	0.400
9*	03/07/08	0.95	8	0.595	0.268
10*	03/15/08	0.76	4	0.707	0.221
11	04/27/08	0.86	10	0.720	0.257
12	05/15/08	0.40	8	0.547	0.100
13	05/18/08	0.48	2	0.529	0.137
14	05/20/08	0.84	2	0.846	0.319
15**	06/29/08	1.30	6	0.845	0.386
16	07/04/08	1.27	3	0.864	0.447
17	07/28/08	0.67	1	0.746	0.223
18*	09/10/08	0.67	8	0.550	0.234
19	09/16/08	1.43	6	0.631	0.435
20	10/17/08	0.61	9	0.687	0.194
21	11/24/08	0.35	8	0.683	0.062
22	12/20/08	0.71	12	0.849	0.231
23	12/25/08	0.29	3	0.582	0.290
24	01/28/09	0.36	2	0.567	0.035
25	02/28/09	0.76	13	0.453	0.226
26	04/10/09	0.33	8	0.550	0.052
Average		0.71	7.0	0.684	0.237

*Weir samples only ** Ditch samples only

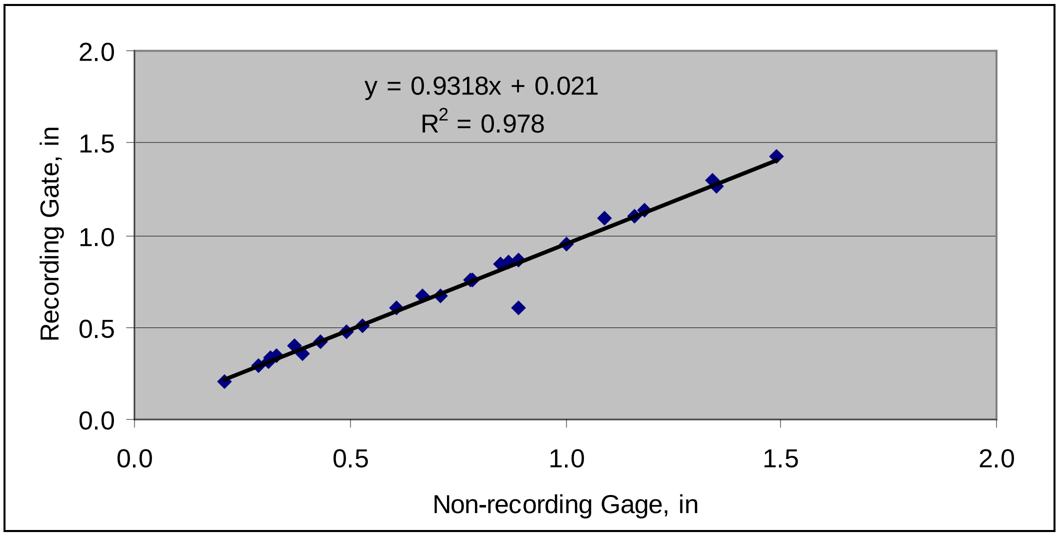

Figure 6. 4 Comparison of Recording and Non-recording Raingage Data at JLN Station

6.2.2 Flow Hydraulics

The hydraulic test on July 9, 2007, using a water truck to supply flow through the weir box has resulted in a depth-flow relationship of Q (cfs) = $1.3768(H)^{2.2965}$. Where Q is the weir flow, cfs, and H is water depth, ft. The volumetric flow calculated using this expression is slightly lower than that given by the standard 60^{o} weir equation of $Q = 1.443\ (H)^{2.5}$. Several well-defined storms were selected for calibration of runoff volume requirements as determined by the curve number technique and adjustment of flow depths recorded by the auto sampler. This has resulted in an equation of $Q = 1.3768\ (H' - \alpha)^{2.2965}$. In this equation, H' equals to (1.0133 H - 0.7821), H is the recorded water level above where the bubbler module is fixed, and α is an event-based correction factor ranging from 0.006 to 0.043 ft. This factor was determined on the basis of the initial flow level, event duration, intensity, and time since the previous event.

Flow hydraulics along the roadside ditch was determined by the following equations.

$A = H' + 4.5\ (H')^{2}$

$v = 1.32\ (H')^{1.0895}$

$Q = Av = [H' + 4.5\ (H')^{2}]\ [1.32\ (H')^{1.0895}]$

Where H' is the adjusted flow depth (H – β); H is the flow depth in feet recorded by the bubbler module; and β is an event-based correction factor, ranging from 0.042 to 0.12 ft, determined mainly on the basis of the subsidence of the fixed point of the bubbler module line below the ditch bottom. The channel geometry of the vegetated ditch at the JLN-D monitoring site is shown in Figure 6.5. Flows calculated using the previously stated equations were calibrated by the Manning's equation and curve number technique. To do this, the hydrologic connectivity method described in Chapter 3 was employed to determine the appropriate Manning's coefficient, based on runoff volume balance. It was found that a Manning's coefficient of 0.40 provides acceptable results for most storm events at this monitoring station.

Due to site disturbance, the hydrology of the JLN-D site has been altered from time to time; therefore, the hydrologic calculations for the JL-D site could only be regarded as the best attempt to minimizing its errors and some of the pollutant constituents were not used for characterizing the respective pollutant loadings.

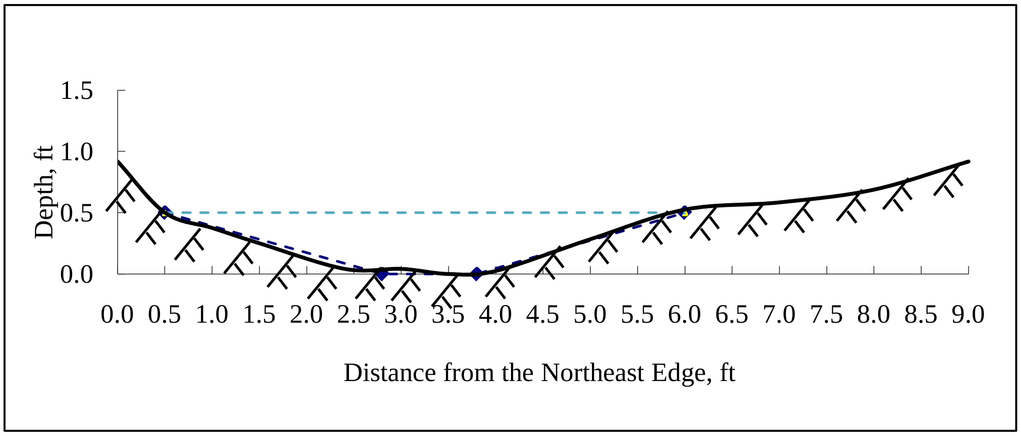

Figure 6. 5 Cross-sectional View of JLN Ditch

6.2.3 Rainfall and Runoff Relationships

The relationship between runoff-to-rainfall ratio and rainfall depth for the JLN-W site is shown in Figures 6.6. The general trend in the figure indicates that depending on the magnitude of rainfall, approximately 51%-77% of rainfall within the range of 0.20-1.50 inches/event runs off at the JLN-W site.

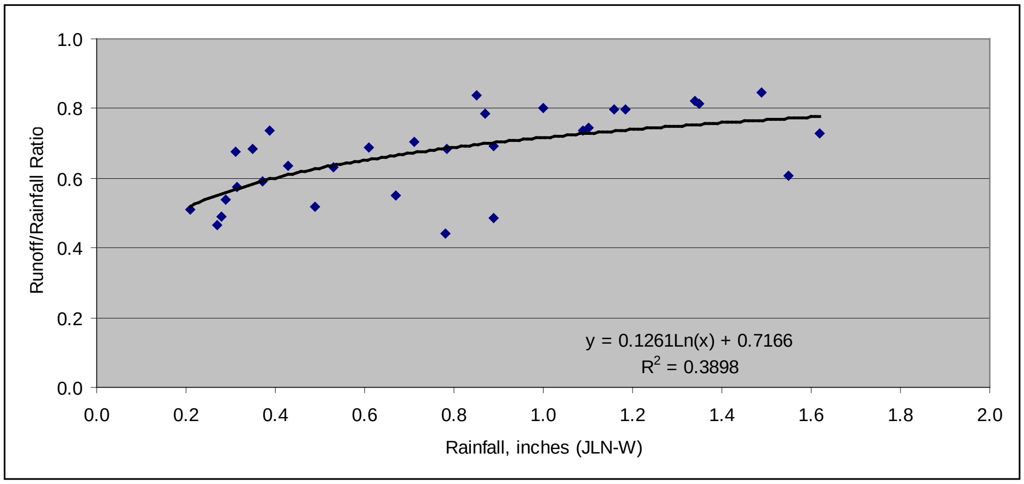

Figure 6.6 Rainfall-Runoff Relationship at JLN-W site

The relationship of rainfall ratio to rainfall depth for the JLN-W site is shown in Figures 6.7. It appears that depending on the magnitude of rainfall, approximately 0%-42% of rainfall within the range of 0.20-1.50 inches/event runs off at the JLN-D site. Obviously, the runoff ratios are more scattered than those at the JLS-D and MIL-D sites (Figure 4.8 and Figure 5.6). The average runoff ratio at the JLN-D site of 0.237 is 22% lower than the value of 0.313 at the JLS-D site, due mainly to the disturbance in the ditch area causing likely increased infiltration losses.

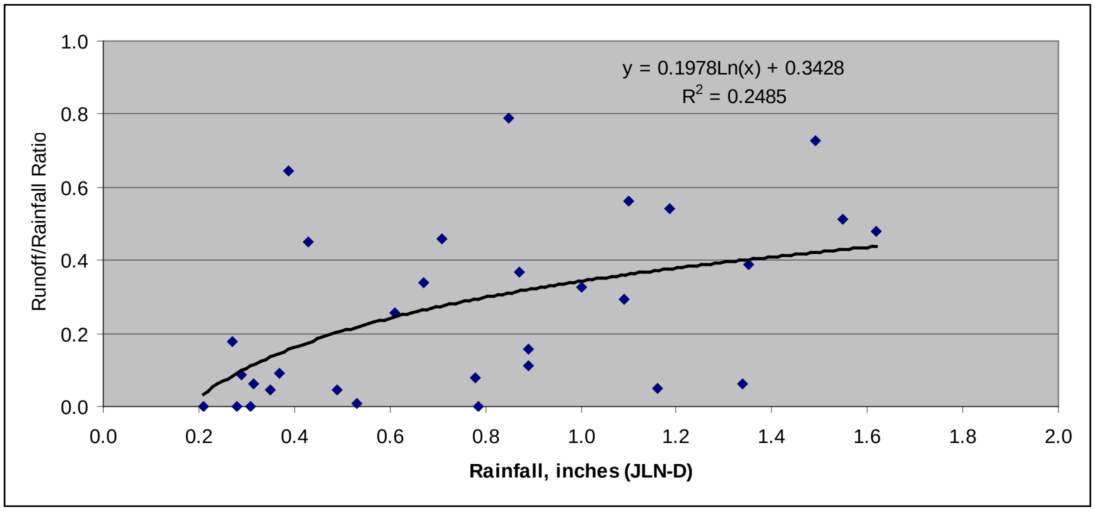

Figure 6. 7 Rainfall-Runoff Relationship at JLN-D site

6.3 Event Mean Concentrations

Composite samples were analyzed for each storm event. These concentrations are referred to as event mean concentrations (EMCs) because they represent the flow-weighted average concentration over a storm event. Appendix A includes the EMCs for each pollutant constituent that was collected at all monitoring locations. Whenever the sample concentration is below its detection limit, the sample concentration is reported as its equivalent detection limit. Site-averaged EMCs are calculated as the arithmetic mean of event-based EMCs. Table 6.2 presents these site-averaged EMCs of key pollutant constituents for the JLN paired sites. For comparison purpose, Table 5.2 also includes EMC data of the NC Piedmont sites (CLT-1, CLT-2, US-74, WIN, GAR, MON) reported by Wu and Allan (2001), and the national dataset for urban and rural highway runoff (Driscoll et al., 1999).

Table 6. 2 Site-averaged EMCs for the JLN Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS (mg/L)	NO_3-N (mg/L)	PO_4-P (mg/L)	NH_4-N (mg/L)	TN* (mg/L)	TP_{fil} (mg/L)	TP_{unfil} (mg/L)
JLN-W	2.6	0.026	100	67	0.23	0.01	0.41	0.77	0.04	0.15
JLN-D	2.6	0.529	47	566	0.10	0.02	0.02	0.41	0.08	0.39
% Reduction				-	57	-	95	47	-	-
CLT-1	50.2	0.37	100	135	0.83	0.09	1.05	3.23		0.24
CLT-2	33.4	0.57	61	86	0.61	0.21	0.97	2.81		0.35
US-74	9.3	0.86	50	8	0.31	0.24	0.11	1.61		0.31
WIN	52.2	2.16	48	15	0.54	0.16	0.13	1.82		0.25
GAR	78.8	3.46	33	11	0.84	0.14	0.13	1.94		0.20
MON	9.4	13.46	22	139	0.51	0.12	0.28	2.01		0.26
25 Percentile**	17.9	0.44	37	9	0.41	0.11	0.11	1.67		0.22
Site Average**	44.8	1.06	58	51	0.63	0.17	0.48	2.28		0.27
Urban***	> 30			142	0.76	0.40		2.59		
Rural***	< 30			41	0.46	0.16		1.33		

* TN for the Piedmont sites are obtained as TKN + NO_3-N
** Excluding MON site data
***National database as site-median EMC concentrations (Driscoll et al., 1999)

6.3.1 Site-averaged TSS EMCs

A site-averaged TSS EMC of 67 mg/L was obtained for surface runoff at JLN-W. This concentration is slightly higher than the average value (51 mg/L) of the Piedmont sites, 1.6 times higher than the rural highway value of 41 mg/L, and about half of the bridge deck data (CLT-1). JLN-D has a site-averaged TSS of 566 mg/L that is 8.5 times higher than that of JLN-W as a result of site disturbance. TSS EMCs without disturbance would be 14-16 mg/L as reported at JLS and MIL sites.

6.3.2 Site-averaged TN and TP EMCs

The site-averaged TN concentration at JLN-D (0.41 mg/L) is about half of the JLN-W impervious site, resulting in an overall EMC reduction credit of 47% presumably provided by the vegetative treatment. This result demonstrates the beneficial use of vegetative treatment even under unstable land cover conditions. TN EMCs observed at this monitoring location are generally 66-82% lower than those of NC Piedmont major/primary roads and did not seem to be influenced by site disturbance.

The site-averaged TP (unfiltered) concentration of 0.15 mg/L at the JLN-W site is about 44% below the averaged of the Piedmont highway data. Site disturbance has elevated TSS EMCs at the vegetated ditch, which has caused a simultaneous increase of the TP concentration of the ditch runoff, approximately 2.6 times greater than the roadway runoff from JLN-W site. This site-averaged TP (unfiltered) concentration of 0.39 mg/L at the JLN-D site is at least 1.4 times higher than the average of the Piedmont highway runoff data. The unfiltered and TP EMC at the JLN-D is double that of the JLN-W site.

6.3.3 Inorganic N and P Constituents

Ammonium-N EMC from roadway surface runoff of 0.41 mg/L at JLN-W is 15% higher than the averaged Piedmont highway runoff concentration of 0.48 mg/L. The site averaged NH_4-N of 0.02 mg/L at JLN-D is substantially lower (96%) than the averaged Piedmont highway runoff data of 0.48 mg/L. A ninety five percent (95%) reduction of NH_4-N EMCs is observed at this paired-site location.

Nitrate-N EMCs of 0.23 mg/L from roadway surface runoff at JLN-W is 64% less than the averaged Piedmont data of 0.63 mg/L. The site averaged NO_3-N of 0.10 mg/L at JLN-D is 84% lower than the averaged Piedmont highway runoff data of 0.63 mg/L. A fifty seven percent (57%) reduction of NO_3-N EMCs is obtained at this paired site location.

PO_4-P EMCs at both JLN-W and JLN-D (0.01-0.02 mg/L) are much lower than those obtained at the Piedmont highway runoff sites; however, the JLN-D data is twice higher than the JLN-W data.

6.4 Pollutant Loading Rates

6.4.1 Unit Event Load

The calculation of unit event load, mg/m^2 or lb/ac, is based on the methodology as described in Chapter 4. Table 6.3 presents the site-averaged unit event loads for the JLN paired sites, together with previously reported data from several Piedmont highway sites. Reductions in unit event loads due to vegetative treatment at JLN-D are 97% for NH_4-N, 74% for NO_3-N, 70% for TN, and 23% for PO_4-P. Construction and maintenance activities have elevated the export of TSS and TP from the JLN-D site. The export of TSS and TP (unfiltered) from the JLN-D site is 5.7 and 1.3 times higher than the respective unit loads of the JLN-W site. TSS export at JLN-D site is almost 2.9 times higher than the CLT-1 data.

Table 6. 3 Site-averaged Unit Event Load for the JLN Monitoring Location

Sampling Location	ADT ($x10^3$)	D.A. (acres)	Imp. (%)	TSS (mg/m^2)	NO_3-N (mg/m^2)	PO_4-P (mg/m^2)	NH_4-N (mg/m^2)	TN* (mg/m^2)	TP_{fil} (mg/m^2)	TP_{unfil} (mg/m^2)
JLN-W	2.6	0.026	100	812	2.38	0.13	4.17	7.83	0.49	1.58
JLN-D	2.6	0.529	46.5	4,649	0.62	0.10	0.13	2.33	0.50	2.04
Reduction				-473%	74%	23%	97%	70%	-2%	-29%
CLT-1	50.2	0.37	100	1,619	8.37	1.23	10.67	34.14		3.10
CLT-2	33.4	0.57	61	876	6.06	2.54	8.50	28.76		4.07
US-74	9.3	0.86	50	138	1.52	2.35	1.19	14.33		3.13
WIN	52.2	2.16	48	64	1.42	0.89	0.50	7.01		1.27
GAR	78.8	3.46	33	92	4.16	0.93	0.93	12.67		1.45
MON	9.4	13.46	22	881	1.34	0.42	0.70	7.88		1.23

*TNs for the Piedmont sites are obtained as TKN + NO_3-N

6.4.2 Annual Pollutant Load

The procedure of calculation for annual pollutant loadis similar to that employed by Wu and Allan (2001), as described in Chapter 4. The annual storm pollutant load can be used to compare with the continuous discharge of point sources for pollutant load allocation or watershed planning and management activities. Site-averaged annual pollutant loads obtained for the JLN monitoring sites are given in Table 6.4, together with the Piedmont highway runoff data urban runoff data. Annual loads of

TSS, TN and TP for the JLN-D site are, respectively, 4.3 times greater than, and 83% and 49% below the averaged values of the NC Piedmont highway runoff data.

Table 6. 4 Site-averaged Annual Pollutant Loads for the JLN Monitoring Location

Sampling Location	ADT (x10^3)	D.A. (acres)	Imp. (%)	TSS (lb/ac-yr)	NO_3-N (lb/ac-yr)	PO_4-P (lb/ac-yr)	NH_4-N (lb/ac-yr)	TN* (lb/ac-yr)	TP$_{fil}$ (lb/ac-yr)	TP$_{unfil}$ (lb/ac-yr)
JLN-W	2.6	0.026	100	137	0.40	0.02	0.70	1.32	0.08	0.27
JLN-D	2.6	0.529	47	587	0.08	0.01	0.02	0.29	0.06	0.29
Piedmont Site Averages	9.3-78.8	0.37-3.46	22-100	138	0.98	0.35	1.03	4.20		0.57
National**				280-10,580	0.71-7.14		0.92-4.10	2.19-35.64		4.07

*TNs for the Piedmont sites are obtained as TKN + NO3-N
** Driscoll et al., (1999)

6.5 Vegetative Treatment Performance

Vegetated roadside ditches associated with secondary road networks potentially offer a variety of treatment effectiveness to most pollutants of concern. Table 6.5 presents EMC attenuations and annual load reductions by comparing constituent data at the paired monitoring sites.

Table 6. 5 Summary of Performance Data at the JLN Monitoring Location

Sampling Location	TSS	NO_3-N	PO_4-P	NH_4-N	TN*	TP$_{fil}$	TP$_{unfil}$
				EMC, mg/L			
JLN-W	67	0.23	0.01	0.41	0.77	0.04	0.15
JLN-D	566	0.10	0.02	0.02	0.41	0.08	0.39
Reduction	-745%	57%	-100%	95%	47%	-100%	-160%
				Annual Load, lb/ac-yr			
JLN-W	137	0.40	0.02	0.70	1.32	0.08	0.27
LJN-D	587	0.08	0.01	0.02	0.29	0.06	0.29
Reduction	-328%	80%	50%	97%	78%	25%	-7%

Vegetative treatment at this JLN location has resulted in EMC attenuation of 95% for NH_4-N, 57% for NO_3-N, 47% for TN, and a net export of -745% for TSS, -160% for TP (unfiltered), and -100% for TP (filtered). Annual pollutant loads are reduced in the order of 97% (NH_4-N), 80% (NO_3-N), 78% (TN), 50% (PO_4-P), and 25% (TP-unfiltered) and a net export of -328% for TSS, and -7% for TP (unfiltered).

According to Schuler (1987), TN export from a development site at 65% imperviousness would be approximately 11 lb/ac-yr (based on 1.4 mg/L and 2.6 mg/L of TN for pervious and impervious surfaces, respectively). TN export in surface runoff from this JLN-W secondary road is 1.32 lb/ac-yr. After vegetative treatment, it was reduced to 0.29 lb/ac-yr or 2.6% of the expected export at a typical development site.

6.6 Bulk Precipitation

Figure 6.8 displays the ratios of event-averaged bulk precipitation concentrations to site-averaged EMCs at JLN-W. Less than 10% of TSS in roadway surface runoff may be attributed to atmospheric input. Over 60% atmospheric inputs appear to account for each of other pollutant constituents. These observations may help demonstrate the importance of atmospheric contribution to roadway surface runoff. However, caution must be used when interpreting these results as some of these materials collected in the bulk precipitation collectors could have originated from the road surface.

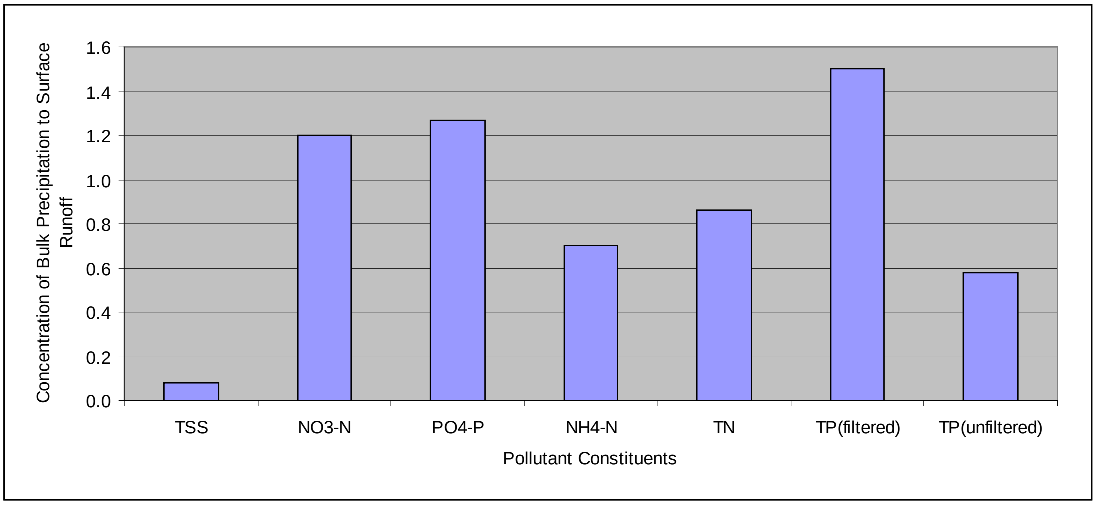

Figure 6. 8 Comparison of Bulk Precipitation to Roadway Surface Runoff

6.7 Summary

- Twenty six eligible storm events were monitored at the Jordan Lake North paired sites. Concurrent roadway and water quality data were collected for eighteen storm events at both paired sites of JLN-W and JLN-D.

- Runoff ratios varied in the range of 51-77% and 0-42% for rainfall events ranging from 0.21-1.50 inches at the JLN-W impervious site and the JLN-D vegetative treatment site, respectively.
- The site-averaged TSS EMC of 566 mg/L for roadway runoff at MIL-D is about four times higher than the urban highway average value reported in the national database and 11 times greater than the averaged highway runoff data for the NC Piedmont region.
- The site-averaged TN EMC of 0.41 mg/L for roadway runoff at JLN-D is 69% below the rural highway value and 82% lower than the averaged highway runoff data for the NC Piedmont region.
- Site averaged TP EMC of 0.39 mg/L is 1.4 times higher than the respective NC Piedmont data of 0.27 mg/L.
- The presence of vegetated roadside ditch at this JLN location has resulted in EMC attenuation for NH_4-N (95%), NO_3-N (57%), and TN (47%). EMCs for TSS, PO_4-N, and TP at the JLN-D site exceed those at the JLN-W site due to site disturbance.
- The observed reductions in annual pollutant loads due to vegetative treatment are better for soluble constituents such as NH_4-N (97%), NO_3-N (80%), TN (78%), PO_4-P (50%), and filtered TP (25%). The export of TSS and TP (filtered) at the JLN-D site were elevated by 329% and 7%, respectively, as compared to the JLN-W site data.
- TN export of 1.32 lb/ac-yr from JLN-W site is approximately 12% of that from a typical development site. After vegetative treatment, it was reduced to 0.29 lb/ac-yr or 2.6% of the expected export for a typical development site.

7. Pollutant Credits for Secondary Roads

Secondary roads are mostly connected or interconnected to vegetated strips and ditches. The inherent and environmental-friendly benefits of vegetative coverage that exists in secondary roads should be integrated into an overall highway runoff BMP management strategy. A major goal of this research was to derive nutrient loading rates for secondary roads taking into consideration of the existing vegetative coverage alongside of these secondary roads. Research findings will be particularly useful for watersheds, e.g. Jordan Lake watershed, characterized by a large percentage of secondary road mileage and subject to TMDL mandated reductions in nutrients loadings on a watershed scale.

7.1 Event-Mean-Concentrations for Secondary Roads

Table 7.1 summarizes EMCs for roadway runoff from three secondary roads located in the Jordan Lake and Mt. Island Lake watersheds. Both watersheds are situated in the Piedmont region of North Carolina. Roadway runoff drains directly from roadway segments (JLS-W, MIL-W, and JLN-W) to the weir-box sampling device is defined as roadway edge runoff in Table 7.1. Hence, roadway edge runoff represents the direct runoff from the 100% impervious paved roadway surface. Outflow from the roadside ditch, on the other hand, involves the passage of roadway edge runoff through the vegetated roadside ditch (JLS-D, MIL-D, and JLN-D) to receiving streams. Attenuation of pollutant concentrations or loads occurs as runoff flows through the vegetated ditch.

The drainage areas for JLS-W, MIL-W, and JLN-W varied within a narrow range of 1,042 ft^2 to 1,291 ft^2; but differed in traffic counts in the order of 2,600 vehicles/day for JLN, 1,400 vehicles/day for MIL and 590 vehicles/day for JLS. These differences in traffic counts appear to exert essentially no effects on EMCs among sites, except possibly EMCs of TSS, and NH_4-N at the JLN-W site. TSS EMC at JLN-W site is almost twice of EMCs at JLS-W and MIL-W sites due to site disturbance throughout the period of field monitoring. EMC NH_4-N at JLN-W is also twice of EMCs compared to other monitoring locations, which may be due to site disturbance and/or higher traffic counts. TSS and NH_4-N EMCs at JLN-W were not used to compute the average EMCs for these three monitoring sites.

Table 7. 1 EMCs for Monitoring Sites of Secondary Roads

Sampling Location	TSS (mg/L)	NO_3-N (mg/L)	PO_4-P (mg/L)	NH_4-N (mg/L)	TN* (mg/L)	TP_{fil} (mg/L)	TP_{unfil} (mg/L)
				Roadway Edge Runoff (a)			
JLS-W	35	0.23	0.02	0.26	0.63	0.05	0.12
MIL-W	28	0.22	0.02	0. 17	0.55	0.06	0.13
JLN-W	67	0.23	0.01	0.41	0.77	0.04	0.15
				Outflow from Roadside Ditch (b)			
JLS-D	14	0.07	0.02	0.03	0.50	0.06	0.13
MIL-D	16	0.09	0.02	0.03	0.56	0.07	0.12
JLN-D	566	0.10	0.02	0.02	0.41	0.08	0.39
				Pollutant Credits			
Average (a)*	32	0.23	0.02	0.22	0.65	0.05	0.13
Average (b)*	15	0.08	0.02	0.03	0.49	0.07	0.13
% Credit	53	65	0	86	25	-	0
Piedmont Primary State Roads**	51	0.63	0.17	0.48	2.28		0.27
National Rural***	41	0.46	0.16		1.33		
National Urban***	142	0.76	0.40		2.59		

*Excluding TSS (JLN-W, JLN-D) and NH_4-N (JLN-W)
**Wu and Allan (2001)
***Driscoll et al. (1999)

The drainage areas for JLS-D and MIL-D including roadway segment and vegetated ditch are 15,696 ft^2 and 10,343 ft^2, respectively. JLN-D has a drainage area of 23,027 ft^2 that is about twice the size of the other two area, but with the inclusion of mixed land use draining to the site, the total drainage area increases to 48,352 ft^2 (Table 3.1). The resulting impervious covers for JLS-D, MIL-D and JLN-D are 65.4%, 47.9% and 37.3% respectively. JLN-D would have been 46.5% imperviousness, instead of 37.3%, without runoff contribution from the mixed land use. The impact due to inflow from this land use is likely to vary with rainfall amount and periodicity.

Despite these differences, EMCs for most pollutant constituents were relatively similar with the exception of TSS and TP (unfiltered). Site disturbance occurred at JLN-D has resulted in elevated TSS and associated TP discharged into the vegetated ditch area. Therefore, EMC TSS and TP at JLN-D are not included in the computation of the average EMCs for these three sites.

The following conclusions pertaining to general characterization of EMCs for the secondary-road monitoring locations can be reached:

- EMCs for roadway runoff of secondary roads with vegetated roadside ditch can be characterized by 15 mg/L of TSS, 0.08 mg/L of NO_3-N, 0.02 mg/L PO_4-N, 0.03 mg/L NH_4-N, 0.49 mg/L TN, 0.07 mg/L of TP (filtered) and 0.13 mg/L of TP (unfiltered). These EMCs for secondary roads are substantially lower than those of the NC Piedmont primary roads and the national rural roads.
- With reference to the Piedmont primary roads, EMC ratios computed as secondary/primary roads are 0.29, 0.13, 0.12, 0.06, 0.22 and 0.48 for TSS, NO_3-N, PO_4-N, NH_4-N, TN and TP (unfiltered), respectively.

7.2 Pollutant Credits for Secondary Roads

Pollutant credits are evaluated as the percentage difference of constituent concentrations or loads between roadway edge runoff and outflow from the roadside ditch.

Pollutant credits based on EMCs, as shown in Table 7.1, are as follows:

- 53% for TSS, 65% for NO_3-N, 88% for NH_4-N, and 25% for TN.
- Essentially no credits can be claimed for phosphorus species (PO4-N), TP (unfiltered) and TP (filtered).

Pollutant credits based on annual loads (lb/ac-yr), as shown in Table 7.2, are as follows:

- Pollutant discharge from secondary roads for TSS, TN and TP (unfiltered) are 11, 0.35 and 0.09 lb/ac-yr.
- The presence of vegetated roadside ditch would provide pollutant credits of 77% for TSS, 87% for NO_3-N, 50% for PO4-N, 94% NH_4-N, 67% for TN, 33% for TP (unfiltered) and 59% for TP (filtered)

Table 7. 2 Annual Pollutant Loads for Monitoring Sites of Secondary Roads

Sampling Location	TSS (lb/ac-yr)	NO_3-N (lb/ac-yr)	PO_4-P (lb/ac-yr)	NH_4-N (lb/ac-yr)	TN* (lb/ac-yr)	TP_{fil} (lb/ac-yr)	TP_{unfil} (lb/ac-yr)
				Roadway Edge Runoff (a)			
JLS-W	53	0.42	0.04	0.46	1.11	0.09	0.20
MIL-W	40	0.28	0.05	0. 23	0.76	0.11	0.20
JLN-W	137	0.40	0.02	0.70	1.32	0.08	0.27
				Outflow from Roadside Ditch (b)			
JLS-D	12	0.04	0.02	0.02	0.48	0.05	0.09
MIL-D	10	0.03	0.01	0.02	0.29	0.06	0.09
JLN-D	587	0.08	0.01	0.02	0.29	0.06	0.29
				Pollutant Credits			
Average (a)*	47	0.37	0.04	0.35	1.06	0.09	0.22
Average (b)*	11	0.05	0.02	0.02	0.35	0.06	0.09
% Credit	77	87	50	94	67	33	59
Piedmont Primary State Roads**	138	0.98	0.35	1.03	4.20		0.57
National Low***	280	0.71		0.92	2.19		0.54
National High***	10,580	7.14		4.10	35.64		7.33

*Excluding TSS (JLN-W, JLN-D) and NH_4-N (JLN-W)
**Wu and Allan (2001)
***Driscoll et al. (1999)

8. Conclusions and Recommendations

A comprehensive sampling program of storm runoff has been successfully conducted on three secondary roads in Chatham and Lincoln counties of North Carolina. At each sampling location, a sampling site was configured to collect storm runoff at the roadside edge whereas the paired site was instrumented inside the vegetated ditch to monitor roadway runoff upon passing through the roadside ditch. This paired-site monitoring strategy provides a consistent database to compare and characterize storm runoff from secondary roads and to assess the pollutant removal performance of the vegetated roadside ditch.

Hydrologic and water quality data were collected for a total of 82 storm events with 65 events containing concurrent data of the same storm at each paired site. The Jordan Lake South (JLS) monitoring location is a two-lane paved road (SR 1943) in Pittsboro (near Raleigh), carrying an average ADT of 590 vehicles/day in both directions. The roadway drainage area accounts for 65% of the combined roadway and ditch areas. This contributing drainage area is significantly greater than the 1% criterion for grass swale cited by Storey et al. (2009). The Mountain Island Lake (MIL) location is also a two-lane paved road in Ironton, next to the city of Charlotte. It has an average ADT of 1,400 vehicles in both directions and a 48% impervious cover. The Jordan Lake North (JLN) location has characteristics similar to MIL (two-lane paved road and 48% impervious) but with an ADT of 2,600 vehicles/day. This JLN location has experienced numerous near-site and on-site disturbances due to road construction and utility work. The respective paired-site at each monitoring location has a 100% impervious cover because roadway runoff is intercepted at the roadside edge for sampling. The sampling period was from late 2007 to the middle of 2009.

The following conclusions can be drawn with regard to generalized EMCs of storm runoff from secondary roads:

- EMCs for secondary roadway runoff with vegetated roadside ditch are 15 mg/L TSS, 0.08 mg/L NO_3-N, 0.02 mg/L PO_4-N, 0.03 mg/L NH_4-N, 0.49 mg/L TN, 0.07 mg/L of TP (filtered) and 0.13 mg/L TP (unfiltered). These EMCs for secondary roadway runoff are substantially lower than those of the Piedmont primary roads and the national rural roads.
- With reference to the Piedmont primary roads, site averaged EMC ratios computed as secondary-to-primary roads are 0.29 (TSS), 0.13 (NO_3-N), 0.12 (PO_4-N), 0.06 (NH_4-N), 0.22 (TN) and 0.48 (TP, unfiltered).

The following conclusions can be provided to characterize pollutant loads of storm runoff from secondary roads:

- Annual pollutant loads for secondary roadway runoff with vegetated roadside ditch are 11 lb/ac-yr TSS, 0.05 lb/ac-yr NO_3-N, 0.02 lb/ac-yr PO_4-P, 0.02 lb/ac-yr NH_4-N, 0.35 lb/ac-yr TN, 0.06 lb/ac-yr (TP, filtered) and 0.09 lb/ac-yr (TP, unfiltered).
- According to Schuler (1987), TN export from a development site at 65% imperviousness would be around 11 lb/ac-yr (based on 1.4 mg/L and 2.6 mg/L of TN for pervious and impervious surfaces, respectively). TN export from secondary roads would be about 3-5% of that from a typical development site.

The following conclusions are related to the effectiveness of or pollutant credits gained from vegetated roadside ditch treating secondary roadway runoff:

- Pollutant credits or treatment effectiveness based on EMCs, as shown in Table 7.1, are 53% TSS, 65% NO_3-N, 86% NH_4-N, 25% for TN, and essentially no credits can be claimed for phosphorus species (PO4-N), TP (unfiltered) and TP (filtered).
- Pollutant credits or treatment effectiveness based on annual loads (lb/ac-yr), as shown in Table 7.2, are 77% TSS, 87% NO_3-N, 50% PO_4-N, 94% NH_4-N, 67% TN, 33% TP (unfiltered) and 59% TP (filtered).

The following Recommendations are provided:

- Data pertaining to vegetative treatment effectiveness and characterization of secondary roadway runoff, as cited in this report, are based on site-averaged performance. Although the number of rainfall events and the amount of rainfall for each event are fairly and evenly distributed within the range of 0.20-1.50 inches, caution should be taken to consider the statistical uncertainty of these averaged values.
- Research is needed to incorporate the pollutant credits that can be offered by vegetated ditch into TMDL modeling on a watershed scale. This is particularly important for watersheds comprised of a large percentage of secondary roads.
- Research is needed to evaluate pollutant removal mechanisms in vegetated ditch including vegetative management. Ccriteria to maximize the adjoining filter strip and/or optimize the performance within the ditch need to be investigated.

- As evidenced in this study that near-site and on-site disturbances due to new road construction and utility work have exerted great impacts to the vegetated ditch. Coordination among agencies is needed to minimize these impacts.
- Finally, vegetated roadside ditches may play a significant role to alleviate or even eliminate the need of structural best management practices for secondary roads, if they are properly constructed and maintained.

Literature Cited

Allan, C.J., and Wu, J.S. (2004). “Development of a GIS-based Methodology to Estimate Stormwater Runoff Pollutant Loadings from North Carolina Highways.” *Rep. No. FHWA/NC/2004-06*, U.S. Department of Transportation.

Allan, C.J. and Wu, J.S. (2009). “Evaluation of Manufactured Stormwater Best Management Practices.” In Press, U.S. Department of Transportation.

Bren, L., Dyer, F., Hairsine, P., Riddiford, J., Siriwardhena, V. Zierholz, C. (1997). “Controlling Sediment and Nutrient Movement within Catchments.” *Rep. No. 97/9*, Cooperative Research Centre for Catchment Hydrology, Melbourne.

Barrett, M.E., Walsh, P.M., Malina Jr., J.F., Jr., and Charbeneau, R.J. (1998). Performance of Vegetative Controls for Treating Highway Runoff.” *J. Envir. Engrg*., ASCE, 124(11):1121-1128.

Barrett, M., Kearfott, P., Malina Jr., J.F., Landphair, H., Li, M.H., Olivera, F., and Rammohan, P. (2006). “Pollutant Removal on Vegetated Highway Shoulders.” *Rep. No. FHWA/TX-05/04605-1*, Texas Department of Transportation.

Deletic, A. and Fletcher, T.D. (2006). “Performance of Grass Filters used for Stormwater Treatment-A Field and Modeling Study.” *J. Hydro*., 317:261-275.

Dillaha, T.A., Renear, R.B., Mostaghimi, S., and Lee, D. (1989). “Vegetative Filter Strips for Agricultural Nonpoint Source pollution Control.” *Trans. American Society of Agricultural Engineers*, 32(2):513-519.

Driscoll, E.D., Shelley, P.E., and Strecker, E.W. (1990). “Pollutant Loadings and Impacts from Highway Stormwater Runoff. Vol. III: Analytical Investigation and Research Report.” *Rep. No. FHWA-RD-99-008*, Fed. Hwy. Administration, Ofc. Of Res. and Devel., Washington, D.C.

Han, Y., Lau, S.L., Kayhanian, M. and Stenstorm, M.K. (2006). “Characteristics of Highway Stormwater Runoff.” *Water Envir. Res.,* 78(12):2377-2388.

Han, J., Wu, J.S., and Allan, C.J. (2005). “Suspended Sediment Removal by Vegetative Filter Strip Treating Highway Runoff.” *J. Envir. Sci. and Health*, 40:1637-1649.

Hoffman, E.J., Latimer, J.S., and Hunt, C.D. (1985). “Stormwater Runoff from Highways.” *Water, Air and Soil Pollution*, 25(4):349-364.

Irish, L.B. Jr., Barrtee, M.E., Malina, J.F. Jr., Charbeneau, R.J. (1998). “Use of Regression Models for Analyzing Highway Storm-Water Loads.” *J. Envir. Engrg.,* 124(10):987-993.

Kayhanian, M., Singh, A., Suverkropp, C., Borroum, S. (2003). “Impact of Annual Average Daily Traffic on Highway Runoff Pollutant Concentrations.” *J. Envir. Engrg*., 129(9):975-990.

Kayhanian, M., Suverkropp, C., Ruby, A., and Tsay, K. (2007). “Characterization and Prediction of Highway Runoff Constituent Event Mean Concentration.” *J. Envir. Management*, 85:279-295.

Kercher, W.C., Landon, J.C., and Massarelli, R. (1983). “Grassy Swales Prove Cost-Effective for Water Pollution Control.” *Public Works*, 114:53.

Li, M. H., and Barrett, M.E. (2008). ”Relationships Between Antecedent Dry Period and Highway Pollutant: Conceptual Models of Buildup and Removal Process.” *Water Envir. Res*. 80(8):740-747.

Magetter, W.L., Brinsfield, R.B., Palmer, R.E., and Wood, J.D. (1989). “Nutrient and Sediment Removal by Vegetated Filter Strips.” *Trans. American Society of Agricultural Engineers*, 32(2):663-667.

NC DENR DWQ. (2007). “B. Everett Jordan Reservoir, North Carolina Phase I (Nutrient) Total Maximum Daily Load” – Final. Raleigh, North Carolina.

Schueler, T.R. (1987). “Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.” U.S. Metropolitan Washington Council of Governments, Washington, D.C.

Storey, B.J., Li, M.H., McFalls, J.A. and Yi, Y.J. (2009). “Stormwater Treatment with Vegetated Buffers.” *Draft Rep. NCHRP Project 25-25(53)*, Transportation Research Board.

Walsh, P.M., Barrett, M.E., Malina Jr., J.F. and Charbeneau, R.J.(1997). “Use of Vegetative Controls for Treatment of Highway Runoff.” *Online Rep. No. 97-5*, Center for Research in Water Resources, University of Texas at Austin, Tex.

Wu, J.S., and Allan, C.J. (2001). “Sampling and Testing of Stormwater Runoff from North Carolina Highways.” *Rep. No. FHWA/NC/2001-002*, U.S. Dept. of Transportation.

Wu, J.S. and Allan, C.J. (2006). “Evaluation and Implementation of BMPs for NCDOT’s Highways and Industrial Facilities.” *Rep. No. FHWA/NC/2006-02*, U.S. Department of Transportation.

Wu, J.S., Allan, C.J., Saunders, W.L. and Evett, J.B. (1998). “Characterization and Pollutant Loading Estimation for Highway Runoff.”, *J. Envir. Engrg.*, ASCE, 124(7):584-592.

Appendix A – EMCs for Monitoring Sites

Jordan Lake South (JLS-W) Roadside Edge EMCs

Event	Date (MDY)	Rain (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/L)	Turbidity (NTU)	Chloride (mg/L)	NO3-N (mg/L)	PO4-P (mg/L)	NH4-N (mg/L)	NPOC (mg/L)	TN (mg/L)	TP (fil) (mg/L)	TP (unfil) (mg/L)
1	10/26/07	0.84	0.544	0.648	7	4	0.12	0.08	0.01	0.10	1.5	0.21	0.03	0.03
2	12/15/07	1.15	0.941	0.818										
3	01/17/08	0.55	0.330	0.600										
4	02/01/08	0.75	0.551	0.734	16	12	0.96	0.15	0.11	0.19	1.8	0.22	0.18	0.21
5	02/12/08	1.00	0.849	0.849	25	14	12.82	0.28		0.40	3.6	0.44	0.04	0.08
6	02/18/08	0.30	0.201	0.671	16	18	0.94	0.10	0.01	0.12	2.7	0.17	0.02	0.06
7	03/04/08	0.94	0.674	0.717	49	33	1.21	0.35	0.01	0.51	3.4	1.30	0.05	0.12
8	03/15/08	0.95	0.839	0.883	29	21	0.36	0.17	0.01	0.33	2.6	0.64	0.01	0.12
9	04/27/08	1.08	0.704	0.652										
10	05/18/08	0.44	0.330	0.749	12	7	0.74	0.15	0.01	0.57	4.3	0.83	0.04	0.14
11	05/20/08	0.52	0.340	0.654	68	36	0.79	0.16	0.01	0.42	4.0	0.71	0.04	0.20
12	07/04/08	0.44	0.236	0.536	36	20	0.70	0.47	0.01	0.68	8.9	1.39	0.03	0.10
13	07/05/08	0.67	0.432	0.645	50	20	0.41	0.14	0.01	0.11	2.7	0.36	0.03	0.07
14	07/06/08	1.26	1.039	0.825	19	10	0.41	0.16	0.01	0.19	2.8	0.41	0.03	0.07
15	07/18/08	0.53	0.266	0.502	51	16	1.05	0.55	0.01	0.72	5.5	1.50	0.04	0.10
16	07/23/08	0.38	0.261	0.688	8	7	0.45	0.73	0.03	0.20	9.0	1.18	0.05	0.07
17	07/27/08	0.24	0.138	0.577	15	7	0.64	0.28	0.01	0.51	7.2	1.01	0.12	0.30
18	08/13/08	0.28	0.098	0.351	6	7	0.34	0.16	0.01	0.16	19.9	1.05	0.03	0.06
19	08/26/08	2.73	2.139	0.784	6	5	0.70	0.18	0.01	0.08	4.2	0.46	0.04	0.05
20	09/10/08	0.73	0.471	0.646	11	5	0.49	0.15	0.01	0.12	2.8	0.40	0.04	0.05
21	09/16/08	0.98	0.780	0.796	32	5	0.31	0.16	0.01	0.10	1.9	0.33	0.03	0.03
22	10/17/08	0.60	0.493	0.822	7	7	0.33	0.15	0.03	0.05	1.6	0.27	0.08	0.18
23	11/03/08	0.65	0.550	0.846	8	6	0.66	0.11	0.05	0.12	1.9	0.28	0.07	0.09
24	11/24/08	0.30	0.060	0.199	8	9	0.41	0.26	0.14	0.13	3.0	0.49	0.05	0.19
25	12/20/08	1.28	1.064	0.831										
26	12/25/08	0.28	0.114	0.405	3	5	1.74	0.18	0.01	0.13	2.3	0.48	0.04	0.05
27	01/28/09	0.27	0.183	0.680	350	235	2.24	0.31	0.01	0.30	3.9	0.73	0.03	0.50
28	02/28/09	0.57	0.380	0.669	12	11	0.18	0.09	0.01	0.12	1.9	0.28	0.05	0.08
29	04/06/09	0.20	0.102	0.511	27	16	0.98	0.19	0.01	0.15	5.9	0.54	0.03	0.13
30	04/10/09	0.41	0.281	0.685	32	6	1.24	0.35	0.01	0.22	4.4	0.73	0.02	0.12
Average		0.71	0.513	0.666	35	21	1.20	0.23	0.02	0.26	4.4	0.63	0.05	0.12
Median		0.58	0.406	0.676	16	9	0.68	0.17	0.01	0.18	3.2	0.49	0.04	0.10
S.D.		0.50	0.423	0.158	67	44	2.42	0.15	0.03	0.20	3.8	0.39	0.03	0.10
C.V.		0.70	0.825	0.238	1.92	2.13	2.01	0.66	1.45	0.76	0.87	0.62	0.74	0.81
10th Percentile		0.28			6			0.11	0.01	0.14		0.25	0.03	0.05
90th Percentile		1.15			51			0.45	0.05	0.74		1.20	0.08	0.21

Jordan Lake South (JLS-D) Vegetated Ditch EMCs

Event	Date (MDY)	Rain (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/L)	Turbidity (NTU)	Chloride (mg/L)	NO3-N (mg/L)	PO4-P (mg/L)	NH4-N (mg/L)	NPOC (mg/L)	TN (mg/L)	TP (fil) (mg/L)	TP (unfil) (mg/L)
1	10/26/07	0.84	0.452	0.538	7	8	0.67	0.01	0.09	0.01	7.3	0.27	0.04	0.04
2	12/15/07	1.15	0.577	0.502	9	13	0.81	0.01	0.13	0.01	16.2	2.63	0.11	0.12
3	01/17/08	0.55	0.114	0.208	7	13	0.70	0.02	0.09	0.02	6.0	0.29	0.05	0.07
4	02/01/08	0.75	0.258	0.344										
5	02/12/08	1.00	0.481	0.481	4	6	10.54	0.10		0.04	7.8	0.26	0.04	0.06
6	02/18/08	0.30	0.034	0.112	1	12	1.36	0.02	0.01	0.01	8.4	0.17	0.02	0.07
7	03/04/08	0.94	0.193	0.205	13	18	0.94	0.03	0.01	0.02	7.0	0.35	0.05	0.09
8	03/15/08	0.95	0.464	0.488	14	22	0.53	0.06	0.01	0.02	5.3	0.30	0.04	0.10
9	04/27/08	1.08	0.425	0.393	9	8	0.98	0.03	0.01	0.02	9.8	0.42	0.06	0.18
10	05/18/08	0.44	0.090	0.204	16	13	0.92	0.03	0.01	0.01	9.3	0.52	0.05	0.13
11	05/20/08	0.52	0.079	0.152	36	37	0.82	0.10	0.01	0.01	8.2	0.48	0.06	0.13
12	07/04/08	0.44	0.058	0.131	7	5	1.69	0.11	0.01	0.02	15.9	0.74	0.05	0.10
13	07/05/08	0.67	0.256	0.382	81	117	0.59	0.07	0.01	0.01	8.5	0.39	0.03	0.22
14	07/06/08	1.26	0.670	0.532	33	43	0.53	0.12	0.01	0.01	6.6	0.39	0.04	0.12
15	07/18/08	0.53	0.117	0.220	5	3	1.19	0.29	0.02	0.12	8.2	0.80	0.06	0.08
16	07/23/08	0.38	0.068	0.179	7	8	0.46	0.06	0.01	0.01	10.6	0.45	0.03	0.07
17	07/27/08	0.24	0.027	0.112	6	5	0.94	0.10	0.01	0.02	11.0	0.56	0.07	0.34
18	08/13/08	0.28	0.012	0.043										
19	08/26/08	2.73	1.388	0.508	4	16	0.75	0.01	0.01	0.03	7.6	0.29	0.04	0.06
20	09/10/08	0.73	0.344	0.472	3	6	0.69	0.02	0.01	0.04	12.8	0.58	0.04	0.07
21	09/16/08	0.98	0.445	0.454	7	10	0.43	0.03	0.01	0.02	7.7	0.35	0.04	0.08
22	10/17/08	0.60	0.236	0.393	1	6	0.63	0.01	0.01	0.05	8.8	0.40	0.08	0.10
23	11/03/08	0.65	0.227	0.349	5	6	0.91	0.01	0.01	0.03	11.4	0.48	0.07	0.08
24	11/24/08	0.30	0.057	0.190	7	10	1.30	0.04	0.01	0.01	10.9	0.48	0.08	0.11
25	12/20/08	1.28	0.732	0.572	12	15	0.87	0.01	0.01	0.01	7.8	0.30	0.05	0.06
26	12/25/08	0.28	0.028	0.100	9	10	2.41	0.02	0.01	0.01	7.3	0.33	0.04	0.07
27	01/28/09	0.27	0.077	0.284	60	38	1.66	0.13	0.03	0.06	8.8	0.38	0.18	0.31
28	02/28/09	0.57	0.136	0.239	8	18	0.39	0.01	0.01	0.05	9.4	0.37	0.07	0.08
29	04/06/09	0.20	0.020	0.100	8	6	1.26	0.02	0.01	0.01	15.0	0.52	0.10	0.50
30	04/10/09	0.41	0.106	0.259	18	8	1.25	0.35	0.01	0.22	11.4	0.43	0.04	0.07
Average		0.71	0.272	0.305	14	17	1.29	0.07	0.02	0.03	9.5	0.50	0.06	0.13
Median		0.58	0.164	0.271	7	10	0.89	0.03	0.01	0.02	8.6	0.40	0.05	0.09
S.D.		0.50	0.296	0.161	18	22	1.87	0.08	0.03	0.04	2.8	0.44	0.03	0.10
C.V.		0.70	1.086	0.528	1.28	1.29	1.44	1.26	1.42	1.43	0.30	0.89	0.54	0.81
10th Percentile		0.28			4			0.01	0.01	0.01		0.28	0.04	0.06
90th Percentile		1.15			35			0.13	0.05	0.08		0.65	0.09	0.26

Mt. Island Lake (MIL-W) Roadside Edge EMCs

Event	Date (MDY)	Rainfall (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/L)	Turbidity (NTU)	Chloride (mg/L)	NO3-N (mg/L)	PO4-P (mg/L)	NH4-N (mg/L)	NPOC (mg/L)	TN (mg/L)	TP (fil) (mg/L)	TP (unfil) (mg/L)
1	10/24/07	0.41	0.232	0.565	28	18	0.17	0.03	0.01	0.07	12.1	0.63	0.07	0.15
2	11/15/07	0.27	0.152	0.565	26	11	0.30	0.11	0.07	0.11	4.9	0.45	0.06	0.10
3	11/25/07	0.25	0.100	0.400	26	33	2.00	0.50	0.01	0.23	6.8	1.00	0.05	0.07
4	01/10/08	0.29	0.134	0.463	35	22	0.13	0.06	0.08	0.07	1.7	0.23	0.05	0.10
5	01/31/08	0.44	0.257	0.584	19	27	0.96	0.23	0.01	0.16	3.0	0.30	0.02	0.07
6	02/13/08	0.22	0.180	0.820	25	19	1.42	0.26	0.01	0.23	3.4	0.38	0.03	0.07
7	02/17/08	0.28	0.178	0.637	36	13	1.07	0.14	0.01	0.05	3.0	0.19	0.03	0.11
8	03/04/08	0.57	0.438	0.767	44	14	1.01	0.33	0.02	0.26	3.3	0.81	0.07	0.13
9	03/07/08	0.64	0.427	0.666	24	10	0.46	0.09	0.01	0.19	2.6	0.49	0.04	0.09
10	03/15/08	0.64	0.427	0.668	20	12	0.49	0.18	0.01	0.22	3.4	0.58	0.04	0.10
11	03/19/08	0.55	0.392	0.709	36	21	1.46	0.11	0.01	0.11	4.0	0.54	0.06	0.09
12	04/26/08	0.65	0.279	0.430	32	13	0.72	0.21	0.01	0.14	6.0	0.61	0.05	0.17
13	05/15/08	0.28	0.134	0.479	17	9	1.00	0.30	0.01	0.10	9.6	0.79	0.05	0.09
14	07/04/08	0.34	0.232	0.683	20	11	1.58	0.12	0.05	0.12	7.1	0.45	0.09	0.36
15	07/05/08	0.34	0.136	0.399	16	6	0.66	0.38	0.01	0.19	7.5	0.75	0.03	0.10
16	07/08/08	0.36	0.192	0.535	15	7	0.46	0.36	0.01	0.06	5.6	0.62	0.03	0.05
17	07/22/08	0.80	0.543	0.679	32	7	0.60	0.27	0.01	0.08	0.5	0.02	0.04	0.14
18	07/28/08	0.25	0.143	0.573	15	6	0.46	0.22	0.01	0.65	17.7	0.82	0.13	0.32
19	10/08/08	0.90	0.785	0.873	10	2	0.89	0.13	0.02	0.25	2.4	0.51	0.07	0.10
20	10/17/08	0.35	0.249	0.711	6	7	0.95	0.47	0.02	0.15	8.3	1.00	0.08	0.14
21	11/24/08	0.23	0.129	0.562	19	9	0.84	0.26	0.03	0.20	4.1	0.70	0.10	0.08
22	12/10/08	2.60	2.386	0.918	20		0.85	0.10	0.06	0.09	2.2	0.42	0.11	0.13
23	12/24/08	0.36	0.198	0.544	31	8	2.40	0.25	0.06	0.17	1.7	0.56	0.07	0.11
24	01/28/09	0.32	0.157	0.491	115	18	4.00	0.20	0.01	0.22	3.9	0.56	0.04	0.23
25	02/18/09	0.58	0.452	0.780	46	10	1.49	0.15	0.03	0.15	3.3	0.40	0.09	0.13
26	02/28/09	0.72	0.596	0.833	23	9	0.93	0.15	0.01	0.16	3.1	0.40	0.07	0.11
Average		0.52	0.367	0.628	28	13	1.05	0.22	0.02	0.17	5.0	0.55	0.06	0.13
Median		0.36	0.232	0.610	25	11	0.91	0.21	0.01	0.16	3.7	0.55	0.06	0.11
S.D.		0.46	0.446	0.146	20	7	0.81	0.12	0.02	0.12	3.7	0.23	0.03	0.07
C.V.		0.89	1.218	0.232	0.72	0.56	0.77	0.56	0.94	0.68	0.7	0.43	0.46	0.56
10th Percentile		0.26			15			0.10	0.01	0.07		0.26	0.03	0.07
90th Percentile		0.76			42			0.37	0.06	0.25		0.81	0.10	0.20

Mt. Island Lake (MIL-D) Vegetated Ditch EMCs

Event	Date (MDY)	Rainfall (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/L)	Turbidity (NTU)	Chloride (mg/L)	NO3-N (mg/L)	PO4-P (mg/L)	NH4-N (mg/L)	NPOC (mg/L)	TN (mg/L)	TP (fil) (mg/L)	TP (unfil) (mg/L)
1	10/24/07	0.41	0.024	0.059	10	6	0.22	0.02	0.01	0.08	1.9	0.29	0.04	0.05
2	11/15/07	0.27	0.011	0.039	11	9	4.25	0.18	0.08		15.4	0.87	0.09	0.18
3	11/25/07	0.25												
4	01/10/08	0.29	0.042	0.146	41	38	3.38	0.06	0.08	0.01	12.4	0.78	0.09	0.17
5	01/31/08	0.44	0.074	0.168	2	0	2.34	0.08	0.09	0.01	7.7	0.23	0.07	0.09
6	02/13/08	0.22	0.007	0.032	12	32	5.74	0.08	0.01	0.02	12.2	0.36	0.04	0.06
7	02/17/08	0.28	0.039	0.140	34	34	0.96	0.15	0.01	0.19	9.3	0.31	0.05	0.12
8	03/04/08	0.57	0.120	0.211	15	28	1.46	0.01	0.01	0.01	10.6	0.43	0.07	0.10
9	03/07/08	0.64	0.170	0.265	14	32	0.83	0.02	0.01	0.01	7.0	0.30	0.06	0.10
10	03/15/08	0.64	0.124	0.194	10	23	3.65	0.06	0.01	0.02	9.6	0.48	0.08	0.12
11	03/19/08	0.55	0.111	0.202	18	38	1.58	0.02	0.01	0.01	10.0	0.43	0.08	0.12
12	04/26/08	0.65	0.149	0.230	7	11	2.92	0.17	0.03	0.02	11.9	0.77	0.11	0.17
13	05/15/08	0.28	0.013	0.048	16	45	1.68	0.01	0.01	0.01	22.7	1.15	0.10	0.13
14	07/04/08	0.34	0.023	0.068										
15	07/05/08	0.34	0.022	0.065	6	14	1.57	0.02	0.01	0.01	19.9	0.91	0.04	0.07
16	07/08/08	0.36	0.044	0.122	9	12	1.41	0.15	0.01	0.05			0.04	0.08
17	07/22/08	0.80	0.208	0.260	9	6	2.47	0.08	0.04	0.01	8.9	0.43	0.08	0.14
18	07/28/08	0.25	0.002	0.009										
19	10/08/08	0.90	0.350	0.388	9	13	1.60	0.01	0.01	0.05	8.9	0.47	0.07	0.08
20	10/17/08	0.35	0.032	0.092	5	10	2.17	0.20	0.02	0.09	8.5	0.73	0.08	0.12
21	11/24/08	0.23	0.003	0.014	20	32	3.23	0.17	0.01	0.01	11.7	0.70	0.09	0.14
22	12/10/08	2.60	1.758	0.676	10		0.92	0.02	0.01	0.02	7.1	0.33	0.08	0.12
23	12/24/08	0.36	0.018	0.050	11	26	0.43	0.10	0.02	0.01	6.3	0.42	0.05	0.10
24	01/28/09	0.32	0.024	0.075	23	50	3.91	0.31	0.01	0.01	13.0	0.85	0.07	0.16
25	02/18/09	0.58	0.168	0.289	36	77	1.94	0.05	0.01	0.01	12.2	0.52	0.12	0.17
26	02/28/09	0.72	0.260	0.363	35	63	2.48	0.02	0.01	0.04	12.5	0.53	0.10	0.18
Average		0.52	0.152	0.168	16	27	2.22	0.09	0.02	0.03	10.9	0.56	0.07	0.12
Median		0.36	0.042	0.140	11	27	1.94	0.06	0.01	0.01	10.3	0.48	0.08	0.12
S.D.		0.46	0.347	0.151	11	20	1.34	0.08	0.03	0.04	4.4	0.25	0.02	0.04
C.V.		0.89	2.282	0.898	0.69	0.72	0.60	0.92	1.12	1.43	0.41	0.44	0.31	0.32
10th Percentile		0.26			6			0.01	0.01	0.01		0.30	0.04	0.07
90th Percentile		0.76			35			0.18	0.08	0.08		0.87	0.10	0.18

Jordan Lake North (JLN-W) Roadside Edge EMCs

Event	Date (MDY)	Rainfall (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/L)	Turbidity (NTU)	Chloride (mg/L)	NO3-N (mg/L)	PO4-P (mg/L)	NH4-N (mg/L)	NPOC (mg/L)	TN (mg/L)	TP (fil) (mg/L)	TP (unfil) (mg/L)
1	11/15/07	0.31	0.210	0.677	62	57	1.52	0.26	0.04	0.79	11.5	1.60	0.04	0.09
2	12/16/07	0.95	0.801	0.843										
3	01/17/08	0.61	0.433	0.710										
4	02/02/08	0.77	0.633	0.822	65	33	1.63	0.23	0.01	0.33	4.1	0.39	0.03	0.09
5	02/14/08	0.96	0.771	0.803	31	20	8.84	0.21	0.01	0.51	5.5	0.46	0.03	0.21
6	02/18/08	0.42	0.273	0.651	43	22	0.75	0.12	0.01	0.33	4.5	0.31	0.05	0.19
7	02/22/08	0.26	0.125	0.481	33	27	0.99	0.26	0.01	0.46	7.7	0.54	0.06	0.22
8	03/04/08	1.13	0.947	0.838	71	28	1.13	0.08	0.01	0.22	4.6	0.48	0.03	0.11
9	03/07/08	0.95	0.565	0.595	23	21	0.88	0.16	0.01	0.17	3.6	0.46	0.03	0.06
10	03/15/08	0.76	0.538	0.707	23	15	0.63	0.20	0.01	0.30	4.5	0.64	0.05	0.07
11	04/27/08	0.86	0.620	0.721	129	35	0.82	0.17	0.01	0.31	11.5	0.79	0.04	0.12
12	05/16/08	0.40	0.219	0.547	22	18	2.62	0.79	0.01	0.76	15.2	1.91	0.04	0.11
13	05/18/08	0.48	0.254	0.529	28	10	0.71	0.12	0.01	0.62	5.0	0.80	0.04	0.07
14	05/20/08	0.84	0.711	0.846	131	53	0.71	0.27	0.01	0.58	8.9	1.13	0.04	0.24
15	06/29/08	1.30	1.099	0.845										
16	07/04/08	1.27	1.097	0.864	151	11	0.38	0.17	0.01	0.21	5.4	0.49	0.04	0.06
17	07/28/08	0.67	0.500	0.746	45	7	0.43	0.23	0.01	0.33	5.7	0.74	0.07	0.37
18	09/10/08	0.67	0.369	0.550	23	11	0.41	0.13	0.01	0.13	4.0	0.39	0.04	0.07
19	09/16/08	1.43	0.902	0.631	35	5	0.33	0.12	0.01	0.09	2.2	0.33	0.04	0.05
20	10/17/08	0.61	0.419	0.687	16	10	0.32	0.17	0.01	0.17	2.4	0.43	0.05	0.07
21	11/24/08	0.35	0.239	0.683	17	8	0.55	0.33	0.01	0.47	4.7	1.00	0.08	0.34
22	12/20/08	0.71	0.603	0.850	11	8	0.87	0.18	0.01	0.47	2.6	0.67	0.04	0.10
23	12/25/08	0.29	0.169	0.582	21	6	2.81	0.25	0.01	0.43	3.1	0.91	0.03	0.07
24	01/28/09	0.36	0.204	0.567	470	270	3.95	0.29	0.01	0.79	6.8	0.94	0.02	0.39
25	02/27/09	0.76	0.345	0.453	15	16	0.59	0.14	0.01	0.37	4.7	0.62	0.06	0.08
26	04/10/09	0.33	0.182	0.550	77	25	1.55	0.49	0.01	0.62	12.2	1.62	0.03	0.22
Average		0.71	0.509	0.684	67	31	1.45	0.23	0.01	0.41	6.1	0.77	0.04	0.15
Median		0.69	0.466	0.685	33	18	0.82	0.20	0.01	0.37	4.7	0.64	0.04	0.10
S.D.		0.33	0.294	0.128	96	54	1.85	0.15	0.01	0.21	3.5	0.44	0.01	0.10
C.V.		0.47	0.579	0.187	1.44	1.73	1.27	0.64	0.55	0.51	0.57	0.57	0.33	0.71
10th Percentile		0.32			16			0.12		0.18		0.39	0.03	0.07
90th Percentile		1.20			130			0.32		0.75		1.50	0.06	0.32

Jordan Lake North (JLN-D) Vegetated Ditch EMCs

Event	Date (MDY)	Rainfall (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/L)	Turbidity (NTU)	Chloride (mg/L)	NO3-N (mg/L)	PO4-P (mg/L)	NH4-N (mg/L)	NPOC (mg/L)	TN (mg/L)	TP (fil) (mg/L)	TP (unfil) (mg/L)
1	11/15/07	0.31	0.020	0.065										
2	12/16/07	0.95	0.308	0.324	207	442	7.23	0.14	0.08	0.054	8.3	0.49	0.07	0.30
3	01/17/08	0.61	0.147	0.241	128	233	5.69	0.18	0.01	0.039	8.8	0.57	0.09	0.32
4	02/02/08	0.77	0.220	0.285	471	746	4.29	0.23	0.05	0.008	8.5	0.52	0.15	0.32
5	02/14/08	0.96	0.323	0.337	171	241	11.43	0.20	0.01	0.047	7.3	0.31	0.07	0.23
6	02/18/08	0.42	0.096	0.230	303	446	5.15	0.09	0.01	0.008	7.1	0.21	0.06	0.26
7	02/22/08	0.26	0.045	0.174										
8	03/04/08	1.13	0.452	0.400	539	744	4.44	0.06	0.01	0.008	9.0	0.43	0.06	0.48
9	03/07/08	0.95	0.254	0.268										
10	03/15/08	0.76	0.168	0.221										
11	04/27/08	0.86	0.221	0.257	1234	1163	3.59	0.04	0.01	0.008	8.9	0.35	0.06	1.01
12	05/16/08	0.40	0.040	0.100	212	218	4.85	0.04	0.01	0.008	0.1	0.01	0.06	0.31
13	05/18/08	0.48	0.066	0.138	446	496	3.70	0.07	0.01	0.008	10.2	0.60	0.05	0.45
14	05/20/08	0.84	0.268	0.319	935	800	3.54	0.06	0.01	0.008	7.1	0.46	0.06	0.63
15	06/29/08	1.30	0.502	0.386	2038	47	0.39	0.16	0.01	0.039	8.2	0.45	0.06	
16	07/04/08	1.27	0.568	0.447	1409	2112	3.73	0.03	0.01	0.008	5.7	0.29	0.05	
17	07/28/08	0.67	0.150	0.223	686	892	6.80	0.11	0.01	0.132	5.5	0.42	0.12	0.47
18	09/10/08	0.67	0.156	0.233										
19	09/16/08	1.43	0.623	0.435	1190	300	3.54	0.18	0.01	0.008	5.6	0.51	0.19	0.56
20	10/17/08	0.61	0.118	0.194	120	100	2.89	0.01	0.04	0.008	9.6	0.38	0.12	0.24
21	11/24/08	0.35	0.022	0.062	74	77	4.26	0.01	0.12	0.008	13.1	0.48	0.08	0.21
22	12/20/08	0.71	0.164	0.231	220	660	2.05	0.08	0.01	0.008	7.9	0.43	0.06	0.28
23	12/25/08	0.29	0.084	0.290	110	510	4.80	0.12	0.01	0.008	7.6	0.48	0.06	0.20
24	01/28/09	0.36	0.012	0.035	1040	325	4.23	0.18	0.01	0.008	8.8	0.49	0.07	0.77
25	02/27/09	0.76	0.172	0.226	148	214	1.62	0.07	0.01	0.054	7.9	0.40	0.14	0.24
26	04/10/09	0.33	0.017	0.052	197	455	2.32	0.01	0.01	0.039	10.5	0.37	0.06	0.19
Average		0.71	0.201	0.237	566	534	4.31	0.10	0.02	0.024	7.9	0.41	0.08	0.39
Median		0.69	0.160	0.232	303	446	4.23	0.08	0.01	0.008	8.2	0.43	0.06	0.31
S.D.		0.33	0.173	0.116	542	465	2.29	0.07	0.03	0.030	2.5	0.13	0.04	0.22
C.V.		0.47	0.86	0.49	0.96	0.87	0.53	0.69	1.31	1.24	0.32	0.32	0.46	0.56
10th Percentile		0.32			120			0.02	0.01	0.01		0.29	0.06	0.21
90th Percentile		1.20			1234			0.19	0.05	0.05		0.52	0.14	0.68

Appendix B – Unit Event Loads for Monitoring Sites

Jordan Lake South (JLS-W) Roadside Edge Unit-event-loads

Event	Date (MDY)	Rain (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/m^2)	Turbidity (NTU)	Chloride (mg/m^2)	NO3-N (mg/m^2)	PO4-P (mg/m^2)	NH4-N (mg/m^2)	NPOC (mg/m^2)	TN (mg/m^2)	TP (fil) (mg/m^2)	TP (unfil) (mg/m^2)
1	10/26/07	0.84	0.544	0.648	97	4	1.66	1.11	0.14	1.40	20	2.90	0.41	0.41
2	12/15/07	1.15	0.941	0.818										
3	01/17/08	0.55	0.330	0.600										
4	02/01/08	0.75	0.551	0.734	228	12	13.43	2.10	1.54	2.61	25	3.08	2.52	2.94
5	02/12/08	1.00	0.849	0.849	535	14	276.52	6.04	0.00	8.56	77	9.49	0.86	1.73
6	02/18/08	0.30	0.201	0.671	79	18	4.81	0.51	0.05	0.62	14	0.87	0.10	0.31
7	03/04/08	0.94	0.674	0.717	832	33	20.72	5.99	0.17	8.79	58	22.26	0.86	2.06
8	03/15/08	0.95	0.839	0.883	618	21	7.67	3.62	0.21	6.96	54	13.64	0.21	2.56
9	04/27/08	1.08	0.704	0.652										
10	05/18/08	0.44	0.330	0.749	100	7	6.20	1.26	0.08	4.75	36	6.95	0.33	1.17
11	05/20/08	0.52	0.340	0.654	584	36	6.83	1.38	0.09	3.63	35	6.14	0.35	1.73
12	07/04/08	0.44	0.236	0.536	215	20	4.19	2.81	0.06	4.05	53	8.32	0.18	0.60
13	07/05/08	0.67	0.432	0.645	549	20	4.50	1.54	0.11	1.19	30	3.95	0.33	0.77
14	07/06/08	1.26	1.039	0.825	514	10	10.82	4.22	0.26	4.93	73	10.82	0.79	1.85
15	07/18/08	0.53	0.266	0.502	342	16	7.09	3.71	0.07	4.83	37	10.13	0.27	0.68
16	07/23/08	0.38	0.261	0.688	52	7	2.99	4.85	0.20	1.34	60	7.83	0.33	0.46
17	07/27/08	0.24	0.138	0.577	54	7	2.25	0.98	0.04	1.78	25	3.55	0.42	1.05
18	08/13/08	0.28	0.098	0.351	15	7	0.85	0.40	0.02	0.41	50	2.62	0.07	0.15
19	08/26/08	2.73	2.139	0.784	348	5	38.04	9.78	0.54	4.23	229	25.00	2.17	2.72
20	09/10/08	0.73	0.471	0.646	129	5	5.87	1.80	0.12	1.40	33	4.79	0.48	0.60
21	09/16/08	0.98	0.780	0.796	624	5	6.14	3.17	0.20	2.00	37	6.54	0.59	0.59
22	10/17/08	0.60	0.493	0.822	85	7	4.13	1.88	0.38	0.58	20	3.38	1.00	2.26
23	11/03/08	0.65	0.550	0.846	105	6	9.22	1.54	0.70	1.63	27	3.91	0.98	1.26
24	11/24/08	0.30	0.060	0.199	12	9	0.62	0.40	0.21	0.20	5	0.74	0.08	0.29
25	12/20/08	1.28	1.064	0.831										
26	12/25/08	0.28	0.114	0.405	10	5	5.02	0.52	0.03	0.38	7	1.38	0.12	0.14
27	01/28/09	0.27	0.183	0.680	1631	235	10.44	1.44	0.05	1.41	18	3.40	0.14	2.33
28	02/28/09	0.57	0.380	0.669	111	11	1.74	0.87	0.10	1.20	19	2.70	0.48	0.77
29	04/06/09	0.20	0.102	0.511	71	16	2.55	0.49	0.03	0.38	15	1.40	0.08	0.34
30	04/10/09	0.41	0.281	0.685	228	6	8.84	2.50	0.07	1.55	31	5.20	0.14	0.86
Average		0.71	0.513	0.666	314	21	17.81	2.50	0.21	2.72	41.8	6.58	0.55	1.18
Median		0.58	0.406	0.676	172	9	6.00	1.67	0.10	1.59	32.3	4.37	0.34	0.81
S.D.		0.50	0.423	0.158	359	44	53.31	2.23	0.32	2.49	42.7	6.01	0.60	0.87
C.V.		0.70	0.825	0.238	1.14	2.13	2.99	0.89	1.51	0.91	1.02	0.91	1.10	0.74
10th Percentile		0.28			34			0.50	0.03	0.40		1.39	0.09	0.3
90th Percentile		1.15			621			5.42	0.46	5.95		12.23	0.99	2.45

Jordan Lake South (JLS-D) Vegetated Ditch Unit-event-loads

Event	Date (MDY)	Rain (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/m^2)	Turbidity (NTU)	Chloride (mg/m^2)	NO3-N (mg/m^2)	PO4-P (mg/m^2)	NH4-N (mg/m^2)	NPOC (mg/m^2)	TN (mg/m^2)	TP (fil) (mg/m^2)	TP (unfil) (mg/m^2)
1	10/26/07	0.84	0.452	0.538	80	8	7.69	0.11	1.03	0.09	84	3.10	0.46	0.46
2	12/15/07	1.15	0.577	0.502	132	13	11.87	0.15	1.91	0.11	238	38.54	1.61	1.76
3	01/17/08	0.55	0.114	0.208	20	13	2.03	0.06	0.26	0.05	17	0.84	0.15	0.20
4	02/01/08	0.75	0.258	0.344										
5	02/12/08	1.00	0.481	0.481	43	6	128.74	1.22	0.00	0.48	95	3.18	0.49	0.73
6	02/18/08	0.30	0.034	0.112	1	12	1.16	0.02	0.01	0.01	7	0.14	0.02	0.06
7	03/04/08	0.94	0.193	0.205	63	18	4.60	0.15	0.05	0.08	34	1.71	0.24	0.44
8	03/15/08	0.95	0.464	0.488	169	22	6.25	0.71	0.12	0.18	62	3.54	0.47	1.18
9	04/27/08	1.08	0.425	0.393	93	8	10.57	0.32	0.11	0.17	105	4.53	0.65	1.94
10	05/18/08	0.44	0.090	0.204	37	13	2.10	0.07	0.02	0.02	21	1.19	0.11	0.30
11	05/20/08	0.52	0.079	0.152	72	37	1.65	0.20	0.02	0.02	16	0.96	0.12	0.26
12	07/04/08	0.44	0.058	0.131	10	5	2.48	0.16	0.01	0.03	23	1.09	0.07	0.15
13	07/05/08	0.67	0.256	0.382	524	117	3.84	0.46	0.07	0.05	55	2.54	0.20	1.43
14	07/06/08	1.26	0.670	0.532	560	43	9.02	2.04	0.17	0.13	113	6.64	0.68	2.04
15	07/18/08	0.53	0.117	0.220	15	3	3.52	0.86	0.06	0.37	24	2.37	0.18	0.24
16	07/23/08	0.38	0.068	0.179	12	8	0.80	0.10	0.02	0.01	18	0.78	0.05	0.12
17	07/27/08	0.24	0.027	0.112	4	5	0.64	0.07	0.01	0.01	7	0.38	0.05	0.23
18	08/13/08	0.28	0.012	0.043										
19	08/26/08	2.73	1.388	0.508	135	16	26.40	0.35	0.35	1.13	269	10.30	1.41	2.24
20	09/10/08	0.73	0.344	0.472	29	6	6.04	0.17	0.09	0.34	112	5.07	0.35	0.61
21	09/16/08	0.98	0.445	0.454	73	10	4.86	0.34	0.11	0.26	87	3.96	0.45	0.90
22	10/17/08	0.60	0.236	0.393	4	6	3.77	0.06	0.06	0.33	52	2.39	0.48	0.60
23	11/03/08	0.65	0.227	0.349	27	6	5.25	0.06	0.06	0.18	66	2.77	0.40	0.46
24	11/24/08	0.30	0.057	0.190	10	10	1.88	0.06	0.01	0.01	16	0.69	0.12	0.16
25	12/20/08	1.28	0.732	0.572	223	15	16.18	0.19	0.19	0.14	144	5.58	0.93	1.12
26	12/25/08	0.28	0.028	0.100	6	10	1.71	0.01	0.01	0.01	5	0.23	0.03	0.05
27	01/28/09	0.27	0.077	0.284	117	38	3.23	0.25	0.06	0.12	17	0.74	0.35	0.60
28	02/28/09	0.57	0.136	0.239	27	18	1.35	0.03	0.03	0.19	33	1.28	0.24	0.28
29	04/06/09	0.20	0.020	0.100	4	6	0.64	0.01	0.01	0.00	8	0.26	0.05	0.25
30	04/10/09	0.41	0.106	0.259	49	8	3.38	0.95	0.03	0.59	31	1.16	0.11	0.19
Average		0.71	0.272	0.305	91	17	9.70	0.33	0.17	0.18	62.9	3.78	0.37	0.68
Median		0.58	0.164	0.271	40	10	3.65	0.15	0.06	0.12	33.3	2.04	0.24	0.45
S.D.		0.50	0.296	0.161	139	22	23.98	0.46	0.39	0.24	66.5	7.19	0.40	0.65
C.V.		0.70	1.086	0.528	1.54	1.29	2.47	1.39	2.27	1.32	1.06	1.90	1.06	0.96
10th Percentile		0.28			4			0.03	0.01	0.01		0.35	0.05	0.14
90th Percentile		1.15			196			0.91	0.31	0.43		6.11	0.81	1.85

Mt. Island Lake (MIL-W) Roadside Edge Unit-event-loads

Event	Date (MDY)	Rainfall (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/m^2)	Turbidity (NTU)	Chloride (mg/m^2)	NO3-N (mg/m^2)	PO4-P (mg/m^2)	NH4-N (mg/m^2)	NPOC (mg/m^2)	TN (mg/m^2)	TP (fil) (mg/m^2)	TP (unfil) (mg/m^2)
1	10/24/07	0.41	0.232	0.565	162	18	1.00	0.18	0.06	0.41	71	3.71	0.41	0.88
2	11/15/07	0.27	0.152	0.565	101	11	1.16	0.43	0.27	0.42	19	1.74	0.23	0.39
3	11/25/07	0.25	0.100	0.400	66	33	5.08	1.27	0.03	0.59	17	2.54	0.13	0.18
4	01/10/08	0.29	0.134	0.463	120	22	0.44	0.20	0.27	0.24	6	0.79	0.17	0.34
5	01/31/08	0.44	0.257	0.584	123	27	6.26	1.50	0.07	1.07	20	1.96	0.13	0.46
6	02/13/08	0.22	0.180	0.820	114	19	6.50	1.19	0.05	1.03	15	1.74	0.14	0.32
7	02/17/08	0.28	0.178	0.637	163	13	4.85	0.63	0.05	0.21	13	0.86	0.14	0.50
8	03/04/08	0.57	0.438	0.767	493	14	11.23	3.67	0.22	2.94	36	9.01	0.78	1.45
9	03/07/08	0.64	0.427	0.666	264	10	4.98	0.98	0.11	2.11	29	5.31	0.43	0.98
10	03/15/08	0.64	0.427	0.668	213	12	5.32	1.95	0.11	2.36	37	6.29	0.43	1.09
11	03/19/08	0.55	0.392	0.709	358	21	14.52	1.09	0.10	1.08	39	5.37	0.60	0.90
12	04/26/08	0.65	0.279	0.430	224	13	5.11	1.49	0.07	0.99	43	4.33	0.35	1.21
13	05/15/08	0.28	0.134	0.479	58	9	3.41	1.02	0.03	0.34	33	2.69	0.17	0.31
14	07/04/08	0.34	0.232	0.683	116	11	9.31	0.71	0.29	0.69	42	2.65	0.53	2.12
15	07/05/08	0.34	0.136	0.399	55	6	2.27	1.31	0.03	0.64	26	2.58	0.10	0.34
16	07/08/08	0.36	0.192	0.535	74	7	2.25	1.76	0.05	0.30	27	3.03	0.15	0.24
17	07/22/08	0.80	0.543	0.679	440	7	8.27	3.72	0.14	1.07	6	0.28	0.55	1.93
18	07/28/08	0.25	0.143	0.573	55	6	1.67	0.80	0.04	2.35	64	2.98	0.47	1.16
19	10/08/08	0.90	0.785	0.873	192	2	17.75	2.59	0.40	4.97	48	10.17	1.40	1.99
20	10/17/08	0.35	0.249	0.711	35	7	6.01	2.97	0.13	0.93	52	6.32	0.51	0.89
21	11/24/08	0.23	0.129	0.562	63	9	2.76	0.85	0.10	0.66	14	2.30	0.33	0.26
22	12/10/08	2.60	2.386	0.918	1201		51.51	6.06	3.64	5.18	133	25.45	6.67	7.88
23	12/24/08	0.36	0.198	0.544	154	8	12.08	1.26	0.30	0.86	9	2.82	0.35	0.55
24	01/28/09	0.32	0.157	0.491	458	18	15.96	0.80	0.04	0.87	16	2.23	0.16	0.92
25	02/18/09	0.58	0.452	0.780	528	10	17.11	1.72	0.34	1.70	38	4.59	1.03	1.49
26	02/28/09	0.72	0.596	0.833	343	9	14.08	2.27	0.15	2.47	46	6.06	1.06	1.67
Average		0.52	0.367	0.628	237	13	8.88	1.63	0.27	1.40	34.6	4.53	0.67	1.17
Median		0.36	0.232	0.610	158	11	5.66	1.26	0.10	0.96	30.7	2.90	0.38	0.89
S.D.		0.46	0.446	0.146	246	7	10.16	1.30	0.69	1.32	26.5	4.90	1.27	1.49
C.V.		0.89	1.218	0.232	1.04	0.56	1.14	0.80	2.55	0.94	0.8	1.08	1.89	1.27
10th Percentile		0.26			57			0.32	0.03	0.32		0.52	0.14	0.29
90th Percentile		0.76			476			3.32	0.32	2.71		7.67	1.05	1.96

Mt. Island Lake (MIL-D) Vegetated Ditch Unit-event-loads

Event	Date (MDY)	Rainfall (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/m^2)	Turbidity (NTU)	Chloride (mg/m^2)	NO3-N (mg/m^2)	PO4-P (mg/m^2)	NH4-N (mg/m^2)	NPOC (mg/m^2)	TN (mg/m^2)	TP (fil) (mg/m^2)	TP (unfil) (mg/m^2)
1	10/24/07	0.41	0.024	0.059	6	6	0.13	0.01	0.01	0.05	1	0.18	0.02	0.03
2	11/15/07	0.27	0.011	0.039	3	9	1.14	0.05	0.02	0.00	4	0.23	0.02	0.05
3	11/25/07	0.25												
4	01/10/08	0.29	0.042	0.146	45	38	3.64	0.06	0.09	0.01	13	0.84	0.10	0.18
5	01/31/08	0.44	0.074	0.168	3	0	4.39	0.15	0.17	0.01	15	0.43	0.13	0.17
6	02/13/08	0.22	0.007	0.032	2	32	1.03	0.01	0.00	0.00	2	0.06	0.01	0.01
7	02/17/08	0.28	0.039	0.140	34	34	0.95	0.15	0.01	0.19	9	0.31	0.05	0.12
8	03/04/08	0.57	0.120	0.211	46	28	4.47	0.03	0.03	0.02	32	1.32	0.21	0.31
9	03/07/08	0.64	0.170	0.265	58	32	3.58	0.09	0.04	0.03	30	1.29	0.26	0.43
10	03/15/08	0.64	0.124	0.194	31	23	11.52	0.19	0.03	0.05	30	1.51	0.25	0.38
11	03/19/08	0.55	0.111	0.202	51	38	4.46	0.06	0.03	0.02	28	1.21	0.23	0.34
12	04/26/08	0.65	0.149	0.230	27	11	11.08	0.64	0.11	0.09	45	2.92	0.42	0.64
13	05/15/08	0.28	0.013	0.048	5	45	0.57	0.00	0.00	0.00	8	0.39	0.03	0.04
14	07/04/08	0.34	0.023	0.068										
15	07/05/08	0.34	0.022	0.065	4	14	0.88	0.01	0.01	0.00	11	0.51	0.02	0.04
16	07/08/08	0.36	0.044	0.122	10	12	1.58	0.17	0.01	0.05	0	0.00	0.04	0.09
17	07/22/08	0.80	0.208	0.260	47	6	13.03	0.42	0.21	0.04	47	2.27	0.42	0.74
18	07/28/08	0.25	0.002	0.009										
19	10/08/08	0.90	0.350	0.388	76	13	14.20	0.09	0.09	0.48	79	4.17	0.62	0.71
20	10/17/08	0.35	0.032	0.092	4	10	1.78	0.16	0.02	0.07	7	0.60	0.07	0.10
21	11/24/08	0.23	0.003	0.014	2	32	0.26	0.01	0.00	0.00	1	0.06	0.01	0.01
22	12/10/08	2.60	1.758	0.676	442		41.08	0.89	0.45	0.69	317	14.73	3.57	5.36
23	12/24/08	0.36	0.018	0.050	5	26	0.20	0.05	0.01	0.00	3	0.20	0.02	0.05
24	01/28/09	0.32	0.024	0.075	14	50	2.39	0.19	0.01	0.00	8	0.52	0.04	0.10
25	02/18/09	0.58	0.168	0.289	153	77	8.26	0.21	0.04	0.03	52	2.21	0.51	0.72
26	02/28/09	0.72	0.260	0.363	229	63	16.36	0.13	0.07	0.26	82	3.50	0.66	1.19
Average		0.52	0.152	0.168	56	27	6.39	0.16	0.06	0.09	35.9	1.72	0.34	0.51
Median		0.36	0.042	0.140	27	27	3.58	0.09	0.03	0.03	13.3	0.60	0.10	0.17
S.D.		0.46	0.347	0.151	100	20	9.07	0.22	0.10	0.17	65.7	3.07	0.73	1.10
C.V.		0.89	2.282	0.898	1.77	0.72	1.42	1.31	1.59	1.85	1.83	1.79	2.19	2.15
10th Percentile		0.26			3			0.01	0.01	0.01		0.07	0.02	0.03
90th Percentile		0.76			150			0.41	0.15	0.25		3.40	0.60	0.72

Jordan Lake North (JLN-W) Roadside Edge Unit-event-loads

Event	Date (MDY)	Rainfall (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/m^2)	Turbidity (NTU)	Chloride (mg/m^2)	NO3-N (mg/m^2)	PO4-P (mg/m^2)	NH4-N (mg/m^2)	NPOC (mg/m^2)	TN (mg/m^2)	TP (fil) (mg/m^2)	TP (unfil) (mg/m^2)
1	11/15/07	0.31	0.210	0.677	331	57	8.11	1.39	0.21	4.23	61	8.53	0.21	0.48
2	12/16/07	0.95	0.801	0.843										
3	01/17/08	0.61	0.433	0.710										
4	02/02/08	0.77	0.633	0.822	1041	33	26.19	3.70	0.16	5.37	65	6.27	0.48	1.45
5	02/14/08	0.96	0.771	0.803	603	20	173.03	4.11	0.20	9.90	107	9.00	0.59	4.11
6	02/18/08	0.42	0.273	0.651	301	22	5.21	0.83	0.07	2.32	31	2.15	0.35	1.32
7	02/22/08	0.26	0.125	0.481	106	27	3.15	0.83	0.03	1.46	24	1.72	0.19	0.70
8	03/04/08	1.13	0.947	0.838	1711	28	27.19	1.92	0.24	5.24	111	11.55	0.72	2.65
9	03/07/08	0.95	0.565	0.595	336	21	12.64	2.30	0.14	2.46	52	6.61	0.43	0.86
10	03/15/08	0.76	0.538	0.707	314	15	8.60	2.73	0.14	4.04	62	8.74	0.68	0.96
11	04/27/08	0.86	0.620	0.721	2024	35	12.91	2.68	0.16	4.90	181	12.44	0.63	1.89
12	05/16/08	0.40	0.219	0.547	120	18	14.57	4.39	0.06	4.24	85	10.62	0.22	0.61
13	05/18/08	0.48	0.254	0.529	183	10	4.58	0.77	0.06	4.01	32	5.16	0.26	0.45
14	05/20/08	0.84	0.711	0.846	2371	53	12.82	4.88	0.18	10.53	161	20.40	0.72	4.33
15	06/29/08	1.30	1.099	0.845										
16	07/04/08	1.27	1.097	0.864	4195	11	10.59	4.74	0.28	5.85	151	13.66	1.12	1.67
17	07/28/08	0.67	0.500	0.746	567	7	5.46	2.92	0.13	4.15	73	9.39	0.89	4.70
18	09/10/08	0.67	0.369	0.550	216	11	3.84	1.22	0.09	1.24	37	3.65	0.37	0.66
19	09/16/08	1.43	0.902	0.631	802	5	7.56	2.75	0.23	2.14	51	7.56	0.92	1.15
20	10/17/08	0.61	0.419	0.687	169	10	3.40	1.81	0.11	1.82	26	4.58	0.53	0.74
21	11/24/08	0.35	0.239	0.683	101	8	3.34	2.00	0.06	2.83	28	6.07	0.49	2.07
22	12/20/08	0.71	0.603	0.850	164	8	13.33	2.76	0.15	7.15	40	10.27	0.61	1.53
23	12/25/08	0.29	0.169	0.582	89	6	12.05	1.07	0.04	1.84	13	3.90	0.13	0.30
24	01/28/09	0.36	0.204	0.567	2435	270	20.47	1.50	0.05	4.07	35	4.87	0.10	2.02
25	02/27/09	0.76	0.345	0.453	131	16	5.16	1.23	0.09	3.20	41	5.43	0.53	0.70
26	04/10/09	0.33	0.182	0.550	354	25	7.15	2.26	0.05	2.87	56	7.47	0.14	1.01
Average		0.71	0.509	0.684	811	31	17.45	2.38	0.13	4.17	66.3	7.83	0.49	1.58
Median		0.69	0.466	0.685	331	18	8.60	2.26	0.13	4.04	52.0	7.47	0.49	1.15
S.D.		0.33	0.294	0.128	1048	54	34.59	1.27	0.07	2.43	46.3	4.20	0.27	1.26
C.V.		0.47	0.579	0.187	1.29	1.73	1.98	0.53	0.56	0.58	0.70	0.54	0.56	0.80
10th Percentile		0.32			110			0.90	0.05	1.83		3.70	0.15	0.50
90th Percentile		1.20			2360			4.20	0.22	7.10		12.20	0.82	4.10

Jordan Lake North (JLN-D) Vegetated Ditch Unit-event-loads

Event	Date (MDY)	Rainfall (inches)	Runoff (inches)	Runoff Ratio	TSS (mg/m^2)	Turbidity (NTU)	Chloride (mg/m^2)	NO3-N (mg/m^2)	PO4-P (mg/m^2)	NH4-N (mg/m^2)	NPOC (mg/m^2)	TN (mg/m^2)	TP (fil) (mg/m^2)	TP (unfil) (mg/m^2)
1	11/15/07	0.31	0.020	0.065										
2	12/16/07	0.95	0.308	0.324	1618	442	56.51	1.09	0.63	0.43	65	3.83	0.55	2.34
3	01/17/08	0.61	0.147	0.241	478	233	21.28	0.67	0.04	0.15	33	2.13	0.34	1.20
4	02/02/08	0.77	0.220	0.285	2625	746	23.92	1.28	0.28	0.04	48	2.90	0.84	1.78
5	02/14/08	0.96	0.323	0.337	1401	241	93.91	1.64	0.08	0.38	60	2.55	0.58	1.89
6	02/18/08	0.42	0.096	0.230	742	446	12.61	0.22	0.02	0.02	17	0.51	0.15	0.64
7	02/22/08	0.26	0.045	0.174										
8	03/04/08	1.13	0.452	0.400	6193	744	51.03	0.69	0.11	0.09	103	4.94	0.69	5.52
9	03/07/08	0.95	0.254	0.268										
10	03/15/08	0.76	0.168	0.221										
11	04/27/08	0.86	0.221	0.257	6926	1163	20.14	0.22	0.06	0.04	50	1.96	0.34	5.67
12	05/16/08	0.40	0.040	0.100	217	218	4.95	0.04	0.01	0.01	0	0.01	0.06	0.32
13	05/18/08	0.48	0.066	0.138	747	496	6.21	0.12	0.02	0.01	17	1.01	0.08	0.75
14	05/20/08	0.84	0.268	0.319	6359	800	24.07	0.41	0.07	0.05	48	3.13	0.41	4.28
15	06/29/08	1.30	0.502	0.386	25968	47	4.97	2.04	0.13	0.50	104	5.73	0.76	
16	07/04/08	1.27	0.568	0.447	20315	2112	53.78	0.43	0.14	0.11	82	4.18	0.72	
17	07/28/08	0.67	0.150	0.223	2608	892	25.85	0.42	0.04	0.50	21	1.60	0.46	1.79
18	09/10/08	0.67	0.156	0.233										
19	09/16/08	1.43	0.623	0.435	18819	300	55.98	2.85	0.16	0.12	89	8.07	3.00	8.86
20	10/17/08	0.61	0.118	0.194	359	100	8.67	0.03	0.12	0.02	29	1.14	0.36	0.72
21	11/24/08	0.35	0.022	0.062	41	77	2.35	0.01	0.07	0.00	7	0.27	0.04	0.12
22	12/20/08	0.71	0.164	0.231	917	660	8.54	0.33	0.04	0.03	33	1.79	0.25	1.17
23	12/25/08	0.29	0.084	0.290	235	510	10.25	0.26	0.02	0.02	16	1.03	0.13	0.43
24	01/28/09	0.36	0.012	0.035	328	325	1.34	0.06	0.00	0.00	3	0.15	0.02	0.24
25	02/27/09	0.76	0.172	0.226	647	214	7.08	0.31	0.04	0.24	35	1.75	0.61	1.05
26	04/10/09	0.33	0.017	0.052	86	455	1.01	0.00	0.00	0.02	5	0.16	0.03	0.08
Average		0.71	0.201	0.237	4649	534	23.55	0.62	0.10	0.133	41.1	2.33	0.50	2.04
Median		0.69	0.160	0.232	917	446	12.61	0.33	0.06	0.044	32.7	1.79	0.36	1.17
S.D.		0.33	0.173	0.116	7534	465	24.74	0.76	0.14	0.170	32.4	2.08	0.63	2.37
C.V.		0.47	0.86	0.49	1.62	0.87	1.05	1.21	1.39	1.28	0.79	0.89	1.28	1.16
10th Percentile		0.32			217			0.03	0.01	0.01		0.16	0.04	0.21
90th Percentile		1.20			18820			1.64	0.16	0.43		4.94	0.76	5.60