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Final Report

Sampling and Testing of Stormwater Runoff from North Carolina Highways

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16. Abstract

This report presents research findings pertaining to the implementation of a comprehensive monitoring program for characterization of North Carolina highway runoff. Ten monitoring sites distributed in the Piedmont (6 sites), Mountains (2 sites) and Coastal (2 sites) regions were included in the study. Contributing drainage areas ranged from 0.15 to 13.26 acres. Roadway imperviousness and traffic volumes ranged from 22% to 100% and 9,400 to 78,800 vehicles/day both directions, respectively. Rainfall-runoff data and composite storm water samples were obtained from 237 storm events. The effectiveness of vegetative best management practices (BMPs) was assessed by comparing pollutant exports from 3 groups of paired monitoring sites. A database was established for estimation of seasonal and annual pollutant loads and event-mean-concentrations (EMCs). The study was part of NC DOT's effort in compliance with NPDES requirements.

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This study was supported as Research Project 99-6 by the U.S. Department of Transportation and the North Carolina Department of Transportation through the Center for Transportation and the Environment, N.C. State University.

Executive Summary

This report presents research findings pertaining to the implementation of a comprehensive monitoring program for characterization of North Carolina highway runoff. Ten monitoring sites distributed in the Piedmont (6 sites), Mountains (2 sites) and Coastal (2 sites) regions were included in the study. Contributing drainage areas ranged from 0.15 to 13.26 acres. Roadway imperviousness and traffic volumes ranged from 22% to 100% and 9,400 to 78,800 vehicles/day both directions, respectively. Rainfall-runoff data and composite storm water samples were obtained from 237 storm events. The effectiveness of vegetative best management practices (BMPs) was assessed by comparing pollutant exports from three groups of paired monitoring sites. A database was established for estimation of seasonal and annual pollutant loads and event-mean-concentrations (EMCs). The study was part of NC DOT's effort in compliance with NPDES requirements.

EMCs for Cd, Cr and Ni were found to be essentially below method detection limits (MDLs). Pb was typically at or slightly above MDLs. Zn was consistently well below the secondary drinking water standard of 5 mg/L. Site average EMCs for COD, NH_3-N, TKN, OP and TP are generally within the North Carolina urban runoff concentration ranges. All monitoring sites exhibit site median EMCs ranging from 10% to 25% below the national rural highway runoff concentrations. TKN is 25% below the national urban highway runoff concentration.

The annual loads expressed as lb/ac-yr for COD, TKN, NH_3-N, NO_{3+2}-N and TP in North Carolina highway runoff are within the lower percentiles (10-30%) of the national highway runoff data, when the reported national data range is linearly scaled between its upper and lower values. Seasonal loads are reported according to the 4 quarters of a year. Statistical relationships have been obtained to correlate pollutant loadings to daily traffic and/or watershed imperviousness.

Vegetative coverage was found to be effective in reducing TSS and the associated pollutants. Pervious roadside surfaces may release higher loadings of COD, P and N when compared to equivalent impervious surfaces. The reduction of pollutant export in highway runoff mainly results from infiltration losses as runoff moves over the pervious surfaces and efforts to maximize infiltration capacity of these surfaces should be encouraged.

Individual export functions for total nitrogen (TN) from highway runoff have been developed for the "Piedmont and Mountains" and "Coastal plain," respectively. These export functions were based on the use of monitoring data to validate model parameters required by the Schueler's Simple Method, and could serve as a practical tool for NC DOT to design new BMPs or retrofit existing ones. When applying the Simple Method using parameter values derived from North Carolina urban watersheds, the estimated export of TN from North Carolina highways may be overestimated by as much as 1.48 times.

Further research is needed to incorporate additional factors, in additional to contributing drainage imperviousness, into the export functions; to quantify the mechanisms of pollutant removal by vegetative coverage; and to apply GIS and computer models for watershed-level pollutant loading calculations.

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1. Introduction

The North Carolina Department of Transportation (NC DOT), under its regulatory mandate, is required to perform storm water characterization and retrofit studies to minimize pollutant discharges. According to the National Pollutant Discharge Elimination System (NPDES) permit that was issued to NC DOT, storm water discharging from facilities owned by NC DOT including roadway drainage, construction sites, and borrow pit wastewater, are covered by the permit requirements.

Drs. Jy S. Wu, Craig Allan and Jack Evett from the University of North Carolina at Charlotte were contracted by NC DOT, through ITRE, to implement the characterization study of roadway drainage for the period of October 1998 through June 2001. Section A of the NPDES permit specifies that characterization of roadway drainage must include the implementation of an analytical monitoring program:

- that is a comprehensive monitoring program following guidelines recommended by Young et al. (1996)
- that provides seasonal and annual pollutant loading estimates and event mean concentrations (EMCs)
- that examines the effectiveness of best management practices (BMP), and
- that shall be implemented upon the approval by the North Carolina Division of Water Quality (NC DWQ)

Accordingly, the primary objective of this study was to develop a database by which seasonal and annual pollutant loadings and EMCs can be estimated for a variety of roadway surfaces and traffic volumes. The database was established through the implementation of a comprehensive monitoring program on roadways throughout the Piedmont, Coastal and Mountains regions. The effectiveness of certain BMPs was assessed by comparing pollutant exports from paired monitoring sites with and without vegetative coverage. In addition, the export of total nitrogen (TN) in relation to imperviousness of the drainage area was examined. Separate export functions of TN have been developed for "the Piedmont and Mountains region" and "the Coastal Plain," respectively. NC DOT can refer to these export function in designing new BMPs or retrofitting existing ones for the control of nitrogen discharge with potential cost savings.

This report presents research findings of storm water characterization from N.C. roadways in an effort to assist NC DOT to be in compliance with NPDES requirements. The report is divided into eight chapters and includes five Appendixes. Monitoring site characteristics and the associated monitoring methodology and laboratory procedures are described in Chapter 2. Chapter 3 documents the rainfall statistics and hydrologic findings pertaining to rainfall-runoff relationships. Chapter 4 presents the site-average and site-median EMCs, compares these EMCs with the national highway runoff data, evaluates the effects of imperviousness and traffic volumes on EMCs, and assesses the variability of EMCs among monitoring sites. Chapter 5 summarizes the pollutant discharges as unit event load, unit pollutant loading rates, and seasonal and annual loads.

The variability of seasonal loads for particulate and dissolved pollutants was also examined. Chapter 6 investigates the effectiveness of BMPs and identifies the relative removals between hydrologic and vegetative retention. Export functions of total nitrogen as related to roadway drainage imperviousness are presented in Chapter 7. Separate export functions have been developed for "the Piedmont and Mountains" and "the Coastal plain," respectively. Concluding remarks and recommendations are given in Chapter 8.

2. Methodology and Procedures

2.1 Selection of Monitoring Sites

Upon consulting NC DOT, the following criteria were developed and adopted for the selection of highway runoff monitoring sites:

Criterion 1: Providing geographical representation of the Piedmont, Mountains and Coastal regions.

Criterion 2: Encompassing a wide range of daily traffic volumes.

Criterion 3: Allowing an evaluation of BMPs such as connection to pervious vegetative coverage, drainage swales etc.

Criterion 4: Enabling an examination of covariance of roadway segments along I-40 stretching from the Mountains to the Coastal region.

Site surveys were initiated shortly after the project startup in October of 1998. The project team examined a number of potential sites including those suggested by NC DOT. A total of ten monitoring sites were strategically selected to meet the selection criteria with optimal numbers of site locations. Table 2.1 summarizes the physical characteristics of each monitoring site. Drainage maps are included in Appendix 1. Sites meeting the selection criteria are described below.

Criterion 1: These are sites 1 and 2, 3, 4, 5 and 10 in the Piedmont, sites 6 and 7 in the Coastal plain, and sites 8 and 9 in the Blue Ridge Mountains. Each physiographic region included a pair of sites, e.g. sites 1 and 2, 6 and 7 and 8 and 9. One of the paired-sites was 100% imperviousness while the second site contained a mix of impervious and pervious vegetation coverage. Traffic counts for these sites are in the range of 4,000 to 20,000 vehicles/day per traffic direction.

Criterion 2: These are sites 1, 3, 4, 5 10. All of these sites are in the Piedmont with traffic counts ranging from 4,000 to 40,000 vehicles/day per traffic direction.

Criterion 3: These are the paired sites of 1 and 2, 6 and 7, and 8 and 9. Other sites with a portion of their roadway runoff draining into pervious areas are also included. These sites can be characterized by increasing percentage of pervious coverage due to vegetative connection or drainage swale.

Criterion 4: These are sites 4, 5, 6, 7, 8, and 9 with traffic counts varying from 10,000 to 40,000 vehicles/day per traffic direction.

Table 2.1 Characteristics of the Ten Highway Runoff Monitoring Sites in North Carolina

Site No.	Site Name Abbreviation	Site location City/County	Geographical Location	ADT (x1000) Vehicles/day*	Drainage area, acres	Imperviousness, %
1	CLT-1	W.T. Harris blvd., bridge deck, Charlotte, Mecklenburg county	Piedmont	50.2	0.37	100
2	CLT-2	N.C. 49 and W.T. Harris Blvd. Overpass Charlotte, Mecklenburg county	Piedmont	33.4	0.57	61
3	US-74	US Hwy 74, west of SR 1005 at Broad River and east to west of US 221, Rutherford county	Piedmont	9.3	0.86	50
4	WIN	I-40 Bypass Near Winston Salem, Guilford county.	Piedmont	52.5	2.16	48
5	GAR	I-40, north of Garner, Wake county	Piedmont	78.8	3.46	33
6	WIL-1	I-40, North of Kings Grant, New Hanover country	Coastal	20.3	0.15	100
7	WIL-2	I-40, North of Kings Grant, New Hanover county	Coastal	20.3	0.22	47
8	ASH-1	I-40, Asheville, Buncombe county	Mountains	39.0	0.16	100
9	ASH-2	I-40, Asheville, Buncombe county	Mountains	39.0	0.36	42
10	MON	US601, near Monroe, Union County	Piedmont	9.4	13.46	22

* Data represents a typical weekly average and includes traffic counts for east/west or north/south bounds

2.2 Site Descriptions

Figure 2.1 displays the general locations of each monitoring site. Details of site characteristics and drainage conditions are provided below and in Table 2.1.

Site 1 (CLT-1): This section of W.T. Harris Blvd. is a major artery around the north and east sides of the city of Charlotte, extending from I-77 on the north to U.S. 74 on the southeast. The highway segment that was sampled is located on a three-lane concrete bridge with a posted speed limit of 89 km/h (55 mi/h). Runoff originating from the bridge deck enters a pipe located at the northeast corner of the bridge, flows through a pipe under the bridge, and finally discharges through a sample collection trough with 60^o v-notch weir into a vegetated area.

Site 2 (CLT-2): N.C. 49 is a state highway connecting Charlotte and Raleigh. The highway segment that was sampled is located along a three-lane asphalt section and included a mixed impervious and pervious runoff contributing area. The posted speed limit is 81 km/h (50 mi/h). Runoff at this site drains to a catch basin located at the north edge of the grassy shoulder, and then flows through an underground pipe and discharges through a sample collection trough 60^o v-notch weir into a vegetation area. Runoff may occasionally bypass the pervious area and flow directly into the catch basin from the impervious roadside.

Site 3 (US-74): U.S. 74 is a state highway running from Wilmington, N.C. to the Tennessee border along the southern part of the state. The highway segment that was sampled is located along a four-lane asphalt section approximately midway between exit 178 (Forest City) and SR 2169. The site includes a mix of impervious and pervious runoff contributing areas. The posted speed limit is 90 km/h (55 mi/h). Runoff at this site is collected from a central medium drain and is routed by a 12-inch culvert under the two lanes of eastbound traffic, discharging through a 60^o v-notch weir before emptying into an adjacent surface drainage ditch.

Site 4 (WIN): I-40 is a major interstate highway running from Wilmington, N.C. to the Tennessee border. The highway segment that was sampled is located along a four-lane asphalt section approximately 2 miles west of Exit 208 and east of Kernersville, near Winston Salem. This site includes a mix of impervious and pervious runoff contributing areas. The posted speed limit is 105 km/h (65 mi/h). Runoff at this site is collected from a central medium drain which is routed by a 24-inch culvert under the two lanes of eastbound traffic where curb and gutter runoff from the east bound lane enters before the combined runoff discharges through a 60^o v-notch weir into an adjacent surface drainage ditch.

Site 5 (GAR): This section of I-40 is a major interstate connection running between Wilmington and Raleigh, N.C. The highway segment that was sampled is located along a six-lane asphalt/concrete section immediately south of exit 303, near Garner. The posted speed limit is 110 km/h (70 mi/h). Runoff from this site is collected from a roadside drain in the swale west of the southbound lanes of I-40, two central median drains, and a roadside drain just east of the northbound lanes of I-40. Runoff was collected from the 24-inch culvert draining this system onto the eastside of the northbound lanes after passing through a 90^o v-notch weir that emptied the runoff into an adjacent ravine.

Site 6 (WIL-1): This section of I-40 is a major interstate connection running between Wilmington and Raleigh, N.C. The highway segment that was monitored is a curb and gutter drain, 1/4 mile south of exit 414. The site is 100% impervious with an exposed steel pipe carrying runoff from the two southbound lanes through a 60^o v-notch weir to an offsite drainage ditch. The posted speed limit is 110 km/h (70 mi/h).

Site 7 (WIL-2): This section of I-40 is a major interstate connection running between Wilmington and Raleigh, N.C. The highway segment that was monitored is located just north of exit 420 approximately 300' south of SR 1322. The site is a mix of impervious and pervious cover with runoff originating from the central median culvert and draining to the west of the two southbound lanes of I-40. The posted speed limit is 110 km/h (70 mi/h).

Site 8 (ASH-1): This section of I-40 is a major interstate entering NC from Tennessee and carries considerable truck traffic. The highway segment that was sampled is located along a four-lane asphalt section one mile west of exit 59 (approx. mile 57.5), just to the east of Asheville, N.C. The posted speed limit is 90 km/h (55 mi/h). Runoff from this site is generated from the two lanes of westbound traffic and collected by a curb and gutter drain. The site is 100% impervious. Runoff was collected from an 8-inch culvert draining to the north side of the westbound lanes. Access to the drain is from a side road within an industrial park adjacent to the highway.

Site 9 (ASH-2): This section of I-40 is a major interstate entering NC from Tennessee and carries considerable truck traffic. The highway segment that was sampled is located along a four-lane asphalt section one mile west of exit 59 (approx. mile 57.5), just to the east of Asheville, N.C. This site is directly opposite from Site 8. The posted speed limit is 90 km/h (55 mi/h). Runoff from this site is collected from the center and side medians of I-40 as well as from the side median of an adjacent access road. The site is a mix of pervious and impervious cover. Runoff was collected from a 24-inch culvert draining to the south side of the eastbound lanes. Access to the drain is from an access road (Buckeye) that runs parallel to the eastbound lanes of I-40.

Site 10 (MON): This section of US-601 carries traffic between US-74 to the north and Pageland, SC. The highway segment that was sampled is located along a five-lane asphalt section 1.5 miles south of US74, just to the south east of Monroe, N.C. The posted speed limit is 90 km/h (55 mi/h). Runoff from this site is generated from five traffic lanes and is collected by a curb and gutter drain and both side medians. Runoff was collected from a 12-inch culvert at the outlet of a “sluice gate” detention basin draining to the west side of the southbound lanes. Runoff from this basin enters a small stream draining into Lake Lee, a water supply reservoir for the city of Monroe.

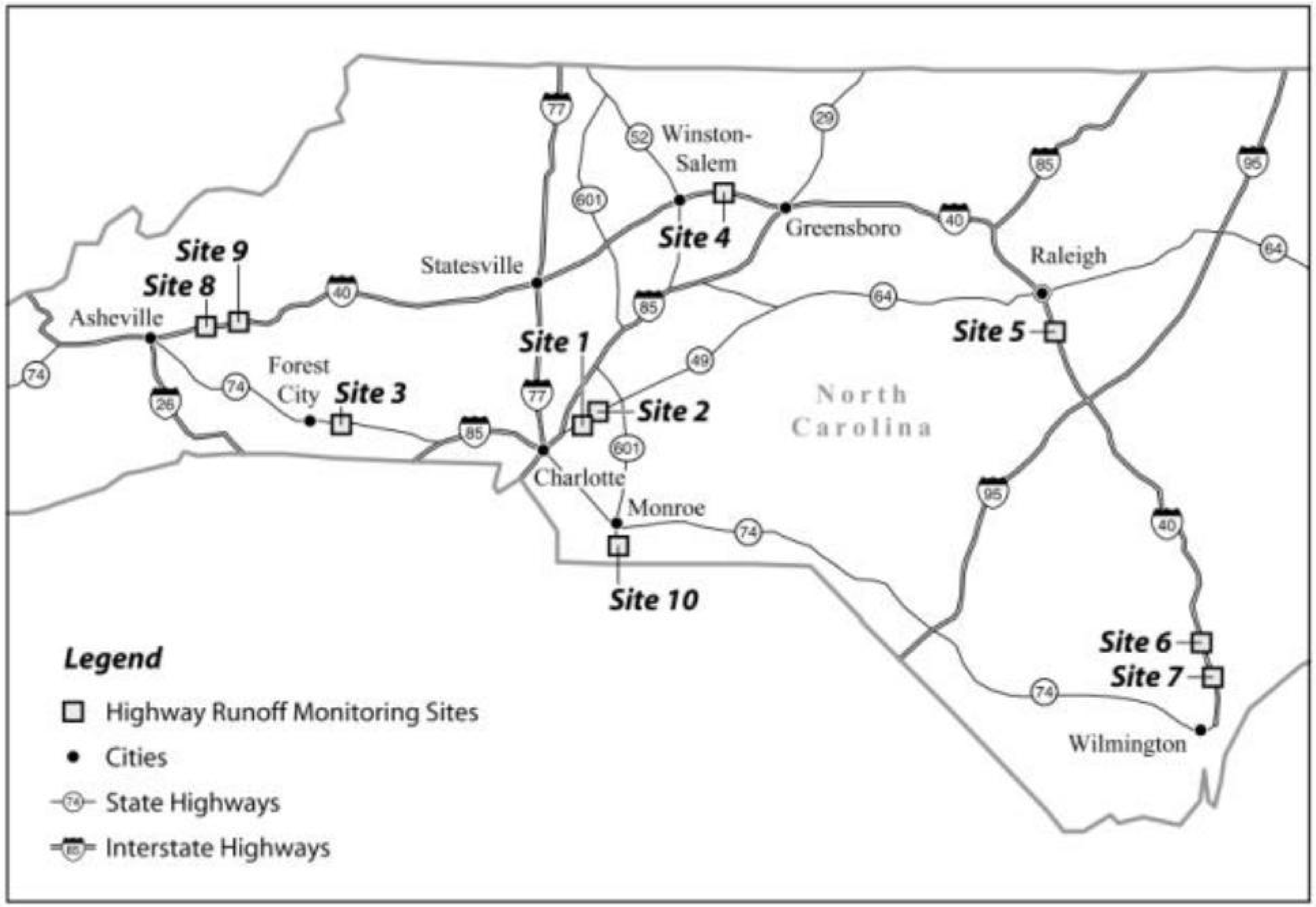


Figure 2.1 Locations of Highway Runoff Monitoring Sites

2.3 Sampling Methodology

The sampling period was from May 1999 to December 2000. As suggested by NC DWQ, a minimum of twenty storm events, distributed approximately evenly in each quarter of a calendar year, was required at each monitoring site. Table 2.2 summarizes the number of composite samples collected at all monitoring sites.

Table 2.2: Collection of Composite Highway Runoff Samples

Site no.	Ending June 99	Ending Sept 99	Ending Dec 99	Ending Mar 00	Ending Jun 00	Ending Sept. 00	Ending Dec. 00	Total number of samples/site
1	5	6	6	6	4	-	-	27
2	4	6	3	6	5	-	-	24
3		3	7	7	5	4	-	26
4	1	6	6	7	5	-	-	25
5	1	4	7	7	4	2	-	25
6	1	4	4	6	6	4	-	25
7			3	4	6	3	4	20
8		1	5	6	5	5	-	22
9			5	5	5	5	-	20
10		5	6	6	6	-	-	23
Sub-total	12	35	52	60	51	23	4	Total = 237

A document titled "Procedures and Quality Control for Sampling and Analysis of Highway Runoff Storm Water Samples" was submitted to NC DWQ for approval in April of 1999. This document provides details of the sampling methodology and procedures. The following sections summarize the key features of the sampling methodology that was included in the Procedures and QC document.

2.3.1 Storm criteria:

A representative storm event, for sampling purpose, is defined as a single storm event that accumulates greater 0.2 inches of rainfall preceded by at least 72 hours in which no storm event measuring greater 0.2 inches has occurred. A single storm event may contain up to 10 consecutive hours of no precipitation. For example, if it rains for 2 hours without producing any collectable discharge and then stops, a sample may be collected if a rain producing discharge begins again within the next 10 hours.

2.3.2 Sample handling requirements

Procedures of sample collection, storage, and preservation were performed in accordance to guidelines for sample preservation and storage as recommended by Standard Methods (APHA, 1998). Volume-weighted composite runoff samples were collected by American Sigma 800 or 900 Max automatic water samplers at all sites except 8 and 9. Composite runoff samples were collected at sites 8 and 9 through the use of a passive elliptical splitter that was designed to divert a constant fraction of flow into a large collection tank. Runoff samples in the tank were stirred with a plastic paddle to be homogenized prior to collection. Samples were transferred to the analytical laboratory within 24-48 hours after the cessation of runoff.

2.3.3 Laboratory procedures

The Mecklenburg County Laboratory was contracted to perform all chemical analyses. As a certified laboratory, the Mecklenburg County Laboratory provided documentation of QA/QC procedures and detection limits for each of the following water quality parameter constituents that had been analyzed.

1. Total suspended solids (TSS)
2. Total dissolved solids (TDS)
3. Oil and grease (O&G)
4. Chemical oxygen demand (COD)
5. Acidity and alkalinity
6. Nitrate-N (NO_3-N)
7. Nitrite-N (NO_2-N)
8. Ammonium (NH_3-N)
9. Total Kjeldald nitrogen (TKN as N)
10. ortho-phosphorus (OP as P),
11. Total phosphorus (TP as P), and
12. Trace Metals including cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni) and zinc (Zn)

Samples for metal analysis were preserved with nitric acid for at least seven days prior to determination of metal concentrations in the aliquot. The measured metal concentrations may or may not be equivalent to total metal (with sample digestion). However, it represents the maximum leachable metals that would appear in receiving waters under extremely acidic conditions. Results of laboratory analyses and QA/QC procedures are provided in a computer diskette as an attachment to this report.

To assure data reproducibility, the Environmental Research laboratory at UNC-Charlotte also performed chemical analyses for TSS, COD, acidity, alkalinity, nitrate-N, nitrite-N, and orth-P. Satisfactory and consistent analytical results have been reported to NC DWQ, when comparing both laboratories' data. However, only analytical data provided by the Mecklenburg laboratory, as the data source from a certified laboratory, are presented in this report.

2.3.4 Precipitation

The depth and timing of precipitation was measured at each of the monitoring sites. Each site was equipped with a standard non-recording and a tipping bucket installed on a 2.5-meter pole. For each of the paired sites, these gauges were installed at only one of the two sites of each pair. Temporal precipitation data was logged either by an American Sigma 800 or 900 Max automatic water sampler or an American Sigma 950 water level recorder. Tipping bucket precipitation totals were corrected to standard gauge rainfall totals. When snow or mixed precipitation occurred for events with missing field data, precipitation totals were derived from the nearest US weather bureau meteorological station.

A limited number of bulk precipitation samples was collected at sites 1, 6 and 8. The collection samplers consisted of 5-gallon plastic buckets with removable plastic liners suspended 2.5 meters above the ground surface. Precipitation samples were analyzed for several selected water quality constituents in the same manner as runoff samples.

2.4 Hydrologic Monitoring

Runoff data was collected from pipe outlets draining impervious roadway surfaces (sites 1, 6 and 8), or a mixture of impervious roadway and pervious vegetated surfaces (sites 2, 3, 4, 5, 7, 9 and 10). A 60^{o} or 90^{o} v-notch weir was installed at the end of the pipe outlet at sites 1-6. Water levels were logged by either an American Sigma 800 (sites 1 and 2) or 900MAX (sites 3-6) automatic water sampler and converted to discharge using rating relationships appropriate for each v-notch.

Insufficient elevation existed below the outlet pipe to install a v-notch weir at sites 7 and 10. At site 7, the discharge from the pipe outlet was determined from water elevations recorded in the drainage pipe by an American Sigma 900 Max automatic water sampler and converted to discharge using Manning's equation, based on the slope and dimensions of the outlet pipe. At site 10, a significant backwater condition existed during most runoff events as the pipe outlet elevation was partially submerged by an adjacent creek. A unique water level/discharge relationship was determined for this pipe outlet by using an American Sigma 900MAX water sampler with the capability of recording water level elevation (pressure transducer) and flow velocity (Doppler). This sampler was run in parallel with an American Sigma 800 sampler that logged the data for most of the events at this site. Dual stage regression was established between the two samplers to correct the discharge data originally logged by the Sigma 800 sampler.

A passive flow proportional sampling system was installed at sites 8 and 9. This system consisted of an elliptical splitter installed at each site's pipe outlet. The splitter was designed to divert 10% of the total flow volume, as shown in Figure 2.2. Runoff from the elliptical splitter was further subdivided by a series of gated flow diversions until only a fraction of the original flow discharged into a 100-gallon (site 8) or 200-gallon (site 9) collecting vessel. The runoff collected in the sampling vessel represents a flow-weighted composite sample for the entire runoff event. Temporal changes in water level in the collecting vessel were logged by either an American Sigma 950 "bubbler" water level recorder (site 9), or a Campbell Scientific CR510 data logger monitoring a DRUC pressure transducer (site 8). Stage/volume curves were determined for both of the two collecting vessels. Runoff from each site was determined by multiplying the volume of sample in the tank at any particular time by the inverse of the fraction of flow collected at each site.

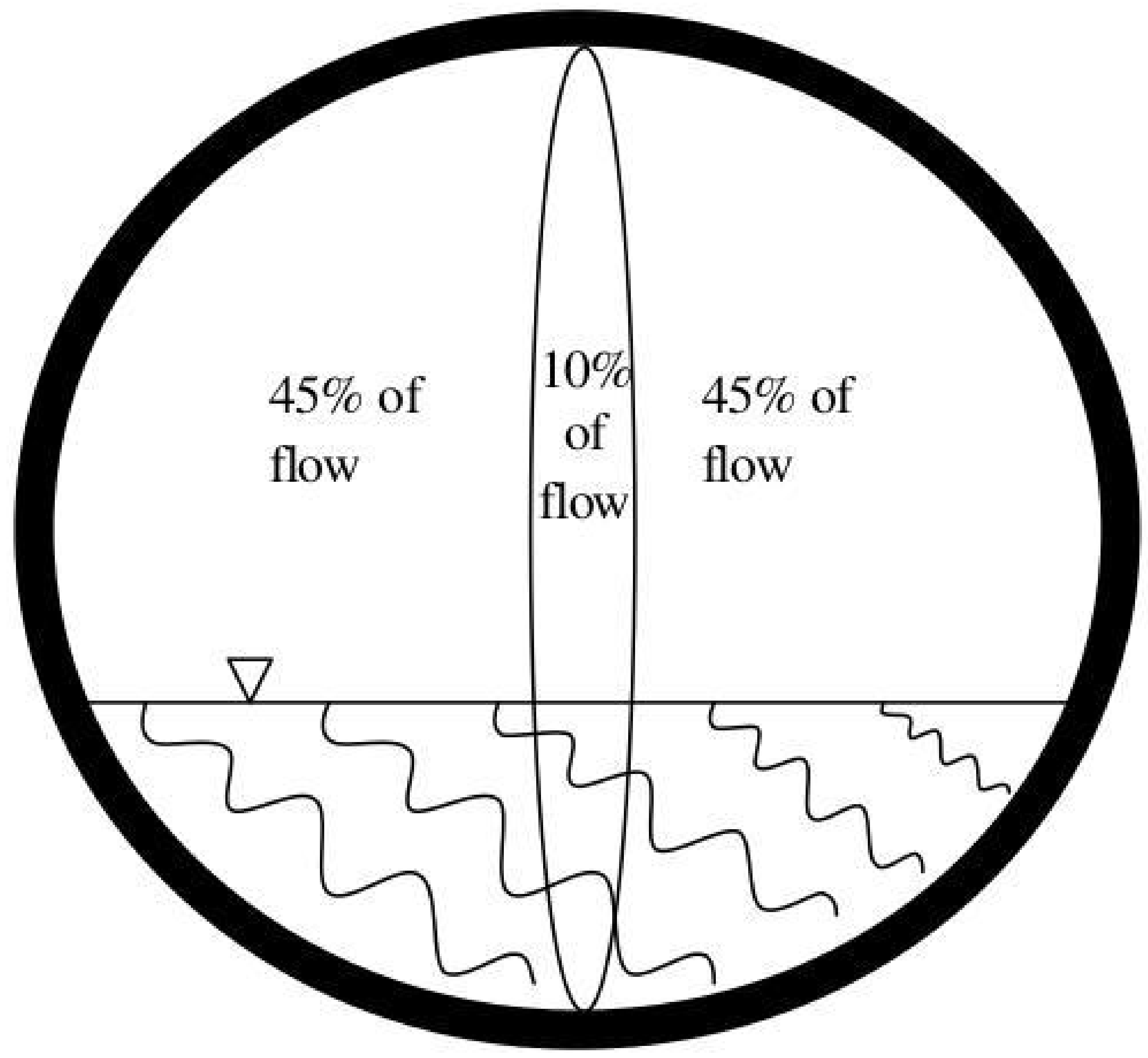


Figure 2.2 Elliptical Flow Splitter

"Two flow dividers, made of aluminum, were fabricated for use in pipes of 8- and 24-inch internal diameters. The dividers were fabricated using a 4-axis wire electrical discharge machine (EDM), with a specified elliptical cross section to provide constant division with water height. Because the divider must have finite thickness to be self-supporting, the 4-axis capabilities of the EDM were used to produce a triangular cross-section in which a sharp edge of the cross-section faced into the in-coming water flow and followed the elliptical contour. The cross-section expands downstream until the divider is 0.125-inch thick 1.5- inch from the leading edge. The total cost for the two splitters was about $500. The total cost of system installation was less than $1,000 as compared to the cost of $6000-7000 of an automatic sampler."

3. Hydrology

3.1 Rainfall Statistics

Rainfall statistics covering a 12-month duration in which the majority of sampling efforts were accomplished is presented in Table 3.1. The average storm duration, D, from Table 3.1 was taken as the average of individual storm duration. The time-between-storm, Δ, is the time elapsed from the previous storm to the beginning of the next storm. The ratio of D/Δ is of particular importance for computing the annual pollutant loads, as explained in Chapter 5. The unusually higher average rainfall intensity at Monroe was due to several extremely short-duration storms, typically with less than 5-minute duration and rainfall of 0.2-0.3 inches. When these storms are excluded from computing the average, the annual average rainfall intensity at Monroe becomes 0.37 in/hr. In general, the average storm duration is relatively shorter than the typically cited duration of 6 hrs and the time-between-storms is longer than the normally reported value of 77 hours for North Carolina conditions. During the period of 1999-2000, Piedmont and Mountains regions experienced precipitation deficits greater than 10 inches below normal, while rainfall at Wilmington was exceeding 50 inches due to hurricane Floyd.

Table 3.1. Rainfall Statistics at Monitoring Sites

Raingage Location	Monitoring sites Served by Raingage	Average Duration D, hrs	Average Time Between Storm Δ, hrs	Annual Rainfall Intensity in/hr	Ratio of D/Δ
Charlotte	CLT-1, CLT-2	2.60	182.86	0.25	0.0142
US-74	US-74	2.74	149.27	0.20	0.0094
Asheville	ASH-1, Ash-2	2.61	224.75	0.31	0.0116
Winston	WIN	2.42	121.03	0.24	0.0199
Garner	GAR	3.24	196.32	0.29	0.0165
Monroe	MON	1.94	205.71	0.70	0.0094
Wilmington	WIL-1, WIL-2	2.03	120.52	0.43	0.0169

3.2 Precipitation Comparison

In order to put the precipitation for the period of sampling into perspective with the "normal" precipitation for the three physiographic zones in the state, the National Weather Service precipitation records during the study period for Charlotte, Asheville and Wilmington are compared to the climatic normals of each location (Tables 3.2, 3.2 and 3.4). The precipitation totals are recorded at the local airport for each location.

The precipitation recorded for each region of the state during the study period differed dramatically. The Charlotte precipitation total was 85% of normal, Asheville 76% of normal and Wilmington 114% of normal. The Charlotte and Asheville precipitation totals reflect the prolonged drought experienced in the western and central regions of the state during the 1990's. The Asheville sites were particularly affected with all but one month recording above normal precipitation. Precipitation at the Charlotte site was more erratic than Asheville, with most months exhibiting precipitation deficits but above normal months were also recorded. The Wilmington record is dominated by the precipitation totals associated with Hurricane Floyd, 23.41 inches in September of 1999. Beyond this one event, the Coastal plain experienced slightly below normal precipitation for the study period.

Table 3.2. Precipitation Comparison for Charlotte

Month	Charlotte Data	Monthly Normals	Deviation
1999 May	1.50	3.82	-2.32
June	4.02	3.39	0.63
July	3.39	3.92	-0.53
August	1.42	3.73	-2.31
September	4.26	3.50	0.76
October	5.47	3.36	2.11
November	1.49	3.23	-1.74
December	1.74	3.48	-1.74
2000 January	4.07	3.71	0.36
February	2.59	3.84	-1.25
March	3.59	4.43	-0.84
April	5.48	2.68	2.80
May	1.17	3.82	-2.65
Total	40.09	46.91	-6.82

Table 3.3. Precipitation Comparison for Asheville

Month	Asheville Data	Monthly Normals	Deviation
1999 September	2.20	3.87	-1.67
October	3.31	3.59	-0.28
November	3.31	3.59	-0.28
December	1.54	3.52	-1.98
2000 January	3.10	3.25	-0.15
February	2.33	3.91	-1.58
March	3.83	4.63	-0.81
April	5.11	3.36	1.75
May	4.43	4.43	-3.16
June	4.23	4.23	-1.45
July	2.84	4.52	-1.68
August	4.45	4.69	-0.24
Total	36.06	47.59	-11.53

Table 3.4. Precipitation Comparison for Wilmington

Month	Wilmington Data	Monthly Normals	Deviation
1999 June	3.91	5.98	-2.07
July	4.54	8.13	-3.59
August	8.35	6.94	1.41
September	23.41	5.04	18.37
October	3.81	2.69	1.12
November	3.58	3.11	0.47
December	1.41	3.63	-2.22
2000 January	4.66	3.87	0.79
February	1.31	3.70	-2.39
March	2.61	3.88	-1.27
April	4.64	2.87	1.77
May	3.70	4.43	-0.73
June	6.26	5.98	0.28
July	7.83	8.13	-0.30
August	8.38	6.94	1.44
September	7.77	5.04	2.73
October	0.38	2.69	-2.31
November	4.67	3.11	1.56
December	1.64	3.63	-1.99
Total	102.86	89.79	13.07

3.3 Rainfall-Runoff Relationships

Runoff data from each site was examined on an event-by-event basis to ensure the integrity and consistency of the hydrologic data. During the study, both missing and erroneous runoff data had to be considered. Missing data was generally attributed to intermittent faults in the Data Transfer Units used to collect the digital data from the automatic water sampler. If the site was at a paired location and the temporal rainfall record was available from the sister site, the missing hydrograph was synthesized using the SCS dimensionless hydrograph technique. The curve numbers and travel times required for this technique were derived from survey data and the SCS segmental travel time methodology. Synthetic hydrographs were generated using the Virginia Tech Pennsylvania State Hydrologic Model (VTPSHM) (Seybert and Kibler, 1990) and compared to runoff for events with complete hydrologic data. SCS curve numbers and travel times were adjusted until runoff totals from the synthetic hydrograph most closely matched measured data. The "fitted" dimensionless hydrograph technique was then applied to the event with missing data. If the temporal rainfall record was unavailable for an event with missing data, the runoff total was estimated using the rainfall-runoff relationship for that site.

Erroneous data was generally attributed to the blockage of drainage pipe intakes or pipe/weir outlets by roadside debris. On one or two instances, erroneous data was obtained from the "bubbler" sampler at site 9 when the bubbler tubing was dislodged from the bottom of the collection tank. Cumulative runoff and precipitation curves were plotted for each storm event in order to analyze the consistency of the measured runoff data. When significant positive or negative diversions occurred between cumulative runoff and precipitation total, the complete or partial hydrograph was estimated by using the SCS dimensionless hydrograph utility within VTPSHM. The rainfall-runoff relationships are contained in Appendix 2 and shown in Figures 3.1-3.10.

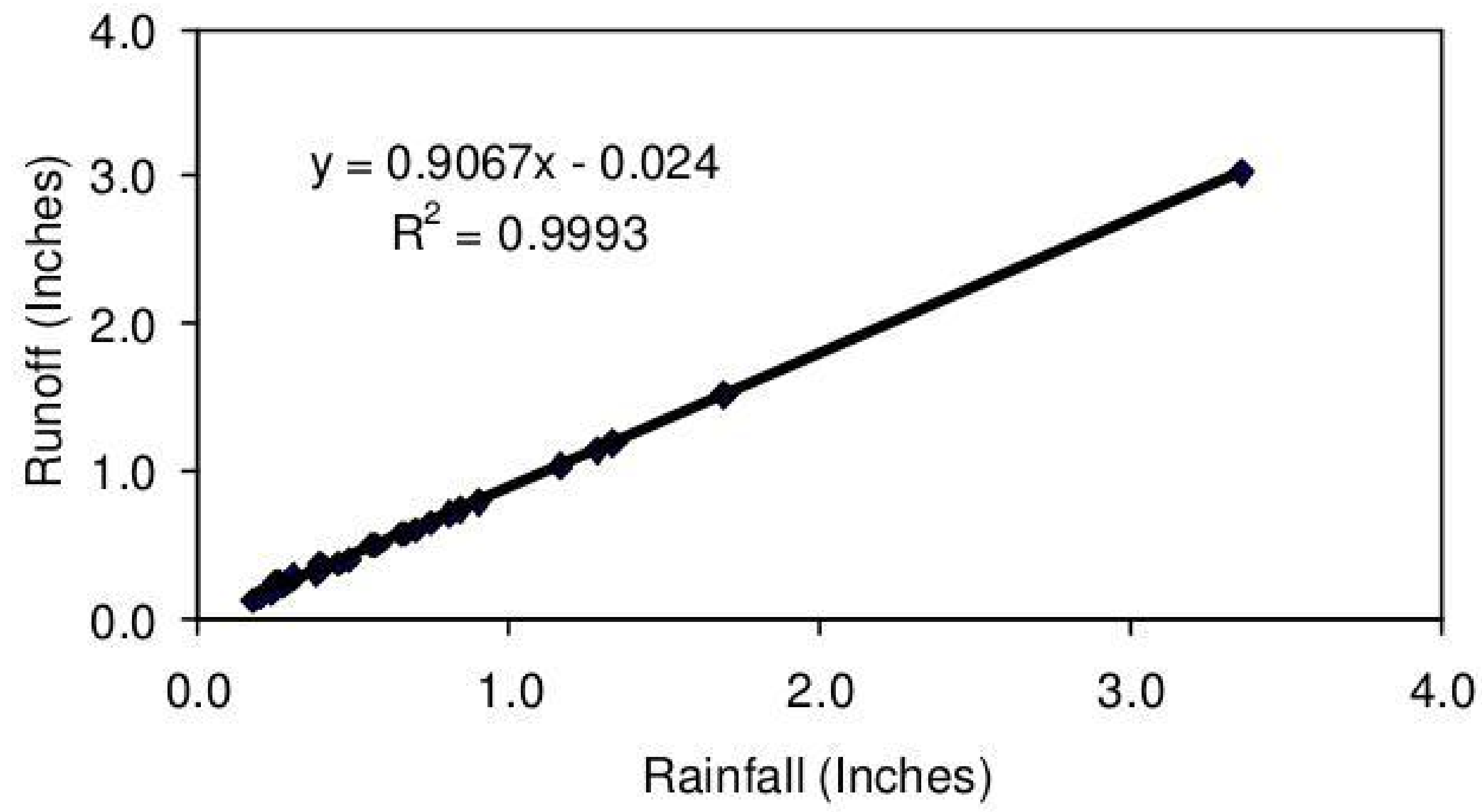


Figure 3.1 Rainfall-Runoff Relationship at CLT-1

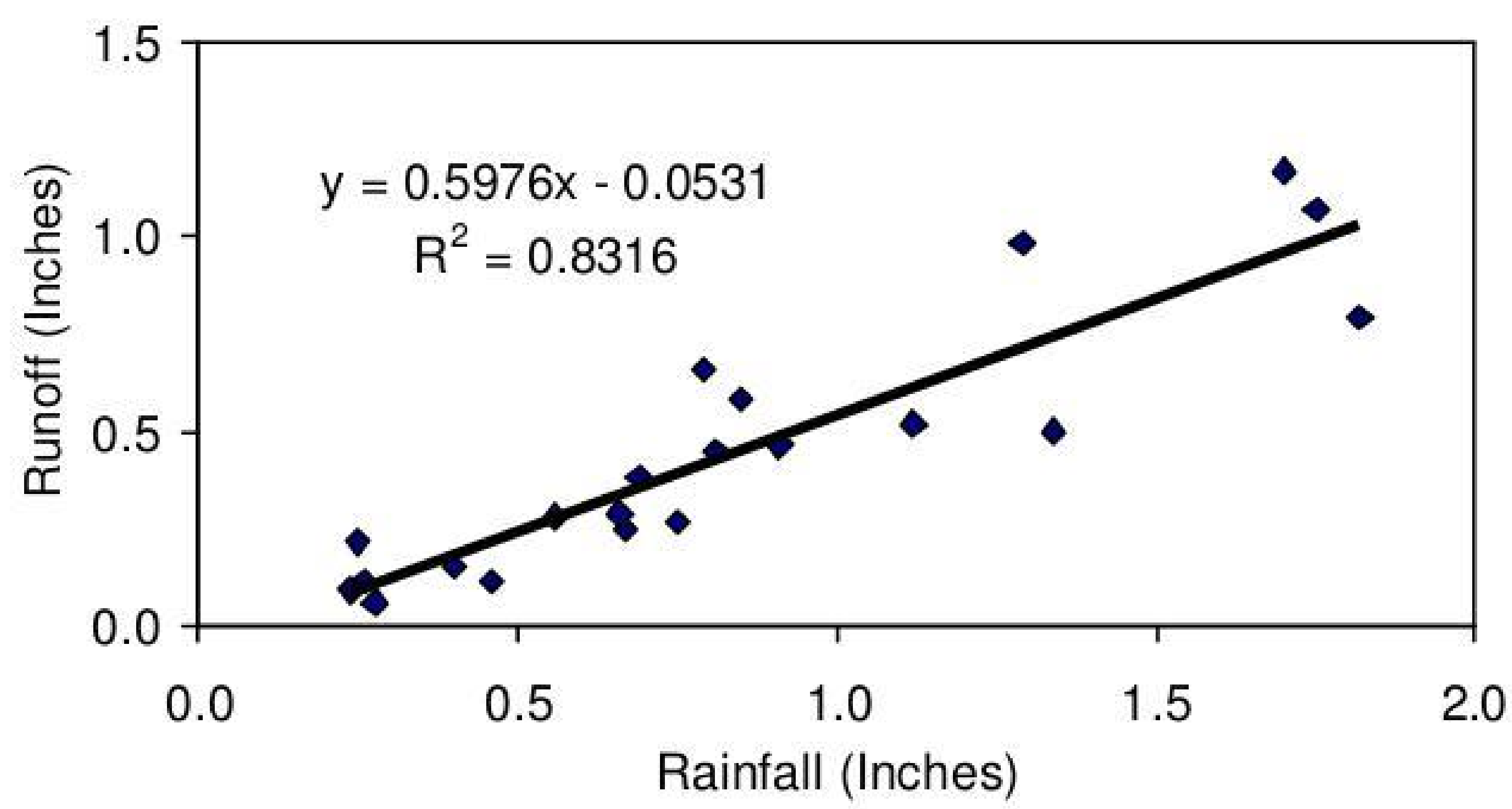


Figure 3.2 Rainfall-Runoff Relationship at CLT-2

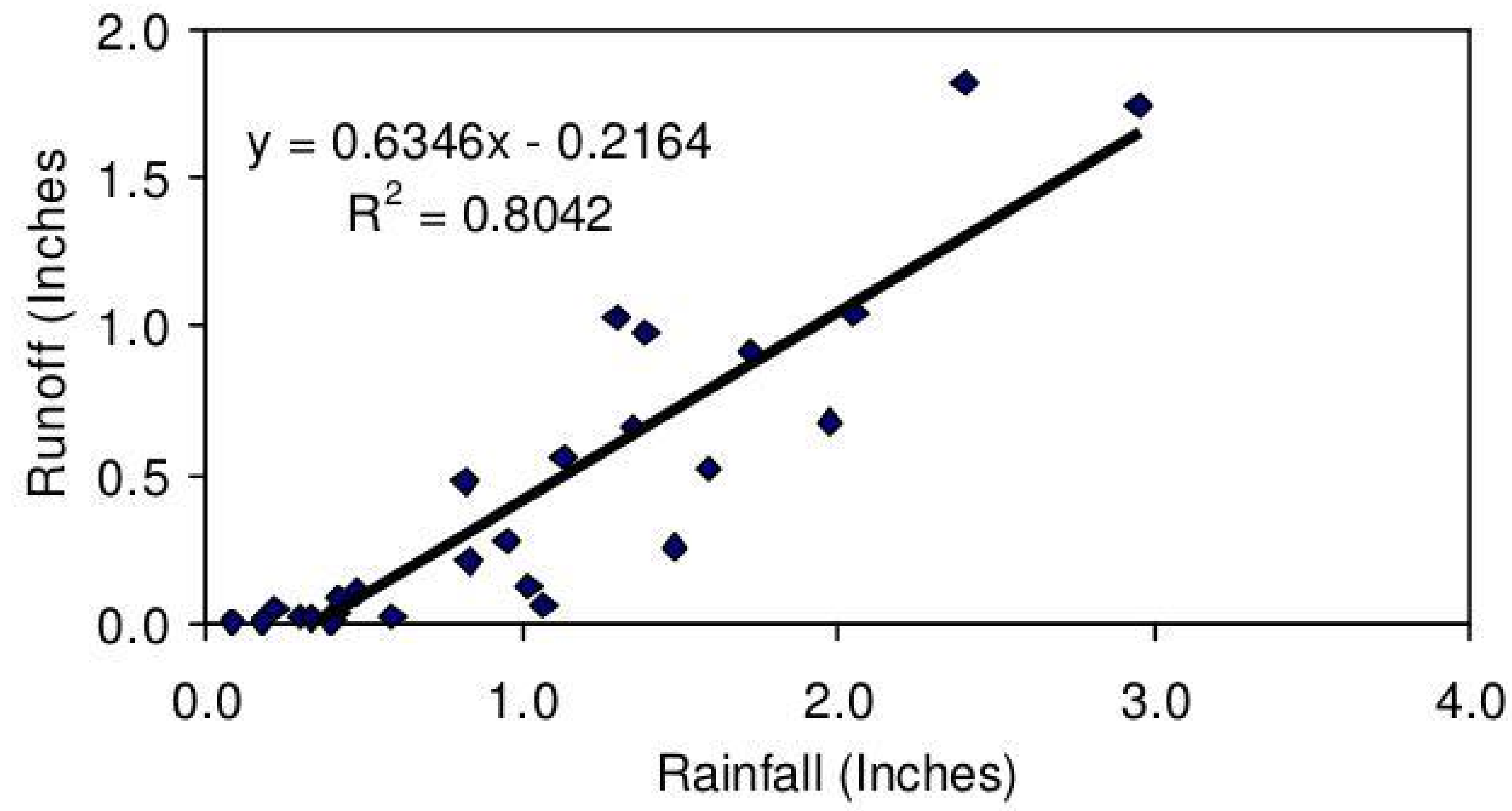


Figure 3.3 Rainfall-Runoff Relationship at US-74

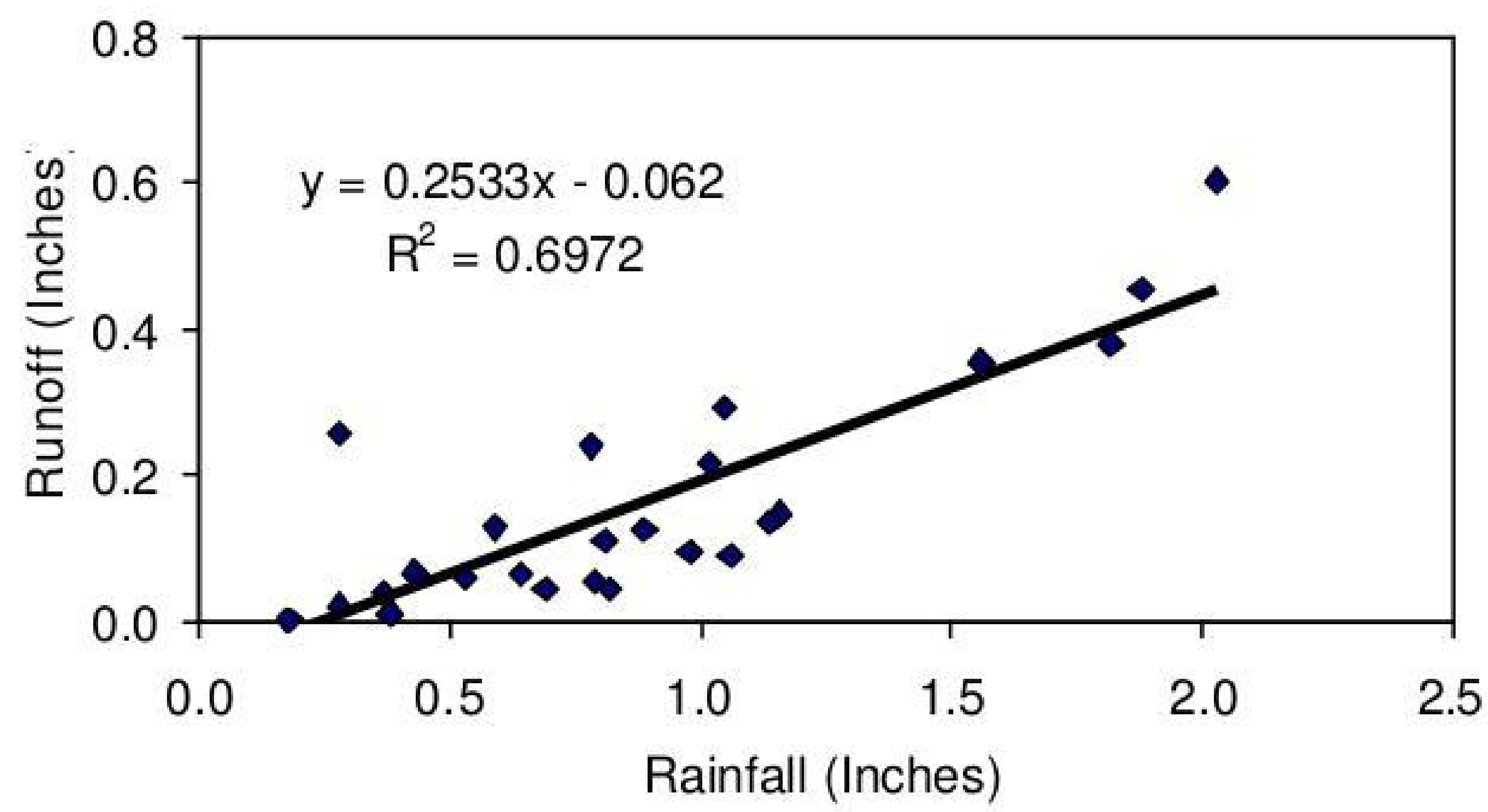


Figure 3.4 Rainfall-Runoff Relationship at WIN

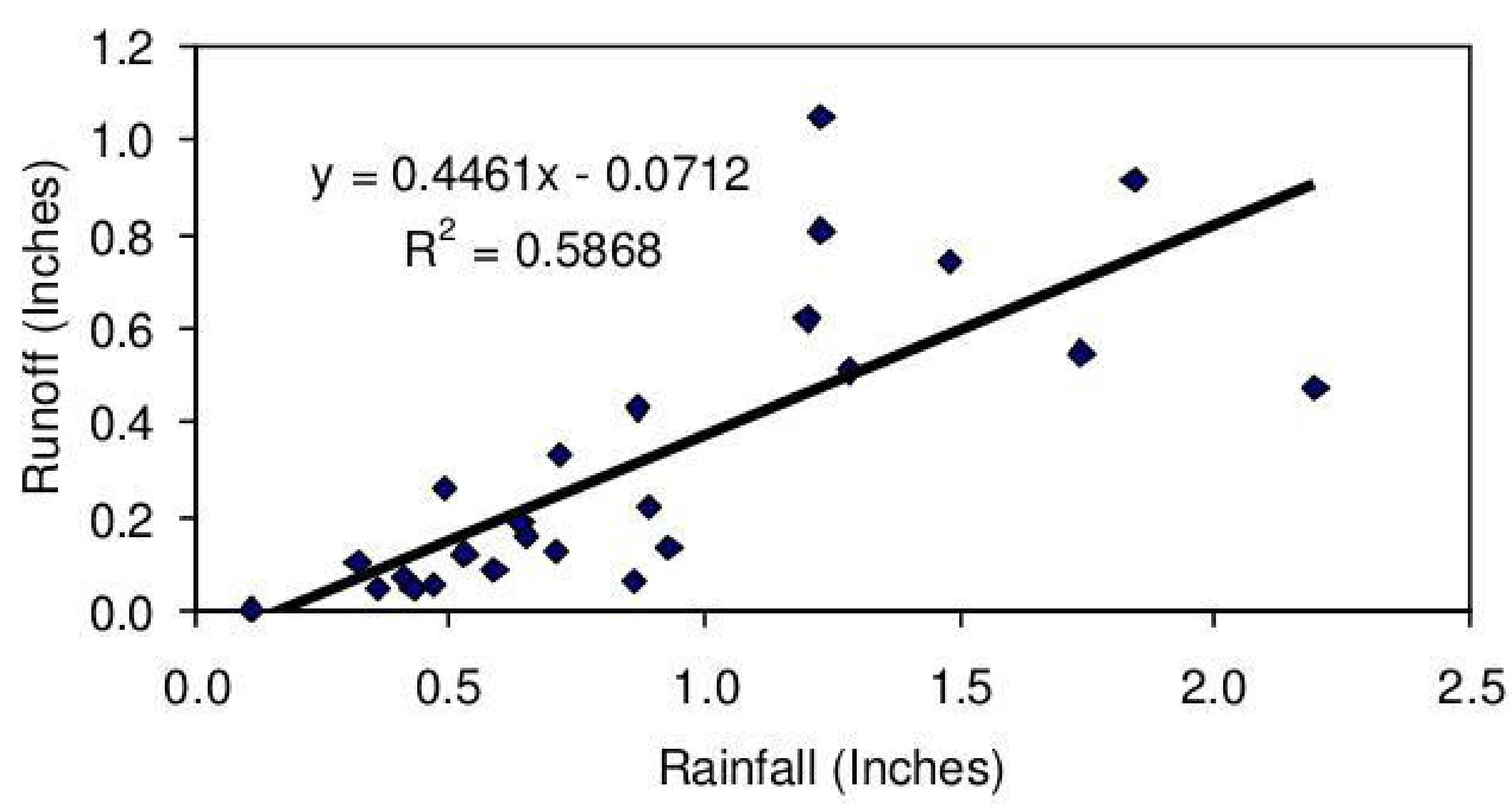


Figure 3.5 Rainfall-Runoff Relationship at GAR

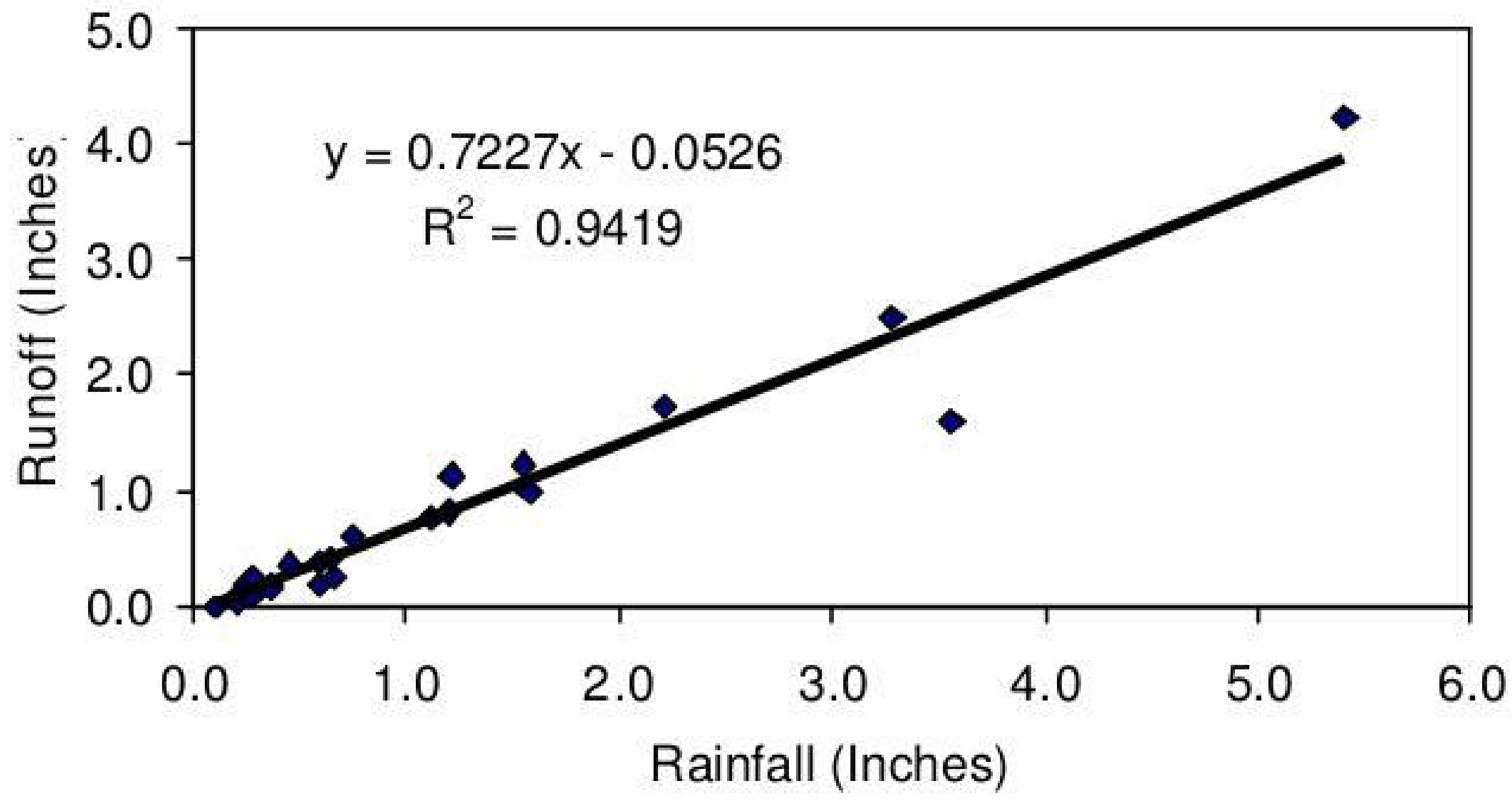


Figure 3.6 Rainfall-Runoff Relationship at WIL-1

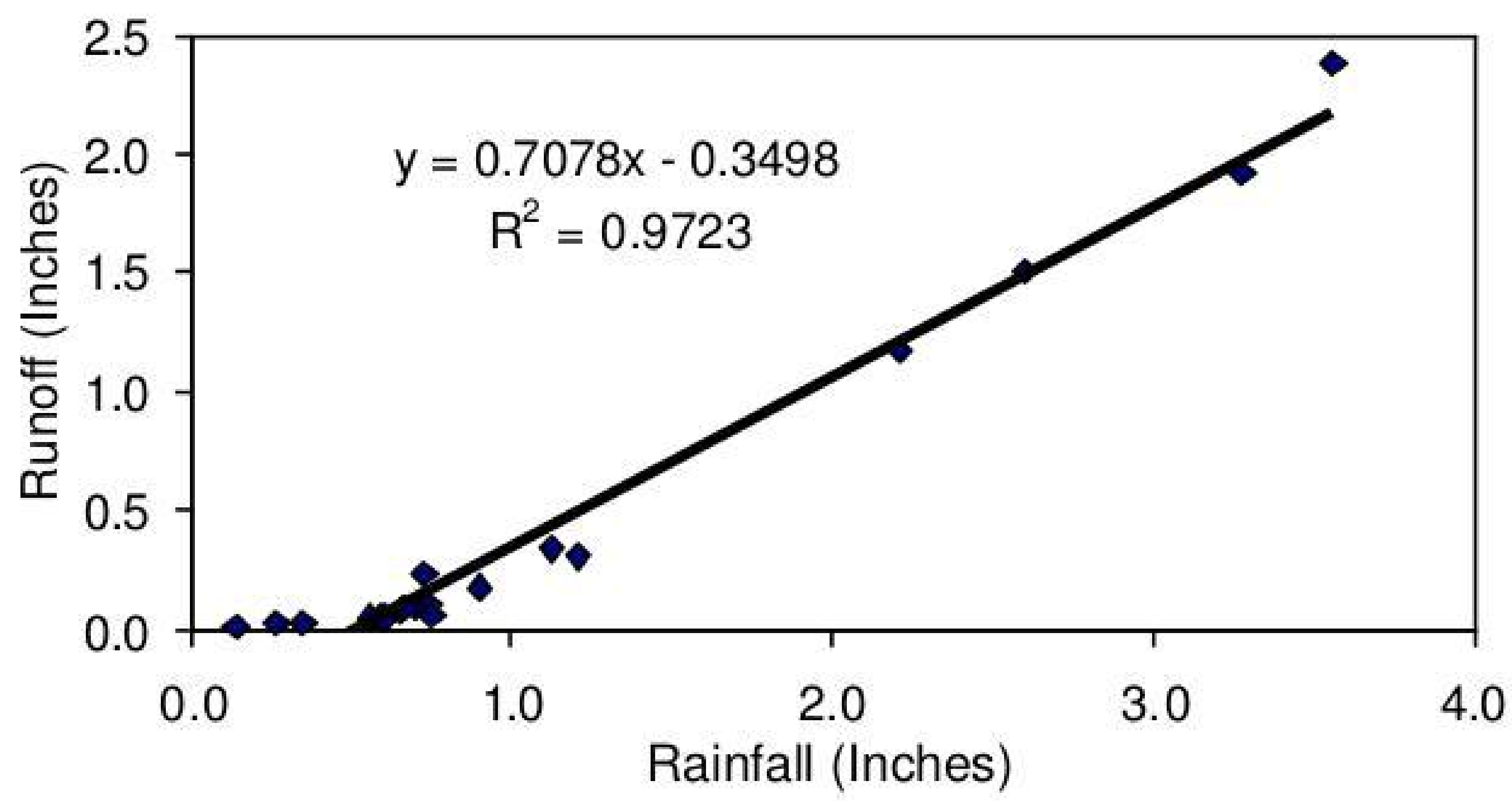


Figure 3.7 Rainfall-Runoff Relationship at WIL-2

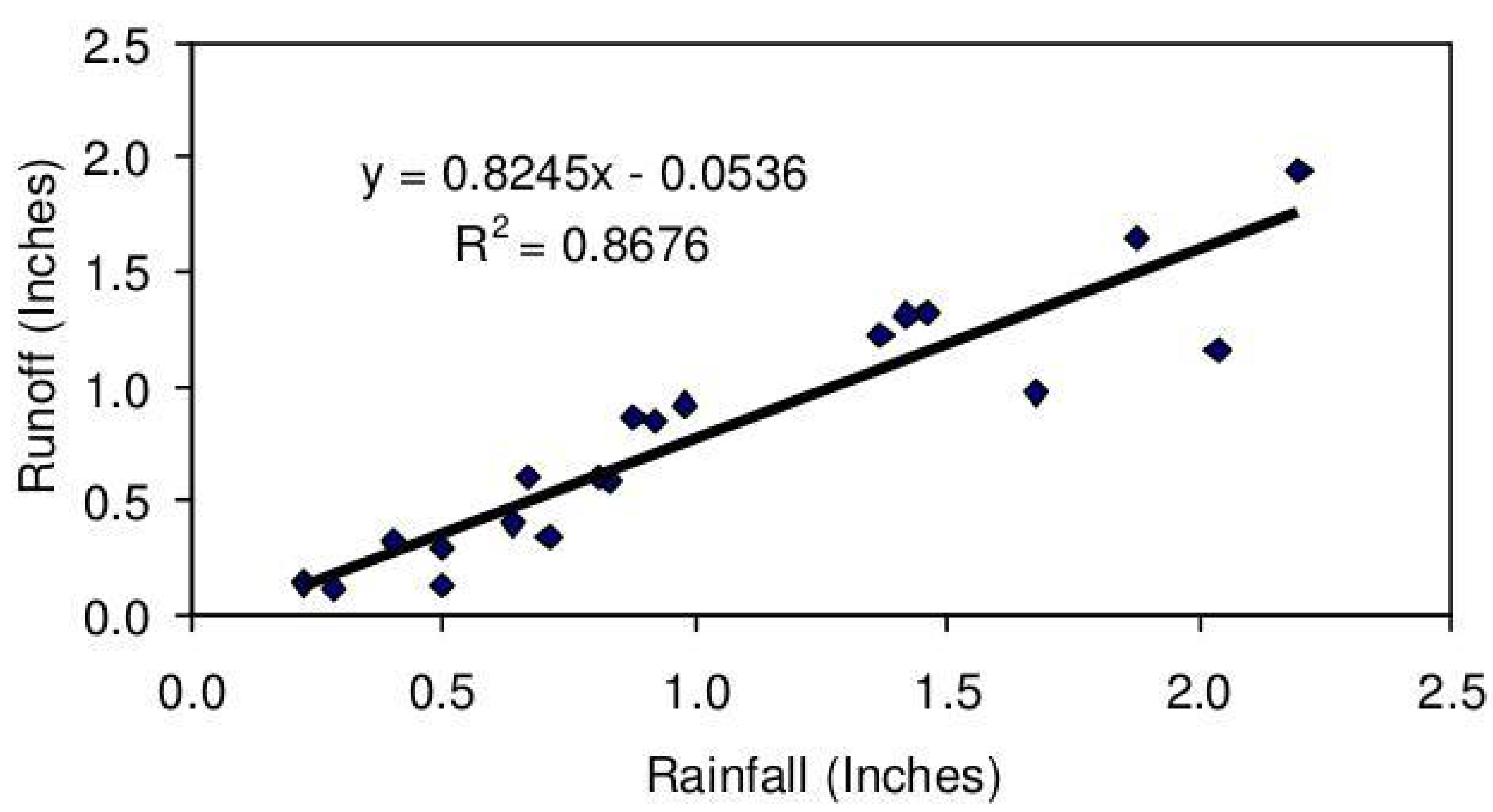


Figure 3.8 Rainfall-Runoff Relationship at ASH-1

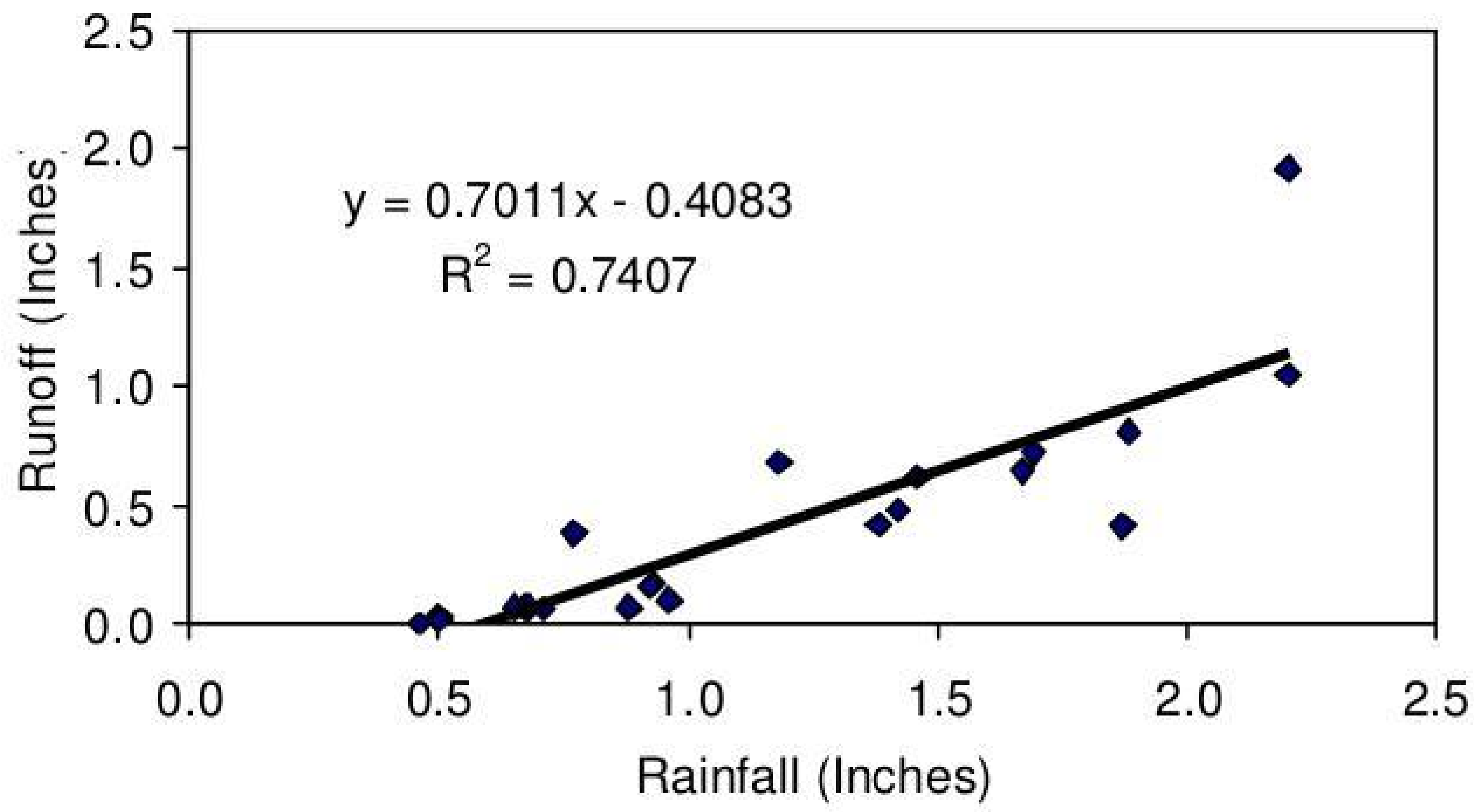


Figure 3.9 Rainfall-Runoff Relationship at ASH-2

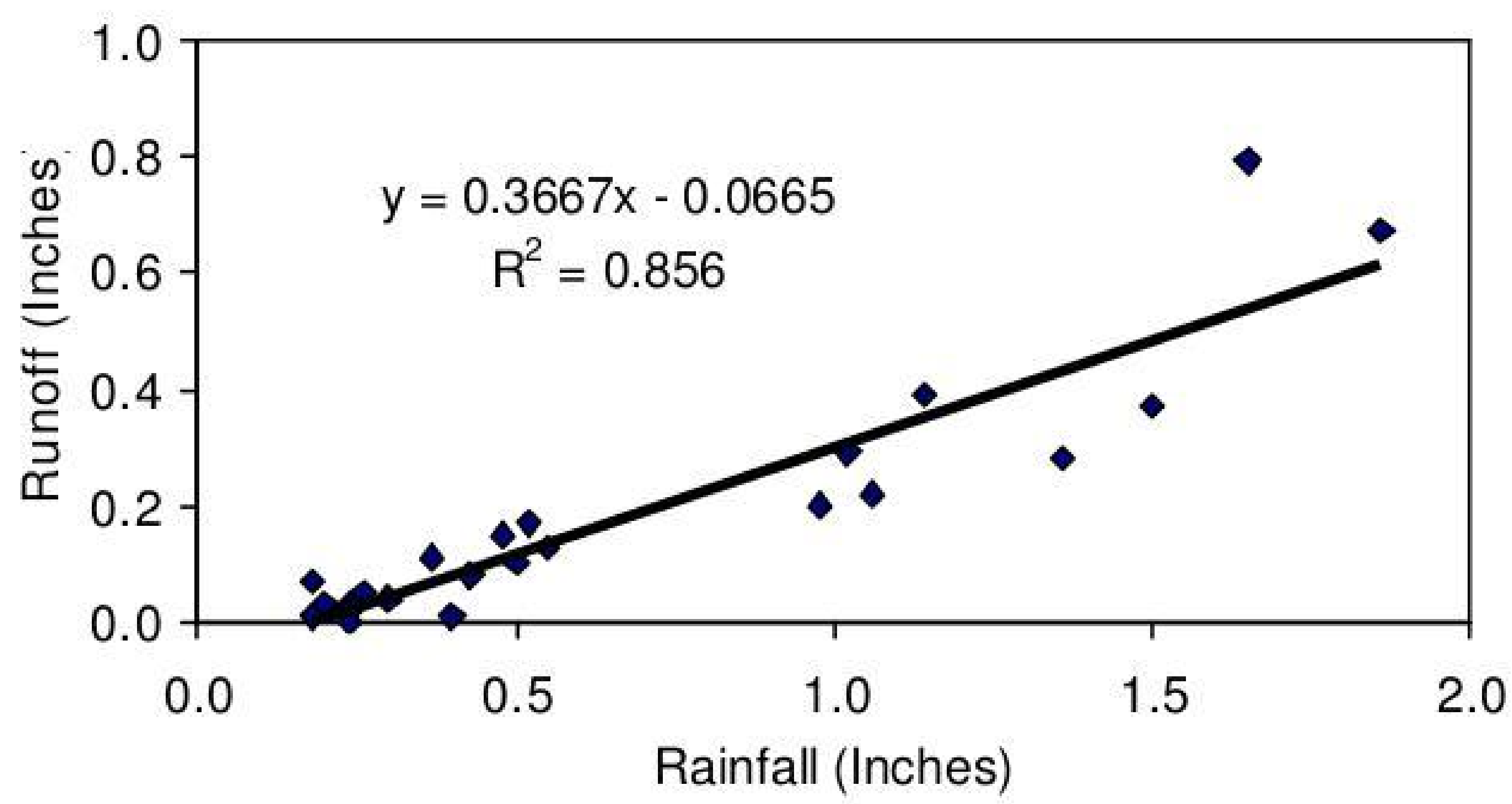


Figure 3.10 Rainfall-Runoff Relationship at MON

4. Event Mean Concentrations

4.1 Data Quality

Composite samples collected from monitored storm events were analyzed for the selected pollutant concentrations. These concentrations are designated as event mean concentrations (EMCs) because they represent the average concentration of a pollutant in the total runoff volume. Appendix 3 documents the EMCs for all water quality constituents analyzed at each monitoring site and the associated statistics. According to Driscoll et al. (1990), EMCs can be treated as random variables that conform to a lognormal probability distribution. Highway runoff at a given monitoring site can then be characterized by specifying the median of the EMCs and the coefficient of variation (CV). The mean, median and CV of a lognormal distribution presented in Appendix 3 are calculated as:

$$\text{Mean} = \exp(U + 0.5W^2)$$
$$\text{Median} = \exp(U)$$
$$\text{CV} = \text{sqrt}(\exp(W^2) - 1)$$

Where U = average of lognormal transformed data
W = standard deviation of lognormal transformed data

Whenever the sample concentration of a given water quality constituent was below its method detection limit (MDL), the sample concentration was reported as its equivalent MDL. For instance, if laboratory results indicated that Ni was below its MDL, the numerical value of its equivalent MDL or 10 μg/L would be recorded. Water quality constituents with more than 50% measurements below MDLs are summarized in Table 4.1.

Table 4.1 Water Quality Constituents with More Than 50% Measurements ≤ MDLs

	Percent Measurements ≤ MDLs, %							
Sampling site	O&G	NO_2-N	TP	OP	Cd	Cr	Pb	Ni
1. CLT-1	63	64			96	59		96
2. CLT-2	74	90			100	100	48	100
3. US-74	100	100			96	96	100	100
4. WIN	96	83			100	100	96	100
5. GAR	100	75			100	96	91	100
6. WIL-1	96	88		84	100	91	86	100
7. WIL-2	100	100			100	94	88	100
8. ASH-1	85	85	50	90	100	82	76	100
9. ASH-2	100	91			100	96	94	100
10. MON	83	92			100	83		100
MDLs	5[a]	0.05[a]	0.05[a]	0.05[a]	2[b]	5[b]	5[b]	10[b]

[a]mg/L [b]μg/L

It can be seen from Table 4.1 that O&G, NO_2-N, Cd, Cr and Ni are essentially absent or present at or below its MDLs at all 10 highway runoff monitoring sites. Water quality impact due to the discharge of NO_2-N, Cd, Cr and Ni in N.C. highway runoff could be of less significance. It is not possible to draw a definitive conclusion on the significant impact of oil and grease despite its EMCs are mostly below 5 mg/L. Further study is needed to collect grab O&G samples during the peak runoff period.

Most of the runoff samples at two impervious sites, ASH-1 and WIL-1, contained OP concentrations at MDLs. About 30% samples at another impervious site, CLT-1, had OP concentrations below its MDLs (data not shown, see Appendix 3). TP varied from 0-20% below MDLs for all monitoring sites (Appendix 3), except ASH-1 with 50% samples below MDLS. Pb was more than 50% below MDLs at 8 monitoring sites except 26% at CLT-1 and 25% at MON (Appendix 3).

4.2 Site Average EMCs

Site average EMCs are calculated as the arithmetic average of EMCs from individual storms at a given monitoring site. Table 4.2 presents site average EMCs of several key water quality constituents. Included in this table are the Nationwide Urban Runoff Program, NURP, (U.S. EPA 1983), and the Charlotte urban runoff data (Wu et al 1996). Additional EMCs data for TDS, acidity, alkalinity, and NO_{3+2}-N, and metals can be found in Appendix 3.

Table 4.2 Site Average EMCs at Monitoring Sites and Urban Runoff Data

	Site Average EMCs, mg/L					
Data source	TSS	COD	NH_3-N	TKN	OP	TP
Charlotte Urban Runoff[1]	135	-	0.22	0.88	0.10	0.14
NURP/residential	228	-	-	2.58	-	0.62
NURP/commercial	-	65	1.50	0.12	0.33	-
1. CLT-1	135	66	1.05	2.40	0.09	0.24
2 CLT-2	86	65	0.97	2.20	0.21	0.35
3. US-74	8	38	0.11	1.30	0.24	0.31
4. WIN	15	34	0.13	1.30	0.16	0.25
5. GAR	11	28	0.13	1.10	0.14	0.20
6. WIL-1	20	29	0.21	0.80	0.05	0.09
7. WIL-2	210	113	0.13	3.00	0.32	0.69
8. ASH-1	60	25	0.33	1.10	0.06	0.13
9. ASH-2	20	37	0.11	1.20	0.13	0.20
10. MON	139	58	0.28	1.50	0.12	0.26

[1]Land use included single and multi-family and wooded, 38% imperviousness

4.2.1 Data Evaluation

In order to evaluate the relative pollution potential of highway runoff with respect to other nonpoint source pollution, site average EMCs presented in Table 4.2 are compared to urban runoff data available in the literature.

The site average EMCs of all water quality constituents at CLT-1 resembles the characteristics of the Charlotte urban runoff, with TKN approaching that of the NURP residential data. Site average TSS EMCs of CLT-2 and ASH-1 are 64% and 45%, respectively, of the Charlotte runoff data. Site average TSS EMCs of all other sites are within the range of 8 to 20 mg/L, with exception of WIL-2 and MON.

Site average COD EMCs of 65 mg/L is reported in the NURP study. Site average COD EMCs of the monitoring sites are generally within the range of 25 to 66 mg/L, except WIL-2. Site average EMCs of NH_3-N, TKN, OP and TP are within the EMCs range of urban runoff data reported by the Charlotte and NURP studies.

The Wilmington pervious site, WIL-2, exhibited significant erosion at the drainage pipe outlet and elsewhere over the period when water samples were being collected. We had attempted to stabilize the area around the sampling point with little success due to disturbance by hurricane Floyd and severe storms occurring during the course of sampling. Roadway runoff at MON drains into an earthen ditch of approximately 300-ft prior to entering a discharge pipe where the sampling equipment was stationed. Erosion of the conveying ditch took place occasionally to cause elevated levels of TSS in the collected runoff sample.

It should also be noted that the Charlotte runoff data are representative of urban watersheds implementing good management practices and the NURP data were collected in the early 1980's at which time watershed management practices had not been widely practiced.

4.2.2 Influence of Imperviousness and ADT

The influence of watershed drainage impervious (Imp) and ADT on EMCs was investigated using nonlinear regression analysis.. Significant statistical correlation exists between TSS EMC and ADT when sites with greater than 50% imperviousness were included in the analysis (CLT-1, CLT2, ASH-1, WIL-1, and US-74), Figure 4.1. Correlation also exits between TSS EMC and imperviousness with sites having ADT greater than 30,000 vehicles/day (CLT-1, CLT-2, ASH-1, ASH-2, WIN, and GAR), Figure 4.2. The overall imperviousness of the WIN site is 48%. However, because most of the roadway runoff at the WIN site drains into connecting pervious areas prior to discharging into receiving waters, its effective imperviousness was estimated to be 11% which was then used in the above regression analysis. Data from the other two monitoring sites (WIL-1 and US-74) with ADT less than 30,000 vehicles/day are not sufficient for performing similar statistical analysis. MON and WIL-2 were excluded from the TSS analysis for reasons mentioned earlier. No significant correlation was observed between COD EMC and Imp or ADT. Statistical analyses for nitrogen and phosphorus species are presented in a subsequent chapter of this report.

It is obvious from the above analysis that TSS EMCs increases with increasing either or both the imperviousness and ADT. This observation is valid for roadways with higher percentages of imperviousness and ADTs. For roadways with lower imperviousness and ADTs, the influence of imperviousness and ADTs could not be reliably quantified due to the potential attenuation of pollutant discharge by vegetation and/or the uncertainty of traffic pattern associated with infrequent or low traffic conditions. We adopted the criteria of 50% imperviousness and 30,000 vehicle/day ADT in the analysis based on available data. A more thorough analysis with a large database should be pursued, if possible.

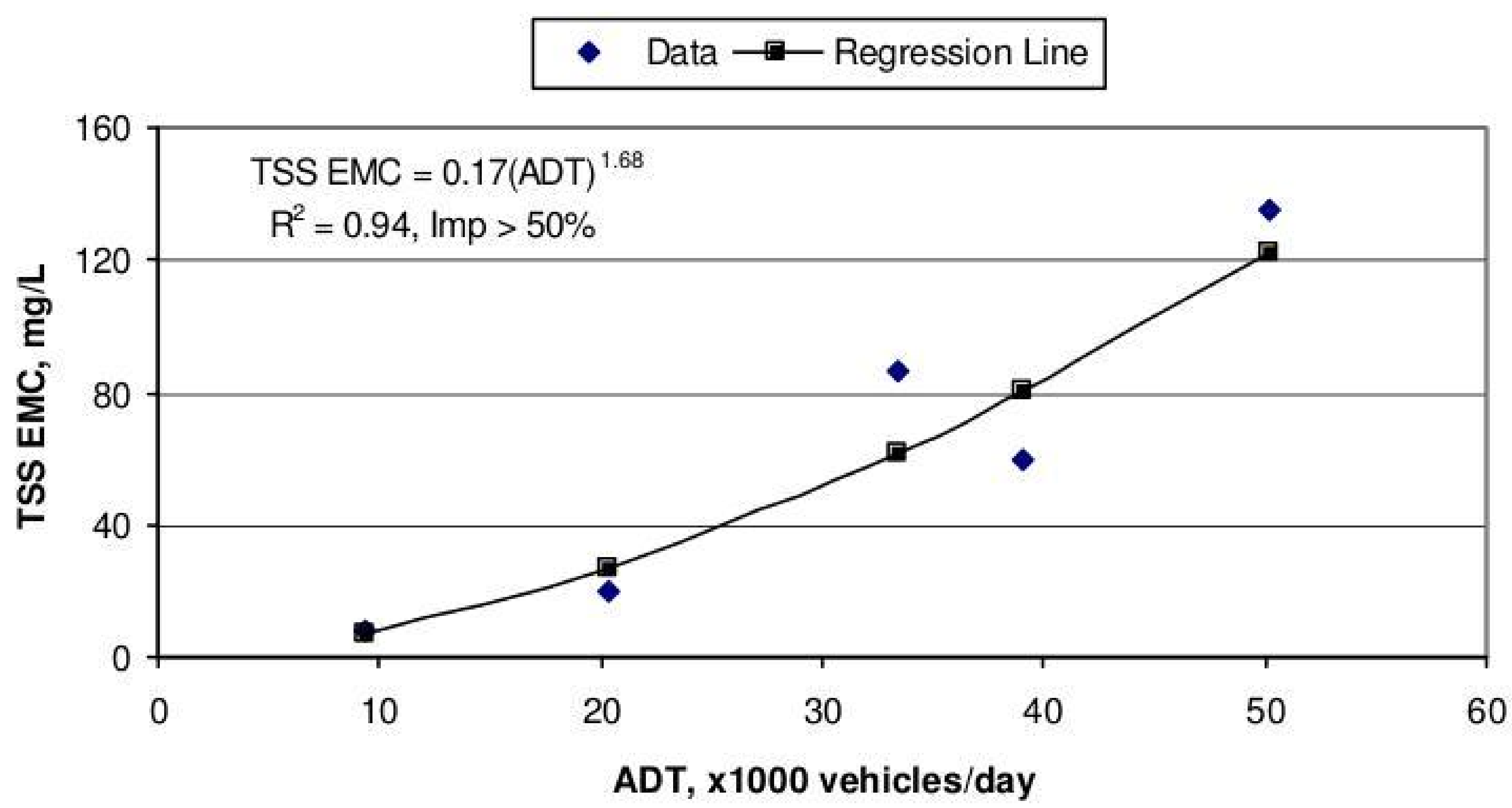


Figure 4.1 Influence of Traffic Volumes on TSS EMC

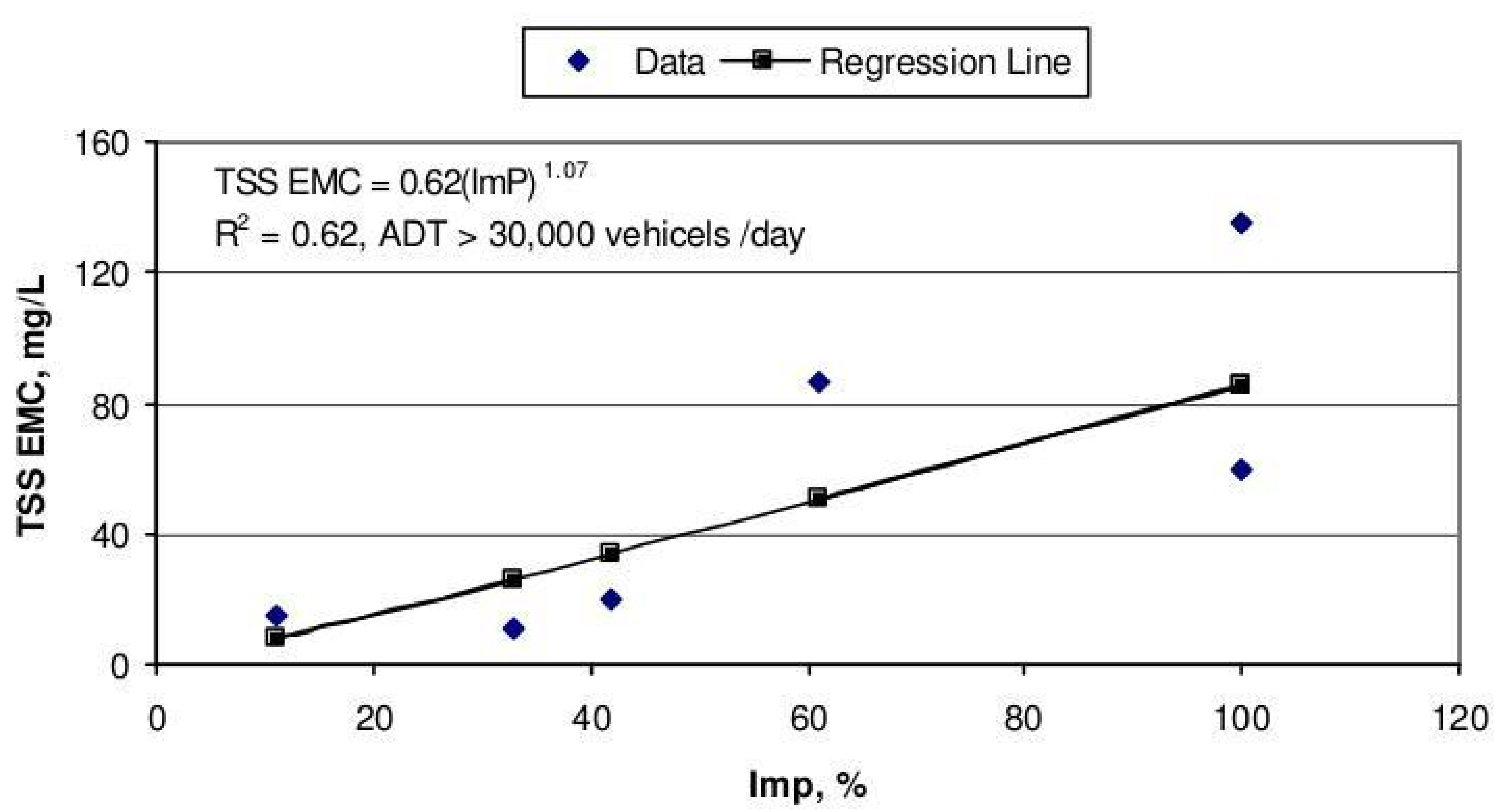


Figure 4.2 Influence of Imperviousness on TSS EMC

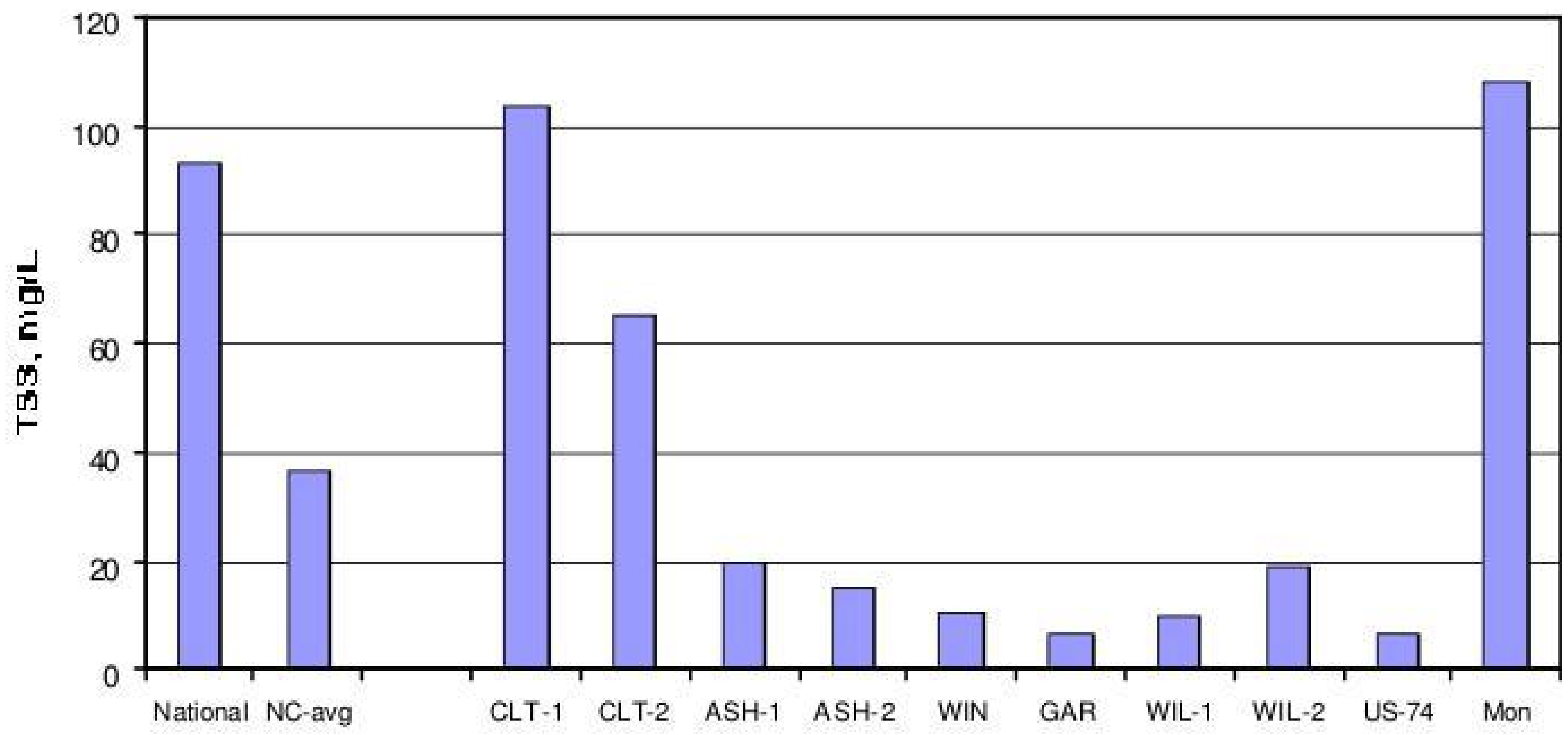
4.3 Site Median EMCs

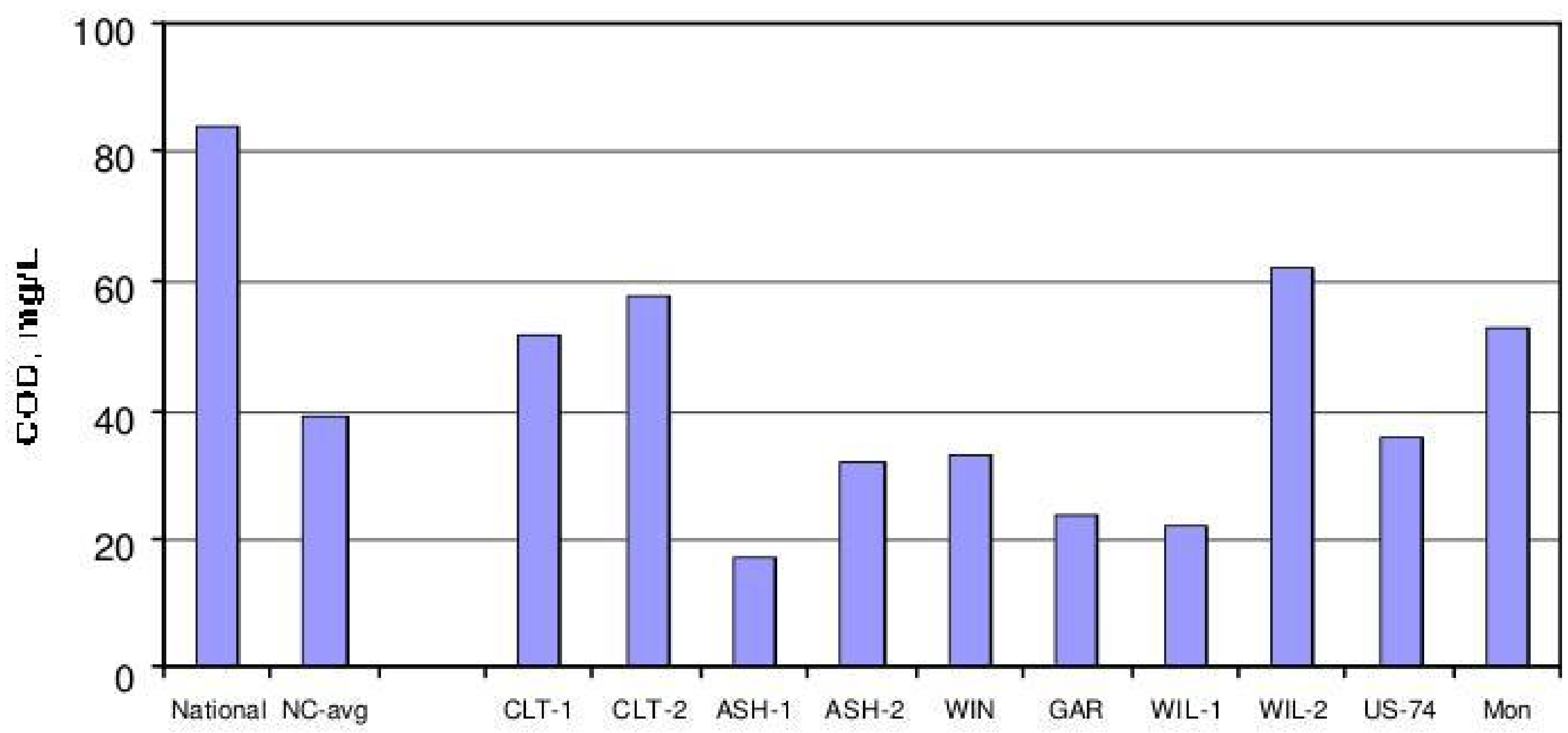
Site median EMCs which are based on lognormal distribution of 7 water quality constituents have been compiled by the nationwide highway runoff assessment program, as shown in Table 4.3. Included in this table are similar statistics obtained from our study. Figures 4.3 and 4.4 display the site median EMCs for TSS, COD, TKN, NO_{3+2}-N,

Table 4.3. Site Median EMCs at Ten N.C. Highway Runoff Monitoring Sites

	Highway Characteristics			Site Median Event-Mean-Concentrations (EMCs)						
Sampling Location	ADT (x1000)	D.A. (acres)	Imp. (%)	TSS (mg/L)	COD (mg/L)	NO_{3+2}-N (mg/L)	TKN (mg/L)	OP-P (mg/L)	Pb (µg/L)	Zn (µg/L)
1. CLT-1	50.2	0.37	100	104	52	0.75	2.07	0.08	9	138
2. CLT-2	33.4	0.57	61	65	58	0.56	2.15	0.17	7	105
3. US-74	9.3	0.86	50	7	36	0.24	1.24	0.16	5	16
4. WIN	52.2	2.16	48	11	33	0.48	1.20	0.13	5	31
5. GAR	78.8	3.46	33	7	24	0.45	0.93	0.11	5	17
6. WIL-1	20.3	0.15	100	10	22	0.34	0.72	0.06	5	46
7. WiIL-2	20.3	0.22	47	19	62	0.15	1.95	0.25	5	15
8. ASH-1	39.0	0.16	100	20	17	0.30	0.86	0.06	7	198
9. ASH-2	39.0	0.36	42	15	32	0.23	1.10	0.11	5	25
10. MON	9.4	13.46	22	108	53	0.45	1.47	0.10	8	52
Average	35.2	2.18	58	37	39	0.40	1.37	0.12	6	64
Urban*	>30			142	114	0.76	1.83	0.40	400	329
Rural*	<30			41	49	0.46	0.87	0.16	80	80
Combined*	4-200	0.01-106	27-100	93	84	0.66	1.48	0.29	234	217

*National data (Driscoll et al., 1990)





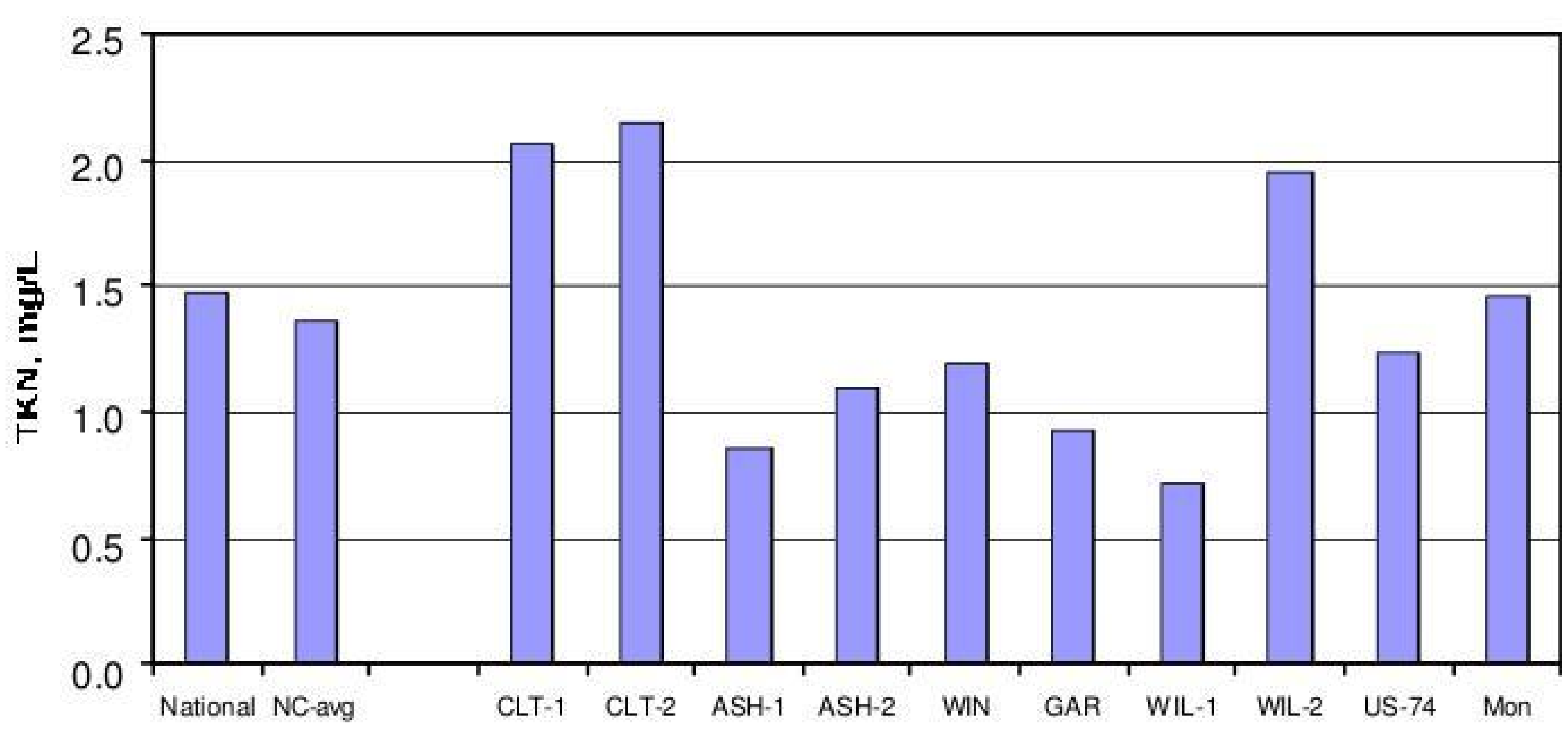


Figure 4.3. Site Median EMCs for TSS, COD and TKN

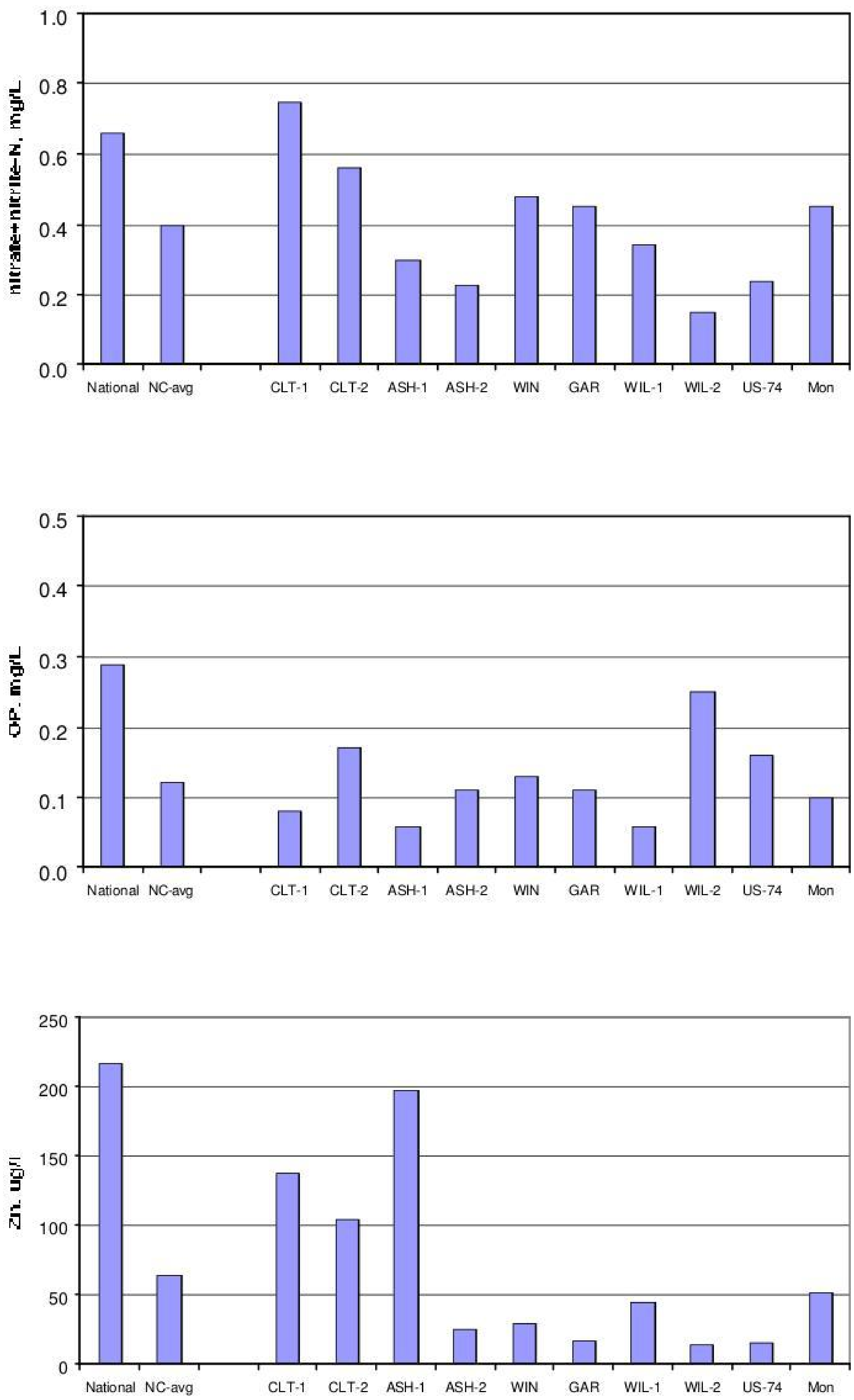


Figure 4.4. Site Median EMCs for NO_{3+2}-N, OP and Zn

OP, and Zn. The national data have been divided into two categories according to traffic counts. Those with ADTs greater than 30,000 vehicles/day are classified as urban highway runoff, while those with less than 30,000 vehicles/day are considered rural highway runoff.

4.3.1 Data Evaluation

The averages of site median EMCs from all 10 monitoring sites are calculated and compared with the national data, see Table 4.3. TSS, COD, NO_{3+2}-N, OP and Zn concentrations are approximately 10%, 20%, 13%, 25% and 20% less than the respective rural highway runoff concentrations. TKN is 1.57 times higher than the rural runoff concentration but is 25% less than the urban highway runoff data. Pb is substantially less than the rural data and only slightly higher than the its MDL of 5 μg/L. The average ADT of all 10 monitored sites is 35,200 vehicles/day which is very close to the 30,000 vehicles/day figure used to classify the urban versus rural runoff characteristics.

Table 4.4 presents the CV values of the aforementioned pollutants. Most of the CV values follow closely the national trend with two exceptions. The CV values for TSS obtained at ASH-1 and WIL-2 are 3.19 and 16.25, respectively. EMCs of TSS at ASH-1 are in the range of 2 to 366 mg/L, with an arithmetic average of 60 mg/L, a lognormal mean of 68 mg/L, and a site median EMC of 20 mg/L. The site median mean EMC of TSS of the national rural data is 41 mg/L. The greater variability of TSS at the ASH-1 site (100% impervious) can be attributed to the steep slopes in the mountain region, which could result in variable TSS transport in response to storms of differing magnitudes and intensities, and/or grits application to roadways. Variations of TSS discharges from WIL-2 were caused by localized erosion at the roadway runoff discharge area.

4.3.2 Covariance Among Monitoring Sites

The covariance of site median EMCs among the 10 monitoring sites can be examined by comparing the individual site median EMCs with the average of site median EMCs from all monitoring site. Sites with median EMCs that are greater than or equal to these averages are shown in Table 4.5

CLT-1 is a bridge deck site with 100% imperviousness located within the city of Charlotte, in the Piedmont region of the state. It exhibits the highest site median EMCs of COD, NO_{3+2}-N, TKN, Pb, and Zn; and the second highest of site median TSS. The relatively higher levels of pollutant concentrations found at CLT-1 can be attributed to: (1) traffic at CLT-1 is relatively congested with frequent stops resulting in potentially more deposits on the roadway surface, (2) vegetative coverage is not available for pollutant attenuation, and (3) the curb wall on the bridge deck protects the deposited pollutants from being removed from the roadway surface. However, the export of OP was relatively low at this site due to the absence of vegetation. Runoff from bridge decks has drawn national attention for further research.

Table 4.4 Coefficient of Variations for Site Median EMCs at Ten N.C. Highway Runoff Monitoring Sites

Sampling Location	Highway Characteristics ADT (x1000)	D.A. (acres)	Imp. (%)	Coefficient of Variation for Site Median EMCs TSS	COD	NO_{3+2}-N	TKN	OP-P	Pb	Zn
1. CTE-1	50.2	0.37	100	1.09	1.01	0.73	0.56	0.55	0.54	0.92
2. CTE-2	33.4	0.57	61	1.05	0.54	0.62	0.31	0.83	0.35	0.61
3. US-74	9.3	0.86	50	0.77	0.39	1.24	0.34	1.10	0.00	0.85
4. Win	52.2	2.16	48	1.17	0.40	0.72	0.41	0.86	0.04	0.68
5. Gar	78.8	3.46	33	1.33	0.63	1.50	0.52	0.72	0.32	0.75
6. Wil-1	20.3	0.15	100	1.77	0.92	0.97	0.60	0.75	0.39	0.93
7. Wil-2	20.3	0.22	47	16.25	1.35	1.01	1.20	0.77	0.23	0.47
8. Ash-1	39.0	0.16	100	3.19	1.12	0.96	0.73	0.36	0.62	0.68
9. Ash-2	39.0	0.36	42	1.01	0.56	1.42	0.41	0.60	0.04	0.79
10. Mon	9.4	13.46	22	0.97	0.43	0.89	0.34	0.66	0.52	0.94
Average	35.2	2.18	58	2.86	0.74	1.01	0.54	0.72	0.31	0.76
Urban*	>30			0.62	0.58	0.56	0.45	0.89	1.45	0.44
Rural*	<30			1.17	0.45	0.57	0.83	1.02	1.22	0.73
Combined*	4-200	0.01-106	27-100	1.16	0.71	0.77	0.67	1.10	2.01	1.37

*National data (Driscoll et al., 1990)

Table 4.5 Monitoring Sites with Site Median EMCs Greater Than or Equal to Site Averages

Water Quality Parameter	Sites with Median EMCs ≥ Site Averages
TSS	CLT-1, CLT-2, MON
COD	CLT-1, CLT-2, WIL-2, MON
NO_{3+2}-N	CLT-1, CLT-2, WIN, GAR, MON
TKN	CLT-1, CLT-2, WIL-2, MON
OP	CLT-2, WIN, GAR, WIL-2
Pb*	CLT-1, CLT-2, ASH-1, MON
Zn	CLT-1, CLT-2, ASH-1

* Pb concentrations are typically at or near MDLs

CLT-2 is adjacent and under the bridge deck site. Traffic congestion at CLT-2 is similar to CLT-1 with frequent stops at the traffic light. Runoff from this site could occasionally bypass the pervious shoulder and drain directly into the catch basin from the impervious portion of the roadside. This has resulted in higher levels of TSS, COD, NO_{3+2}-N, Pb and Zn. However, TKN and OP are the highest among other monitoring sites. The pervious coverage at CLT-2 is about 40%, which may partially explain the elevated levels of TKN and OP appearing in the runoff. This site also may be impacted by landscape maintenance activities along the north shoulder.

Although runoff from ASH-1 has the highest Zn concentration of 198 μg/L or 0.198 mg/L, it is well below the secondary maximum contaminant level of 5 mg/L for drinking water.

WIN and GAR near the Raleigh area are located along I-40 with ADTs of 52,200 and 78,800 vehicles/day, respectively. The percentages of pervious coverage at these two sites are relatively higher, i.e.52% for WIN and 67% for GAR. It is particularly important to note that most of the roadway runoff at the WIN site drains into the connecting pervious area prior to discharging into receiving waters. Because of the indirect connection of impervious area to discharge, the effective imperviousness at WIN was estimated to be 11%, as opposed to an overall imperviousness of 48%. Large percentages of pervious coverage may be beneficial for the reduction of most pollutant concentrations like TSS, COD, and Zn, but may provide relatively higher nutrient concentrations with respect to an equivalent impervious site.

The Wilmington pervious site, WIL-2, experienced erosion at the drainage outlet pipe and elsewhere when water samples were being collected. The sampling area was frequently disturbed by Hurricane Floyd and other severe storms during the course of monitoring. The above-average concentrations of COD, NO_{3+2}-N, TKN and OP may be associated with the organic content of eroded soils and/or vegetation decomposition.

Site median TSS EMC at the MON site is as high as that of CLT-1 while its ADT is only 9,400 vehicles/day. US-74 is another site with similarly low traffic counts (9,300 vehicles/day). Both US-74 and MON sites could serve as a baseline for characterization of highway runoff subject to minimal traffic activities. However, the roadway runoff at MON drains into an earthen ditch of approximately 300 ft prior to entering a discharge culvert where the sampling station was located. Erosion of the earthen ditch took place occasionally causing elevated levels of TSS in the collected runoff sample. When comparing the site median TSS of 108 mg/L at MON with that of 7 mg/L at US-74, it strongly suggests that elevated levels of pollutant discharge from a particular site may not originate from the roadway surface but could be caused by localized erosion at the discharge point near the receiving stream. Data from MON illustrate the importance of proper site maintenance at highway discharge areas to avoid additional pollutant input due to erosion or other land disturbing activities.

5. Pollutant Loads

5.1 Introduction

The amount of pollutant yield by a single storm event can be expressed as unit event load (mg/m^2 or lb/ac) and unit pollutant loading rate (mg/m^2-hr or lb/ac-hr).

Unit event load = (EMCs* Vr)/A

Unit pollutant loading rate = unit event load $\div$ runoff duration

Where Vr = total runoff volume per storm event
A = total drainage area of a sampling site

The unit event load can be considered as a lumped-parameter variable of which the effects of precipitation, rainfall intensity, and antecedent dry days are implicitly included into its calculation. It is used to examine the seasonal variation of pollutant discharge from a highway-runoff monitoring site. When the unit event load is divided by the runoff duration, it yields the average rate of pollutant discharge over the entire runoff period. With additional information, the average of unit pollutant loading rates at a monitoring site can be converted to annual pollutant loads as required by the NPDES permit.

5.2 Unit Event Load

Table 5.1 presents the site-averaged unit event loads at each monitoring site. Unit event loads for metals are not presented since most of the metal measurements are below MDLs. Unit event loads from WIL-2 were obtained by excluding several problematic storms as described earlier.

TSS loads are generally higher in the Piedmont than in the Mountains or Coastal area. A combination of mild roadway slopes and heavier traffic volumes render favorable conditions for TSS transport from the Piedmont roadway surface. Roadway slopes are steeper in the Mountains but with lighter traffic. For instance, the TSS load at ASH-1 is about 78% of that at the CLT-1 site. The impervious coverage at both sites is 100% while the traffic at ASH-1 is 76% of the CLT-1 site. Roadways in the Coastal area are of flat slope and lighter traffic, resulting in a substantially lower TSS load. Similar trends can be generalized for other water quality constituents.

When taking the TSS data from the Piedmont monitoring sites (CLT-1, CLT-2, US-74, WIN, GAR) for multiple regression analysis, it was possible to obtain a highly correlated relationship for site-averaged TSS unit event load with ADT and Imp:

$$\text{TSS unit event load, } mg/m^2 = -643.21 + 4.45\times10^{-3}\,(ADT) + 19.64\,(Imp) \qquad R^2 = 0.88$$

Figure 5.1 Unit Event (Pollutant) Loads at 10 Monitoring Sites
(lb/ac = mg/m^2 divided by 112.08)

Monitoring Site		TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP
CLT-1	mg/m^2	1619	850	82	717	25.77	10.67	8.37	0.96	3.10	1.23
	CV	0.95	0.70	0.92	0.76	0.62	0.46	0.48	0.85	0.93	1.05
CLT-2	mg/m^2	876	651	58	666	22.70	8.50	6.06	0.59	4.07	2.54
	CV	1.17	0.81	0.70	0.84	0.76	0.75	1.01	0.72	1.11	1.38
US-74	mg/m^2	138	592	57	347	12.81	1.19	1.52	0.57	3.13	2.35
	CV	2.18	1.02	1.16	1.06	1.04	1.28	1.31	1.16	1.22	1.33
WIN	mg/m^2	64	541	21	160	5.59	0.50	1.42	0.22	1.27	0.89
	CV	1.18	1.20	0.94	1.00	0.98	1.07	0.70	0.89	1.40	1.59
GAR	mg/m^2	92	844	41	220	8.51	0.93	4.16	0.44	1.45	0.93
	CV	1.81	1.06	0.94	0.98	1.10	1.47	1.86	0.89	0.95	0.92
WIL-1	mg/m^2	148	650	74	223	8.33	1.66	3.28	0.82	1.07	0.91
	CV	1.36	0.90	1.04	0.59	0.82	1.16	0.86	1.00	0.90	1.02
WIL-2	mg/m^2	24	176	11	120	4.13	0.27	0.26	0.10	1.16	0.76
	CV	0.98	0.75	0.75	1.14	0.88	1.08	1.00	0.75	1.13	1.36
ASH-1	mg/m^2	1232	351	105	485	20.23	5.51	4.89	1.10	2.43	1.07
	CV	1.71	1.04	0.63	1.29	0.96	0.67	0.60	0.58	1.25	0.57
ASH-2	mg/m^2	155	588	49	244	7.23	0.60	1.43	0.49	1.56	1.16
	CV	1.27	1.60	1.12	0.95	0.92	1.15	1.14	1.12	0.98	1.21
MON	mg/m^2	881	341	22	218	6.54	0.70	1.34	0.22	1.23	0.42
	CV	1.80	1.13	1.16	1.02	1.20	0.90	0.94	1.16	1.34	1.08

Where ADT is expressed as vehicles/day, and Imp is given as percentage. An effective imperviousness of 11% was employed for the WIN site in the above analysis. With a R^2 value of 0.88, it can be stated that the TSS unit event load of highway runoff in the Piedmont can be reliably predicted by specifying ADT and Imp as independent variables. The above equation was derived from the Piedmont data; therefore, it is not advisable to be used for predicting pollutant loads for the other two regions. Nevertheless, it can be used to (1) determine the sensitivity of Piedmont roadway runoff loads by holding ADT or Imp constant and varying the other variable, and (2) to determine the variance of pervious coverage requirements for a roadway section running through the regions to achieve the same level of pollutant loads. We can examine the latter application with the following example.

Problem statement: If the same traffic and pollutant loads are to be expected for a roadway originating from ASH-1 and running through the Raleigh-Durham area, what is the required increase in pervious coverage for the section of roadway near the Raleigh-Durham area?

Taking the ASH-1 data as the basis, the site-averaged TSS load would be 1,232 mg/m^2 with ADT equal to 39,000 and Imp equal to 100%, the required impervious percentage at the Piedmont section of the roadway can be calculated from the above equation.

$$Imp = (1232 + 643.21 - 4.45\times10^{-3}*39{,}000)/19.64 = 87\%$$

The design engineer would then recommend at least 13% pervious coverage by incorporating vegetative best management practices (BMPs). If the traffic at the Raleigh-Durham section increases to 90,000, the recommended pervious coverage would be 25%.

Multiple regression analyses for site-averaged unit event loads of other water quality constituents in the Piedmont were performed similarly, as summarized below:

$$TDS = 346.33 + 4.25\times10^{-3}\,(ADT) + 3.12\,(Imp) \qquad R^2 = 0.87$$

$$COD = 111.62 - 0.90\times10^{-3}\,(ADT) + 6.88\,(Imp) \qquad R^2 = 0.84$$

$$TKN = 3.72 - 0.025\times10^{-3}\,(ADT) + 0.244\,(Imp) \qquad R^2 = 0.89$$

$$NH_3\text{-}N = -3.21 + 0.019\times10^{-3}\,(ADT) + 0.132\,(Imp) \qquad R^2 = 0.79$$

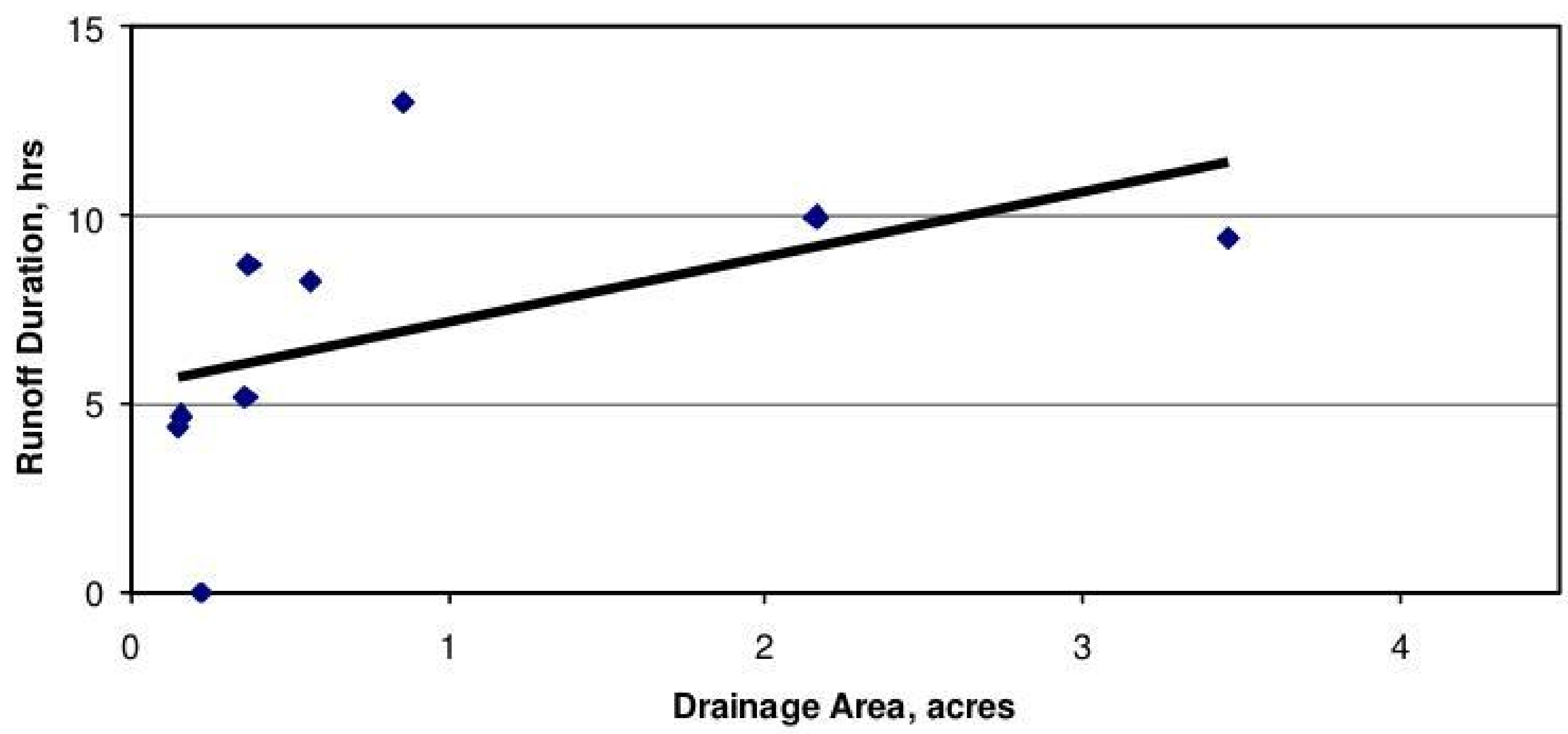
$$NO_{3+2}\text{-}N = -2.03 + 0.049\times10^{-3}\,(ADT) + 0.094\,(Imp) \qquad R^2 = 0.89$$

$$TP = 2.65 - 0.025\times10^{-3}\,(ADT) + 0.021\,(Imp) \qquad R^2 = 0.77$$

$$OP = 2.55 - 0.025\times10^{-3}\,(ADT) + 0.003\,(Imp) \qquad R^2 = 0.70$$

5.3 Unit Pollutant Loading Rate

The unit pollutant loading rate provides a means of quantifying pollutant discharge from individual storm events. For highway runoff, this loading rate is influenced by traffic, vegetative coverage, and other hydrologic factors. Unit pollutant loading rates are obtained by dividing the unit event load by runoff duration. Runoff duration is essentially a time factor similar to time-of-concentration. It tends to increase with increasing drainage area and with decreasing imperviousness, as shown in Figure 5.1. Included in this figure are site-averaged runoff durations from 9 monitoring sites, with the exception of MON. The MON site has a large drainage area of 13.46 acres of which a large percentage is non-highway origin. Its hydrologic response may not be consistent with the other monitoring sites.



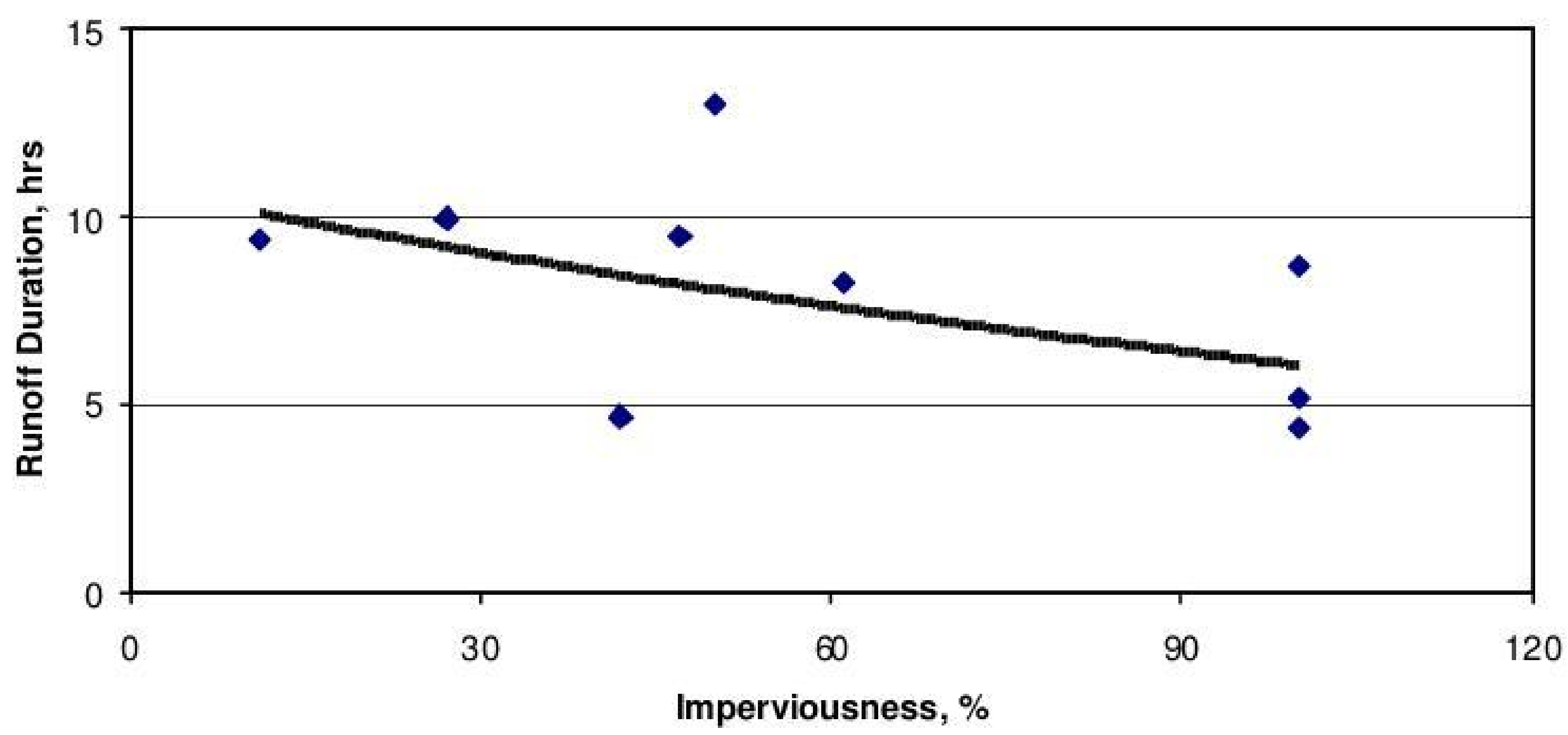


Figure 5.1 Data Trend of Runoff Duration in Relation to Drainage Area and Imperviousness

The calculated unit pollutant loading rates for water quality constituents (TSS, TN, TP) of most concern to the NPDES permit are shown in Figure 5.2. TN is computed as the sum of TKN and NO_{3+2}-N. Table 5.2 categorizes the unit pollutant loading rates as high, medium, low and very low. In general, sites that are mostly impervious (CLT-1 and ASH-1) yield "high" TSS and TN and "medium" TP loading rates. Sites with indirectly connected imperviousness appear to be extremely effective in reducing TSS, TN and TP loading rates (e.g. WIN and GAR). Sites with mixed flows from pervious and impervious runoff contributing areas provides both "high" TN and TP loadings rates due to roadway maintenance and landscaping activities, but “medium to very low” TSS loading rates depending on the runoff flow dynamics during storm events (e.g. CLT-2 and WIL-2). WIL-1 is categorized under “low” in TSS and TP and “medium” in TN due to its lower traffic activity as compared to either CLT-1 or ASH-1. US-74 also has large indirectly connected imperviousness and low traffic activity, resulting in “low” TN and TP and “very low” TSS loading rates.

Table 5.2 Ranking of Site-averaged Unit Pollutant Loading Rates

Loading	TSS		TN		TP	
Category	lb/ac-hr	Site	lb/ac-hr	Site	lb/ac-hr	Site
High	> 2.0	CLT-1 ASH-1	>0.05	ASH-1 CLT-1 CLT-2 WIL-2	>0.01	WIL-2 CLT-2
Medium	1.0 – 2.0	CLT-2 MON	0.025-0.05	ASH-2 WIL-1	0.005-0.01	CLT-1 ASH-1 ASH-2
Low	0.5 – 1.0	ASH-2 WIL-1	0.01-0.025	US-74 MON	0.0025-0.005	WIL-1 US-74 MON
Very Low	< 0.5	WIN GAR, WIL-2 US-74	<0.01	WIN GAR	<0.0025	WIN GAR

5.4 Annual Pollutant Load

Due to the intermittent nature of storm water pollution, it is desirable to express its pollutant loads as a continuous, uniform long-term pollution source encompassing both dry and wet weather periods. The annual pollutant load, which is obtained by normalizing the unit pollutant loading rates of wet weather flows, can then be used to compare with the continuous discharge of point sources for pollutant load allocations or design of best management practices. Consequently, the annual average pollutant load is obtained by multiplying the site mean loading rates by the ratio of average storm duration (D) to the average time between storms (Δ). There were seven recording raingages installed for the monitoring stations. The average values of D (1.94-3.24 hrs) and Δ (150-225 hrs) were taken over a 12-month monitoring period at each of the raingage sites, as shown in Table 3.1.

Table 5.3 summarizes the annual pollutant loads for major water quality constituents with the exception of metals. The data trends are discussed with respect to the national database, and the variance among monitoring sites including the effects of meteorological factors and the effectiveness of vegetative coverage.

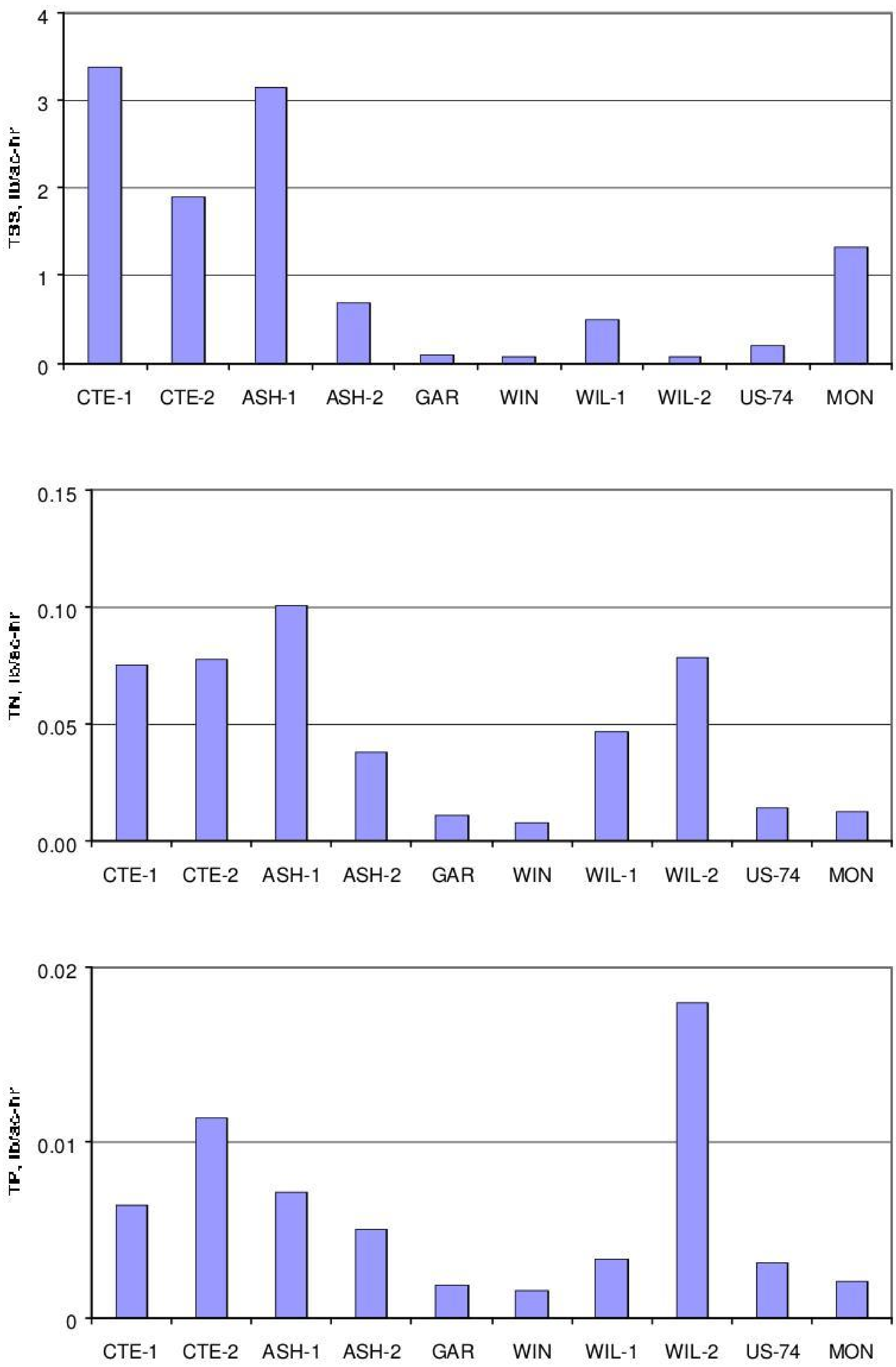


Figure 5.2 Unit Pollutant Loading Rates for TSS, TN, and TP

Table 5.3 Annual Pollutant Loads at 10 Monitoring Sites

		TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP
CLT-1	lb/ac-yr	423	210	19.5	180	6.58	2.88	2.55	0.22	0.80	0.31
	CV	1.11	1.07	1.05	0.95	0.94	1.11	1.50	1.07	1.10	1.22
CLT-2	lb/ac-yr	235	177	16.3	202	7.32	2.73	2.15	0.14	1.43	1.01
	CV	1.35	1.37	1.21	1.33	1.41	1.40	1.79	1.14	1.84	2.12
ASH-1	lb/ac-yr	321	117	32.8	149	7.43	2.25	2.40	0.39	0.73	0.35
	CV	1.63	1.35	1.09	1.20	1.29	1.29	1.39	1.21	1.17	1.05
ASH-2	lb/ac-yr	69	171	14.1	81	2.97	0.19	0.75	0.14	0.52	0.35
	CV	1.48	1.44	0.92	0.94	1.04	1.22	2.05	0.92	1.05	1.23
WIN	lb/ac-yr	12	88	3.5	28	1.02	0.11	0.32	0.04	0.26	0.19
	CV	1.07	0.98	0.84	0.95	1.00	1.39	1.24	0.78	1.49	1.75
GAR	lb/ac-yr	14	98	5.1	29	1.08	0.15	0.42	0.06	0.27	0.15
	CV	1.33	0.74	0.65	0.75	0.95	1.57	0.75	0.72	1.13	1.05
WIL-1	lb/ac-yr	72	287	27.6	123	4.30	1.08	2.08	0.45	0.49	0.41
	CV	1.20	0.87	0.82	1.05	0.98	1.49	1.18	2.10	1.25	1.47
WIL-2	lb/ac-yr	12*	180	13.4	303	7.87	0.42	0.43	0.13	2.07	1.16
	CV	1.64	1.31	1.47	1.46	1.19	1.64	1.63	0.51	1.13	1.48
US-74	lb/ac-yr	33	77	14.2	50	1.92	0.21	0.29	0.08	0.50	0.36
	CV	3.85	1.77	1.57	2.09	2.16	2.75	2.79	2.28	2.18	2.01
MON	lb/ac-yr	109	41	2.4	29	0.84	0.09	0.16	0.02	0.17	0.08
	CV	1.90	1.46	1.22	1.58	1.55	1.06	1.12	1.23	1.80	2.36
Average	lb/ac/yr	130	144	15	118	4.13	1.01	1.16	0.17	0.72	0.44
National	lb/ac-yr	280-10,580	132	114-3,450	4 - 684	1.48-28.50	0.92-4.10	0.71-7.14**		0.54-7.33	

*Excluding data with erosion at sampling location
*Including NO_3-N and NO_2-N

5.4.1 Comparison with the National Database

The annual TSS loads as reported in the national database are in the range of 280 to 10,580 lb/ac-yr. The site-averaged TSS load of 130 lb/ac-yr obtained from this study is below the low-end range of the national data. CLT-1 and ASH-1 are the two impervious sites with TSS annual load slightly higher than the low-end value of the national data.

The site-averaged TDS load of 144 lb/ac-yr is close to the reported value of 132 lb/ac-yr from the national data. The national data did not report the data range of this parameter and hence its validity can not be assessed. The data range of our study is within 41 to 381 lb/ac-yr.

The lowest annual load of oil and grease reported in the national database is 114 lb/ac-yr. The site-averaged value obtained is only 15 lbs/ac-yr and the highest data is 32 lb/ac-yr at the ASH-1 site. As mentioned in Section 4.1, most of the samples had O&G EMCs at or near its MDLs of 5 mg/L.

The national annual bad for COD ranged from 4 to 684 lb/ac-yr. The site-averaged COD value is 118 lb/ac-yr. The paired monitoring sites at CLT, ASH and WIL are at or above this average value.

The site-averaged TKN load is 4.13 lb/ac-yr as compared to the national data of 1.40 to 28.50 lb/ac-yr. The above average TKN loads are observed at CLT-1, CLT-2, ASH-1, WIL-1 and WIL-2.

The site-averaged NH_3-N of 1.10 lb/ac-yr is close to the low-end value of the national data range of 0.92 to 4.10 lb/ac-yr. The above average readings of NH_3-N are at CLT-1 (2.88 lb/ac-yr), CLT-2 (2.73 lb/ac-yr) and ASH-1 (2.25 lb/ac-yr).

CLT-1 (2.55 lb/ac-yr), CLT-2 (2.15 lb/ac-yr), ASH-1 (2.40 lb/ac-yr) and WIL-1 (2.08 lb/ac-yr) are sites with NO_{3+2}-N loads above the site-averaged value of 1.23 lb/ac-yr. The nationally reported data is 0.71 to 7.14 lb/ac-yr.

WIL-2 has the highest TP load of 2.65 lb/ac-yr while the site-averaged value of 0.72 lb/ac-yr is slightly higher than the low-end value of the national data range of 0.54 to 7.33 lb/ac-yr

The annual loads for ortho-phosphorus, OP, at WIL-2 (1.45 lbs/ac-yr) and CLT-2 (1.01 lb/ac-yr) are above the site-averaged value of 0.44 lb/ac-yr. No national data is available for comparison.

5.4.2 Variance among Monitoring Sites

Based on the Piedmont monitoring data, the dependence of unit event load on ADT and Imp is shown in Section 5.1. Additional factors that may influence the variability of annual pollutant loads are annual average rainfall intensity and the ratio of D/Δ. The influence of these factors are discussed in this section.

Monitoring sites at Charlotte (CLT-1 and CLT-2), Winston Salem (WIN), Garner (GAR), and Monroe (MON) are located in the Piedmont region. The meteorological factors of annual rainfall intensity and D/Δ are very similar but with differing site characteristics, see data below. Despite the relatively higher traffic at WIN and GAR, the annual pollutant loads of all water quality constituents at these two sites are substantially lower than that at the Charlotte sites. It is obvious that the orientation of the vegetative coverage at WIN and GAR is extremely effective in reducing pollutant export from these two sites. Other factors which may contribute to the high pollutant loads at the Charlotte sites are its urban surroundings and stop-and-go traffic.

Several extremely short-duration storms encountered at the Monroe area had caused the average (arithmetic) intensity to be higher, see data below. When these events were excluded from the annual data series, the corrected average intensity at Monroe becomes 0.37 in/hr. The MON site has a very large drainage area (13.46 acres) including some roadway and residential areas. Its site median TSS EMC is one of the highest among all sites (the other one is CLT-1). However, when incorporating the meteorological factors (particularly D/Δ) into the annual load calculation, its TSS annual load becomes 10% below the site-averaged load value. The above analysis illustrates the significance of integrating meteorological and site characteristics into the annual load calculations.

Site Location	Annual average intensity, in/hr	D/Δ	Imperviousness %	ADT (x1000) vehicles/day
Charlotte	0.25	0.0142	100 and 61	50.2 and 33.4
Winston Salem	0.29	0.0199	48	52.2
Garner	0.29	0.0165	33	78.8
Monroe	0.70	0.0094	22	9.4

Monitoring sites located to the east of Piedmont include US-74 and the Asheville sites (ASH-1 and ASH-2). The Asheville sites are located in the Mountains with steep terrains. Taking ASH-2 and US-74 as an example, the percent imperviousness of both sites is quite similar (50 vs. 42) but they differ in annual rainfall intensity, ADT and D/Δ, see data below. ASH-2 has higher ADT, rainfall intensity and D/Δ, resulting in higher TSS, COD, TDS, TKN and NO_3-N loads but exhibit similar loads in O&G, NH_3-N, TP and OP. Note that the drainage area of US-74 is about 2.4 times larger than that of ASH-2. In other words, the pervious area at I-74 is proportionally larger than the ASH-2 site. It can be reasoned that the availability of NH_3-N, TP and OP in highway runoff is not solely related to roadway traffic but may also be affected by roadside vegetation.

Site Location	Annual average intensity, in/hr	D/Δ	Imperviousness %	ADT (x1000) vehicles/day
US-74	0.20	0.0094	50	9.3
Asheville	0.31	0.0116	100 and 43	39.0

Monitoring sites located to the west of Piedmont include the Wilmington sites (WIL-1 and WIL-2). The annual average rainfall intensity of 0.43 in/hr at Wilmington is relatively higher than other site locations, see data below. On the other hand, the annual TSS load at the impervious ASH-1 site is relatively lower than impervious sites at Charlotte and Asheville. This is due to the low roadway traffic along this segment of I-40 near Wilmington. Annual loads for TSS, TKN, NH_3-N and NO_{3+2}-N are higher at the impervious WIL-1 site than WIL-2. Whereas COD, TKN, TP and OP loads are higher at WIL-2.

Site Location	Annual average intensity, in/hr	D/Δ	Imperviousness %	ADT (x1000) vehicles/day
Wilmington	0.43	0.0169	100 and 47	20.3

5.4.4 Impact of Annual Rainfall

The annual pollutant loads presented are based on monitoring data collected in the period of May 1999 through September 2000. The impact due to the variability of annual rainfall totals is beyond the scope of this research. Taking the annual rainfall records at the Charlotte Douglas airport as an example, there are approximately ± 6 to 8 inches above or below the average of 40 inches per year, as shown below:

	1993	1994	1995	1996	1997	1998	1999	2000
Charlotte rainfall, inches	35.81	36.64	48.18	39.59	48.74	40.32	34.04	34.99

Years with higher rainfall may result in lower pollutant concentrations in the runoff. The annual pollutant load of highway runoff is a complex, nonlinear function of traffic activity, a balance of pollutant deposit and washoff from roadway surface, atmospheric chemistry and deposition, and hydrologic responses.

From a previous study, eleven storm events had been monitored at CLT-2 during the period of 1995-1996 (Wu et al., 1998). The annual rainfall average was 44 inches in this period (48.18 inches in 1995 and 39.59 inches in1996). When the annual pollutant loads are compared between the 1995-1996 and the current studies; TSS, TDS, TP and OP are substantially higher from the 1995-1996 study. The annual loads of O&G, COD, and TKN are not much different, while NO_{3+2}-N is slightly lower in the 1995-1996 data (see Table 5.4). It is noted that the twenty-three storm events that have been monitored in the current study are approximately evenly distributed within the four quarters of a 12-month sampling period. The statistical significance of this data set is deemed more comprehensive than the previous study. In brief, the annual pollutant loads may be higher for certain water quality constituents in wet years but the impact appears to be less with respect to TKN and NO_{3+2}-N.

5.5 Seasonal Pollutant Loads

The quarterly distribution of seasonal loads was obtained by averaging the unit pollutant loads of individual storm events in each quarter, summing these quarterly averages for yearly totals, and expressing it as percentages of the yearly total. The calculated seasonal distributions of pollutant loads, together with variations of quarterly rainfall amount and intensity are given in Appendix 4. The four quarters of a year are designated as 1st quarter (January-March), 2nd quarter (April-June), 3rd quarter (July-September), and 4th quarter (October-December). Defining the four quarters in this manner enables us to be consistent with data reporting submitted in quarterly progress reports. The classification is more or less representative of the seasonal changes in a calendar year.

Table 5.4 Comparison of Annual Pollutant Loads at CLT-2

Water Quality Constituents	CLT-2 (1995-1996)*	CLT-2 (1999-2000)*	Percent Difference** %
TSS	470	235	+100
TDS	487	176	+170
O&G	23	21	+9
COD	226	203	+11
TKN	8.3	7.3	+14
NH_3-N	4.6	2.7	+70
NO_{3+2}-N	1.8	2.3	-22
TP	4.3	1.4	+207
OP	2.5	1.0	+150
Annual rainfall, inches	39.59-48.18	34.05-34.99***	+16-41%

* All in lb/ac-yr except rainfall ** As compared to the 1999-2000 data set

***Rainfall recorded at the Charlotte airport. It was about 30 inches at CLT-2

Users of Appendix 4 can follow the following example to perform similar calculations for the desired seasonal loads at selected sites.

Given: TSS annual load at CLT-1 = 423 lb/ac-yr

Required: Calculation for TSS seasonal load distribution at CLT-1

1st quarter = 423*34% = 144 lb/ac-quarter
2nd quarter = 423*19 % = 80 lb/ac-quarter
3rd quarter = 423*17% = 72 lb/ac-quarter
4th quarter = 423* 30% = 127 lb/ac-quarter

Seasonal variations in rainfall amount and intensity appear to greatly influence the seasonal distribution patterns. These variations are explained using examples of the discharge of particulate pollutants such as TSS and soluble pollutants such as NH_3-N or NO_3-N from roadways with and without pervious coverage.

5.5.1 **Seasonal TSS loads from impervious roadway surfaces** (CLT-1, ASH-1, and WIL-1)

AT CLT-1, over 50% of the annual TSS load can be accounted for in the 1st and 4th quarters, or between late fall and early spring, Figure 5.3. Rainfall intensities, which are equal to or greater than the annual average, are sufficient for flushing solids from the roadway surface. In addition, this period also accounts for 50% of the annual rainfall amount.

The relatively lower TSS loads in the 2nd and 3rd quarters at CLT-1 can be attributed to the balancing effects of either higher rainfall but lower intensity or lower rainfall but higher intensity. Storms in the 3rd quarter are typical of high-intensity and low-duration summer storms. These storms provide sufficient intensity for flushing of solids on roadway surface, but have low runoff volumes resulted in reduced solids transport.

At ASH-1, more than 85% of the annual TSS load occurs in the first 2 quarters of the year, i.e. mid-Winter to early Spring, Figure 5.4. Rainfall intensities here are at or near the annual average and the rainfall accounts for 70% of the yearly total. These rainfall intensities plus steeper roadway gradients are effective for flushing and transporting solids, including winter deicing salts, from the Mountains highways.

Storms of relatively higher rainfall intensity but low rainfall volumes in the 3rd quarter, or the low intensity storms in the 4th quarters appeared to be less effective at transporting solids at ASH-1.

The Wilmington WIL-1 site is within the general region of flat slopes. Storms occurring in the 1st and 2nd quarters are of sufficient intensity and magnitude to be responsible for the export of more than 50% of the annual TSS load, Figure 5.5.

In the 3rd quarter, there were more than 35 inches of rainfall at WIL-1. Hurricane Floyd brought in more tan 10 inches of rain. Although samples were not collected from the hurricane-type storms, this period accounted for more than 30% of the annual TSS load. The low TSS load in the 4th quarter could be affected by hurricane-type storms in the 3rd quarter or due to a combination of low quarterly rainfall amount and intensity.

5.5.2 Seasonal TSS load from roadways with pervious coverage (GAR)

Infiltration is another variable affecting TSS delivery from roadway surfaces connecting to pervious coverage. This is the so-called hydrologic retention as explained in chapter 6. The GAR site can serve as an example to demonstrate the influences of rainfall intensity and infiltration on TSS seasonal load. As seen from the following data, over 50% TSS load occurring in the first quarter was dictated by the high runoff coefficient, see data below. Relatively higher rainfall amount and intensity in the 3rd quarter did not result in higher TSS load due to increased infiltration and evapotranspiration in the summer months. In the 4th quarter, the low TSS load was attributed to continuing decreasing trend of the runoff coefficient and rainfall amount and intensity.

	Runoff Coefficient	Rainfall %	Quarterly to Annual Intensity Ratio	TSS Load %
Quarter 1	0.54	16	0.77	52
Quarter 2	0.52	8	0.60	31
Quarter 3	0.42	65	1.36	8
Quarter 4	0.31	11	0.58	9

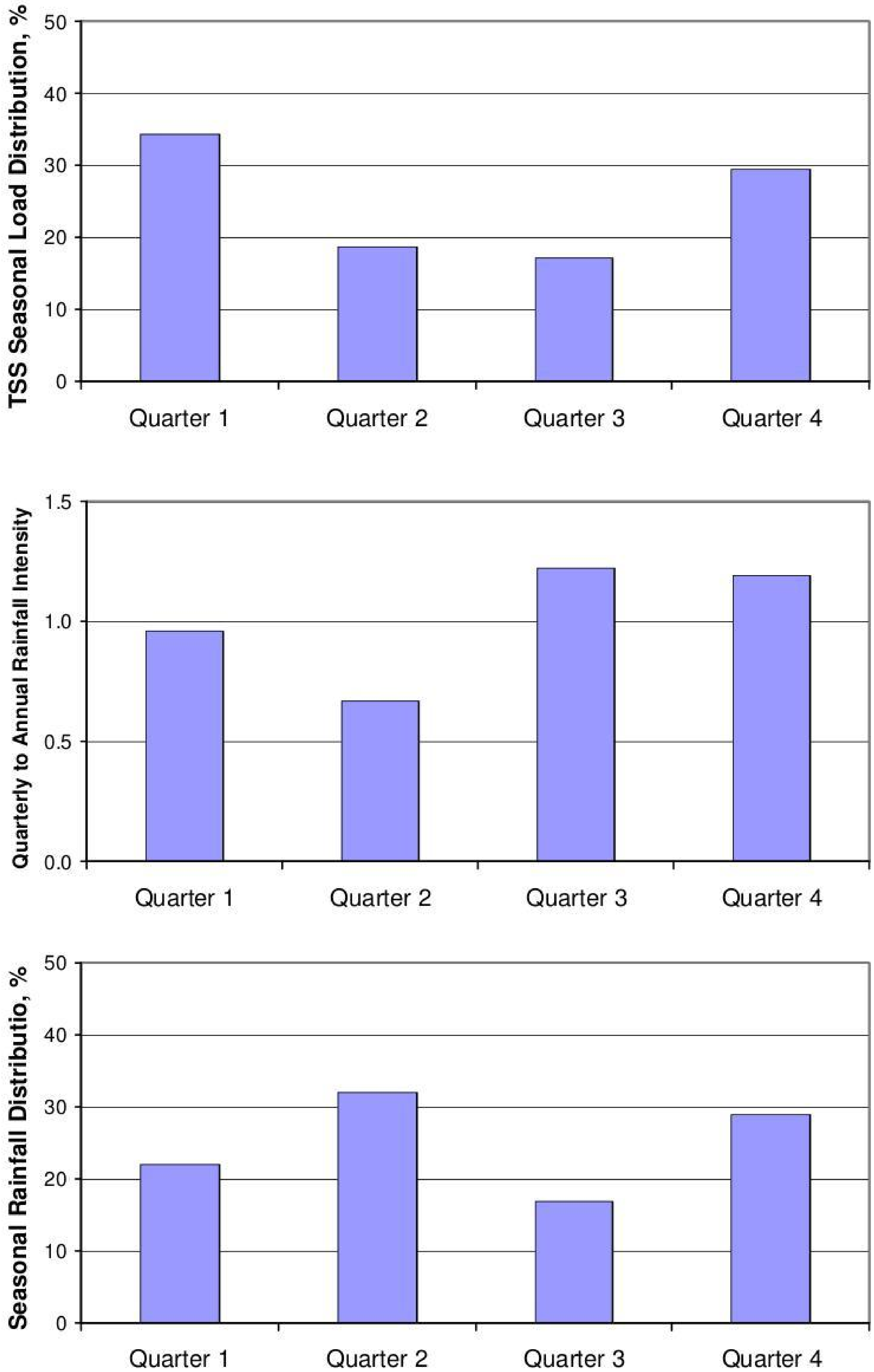


Figure 5.3. Seasonal TSS Loads at CLT-1

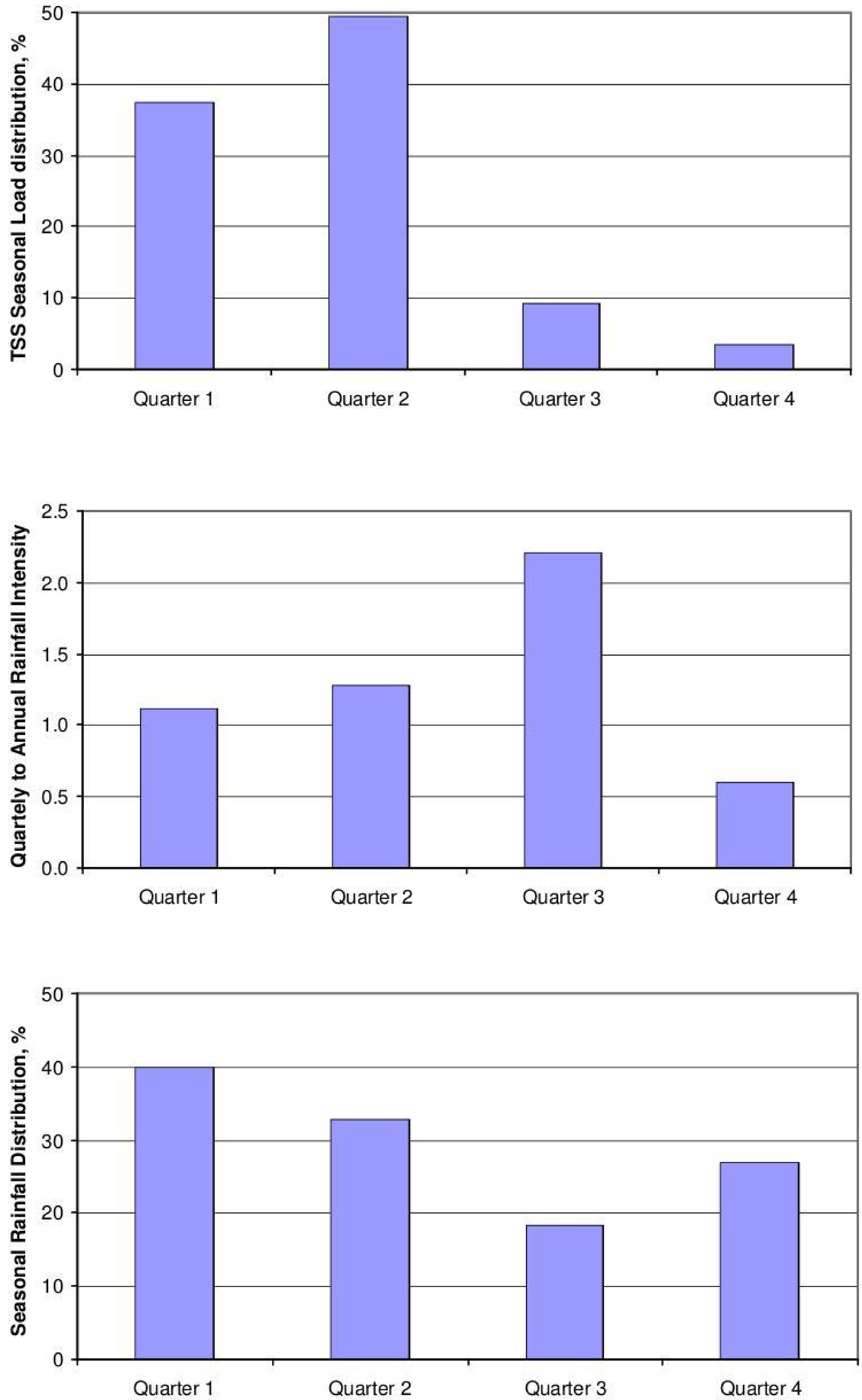


Figure 5.4 Seasonal TSS Loads at ASH-1

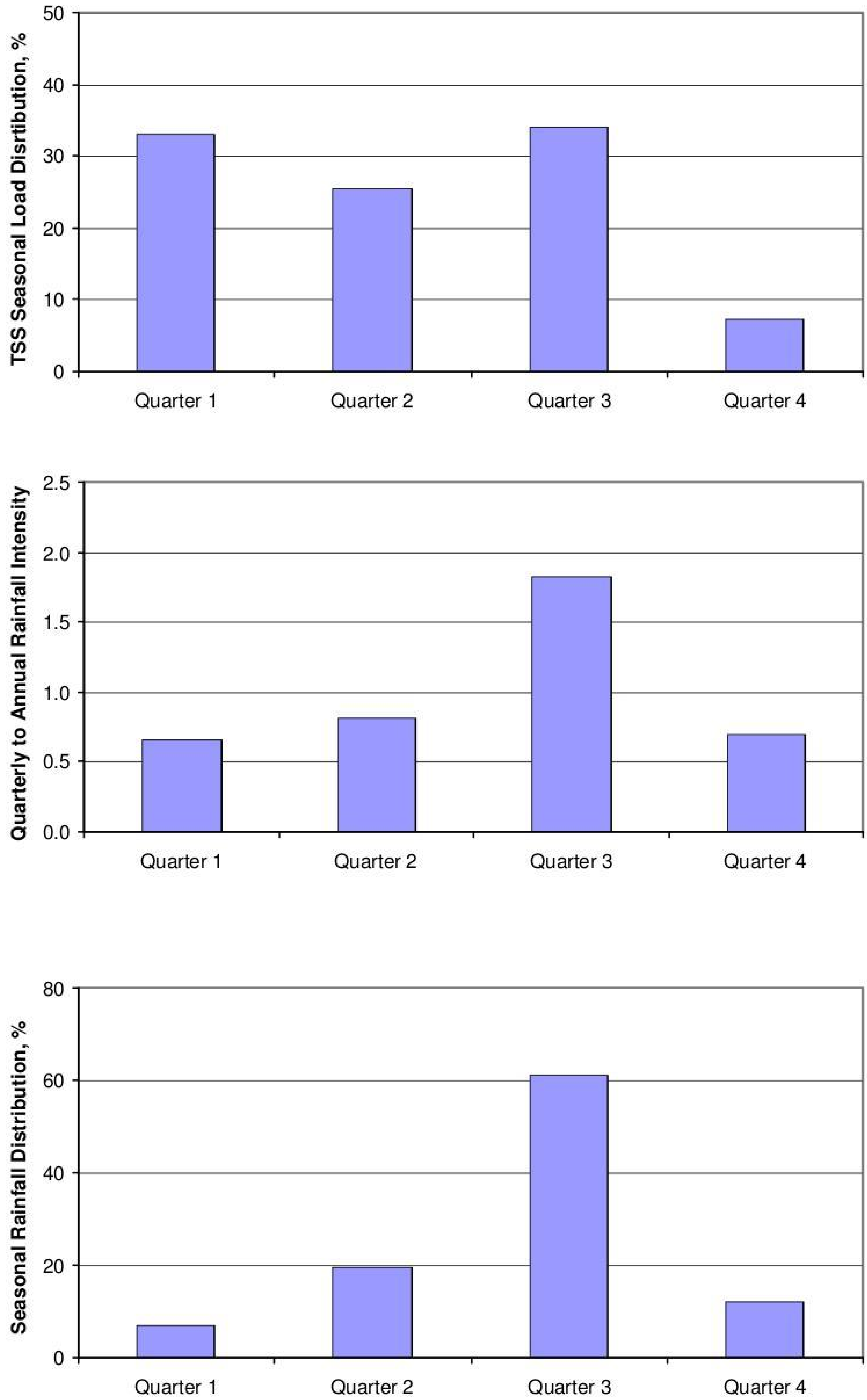


Figure 5.5 Seasonal TSS Loads at WIL-1

5.5.3 Seasonal NH_3-N and NO_3-N Load Pattern

The NH_3-N load appears to be relatively higher in the 1st and/or 2nd quarters for all three impervious sites (CLT-1, ASH-1 and WIL-1), see data below. Sites with pervious coverage such CLT-2 and GAR, typically exhibit higher NH_3-N load in the 2nd quarter with less dependence on meteorological conditions. The NO_3-N loads for both impervious and pervious sites are higher in the 3rd and/or 4th quarters of the year. There appears to exist an annual cycle of NH_3-N and NO_3-N transport in roadway runoff, with higher NH_3-N transport in the first two quarters of the year followed by higher NO_3-N transport in the last two quarters. The transport cycle is influenced by interacting mechanisms among atmospheric deposition, vegetative uptake, vegetative decay, nitrification/denitrification reactions, and fertilizer application. In addition, the seasonal load distributions of NH_3-N and NO_3-N are less variable among quarters at impervious sites than at sites with pervious coverage (e.g. the percent distribution of NH_3-N at CLT-1 is 19-28%, while it varies within 8-57% at GAR).

	Relatively Higher Transport of NH_3-N and NO_3-N for Indicated Quarters				
	CLT-1	CLT-2	ASH-1	WIL-1	GAR
NH_3-N	1st, 2nd	2nd	1st	2nd	2nd
NO_3-N	3rd	3rd	3rd	3rd	4th

6. Evaluation of Best Management Practices

6.1 Introduction and Methodology

One of the objectives of the current study was to evaluate the effectiveness of vegetation BMPs in controlling the volume of highway stormwater runoff and the removal of particulate and dissolved pollutants associated with this runoff. The selection of paired monitoring locations (CLT-1/CLT-2, ASH-1/ASH-2 and WIL-1/WIL-2) in close proximity to each other with one site being 100% impervious and the second comprising a mixture of pervious and impervious surfaces allows us to examine the effectiveness of vegetation BMPs. The vegetation BMPs common to all three locations are pervious shoulders and grassed central medians. The percent of pervious coverage of the mixed-cover monitoring sites is 49%, 53% and 58% for CLT-2, WIL-2 and ASH-2, respectively. In this analysis we examined runoff events in which hydrologic and water quality data were collected from the common rainfall events of the paired monitoring sites. The hydrologic retention attributed to the vegetation BMP is calculated as:

$$(RO_{imp} - RO_{mix}) / RO_{imp} = HR \qquad (6.1)$$

Where RO_{mix} and RO_{imp} are runoff in inches for the mixed site (e.g. CLT-2) and impervious site (e.g. CLT-1), respectively. HR is the hydrologic retention as a fraction of the runoff reduction from the impervious monitoring site. The total or relative pollutant retention attributed to the vegetation BMP is calculated as:

$$(PL_{imp} - PL_{mix}) / PL_{imp} = PR_{total} \qquad (6.2)$$

Where PL_{mix} and PL_{imp} are pollutant loadings in mg/m^2 for the mixed site and impervious site, respectively. PR_{total} is the total or relative pollutant retention as a fraction of the pollutant loading of the impervious site. Note that in this nomenclature, a negative retention value represents a net export from the pervious site in relation to the impervious site. The vegetative BMPs serve to reduce runoff and remove pollutants through the infiltration of stormwater, the physical retention of material, vegetative uptake, adsorption and possibly microbial immobilization. An estimate of the importance of infiltration as a removal mechanism can be described by the magnitude of HR in relation to PR_{total}:

$$HR / PR_{total} = PR_H \qquad (6.3)$$

Where PR_H is the fraction of pollutant retention associated with the reduction in water yield attributed to infiltration. The pollutant retention associated with particle retention, vegetative uptake, adsorption and microbial immobilization (PR_{veg}) is estimated by:

$$PR_{total} - PR_H = PR_{veg} \qquad (6.4)$$

The pollutant removal statistics for the three-paired sites are presented in Tables 6.1-6.2 (CLT-1, CLT-2), 6.3-6.4 (WIL-1, WIL-2) and 6.5-6.6 (ASH-1, ASH-2). We have purposely excluded runoff events where site-specific erosion affected the water quality at the WIL-2 monitoring location. Interpretation of data presented in these tables is illustrated below.

(1) The average PR_{tot} for TSS from Table 6.1 = 0.54

This indicates that the vegetative coverage contributes 54% attenuation of TSS, when comparing the TSS export between an impervious site (CLT-1) and a mixed pervious/impervious site (CLT-2). In other words, the effectiveness of vegetative BMP is 54%.

(2) The average PR_h for TSS from Table 6.2 = 0.48

This implies that of the 54% attenuation of TSS due to the presence of vegetative coverage, 48% of which can be associated with the reduction of water yield as a result of infiltration or hydrologic retention (HR).

(3) The average PR_{veg} for TSS from Table 6.2 = 0.07

That is approximately 7% of the 54% attenuation is accounted for by other removal mechanisms such as particle retention, vegetative uptake, adsorption and microbial immobilization caused by the presence of vegetation.

Note that $PR_{veg} + PR_h = PR_{tot}$

6.2 Charlotte Sites

Sixteen paired runoff events are included in the analysis for the two Charlotte sites. These events ranged from 0.24" to 1.70" with an average event size of 0.65" which is near the average rainfall total of our sample set for this location.

The reduction in pollutant load attributed to the routing of runoff over the vegetated pervious surfaces was fairly consistent for most water quality constituents at this site, averaging between 36% and 62% (Table 6.1). The exception to this general retention occurred with phosphorus. The yield of total phosphorus from CLT-2 was essentially the same as the 100% impervious CLT-1. The yield of ortho-P from CLT-2 was higher than CLT-1 for the events examined. The pervious surfaces at this location were a net source for phosphorus. There was a strong seasonal component to this transport with net phosphorus export occurring during August, 1999 through November, 1999 period, and net phosphorus retention observed for events outside this period. A possible explanation for this pattern may be the application of fertilizer to roadside landscaping at this site during the August-November period. However, no similar pattern is observed for nitrogen.

Table 6.1 Proportion of Pollutant Loading Retained by Vegetative BMP, Charlotte Sites

	PR_{tot}									
	TSS	TDS	TKN	NH_3-N	NO_3-N	TN	NO_2-N	TP	OP	COD
05/26/99	0.31	0.45	0.38	0.40	0.51	0.52			0.04	0.20
06/20/99	0.76	0.67	0.48	0.26	0.71	0.56	0.61	0.21	0.21	0.57
07/11/99	0.87	0.78	0.61	0.47	0.76	0.66	0.65	0.29	-1.33	0.80
07/24/99	0.61	0.66	0.18	-0.16	0.54	0.28	0.77	-0.59	-1.77	0.28
08/24/99	0.34	0.74	0.54	0.65	0.69	0.58	0.70	0.20	-0.13	0.51
09/05/99	-0.23	0.65	0.52	0.57	0.53	0.52	0.58	-0.68	-1.18	0.46
09/09/99	0.48	0.63	0.25	0.37	0.41	0.31	0.44	-0.80	-2.47	0.38
11/02/99	0.88	0.55	0.51	0.68	0.51	0.51	0.57	0.06	-1.41	-0.34
11/26/99	0.63	0.09	-0.24	0.70	0.70	0.02	0.22	-1.25	-3.70	0.03
02/12/00	0.70	0.78	0.62	0.62	0.67	0.63	0.72	0.60	0.32	0.62
03/04/00	0.14	0.77	0.34	0.31	0.80	0.62	0.68	0.36	0.16	0.04
03/11/00	0.75	0.72	0.72	0.71	0.78	0.73	0.73	0.60	0.51	0.67
03/16/00	0.38	0.27	0.34	0.50	0.59	0.37	0.23	0.12	0.12	0.20
04/08/00	0.63	0.42	0.39	0.44	0.62	0.44	0.42	0.20	0.16	0.39
04/24/00	0.69	0.67	0.50	0.42	0.63	0.54	0.58	0.56	0.31	0.51
05/02/00	0.75	0.58	0.52	0.28	0.49	0.66	0.51	0.74	0.59	0.53
Average	0.54	0.59	0.41	0.45	0.62	0.50	0.56	0.04	-0.60	0.36
S.D.	0.30	0.20	0.22	0.22	0.12	0.18	0.17	0.59	1.25	0.29
CV	0.54	0.33	0.54	0.49	0.19	0.36	0.30	14.69	-2.08	0.79
Max	0.88	0.78	0.72	0.71	0.80	0.73	0.77	0.74	0.59	0.80
Min	-0.23	0.09	-0.24	-0.16	0.41	0.02	0.22	-1.25	-3.70	-0.34

Table 6.2 Partitioning of Pollutant Retention Between Hydrologic Retention (PR_h) and Vegetative Retention (PR_{veg}), Charlotte Sites.

		PR_{veg}									
	PR_h	TSS	TDS	TKN	NH_3-N	NO_3-N	TN	NO_2-N	TP	OP	COD
05/26/99	0.12	0.19	0.33	0.26	0.28	0.39	0.40	-0.12	-0.12	-0.08	0.08
06/20/99	0.50	0.26	0.17	-0.03	-0.24	0.21	0.06	0.11	-0.29	-0.29	0.07
07/11/99	0.58	0.28	0.20	0.03	-0.11	0.18	0.08	0.07	-0.29	-1.92	0.22
07/24/99	0.37	0.25	0.29	-0.19	-0.53	0.18	-0.08	0.41	-0.96	-2.14	-0.08
08/24/99	0.70	-0.36	0.04	-0.17	-0.05	-0.01	-0.12	0.00	-0.50	-0.83	-0.20
09/05/99	0.58	-0.81	0.07	-0.06	-0.01	-0.05	-0.05	0.00	-1.26	-1.76	-0.12
09/09/99	0.44	0.04	0.19	-0.19	-0.07	-0.04	-0.13	0.00	-1.24	-2.91	-0.06
11/02/99	0.57	0.31	-0.02	-0.06	0.11	-0.06	-0.06	0.00	-0.51	-1.98	-0.91
11/26/99	0.22	0.41	-0.13	-0.46	0.48	0.48	-0.19	0.00	-1.46	-3.92	-0.19
02/12/00	0.49	0.21	0.29	0.13	0.13	0.18	0.14	0.23	0.11	-0.17	0.13
03/04/00	0.68	-0.54	0.09	-0.34	-0.36	0.12	-0.06	0.00	-0.32	-0.51	-0.64
03/11/00	0.73	0.03	-0.01	-0.01	-0.02	0.05	0.00	0.00	-0.13	-0.22	-0.05
03/16/00	0.23	0.15	0.04	0.10	0.27	0.36	0.14	0.00	-0.11	-0.11	-0.03
04/08/00	0.42	0.22	0.00	-0.03	0.02	0.20	0.02	0.00	-0.22	-0.26	-0.03
04/24/00	0.58	0.11	0.08	-0.09	-0.16	0.05	-0.04	0.00	-0.02	-0.28	-0.07
05/02/00	0.41	0.34	0.17	0.10	-0.14	0.08	0.25	0.10	0.33	0.18	0.12
Average	0.48	0.07	0.11	-0.06	-0.03	0.15	0.02	0.05	-0.44	-1.07	-0.11
Stdev	0.18	0.34	0.13	0.18	0.25	0.16	0.15	0.12	0.52	1.21	0.29
CV	0.37	5.12	1.13	-2.92	-10.01	1.12	7.01	2.44	-1.19	-1.13	-2.57
Max	0.73	0.41	0.33	0.26	0.48	0.48	0.40	0.41	0.33	0.18	0.22
Min	0.12	-0.81	-0.13	-0.46	-0.53	-0.06	-0.19	-0.12	-1.46	-3.92	-0.91

Table 6.3 Proportion of Pollutant Load Removed by Vegetation BMP, Wilmington Sites

	PR_{tot}									
	TSS	TDS	TKN	NH_3-N	NO_3-N	TN	NO_2-N	TP	OP	COD
1/9/00	0.98	0.81	0.58	0.62	0.97	0.70	0.87	0.03	0.41	0.69
2/14/00	0.89	0.81	0.77	0.95	0.82	0.78	0.81	0.67	0.39	0.76
4/18/00	0.90	0.80	0.75	0.70	0.92	0.77	0.90	0.72	0.80	0.58
4/25/00	0.56	0.48	-0.03	0.85	0.94	0.35	0.43	-1.67	-1.15	0.34
5/22/00	0.73	0.50	0.25	0.33	0.71	0.41	0.94	-3.47	-3.00	0.19
5/26/00	0.80	0.04	-0.02	0.74	0.87	0.28	0.32	-2.62	-2.80	-0.54
Average	0.81	0.58	0.38	0.70	0.87	0.55	0.71	-1.06	-0.89	0.34
S.D.	0.15	0.31	0.37	0.21	0.10	0.23	0.27	1.79	1.69	0.48
CV	0.18	0.53	0.95	0.31	0.11	0.42	0.37	-1.69	-1.90	1.43
Max	0.98	0.81	0.77	0.95	0.97	0.78	0.94	0.72	0.80	0.76
Min	0.56	0.04	-0.03	0.33	0.71	0.28	0.32	-3.47	-3.00	-0.54

Table 6.4 Partitioning of Pollutant Retention Between Hydrologic Retention (PR_h) and Vegetative Retention (PR_{veg}), Wilmington Sites

		PR_{veg}									
	PR_h	TSS	TDS	TKN	NH_3-N	NO_3-N	TN	NO_2-N	TP	OP	COD
1/9/00	0.87	0.11	-0.06	-0.29	-0.26	0.10	-0.17	0.00	-0.85	-0.46	-0.18
2/14/00	0.81	0.08	0.00	-0.04	0.14	0.01	-0.03	0.00	-0.14	-0.42	-0.05
4/18/00	0.90	0.00	-0.10	-0.15	-0.20	0.02	-0.12	0.00	-0.18	-0.10	-0.32
4/25/00	0.43	0.13	0.05	-0.46	0.42	0.51	-0.09	0.00	-2.10	-1.58	-0.09
5/22/00	0.67	0.06	-0.16	-0.41	-0.33	0.04	-0.26	0.28	-4.13	-3.67	-0.48
5/26/00	0.32	0.48	-0.28	-0.34	0.42	0.55	-0.04	0.00	-2.94	-3.12	-0.86
Average	0.67	0.14	-0.09	-0.28	0.03	0.20	-0.12	0.05	-1.72	-1.56	-0.33
S.D.	0.24	0.17	0.12	0.16	0.34	0.25	0.09	0.11	1.62	1.52	0.30
CV	0.36	1.19	-1.30	-0.57	10.89	1.25	-0.73	2.45	-0.94	-0.97	-0.92
Max	0.90	0.48	0.05	-0.04	0.42	0.55	-0.03	0.28	-0.14	-0.10	-0.05
Min	0.32	0.00	-0.28	-0.46	-0.33	0.01	-0.26	0.00	-4.13	-3.67	-0.86

Table 6.5 Proportion of Pollutant Load Removed by Vegetation BMP, Asheville Sites

	PR_{tot}

	TSS	TDS	TKN	NH_3-N	NO_3-N	TN	NO_2-N	TP	OP	COD
10/20/99	0.98	0.77	0.89	0.99	0.97	0.90	0.92	0.87	0.92	0.68
11/01/99			0.26	0.69	0.65	0.32	0.53	-0.78	-0.50	-0.13
11/25/99	-0.58	-1.00	1.00	0.80	0.56	0.95	0.21	-0.73	-0.73	-1.03
01/09/00	-0.20	-35.15	-0.61	0.78	-0.24	-0.54	-0.34	-1.95	-0.61	-1.49
02/13/00	0.94	-2.59	0.19	0.66	-0.02	0.14	0.26	0.26	-0.48	0.72
02/14/00	0.24	-0.46	0.73	0.95	0.80	0.74	0.88	0.60	0.74	0.25
03/12/00	0.06	0.01	0.54	0.89	0.57	0.55	0.63	-0.17	0.41	-0.03
03/20/00	0.82	-0.19	0.32	0.51	0.59	0.36	0.51	0.40	0.02	0.38
04/15/00	0.82	-2.71	0.37	0.90	0.63	0.41	0.26	0.33	-1.67	0.51
04/28/00	0.99	0.67	0.95	0.96	0.96	0.95	0.84	0.95	0.62	0.95
05/21/00	1.00	0.96	0.99	0.99	0.97	0.99	0.99	0.98	0.96	0.98
06/05/00	0.76	0.75	0.90	0.99	0.92	0.90	0.97	0.70	0.82	0.69
08/03/00	0.17	0.95	0.62	0.97	0.89	0.77	0.83	0.17	0.40	0.51
08/07/00	0.44	-1.03	0.90	0.98	0.93	0.91	0.92	0.63	0.82	0.87
08/31/00	0.98	0.48	0.80	0.98	0.91	0.83	0.83	0.75	0.67	0.67
Average	0.53	-2.75	0.59	0.87	0.67	0.61	0.62	0.20	0.16	0.30
S.D.	0.51	9.40	0.43	0.15	0.36	0.42	0.38	0.81	0.79	0.71
CV	0.97	-3.41	0.74	0.17	0.54	0.69	0.61	4.06	4.93	2.36
Max	1.00	0.96	1.00	0.99	0.97	0.99	0.99	0.98	0.96	0.98
Min	-0.58	-35.15	-0.61	0.51	-0.24	-0.54	-0.34	-1.95	-1.67	-1.49

Table 6.6 Partitioning of Pollutant Retention Between Hydrologic Retention (PR_h) and Vegetative Retention (PR_{veg}), Asheville Sites

PR_{veg}

	PR_h	TSS	TDS	TKN	NH_3-N	NO_3-N	TN	NO_2-N	TP	OP	COD
10/20/99	0.92	0.06	-0.14	-0.03	0.07	0.05	-0.01	0.00	-0.05	0.00	-0.24
11/01/99	0.53	-0.53		-0.27	0.16	0.12	-0.21	0.00	-1.32	-1.03	-0.66
11/25/99	0.21	-0.79	-1.21	0.79	0.59	0.35	0.73	0.00	-0.95	-0.95	-1.24
01/09/00	0.66	-0.86	-35.80	-1.27	0.12	-0.90	-1.20	-1.00	-2.60	-1.27	-2.15
02/13/00	0.26	0.68	-2.86	-0.07	0.40	-0.28	-0.12	0.00	0.00	-0.74	0.46
02/14/00	0.88	-0.64	-1.34	-0.15	0.07	-0.08	-0.14	0.00	-0.28	-0.14	-0.63
03/12/00	0.63	-0.57	-0.63	-0.10	0.25	-0.06	-0.09	0.00	-0.81	-0.22	-0.66
03/20/00	0.51	0.31	-0.70	-0.19	0.00	0.08	-0.15	0.00	-0.11	-0.49	-0.13
04/15/00	0.26	0.57	-2.97	0.11	0.64	0.37	0.15	0.00	0.07	-1.93	0.25
04/28/00	0.81	0.18	-0.14	0.14	0.15	0.15	0.14	0.03	0.14	-0.19	0.14
05/21/00	0.99	0.01	-0.03	0.00	0.00	-0.02	0.00	0.00	0.00	-0.03	-0.01
06/05/00	0.91	-0.15	-0.16	-0.01	0.08	0.00	-0.01	0.06	-0.21	-0.09	-0.22
08/03/00	0.83	-0.67	0.11	-0.22	0.14	0.06	-0.07	0.00	-0.67	-0.43	-0.32
08/07/00	0.92	-0.47	-1.95	-0.02	0.06	0.01	-0.01	0.00	-0.29	-0.10	-0.05
08/31/00	0.83	0.16	-0.35	-0.02	0.15	0.08	0.01	0.00	-0.08	-0.16	-0.16
Average	0.68	-0.18	-3.44	-0.09	0.19	0.00	-0.07	-0.06	-0.48	-0.52	-0.37
S.D.	0.27	0.50	9.37	0.41	0.20	0.30	0.38	0.26	0.72	0.56	0.65
CV	0.39	-2.76	-2.72	-4.70	1.04	-66.66	-5.87	-4.33	-1.52	-1.08	-1.73
Max	0.99	0.68	0.11	0.79	0.64	0.37	0.73	0.06	0.14	0.00	0.46
Min	0.21	-0.86	-35.80	-1.27	0.00	-0.90	-1.20	-1.00	-2.60	-1.93	-2.15

Reduction in pollutant loading by the vegetated surfaces is largely attributed to the reduction in runoff volume through infiltration (PR_h, Table 7.2). Other processes such as particle retention, adsorption, vegetative uptake or microbial immobilization appear to be a variable, minor component of PR_{total}. When HR is accounted for, the pervious areas within CLT-2 appear to be a consistent year-round source of P and to a lesser degree N and COD.

6.3 Wilmington Sites

Six paired runoff events are included in the analysis for the two Wilmington sites. These events ranged from 0.20" to 2.21" with an average event size of 0.98" which is near the average rainfall total of our sample set for this location. The Wilmington analysis is more limited than the other two sites owing to the exclusion of several paired storm events where site-specific erosion affected the water quality of the WIL-2 sample. There are no common sample events available from the July through December period.

The pattern of pollutant retention at this site is similar to the Charlotte location (Table 6.3). The pollutant retention for most constituents was typically higher at Wilmington as compared to the Charlotte location because of the greater HR for those events examined. The higher HR for Wilmington occurred despite a larger average event size than that for the Charlotte site, and likely reflects the higher infiltration capacity of the porous, sandy soils of the coastal plain. As observed for the Charlotte sites, the pervious surfaces were a net source of P during the events examined. Here again the reduction in pollutant loading is largely attributed to the reduction in runoff volume through infiltration losses (Table 6.4). When HR is accounted for, the pervious areas within WIL-2 appear to be a net source of P and COD and to a lesser degree TDS and TKN.

6.4 Asheville Sites

Fifteen paired runoff events are included in the analysis for the two Asheville sites. These events ranged from 0.46" to 2.20" with an average event size of 1.13" which is near the average rainfall total of our sample set from this site.

Significant differences in the pattern of pollutant retention were observed at this site when compared to the other two locations (Table 6.5). Firstly, the pervious surfaces at this site were a lesser source of P than the other two locations and a net retention of P was observed during the runoff events examined. Secondly, the pervious surfaces served as a net source of TDS at this location. An examination of the data reveals that the largest net export of TDS occurred during the 01/09/00 runoff event and may reflect deicing activities at this site. The consistent pattern of TDS leaching from the Asheville and Wilmington sites, particularly when the influence of HR is removed (Tables 6.4 and 6.6) may reflect the flushing of salts from surface soils deposited by oceanic source precipitation at Wilmington and deicing activities at Asheville. Here as for the other two locations, the reduction in pollutant loading is largely attributed to the reduction in runoff volume through infiltration losses (Table 6.6). When HR is accounted for, the pervious areas within ASH-2 appear to be a net source of TDS, P and COD and to a lesser degree TKN and TSS.

6.5 Summary

The vegetated pervious coverage at the three sites examined appeared to reduce the total pollutant export for most chemical constituents in proportion to the reduction in runoff volume through infiltration losses. The consistent exception to this was phosphorus. At two of the three sites a net export of phosphorus was observed from the mixed site in relation to the 100% impervious sites. The contribution of the vegetated pervious surfaces to net phosphorus exports is even more striking when the effect of infiltration losses is removed (Tables 6.2, 6.4, and 6.6). In a similar analysis, pervious roadside surfaces often appear to be net sources of COD and N but still exhibit a net retention owing to their retention of runoff water. The mixed surface Blue Ridge site near Asheville also exhibited a net loss of TDS in relation to its paired impervious site. The majority of this export was attributed to one winter runoff event and may reflect deicing activities and road clearing activities. As mentioned above, the reduction in pollutant export in highway runoff mainly results from infiltration losses as runoff moves over these pervious surfaces and efforts to maximize infiltration capacity of these surfaces should be encouraged.

7. Estimation of Nitrogen Export

Highways provide crossings to a variety of environmental settings including sensitive waters. The export of nitrogen from highway runoff is of particular concern from a watershed-level management perspective. This chapter examines Schueler's Simple Method for determining TN (total nitrogen) export from new development, compares the calculated export of TN loadings to monitoring data, and recommends export functions for highway runoff in the Piedmont, Mountains and Coastal regions. TN refers to the sum of TKN and NO_{3+2}-N constituents.

7.1 Schueler's Simple Method

The basic TN export equation for new development is given by Schueler (1987):

$$TN\ (lb/ac\text{-}yr) = [\ (P)\ (Pi)\ (Rv)\ /\ 12]\ (C)\ (2.72) \quad (7.1)$$

Where P = annual rainfall, inches
Pi = correction factor for excluding storms without measurable runoff (0 to 1)
Rv = runoff coefficient
C = flow-weighted mean concentration of TN, mg/L

Based on monitoring data collected from Fayetteville, Raleigh and Durham, NC DWQ recommended the following values:

C (pervious)	=	1.4 mg/L TN
C (impervious)	=	2.6 mg/L TN
P	=	42 in
Pi	=	0.9
Rv	=	0.05 + 0.009 (Imp)

Where Imp is given as percent imperviousness. According to Schueler's original definition, the imperviousness refers to the impervious portion of the area of a development site. Taking C(pervious) and C(impervious) as the lower- and upper-bound concentrations of TN, respectively, and using linear interpolation within the concentration range, the export of TN can be obtained, as shown in Table 7.1.

7.2 TN Export Data from Monitoring Sites

The annual TKN and NO_{3+2}-N loads taken from Table 5.3 are combined to derive the annual TN loads and arranged in ascending order by percent imperviousness in Table 7.2. Multiple regression analyses indicated that when the TN data from the Wilmington sites were excluded, an improved correlation between TN load and ADT and Imp can be obtained:

All 10 sites:

$$TN = 0.288071 + 2.09\times10^{-3}\ (ADT) + 0.091323\ (Imp) \quad (7.2)$$
$$(R^2 = 0.63)$$

Table 7.1. TN Export from a Development Site using Schueler's Method of Estimation

Imperviousness, %	TN, mg/L	TN Export, lb/ac-yr
0	1.40	0.6
10	1.52	1.8
20	1.64	3.2
30	1.76	4.8
40	1.88	6.6
50	2.00	8.6
60	2.12	10.7
70	2.24	13.1
80	2.36	15.6
90	2.48	18.3
100	2.60	21.2

Table 7.2. TN Export Data from Monitoring Sites in North Carolina

	ADT vehicles/day	Imp, %	Rv	TN, lb/ac-yr
WIN	52,200	11*	0.18	1.38
MON	9,400	22	0.20	1.02
GAR	78,800	33	0.33	1.56
ASH-2	39,000	42	0.26	3.87
WIL-2	20,300	47	0.24	8.43
US-74	9,300	50	0.32	2.30
CLT-2	33,400	61	0.53	9.61
WIL-1	20,300	100	0.60	6.83
CLT-1	50,200	100	0.85	9.34
ASH-1	39,000	100	0.71	10.22

***effective hydraulic imperviousness**

Excluding Wilmington sites: $TN = -1.06 + 0.006582\times10^{-3} (ADT) + 0.1098 (Imp)$ (7.3)
$(R^2 = 0.81)$

Where TN = lb/ac-yr, ADT = vehicles/day, and Imp = imperviousness of contributing drainage area in percentage. It also appears from Eq. 7.3 that ADT is of less significance due to the small coefficient associated with it. Hence a revised relationship between TN loading and imperviousness with further exclusion of the ADT data can be established for the Piedmont and Mountains regions.

$$TN = 0.8912\, e^{0.0256\, Imp} \qquad R^2 = 0.80 \qquad (7.4)$$

7.3 Validation of Schueler's Simple Method

The site-averaged TN concentrations taken from Appendix 3 are used for the following calculations:

C_{TN}(impervious) = average of CLT-1, CLT-2 and ASH-1
= 2.56 mg/L
C_{TN}(pervious) = average of all pervious sites except WIL-2
= 1.80 mg/L
P = 37 inches (average of raingage data from Greensboro, RDU, Monroe, Charlotte, Forest city, and Asheville for 1999-2000 with exclusion of Hurricane Floyd)
Pi = 0.80
Rv = $0.6585\,(Imp/100)^2 + 0.0333\,(Imp/100) + 0.1684$ (7.5)
($R^2 = 0.93$)

By analyzing the annual rainfall data, it was found that the percentages of rainfall events not producing measurable runoff ranged from 2% to 62% with an average of 30%. A conservative estimate of 25% events not producing measurable runoff, Pi = 0.75, provides reasonable fit of the monitoring data, see Figure 7.1. The power-function regression, Eq. 7.5, provides the best estimates of runoff coefficients from imperviousness of the contributing drainage area. Thus, Schueler's Simple Method can be reasonably applied to model the export of TN from roadways based on information derived from the monitoring data.

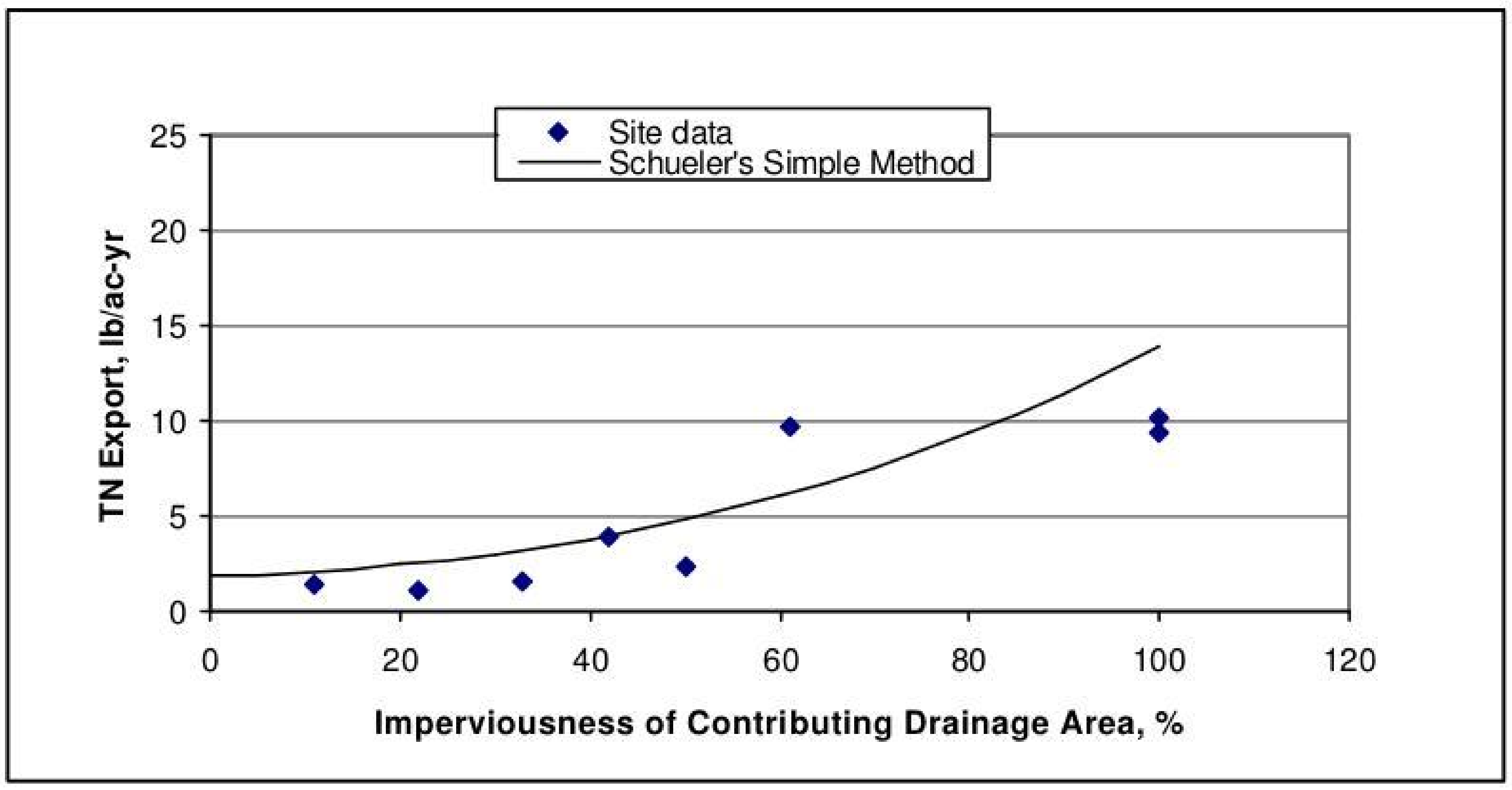


Figure 7.1 Validation of Schueler's Simple Method

7.4 TN Export Functions for Piedmont and Mountains

With the assumption that Schueler's Simple Method has been validated, the TN loads can be estimated by retaining the values of all model parameters except the annual rainfall and Pi. The "P" value was adjusted to 42 inches to be consistent with section 7.1 calculations and representative of the rainfall amount in a normal year. Pi was revised from 0.25 to 0.2 to account for the possible increase in runoff-producing storm events of a normal year. Results of computations are given in Figure 7.2 and Table 7.3. The monitoring data trend is also included in Figure 7.2, as computed by Eq. 7.4. It can be concluded from Table 7.1 that when applying the Simple Method for estimating TN export from highway runoff, the resulting TN exports calculated based on the New Development scenario for urban runoff could be overestimated by as much as 1.48 times. Estimate of TN export for highway runoff should rely on the application of actual monitoring data for model validation and parameter estimation.

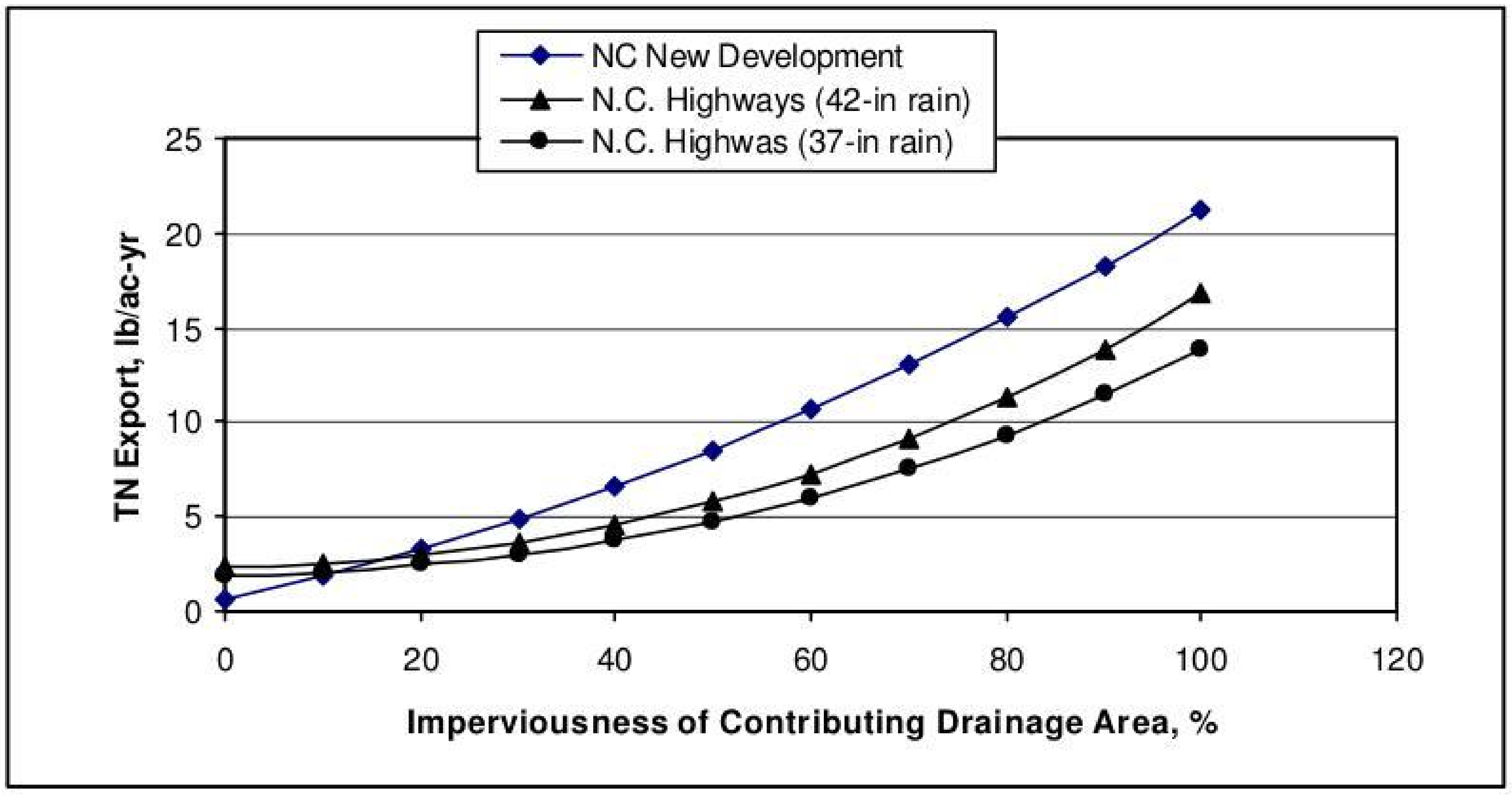


Figure 7.2 TN Export Function for Highway Runoff (Piedmont and Mountains)

Table 7.3 TN Export in Highway Runoff for Piedmont and Mountains

Imperviousness of Contributing Drainage Area, %	New Development[1] (42-in rain) lb/ac-yr	Highway Export[2] (42-in rain) lb/ac-yr	Deviation between Estimates[3] Ratio	Highway Data[4] (37-in rain) lb/ac/yr
0	0.60	2.31	0.26	1.91
10	1.82	2.55	0.71	2.10
20	3.23	2.99	1.08	2.47
30	4.83	3.67	1.32	3.03
40	6.60	4.60	1.43	3.80
50	8.57	5.81	1.48	4.79
60	10.72	7.31	1.47	6.04
70	13.05	9.14	1.43	7.54
80	15.57	11.31	1.38	9.34
90	18.27	13.84	1.32	11.43
100	21.16	16.77	1.30	13.85

[1]based on section 7.1 calculations

[2]Simple Method, based on validated model parameters with the exception of rainfall (applicable to normal yearly rainfall conditions).

[3]Ratio of estimated TN loads (column 2/column 3)

[4]Simple Method, based on monitoring data (applicable to below normal yearly rainfall conditions).

7.5 TN Export Function for the Coastal Plain

Because of the obvious deviations in annual rainfall totals and average rainfall intensity (refer to Sections 3.1 and 5.4.2), it was deemed necessary to develop a separate TN export function for the Coastal plain based on actual monitoring data.

C_{TN} (pervious) was based on the WIL-2 data of 3.20 mg/L at 47% imperviousness and runoff coefficient equal to 0.24 (WIL-2 data). All TN concentrations below 47% imperviousness were then taken as 3.20 mg/L. C_{TN} (impervious) was taken as 1.22 mg/L at 100% imperviousness and runoff coefficient equal to 0.6 (WIL-1 data). TN concentrations between 47% and 100% were obtained by linear interpolation. Runoff coefficient at 0% imperviousness was taken as 0.1 and linear interpolation was used to obtain runoff coefficients within the ranges. Schueler's Simple Method was then used to calculate TN exports with Pi = 0.85 and P = 50 inches. The basis of selecting Pi equal to 0.85 was based on the observed percentages of storm events not producing measurement runoff at WIL-1 (16%) and WIL-2 (70%). The annual rainfall of 50 inches is considered typical for a normal year. The resulting TN exports calculated by the Simple Method were smoothed by regression analysis and the following export function was obtained (see also Figure 7.3 and Table 7.2)

TN export function for the Coastal region:

$$\text{TN (lb/ac-yr)} = 3.986\, e^{0.0091*\text{Imp}} \qquad \text{Imp} = \%; \qquad R^2 = 0.74 \qquad (7.6)$$

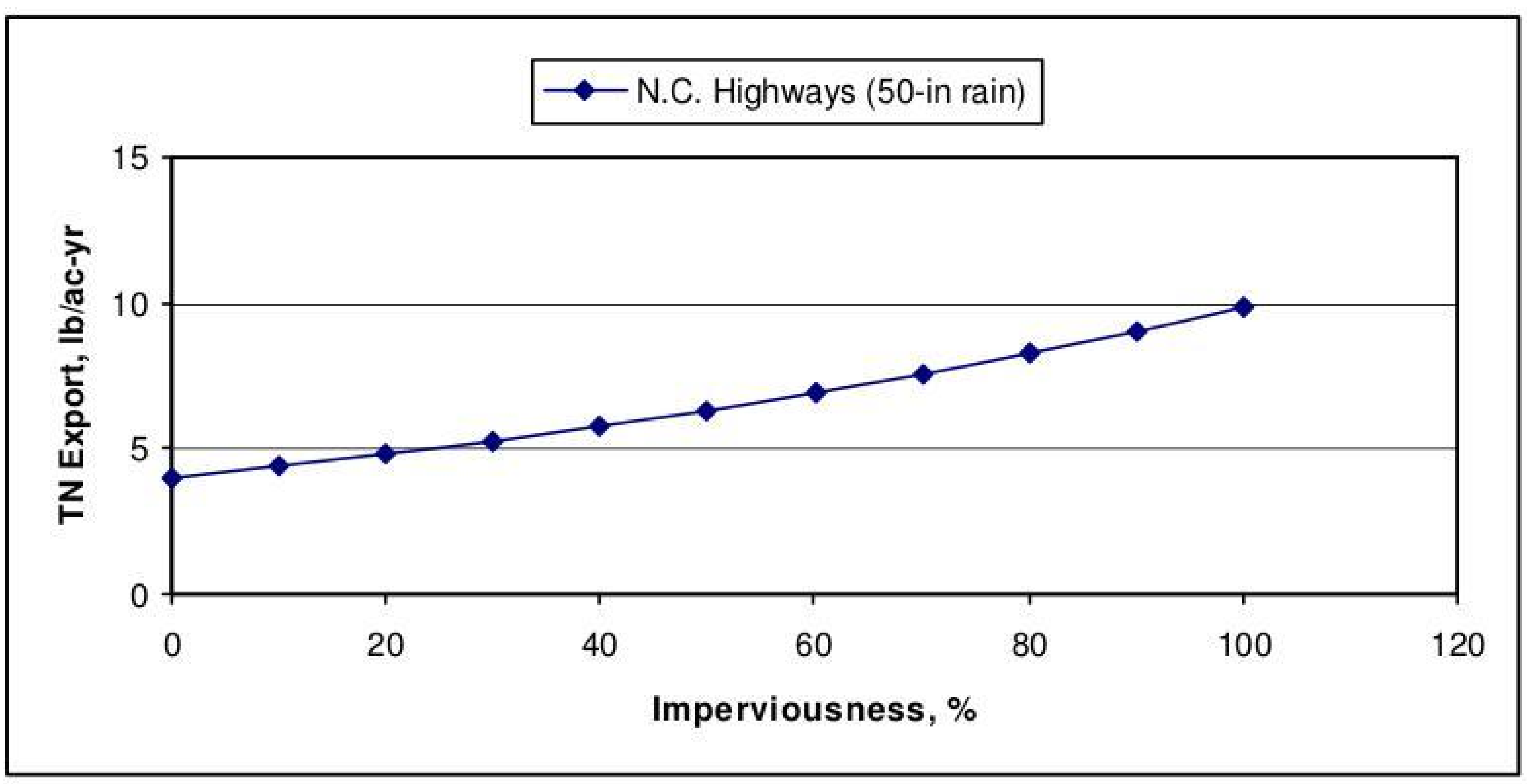


Figure 7.3 TN Export Function for Coastal Region

Table 7.2 TN Export for Coastal Region (50-in Yearly Rainfall)

Imp, %	0	20	40	60	80	100
TN, lb/ac-yr	3.99	4.78	5.74	6.88	8.25	9.90

8. Conclusions and Recommendations

A comprehensive monitoring program has been implemented for collecting hydrologic and water quality information from 10 monitoring sites across the Piedmont (6 sites), Mountains (2 sites) and Coastal (2 sites) regions of North Carolina. Site characteristics included drainage area ranging from 0.15 to 13.46 acres, roadway imperviousness covering 22% to 100%, and traffic volumes varying from 9,400 to 78,800 vehicles/day on both north/south bounds or east/west bounds. Rainfall/runoff data and composite storm samples were collected from 237 storm events. The effectiveness of certain BMPs was assessed by comparing pollutant exports from three groups of paired-monitoring sites with and without vegetative coverage.

The following conclusions/recommendations can be drawn with regard to highway runoff characterization based on event mean concentrations:

- Metals of Cd, Cr, and Ni were essentially present at below MDLs in all runoff samples. Pb was typically at or slightly above MDLs. Zn was consistently well below the secondary drinking water standard of 5 mg/L.

- From 63% to 100% of highway runoff samples exhibited oil and grease and NO_2-N concentrations below their respective MDLs of 5 mg/L and 0.05 mg/L.

- Site average EMCs of COD, NH_3-N, TKN, OP and TP are generally within the urban runoff concentration ranges as reported for Charlotte watershed and the National Urban Runoff Program, with the exception of WIL-2.

- All monitoring sites exhibit site median EMCs ranging from 10% to 25% below the national rural highway runoff concentrations, except TKN. TKN is about 8% below the national average, and 25% below the national urban highway runoff concentration.

- Elevated levels of EMCs can be expected from roadways with increasing ADTs or imperviousness. However, whenever there exists a large percentage of indirectly connected impervious area, a significant reduction in site median EMCs can be expected.

- No obvious pattern was observed on the variation of site median EMCs for monitoring sites among the Mountain, Piedmont and Coastal regions. Instead, statistical analysis suggests strong correlations between TSS EMC and ADT for sites with greater than 50% impervious, and between TSS EMC and imperviousness for sites with ADTs greater than 30,000 vehicles/day.

- A greater variance of TSS concentrations can be expected from roadways of steep slope such as the 100% impervious site at ASH-1 located in the Mountains region. This is a combined effect of steep slope and intensive thunderstorms occurring in the mountain area.

- Erosion prevention is particularly important at the roadway discharge area to minimize additional pollutant input due to erosion and other land disturbing activities.

- As a best management practice, vegetation is effective in reducing TSS and the associated pollutant concentrations. It generally contributes higher levels of TKN and OP when comparing to runoff originating from an equivalent impervious site.

The following conclusions/recommendations can be drawn with regard to highway runoff characterization based on pollutant loads:

- North Carolina highway runoff can be characterized as a relatively less polluting source of storm water pollution when compared with the national highway runoff database.

- Water quality constituents with annual loads less than the low-end value of the national data range include TSS and oil and grease. TDS load is similar to the nationally reported data.

- If the national data range is linearly scaled between its upper and lower values, the annual loads of COD, TKN, NH_3-N, NO_{3+2}-N and TP in North Carolina highway runoff would be 17%, 15%, 30% 20%, and 10%, respectively, within the lower percentiles of the national database.

- Based on the site-averaged annual loads, it can be concluded that of all forms of TN discharged (5.46 lb/ac-yr), TKN (4.13 lb/ac-yr) makes up about 75% of the TN load. The remaining 25% is attributed to NO_3-N and NO_2-N.

- NH_3-N and OP account for 24% and 61% of the TKN and TP loads, respectively.

The following conclusions/recommendations pertaining to the effectiveness of best management practices (pervious shoulders and grassed central medians) can be provided:

- The vegetated pervious coverage at the three sets of paired sites examined appeared to reduce the pollutant export for most chemical constituents in proportion to the reduction in runoff volume through infiltration losses.

- Pervious roadside surfaces often appear to release higher loadings of COD, P and N when compared to equivalent impervious surfaces. However, pervious roadside surfaces would exhibit a net retention of CON and N owing to their retention of runoff water. Pervious surfaces often contribute enough P to overcome the hydrologic retention and can act as net sources of P.

- The reduction of pollutant export in highway runoff mainly results from infiltration losses as runoff moves over the pervious surfaces and efforts to maximize infiltration capacity of these surfaces should be encouraged.

The following conclusions/recommendations are related to the development of total nitrogen export functions:

- TN exports from "the Piedmont and Mountains area" and "Coastal plain" can be statistically correlated to the imperviousness of contributing drainage area.

- When applying Schueler's Simple Method using recommended parameters for the new development scenario of N.C. urban watersheds, the estimated TN exports in highway runoff may be overestimated by as much as 1.48 times.

- Application of the Simple Method should rely on actual monitoring data for model validation and parameter estimation.

- With appropriate validation of the Simple Method using highway runoff data, individual export functions for TN for "the Piedmont and Mountains" and "the Coastal plain" have been developed. It is hoped that these TN export functions would serve as a practical tool for NC DOT to design new BMPs or retrofit existing ones.

- Application of the export functions should be based on similar highway site characteristics from which these functions were derived. Further research is suggested to incorporate traffic conditions into the export functions, and to apply GIS for watershed-level pollutant loading calculations.

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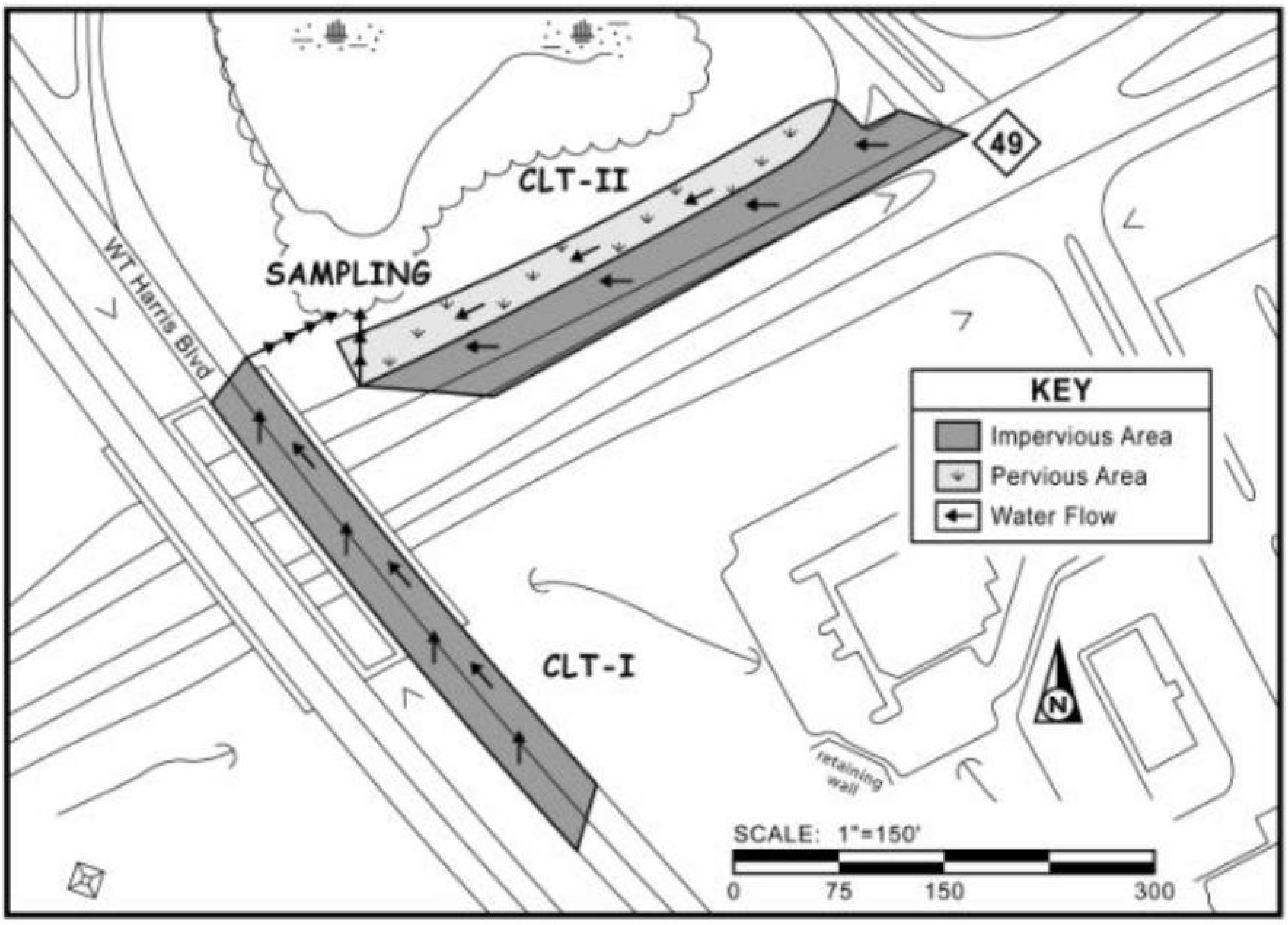
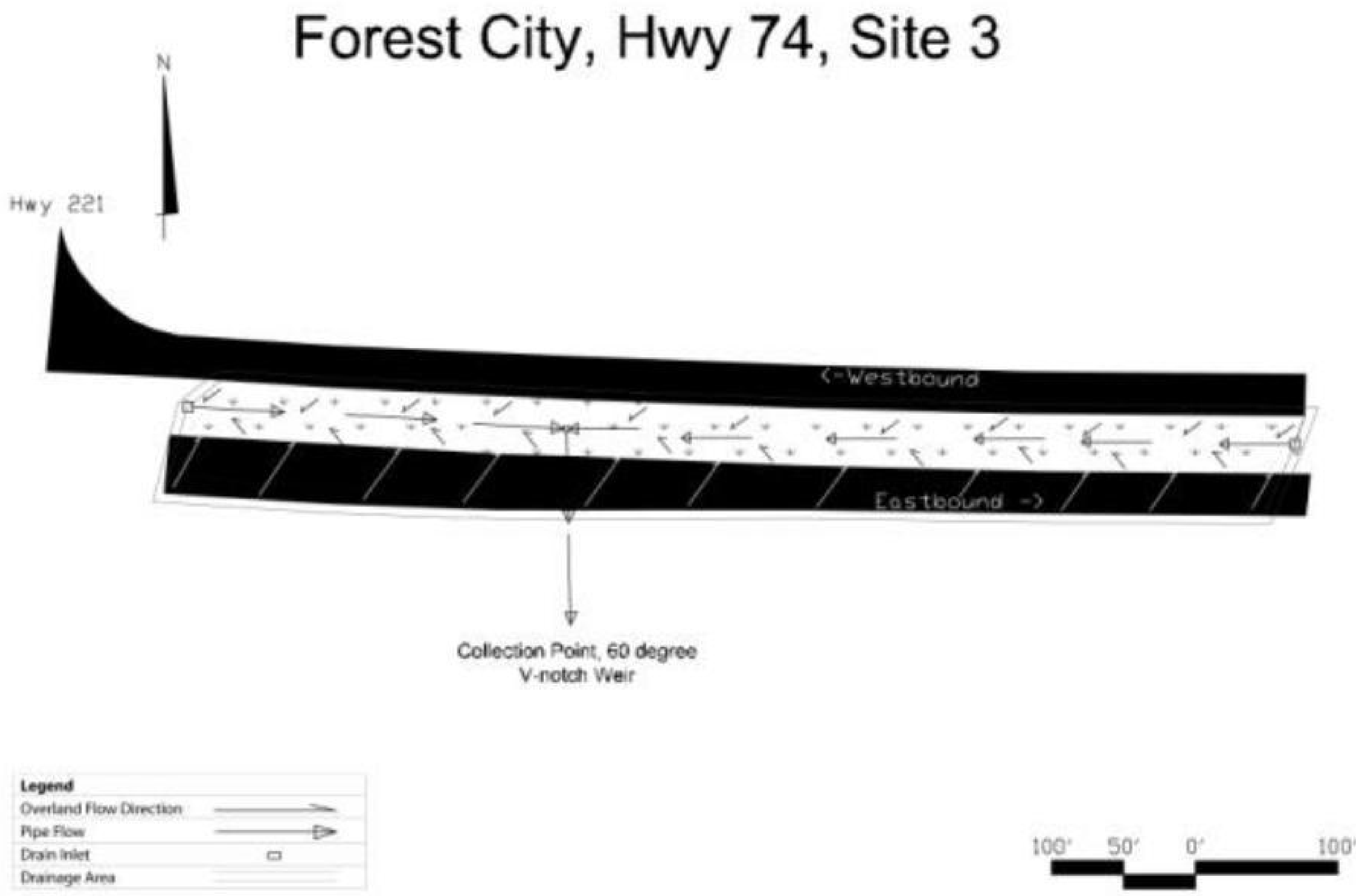
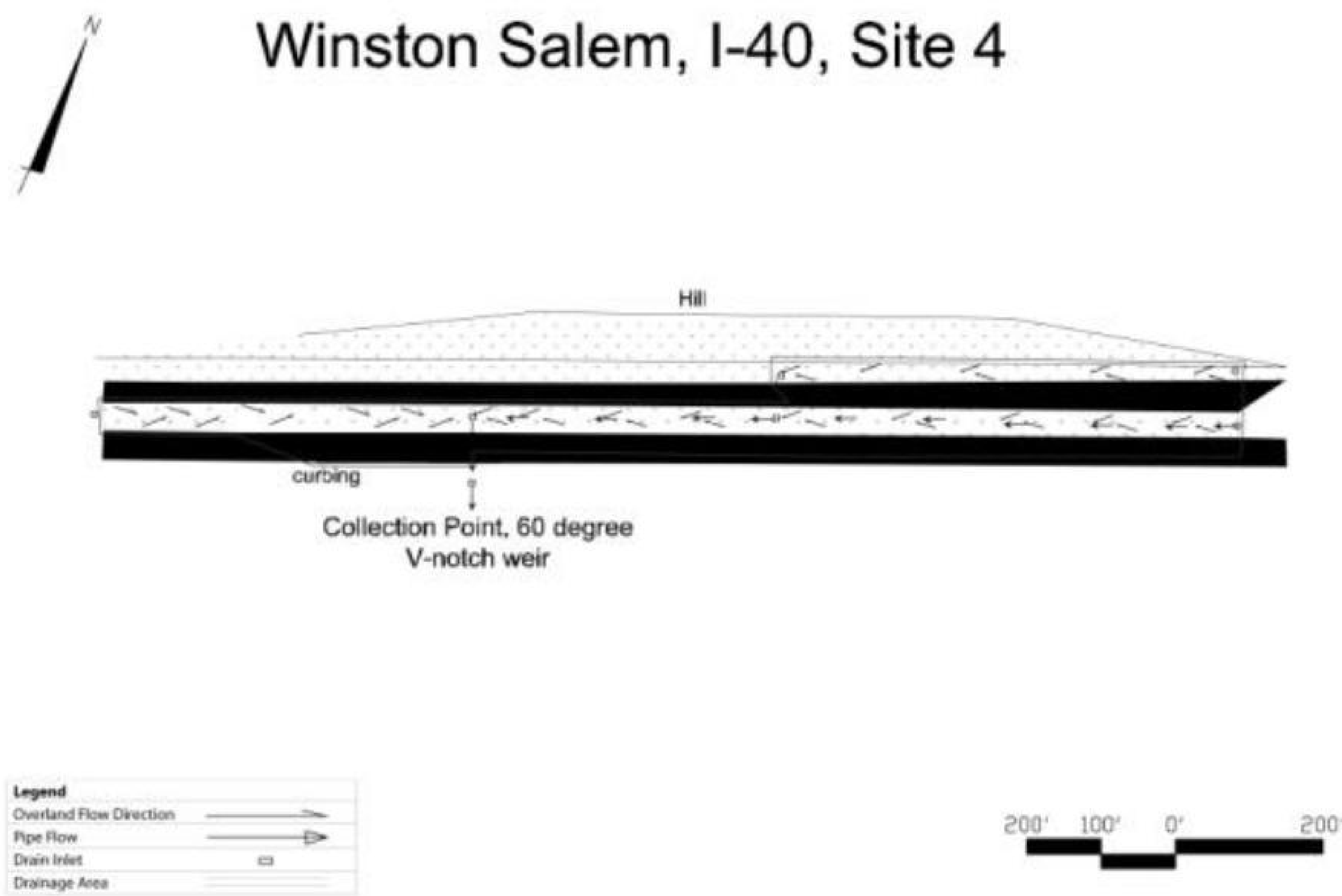
Appendix 1: Drainage Maps

Charlotte Sites (CLT-1 and CLT-2)

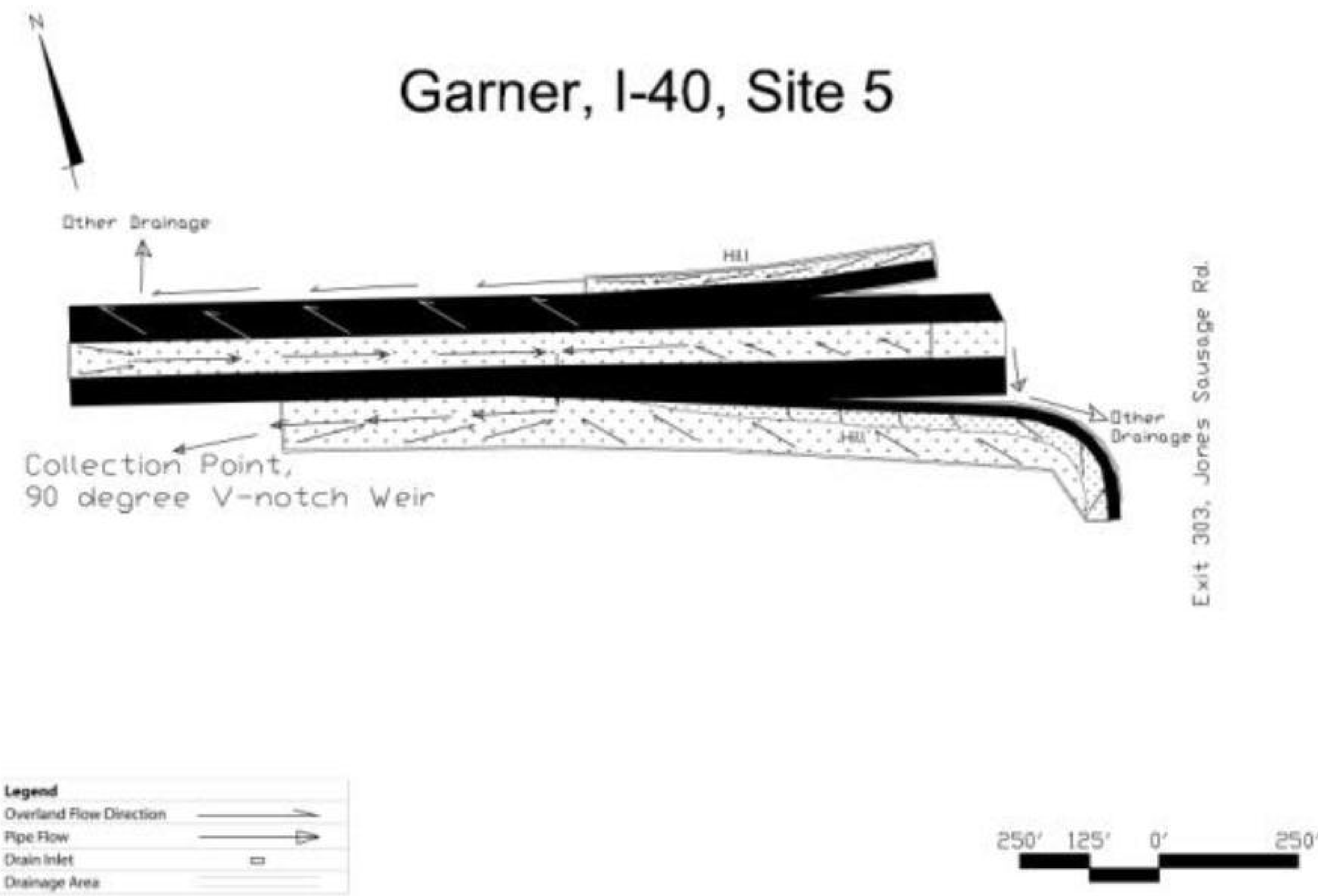




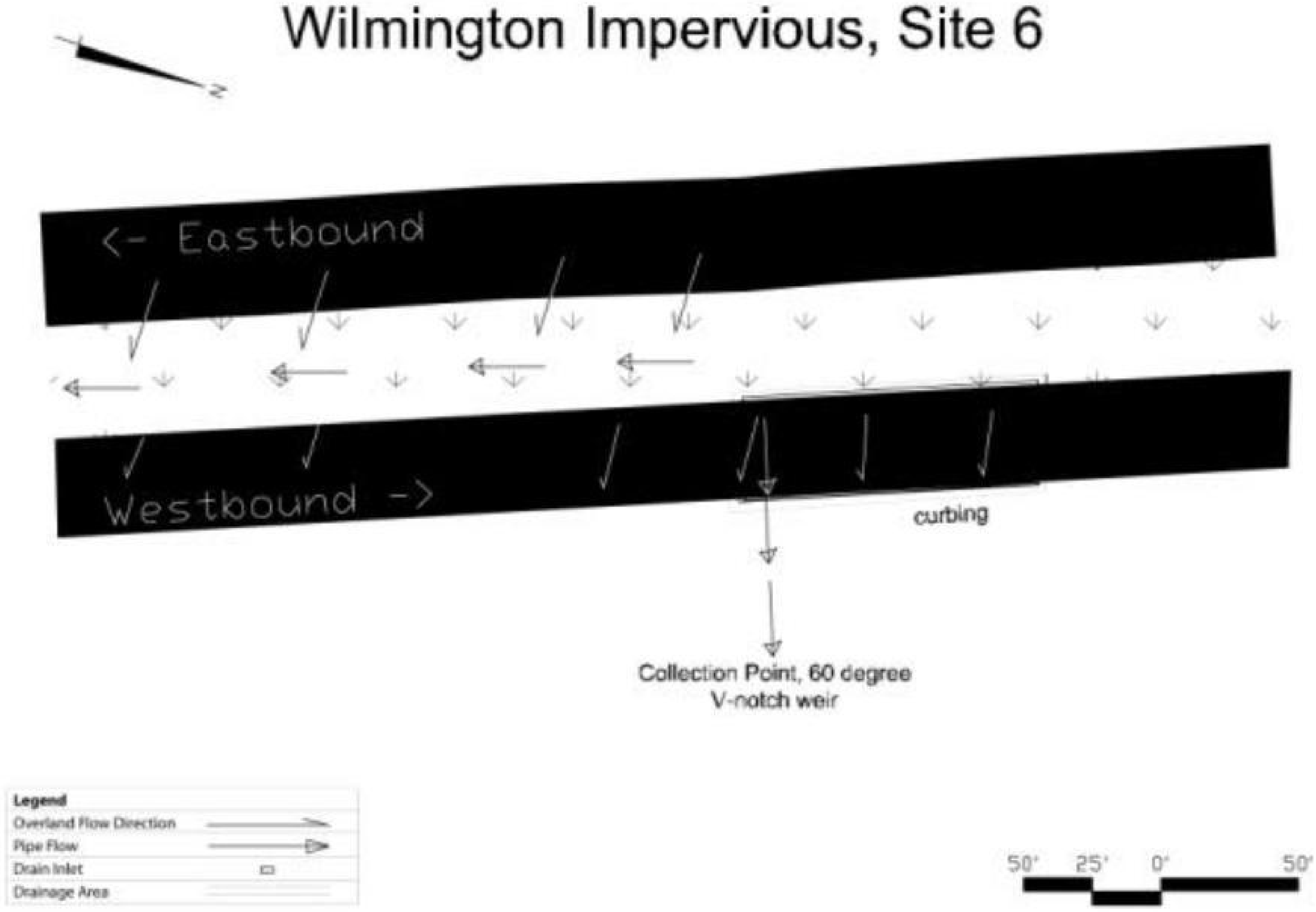
Forest City, Hwy 74, Site 3
N
Hwy 221
<-Westbound
Eastbound ->
Collection Point, 60 degree
V-notch Weir
Legend
Overland Flow Direction
Pipe Flow
Drain Inlet
Drainage Area
100'
50'
0'
100'


Winston Salem, I-40, Site 4
N
Hill
curbing
Collection Point, 60 degree
V-notch weir
Legend
Overland Flow Direction
Pipe Flow
Drain Inlet
Drainage Area
200'
100'
0'
200'

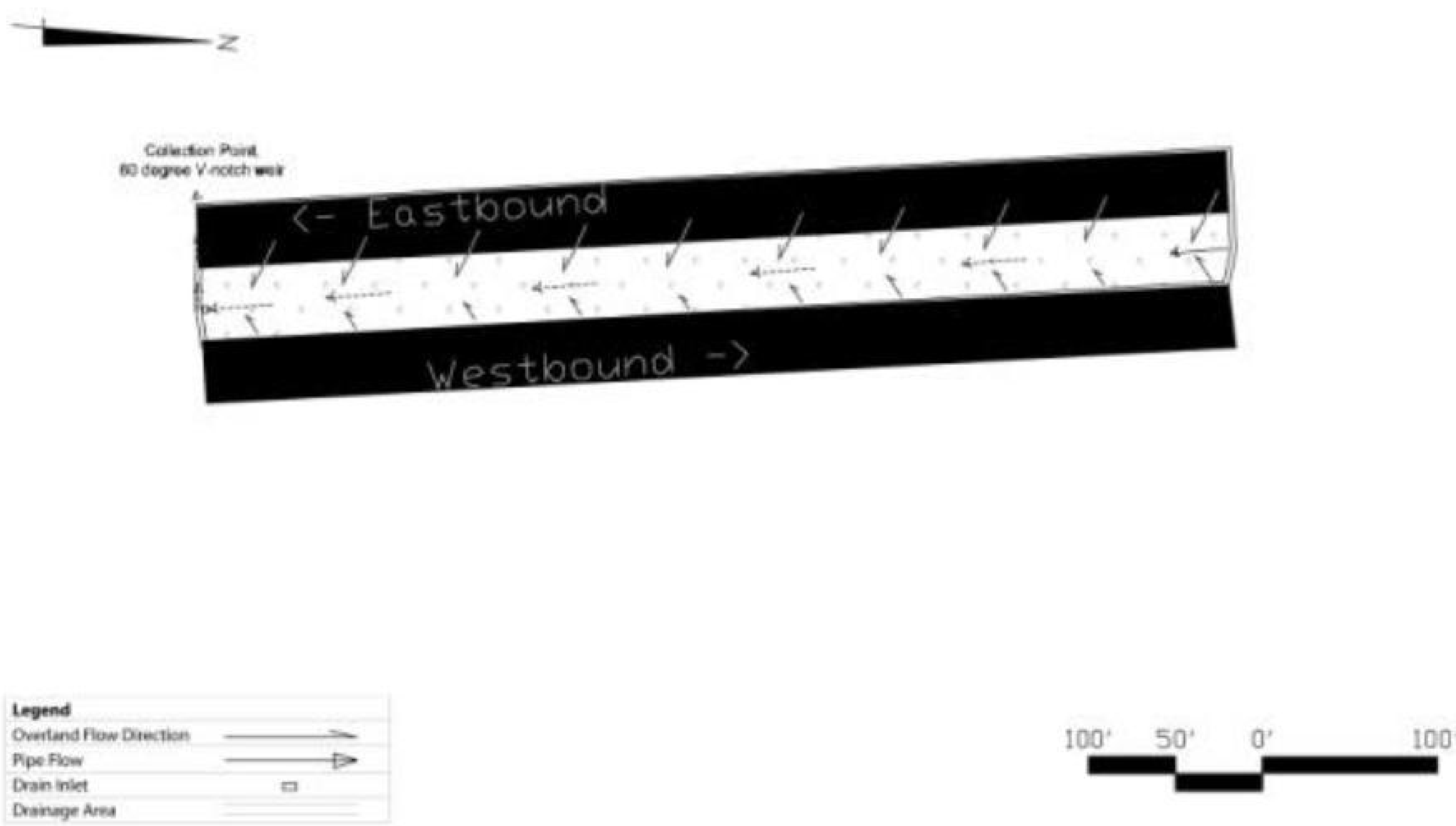
Garner, I-40, Site 5



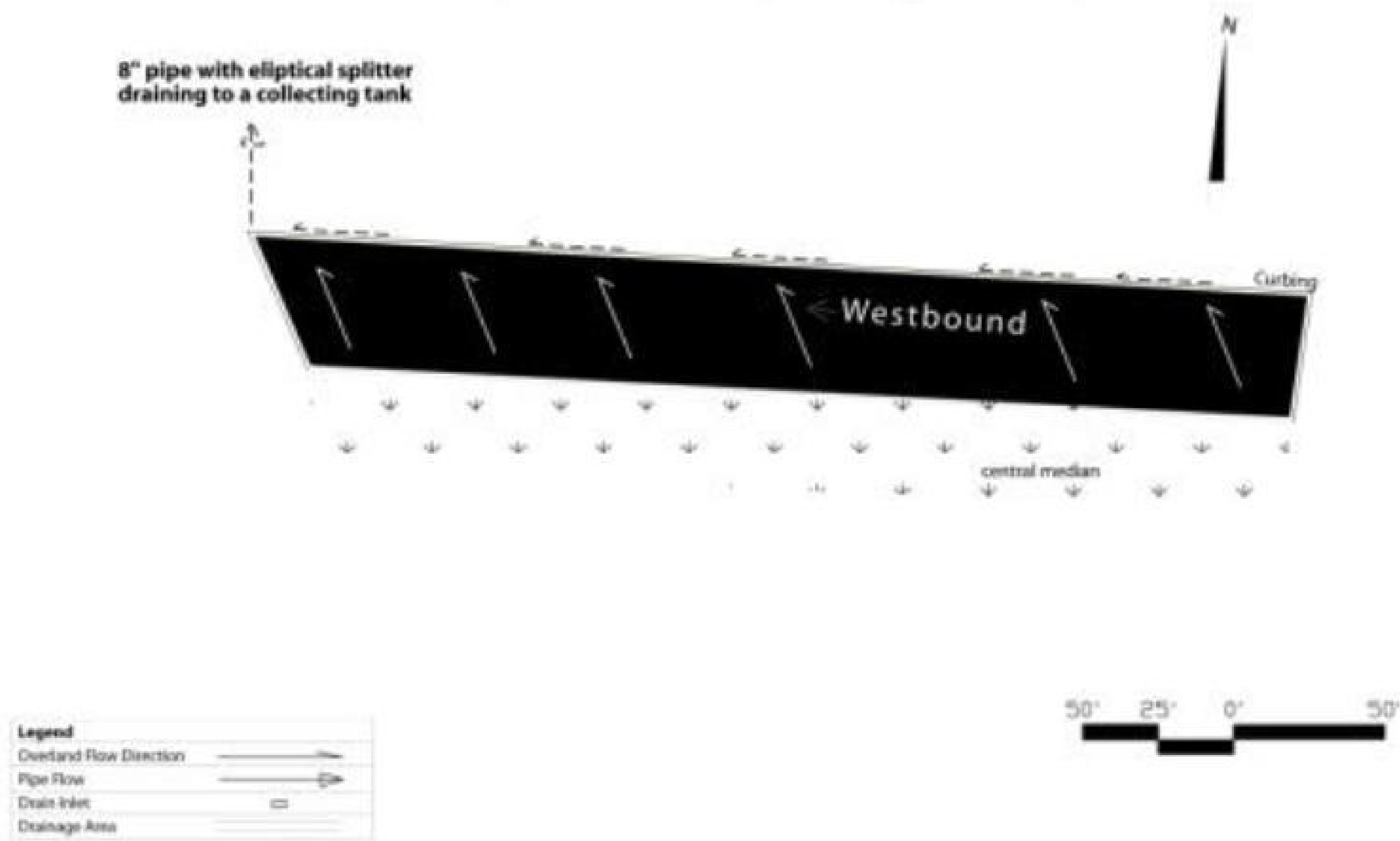
Wilmington Impervious, Site 6



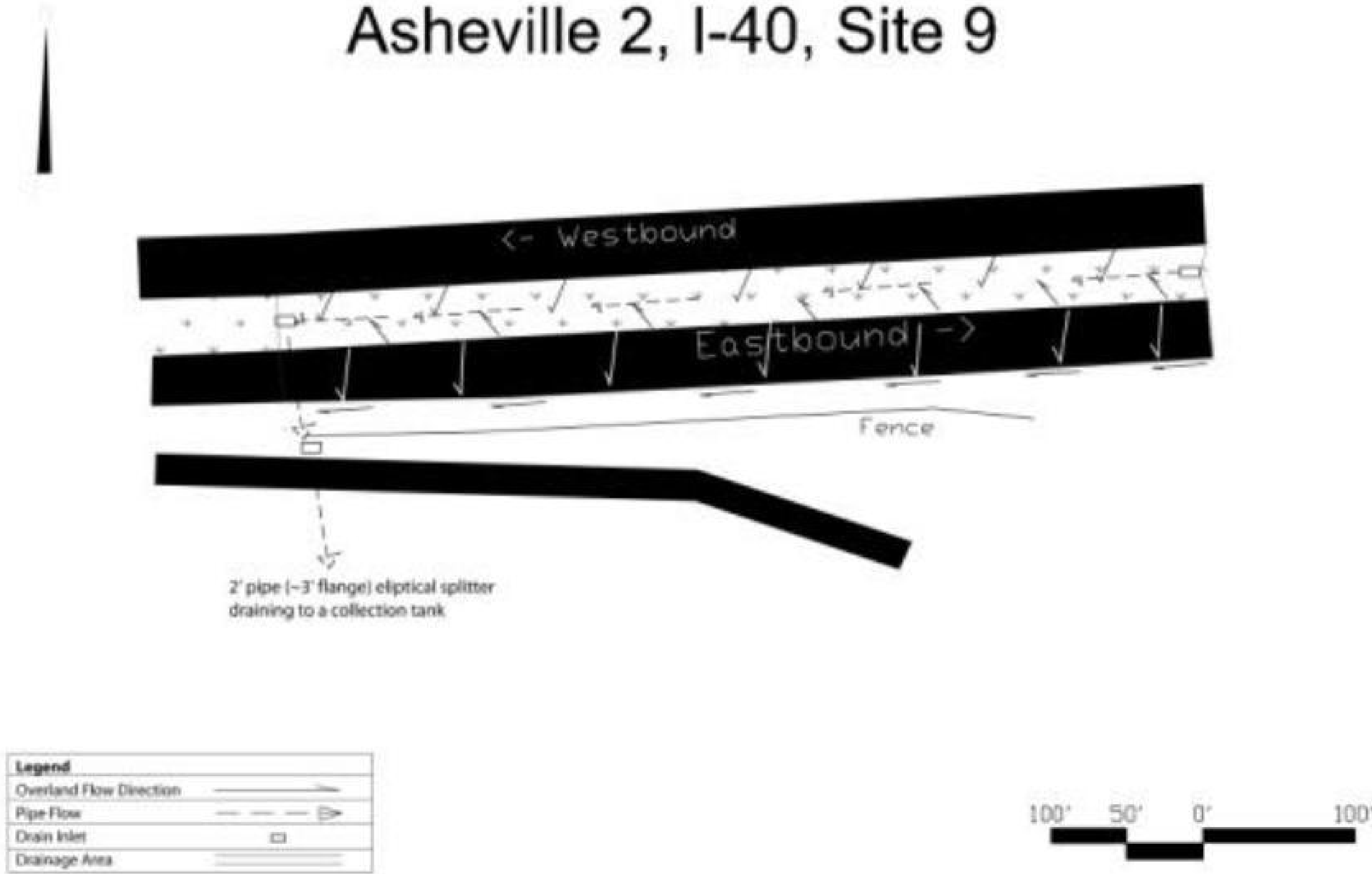
Wilmington Pervious, I-40, Site 7

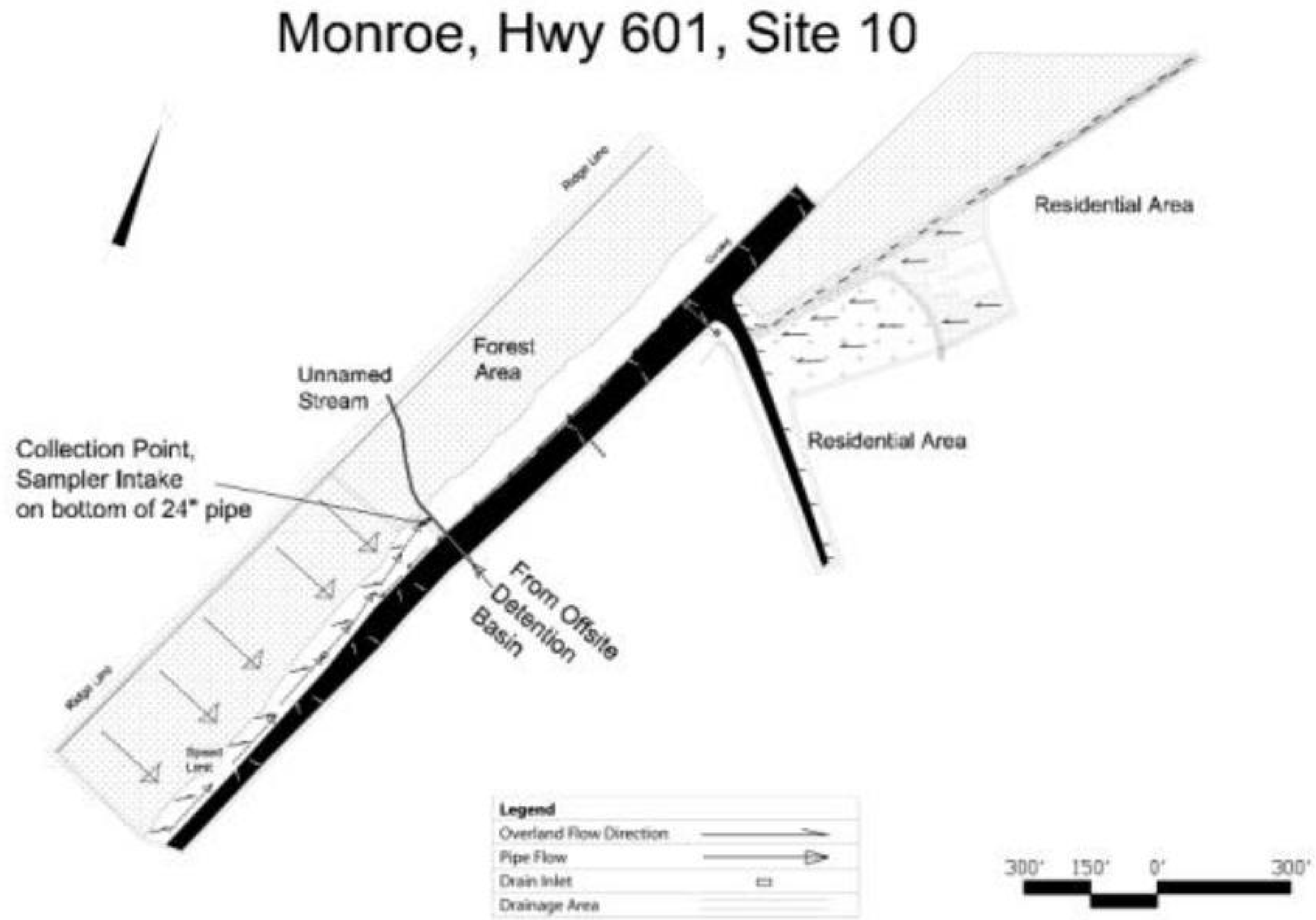


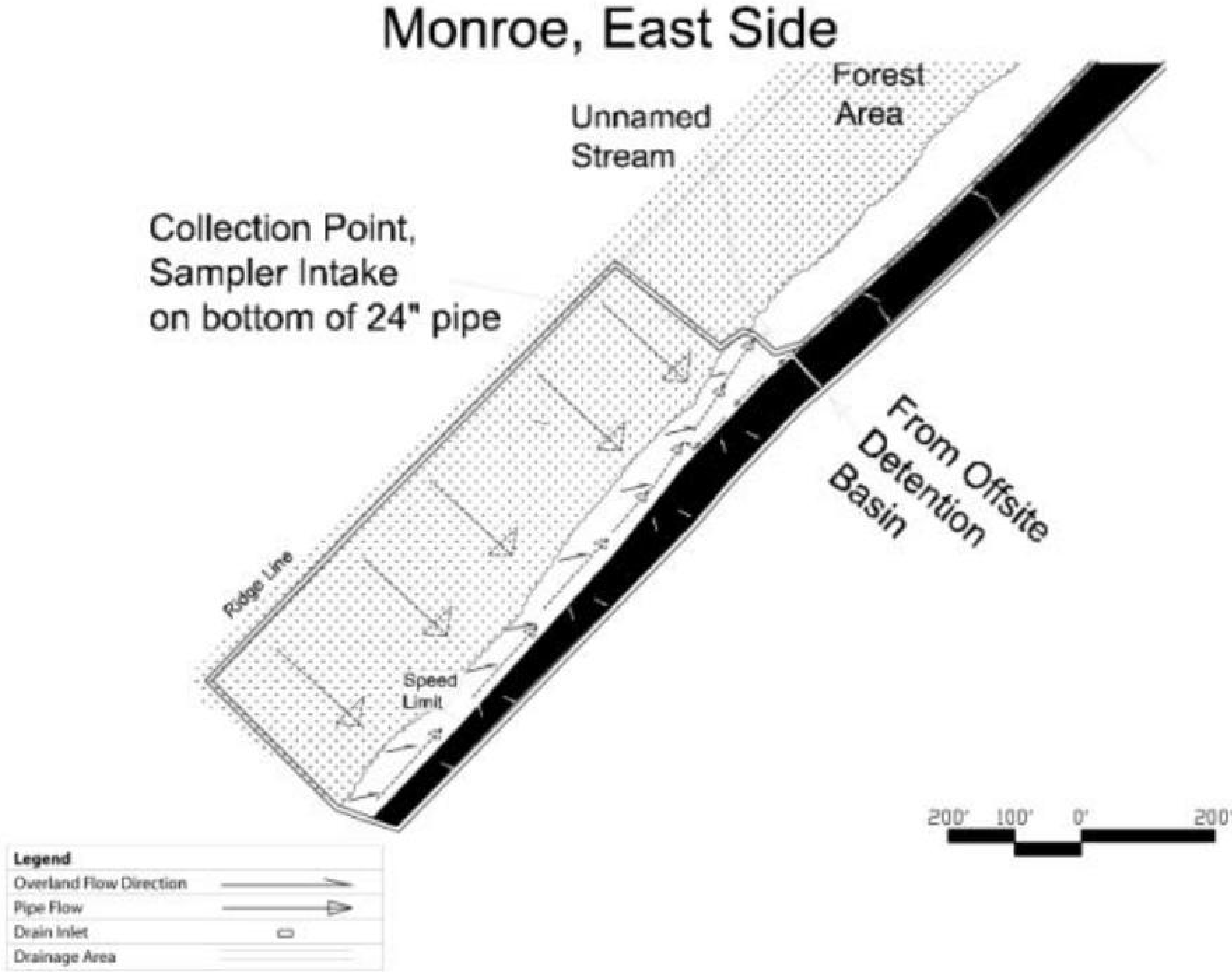
Asheville 1, I-40, Site 8

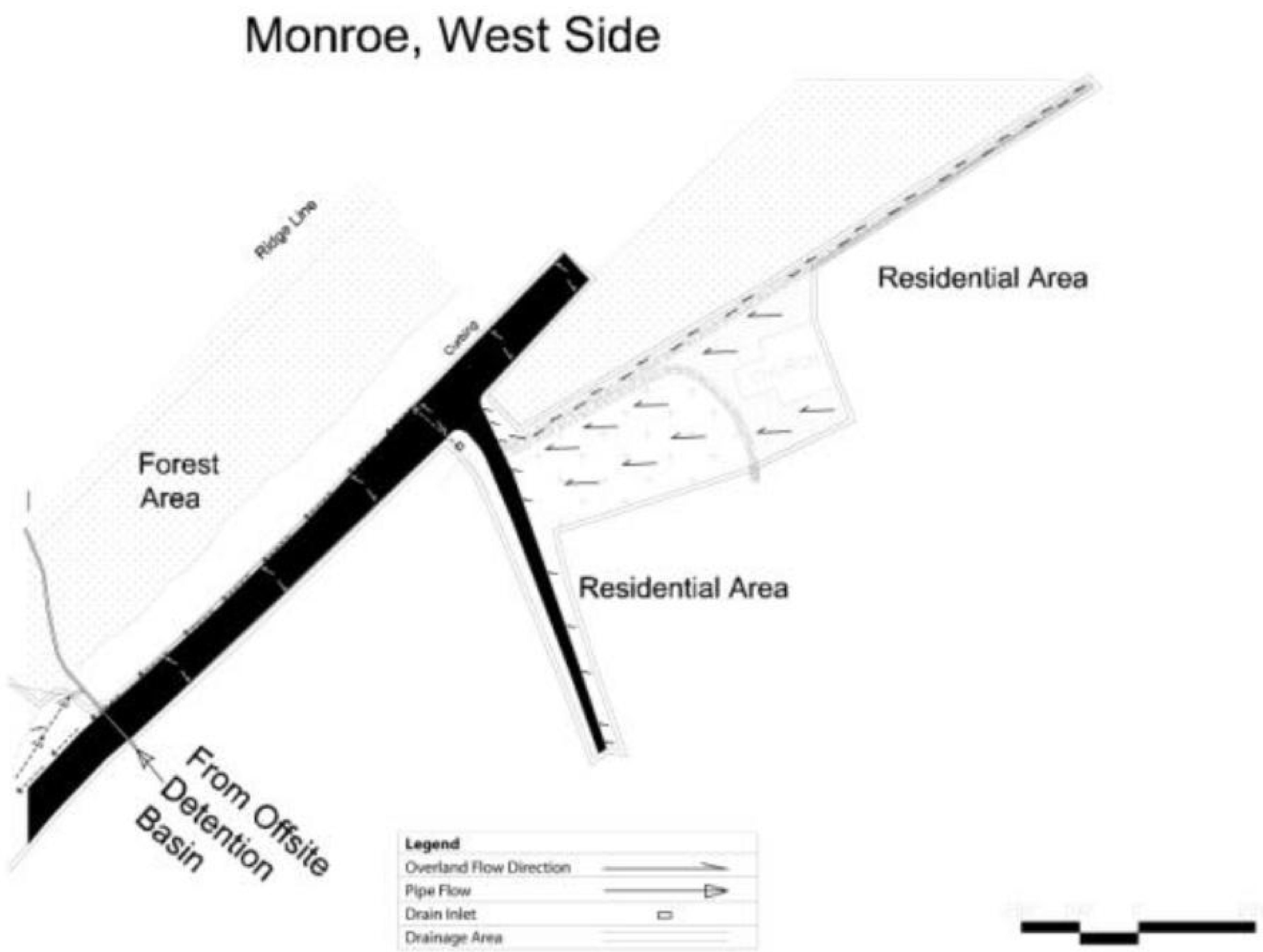


Asheville 2, I-40, Site 9




Monroe, Hwy 601, Site 10
Residential Area
Forest Area
Unnamed Stream
Collection Point, Sampler Intake on bottom of 24" pipe
Residential Area
From Offsite Detention Basin
Legend
Overland Flow Direction
Pipe Flow
Drain Inlet
Drainage Area
300' 150' 0' 300'


Monroe, East Side
Forest Area
Unnamed Stream
Collection Point, Sampler Intake on bottom of 24" pipe
From Offsite Detention Basin
Ridge Line
Speed Limit
200' 100' 0' 200'
Legend
Overland Flow Direction
Pipe Flow
Drain Inlet
Drainage Area


Monroe, West Side
Ridge Line
Curbing
Residential Area
Forest
Area
Residential Area
From Offsite
Detention
Basin
Legend
Overland Flow Direction
Pipe Flow
Drain Inlet
Drainage Area

Appendix 2: Rainfall-Runoff data

W.T. Harris at Highway 49, Charlotte, Site 1. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient
05/19/1999	0.27	0.24	0.89
05/26/1999	0.25	0.25	1.00
06/09/1999	0.18	0.13	0.72
06/15/1999	0.38	0.31	0.82
06/20/1999	0.26	0.22	0.85
07/06/1999	1.29	1.14	0.88
07/11/1999	0.40	0.36	0.91
07/24/1999	0.81	0.71	0.88
08/24/1999	0.46	0.37	0.81
09/05/1999	1.34	1.19	0.89
09/09/1999	0.56	0.50	0.89
09/21/1999	0.20	0.15	0.75
10/09/1999	3.36	3.03	0.90
11/02/1999	0.67	0.58	0.87
11/11/1999	1.17	1.04	0.89
11/26/1999	0.85	0.74	0.87
12/10/1999	0.70	0.60	0.86
12/18/1999	0.58	0.50	0.86
01/04/2000	0.40	0.34	0.85
02/12/2000	0.66	0.57	0.86
02/18/2000	0.31	0.28	0.92
03/05/2000	0.24	0.19	0.79
03/11/2000	0.28	0.22	0.79
03/16/2000	1.70	1.52	0.89
04/07/2000	0.91	0.79	0.87
04/24/2000	0.75	0.65	0.87
04/27/2000	0.49	0.40	0.82
05/02/2000	0.24	0.17	0.72
Maximum	3.36	3.03	1.00
Minimum	0.18	0.13	0.72
Average	0.70	0.61	0.86
Standard Deviation	0.65	0.59	0.06

Highway 49 at W.T. Harris, Charlotte, Site 2. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient
05/26/1999	0.25	0.22	0.86
06/16/1999	1.12	0.52	0.46
06/20/1999	0.26	0.11	0.44
07/06/1999	1.29	0.99	0.76
07/11/1999	0.40	0.15	0.39
07/24/1999	0.81	0.45	0.55
08/24/1999	0.46	0.11	0.25
09/05/1999	1.34	0.50	0.37
09/09/1999	0.56	0.28	0.50
10/19/1999	0.79	0.66	0.83
11/02/1999	0.67	0.25	0.37
11/26/1999	0.85	0.58	0.68
01/30/2000	0.69	0.38	0.55
02/12/2000	0.66	0.29	0.44
03/04/2000	0.24	0.09	0.38
03/11/2000	0.28	0.06	0.22
03/16/2000	1.70	1.17	0.69
03/27/2000	1.75	1.07	0.61
04/08/2000	0.91	0.46	0.51
04/14/2000	1.82	0.79	0.43
04/24/2000	0.75	0.27	0.35
05/02/2000	0.24	0.10	0.41
Maximum	1.82	1.17	0.86
Minimum	0.24	0.06	0.22
Average	0.81	0.43	0.50
Standard Deviation	0.50	0.33	0.17

US 74 at Forest City, Site 3. Rainfall and Runoff Totals.

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient
07/11/1999	1.02	0.13	0.13
08/23/1999	1.97	0.68	0.35
09/21/1999	1.07	0.06	0.06
10/04/1999	0.83	0.21	0.25
10/10/1999	2.05	1.05	0.51
11/01/1999	1.35	0.66	0.49
11/25/1999	1.59	0.52	0.33
12/06/1999	0.41	0.04	0.10
12/10/1999	0.18	0.01	0.06
12/13/1999	0.82	0.48	0.59
01/18/2000	0.42	0.09	0.21
01/19/2000	1.39	0.98	0.71
02/27/2000	0.22	0.05	0.23
03/04/2000	0.08	0.01	0.13
03/11/2000	0.30	0.03	0.10
03/16/2000	1.30	1.03	0.79
03/20/2000	2.40	1.82	0.76
04/02/2000	1.13	0.56	0.50
04/13/2000	0.48	0.11	0.23
04/24/2000	0.95	0.28	0.29
05/23/2000	0.33	0.02	0.06
06/05/2000	0.40	0.01	0.03
07/12/2000	1.48	0.26	0.18
07/23/2000	2.95	1.74	0.59
09/18/2000	0.59	0.03	0.05
09/21/2000	1.72	0.92	0.53
Maximum	2.95	1.82	0.79
Minimum	0.08	0.01	0.03
Average	1.03	0.43	0.31
Standard Deviation	0.75	0.53	0.24

Winston Salem I-40, Site 4. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient
06/16/1999	1.16	0.15	0.13
07/30/1999	0.43	0.07	0.16
08/14/1999	0.98	0.10	0.10
08/25/1999	2.03	0.60	0.30
09/05/1999	1.88	0.46	0.24
09/15/1999	1.56	0.36	0.23
09/28/1999	1.14	0.14	0.12
10/10/1999	0.82	0.05	0.06
10/20/1999	0.53	0.06	0.11
11/02/1999	0.38	0.01	0.03
11/26/1999	1.82	0.38	0.21
12/06/1999	0.28	0.02	0.08
12/10/1999	0.18	0.00	0.02
01/05/2000	0.59	0.13	0.22
01/11/2000	1.02	0.22	0.21
01/20/2000	0.79	0.06	0.07
02/15/2000	0.28	0.26	0.92
02/19/2000	0.37	0.04	0.10
03/17/2000	0.78	0.24	0.31
03/21/2000	1.05	0.29	0.28
04/06/2000	0.89	0.13	0.14
04/11/2000	0.64	0.06	0.10
04/13/2000	0.69	0.05	0.07
04/30/2000	0.81	0.11	0.14
05/22/2000	1.06	0.09	0.09
Maximum	2.03	0.60	0.92
Minimum	0.18	0.00	0.02
Average	0.89	0.16	0.18
Standard Deviation	0.51	0.15	0.18

Garner I-40, Site 5. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient
06/16/1999	1.28	0.51	0.40
08/09/1999	0.47	0.06	0.12
08/26/1999	0.87	0.43	0.49
09/09/1999	0.72	0.33	0.46
09/21/1999	0.59	0.09	0.15
10/18/1999	1.84	0.92	0.50
10/21/1999	1.20	0.62	0.52
11/02/1999	0.65	0.16	0.25
11/26/1999	1.74	0.55	0.32
12/06/1999	0.36	0.05	0.13
12/10/1999	0.11	0.00	0.03
12/18/1999	0.32	0.10	0.32
01/05/2000	0.64	0.19	0.30
01/11/2000	1.23	1.05	0.85
02/15/2000	1.23	0.81	0.66
02/19/2000	0.49	0.26	0.53
02/29/2000	0.41	0.07	0.18
03/18/2000	1.48	0.74	0.50
03/29/2000	0.53	0.12	0.23
04/11/2000	0.89	0.22	0.25
04/13/2000	0.43	0.05	0.11
04/30/2000	0.93	0.14	0.15
05/22/2000	0.71	0.13	0.18
08/01/2000	2.20	0.47	0.22
08/28/2000	0.86	0.06	0.07
Maximum	2.20	1.05	0.85
Minimum	0.11	0.00	0.03
Average	0.89	0.32	0.32
Standard Deviation	0.52	0.30	0.20

Wilmington-1 I-40 at Castle Hayne, Site 6. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient	
06/30/1999	0.32	0.17	0.53	
07/11/1999	1.20	0.82	0.68	
08/08/1999	0.28	0.11	0.39	
08/11/1999	0.25	0.18	0.72	
08/25/1999	0.46	0.37	0.80	
10/17/1999	3.28	2.49	0.76	
11/02/1999	1.55	1.23	0.79	
12/06/1999	0.28	0.26	0.93	
12/10/1999	0.36	0.19	0.53	
01/04/2000	0.36	0.16	0.44	
01/09/2000	0.59	0.39	0.66	
01/22/2000	3.56	1.60	0.45	Snow
01/30/2000	0.60	0.19	0.32	Snow
02/14/2000	0.65	0.42	0.65	
02/21/2000	0.10	0.00	0.01	
04/12/2000	0.21	0.09	0.43	
04/15/2000	1.58	0.99	0.63	
04/25/2000	0.20	0.05	0.27	
05/22/2000	0.66	0.27	0.41	
05/25/2000	2.21	1.72	0.78	
06/06/2000	0.75	0.60	0.80	
07/21/2000	5.41	4.21	0.78	
08/24/2000	1.12	0.77	0.69	
08/28/2000	0.27	0.10	0.37	
09/02/2000	1.21	1.14	0.94	
Maximum	5.41	4.21	0.94	
Minimum	0.10	0.00	0.01	
Average	1.10	0.74	0.59	
Standard Deviation	1.28	0.96	0.23	

Wilmington-2 I-40 at Gordon Road, Site 7. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient	
10/17/1999	3.28	0.92	0.59	
11/25/1999	0.90	0.18	0.20	
12/19/1999	0.73	0.24	0.33	
01/09/2000	0.59	0.05	0.08	
01/22/2000	3.56	2.38	0.67	Snow
01/30/2000	0.60	0.05	0.08	Snow
02/14/2000	0.65	0.08	0.12	
04/18/2000	0.74	0.10	0.14	
04/25/2000	0.35	0.03	0.09	
04/28/2000	0.70	0.09	0.13	
05/22/2000	0.66	0.09	0.14	
05/26/2000	2.21	1.17	0.53	
06/04/2000	0.75	0.06	0.08	
08/24/2000	1.12	0.34	0.30	
08/27/2000	0.27	0.03	0.11	
09/03/2000	1.21	0.31	0.26	
10/09/2000	0.14	0.01	0.07	
11/26/2000	2.60	1.51	0.58	
12/02/2000	0.67	0.09	0.13	
12/10/2000	0.56	0.05	0.09	
Maximum	3.56	2.38	0.67	
Minimum	0.14	0.01	0.07	
Average	1.11	0.44	0.24	
Standard Deviation	0.99	0.71	0.20	

Asheville-1 I-40 Impervious, Site 8. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient
10/20/1999	0.50	0.30	0.60
11/01/1999	1.46	1.32	0.90
11/25/1999	2.20	1.94	0.88
12/10/1999	0.22	0.14	0.64
12/14/1999	2.04	1.16	0.57
01/10/2000	1.37	1.22	0.89
02/12/2000	0.98	0.92	0.94
02/14/2000	0.67	0.60	0.90
03/12/2000	1.42	1.31	0.92
03/19/2000	1.88	1.65	0.88
04/03/2000	0.40	0.32	0.80
04/13/2000	1.68	0.97	0.58
04/28/2000	0.92	0.85	0.92
05/23/2000	0.83	0.59	0.71
06/05/2000	0.71	0.34	0.48
07/23/2000	0.50	0.13	0.26
08/02/2000	0.81	0.60	0.74
08/07/2000	0.88	0.86	0.98
08/31/2000	0.64	0.40	0.63
09/25/2000	0.28	0.12	0.43
Maximum	2.20	1.94	0.98
Minimum	0.22	0.12	0.26
Average	1.02	0.79	0.73
Standard Deviation	0.59	0.52	0.20

Asheville-2 I-40 pervious, Site 9. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient
09/28/1999	1.67	0.64	0.38
10/09/1999	1.87	0.41	0.22
10/20/1999	0.50	0.03	0.05
11/01/1999	1.46	0.62	0.42
11/25/1999	2.20	1.92	0.87
12/13/1999	0.93	0.17	0.18
01/09/2000	1.38	0.42	0.30
02/13/2000	1.18	0.68	0.58
02/14/2000	0.67	0.07	0.10
03/12/2000	1.42	0.48	0.34
03/16/2000	0.68	0.07	0.10
03/20/2000	1.88	0.81	0.43
04/03/2000	2.20	1.05	0.48
04/15/2000	1.69	0.72	0.43
04/28/2000	0.92	0.16	0.17
05/21/2000	0.46	0.01	0.02
06/05/2000	0.71	0.06	0.08
07/27/2000	0.77	0.38	0.49
08/03/2000	0.96	0.10	0.10
08/07/2000	0.88	0.07	0.08
08/20/2000	0.50	0.02	0.04
08/31/2000	0.65	0.07	0.11
09/21/2000	1.12	0.36	0.32
Maximum	2.20	1.92	0.87
Minimum	0.46	0.01	0.02
Average	1.16	0.40	0.27
Standard Deviation	0.55	0.45	0.21

Highway 601 at Monroe, Site 10. Rainfall and Runoff Totals (Inches)

	Rainfall (Inches)	Runoff (Inches)	Runoff Coefficient
09/05/1999	1.06	0.22	0.21
09/09/1999	1.86	0.67	0.36
09/15/1999	1.36	0.27	0.20
09/21/1999	1.14	0.39	0.34
09/27/1999	1.02	0.29	0.28
10/17/1999	0.24	0.03	0.13
11/02/1999	0.24	0.02	0.08
11/11/1999	0.30	0.04	0.13
11/25/1999	0.98	0.20	0.20
12/10/1999	0.18	0.01	0.06
12/13/1999	0.48	0.15	0.31
12/19/1999	0.50	0.10	0.20
01/04/2000	0.40	0.01	0.03
01/09/2000	1.65	0.79	0.48
02/18/2000	0.18	0.07	0.39
03/05/2000	0.55	0.13	0.24
03/11/2000	0.23	0.02	0.09
03/16/2000	0.43	0.08	0.19
04/14/2000	0.26	0.05	0.19
04/25/2000	0.24	0.00	0.01
04/30/2000	0.20	0.03	0.15
05/21/2000	0.52	0.17	0.33
05/25/2000	0.37	0.11	0.30
06/04/2000	1.50	0.37	0.25
Maximum	1.86	0.79	0.48
Minimum	0.18	0.00	0.01
Average	0.66	0.18	0.21
Standard Deviation	0.52	0.21	0.12

Appendix 3: Event Mean Concentrations (EMCs)

CLT-1 (Charlotte) EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	05/19/99	0.27	0.25		6	15	170	53	5	65	2.4	1.10	0.90	0.05		0.1	2	5	7	10	
2	05/26/99	0.25	0.25	6.9	8	15	187	109	11	145	4.8	2.80	1.45	0.21	0.36	0.23	2	5	6	10	
3	06/09/99	0.18	0.13	7.1	2	37	360	370	7	204	7.7	2.80	2.75	0.42	0.58	0.16	7	12	19	17	540
4	06/15/99	0.38	0.31		3	16	139	85	5	66	1.9	0.61	0.47	0.08	0.25	0.09	2	7	15	10	190
5	06/20/99	0.26	0.22	7.3	2	23	25	112	6	65	2.0	0.94	1.07	0.09	0.12	0.07	2	5	5	10	130
6	07/11/99	0.42	0.36	7.0	2	27	87	94	5	52	1.4	0.49	0.68	0.05	0.20	0.05	2	5	7	10	240
7	07/24/99	0.81	0.71	6.9	4	25	196	99	5	64	2.0	0.47	0.83	0.14	0.37	0.16	2	12	13	10	280
8	08/24/99	0.42	0.37	7.0	1	22	71	45	5	37	1.6	0.94	0.71	0.05	0.16	0.05	2	5	5	10	100
9	09/05/99	1.34	1.19	7.0	2	11	13	51	5	23	1.0	0.39	0.33	0.05	0.07	0.05	2	5	5	10	40
10	09/09/99	0.56	0.50	6.6	2	5	91	42	5	33	1.5	0.79	0.96	0.05	0.14	0.05	2	5	9	10	160
11	09/21/99	0.20	0.15	7.3	5	17	89	70	6	63	2.7	1.50	1.46	0.07	0.32	0.09	2	5	6	10	100
12	10/09/99	3.36	3.03	7.0	1	9	9	8	5	5	0.5	0.19	0.10	0.05	0.05	0.05	2	5	5	10	10
13	11/02/99	0.67	0.58	7.0	3	8	124	60	5	5	1.4	0.63	0.21	0.05	0.17	0.05	2	6	10	10	100
14	11/11/99	1.17	1.04	6.8	4	8	156	75	5	52	1.6	0.63	0.53	0.05	0.33	0.15	2	6	13	10	150
15	11/26/99	0.85	0.74	7.2	2	11	80	55	5	37	1.2	0.60	0.47	0.05	0.15	0.05	2	5	5	10	50
16	12/10/99	0.70	0.60	7.2	4	9	206	40	8	78	2.0	1.00	0.50	0.05	0.28	0.05	2	5	11	10	240
17	12/19/99	0.24	0.18	7.4	3	13	117	51	5	55	2.0	1.10	0.51	0.08	0.17	0.08	2	5	8	10	160
18	01/04/00	0.40	0.34	7.3	4	15	139	53	7	58	2.2	1.30	0.66	0.05	0.19	0.05	2	5	5	10	90
19	02/12/00	0.66	0.57	7.0	5	14	282	159	10	134	3.1	1.20	0.94	0.09	0.48	0.06	2	12	30	10	300
20	02/18/00	0.31	0.28	6.8	4	13	28	50	5	25	1.5	0.89	1.11	0.05	0.09	0.05	2	5	5	10	100
21	03/05/00	0.24	0.19	6.9	4	12	133	56	7	87	3.9	1.60	0.78	0.06	0.19	0.10	2	8	12	10	200
22	03/11/00	0.28	0.22	7.0	3	13	122	74	7	91	3.5	1.40	0.81	0.05	0.25	0.10	2	10	8	10	190
23	03/16/00	1.70	1.52	6.3	6	10	180	52	5	65	2.2	0.54	0.38	0.05	0.34	0.14	2	12	20	10	170
24	04/07/00	0.91	0.79	6.2	4	7	108	35	5	58	1.9	0.60	0.54	0.05	0.21	0.09	2	7	9	10	130
25	04/24/00	0.75	0.65	6.5	7	13	100	69	5	50	2.4	1.30	1.10	0.05	0.17	0.06	2	5	5	10	160
26	04/27/00	0.49	0.40	6.3	5	8	150	67	6	74	2.2	1.20	0.78	0.05	0.18	0.06	2	5	12	10	190
27	05/02/00	0.24	0.17	6.4			285	74	5	109	3.4	1.30	1.40	0.06	0.54	0.26	2	6	13	10	290
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									63%	7%				64%	4%	30%	96%	59%	26%	96%	
Average		0.67	0.58	6.9	4	14	135	78	6	66	2.4	1.05	0.83	0.08	0.24	0.09	2	7	10	10	172
Median		0.42	0.37	7.0	4	13	124	60	5	63	2.0	0.94	0.78	0.05	0.20	0.07	2	5	8	10	160
S.D.		0.66	0.60	0.3	2	7	83	65	2	43	1.4	0.62	0.52	0.08	0.14	0.06	1	3	6	1	108
CV		0.98	1.02	0.05	0.48	0.50	0.62	0.84	0.27	0.65	0.60	0.60	0.63	0.96	0.56	0.61	0.44	0.39	0.59	0.13	0.63

Lognormal distribution

	TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
Mean	153	78	6	74	2.4	1.06	0.86	0.08	0.25	0.09	2	7	10	10	188
Median	103	64	6	52	2.1	0.90	0.69	0.07	0.21	0.08	2	6	9	10	138
CV	1.09	0.71	0.23	1.01	0.56	0.64	0.73	0.55	0.65	0.55	0.24	0.34	0.54	0.10	0.92

CLT-2 (Charlotte) EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	05/26/99	0.25	0.22	6.2	7	5	147	68	9	133	3.4	1.90	0.80	0.17	0.33	0.25	2	5	7	10	
2	06/16/99	1.12	0.52	6.6	4	5	204	87	7	100	2.2	0.95	0.61	0.09	0.43	0.15	2	5	5	10	40
3	06/20/99	0.26	0.11	6.6	3	5	12	73	6	56	2.1	1.40	0.63	0.05	0.19	0.11	2	5	5	10	100
4	07/06/99	1.29	0.99	5.8	4	8		64	5	58	2.6	0.86	1.13	0.05	0.78	0.64	2	5	6	10	180
5	07/11/99	0.42	0.15	6.3	3	6	28	49	5	25	1.3	0.62	0.39	0.05	0.34	0.28	2	5	5	10	40
6	07/24/99	0.81	0.45	6.5	6	13	120	53	5	72	2.6	0.86	0.60	0.05	0.93	0.70	2	5	12	10	170
7	08/24/99	0.46	0.11	6.2	5	3	158	39	5	61	2.5	1.10	0.74	0.05	0.43	0.19	2	5	8	10	80
8	09/05/99	1.34	0.50	6.5	3	3	38	42	5	29	1.1	0.40	0.37	0.05	0.28	0.26	2	5	5	10	40
9	09/09/99	0.56	0.28	6.2	2	1	85	28	5	36	2.0	0.89	1.02	0.05	0.45	0.31	2	5	5	10	110
10	10/19/99	0.79	0.66	6.4	3	4	34	61	5	40	1.9	1.20	0.81	0.05	0.15	0.07	2	5	5	10	120
11	11/02/99	0.67	0.25	6.4	5	4	35	63	5	16	1.6	0.47	0.24	0.05	0.37	0.28	2	5	5	10	80
12	11/26/99	0.85	0.58	7.1	4	7	38	64	5	46	1.9	0.23	0.18	0.05	0.43	0.30	2	5	5	10	40
13	01/30/00	0.69	0.38	7.2	2	3	8	138	5	62	1.4	0.07	0.21	0.05	0.33	0.02	2	5	5	10	70
14	02/12/00	0.66	0.29	6.4	3	3	166	69	7	101	2.3	0.90	0.61	0.05	0.38	0.08	2	5	16	10	170
15	03/04/00	0.24	0.09	6.2	6	6	75	36	6	75	3.1	1.90	0.70	0.05	0.18	0.13	2	5	9	10	160
16	03/11/00	0.28	0.06	6.0	6	5	110	76	6	109	3.6	1.50	0.66	0.05	0.37	0.18	2	5	7	10	190
17	03/16/00	1.71	1.17	6.0	6	6	146	49	5	68	1.9	0.35	0.20	0.05	0.39	0.16	2	5	12	10	130
18	03/27/00	1.75	1.07	5.9	5	4	85	70	5	74	2.1	0.89	0.59	0.05	0.25	0.15	2	5	7	10	170
19	04/08/00	0.91	0.46	5.7	6	3	68	35	5	61	2.0	0.58	0.35	0.05	0.29	0.13	2	5	5	10	110
20	04/14/00	1.82	0.79	6.0	5	5	31	42	5	42	1.7	0.63	0.33	0.05	0.14	0.11	2	5	5	10	80
21	04/24/00	0.75	0.27	5.8	7	4	74	55	6	59	2.9	1.80	0.97	0.05	0.18	0.10	2	5	8	10	180
22	04/27/00	0.49	0.34	5.9	6	5	100	57	5	78	2.6	1.10	0.61	0.05	0.19	0.13	2	5	8	10	170
23	05/02/00	0.24	0.10	5.9	5	4	120	53	5	88	2.8	1.60	1.21	0.05	0.24	0.18	2	5	8	10	210
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									74%					90%			100%	100%	48%	100%	
Average		0.80	0.43	6.3	5	5	86	60	6	65	2.2	0.97	0.61	0.06	0.35	0.21	2	5	7	10	120
Median		0.69	0.34	6.2	5	5	80	57	5	61	2.1	0.89	0.61	0.05	0.33	0.16	2	5	6	10	115
S.D.		0.49	0.32	0.4	2	2	55	23	1	29	0.6	0.53	0.30	0.03	0.19	0.16	0	0	3	0	56
CV		0.62	0.75	0.06	0.33	0.48	0.65	0.38	0.18	0.44	0.29	0.55	0.49	0.46	0.54	0.77	0.00	0.00	0.41	0.00	0.47

Lognormal distribution

Mean							94	60	6	66	2.3	1.05	0.58	0.05	0.35	0.22	2	5	7	10	123
Median							65	56	5	58	2.2	0.78	0.50	0.05	0.31	0.17	2	5	7	10	105
CV							1.05	0.35	0.16	0.54	0.31	0.89	0.62	0.00	0.51	0.83	0.00	0.00	0.35	0.00	0.61

US-74 (Forest City) EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	07/11/99	1.02	0.13	8.3	3	30	4	94	5	46	1.7	0.04	0.09	0.05	0.27	0.21	2	5	5	10	190
2	08/23/99	1.97	0.68	7.0	3	15	3	62	5	30	1.3	0.10	0.20	0.05	0.73	0.68	2	5	5	10	10
3	09/21/99	1.07	0.06	7.2	6	14	4	71	5	59	2.0	0.08	0.47	0.05	1.25	1.19	22	5	5	10	10
4	10/04/99	0.83	0.21	7.2	2	23	4	70	5	35	1.1	0.09	0.05	0.05	0.37	0.31	2	5	5	10	10
5	10/10/99	2.05	1.05	7.2	2	23	3	47	5	31	1.1	0.10	0.05	0.05	0.18	0.15	2	5	5	10	10
6	11/01/99	1.35	0.66	7.2	3	17	5	82	5	27	1.2	0.06	0.06	0.05	0.23	0.18	2	5	5	10	10
7	11/25/99	1.59	0.52	7.1	2	16	6	61	5	28	1.0	0.17	0.05	0.05	0.28	0.21	2	5	5	10	10
8	12/05/99	0.41	0.04	7.1	3	14	1	78	5	34	1.0	0.17	0.27	0.05	0.40	0.38	2	5	5	10	30
9	12/10/99	0.18	0.01	7.3	3	14	7	64	5	46	1.2	0.13	0.42	0.05	0.35	0.31	2	5	5	10	20
10	12/13/99	0.82	0.48	7.4	3	17	11	41	5	27	1.0	0.06	0.11	0.05	0.24	0.14	2	5	5	10	10
11	01/09/00	1.39	0.98	7.1	2	14	11	30	5	14	0.7	0.05	0.10	0.05	0.17	0.13	2	5	5	10	10
12	01/18/00	0.42	0.09	7.1	4	12	8	37	5	40	1.5	0.21	0.62	0.05	0.22	0.13	2	5	5	10	10
13	02/27/00	0.22	0.05	6.7	3	21	9	93	5	62	1.5	0.11	0.60	0.05	0.19	0.09	2	5	5	10	20
14	03/04/00	0.08	0.01	7.3	3	18	7	71	5	46	1.0	0.07	1.75	0.05	0.06	0.05	2	5	5	10	30
15	03/11/00	0.30	0.03	7.1	2	26	10	114	5	52	1.4	0.09	0.70	0.05	0.14	0.06	2	5	5	10	20
16	03/16/00	1.30	1.03	6.5	4	12	16	69	5	41	1.4	0.12	0.16	0.05	0.23	0.12	2	5	5	10	10
17	03/20/00	2.40	1.82	6.5	3	12	12	19	5	17	0.6	0.04	0.07	0.05	0.09	0.06	2	5	5	10	20
18	04/02/00	1.13	0.56	6.5	5	13	7	57	5	30	1.0	0.10	0.13	0.05	0.11	0.06	2	5	5	10	10
19	04/13/00	0.48	0.11	6.5	4	16	7	63	5	34	1.5	0.09	0.26	0.05	0.15	0.08	2	5	5	10	10
20	04/24/00	0.95	0.28	6.6	5	15	10	62	5	37	1.3	0.06	0.12	0.05	0.16	0.06	2	5	5	10	20
21	05/23/00	0.33	0.02	6.6	3	15	11	65	5	28	1.0	0.05	0.40	0.05	0.08	0.06	2	5	5	10	10
22	06/05/00	0.40	0.01	6.5	6	14	9	62	5	46	1.5	0.09	0.67	0.05	0.14	0.05	2	5	5	10	50
23	07/12/00	1.48	0.26	6.7	5	18	12	95	5	76	3.4	0.40	0.22	0.05	0.81	0.59					
24	07/23/00	2.95	1.74	6.4	4	9	33	36	5	28	1.1	0.15	0.22	0.05	0.28	0.18					
25	09/18/00	0.59	0.03	6.9	3	14	4	60	5	40	1.4	0.16	0.18	0.05	0.44	0.36					
26	09/21/00	1.72	0.92	6.7	4	23	4	87	5	47	1.3	0.14	0.08	0.05	0.50	0.43					
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									100%					100%	4%	8%	96%	96%	100%	100%	
Average		1.06	0.45	7.0	3	17	8	65	5	38	1.3	0.11	0.31	0.05	0.31	0.24	3	5	5	10	24
Median		0.98	0.23	7.1	3	15	7	64	5	36	1.3	0.10	0.19	0.05	0.23	0.15	2	5	5	10	10
S.D.		0.74	0.53	0.4	1	5	6	22	0	14	0.5	0.07	0.36	0.00	0.27	0.26	4	0	0	0	38
CV		0.70	1.16	0.06	0.34	0.29	0.74	0.34	0.00	0.36	0.40	0.65	1.16	0.00	0.86	1.06	1.47	0.00	0.00	0.00	1.59

Lognormal distribution

	TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
Mean	9	66	5	39	1.3	0.11	0.31	0.05	0.31	0.24	3	5	5	10	21
Median	7	61	5	36	1.2	0.10	0.19	0.05	0.24	0.16	2	5	5	10	16
CV	0.77	0.41	0.00	0.39	0.34	0.58	1.24	0.00	0.82	1.10	0.55	0.00	0.00	0.00	0.85

MON EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	09/05/99	1.06	0.22	6.7	4	11	22	124	5	55	1.2	0.15	0.47	0.05	0.16	0.11	2	5	5	10	70
2	09/09/99	1.86	0.67	6.7	4	6	395	75	5	33	1.6	0.11	0.29	0.05	0.38	0.07	2	5	12	10	50
3	09/15/99	1.36	0.28	7.2	2	3	27	66	5	64	0.7	0.10	0.15	0.05	0.13	0.10	2	5	5	10	10
4	09/21/99	1.14	0.39	7.2	4	11	338	58	5	47	1.4	0.11	0.33	0.05	0.30	0.05	2	5	12	10	20
5	09/27/99	1.02	0.29	6.4	2	11	204	69	5	44	1.1	0.06	0.16	0.05	0.23	0.05	2	5	5	10	60
6	10/17/99	0.24	0.03	7.1	2	13	31	55	5	48	0.9	0.21	0.37	0.05	0.09	0.05	2	5	6	10	20
7	11/02/99	0.24	0.02	6.9	4	12	198	96	5	23	1.8	0.64	0.69	0.05	0.49	0.20	2	8	19	10	80
8	11/11/99	0.30	0.04	7.0	3	8	110	112	6	68	2.0	0.57	0.93	0.05	0.34	0.20	2	5	10	10	60
9	11/25/99	0.98	0.20	6.8	3	9	61	65	5	25	1.1	0.21	0.22	0.05	0.23	0.11	2	5	5	10	10
10	12/10/99	0.18	0.01	7.0	2	9	113	52	5	84	1.7	0.63	0.81	0.05	0.31	0.10	2	5	9	10	110
11	12/13/99	0.48	0.15	7.0	4	10	130	58	5	46	1.4	0.18	0.32	0.05	0.25	0.11	2	5	10	10	50
12	12/19/99	0.50	0.10	7.1	3	10	31	63	5	40	1.1	0.21	0.52	0.05	0.12	0.08	2	5	5	10	30
13	01/04/00	0.40	0.01	7.0	3	10	129	38	5	59	1.4	0.40	0.78	0.05	0.21	0.05	2	5	5	10	30
14	01/09/00	1.65	0.79	6.8	2	8	180	71	5	43	1.3	0.10	0.12	0.05	0.24	0.05	2	5	5	10	20
15	02/18/00	0.18	0.07	6.6	3	8	89	86	5	40	1.1	0.19	0.54	0.05	0.14	0.06	2	5	7	10	60
16	03/05/00	0.55	0.13	6.8	2	9	95	64	5	60	1.6	0.33	0.64	0.05	0.18	0.10	2	5	8	10	80
17	03/11/00	0.23	0.02	6.8	3	13	71	90	5	68	1.3	0.18	0.69	0.05	0.13	0.06	2	5	6	10	70
18	03/16/00	0.43	0.08	6.6	5	13	253	110	5	83	2.3	0.18	0.49	0.05	0.39	0.17	2	5	23	10	120
19	04/14/00	0.26	0.05	6.2	3	10	42	59	5	34	1.2	0.19	0.24	0.05	0.10	0.07	2	5	7	10	60
20	04/25/00	0.24	0.00	6.6	7	6	132	109	8	111	2.7	0.82	1.32	0.08	0.34	0.16	2	8	20	10	160
21	04/30/00	0.20	0.03	6.4	5	11	132	88	7	87	1.8	0.48	0.93	0.08	0.25	0.08	2	6	16	10	130
22	05/21/00	0.52	0.17	6.0	10	11	266	128	5	106	2.7	0.18	0.05	0.05	0.65	0.44	2	5	9	10	170
23	05/25/00	0.37	0.11	5.9	6	7	152	90	5	68	1.6	0.20	0.60	0.05	0.30	0.28	2	5	6	10	80
24	06/06/00	1.50	0.37	6.1	7	8	189	81	5	55	2.2	0.26	0.41	0.05	0.31	0.06	2	5	9	10	70
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									83%					92%		17%	100%	83%	25%	100%	
Average		0.63	0.17	6.7	4	10	139	79	5	58	1.5	0.28	0.51	0.05	0.26	0.12	2	5	9	10	67
Median		0.43	0.10	6.8	3	10	129	71	5	55	1.4	0.19	0.49	0.05	0.24	0.10	2	5	7	10	60
S.D.		0.52	0.21	0.4	2	2	98	24	1	23	0.5	0.20	0.31	0.01	0.13	0.09	0	1	5	0	44
CV		0.83	1.23	0.06	0.53	0.26	0.71	0.30	0.14	0.40	0.34	0.73	0.61	0.16	0.51	0.76	0.00	0.16	0.56	0.00	0.66

Lognormal distribution

Mean							150	80	5	58	1.6	0.28	0.54	0.05	0.26	0.11	2	5	9	10	72
Median							108	76	5	53	1.5	0.22	0.40	0.05	0.23	0.10	2	5	8	10	52
CV							0.97	0.31	0.12	0.43	0.34	0.75	0.89	0.13	0.54	0.66	0.00	0.14	0.52	0.00	0.94

ASH-1 EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	10/20/99	0.50	0.30	6.6	2	3	17	19	5	7	0.8	0.27	0.14	0.05	0.05	0.05	2	5	5	10	150
2	11/01/99	1.46	1.32	6.5	1	2			5	5	0.5	0.06	0.08	0.05	0.05	0.05	2	5	5	10	90
3	11/25/99	2.20	1.94	6.6	2	3	2	15	5	7	0.6	0.16	0.09	0.05	0.05	0.05	2	5	5	10	80
4	12/10/99	0.22	0.14	6.8	3	4	43	13	7	31	0.8	0.46	0.34	0.05	0.1	0.05	2	5	5	10	270
5	12/14/99	2.04	1.16	6.7	2	2	10	1	5	14	0.4	0.19	0.11	0.05	0.05	0.05	2	5	5	10	140
6	01/09/00	1.38	1.22	6.5	2	2	10	1	5	11	0.6	0.3	0.14	0.05	0.05	0.05	2	5	5	10	130
7	02/12/00	0.98	0.92	6.8	2	8	161	51	8	83	1.0	0.35	0.29	0.05	0.17	0.05	2	7	19	10	240
8	02/14/00	0.67	0.60	6.6	2	4	6	6	5	5	0.4	0.17	0.11	0.05	0.05	0.05	2	5	5	10	80
9	03/12/00	1.42	1.31	6.1	2	2	9	24	5	11	0.9	0.45	0.30	0.05	0.05	0.05	2	5	5	10	160
10	03/19/00	1.88	1.65	6.1	3	1	105	7	5	13	0.5	0.04	0.06	0.05	0.13	0.05	2	5	9	10	600
11	04/03/00	0.40	0.32	6.0	3	2	4	35	5	7	0.4	0.19	0.17	0.05	0.05	0.05	2	5	5	10	420
12	04/13/00	1.68	0.97	5.8	4	4	122	9	5	43	1.3	0.3	0.22	0.05	0.2	0.05	2	5	12	10	240
13	04/28/00	0.92	0.85	6.0	6	9	366	37	5	110	3.7	0.35	0.30	0.06	0.63	0.05	2	8	28	10	400
14	05/23/00	0.83	0.59	6.0	5	8	47	33	5	49	4.0	0.72	0.51	0.08	0.23	0.05	2	5	5	10	300
15	06/05/00	0.71	0.34	6.4	4	6	7	26	5	12	1.2	0.59	0.39	0.16	0.07	0.05	2	5	5	10	240
16	07/27/00	0.77	0.38	6.1	3	2	5	25	5	11	0.9	0.4	0.80	0.05	0.08	0.05					
17	08/02/00	0.81	0.60	6.0	4	14	4	62	5	14	0.5	0.26	0.61	0.05	0.05	0.05					
18	08/07/00	0.88	0.86	6.1	4	4	6	1	5	16	0.9	0.35	0.41	0.05	0.05	0.05					
19	08/31/00	0.64	0.40	6.3	1	6	180	2	6	34	1.5	0.52	0.70	0.05	0.24	0.12					
20	09/26/00	0.28	0.12	6.2	3	3	39	20	5	30	1.0	0.4	0.84	0.05	0.25	0.19					
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									85%	10%				85%	50%	90%	100%	82%	76%	100%	
Average		1.03	0.80	6.3	3	4	60	20	5	25	1.1	0.33	0.33	0.06	0.13	0.06	2	5	8	10	236
Median		0.86	0.73	6.3	3	4	10	19	5	14	0.9	0.33	0.30	0.05	0.06	0.05	2	5	5	10	240
S.D.		0.58	0.51	0.3	1	3	93	17	1	28	1.0	0.17	0.25	0.03	0.14	0.03	0	1	7	0	147
CV		0.56	0.64	0.05	0.45	0.72	1.55	0.85	0.15	1.09	0.91	0.53	0.74	0.44	1.06	0.57	0.00	0.17	0.82	0.00	0.62

Lognormal distribution

	TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
Mean	68	28	5	25	1.1	0.35	0.34	0.06	0.12	0.06	2	5	8	10	240
Median	20	11	5	17	0.9	0.27	0.25	0.05	0.09	0.06	2	5	7	10	198
CV	3.19	2.29	0.13	1.12	0.73	0.82	0.96	0.28	0.91	0.36	0.00	0.14	0.62	0.00	0.68

ASH-2 EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	09/28/99	1.67	0.64	6.6	2	10	6	50	5	44	1.0	0.04	0.13	0.05	0.3	0.25	2	5	5	10	30
2	10/09/99	1.87	0.41	7.0	2	11	4	55	5	34		0.04	0.05	0.05	0.12	0.06	2	5	5	10	50
3	10/20/99	0.50	0.03	6.9	2	7	5	52	5	27	1.1	0.04	0.05	0.05	0.08	0.05	2	5	5	10	30
4	11/01/99	1.46	0.62	6.9	3	6	5	60	5	12	0.7	0.04	0.06	0.05	0.19	0.16	2	5	5	10	10
5	11/25/99	2.20	1.76	6.8	2	9	4	38	5	18		0.04	0.05	0.05	0.11	0.11	2	5	5	10	10
6	12/13/99	0.93	0.17	6.7	2	5	45	14	5	25	0.8	0.05	0.11	0.05	0.17	0.06	2	5	5	10	20
7	01/09/99	1.38	0.42	6.7	2	5	9	27	5	20	0.7	0.05	0.13	0.05	0.11	0.06	2	5	5	10	10
8	02/13/00	1.18	0.68	6.5	3	6	13	248	5	31	1.1	0.16	0.40	0.05	0.17	0.10	2	5	5	10	50
9	02/14/00	0.67	0.07	6.5			39	75	5	32	1.0	0.07	0.19	0.05	0.17	0.11	2	5	6	10	30
10	03/12/00	1.42	0.48	6.6	3	4	23	65	5	30	1.1	0.14	0.35	0.05	0.16	0.08	2	5	5	10	10
11	03/16/00	0.68	0.07	6.4	4	9	6	114	5	43	1.2	0.04	0.14	0.05	0.13	0.06	2	5	5	10	40
12	03/19/00	1.88	0.81	6.3	2	6	39	17	5	17	0.6	0.04	0.05	0.05	0.16	0.10	2	5	5	10	30
13	04/03/00	2.20	1.05	6.2	4	7	14	45	5	18	0.6	0.04	0.07	0.05	0.09	0.06	2	5	5	10	10
14	04/15/00	1.69	0.72	5.9	4	7	29	45	5	28	1.1	0.04	0.11	0.05	0.18	0.18	2	5	5	10	30
15	04/28/00	0.92	0.16	6.1	3	9	14	64	5	28	1.0	0.08	0.06	0.05	0.17	0.10	2	5	5	10	30
16	05/21/00	0.46	0.01	5.8	7	8	11	119	5	95	2.7	0.54	1.39	0.05	0.32	0.18	2	5	5	10	90
17	06/06/00	0.71	0.07	5.7	13	6	19	74	5	43	1.4	0.04	0.37	0.05	0.24	0.10	2	5	5	10	50
18	07/27/00	0.78	0.13	5.9	6	4	50	58	5	34	1.3	0.13	0.96	0.05	0.28	0.18					
19	08/03/00	0.96	0.10	6.1	5	20	20	20	5	41	1.2	0.04	0.39	0.05	0.25	0.18					
20	08/07/00	0.88	0.07	6.7	4	8	41	25	5	27	1.1	0.09	0.34	0.05	0.23	0.11					
21	08/20/00	0.50	0.02	6.7	9	4	31	68	5	100	2.5	0.68	0.83	0.05	0.47	0.39					
22	08/31/00	0.65	0.07	6.1	1	12	16	6	5	65	1.7	0.07	0.38	0.05	0.35	0.23					
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									100%					91%	0%	5%	100%	96%	94%	100%	
Average		1.16	0.39	6.4	4	8	20	61	5	37	1.2	0.11	0.30	0.05	0.20	0.13	2	5	5	10	31
Median		0.95	0.17	6.5	3	7	15	54	5	30	1.1	0.05	0.14	0.05	0.17	0.11	2	5	5	10	30
S.D.		0.56	0.44	0.4	3	4	15	51	0	23	0.5	0.17	0.35	0.00	0.10	0.08	0	0	0	0	21
CV		0.48	1.12	0.06	0.72	0.46	0.73	0.83	0.00	0.62	0.46	1.46	1.15	0.00	0.47	0.62	0.00	0.00	0.05	0.00	0.67

Lognormal distribution

	TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
Mean	21	64	5	37	1.2	0.10	0.30	0.05	0.20	0.13	2	5	5	10	32
Median	15	46	5	32	1.1	0.07	0.18	0.05	0.18	0.11	2	5	5	10	25
CV	1.01	0.95	0.00	0.56	0.41	1.00	1.42	0.00	0.48	0.60	0.00	0.00	0.04	0.00	0.79

WIN EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	06/16/99	1.16	0.15	7.7	2	44	11	129	5	40	0.9	0.04	1.13	0.10	0.16	0.10	2	5	5	10	40
2	07/30/99	0.43	0.07	7.2	4	31	8	70	5	43	1.9	0.32	0.90	0.05	0.76	0.64	2	5	5	10	40
3	08/14/99	0.98	0.10	7.1	5	22	8	83	5	34	1.2	0.17	0.79	0.05	0.49	0.05	2	5	5	10	30
4	08/25/99	2.03	0.60	7.0	3	32	9	81	5	42	1.3	0.13	0.17	0.05	0.55	0.44	2	5	5	10	10
5	09/05/99	1.88	0.46	7.2	3	30	4	87	5	34	1.0	0.09	0.20	0.05	0.25	0.24	2	5	5	10	50
6	09/15/99	1.56	0.36	7.6	2	29	6	84	5	31	1.1	0.04	0.23	0.05	0.19	0.14	2	5	5	10	10
7	09/28/99	1.14	0.14	6.7	4	35	4	51	5	30	0.8	0.04	0.35	0.05	0.20	0.15	2	5	5	10	50
8	10/10/99	0.82	0.05	7.6	2	52	3	94	5	20	0.7	0.06	0.69	0.05	0.10	0.08	2	5	5	10	40
9	10/20/99	0.53	0.06	7.6	2	47	6	105	5	23	1.3	0.09	0.62	0.05	0.11	0.08	2	5	5	10	10
10	11/02/99	0.38	0.01	7.7	2	40	7	116	5	11	0.8	0.05	0.96	0.10	0.10	0.05	2	5	5	10	20
11	11/26/99	1.82	0.38	7.1	3	20	24	66	5	34	1.5	0.18	0.22	0.05	0.34	0.21	2	5	5	10	40
12	12/06/99	0.28	0.02	7.8	2	45	1	126	5	22	0.6	0.13	1.07	0.17	0.09	0.05	2	5	5	10	41
13	12/10/99	0.18	0.00	7.9	2	44	5	100	6	31	0.5	0.05	1.37	0.08	0.08	0.05	2	5	5	10	60
14	01/05/00	0.59	0.13	7.5	2	28	12	76	5	30	1.2	0.12	0.41	0.05	0.18	0.09	2	5	5	10	20
15	01/11/00	1.02	0.22	7.6	2	63	14	145	5	25	1.0	0.13	0.58	0.05	0.11	0.05	2	5	5	10	30
16	01/20/00	0.79	0.06	8.1	4	113	6	345	5	23	1.4	0.37	0.42	0.05	0.10	0.05	2	5	5	10	110
17	02/15/00	0.28	0.26	7.3			22	477	5	49	1.4	0.14	0.33	0.05	0.31	0.26	2	5	6	10	40
18	02/19/00	0.37	0.04	7.4	3	51	18	387	5	43	1.4	0.07	0.55	0.06	0.20	0.12	2	5	5	10	40
19	03/17/00	0.78	0.24	6.8	6	41	48	189	5	59	2.7	0.24	0.23	0.05	0.48	0.23	2	5	5	10	90
20	03/21/00	1.05	0.29	6.9	5	38	19	123	5	48	1.5	0.05	0.13	0.05	0.24	0.17	2	5	5	10	20
21	04/06/00	0.89	0.13	6.6	6	31	26	136	5	50	1.9	0.16	0.28	0.05	0.24	0.14	2	5	5	10	30
22	04/11/00	0.64	0.06	6.9	5	34	12	147	5	38	1.6	0.12	0.34	0.05	0.22	0.14	2	5	5	10	20
23	04/13/00	0.69	0.05	6.9	5	29	71	94	5	31	1.3	0.09	0.43	0.05	0.19	0.13	2	5	5	10	20
24	04/30/00	0.81	0.11	7.0	6	39	12	128	5	61	2.0	0.09	0.22	0.05	0.18	0.08	2	5	5	10	30
25	05/22/00	1.06	0.09	6.4	4	22	30	102	5	40	1.2	0.17	0.82	0.05	0.48	0.41	2	5	5	10	20
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									96%					83%	0%	20%	100%	100%	96%	100%	
Average		0.88	0.17	7.3	3	41	15	144	5	34	1.3	0.13	0.54	0.06	0.25	0.16	2	5	5	10	37
Median		0.79	0.13	7.3	3	37	9	105	5	34	1.3	0.12	0.42	0.05	0.20	0.13	2	5	5	10	40
S.D.		0.51	0.15	0.4	1	19	16	105	0	12	0.5	0.08	0.34	0.03	0.17	0.14	0	0	0	0	23
CV		0.57	0.92	0.06	0.44	0.46	1.05	0.73	0.04	0.35	0.39	0.67	0.64	0.44	0.70	0.91	0.00	0.00	0.04	0.00	0.63

Lognormal distribution

	TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
Mean	16	138	5	36	1.3	0.13	0.52	0.06	0.25	0.16	2	5	5	10	37
Median	10	120	5	33	1.2	0.10	0.42	0.06	0.21	0.13	2	5	5	10	31
CV	1.17	0.58	0.04	0.40	0.41	0.71	0.72	0.30	0.69	0.86	0.00	0.00	0.04	0.00	0.68

GAR EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	06/16/99	1.28	0.51	7.4	2	28	29	137	5	50	2.6	0.36	3.37	0.15	0.42	0.27	5	5	5	10	150
2	08/09/99	0.47	0.06	7.7	3	44	12	140	5	64	1.5	0.04	0.78	0.10	0.33	0.20	2	5	5	10	30
3	08/26/99	0.87	0.43	7.8	2	40	3	72	5	27		0.04	0.33	0.05	0.12	0.10	2	5	5	10	10
4	09/09/99	0.72	0.33	7.1	3	28	3	74	5	26	0.9	0.08	0.13	0.05	0.19	0.16	2	5	5	10	20
5	09/21/99	0.59	0.09	7.6	3	25	3	41	5	18	0.8	0.04	0.21	0.05	0.09	0.08	2	5	5	10	10
6	10/18/99	1.84	0.92	7.5	1	33	4	63	5	12	0.6	0.04	0.09	0.05	0.07	0.05	2	5	5	10	10
7	10/21/99	1.20	0.62	7.7	1	48	1	83	5	12	0.5	0.04	0.20	0.05		0.05	2	5	5	10	10
8	11/02/99	0.65	0.16	6.9	8	27	8	105	5	29	1.3	0.04	0.05	0.05	0.52	0.42	2	5	5	10	10
9	11/26/99	1.74	5.22	7.4	2	22	5	105	5	18	0.6	0.06	2.75	0.05	0.17	0.12	2	5	5	10	10
10	12/06/99	0.36	0.05	7.4	2	29	8	100	5	5	0.8	0.04	0.05	0.78	0.25	0.21	2	5	5	10	30
11	12/10/99	0.11	0.00	7.6	2	23	2	99	5	9	0.3	0.04	4.30	0.05	0.08	0.05	2	5	5	10	10
12	12/18/99	0.32	0.96	7.4	2	25	5	47	5	25	0.7	0.08	0.23	0.05	0.15	0.08	2	5	5	10	10
13	01/05/00	0.64	0.19	7.4	3	29	6	68	5	22	0.9	0.09	0.74	0.05	0.18	0.13	2	5	5	10	10
14	01/11/00	1.23	1.05	7.4	2	36	5	85	5	22	0.6	0.05	0.31	0.05	0.09	0.05	2	5	5	10	10
15	02/15/00	1.23	0.81	7.6	4	29	17	186	5	31	1.2	0.13	0.56	0.05	0.15	0.10	2	5	6	10	20
16	02/19/00	0.49	0.26	7.2	2	34	2	138	5	37	0.7	0.11	0.86	0.05	0.09	0.06	2	5	5	10	20
17	02/29/00	0.41	0.07	7.0	5	33	16	121	5	40	0.8	0.08	1.03	0.05	0.12	0.07	2	5	5	10	30
18	03/18/00	1.48	0.74	6.8	4	27	40	89	5	40	1.6	0.08	0.24	0.05	0.23	0.09	2	5	5	10	30
19	03/29/00	0.53	0.12	6.9	4	24	8	114	5	34	0.9	0.04	0.38	0.05	0.11	0.06	2	5	5	10	20
20	04/11/00	0.89	0.22	6.5	6	22	10	102	5	34	2.4	0.95	0.78	0.05	0.43	0.37	2	5	5	10	10
21	04/13/00	0.43	0.05	7.1	5	38	53	94	5	31	1.1	0.11	0.68	0.07	0.15	0.12	2	5	22	10	30
22	04/30/00	0.93	0.14	6.9	5	32	11	98	5	30	1.0	0.08	0.47	0.05	0.10	0.05	2	5	5	10	20
23	05/22/00	0.71	0.13	6.4	5	20	10	72	5	37	1.8	0.32	0.75	0.06	0.31	0.22	2	5	5	10	10
24	08/01/00	2.20	0.47	7.3	5	35	3	89	5	31	0.9	0.04	0.20	0.05	0.16	0.11					
25	08/28/00	0.86	0.06	6.6	1	12	35		5	11	0.7	0.18	0.46	0.05	0.87	0.18					
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									100%	4%				75%		12%	100%	96%	91%	100%	
Average		0.83	0.57	7.2	3	30	11	97	5	28	1.1	0.13	0.84	0.09	0.20	0.14	2	5	6	10	23
Median		0.71	0.22	7.4	3	29	8	98	5	29	0.9	0.08	0.47	0.05	0.15	0.10	2	5	5	10	10
S.D.		0.52	1.03	0.4	2	8	13	32	0	13	0.6	0.19	1.07	0.15	0.18	0.10	1	0	4	0	29
CV		0.63	1.80	0.05	0.54	0.26	1.18	0.33	0.00	0.47	0.53	1.49	1.27	1.63	0.93	0.74	0.29	0.00	0.61	0.00	1.28

Lognormal distribution

	TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
Mean	12	97	5	28	1.0	0.11	0.70	0.07	0.22	0.14	2	5	6	10	21
Median	7	92	5	24	0.9	0.08	0.39	0.06	0.18	0.11	2	5	5	10	17
CV	1.33	0.35	0.00	0.63	0.52	1.00	1.50	0.62	0.74	0.72	0.19	0.00	0.32	0.00	0.75

WIL-1 EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	06/30/99	0.32	0.17	7.4	2	32	7	114	5	78	1.0	0.09	0.43	0.05	0.09	0.05	2	6	5	10	90
2	07/11/99	1.20	0.82	7.5	1	24	13	57	5	18	0.5	0.04	0.18	0.05	0.06	0.05	2	5	5	10	20
3	08/08/99	0.28	0.11	7.6	2	30	9	82	5	37	1.3	0.55	0.77	0.05	0.08	0.05	2	5	5	10	60
4	08/11/99	0.25	0.18	7.5	3	26	7	66	5	40	1.1	0.42	0.66	0.05	0.06	0.05	2	5	5	10	50
5	08/25/99	0.46	0.37	7.5	2	23	11	50	5	34		0.06	0.34	0.05	0.16	0.11	2	5	5	10	10
6	10/17/99	3.28	2.49	7.5	2	21	1	38	5	5	0.3	0.05	0.06	0.05	0.05	0.05	2	5	5	10	30
7	11/02/99	1.55	1.23	7.8	1	21	1	46	5	5	0.4	0.04	0.06	0.05	0.05	0.05	2	5	5	10	10
8	12/06/99	0.28	0.26	7.6	2	24	7	69	5	27	1.0	0.27	0.24	0.05	0.07	0.05	2	5	5	10	80
9	12/10/99	0.36	0.19	7.7	1	24	10	64	5	28	0.6	0.06	0.29	0.05	0.06	0.05	2	5	5	10	60
10	12/20/99	0.73	0.46	7.9	1	21	2	29	5	13	0.4	0.07	0.11	0.05	0.05	0.05	2	5	5	10	30
11	01/04/00	0.36	0.16	7.7	2	24	8	46	5	22	0.7	0.17	0.36	0.05	0.07	0.05	2	5	5	10	40
12	01/09/00	0.59	0.39	8.1	1	28	19	51	5	25	0.5	0.04	0.24	0.05	0.05	0.05	2	5	5	10	50
13	01/30/00	0.60	0.27	7.3	2	33	10	251	5	14	0.7	0.34	0.51	0.05	0.05	0.05	2	5	5	10	200
14	02/01/00			8.2	1	72	123	148	6	86	1.8	0.22	0.1	0.05	0.42	0.08	2	6	29	10	170
15	02/14/00	0.65	0.42	7.7	1	27	34	65	5	27	1.0	0.29	0.23	0.05	0.14	0.05	2	5	6	10	60
16	02/21/00	0.10	0.00	7.5	3	43	44	192	5	52	1.7	0.65	0.85	0.05	0.19	0.05	2	5	5	10	120
17	04/12/00	0.21	0.09	7.1	5	30	101	86	5	52	1.9	0.66	0.98	0.06	0.11	0.05	2	5	5	10	60
18	04/14/00	1.58	0.99	7.0	3	21	4	21	5	5	0.3	0.05	0.06	0.05	0.05	0.05	2	5	5	10	20
19	04/25/00	0.20	0.05	7.3	3	24	13	71	5	34	0.8	0.15	0.49	0.05	0.07	0.05	2	5	5	10	60
20	05/22/00	0.66	0.27	7.0	2	23	11	45	5	18	0.7	0.08	0.34	0.3	0.05	0.05	2	5	5	10	40
21	05/25/00	2.21	1.72	6.7	3	18	10	41	5	11	0.5	0.21	0.26	0.05	0.06	0.05	2	5	5	10	20
22	06/06/00	0.75	0.60	7.1	3	22	10	55	5	25	0.9	0.13	0.48	0.05	0.05	0.05	2	5	5	10	50
23	07/27/00	1.08	0.91	7.0	1	16	3	33	5	14	0.4	0.08	0.23	0.05	0.05	0.05					
24	08/24/00	1.12	0.77	7.0	1	26	45	34	5	22	1.3	0.15	0.51	0.05	0.09	0.05					
25	08/28/00	0.27	0.10	7.0	1	28	10	37	5	9	0.5	0.12	0.52	0.05	1.36	1.33					
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL									96%	4%				88%	24%	84%	100%	91%	86%	100%	
Average		0.80	0.55	7.5	2	27	20	75	5	29	0.8	0.21	0.36	0.06	0.09	0.05	2	5	6	10	60
Median		0.60	0.32	7.5	2	24	10	57	5	25	0.7	0.13	0.29	0.05	0.06	0.05	2	5	5	10	50
S.D.		0.75	0.59	0.4	1	11	30	54	0	21	0.5	0.19	0.25	0.05	0.27	0.26	0	0	5	0	48
CV		0.93	1.07	0.05	0.50	0.40	1.51	0.72	0.04	0.72	0.57	0.92	0.69	0.81	2.92	4.74	0.00	0.06	0.83	0.00	0.80

Lognormal distribution

	TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
Mean	21	70	5	29	$0.8	0.20	0.40	0.06	0.11	0.08	2	5	6	10	62
Median	10	60	5	21	$0.7	0.13	0.29	0.05	0.08	0.06	2	5	5	10	46
CV	1.77	0.63	0.04	0.92	0.60	1.12	0.97	0.37	0.92	0.75	0.00	0.05	0.39	0.00	0.93

WIL-2 EMCs

Event	Date (MDY)	Rain (in.)	Runoff (in.)	pH	Acidity (mg/L)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	O&G (mg/L)	COD (mg/L)	TKN (mg/L)	NH3-N (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	TP (mg/L)	OP (mg/L)	Cd (ug/L)	Cr (Ug/L)	Pb (ug/L)	Ni (ug/L)	Zn (ug/L)
1	10/17/99	3.28	1.92	7.3	5	30	51	58	5	44.5	3.7	0.55	0.06	0.05	0.58	0.31	2	5	5	10	20
2	11/25/99	0.90	0.18	7.0	5	30	6	89	5	58	1.7	0.23	0.05	0.05	0.95	0.8	2	5	5	10	20
3	12/19/99	0.73	0.24	7.7	2	40	5	69	5	47	1.9	0.09	0.05	0.05	0.59	0.38	2	5	5	10	10
4	01/09/00	0.59	0.05	7.3	3	33	3	74	5	60	1.7	0.12	0.05	0.05	0.38	0.23	2	5	5	10	10
5	01/22/00			7.2	3	32	1	96	5	18	0.5	0.04	0.2	0.05	0.22	0.07	2	5	5	10	10
6	01/30/00	0.60	0.05	7.4	2	39	6	308	5	30	0.9	0.05	0.06	0.05	0.21	0.15	2	5	5	10	20
7	02/14/00	0.65	0.08	7.1			20	64	5	34	1.2	0.07	0.22	0.05	0.24	0.16	2	5	5	10	10
8	04/18/00	0.74	0.10	6.5	6	26	4	41	5	21	0.8	0.15	0.05	0.05	0.14	0.1	2	5	5	10	10
9	04/25/00	0.35	0.03	6.4	7	20	10	65	5	40	1.4	0.04	0.05	0.05	0.33	0.19	2	5	5	10	20
10	04/28/00	0.70	0.09	7.3	4	34	24	88	5	59	2.7	0.08	0.05	0.05	0.37	0.15	2	5	5	10	30
11	05/22/00	0.66	0.09	6.1	6	14	9	67	5	43	1.5	0.16	0.3	0.05	0.67	0.6	2	5	5	10	10
12	05/26/00	2.21	1.17	6.4	6	23	3	58	5	25	0.8	0.08	0.05	0.05	0.32	0.28	2	5	5	10	10
13	06/04/00	0.75	0.06	7.0	3	26	16	62	5	68	3.7	0.35	0.6	0.05	0.52	0.33	2	5	5	10	30
14	08/24/00	1.12	0.34	6.6	1	34	270	84	5	294	6.5	0.04	0.51	0.05	0.97	0.13					
15	08/27/00	0.27	0.03	7.0	1	68	1600	83	5	680	14.0	0.08	0.21	0.05	2.66	0.25					
16	09/03/00	1.21	0.31	6.9	1	82	980	110	5	298	6.4	0.17	0.08	0.05	1.69	0.24					
17	10/09/00	0.14	0.01	7.3	7	94	264	170	5	127	5.1	0.09	0.12	0.05	0.7	0.32	2	5	5	10	
18	11/26/00	2.60	1.51	6.8	6	22	930	45	5	264	4.5	0.04	0.05	0.05	1.71	1.2	2	9	13	10	
19	12/02/00	0.67	0.09	7.1	3	29	1	75	5	25	0.6	0.04	0.11	0.05	0.34	0.31	2	5	5	10	
20	12/10/00	0.56	0.05		2	23	1	100	5	27	0.5	0.08	0.14	0.05	0.2	0.19	2	5	5	10	
MDL					1	1	1	1	5	5	0.15	0.04	0.05	0.05	0.05	0.05	2	5	5	10	10
% data <= MDL					16%		10%		100%			25%	35%	100%			100%	94%	88%	100%	15%
Average		0.99	0.34	7.0	4	37	210	90	5	113	3.0	0.13	0.15	0.05	0.69	0.32	2	5	5	10	16
Median		0.70	0.09	7.0	3	30	10	75	5	46	1.7	0.08	0.07	0.05	0.45	0.25	2	5	5	10	10
S.D.		0.82	0.55	0.4	2	21	438	58	0	161	3.2	0.13	0.16	0.00	0.64	0.27	0	1	2	0	8
CV		0.83	1.65	0.06	0.54	0.58	2.08	0.65	0.00	1.43	1.07	0.99	1.04	0.00	0.94	0.84	0.00	0.19	0.35	0.00	0.48

Lognormal distribution

	TSS	TDS	O&G	COD	TKN	NH3-N	NO3-N	NO2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
Mean	302	89	5	104	3.0	0.12	0.15	0.05	0.68	0.32	2	5	5	10	16
Median	19	80	5	62	1.9	0.09	0.10	0.05	0.50	0.25	2	5	5	10	15
CV	16.25	0.47	0.00	1.35	1.20	0.88	1.01	0.00	0.94	0.77	0.00	0.14	0.23	0.00	0.47

Appendix 4: Distribution of Seasonal Pollutant Loads (percent)

		% Rain	Ia/Iav	TSS %	TDS %	O&C %	COD %	TKN %	NH_3-N %	NO_3-N %	NO_2-N %	TP %	OP %	Cd %	Cr %	Pb %	Ni %	Zn %
CLT-1	Quarter 1	22	0.96	34	28	25	35	32	28	25	20	33	27	21	32	38	21	31
	Quarter 2	32	0.67	19	20	15	23	23	25	25	19	16	18	16	13	13	15	18
	Quarter 3	17	1.22	17	26	20	19	20	19	28	26	20	21	22	22	17	22	26
	Quarter 4	29	1.19	30	26	40	23	26	28	22	35	31	35	41	33	32	42	25
CLT-2	Quarter 1	22	0.96	42	33	29	37	28	24	21	27	25	16	29	29	40	29	36
	Quarter 2	32	0.67	25	18	22	24	22	27	20	25	13	11	20	20	17	20	17
	Quarter 3	17	1.22	19	20	22	20	24	24	34	22	39	49	23	23	23	23	27
	Quarter 4	29	1.19	14	29	27	18	25	26	24	26	22	23	28	28	20	28	20
ASH-1	Quarter 1	40	0.88	38	35	37	33	24	33	26	33	28	34	32	32	33	32	42
	Quarter 2	33	1.01	50	29	18	44	46	29	25	25	47	18	17	19	28	17	25
	Quarter 3	18	1.74	9	19	15	11	14	20	36	14	12	19	23	23	22	23	19
	Quarter 4	27	0.47	4	17	29	11	17	17	13	28	13	29	28	26	17	28	13
ASH-2	Quarter 1	40	0.88	40	43	26	27	33	42	43	26	26	20	20	20	21	20	24
	Quarter 2	33	1.01	32	21	25	24	31	19	18	25	22	23	19	19	19	19	17
	Quarter 3	18	1.74	12	8	11	19	17	13	24	11	20	21	31	31	31	31	39
	Quarter 4	27	0.47	16	28	38	30	19	26	15	38	32	35	29	29	29	29	20
WIN	Quarter 1	19	0.54	42	49	27	30	32	32	26	26	23	20	27	27	28	27	37
	Quarter 2	29	1.57	22	15	15	18	17	14	26	18	12	11	15	15	15	15	13
	Quarter 3	37	1.04	19	28	44	41	38	38	34	42	53	58	44	44	44	44	35
	Quarter 4	14	0.37	17	8	14	11	14	17	14	14	12	11	14	14	13	14	15
GAR	Quarter 1	16	0.77	52	44	37	40	36	25	34	36	29	24	33	37	38	37	27
	Quarter 2	8	0.60	31	19	17	25	34	57	15	11	32	35	26	17	19	17	52
	Quarter 3	65	1.36	8	15	19	20	14	8	10	19	20	20	16	18	17	18	10
	Quarter 4	11	0.58	9	22	27	15	16	10	41	34	19	22	25	28	26	28	11

		% Rain	Ia/Iav	TSS	TDS	O&G	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TP	OP	Cd	Cr	Pb	Ni	Zn
				%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
WIL-1*	Quarter 1	9	0.57	33	18	14	24	19	22	17	13	18	12	15	15	16	15	24
	Quarter 2	26	0.70	25	24	25	26	26	34	32	31	20	21	26	26	25	26	24
	Quarter 3	49	1.59	34	20	20	29	28	22	34	19	33	33	17	17	17	17	13
	Quarter 4	16	0.61	7	38	41	21	26	23	16	38	29	34	43	42	42	43	38
				%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
WIL-2*	Quarter 1	9	0.57	13	31	20	8	11	13	21	20	9	10	21	21	21	21	14
	Quarter 2	26	0.70	17	18	25	15	21	33	41	25	17	20	26	26	26	26	26
	Quarter 3	49	1.59	59	9	7	49	36	5	11	7	25	5	4	4	4	4	6
	Quarter 4	16	0.61	11	42	47	28	31	49	26	47	50	65	49	49	49	49	55
US-74	Quarter 1	26	0.81	31	22	29	26	24	21	30	29	16	12	30	34	34	34	31
	Quarter 2	20	0.62	7	13	11	12	11	9	13	11	5	4	12	13	13	13	10
	Quarter 3	25	1.46	45	37	31	39	39	46	42	31	55	60	29	20	20	20	40
	Quarter 4	29	0.69	16	28	28	24	25	24	16	28	23	24	29	33	33	33	19
MON	Quarter 1	20	1.62	20	23	24	24	23	23	21	24	21	17	24	24	20	24	19
	Quarter 2	20	1.16	15	19	16	23	24	25	20	16	22	32	16	16	17	16	32
	Quarter 3	47	0.66	61	48	49	45	44	34	46	49	49	38	49	49	54	49	42
	Quarter 4	32	0.66	4	9	10	8	9	17	14	10	8	12	10	11	9	10	7

*Excluding Hurricane Floyd

Ia/Iav = quarterly to annual rainfall average intensity