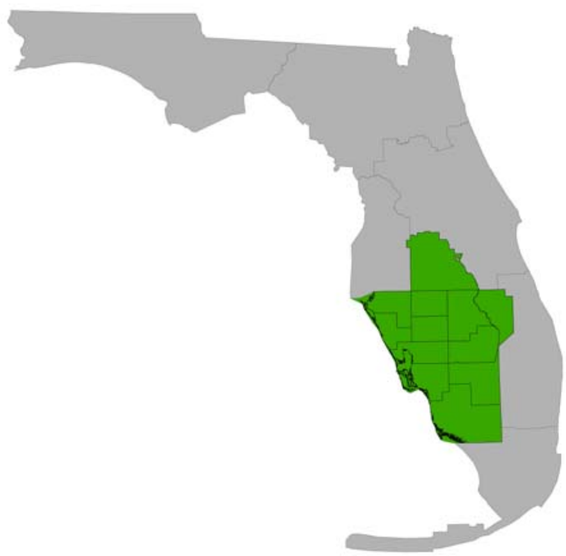
Determination of Appropriate Highway EMC Values for Use within FDOT District 1



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1.0 INTRODUCTION AND PURPOSE

The Florida Department of Environmental Protection (FDEP) is the state agency responsible for implementing the Federal Clean Water Act (CWA), including the development and implementation of Total Maximum Daily Loads (TMDLs). TMDLs are established and implemented in accordance with F.S. 403.067. Once a TMDL is adopted, there are several routes by which FDEP can choose to implement the TMDL. The most formal of these is the Basin Management Action Plan (BMAP). The BMAP process is intended to include the broadest possible range of interested parties, or stakeholders, with the objective of encouraging the greatest amount of cooperation and consensus possible. Through the BMAP process, FDEP determines how much of the pollutant of concern each individual stakeholder is allowed to discharge in order for the water body to meet its TMDL. Then, based upon a calculation of stakeholders' existing pollutant loads, each stakeholder must make appropriate reductions to reach their target. The BMAP is adopted by secretarial order and is an enforceable document.

The Florida Department of Transportation (FDOT), by virtue of its wide geographic coverage area, has been, is, or will be a stakeholder in nearly every BMAP that is developed in the State. As there can be significant capital costs associated with mandated reductions, FDOT has a strong interest in ensuring that the road and highway pollutant loading calculations for each BMAP reflect actual site conditions as accurately as possible.

FDEP currently determines annual highway pollutant loadings statewide using literature values of event mean concentrations (EMC) from 15 sampling sites in Florida based on studies dating from 1975 through 2007. Studies include seven sites in the Orlando area, two sites on the southeast coast, one site in Tallahassee, one site in Tampa, and four sites in southwest Florida. The purpose of this paper is to review the data and methods used in these studies and, based upon this review, to provide recommendations with regard to EMC values that are most appropriate for use within FDOT District 1.

2.0 BACKGROUND

FDOT District 1 manages more than 2,200 miles of roadway within 12 counties in the southwestern portion of the state. The roads and highways traverse both rural and urban areas, including populated jurisdictional areas regulated by the National Pollutant Discharge Elimination System (NPDES) program. The NPDES program is authorized under the CWA and is administered in Florida by FDEP. Municipal separate storm sewer systems (MS4s) are permitted under the NPDES program and as such MS4 stormwater discharges are effectively regulated as a point source. FDOT District 1 is an MS4 co-permittee with Polk, Sarasota, Manatee, and Lee Counties. In addition, District 1 holds an MS4 permit in Charlotte County.

MS4 permits contain specific conditions related to TMDLs and BMAPs. Once a BMAP or other TMDL implementation plan is adopted for a water body into which the MS4 discharges the pollutant of concern, the MS4 operator must comply with the adopted provisions of the BMAP. BMAPs typically include specific activities that are to be undertaken by the MS4 permittee during the permit cycle. BMAP stakeholders outside an MS4 permit area are also required to comply with BMAP provisions. Stakeholders who fail to comply are subject to enforcement action by FDEP or a water management district.

District 1 is currently a stakeholder in nutrient BMAPs for the Caloosahatchee River and tributaries (Lee and Charlotte Counties), Hendry Creek marine and freshwater segments (Lee County), and the Imperial River (Lee County). As such, District 1 will have allocations for each BMAP and will be required to demonstrate reductions in loads of total nitrogen (TN) and total phosphorus (TP) in order to meet their allocations.

3.0 REVIEW OF LITERATURE EMC VALUES

Data used by FDEP to determine highway EMC values are based in part upon summary information provided in Table 4-10 of *Evaluation of Current Stormwater Design Criteria within the State of Florida* (Harper and Baker 2007). In addition, between 2004 and 2007, FDOT District 1 conducted water quality investigations at four wet/dry detention ponds in Lee, Hendry, and Collier Counties (Johnson Engineering 2006; 2008; 2009a; 2009b). The primary objective of the District 1 studies was to evaluate the quality of stormwater runoff from state-managed roadways in southwest Florida. Data were used to develop regionally appropriate EMCs for nutrients, metals, and total suspended solids.

The District 1 reports were recently submitted to FDEP for review. Subsequent to FDEP review, the data were incorporated into the state's generalized EMC table for highway runoff for inclusion in *the Environmental Resource Permit Applicant's Handbook for Stormwater Treatment Systems in Florida*. EMC values for many land uses, including highways, are summarized in Table 3-4 of the draft handbook and will be incorporated into the Statewide Stormwater Rule once the rule is adopted. Appendix C of the handbook is currently being revised to reflect the additional data.

The EMC sampling site locations are shown in Figure 1 and characteristics of each of the sites and studies utilized to develop the statewide EMCs are shown in Table 1. TP and TN data for all but the Johnson Engineering studies for District 1 are based upon the information provided in Table 4-10 in Harper and Baker (2007). Additional data on rainfall, number of events sampled, average daily traffic counts, and percent impervious is based upon a review of the original studies or related journal articles. The ERD (2000) report and 2005 unpublished data were unavailable for review, so additional details cannot be provided for these studies.

The data presented in Table 1 and Figure 1 are notable in several respects. First, the data set is heavily weighted towards studies conducted in the Orlando area along the I-4 corridor. Seven of the 15 site investigations are within 20 miles of one another, and six of those are within eight miles of one another. In addition, the data suggest (and ATM later confirmed) that two of the cited Orlando area studies were from the same interchange. In fact, detailed review of both the Harper (1985) and Yousef et al. (1986) reports confirmed that the results

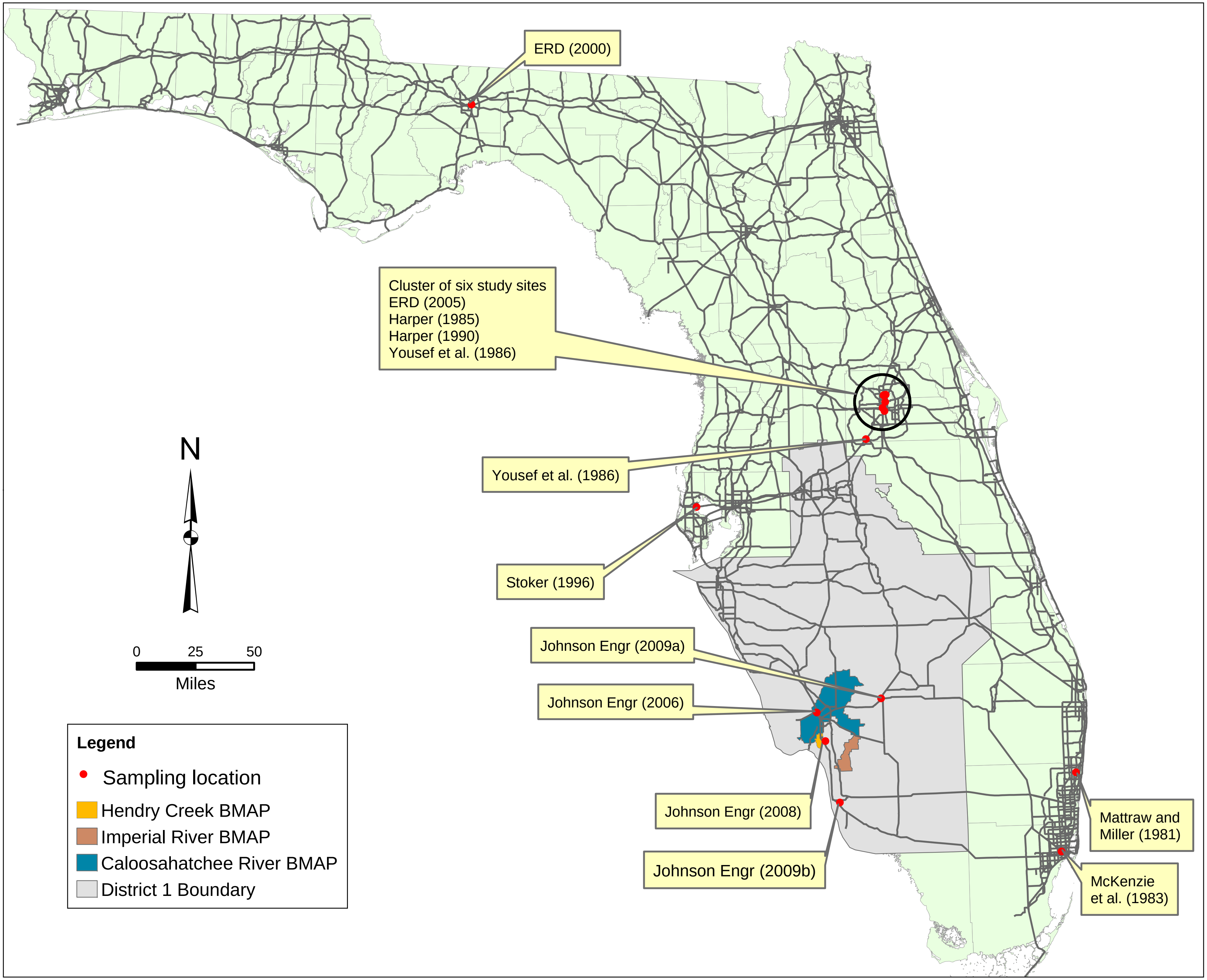

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Figure 1
Distribution of Stormwater Sampling Sites Used to Determine Statewide EMC Values

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Table 1. Characteristics of Stormwater Sampling Sites Used to Determine Highway EMCs (based in part on Table 4-10, Harper and Baker [2007])

Location	Reference	Dates of Sample Collection	# of events sampled	Drainage area (acres)	% Impervious	Average Daily Traffic	Range of Rainfall for Events Sampled (inches)	TN (mg/L)	TP (mg/L)
Broward County (6-lane)	Mattraw and Miller (1981)	April 1975-July 1977	42	58.3	36%	20,000	0.06-2.50	0.96	0.077
I-95 Miami bridge	McKenzie et al. (1983)	Nov 1979 (1 event); Mar 1981 (1 event); May 1981 (2 events)	4	1.43	100%	70,000	0.08-0.65	3.20	0.160
Maitland Blvd	German (1983)	April 1975-April 1979 (Samples collected in April, August, and December)	13-18	16.8[1]	Not specified	Not specified	Not specified	1.30	0.240
I-4 Maitland Interchange	Harper (1985)	April 1983-May 1984	16	3.95[2]	Not specified	31,400[4]	0.33-3.23	1.40	0.170
I-4 Maitland Interchange	Yousef et al. (1986)	April 1983-May 1984	16	48.9[3]	Not specified	15,000	0.33-3.23	1.40	0.170
I-4 Epcot Interchange	Yousef et al. (1986)	June 1983 - November 1984	14	20.5	Not specified	Not specified	Not specified	3.16	0.420
Winter Park I-4	Harper (1990)	January 1987-January 1988	10	1.17	100%	60-70,000	0.08-2.19	1.60	0.230
Orlando I-4	Harper (1990)	January 1987-December 1987	13	1.30	70%	60-70,000	0.04-2.77	2.15	0.550
Bayside Bridge - Tampa	Stoker (1996)	April 1993 - September 1996	24	12.9	100%	36-56,000	0.12-3.15	1.10	0.100
Tallahassee	ERD (2000)	NA	NA	NA	NA	NA	NA	1.10	0.166
Orlando - US 441	ERD (2005) - unpublished data	NA	NA	NA	NA	NA	NA	0.683	0.085
Richard Road (Lee County)	Johnson Engineering (2006)	Dec 2004-Nov 2005	9	7.56	49%	33,000	0.32-3.21	1.56	0.279
US 41 (Lee County)	Johnson Engineering (2008)	Sept 2005-August 2006	6	6.89	62%	61,000	0.25-1.03	0.832	0.121
Labelle (Hendry County)	Johnson Engineering (2009a)	August 2006-Oct 2007	7	6.80	84%	9,000	0.16-4.40	1.306	0.17
Flamingo Drive (Collier County)	Johnson Engineering (2009b)	April 2007-Sept 2007	8	16.95	65%	28,500	0.19-2.47	0.937	0.060
Geometric Mean								1.37	0.17

NA - Report and data were not available for review

[1] Drainage area is estimated

[2] Represents just the area draining to the sampling point at the retention pond

[3] Includes total area draining to the retention pond

[4] Includes both east and westbound traffic

presented from the I-4/Maitland Boulevard interchange are from the same field investigation in 1983-1984. A third study was conducted along Maitland Boulevard at holding ponds within 2 miles of the I-4/Maitland interchange (German 1983).

Secondly, there are considerable differences between the 15 studies with respect to number of events sampled, range of total rainfall per event and overall study length. Ideally, each stormwater study should include at least an entire year of sampling, with both small and large rain events represented.

Mattraw and Miller (1981), the earliest study in the data set, is also one of the most rigorous. Flow-weighted water quality samples were collected over a 27-month period from 45 events. Events sampled include storms as small as 0.06 inch up to events of 2.5 inches. The highway watershed in this study, which included 3,000 feet of 6-lane road, was chosen to determine the impact of moderate traffic (approximately 20,000 vehicles per day) on stormwater quality, so the study designers located a drainage with negligible runoff from adjacent commercial and residential areas. The TN and TP values reported in Table 1 are the averages of 436 individual sample aliquots collected over the course of the study. Corresponding median values for TN and TP are 0.600 mg/L and 0.060 mg/L, respectively. Data from this study are included in Appendix A.

In contrast, McKenzie et al. (1983) was a reconnaissance study of a small bridge area on I-95 in Miami and includes data from just four events, with rainfall ranging from 0.08 inch to just 0.65 inch. For the four storms sampled, a total of 35 individual sample aliquots were collected at approximately 3.8-minute intervals. The TN and TP values reported in Table 1 represent the medians of these individual samples. Data from this study are included in Appendix B.

The absence of higher rainfall events from the I-95/Miami Bridge biases the data toward higher EMCs since much of the pollutant load is often contained in the earlier portions of runoff. In addition, the authors note that a portion of the stormwater runoff from the I-95/Miami Bridge study was discharged before reaching the sample outfall point so the samples collected do not give a true picture of the actual concentrations of pollutants in the runoff. The total bridge drainage area comprised a 1,387-ft section along which some of the stormwater was intercepted and discharged through downdrains and a 339-ft section without downdrains that ended at the sample point. Because of these flow losses, estimated to be as high as 93 percent, and the limited number of events sampled, it is recommended that these data be removed from the database for use in calculating the statewide EMCs.

German (1983) conducted an investigation of water quality of four lakes in central Florida before, during, and after construction of an interchange at I-4 and a four-lane section of road connecting the interchange to US 17/92. The multi-purpose water quality monitoring program began in April 1971 and went through June 1979. The following study objectives were identified:

- Document lake water quality before, during, and after the start of road construction
- Determine quality and quantity of runoff entering the lakes and bulk precipitation falling on the surface of the lakes
- Determine water quality in the surficial aquifer around the lakes
- Determine loads of materials carried into the lakes by runoff and precipitation
- Determine the quality and quantity of bulk precipitation falling on the surface of the lakes

Water quality monitoring of direct runoff from residential areas into the lakes, highway runoff from Maitland Boulevard into two holding ponds, groundwater, precipitation, lake water, and holding pond water was conducted. Sampling of roadway runoff was started in April 1975 at one holding pond and in December 1977 at a second holding pond. Highway runoff samples were collected approximately three times per year in April, August, and December until April 1979. Road construction started in 1974 and was completed in April 1977. Runoff at each holding pond was sampled once during each rainfall event, i.e., samples were not flow-weighted over the duration of the storm). The author notes that initial sampling of runoff from residential areas into the lakes (August 1971 to August 1973) included collection of samples near the beginning and near the end of each storm. This was based upon the assumption that the early samples would contain the bulk of the pollutants. This did not turn out to be consistently true, however, so the method was modified to include just one sample at each site per event. Median values of TN and TP for highway runoff are represented in Table 1.

Harper (1985) investigated roadway runoff from Maitland Boulevard into one of three ponds at the I-4/Maitland Boulevard interchange with the primary objective of determining the fate and movement of heavy metals from highway runoff. Flow weighted samples were collected for sixteen events during a 13-month period from April 1983 to May 1984. Samples were collected at an outfall to one of three retention ponds at the interchange. The outfall drained a 3.95 acre area of Maitland Boulevard. Nutrient data were also collected at the outfall pipe, but the results of nutrient sample analyses are not presented in Harper's dissertation.

Yousef et al. (1986) presents results of highway runoff investigations at the I-4/Maitland Boulevard interchange and the Epcot/I-4 interchange. The data from the Maitland Boulevard study location are taken from the Harper (1985) study, but additional nutrient parameters not presented by Harper as part of his dissertation are also included.

Nitrogen values for the Maitland site are presented by Yousef et al. (1986) as averages of organic nitrogen (55 samples), ammonia nitrogen (108 samples), nitrate nitrogen (111 samples), and nitrite nitrogen (117 samples). For purposes of inclusion in the calculation of the statewide EMC value, the value of total nitrogen for this site is computed as the sum of the averages of each of these species of nitrogen (see Harper and Baker 2007). If there were equal numbers of samples for each of the constituents, this method would be equivalent to computing TN for each sample and then taking the average. However, since there is such a wide disparity in the numbers of samples used to determine each of the four nitrogen numbers, in particular organic nitrogen, it is incorrect to simply add up the averages. The correct approach is to take all of the samples for which all four constituents are known, compute TN for each sample and then average those values. The problem with this approach, however, is that the full range of events is not included and the average may not be representative of the actual long term average. No additional details about the nutrient samples are presented in either report, so additional review of the data could not be completed.

Harper and Baker (2007) also present two different sets of EMC values for the metals evaluated by Harper (1985) from the I-4/Maitland Boulevard interchange. Since the numbers come from the same study, they should be the same. The differences come about because the numbers presented under the Harper (1985) reference are flow-weighted averages, and the numbers presented under the Yousef et al. (1986) reference are simply averages of each individual sample collected over the course of the study. For purposes of determining EMCs, the flow-weighted averages should be used.

The objective of the study conducted at the Epcot interchange was to investigate and quantify the amount and character of nutrients and heavy metals at a succession of points in a stormwater treatment train consisting of swales, retention/detention ponds, and wetlands. Water quality data were collected at seven locations within the treatment train. Sample point #1 drained a median section of the connector road and was located in a grassy swale approximately 40 ft downstream from the exit from a 15-in culvert. Sample point #2 was located at the exit to a 15-in culvert that received direct runoff from the connector road. Sample point #3 received direct runoff from the I-4 interchange overpass that discharged through a 15-in culvert. Sample points #4 through #7 were all located downstream of the sites receiving direct roadway runoff at various locations along the treatment train.

Water samples at the Epcot stations were collected using open plexiglass trays connected to a Tygon tube that allowed collected flow to discharge into a 1-gallon bottle placed below the collection tray. The samples collected in this manner were not flow-weighted, but were instead representative of first flush conditions, or the first gallon of runoff. Because the samples represent the first flush and not EMC values, these data are not appropriate for inclusion in the calculation of statewide EMC values. Although these samples are referred to at one point in the report as “composites,” they are more accurately described as grab samples collected over a period of time. Collection of runoff begins at the start of the event and stops when the bottle is full.

It is also noted that although three of the stations directly drain roadway areas, only the data for Station #2 was selected for inclusion in the statewide EMC calculations. TN values for Stations #1 and #3 are 1.91 and 1.00 mg/L, respectively. TP values for Stations #1 and #3 are 0.36 and 0.19 mg/L, respectively. These values are substantially less than the TN and TP values of 3.16 and 0.42 mg/L used in the statewide EMC calculations. Averaging the results from the three stations yields TN and TP values of 2.02 and 0.32 mg/L, respectively.

In conjunction with an investigation on the effects of stormwater management systems on groundwater quality, Harper (1990) investigated water quality of runoff from two small road areas (1.17 and 1.30 acres) on I-4. Flow-weighted samples of highway runoff were collected from 10 events at one site and 13 events at the second site. These sites are both similar to the I-95/Miami bridge site in that all three are small drainage areas with high traffic volumes. For this study, Harper used a collection system similar to that used at the Epcot site, but the system was modified to enable collection of flow-weighted samples of up to 2 gallons. Data collection and analyses were conducted in accordance with approved Quality Assurance Plans. The TN and TP values in Table 1 are averages.

As part of an investigation into the effectiveness of a detention pond for reducing pollutants in bridge runoff, Stoker (1996) collected flow-weighted runoff samples from 24 rain events for a 12.9 acre impervious area of Bayside Bridge near Tampa. Up to 8 individual aliquots were collected over a period of up to 87 minutes. Sample collection started after the bridge opened in 1993 and continued for two years. During this time, the average daily traffic count was estimated to grow from approximately 36,000 to 56,000. The TN and TP values in Table 1 are the medians of 182 individual samples.

The four sample locations included in the District 1 EMC study included roadways with a range of characteristics representative of many of the roadways within District 1. Details of the areas sampled are included in Table 1, with additional information summarized in Table 2. Sample site locations are shown in Figure 2. The sites are all within 50 miles of one another and collectively include sampling from 30 different events ranging from 0.16 to 4.40 inches of rainfall. The sites are representative of both lightly traveled and more heavily traveled roadways in District 1. In addition, all four sites are located within the boundaries of or in proximity to the three BMAPs in which District 1 is a stakeholder.

Pond inflow EMCs for the District 1 studies were determined by compositing flow-weighted samples collected with an automated sampler. All samples were collected and analyzed in accordance with FDEP Standard Operating Procedures, including sample analyses by a laboratory accredited by the National Environmental Laboratory Accreditation Conference (NELAC). Details of the TN and TP data collected at each of the sites is presented in Table 3. The average TN value for the four sites ranged from 0.832 mg/L at US 41 to 1.56 mg/L at Richard Road. TP ranged from 0.06 mg/L at Flamingo Drive to 0.279 mg/L at Richard Road. The overall TN and TP averages for all sites are 1.16 and 0.157 mg/L, respectively. Except for TN at Richard Road, the median values were consistently less than the average values. TN and TP values included in Table 1 are averages.

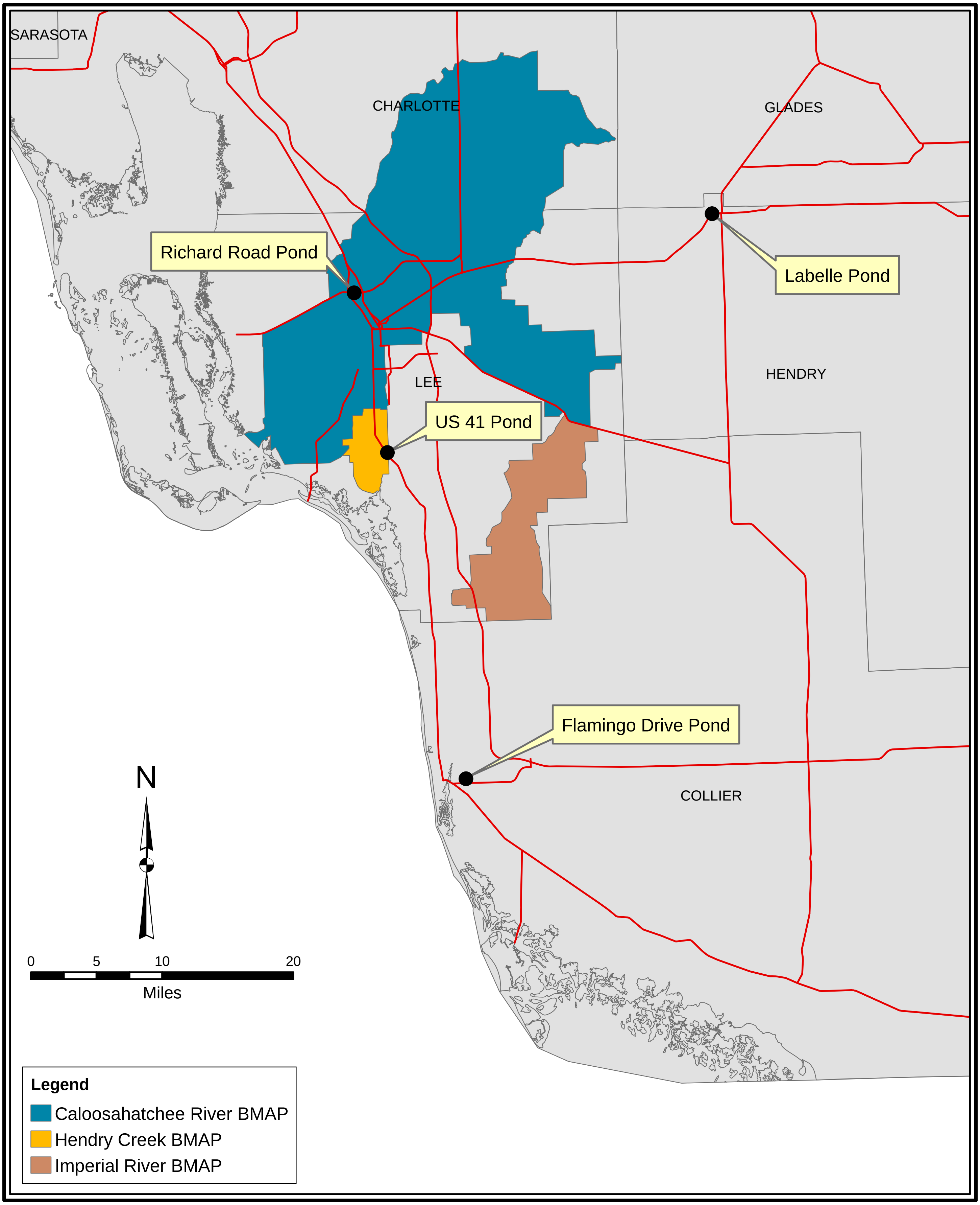

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Figure 2. Locations of District 1 EMC Sampling Sites Relative to Ongoing BMAPs

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Table 2. Summary of Roadway Segment Characteristics

	Roadway Segment			
Characteristic	Richard Road (Lee Co.)	U.S. 41 (Lee Co.)	LaBelle (Hendry Co.)	Flamingo Dr. (Collier Co.)
Age of Facility (Years)	11	11	12	10
Drainage Area (Acres)	7.56	6.89	6.8	16.95
Drainage Basin Impervious (%)	49	62	84	65
Average Daily Traffic (2003) (Vehicles)	33,000	61,000	9,000	28,500
Roadway Section	4 Lanes w/ Bike Lanes, Sidewalks	6 Lanes, Extensive Turn Lane, Sidewalks	4 Lanes, Sidewalks	4 Lanes w/ Bike Lanes, Sidewalk
Drainage	Curb/Gutter	Curb/Gutter	Curb/Gutter	Curb/Gutter
Median	Wide, MinorLandscaping	Narrow	Center Turn Lane	Wide, Heavily Landscaped
Adjacent Landuse	Commercial	Commercial	Commercial	Commercial, Golf Course, SFRa, HDRb

Notes:

a) SFR = single family residential

b) HDR = high density residential

Sources: Johnson Engineering, Inc. (2006, 2008, 2009a, 2009b)
FDOT District 1 (percent impervious)

Table 3. EMC Data Collected in Conjunction with the FDOT District 1 Stormwater Study

Location	Date	Rainfall	TN (mg/L)	TP (mg/L)
Richard Road				
	12/25/2004	1.42	2.00	0.339
	3/17/2005	3.21	2.09	0.461
	3/23/2005	0.32	1.22	0.218
	4/27/2005	2.41	1.03	0.247
	5/31/2005	1.06	2.39	0.355
	7/8/2005	3.8	1.73	0.360
	8/16/2005	0.87	1.68	0.239
	9/26/2005	1.35	1.20	0.174
	11/29/2005	1.05	0.714	0.117
Mean			**1.56**	**0.279**
Median			**1.68**	**0.247**
US 41				
	11/29/2005	1.03	0.328	0.136
	2/3/2006	0.82	2.16	0.241
	7/2/2006	0.54	0.694	0.079
	7/6/2006	0.65	0.471	0.055
	7/19/2006	0.25	0.637	0.102
	8/14/2006	0.99	0.704	0.115
Mean			**0.832**	**0.121**
Median			**0.666**	**0.109**
Labelle				
	8/7/2006	0.16	0.428	0.055
	8/30/2006	4.4	2.54	0.129
	9/6/2006	0.27	1.33	0.075
	9/14/2006	0.47	0.927	0.156
	4/12/2007	0.18	1.10	0.358
	5/6/2007	0.4	1.73	0.109
	10/23/2007	0.4	1.08	0.292
Mean			**1.31**	**0.168**
Median			**1.10**	**0.129**
Flamingo Dr.				
	4/12/2007	0.20	1.04	0.042
	5/14/2007	2.47	1.50	0.138
	6/27/2007	0.87	0.973	0.066
	7/3/2007	0.24	0.788	0.060
	8/27/2007	0.19	1.09	0.055
	9/5/2007	2.46	0.664	0.039
	9/8/2007	0.37	0.675	0.043
	9/16/2007	1.44	0.767	0.040
Mean			**0.937**	**0.060**
Median			**0.881**	**0.049**
OVERALL AVERAGE			**1.16**	**0.157**

4.0 CONCLUSIONS AND RECOMMENDATIONS

Researchers have investigated the water quality of highway runoff in Florida for more than 35 years in conjunction with a variety of research objectives, including studies specifically designed to determine highway EMC values. Runoff data consistently show a high degree of variability between different events, so it is important whenever possible for individual sample sets to include a sufficient number and variety of rainfall events such that the calculated EMC values are representative of average annual conditions.

EMC data from 15 site investigations, including four studies conducted by District 1, are being used by FDEP to define highway EMC values to be used for loading calculations for BMAPs and by applicants for Environmental Resource Permits. Data and methods for 13 of these 15 site investigations were reviewed in order to better understand the data sets and methodologies used to determine the EMCs. While limited in many respects, and except for McKenzie et al. (1983) and the Epcot Interchange site investigated by Yousef et al. (1986), the studies reviewed appear to be acceptable for use in calculating the statewide EMCs where adequate site specific EMC data are not available.

Based upon an assessment of the available EMC data, the following actions are recommended:

1. Remove the duplicate data for the I-4/Maitland Boulevard interchange from the statewide EMC calculations.
2. Remove the EMC values from McKenzie et al. (1983) from the calculation of the overall statewide EMCs. There are sufficient studies with more robust data sets on which to base the EMCs. The manner in which the calculations are currently being done gives the McKenzie EMC values, with just four sample events collected over a short time frame and for a small range of events, the same weight as EMC values from other more rigorous studies, e.g., Mattraw and Miller (1981) with 45 events with representative rainfall collected in all seasons over a period of more than 2 years. This introduces an unreasonable bias into the overall calculation. Since the authors themselves describe their study as reconnaissance in nature, it is not appropriate to include the data in calculation of a number that has such far-reaching impacts. Removal of the duplicate data and the McKenzie values does not affect TP, but reduces TN to 1.28 mg/L.

3. Remove the EMC values for the Epcot Interchange (Youset et al. 1986) from the calculation of the overall statewide EMCs. The data from this investigation are representative of first flush values and are not appropriate for use in the statewide EMC calculations. Removal of the duplicate data, the McKenzie data, and the Epcot data yields TN and TP values of 1.19 and 0.155 mg/L, respectively.
4. Utilize the flow-weighted total metals EMC values computed by Harper (1985) for the I-4/Maitland Boulevard interchange.
5. Utilize the site-specific EMC data from the District 1 studies for calculation of the BMAP loadings in the ongoing Caloosahatchee, Hendry Creek, and Imperial River BMAPs. Collectively, these studies provide a more reasonable representation of conditions in the BMAP area than a generalized average that incorporates a plethora of data from regions that are not as representative of the roads in District 1. The recommended values for TN and TP are 1.16 and 0.157 mg/L, respectively.
6. Continue to update the statewide EMC values as additional data become available and promote the use of regional values in lieu of generalized statewide values whenever sufficient data are available.

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Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
0.06	4/15/1975	4.72	0.53
		4.12	0.26
		2.94	0.39
		2.7	0.32
		3.43	0.23
		3.23	0.21
		2.91	0.26
		4.82	0.4
		4.07	0.28
		3.46	0.22
		4.68	0.26
0.23	5/5/1975	6.48	0.17
		5.47	0.17
		4.9	0.2
		5.04	0.16
		4.44	0.15
		5.05	0.15
		5.21	0.2
		5.21	0.18
0.38	5/9/1975	3.36	0.12
		3.53	0.16
		3.27	0.13
		2.89	0.1
		3.24	0.13
		3.52	0.11
		2.83	0.13
		3.07	0.13
		3.54	0.1
		3.1	0.12
		3.31	0.18
		3.5	0.24
0.11	5/22/1975	1.78	0.09
		2.45	0.12
		2.7	0.16
		1.8	0.11
		2.11	0.12
		2.35	0.1
		1.78	0.1
		1.7	0.09
		2.16	0.09
		1.98	0.08
		1.5	0.08

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
		2.52	0.09
0.88	5/29/1975	0.58	0.03
		0.58	0.04
		0.59	0.03
		0.52	0.04
		0.56	0.04
		0.39	0.12
		0.42	0.03
		0.41	0.04
		0.39	0.04
		0.32	0.04
		0.33	0.04
		0.38	0.03
0.22	7/14/1975	0.62	0.02
		0.4	0.03
		0.4	0.04
		0.39	0.03
		0.32	0.04
		0.32	0.04
		0.3	0.04
		0.3	0.05
		0.25	0.04
		0.31	0.03
		0.32	0.03
		0.32	0.03
1.23	8/23/1975	1.2	0.1
		1.11	0.05
		0.83	0.04
		0.84	0.03
		0.8	0.04
0.27	8/29/1975	0.66	0.06
		0.65	0.05
		0.5	0.06
		0.52	0.05
		0.45	0.05
		0.97	0.05
		0.51	0.05
		0.35	0.04
		0.38	0.05
		0.33	0.05
		0.37	0.05
		0.26	0.05

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
0.45	9/17/1975	0.69	0.06
		0.71	0.04
		0.57	0.06
		0.65	0.06
		0.58	0.06
		0.5	0.05
		1.24	0.06
		0.49	0.06
		0.69	0.05
		0.45	0.06
		~	0.06
		0.7	0.06
0.36	10/22/1975	0.47	0.04
		0.5	0.06
		0.86	0.39
		0.98	0.48
		0.62	0.36
		0.61	0.3
		0.5	0.26
		0.47	0.25
		0.54	0.27
0.38	10/31/1975	0.51	0.03
		0.48	0.04
		0.53	0.03
		0.58	0.03
		0.6	0.03
		0.56	0.03
		0.54	0.03
		0.53	0.03
		0.55	0.03
		0.57	0.03
		0.54	0.03
		0.58	0.03
0.3	1/5/1976	1.6	0.12
		1.65	0.09
		1.57	0.09
		1.49	0.08
		1.15	0.07
		1.2	0.07
		1.13	0.07
		1.09	0.08
		1.07	0.08

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
		0.95	0.08
		0.96	0.08
		0.9	0.08
0.63	5/15/1976	1.17	0.09
		0.93	0.07
		0.94	0.06
		0.9	0.06
		0.82	0.08
		0.72	0.06
		0.83	0.07
		0.67	0.06
		0.66	0.08
		0.62	0.06
		0.61	0.06
		0.57	0.06
0.3	5/17/1976	1.61	0.11
		1.68	0.08
		1.14	0.06
		1.05	0.05
		0.96	0.05
		0.88	0.05
		1.12	0.05
		1.07	0.05
		1.29	0.09
		0.98	0.05
		0.91	0.05
		0.9	0.05
0.63	5/21/1976	1.37	0.08
		0.73	0.06
		0.59	0.06
		0.5	0.05
		0.19	0.05
		0.23	0.04
		0.15	0.04
		0.15	0.04
		0.09	0.04
		0.12	0.04
		0.12	0.04
		0.13	0.04
		1.15	0.07
		0.43	0.06
		1.06	0.07

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
2.09	5/28/1976	0.67	0.07
		0.67	0.07
		0.59	0.06
		0.48	0.05
		0.26	0.05
		0.23	0.04
		0.23	0.04
		0.33	0.04
		0.3	0.05
0.38	6/4/1976	1.13	0.05
		0.76	0.04
		0.74	0.04
		0.65	0.03
		0.45	0.03
		0.44	0.03
		0.32	0.03
		0.33	0.03
		0.31	0.16
		0.28	0.03
		0.29	0.04
		0.3	0.03
		0.27	0.03
		0.26	0.03
		0.27	0.03
		0.27	0.03
		0.32	0.03
		0.29	0.04
		0.27	0.03
		0.28	0.03
		0.29	0.03
		0.26	0.03
		0.34	0.04
		0.36	0.04
0.65	6/7/1976	0.85	0.06
		0.58	0.05
		0.47	0.04
		0.42	0.04
		0.4	0.04
		0.42	0.04
		0.41	0.04
		0.41	0.04
		0.44	0.05

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
		0.46	0.05
		0.45	0.05
		0.48	0.05
0.84	6/11/1976	0.2	0.04
		0.12	0.04
0.29	6/11/1976	0.22	0.07
0.08	6/16/1976	0.66	0.08
		0.5	0.05
		0.4	0.06
		0.41	0.07
		0.37	0.07
		0.34	0.06
		0.33	0.8
		0.4	0.8
1.36	6/19/1976	0.5	0.07
		0.45	0.06
		0.37	0.06
		0.39	0.08
		0.19	0.04
		0.15	0.04
		0.17	0.04
		0.2	0.03
		0.37	0.04
		0.44	0.05
		0.31	0.04
0.95	6/23/1976	0.46	0.06
		0.55	0.05
		0.42	0.01
		0.39	0.07
		0.34	0.07
0.58	6/25/1976	0.23	0.03
		0.17	0.03
		0.12	0.03
		0.22	0.05
0.2	6/27/1976	0.57	0.06
		0.52	0.04
		0.34	0.04
		0.22	0.03
0.18	7/6/1976	1.9	0.09
		1.61	0.07
		1.63	0.07
		1.28	0.07

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
		1.65	0.07
		1.53	0.08
0.53	7/7/1976	0.53	0.05
		0.45	0.04
		0.3	0.03
		0.31	0.04
		0.29	0.04
0.12	7/13/1976	1.59	0.1
		2.31	0.07
		1.49	0.05
1.92	7/22/1976	1.66	0.09
		1.19	0.06
		1.71	0.06
		1.37	0.06
		1.48	0.07
		0.55	0.06
		0.91	0.06
		0.79	0.06
		0.76	0.05
		0.71	0.06
		0.4	0.05
		0.68	0.05
1.39	8/16/1976	0.72	0.08
		0.87	0.07
		0.76	0.07
		0.63	0.07
		0.66	0.07
		0.55	0.06
		0.49	0.06
		0.53	0.04
		0.57	0.05
		0.56	0.05
		0.64	0.05
0.56	8/18/1976	0.6	0.04
		0.49	0.06
		0.33	0.05
		0.29	0.05
		0.35	0.06
		2.31	0.08
		1.53	0.07
		1.41	0.08
		1.17	0.08

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
0.37	10/9/1976	1.13	0.08
		0.86	0.08
		0.86	0.08
		0.82	0.07
		1.26	0.07
2.42	11/2/1976	1.37	0.08
		1.23	0.11
		2.06	0.11
		0.76	0.08
		0.33	0.06
		0.2	0.06
1.07	11/17/1976	3.31	0.07
		3.01	0.07
		0.46	0.05
		0.91	0.05
		0.89	0.05
		0.28	0.05
		0.21	0.05
		0.16	0.04
		0.17	0.04
		0.25	0.04
		0.21	0.04
		0.23	0.05
2.50	12/13/1976	0.63	0.03
		0.59	0.03
		0.66	0.03
		0.39	0.03
		0.34	0.03
		0.41	0.03
		0.58	0.04
		0.6	0.04
		0.63	0.06
		0.64	0.07
		0.74	0.07
0.71	2/8/1977	1.37	0.07
		0.97	0.07
		0.71	0.06
		0.35	0.04
		0.34	0.04
		0.27	0.04
		0.39	0.04
		0.25	0.04

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
0.32	4/10/1977	1.32	0.1
		1.21	0.09
		0.96	0.07
		0.78	0.06
		0.79	0.07
		0.55	0.06
		0.56	0.06
		0.59	0.06
		0.58	0.06
		0.83	0.06
		0.61	0.06
		0.53	0.06
		0.56	0.06
		0.5	0.06
		0.5	0.06
		0.57	0.06
		0.51	0.06
		0.51	0.06
		0.51	0.06
		0.5	0.06
		0.61	0.06
		0.53	0.06
		0.56	0.07
0.27	4/12/1977	1	0.11
		1.03	0.09
		0.99	0.09
		0.7	0.08
		0.58	0.06
		0.55	0.06
		0.49	0.06
		0.57	0.06
1.14	4/13/1977	0.62	0.07
		0.75	0.05
		1.02	0.04
		0.63	0.05
		0.43	0.05
		0.36	0.05
		0.39	0.05
		0.38	0.05
		1.13	0.12
		0.91	0.05
		0.83	0.06

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
0.16	4/24/1977	0.99	0.06
		0.87	0.05
		1.37	0.05
		1.21	0.06
		0.88	0.04
		0.84	0.04
		1.16	0.05
		1.26	0.06
		1.08	0.06
		0.87	0.06
		0.7	0.05
		0.63	0.05
		0.72	0.05
		0.71	0.05
		0.74	0.05
		0.75	0.06
		0.61	0.05
		0.59	0.05
		0.6	0.05
2.08	5/4/1977	2.75	0.23
		2.7	0.21
		1.93	0.18
		1.17	0.15
		0.8	0.14
		0.67	0.12
		0.55	0.11
		0.51	0.1
		0.5	0.1
		0.35	0.08
0.88	5/9/1977	1.47	0.12
		0.74	0.06
		0.71	0.06
		0.45	0.03
		0.39	0.05
		0.28	0.03
		0.2	0.04
		0.22	0.04
		2.17	0.12
		0.59	0.03
		0.88	0.05
		0.76	0.04
		0.66	0.06

Appendix A. TN and TP data from Mattraw and Miller (1981)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
1.04	5/10/1977	0.58	0.05
		0.44	0.04
		0.43	0.04
		0.5	0.05
		0.54	0.06
		0.81	0.08
		0.68	0.07
		0.66	0.08
1.48	6/1/1977	0.98	0.17
0.29	7/1/1977	1.35	0.06
		1.23	0.06
		1.3	0.08
		1.09	0.06
		0.78	0.08
		0.52	0.09
		0.58	0.05
Mean		0.961	0.077
Median		0.600	0.060

Appendix B. TN and TP data from McKenzie et al. (1983)

Rainfall (inches)	Date	Total Nitrogen (MG/L)	Total Phosphorous (MG/L)
0.4	11/3/1979	7.7	0.35
		8.2	0.23
		8	0.23
		7.6	0.23
		7.7	0.23
		7.7	0.23
		8.1	0.22
		7.8	0.22
		7.8	0.23
		7.9	0.23
		7.7	0.23
0.12	3/23/1981	6.2	0.66
		6.9	0.02
		3.2	0.15
		3.6	0.34
		2.9	0.18
		2.1	0.14
		1.5	0.08
		-	0.0
0.08	5/1/1981	5.8	0.26
		3.7	0.18
		3.3	0.15
		0.8	0.18
		1.1	0.1
		1.3	0.08
		1.4	0.09
		1.9	0.09
		2.6	0.1
		-	0.02
0.65	5/20/1981	2	0.14
		0.55	0.05
		0.59	0.06
		0.49	0.04
		0.59	0.05
		0.69	0.05
		0.91	0.06
Mean		4.1	0.16
Median		3.3	0.15