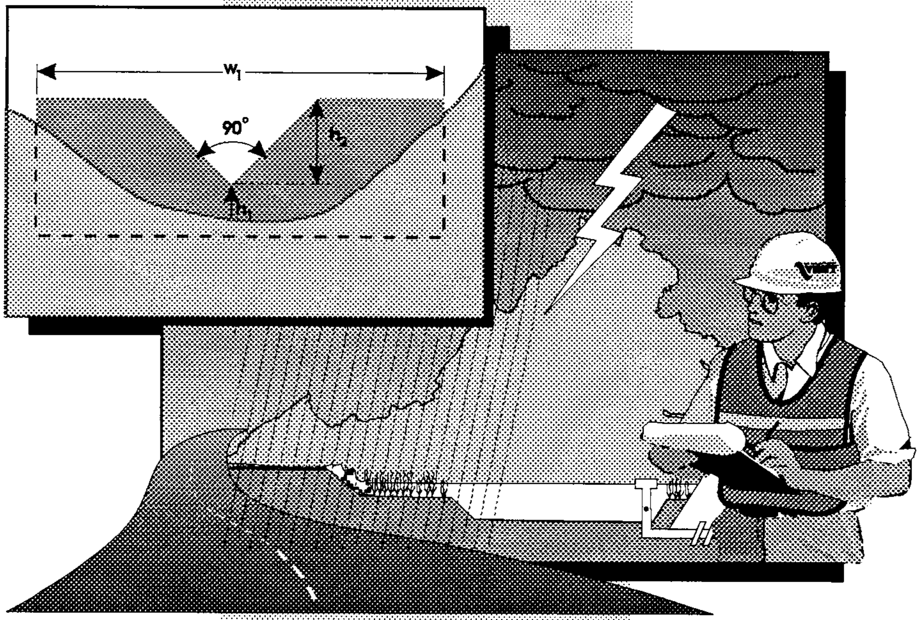
FINAL REPORT

TESTING OF BEST MANAGEMENT PRACTICES FOR CONTROLLING HIGHWAY RUNOFF

PHASE II



SHAW L. YU, Ph.D.
Faculty Research Scientist

ROBERT J. KAIGHN, JR.
Graduate Research Assistant

SHIH-LONG LIAO
Graduate Research Assistant

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TRANSPORTATION RESEARCH COUNCIL

VIRGINIA TRANSPORTATION RESEARCH COUNCIL

Technical Report Documentation Page

1. Report No.
FHWA/VA-94-R21

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Testing of Best Management Practices for Controlling Highway Runoff, Phase II

5. Report Date
June 1994

6. Performing Organization Code

7. Author(s)
Shaw L. Yu, Robert J. Kaighn, Jr., & Shih-Long Liao

8. Performing Organization Report No.
VTRC 94-R21

9. Performing Organization Name and Address
Virginia Transportation Research Council
Box 3817, University Station
Charlottesville, Virginia 22903-0817

10. Work Unit No. (TRAIS)
SPR 2971

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Virginia Department of Transportation
1401 E. Broad Street
Richmond, Virginia 23219

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes
In cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

In order to obtain the detailed information necessary to develop design guidelines for the stormwater best management practices (BMPs) included in the Virginia Department of Transportation's *Stormwater Management Manual*, a field program was initiated in 1991 for testing the pollutant removal efficiency of selected BMPs. This report summarizes Phase II of this endeavor. A dry detention pond that drained a small, highly impervious area and a vegetated swale that received runoff from an urban highway were examined. Manual and automatic sampling techniques were used to monitor stormwater flowing into and out of the two facilities. Pollutant removal efficiencies were determined using a mass balance method. Pollutants measured were total suspended solids, chemical oxygen demand, total phosphorus, and zinc. The results suggest that, if properly designed, these types of facilities can be effective tools for removing stormwater pollution from highway runoff.

17. Key Words
Highway runoff, best management practices, pollution control, roadside swale, dry detention pond, environment, field monitoring

18. Distribution Statement
No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
62

22. Price

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Shaw L. Yu, Ph.D.
Faculty Research Scientist

Robert J. Kaighn, Jr.
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Shih-Long Liao
Graduate Research Assistant

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

June 1994
VTRC 94-R21

ENVIRONMENTAL RESEARCH ADVISORY COMMITTEE

ACKNOWLEDGMENTS

The research reported herein was conducted under the general supervision of Dr. Gary R. Allen, Director of the Virginia Transportation Research Council. Special thanks go to Michael M. Sprinkel, Research Manager of the Materials and Environmental Group, for his assistance during the course of this study. The project was financed with HPR funds administered by the Federal Highway Administration.

Charles A. McIver, State Hydraulics Engineer, VDOT, and his colleagues Roy T. Mills and Wayne Richards are gratefully acknowledged for their assistance and many suggestions and comments made through the duration of this project.

Michael Stickley, David Wyant, Jr., and Stewart L. Barnes are recognized for their help with this project, including field sampling and site preparation.

The Department of Civil Engineering, University of Virginia, and the U.S. Geological Survey, Richmond office, are thanked for providing partial financial support for Messrs. Barnes and Stickley. Thanks also go to Kirk A. Bowers, University of Virginia Facilities Management, for his assistance with regard to the use of the detention pond facility.

The writers also thank Michael Fitch and Michael Sprinkel of VTRC, Charles McIver of VDOT, and Dr. Charles Woo of FHWA for peer reviewing the draft report.

Last, but not least, the writers thank Linda Evans, Roger Howe, Linda Barsel, Randy Combs, Ed Deasy, Arlene Fewell, and Jerry Garrison for their assistance in the production of this report.

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ABSTRACT

In order to obtain the detailed information necessary to develop design guidelines for the stormwater best management practices (BMPs) included in the Virginia Department of Transportation's *Stormwater Management Manual*, a field program was initiated in 1991 for testing the pollutant removal efficiency of selected BMPs. This report summarizes Phase II of this endeavor. A dry detention pond that drained a small, highly impervious area and a vegetated swale that received runoff from an urban highway were examined. Manual and automatic sampling techniques were used to monitor stormwater flowing into and out of the two facilities. Pollutant removal efficiencies were determined using a mass balance method. Pollutants measured were total suspended solids, chemical oxygen demand, total phosphorus, and zinc. The results suggest that, if properly designed, these types of facilities can be effective tools for removing stormwater pollution from highway runoff.

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Shaw L. Yu, Ph.D.
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Shih-Long Liao
Graduate Research Assistant

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) issued federal stormwater regulations in November 1990. Permits in accordance with the regulations of the National Pollutant Discharge Elimination System (NPDES) are now required for major municipal and industrial (including transportation) stormwater discharge. Currently, the Virginia Department of Environmental Quality (VDEQ) is working with the EPA to develop a "general permit" program that will be available to the Virginia Department of Transportation (VDOT) for compliance with the NPDES regulations.

In addition to the EPA stormwater regulations, VDOT must comply with the Virginia Stormwater Management Regulations, the Chesapeake Bay Preservation Act, and the Virginia Erosion and Sediment Control Regulations. In a previous project entitled "Stormwater Management Regulations and VDOT," a manual of practice was developed that outlined specifications and practices that VDOT will follow in order to satisfy all relevant state regulations.[1] This document, the *Stormwater Management Manual*, will be part of VDOT's annual submission to the Virginia Department of Conservation and Recreation (VDCR) for a "blanket" approval of all VDOT construction and maintenance projects in lieu of an application for a permit for each project. Currently, VDOT is working with VDEQ to allow the manual to be used in satisfying the EPA NPDES requirements.

In order to obtain the necessary detailed design guidelines for selected stormwater best management practices (BMPs) included in the *Stormwater*

Management Manual, a field test program was initiated in 1991 for monitoring the performance of such BMPs in controlling stormwater quantity and quality. Two sites in Charlottesville, a dry detention pond and a highway median swale, were selected for the study (see Figure 1). Field monitoring work was started in March 1992 and continued through June 1992. A report summarizing the field test results was published in June 1993.[2]

A Phase II study of the BMPs was needed for the purposes of (1) obtaining adequate data for quantifying BMP pollutant removal efficiencies; (2) allowing the detection of possible seasonal variations in BMP performance; (3) better defining guidelines for BMP design; and (4) developing laboratory and field test strategies for other BMPs not tested under the Phase I program.

PURPOSE AND SCOPE

The objectives of the Phase II study were as follows:

1. to continue performing field tests of stormwater management practices selected for the Phase I study, i.e., a modified dry detention pond and an urban highway swale. Of particular interest were the pollutant removal efficiencies under different storm conditions.

2. to develop design guidelines for the practices to be incorporated into VDOT's *Stormwater Management Manual*[1]

3. to continue updating and modifying VDOT's *Stormwater Management Manual* with respect to (a) new information on BMP design, (b) recommendations made by VDOT, and (c) comments from other agencies such as the Federal Highway Administration (FHWA), other state departments of transportation (DOTs), etc.

MATERIALS AND METHODS

Site Description and Preparation

Pond

As shown in Figure 1, a dry detention pond near the intersection of Massie Road and Emmett Street in Charlottesville, Virginia, was monitored after a 7.6 cm (3 in) orifice outlet was installed in the Phase I study.[2] The basin is a

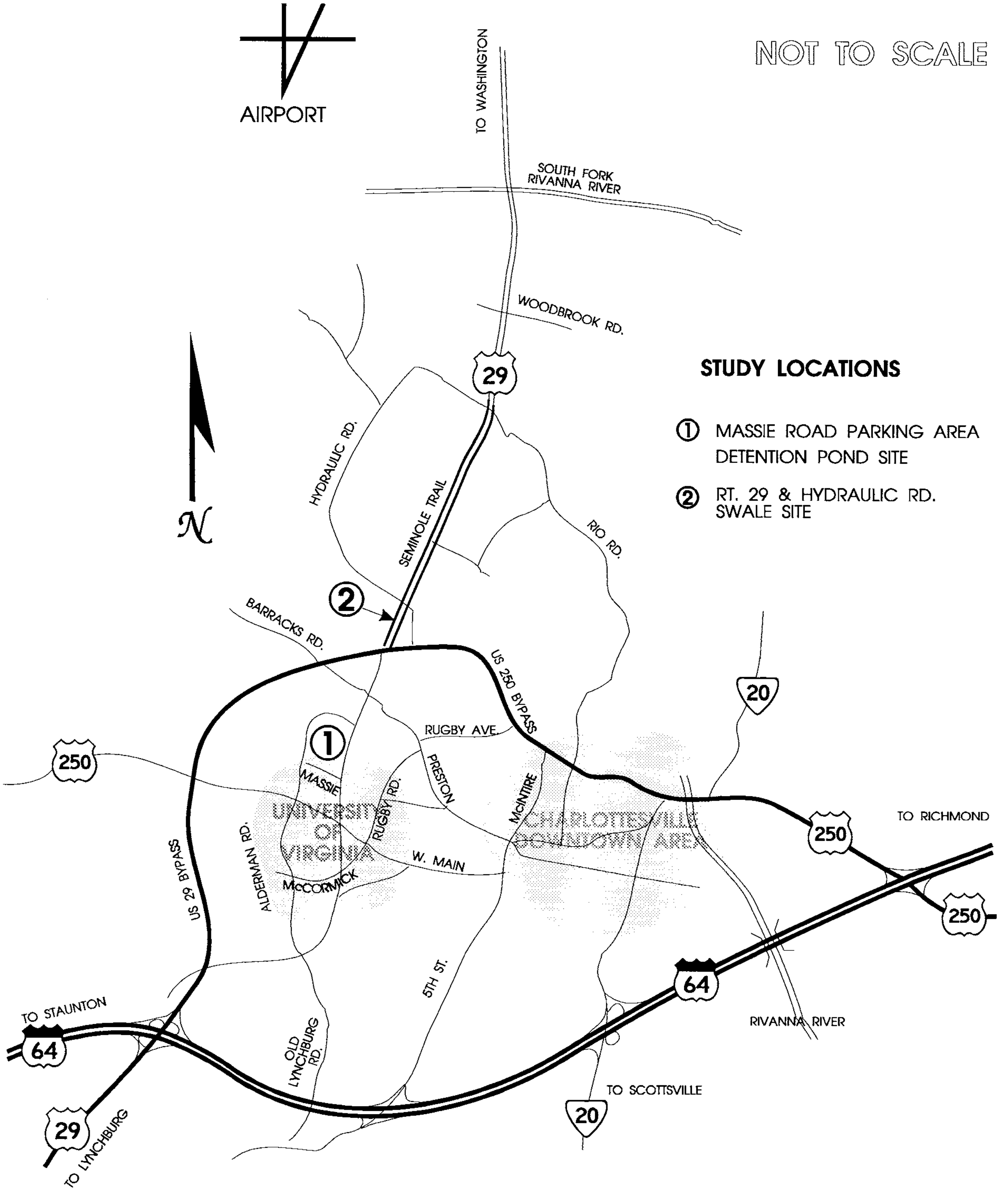


Figure 1. Vicinity map of Charlottesville showing study sites.

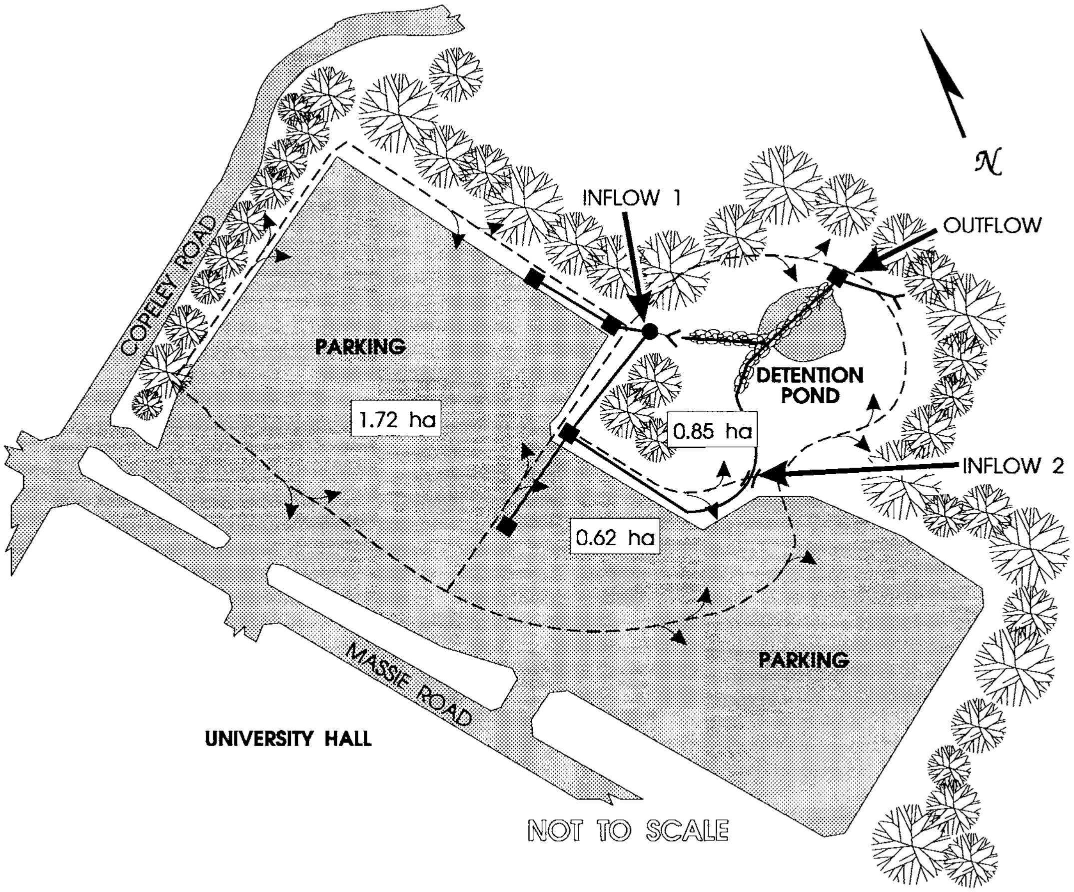


Figure 2. Sketch of Massie Road parking lot and pond.

University of Virginia parking facility for daily commuter and athletic event traffic. The total drainage area is about 3.2 ha (7.9 acres), with two subcatchments draining into the pond. One is 1.7 ha (4.2 acres) with a 61 cm (24 in) concrete storm sewer discharging into the pond; the other is 0.6 ha (1.5 acres) with a concrete trapezoidal ditch. The remainder of the area, 0.9 ha (2.2 acres), surrounds the pond. The effluent of the pond discharges through a 30 cm (12 in) concrete pipe to a tributary of Meadow Creek (Figure 2). The pond was designed to attenuate the postdevelopment peak of runoff to the predevelopment level for 2-year and 10-year storms, but not for water quality purposes.

The Phase I monitoring work was started in May 1991 and continued through June 1992. The Phase I study focused on the pond removal efficiency of total suspended solids (TSS) and total phosphorus (TP). For the Phase II study, chemical oxygen demand (COD) and zinc (Zn) were added to the list of water quality parameters.

In order to reduce the need for chemical analysis, a rectangular weir was installed below the confluence of inflow 1 (concrete pipe) and inflow 2 (concrete channel) so that only one inflow point needed to be monitored (Figure 3).

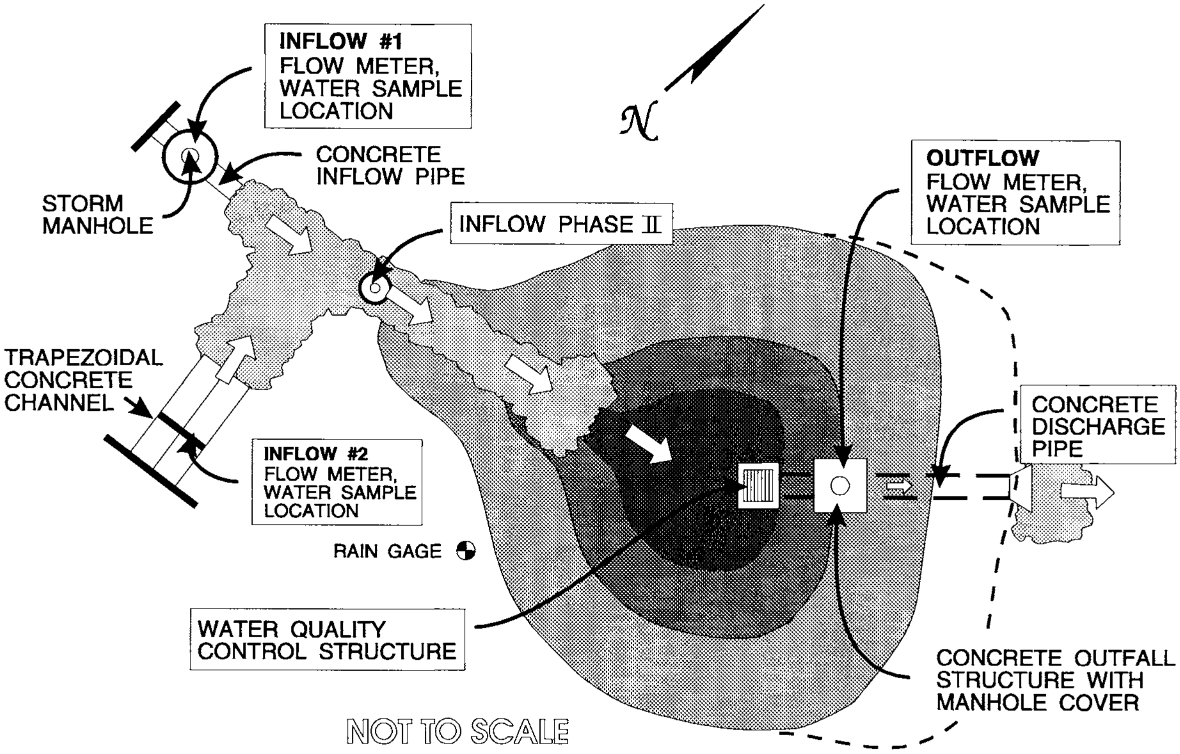


Figure 3. Layout of pond.

Swale

For the highway median swale site at the intersection of U.S. Route 29 and Hydraulic Road (Figure 1), wooden barriers were constructed to limit lateral inflows into the swale so that the pollutant mass balance estimates could be made more accurately. See Figure 4 for the modified swale layout.

The longitudinal slope of the swale is approximately 5 percent, and the drainage area is approximately 0.35 ha (0.88 acres). The only maintenance occurring in the swale is the mowing of the grass approximately once every 2 weeks, yielding a grass height usually between 8 and 15 cm (3–6 in). The average daily traffic (ADT) was estimated at approximately 50,000.

Sampling Methods

Pond

Data were collected for 11 storms during the Phase I and Phase II sampling periods. Of the 11, the first 3 were monitored to characterize the runoff, with only the pollutant concentration determined. The flow monitoring equipment was not yet in place for measuring the corresponding flow into and out of

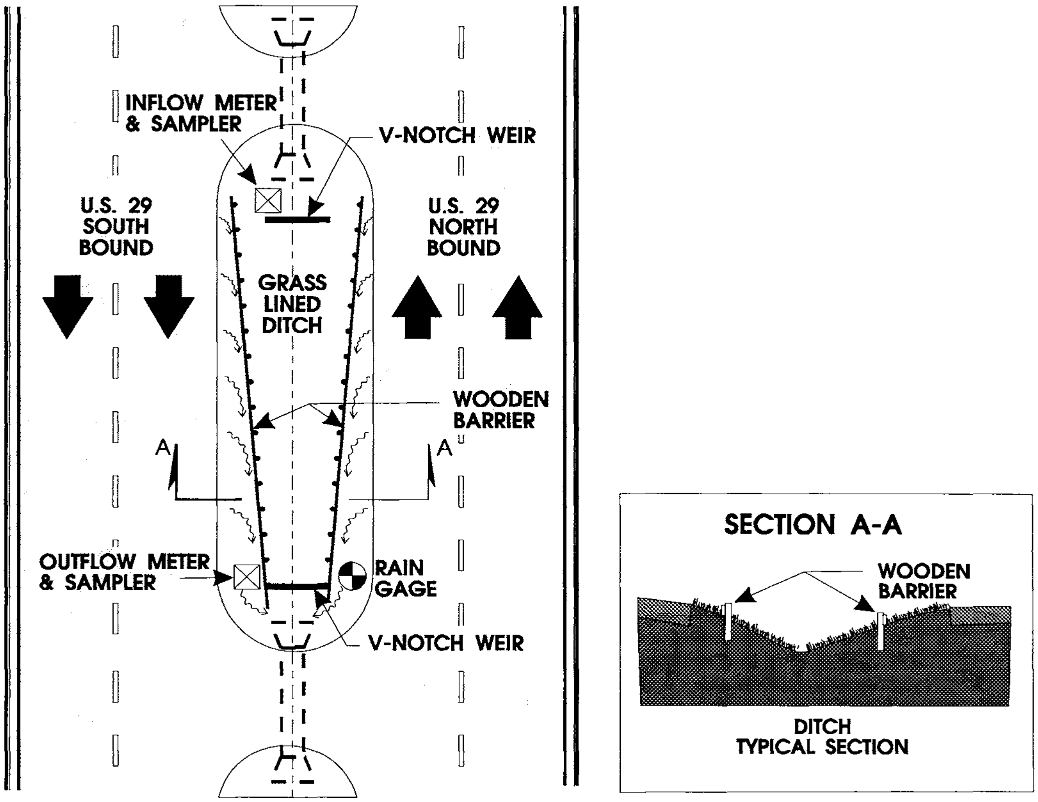


Figure 4. Modified swale with barrier to lateral flow.

the pond. These storms occurred on 3/6, 3/10, and 3/18/92. The other 8 storms were monitored for both flow and concentration to allow the determination of pollutant mass fluxes. Of these 8 storms, the 4/30 and 5/5/92 storms comprised a baseline study of the efficiency; no modification was in place to increase the detention time of the pond. The 5/29 and 6/4/92 storms occurred after a 7.6 cm (3 in) orifice was installed at the outlet of the pond.

Rainfall was measured using a Plexiglas wedge gage at the site. Information was corroborated at a rainfall gaging station located at Birdwood Golf Course, which is continuously monitored by the State Climatology Office. The Birdwood gage is located approximately 2.5 km (1.6 mi) from the Massie Road parking area. During Phase II, tipping bucket rain gages were also used.

Flow was measured at all inflow and outflow points. During Phase I, measurements were made using 90-degree V-notch weirs with a continuous bubble-type flow meter and a tube secured just below the notch of the weir. A portable Plexiglas weir designed to fit into a circular pipe was installed at inflow location 1 (see Figure 3) and the outflow. A plywood 90-degree V-notch weir was used for measuring flows in the concrete channel at inflow location 2. Beginning with the Phase II monitoring, for the 3/31/93 storm, samples were taken at only one inflow point, which was located below the confluence of inflow 1 and inflow 2 (see Figure 3).

Water quality samples were taken at the inflow and outflow locations by using both manual grab sampling and automatic samplers.

Swale

In the Phase I study, the entire length (128 m, or 420 ft) of the swale was examined. However, Phase II focused on the lower 30 m (100 ft) of the swale. The swale was modified, as shown in Figure 4, according to the recommendations of the Phase I report.[2] The modification included the installation of lateral barriers to divert inflow from the sides of the swale away from the study area. The swale site is pictured in Figure 5.

Data were collected at the swale for five storms (a sixth storm was also monitored that generated no outflow) between November 5, 1992, and July 19, 1993. Flow into and out of the swale was measured using 90-degree V-notch weirs, and rainfall was determined using a wedge gage and a tipping bucket gage. Automatic samplers were used to take runoff samples at timed intervals; these samples were then analyzed.

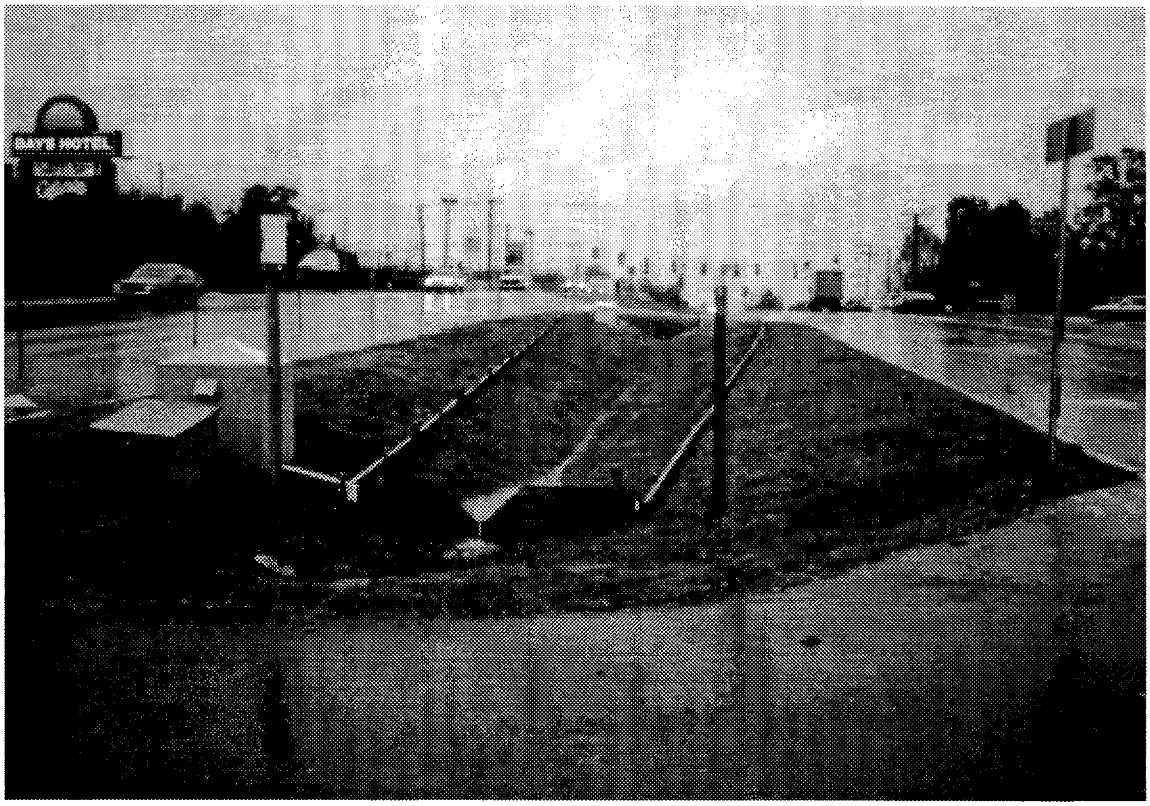


Figure 5. Swale site.

During the Phase I study, six storms were monitored, with only the last four storms having both flow and water quality data.

Laboratory Analysis

A quality assurance/quality control program of chemical analyses implemented in the study was conducted.

Quality Assurance

1. *Adequately trained and experienced personnel.* Shih-Long Liao, a graduate research assistant who was responsible for the chemical analyses of all samples, had 18 months experience as a laboratory supervisor at Tulane University of Louisiana.

2. *Good physical facilities and equipment.* A new COD reactor and a DR/2000 spectrophotometer from Hach were used. The oven, hot plates, and desiccators functioned properly. Glassware was washed with acid or rinsed with deionized water in accordance with standard methods for examination of water and wastewater.[3]

3. *Certified reagents and standards.* All chemicals were specified by the grade of chemical.

4. *Frequent servicing and calibration of instrumentation.* All instruments were calibrated before each test.

5. *Use of replicate a and known addition analysis.* All chemical tests were done by using replicates and known addition as a control (or blank).

Quality Control

1. Only methods that had been studied collaboratively and found to be acceptable (such as EPA-approved reporting methods) were used.

2. A control sample was analyzed at least once each day on which samples were being analyzed (internal quality control). The following control charts were used: (a) vertical (or horizontal) plotting of the test charts results; (b) the mean, limit, and standard deviation plot in control charts; and (c) periodic recalculation of the control limit.

3. The ability of a laboratory to produce acceptable results was confirmed by requiring analysis of a few reference samples once or twice a year (external quality control). A check on whether the laboratory being tested had an acceptable internal control program was performed by sending reference

samples to another laboratory (the Aqua Laboratory in Charlottesville, Virginia).

Calculation of Pollutant Removal Efficiency

Removal efficiencies were calculated using the change in mass of pollutants flowing in and the mass of pollutants flowing out. The method is illustrated by Equation 1.

$$\text{Removal efficiency (\%)} = \frac{(\text{Mass in} - \text{Mass out})}{(\text{Mass in})} \times 100 \qquad [1]$$

The mass of pollutants flowing through the system was determined by multiplying the flow by the concentration at each time interval to yield a pollutograph. The mass of pollutants discharged into and out of the system was obtained by computing the area beneath the pollutograph. Equation 1 was then applied to determine the pollutant removal efficiency for each constituent measured.

RESULTS

Pond

Precipitation

Data were collected for 7 storms during the Phase I study period of 1991–1992 and 4 storms during the Phase II period of 1992–1993. The total data for the 11 storms during the two monitoring periods are summarized in Table 1. All of these storms were considered to be relatively small storms (less than 50 mm). The 3/10/92 and 7/3/93 storms were considered to be high-intensity storms (greater than 4 mm/hr).

Pollutant Parameters

The detailed results of the field measurements and the chemical analyses for all 11 storms monitored are presented in Appendix A. Table A-1 lists pollutant concentrations measured over runoff hydrographs at the inflow and outflow locations. A typical inflow and outflow hydrograph is shown in Figure 6. The high and low concentrations of pollutants measured for all storms are given in Table 2.

Table 1
STORM CHARACTERISTICS AT POND

Storm No.	Date (mm/dd/yr)	Total Depth (mm)	Total Duration (hr)	Average Intensity (mm/hr)	Number of Previous Dry Days
1	03/06/92	28.0	15.0	1.90	—
2	03/10/92	9.1	2.0	4.60	—
3	03/18/92	10.4	7.0	1.50	—
4	04/30/92	3.6	2.0	1.80	—
5	05/05/92	2.0	1.5	1.30	—
6	05/29/92	26.7	41.0	0.70	6
7	06/04/92	50.8	27.0	1.90	1
8	03/31/93	4.8	9.5	0.51	2
9	04/09/93	36.8	13.5	2.73	2
10	04/26/93	6.4	3.0	2.12	4
11	07/03/93	17.6	2.0	8.82	4

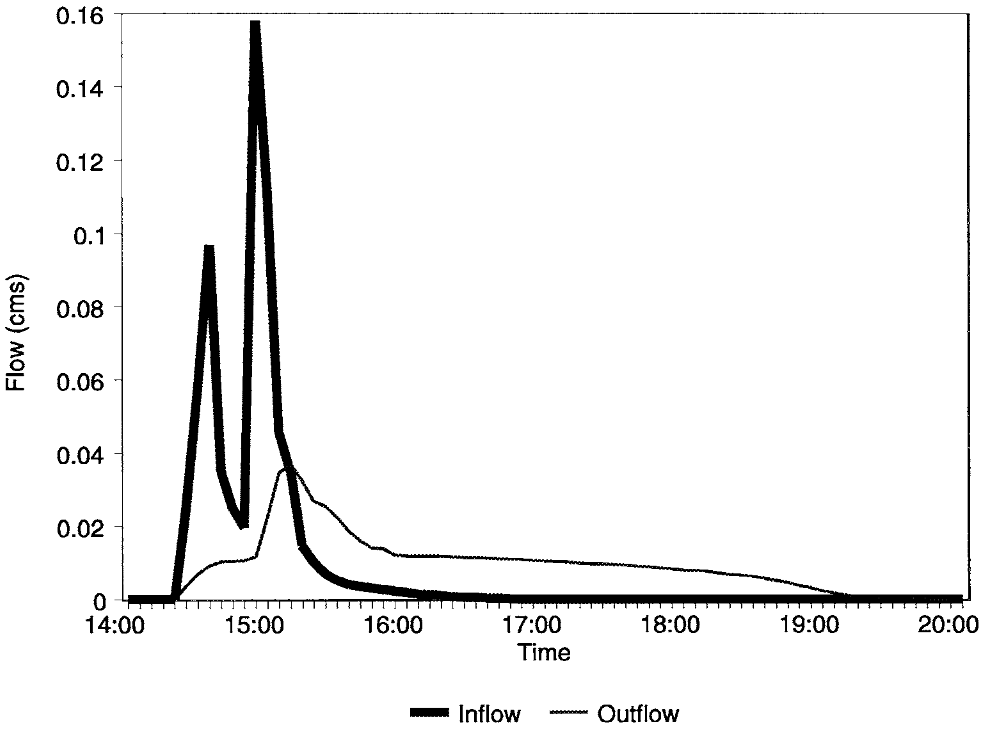


Figure 6. Inflow and outflow hydrographs for pond, 7/3/93 storm.

Table 2
POLLUTANT CONCENTRATIONS IN POND

Parameter	Number of Samples	High (mg/l)	Low (mg/l)	Average (mg/l)
TSS	134	450.0	N/D	27.20
COD	50	118.0	N/D	31.08
TP	135	3.1	N/D	0.52
Zn	60	3.5	N/D	0.38

TSS = Total Suspended Solids; N/D = Not Detected; COD = Chemical Oxygen Demand;
TP = Total Phosphorus; Zn = Zinc.

Figure 7 depicts the pollutographs for the 7/3/93 storm. In general, the "first-flush" phenomenon is quite evident; pollutant concentration is high at the beginning of the runoff and decreases rapidly as time progresses.

Inflow and outflow hydrographs and pollutographs for the remaining storms are presented in Appendix B.

Pollutant Removal Efficiency

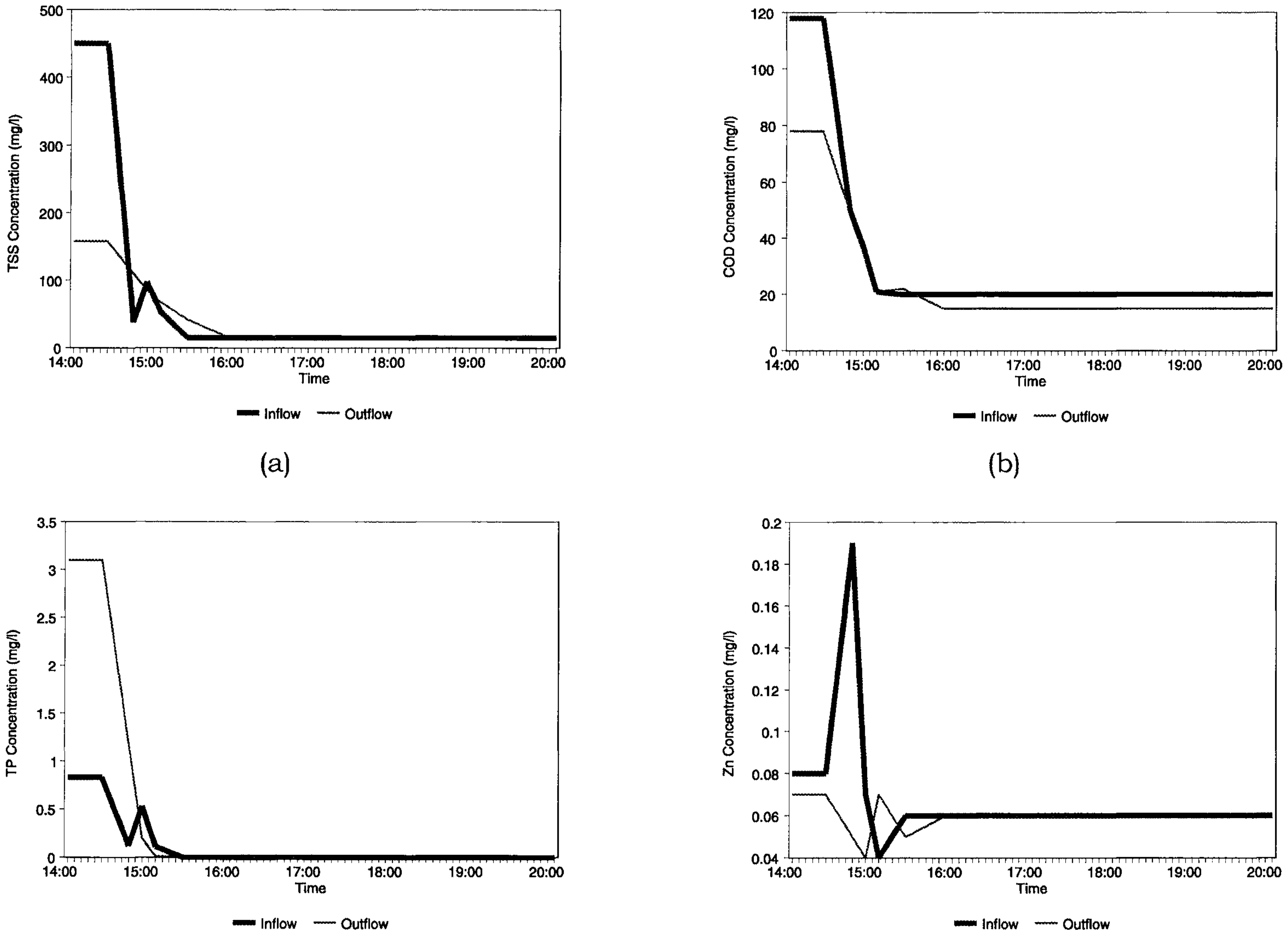
Equation 1 was used to compute the pond pollutant removal efficiency for each pollutant for each storm. The results, together with pollutant mass fluxes and estimated detention time and drawdown time, are given in Table 3. The detention time was approximated by the lag time between the centroids of the inflow and outflow hydrographs, whereas the drawdown time was taken as the base time of the outflow hydrograph.

Table 4 shows the range of and average removal efficiencies for each pollutant for all storms for which data were sufficient for computing the removal rates.

Particle Size Distribution

In the Phase I study, a particle size distribution (PSD) analysis of the inflow and outflow was calculated for two storms. In the present study, two more storms, on 4/26/93 and 7/3/93, were analyzed for PSD. Results of inflow PSD for all four storms were plotted against data presented by Pitt, which were included in the Phase I report in Figure 8.[2, 4] The results showed that a relatively wide range of solids concentrations can be expected in stormwater runoff from parking lots.

In comparing the inflow and outflow PSD results, a significant reduction in composite solids concentration was obtained, as shown in Table 5.



(a) (b)

(c) (d)

Figure 7. Pond pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, (c) total phosphorus, and (d) zinc for 7/3/93 storm.

Table 3
POLLUTANT LOADINGS AND REMOVAL EFFICIENCY FOR POND

Storm Date	Detention Time (hr)		Pollutant Fluxes (g)		Removal Efficiency (%)
			In	Out	
4/30/92	1.50	TSS	411	146	64.4
		TP	9.6	5.8	39.5
		Zn	*	*	*
5/05/92	0.02	TSS	512	51	89.9
		TP	14.5	1.8	87.4
		Zn	*	*	*
5/29/92	0.91	TSS	18070	10666	41.0
		TP	441	587	(33.1)
		Zn	*	*	*
6/04/92	0.99	TSS	16460	10144	38.4
		TP	343	485	(41.4)
		Zn	619	176	71.6
3/31/93	0.34	TSS	2236	1960	12.3
		COD	2023	1000	50.6
		TP	27.4	6.4	76.5
		Zn	48.1	23.4	51.3
4/09/93	1.55	TSS	12522	7388	41.0
		COD	14446	12934	10.5
		TP	39.0	22.4	42.5
		Zn	117.4	91.7	21.9
4/26/93	0.09	TSS	4698	879	81.3
		COD	4650	2471	46.9
		TP	42.6	19.9	53.3
		Zn	31.5	25.4	19.4
7/03/93	1.45	TSS	18965	7517	60.4
		COD	7715	4159	46.1
		TP	61.7	24.8	59.8
		Zn	15.6	11.9	23.7

TSS = Total Suspended Solids; TP = Total Phosphorus; Zn = Zinc;
COD = Chemical Oxygen Demand; * = Not Measured.

Table 4
REMOVAL EFFICIENCIES BY POLLUTANT FOR POND

Pollutant	Number of Storms	Removal Efficiency		
		High (%)	Low (%)	Average (%)
TSS	8	89.9	12.3	53.6
COD	4	87.4	(41.0)	35.6
TP	8	56.1	10.5	38.5
Zn	5	71.6	19.4	29.1
			Average	41.0

TSS = Total Suspended Solids; COD = Chemical Oxygen Demand; TP = Total Phosphorus; Zn = Zinc.

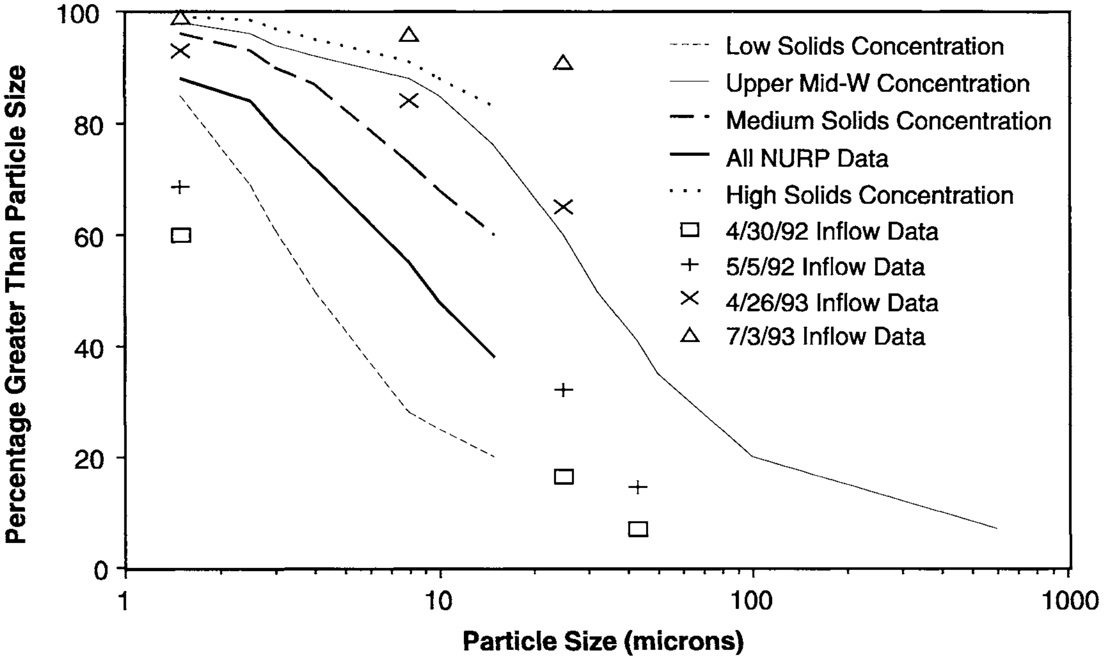


Figure 8. Particle size distribution for 4/30/92, 5/5/92, 4/26/93, and 7/3/93 storms, inflow to pond, and reference data from other studies.[4] Upper Mid-W = Upper Midwest; NURP = National Urban Runoff Program.

Table 5
COMPARISON OF INFLOW AND OUTFLOW PARTICLE SIZE DISTRIBUTION FOR POND

Storm	Composite TSS Concentration (mg/l)		Percent Reduction
	Inflow	Outflow	
04/30/93	43	19	56
05/05/92	64	15	77
04/26/93	87	52	40
07/03/93	245	148	40
		Average	53.3

TSS = Total Suspended Solids.

Swale

Precipitation

A summary of the six storms monitored in this study and the five storms monitored in the Phase I study is presented in Table 6.

Table 6
PRECIPITATION DATA FOR SWALE

Storm No.	Date (mm/dd/yr)	Depth (mm)	Duration (hr)	Average Intensity (mm/hr)
1	03/10/92	—	—	—
2	04/24/92	20.0	0.7	30.00
3	04/26/92	—	—	—
4	05/08/92	16.0	4.0	4.00
5	05/15/92	11.0	1.0	11.00
6	06/04/92	40.0	17.0	2.35
7	11/05/92	9.0	5.0	1.80
8	11/12/92	17.3	12.0	1.44
9	05/31/93	9.9	8.0	1.23
10	07/10/93	5.1	0.5	10.20
11	07/12/93	10.9	0.8	14.56
12	07/19/93	16.3	1.5	10.84

Pollutant Parameters

Typical results from a monitored storm are shown in Figures 9 and 10. Figure 9 shows the flows into and out of the swale for the 7/19/93 storm. Figure 10 shows pollutant concentrations measured for the same storm. Data for all the storms are given in Appendix C. Inflow and outflow hydrographs for the other storms are presented in Appendix D.

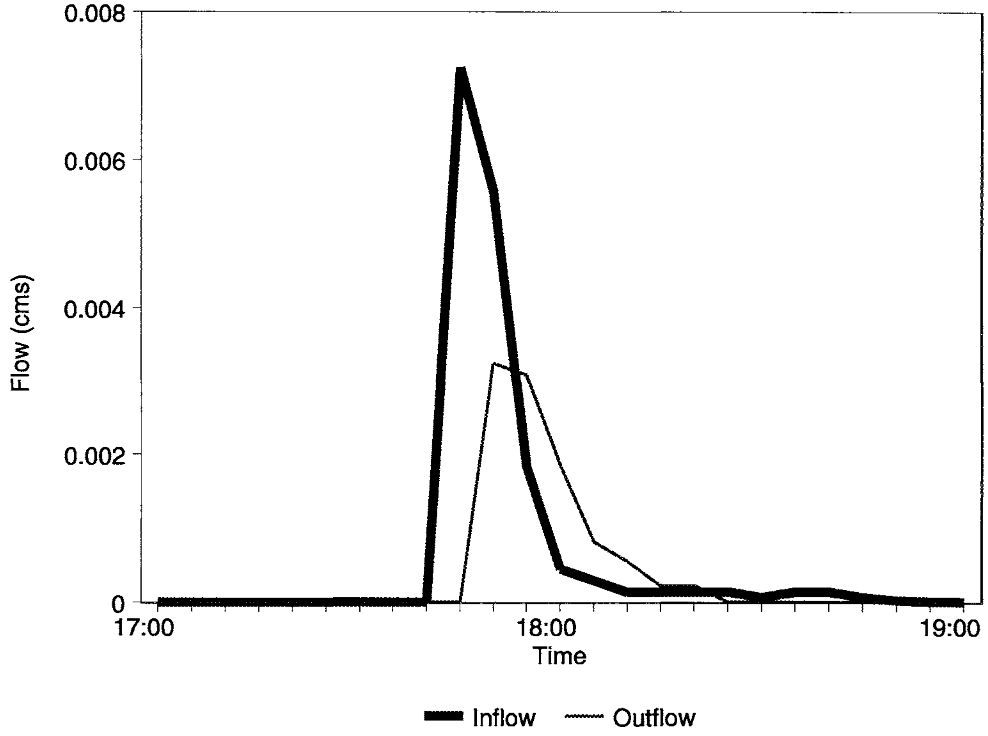


Figure 9. Flow into and out of swale, 7/19/93 storm.

Pollutant Removal Efficiency

Equation 1 was used to calculate the pollutant removal efficiency of the swale. The results, together with those obtained in the Phase I study, are listed in Table 7.

When examining the removal efficiencies in Table 7, one will notice the negative removal rates for pollutants in Storms 7 and 8. This was caused by a higher flow leaving the swale than entering the swale. These were the first two storms monitored during this report, and thus the first two utilizing lateral inflow barriers. In these two storms, the barrier failed to stop flow from entering the swale laterally. Thus the mass flux into the swale did not include this extra inflow, but the extra was included in the outflow. During the rest of the monitoring, a plastic liner was placed along the lateral barrier to improve its performance.

The removal efficiency for Storms 9 through 12 was fairly high. In examining these storms, one will notice that the high removal rate was caused by a significant loss of flow. In some cases, more than 70 percent of the flow was lost between the two ends of the swale. Because the equation used to determine removal efficiency is flow dependent, this yields higher removal efficiencies.

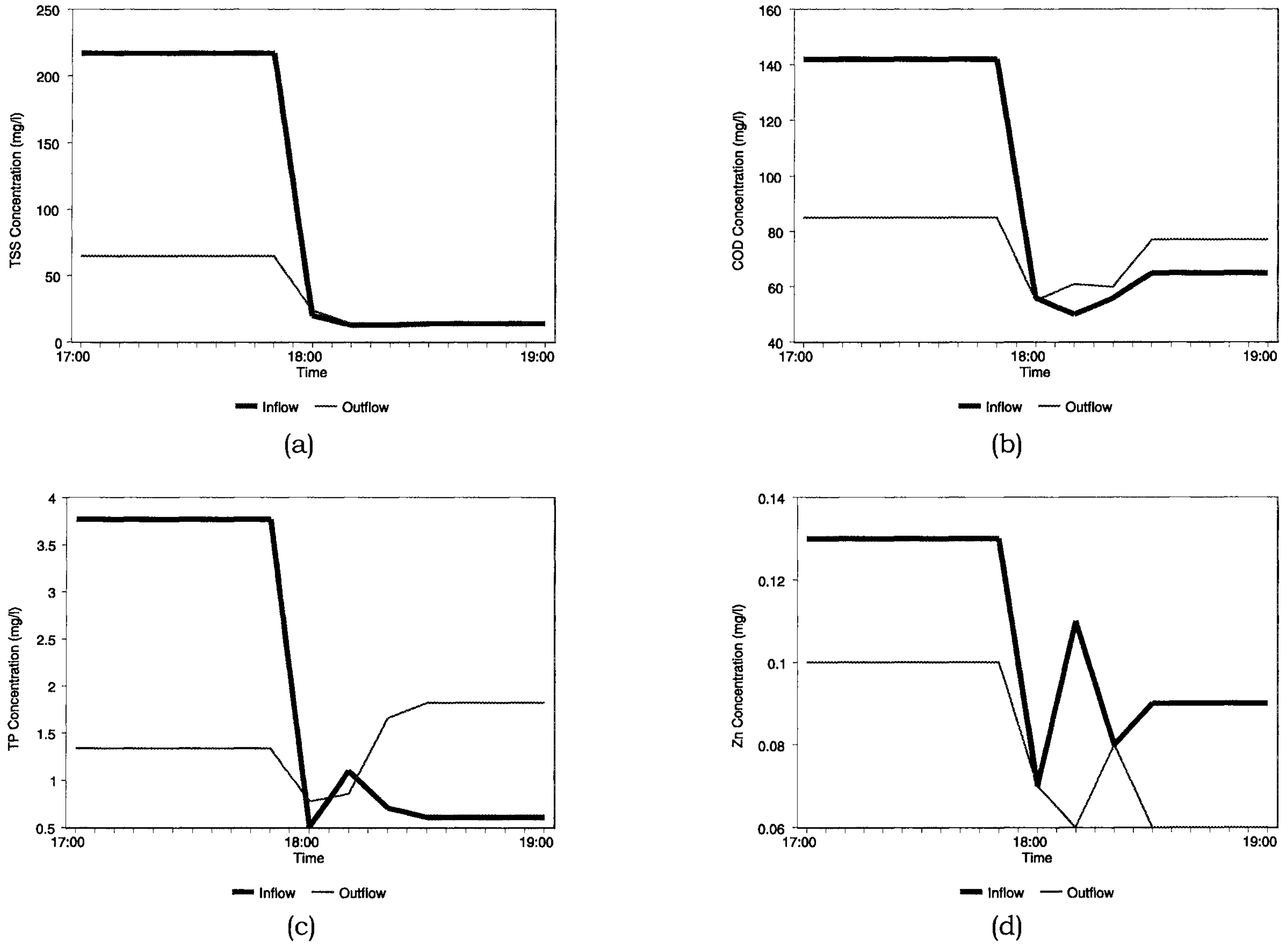


Figure 10. Swale pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, (c) total phosphorus, and (d) zinc, 7/19/93 storm.

Table 7
REMOVAL EFFICIENCY FOR SWALE

Storm No.[a]	Efficiency (%)				Rainfall Intensity
	TSS	COD	TP	Zn	
2	72	—	70	—	High
4	95	—	85	—	Low
5	21	—	32	—	High
6	82	—	52	74	Low
7	(77)	(128)	(14)	—	Low
8	(44)	(54)	(32)	(117)	Low
9	89	88	92	88	Low
10	100	100	100	100	High
11	73	81	94	89	High
12	86	67	80	58	High

[a] Data insufficient for Storms 1 and 3. For Storms 1 through 6, no lateral inflow barriers were in place.

TSS = Total Suspended Solids; COD = Chemical Oxygen Demand; TP = Total Phosphorus; Zn = Zinc.

Another way to examine the data collected is to examine just the pollutant concentrations. Average concentrations at the inflow and outflow points of the swale are presented in Table 8, along with ranges and the percent change in concentration between the two sampling points. It can be seen that there was a significant reduction (47%) in TSS concentration between the inflow and outflow. This was most likely due to particle settling as runoff passed over the swale and was temporarily detained by the downstream weir. For the other three pollutants, the reduction was quite small. This might be due to the fact that these pollutants exist in a dissolved form.

Table 8
CONCENTRATIONS OF POLLUTANTS FLOWING
INTO AND OUT OF SWALE

Pollutant	Inflow		Outflow		% Decrease in Average Concentration from Inflow Pollutograph
	Range	Average	Range	Average	
TSS	12–332	38.7	6.3–65	19.9	49
COD	16–143	61.1	23–128	59.3	3
TP	0–3.77	1.08	0–1.82	0.72	33
Zn	0–0.44	0.15	0–0.41	0.13	13

TSS = Total Suspended Solids; COD = Chemical Oxygen Demand; TP = Total Phosphorus; Zn = Zinc.

Table 9
CHANGE IN PARTICLE SIZE DISTRIBUTION FOR 7/19/93 STORM AT SWALE

Particle Size	Percent Particles		Change
	Inflow	Outflow	
>25 μ	61.7	36.4	(25.3)
> 8 μ	72.0	58.0	(14.0)
> 3 μ	76.0	73.4	(2.6)

1μ = 10^{-6} meter.

For the final storm on July 19, PSD analysis was done. The results are shown in Table 9. Composite samples were made for the inflow and outflow points. The change in PSD suggests the manner in which pollutants are being removed. The larger particles (25 μ), which settle faster, show a significant reduction, whereas the smaller particles (3 μ) show a minimal reduction. Thus, sedimentation would seem to be a significant factor in the removal of suspended particles in the swale.

DISCUSSION

Pollutant Concentrations in Highway Runoff

As reported in the Phase I report, the quality of stormwater runoff that immediately exits the highway pavement was determined at the intersection of U.S. Route 29 and Hydraulic Road.[1] The results of the edge-of-pavement analysis showed that pollutant concentrations were generally lower than those reported in the literature, except for TP and Zn.

A comparison was also made of the pollutant concentrations at the pond site (representing a parking lot) and at the swale (representing a highway of medium traffic volume) and values reported in the literature. Table 10 is a summary of the ranges and averages of pollutant concentrations at the two sites together with the values reported by the FHWA[5] from sampling at major highway sites. The results suggest that highways with a medium traffic volume and parking lots may yield smaller amounts of suspended solids when compared with major highways. On the other hand, for pollutants such as organics, nutrients, and metals, similar concentrations might be obtained for major and minor highways and parking lots.

Table 10
COMPARISON OF POLLUTANT CONCENTRATIONS AT POND AND SWALE

Pollutant Parameter	Pollutant Concentration From FHWA[5] (mg/l)		Pollutant Concentration From Pond Site (mg/l)		Pollutant Concentration From Swale Site (mg/l)	
	Average	Range	Average	Range	Average	Range
TSS	261	4–1656	27.2	0–450	112.9	21–410
COD	147	4–1058	14.7	0–118	295.4	86–458
TP	0.79	0.0–3.555	0.52	0–3.1	3.71	0.91–6.51
Zn	0.41	0.01–3.4	0.38	0–3.5	0.65	0.25–1.60

TSS = Total Suspended Solids; COD = Chemical Oxygen Demand; TP = Total Phosphorus; Zn = Zinc.

Pond

Comparative Pollutant Removal

The literature suggests that dry detention ponds are only moderately effective in removing pollutants in stormwater runoff. For example, the Phase I report presented a summary of removal efficiencies for a number of BMPs. For dry detention ponds, a TSS removal of between 30 to 70 percent can be achieved for a detention time of 4 to 12 hours. The corresponding removal rates are 10 to 50 percent for TP and 20 to 60 percent for Zn.

In this study, the average removal rates as listed in Table 4 were 12 to 90 percent for TSS, 0 to 88 percent for COD, 10 to 56 percent for TP, and 20 to 70 percent for Zn. The efficiencies are comparable to values in the literature, yet the detention time computed in this study ranged from only less than 10 minutes to close to 2 hours. In order to allow further examination of the possible effect of various factors on the removal efficiency, the removal rates together with the detention time, drawdown time (total time base of the outflow hydrograph), average rainfall intensity, and antecedent dry days are listed in Table 11.

Although the data in Table 11 are not sufficient for definitive conclusions to be drawn, some observations can be made:

1. Detention time is usually used as an important design parameter, yet it appears that it is not the only determinant of pond efficiency.
2. Rainfall intensity and prior dry days appear to have some effect on pollutant removal, especially for TSS. Longer dry days and higher rainfall intensity both tend to yield higher solids concentration in the runoff. Since particle settling is the primary mechanism for removal,

Table 11
REMOVAL EFFICIENCIES WITH PERTINENT PARAMETERS FOR POND

Storm	Pollutant				Total Rain Volume (mm)	Average Rainfall Intensity (in/hr)	Dry Days	Detention Times (hr)	Drawdown Time (hr)
	TSS	COD	TP	Zn					
5/05/92	90	—	87	—	2.0	1.30	6	—	2.5
3/31/93	12	50	77	51	4.8	0.51	2	0.34	8.0
4/9/93	41	10	43	22	36.8	2.73	2	1.55	15.0
4/26/93	81	47	53	19	6.4	2.12	4	0.09	4.0
7/3/93	60	46	60	24	17.6	8.82	4	1.45	5.0

TSS = Total Suspended Solids; COD = Chemical Oxygen Demand; TP = Total Phosphorus; Zn = Zinc.

the efficiency would be higher for larger particles and higher concentrations.

3. Drawdown time appears to be an important factor. A longer drawdown time should promote particle settling and other processes of removal such as decay and plant uptake. However, the present results are not sufficient for drawing such a conclusion.

On the whole, the pond performed fairly well when compared with removal rates reported in the literature. One reason could be the "enhanced" removal by the riprap channels transporting inflows into the pond (Figure 11). The riprap could cause a slowdown of inflow runoff and thereby promote settling of solids and could also provide some "filtration" effect through which pollutants are removed due to adsorption and sedimentation.

Design Guidelines

Design guidelines derived from the literature were included in VDOT's *Stormwater Management Manual.*[1] Because detention ponds are most widely used as a stormwater BMP, more information about designing ponds has become available in recent years. Examples are found in Schueler,[6] ASCE and WPCF,[7] and Urbonas and Stahre.[8]

Table 12 is a summary of design guidelines for extended dry detention ponds compiled from the literature.[8] This table is an updated version of Table 10 in VDOT's *Stormwater Management Manual.*[1]

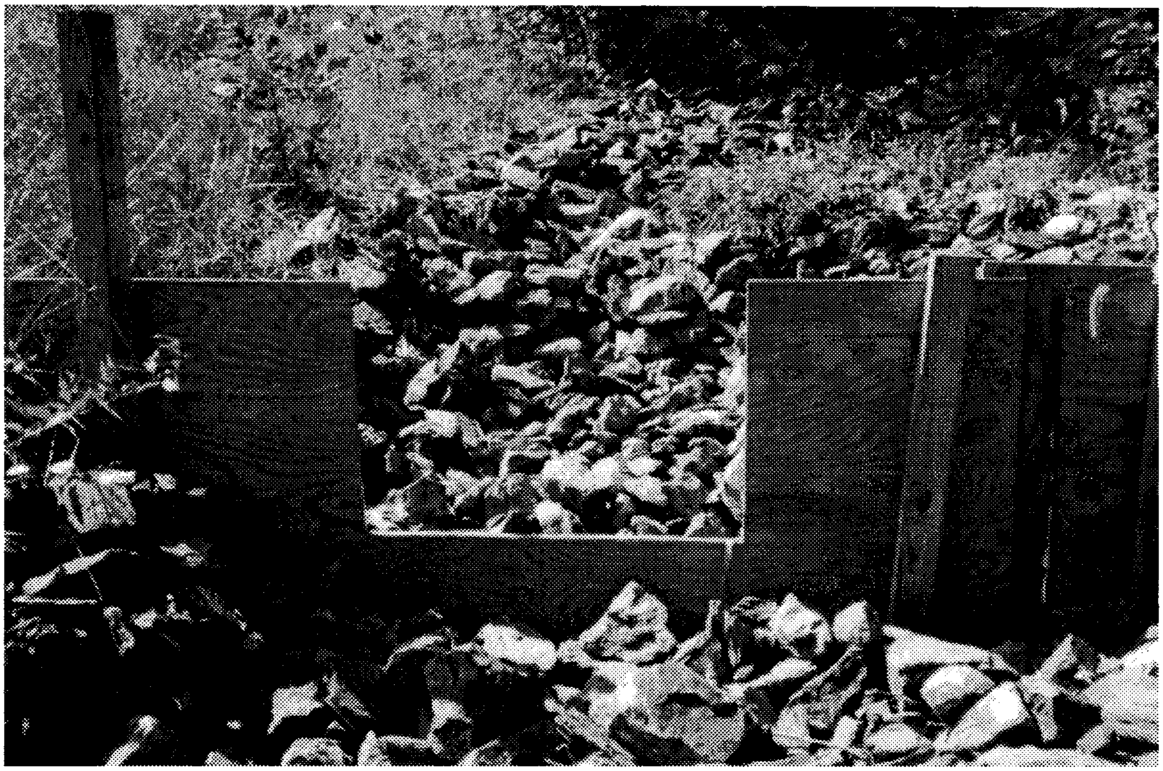


Figure 11. Riprap channels of pond.

Table 12
DESIGN GUIDELINES FOR EXTENDED DRY DETENTION PONDS

Characteristic	Suggested Design Guidelines
Storage volume and outlet design	Should capture the first 0.5 inch of runoff and satisfy the maximum discharge requirement; detention time greater than 6 hours; drawdown time greater than 24 hours
Basin geometry	Length-to-width ratio greater than 2; expands gradually from the inlet and contracts gradually toward the outlet
Forebay and channel	Provide a shallow forebay near the inlet to allow easy sediment removal; a low flow channel is desirable
Basin side slopes	Should be a minimum of 3:1 to ensure stability and for maintenance access
Two-stage design	Upper stage, or top pool, is to remain dry normally and a bottom stage is regularly inundated with its volume set to store about 0.5 inch of runoff
Vegetation	Marshes may be established at the bottom stage to increase pollutant uptake

Modeling Approaches

Computer models, when properly calibrated and verified, can be used to simulate the behavior of a system such as a detention pond under a variety of given environmental conditions. The results are useful for determining design guidelines.

In this study, a stormwater management model called VAST, or VirginiA STorm Model, was used for simulating the dry detention pond system. Details of the VAST model are described in Tisdale and Yu[9] and summarized in the *Stormwater Management Manual.*[1] VAST computes rainfall abstractions, generates overland flow hydrographs, routes outflow from upstream sub-basins to downstream sub-basins or detention ponds, and computes non–point source pollution washoff from sub-basins.

VAST was tested using data collected in 1992. The results in general were satisfactory. However, some stability problems were encountered in using the numerical schemes installed in the model. These problems are being resolved, and when they are corrected, the model will be tested with the 1993 data. Results will be incorporated into future revisions of the *Stormwater Management Manual.*[1]

Highway Applications

Even though wet detention ponds are known to be more effective in pollutant removal and flood control, dry detention ponds are still the primary type used by VDOT and other highway agencies. This is because most VDOT projects are for small drainage areas and without regional cooperation. VDOT can seldom serve a watershed large enough to support a wet pond.

On the other hand, dry detention ponds serving small areas are prone to clogging problems because of the small-sized outflow orifices required to increase detention times. Many dry ponds lose their design functions quickly if their outflow orifices are clogged. Another drawback of constructing numerous small, on-site dry ponds concerns aesthetics. It is not aesthetically appealing to have many small ponds, or "depressions," scattered along highways.

Regional cooperation should be promoted that can lead to the construction of larger and fewer, but more efficient, facilities such as wet detention ponds. This would be preferable not only because of economic considerations, but also because of maintenance, safety, and liability concerns.

Swale

Comparative Pollutant Removal

Relatively little information is available regarding swale pollutant removal performance and design guidelines. A review of swale performance and design suggestions was presented in the Phase I report.[2] In general, swales that are situated on low slopes, are densely vegetated, are long in total length, and have check dams for ponding runoff can be expected to have the following removal rates[10]:

TSS: 70%

TP: 30%

Metals: 50%–90%

Wanielista and Yousef[11] reported results obtained through monitoring highway swales in central Florida. As a comparison, the results reported by Schueler et al.[10] and Wanielista and Yousef,[11] together with those obtained in this study, are listed in Table 13.

The longitudinal slope for the U.S. Route 29 swale is considered large (5%). However, the relatively high removal rate, especially for TP, may be due to the fact that the weir, installed at the downstream end of the swale for flow measurement, also served as a check dam in backing up water. Another factor in assessing swale performance is the infiltration rate. If all the runoff is infiltrated, as was the case for the 7/10/93 storm, there would be no runoff out of the swale, and thus the removal rate would be 100 percent.

Even without check dams and other modifications, conventionally designed swales should provide some benefits in terms of reducing the quantity and quality impact of small storms. It was observed in this study that rainfalls with a volume of less than 5 mm (0.2 in) did not produce any runoff in the swale.

Table 13
COMPARISON OF SWALE REMOVAL RATES

Pollutant	Average Removal Rates (%)		
	Schueler et al.[10]	Wanielista and Yousef[11]	This Study
TSS	70	—	50
TP	30	52	56
Zn	70	80	49

TSS = Total Suspended Solids; TP = Total Phosphorus; Zn = Zinc.

Design Guidelines

Currently, most of the design suggestions in the literature are based on a procedure presented by Chow and adopted by the FHWA in its Hydraulic Engineering Circular No. 15.[12] The design includes vegetated channels for channel stability and hydraulic capacity. Modifications of Chow's procedure have been proposed in recent years for the purpose of improving a swale's pollutant removal efficiency. Examples of these improved design guidelines can be found in Horner,[13] Hampton Roads Planning District Commission,[14] and ASCE and WPCF.[7]

Table 14 is a list of design guidelines compiled from information in several recently published references.

Highway Applications

Recent reports published by the FHWA and Transportation Research Board[16] suggested that vegetative controls, such as swales, be considered as the primary measure for controlling the quality of highway runoff. Swales are of particular interest because of their widespread use and relatively low cost of construction and maintenance. The results obtained in this study also show that swales can provide significant water quality benefits.

Table 14
DESIGN GUIDELINES FOR SWALE

Characteristic	Suggested Design Guidelines
Longitudinal slope	5% maximum; 3% more realistic Needs to be as flat as possible to increase residence time in swale
Length of swale	30 m to 60 m (100 ft to 200 ft)
Side slope	3:1 (h:v) maximum, the flatter the better to increase contact area
Bottom width	0.6 m (2 ft) minimum
Infiltration rate	The higher the better; 0.5 inch per hour or more may significantly improve removal efficiency
Vegetation type	Dense, deep rooted, and flood tolerant; reed canary grass, fescues, and bermuda grass are examples
Check dams	Used to increase residence time in swale, thus promoting removal processes; they should not be used where they might constitute a traffic hazard
Pollutant characteristics	Suspended pollutants are removed more easily than dissolved pollutants; infiltration is main removal process for dissolved pollutants

Source: Compiled from References 10, 11, 13, and 14.

One of the concerns of VDOT's maintenance crews regarding check dams or "ditch checks" is that they hinder grass mowing operations. It may be desirable therefore to consider using longer swales and a milder longitudinal slope in designing highway swales for stormwater management.

UPDATE OF VDOT'S *STORMWATER MANAGEMENT MANUAL*

The following materials were added to the *Stormwater Management Manual*:

1. a glossary of terms

2. a checklist for maintenance

3. a stormwater survey of state DOTs.

A survey of stormwater management issues was sent to all state DOTs (including Washington, D.C., and Puerto Rico) and appears in Appendix E. Of the 52 surveys sent, 33 were returned.

The main purpose of the survey was to see what other DOTs were doing with regard to stormwater management and if any innovative techniques were being tried that could be used by VDOT. It was found that most DOTs are in the same situation as VDOT, just starting to look at stormwater management and hoping that innovative techniques can be developed to deal with new regulations in their state.

With regard to NPDES permits, the majority of states obtain general permits; the few exceptions depend on the site requiring a permit. Through telephone conversations with different state officials, it was determined that NPDES permits required in metropolitan areas are coordinated with each city that must obtain the permit. Table 15 is a representative list of the states' responses, with two states provided from each federal highway region.

All of the states surveyed have some form of erosion and sediment control guidelines they follow during and after construction. This study, however, was aimed at postconstruction water quality BMPs. Many states are now faced with stormwater management regulations that require treatment; detention is the most commonly used method to treat a volume of stormwater. Detention times are usually between 24 and 36 hours. (See Table 16.)

The majority of states use detention ponds and swales for controlling highway drainage. For the most part though, they will try anything and are always looking for new BMP designs that look promising.

Table 15
SURVEY OF STORMWATER MANAGEMENT PRACTICES

FHWA Region/ State	NPDES Permit Strategy	Stormwater BMPs Used				Remarks
		Ponds	Infiltration Facilities	Swale/ Vegetative	Wetlands	
Region 1						
Massachusetts	General Permit	•	•	•	•	
New Jersey	General Permit	•	•	•	•	
Region 3						
Maryland		•	•			
Virginia	General Permit	•		•		Design manual used to satisfy state regulations
Region 4						
Florida	General Permit	•	•	•		
Georgia	General Permit	•	•	•	•	Control 2-year storm for quantity and quality
Region 5						
Illinois	General Permit	•		•	•	
Wisconsin	General Permit	Not in place yet				Co-permitted with cities of Milwaukee & Madison
Region 6						
Arkansas	General Permit	•	•			
Texas	General Permit	•		•	•	
Region 7						
Kansas	General Permit			•	•	
Missouri	General Permit	•		•		
Region 8						
Colorado	General Permit	Planning to use all of the above				
Utah	General Permit	•		•	•	

continues

Table 15
SURVEY OF STORMWATER MANAGEMENT PRACTICES (continued)

FHWA Region/ State	NPDES Permit Strategy	Stormwater BMPs Used				Remarks
		Ponds	Infiltration Facilities	Swale/ Vegetative	Wetlands	
Region 9						
Arizona	Individual Permit (Tucson & Phoenix)	•	•			
California	Group Permit/ Individual Permit	Types not dictated				Group permits in LA & SF, individual permits other areas
Region 10						
Oregon			•	•		
Washington	General Permit	•		•	•	

Table 16
STATES WITH STORMWATER MANAGEMENT CRITERIA

State	Volume of Stormwater Treated
AL	Runoff from 0.75 inch
AK	0.5 inch of runoff
CO	Runoff from 0.5 inch
CT	1.0 inch of runoff
DE	Runoff from 1 inch
RI	Runoff from 0.5 inch
VT	0.5 inch of runoff
VA	0.5 inch of runoff

Regulations usually require treatment of either a set amount of runoff or the runoff from a set amount of rainfall.

CONCLUSIONS

1. Dry detention ponds, when modified hydraulically by using small outlet orifices, could provide pollutant removal rates ranging from 30 percent for zinc to about 55 percent for total suspended solids. The overall average removal for all pollutants tested was about 40 percent.
2. Detention pond storage volume, outlet structure, and basin geometry are important design parameters. Riprap low flow channels and vegetation at the pond bottom help increase the removal efficiency.
3. Highway swales, when properly designed and maintained, can be cost-effective in removing pollutants in highway runoff, especially for smaller and low-intensity, long-duration storms.
4. Swale length, longitudinal slope, and vegetation type are important considerations in swale design. The use of swale blocks, or ditch checks, should improve swale pollutant removal efficiency, though they may cause maintenance problems.
5. Very small, on-site dry detention ponds are not usually desirable because of maintenance and aesthetic problems.

RECOMMENDATIONS

1. For extended dry detention ponds, it is recommended that the design guidelines compiled in Table 12 be considered in conjunction with guidelines presented previously in the *Stormwater Management Manual.*[1]
2. In designing highway swales for water quality benefits, it is recommended that the guidelines presented in Table 14 be considered. Longitudinal slope and length should be manipulated first to achieve the desirable removal rate before swale blocks are considered.
3. If resources are available, BMPs such as detention ponds, swales, and wetlands should be monitored on a long-term (multiyear) basis. Long-term observations are needed to allow an accurate evaluation of the overall performance, longevity, and maintenance needs of these practices.
4. VDOT should seek regional cooperation in dealing with stormwater management issues. Regional facilities are usually more cost-effective and aesthetically appealing than small, on-site facilities.

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APPENDIX A

Field Data for Pond

Table A-1
POLLUTANT CONCENTRATIONS

Time	Inflow 1[a] Concentration (mg/l)				Inflow 2[a] Concentration (mg/l)				Outflow[a] Concentration (mg/l)			
	TSS	COD	TP	Zn	TSS	COD	TP	Zn	TSS	COD	TP	Zn
30 April 1992												
15:20	72.0	*	1.24	*	68.5	*	2.10	*	29.0	*	0.70	*
16:00	16.5	*	0.25	*	23.5	*	0.60	*	8.5	*	0.63	*
16:45	13.0	*	0.32	*	16.5	*	0.36	*	5.0	*	0.09	*
17:00	7.5	*	0.13	*	15.5	*	0.27	*	6.0	*	0.22	*
5 May 1992												
04:50	121.0	*	2.99	*	88.0	*	2.02	*	*	*	*	*
05:15	*	*	*	*	24.0	*	0.33	*	*	*	*	*
05:30	25.0	*	1.63	*	*	*	*	*	*	*	*	*
05:45	*	*	*	*	*	*	*	*	23.0	*	0.84	*
06:15	*	*	*	*	6.5	*	0.29	*	*	*	*	*
06:30	5.0	*	0.64	*	*	*	*	*	7.0	*	0.22	*
07:15	*	*	*	*	*	*	*	*	6.0	*	0.03	*
29 May 1992												
22:00	12.0	*	0.22	*	19.5	*	0.82	*	*	*	*	*
22:10	*	*	*	*	*	*	*	*	38.0	*	0.78	*
22:15	7.0	*	0.07	*	10.0	*	0.51	*	*	*	*	*
22:30	3.0	*	*	*	12.0	*	0.35	*	*	*	*	*
22:40	*	*	*	*	*	*	*	*	2.0	*	0.35	*
23:15	*	*	*	*	*	*	*	*	7.0	*	0.20	*
30 May 1992												
11:30	21.0	*	0.56	*	39.0	*	0.01	*	*	*	*	*
11:40	*	*	*	*	*	*	*	*	5.0	*	0.24	*
12:00	*	*	*	*	*	*	*	*	20.0	*	0.16	*
12:30	12.0	*	0.45	*	16.0	*	0.00	*	10.5	*	0.39	*
16:00	7.0	*	0.43	*	5.0	*	0.01	*	11.0	*	0.01	*

continues

Table A-1
POLLUTANT CONCENTRATIONS (continued)

Time	Inflow 1[a] Concentration (mg/l)				Inflow 2[a] Concentration (mg/l)				Outflow[a] Concentration (mg/l)			
	TSS	COD	TP	Zn	TSS	COD	TP	Zn	TSS	COD	TP	Zn
4 June 1992												
09:00	59.0	*	2.61	0.60	66.0	*	1.14	3.50	*	*	*	*
10:15	7.5	*	0.27	2.70	9.0	*	0.01	2.00	7.0	*	0.22	2.80
11:15	*	*	*	*	*	*	*	*	6.0	*	0.38	0.20
14:15	4.0	*	0.03	0.80	3.5	*	0.23	0.20	2.5	*	0.45	0.20
5 June 1992												
01:00	21.0	*	0.89	0.23	19.5	*	0.06	0.04	20.5	*	0.61	0.00
02:15	4.0	*	0.16	0.00	9.5	*	0.01	0.16	6.5	*	0.24	0.00
04:15	11.0	*	0.06	0.00	11.5	*	0.01	0.00	5.5	*	0.27	0.00
31 March 1993												
21:00	18.0	35.0	0.03	0.37					4.5	24.0	0.00	0.29
22:30	36.0	25.0	0.40	0.52					24.0	20.0	0.22	0.41
24:00	3.0	8.0	0.22	0.48					21.0	2.0	0.00	0.35
04:30	29.5	19.0	0;37	0.40					14.0	3.0	0.01	0.37
06:30	9.5	12.0	0.35	0.48					8.5	2.0	0.06	0.35
9 April 1993												
22:00	78.5	58.0	0.11	0.15					13.0	82.0	0.28	0.11
23:30	32.5	24.0	0.15	0.15					23.5	29.0	0.21	0.13
01:00	16.0	18.0	0.24	0.24					9.0	18.0	0.16	0.13
02:30	10.5	15.0	0.13	*					7.0	20.0	0.07	*
04:00	14.0	20.0	0.02	0.14					12.0	10.0	0.00	0.15
05:30	8.5	41.0	0.03	*					10.5	16.0	0.00	*
07:00	12.0	12.0	0.01	0.14					8.0	16.0	0.00	0.14
08:30	13.0	20.0	0.00	*					14.5	7.0	0.00	*
10:00	42.5	20.0	0.00	0.12					13.5	0.0	0.00	0.13
11:30	32.5	22.0	0.00	*					11.0	22.0	0.00	*

continues

Table A-1
POLLUTANT CONCENTRATIONS (continued)

Time	Inflow 1[a] Concentration (mg/l)				Inflow 2[a] Concentration (mg/l)				Outflow[a] Concentration (mg/l)			
	TSS	COD	TP	Zn	TSS	COD	TP	Zn	TSS	COD	TP	Zn
26 April 1993												
9:20	165.0	97.0	0.50	0.33					61.5	88.0	0.90	0.30
9:50	85.0	80.0	0.39	0.30					13.5	59.0	0.70	0.27
10:20	39.0	49.0	0.63	0.40					13.0	30.0	0.39	0.20
10:50	18.0	27.0	0.39	0.38					9.0	20.0	0.00	0.43
11:50	26.0	25.0	0.33	0.29					5.0	22.0	0.15	0.25
3 July 1993												
14:25	450.0	118.0	0.83	0.08					158.0	78.0	3.10	0.07
14:45	38.0	50.0	0.12	0.19					*	*	*	*
14:55	98.0	37.0	0.53	0.07					85.0	35.0	0.20	0.04
15:05	54.0	21.0	0.11	0.04					68.0	21.0	0.01	0.07
15:25	15.0	20.0	0.00	0.06					42.0	22.0	0.00	0.05
15:55	*	*	*	*					16.0	15.0	0.00	0.06

[a] Inflow and outflow sampling locations are shown in Figure 3. For all storms after March 1993, inflow measurements were made at a point below the confluence of inflow 1 and inflow 2.

TSS = Total Suspended Solids; COD = Chemical Oxygen Demand; TP = Total Phosphorous; Zn = Zinc; * = Not measured.

Table A-2
PARTICLE SIZE DISTRIBUTION

Storm Date	Particle Size (μ)	Inflow 1 Cumulative Fraction of Particle Size Less than (%)	Inflow 2 Cumulative Fraction of Particle Size Less than (%)	Outflow Cumulative Fraction of Particle Size Less than (%)
30 April 1992	3	37	43	37
	25	89	80	87
	43	95	91	100
5 May 1992	3	20	43	37
	25	57	80	87
	43	80	91	100
26 April 1993	3	07		02
	8	16		07
	25	35		11
03 July 1993	3	01		02
	8	04		05
	25	09		17

Sample Information:

30 April 1992
Rain depth: 5.2 mm
Average rain intensity: 1.8 mm/hr
Mean TSS concentration (Inflow 1/Inflow 2/Outflow): 44/41/19 mg/l
Collected 20 min after storm began

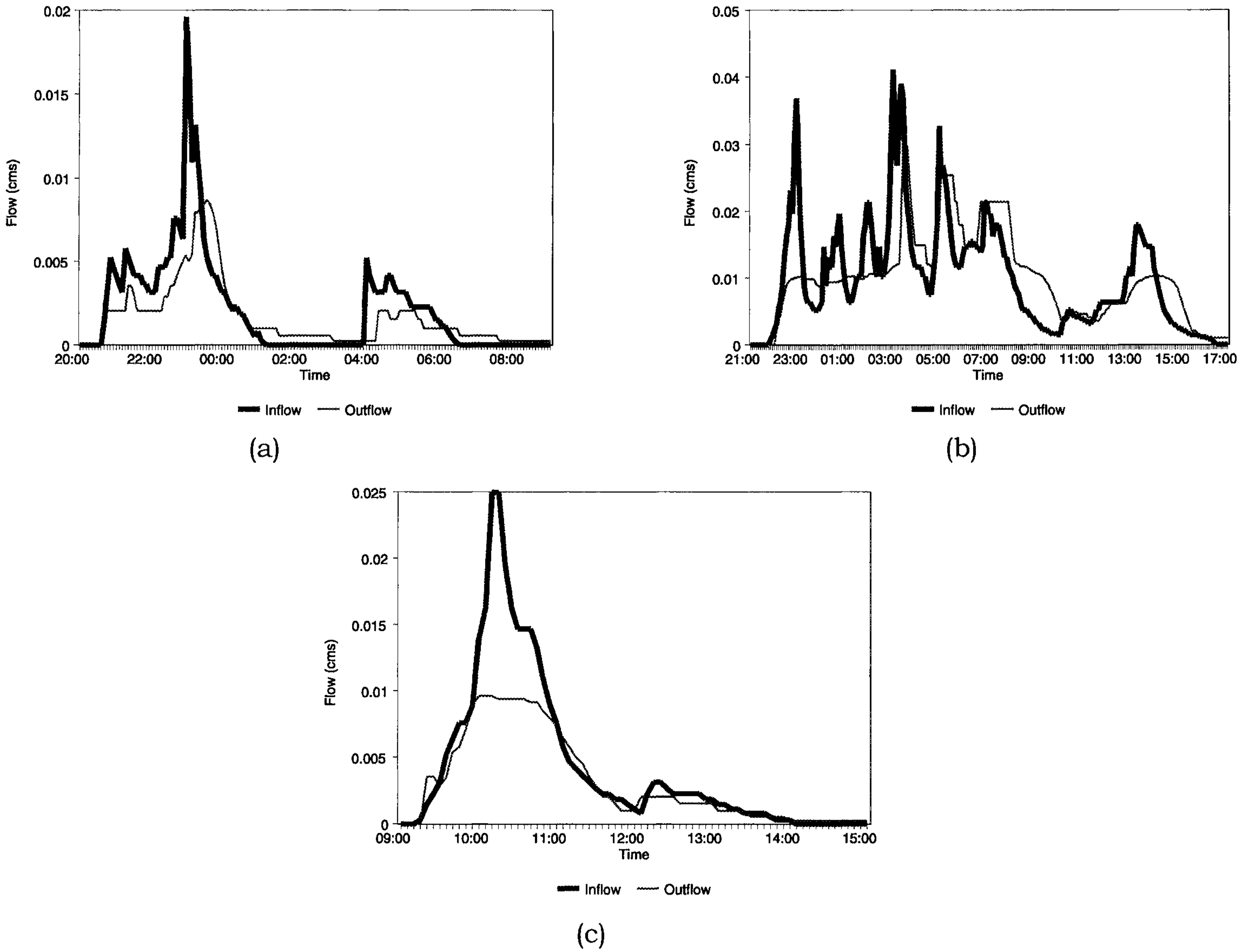
5 May 1992
Rain depth: 2.0 mm
Average rain intensity: 1.3 mm/hr
Mean TSS concentration (Inflow 1/Inflow 2/Outflow): 73/56/15 mg/l
Collected 25 min after storm began

26 April 1993
Rain depth: 6.4 mm
Average rain intensity: 2.1 mm/hr
Mean TSS concentration (Inflow/outflow): 87/52 mg/l
Composite sample over 3-hr rain
Sampling interval: 30 min

3 July 1993
Rain depth: 17.6 mm
Average rain intensity: 8.82 mm/hr
Mean TSS concentration (Inflow/outflow): 245/148 mg/l
Composite sample over 2-hr rain
Sampling interval: 10 min

APPENDIX B

Hydrographs and Pollutographs for Pond

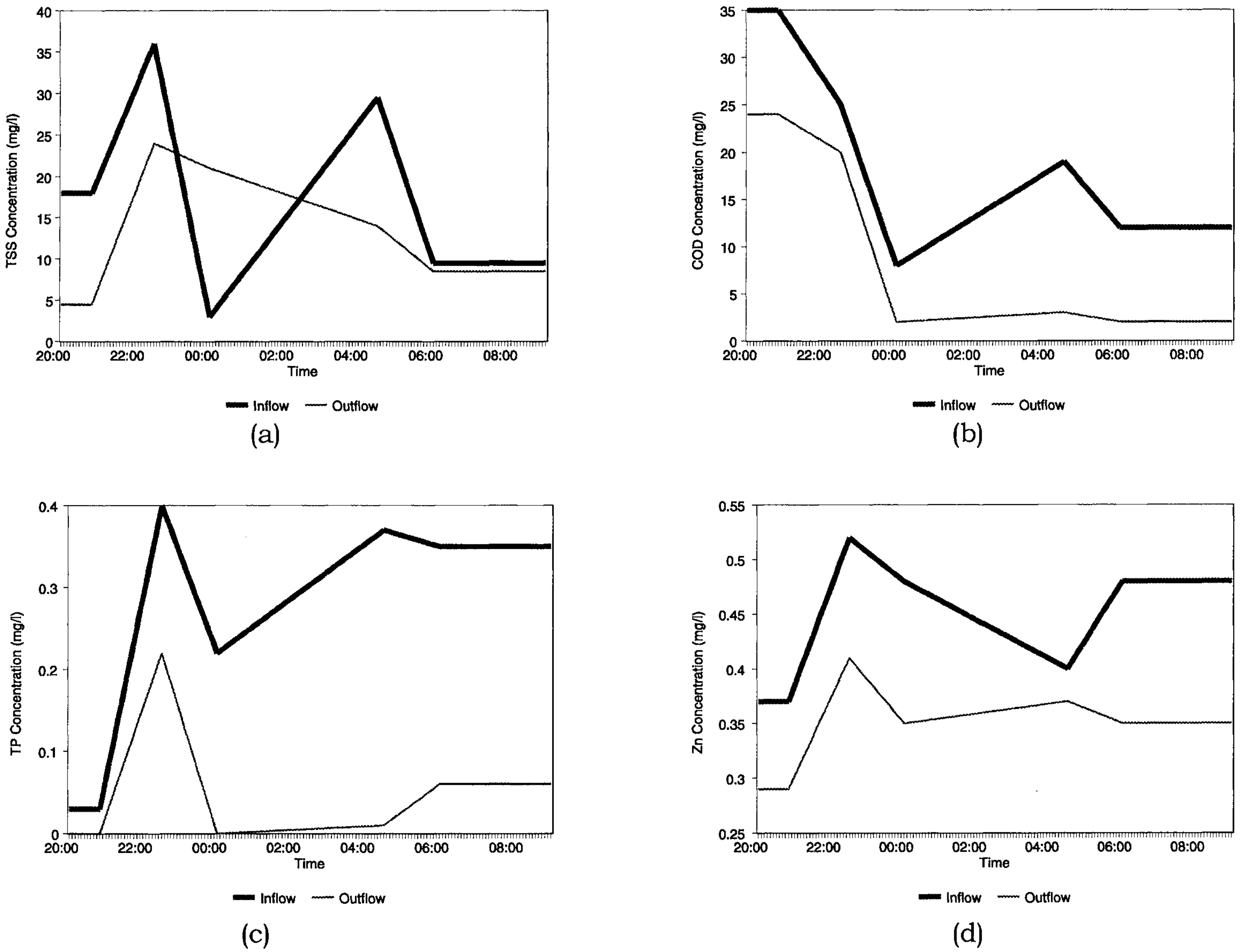


(a)

(b)

(c)

Figure B-1. Inflow and outflow hydrographs for (a) 3/31/93, (b) 4/9/93, and (c) 4/26/83 storms.



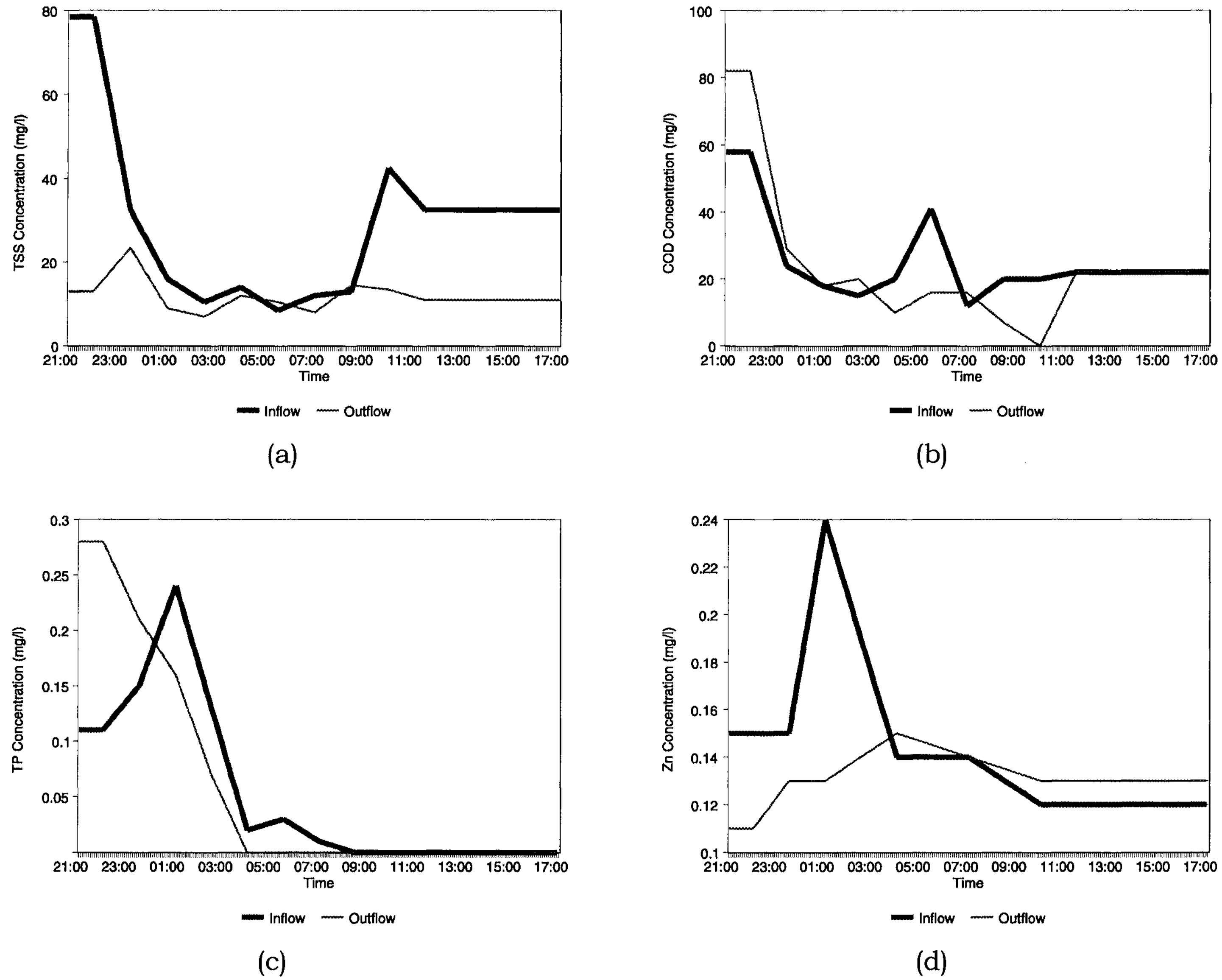
(a)

(b)

(c)

(d)

Figure B-2. Pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, (c) total phosphorus, and (d) zinc, 3/31/93 storm.



(a) (b)

(c) (d)

Figure B-3. Pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, (c) total phosphorus, and (d) zinc, 4/9/93 storm.

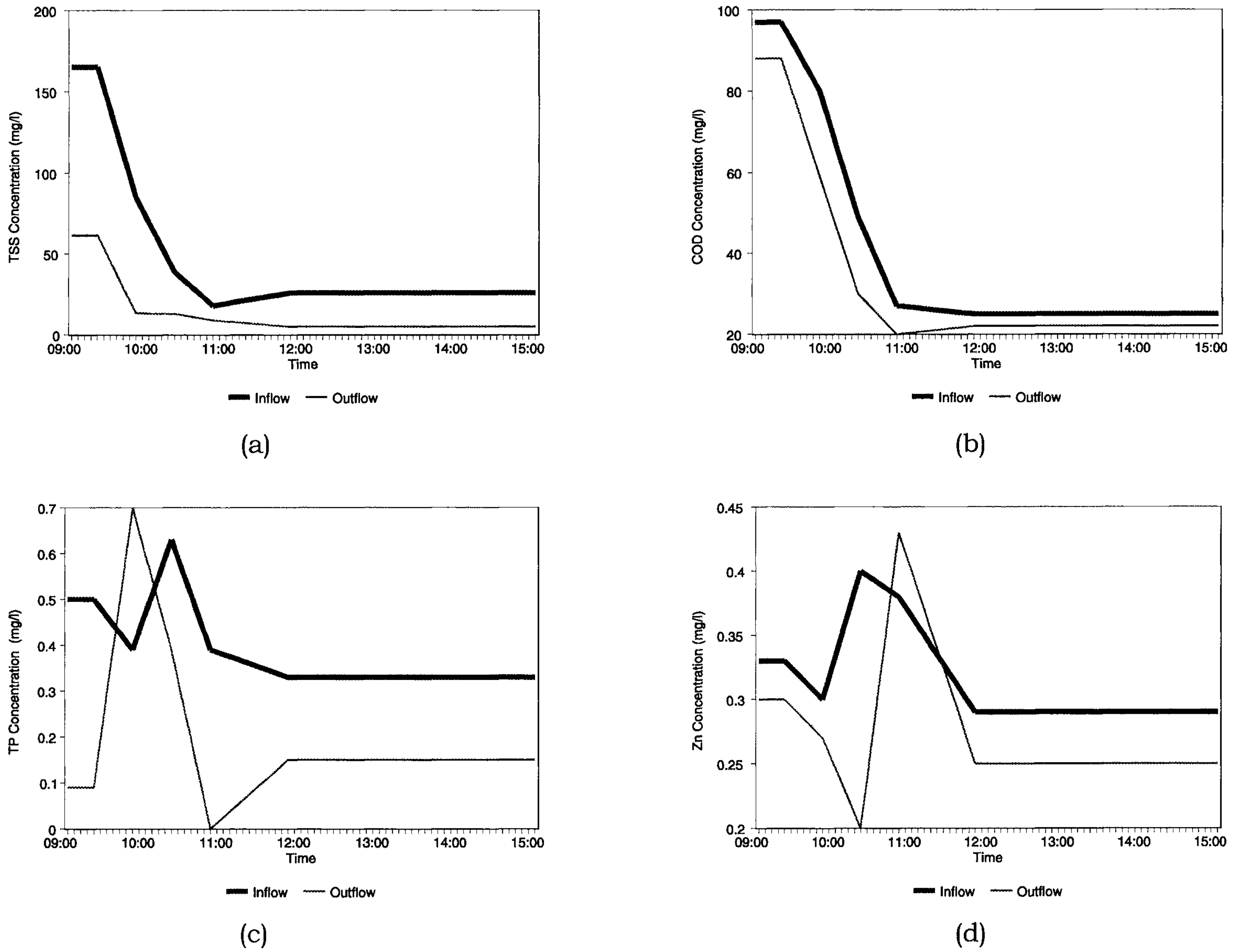


Figure B-4. Pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, (c) total phosphorus, and (d) zinc, 4/26/93 storm.

APPENDIX C

Field Data for Swale

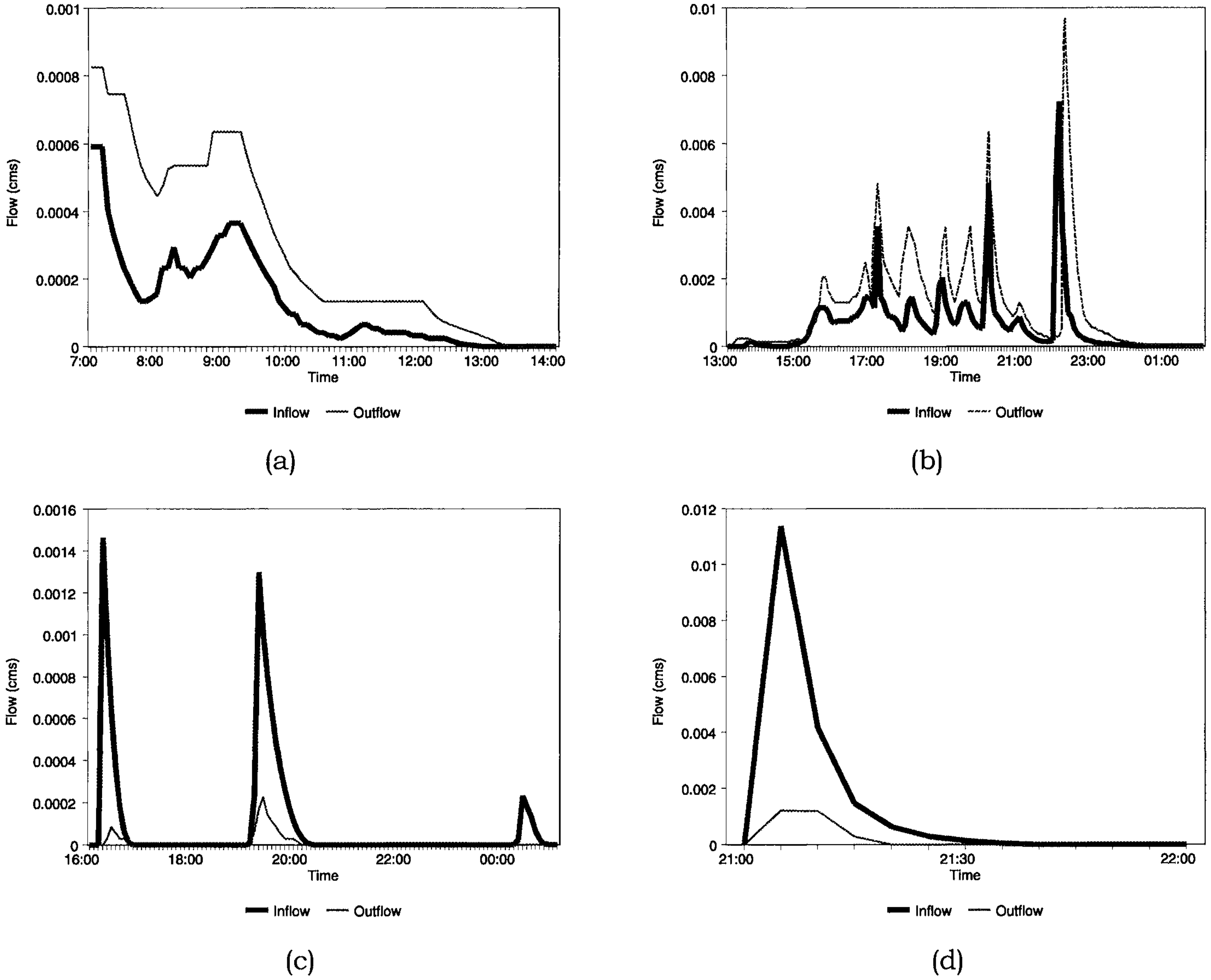
Pollutant Concentrations

Date	Inflow					Outflow				
	Time	Pollutant Concentration (mg/l)				Time	Pollutant Concentration (mg/l)			
		TSS	COD	TP	Zn		TSS	COD	TP	Zn
11/5/92	7:05	13.5	52	1.74	—	7:05	12.5	68	1.37	—
	7:20	12.5	60	20.8	0.00	7:20	6.3	56	1.33	0.00
	7:35	20.8	52	2.48	—	7:35	10.0	50	0.44	—
	8:05	12.5	42	3.48	—	8:05	10.3	50	0.45	—
	8:35	14.8	64	2.08	0.05	8:35	13.0	64	1.36	0.17
11/12/92	13:45	23.0	55	0.52	0.10	13:45	14.5	35	0.38	0.08
	15:15	23.0	55	0.58	0.07	15:15	14.5	39	0.32	0.07
	15:45	13.5	50	0.50	0.00	15:45	16.5	40	0.41	0.01
	17:15	18.5	59	0.75	0.02	17:15	15.0	49	0.55	0.02
	19:15	15.5	48	0.48	—	19:15	10.5	39	0.31	—
5/31/92	16:00	35.0	121	0.72	0.36	16:22	24.0	128	0.78	0.41
	16:22	22.0	112	0.52	0.42	19:25	24.0	113	0.00	0.38
	18:22	23.0	120	0.00	0.38	19:55	18.0	100	0.00	0.36
	18:52	17.0	97	0.00	0.44					
7/12/93	21:00	19.0	22	2.47	0.12	21:00	62.0	25	0.33	0.13
	21:10	14.0	16	0.13	0.18	21:10	19.0	23	0.37	0.11
	21:20	15.0	18	0.15	0.10	21:20	17.0	28	0.29	0.11
	21:30	12.0	21	0.04	0.16					
	21:40	13.0	23	0.07	0.13					
7/19/93	17:50	217.0	143	3.77	0.13	17:50	65.0	85	1.34	0.10
	18:00	20.0	56	0.51	0.07	18:00	24.0	55	0.78	0.07
	18:10	13.0	50	1.10	0.11	18:10	14.0	61	0.86	0.06
	18:20	13.0	56	0.71	0.08	18:20	13.0	60	1.66	0.08
	18:30	14.0	65	0.61	0.09	18:30	14.0	77	1.82	0.06

TSS = Total Suspended Solids; COD = Chemical Oxygen Demand; TP = Total Phosphorus; Zn = Zinc.

APPENDIX D

Hydrographs and Pollutographs for Swale



(a) (b)

(c) (d)

Figure D-1. Inflow and outflow hydrographs for (a) 11/5/92, (b) 11/12/93, (c) 3/31/93, and (d) 7/12/93 storms.

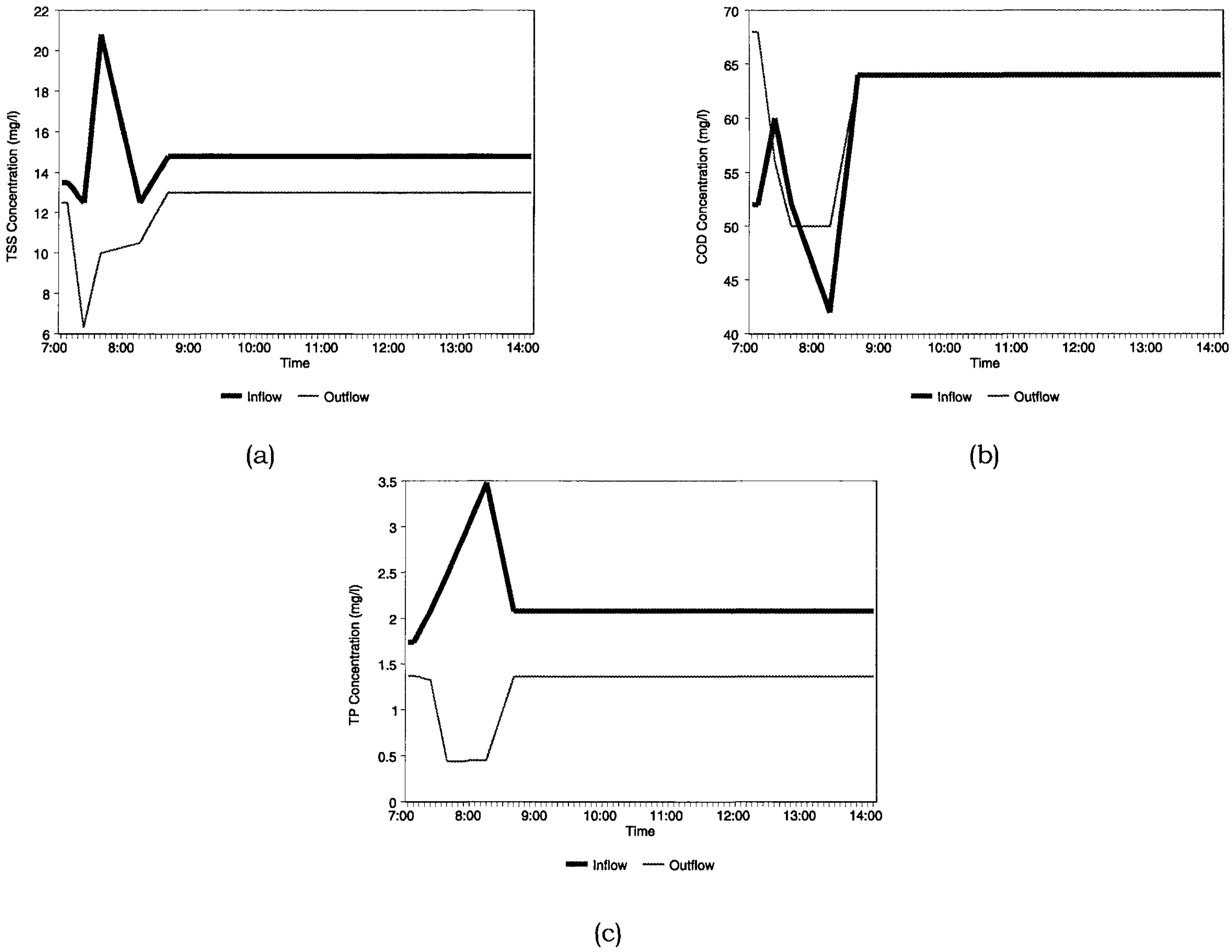
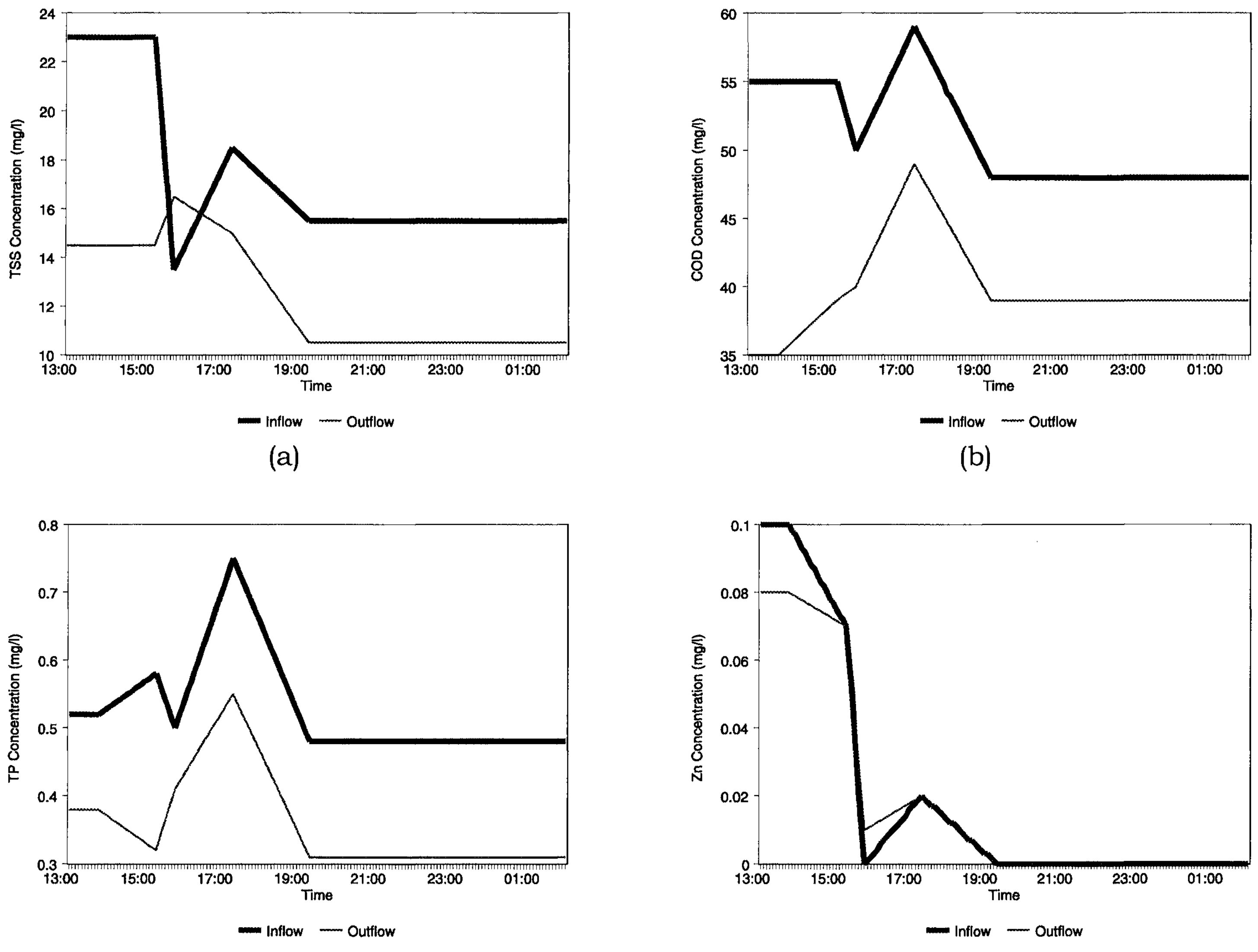


Figure D-2. Pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, and (c) total phosphorus, 11/5/92 storm.



(a) (b)

(c) (d)

Figure D-3. Pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, (c) total phosphorus, and (d) zinc, 11/12/92 storm.

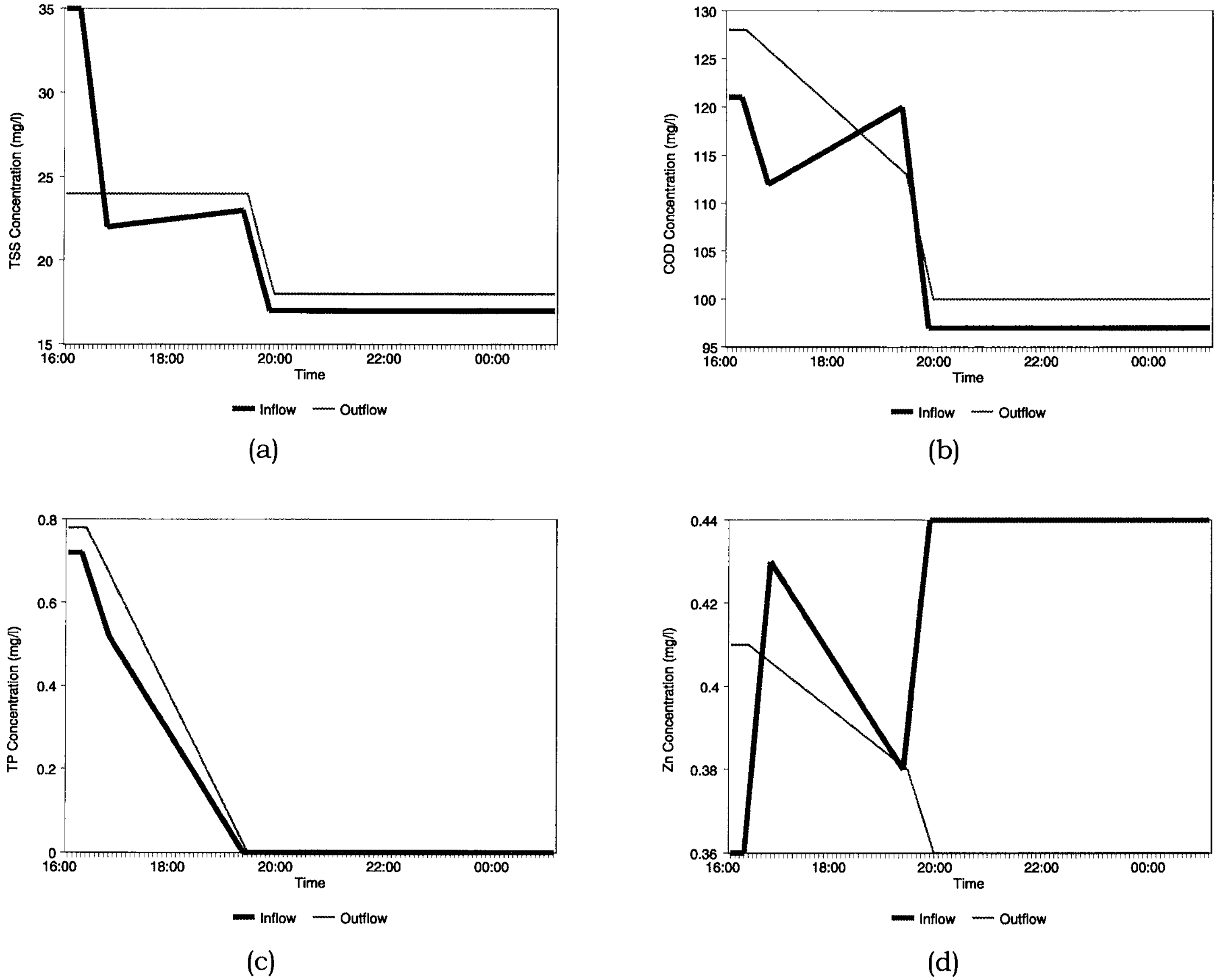
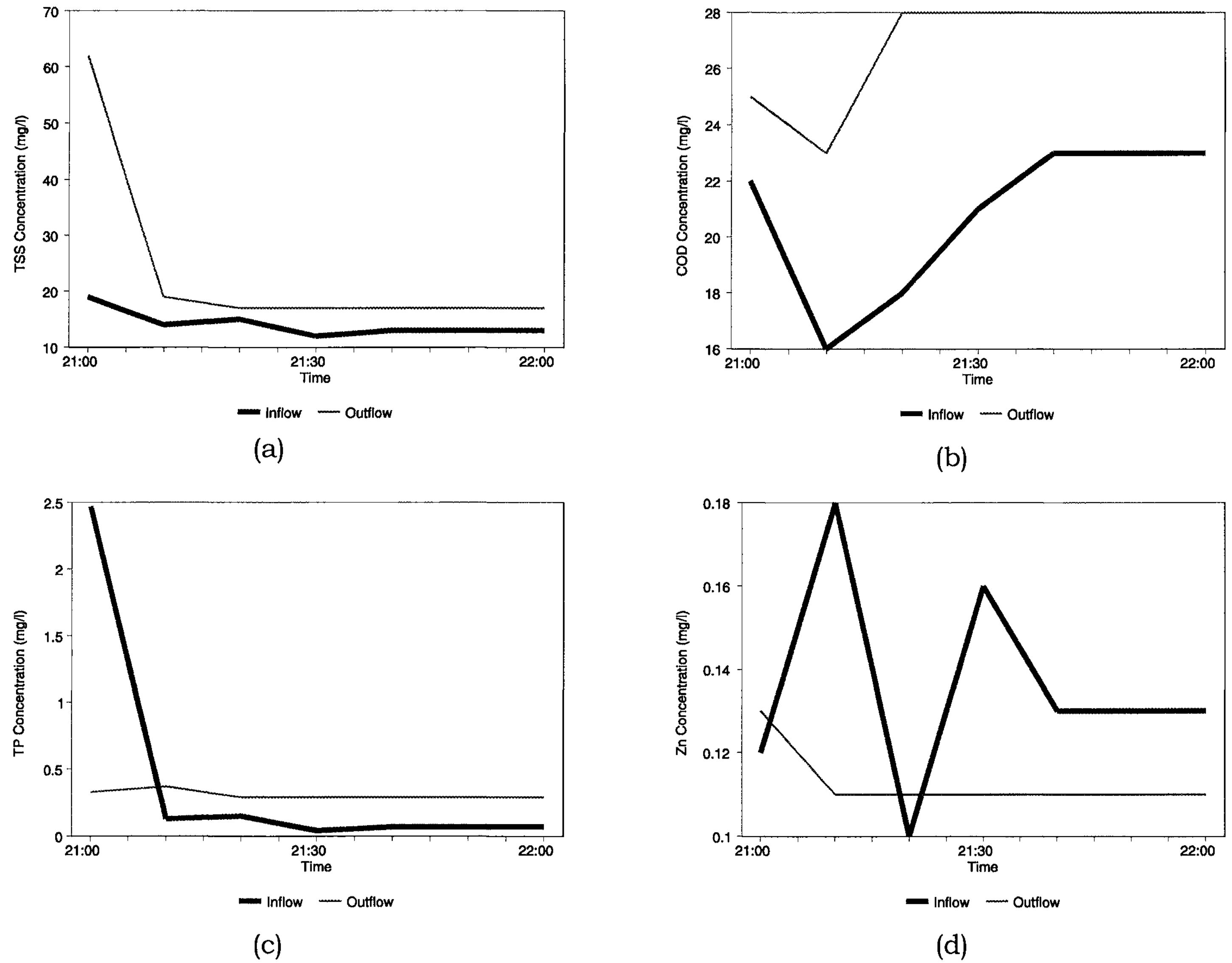


Figure D-4. Pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, (c) total phosphorus, and (d) zinc, 3/31/93 storm.



(a) (b) (c) (d)

Figure D-5. Pollutant concentrations of (a) total suspended solids, (b) chemical oxygen demand, (c) total phosphorus, and (d) zinc, 7/12/93 storm.

APPENDIX E

Stormwater Survey Sent to State DOTs

National Survey of State Departments of Transportation
Regarding
Stormwater Management Issues
by the
Virginia Transportation Research Council

Contact person for stormwater management at your Department of Transportation (DOT):

Name: ______________________________

Department: ______________________________

Address: ______________________________

Phone: (___) __________ Fax: (___) ____________

Stormwater management facilities commonly used by your DOT:

Facility	**Yes**	**No**
dry detention ponds	☐	☐
extended dry ponds	☐	☐
wet detention ponds	☐	☐
infiltration trenches	☐	☐
infiltration basins	☐	☐
dry wells	☐	☐
porous pavement	☐	☐
vegetated buffer strips	☐	☐
vegetated swales	☐	☐
natural wetlands	☐	☐
constructed wetlands	☐	☐

other: ____

Design guidelines for stormwater management facilities:

Has your DOT developed their own set of design guidelines for stormwater management facilities?

☐ Yes ☐ No

If *no*, what agency dictates the design criteria to be used:

____

Design frequency for stormwater management facilities:

Water quality control (check all applicable):

☐ ____ year ____ hour event

☐ first ____ inch of runoff

☐ runoff from first ____ inch of rainfall

☐ other: ____

____

Water quantity control (check all applicable):

☐ designed for the ____ year ____ hour event

☐ checked for the ____ year ____ hour event

☐ other: ______________________________

____

Has your DOT conducted any studies or reports on the design or efficiency of stormwater management facilities? ☐ Yes ☐ No

Maintenance of stormwater management facilities:

How often are facilities inspected? _____ per _____
Department responsible for inspection: ______________________________
On the average, how often are facilities mowed? ______ per _____
On the average, how often are ponds dredged? ______ per ______
Is any special disposal of dredged material required?

☐ Yes ☐ No

Does your DOT track maintenance costs for stormwater facilities?

☐ Yes ☐ No

If *yes*, please provide contact:

____
____
____

Has your DOT conducted any studies or reports on maintenance aspects of stormwater management facilities? ☐ Yes ☐ No

Safety of stormwater management facilities:

Do you fence all detention ponds? ☐ Yes ☐ No
Maximum side slopes used in ponds: _____ : ____ (horizontal:vertical)
Maximum water depth for ponds: ______ ft
Other safety features or criteria:

____

____

Has your DOT conducted any studies or reports of safety with respect to stormwater management facilities? ☐ Yes ☐ No

Stormwater management strategy:

EPA NPDES Stormwater Regulations:

Permitting strategy for your DOT	General	☐
	Group	☐
	Individual	☐

Does your state have general permitting authority for NPDES stormwater permits?

☐ Yes ☐ No

If *yes*, what agency (address, if possible) in your state administers these permits:

____

____

____

State stormwater management regulations:

Is there a state stormwater management regulation in effect in your state that affects DOT projects? ☐ Yes ☐ No

Miscellaneous:

Has your DOT produced any videos or short courses on design, maintenance, or operation of stormwater management facilities? ☐ Yes ☐ No

Are there any other issues or comments you would like to include? If so, please include them below.

Please complete and send to:

Virginia Transportation Research Council
P.O. Box 3817 University Station
Charlottesville, Virginia 22903
Attn: Dr. Shaw L. Yu, c/o Robert J. Kaighn

If you have any questions or wish to discuss any of the issues we are concerned with, please feel free to call between 8 am–5 pm (EST)

Dr. Shaw L. Yu	(804) 924-6377	fax: (804) 982-2951
Stewart L. Barnes	(804) 293-1979	fax: (804) 293-1990
Robert J. Kaighn	(804) 293-1979	fax: (804) 293-1990

A copy of the survey report will be forwarded to all those participating in the survey.

Thank you very much for your cooperation.