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Management practice evaluation for urban areas in the Hampton Roads vicinity: a report to Hampton Roads Water Quality Agency

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MANAGEMENT PRACTICE EVALUATION FOR URBAN AREAS IN THE HAMPTON ROADS VICINITY

A report to:

Hampton Roads Water Quality Agency

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SUMMARY OF FINDINGS

Data was collected by the Virginia Institute of Marine Science from study sites in the designated Hampton Roads 208 area, and information from other studies published in the literature were used to examine the change in pollutant loadings brought about by the presence of management practices in urban test watersheds. The focus was on nutrients, BOD, and suspended solids. Examples of established management practices in the study area which were conducive to monitoring were difficult to find. The practices evaluated by the field studies were 1) swale drainage in residential areas; 2) artificial seeding of a construction site, and; 3) stormwater detention ponds. It should be pointed out that the results reported in this study may differ from those of similar studies conducted in other physiographic provinces. The data from other sources have been used in section II of this report to develop a more complete list of management practice effectiveness information applicable to Tidewater Virginia.

The conclusions from the field study are summarized as follows:

1. Grassed swale waterways had lower pollutant loadings than similar sites served by curb and gutter drainage. The differences among the two types ranged from 30 - 90 percent for nutrients, and from 60 - 90 percent for suspended solids and BOD.

2. Artificial seeding of a construction site did not effectively influence total nutrient loadings, however, there was a conversion from organic to inorganic forms of nitrogen and phosphorus after the establishment of grass. Suspended solids loads were reduced by about 40 percent, which represented as much as 1500 lb/ac/yr.

3. Detention ponds in the Tidewater region are influenced by the shallow groundwater table which reduces the trapping efficiency of the reservoirs.

Suspended solids trapping was shown to be related to pond volume. Retention of the inflowing sediment loads ranged from 46 to 75 percent, depending on the size of the reservoir.

4. Nutrient and BOD trapping by the reservoirs also increased with pond volume. These constituents are affected by biological processes which precluded the development of a functional relationship between them and solids trapping or pond volume since the different ponds were monitored during different seasons of the year. Longer term records covering at least one full year are needed to better understand the net trapping of these constituents. There was an increase in some forms of nutrients passing through the smallest pond, while the larger reservoirs retained up to 98% of the total nitrogen and phosphorus entering them.

5. Although the grassed swales and detention ponds reduced pollutant loads by similar percentages, the net reduction in pollutant loading was greater at the ponds since the inflow to them was more polluted than runoff at the residential catchments. It is likely that there is an upper limit to the assimilative capacity of the grassed swales which is lesser than that for ponds, limiting their usefulness by comparison as a practice for treating certain high pollutant potential land uses.

6. Monitoring the management practices also provided much needed pollutant loading data for land use types in the coastal plain physiographic province. It was found that the steep-sloped construction site produced suspended solids loadings which were ten times higher than that in parking lot runoff. Nutrient loads between the two were about equal. The parking lot/impervious catchments yielded nearly 10 times greater loading for both nutrients and suspended solids than the residential sites.

7. Groundwater processes remain an unknown term in the transport of nonpoint source pollutants to recieving waters in the Tidewater Virginia region. Samples taken from six shallow observation wells in the Lynnhaven basin showed

that concentrations of nutrients were high (eg: >20.0 mg/l nitrite-nitrate) indicating that groundwater contributions may be significant.

Data on the effectiveness of the following management practices were taken from the available literature:

Small detention ponds
Large detention ponds
Grassed swale roadways
Fertilizer management
Concrete grid pavement

The effectiveness data were then applied to the following land use planning categories:

Low density residential
High density residential
Multifamily residential
Commercial-strip
Commercial-central business district
Light industry
Heavy industry
Institutional
Open land

The following statements summarize the effectiveness of the various management practices in their application to urban uses in the Tidewater vicinity:

1. In all land use categories, large detention ponds removed the greatest amount of the baseline pollutant loadings.

2. Grassed swale waterways appear to be as effective as small detention ponds in trapping pollutants from residential uses. Swales were particularly effective in reducing BOD loadings.

3. Since there are large areas of impervious cover in institutional and industrial uses, only a small fraction of these areas can be treated by swales. Small detention ponds would achieve greater loading reductions than swales when applied to these uses.

4. Due to the large fraction of light use pavements (parking lots and driveways), permeable concrete grid pavements appear to have the potential to reduce loadings as much as small detention ponds for the commercial uses. The grids were not as effective as swales for those uses where both practices were applicable (residential, industrial, institutional).

5. Reducing the application of fertilizers through a public education program has the potential of lowering nutrient loads from residential and commercial uses by 50%.

INTRODUCTION

Stormwater runoff rates, groundwater recharge, and runoff borne pollutants are problems of growing concern in developing urban regions, typified by the Hampton Roads area of Tidewater Virginia. Fallow and farm land is being replaced by roads, homes, parking lots, and other impervious cover which all serve to 1) increase downstream flood peaks and runoff volume, 2) accelerate the transport of land derived pollutants to recieving waters, and 3) reduce the recharge of groundwater which was once available to users. Man made drainage improvements reduce the natural ability of the land to assimilate pollutant loads generated during storms. This results in increased transport of pollutants into coastal receiving waters.

This study focuses on engineering solutions (management practices) designed to reduce the impacts of urbanization on stormwater quantity and quality. Prior to the passage of the Clean Water Act Amendments of 1972 (PL92-500), little attention had been given to the subject of ameliorating nonpoint sources of pollution. Since that time, the Hampton Roads Water Quality Agency and others have been trying to document the costs and effectiveness of various methods for reducing or controlling nonpoint source loads so that meaningful conclusions and programs can be developed for lessening their impact. Until such information is available, it will be impossible to develop effective management strategies or forcefully argue for the implementation of management practices (MP's) which are designed to reduce stormwater runoff loadings.

The report is comprised of two sections. The first describes the field studies of existing practices conducted by the Virginia Institute of Marine Science. In Section Two, reference tables are presented showing the pollutant reduction potential of various practices when they are applied to the urban land use categories used by planning agencies in the designated 208 area (HRWQA, 1978). Data from the field studies were used in compiling the tables, along with management practice information available in the literature.

I. FIELD STUDIES

Rainfall/runoff data were collected from study sites selected within the designated Hampton Roads 208 area. The catchments monitored were primarily within the drainage basin of Lynnhaven Bay, which currently suffers from nutrient enrichment problems. It was often necessary, however, to monitor study sites outside of the Bay watershed simply because of the lack of management practice examples within that system which were suitable or conducive to testing. For example, an attempt to sample the affects of a perimeter dike/pumping system was thwarted by the fact that the pump was never working during storms. In another case, a sediment curtain designed to protect a small lake was improperly installed by the construction firm. Financial constraints required us to use automatic samplers to collect composite samples of runoff. Although fecal coliform contamination is a known problem in the Lynnhaven, coliform studies were not conducted because representative bacteriological samples could not be obtained using the automatic samplers. Actual data collection began in September of 1980 and continued until the end of March 1982.

Description of the Selected Study Sites

Although eleven monitoring stations were established during the study, only three management practices were actually evaluated because several of the stations represented variations of the same practice. These included a comparison of two types of residential drainage (5 stations), a comparison of stormwater detention ponds of various sizes (5 stations), and a before and

Table 1. A comparison of the catchment characteristics of the curb and gutter and swale drainage study sites.

Station Name	Description	Catchment Area (ha)	(ac)	Dwellings (units/ha)	Estimated % Impervious
Thalia	Swale drainage	4.82	11.91	4.77	10-20%
Kings Grant	Curb and gutter subsurface drainage	0.72	1.78	15.28	30-40%
Wolfsnare Swales	Swale drainage	3.98	9.83	5.77	10-20%
Wolfsnare Curbs	Curb and gutter	2.35	5.81	3.83	20-30%
Great Neck Rd.	Curb and gutter, primarily highway	2.36	5.83	2.12	>50%

after look at artificial seeding of a construction site (one station).

The characteristics of the residential catchments are presented in Table 1. These were occupied to compare differences between areas having curb and gutter drainage with those having open roadside ditches (swales). In this urban setting, the ditches are included as part of the residential lots, and are often mowed and fertilized along with the rest of the lawn. For this reason the ditches are referred to as drainage 'swales'. It was expected that the swales would provide more contact with pervious surfaces, thereby reducing the amount and improving the quality of storm runoff leaving the catchment. The Thalia and Kings Grant sites were in close proximity to one another, and were monitored concurrently from September 1980 to February 1981. The Wolfsnare and Great Neck Road sites were within the Wolfsnare Lake watershed, providing input data from September 1981 through March 1982 to be compared with the measurements made at the outfall of Wolfsnare Lake during the same period.

The detention ponds were chosen in particular to allow for the comparison of the behavior of ponds having different pond volume-to-inflow area ratios. Wolfsnare Lake, the largest of the three systems, had a watershed area that was only four times greater than the surface area of the pond (Table 2). The smallest was the small detention basin at Riverside Hospital, a dry reservoir where water becomes ponded only during periods of storm runoff. The Lynnhaven Mall pond was more or less 'average' in basin size properties, having nearly 100 percent of its watershed occupied by commercial parking areas. It was anticipated that the smaller the pond size, the less pollutants would be retained in the ponds. Although a crude model, this principle has been successfully demonstrated for reservoirs in the past (cf. Brune, 1953; Dendy, 1974).

In monitoring the ponds it was necessary to instrument a number of catchments flowing into them in addition to the outlet structure. As a result,

Table 2. A comparison of the characteristics of the detention pond study sites.

Station Name	Description	Inflow Area (ha)	Inflow Area (ac)	Pond Area (ha)	Pond Area (ac)	Pond volume:Inflow area ratio
Wolfsnare Pond	Med. Density Residential	66.01	163.11	15.74	38.89	7.15
Lynnhaven Mall Pond	Commercial Parking Area	43.30	106.99	1.699	4.20	1.18
Riverside Hospital	Institutional	3.12	7.71	0.017	0.04	0.16

valuable data was collected which characterize the pollutant loadings derived from a variety of urban land uses in addition to making the intended management practice comparisons. The physical attributes of these urban catchments will be further described along with the presentation of results in the section following.

The construction site was a small area (0.776 acres) of entirely pervious cover which was monitored while denuded (Fall 1980), and again in the summer of 1981, well after the establishment of grass. The site was part of the grounds of the York County Courts Office Facility (YCCOF) located at Yorktown on the Virginia Peninsula.

Methods and Materials

The following information describes the field procedures and laboratory techniques used in the management practice runoff monitoring studies.

Field - Each monitoring station was instrumented to collect rainfall and flow volume data, and automatically take samples during periods of storm runoff. Some of the sites had continuous flows between storms (particularly at the ponds); flows were measured and grab samples collected by hand to assess the quality of the baseflow.

An H-type flume for channeling and gaging runoff was installed at each station as the primary control device. These were built out of sheet steel according to specifications outlined in 'A Manual for Research in Agricultural Hydrology' published by the U.S. Department of Agriculture (Handbook 224, 1979 ed.). An exception to this was the large outlet of Wolfsnare Lake, where a 4-foot sharp crested rectangular weir was used as the primary control. Runoff volume was not measured at the Riverside Hospital detention pond facility because it was assumed that the volume flowing into the pond was equal to that flowing out, and that any pollutant reduction function of the pond would be evidenced by simply a change in concentration between inflow and outflow. This allowed for a more simple and reliable instrument set-up at this location and made flowmeters available for use at other stations during the same period in 1981.

Rainfall data for each station was provided by a tube type raingage. A single recording gage sensitive to 0.01 inch was placed in close proximity to the sites to provide data characterizing the duration and intensity of the storms.

The flowmeters used were ISCO model 1870 pressure transducer type, having the appropriate stage-discharge information for the particular weir or flume at the station. This allowed for direct measurement of flow in units of cubic feet, and a trace of flow rate (cubic ft. per second) on a stripchart recorder at a chart speed of one inch per hour. The meter was connected by cable to an ISCO model 1530 water sampler to collect flow proportioned composite samples of storm runoff. Composites were picked up within 18 hours after the end of the storm hydrograph.

Laboratory - Upon receipt at the VIMS facility in Gloucester Point, volumes from the composite were poured into containers, treated with the appropriate preservatives, and stored at 4 °C until analysis. Stripchart records and data in the field log were scrutinized at this point to determine whether the records were complete and accurate to warrant continuing with chemical analysis. If records were complete, the analyses were made, and the event data were included in the data base for the site.

The focus of the study was on nutrient forms and suspended solids. The analyses were made following the preservation, storage, and analytical proceedures outlined in 'Methods for the Chemical Analysis of Water and Wastes' U.S. EPA, 1979 ed.). Quality control in the laboratory employed the Shewart replicate procedure for determining precision and accuracy of environmental sample analyses, outlined in the 'Handbook for Analytical Quality Control in Water and Wastewater Laboratories' (U.S. EPA, 1979 ed.). The following tests were performed on grab and composite samples:

1. total Kjeldahl nitrogen (TKN)
2. dissolved ammonia nitrogen (NH3)
3. dissolved nitrite-nitrate nitrogen (NO2NO3)
4. total phosphorus (TP)
5. dissolved orthophosphate (OP)
6. biochemical oxygen demand (BOD5)
7. total organic carbon (TOC)
8. suspended solids (SS)

From these measurements, the various organic fractions of the forms of nitrogen and phosphorus were calculated as follows:

1. organic nitrogen (ORG-N) = TKN - NH3
2. total nitrogen (TN) = TKN + NO2NO3
3. organic phosphorus (ORG-P) = TP - OP

RESULTS

During the period from September 1980 through March 1982, a total of 91 storm runoff events were monitored for water quality and quantity. The storms were distributed among 11 study catchments within the designated Hampton Roads 208 area. Figure 1 is a monthly synopsis of the activity at each site. Since only four sets of automatic flow gaging and sampling equipment were available, stations were occupied over an average of four months each to collect data. In the meantime, potential sites were visited to locate new study catchments which would provide the requisite management practice comparisons for future monitoring.

The Tidewater area of Virginia experienced drought conditions from the summer of 1980 through fall 1981 (U.S. Env. Data Service, 1981). As a result, the collection of data at each catchment was slower than anticipated. We expected four storms per month per station, while actually averaged somewhere between 2 and 3. The field efforts were particularly hindered during the winter months, when freezing conditions made flow gaging impossible.

The water quality and flow data measured for each storm are tabulated in Appendix A. The results of all chemical analysis are represented in units of mg/l. In the case of flow-weighted composite data, the values represent the concentrations which would have been observed had all of the runoff been collected into one large sample container. The flow-weighted values can thus be multiplied by the amount of water leaving the catchment as runoff to arrive at the amount of mass passing through the monitoring station during the course of the storm event. In addition to composite sampling, grab samples were collected at sites having continuous flow during periods between storms, so that the flux of pollutant constituents during non-storm conditions could be

Figure 1. A synopsis of runoff events monitored at the management practice evaluation sites, September, 1980 - March, 1982.

	1980				1981												1982			
Site:	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	Totals
Thalia	1	2				2														5
Kings Grant	1	2	1	1		2														7
YCCOF		2	1	1		2				2	1	3	1							13
Lynn Mall Roof							1	4	3											8
Lot							1	3	3											7
Pond							1	4	3	1										9
Riverside Pond										2	5	6	4	1						18
Wolfsnare Swales															2	2		1		5
Curbs														1	4	2	1		1	9
Great Neck Rd.															3	2	1			6
Wolfsnare Pond																	1		3	4
Totals	2	6	2	2	0	6	3	11	9	5	6	9	5	2	9	6	3	1	4	91

accounted for. The tables in the Appendix indicate whether the concentration values were measured from grab or composite samples.

OVERALL SITE COMPARISONS

Although the study is intended to evaluate the reduction in stormwater pollutant loadings brought about by the installation of management practices, it is useful to compare runoff loadings among all of the sites since the catchments monitored represent several types of urban land uses. Runoff quantity and quality were measured from residential, commercial, institutional, construction, and reservoir watersheds within the Hampton Roads 208 area.

It is important to place the pollutant loading rates of these land use types in perspective before discussing the performance of management practices, since the land uses contributing the greatest areal loads should be identified as priority areas for treatment when water quality problems exist. Although there may be a very large percent reduction in pollutant loading due to the implementation of a particular management practice, it is the net reduction that is important in terms of impacts on the receiving waters.

Nutrient Concentrations

A directly measured indicator of pollution levels in runoff is that of nutrient concentration. Because there was often a large variation in any given parameter at a single site, it should be pointed out that there was often considerable overlap in the data when comparing among the different catchments. Since a single number was desired for making comparisons, the median was chosen as best representing the central tendency of the observations for each parameter at each site. The median is the value which is at the midway point of the range of data, i.e., there are an equal number of data points above and below the median value. It is a better choice than the arithmetic mean because the mean can be uncharacteristically high or low due to the influence of an extreme observation.

Median values for pollutant concentrations measured at the various catchments and land use categories are given in Table 3. In general, the catchments having nearly 100% impervious cover (commercial/institutional) have higher concentrations of pollutants associated with the particulate fractions of runoff (i.e. suspended solids, organic nitrogen and phosphorus, total organic carbon, and BOD5). The concentrations of these constituents were all higher in commercial/institutional runoff than at the residential catchments by a factor of roughly 2.5, except in the case of suspended solids, which was higher by a factor less than two. The dissolved nutrient concentrations, on the other hand, were not notably higher in the parking lot runoff except in the case of ammonia, which also was higher roughly by a factor of two. In fact, dissolved orthophosphorus concentrations were obviously higher in runoff from the three swale drainage sites, perhaps an affect of greater contact with soils and vegetation, or from the use of fertilizers in the residential areas.

It is notable that concentrations in runoff from the construction site were most similar to those from the commercial/institutional catchments. Concentrations of dissolved constituents were low, again indicating that most of the pollutant load was associated with the particulate fraction. Most significantly, suspended solids concentrations here were 100 times greater than at any other site, and total organic carbon concentrations greater by a factor of five.

In the case of the detention ponds, pollutant concentrations were generally less flowing out of the ponds than were measured in runoff entering them. These ponds were chosen in particular to allow for a comparison of the performance of ponds having different pond volume-to-inflow area ratios. The ratios of volume (acre-inch) to watershed area (acres) were 0.16, 1.18,

Table 3. A comparison of median pollutant concentrations among all of the study sites.

	Total P	Ortho P	Org P	NH_3 N	NO_2+NO_3 N	Org N	Total N	SS	BOD_5	TOC
	Concentrations (mg/l)									
<u>Curb and Gutter</u>										
Kings Grant	0.26	0.10	0.16	0.15	0.20	0.62	0.97	46.0	5.6	6.2
Wolfsnare Curbs	0.18	0.09	0.09	0.11	0.39	0.53	1.03	14.6	9.0	11.8
<u>Swales</u>										
Thalia	0.47	0.28	0.19	0.04	0.35	0.75	1.14	22.0	8.38	12.0
Wolfsnare Swales	0.45	0.30	0.15	0.15	0.36	0.76	1.27	14.0	4.50	12.1
<u>Institutional/Commercial</u> (inflow)										
Riverside Hosp.	0.82	0.09	0.73	0.16	0.36	2.61	3.13	51.5	11.10	17.0
Lynnhaven Mall Lot	0.35	0.12	0.23	0.38	0.46	1.18	2.02	19.0	6.80	18.0
Great Neck Road	0.21	0.06	0.15	0.30	0.70	0.07	1.07	21.8	6.03	16.5
<u>Detention Ponds</u> (outflow)										
Riverside Hosp.	0.40	0.11	0.29	0.31	0.48	1.14	1.93	27.5	8.75	19.0
Lynnhaven Mall Pond	0.14	0.01	0.14	0.01	0.01	1.10	1.12	22.0	6.8	10.0
Wolfsnare Lake	0.07	<0.01	0.07	0.03	<0.01	1.14	1.18	7.0	3.00	9.2
<u>Construction</u>										
York County Office Facility	0.61	<0.01	0.60	0.02	0.04	2.42	2.48	2308.0	15.05	59.0

and 7.15 for the Riverside Hospital, Lynnhaven Mall, and Wolfsnare ponds, respectively, assuming a mean depth of 2.5 ft (Table 2). The Riverside pond was small and normally dry, containing water only during storm episodes. The particulate nutrient concentrations in pond outflow decreased as the drainage:pond area decreased. Thus, the larger ponds appeared to release less pollutants than the smaller ones, however, concentrations in runoff entering the larger ones were also less. An important effect of the ponds is the apparent conversion of dissolved nutrients into organic forms, probably by incorporation in the phytoplankton biomass evidenced by the large decrease in orthophosphorus, ammonia, and nitrite-nitrate between inflow and outflow. This was not the case for the Riverside pond, which has no standing phytoplankton populations. As a result of phytoplankton incorporation and subsequent transport of them out of the ponds in outflow, organic nitrogen concentrations were not less than in the inflow to the larger ponds. Organic phosphorus was lowered, however, probably due to the fact that the phytoplankton incorporate nitrogen into biomass at roughly a 12:1 ratio over phosphorus.

Pollutant Loading Rates

Of course, concentration values do not reflect the total mass of a pollutant leaving a catchment or reservior. Instead, the product of concentration and runoff flow yields the amount of mass transported over the sampling period. To account for differences in drainage areas among the various catchments, the mass flux is divided by the area, in hectares, of each. To allow for a comparison among storm events having different amounts of precipitation, the areal loadings are further divided by the amount of rainfall for each individual storm to yield a loading value in terms of mass per unit area per unit rainfall (g/ha/cm). Appropriate conversion factors to more familiar units of lbs/acre/yr are given as the data are reported. In this way comparisons of individual loading rates can be made among different catchments for different storms. In the case of the ponds, where there was continuous flow between storms, the baseflow or non-storm loadings had to be accounted for.

A statistic which is very useful for comparison among sites is the runoff coefficient, R. R is often referred to as the hydraulic effficiency of a catchment, and is computed on an individual storm basis as the volume of water measured leaving the catchment as surface runoff, divided by the volume of water falling on it. It is therefore the fraction of rainfall which leaves the catchment as surface runoff, and can never have a value greater than 1.0. Catchments which are hydraulically more efficient, such as those which have large areas of asphalt and concrete, transmit more rainfall as surface runoff and have a higher R value. R values usually range from less than 0.05 to greater than 0.90. Since concentrations among the catchments varied by only a factor of 2, one can see that the hydraulic efficiency becomes the primary factor influencing the flux of pollutant mass leaving a watershed, since R values can be expected to range over an order of magnitude among sites.

Again, the median value provides a single statistic which is useful for comparing the loading rates calculated for the storms at each site. The median loading rates and R values for all the sites, except Riverside Hospital, are reported in Table 4. It can be seen that when one considers pollutant loading rather than concentration, the differences among sites becomes striking. In general, the catchments that have little or no pervious cover had R values and loading rates that were an order of magnitude greater than any of the residential catchments.

A plot of R values (Figure 2) and Total Phosphorus loading (Figure 3) more completely details the trends presented in Table 4. The diagrams

Table 4. A comparison of the median pollutant loading rate and runoff coefficients among all of the study sites.

	R	Total P	Ortho P	NH_3 N	NO_2+NO_3 N	Org N	Total N	SS	BOD_5	TOC
		Loading (g/ha/cm)								
Curb and Gutter										
Kings Grant	0.269	4.60	1.69	3.41	5.34	12.61	22.24	857.6	126.3	148.1
Wolfsnare Curbs	0.104	2.41	1.26	1.51	5.18	7.51	13.52	232.6	113.5	161.7
Swales										
Thalia	0.064	3.14	2.35	0.33	2.05	6.73	10.28	195.4	54.9	90.2
Wolfsnare Swales	0.017	0.79	0.55	0.14	0.59	1.11	2.52	21.2	10.5	22.2
Institutional/Commercial (inflow)										
Lynnhaven Mall Lot	0.688	26.8	12.0	53.9	44.6	62.7	176.1	1.67×10^3	605.6	1.12×10^3
Great Neck Road	0.667	15.65	2.07	26.25	25.71	46.9	80.5	1.77×10^3	413.9	920.3
Detention Ponds (outflow)										
Lynnhaven Mall	0.463	5.78	0.49	0.50	0.54	44.4	46.3	672.4	253.2	394.4
Wolfsnare Lake	0.299	2.85	0.29	1.04	3.49	37.94	40.1	441.9	137.6	311.2
Construction										
York County Office (before)	0.142	13.2	0.14	0.18	0.38	43.9	44.3	19.9×10^3	156.0	504.9

1 g/ha/cm = 0.00226 lb/ac/in 1/lb/ac/in = 442 g/ha/cm

Figure 2. Runoff coefficients for the residential catchments.

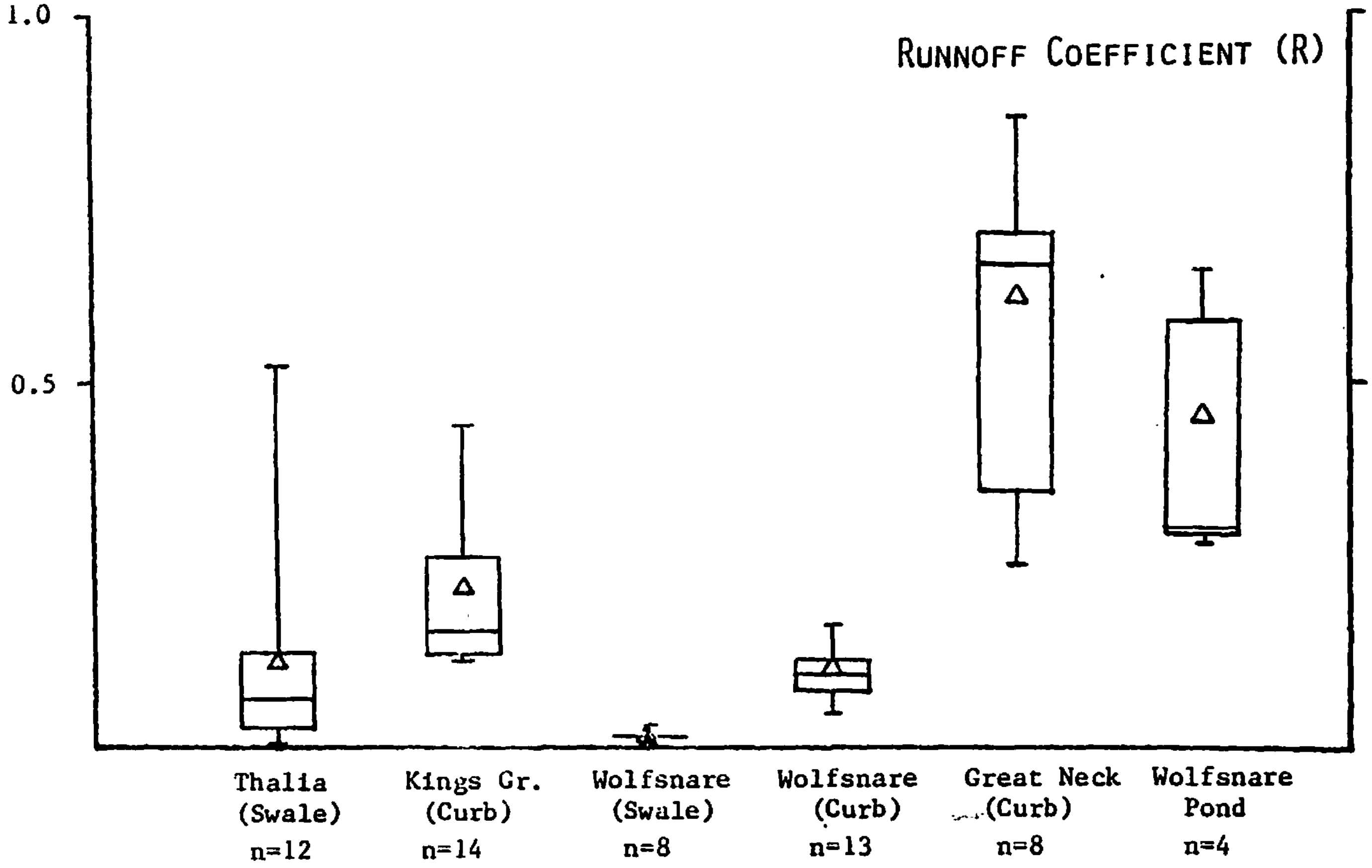


Figure 2. Runoff coefficients for the commercial study sites and construction site.

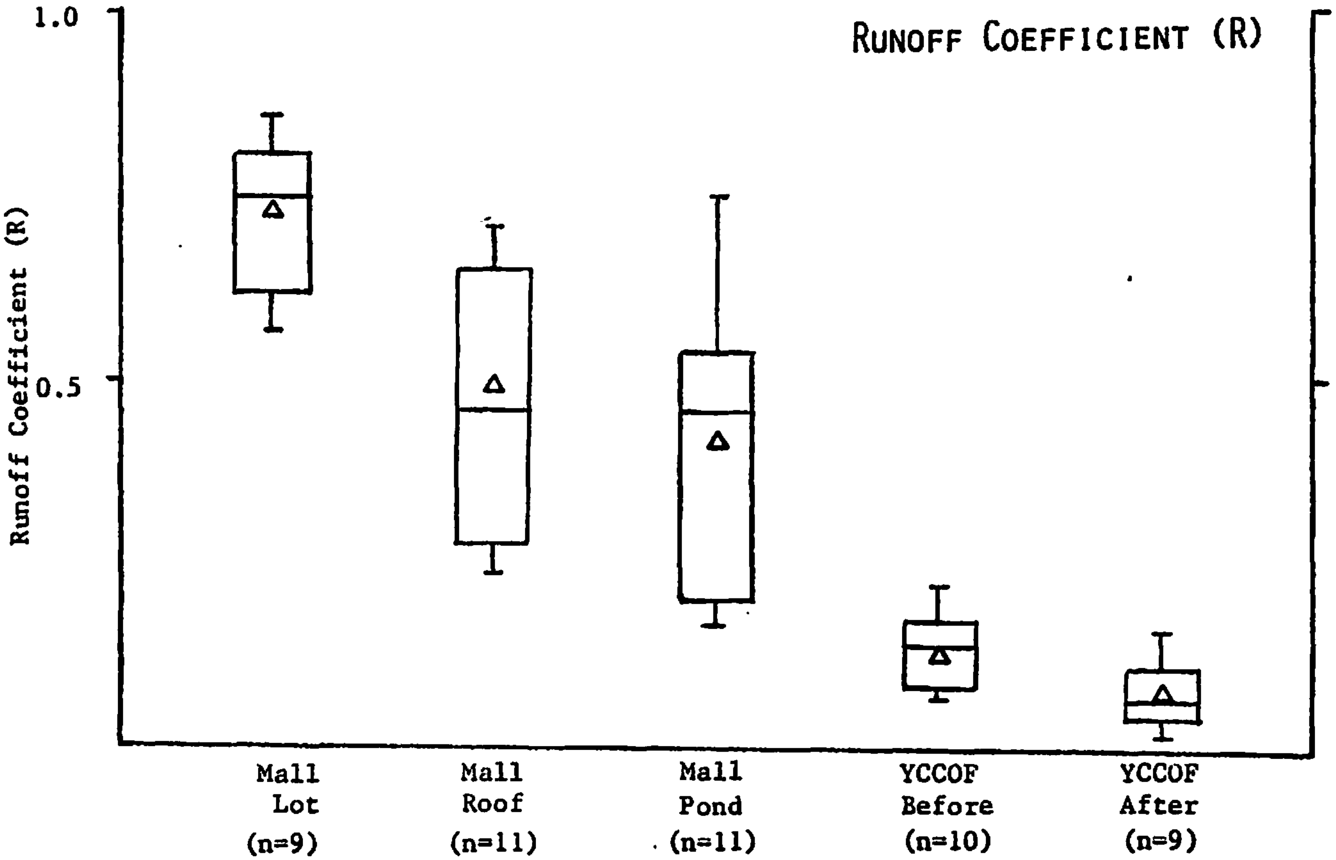


Figure 3. Loading rates for total phosphorus at the residential study catchments.
(1 g/ha/cm = 0.00226 #/ac/in)

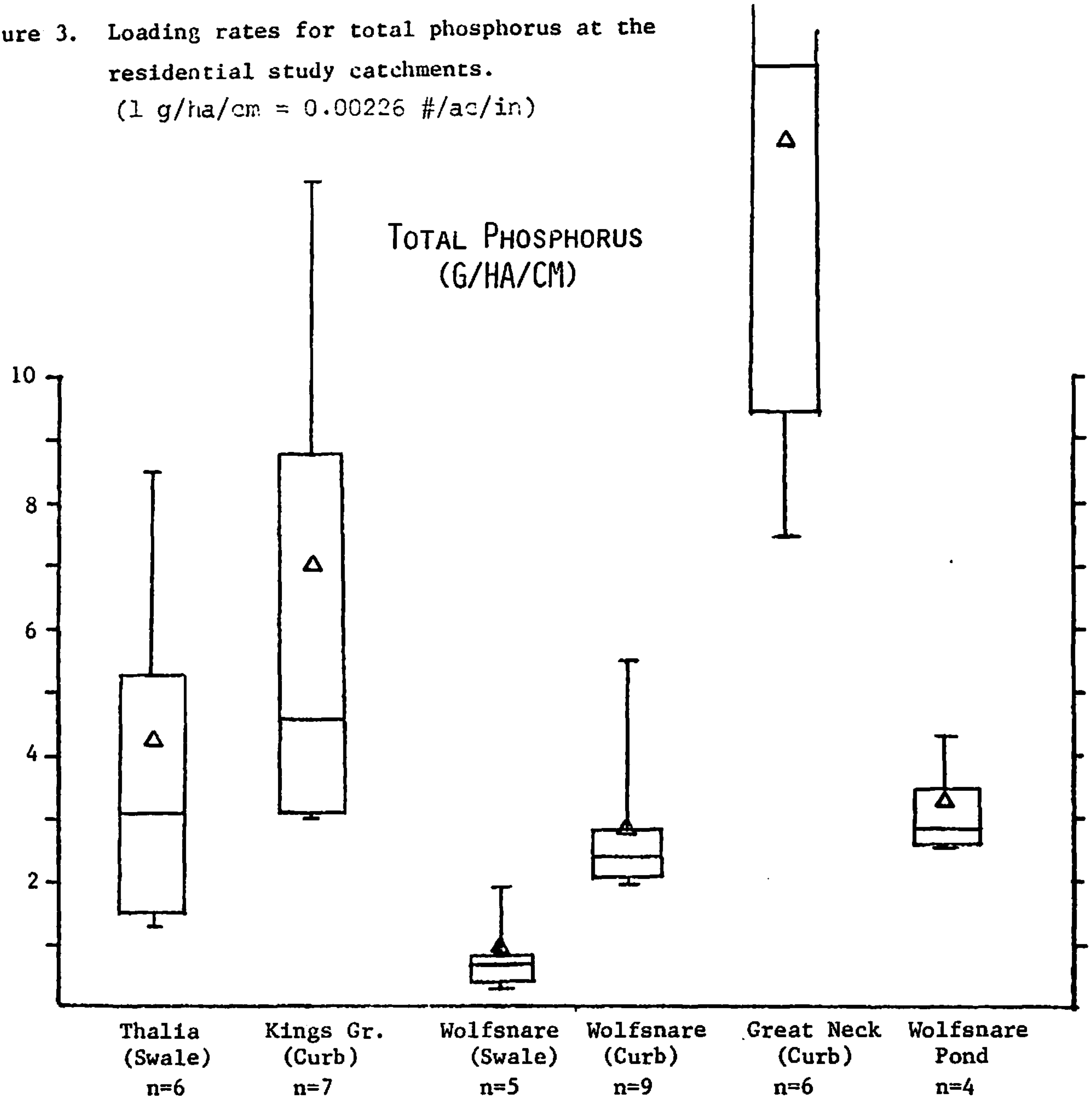
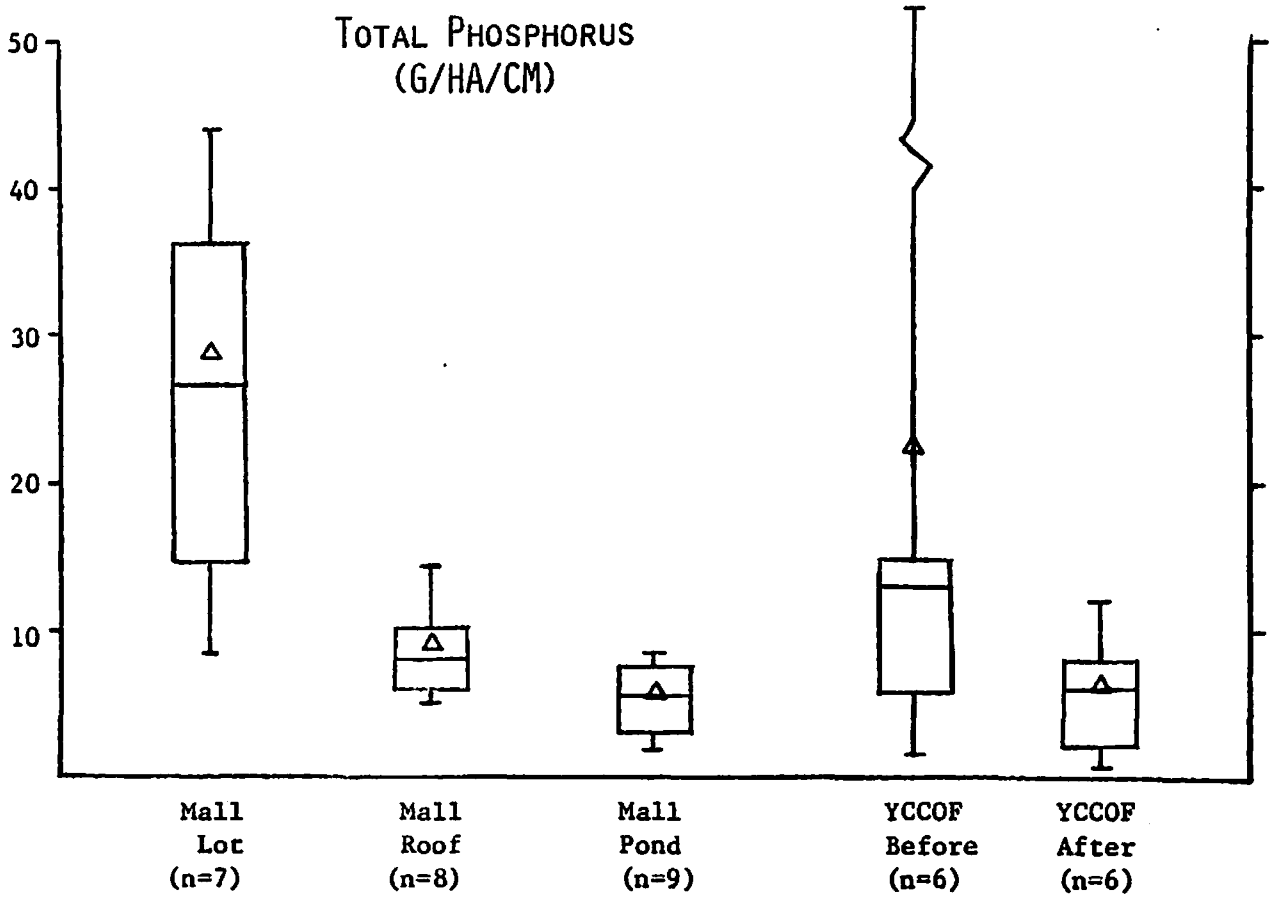


Figure 3 (continued). Loading rates for total phosphorus at the commercial study sites and construction site.
(1 g/ha/cm = 0.00226 #/ac/in)



represent the distribution of all of the loading rates for the number of storms (n) monitored at each site. The minimum and maximum values are represented by the upper and lower limits of the vertical bars. The horizontal bars forming the box represent the median value, or 50th percentile (middle bar) and the 25th and 75th percentile (upper and lower limits of the box). The triangle represents the arithmetic mean value.

In almost all cases, the mean values are higher than the median, and is explained simply by the distribution of rain events. As a rule, there are more small storms than larger ones, the larger producing more runoff per unit of precipitation (Grizzard, 1982). The loadings from the many smaller storms would reduce the median value, while one very large storm tends to inflate the arithmetic mean significantly.

The most important feature illustrated by the figure is the fact that there is considerable overlap in the calculated loading rates and R values among the sites. It therefore becomes difficult to quantify differences in loading rates among the sites or management practices. Statistical methods must be used which examine the entire distribution of the data sets, rather than simply compare the mean or median value. The statistical methods employed in the next section to quantitatively compare sites having different practices will be discussed in detail as they are used.

MANAGMENT PRACTICE EVALUATION

The study sites were chosen in an attempt to discern differences brought about by the implementation of management practices within the catchments. It is important to point out that no two sites can be expected to be exactly identical in their physical characteristics. Differences in soil types and slope, for example, influence the results and confound any attempt to pinpoint differences among the sites as being attributed solely due to the employment of a given practice. For this reason, sites were selected having similar physical characteristics insofar as was possible, so that the management practices constituted the primary difference among sites. Sites that were to be directly compared were selected in close proximity to one another in order to minimize differences in runoff response due to variations in storm characteristics and antecedent rainfall.

Comparisons made in this chapter are intended to provide a quantitative assesment of the differences in pollutant loading among practices. Because of the factors mentioned above, comparisons are made only between sites which were occupied in close proximity and during the same period in time. In the cases in which there is reason to compare among different stations which were not monitored concurrently, the reader is cautioned that differences in climate and season may have influenced the hydraulic efficiency of the catchments, and thereby affected the loading rates presented. Due to the physical differences among sites, it should also be pointed out that the results presented here are differences in toto, and include differences due to management practices as well as physical characteristics, the precipitation record at the sites, and even the success rate of the monitoring effort, which was subject to the occasional malfunction of the automated sampling and data recording equipment. Given these cautions, quantitative comparisons are reported in this section for the site pairs as follows:

Station(s)	MP Evaluated	Table Number
Kings Grant v. Thalia	Curbs v. Swales	5
Wolfsnare curbs v. WS*swales	Curbs v. Swales	6
York County Courts Office	Artificial seeding	7
Riverside Hospital	Small detention pond	8
Lynnhaven Mall Lot v. Pond	Medium detention pond	9
Wolfsnare swales v. WS Lake	Large pond	10
Great Neck Road v. WS Lake	Large pond	11

*WS = Wolfsnare

Curb and Gutter v. Swale Drainage

In the previous Chapter it was pointed out that the pollutant loading rate calculations for individual storms yielded results that were highly variable for each of the study catchments. Most of the calculated loadings fell within the lower range of the distribution of the data points, a feature typical of hydrologic data sets (Grizzard, 1982). This feature has definite implications for the statistical treatment of the results. For example, the arithmetic mean is seriously affected by the few extreme points, and no longer represents the central point of the distribution of the data. Familiar statistics such as analysis of variance, which use the mean as the center of the distribution, cannot be applied to test for significant differences among two data sets having skewed, non-normal distributions. To overcome this problem, non-parametric statistical methods can be used which do not require that the data be normally distributed about the arithmetic mean.

The Mann-Whitney U rank sum test is one such method. It compares two sample populations of data to see if they are different, based on the amount of overlap in their distribution. Ranks are assigned to each observation in the entire data set. If one of the sample populations differs substantially from the other, it can be expected to have a greater number of either higher or lower ranks than the second population. The sum of the ranks are evaluated relative to established numerical criteria which determine whether the difference in ranks are large enough to be from truely different populations (Sokal and Rohlf, 1969).

Actually, the criteria for making such a decision are applied at the discretion of the user, and are referred to as the 'level of significance', which is a measure of the probability that the populations are actually different. If the difference between ranks is large or the overlap in distributions small, then there is a high probability that the two populations are different. In scientific circles, a probability of 0.95 or greater (or, conversely, $p<0.05$ or lesser) are usually employed as the cut off level for labeling populations as being 'statistically different' (Sokal and Rohlf, 1969).

Tables 5 and 6 depict the differences in median pollutant loading and the results of the Mann-Whitney rank sum test for the two swale v. curb and gutter comparisons made during the study. Efficiencies in the reduction of pollutant loading, expressed as the percent difference relative to the loading at the curb sites, ranged from an increase to over 90% reduction in pollutant loading (right column). In general there was greater efficiency in reduction at the two Wolfsnare sites (Table 5) than between Kings Grant and Thalia. Although the Mann-Whitney test indicted that there were significant differences in some cases ($p<0.05$), there were no commonalities in the parameters that were statistically different on both tables, except in the case of R values.

Swale drainage appears to influence ammonia loadings the greatest, and orthophosphorous the least. Loading differences in total nitrogen and phosphorous may be attributed to the reduction of the particulate fraction of runoff, evidenced by the high percent reduction of suspended solids and generally higher net reduction of the organic rather than dissolved inorganic forms of the nutrients.

Table 5. A comparison of median pollutant loading, Kings Grant (curbs) vs. Thalia (swales), September 1980 - March 1981.

	Median Loading (g/ha/cm)				
Pollutant	Kings Grant	Thalia	Net Change	Mann-Whitney U Significance Level	% Reduction in Loading
Total P	4.60	3.14	- 1.46	0.295	-31.7
Ortho P	1.69	2.35	+ 0.66	0.836	+39.4
NH_3-N	3.41	0.33	- 3.08	0.018*	-90.3
NO_2+NO_3-N	5.34	2.05	- 3.29	0.181	-61.6
Organic N	12.61	6.73	- 5.88	0.148	-46.6
Total N	22.24	10.28	-11.96	0.022*	-53.8
Susp. Solids	857.6	195.4	-662.2	0.042*	-77.2
BOD_5	126.3	54.9	-71.4	0.393	-56.5
TOC	148.1	90.2	-57.9	0.126	-39.1
R	0.269	0.064	- 0.205	0.001*	-76.0

1 gm/ha/cm = 0.00226 lb/ac/in   1 lb/ac/in = 442 g/ha/cm

*indicates $p \leq 0.05$

Table 6. A comparison of median pollutant loadings, Wolfsnare Lake Curbs vs. Swales Drainage, October 1981 - March 1982.

	Median Loading (g/ha/cm)				
Pollutant	Wolfsnare Curbs	Wolfsnare Swales	Net Change	Mann-Whitney U Significance Level	% Reduction in Loading
Total P	2.41	0.79	- 1.62	0.001*	-67.2
Ortho P	1.26	0.55	- 0.71	0.060	-56.3
NH_3-N	1.51	0.14	- 1.37	0.147	-90.7
NO_2+NO_3-N	5.18	0.59	- 4.59	0.001*	-88.6
Organic N	7.51	1.11	- 6.40	0.154	-85.2
Total N	13.52	2.52	-11.00	0.154	-81.4
Susp. Solids	232.6	21.2	-211.4	0.073	-90.9
BOD_5	113.5	10.5	-103.0	0.010*	-90.7
TOC	161.7	22.2	-139.5	0.001*	-86.3
R	0.104	0.017	- 0.087	0.001*	-83.7

1 g/ha/cm = 0.00226 lb/ac/in 1 lb/ac/in = 442 g/ha/cm

*indicates $p \leq 0.05$

Artificial Seeding of a Construction Site

The results of Mann-Whitney comparisons for the York County Office Facility, before and after establishment of seedlings on the site are depicted in Table 7. Although grass was planted in September 1980 before the initial monitoring began, the seedlings were minimally successful, and the site was essentially bare throughout the fall. The seeded area became established during the following spring, and the turf was well developed by the second monitoring period, beginning in June 1981.

Two very notable features arise from the table. The first is that export of dissolved nutrients from the site increased after the establishment of grass (significantly for NO2+NO3). The site was monitored three months after seeding, and over a four month period from June - September, 1981. Examination of the data indicates that dissolved nutrient concentrations remained consistently high throughout the four month period rather than exhibit a decay curve which would be expected had the high levels been brought about by a past application of fertilizer. The second noteworthy feature is the drastic reduction in suspended solids loading, presumbably due to stabilization of the denuded soils. The median loading rate of suspended solids after the establishment of grass was still an order of magnitude greater than was measured at any other catchment, probably because the much steeper slopes at the York County site provide greater energy for erosion and transport of particulate material. The reduction in loading due to seeding represented a difference in suspended solids of over 15,000 g/ha/cm (33.9 lb/ac/in).

Table 7. A comparison of median pollutant loadings, York County Courts Office before and after artificial seeding, October 1980 - October 1981.

Pollutant	Median Loading (g/ha/cm) YCCOF (Before)	YCCOF (After)	Net Change	Mann-Whitney U Significance Level	% Reduction in Loading
Total P	13.2	6.23	- 6.97	0.065	-52.8
Ortho P	0.14	0.43	+ 0.29	0.333	+207.1
NH_3-N	0.18	1.42	+ 1.24	0.191	+688.9
NO_2+NO_3-N	0.38	3.60	+ 3.22	0.032*	+847.4
Organic N	43.9	36.5	- 7.4	0.691	-16.9
Total N	44.3	44.5	+ 0.2	1.000	0
Susp. Solids	19.9×10^3	4.63×10^3	-15.3×10^3	0.022*	-76.8
BOD_5	156.0	92.1	-63.9	0.556	-40.9
TOC	504.9	127.9	-377.0	0.016*	-74.7
R	0.142	0.068	- 0.074	0.181	-52.1

1 g/ha/cm = 0.00226 lb/ac/in   1 lb/ac/in = 442 g/ha/cm

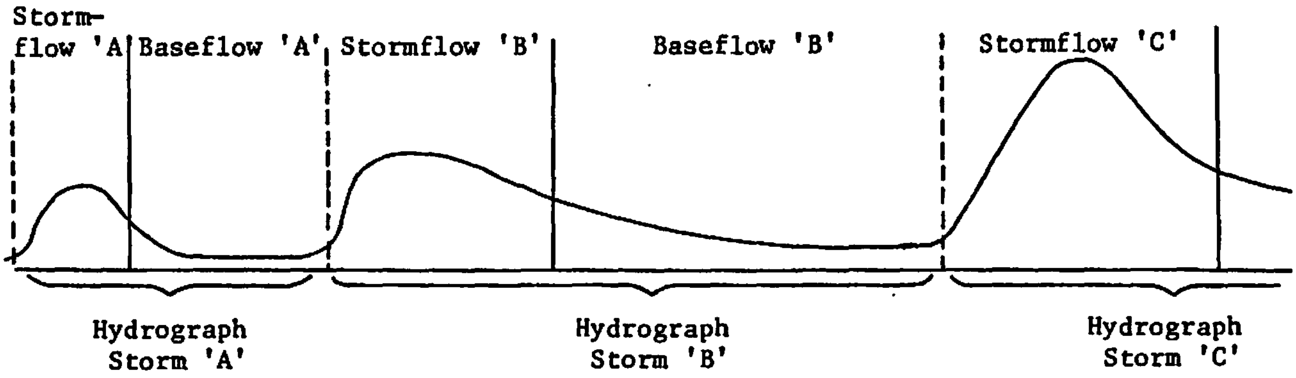
*indicates $p \leq 0.05$

Detention Ponds

Runoff volumes were not monitored into and out of the detention pond at Riverside Hospital. Since the pond was normally dry between storm events, and runoff entered it through a single inflow point, it was assumed that the volume of water entering during runoff episodes was equal to the amount leaving the pond. Therefore, only pollutant concentration was monitored, and the differences between inflow and outflow considered as representive of the reduction in pollutant loading during passage through the pond. Thus, the Mann-Whitney comparisons depicted in Table 8 are based on concentration data rather than areal loading rate. Although this provides a valid calculation of the efficiency of the pond (as percent reduction in concentration), it does not allow for a direct comparison with the net reduction in areal loading that have been calculated for Lynnhaven Mall and Wolfsnare Lake where flow volumes were monitored.

It was recognized that the larger ponds flowed continuously between storm episodes, and therefore nonstorm flow contributed to the total flux of pollutants leaving them. The quantity of water leaving the ponds was monitored continuously, with composite sampling at the outfall only during storm periods. The quality of the nonstorm flow was determined by taking grab samples between rainfall events. The baseflow pollutant loading between composite sampling episodes was calculated from these observations and then added to the storm loading for the preceding event to arrive at a total pollutant loading for each discrete storm. The calculations of outflow storm loadings are represented schematically in Figure 4.

Figure 4. Schematic representation of hydrograph analysis at detention pond outlets.



Stormload 'B' = (Stormflow 'A') x (composite pollutant concentration)

Baseload 'B' = (Baseflow 'B') x (mean grab pollutant concentration)

= Total load 'B'

Table 8 presents the results from the Riverside Pond inflow and outflow comparison. Dissolved nutrients and total organic carbon increased as runoff passed through the pond. The largest reductions in concentration were in total phosphorous and organic nitrogen, which are probably associated with the particulate fraction of runoff. However, none of the differences between inflow and outflow were statistically significant.

Table 9 compares the results from the Lynnhaven Mall parking lot station and the pond outfall. In this case there were significant reductions ($p<0.05$) in the loading of all constituents except organic nitrogen. Dissolved nutrients were reduced by over 90%, presumably due to uptake by the phytoplankton in the pond. The net reduction in pollutant loading were an order of magnitude greater than the net reductions determined in the swale v. curb and gutter comparisons for all constituents except suspended solids. This illustrates an important point about the interpretation of the loading rate reduction data: although the reduction efficiencies were nearly equal for the pond and swale comparisons, the NET reductions, and therefore amount of pollutants retained on site were greater in the case of the pond by a factor of 10.

Two tables comparing loading rates for the Wolfsnare Lake outlet and the swale and Great Neck road stations are presented because of the striking differences in loading rate between the two catchments flowing into the pond. In the case of the swale comparison (Table 10), there were consistantly higher loadings leaving the pond than were entering in swale runoff. On the other hand, there were always net reductions in pollutant loads leaving the pond when compared to that entering from Great Neck Road. These were of similar order of magnitude as the net reduction in loadings observed at the Lynnhaven Mall pond. Similarly, the greatest percent reduction occurred in the case of the dissolved nutrients.

Table 8. A comparison of median pollutant concentration in inflow and outflow at the Riverside Hospital stormwater detention pond, June - October 1981.

	Median Concentration (mg/l)				
Pollutant	Inflow	Outflow	Net Change	Mann-Whitney U Significance Level	% Reduction in Loading
Total P	0.82	0.40	-0.42	0.165	-51.2
Ortho P	0.09	0.11	+0.02	0.189	+22.2
NH_3-N	0.16	0.31	+0.15	0.279	+93.8
NO_2+NO_2-N	0.36	0.48	+0.12	0.328	+33.3
Organic N	2.61	1.14	-1.47	0.053	-56.3
Total N	3.13	1.93	-1.20	0.318	-38.3
Susp. Solids	51.5	27.5	-24.0	0.161	-46.6
BOD_5	11.1	8.75	-2.35	0.645	-21.2
TOC	17.0	19.0	+2.0	0.546	+11.2

Table 9. A comparison of median pollutant loadings, Lynnhaven Mall Parking Lot vs. Lynnhaven Mall Pond.

	Median Loading (g/ha/cm)				
Pollutant	Mall Lot	Mall Pond	Net Change	Mann-Whitney U Significance Level	% Reduction in Loading
Total P	26.8	5.78	-21.0	<0.001*	-78.4
Ortho P	12.0	0.49	-11.5	0.004*	-95.9
NH_3-N	53.9	0.50	-53.4	0.003*	-99.1
NO_2+NO_3-N	44.6	0.54	-44.1	0.003*	-98.7
Organic N	62.7	44.4	-18.3	0.268	-29.2
Total N	176.1	46.3	-129.8	0.030*	-73.7
Susp. Solids	1.67×10^3	672.4	-997.6	0.093*	-59.7
BOD_5	605.6	253.2	-352.4	0.030*	-58.2
TOC	1.12×10^3	394.4	-725.6	<0.001*	-64.7
R	0.688	0.463	- 0.225	<0.001*	-32.7

1 g/ha/cm = 0.00226 lb/ac/in 1 lb/ac/in = 442 g/ha/cm

*indicates $p \leq 0.05$

Table 10. A comparison of median pollutant loadings, Wolfsnare Swales vs. Wolfsnare Lake, October 1981 - March 1982.

Pollutant	Median Loading (g/ha/cm) Wolfsnare Swales	Wolfsnare Lake	Net Change	Mann-Whitney U Significance Level	% Reduction in Loading
Total P	0.79	2.85	+ 2.06	0.016*	+260.7
Ortho P	0.55	0.29	- 0.26	0.730	- 47.2
NH_3-N	0.14	1.04	+ 0.90	0.286	+642.8
NO_2+NO_3-N	0.59	3.49	+ 2.90	0.286	+491.2
Organic N	1.11	37.9	+36.8	0.029*	+3,314
Total N	2.52	40.1	+37.6	0.029*	+1,491
Susp. Solids	21.2	441.9	+420.7	0.029*	+1,984
BOD_5	10.5	137.6	+127.1	0.133	+1,210
TOC	22.2	311.2	+289.0	0.016*	+1,302
R	0.017	0.299	+ 0.282	0.016*	+1,659

1 g/ha/cm = 0.00226 lb/ac/yr 1 lb/ac/yr = 442 g/ha/cm

*indicates $p \leq 0.05$

Table 11. A comparison of median pollutant loadings, Great Neck Road vs. Wolfsnare Lake, October 1981 - March 1982.

	Median Loading (g/ha/cm)				
Pollutant	Great Neck Road	Wolfsnare Lake	Net Change	Mann-Whitney U Significance Level	% Reduction in Loading
Total P	15.65	2.85	-12.8	0.010*	-81.7
Ortho P	2.07	0.29	- 1.8	0.010*	-86.9
NH_3-N	26.25	1.04	-25.2	0.010*	-96.0
NO_2+NO_3-N	25.71	3.49	-22.2	0.038*	-86.4
Organic N	46.9	37.9	- 9.0	0.905	-19.2
Total N	80.5	40.1	-40.4	0.486	-50.2
Susp. Solids	1.77×10^3	441.9	-1.33×10^3	0.057	-75.1
BOD_5	413.9	137.6	-276.3	0.057	-66.6
TOC	920.3	311.2	-609.1	0.032*	-66.2
R	0.667	0.299	- 0.368	0.038*	-55.2

1 g/ha/cm = 0.0026 lb/ac/in   1 lb/ac/in = 442 g/ha/cm

*indicates $p \leq 0.05$

The fact that the two tables for Wolfsnare Lake show opposite directions in pollutant transformation during passage through the pond illustrates the problems with treating the pond data on a per catchment-per event basis. The inflow catchments cannot be realistically compared with the pond outflow because the two larger ponds were influenced by catchments having multiple land uses. Only a small proportion of the total watershed draining into the ponds were actually monitored.

An attempt was made to account for the total pollutant inflow into the Lynnhaven Mall Pond and Wolfsnare Lake so that these loadings could be compared directly with the pollutant flux leaving the ponds. A simple linear approach was used. The drainage basin feeding each pond was divided into land use types and the subareas were then calculated. Areal loading rates measured for each storm were applied for that particular storm to the unmonitored areas in the pond drainage basin. The calculated inflow loads were then compared to the calculated outflow loads on a per event basis and also as total loads for the time period over which measurements were made. The results for certain key constituents are discussed here. The remaining calculations are tabulated in Appendix B.

The results of the pond budgets for total phosphorus are presented in Table 12 for Lynnhaven Mall Pond and Table 13 for Wolfsnare Lake. Note that the loading rates are not divided by rainfall, and are reported in units of mass per area. The total areal loads, however, are divided by total rainfall so that the results can be directly compared with those from the Mann-Whitney tables. The Lynnhaven Mall data set is more complete and covers a greater time period. Freezing conditions precluded monitoring at Wolfsnare Lake during the winter of 1982.

TABLE 12. Estimated inputs and outputs of TOTAL PHOSPHORUS at Lynnhaven Mall detention pond, March - June 1981.

	Storm	Outflow			
Date	Input (g/ha)	Storm	Base	Total (g/ha)	% Reduction
March 30	17.26	5.17	1.85	7.02	59.3%
April 4	44.61	16.70	8.52	25.22	43.5%
20	NS*	7.81	1.12	8.93	-
24	44.05	3.34	4.12	7.46	83.1%
27	10.98	1.98	2.32	4.30	60.8%
May 7	15.02	5.00	3.22	8.22	45.3%
11	10.69	7.48	3.05	10.53	1.5%
28	29.59	9.65	5.10	14.75	50.2%
June 5	NS	NS	-	-	-
Total	172.20	49.32	28.18	77.50	55.0%

Net reduction = 6.52 g/ha/cm

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE 13. Estimated inputs and outputs of TOTAL PHOSPHORUS at Wolfsnare Lake, March 1982.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	2.69	4.79	-	4.79	increase
17	1.58	1.88	1.65	3.53	increase
21	4.30	4.69	5.73	10.42	increase
Total	8.57	11.36	7.38	18.74	increase

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE 14. Estimated inputs and outputs of AMMONIA-N at Lynnhaven Mall detention pond, March - June 1981.

Date	Storm Input (g/ha)	Outflow			% Reduction
		Storm	Base	Total (g/ha)	
March 30	NS*	NS	-	-	-
April 4	113.2	1.12	1.12	2.24	98.0%
20	NS	NS	-	-	-
24	60.5	0.45	3.36	3.81	93.7%
27	NS	NS	-	-	-
May 7	43.0	6.72	5.60	12.32	71.3%
11	12.55	7.85	8.97	16.82	increase
28	10.98	6.28	1.12	7.40	32.6%
June 5	NS	NS	-	-	-
Total	240.23	22.42	20.17	42.59	82.3%

Net reduction = 28.2 g/ha/cm

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE 15. Estimated inputs and outputs of AMMONIA-N at Wolfsnare Lake, March 1982.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	1.68	1.95	-	1.95	increase
17	0.99	1.11	0.54	1.65	increase
21	2.67	1.73	1.88	3.61	increase
Total	5.34	4.79	2.42	7.21	increase

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE 16. Estimated inputs and outputs of ORGANIC NITROGEN at Lynnhaven Mall detention pond, March - June 1981.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 30	NS*	NS	-	-	-
April 4	121.0	140.1	96.4	236.5	increase
20	NS	84.1	13.45	97.6	-
24	221.9	31.4	47.1	78.5	64.6%
27	NS	NS	-	-	-
May 7	50.4	37.0	37.0	74.0	increase
11	31.4	59.4	34.7	94.1	increase
28	130.0	81.1	57.9	139.0	increase
June 5	NS	NS	-	-	-
Total	554.7	433.1	286.55	622.1	increase

*Not sampled.

1 g/ha = 0.000891 lb/ac 1 lb/ac = 1,122 g/ha

TABLE 17. Estimated inputs and outputs of ORGANIC NITROGEN at Wolfsnare Lake, March 1982.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	8.40	74.84	-	74.84	increase
17	4.96	42.24	23.71	65.95	increase
21	13.36	53.85	82.25	136.10	increase
Total	26.72	170.93	105.96	276.89	increase

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

Table 18. Water budget at the outfall of Wolfsnare Lake, March 1982.

Date	Rain (cm)	Storm Runoff (cm)	Baseflow (cm)	Total (cm)	R
March 8	5.08	2.02	1.41	3.43	0.675
16	1.12	0.73	0	0.73	0.652
17	0.66	0.31	0.23	0.54	0.818
21	1.78	0.48	0.78	1.26	0.708
Total	8.64	3.54	2.42	5.96	0.690

1 cm = 0.4 in; 1 in = 2.54 cm.

A general and striking feature of the pond loading data is the fact that Wolfsnare Lake exported more pollutants than were calculate(md as entering via surface runoff. This is true during all storms and for all water quality constituents. In the case of total phosphorus, the net reduction in loading for the Lynnhaven Mall Pond (Table 12) was 6.52 g/ha/cm, far less than the 21.0 value calculated in the Mann-Whitney table. Ammonia nitrogen is presented as an example of a dissolved nutrient (Tables 14 and 15). Again, the Lynnhaven Mall Pond reduced ammonia loadings while there was an increase at Wolfsnare Lake. Organic nitrogen, which was observed to be affected the least by the ponds using the Mann-Whitney analysis, showed increases in loading from both Lynnhaven Mall Pond and Wolfsnare Lake (Tables 16 and 17).

The behavior of Wolfsnare Lake can be explained by inspecting the water budget monitored at the outflow over the monitoring period. Table 18 presents the rainfall and runoff data, broken down into storm and baseflow components. The overall runoff coefficient was quite high, 0.696. The majority of the inflow area to the pond is residential, having coefficients generally lower than 0.15. Great Neck Road, which comprised only 2.9% of the Lake watershed had a coefficient of 0.699. Direct rainfall on the pond surface accounted for about 25% of the total stormwater runoff volume measured leaving the pond, however, subtracting this amount from the outflow still yielded runoff coefficients in excess of 0.50.

The data suggest some source of water to the pond other than direct surface runoff. This is probably in the form of groundwater, seeping into the pond from the surrounding water table. The water table in this part of the coastal zone generally resides between 1 - 3 meters below the surface of the land. Ponds in this area tap into the groundwater and serve as large open wells, converting groundwater into surface water. Anecdotal evidence indicates that groundwater flux of dissolved nutrients can be important, particularly if septic tank systems are present. Algae levels in Lake Joyce near the Chesapeake Bay Bridge-Tunnel have decreased notably since nearby residences connected to the municipal treatment system. Samples taken during this study from six shallow observation wells near septic drainfields showed that concentrations of nutrients were high (eg: >20.0 mg/l nitrite-nitrate), indicating that groundwater contributions may be significant.

The water budget for the outfall of Lynnhaven Mall Pond is presented in Table 19. Note that the runoff coefficient is larger than for Wolfsnare Lake. It is difficult to evaluate whether it is an effect of pond size which causes the difference in pollutant loadings and K values between the two systems simply because the loadings into Lynnhaven Mall Pond are considerably higher. It can be anticipated that a greater fraction of surface runoff would pass through the pond having a smaller size, since there is less time for evaporation to remove water from the pond. However, groundwater flow can be highly variable from location to location, confounding any attempt to attribute differences among these ponds as being due to their size or due to groundwater processes. The mass loading computations are implying that a very important term in the pollutant budget of the ponds are missing, namely groundwater contributions, rather than that there are differences in treatment of stormwater runoff among the ponds due to their physical attributes.

The pollutant reduction data from the three pond systems (Tables 8, 9, and 11) were compared to the relationship established by Brune (1953) which predicts sediment trapping of reservoirs based on pond volume and inflowing watershed area. The relationship was first developed using 44 impoundments from various locations throughout the U.S. and has been further tested and verified by others (cf. Dendy, 1973). The results of the suspended solids data from the three ponds are compared to Brune's model in Figure 5.

Table 19 . Water budget at the outfall of Lynnhaven Mall Pond, 30 March – 5 June 1981.

Date	Rain (cm)	Storm Runoff (cm)	Baseflow (cm)	Total (cm)	R
March 30	0.64	0.36	0.31	0.66	1.04
April 6	1.96	1.11	0.81	1.93	0.99
20	0.97	0.48	0.20	0.69	0.71
24	1.24	0.25	0.74	0.99	0.80
27	0.33	0.08	0.36	0.43	1.31
May 7	0.86	0.15	0.25	0.41	0.47
11	1.30	0.71	0.53	1.24	0.96
19	1.05	0.20	0.69	0.89	0.88
28	1.65	0.81	0.76	1.57	0.95
June 2	0.61	0.08	0.25	0.33	0.54
5	3.58	1.17	1.68	2.84	0.79
Total	14.15	5.41	6.58	11.99	0.85

1 cm = 0.4 in   1 in = 2.54 cm

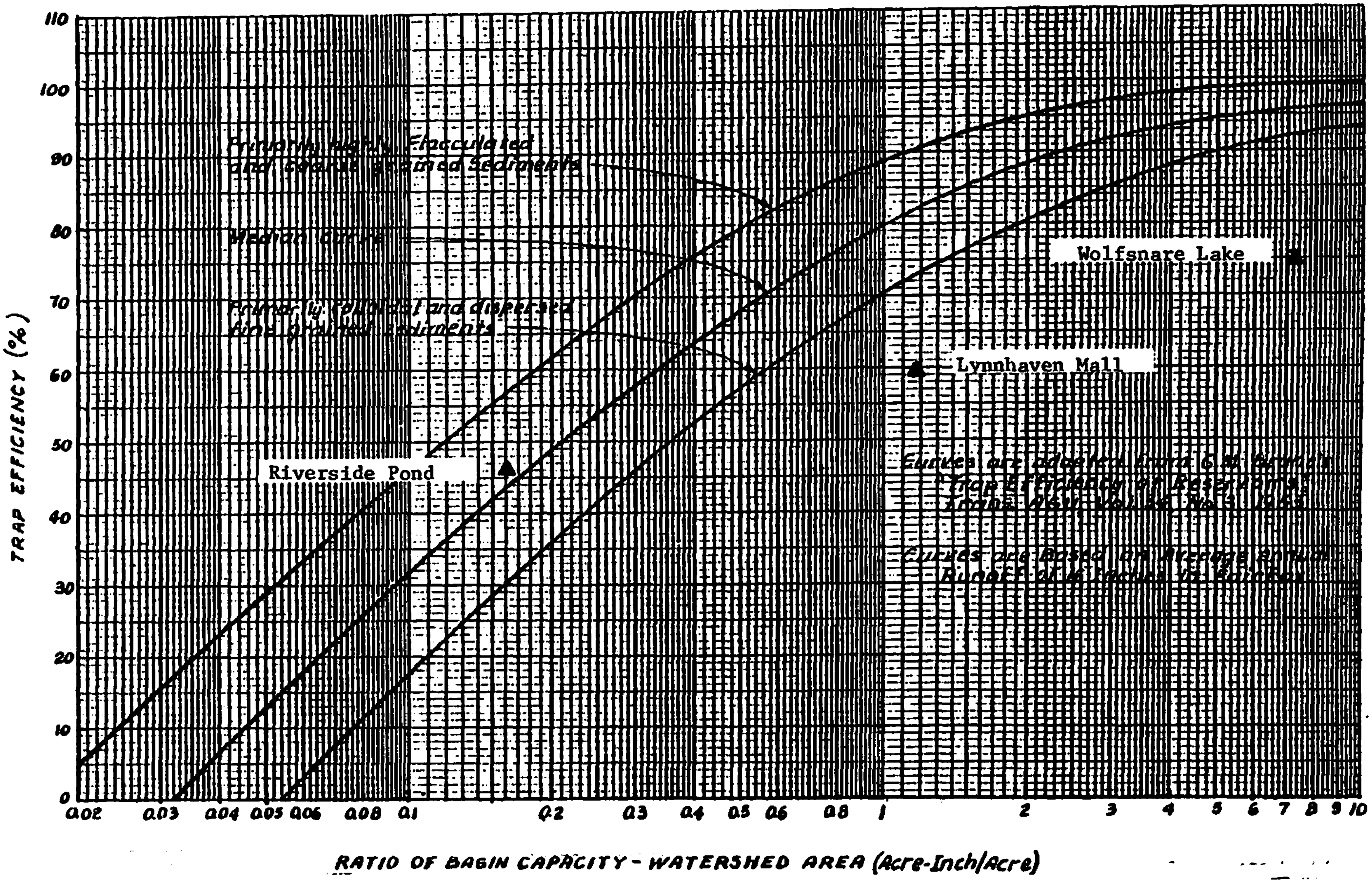


Figure 5. The relationship between pond volume (acre-in), inflow area (acres), and sediment trapping efficiency (%) of reservoirs. Source: Brune (1953).

The data agree with the relationship in that trapping of sediment increases as the pond volume-to-inflow area ratio increases, however, the data fall below the anticipated curve. From this figure, the effect of groundwater influence can be visualized. Groundwater increases the flow into the pond having the same effect as increasing the watershed size, thus reducing the ratio and the trapping efficiency of the reservoir. The decrease in trapping rate is caused by the decrease in the residence time for water due to higher inflow, and the increase in flow rate through the pond serves to maintain sediment in suspension.

The relationship is promising, but is based on only three points. There is a need to establish a functional relationship which can be used to predict sediment trapping performance which is applicable to areas normally influenced by a shallow water table. The Brune relationship did not hold true for nitrogen and phosphorus due to the fact that these constituents respond to biological activity which can vary among ponds and seasonally. The data from Wolfsnare Lake were collected in mid-winter, while the stations at Lynnhaven Mall and Riverside Hospital were occupied during spring and early summer. In regard to collecting further data on pond performance, long term records are needed for nutrients, while at the same time, many ponds should be monitored to better define the performance v. pond size relationship for shallow groundwater areas such as the Hampton Roads vicinity.

SUMMARY OF RESULTS AND CONCLUSIONS

The following paragraphs summarize the findings of the field study of management practices in the Hampton Roads 208 vicinity.

Data was collected to determine the change in pollutant loadings brought about by the presence of management practices in urban test watersheds. The management practices evaluated were 1) swale drainage in residential areas; 2) artificial seeding of a construction site, and; 3) stormwater detention ponds. The results are reported in terms of the differences in areal pollutant mass loading which were observed between similar sites with and without the chosen practice in place. Tables 20 and 21 summarize the reductions in pollutant loadings for each constituent for each management practice, in terms of the percent and net change in loadings, respectively. Note that the pollutant loading rates reported in Table 21 are converted to units of pounds/acre/year, since this is the most common reporting unit found in the literature, and is useful for comparing the results of this study to those from other investigations. The annual rates were calculated by multiplying the values from Tables 5 - 11 by the average annual rainfall of 46 inches per year, plus the appropriate metric to english conversions.

The greatest differences in areal pollutant loads observed during the study were among sites occupied by different land uses (ie. parking lots v. residential) rather than by implementation of a specific practice. However, since zoning land uses solely for the purpose of improving water quality is not a viable management option, the land use data are not summarized here. The reader is referred to Tables 3 and 4 for a comparison of loading rates among the different uses monitored.

Conclusions from the management practice evaluations are summarized as follows:

Table 20. Summary of pollutant reduction efficiency (percent) by management practice.

Pollutant	Grassed Swales	Artificial Seeding	Detention Ponds: Small	Detention Ponds: Large
	percent change			
Total P	30-70	53	51	78-82
Ortho P	-60 - +40	+207*	+22	86-96
NH_3-N	90	+688	+94	96-99
NO_2+NO_3-N	60-90	+847	+33	86-99
Organic N	45-85	17	56	19-29
Total N	50-80	77	38	50-74
Susp. Solids	75-90	41	47	60-75
BOD_5	55-90	75	21	58-67
TOC	40-90	52	+11	65-66

*All changes are negative unless indicated by a positive (+) sign.

Table 21. Summary of net change in pollutant loading (lb/acre/year) by management practice.

Pollutant	Grassed Swales	Artificial Seeding	Detention Ponds: Wolfsnare	Lynnhaven
	net change (lb/ac/yr)			
Total P	0.16	0.73	1.33	2.18
Ortho P	0.01	+0.03*	0.18	1.20
NH_3-N	0.22	+0.13	2.62	5.55
NO_2+NO_3-N	0.41	+0.34	2.31	4.49
Organic N	0.64	0.77	0.93	1.90
Total N	1.19	+0.02	4.20	13.50
Susp. Solids	45.4	1590.5	138.3	103.71
BOD_5	9.10	6.66	28.7	36.62
TOC	10.3	39.20	63.3	75.51

*All changes are negative unless indicated by a positive (+) sign.

Swale Drainage

1. The pollutant reduction efficiency of swale drainage v. conventional curb and gutter drainage ranged from 30 - 90% for nutrients, and from 60 - 90% for suspended solids and BOD5. The net reduction of total phosphorus was 0.16 lb/ac/yr, and there was a net reduction of 1.12 lb/ac/yr for total nitrogen.

2. The dissolved constituents comprised less than 40% of the total nitrogen and phosphorus in runoff from the residential catchments. This fraction of the nutrients were affected less by the presence of swales than the particulate forms. Suspended solids were reduced by 4.55 lb/ac/yr.

3. The pollutant reductions measured here were greater than those reported for swale drainage in studies from the Virginia region of the Washington metropolitan area. Model estimates from these studies computed loading reductions of 10 - 20% for nutrients, and 20 - 30% for BOD5 and suspended solids (Northern Va. Planning Dist. Comm., 1979). It is likely that the difference can be attributed to the fact that soils in the Virginia Beach area are more permeable due to their high sand content. Studies show that permeabilities can vary by a factor of 5 among soil types ranging from clayey to sandy loams (Hartigan, 1976). In addition, the slopes are likely to be lesser in the coastal zone, increasing the time available for runoff to infiltrate into the soils.

Detention Ponds

1. Trapping of suspended solids varied according to the pond volume - inflow area ratio of the three pond systems monitored. The percent reductions were less than those expected based on the commonly used relationship between volume:inflow area and sediment trapping established by Brune (1953) and others (Dendy, 1974) as illustrated in Figure 5 (page 51). This is likely due to the

increased transport out of the ponds brought about by the influence of the shallow groundwater table in the study area.

2. Nutrient trapping by the ponds was more variable, and did not follow the relationship that was observed for suspended solids. The nutrients are affected by biological processes which vary among ponds and seasonally throughout the year. More data are needed to look for relationships and draw conclusions about the nutrients since the data from the ponds in this study were collected at different times of the year. The Riverside Hospital pond, which was normally dry, had no standing crop of phytoplankton, and nutrients actually increased while passing through this system, perhaps due to resuspension of debris that had accumulated from past runoff events.

3. Net loading reductions by the larger ponds were greater than for the grassed waterway management practice. However, reductions by the small pond at Riverside Hospital were less than the net reductions measured due to the presence of swales (Table 21).

4. The behavior of the ponds illustrates a need to collect more data characterizing the influence of the typically shallow water table of Tidewater area. The data should be collected towards the goal of establishing a functional relationship between pond size and inflow area or volume since the results from this study show that trapping efficiencies are lower than those expected based on currently accepted models.

Artificial Seeding

1. Dissolved nutrient loadings increased after the establishment of grass on the construction study area. Particulate forms were trapped by the seedlings and, as a result, total phosphorus loading was reduced. There was no net change in total nitrogen loading (Table 21).

2. Soil erosion was reduced significantly by the practice. Suspended solids loads were reduced by 1595 lb/ac/yr, which is ten times greater than the net trapping observed in the most efficient of the ponds. Of course, the loading of solids from the steep-sloped denuded area before seeding was 10 times greater than the highest loadings observed in parking lot runoff entering the pond. After seeding, the loads were still greater than at the parking lot by a factor of about 3, which is attributed to the increased erosion and transport energy provided by the steeper slopes (8% at the construction site v. 1% at the parking lots).

II. APPLICATION TO URBAN LAND USES

The purpose of this section is to provide a comparison of the performance of a variety of management practices for planners to use in making water quality management decisions for urbanizing basins in the Hampton Roads 208 area. To achieve this goal it was necessary to rely on additional data sources since only three practices and four land use categories were evaluated in the field portion of this study. Effectiveness data were available for the following urban practices:

Small detention ponds
Large detention basins
Grassed swale roadways
Fertilizer management
Concrete grid pavement

In presenting the following management practice effectiveness tables it is assumed that the user already has his nonpoint source water quality goals in mind. He should be aware of the problems of his particular recieving water, whether it is caused by excessive BOD, nutrients, or fecal bacteria, for example, and whether point or nonpoint source management is appropriate to ameliorating those problems. In the case of nonpoint sources, the appropriate strategy will require additional knowledge of the current and future land uses in the watershed. Only with these facts in mind can the tables be used for developing a sensible nonpoint source strategy.

Land Use Loading Rates

The first step in calculating BMP loading reductions is to assign 'typical' pollutant loading rates to each of the land use planning categories. In developing the Hampton Roads Water Quality Management Plan (HRWQA, 1978) nonpoint loadings were projected for various sub-basins in Tidewater Virginia using the watershed simulation model STORM (Storage, Treatment, Overflow, Runoff Model; U.S. Army COE, Hydrologic Engineering Center, 1976). Runoff data collected during 1975-76 in the Hampton Roads area were used to calibrate the model for each of the following land use catagories:

Low density residential
High density residential
Multifamily residential
Commercial-strip
Commercial-central business district
Light industry
Heavy industry
Institutional
Open land

In calculating the performance of the practices, the STORM calibrated loading rates for each of these land uses have been used as the baseline loadings, and are presented in Table 22. A comparison with the values for similar categories reported recently in a 'Guidebook for Screening Urban Nonpoint Pollution Management Strategies' (NVPDC, 1979) show good agreement with the calibrated STORM loadings. Note that the STORM loading rates were nearly identical for both high density and multifamily residential, and for light and heavy industrial uses.

The loading reductions due to MP implementation were then calculated from the baseline loadings for each water quality constituent and land use.

The pollutant reduction factors represent the fraction of the baseline loading which is removed from runoff by the particular management practice, and were derived from the results of the field study and literature values. A number of assumptions had to be made depending on the specific practice, land use, and the nature of the available MP data. For this reason, the methodology used to calculate the reduction factors will be discussed prior to each of the following tables.

TABLE 22. A comparison of land use pollutant loading rates from STORM and the Northern Virginia Planning District Commission (1979).

	STORM (HRWQA, 1978)					NVPDC (1979)				
	(lb/ac/yr)					(lb/ac/yr)				
Land Use	Total P	Total N	BOD_5	SS 10^3	Fecal Colif. 10^9 cells	Total P	Total N	BOD_5	SS 10^3	Fecal Colif. 10^9 cells
Low Density Residential	0.75	7.4	18.7	0.145	87.1	0.75	6.1	19.5	0.20	148
High Density Residential	1.34	13.2	36.3	0.255	361.4	1.30	10.4	32.0	0.46	194
Multifamily Residential	1.34	13.2	36.5	0.256	360.1	1.55	11.4	36.5	0.26	215.8
Commercial Strip	1.14	11.4	26.9	0.222	118.4	1.25	20.3	97.5	0.13	NA*
Commercial CBD	3.09	30.3	71.8	0.591	315.7	2.70	24.6	206.0	0.50	NA
Light Industry	0.86	8.6	21.8	0.167	53.5	1.20	10.1	115.0	0.18	NA
Heavy Industry	0.86	8.6	21.8	0.167	53.5	1.50	12.2	146.0	0.22	NA
Institutional	0.36	3.5	13.5	0.068	27.7	1.55	11.4	36.5	0.26	NA
Open Land	0.05	0.6	1.7	0.012	1.0	0.10	2.5	7.0	0.04	NA

*Not available.

Small Detention Ponds

Small detention ponds are considered as an on-site management practice, that is, each individual parcel of a given land use within a large watershed would be served by its own individual pond. It was assumed that all land use types except open land could be served by these ponds. To achieve a 50% reduction of the inflowing suspended solids loading, (which was observed at Riverside Hospital pond) it would be necessary for such a pond to have a volume-to-inflow area ratio of 0.21 (Brune, 1953, see Figure 5). Trapping of total phosphorus, nitrogen and BOD were scaled in proportion to the suspended solids trapping observed at the small detention pond monitored at Riverside Hospital in this study (Table 8). It was assumed that coliform bacteria behaved as particles, since almost all of the bacteria in water are attached to suspended sediment. For this parameter the same trapping rate was used as for solids. The pollutant reduction factors are expressed as the fraction of the total baseline land use loading which would be removed by installing a pond (Table 23, left hand side). Once established, the factor was multiplied by the STORM loading rate in Table 22 to yield the total mass removed due to the implementation of the practice (expressed in lbs/acre/year, right-hand side, Table 23). Fecal coliform loadings are expressed in terms of billion cells/acre/year.

TABLE 23. Pollutant loading reductions for SMALL DETENTION PONDS.

	Load Reduction Factor					Mass Removal Rate (lb/ac/yr)				
Land Use	Total P	Total N	BOD_5	SS	Fecal Colif.	Total P	Total N	BOD_5	SS 10^3	Fecal Colif. 10^9 cells
Low Density Residential	0.50	0.40	0.20	0.50	0.50	0.38	2.96	3.74	0.075	43.6
High Density Residential	0.50	0.40	0.20	0.50	0.50	0.67	5.28	7.30	0.128	180.1
Multifamily Residential	0.50	0.40	0.20	0.50	0.50	0.67	5.28	7.30	0.128	180.1
Commercial Strip	0.50	0.40	0.20	0.50	0.50	0.57	4.56	5.38	0.111	59.2
Commercial CBD	0.50	0.40	0.20	0.50	0.50	1.55	12.12	14.36	0.296	157.9
Light Industry	0.50	0.40	0.20	0.50	0.50	0.43	3.44	4.36	0.084	26.8
Heavy Industry	0.50	0.40	0.20	0.50	0.50	0.43	3.44	4.36	0.084	26.8
Institutional	0.50	0.40	0.20	0.50	0.50	0.18	1.40	2.70	0.034	13.9
Open Land	0	0	0	0	0	0	0	0	0	0

Large Detention Basins

Large basins provide greater pollutant reduction than small ponds, due to longer runoff storage time which allows a greater fraction of stormwater borne solids to settle out. Biological processes in the water column also increase the trapping of nutrients and BOD. These types of basins can be applied on a site specific basis, as was the case for the Lynnhaven Mall pond, or, they can be placed to intercept runoff from large watersheds having a combination of land uses, such as Wolfsnare Lake. An average trapping of 70% of the inflowing suspended solids (measured at the two ponds in this study) was used as the reduction factor for solids, and the trapping of total nitrogen, phosphorus and BOD were scaled accordingly. Large basins would require a pond volume-to-inflow area ratio of 0.67 to achieve this amount of sediment trapping. Open land was included as being treated since large ponds at the outfalls of major tributaries could conceivably include all of the land uses in a watershed.

TABLE 24. Pollutant loading reductions for LARGE DETENTION BASINS.

	Load Reduction Factor					Mass Removal Rate (lb/ac/yr)				
Land Use	Total P	Total N	BOD_5	SS	Fecal Colif.	Total P	Total N	BOD_5	SS_3 10	Fecal Colif. 10^9 cells
Low Density Residential	0.80	0.57	0.63	0.70	0.70	0.60	4.22	11.78	0.102	61.0
High Density Residential	0.80	0.57	0.63	0.70	0.70	1.07	7.52	22.86	0.179	252.1
Multifamily Residential	0.80	0.57	0.63	0.70	0.70	1.07	7.52	22.86	0.179	252.1
Commercial Strip	0.80	0.57	0.63	0.70	0.70	0.91	6.50	16.95	0.155	82.9
Commercial CBD	0.80	0.57	0.63	0.70	0.70	2.47	17.27	45.23	0.414	220.9
Light Industry	0.80	0.57	0.63	0.70	0.70	0.70	4.90	13.73	0.117	37.5
Heavy Industry	0.80	0.57	0.63	0.70	0.70	0.70	4.90	13.73	0.117	37.5
Institutional	0.80	0.57	0.63	0.70	0.70	0.28	2.00	8.51	0.047	19.4
Open Land	0.80	0.57	0.63	0.70	0.70	0.04	0.34	1.07	0.008	0.7

Grassed Swale Waterways

It was decided that grassed swale waterways were appropriate for all land uses except the commercial category. The average data from the two residential curb and gutter v. swale comparisons (see Table 20) were used to obtain the load reduction factors for each pollutant constituent. Both low and high density residential were considered to be 100% treatable by swales, while it was felt by HRWQA planners that this MP could be applied to only 30% of the intstitutional and 20% of the industrial use areas. Thus, the reduction factor for each constituent was multiplied by 0.30 and 0.20 for the institutional and industrial categories. An example of the reduction in total nitrogen brought about by using swales on the light industry category is as follows:

0.65 = Measured performance of swales

0.20 = Fraction of light industry treatable by swales

Therefore, the load reduction factor is 0.65 x 0.20 = 0.13 for total N for swales in a light industry application. The amount of nitrogen removed by swales is calculated as:

0.13 x 8.6 lb/ac/yr (Table 22) = 1.12 lb/ac/yr

TABLE 25. Pollutant loading reductions for GRASSED SWALE ROADWAYS.

	Load Reduction Factor					Mass Removal Rate (lb/ac/yr)				
Land Use	Total P	Total N	BOD_5	SS	Fecal Colif.	Total P	Total N	BOD_5	SS 10^3	Fecal Colif. 10^9 cells
Low Density Residential	0.50	0.65	0.73	0.77	0.77	0.36	4.81	13.65	0.112	67.1
High Density Residential	0.50	0.65	0.73	0.77	0.77	0.67	8.58	26.65	0.197	278.3
Multifamily Residential	0.50	0.65	0.73	0.77	0.77	0.67	8.58	26.65	0.197	278.3
Commercial Strip	0	0	0	0	0	0	0	0	0	0
Commercial CBD	0	0	0	0	0	0	0	0	0	0
Light Industry	0.10	0.13	0.15	0.15	0.15	0.09	1.12	3.27	0.025	8.04
Heavy Industry	0.10	0.13	0.15	0.15	0.15	0.09	1.12	3.27	0.025	8.04
Institutional	0.15	0.19	0.23	0.22	0.22	0.05	0.67	3.11	0.015	6.1
Open Land	0	0	0	0	0	0	0	0	0	0

Fertilizer Management

The fertilizer management MP affects nitrogen and phosphorus loadings only, and is applicable to residential and institutional uses. NVPDC (1979) assumed that a 50% reduction in nutrient loading could be achieved through public awareness and voluntary participation.

TABLE 26. Pollutant loading reductions for FERTILIZER MANAGEMENT.

	Load Reduction Factor					Mass Removal Rate (lb/ac/yr)				
Land Use	Total P	Total N	BOD_5	SS	Fecal Colif.	Total P	Total N	BOD_5	SS 10^3	Fecal Colif. 10^9 cells
Low Density Residential	0.50	0.50	0	0	0	0.38	3.70	0	0	0
High Density Residential	0.50	0.50	0	0	0	0.67	6.60	0	0	0
Multifamily Residential	0.50	0.50	0	0	0	0.67	6.60	0	0	0
Commercial Strip	0	0	0	0	0	0	0	0	0	0
Commercial CBD	0	0	0	0	0	0	0	0	0	0
Light Industry	0	0	0	0	0	0	0	0	0	0
Heavy Industry	0	0	0	0	0	0	0	0	0	0
Institutional	0.50	0.50	0	0	0	0.18	1.75	0	0	0
Open Land	0	0	0	0	0	0	0	0	0	0

Concrete Grid Pavement

Concrete grid surfaces reduce runoff from otherwise impervious cover by allowing rainwater to percolate into the soils beneath them. The grids are intended to serve as light use pavements, such as parking lots and driveways. There are several grids commercially available, and of those which have been tested to date, all have been shown to allow 100% percolation into the groundwater, thereby reducing surface runoff and pollutant loading to zero (Day, et al., 1981, Gburek and Urban, 1980). The amount of each land use area which is treatable by such grids is dependent on the density of parking lots and driveways present. Specific data on the density of this type of impervious cover were not available for the land use categories. Instead, data defining the percent of land covered by roads were used to proportion the load reduction factors for each use. Low density residential impervious cover was used as a baseline. The difference between this and the amount of roads present in each category was assumed to consist of parking lots and driveways, the difference being the percent of cover for that land use treatable by concrete grid. A 100% loading reduction was thus applied to this fraction of each use. For example, there was 20% of low density residential and 37% of light industry covered by roads. Thus 17% of the light industry category was assumed to be occupied by parking lots and driveways and the load factor was 1.00 x 0.17 = 0.17 . It was decided that low density residential was not treatable by this BMP since implementation would require voluntary installation of grid driveways by individual landowners. However, in developments where several homes are being built at the same time, planners might encourage the builder to incorporate concrete grid or other pervious pavement.

TABLE 27. Pollutant loading reductions for CONCRETE GRID PAVEMENT.

	Load Reduction Factor					Mass Removal Rate (lb/ac/yr)				
Land Use	Total P	Total N	BOD_5	SS	Fecal Colif.	Total P	Total N	BOD_5		Fecal Colif. 10^9 cells
Low Density Residential	0	0	0	0	0	0	0	0	0	0
High Density Residential	0	0	0	0	0	0	0	0	0	0
Multifamily Residential	0.19	0.19	0.19	0.19	0.19	0.25	2.51	6.94	0.048	68.4
Commercial Strip	0.10	0.10	0.10	0.10	0.10	0.11	1.14	2.69	0.022	11.8
Commercial CBD	0.17	0.17	0.17	0.17	0.17	0.53	5.15	12.21	0.100	53.7
Light Industry	0.05	0.05	0.05	0.05	0.05	0.04	0.43	1.09	0.008	2.68
Heavy Industry	0.05	0.05	0.05	0.05	0.05	0.04	0.43	1.09	0.008	2.68
Institutional	0.19	0.19	0.19	0.19	0.19	0.07	0.67	2.57	0.013	5.26
Open Land	0	0	0	0	0	-	-	-	-	-

SUMMARY OF EFFECTIVENESS DATA

The following statements summarize the management practice effectiveness data applied to the general land use categories presented in the preceding tables:

1. In all land use categories, large detention ponds removed the greatest amount of the baseline pollutant loadings. Based on the Brune model (Figure 5), one acre of inflowing watershed would require 973 sq. feet of pond to achieve the reductions presented in Table 24, assuming a mean pond depth of 2.5 feet.

2. Grassed swale waterways appear to be as effective as small onsite detention ponds in trapping pollutants from residential uses. The swales are particularly effective in reducing BOD loadings.

3. Since impervious surfaces are large in institutional and industrial uses, only a small fraction can be treated by grassed swales. Greater loading reductions appear to be achievable through the installation of onsite detention ponds.

4. Concrete grid pavement reduced loadings by a lesser amount than swales for the land uses where both practices were applicable. However, concrete grid appears to have the potential to reduce loadings as much as small detention ponds when applied to the two commercial uses, due to the large amount of light use impervious cover (parking lots) to which the permeable grid could be applied.

5. Through public education, fertilizer management could potentially eliminate up to 50% of the nitrogen and phosphorus loads from residential areas (NVPDC, 1979).

REFERENCES

Brune, G. M., 1953. Trap efficiency of reservoirs. Trans. Am. Geophys. Union. 34:407-418.

Chow, V. T., 1964. Handbook of Applied Hydrology. McGraw-Hill Co., N.Y.

Clark, L. J., V. Guide, and T. H. Pheiffer, 1974. Summary and conclusions: Nutrient transport and accountability in the lower Susquehanna River basin. Tech. report 60, Annapolis Field Office, Region III, U.S. Environmental Protection Agency, Annapolis, Md.

Correll, D. L., T. L. Wu, E. S. Friebele, and J. Miklas, 1977. Nutrient discharge from Rhode River watersheds and their relationship to land use patterns. In: D. L. Correll, ed. Watershed Research in Eastern North America: A Workshop to Compare Results. Ches. Bay Ctr. for Env. Studies, Smithsonian Inst., Edgewater, Md.

Day, et. al., 1982. Runoff and pollution abatement characteristics of concrete grid pavements. Water Res. Research Bull. 135. Va. Polytechnic Inst. and State Univ. Blacksburg, Virginia.

Dendy, F. E., 1974. Sediment trap efficiency of small reservoirs. Trans. Am. Soc. Agr. Eng. 1974 p. 898-908.

Gambrell, R. P., J. W. Gilliam, and S. B. Weed, 1975. Nitrogen losses from soils of the North Carolina coastal plain. J. Env. Qual. 4:317-323.

Gburek, W.J. and J.B. Urban, 1980. Storm water detention and groundwater recharge using porous asphalt - initial results. In: M.E. Meadows and R.W. De Vore (eds). Proceedings of the International Symposium on Urban Storm Runoff, 28-31 July, 1980. University of Kentucky, Lexington, Ky. pp 89-97.

Grizzard, T. J., and F. X. Brown, 1979. Nonpoint sources. J. Wat. Poll. Cont. Fed. 51(6):1428-1444.

Groszyk, W. S., 1979. Nonpoint soure pollution control strategy. In: R. C. Loehr, D. A. Haith, M. F. Walter, and C. S. Martin, eds. Best Management Practices for Agriculture and Silviculture. Ann Arbor Science Pub., Inc. Ann Arbor, Mich.

Harms, L. L. and E. V. Southerland, 1975. A case study of non-point source pollution in Virginia. Bull 88, Water Resources Research Center, Va. Polytechnic Institute and State Univ., Blacksburg, Va.

Hartigan, J. P., 1978. Calibration of urban nonpoint source loading models. Proceedings of an ASCE Hydraulics Division Specialty Conference on Verification of Mathematical and Physical Models in Hydraulic Engineering. Am. Soc. Civil Eng., New York, N. Y., August 1978. pp. 363-372.

Northern Virginia Planning District Commission. 1979. Guidebook for Screening Urban Nonpoint Management Strategies. report to the Washington D.C. Council of Governments, NVPDC, Falls Church, Virginia. 160pp.

Randall, C. W., T. J. Grizzard, and R. C. Hoehn, 1978. Impact of urban runoff on water quality in the Occoquan watershed. Bull. 80, Water Resources Research Center, Va. Polytechnic Institute and State Univ., Blacksburg, Va.

Rimer, A. E., J. A. Nissen and D. E. Reynolds, 1978. Characterization and impact of stormwater runoff from various land cover types. J. Wat. Poll. Cont. Fed. 50:252-264.

Smith, C. N., R. A. Leonard, G. W. Langdale, G. W. Baily, 1978. Transport of agricultural chemicals from small upland peidmont watersheds. Rept. No. EPA-600/3-78-056. Env. Res. Lab., U.S. Environmental Protection Agency, Athens, Ga.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W.H. Freeman and Co. San Fransisco. 776 pp.

Strickland, J. D. H. and T. R. Parsons, 1972. A Practical Handbook of Seawater Analysis. 2nd Ed. Bull. 167, Fisheries Research Board of Canada, Ottawa, Canada.

U. S. Department of Agriculture, 1979. Field Manual for Research in Agricultural Hydrology. Science and Education Administration, U. S. Department of Agriculture, Washington, D.C. Agriculture Handbook Number 224.

U. S. Environmental Data Service. 1980-82. Climatological summary for Virginia. National Oceanographic Atmospheric Administration.

U. S. Environmental Protection Agency, 1973. Biological Field and Laboratory Methods. EPA-670/4-73-001, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

U. S. Environmental Protection Agency, 1979. Methods for Chemical Analysis of Water and Wastes. Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

U. S. Environmental Protection Agency, 1979. Methods for Analytical Quality Control in Water and Wastewater Laboratories. Environmental Monitoring and Support Laboratory, U.S. EPA, Cincinnati, Ohio.

Virginia Polytechnic Institute and State University. 1982. Evaluation of Management Tools in the Occoquan Watershed. Occoquan Watershed Monitoring Laboratory, Dept. of Civil Engineering, VPI and SU, Manassas, Virginia. 190 pp.

Wanielista, M. P., 1978. Stormwater Management: Quantity and Quality. Ann Arbor Science Pub., Inc. Ann Arbor, Mich.

APPENDICES

Appendix A: Storm Event Water Quality and Flow Data.........75 - 78

Appendix B: Detention Pond Loading Calculations............79 - 91

Table A1. Stormwater quality and quantity data for residential sites

STATION	DATE	RAIN (IN)	RUNOFF (FT3)	TOTAL P	ORTHO P	NH3 N	NO2+NO3 N	ORG N	TOTAL N	SUSP. SOLIDS	BOD5	TOC
				MG/L								
Curb and Gutter:												
Kings Grant	30 Sep 80	1.00	.90	.22	.12	.10	.16	.60	.88	44.00	8.42	-
	19 Oct 80	.90	2.13	.36	.21	.23	.22	.60	1.05	58.00	4.25	8.85
	30 Oct 80	.42	.60	.33	.24	.20	.40	.48	1.08	3.30	-	6.75
	18 Nov 80	.34	.68	.43	.30	1.26	.23	2.07	3.56	64.00	13.40	17.01
	10 Dec 80	1.05	1.50	.14	.08	.21	.32	.30	.83	20.00	5.49	6.20
	02 Feb 81	.62	.92	.21	.04	.10	.16	.64	.90	48.00	5.80	9.40
	11 Feb 81	.69	.54	.31	.03	.09	.12	1.07	1.92	244.00	-	30.00
Wolfsnare Curbs	25 Oct 81	1.52	4.60	.16	.07	.03	.10	.54	.67	20.00	5.35	6.98
	06 Nov 81	.57	1.30	.25	.11	.13	.28	.70	1.11	5.00	14.50	14.66
	14 Nov 81	.46	1.40	.20	.10	.07	.50	.46	1.03	-	5.60	12.01
	17 Nov 81	.72	2.00	.16	.09	.20	.53	.35	1.08	-	-	11.57
	24 Nov 81	.34	.80	.18	.12	.24	.58	.38	1.21	5.00	23.70	19.43
	02 Dec 81	.68	1.70	.19	.06	.03	.12	.76	.91	35.50	12.30	11.54
	15 Dec 81	1.35	5.50	.13	.07	.08	.23	.39	.70	9.20	-	11.60
	07 Jan 82	.17	.30	.41	.04	.39	1.20	-	-	24.00	-	21.00
	21 Mar 82	.75	1.50	.55	.24	.21	.57	3.35	4.14	117.00	-	14.30
Swales:												
Thalia Swales	30 Sep 80	1.10	1.50	.54	.39	-	.55	1.13	1.66	62.00	8.65	-
	19 Oct 80	.96	2.20	.59	.44	.02	.48	1.44	1.94	1.00	-	14.80
	30 Oct 80	.54	.90	.33	.24	.03	.31	.79	1.13	-	-	5.69
	18 Nov 80	.33	1.40	.86	.32	.29	.82	1.53	2.64	-	19.80	26.39
	02 Feb 81	.68	3.00	.41	.28	.07	.35	.66	1.08	36.00	8.10	10.40
	11 Feb 81	.61	3.60	.47	.26	.04	.15	.95	1.14	22.00	-	14.10
Wolfsnare Swales	06 Nov 81	.57	.11	.66	.41	.23	.38	-	-	14.00	-	20.29
	18 Nov 81	.84	.65	.40	.27	.39	.38	.51	1.27	-	-	13.66
	02 Dec 81	.76	.48	.50	.34	.06	.29	1.07	1.42	37.00	14.10	20.57
	15 Dec 81	1.44	1.04	.36	.26	.08	.33	.51	.92	10.50	-	9.17
	21 Mar 82	1.17	.97	.83	.57	3.84	.48	4.29	8.62	51.10	4.56	11.23

Table A2. Stormwater quality and quantity data for commercial/institutional study sites.

STATION	DATE	RAIN (in)	RUNOFF (ft3)	TOTAL P	ORTHO P	NH3 N	NO2+NO3 N	ORG N	TOTAL N	SUSP. SOLIDS	BOD5	TOC
								MG/L				
Institutional/Commercial (pond inflow)												
Riverside	21 Jun 81	.93	-	.44	.11	.20	.55	1.24	1.99	27.50	9.15	23.40
Hosp.	26 Jul 81	1.25	-	.31	.12	.61	.47	.79	1.87	45.50	5.75	12.30
	06 Aug 81	.23	-	.61	.14	.31	1.04	1.91	3.26	8.00	13.00	28.20
	06 Aug 81	.40	-	.31	.10	.62	.86	.84	2.32	36.00	7.70	15.30
	25 Aug 81	.13	-	.57	.11	.31	1.24	1.85	3.41	19.50	14.45	30.50
	07 Sep 81	1.29	-	-	-	.09	.18	-	-	41.00	11.20	27.00
	15 Sep 81	2.55	-	.34	.06	.28	.29	.84	1.42	178.00	6.20	10.90
	02 Oct 81	.45	-	.46	.16	.33	.33	.55	1.21	14.00	8.75	32.80
Lynnhaven	30 Mar 81	.25	.44	.54	-	-	-	-	-	100.00	-	18.00
Mall	06 Apr 81	.77	1.62	.36	.21	.82	.60	.95	2.37	15.50	8.15	15.40
Parking	24 Apr 81	.49	1.20	.51	.23	.63	.79	2.61	4.03	-	10.85	65.67
Lot	27 Apr 81	.33	.32	.47	-	-	-	-	-	135.00	-	26.50
	07 May 81	.34	.61	.33	.19	.85	1.56	.99	3.40	19.00	10.05	21.70
	11 May 81	.51	.63	.15	.04	.13	.15	.50	.78	37.50	5.45	16.60
	26 May 81	.65	2.50	.26	.05	.03	.32	1.32	1.67	5.00	4.95	18.00
Lynnhaven	30 Mar 81	.25	.33	.25	-	-	-	-	-	4.00	-	-
Mall	06 Apr 81	.77	2.95	.14	.09	.67	.62	.47	1.76	.50	4.70	6.20
Rooftop	20 Apr 81	.38	1.40	.15	.06	.79	1.18	.63	2.60	-	7.50	5.60
	24 Apr 81	.49	1.43	.13	.05	.54	.59	.32	1.45	-	4.40	21.30
	27 Apr 81	.33	.50	.16	-	-	-	-	-	6.00	-	21.00
	07 May 81	.34	.73	.14	.06	.95	2.52	1.19	4.66	3.00	9.30	7.10
	11 May 81	.51	.82	.27	.20	.57	1.18	.36	2.11	2.00	6.40	7.90
	26 May 81	.65	1.66	.28	.18	.39	.43	.29	1.11	11.00	9.05	8.60
Great	14 Nov 81	.46	6.90	.23	.20	.97	1.77	.92	3.66	-	5.55	29.06
Neck	17 Nov 81	.77	10.80	.24	.02	.40	.70	1.57	2.67	-	-	22.51
Pond	24 Nov 81	.37	2.80	.20	.05	.73	.72	0.0	-	-	-	19.95
	02 Dec 81	.70	9.90	.24	.08	.08	.12	.31	.52	63.00	6.50	-
	15 Dec 81	1.35	21.50	.21	.12	.17	.27	.62	1.07	18.00	-	7.23
	07 Jan 82	.17	3.10	.14	.02	.38	1.59	-	-	25.50	6.05	13.15

Table A3. Stormwater quality and quantity data for detention pond outflow.

STATION	DATE	RAIN (in)	RUNOFF ft3	TOTAL P	ORTHO P	NH3 N	NO2+NO3 N	ORG N	TOTAL N	SUSP. SOLIDS	BOD5	TOC
								MG/L				
Detention Ponds (outflow)												
Riverside Hosp.	21 Jun 81	.93	-	1.29	.09	.11	.44	3.74	4.29	192.00	12.30	50.20
	28 Jul 81	1.25	-	.22	-	.45	.39	2.18	3.02	162.00	7.30	9.70
	06 Aug 81	.23	-	5.26	.11	.03	.59	6.88	7.51	36.00	23.30	22.60
	06 Aug 81	.40	-	1.17	.12	.45	.74	2.05	3.24	78.00	11.70	13.90
	19 Aug 81	.13	-	1.35	.09	.19	.31	3.06	3.56	51.50	19.50	17.00
	07 Sep 81	1.29	-	-	-	.06	.14	-	-	16.00	7.30	17.00
	15 Sep 81	2.55	-	.37	.05	.16	.27	.72	1.15	78.00	5.70	6.90
	02 Oct 81	.45	-	.47	.15	.36	.36	.95	1.68	23.00	11.10	19.70
Lynnhaven Mall Pond	30 Mar 81	.25	52.50	.15	-	-	-	-	-	11.00	-	-
	06 Apr 81	.77	171.[illegible]	.15	.01	.01	.01	1.25	1.25	26.00	6.75	11.30
	20 Apr 81	.38	75.[illegible]	.16	.01	.01	.01	1.71	1.71	-	-	7.8[illegible]
	24 Apr 81	.47	39.[illegible]	.13	.01	.01	.01	1.23	1.23	-	7.2[illegible]	25.[illegible]
	27 Apr 81	.13	12.[illegible]	.25	-	-	-	-	-	73.50	-	16.[illegible]
	07 May 81	.34	22.[illegible]	.33	.01	.01	.04	2.47	2.50	21.50	16.[illegible]	8.40
	11 May 81	.51	111.00	.10	.01	.01	.13	.82	.95	12.00	6.80	10.40
	28 May 81	.65	123.00	.10	.01	.01	.00	1.01	1.01	22.00	9.60	15.80
	05 Jun 81	1.41	240.00	.04	-	.04	.06	.82	.92	-	5.30	9.10
Wolfsnare Lake	06 Nov 81	.57	-	-	.00	.03	.00	1.21	1.24	6.50	5.[illegible]	10.[illegible]
	14 Nov 81	.46	-	.08	.00	.03	.00	1.13	1.17	-	3.7[illegible]	10.72
	17 Nov 81	.77	-	.08	.01	.03	.02	.85	.90	-	-	11.91
	24 Nov 81	.37	-	.07	.00	.02	.01	.88	.91	3.40	2.45	10.29
	02 Dec 81	.70	-	.06	.00	.02	.00	.87	.89	7.00	3.[illegible]	9.20
	15 Dec 81	1.35	-	.06	.00	.02	.01	1.19	1.21	6.00	-	7.30
	07 Jan 82	.17	37.30	.09	.00	.02	.00	1.27	1.29	8.50	4.[illegible]	10.42
	15 Mar 82	.44	209.90	.07	.01	.03	.21	1.03	1.26	11.50	3.0[illegible]	9.01
	17 Mar 82	.21	90.20	.05	.01	.03	.20	.95	1.19	16.50	3.15	8.76
	21 Mar 82	.65	138.60	.10	.01	.04	.12	1.12	1.38	15.20	2.[illegible]	8.99

Table A4. Stormwater quality and quantity data for the construction site.

STATION	DATE	RAIN (in)	RUNOFF (ft3)	TOTAL P	ORTHO P	NH3 N	NO2+NO3 N	ORG N	TOTAL N	SUSP. SOLIDS	BOD5	TOC
				MG/L								
Construction - York County Courts Office Facility												
Before	19 Oct 80	.69	.21	1.82	-	.02	-	6.47	6.49	2376.0	18.60	59.60
	30 Oct 80	.36	.23	.58	-	-	.14	2.77	2.91	808.00	-	-
	24 Nov 80	.90	.46	.61	-	.01	.02	1.85	1.88	2308.0	10.65	-
	10 Dec 80	.46	.10	.21	-	.04	.05	1.95	2.04	154.00	20.60	81.60
	02 Feb 81	.54	.13	1.70	-	-	-	-	-	4240.0	15.05	59.00
	11 Feb 81	.60	.24	5.63	.01	.04	.04	32.60	32.70	13840	-	139.00
After	19 Jun 81	.61	.10	-	-	-	-	-	-	523.00	39.20	29.30
	21 Jun 81	1.15	.41	.67	.06	.64	.26	3.89	4.79	490.00	13.20	24.50
	28 Jul 81	1.83	.52	.80	.16	.44	.52	3.98	4.95	676.00	8.15	26.10
	06 Aug 81	1.08	.24	.79	.06	.25	.55	4.14	4.94	830.00	12.90	11.20
	11 Aug 81	.84	.10	.86	.09	.20	.62	4.97	5.75	66.00	14.40	14.00
	22 Aug 81	1.00	.07	.54	-	-	-	-	-	96.00	-	-
	15 Sep 81	1.75	.80	.76	.01	.00	.24	4.13	4.39	508.00	-	-

TABLE B1. Estimated inputs and outputs of ORTHOPHOSPHORUS at Lynnhaven Mall detention pond, March - June 1981.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 30	NS*	NS	-	-	-
April 4	25.78	2.24	1.12	3.36	87.0%
20	NS	0.45	0.22	0.67	-
24	20.17	0.22	0.67	0.89	95.6%
27	NS	NS	-	-	-
May 7	8.97	0.11	0.56	0.67	92.5%
11	3.36	0.67	0.56	1.23	63.4%
28	84.06	0.78	0.90	1.68	98.0%
June 5	-	-	-	-	-
Total	142.34	4.02	3.81	7.83	94.5%

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE B2. Estimated inputs and outputs of NITRITE+NITRATE-N at Lynnhaven Mall detention pond, March - June 1981.

Date	Storm Input (g/ha)	------------Outflow------- Storm	Base	Total (g/ha)	% Reduction
March 30	NS*	NS	-	-	-
April 4	86.30	1.12	1.12	2.24	97.4%
20	NS	0.22	0.45	0.67	-
24	73.97	0.67	0.22	0.89	98.8%
27	NS	NS	-	-	-
May 7	85.52	0.56	0.56	1.12	98.7%
11	19.16	0.90	0.45	1.35	93.0%
28	38.89	0.78	0.78	1.56	96.0%
June 5	NS	0.90	1.23	2.13	-
Total	303.84	4.03	3.13	7.16	97.6%

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE B3. Estimated inputs and outputs of TOTAL NITROGEN at Lynnhaven Mall detention pond, March - June 1981.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 30	NS*	NS	-	-	-
April 4	320.55	140.10	97.84	237.94	25.8%
20	NS	84.06	13.45	97.51	-
24	356.41	31.27	47.63	78.90	77.9%
27	NS	NS	-	-	-
May 7	179.33	37.43	37.10	74.53	58.4%
11	63.55	69.38	35.08	104.46	increase
28	179.33	81.14	58.73	139.87	22.0%
June 5	NS	144.58	85.18	229.76	-
Total	1099.17	359.32	276.38	635.70	42.2%

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE B4. Estimated input and output of SUSPENDED SOLIDS at Lynnhaven Mall detention pond, March - June 1981.

Date	Storm Input (kg/ha)	Outflow Storm	Outflow Base	Outflow Total (kg/ha)	% Reduction
March 30	3.03	0.39	0.15	0.54	82.2%
April 4	1.74	2.90	0.68	3.58	increase
20	NS*	NS	0.09	-	-
24	NS	NS	0.33	-	-
27	2.93	0.61	0.18	0.79	73.0%
May 7	0.82	0.45	0.28	0.73	11.0%
11	2.16	0.90	0.24	1.14	47.2%
28	0.66	1.82	0.41	2.23	increase
June 5	NS	NS	-	-	-
Total	11.34	7.07	1.94	9.01	20.5%

*Not sampled.

1 g/ha = 0.000891 lb/ac 1 lb/ac = 1,122 g/ha

TABLE B5. Estimated inputs and outputs of BOD_5 at Lynnhaven Mall detention pond, March - June 1981.

Date	Storm Input (g/ha)	Outflow			% Reduction
		Storm	Base	Total (g/ha)	
March 30	NS*	NS	-	-	-
April 4	1064.8	0.0	551.4	551.4	48.2%
20	NS	NS	-	-	-
24	963.9	193.9	233.1	427.0	55.7%
27	NS	NS	-	-	-
May 7	496.5	218.6	181.6	400.2	19.4%
11	368.7	493.2	172.6	665.8	increase
28	647.8	691.5	288.0	979.5	increase
June 5	NS	NS	-	-	-
Total	3541.7	1597.2	1426.7	3023.9	14.6%

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE B6. Estimated inputs and outputs of TOTAL ORGANIC CARBON at Lynnhaven Mall detention pond, March - June 1981.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 30	NS*	NS	-	-	-
April 4	746.45	1266.50	1165.63	2432.13	increase
20	1810.09	374.35	162.52	536.87	70.3%
24	5816.95	736.36	569.37	1305.73	77.6%
27	689.29	132.25	319.43	451.68	34.5%
May 7	959.40	125.53	300.37	425.90	55.6%
11	1018.81	755.42	446.08	1201.50	increase
28	1863.89	1270.99	703.86	1974.85	increase
June 5	NS	1427.90	1023.29	2451.19	-
Total	12904.88	4661.40	3667.26	8328.66	35.5%

*Not sampled.

1 g/ha = 0.000891 lb/ac 1 lb/ac = 1,122 g/ha

TABLE B7. Estimated inputs and outputs of ORTHOPHOSPHORUS at Wolfsnare Lake, March 1982.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	1.41	1.95	-	1.95	increase
17	0.84	0.32	0.12	0.44	47.6%
21	2.25	0.47	0.47	0.94	58.2%
Total	4.50	2.74	0.59	3.33	26.0%

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

TABLE B8. Estimated inputs and outputs of NITRITE-NITRATE-N at Wolfsnare Lake, March 1982.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	5.80	15.26	-	15.26	increase
17	3.41	3.75	1.24	4.99	increase
21	9.21	5.76	4.30	10.06	increase
Total	18.42	24.77	5.54	30.31	increase

*Not sampled.

1 g/ha = 0.000891 lb/ac 1 lb/ac = 1,122 g/ha

TABLE B9. Estimated inputs and outputs of TOTAL NITROGEN at Wolfsnare Lake, March 1982.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	15.14	91.27	-	91.27	increase
17	8.92	37.32	25.76	63.08	increase
21	24.06	66.22	89.32	155.54	increase
Total	48.12	194.81	115.08	309.89	increase

*Not sampled.

1 g/ha = 0.000891 lb/ac   1 lb/ac = 1,122 g/ha

Table B10. Estimated inputs and outputs of SUSPENDED SOLIDS at Wolfsnare Lake, March 1982.

Date	Storm Input (kg/ha)	Outflow Storm	Outflow Base	Outflow Total (kg/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	0.26	0.84	-	0.84	increase
17	0.15	0.48	0.21	0.69	increase
21	0.41	0.73	0.73	1.46	increase
Total	0.82	2.05	0.94	2.99	increase

*Not sampled.

1 g/ha = 0.000891 lb/ha   1 lb/ac = 1,122 g/ha

Table B11. Estimated inputs and outputs of BOD_5 at Wolfsnare Lake, March 1982.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	126.96	218.10	-	218.10	increase
17	75.09	81.76	74.84	156.60	increase
21	202.05	124.74	259.35	384.09	increase
Total	404.10	424.60	334.19	758.79	increase

*Not sampled.

1 g/ha = 0.000891 lb/ac 1 lb/ac = 1,122 g/ha

Table B12 . Estimated inputs and outputs of TOTAL ORGANIC CARBON at Wolfsnare Lake, March 1982.

Date	Storm Input (g/ha)	Outflow Storm	Outflow Base	Outflow Total (g/ha)	% Reduction
March 8	NS*	NS	-	-	-
16	181.05	654.06	-	654.06	increase
17	106.70	280.84	219.83	500.67	increase
21	287.76	427.06	761.50	1188.56	increase
Total	575.51	1361.96	981.33	2343.29	increase

*Not sampled.

1 g/ha = 0.000891 lb/ac 1 lb/ac = 1,122 g/ha