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Enhanced Parking Lot Design for Stormwater Treatment

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ABSTRACT

A low impact (dispersed) design demonstrates how small alterations to parking lots can reduce runoff and pollutant loads. Storm runoff was treated as soon as rain hit the ground by encorporating a network of swales, strands and a small wet detention pond into the overall design (Figure 1). When the volume of water discharged from all the different elements to the treatment train (the swales, the strand, and the pond) are compared, calculations showed that almost all the runoff was retained on site. The most effective method for reducing pollutant loads is to keep runoff on site and allow time for infiltration as well as for chemical, biological and hydrological processes to take place. Basins paved with porous pavement had the best percent removal of pollution loads with many removal rates for metals greater than 75 percent in the basin with a smaller garden area and greater than 90 percent with larger gardens. More phosphorus loads were discharged from basins with vegetated swales than from basins with no swales. It should be emphasized here that even with some poor removal rates by swales in the parking lot for phosphorus, when the entire system is evaluated, efficiencies are good since the site retained over 99 percent of the storm runoff during the year that it was evaluated. Sediment sampling identified polycyclic aromatic hydrocarbons, chlordane and DDT products as problems. Phosphorus and nitrogen in the sediments increased from year one to year two. Metal and nutrient pollutants in the sediments were not found to be migrating to the deeper strata.

INTRODUCTION

An innovative parking lot at the Florida Aquarium in Tampa was used as a research site and demonstration project to determine whether small alterations to parking lot designs can decrease runoff and pollutant loads. Over two years of data were collected which included most storm events that produced enough flow to collect water samples. A total of 59 rain events were included in the data set and represented storms that produced as little as 0.38 cm (0.15 in) of rain to a maximum amount of 7.39 cm (2.91 in). Three paving surfaces were compared as well as basins with and without swales to measure pollutant concentrations and estimate infiltration. To determine how these modifications and paving types might change runoff amounts and pollutant concentrations, both water quality and quantity were measured in eight small basins in the parking lot. To evaluate long term consequences and estimate maintenance requirements, sediment samples were collected. To understand conditions that influence pollutant concentrations, rainfall characteristics, vegetated areas and paving types were analyzed. Once the berm between the strand and Ybor channel was repaired, water quality, sediment samples, and flow measurements were collected in the strand and the wet detention pond to estimate the additional stormwater treatment they provide. Finally the data were evaluated statistically to determine differences between years, differences between basins and relationships between variables. In this report, swales were defined as vegetated open channels that infiltrate and transport runoff water while strands were larger vegetated channels collecting runoff after treatment by swales.

METHODS

Site Description - The parking lot design for the Florida Aquarium uses the entire drainage basin for low-impact (dispersed) stormwater treatment. The study site is a 4.65 hectare (11.25 acre) parking lot serving 700,000 visitors annually. The research is designed to determine pollutant load reductions measured from three elements in the treatment train: different treatment types in the parking lot, a planted strand with native wetland trees, and a small pond used for final treatment (Figure 1). The final treatment pond discharges directly to Tampa Bay (HUC 03100206), an Estuary of National Significance included in the National Estuary Program and identified as a water body in need of attention (Section 19, Township 29, Range 19, Hillsborough County).

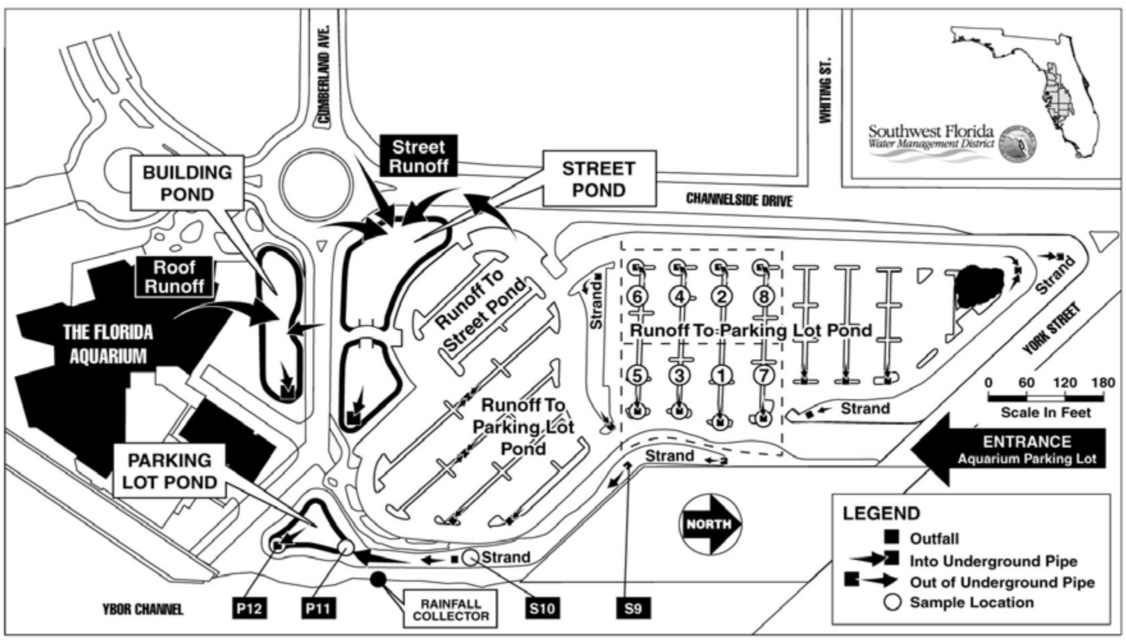

Figure 1a. Site Plan of the Parking Lot Demonstration Project showing sampling locations. The eight drainage basins evaluated in the parking lot are outlined by the dotted lines and shown in more detail in the next diagram. Numbered black boxes indicate sampling locations in the strand and the pond.

Experimental Design - The experimental design in the parking lot allowed for the testing of three paving surfaces as well as basins with and without swales, creating four treatment types with two replicates of each type. The eight basins were instrumented to measure discharge volumes and take flow-weighted water quality samples during storm events. The four treatment types included: 1) asphalt paving with no swale (typical of most parking lots), 2) asphalt paving with a swale, 3) concrete (cement) paving with a swale, and 4) porous (permeable) paving with a swale. The swales are planted with native vegetation. The basins without swales still had depressions similar to the rest of the parking lot, but the depressions were covered over with asphalt. All basins had some landscaped garden areas providing opportunities for runoff to infiltrate. The comparative size of the garden areas can be seen in Figure 1b. Three different breaches through the berm that was located between the strand and Ybor Channel interfered with collecting data in the strand and pond as planned, but even so, over one year of data were collected and analyzed once the problem was corrected in July 1999.

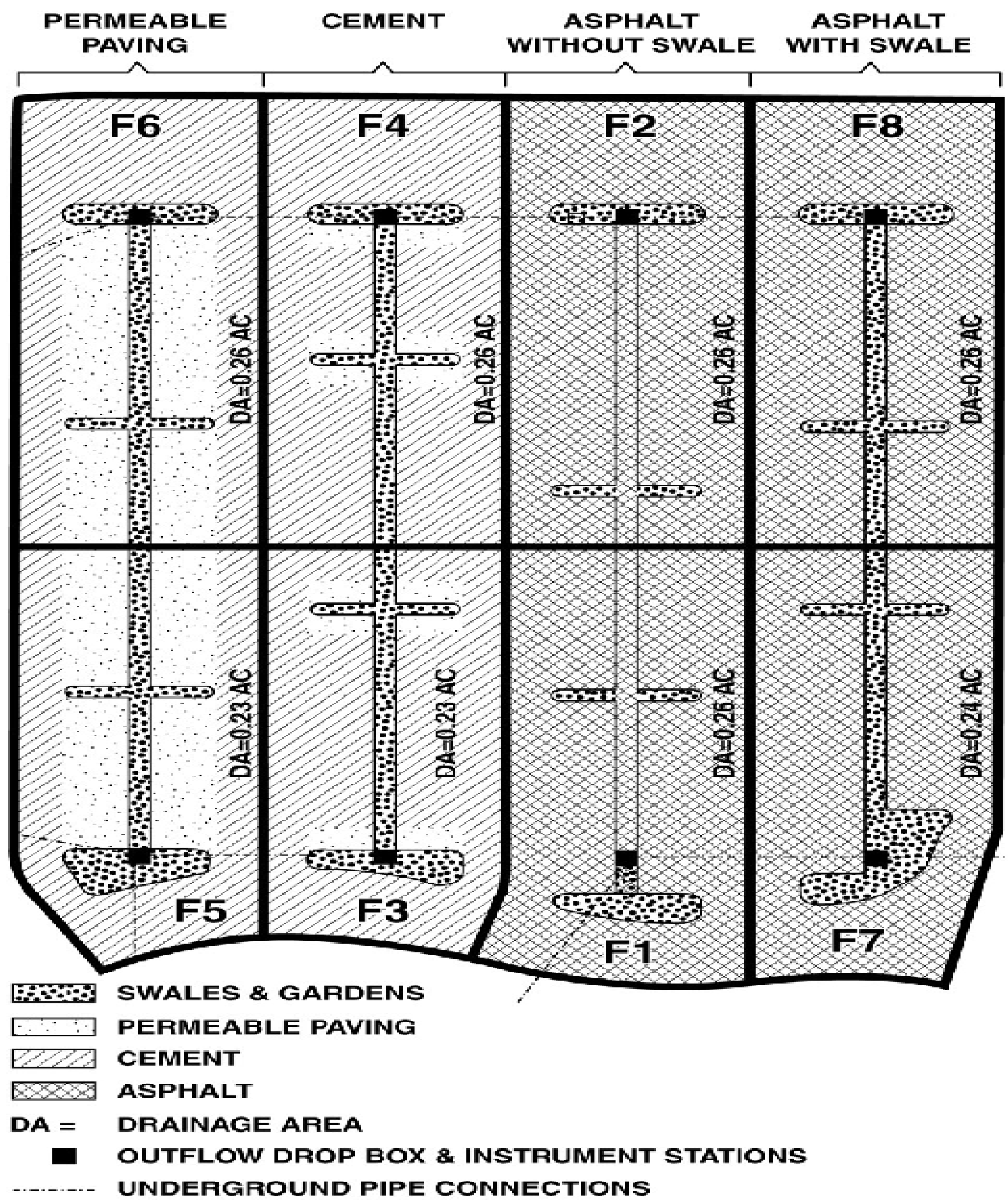

Figure 1b. Site plan of the parking lot swales delineated by the dotted lines in Fig 1a.

Flow out of each of the eight small parking lot drainage basins (0.09 to 0.105 ha) was measured using identical H-type flumes and shaft encoders (float and pulleys) connected to four Campbell Scientific CR10™ data loggers. The major differences at the pond site compared to the parking lot were the primary measuring devices that were weirs instead of flumes.

Rainfall characteristics were calculated using measurements from a tipping bucket rain gauge, summed over 15 minute intervals and stored in Campbell Scientific CR10™ data loggers. Rainfall was characterized by calculating total rainfall, duration, inter-event dry period, and rainfall intensity. Runoff coefficients (RC), LOADS, and LOAD EFFICIENCY were calculated using the following formulas:

$$\text{RC} = (\text{volume discharged}) / ((\text{basin size})*(\text{rainfall amount}))$$
$$\text{LOADS (kg/ha-yr)} = ((\text{concentrations})*(\text{volume discharged}))/(\text{basin size})$$
$$\text{LOAD EFFICIENCY (\%)} = ((\text{Sum of Loads (SOL) in} - \text{SOL out})/\text{SOL in})*100$$

Water quality samples were collected on a flow-weighted basis and stored in iced ISCO samplers until picked up, fixed with preservatives and transported to the Southwest Florida Water Management District (SWFWMD) laboratory. Samples were analyzed according to the guidelines published in their Quality Assurance Plan. Rainfall was collected using an Aerochem Metrics™ model 301 wet/dry precipitation collector. A small refrigerator was mounted under the collector to immediately store the sample until it could be fixed with the appropriate preservatives and transported to the laboratory.

Sediment samples were collected in front of the outfall (drop box) in each of the swales, and also at one location in the strand and two locations in the pond during the fall of 1998 and again in the fall of 2000 (see Figure 1). Samples were extracted intact from the sediments using a two-inch diameter hand driven stainless steel corer. Cores were collected at two depths, representing sediments in the top 2.54 cm (1 in) layer and sediments 10 to 13 cm (5 to 6 in) below the surface. Residue in the drop boxes used to transport stormwater to the strand were also collected in 1998. Sediment samples were analyzed by the Department of Environmental Protection laboratory in Tallahassee by the methods outlined in their approved Comprehensive Quality Assurance plan .

Statistical computations were performed using the SAS system (v 8.1) to determine significant differences and to analyze relationships among variables. Most statistical tests assume the variables are from an independent and normally distributed population and that the variances are homogeneous. This condition rarely prevails for water quality data, and most test were run using non-parametic statistics such as Spearman correlations, Wilcoxon rank sum test and the Kruskal-Wallis chi-square test.

RESULTS AND DISCUSSION

Data for the two-year study are reported here with emphasis on rainfall characteristics, hydrology, water quality, sediment analyses and statistical verification.

Hydrology

Rainfall Characteristics - The type of storms and the amount of rainfall are relevant to water quantity issues such as flooding, volume of runoff and peak discharge, and also to water quality, particularly constituent concentrations and removal efficiency. Antecedent conditions (inter-event dry period) and rainfall intensity increase pollutant concentrations by providing time for pollutant accumulation on land surfaces as well as the rain energy to flush pollutants through the system. Also whether it is a wet or dry years affect input and output concentrations by changing subsurface flow and evapotranspiration. Rainfall during both years of the study can be described as drought conditions (Table 1), but the rainfall deficit was much more severe during the second year..

Table 1. Comparison of rainfall characteristics calculated between years (August through July of each year). The long-term average for the region is 127.0 to 137.7 cm per year. The data include all storm events greater than 0.40 cm.

STATISTICS	RAIN (cm)	INTER-EVENT (hrs)	DURA-TION (hrs)	MAX. INT, (cm/hr)	AVG. INT, (cm/hr)
Year One Summary Data	**Total rain 105.83 cm Number of storms 60**				
Average	1.79	143.78	2.58	1.23	1.02
Median	1.30	70.25	1.50	0.94	0.93
Maximum	6.45	921.25	20.50	3.73	4.11
Minimum	0.38	3.75	0.25	0.28	0.15
Standard Dev.	1.35	194.36	3.05	0.85	0.75
C.V.	0.75	1.35	1.18	0.69	0.73
Year Two Summary Data	**Total rain 86.30 cm Number of storms 48**				
Average	1.76	155.13	3.07	1.16	0.95
Median	1.09	50.50	2.25	0.71	0.79
Maximum	7.39	1723.00	12.75	5.05	5.05
Minimum	0.41	6.00	0.25	0.23	0.09
Std.Dev.	1.51	284.70	2.89	1.13	0.88
C.V.	0.89	1.84	0.95	0.97	0.92

Runoff - Drought conditions also reduced the amount of runoff and the runoff coefficients for the parking lot. But even with drought conditions, the calculation of runoff coefficients for each basin demonstrated the reductions that can result from even small swales and garden areas. The runoff coefficient (Table 2) accounts for the integrated effect of rainfall interception, infiltration, depression storage, evaporation and temporary storage in transit. If all the rain falling on a drainage basin ran off, the coefficient would be 1.0 or 100 percent. Except for basin F1, the odd numbered basins were slightly smaller and had larger recessed garden areas than the even numbered basins. The larger garden areas (less than the size of one parking space) in the odd numbered basins accounted for their 40 to 50 percent lower runoff coefficients. Another factor that may account for the good infiltration rate is the soil structure. The site is constructed on filled land and from soil analysis, the Florida Aquarium parking lot had a high gravel content (average 9.9% for soil particles > 2 mm) and it usually took a rain event of at least 0.84 cm (0.33 in) to produce enough flow to collect samples, especially in the basins with swales. Also the data suggest that for large rain events, basin F2 overflows its boundaries and some of its runoff is actually discharged from basin F1. This accounts for the smaller runoff coefficient for both years in basin 2 despite the similarity between the two basins.

Table 2. Summary of runoff coefficients for the eight basins calculated separately for two years. Total rainfall amount (cm) for the storms sampled.

	RAIN AM'T cm	ASPHALT WO/SWALE F1	F2	ASPHALT W/SWALE F7	F8	CONCRETE W/SWALE F3	F4	POROUS W/SWALE F5	F6
YEAR ONE		**total rain**	**87.71**						
Average	2.66	0.58	0.50	0.15	0.31	0.19	0.29	0.09	0.17
Median	2.08	0.57	0.48	0.12	0.30	0.13	0.25	0.02	0.14
max	6.60	0.97	0.86	0.43	0.78	0.67	0.75	0.51	0.59
Stddev	1.57	0.18	0.17	0.12	0.19	0.19	0.22	0.12	0.17
c.v.	0.59	0.31	0.33	0.83	0.60	1.01	0.76	1.44	0.98
YEAR TWO		**total rain**	**77.22**						
Average	3.09	0.50	0.43	0.15	0.29	0.17	0.27	0.10	0.15
Median	2.72	0.53	0.46	0.08	0.29	0.06	0.26	0.04	0.13
max	7.49	0.78	0.67	0.53	0.74	0.65	0.72	0.56	0.72
Stddev	1.55	0.18	0.15	0.15	0.18	0.20	0.18	0.15	0.17
c.v.	0.50	0.36	0.34	1.00	0.63	1.18	0.66	1.49	1.09

Comparison of Flow One of the major advantages of low impact designs for parking lots is the reduction in the volume of water discharged from the site. When the volume of water discharged from the different elements of the treatment train at the Florida Aquarium site were compared, the results showed almost all runoff was retained on site (Table 3). Although the year sampled was during an extreme drought, it is still remarkable that stormwater was discharged for only one storm event and would probably have only discharged four or five times in a normal year. The data represented almost all major storms that produced significant flow for a one year period.

Table 3. Discharge volumes measured for four basins with paving similar to most of the 4.65 hectare parking lot compared to the measured flow from the strand, under drain and out of the pond. Since the four basins included in the analysis represent about 8.8% of the parking lot that ratio was used to estimate the total discharge from all basins.

SAMPLE DATE	RAIN AMOUNT	ASPHALT W/SWALE		CONCRETE W/SWALE		SUM 4 BASINS	ESTIMATE ALL PARKING	STRAND OVER WEIR	UNDER DRAIN	POND
		F7	F8	F3	F4	8.8%	100%			
	cm	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3
11/01/99	4.14	7.22	16.25	6.09	12.94	42.50	374.04	0.00	248.68	0.00
12/17/99	1.91	0.00	0.42	0.00	0.14	0.57	4.98	0.00	0.00	0.00
01/06/00	2.01	1.76	6.48	0.88	4.36	13.48	118.62	0.00	0.00	0.00
01/24/00	1.73	0.00	1.81	0.00	1.70	3.51	30.90	0.00	0.00	0.00
01/31/00	1.78	0.31	3.45	0.00	2.52	6.29	55.32	0.00	0.00	0.00
06/13/00	3.28	1.61	5.41	1.56	9.74	18.32	161.23	0.00	0.00	0.00
06/22/00	0.99	0.06	0.57	0.00	0.17	0.79	6.98	0.00	0.00	0.00
06/24/00	3.53	0.28	3.43	0.06	2.89	6.65	58.56	0.00	0.00	0.00
06/29/00	1.80	1.16	5.01	1.05	4.47	11.70	102.92	0.00	0.00	0.00
07/01/00	2.06	0.82	4.53	0.48	4.81	10.65	93.70	0.00	34.04	0.00
07/04/00	4.95	16.99	30.78	25.26	30.95	103.98	915.04	0.00	381.89	0.00
07/08/00	2.72	8.50	12.74	3.26	11.44	35.93	316.23	0.00	0.00	0.00
07/15/00	5.03	17.67	28.09	21.32	24.64	91.72	807.14	0.00	211.67	0.00
07/26/00	3.15	2.15	4.87	0.65	5.01	12.69	111.64	0.00	0.00	0.00
07/31/00	6.83	35.43	36.50	35.93	31.86	139.72	1229.52	0.00	413.94	19.65
08/29/00	3.05	7.82	13.79	11.04	13.90	46.55	409.67	0.00	5.18	0.00
09/07/00	4.98	13.76	23.08	18.04	22.14	77.02	677.80	0.00	182.82	0.00
09/17/00	5.21	12.03	19.88	12.12	23.73	67.76	596.32	0.00	173.47	0.00
09/24/00	2.95	7.08	11.30	7.31	10.59	49.81	438.33	0.00	60.23	0.00
11/26/00	3.48	5.04	10.00	6.26	6.20	27.50	242.00	0.00	79.35	0.00
total	65.58	139.7	238.4	151.3	224.2	767.14	6750.94	0	1791.3	19.65

Water Quality

The concentration of pollutants is useful for investigating processes taking place in stormwater systems, while pollutant loads are more appropriate for assessing impacts to downstream habitats. Both types are discussed below.

Concentrations - The average concentrations of constituents measured in each of the basins for all storms sampled showed some differences between paving types as well as other variables. A comparison of constituents for all storms (Figure 2) indicated some of the processes taking place in the parking lot, the strand, the under drain and the pond. For inorganic nitrogen, nitrate levels were highest in the parking lot and much lower once water collected in the strand and pond. High concentrations were also measured in rainfall. Ammonia reflects almost the same pattern as nitrates except it exhibits about the same concentration as nitrate in the strand and pond and measures higher concentrations in the basins paved with asphalt. At least some of the higher than expected ammonia concentrations in the strand and pond can be attributed to stagnant conditions since they seldom discharged. The lowest concentrations of organic nitrogen were measured in rainfall and the basins without a planted swale and concentrations are highest in the strand and pond.

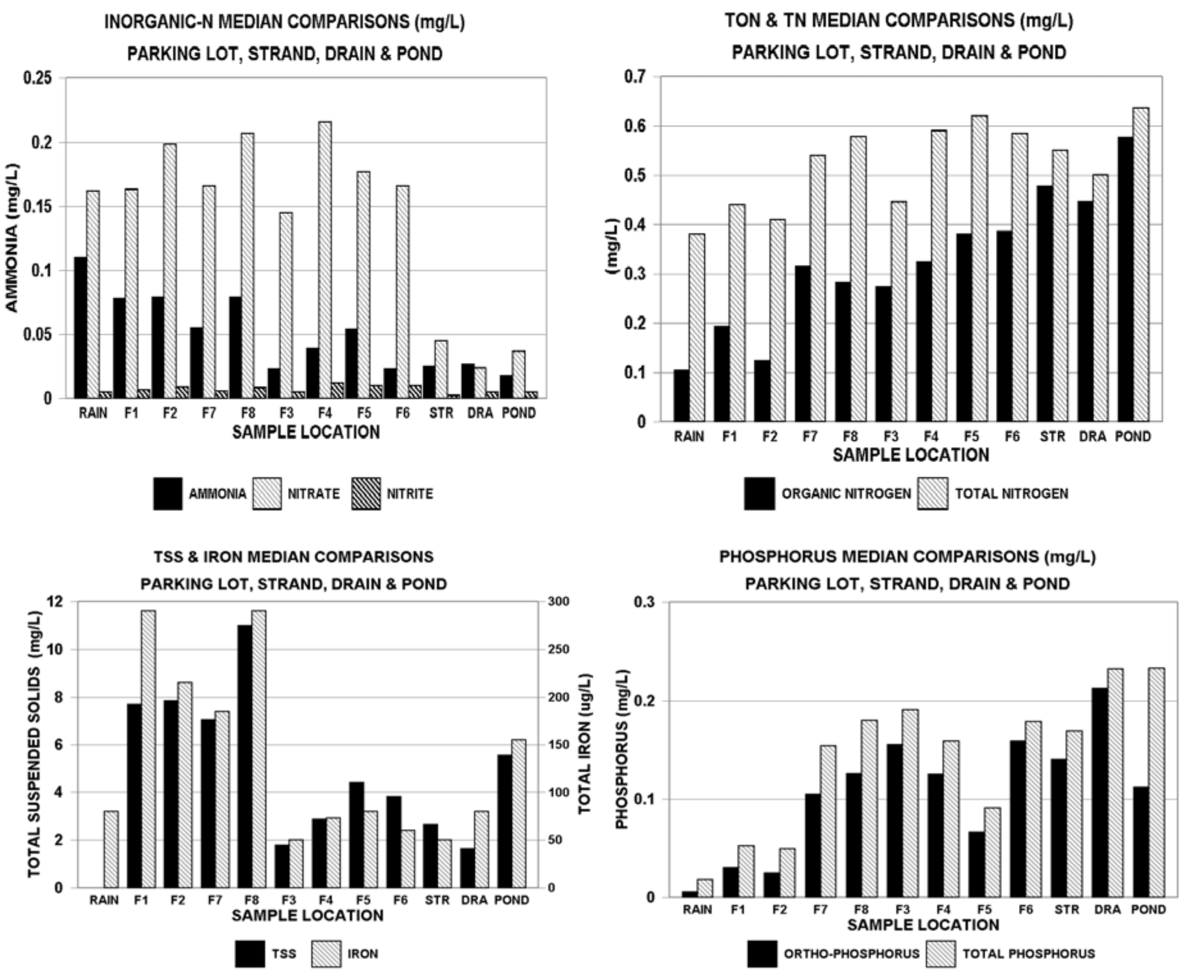

Figure 2. Comparison of median water quality concentrations at the outflows of the various elements of the stormwater system. See Figure 1 for sample locations. Abbreviations: STR=strand, DRA=under drain, POND=pond.

Phosphorus concentrations (Figure 2) were much lower in rainfall and only somewhat higher than rainfall in the basins without planted swales (F1, F2). The highest concentrations of phosphorus were measured in basins where runoff had traveled through grassed areas (F3, F4, F5, F6, F7, F8) and in the vegetated strand. Even higher concentrations were measured in the under drain and in the pond. These may have been caused by mulch that was applied when the pond and strand were constructed and by the filter material used in the under drain when it was installed. Some metals in runoff reflected the type of paving material over which it traveled as illustrated in Figure 2 with iron. Iron, manganese, lead, copper and zinc were measured at concentrations over twice as high in the basins paved with asphalt (F1, F2, F7, F8) compared to the basins paved with concrete products. Total suspended solids were also higher in basins paved in asphalt, although TSS was measured at low concentrations at the site.

Water Quality Loads - A more reliable measurement than pollutant concentrations for understanding the impact of stormwater on receiving waters is to evaluate pollutant loads. Pollutant loads include in the calculations both the volume of water discharged and the concentration of pollution measured. The most effective method for reducing pollutant loads is to retain runoff on site and allow time for infiltration and evaporation as well as for chemical, biological and hydrological processes to take place. The positive effect of the low impact design features is demonstrated with summary data in Table 4. Higher runoff volumes were discharged from the basins without swales (F1, F2), consequently they usually had much higher loads for all the constituents except phosphorus. In contrast the basins with larger garden areas (F7, F3, and F5) had much lower runoff volumes (Table 4) demonstrating the value of recessed areas for infiltration to occur in much the same manner as it did before development. Although it is important to reduce pollutant concentrations, it is an even better strategy to reduce runoff volume using low impact concepts.

Load efficiencies were calculated to quantify how much pollutant loads can be reduced by infiltration with vegetated depressions (Tables 5a and 5b). The low impact design produced significantly reductions for most constituents, especially in the basins with larger garden areas (Table 5b). The basins paved with porous pavement had the best per cent removal, with most removal rates greater than 75%. Phosphorus was a notable exception to this pattern of increased efficiency in basins with swales. Higher phosphorus loads were discharged from basins with vegetated swales than from the basins with no swales. This might be expected since there is not much phosphorus in rainfall, asphalt or automobile residues, but there is phosphorus in vegetation and especially in soils. Also total nitrogen was not removed as well as other pollutants. As almost all runoff was retained on site, these were not serious problems.

In general, removal efficiency was much better for the first year than for the second year. This is probably the result of more rainfall and runoff during the first year (see Table 1), or perhaps, the storage capacity in the swales had been decreased by the second year as a result of increased vegetative mass when the grass in the swales was replaced with shrubs. Reduced efficiency was most noticeable in the asphalt basin with a swale (F8). In contrast, efficiency of total nitrogen was usually improved during the second year especially in basins with larger garden areas. Some of the poor reduction in phosphorus loads may be attributed to landscaping practices since high concentrations, some greater than 1 mg/L, were sometimes measured in the basins with swales during the spring.

Additional infiltration capacity such as porous paving or larger garden areas (F5, F3, F7) improved efficiency, indicating both infiltration and more mature vegetation can improve total nitrogen efficiency (Table 7b). Better efficiency was most evident in the basin with porous pavement and both a swale and larger garden area (F5). This basin (F5) reduced by over 80 percent almost all constituents except phosphorus. Eighty percent removal of pollutant loads, especially for TSS, is a state water quality goal.

Table 4. Yearly constituent loads for the basin as calculated for each pavement type *.

Constituents	units	Asphalt no swale		Asphalt with swale		Concrete with swale		Porous with swale	
		YR 1	YR 2	YR 1	YR 2	YR 1	YR 2	YR 1	YR 2
		F2		**F8**		**F4**		**F6**	
Ammonia	kg/ha-yr	0.43	0.38	0.23	0.22	0.12	0.19	0.08	0.06
Nitrate	kg/ha-yr	0.61	0.74	0.34	0.58	0.36	0.58	0.21	0.29
Tot. Nitrogen	kg/ha-yr	1.58	1.77	0.73	1.56	1.33	1.64	0.92	0.80
Ortho Phos.	kg/ha-yr	0.19	0.11	0.54	0.36	0.54	0.48	0.34	0.28
Total. Phos	kg/ha-yr	0.34	0.20	0.66	0.51	0.55	0.63	0.33	0.35
TSS	kg/ha-yr	58.61	29.12	32.79	7.31	12.76	15.43	5.11	20.83
Copper	kg/ha-yr	0.033	0.031	0.025	0.027	0.009	0.013	0.006	0.006
Iron	kg/ha-yr	1.396	0.994	0.667	1.150	0.228	0.165	0.107	0.132
Lead	kg/ha-yr	0.017	0.009	0.007	0.007	0.004	0.002	0.003	0.009
Manganese	kg/ha-yr	0.041	0.029	0.024	0.025	0.013	0.007	0.003	0.029
Zinc	kg/ha-yr	0.147	0.098	0.079	0.083	0.056	0.049	0.036	0.057
		F1		**F7**		**F3**		**F5**	
Ammonia	kg/ha-yr	0.57	0.47	0.11	0.10	0.08	0.08	0.11	0.09
Nitrate	kg/ha-yr	0.72	0.81	0.19	0.27	0.26	0.37	0.15	0.16
Tot. Nitrogen	kg/ha-yr	1.86	2.04	1.07	0.69	1.15	0.93	0.53	0.39
Ortho-Phos.	kg/ha-yr	0.15	0.14	0.15	0.15	0.31	0.35	0.06	0.06
Tot. Phosphor	kg/ha-yr	0.28	0.25	0.21	0.21	0.37	0.42	0.07	0.08
TSS	kg/ha-yr	52.28	37.06	8.68	16.33	4.47	3.41	4.26	3.99
Copper	kg/ha-yr	0.042	0.039	0.008	0.010	0.008	0.008	0.003	0.003
Iron	kg/ha-yr	1.805	1.361	0.227	0.287	0.156	0.086	0.114	0.076
Lead	kg/ha-yr	0.018	0.010	0.002	0.003	0.003	0.002	0.001	0.001
Manganese	kg/ha-yr	0.042	0.031	0.007	0.008	0.004	0.003	0.003	0.002
Zinc	kg/ha-yr	0.174	0.115	0.037	0.032	0.042	0.032	0.020	0.016

* For missing data, which occurred in the basins with swales, a median water quality value for the measured rain event was used in the calculations.

Table 5a. Load efficiency (%reduction) of pollutants for the even numbered basins as compared to Basin F2 (no swale).

Constituents	Asphalt with swale F8		Concrete with Swale F4		Porous w/swale F6	
	YEAR 1	YEAR 2	YEAR 1	YEAR 2	YEAR 1	YEAR 2
Ammonia	46%	42%	73%	49%	85%	75%
Nitrate	44%	21%	41%	22%	66%	60%
Total Nitrogen	4%	12%	16%	8%	42%	55%
*Ortho Phosphorus	-180%	-230%	-180%	-337%	-74%	-153%
*Total Phosphorus	-94%	-157%	-62%	-216%	3%	-77%
Suspended Solids	46%	-11%	78%	78%	91%	71%
Copper	23%	14%	72%	60%	81%	82%
Iron	52%	-16%	84%	83%	92%	87%
Lead	59%	28%	78%	75%	85%	83%
MangGanese	40%	15%	68%	76%	92%	91%
Zinc	46%	15%	62%	50%	75%	41%

Table 5b. Load efficiency (%reduction) of pollutants for the odd numbered basins with larger garden areas (F7, F3, F5) as compared to Basin F1 (no swale).

Constituents	Asphalt with swale F7		Concrete w/ Swale F3		Porous w/swale F5	
	YEAR 1	YEAR 2	YEAR 1	YEAR 2	YEAR 1	YEAR 2
Ammonia	80%	79%	86%	83%	80%	90%
Nitrate	73%	67%	64%	55%	79%	80%
Total Nitrogen	58%	66%	58%	54%	71%	81%
Ortho Phosphorus	-1%	-4%	-105%	-149%	-61%	55%
Total Phosphorus	-26%	16%	-32%	-69%	76%	66%
Suspended Solids	83%	56%	91%	91%	92%	89%
Copper	81%	75%	81%	79%	94%	94%
Iron	87%	79%	91%	94%	94%	94%
Lead	87%	73%	83%	85%	93%	94%
Manganese	83%	75%	90%	90%	93%	95%
Zinc	79%	72%	76%	72%	89%	86%

* Notice that some efficiencies are negative, indicating an increase in loads in the basins with a swale.

Sediment Samples

Soil samples were collected in the swales, the strand and the pond in 1998 and again in 2000 (see Figure 1 for sampling locations). For 1998, samples were also collected in the drop boxes that received runoff from the swales. For the basins without swales, the sediments that had accumulated in the asphalt depressions were analyzed and there were no deeper soils to sample.

Metals - Consistent results were seen for 1998, with metals usually measured at higher concentrations in basins paved in asphalt (F1, F2, F7, F8) compared to basins paved with concrete (F3, F4) or porous paving (F7, F8). Aluminum, iron and copper concentrations measured in the strand and pond only occasionally showed concentrations as high or higher than the asphalt basins in the parking lot even though most of the 10-acre parking lot is paved in asphalt. Results indicate that the swales, strand and pond are effective for sequestering metals near the source. An example with zinc is shown in Figure 3.

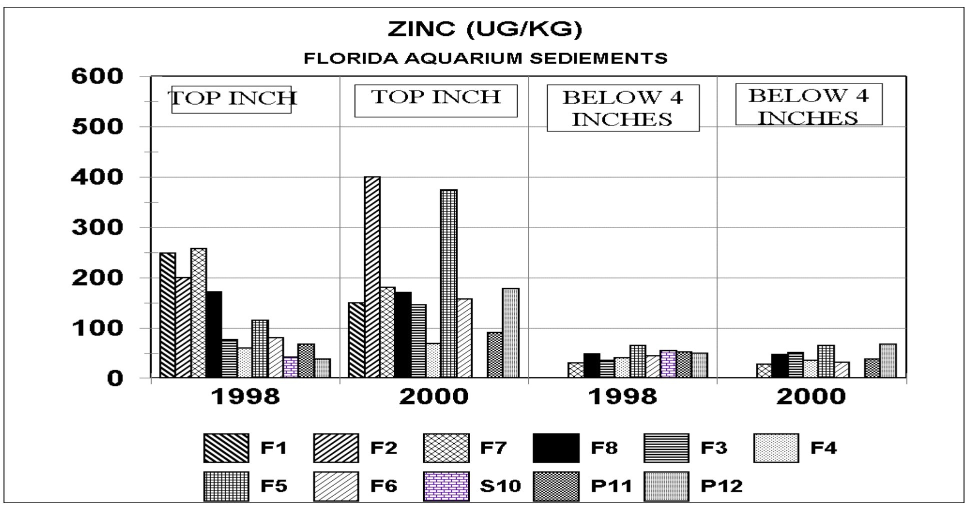

Figure 3. Sediment samples for zinc collected in 1998 and again in 2000 at the outfall of each drainage basin as well as in the swale and pond.

When the metal concentrations in 1998 in the swales are compared to 2000, values are about the same or only marginally higher in 2000 when considering the inherent variability that is characteristic of soils. The possible exception of comparable concentrations is porous pavement (F5, F6) that almost always had higher concentrations in 2000. When the site in the strand in 1998 (S10) is compared to values in 2000, the year 2000 concentrations are usually significantly lower and these results can be explained by the berm repair. All of the soils in the strand were excavated during berm construction, so these data are the result of deeper, cleaner soils. When the Pond data are compared between years, the concentrations are much higher in 2000, probably the result of Ybor channel water pumped into the pond during the repair and the subsequent inflow of stormwater from the channel into the pond through the under drain.

Nutrients - Total phosphorus and Kjeldahl nitrogen measured in the soils showed an increase in most basins from 1998 to 2000, especially for nitrogen (Figure 4). Usually nutrients are quite low for the basin without a swale that has no vegetation or deeper soils to cycle nutrients. Nitrogen, and to a certain extent phosphorus, increased in the swales from 1998 to 2000. The pond showed a considerable increase in phosphorus and nitrogen from 1998 to 2000. Total phosphorus in the deeper sediments also increased by 2000, but a corresponding increase in nitrogen in the deeper sediments was not usually seen.

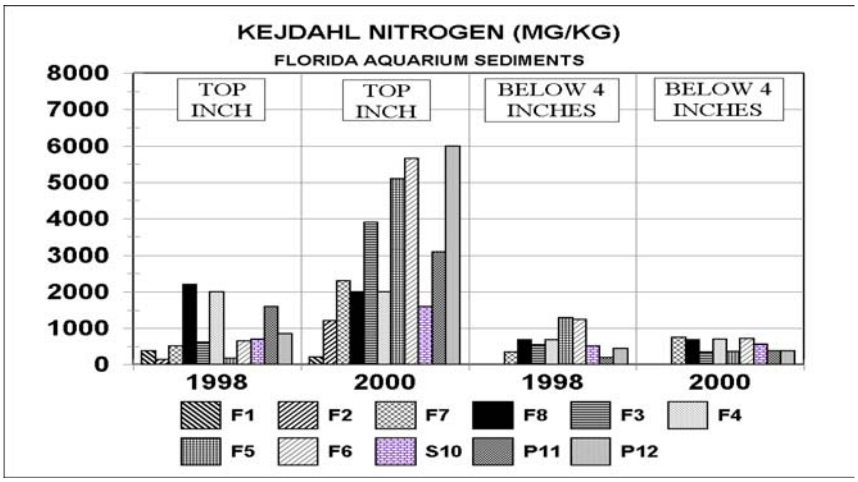

Figure 4. Sediment samples for total Kjeldahl nitrogen collected in 1998 and again in 2000 at the outfall of each drainage basin, the swale, and the pond.

Polycyclic Aromatic hydrocarbons (PAHs) - PAHs are compared by percentages in Table 6. The highest percentage of detection was found at the deeper depths (12.7 cm) suggesting previous hydrocarbon contamination. The lowest number of samples with hydrocarbon detection occurred in the surface soils in 2000. In 1998 more PAHs were detected in the soils of more sites than in 2000 indicating that hydrocarbon pollution may be decreasing at the site. The most frequently measured hydrocarbon was fluoranthene, which was detected in at least 50 percent of the samples collected in each category. Chrysene and pyrene were also frequently detected, followed by the benzo-series (Table 6).

Pesticides & PCB's - At most sites pesticides and polychlorinated biphenyls (PCBs) were not detected but there were some exceptions (Table 6). Chlordane was the pesticide most often detected in measurable quantities and it was found at all locations but three. Unlike the PAH data where concentrations in the boxes were low, the sediments in the drop boxes had the highest percent detection of pesticides. Dichlorodiphenyltrichloroethane (DDT) and its daughter products were measured at almost all locations, and DDE was found in measurable quantities. But the quantities were not considered toxic. At the Florida Aquarium, DDT and DDD were more often measured in the deeper soil profile and DDE in the surface soils. Polychlorinated biphenyl (PCB-

1260) was frequently detected in the soils and it was more often detected in the deeper sediments than in the surface soils.

Table 7. Percentage of samples that detected pollutants in each of the soil strata for each of the eleven sampling sites.

PAH SEMI-VOLATILE ORGANIC		1998 TOP	1998 DEEP	1998 BOX	2000 TOP	2000 DEEP
Acenaphthene	ug/kg	0	20	25	0	17
Acenaphthylene	ug/kg	0	0	0	0	17
Anthracene	ug/kg	0	17	25	0	17
Benzo(a)anthracene	ug/kg	67	70	38	40	70
Benzo(a)pyrene	ug/kg	75	70	38	33	60
Benzo(b)fluoranthene	ug/kg	42	70	25	17	70
Benzo(k)fluoranthene	ug/kg	50	50	25	17	20
Benzo(g,h,i)perylene	ug/kg	17	30	13	17	20
Bis(2-ethylhexyl)phthalate	ug/kg	8	0	0	0	10
Butyl benzyl phthalate	ug/kg	0	0	50	0	10
Chrysene	ug/kg	67	70	38	50	70
Di-n-octyl phthalate	ug/kg	8	0	0	0	10
Dibenzo(a,h)anthracene	ug/kg	0	0	0	0	10
Diethyl phthalate	ug/kg	0	0	0	0	10
Fluoranthene	ug/kg	75	100	63	50	80
Fluorene	ug/kg	17	0	13	0	10
Indeno(1,2,3-cd)pyrene	ug/kg	17	30	25	17	30
Phenanthrene	ug/kg	75	70	25	25	40
Pyrene	ug/kg	83	90	50	58	80
PESTICIDES						
Chlorpyrifos Ethyl	ug/kg	0	0	25	0	0
Diazanon	ug/kg	10	0	50	0	0
Parathion Methyl	ug/kg	0	10	0	0	10
Aldrin	ug/kg	8	0	0	0	10
Chlordane	ug/kg	75	40	63	25	10
DDD-p,p'	ug/kg	17	30	13	8	20
DDE-p,p'	ug/kg	83	60	50	66	30
DDT-p,p'	ug/kg	33	50	12	42	50
Dieldrin	ug/kg	0	20	63	0	8
Endosulfan Sulfate	ug/kg	0	0	8	42	10
Endrin Aldehyde	ug/kg	0	0	0	8	0
Methoxychlor	ug/kg	0	0	0	17	8
PCB-1248	ug/kg	8	0	13	0	0
PCB-1260	ug/kg	33	70	38	17	20

Particle Size Analysis and percent organic matter - The size of sediment particles affects the removal of pollutants in stormwater runoff by sedimentation. Most sites exhibited a similar pattern for particle size (medium fine sand) and there were no obvious differences between paving types or the pond and the strand. Organic matter improves soil structure and provides conditions conducive to healthy soil microbes. These microbes are important for transformation and degradation processes that remove pollutants. Organic matter content ranged from 1.6 to 8.4%.

Statistical Analysis

Differences Between Basins - Since there were few significant differences between years, all 59 of the storms sampled were combined for hypothesis testing. The basins exhibited at least one significant difference for all parameters except nitrate (Table 8). Some of the patterns can be explained by basin characteristics. For example, the basins paved in asphalt had significantly higher concentrations of metals and total suspended solids, which may be increased by the paving material itself. Higher phosphorus concentrations were measured in basins with planted swales, probably a result of the vegetation and soil particles. Inorganic nitrogen is usually measured at relatively high levels in rainfall and nitrogen transformations may explain the differences measured in runoff between the various basins especially after runoff travels through vegetation. To test this theory further, correlations were run.

Table 8. Significant differences between even numbered basins. Data from Duncan Multiple Range Test and significant differences calculated by the Kruskal-Wallis test.

Parameter	Pr>Chi-Square	Asphalt wo/ swale	Asphalt with swale	Concrete with swale	Porous with swale
		F2	F8	F4	F6
Ammonia	0.0004	0.111 a	0.112 a	0.069 b	0.049 b
Nitrate	0.76 ns	0.264 a	0.263 a	0.242 a	0.221 a
Total Nitrogen	0.05	0.511 b	0.737 a	0.684 ab	0.639 ab
Ortho-Phosphorus	< 0.0001	0.047 b	0.192 a	0.203 a	0.195 a
Total Phosphorus	< 0.0001	0.082 b	0.267 a	0.253 a	0.237 a
Total Copper	< 0.0001	12.70 a	9.929 a	4.892 b	4.08 b
Total Iron	< 0.0001	431.67 a	328.93 a	85.40 b	87.73 b
Total Lead	< 0.0001	3.43 a	3.42 a	1.14 b	1.30 b
Total Zinc	< 0.0001	40.62 a	35.01 a	20.80 b	22.12 b
Total Susp. Solids	< 0.0001	16.02 a	11.48 a	4.70 b	5.53 b

Correlations - The small basin size and the short time of concentration contributed to close correlations between the nitrate measured in rainfall and the nitrate measured in runoff from each of the basins. The results of the correlations show the closest relationship among the asphalt basins without a swale, the next highest correlations were among the basins with smaller garden areas (F4 is an exception) and the weakest relationship was observed in the basins with larger garden areas. The data demonstrated an effect of vegetation in transforming the nitrogen found in rainfall.

Table 8. Correlations between nitrate measured in rainfall and nitrate measured in runoff. Results listed in order of decreasing correlation coefficient. SM=small garden LG=large garden

	Site Description	N	Prob > r	Coefficient
F1	Asphalt without a swale (SM)	51	< 0.001	0.924
F2	Asphalt without a swale (SM)	52	< 0.001	0.908
F6	Porous with swale (SM)	35	< 0.001	0.855
F8	Asphalt with swale (SM)	43	< 0.001	0.821
F3	Concrete with swale (LG)	32	< 0.001	0.799
F7	Asphalt with swale (LG)	30	< 0.001	0.789
F4	Concrete with swale (SM)	47	< 0.001	0.700
F5	Porous with swale (LG)	27	0.004	0.632

MAJOR FINDINGS

- Basins with swales and paved in asphalt or concrete reduced runoff to 30 percent and porous paving to about 16 percent compared to basins without planted swales, 55 percent. The basins with larger garden areas reduced runoff by an additional 50 percent (Table 2)
- Basins paved with porous pavement had the best percent removal of pollutant loads with greater than 90 percent removal in basins with larger garden areas. More phosphorus loads were discharged from basins with vegetated swales than from basins with no swales (Table 5). When the entire system is evaluated percent pollution reduction is greater than 99 percent since almost all runoff was retained on site (Table 3).
- Sediment samples implicated asphalt paving material as a source for metals (Figure 3). TKN and phosphorus in the sediments showed a considerable increase from 1998 to 2000 (Figure 4). Polycyclic aromatic hydrocarbons (PAHs) were detected in the soils at the site and some approached the significantly toxic levels (Table 6).

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Copies of the complete report are available from the author upon request