



***A low-impact design demonstrates how small alterations can reduce runoff and pollutant loads.***

By Betty Rushton *Ph.D.*,

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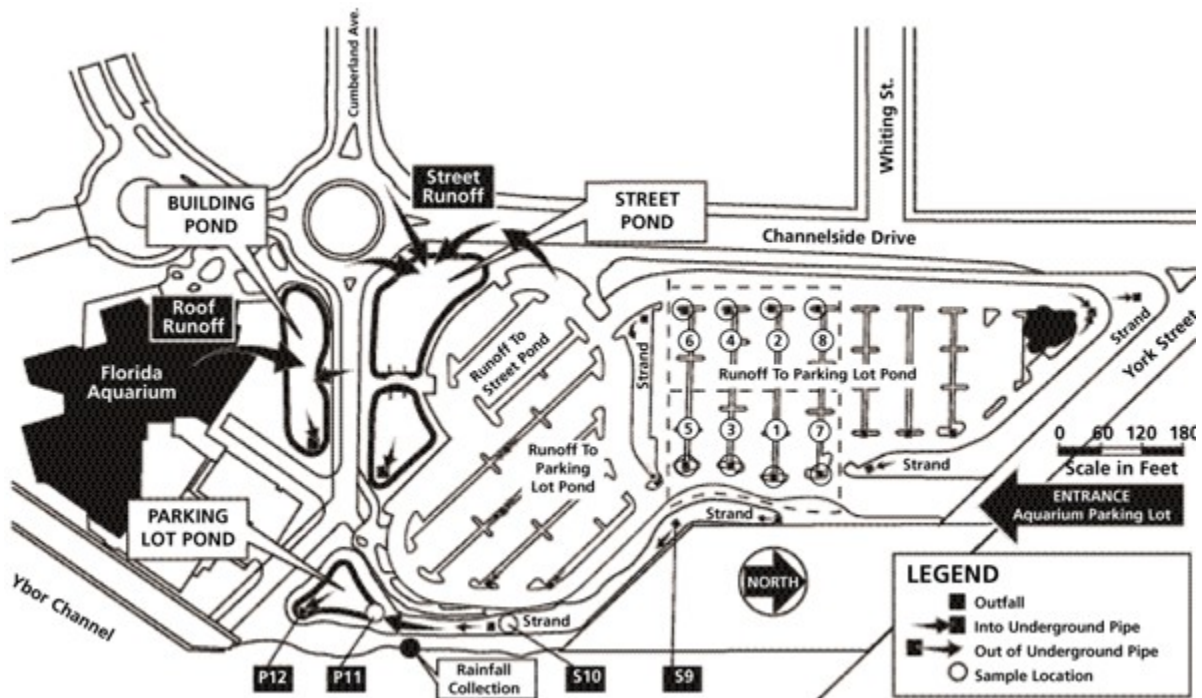
Florida's lakes are being rapidly degraded by storm runoff from urban development. For seriously impaired lakes, visible signs include obnoxious vegetation, dying fish, and oily scums; but even in seemingly healthy lakes, much less obvious signs of eutrophication are also taking place, such as the loss of species diversity and changing lake dynamics. One method to reduce runoff impacts is to provide opportunities for soil infiltration as soon as rain hits the ground. Where soils contain any degree of clay or humus, the earth is a powerful filter that can protect lakes from urban contamination. It takes only a few inches of soil to trap and accumulate oils, metals, and nutrients. As long as the infiltrating runoff contains only the common, mostly biodegradable, constituents from residential and commercial development, then it is within most soil's treatment capacity. Although most nitrogen compounds tend to decompose and return to the atmosphere, nitrates may be an exception to removal by soils since inorganic nitrogen is exceedingly soluble and can migrate to the groundwater supply. Although infiltration by itself will probably not solve all runoff pollution problems, when it is used in conjunction with other techniques, it can reduce impervious areas and thereby help reduce runoff to predevelopment levels.

Impervious surfaces, such as parking lots and rooftops, cause more stormwater runoff and pollutant loads than any other type of land use. These hard surfaces, which often replace natural vegetative cover, increase both the volume and the peak rate of runoff and also provide a place for traffic-generated residues and airborne pollutants to accumulate and become available for wash-off.

An innovative parking lot at the Florida Aquarium in Tampa was used as a research site to determine whether small alterations to parking-lot designs can decrease runoff and pollutant loads. During a two-year period, more than 50 storm events were sampled to measure water quality and quantity from eight small basins in the parking lot. In addition, once the berm between Ybor Channel and the strand was repaired, data for one year included the strand and the pond. Sediment samples were analyzed to estimate long-term consequences, and statistics were used to evaluate relationships. 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

**Figure 1a.**



The parking-lot design for the Florida Aquarium used the entire drainage basin for low-impact (dispersed) stormwater treatment. The study site is a 4.65-ha (11.25-ac.) parking lot serving 700,000 visitors annually. Incorporating pervious vegetated areas into the overall design reduced the amount of stormwater runoff. Changing regulations by making parking spaces 0.62 m (2 ft.) shorter provided land for swales without reducing the number of parking spaces. It also did not compromise parking since the design had the front end of vehicles hanging over grass rather than impermeable paving. The research was designed to determine pollutant load reductions measured from three elements in the treatment train: different treatment types in the parking lot, a strand planted with native wetland trees, and a small pond used for final treatment (Figures 1a and 1b). The final-treatment pond discharges 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).

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 with asphalt. 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, more than one year of data were collected and analyzed once the problem was corrected in July 1999.

*Flow* out of each of the eight small parking-lot drainage basins (0.09—0.105 ha) was measured using identical H-type flumes and shaft encoders (floats 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. Runoff coefficients (RC), loads, and load efficiency were calculated using the following formulas:

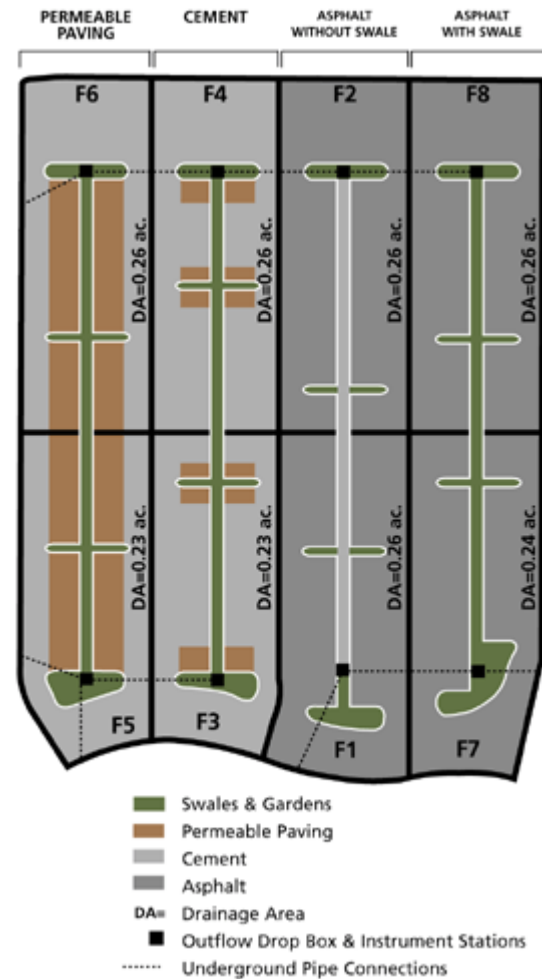
$$RC = (\text{volume discharged}) \div ([\text{basin size}] \times [\text{rainfall amount}])$$

$$\text{Loads (kg/ha-yr.)} = ([\text{concentrations}] \times [\text{volume discharged}]) \div (\text{basin size})$$

$$\text{Load efficiency (\%)} = ([\text{sum of loads (SOL) in} - \text{SOL out}] \div \text{SOL in}) \times 100$$

*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 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.

Figure 1b.



Site plan of the parking-lot swales delineated by the dotted lines in Figure 1a

*Sediment samples* were collected in front of the outfall (drop box) in each of the swales in 1998 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. Samples were extracted intact from the sediments using a 2-in.-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 10-13 cm (5-6 in.) below the surface. Residue in the drop boxes used to transport stormwater to the strand was also collected in 1998. Sediments were analyzed by the Department of Environmental Protection (DEP) laboratory in Tallahassee using the methods outlined in its 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, and most tests were run using nonparametric statistics, such as Spearman correlations, Wilcoxon rank sum test, and Kruskal-Wallis chi-square test.

## Results and Discussion

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### Hydrology

**Table 1. Summary of Runoff Coefficients for the Eight Basins Calculated Separately for the Two Years**

Rain Amount (cm)	Asphalt Without Swale		Asphalt With Swale		Concrete With Swale		Porous With Swale		
	F1	F2	F7	F8	F3	F4	F5	F6	
<b>Year One</b>	<b>Total Rain (cm)</b>		<b>87.71</b>						
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
Std. Dev.	1.57	0.18	0.17	0.12	0.19	0.19	0.22	0.12	0.17
Cu. Yd.	0.59	0.31	0.33	0.83	0.60	1.01	0.76	1.44	0.98
<b>Year Two</b>	<b>Total Rain (cm)</b>		<b>77.22</b>						
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
Std. Dev.	1.55	0.18	0.15	0.15	0.18	0.20	0.18	0.15	0.17
Cu. Yd.	0.50	0.36	0.34	1.00	0.63	1.18	0.66	1.49	1.09

*Runoff.* Drought conditions existed for both years but were much more severe the second year with only 77.22 cm (30.4 in.) of rain instead of the average 132 cm (52 in.). This also reduced the runoff coefficient and storm flow that would have been expected in a normal year. The runoff coefficient (Table 1) 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%. 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 40-50% lower runoff coefficients. Another factor that might account for the good infiltration rate is the soil structure.

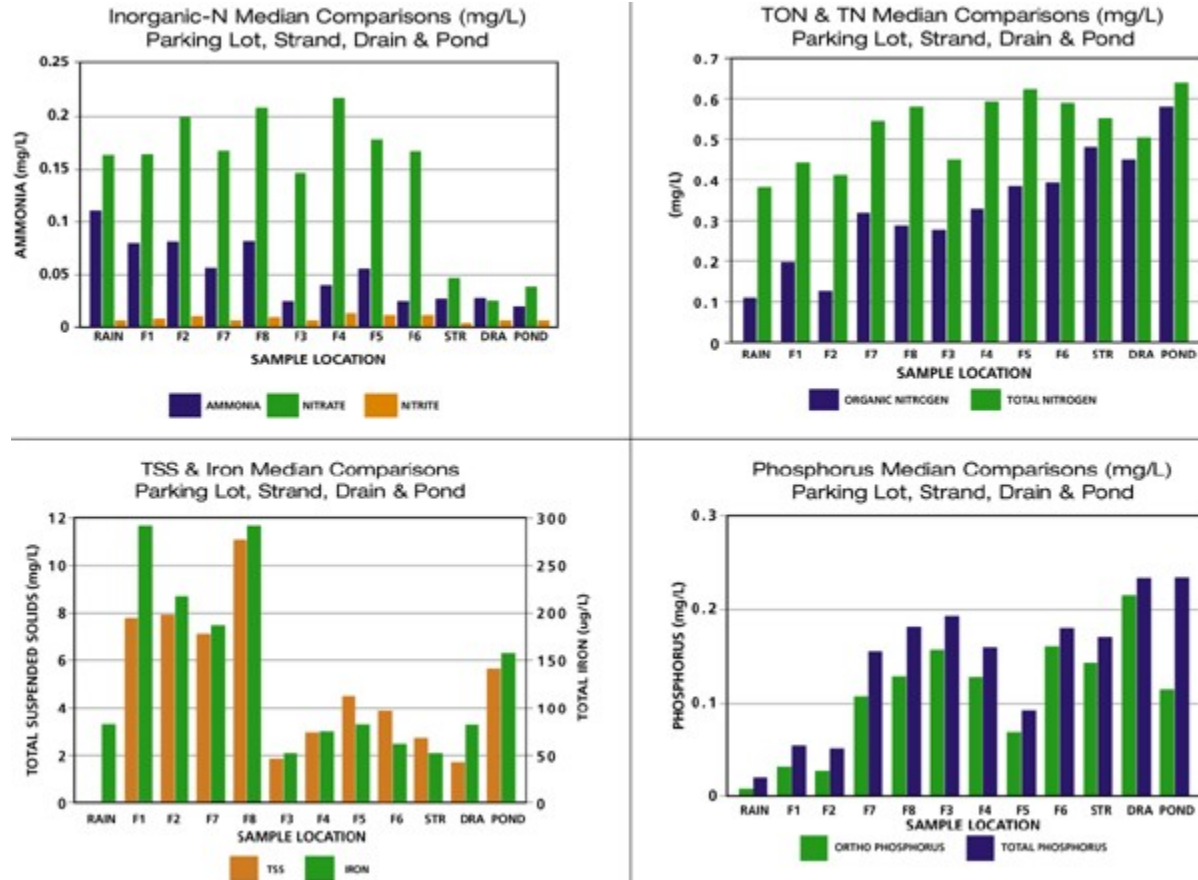
The site is constructed on filled land; from soil analysis, the Florida Aquarium parking lot had a high gravel content (average 9.9% for soil particles > 2 mm), and it usually took a rain event of at least 0.84 cm (0.33 in.) to produce enough flow to collect samples in the basins with planted swales. Also the data suggest that for large rain events, basin F2 overflowed its boundaries and some of its runoff was actually discharged from basin F1. This accounted for the smaller runoff coefficient for both years in basin F2 despite the similarity between the two basins.

*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. It was estimated that 6,751 m<sup>3</sup> (231,342 ft.<sup>3</sup>) were discharged from the parking lot into the strand, while 1,791 m<sup>3</sup> (63,258 ft.<sup>3</sup>) were discharged from the strand through the underdrain pipe and into the pond. Only 20 m<sup>3</sup> (706 ft.<sup>3</sup>) were actually discharged from the pond into the receiving waters. Although the year sampled was during an extreme drought, which reduced flow considerably, 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 all major storms that produced significant flow for the one-year period.

### ***Water Quality***

*Concentrations.* The median concentrations of constituents measured in each of the basins for all storms sampled showed some differences among paving types as well as between 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 underdrain, 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 was measured at lower concentrations than nitrate in the parking lot and at about the same concentrations in the strand and pond. At least some of the higher-than-expected ammonia concentrations in the strand and pond can be attributed to stagnant conditions since stormwater seldom flowed this far through the system. Ammonia had its highest concentrations in rainfall and the basins paved with asphalt. The lowest concentrations of organic nitrogen were measured in rainfall and also the basins without a planted swale, while concentrations were highest in the strand and pond.

Figure 2.



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. The higher concentrations measured in the underdrain and in the pond might have been caused by added mulch. Some metals in runoff reflected the type of paving material over which the runoff traveled, as illustrated in Figure 2 with iron. In the basins paved with asphalt (F1, F2, F7, F8), iron, manganese, lead, copper, and zinc were measured at concentrations more than twice as high compared to the basins paved with concrete products.

*Load Efficiencies.* Load efficiencies, which include both runoff volume and water-quality concentrations in the calculations, quantified how much pollution can be reduced by infiltration in vegetated depressions (Table 2). The basins paved with porous pavement had the best percent removal, with most removal rates greater than 75%. Phosphorus was a notable exception; 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. Some of the poor reduction in phosphorus loads might also 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.

Also, total nitrogen was not removed as well as other pollutants. As almost all runoff was eventually retained on-site, these were not serious problems. 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 2).

**Table 2. Load Efficiency (% Reduction) of Pollutants Compared to Basins With No Swales**  
(F2 for even-numbered basins and F1 for odd-numbered basins)

Constituents Smaller Gardens	Asphalt With Swale F8		Concrete With Swale F4		Porous With 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%
Zinc	46%	15%	62%	50%	75%	41%

Constituents Larger Gardens	Asphalt With Swale F7		Concrete With Swale F3		Porous With 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%
Zinc	79%	72%	76%	72%	89%	86%

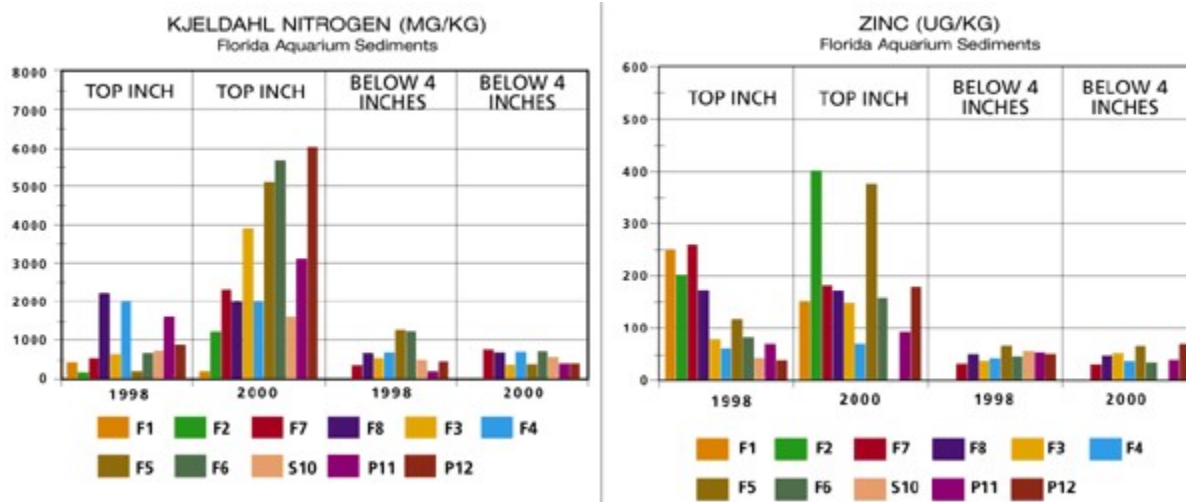
\* Notice that some efficiencies are negative, indicating an increase in loads in the basins with a swale.

### 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.* In 1998, metals were usually measured at higher concentrations in basins paved with asphalt (F1, F2, F7, F8) compared to basins paved with concrete (F3, F4) or porous paving (F7, F8), while inconsistent concentrations were measured in 2000 (Figure 3). 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-ac. parking lot is paved in asphalt. At least for 1998, results suggest that the swales and strand are effective for sequestering metals near the source. An example with zinc is shown in Figure 3.

Figure 3.



When the site in the strand in 1998 (S10) is compared to values in 2000, the year 2000 concentrations are usually significantly lower and can be explained by the berm repair that uncovered 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 underdrain.

*Nutrients.* Total phosphorus and Kjeldahl nitrogen measured in the soils showed an increase in most basins from 1998 to 2000, especially for nitrogen (Figure 3). 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 both 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.

*Polycyclic Aromatic Hydrocarbons (PAHs).* The most commonly measured PAHs are compared by percentages in Table 3. The highest percentages of detection were found at the deeper depths (12.7 cm), implicating previous hydrocarbon contamination. The lowest number of samples with hydrocarbon detection occurred in the surface soils in 2000, suggesting that hydrocarbon pollution is decreasing at the site. The most frequently measured hydrocarbon was fluoranthene, which was detected in at least 50% of the samples collected in each category. Chrysene and pyrene were also frequently detected, followed by the benzo-series.

**Table 3. Percentage of Samples That Detected Pollutants in Each of the Soil Strata for Each of the 11 Sampling Sites**

PAH Semivolatile 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
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
<b>Pesticides</b>						
Diazanone	ug/kg	10	0	50	0	0
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
Methoxychlor	ug/kg	0	0	0	17	8
PCB-1260	ug/kg	33	70	38	17	20

**Table 4. Significant Differences Between Even-Numbered Basins\***

Parameter	Pr>Chi-Square	Asphalt No 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 Suspended Solids	< 0.0001	16.02 a	11.48 a	4.70 b	5.53 b

\* Data from Duncan Multiple Range Test and significant differences calculated by the Kruskal-Wallis test.

*Pesticides and Polychlorinated Biphenyls (PCBs).* At most sites, pesticides and PCBs were not detected, but there were some exceptions (Table 3). Chlordane was the pesticide most often detected in measurable quantities and was found at all locations but three. Dichloro-diphenyl-trichloroethane and its daughter products were measured at almost all locations, and dichloro-diphenyl-ethylene was found in measurable quantities. But the quantities were not considered toxic. PCB-1260 was frequently detected in the soils, and it was more often detected in the deeper sediments than in the surface soils.

## **Statistical Analysis**

*Differences Among Basins.* Since there were few significant differences between years, all 59 storms sampled were combined for hypothesis testing. The basins exhibited at least one significant difference for all parameters except nitrate (Table 3). 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 due to the paving material itself. Higher phosphorus concentrations were measured in basins with planted swales, a result of vegetation, landscape practices, and soil particles.

## **Major Findings**

- Basins with swales and paved in asphalt or concrete reduced runoff to 30%, and basins with porous paving reduced runoff to about 16%. Basins without planted swales and only small garden areas reduced runoff to 55%. The basins with larger garden areas reduced runoff by an additional 40-50%.
- Basins paved with porous pavement showed the best percent removal of pollutant loads with greater than 80% removal (except phosphorus) in basins with larger garden areas. When the entire system is evaluated, pollution reduction is greater than 99% since almost all runoff was retained on-site.
- Sediment samples implicated asphalt paving material as a source for metals. Total Kjeldahl nitrogen and phosphorus in the sediments showed a considerable increase from 1998 to 2000. Polycyclic aromatic hydrocarbons (PAHs) were detected in the soils at the site, and some approached significantly toxic levels.

## **Acknowledgements**

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Copies of the complete report are available from the author by request.

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