# INFILTRATION OPPORTUNITIES IN PARKING LOT DESIGNS REDUCE RUNOFF AND POLLUTION

*Betty Rushton, Ph.D.*
Southwest Florida Water Management District, 2379 Broad St., Brooksville, FL 32604
Phone: 352-796-7211 ext. 4276; email: betty.rushton@swfwmd.state.fl.us

## ABSTRACT

A low impact (dispersed) design demonstrated how small alterations to parking lots can reduce runoff and pollutant loads. A whole basin approach utilized the entire watershed for stormwater management. Storm runoff was treated as soon as rain hit the ground by routing it through a network of swales, strands and finally into a small wet detention pond. When the volume of water from all the different elements of the treatment train (the swales, the strand and the pond) were compared, almost all the storm runoff was retained on site. Further, the size of the wet detention pond used for final treatment could be greatly reduced because of more pervious areas. Individual basins in the parking lot, the various elements in the treatment train, and rainfall usually had significantly different water quality concentrations. Most of the nitrate and ammonia entered the system directly in rainfall and concentrations in runoff were usually reduced as it traveled through the system. Ammonia-nitrogen was highest in the runoff from the basin without a swale and organic nitrogen and phosphorus highest in the strand and pond; metal concentrations were highest in basins paved in asphalt. Polycyclic aromatic hydrocarbons (PAHs) were detected in the soils at the site and some approached the significantly toxic levels. Chlordane was the pesticide most often detected in measurable quantities in soils. Dichlorodiphenyltrichloroethante (DDT) and its daughter products were detected in almost all soils tested and DDE was found in measurable quantities.

## INTRODUCTION

Impervious surfaces, such as parking lots and roof tops, 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 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 over 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

*Site description* - 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 hectare (11.25 acre) parking lot serving 700,000 visitors annually. The amount of stormwater runoff was reduced by incorporating pervious vegetated areas into the overall design. Changing regulations by making parking spaces 0.62 meters (2 feet) 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 (Figure 1a.). 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).

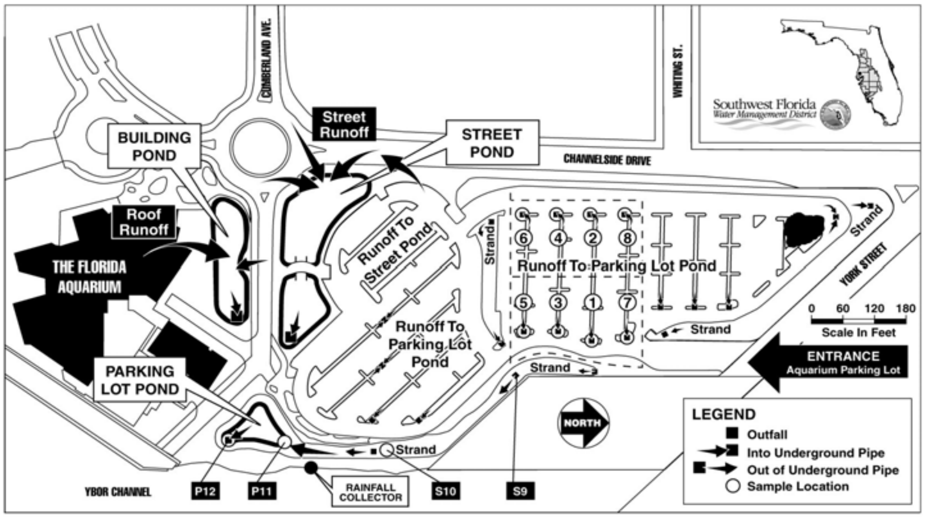

**Figure 1a. Site Plan of the Parking Lot Demonstration Project showing sampling locations. The eight drainage basins evaluated in the parking lot are outlined by the dotted lines and are shown in more detail in Figure 1b. Numbered black boxes indicate sampling locations in the strand and the pond.**

*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 (Figure 1b.). 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. 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.

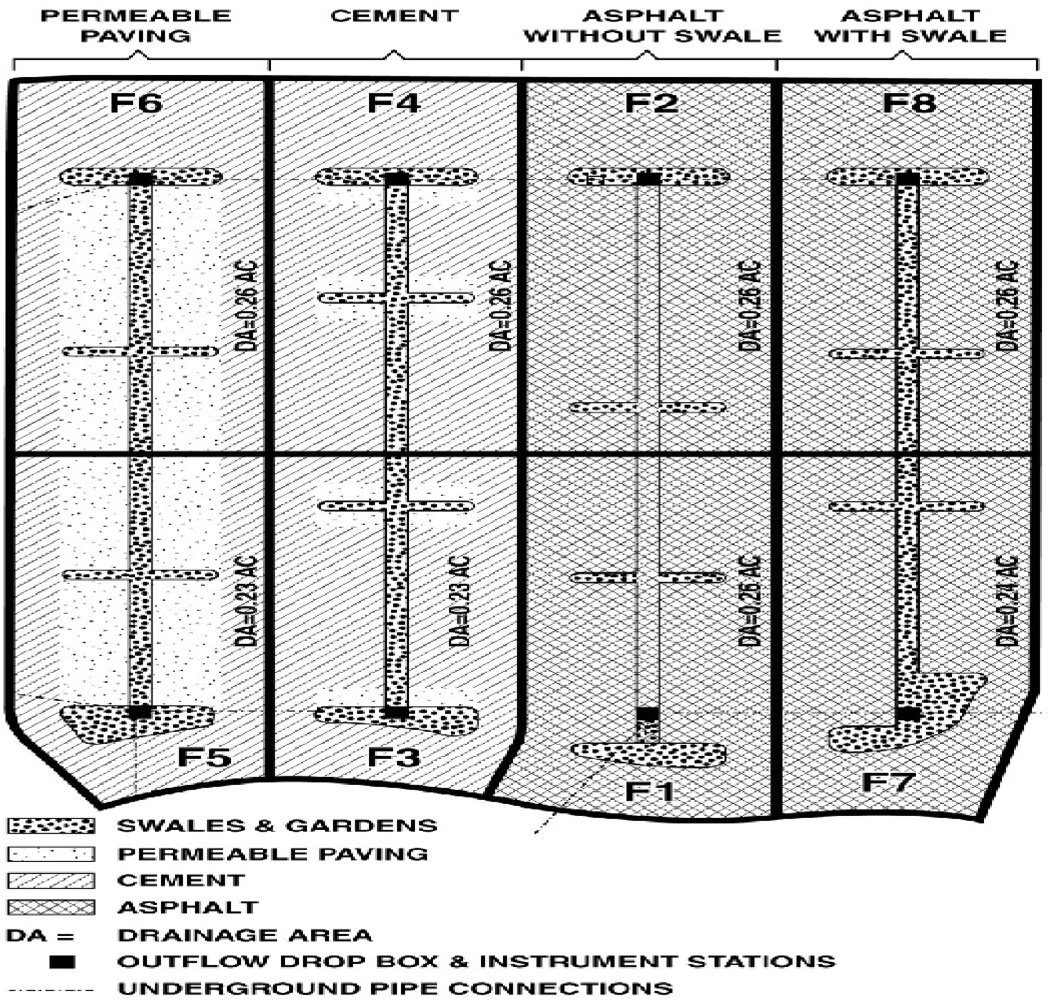

**Figure 1b. Site plan of the parking lot swales delineated by the dotted lines in Fig 1a.**

*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$^{TM}$ 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$^{TM}$ data loggers. Runoff coefficients (RC), LOADS, and LOAD EFFICIENCY were calculated using the following formulas:

RC = (volume discharged) / ((basin size)*(rainfall amount))
LOADS (kg/ha-yr) = ((concentrations)*(volume discharged))/(basin size)
LOAD EFFICIENCY (%) = ((Sum of Loads (SOL) in - SOL out)/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$^{TM}$ model 301 wet/dry precipitation collector. *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 1a.). 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 was also collected in 1998. Sediments were analyzed by the Department of Environmental Protection laboratory in Tallahassee using 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, 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

### Hydrology

*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 (52in). 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 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 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 2 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 6751 cubic meters (231,342 cubic feet) were discharged from the parking lot into the strand, while 1791 cubic meters (63,258 cubic feet) were discharged from the strand through the under drain pipe and into the pond. Only 20 cubic meters (706 cubic feet) 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.

**Table 1. Summary of runoff coefficients for the eight basins calculated separately for the two years.**

| | RAIN AM'T | ASPHALT WO/SWALE | | ASPHALT W/SWALE | | CONCRETE W/SWALE | | POROUS W/SWALE | |
|---|---|---|---|---|---|---|---|---|---|
| | cm | F1 | F2 | F7 | F8 | F3 | F4 | F5 | F6 |
| **YEAR ONE** | | **Total rain (cm)** | | **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 (cm)** | | **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 |

## Water Quality

*Concentrations* - The median 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 was measured at lower concentrations than nitrate in the parking lot and 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 storm water 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 are highest in the strand and 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. The higher concentrations measured in the under drain and in the pond may have been caused by added mulch. 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.

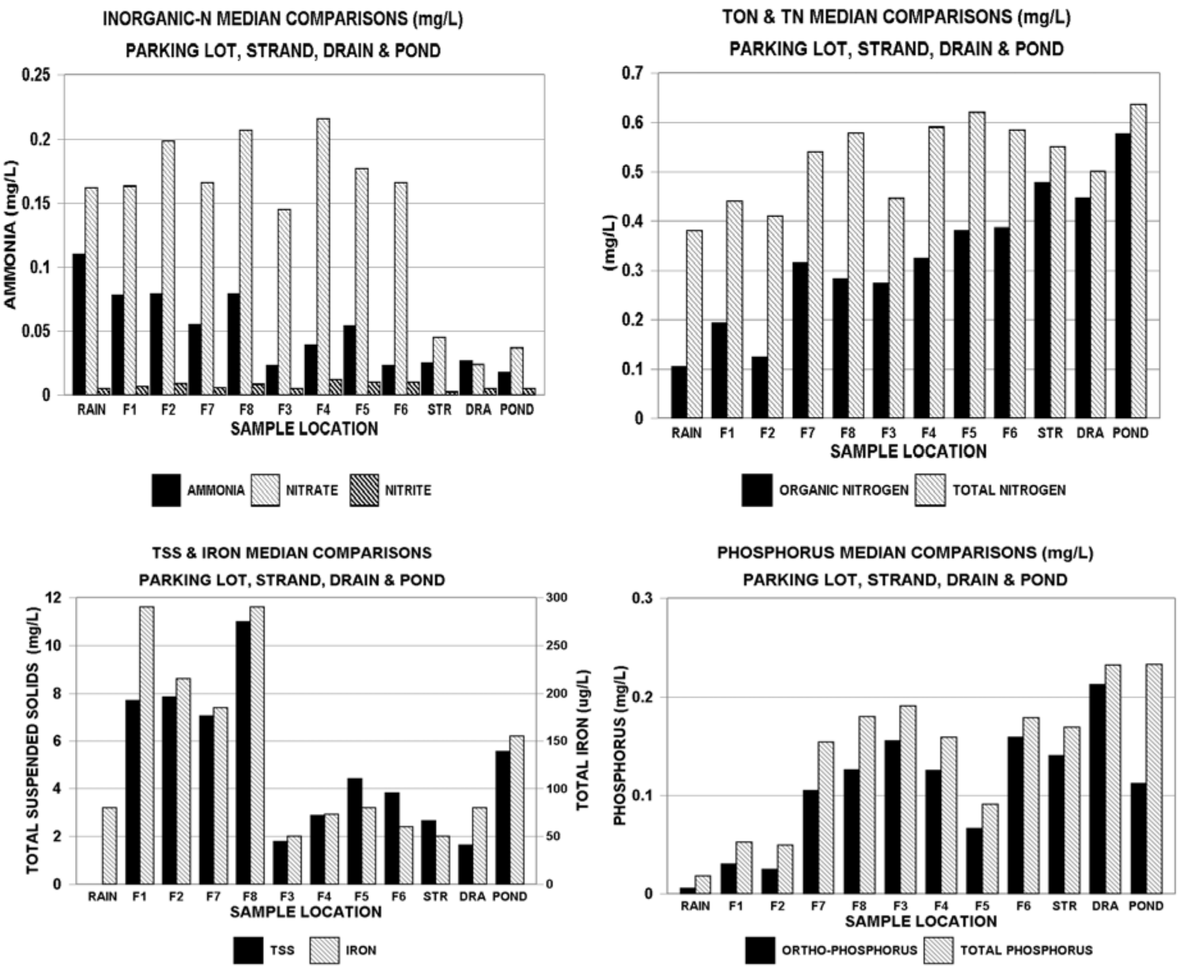

**Figure 2. Comparison of median water quality concentrations at the outflows of the various elements of the stormwater system. See Figure 1 for sample locations. Abbreviations: STR=strand, DRA=under drain, POND=pond.**

*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 per cent removal, with most removal rates greater than 75%. Phosphorus was a notable exception and 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 may 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 w/ 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% |
| Zinc | 46% | 15% | 62% | 50% | 75% | 41% |
| **Constituents Larger gardens** | **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% |
| 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 in 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-acre 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.

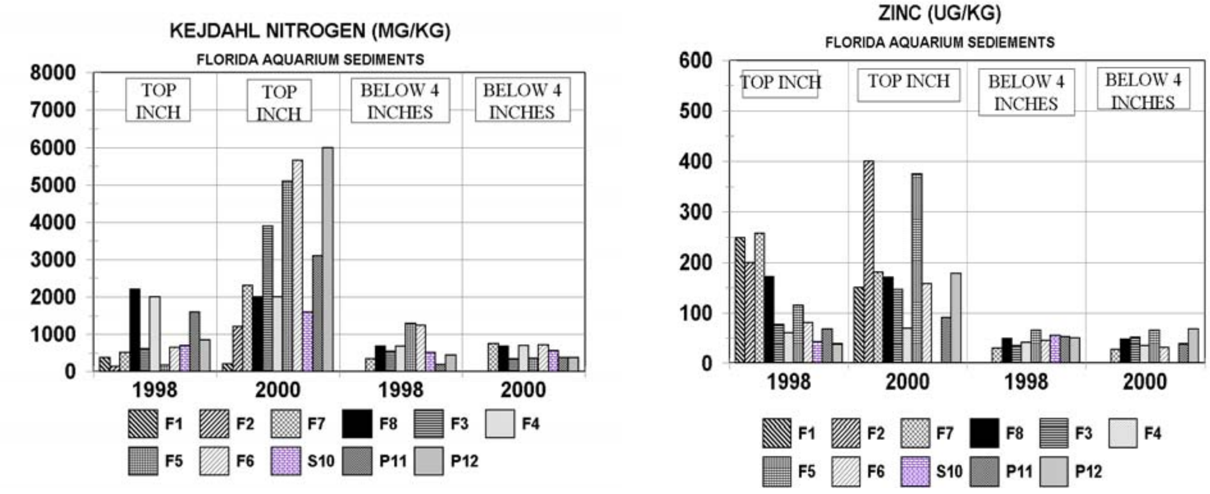

**Figure 3. Sediment samples for zinc and total Kejdahl nitrogen collected in 1998 and again in 2000 at the outfall of each drainage basin as well as in the swale (S) and pond (P).**

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 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 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 percent of the samples collected in each category. Chrysene and pyrene were also frequently detected, followed by the benzo-series (Table 3).

**Table 3. Percentage of samples that detected pollutants in each of the soil strata for each of the eleven sampling sites.**

| PAH<br>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 |
| 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** | | | | | | |
| Diazanon | 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 |

*Pesticides & PCB's* - At most sites pesticides and polychlorinated biphenyls (PCBs) were not detected but there were some exceptions (Table 3). Chlordane was the pesticide most often detected in measurable quantities and it was found at all locations but three. Dichloro-diphenyltrichloroethante (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. 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.

## 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 increased by the paving material itself. Higher phosphorus concentrations were measured in basins with planted swales, a result of vegetation, landscape practices, and soil particles.

**Table 4. 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 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 |

## MAJOR FINDINGS

- Basins with swales and paved in asphalt or concrete reduced runoff to 30 percent and porous paving, to about 16 percent; while basins without planted swales and only small garden areas reduced runoff to 55 percent. The basins with larger garden areas reduced runoff by an additional 40-50 percent (Table 1)
- Basins paved with porous pavement showed the best percent removal of pollutant loads with greater than 80 percent removal (except phosphorus) in basins with larger garden areas. (Table 2). When the entire system is evaluated pollution reduction is greater than 99 percent since almost all runoff was retained on site.
- Sediment samples implicated asphalt paving material as a source for metals (Figure 2). TKN and phosphorus in the sediments showed a considerable increase from 1998 to 2000 (Figure 2). Polycyclic aromatic hydrocarbons (PAHs) were detected in the soils at the site and some approached the significantly toxic levels (Table 3).

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