MEMORANDUM

TO: Fort Myers Beach Local Planning Agency
FROM: Bill Spikowski
DATE: December 5, 2006
SUBJECT: Neighborhood Flooding — December 12, 2006

A discussion has been scheduled for your December 12th meeting about potential stormwater changes to the land development code (see attached memorandum from David Sallee and Jack Green).

Poor drainage is a serious problem at Fort Myers Beach, despite seemingly ideal conditions for drainage: naturally porous sandy soils, and a narrow island where every property is close to a discharge point for stormwater (tidal water).

Stormwater requirements for a new development are virtually the same as those that apply in unincorporated Lee County and throughout the South Florida Water Management District. Stormwater detention basins, either lakes or dry depressions, are created to store rainfall so that it can be released slowly in order to mimic the behavior of undisturbed land.

These requirements are generally adequate for larger developments but were never designed to deal with existing neighborhoods created prior to modern stormwater requirements.

Trying to apply similar requirements to existing neighborhoods fails in two ways:

- Where lots are fairly small (less than ½ acre), there isn't room on individual lots for stormwater basins.
- Where the drainage system for the entire neighborhood is inadequate (or non-existent), detaining rainfall for a few hours doesn't prevent flooding because the problem is a lack of neighborhood-wide drainage that cannot be solved by individual lot owners.

The town has addressed drainage problems in two ways:

- Through minor public works projects, which have been completed or are in planning stages for Palmetto Street, Lenell Road, Santos Road, Primo Drive, Lanark & Lauder, Bayland area, Matanzas Street, Miramar Drive, Pearl Street, St. Peter's Drive, Andre Mar Drive, Gulfview/Bayview/Strandview area, Mid-Island Drive, and Laguna Shores (Buccaneer Drive, Lagoon Road, Redfish Road, and Starfish Circle). Future drainage projects are also being considered for Sabal, Coconut, Pearl, and Miramar. See Section 6 of the Evaluation/Appraisal Report for details (copy attached).

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- Through the land development code, particularly § 6-14 and § 34-2017 (copies attached).

  The neighborhood flooding rules in § 6-14 were adopted in April 2005 after an exhaustive search of the stormwater literature for useful ideas from other communities. In the absence of a good model, these rules were created for the town to take advantage of Estero Island's porous soils to infiltrate rainfall directly into the ground. This technique not only keeps stormwater from flooding nearby properties, but excellent treatment is provided as the water moves through the soil. These new rules are triggered whenever a lot owner adds gutters or fills a lot to raise its elevation six inches above adjoining lots. Town staff will be available to comments on their experience implementing this rule and may be able to offer suggestions for improving it based on that experience

  The rules for parking lot surfaces in § 34-2017 were rewritten in 2003 to encourage the use of porous paving materials such as specially formulated asphalt and concrete, gravel, or even grass surfaces that are stabilized with turfblocks or cellular paving systems. These surfaces allow parking lots to infiltrate rainfill directly into the ground rather than collecting it, detaining it, then trying to route it to an acceptable outfall. Some literature on this subject is attached.

For further information on stormwater issues, please refer to these web sites:

— Low Impact Development Center: *www.lowimpactdevelopment.org/research.htm*
— Stormwater Manager's Resource Center: *www.stormwatercenter.net*
— Center for Watershed Management: *www.cwp.org/stormwater_mgt.htm*
— Florida Stormwater Association: *www.florida-stormwater.org/publications.htm*

Attachments:

– Memorandum of November 9, 2006 from David Sallee and Jack Green
– Draft Evaluation/Appraisal Report, Section 6 on Stormwater Management
– Land Development Code, §§ 6-14 and 34-2017
– "Enhanced Parking Lot Design for Stormwater Treatment" by Betty Rushton, Ph.D.
– Manufacturer's literature from Invisible Structures Inc. on their "Grasspave and "Gravelpave" products

Memo

To: Local Planning Agency

CC: Jerry Murphy, Cathie Lewis, Anne Dalton

From: David Sallee, Jack Green

Date: November 9, 2006,

Re: Stormwater Management Changes to Land Development Code (LDC)

It's well known that the Town suffers from inadequate drainage and is subject to periodic flooding especially during heavy rainfalls during the summer. This is an issue for which we are aggressively pursuing solutions.

The LDC addresses stormwater management requirements for large developments to some degree but fails to adequately address stormwater management in smaller scale developments which typically take place in residential neighborhoods. In several cases we have see the negative effects caused by property owners who have brought in fill to raise the grade of their property only to increase the effects of flooding on their neighbors. Additionally, the use of impervious surfaces for driveways and parking lots seriously exacerbates flooding in Town.

We are requesting the LPA undertake a review of the current LDC stormwater requirements and propose changes and modifications that are best suited for the Town's particular situation.

SECTION 6. STORMWATER MANAGEMENT

ISSUE STATEMENT: The Stormwater Management element called for the town to prepare a Stormwater Master Plan. Is this plan still a priority for the town?

BACKGROUND: Objective 9-F of this element called for a town-wide Stormwater Master Plan to be conducted by the year 2000. This plan would determine the nature of potential improvements to the existing stormwater drainage system to improve drainage and also to reduce the level of contaminants ending up in tidal waters. It would also evaluate permanent funding sources to carry out such improvements. Instead of conducting this plan, the town has begun to construct specific improvements to fix some of the worst drainage problems while experimenting with various methods of reducing contaminants. This alternate program has been successful and provides a reasonable alternative to the Stormwater Master Plan as originally proposed. However, without a Stormwater Master Plan, certain funding mechanisms would not be available, such as a stormwater utility.

A. Evaluation of Existing Policies

POLICY 9-A-1 *Establish, fund, and implement a program to monitor the environmental impacts of stormwater runoff. This monitoring plan shall be designed to ensure that data collected will be useful in leading the town toward pollution-reducing strategies. If appropriate, this program may incorporate any monitoring requirements under the National Pollution Discharge Elimination System.*

EVALUATION OF POLICY 9-A-1: The town submits annual reports to the federal government as part of its responsibilities under the NPDES program (National Pollutant Discharge Elimination System). Many monitoring requirements are spelled out by permits issued to the town under this program.

POLICY 9-A-3 *Seek available grant funding and other potential revenue sources to retrofit the existing drainage pattern in redevelopment areas to reduce stormwater contamination.*

EVALUATION OF POLICY 9-A-3: Engineering consultants to the town are now designing major improvements to the northern mile of Estero Boulevard from Lynn Hall Park to Bowditch Point. Drainage improvements are a major goal of this effort. Because this road segment belongs to the town, approval is not needed from the or state. Funding is from accumulated gas tax revenues and previously collected transportation impact fees.

Lee County maintains Estero Boulevard from about Crescent Street to Big Carlos Pass and is very aware of its generally poor condition. A partnership with Lee County is possible whereby Lee County would pay the costs of drainage retrofits and certain other improvements such as surfacing if the town agrees to pay the remaining streetscape costs. Negotiations with Lee County have been underway during the past year.

Conditions improve somewhat toward the southern half of the island, where drainage facilities are more abundant and better maintained. These facilities can last 20-50 years if properly maintained. Commercial and condo buildings constructed after the mid-1980s were built to restrict the rate of runoff after development to no greater than the rate before development.

POLICY 9-C-3 *Establish the following priorities for the discharge of swimming pool water, in order to minimize erosion and protect the quality of receiving waters and sea turtle nesting habitat:*

i. discharge to roadside swales;
ii. discharge into the public sewer system (within any limits established by Lee County Utilities); and
iii. discharge directly to tidal waters only under extreme conditions and in conformance with all federal, state, and local regulations.

EVALUATION OF POLICY 9-C-3: This policy has been implemented through the addition of the following section to the property maintenance code (which is part of the land development code):

> ***Sec. 6-12. Disposal of swimming pool water.*** *Prior to disposal of swimming pool water, chlorine and bromine levels must be reduced by not adding chlorine or bromine for at least five days or until levels are below 0.1 mg per liter.*
>
> *(1) The preferred method for disposing of swimming pool water is to discharge the water into roadside swales to allow percolation into the ground without any runoff to canals, beaches, wetlands, other tidal waters, or onto adjoining properties. The discharge of dechlorinated water into roadside swales is permitted by § 10-604 of this code.*
>
> *(2) Another acceptable method is to discharge the water into the sanitary sewer system operated by Lee County Utilities.*
>
> *(3) Swimming pool water may not be discharged either directly or indirectly to the beach, canals, wetlands, or any other tidal waters.*

POLICY 9-E-2 *Identify significant existing drainage problem areas through logs of citizen complaints and a public outreach effort.*

EVALUATION OF POLICY 9-E-2: The town has maintained and improved the stormwater drainage system on the island, significantly reducing the road and yard flooding that used to be commonplace during the summer rainy season. Every year the town budgets funds to inspect and maintain the drainage ditches, catch basins, and culverts that comprise the drainage system. The town has also adopted regulations which make it illegal to dump any garbage, refuse, or vegetative debris in any water body to further protect the integrity of the drainage system. Citizen complaints are addressed in response to simple telephone calls to town hall.

OBJECTIVE 9-F *STORMWATER MASTER PLAN — Evaluate by 2000 the need to improve public stormwater management facilities.*

POLICY 9-F-1 *This evaluation shall determine the nature of potential improvements to the existing stormwater system to improve drainage and to reduce the level of contaminants running off into tidal waters.*

POLICY 9-F-2 *This evaluation shall include studies and/or models as needed to determine the capacity of existing facilities if they were fully maintained.*

POLICY 9-F-3 *This evaluation shall also be based on the initial results of the monitoring program, the inventory of existing facilities, the potential for improving drainage and water quality, the potential effects of future development, and the potential cost of the improvements.*

POLICY 9-F-4 *This evaluation shall determine what kind of improvements might better protect life and property against flooding from extreme tides and tropical storms.*

EVALUATION OF OBJECTIVE 9-F AND POLICIES 9-F-1 through 9-F-4: A formal stormwater master plan has not been carried, as discussed earlier.

POLICY 9-F-6 *The Town Council shall establish a funding source within two additional years to begin carrying out the selected stormwater improvements. This funding source may include revenue from gas taxes, ad valorem collections, stormwater utility fees, or other recurring sources.*

EVALUATION OF POLICY 9-F-5: Since incorporation, the town funded stormwater improvements from several sources, including gas taxes and the general fund. Some of improvements, such as those on Palmetto Street and Lenell Road, were initially constructed with general town funds which are now being repaid through special assessments on property owners who benefitted from the projects.

Drainage projects have been completed or are in the planning stages for these areas: Santos Road, Primo Drive, Lanark & Lauder, Bayland area, Matanzas Street, Miramar Drive, Pearl Street, St. Peter's Drive, Andre Mar Drive, Gulfview/Bayview/Strandview area, Mid-Island Drive, and Laguna Shores (Buccaneer Drive, Lagoon Road, Redfish Road, and Starfish Circle). Drainage projects are also being considered for Sabal, Coconut, Pearl, and Miramar.

This policy mentions a potential recurring revenue source, stormwater utility fees. The next section of this report addresses this subject.

B. Potential Funding Sources

A "stormwater utility" is a municipal entity that provides a specific service, like a utility that provides drinking water or sewer service. Rainwater should be treated through an organized drainage system of ditches and pipes that collects, treats, and disposes stormwater runoff. To remain effective, this has to be maintained. At Fort Myers Beach, some parts of the system still have to be designed and constructed.

In most new developments, a homeowners' association is required to maintain whatever parts of the system are built by the original developer (such as lakes). The local government typically maintains other parts of the system, such as ditches and underground pipes that run along the public road system. When this drainage system also provides drainage for the road itself, this maintenance can be paid for with gasoline taxes.

Unfortunately, funding for all other types of stormwater maintenance and improvements has to compete with all other needed government services. The result is often neglect. Without a properly maintained drainage system, the quality of stormwater goes down, resulting in higher levels of pollution in Estero Bay. When a proper drainage system was never installed at all, as is the case with many parts of Fort Myers Beach, pollutant levels in runoff can be very high.

As the problems created by improper stormwater management have become better known, many communities are creating a stormwater utility, a branch of municipal government whose sole purpose is stormwater management. In smaller communities this utility is typically part of the public works department. Most often its funds usually come from a separate fee that is charged to owners of developed property, based on a share of the benefit each will receive from the utility. The base fee is often around $3-$4 per month for a typical home. A fee of this level covers stormwater planning, routine maintenance, and minor improvements to the system. The fee is frequently listed on the monthly water or sewer bill, avoiding a large annual payment at tax bill time. Larger fees can be charged to specific areas if needed to construct entirely new drainage systems.

Fort Myers Beach is a logical candidate for a stormwater utility because there is a broad awareness of the increasing levels of pollution in the canals and in Estero Bay, accompanied by a strong sentiment towards cleaning up pollution generally. The missing link for citizens to accept a stormwater utility fee is a full understanding of how current practices on Estero Island contribute to that pollution and what kinds of steps can be taken to improve the quality of stormwater runoff.

A stormwater master plan, as proposed by Objective 9-F, would be needed prior to establishing a stormwater utility. The master plan essentially creates the work plan for the utility. If a utility is not ultimately established, the work plan could be carried with other funding sources such as ad valorem taxes.

C. Recommendations

The proposed timing for a stormwater master plan in Objective 9-F is obsolete, but the master plan is still needed. Objective 9-F should be revised to set a realistic timetable for the completion of this plan.

(2) Another acceptable method is to discharge the water into the sanitary sewer system operated by Lee County Utilities.
(3) Swimming pool water may not be discharged either directly or indirectly to the beach, canals, wetlands, or any other tidal waters.

Sec. 6-13. Stormwater drainage on the beach.

Tidal waters can become polluted and beaches can be eroded when pipes or culverts discharge directly onto the beach. Point sources of discharge from private property directly onto the beach are prohibited. This prohibition includes drainage collected from parking lots or other paved surfaces and stormwater from the roofs of buildings. Point sources of discharge from private property that were in lawful existence as of April 18, 2005, must be eliminated within 36 months.

Sec. 6-14. Neighborhood flooding.

(a) Chapter 10 of this code requires stormwater management systems for new development (see § 10-321). Development that is not subject to those requirements, such as single-family and two-family dwellings on existing lots, can also flood surrounding lots and streets, especially if the lot is raised higher than adjoining properties or if rainfall is concentrated by gutters and downspouts and discharged without an opportunity for infiltration.

(b) To minimize neighborhood flooding from normal daily rainfall, a fill permit must be obtained from the town when fill material is to be placed on lots that would raise the elevation more than an average of 6 inches above adjoining lots. The fill permit application must show how normal rainfall will have an opportunity to infiltrate into the ground within the lot using one or more of the following methods or equivalent solution:

(1) Gutters and downspouts that collect rainwater must discharge into exfiltration trenches (french drains), or into a subsurface drainfield that meets the construction standards of F.A.C. 64E-6.014(5) (the percolation, depth, location, and setback standards for drainfields need not be met), or onto substantially flat and porous surfaces such as:
  a. Sodded lawns.
  b. Clean (washed) gravel or sand over a well-drained base.
  c. Porous (pervious) paving.

(2) Roof areas not served by gutters and downspouts must not drain to impervious surfaces, and must not drain to pervious surfaces that are sloped in excess of 5%. Surfaces not meeting these requirements must be designed to detain or deflect rainfall, for instance through the use of earthen ridges, curbs, or retaining walls that prevent average rainfall from running onto adjoining lots or streets.

(c) Additions to, renovations of, and replacements for single-family and two-family dwellings that include the installation of gutters and downspouts must also obtain a fill permit showing discharge from the downspouts being directed to the same standards as for filled lots.

Sec. 6-15–6-30. Reserved.

DIVISION 2. HOUSING CODE

Sec. 6-31. Adoption; amendments.

The following chapters and sections of the 1997 Standard Housing Code, as published by the Southern Building Code Congress International, Inc., 900 Montclair Road, Birmingham, Alabama, 35213-1206, are hereby adopted by reference and made a part of this article, with the exceptions set forth as follows:

Chapter 1, Administration.
Exception: Section 103.2.2(4) is deleted and replaced with new section 103.2.2(4) as follows:

4. State that, if such repairs, reconstruction, alterations, removal or demolition are not voluntarily completed within the stated time as set forth in the notice, the housing official shall institute such legal and/or administrative proceeding as may be appropriate.

Exception: Section 103.4 is deleted and replaced with new section 103.4 as follows:

An officer or employee, or member of any board, charged with the enforcement of this code, in the discharge of his duties, shall not thereby render himself liable personally, and is hereby relieved from all personal liability for any damage that may accrue to persons or

b. *Unpaved parking lots.*
1. Perimeter parking spaces in unpaved parking lots shall be delineated by placing a parking block three feet from the end of the parking space and centered between the sides of the space.
2. If a perimeter space abuts a structure, the space may be indicated on the structure, in which case parking blocks shall not be required.

Sec. 34-2017. Parking lot surfaces.

(a) ***High turnover parking lots***. Except as provided in this section, all high turnover parking lot aisles and parking spaces shall be provided with a paved surface, except for the open space beyond parking blocks. The term "paved" shall be interpreted to mean and include asphalt, concrete, brick, paving blocks, porous (pervious) asphalt or concrete, and other similar treatments. Clean (washed) angular gravel (such as FDOT #57 stone) may also be used if stabilized as provided in subsection (b)(1).

(1) Any parking spaces that may be permitted, seaward of the 1978 coastal construction control line shall be stabilized with best management practices approved by the director.

(2) All disabled parking spaces, including disabled parking spaces seaward of the coastal construction control line, shall be provided without gaps or holes that would create a danger to the user.

(b) ***Low turnover parking lots***. Due to the low volume of vehicle turnover in this type lot, alternative unpaved surfaces may also be permitted provided that the areas are adequately drained and continuously maintained in a dustfree manner.

(1) Alternative surfaces may include stabilized surfaces of grass or clean (washed) angular gravel over a well-drained base, or other similar porous materials. Stabilization may be accomplished by turfblocks (concrete or plastic) or proprietary cellular or modular porous paving systems installed in accordance with manufacturers' specifications.

(2) Crushed limerock that has not been washed or otherwise processed to remove fine particles will be permitted as a surface material only when designed, placed, and maintained in a manner that will:
a. prevent the flow of sediment-laden runoff from the lot, and
b. keep the surface dust-free at all times.

(3) The use of unimproved surfaces such as sand or dirt as approved parking shall be prohibited.

(4) Disabled spaces must be provided with a smooth surface without gaps or holes which would create a danger to the user.

(c) ***Reduced surfacing standards***

(1) The director is authorized to permit portions of high turnover parking lots (including parking lot aisles), to meet the surfacing standards for low turnover parking lots (§ 34-2017(b), above) when the reduced surfacing standard will be used in those portions of the parking lot expected to receive the lightest usage, such as overflow or employee parking areas.

(2) This subsection may not be construed inconsistently with the Americans with Disability Act (ADA) of 1990.

(d) ***Reservation of spaces for future use***. When a use or activity is required by this chapter to provide more than ten high turnover parking spaces, the director may approve leaving up to 25 percent of the required spaces as landscaped areas reserved for future use, provided that:

(1) The applicant clearly shows the reserved parking spaces on the site plan;

(2) The reserved parking areas shall not be counted towards the minimum open space or landscaping or buffering requirements of this chapter or chapter 10;

(3) All drainage facilities shall be calculated and built as though the reserved parking areas were impervious surfaces; and

(4) The reserved parking areas shall not be used for any purpose other than landscaped open space or temporary overflow parking during special holiday seasons or sales.

Should the property owner decide to pave the reserved area for parking, he shall submit the original site plan or development order approval to the director, who is authorized to approve the paving provided that such paving does not include any new entrances onto a public street. If the parking areas does involve new entrances, then a limited review development order is required.

Sec. 34-2018. Joint use of parking lots.

(a) A single-purpose parking lot can provide some or all of the required parking spaces for two or more unrelated businesses, provided that such joint-use parking lot:

(1) is built on a site where a commercial parking lot is permitted, and
(2) is placed on the site so as not to violate any applicable build-to lines or block visibility of vehicles (see § 34-3131), and
(3) is built to the same standards as a single-purpose parking lot, and
(4) is located within 750 feet of each use.

(b) The peak parking demands of the different uses must occur at different times. The director may require an applicant to provide a technical analysis of the timing and magnitude of the proposed parking demands.

(c) Applications for joint-use parking lots must include:

(1) A notarized statement from all property owners involved indicating the use of each property and forecasting that the peak level of activities of each separate building or use which create a demand for parking will occur at different times.
(2) A draft joint-use parking agreement, acceptable to the town attorney, that:
    a. specifically identifies the designated spaces that are subject to the agreement;
    b. includes a statement indicating that the parties understand that these designated spaces cannot be counted to support any use other than those identified in the agreement;
    c. identifies the current property uses, property owners, and the entity responsible for maintenance of the parking area.
    d. includes a backup plan to provide sufficient parking if the joint agreement is violated by either party.
(3) Upon approval of the agreement by the town attorney, the agreement(s) must be recorded in the Lee County public records at the applicant's expense.

Sec. 34-2019. Other use of parking lots.

(a) Parking spaces that are not in daily use and are located in parking lots having ten or more parking spaces and meeting the other requirements of this division may be rented to the general public during peak periods.

(b) The following structures and uses may be approved in parking lots by the director provided that a site plan is submitted showing that the structure will not reduce the parking spaces required for the principal use, or create a traffic or pedestrian hazard:

(1) Charitable or other similar dropoff collection stations.
(2) Aluminum can or other similar receiving machines or facilities.
(3) Photo pickup stations.
(4) Telephone booths and pay telephone stations.
(5) Automatic teller machines (ATMs).
(6) Other similar uses which do not unreasonably interfere with the normal functioning of the parking lot.

(c) Except as provided in this section and for ancillary temporary uses as provided in § 34-3048, required parking areas shall not be utilized for the sale, display, or storage of merchandise, or for repair, dismantling, or servicing of any vehicles or equipment. This shall not be interpreted to prohibit a residential property owner from the occasional servicing of his own noncommercial vehicle or conducting normal residential accessory uses.

Sec. 34-2020. Required parking spaces.

(a) ***New developments***. New residential and nonresidential uses are required to provide off-street parking spaces in single-purpose parking lots in accordance with the standards specified in this section, as modified by certain reductions as provided in the DOWNTOWN and SANTINI zoning districts (see division 5 of article III).

(b) ***Existing developments***. Existing buildings and uses may be modernized, altered, or repaired without providing additional parking spaces,

Introduction

History of Porous Paving

Pebbles, cobblestones, and wood decking structures have been used since the dawn of civilization to reinforce where we walk and the roads we use. Little did we realize that these methods had benefits over the modern trends of sealing up the ground with asphalt and concrete. Porous, permeable or pervious paving—whatever you prefer—became a method for addressing stormwater issues in the early 20th century. Concrete turfblock for grass paving began in the mid-1940s and plastic versions were invented in the late '70s and early '80s. Great advancements have occurred in pervious concrete, pervious asphalt, and other permeable surfaces. We introduced Grasspave2 in 1982, improving upon these earlier concepts. In 1993, Gravelpave2 was unveiled, the only product specifically developed for gravel porous paving. Fast forward to this millennium, and Grasspave2 and Gravelpave2 are considered by most, the finest porous pavers developed.

Grasspave2 large rolls and Gravelpave2 large rolls (not shown) install quickly and conform to the contours of the ground.

Infiltration

Porous paving allows rainwater to percolate through the pavement's surface and back into the ground (infiltrating), where the water is cleaned and returned to ground water supplies. Porous paving improves upon impermeable surfaces, such as concrete or asphalt, which do not allow for this natural filtration. Rain collects airborne and surface pollutants such as sediment, brake dust, chemicals, vehicle exhaust, oil, salts, fertilizers, bacteria, and animal waste. On impermeable surfaces the polluted rainwater runoff (non-point source pollution) is collected, concentrated, and discharged to downstream waters such as streams, reservoirs, and lakes—our drinking water. This runoff also harms vegetation and wildlife with increased water volumes, velocities, and higher temperatures. The Grasspave2 and Gravelpave2 systems protect against this dangerous runoff by processing and cleaning the water, thus safeguarding the natural water cycle.

State of the Earth

Invisible Structures, Inc. has developed an entire line of products to address stormwater and environmental concerns. Rainstore3, Slopetame2, Draincore2, and Beachrings2 can work in addition to, or in conjunction with, Grasspave2 and Gravelpave2 to provide your site, home, or office with stormwater and environmental enhancements. Our products can store and collect rain, provide erosion and sediment control, efficiently convey and deliver water, and protect natural areas.

Advanced Technology

The Grasspave2 and Gravelpave2 systems are based on a simple, but impressive technology—a series of rings (cylinders) connected on a flexible grid system. The cylinders are engineered to withstand significant structural loads and the grid provides stability, flexibility, and continuity for large areas. The grid system also has the unique ability to be rolled up for easy shipping, handling and installation.

This engineered design allows for any street-legal vehicle (and sometimes larger) to park or drive on our Grasspave2 or Gravelpave2 surfaces. The point load pressure is transferred from the top of the ring, through the fill material and cylinders, to the engineered base course.

Wallace Residence, Savannah, GA—Gravelpave2 creates a wheelchair-accessible surface by stabilizing gravel and supporting tire pressure. 7% dry cement was mixed with gravel before filling rings.
Cover photo: Westin Kierland Resort and Spa, Scottsdale, Arizona—Grasspave2 fire lane and Gravelpave2 fire lane (concrete widening).

The ring and grid structure is 92 percent void space allowing for the healthiest root zone for grass (in Grasspave^2) and more decorative gravel (in Gravelpave^2) for some of the most attractive paved surfaces around. Less plastic means more natural looking surfaces. This technology also makes for better runoff coefficients and better percolation rates.

120 psi Maximum on Public Highways!

Even empty, Grasspave^2 and Gravelpave^2 will support 2,100 psi (14,470 kPa)—well over the 120 psi highest truck tire pressure allowed on public highways. This is a safety factor of 17 times. When Grasspave^2 is filled with sand for part of the root zone medium, the strength increases to 5,700 psi (39,273 kPa). The safety factor increases from 17 to 47 times. The heavier a vehicle, the more axles and tires it needs to support the load being carried. Grasspave^2 and Gravelpave^2 will meet and exceed all loading criteria.

The University of South Alabama, Mobile used Gravelpave^2 in parking aisles and Grasspave^2 in the spaces.

Vehicle Loading Examples:

Auto tires: 40 psi
Truck tires: 110 psi
DC-10 tires: 250 psi
F-16 tires: 350 psi
Fire truck with outriggers: 78psi

(An 85,000 lb. truck distributed to four outrigger pads is equal to 21,250 lbs. for each outrigger pad with 12″ × 18″ surface contact with Grasspave^2.)

All these vehicles are well within our 5,700 psi loading capability. With a sturdy base course design, our rings will easily perform under all conditions. It's also a good design practice to strengthen concrete sidewalks and curbing that will be mounted by fire trucks.

CSI 32 12 43 Flexible Porous Pavers

In 1997 The Construction Specifiers Institute (CSI) came out with a generalized listing (02795) for all porous paving products. However, since performance and application is varied even in the porous paving industry, the 2004 CSI MasterFormat™ has adopted a new number *32 12 43 Flexible Porous Paving*, to recognize that Grasspave^2 and Gravelpave^2 are in a class by themselves.

Best Management Practice

Porous paving is recognized as a Best Management Practice (BMP) by the Environmental Protection Agency, the Center for Watershed Protection, the U.S. Army Corp of Engineers, and countless other federal, state, regional and local authorities. In addition, Grasspave^2 and Gravelpave^2 are often mentioned by name, as the product of choice for many of these agencies.

Applications

Stormwater Management

The Grasspave^2 and Gravelpave^2 systems can easily handle storm water from an intense storm dropping three inches of rain in less than thirty minutes! In one square meter (40″ × 40″) there are 144 rings, two inches in diameter by one inch high. With one inch of fill in the rings and a standard road base of sandy gravel six

Bowditch Point Regional Park , Fort Myers Beach, Florida—Gravelpave^2 parking bays blend in with the natural surroundings.

inches thick, our porous systems will percolate approximately ½ inch of rain per hour! A seven-inch section can store 2.4 inches of water (about 20 percent void after compaction). Alternatively, hard surfaces, such as asphalt and concrete, shed 95 percent of storm water.

Aesthetics

As a designer, engineer, contractor, or homeowner, you can be sure Grasspave^2 and Gravelpave^2 can deliver a more beautiful surface and add a unique look to a site. Grass simply looks better than asphalt and decorative gravel has been used for centuries in landscaping. Space constraints can be dealt with by combining the beauty of grass or gravel with the utility of paving.

Trees and other vegetation not only survive, they thrive with Grasspave^2 and Gravelpave^2. Porous paving has the ability to deliver water, oxygen and carbon dioxide through the cross section—all essential to root survival. Concrete and asphalt suffocate and starve the root zones of water and air. With Grasspave^2 and Gravelpave^2, you can now design in as many trees and plants as your site will allow. Grasspave^2 and Gravelpave^2 prevent compaction while allowing for ample amounts of water and air. Cars can then drive and park below tree canopies. Saving existing, mature trees is also possible with our products—our structures can come within inches of the mature tree trunk without damage. Our mats have the ability to flex with the tree root growth that would otherwise damage and crack hard surfaces.

Environmental Benefits

Grasspave^2 and Gravelpave^2 not only protect the environment, they enhance it. All of our products are made from 100 percent recycled plastic—plastic that goes into improving the environment and not into a landfill. Through bioremediation, porous pavers have the ability to clean pollutants (heavy metals, 96–99 percent; suspended solids, 95 percent; phosphorous, 65 percent; nitrogen, 82 percent, hydrocarbons, up to 100 percent) out of stormwater. Our products also reduce erosion and soil migration, reduce site disturbance, and contribute to airborne dust capture and retention.

Cooling the atmosphere and reducing the "urban heat island effect" (cities being up to 10 degrees hotter than undeveloped land) are added benefits of Grasspave^2 and Gravelpave^2. Both products can mitigate these increased temperatures. In addition, Grasspave^2 promotes the conversion of carbon dioxide (greenhouse gas) into oxygen and has an "air-conditioning effect."

Driveways

Environmental, economic, and aesthetic enhancements are drawing homeowners and designers to use Grasspave^2 and Gravelpave^2 in driveways. Most residential driveways are good candidates for our porous duo because of the reduced speed and limited frequency of traffic. Our products can add beauty to residential and commercial driveways.

Parking Lots

Parking for churches and synagogues, stadiums, arenas, and overflow at shopping centers, campuses, parks and more are ideal for Grasspave^2 and Gravelpave^2. These sites generally support large numbers of vehicles but only on periodic basis. Stormwater management and green space can be combined with parking, reducing maintenance, real estate, and development costs. A great design idea is combining durable Gravelpave^2 drive aisles with attractive Grasspave^2 parking bays.

Pedestrian, Horse Trails and Bicycle Paths

Garden paths, greenhouse aisles, sidewalks, park paths, and wilderness trails paved with Grasspave^2/Gravelpave^2 provide a stable surface for strollers, bicycles, wheelchairs, and horses. There are no puddles or mud and traction is very good. Tree roots break up hard surface sidewalks, but our mats flex to accommodate such shifts and gradient changes. Plus, with the high proportion of air, roots are discouraged from moving upward. Mountain bikers will not be able to tear up paths reinforced with Grasspave^2/Gravelpave^2. Our products can resist the destructive forces of mountain bikes, allowing your trails to be reopened to bikes.

Fire Lanes

By far, the most common application for Grasspave^2 and Gravelpave^2 installations is for fire lanes. Our long and established history of providing safe, well-constructed fire lanes began in 1982 with our first installation in Snowmass, Colorado, near Aspen Ski Resort. Since then, we have firmly established credibility for this application. Tests have been conducted by several fire departments in Aurora, Colorado and Irvine, California. Nearly every major U.S. metropolitan area has accepted and used Grasspave^2 in a fire lane. You will most likely find a fire lane installation in your area.

All fire fighting vehicles can safely navigate even a wet Grasspave^2 or Gravelpave^2 surface. In a 1983 test this 100-foot ladder truck was lifted off the Grasspave^2 by rear outriggers, and no ruts were caused by either outriggers or tires. The ladder was extended, rotated, and loaded with no depressions in the road surface.

Grasspave2 Installation Procedures

This installation section is only intended as an overview. Please review our Grasspave2 Technical Specifications (available at www.invisiblestructures.com or call 800-233-1510) for comprehensive installation instructions.

Excavate a space for the base course as determined by site soils and loading requirements. Place and compact sandy gravel which should be a mixture of clean sharp sand and gravel varying in size but not exceeding 3⁄4 of an inch. To check porosity, use a hose to see that water flows into the base and drains away. Add subsurface drainage as necessary to low spots or locations with poor draining soils. Install irrigation lines and sprinkler heads if necessary.

Apply the Hydrogrow mixture that is included free with your order. Hydrogrow is a mixture of polymer and fertilizer designed especially for our Grasspave2 system.

Roll out Grasspave2, aligning the side hole fasteners over the side pegs. The warmth of the sun will relax the plastic so it lays flat. Cut the grid between rings using pruning shears. Incorporate the cut pieces in other areas, as needed, keeping the distance between the rings uniform.

Fill rings with clean sharp concrete sand (AASHTO M6 or ASTM C-33) using large rakes and brooms so that the tops of the rings show when done.

Lay turf over the rings. On warm days, wet the sand first to lower sand temperature and provide moisture for grass roots. Seeding and hydromulching is also an accepted vegetating method at this stage. Repeated hydromulching/seeding may be necessary.

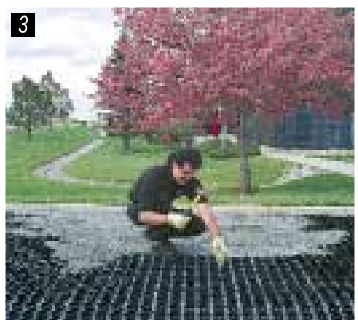
Roll sod with heavy roller to eliminate air pockets and make sure roots are in contact with the sand fill. Water lawn as usual according to climatic requirements.

Whether the area has been seeded or sodded, wait to drive on grass until two mowings have been completed, by which time the root system will be established and the sod pieces locked into place. In an emergency such as the need for fire truck access, grass may be driven on immediately after installation.

Use a regular lawn mower for maintenance. There should be no paver parts protruding through the surface that would damage mowers. Do not aerate!

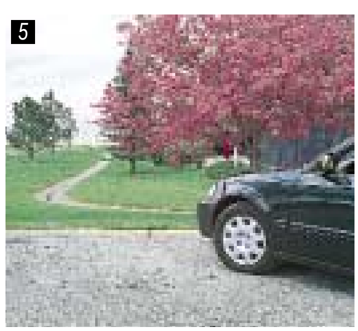
Place and compact sand and gravel road base.

Roll out Gravelpave2, aligning the snap fit fasteners.



Secure mats with anchors provided (size and type may vary).

Fill rings with clean gravel.



Compact gravel with vibrator roller or flat plate compactor (not shown).

Gravelpave2 Installation—

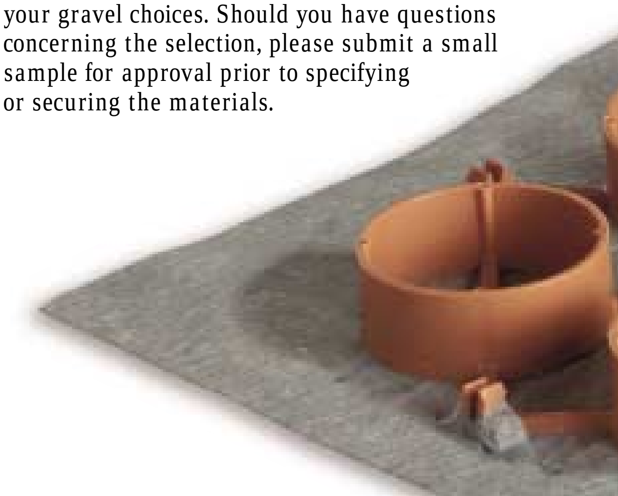
Gravelpave2 Size/Shape Fill Requirements

You will need 1″ of gravel fill, compacted. Be careful to order enough for the compaction process and choose a gravel size that will nest well into the rings. We have found that 3/16″ minus crushed stone and sometime 3/8″ with limited small sharp screenings (#40 to #100 screen) works well. Washed gravel will roll within the rings and will also "roll about." For this reason, we do not recommend pea gravel, even though it is often very attractive. A visit to your local quarry is suggested. We have found that some geological areas of the United States have limited types of sharp gravel available. It has been necessary to import gravel from a neighboring state, but remember the amounts are relatively small—the top one-and-a-quarter inch of the cross section. Gravel should be as free of fines as possible. To maintain porosity, avoid soft stone materials with low durability that will break easily.

Other Fill Materials for Gravelpave2

Please ask our staff for assistance with this category since it is use-specific and often experimental. Ground rubber, crushed glass, crushed brick, and many other materials can be useful as attractive fill materials for various applications. Thermoset (epoxy, polyurethane, etc.) binders may be cost prohibitive for most projects, but offer unique design possibilities, including clarity, color enhancement (wet look), flexibility, and durability.

Our technical support staff will assist with selection of gravel sources. The photographic samples shown on this page will help you narrow your gravel choices. Should you have questions concerning the selection, please submit a small sample for approval prior to specifying or securing the materials.



Mats can be rolled out in minutes!

Gravelpave2 Installation Procedure

This installation section is only intended as an overview. Please review our Gravelpave2 Technical Specifications (available at www.invisiblestructures.com or call 800-233-1510) for comprehensive installation instructions.

Prepare sandy gravel base course to a depth as determined by a soils engineer. Compact with a vibrating plate compactor or use a heavy motorized roller for large jobs. To test porosity, water with a hose and check to see that water drains readily through the base course before installing the Gravelpave2 mats.

Roll out mats with the grain (in the same direction) so that the snap fit fasteners can be used with neighboring mats. To fit around boxes and curbs, cut the grid between the rings with pruning shears and scissors or a small portable electric hand saw.

Fasten the mats together using the snap fit fasteners that are molded into the product inserting the prongs into the rectangular openings. Tuck the fabric underneath the fasteners to keep joints closed. A quarter-inch nut driver head (6 mm) fits nicely over the fastener to compress the pieces together. A piece of lumber placed under the Gravelpave2 mat will provide stability to aid in fastening.

Supplied anchors must be used to secure the mats to the base. Hammer anchors with washers at a rate of one anchor per six rings in both directions. Use extra anchors around the perimeter of the Gravelpave2 install and in high traffic areas. Reciprocating hammers can be used to speed up the anchoring process. Anchors should be placed inside the rings as close to the center as possible. Begin anchoring from one corner in a radial pattern.

Gradually place gravel fill (see suggested fill material on facing page) into rings by using a front-end loader and shaking out the fill as the machine drives forward. Carefully lower the bucket when empty and back up while dragging it *above* the rings to smooth out the gravel, finishing with a stiff broom. Wheel barrow and shovel works well for small jobs. Contractor tip—you can store excess material for future maintenance, top dressing as may be necessary. Use rakes and/or push brooms to distribute the gravel fill to a level slightly above rings so that compacting the fill will not uncover the rings.

Use a vibrating plate compactor or large driving roller again to compact the gravel fill. Additional gravel may be necessary to finish filling the rings. Compact again until the material appears solid in the rings. Wetting the gravel may help it to interlock.

Drive on the installation when finished. If car tires make a pattern, there may be too much gravel or it may need additional compaction. It is expected that tops of the rings may be visible. If sides of the rings show, then add more fill material and repeat the compaction process.

IN Proceedings of 9th International Conference on Urban Drainage, September 8-13, 2002 EWRI/IWA/ASCE

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).

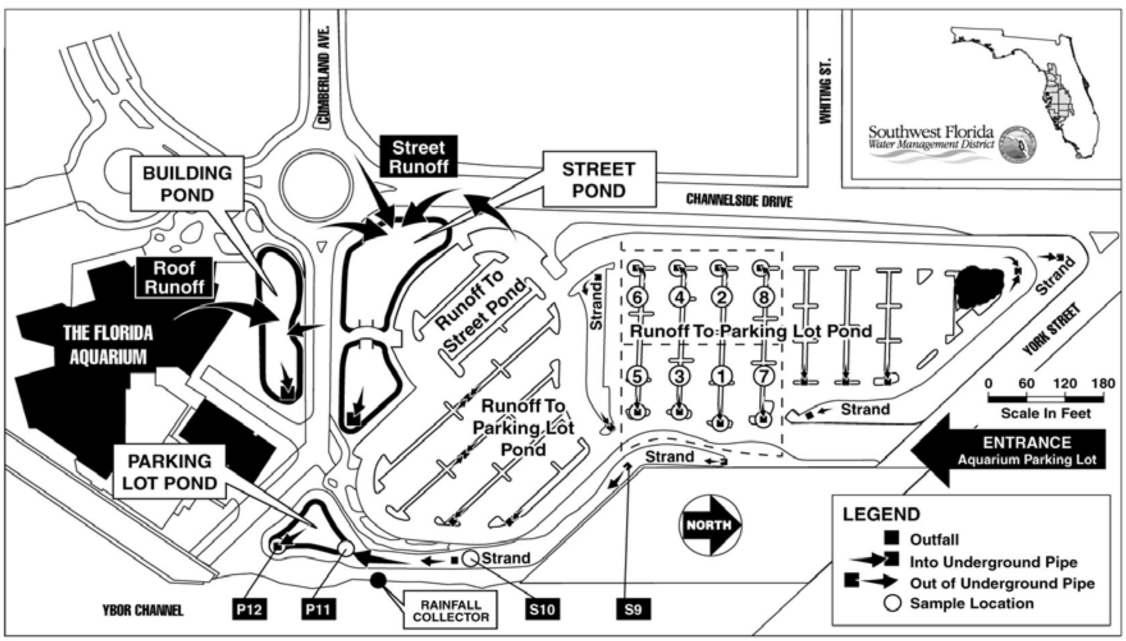

Figure 1a. Site Plan of the Parking Lot Demonstration Project showing sampling locations. The eight drainage basins evaluated in the parking lot are outlined by the dotted lines and shown in more detail in the next diagram. Numbered black boxes indicate sampling locations in the strand and the pond.

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.

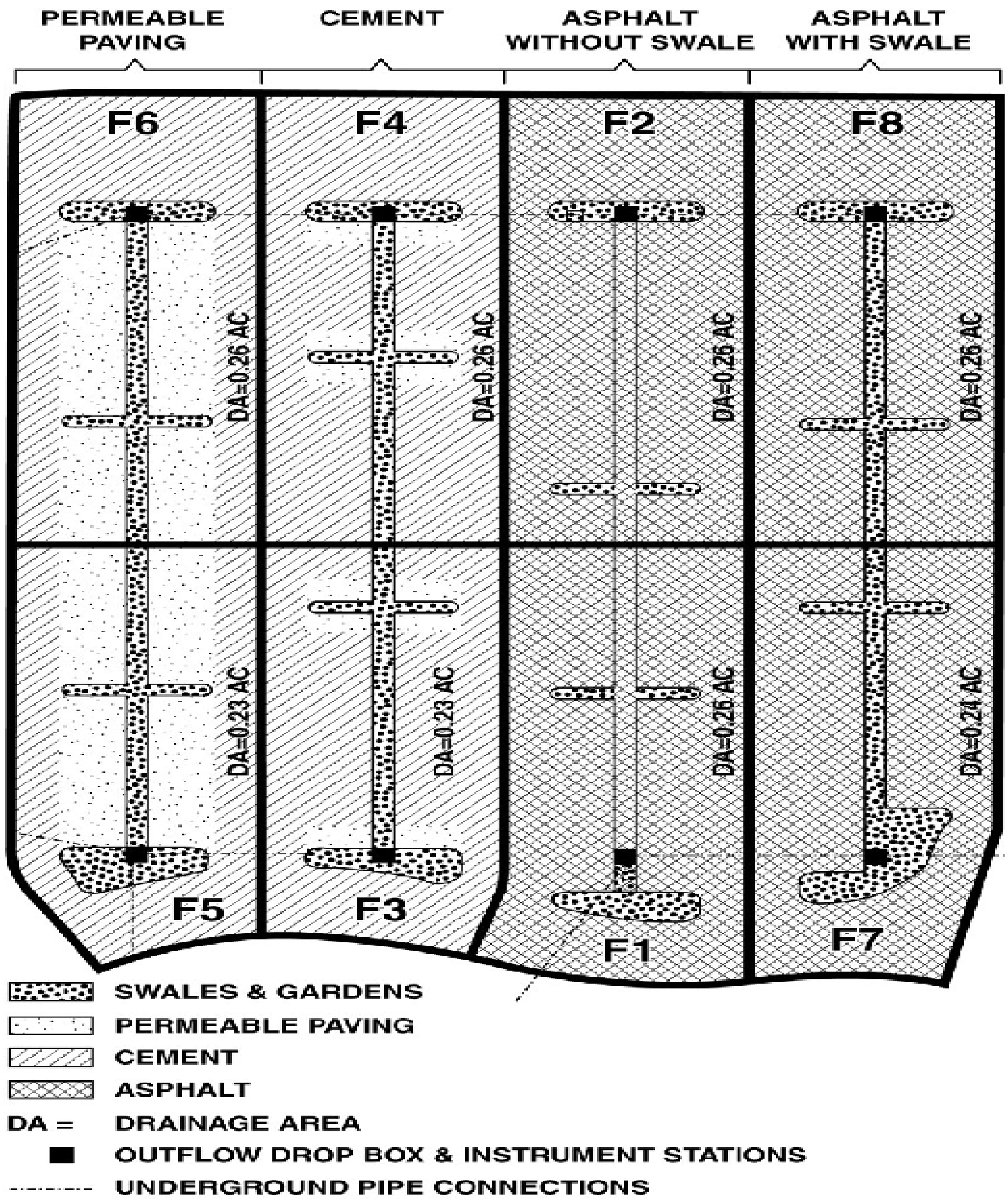

Figure 1b. Site plan of the parking lot swales delineated by the dotted lines in Fig 1a.

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:

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™ 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.

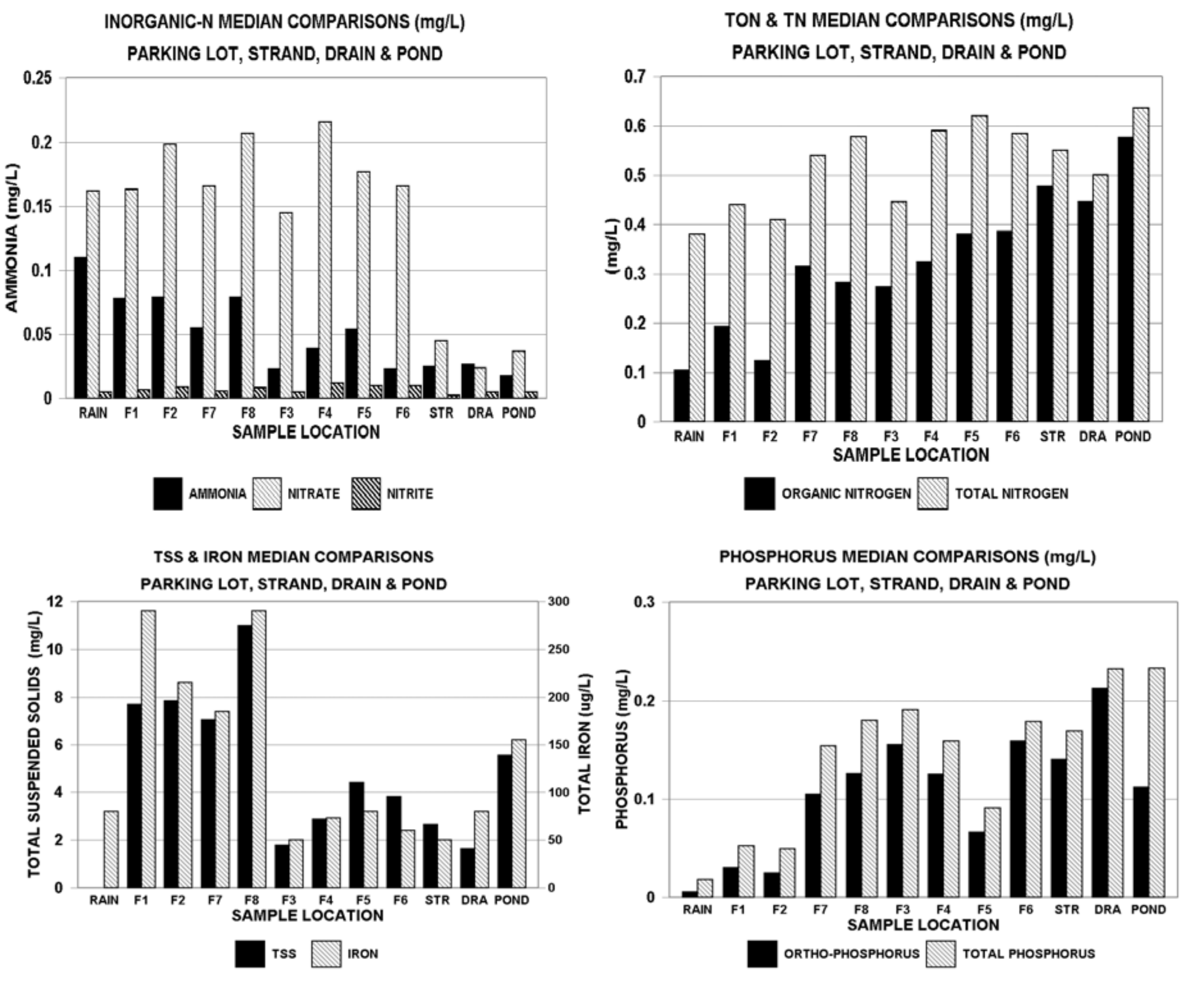

Figure 2. Comparison of median water quality concentrations at the outflows of the various elements of the stormwater system. See Figure 1 for sample locations. Abbreviations: STR=strand, DRA=under drain, POND=pond.

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.

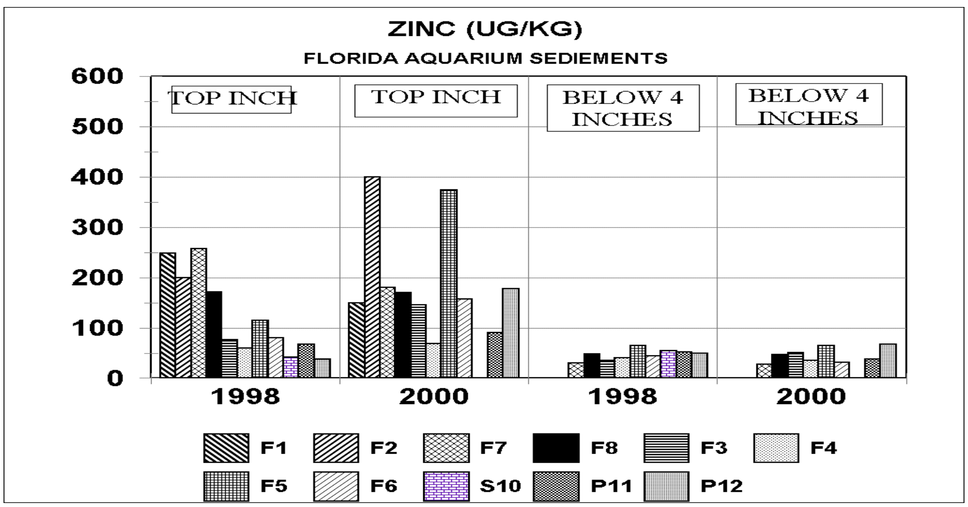

Figure 3. Sediment samples for zinc collected in 1998 and again in 2000 at the outfall of each drainage basin as well as in the swale and pond.

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.

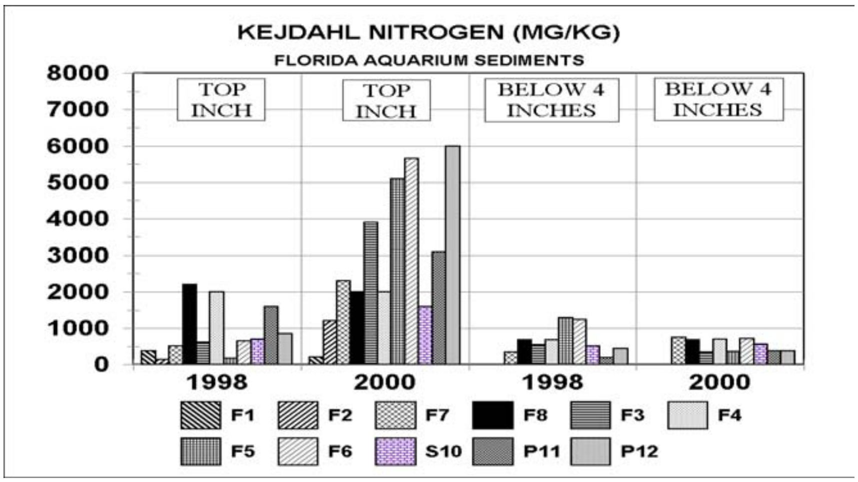

Figure 4. Sediment samples for total Kjeldahl nitrogen collected in 1998 and again in 2000 at the outfall of each drainage basin, the swale, and the pond.

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).

ACKNOWLEDGEMENTS

This project has been funded in part by a Section 319 Nonpoint Source Management Program grant from the U. S. Environmental Protection Agency (US EPA) through a contract with the Stormwater/Nonpoint Source Management Section of the Florida Department of Environmental Protection. The total estimated cost of the monitoring project is $328,327 of which $196,996 was provided by the US EPA. Rebecca Hastings collected samples, kept samplers iced, serviced the electronic equipment, and entered data into tables.

Eric Livingston and David Worley at FDEP provided support and guidance. The parking lot design was prepared by Art Woodworth, Jr., Engineer, Florida Technical Services and Thomas Levin, Environmental Planner, Ekistics Design Studio, Inc. The Southwest

Florida Water Management District laboratory staff was indispensable in carefully analyzing samples that could never be collected on a pre-determined schedule. Innumerable interns kept samplers iced, entered data into tables and collected samples. Allen Yarbrough designed the cover of the report, the site plan and parking lot swale diagrams. The Finance Department and especially Donna Farrell tracked our budgets, submitted invoices and kept us posted about our expenditures. Chuck Tornabene, our librarian, and his staff edited the report and also Dr. Tricia Dooris, Manager of the Environmental Section. A special thanks to the very careful review provided by Dr Woo-Jun Kang, one of our laboratory scientist, who gave special scrutiny and advice about the sediment and water quality data, an area of expertise where he is especially well-qualified. Everyone receives our grateful appreciation.

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