Literature Review
of
Stormwater Treatment
Best Management Practices Research
in Florida

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Prepared for:

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1.0 INTRODUCTION

This report provides the results of a literature review of ongoing and completed research on stormwater treatment best management practices (BMPs) in Florida. The review was limited to literature that evaluated the pollutant removal of different stormwater treatment BMPs. Results from this review will be used to avoid duplication of research projects and determine data gaps of existing stormwater treatment BMPs in southwest Florida.

The review was performed by contacting staff at the South Florida Water Management District (SFWMD), Southwest Florida Water Management District (SWFWMD), Florida Department of Environmental Protection (FDEP), and other agencies in Florida. The review was also perform by reviewing documents available in the International Stormwater BMP database, University of Central Florida Stormwater Academy, Big Cypress Basin – Estero Bay Regional Research Database, Southwest Florida Regional Restoration Coordination Team, Stormwater Resources Library, Low Impact Development Center, United States Geological Survey, and the United States Environmental Protection Agency.

The State of Florida's stormwater rule was adopted in 1982 and required all new development and redevelopment projects to include site appropriate BMPs to treat stormwater (Bateman *et al*, 1998). The program established a performance standard of removing at least 80% of the average annual post-development loading of total suspended solids (TSS) for stormwater discharged to most waters and a reduction of pollutant loadings by 95% for discharges to Outstanding Florida Waters (*e.g.*, Estero Bay Tributaries).

Briefly, a stormwater treatment BMP is a technique, measure or structural control that is used for a given set of conditions to manage the quantity and/or improve the quality of storm water runoff in the most cost-effective manner (EPA, 1999). BMPs can be either engineered and constructed systems ("structural BMPs") that improve the quality and/or control the quantity of runoff such as detention ponds and constructed wetlands, or institutional, education or pollution prevention practices designed to limit the generation of storm water runoff or reduce the amounts of pollutants contained in the runoff ("non-structural BMPs") [EPA, 1999].

1.1 Structural Stormwater Treatment BMPs

Structural stormwater treatment BMPs are commonly used in Florida. According to Strecker *et al* (2004), 171 structural BMPs are listed in the International Stormwater BMP database of which 24 are found in Florida. The following categories of structural BMPs are taken and modified from the American Society of Civil Engineers (ASCE) National Stormwater BMP Database. The following descriptions of the structural BMP categories are intentionally brief. The reader is encouraged to review the ASCE National Stormwater BMP database for more information.

1.1.1 Retention Systems

These systems are designed to capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Pollutant removal in these systems occurs primarily by sedimentation (gravity settling), but also by biological uptake of nutrients by plants and algae, volatilization of organic compounds, uptake of metals by plant tissue, and biological conversion of organic compounds. Examples of retention systems include: 1) retention ponds and 2) retention tanks, tunnels, vaults, and pipes.

1.1.2 Detention Systems

These systems are designed to intercept a volume of storm water runoff and temporarily impound the water for gradual release to the receiving systems. Detention systems are designed to empty out between runoff producing events. Examples of detention systems include: 1) detention pond and 2) underground vaults, pipes, and tanks.

1.1.3 Wetland Systems

These systems incorporate the natural functions of wetlands to aid in pollutant removal from storm water. Limitations of these systems include maintaining a water level that mimics a natural hydroperiod for that type of wetland. Additionally, sediment pretreatment needs to be employed to prevent sediment build-up in the constructed wetland system to prevent degradation of the wetland system.

1.1.4 Filtration Systems

These systems use a media such as sand, gravel, peat, or compost to remove a fraction of the constituents found in storm water. Filtration systems are primarily a water quality control device designed to remove particulate pollutants and are most commonly used to treat runoff from small sites (*e.g.*, parking lots, small developments), areas with high pollution potential (*e.g.*, industrial areas), and highly urbanized areas where land availability is limited. Examples of filtration systems include: 1) surface sand filters, 2) underground vault sand filter, and 3) biofiltration/bioretention systems.

1.1.5 Vegetated Systems (Biofilters)

These systems use vegetation to filter storm water and provide some degree of treatment, storage, and infiltration. Examples include grass filter strips and vegetated swales.

1.1.6 Infiltration Systems

These systems are designed to capture a volume of storm water runoff, retain it, and infiltrate that volume of water into the ground. Advantages of this type of system include water quantity control by reducing discharges, increasing recharge of the surficial aquifer, and water quality control through soil filtration and biodegradation. Disadvantages include potential contamination migration in areas where the surficial aquifer is used as a primary source of drinking water. Performance of infiltration systems is limited by the infiltration capacity of the soil. Types of infiltration systems include: 1) infiltration basins, 2) porous pavement systems, and 3) infiltration trenches and well.

1.1.7 Minimizing Directly Connected Impervious Surfaces

This system involves a variety of practices designed to limit the amount of storm water runoff that is directly connected to the storm drainage system. Runoff is instead directed to landscaped areas, grass buffer strips, and grassed swales to reduce the velocity of runoff, reduce runoff volumes, attenuate peak flows, and encourage filtration and infiltration of runoff (UDFCD, 1992).

1.1.8 Miscellaneous and Vendor-Supplied Systems

These systems include a variety of devices that are used for urban storm water management and incorporate a combination of filtration media, hydrodynamic sediment removal, oil and grease removal, or screening.

1.1.9 Treatment Train Systems

These systems employ a combination of structural stormwater treatment BMPs commonly in series. Research of BMPs containing BMPs from two or more categories is listed as a treatment train system in this report.

1.2 Non-Structural Stormwater Treatment BMPs

Non-Structural stormwater treatment BMPs include institutional and pollution prevention type practices designed to prevent pollutants from entering storm water runoff. Examples include public education programs (*e.g.*, storm drain stenciling), oil recycling programs, and litter control programs. While non-structural BMPs can be effective in controlling pollution generation at the source, research of their pollutant removal efficiency is difficult without well-defined boundaries (*e.g.*, inlets, outlets). Non-structural BMPs are geographically interspersed with many pollutant sources and are virtually impossible to monitor or at best can be evaluated using trend monitoring (ASCE, 2002).

2.0 STORMWATER TREATMENT BMP RESEARCH IN SOUTHWEST FLORIDA

The following is a list of known stormwater treatment BMP research in southwest Florida. Published results are limited at this time.

2.1 Green Roof at Shadow Wood Preserve, Lee County, Florida

Summary: The objective was to develop a green roof model for South Florida that shares many of the characteristics of so-called 'extensive' green cover systems developed in Europe. These are veneer systems incorporating 'engineered soil' and synthetic layers which can support a dense ground covering vegetation layer without active irrigation. The pilot green roof at the Shadow Wood Preserve project included three test plots, each approximately 800 square feet in area. All of these emphasized good drainage, since the threat posed by the hot humid summer conditions seemed greater than the winter dry season. The growth media used in each case was designed with a volumetric maximum moisture content of 35%. To conduct the stormwater monitoring, a stormwater monitoring station was established that would measure flows and collect water quality samples. The core of the sampling equipment is an ISCO Model 6712FR refrigerated, programmable, multi-bottle sampler using a peristaltic pump and Tygon tubing to deliver the sample stream into polyethylene container bottles in the refrigerated unit connected to a 110v standard AC power supply. The sampler is triggered by the accumulation of a specified amount of rain within a time period. Flow composited sampling is accomplished by interconnecting the ISCO sampler with a pressure transducer located in the bottom of a PVC "rain barrel" which has precisely measured openings. The ISCO unit translates the transducer signal into a flow measurement that is in turn used to trigger subsequent flow compositing aliquots. Water quality samples are being analyzed for cadmium, chromium, copper, zinc, dissolved copper, ammonia, nitrite, nitrate, orthophosphate, total Phosphorus, total kjeldahl nitrogen, total nitrogen, and total suspended solids.

Reference: Ongoing, Johnson Engineering, Inc.

2.2 Porous Pavement Evaluation at Shadow Wood Preserve, Lee County, Florida

Summary: The project assesses reductions in stormwater runoff and pollutant loading from porous concrete pavement versus asphalt pavement at Shadow Wood Preserve in Lee County, Florida. Each of the two study areas has a catch basin outfitted with a fiberglass insert box to facilitate flow measurements and sampling. Two automated, refrigerated ISCO sampler units were tied to a nearby rain bucket to facilitate storm event detection, and to put the ISCO units into sample mode. Continuous flow measurements were made utilizing bubbler tube technology, allowing flow composited samples to be collected. Events were collected for both wet season and dry season storms, with a 1-inch event being the target sample event. Data collection for this project is now complete, and lab results, volumes and water levels are being evaluated. Of particular note is the substantial reduction in discharge volumes from the porous system compared to the standard asphalt system. During the initial onset of a storm event, essentially all of the runoff generated in the porous area, percolates through the porous concrete in to the subsurface system and enters the groundwater table. Runoff will occur under very high rainfall intensities that exceed the infiltration rate of the porous pavement, but under normal to low rainfall intensities, it was not unusual to see a 30 minute delay before any water entered the catch basin in the porous area, compared to the standard asphalt area. This can be a significant benefit on its own, for the receiving water body, in addition to any pollutant reduction accomplished by the filtering action of the porous concrete itself. Water quality samples were laboratory analyzed for cadmium, chromium, copper, zinc, ammonia as N, nitrate and nitrite, orthophosphate as P, total phosphate, total kjeldahl nitrogen, total nitrogen, and total suspended solids.

Reference: Ongoing, Johnson Engineering, Inc.

2.3 Littoral Plantings Project at Bonita Bay Lake 62, Lee County, Florida

Summary: This project was designed to assess the water quality impact of a littoral planting in a wet detention system in southwest Florida. The wet detention lake is in a typical residential/golf course community having runoff from residential lawns, roadways, and golf course areas. Three sample stations at the wet detention lake are located at: 1) the inflow pipe, 2) a temporary V-notch controlled outflow, and, 3) at the final outfall control structure. Outflow from the lake passes over a naturally vegetated area before overflowing the final control structure. Automated, refrigerated, ISCO samplers are used at all three sample stations to collect both flow composited samples and weekly composite samples taken during periods of limited rain events. These samplers are sophisticated programmable units capable of sampling a variety of protocols, and have telemetry equipment to allow remote observation of the sample units status, flows, rainfall, and other on site data. The collected water quality samples are laboratory analyzed for cadmium, chromium, copper, zinc, ammonia as N, nitrate and nitrite, orthophosphate as P, total phosphate, total kjeldahl nitrogen, total nitrogen, sulfate, and total suspended solids. The wet detention lake also contains two YSI 6600 EDS Data Sondes, deployed at mid lake depth to provide ongoing data collection at 15 minute intervals for dissolved oxygen, specific conductance, pH, temperature, oxidation/reduction potential, depth, and turbidity. This high resolution data can be compared with lake water levels collected with Infinities USA pressure transducer dataloggers, as well as with laboratory analysis from the ISCO sample units. Data collected to date represents the background data collected prior to construction of the littoral shelf. It is anticipated that the littoral plantings will be done during this dry season and monitoring will begin again at the next wet season.

Reference: Ongoing, Johnson Engineering, Inc.

2.4 Deep and Shallow Wet Detention Ponds Water Quality at The Brooks, Lee County, Florida.

Summary: The primary objective of this study was to evaluate wet detention ponds of various depths to understand whether or not aeration of the ponds is beneficial or desired. The secondary objective of this study was to determine whether or not stratification of the water column occurs in ponds. Four ponds were selected from a shallow and deep wet detention system at The Brooks residential development for this study. Each pond contains multiple aerators. The study consisted of placing water quality data sondes in each of the ponds. The sondes monitored temperature, conductivity, pH, dissolved oxygen, oxidation-reduction potential and turbidity. The study was made up of two phases lasting approximately three weeks each. Background data was collected for approximately one month prior to the first phase. During the background period, the aerators in the ponds were left on as normal. In each phase, aerators in two of the ponds were operated as normal while aerators were turned off in the other two ponds. Ponds selected to be aerated during phase two were different than those being aerated in phase one. In addition to the data collected by the water quality sondes, three sets of water quality data were collected from each lake using a separate water quality meter. The readings taken by the independent meter were used to verify the sonde data and also to provide a vertical profile of the water column. Three sets of water quality samples were also collected using a Van Dorn type sampler from each of the ponds during the study and laboratory analyzed for pH, turbidity, ammonia nitrogen, total nitrogen, nitrate and nitrite, orthophosphate, total phosphate, chlorophyll a, and specific conductance.

Reference: Ongoing, Johnson Engineering, Inc.

2.5 Roadway Runoff and Wet Detention Pond Water Quality Assessment, Metro Parkway, Lee County, Florida

Summary: The objective of this project is to evaluate the quality of water runoff from state-managed roadways similar to that of the proposed expansion of Metro Parkway. The water quality results will be analyzed to characterize stormwater runoff and treatment efficiency of wet detention ponds. In order to achieve this, runoff will be monitored at three separate points: directly from the road surface, at the inflow to an adjacent wet detention pond and at the wet detention pond outfall. In addition, a fourth monitor point will capture rainfall at the site before it reaches the ground surface. The project will involve the collection of water quality samples during at least five rainfall events that produce discharge. Sampling of the treatment pond will be triggered by the same rainfall event. Vehicle traffic counts for the area will be studied to characterize level of service for the roadway. This information will be used to help understand and evaluate the water quality results. The runoff collected directly at the road surface will be compared to that at the inflow to the adjacent treatment pond. The runoff diverted to the treatment pond is part of a closed system. Therefore, any differences between the road surface and treatment pond inflow samples should be attributable to additional runoff entering the system through grates in medians or beside walkways along the stretch of road being analyzed. Collected water quality samples will be laboratory analyzed for total cadmium, total chromium, total copper, total iron, total lead, total manganese, total nickel, total zinc, ammonia as N, nitrate and nitrite, orthophosphate as P, total phosphate, total kjeldahl nitrogen, total nitrogen, and total suspended solids.

Reference: Ongoing, Johnson Engineering, Inc.

2.6 Stormwater and Nutrient Loadings from FDOT Roadways in Southwest Florida

Summary: This project evaluates stormwater runoff and pollutant removal efficiency of wet detention ponds that treat stormwater from FDOT roadways in Lee, Collier, and Hendry counties. The project will involve identifying stormwater treatment ponds suitable for water quality monitoring, hydrologic monitoring, determining level of service for each adjacent roadway, installation of automatic samplers and other required equipment, and the collection of samples from the inflow and outflow for laboratory analyses.

Reference: Ongoing, Johnson Engineering, Inc.

2.7 Leitner Creek By-Pass Canal BMPs, Lee County, Florida

Summary: Leitner Creek By-Pass Canal is an annual public works project to ensure flood control in the relatively flat topography of Lee County, Florida. This canal is over 4400 feet in length and the maintained portion discharges to an Outstanding Florida Waterbody (OFW) tributary emptying into Estero Bay. OFW's have the highest level of water quality protection in the state. As if this were not difficult enough, water levels in the canal vary from several inches to over 4 feet in depth. Typical problems encountered in the past have been: high turbidity levels from the clean-out efforts, lengthy turbidity plumes moving downstream causing environmental and visual impairment, odor complaints associated with organic sediment and vegetation removal, and conflicts between the need for permit compliance and flood control maintenance. A site-specific water/soil sample test showed that APS 706b Floc Logs along with 712 powder could be used to provide flocculation and chelation of the fine mucky soil particles generated from the maintenance activities. The 712 powder could be used to stabilize the canal embankment and provide additional turbidity treatment as needed. The project was able to proceed with minimal changes to current procedure. Odor complaints were significantly reduced. A tremendous visual improvement was apparent in the canal. Future uses will explore more efficient use of floc log mixing devices that are adaptable to different types of drainage maintenance equipment. A metal box was designed and constructed to provide a movable mixing zone for the Floc Logs. Several were attached to this box and to the Water Spyder to allow agitation and current flow to dissolve the APS product for turbidity treatment. Particle curtains, made of PVC pipe and jute were constructed and placed downstream to capture fine flocculent material that did not gravity settle. Turbidity values in the work area ranged between 423 - 1,000 NTUs. These were acted on by the Floc logs, which caused the mucky sediment to form floc materials and chelating bridges between individual particles. As these particles clumped together, they became larger and heavier. Gravity settled out most of these particles leaving the water very clear. Two hundred (200) feet downstream of the work area, turbidity was down to 7.5 NTUs. These levels continued to remain low and resisted resuspension, so that even more than 1,000 feet downstream of the work area, turbidity levels were between 10 - 13.5 NTUs.

Reference: Applied Polymer Systems, Inc., Outstanding Florida Waterbody, Innovations in Stormwater Control, www.swfwc.org/EBNMP/BonitaSpringsCaseStudy1.doc, 2 p.

2.8 Florida Gulf Coast University

Summary: Students and staff at FGCU are performing a water quality study of wet detention ponds in Lee County. According to Win Everham (*personal comm.*), the one-year study consists of collecting water quality samples from twenty-two wet detention ponds and laboratory analyses of total nitrogen, phosphorus, orthophosphorus, and chlorophyll-a. The wet detention ponds are of varying age, size, depth, riparian zones (planted littoral and rip rap), and surrounding land uses. The study will also include hourly sample collection during the rainy season from a subset of the ponds.

Reference: Ongoing, Edwin Everham, Florida Gulf Coast University

3.0 STORMWATER TREATMENT BMP RESEARCH IN FLORIDA

The following provides a summary of completed and ongoing stormwater BMP research in Florida. The following summaries are from published literature. Research of other BMPs in Florida may be underway and may be published in obscure publications.

3.1 Detention Systems

3.1.1 Evaluation of the Performance Efficiency of a Modified Wet Detention Pond for Enhanced Nitrogen Removal

Summary: This project will specifically evaluate the performance efficiency of a modified wet detention pond to reduce input concentrations of nitrogen. A series of floating baffles will be used to create both oxic and anoxic zones which will be used to stimulate denitrification removal processes. The specific objectives of this research project are to: 1) evaluate the pollutant removal effectiveness of an unmodified wet detention pond for nutrients and heavy metals, 2) evaluate the ability of floating curtains and baffles to maintain separate oxic and anoxic environments in segmented portions of a wet detention pond, 3) evaluate the hydraulic impacts of floating curtains and baffles in a wet detention pond, and 4) evaluate the performance efficiency of alternating anoxic and oxic zones on pollutant removal effectiveness, particularly with respect to species of nitrogen.

Reference:
Ongoing (August 13, 2003 until April 12, 2005), Environmental Research and Design, Inc.

3.1.2 Quantifying the Pollutant Load Reduction of Wet Detention Systems Before and After Planting of a Littoral Zone

Summary: To evaluate the effects of littoral zone vegetation planting on wet detention pond performance using an *in situ* investigative approach. This will include determining the effects of both littoral zone vegetation planting and related vegetation management activities on pond performance by establishing large *in situ* compartments within an existing wet detention pond.

Reference: Ongoing (July 7 2003 until January 3, 2005), DB Environmental, Inc.

3.1.3 Water-Quality Survey of Twenty-Four Stormwater Wet-Detention Ponds

Summary: As part of its stormwater management responsibility, the Southwest Florida Water Management District conducts research to implement better stormwater regulations. During 1988-89, the District conducted a water-quality survey of twenty-four stormwater wet-detention ponds that had been permitted by the District in the Tampa Bay Region. These ponds were studied to characterize the discharge effluent water quality and to determine consistency with State water quality standards. The objectives of the survey were threefold: (1) to provide regional, base-line water-quality data in urban, stormwater wet-detention ponds, (2) to document whether the water quality of effluents from wet-detention ponds met State water-quality standards, and (3) to explore relationships among physical/chemical (water-quality) variables, water-level variables, and pond dimension variables. To accomplish the objectives, grab samples were collected in the pond and at the outflow within two days after a storm event. Samples collected at the outfall station (located at the point of discharge from wet detention ponds) found exceedences (non compliance) of State water quality standards, which included: dissolved oxygen (34%), zinc (31%), cadmium (10%), copper (12%), lead (9%), conductivity (6%), turbidity (3%), chromium (3%), nickel (1%) and magnesium (1%). Exceedence of the total suspended solids standard (20 mg/L -- for an efficient secondary sewage treatment) in 10 percent of samples, and exceedence of the turbidity standard (29 NTU) in only 4 percent of samples indicated the wet-detention ponds were effective as sedimentation basins. Evaluation of seasonal patterns in the data indicated that hydrologic conditions (*i.e.*, water levels) were rainfall related, as expected. More importantly, several variables (conductivity, turbidity, cadmium, and possibly zinc and iron) were inversely correlated with rainfall-related water-level indicators (*i e.*, the number or percent of ponds discharging, and the bottom depth at the sample location). Also, as would be expected seasonal temperature patterns were important with regards to dissolved oxygen levels. The inverse relationship between the number of ponds discharging and mean outfall station concentrations for certain water-quality variables also suggests that higher mean values and perhaps more exceedences of standards corresponded with periods of lower rainfall when fewer ponds were discharging. Thus, an exceedence during dry periods might not actually constitute a violation of water quality standards since these are designed to protect receiving waters. Results of multivariate statistical analyses (cluster techniques, multiple regressions, etc.) provided evidence that hydrologic conditions and pond dimensions were important for certain water-quality variables, especially suspended particles and iron. The results also suggested a relationship between water quality and primary production in wet-detention ponds since temperature, dissolved oxygen and pH were closely related. Data from the land-use evaluations and cluster analyses of ponds suggested that multifamily residential ponds are among those with poorest water-quality, probably caused by greater impervious areas. Some additional parameters should be incorporated for more complete evaluation of water-quality data (*e.g.*, total hardness, alkalinity, redox potential, nutrients and/or chlorophyll, and color). These variables are important because of their influence on metal concentrations and metal toxicity, as well as, on other water-quality characteristics. Research concerning the ecological value of stormwater ponds has been mostly overlooked. With ever increasing development pressures reducing wetland and surface water resources, biological sampling (*e.g.*, plants, algae, and benthos) would help determined the strengths and weaknesses of stormwater ponds as fish and wildlife habitat. Stormwater rules should relate percent impervious area to the amount of treatment required for stormwater ponds since the greater the impervious area, the more often these stormwater systems exceed standards.

Reference:

Kehoe, M.J., 1993, Water Quality Survey of Twenty-Four Stormwater Wet-Detention Ponds, Southwest Florida Water Management District, 84 pages.

3.1.4 Comparative Water Quality Data of a Deep and a Shallow Wet-Detention Pond

Summary: Stormwater treatment criteria as stated in State Water Policy 62-40 has a goal of 80% removal efficiencies for annual pollutant loads. A common method used to treat stormwater includes wet-detention. Studies have indicated that some wet-detention systems fail to meet the goal of 80% removal. As a result, this study investigated methods to improve the wet-detention system design. This study examined the effect of the depth of the permanent pool on pollutant removal efficiency. Two adjacent ponds with similar parameters except for the depth (9.0 feet vs. 3.5 feet) were tested for pollutant removal. Pollutant removal efficiencies were calculated based on mass loading numbers. Removal efficiencies for copper were low in both ponds, possibly due to low concentrations entering at the inflow. The highest removal efficiencies for both ponds were for iron. Iron removal was 87% for the deep pond and 85% for the shallow pond. Since iron removal is a good predictor for the behavior of other metals, it can be assumed that efficiencies for copper and zinc would have been better if concentrations had been higher. Suspended solid and volatile suspended solid removal was greater in the deeper pond (77% vs. 69%). Nitrogen removal was modest (<50%) in both ponds. Greater than 80% removal for orthophosphorous was recorded for both ponds. Low dissolved oxygen levels at the bottom of ponds were associated with thermal stratification. The deeper pond was stratified more often than the shallow pond. The removal efficiencies between the two ponds were similar except for greater suspended solid removal in the deeper pond. Wet-detention pond depth does not seem to significantly affect removal efficiencies of nutrients and metals, but low initial concentrations of metals may have skewed this result. Deeper ponds may be more prone to low dissolved oxygen levels at the bottom due to increased frequency of thermal stratification.

<u>Reference</u>:

Cunningham, J., 1993, Comparative Water Quality Data of a Deep and a Shallow Wet Detention Pond, *In* Proceedings of the

3rd Biennial Stormwater Research Conference, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609.

3.1.5 An In-Depth Analysis of a Wet Detention Stormwater System and Three Design Alternatives for Stormwater Detention Ponds

Summary: Wet detention ponds are the most common method used in our District for treating stormwater runoff, but little data is available about how different designs affect pollution removal. The purpose of this study was to provide scientific documentation to support or modify certain aspects of the District's stormwater rule (40D-4). Other objectives included measuring pollutant loading from rainfall, correlating relationships between constituents, determining compliance with state water quality goals, measuring pollutants in the sediments and making recommendations for reducing non-point source pollution. One pond was reshaped three different ways to compare designs that have been used or can be used to meet District surface water runoff rules. Each pond design was studied for an eight month period from June through January of each year. The major features of each design are: a shallow pond was studied in 1990. It was originally one foot deep with an average 2-day wet season residence time and 100% vegetated with planted wetland species and the design followed the early parameters established by SWFWMD rules promulgated in 1988. The same pond was studied in 1993 except that it had been reshaped with a permanent open water pool five feet deep, which allowed a 5-day wet season residence time. An unplanted shallow shelf (littoral zone) occupied 33% of the pond and was allowed to colonize naturally from the available seed source and the largest part of the shelf was located near the outflow. Design parameters represent SWFWMD criteria in effect in our current rules. The pond, reshaped once again, to test the Conservation Wet Detention Design criteria (developed by SWFWMD's regulatory staff), was studied in 1994. These design criteria include a 14-day wet season residence time and a planted littoral shelf similar in area to the previous pond design. These criteria represent an alternative design that can be used by developers seeking SWFWMD permits. The drainage basin for the pond is 6.5 acres with about 30 percent of the watershed covered by rooftops and asphalt paving, 6 percent by a crushed limestone storage compound and the remaining 64 percent is a grassed storage area. The impervious surfaces discharge to ditches that provide some pre-treatment before stormwater enters the pond. Instruments at the inflow and outflow collected flow-weighted samples for over 20 storm events during each eight month sampling period. Rainfall amounts and water quality were also quantified. Since treatment credit is given for some of the storage in the permanent pool, the Conservation Wet-Detention design can reduce the amount of fill needed for elevating house pads and also use less land area for the pond. The most important finding showed the Conservation Wet Detention design that included the 14-day residence time had the best removal efficiency. Also, using these criteria, the reduction of pollutants from the inflow to the outflow usually met the 80 percent pollutant reduction goal specified by the State Water policy. Organic nitrogen and ammonia are the most difficult pollutants to remove with wet detention ponds. Ammonia concentrations were reduced by 18% to 70% and organic nitrogen by 5% to 42%. The Conservation wet-detention design had the highest removal rates compared to the other two designs. Rainfall is a significant source for nitrogen and some metals. Low dissolved oxygen levels (< 2 mg/L near the pond sediments) increase phosphorus concentrations in the water column. Sediment samples indicate polycyclic aromatic hydrocarbons (PAH) concentrations present a problem in stormwater runoff and concentrations in sediments increase as ponds age. Iron is a controlling mechanism for pollution removal forming positive correlations with metals and phosphorus. Iron was present in higher concentrations at the inflow during the final year of the study and since it forms particles that settle easily it may have improved pollution removal for the final year. Macroinvertebrate sampling indicated that newly constructed wet detention ponds can be diverse and productive habitats supporting even some pollution sensitive species. Desirable wetland herbaceous species planted on the wide littoral shelf reduced the amount of torpedo grass that had invaded the pond. In contrast, the steep slopes of the narrow littoral shelf around the pond favored the expansion of torpedo grass. Much more diverse planted wetland vegetation survived on the wide littoral shelf near the outflow than on the narrow shelf that surrounded the pond. The Conservation Wet Detention criteria should be recommended for all stormwater systems where deeper surficial groundwater tables and confining strata allow for adequate pond depth. In this study the effluent, which resulted from using these criteria met almost all State water quality standards and this design can also reduce the need for fill material and produce other economic benefits. Stormwater designs that utilize the entire drainage basin and reduce discharge to predevelopment levels should be encouraged and credit given to developers who use these techniques. Although stormwater ponds reduce peak flows, only a watershed approach will significantly reduce the volume of water discharged downstream. Stormwater rules need to address extreme events. During 1993 in this study, from 32 to 77 percent of all pollutant loads measured during the 22 storms monitored that year were discharged during one storm. Source reduction is needed for stormwater improvement since atmospheric deposition was a significant source of inorganic nitrogen and some metals. Aerobic bottom sediments and a circumneutral pH in a permanent pool with adequate residence times are a necessary condition for stormwater ponds and designs that provide these conditions should be incorporated into stormwater systems. Operation and maintenance information for the care of stormwater systems is needed.

Reference:

Rushton, B.T., Miller, C., Hull, C., and Cunningham, J., 1997, Three Design Alternatives for Stormwater Detention Ponds, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609, 59 pages.

Rushton, B.T. and Dye, C.W., 1993, An In-Depth Analysis of a Wet Detention Stormwater System, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609, 121 pages.

3.1.6 A Survey of Outflow Water Quality from Detention Ponds in Agriculture

Summary: Agriculture is considered the major source of non-point source (NPS) pollution to water bodies in the United States. Because of the diffuse nature of NPS pollution, treatment of the discharge waters has been difficult. One method used to treat agricultural runoff is to direct the runoff from stormwater and irrigation to detention ponds. Detention ponds have been used in urban settings to treat stormwater before discharge into environmentally sensitive waters and have proven to act as a filter for pollutants such as metals, nutrients, and other water contaminants. In this study, discharge from detention ponds at nine agricultural sites, which covered a three county area were investigated to assess the outflow water quality and compliance with State water quality standards. From December 1993 through November 1994, monthly water samples were taken from the outflows of nine detention ponds in agricultural basins to assess compliance with State of Florida water quality standards. Three analyses were performed: 1) discharge water quality data were compared with State surface water and ground water standards, 2) discharge water quality data were compared with treated and untreated agricultural discharge values found in literature, and 3) correlations of water quality data were performed to investigate relationships and trends. For this study, it is important to consider that data was gathered from only the outflow of detention ponds. Water quality data was not gathered at the inflow and therefore, this study does not assess the treatment efficiency nor does it characterize how the detention ponds function. Since the ponds discharged almost continually the samples were collected on a monthly basis and do not necessarily represent storm runoff. Comparison with State Class III surface water standards indicates that out of nine total sites, violations occurred for lead (2 sites), iron (3 sites), alkalinity (1 site), unionized ammonia (1 site), pH (3 sites), and dissolved oxygen (8 sites). Comparisons to ground water were performed to provide additional insight to the water quality because the source of irrigation water which flowed into the ponds was groundwater. Comparison with groundwater standards indicates that violations were noted for iron (6 sites), manganese (7 sites), total dissolved solids (7 sites), sulfates (5 sites), and pH (4 sites). Although violations of both surface water and groundwater standards were detected, the violations were infrequent. Some of the exceedences were related to the summer rainy season and farming schedules which may have elevated certain water quality parameters. Comparisons of agricultural survey data with data from untreated agricultural runoff reported in the literature indicate lower values from the agricultural survey sites in almost all parameters (includes various forms of nitrogen and phosphorous, pH, dissolved oxygen, total suspended solids, and turbidity). Comparisons of agricultural survey data with data from treated agricultural discharges reported in the literature, indicate similar water quality values for all parameters (includes various forms of nitrogen and phosphorous, pH, dissolved oxygen, total suspended solids, and turbidity). In some cases, the values from the agricultural survey were actually lower. High correlations between hardness, conductivity, total dissolved solids and various ion species such as calcium, magnesium, and sulfate confirmed expected relationships between the variables. Unexplained correlations (includes negative correlations) were noted between phosphorous and major ions (rs value range of -0.77 to -0.61), and also copper and zinc to various major ions (rs value range of -0.50 to -0.39). Ponds in this study discharged almost constantly, especially in filtration systems. Designs of detention ponds should be reviewed to maximize treatment ability by increasing retention time and other design criteria. In agricultural systems, organochlorine and organophosphorous pesticides are used to control insects and other pests. Pesticides can be introduced into the water column, and have adverse effects on the reproductive and neurological systems of the biological community in the aquatic systems. Pesticides and other anthropogenic compounds should be addressed in characterizing water quality from agricultural sites.

Reference:

Bahk, B., and Kehoe, M., 1997, A Survey of Outflow Water Quality from Detention Ponds in Agriculture, Southwest Florida Water Management District, 42 pages.

3.1.7 Outfall Water Quality from Wet-Detention Systems

Summary: This survey study was conducted to statistically compare samples collected before and after discharge over the outfall structure. This was done to validate the feasibility of collecting samples before discharge for compliance monitoring. Additionally, the outfall effluent from permitted wet-detention systems were compared to State water quality standards. This study compared the effluent water quality of two types of permitted stormwater systems: constructed wet-detention ponds and natural wetlands. A survey of permitted wet detention ponds was conducted between June 1992 and April 1993. Twenty-two systems in the Tampa Bay area were sampled; nine were natural wetlands and thirteen were constructed ponds. Data collection took place during fourteen sampling events. Samples were collected during system discharge from two locations: 1) in the system just before the outflow weir (***b*** side) and 2) after the outflow weir (***a*** side) but before it entered the receiving water. The ***a*** side is also referred to as the wet detention system effluent. Water quality sampling included eight metal species, six nutrient species, turbidity, total suspended solids, temperature, dissolved oxygen, pH and conductivity. Study goals were to: 1) compare the water quality in front of the outfall weir to that of its effluent, 2) determine whether the effluent complied with class III Florida

State Water Quality Standards and 3) compare the effluent from constructed and natural systems for standard compliance. Additional analyses were conducted to determine relationships between constituents. Unionized ammonia, iron, manganese (class III Standard) and nickel measured during this study complied with water quality standards 100 percent of the time. Most constituents complied >79 percent of the time except dissolved oxygen (in noncompliance 64% of the time). In a comparison of the metals in noncompliance between the natural and constructed systems, the natural systems had a higher percent noncompliance than the constructed systems (ranging from two to nine times higher). Despite these differences between system types, every metal complied with water quality standards >65 percent of the time. A comparison of the data from both sides of the weir in each of the data sets revealed that all constituents measured were not significantly different except dissolved oxygen, turbidity, temperature, and pH. Dissolved oxygen was significantly lower on the ***b*** side of the weir than the ***a*** side in each of the three data sets caused by aeration as water flowed over the weir. The pH was significantly higher on the ***a*** side of the weir in the constructed system data set. Turbidity was significantly higher on the ***a*** side of the weir in the natural system data set. The temperature on the ***a*** side of the weir in the natural system was significantly higher. The discharge from constructed systems met State water quality standards more often than discharges from natural wetland systems for copper, lead, zinc, and cadmium. Better compliance with the metal standards observed in the constructed systems may be the result of the generally harder water found in those systems since the standard is hardness dependent. Non-compliance in natural wetlands were: dissolved oxygen (48%), copper (35%), lead (27%). Alkalinity (27%), zinc (18%), and cadmium (9%). When water quality from constructed wetlands was compared to State standards, the discharge water failed to meet standards for some of the metals and other constituents. For constructed wetlands, the following were in non-compliance: dissolved oxygen (70%), copper (12%), lead (12%), and zinc (6%). No statistical differences were found between the water quality on either side of the weir during discharge (except pH and dissolved oxygen). Thus, samples can be collected from the more accessible ***b*** side of the weir (just before the water discharged across the weir located inside the pond). Current requirements dictate that samples be taken from the ***a*** side (after water exits the pond). Methods to increase dissolved oxygen in ponds should be considered. Examples include aeration devices (*i.e.*, fountains) and maintenance of a deeper area devoid of vegetation immediately adjacent to outfall weirs.

Reference:

Carr, D. W., and Kehoe, M.J., 1997, Outfall Water Quality from Wet-Detention Systems, Southwest Florida Water Management District, 36 pages.

3.1.8 Water Quality Efficiency of an Urban Commercial Wet Detention Stormwater Management System at Boynton Beach Mall in south Palm Beach County, Florida

Summary: Urban wet detention system investigations were conducted at a commercial shopping mall in Boynton Beach, Florida. This study site possessed a permitted drainage area of 25.4 ha (62.8 ac), which was approximately 90 percent impervious. The water management area consisted of three interconnected ponds, each approximately 1.2 ha (3 ac), totaling 3.5 ha (8.7 ac). This site was instrumented with automatic water quality samplers to collect storm-generated runoff samples. In addition, digital stage measurement equipment continually monitored and recorded both surface and ground water elevation. The results were collated with previous results in the literature and comparisons indicated superior treatment efficiencies.

References:

Holler, J.D., 1989, Water Quality Efficiency of an Urban Commercial Wet Detention Stormwater Management System at Boynton Beach Mall in south Palm Beach County, FL, Florida Scientist. Orlando Fl, vol.52, no.1, pp.48-57.

3.1.9 Evaluation of Dry Detention/Filtration Stormwater Management System Receiving Runoff from a Mixed Urban Land Use

Summary: The South Florida Water Management District's Resource Planning Department has initiated a series of applied research projects to aid the Resource Control (Regulatory) Department in refining criteria for the permitting of surface water management systems. This project was designed utilizing criteria developed by the Florida Department of Environmental Regulation to compare respective regulatory criteria. Surface runoff from six discrete storm events was sampled at the Lake Tohopekaliga Demonstration site in Kissimmee, Florida. Parameters included turbidity, specific conductance, pH, soluble reactive phosphorus, and total phosphorus. Samples were taken at the critical depth inflow flume, at the infiltration berm, and at the outfall of the underdrains. Because of the use of native soils containing organic material and clay, the infiltration berm became clogged early in the study, preventing drainage of the basin as designed.

Reference:

Dierberg, F.E., Cullum, M.G., 1988, Evaluation of Dry Detention/Filtration Stormwater Management System Receiving Runoff from a Mixed Urban Land Use, 8th Annual International Symposiun on Lake and Watershed Management, p. 29.

3.1.10 Effects of Detention on Water Quality of Two Stormwater Detention Ponds Receiving Highway Surface Runoff in Jacksonville, Florida

Summary: Water and sediment samples were analyzed for major chemical constituents, nutrients, and heavy metals following ten storm events at two stormwater detention ponds that receive highway surface runoff in the Jacksonville, Florida, metropolitan area. The purpose of the sampling program was to detect changes in constituent concentration with time of detention within the pond system. Statistical inference of a relation with total rainfall was found in the initial concentrations of 11 constituents and with antecedent dry period for the initial concentrations of 3 constituents. Based on graphical examination and factor analysis, constituent behavior with time could be grouped into five relatively independent processes for one of the ponds. The processes were (1) interaction with shallow groundwater systems, (2) solubilization of bottom materials, (3) nutrient uptake, (4) seasonal changes in precipitation, and (5) sedimentation. Most of the observed water-quality changes in the ponds were virtually complete within 3 days following the storm event.

Reference:

Hampson, P.S., 1986, Effects of Detention on Water Quality of Two Stormwater Detention Ponds Receiving Highway Surface Runoff in Jacksonville, Florida, USGS Water

Resources Investigations Report 86-4151, 69p, 20 fig, 16 tab, 34 ref, 2 append.

3.1.11 Treatment of Stormwater Runoff from an Agricultural Basin by a Wet-Detention Pond in Cockroach Bay, Florida (Phase I)

Summary: Agriculture has been identified as a significant source of water pollution in the United States. The use of agricultural fertilizers and pesticides doubled from the mid 1960s to the early 1980s and may be responsible for a major portion of surface and ground water contamination. The effects of agricultural pollution are numerous and include: sediment contamination and deposition with subsequent impairment of aquatic habitat, pesticide contamination, eutrophication of surface waters, and general water quality degradation of downstream water bodies. The Environmental Protection Agency (EPA) ranks agricultural activity as the greatest threat to water quality in streams and lakes. The EPA also notes that nutrient and silt runoff are the leading causes of water quality impairment. Given the water quality problems associated with agriculture, the Southwest Florida Water Management District initiated a study on the effectiveness of a wet-detention pond to treat stormwater runoff from an agricultural basin. The Cockroach Bay Restoration Project in Ruskin, Florida is an effort to reclaim over 650 acres of natural habitat in a landscape historically used for row crop agriculture. As a part of the larger reclamation landscape, two wet-detention ponds in series receive stormwater runoff from 210 acres of active row crop farmland. The monitoring of the Cockroach Bay Stormwater Project included flow-weighted sampling of inflow and outflow to the detention ponds, as well as collection of rainwater for chemical analysis. The main goal of this project is to assess the treatment

efficiency of the wet-detention ponds. The primary constituents monitored include nutrients, metals, ions, pesticides, and bacteria. Additionally, continual measurements of pond water level, temperature, pH, dissolved oxygen and conductivity are recorded in data loggers. Other monitoring efforts include bi-weekly measurements of depth to groundwater around the ponds, quarterly ambient grab samples in the pre-treatment ditch, water quality in groundwater wells and yearly samples of the sediments. A complete water budget estimated for storm events showed most (>70%) of the water enters and leaves the pond at the two control structures. In addition, about 25 percent of all the storm input to the ponds is introduced by rainfall directly on the pond. Additional water export from the pond for the duration of storm events was estimated at 8 percent by evapo-transpiration; and 15 percent by net seepage. The large pervious area in the drainage basin as well as the pre-treatment ditch and sandy soils contributed to low runoff coefficients. During the rainy season when ample moisture was available the estimated runoff coefficient showed that 10 to 30 percent of rainfall was discharged from the drainage basin into the pond. During dry periods only 1 to 10 percent of rainfall ran off. In general, inorganic nitrogen (ammonia and nitrate) have their highest concentrations in rainfall, but even with this atmospheric input, nitrate had the greatest percent reduction of all constituents measured (greater than 90% in 1999 and 2000). In contrast, organic nitrogen often increases between the inflow and outflow, probably as a result of nitrogen transformations taking place. Phosphorus is measured at relatively high levels at the inflow to the pond with average concentrations of total phosphorus near 1 mg/L. Although average concentrations at the outflow for phosphorus are reduced by about 40 percent, the concentrations still exceed by a factor of 5 to 8 the suggested EPA goal for streams and rivers of 0.1 mg/L. During the three years of study (70 rain events), over 65 percent of all the pollutant loads for potentially toxic metals entered the pond during five El Nino storms. Larger loads are more easily reduced in wet-detention ponds and the goal of 80 percent reduction is met for most metals in 1998 and 2000 and nearly so for inorganic nitrogen. Percent reduction was poorer in 1999, a drought year. Ten pesticides or degradation compounds (chlordane, chlorothalonil, DDE-p,p, endosulfan, endosulfan II, diazinon, malathion, metalazyl, metribuzin and endosulfan sulfate) were detected in stormwater runoff at the inflow of the detention pond. At the outflow, only four pesticide degradation compound, the endosulfan series, were detected. Based on the number of pesticides detected at the inflow vs. outflow, the detention pond seems to function as a sink for pesticides. Chlorophyll was measured monthly at the inflow and outflow of the pond and except during periods of stagnant conditions the ponds reduced all species of Chlorophyll by a significant amount (Chlor a at the inflow 37.6 ug/L and at the outflow 8.25 ug/L). Sediment samples for metals and phosphorus increased dramatically from 1997 to 1998. Phosphorus concentrations were highest in the most overgrown part of the pre-treatment ditch and in the center of the two ponds. The highest concentrations of metals occurred in the marsh after water leaves the pond. These elevated levels can by explained by estaurine mixing at the fresh water/salt water interface. Ground water levels were measured in 12 shallow wells surrounding the pond and show a close interaction with pond levels. The water table gradient is toward the pond and eventually the outflow marsh. When pond levels are high the gradient is out of the pond and when pond levels are low the surrounding water table to the north seeps into the pond. The wet-detention pond was effective for reducing most pollutant loads by at least 60 percent, and often, over 80 percent especially in 1998 and 2000 which had higher concentrations of pollutants entering the pond. The differences in efficiency of the pond to reduce pollutants during different years demonstrates the need for more long term studies, especially those that investigate processes going on in the pond. Maintenance guidelines need to be developed for wet-detention ponds especially since maintaining ponds may help reduce total suspended solids and organic nitrogen, which sometimes increased from the inflow to the outflow in these ponds. More data are needed to determine treatment efficiency as ponds age. This study suggests that recently constructed ponds are much better at some forms of pollution removal.

Reference:

Rushton, B. T., 2001, Treatment of Stormwater Runoff from an Agricultural Basin by a Wet-Detention Pond in Ruskin, Florida, DEP Contract Number WM 539, Southwest Florida Water Management District.

3.1.12 Treatment of Stormwater Runoff from an Agricultural Basin by a Wet-Detention Pond in Cockroach Bay, Florida (Phase 2)

Summary: The project will provide data for an additional year to enhance the information collected from an existing three year project (see Cockroach Bay phase I). The wet detention pond is part of a watershed project designed to control non-point source pollution to a priority water body that has an impaired or protected use. Tampa Bay has been designated as the number one priority water body in the Southwest Florida region by SWIM. Field investigation involving treatment for agricultural runoff from row crops is limited. This project will provide insight into methods to support district (WMD), state (DEP) and federal (EPA) stormwater runoff guidelines and will add to the statewide stormwater data base documenting the efficiency of wet detention ponds. The study provides an additional year of hydrology and stormwater data covering all seasons. The data will be used to calculate loading rates and will more thoroughly document the efficiency of the wet detention pond in reducing agricultural pollutants. Samples from a network of wells will indicate possible groundwater pollution from agricultural practices and an adjacent wastewater package treatment plant. Sediment samples in the pre-treatment ditch, the pond and the receiving marsh will indicate pollutant build-up and indicate maintenance requirements.

Reference: On-going

3.1.13 EMS Stormwater Enhancement Project, Pinellas County, Florida

Summary: The original stormwater facility was constructed in accordance with regulations in 1990 to provide stormwater treatment and peak attenuation for the county's new Emergency Medical Services (EMS) complex. The facility discharges indirectly into Boca Ciega Bay. The pond was designed to capture stormwater and treat, using a sand filter encased in a concrete vault, the first half-inch of runoff from the entire site. The facility was constructed with 4:1 side slopes, 2 foot average water depth, and a 0.4 foot treatment prism for capturing and filtering runoff. Prior to the enhancements, a monoculture of primrose willow dominated the entire perimeter of the pond. The primary objective of this project was to demonstrate how stormwater ponds can be designed to enhance their aesthetic and wildlife habitat values while at the same time meeting their intended water quality treatment and/or flood control purposes. The secondary objective was to actually improve the treatment effectiveness of the existing pond by expanding and planting the pond's littoral zone, increasing the treatment volume between the control elevation and overflow weir, and increasing the permanent pool volume, thereby increasing the residence time in the pond. By more than doubling the permanent pool volume of the pond, the pond's residence time was substantially increased. The pond's treatment volume also was increased by 13.4%, from 0.50 inches of runoff to 0.57 inches. The increased residence time allows for longer periods of physical settling as well as biological activity. The reshaping and replanting of the littoral shelf resulted in increased nutrient uptake.

Reference:

Bateman, M., Livingston, E.H., Cox, J., 1998, Overview of Urban Retrofit Opportunities in Florida, in National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments Proceedings Chicago, IL, February 9-12, 1998, p. 166.

3.1.14 Pinellas Park Detention Pond, Pinellas Park, Florida

Summary: A multipurpose wet stormwater-detention pond was studied to determine its effectiveness in reducing the load of selected water-quality constituents commonly found in urban streamflow. This paper studies the loading of 19 chemical and physical constituents during six storm events. Because all stormwater entering the detention pond was not measured at the inflow site, computed stormwater inflow loads were adjusted to account for loads from the unmonitored areas. Stormwater loads of the major ions (chloride, calcium and bicarbonate) and dissolved solids at the outflow site exceeded loads at the inflow site, partly as a result of mixing with base flow stored within the pond. However, the detention pond was effective in reducing the stormwater load of metals (25% to >60%), nutrients (2% to 52%), suspended solids (7% to 11%), and biochemical and chemical oxygen demand (16% to 49%). The author attributes the reductions in base-flow loads to adsorption, chemical precipitation, biologic uptake, and settling within the detention pond. These processes were more effective in reducing base-flow loads after the establishment of aquatic vegetation in the pond.

Reference: International Stormwater BMP Database Basic Database

3.1.15 Duvall County Pond 1, Jacksonville Florida

Summary: Water and sediment samples were analyzed for major chemical constituents, nutrients, and heavy metals following 10 storm events at 2 stormwater detention ponds that receive highway surface runoff. The purpose of the sampling program was to detect changes in constituent concentration with time of detention within the pond system. Pond 1 is in the infield of the intersection of two major highways, U.S. Highway 1 and Interstate 95. Inflow is routed to the pond by three drainage culverts (55%) and by overland flow (45%). Constituent behavior could be grouped into five relatively independent processes for Pond 1: (1) interaction with shallow groundwater system, (2) solubilization of bottom materials, (3) nutrient uptake, (4) seasonal changes in precipitation, and (5) sedimentation. Most of the observed water-quality changes in the ponds were virtually complete within 3 days following the storm event. This study was hampered by problems with one of its ponds (Pond 2), as well drought conditions during the study period, which limited the number of storms suitable for sampling. The study report provides some useful data, but lacks suitable QA/QC discussion, and does not provide flow measurements. There was going to be a second detention pond in the study (Pond 2), which drains a 6 acre shopping center parking lot. However, the pumping system at the site malfunctioned early in the study, and was not promptly repaired. As a result, only limited data was collected, and no conclusions could be made.

Reference: International Stormwater BMP Database Basic Database

3.1.16 Performance Evaluation of Dry Detention Stormwater Management Systems

Summary: Field and laboratory investigations were conducted from August 1997 to March 1998 at a project site in DeBary, Florida to evaluate the hydraulic and water quality characteristics of a dry detention pond system constructed with a perforated pipe vertical filter system as an outlet control structure and anti-clogging device. The *dry* detention pond was constructed in 1996 to provide stormwater treatment for a 9.66 ha (23.86 ac) single-family residential watershed. Field instrumentation was installed at the dry detention pond site to conduct a complete hydrologic budget for the pond, including water level recorder, rainfall recorder, Class A pan evaporimeter, and groundwater piezometers. Automatic sequential samplers with integral flow meters were installed to provide continuous records of inflow and outflow from the pond and to collect stormwater and outflow samples on a flow-weighted basis. On a mass basis, the *dry* detention pond was extremely effective in retaining mass inputs for all measured parameters. Overall mass removal for total nitrogen within the system was approximately 86%, with 84% removal of total phosphorus, 99% removal of TSS, 82% removal of BOD, and 88-96% removal for heavy metals. However, the magnitude of the mass removal efficiencies are due to the fact that more than 70% of the inputs into the pond were lost as a result of groundwater seepage through the pond bottom. On a concentration basis, the water column of the dry detention pond was capable of providing removal efficiencies of 30-90% for all input parameters with the exception of dissolved organic nitrogen, particulate nitrogen, total nitrogen, and BOD. Migration through the filter system provided little additional removal for most parameters. The filter underdrain system was observed to exhibit highly variable hydraulic characteristics and was prone to clogging after only a few weeks of operation. Routine backwashing was necessary to maintain the filter system in an operational manner. In the absence of the substantial losses observed as a result of groundwater seepage from the pond, it appears that the filter underdrain system would be incapable of maintaining the pond in a near-dry condition.

Reference:

Harper, H.H., Herr, J.L., Baker, D., Livingston, E.H., 1999, Performance Evaluation of Dry Detention Stormwater Management Systems, Proceedings of the Sixth Biennial Stormwater Research and Watershed Management Conference, September 14-17, 1999, p. 162-178.

3.1.17 Stormwater Retrofit of the Abandoned Jan-Phyl Wastewater Treatment Plant Site

Summary: The Jan Phyl Stormwater project was completed in January 1998 to retrofit the abandoned wastewater treatment plant site to provide treatment of stormwater runoff through nutrient and sediment removal. The project also created storage volume to reduce localized flooding for a 90 acre portion of the watershed of the Winter Haven Chain of Lakes which is a SWIM Waterbody. Of the seven acre total project area, four acres were utilized for stormwater treatment. The existing wastewater percolation ponds were retrofitted as wet detention ponds to provide stormwater treatment of the runoff from the first 1.25 inches of rainfall, Sediment excavated from the existing percolation ponds was tested for Fecal Coliform, nutrients and Toxic Contaminant Leaching Potential (TCLP) to verify the material met the criteria established under Chapter 17-640 of the Florida Administrative Code (FAC) for the disposal of waste water residuals. It was originally estimated that nine tons of Total Nitrogen and six and one-half tons of Total Phosphorus was removed with the sediment from this site and disposed of in accordance with FDEP approval. Over 25,000 aquatic plants were placed in the littoral zone. The remaining three acres of property have been sodded to allow for passive recreation and to educate visitors through the use of signs depicting native fish, water fowl and aquatic vegetation. Water quality monitoring is being performed to determine the pollutant load reductions achieved at this facility.

Reference:

Kollinger, R.J., 1999, Stormwater Retrofit of the Abandoned Jan-Phyl Wastewater Treatment Plant Site, Proceedings of the Sixth Biennial Stormwater Research and Watershed

Management Conference, September 14-17, 1999, p. 238-247.

3.1.18 Water Quality Assessment of Permitted Stormwater Management Systems

Summary: Preliminary results of a water quality study, performed as part of the St. Johns River Water Management District's, on-going strategy to evaluate the effectiveness of the stormwater rule, found discharges from stormwater treatment facilities to cause violations of Florida's water quality standards for copper, dissolved oxygen, total suspended solids, and zinc. Permitted wet treatment facilities with varying design criteria that serve different land uses are sampled on a monthly basis for variables associated with stormwater runoff. Samples are collected at the treatment facility outfall (discharge), and downstream (affected) and upstream (unaffected) in the receiving waters. Comparison of data to applicable State water quality standards found copper to exhibit the highest percentage of violations followed by dissolved oxygen, total suspended solids, and zinc. Levels of arsenic, cadmium, chromium., iron, and nickel did not violate state standards. Additional data is being collected to allow for future correlations between the water quality data, fertilization and best management practices, and treatment facility design criteria.

Reference:

Nepshinsky, J., Dewey, C., Victor, P., and Brown R., 1995, Water Quality Assessment of Permitted Stormwater Management Systems, St. Johns River Water Management District, 12 p.

3.1.19 Effectiveness of a Stormwater Collection and Detention System for Reducing Constituent Loads from Bridge Runoff in Pinellas County, Florida

<u>Summary</u>: The quantity and quality of stormwater runoff from the Bayside Bridge were evaluated to determine the effectiveness of the stormwater collection and detention pond system of the bridge in reducing constituent loads to Old Tampa Bay. Water quality samples of stormwater runoff from the bridge, and outflow from the detention pond, were collected during and after selected storms. These samples were used to compute loads for selected constituents. Stormwater on the Bayside Bridge drained rapidly during rain events. The volume of stormwater runoff from 24 storms measured during the study ranged from 4,086 to 103,705 cubic feet. Storms were most frequent during July through September and were least frequent from February through May. Concentrations of most constituents in stormwater runoff before the bridge opened to traffic were less than or equal to concentrations measured after the bridge was opened to traffic. However, concentrations of arsenic in the outflow from the detention pond generally were greater before the bridge opened than concentrations after, and concentrations of orthophosphorus in the stormwater runoff and outflow from the pond were greater before the bridge opened than during over half the sampled storms after the bridge opened. Concentrations of most constituents measured in stormwater runoff from the bridge were greatest at the beginning of the storm and decreased as the storm continued. Variations in suspended solids, nutrients, and trace element concentrations were not always concurrent with each other. The source of the measured constituent (rainfall or road debris) and the phase of the constituent (suspended or dissolved) probably affected the timing of concentration changes. The quality of stormwater runoff from the Bayside Bridge varied with total runoff volume,

with the length of the dry period before the storm, and with season. Average concentrations of suspended solids, ammonia plus organic nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, phosphorus, total organic carbon, aluminum, arsenic, copper, and zinc in stormwater runoff generally were inversely related to runoff volume. The quality of outflow from the detention pond also varied during a storm event and with season. Maximum concentrations generally occurred near the beginning of a storm, and decreased as the storm continued. Maximum concentrations of many constituents occurred in June and July 1995. During the summer months, pH exceeded 9.0 while inorganic nitrogen concentrations were very low. These high pH values and low inorganic nitrogen concentrations are most likely associated with photosynthesis by algae or aquatic plants in the pond. Concentrations of nitrogen, phosphorus, and nickel in stormwater runoff were correlated with total organic carbon concentrations. Concentrations of chromium, copper, iron, nickel, lead, and zinc in stormwater runoff were correlated with aluminum concentrations. The source of these metals is probably the bridge materials and metallic debris from vehicles. The northern detention pond system of the Bayside Bridge effectively reduced concentrations of suspended solids, ammonia nitrogen, nitrite plus nitrate nitrogen, phosphorus, aluminum, cadmium, chromium, copper, iron, lead, nickel, and zinc in stormwater runoff before water discharged from the pond. However, concentrations of ammonia plus organic nitrogen, organic carbon, arsenic, and values for alkalinity, pH, and specific conductance generally were greater in outflow from the pond than in stormwater runoff from the bridge. Stormwater runoff and pond outflow for three storm events were evaluated to determine the effective ness of the detention pond system in removing selected constituents from the stormwater runoff. Most constituents and constituent loads were reduced in the outflow from the pond. Suspended solids loads were reduced about 30 to 45 percent, inorganic nitrogen loads were reduced by about 60 to 90 percent, and loads of most trace elements were reduced by about 40 to 99 percent. However, the pond exports ammonia plus organic nitrogen, organic carbon, arsenic, and phosphorus. The source of most of these constituents probably is biological activity in the pond. The export of arsenic and the elevated concentrations of arsenic in the pond outflow before the bridge opened implies that arsenic is stored in the pond sediments and is being released to the overlying pond water. Schiffer (1989) studied the water quality of two wetlands that receive stormwater and reported that water quality improved significantly from the inlet to the outlet of the pond and wetland system. Rushton and Dye (1993) reported that removal rates of selected nutrients and metals in a wet detention pond were between 30 to 60 percent. Kantrowitz and Woodham (I 995) reported that a wet detention pond in Pinellas County was effective in removing selected metals, nutrients, suspended solids, and in reducing oxygen demand.

Reference:

Stoker, Y.E., 1996, Effectiveness of a Stormwater Collection and Detention System for Reducing Constituent Loads from Bridge Runoff in Pinellas County, Florida, U.S. Geological Survey, Open- File Report 96-484.

3.1.20 Pollutant Removal Efficiencies for Typical Stormwater Systems in Florida

Summary: A literature review was conducted of previous research performed within the State of Florida which quantifies pollutant removal efficiencies associated with various stormwater management systems. Comparative removal efficiencies were obtained and summarized for dry retention, wet retention, off-line retention/detention systems, wet detention, wet detention with filtration, dry detention with filtration, and dry detention. Estimated pollutant removal efficiencies were generally available for total nitrogen, orthophosphorus, total phosphorus, TSS, BOD, copper, lead and zinc. Of the stormwater management systems evaluated, only dry retention systems are capable of meeting the State Water Policy Goal of 80% reduction for pollutant inputs. Off-line retention/detention facilities are capable of meeting the 80% reduction goal for total phosphorus, TSS, BOD and zinc, but provide only a 60-75 % annual pollutant reduction for total nitrogen, copper and lead. Wet retention systems can meet the 80% reduction goal for TSS only, with removal efficiencies from 40-50% for total nitrogen, total phosphorus and BOD. Good pollutant removal efficiencies are achieved in wet detention systems for orthophosphorus, total phosphorus, TSS, BOD and heavy metals, although removal efficiencies are less than 80%. Dry detention with filtration systems were found to exhibit a high degree of variability in estimated removal efficiencies. The actual removal efficiencies achieved by these systems is a function of the relationship between the underdrain system and the seasonal high groundwater table. Overall, the most effective stormwater management systems in terms of retaining stormwater pollutants appear to be dry retention, off-line retention/detention ponds, wet retention, and wet detention systems. The use of these systems should be emphasized to maximize the pollutant removal effectiveness of stormwater management programs.

Reference:

Harper, H.H., Pollutant Removal Efficiencies for Typical Stormwater Systems in Florida, Environmental Research & Design, Inc., 3419 Trentwood Blvd., Suite 102, Orlando, Florida 32812-4863, 11 p.

3.2 Wetland Systems

3.2.1 Hydromentia, Inc. S154 Basin Aquatic Plant Based Water Treatment System Prototype

Summary: As one of the thirteen state-funded projects under the Phosphorus Source Control Grant Program, the S-154 Aquatic Plant Based Water Treatment (APBWT) System Prototype is a small scale pilot facility designed to demonstrate the applicability of managed biological treatments for nutrient removal. Operated by Hydromentia, Inc. (HMI), this prototype reduces phosphorus through a two stage treatment process. The first stage consists of water hyacinths, while the second stage consists of algal turf scrubbers. By managing and harvesting the unit processes, the system is being evaluated for maximizing P reduction and estimating scale up costs, while formulating a strategy for the marketability of a useable end product. The prototype has averaged an approximate P concentration reduction of 83% over the first nine months of operations.

Reference:
http://www.sfwmd.gov/org/wrp/wrp_okee/projects/PsourceControlLinks/WebPage/Hydromentia.html

3.2.2 Integrating a Herbaceous Wetland into Stormwater Management

Summary: The large number of natural wetlands and the rapid population growth in Florida make using existing isolated wetlands an attractive alternative for stormwater treatment. Uncertainty exists, however, in their ability to absorb the increased peak volumes and higher levels of pollutants found in urban runoff. This study evaluated the effectiveness of a marsh to treat stormwater, compared water quality results to State water quality standards and documented the effects of urban runoff on marsh vegetation and sediments. This project incorporated an existing isolated wetland as part of a stormwater system at an office complex. The wetland was a 3 acre herbaceous marsh which had historically received most of its hydrologic input directly from rainfall and a small amount of runoff from surrounding native pine forests; therefore, it was characterized by low levels of nutrients, dissolved oxygen, pH and conductivity. After development, it also received hydrologic input from urban runoff (15.3 acres in an office park), which had received some pre-treatment from sedimentation basins. The 0.175 acre east sedimentation basin received its runoff from a central roadway and the 0.012 acre west basin collected runoff from a parking lot and a portion of an office building before discharging into the marsh. To study the effect of stormwater on the marsh, automatic data recording stations were installed to measure water quality and quantity as it was discharged from the sedimentation basins and again as it was discharged from the marsh. A rainfall station measured these parameters for rain. Analysis of 81 storm events during the 30 month study provided extensive water quality and hydrologic data. Removal efficiencies (i.e. the sum of pollutant load from rainfall and surface water inputs compared to

pollutant loads at the outflow) indicate the marsh effectively reduced the following: cadmium by 92 percent, inorganic nitrogen, suspended solids and zinc by at least 85 percent, and copper and phosphorus by at least 71 percent. Removal efficiencies were good because only 27 percent of the water measured coming into the marsh was discharged, the rest was lost by evapotranspiration and infiltration. Marshes can be effective at removing stormwater pollutants, but changes in the physical and chemical properties of the marsh will occur. The sedimentation basins had significantly higher levels of pH, dissolved oxygen, oxidation reduction potential and conductivity than was measured in the marsh but higher levels of these parameters were starting to be measured in the marsh by the end of the study. Event mean concentrations measured at the outflow exceeded State standards in effect after 1992 by the following percentages: Lead 62%, zinc 23%, copper 44%, and cadmium 2%. One reason for the high noncompliance were the result of the soft water that is typical of many natural wetlands. Soft water makes metals more toxic to organisms, therefore, the standard is hardness dependent and wetlands that receive much of their input from rainfall exceed standards more often for equal concentrations of metals. Rainfall was found to be a source of inorganic nitrogen and zinc to the marsh. Total annual rainfall on the marsh represented 45 percent of the annual hydrologic input which approximately equaled the evapotranspiration loss of 41 percent. Surface water inflow accounted for 55 percent of total input and 27 percent of output, while net seepage accounted for 31 percent of the outflow from the marsh. Dominant plant species with the highest percent cover in the marsh were maidencane, pickerelweed, water-lily and arrowhead. Detailed vegetation analyses and historical aerial photographs documented an increase in nuisance plant species such as primrose willow and cattail which first appeared in areas where the wetland margins had been altered with steeper slopes. Subsequently the nuisance species invaded the marsh itself. Soil cores indicate the marsh and sedimentation basins have mineral soils and all concentrations of pesticides, organic priority pollutants, and PCB were below detectable levels. The soils in the west basin contained toxic levels of zinc, probably from roof runoff, and the zinc was increased at the inflow station in the marsh. Correlation analysis showed that phosphorous concentrations increased during extended periods between rainfall events. Other relationships indicate that as total suspended solids increase so do iron, lead, copper, and ammonia. A large wetland to drainage basin ratio should be encouraged. Significant mass pollutant removal occurred in the marsh because only 27 percent of the hydrologic input to the marsh was actually discharged at the outflow. A large wetland to watershed ratio will also protect against detrimental changes in hydroperiod. To maintain the existing integrity of the marsh and avoid the adverse impact of invasive plant species, emphasis should be placed on maintaining an undisturbed upland buffer zone around the wetland. Inspections and maintenance should be required to minimize the impact of non-native and invasive plant species in areas within and adjacent to natural wetlands and invasive species removed. Toxic zinc levels in the sediments of the west basin suggests the need for an operation and maintenance guideline for the periodic removal of accumulated pollutants from pretreatment ponds. The problem of pollutants in atmospheric deposition needs to be addressed by source reduction. The low pH, conductivity and dissolved oxygen typical of many natural wetlands reduces their effectiveness for removing metals and phosphorus.

Reference:

Carr, D.W., and Rushton, B.T., 1995, Integrating a Native Herbaceous Wetland into Stormwater Management, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609, 131 pages.

3.2.3 Effectiveness of an Urban Runoff Detention Pond - Wetlands System

Summary: The effectiveness of a detention pond and wetlands in series in reducing constituent loads carried in runoff was determined. The detention pond was effective in reducing loads of suspended solids and suspended metals. Suspended phase efficiencies for solids, lead, and zinc ranged between 42 and 66%. Nutrient efficiencies were variable, ranging for all species and phases from less than 0 to 72%. The wetlands generally were effective in reducing both suspended and dissolved loads of solids and metals. Total (dissolved + suspended) solids, lead, and zinc efficiencies ranged between 41 and 73%. Efficiencies for total nitrogen and phosphorus were 21 and 17%. The system, by combining the treatment of the pond and wetlands, was very effective in reducing loads of most constituents. Total solids, lead, and zinc efficiencies ranged between 55 and 83%. Total nitrogen and phosphorus efficiencies were 36 and 43%. The Stormwater Detention Facility, comprising part of the Orlando, Florida, urban drainage system, is composed of a detention pond and wetlands in series. The efficacy of the detention system in reducing constituent loads carried in runoff was evaluated. Measurements show the pond was effective in reducing loads of suspended solids and metals. Suspended-phase efficiencies for solids, lead, and zinc were in the 42-66% range. Nutrient efficiencies were variable, ranging for all species and phases from less than 0 to 72%. The wetlands generally were effective in reducing both suspended and dissolved loads of solids and metals.

Reference:

Martin, E. H., 1988, Effectiveness of an Urban Runoff Detention Pond - Wetlands System, Journal of Environmental Engineering (ASCE) JOEDDU, Vol. 114, No. 4, p 810-827, August 1988, 4 fig, 5 tab, 11 ref.

3.2.4 Management of Stormwater Runoff for Water Quality Using an Isolated Natural Wetland

Summary: The management of stormwater runoff water quality will become increasingly important into the 21st century as more natural lands succumb to development. Wetlands are a valuable resource for they are natural water quality filters and enhance groundwater recharge. Utilizing certain natural wetlands for stormwater treatment was approved by the Florida legislature in 1984 (Chapter 17-25, Florida Statutes). Despite legislative approval, the ability of natural wetlands to treat stormwater as well as the extent to which the wetlands themselves are effected have been questioned. Two objectives of the study were: 1) to assess the effectiveness of a natural wetland to treat stormwater runoff and 2) to document the effect of stormwater treatment on wetland vegetation. Flow-weighted water quality samples were taken at each inflow and outflow as well as rainfall and pollutant load removal efficiencies were calculated. Two detailed vegetation analyses were conducted during the study and results were reported as percent cover. During the two and one-half year study, eighty three storm events were sampled for water quality. Dry season pollutant removal was better than the wet season. Pollutant removal during the 1992/1993 period (wet & dry seasons) was better than 1991/1992. Negative Fe (-15%) and Mn (-44%) mean removal efficiencies were detected during the wet seasons. Negative TKN (-5%), TON (-12%) and Fe (-8%) mean removal efficiencies were detected during the 1991/1992 period. A total of 34 and 40 plant species were observed during the 1992 and 1993 detailed vegetation analyses, respectively. Dominant species (including cover types) were Panicum hemitomon, open water, Pontederia cordata, litter and Nymphaea odorata. Physical alteration to the south edge of the wetland and construction of a sediment basin facilitated establishment of Typha latifolia, Typha domingensis, Ludwigia peruviana and Mikania scandens (nuisance plant species). None of these nuisance species were observed at the natural north edge.

Reference:

Carr, D.W., 1994, Management of stormwater runoff for water quality using an isolated natural wetland, Lake Reserv. Manage., vol. 9, no. 2, p. 63, 1994.

3.2.5 Overview of the Lake Jackson Restoration Project with Artificially Created Wetlands for Treatment of Urban Runoff

Summary: The Northwest Florida Water Management District engaged in a federally funded Clean Lakes Restoration Project for Lake Jackson in Tallahassee, Florida, during the late seventies. Construction on this experimental $2.6 million stormwater treatment facility was begun in 1981 with completion in 1983. The design employed a three step process to remove sediment and nutrients from urban runoff prior to entering the lake. The first two steps entail the detention of the stormwater in a 20-acre

impoundment followed by passage through a four-acre filter with an underdrain collection system. The final step consists of the partially treated stormwater flowing to a nine-acre artificial marsh for further sediment removal and nutrient assimilation. The entire process has been monitored to determine the effectiveness of the various steps within the project. A recent report concludes that while the stormwater facility works well (>90% removal of solids by the filter/60-65% removal of nutrients by the marsh) there remain operational deficiencies. One of the major deficiencies cited was the exceedance of the total volume of the impoundment by more than half of the large storms monitored. These larger storms also bypass treatment by the created wetlands in the artificial marsh. Several proposed projects address this concern and would implement measures to help alleviate the current burden on the facility.

Reference:

Esry, D.H., and Cairns, D.J., 1989, Overview of the Lake Jackson Restoration Project with Artificially Created Wetlands for Treatment of Urban Runoff, p. 247-257, in: D.W. Fisk (ed.), Wetlands, Concerns and Successes. Proceedings, American Water Resources Association Symposium in Tampa, Florida, Sept. 17-22, 1989.

3.2.6 Fate of Phosphorus from Residential Stormwater Runoff in a Southern Hardwood Wetland

Summary: The movement and fate of phosphorus inputs from residential stormwater runoff were investigated in a 1.0 hectare hardwood wetland near Sanford, Florida. This wetland receives stormwater runoff from a large residential community through a small shallow canal and provides treatment prior to discharge to Hidden Lake. Field investigations were begun in 1984 and were divided into the following tasks: (1) assessment of the quantity of nutrients and heavy metals entering the wetland by way of stormwater runoff, (2) measurement of the attenuation of these pollutants during travel through the wetland, (3) monitoring of the concentrations of nutrients and heavy metals in groundwaters, (4) accumulation of nutrients and heavy metals in the sediments of the wetland, (5) examination of the typical chemical associations binding nutrients and heavy metals to the sediments using sequential extraction procedures, and (6) investigation of the importance of redox potential and pH on metal-sediment stability with regard to the release of phosphorus from wetland sediments. After entering the wetland treatment system, stormwater inputs were observed to exhibit general reductions in pH, specific conductivity, dissolved oxygen, ORP and alkalinity with increasing flow distance. Concentrations of both dissolved orthophosphorus and total phosphorus increased during flow through the wetland system and were found to be closely correlated to decreases in pH and ORP. A stagnant control area, removed from runoff influence was found to exhibit elevated concentrations of phosphorus when compared to the flowpath area. Water quality characteristics in groundwaters beneath the flowpath were very similar to surface water characteristics, with dissolved oxygen and ORP levels decreasing with depth, whereas phosphorus concentrations increased. Groundwaters in the stagnant control area exhibited significantly elevated concentrations of phosphorus, TOC, color, and iron when compared to groundwaters in other locations. Patterns of accumulation and deposition of sediment bound phosphorus along the wetland flowpath were investigated and found to increase substantially from the inlet canal to a distance of 50 m after which they declined slightly throughout the remainder of the wetland flowpath. Also apparent was the attenuation of sediment phosphorus concentrations with increasing sediment depth, with the majority of the phosphorus being retained in the top 10 cm. The removal potential for dissolved orthophosphorus in wetland systems was found to be greatest in flow-through systems with sediment contact based on kinetic rate experiments performed at the study site. The majority of the dissolved orthophosphorus removal, 75 percent was found to occur within the first 24 hours of contact with the wetland sediments after which only slight decreases in concentration occurred. Stagnant systems as well as systems with less sediment contact were not effective in providing attenuation of dissolved orthophosphorus concentrations as well as other water quality parameters.

Reference:

Fries, B.M., 1986, Fate of Phosphorus from Residential Stormwater Runoff in a Southern Hardwood Wetland, Thesis, Master of Science in Engineering, University of Central Florida, Orlando, Florida.

3.2.7 Utilization of a Freshwater Marsh to Treat Rainfall Runoff from Upland Pasturelands

Summary: A freshwater wetland system in Osceola County, Florida is being used to detain and store agricultural and stormwater runoff. In this process, some degree of treatment is provided, thereby improving water quality. Monitoring of meteorological and hydrological conditions at the site indicates that a first flush phenomenon of nutrients from pastureland occurs simultaneous with the beginning of rains. Mean concentrations of nitrogen and phosphorus are lower in effluent leaving the marsh

than in influent. The marsh acted as a sink for some 3980 kg of total nitrogen and 835 kg of total phosphorus during a nine-month study period.

Reference:

Goldstein, A.L., 1982, Utilization of a Freshwater Marsh to Treat Rainfall Runoff From Upland Pasturelands, Presented at Univ. of Florida *et al*, Nonpoint Pollution Control Technology in Florida Symposium, Gainesville, Florida, March 9-10, 1982, page 106-126.

3.2.8 Stormwater Treatment by Natural Systems

Summary: A study was undertaken to evaluate the feasibility of using wetlands to treat sporadic inputs of stormwater runoff using a Florida wetland. The following tasks were undertaken: 1) characterization of rainfall and runoff inputs into the wetland system, 2) monitoring of hydrological quantities in and out of the wetland, 3) characterization of surface and groundwaters along the wetland flow path and in isolated control areas, 4) investigation of the horizontal and vertical migration of nutrients and heavy metals in wetland sediments 5) determination of the chemical speciation of phosphorus and heavy metals in the sediments and the effect on the ability of the sediments to retain pollutants, 6) determination of the influence of pH and redox potential on the chemistry and stability of phosphorus and heavy metals in the sediments 7) examination of the rate of uptake and removal of nutrients and heavy metals during flow through the wetland 8) examination of the physical mechanisms and characteristics that enhance pollutant removal to aid in development of specific design suggestions, and 9) examination of changes in algal productivity due to stormwater flow through bioassay experiments. The report includes a literature review of pollutant removal mechanisms in wetlands, characteristics of urban stormwater drainage, and experiences of wetland treatment of stormwater runoff. The literature review is followed by a site description, experimental methodology, results, and discussion. Among the general results was the finding that nitrate is rapidly removed from the water column under reduced conditions and maximum removal of total nitrogen occurred after 48 hours. Phosphorus uptake is primarily sediment mediated and is optimized at flow rate of one meter per second or less. Phosphorus is rapidly adsorbed by sediments under aerobic conditions, but is released under reduced conditions and pH values of less than 5.5. Flow path sediments clearly retained a large portion of some metals, including nickel, chromium, aluminum, and iron, while lead, cadmium, and copper were not retained to as great a degree. The authors made the following recommendations concerning the use of wetlands for stormwater treatment: 1) wetland systems best suited for modification for use as stormwater management systems are those that already exhibit relatively long hydroperiods, 2) runoff inputs into wetland treatment systems should be attenuated and released slowly into the system to avoid erosion or high flow velocities that reduce opportunities for adsorption, 3) inflow should be spread evenly over the flow path, 4) retention times should not exceed 48 hours to avoid reduction in uptake potential of sediments and release of pollutants back into the water column, and 5) flow velocities should not exceed one meter per second.

<u>Reference</u>:

Harper, H.H., Wanielista, M.P., Fries, B.M., and Baker, D.M., 1986, Stormwater Treatment by Natural Systems, Florida Department of Environmental Regulation, Star Project number 84-026, 331 pages.

3.2.9 Ecology, Hydrology, and Advanced Wastewater Treatment Potential of an Artificial Wetland in North-Central Florida

Summary: Two artificial marsh/pond systems with a combined area of 21 ha were studied during a one-year period. Since their construction in 1978, volunteer plant colonization has resulted in a shifting mosaic of cattails (Typha spp.), water pennywort (Hydrocotlye umbellata), frog's-bit (Limnobium spongia), duckweed (Lemna spp.), and other less abundant species. At least 45 bird species were observed to use the wetlands during this study with very dense populations noted for several wetland-dependent species. Alligators, fish, turtles, and snakes were abundant in the ponds. The ponds operate as flow-through systems, receiving an average treated wastewater application of 4.8 cm per week. Mass balances indicated significant percent removals for biochemical oxygen demand (82%), total suspended solids (80%), and total nitrogen (93%). Removal of total phosphorus was lower, averaging 31% over the one-year study.

Reference:

Knight, R.L., Winchester, B.H., and Higman, J.C., 1985, Ecology, Hydrology, and Advanced Wastewater Treatment Potential of an Artificial Wetland in North-Central Florida, Wetlands 5: 167-180 (Journal of the SWS).

3.2.10 Artificial Wetlands as Nonpoint Source Wastewater Treatment Systems

Summary: The use of a meadow/marsh/pond natural system for the treatment of agricultural runoff from individual farms was assessed. The primary concern was the ability of these small systems to remove nitrogen and phosphorus to the extent necessary to make them cost-effective and energy-conservative eutrophication abatement devices for the Kissimmee agricultural

region in Central Florida. Design parameters were defined for meadow/marsh/pond systems that would be capable of meeting the nitrogen and phosphorus effluent requirements for discharge.

Reference:

Small, M.M., 1978, Artificial Wetlands as Nonpoint Source Wastewater Treatment Systems, In: Environmental Quality Through Wetlands Utilization, Proceedings from a Symposium Sponsored by the Coordinating Council on the Restoration of the Kissimmee River, Feb 28, Tallahassee, Florida.

3.2.11 A Survey of the Water Quality of Wetlands-Treatment Stormwater Ponds

Summary: Wetlands are associated with the transition from upland to aquatic ecosystems and provide many natural amenities to society including flood control, water quality enhancement, and fish and wildlife habitat. Although surface runoff is a natural source of hydrologic inputs to wetlands and surface waters, non-point sources of pollution associated with human activities make stormwater runoff a major source of degradation of surface waters in Florida. This study investigated the ability of natural wetlands to treat stormwater without degrading the wetland while still meeting State water quality standards at the outflow. A water-quality survey of stormwater treatment systems that employed wetlands-treatment with pretreatment and natural wetlands was conducted. The survey provided regional stormwater data, and documented the exceedence (non-compliance) of State water-quality standards at points of discharge from wetlands-treatment systems. Additionally, statistical analysis of relationships among survey variables provided insight about factors that affect water quality in wetlands-treatment systems. Total percent exceedence of water-quality standards at the twelve wetland outfalls focused attention on variables that frequently exceeded standards in the Wetlands-Treatment Survey (and also the Twenty-Four Pond Survey). Wetland treatment systems failed to meet standards while discharging for: dissolved oxygen 70%, cadmium 37%, zinc 27% and copper 2% of the time. The anaerobic characteristics of many wetlands may account for the fact that percent exceedence was much higher for dissolved oxygen and total cadmium in the Wetlands-Treatment survey than the exceedence for these parameters found in the 24 pond survey. In overall paired statistical comparisons, pre-treatment stations had greater average depths, temperature, dissolved oxygen, pH, zinc, and copper than wetland outfalls, suggesting that natural wetlands are generally effective in reducing some constituents. Notable water-quality relationships observed during the survey suggest that an equilibrium between primary production (*i.e.*, photosynthesis), aerobic (microbial) respiration, and temperature are responsible for temporal and spatial dissolved oxygen distribution. Results also suggest that pH-mediated mechanisms and oxidation-reduction potential affect heavy metal concentrations. Numerous factors were probably involved in establishing ambient water quality at the two stations in the survey wetlands-treatment systems. There were indications of water quality variability between wetlands and of seasonal fluctuations in the data, a result that agrees with the variability noted in an earlier study of 24 wet-detention systems. The data suggest that hydrologic conditions may have a significant impact on constituent concentration and the roles of sediments in samples, internal sediment and biogeochemical cycles, plant and algal cycles, and rainfall and runoff sources of metals. There is potential for both positive and negative impacts when using natural wetlands as part of a stormwater treatment system. Stormwater provides the hydrologic input that may be necessary to keep the wetland viable, but the stormwater it receives may change the character of the wetland. For example, pH and dissolved oxygen were measured at much lower concentrations in wetland water than in stormwater in the pre-treatment basin. Natural wetlands may not meet water quality standards as well as constructed wetlands. Dissolved oxygen, for example, was in non-compliance in the discharge water of natural wetlands 75 percent of the time compared to 40 percent, in constructed wetlands. The use of fountains in many constructed ponds likely caused this result. Some metals were also more problematic in natural wetlands. Toxic levels of cadmium exceeded standards in the discharge water 37 percent of the time compared to 10 percent in constructed ponds. For zinc exceedences were about the same (27% for natural vs. 31% in constructed). Other toxic pollutants were more common in constructed wetlands. Copper noncompliances were higher in constructed wetlands (2% for natural and 12% for constructed) probably caused by maintenance practices in constructed ponds. Lead never exceeded standards in natural wetlands but was measured at toxic levels 8 percent of the time in the discharge water of constructed ponds.

Reference:

Kehoe, M.J., Dye, C.W., and Rushton, B.T., 1994, A Survey of the Water-Quality of Wetlands-Treatment Stormwater Ponds, Southwest Florida Water Management District, 42p.

3.3 Filtration Systems

3.3.1 Naturally Selected Biologically Activated Deep-Bed Slow Sand Filtration for the Enhancement of Water Quality Facilitated by Irrigation Quality Utility Facilities

Summary: The objective of this project is to determine the effectiveness of a naturally selected biologically activated deep bed slow sand filtration system for a stormwater treatment reuse system in which the pond water that has visible algal mass and one that has no visible algal mass.

Reference: Ongoing (December 30, 2003 until December 29, 2006), Dr. Marty Wanielista, Stormwater Management Academy University of Central Florida.

3.3.2 Demonstration of the Tampa Filter BMP for the Removal of Nitrogen from Stormwater Runoff

Summary: The objective of this study is to evaluate a new technology for the enhancement of nitrogen removal in stormwater to supplement or enhance other commonly utilized BMPs in Florida. The Tampa Filter is a stormwater treatment filter design that uses natural zeolites (chabazites and cliniptilolotes) as filtration media to enhance nitrogen removal from stormwater. Specific study objectives are defined as follows: 1) evaluate the physical response of the zeolite filter to varying hydraulic conditions, including loss of hydraulic conductivity over continued operation, 2) evaluate the ability of the zeolite filter to remove total nitrogen and nitrogen species, and the removal response to varying applied stormwater flow rates and quality, 3) demonstrate operational methods that support and sustain nitrification and denitrification and optimize nitrogen removals over extended periods of filter operation, and 4) estimate the overall efficiency and design requirements for a full scale Tampa Filter system that will include pre-sedimentation, a zeolite filter unit, and post-treatment with free surface man-made wetlands, littoral treatment, or other denitrification enhancing media.

Reference: Ongoing (January 21, 2004 until January 20, 2006), Hillsborough County Stormwater Program, Berryman and Henigar.

3.3.3 Packed Bed Filter System

Summary: Three square miles of highly developed urban area drains into Clear Lake and ultimately into the Shingle Creek drainage system. Clear Lake is a 360 acre lake in the southwest section of Orlando. It has had significant water quality problems over the past decade. Clear Lake is characterized by high chlorophyll a concentration, low light penetration and high nutrient levels. The Florida trophic state index has ranged between 60 and 75. Based on estimated index has ranged between 60 and 75. Based on estimated pollutant loadings, there was a clear need for a treatment system to effectively remove a high percentage of biological oxygen demand (BOD), suspended solids, total nitrogen and total phosphorus. Since best management practices were not available in this built out environment, an innovative method of stormwater treatment was needed. Therefore, the treatment facility known as the Packed Bed Filter system was constructed. This system is comprised of 10 discrete unit operations designed for contaminate removal. Each bed can be varied for resident time, filter media and wetland plantings to determine the optimal treatment. There is also a recirculation system that allows treatment of Clear Lake water during periods of insufficient stormwater runoff.

Reference:

Howard, R.M., 1994, Packed bed filter system, Lake Reserv. Manage, vol. 9, no. 2, p. 83.

3.3.4 The Demonstration Project and Stormwater Management

Summary: A monitoring project was designed to measure pollutant concentrations as well as the amount of water discharged from an effluent filtration (underdrain) system during storm events. The system was analyzed for water quality discharged from a stormwater pond that ultimately flows into the Tampa Bay estuary in Florida. The volume of stormwater runoff was also measured to estimate a water budget for the system. Also, the water quality and flow discharged through the underground filter system on a daily basis was quantified. The data in this report include nineteen rain events and concluded the first year of the study, which was designed to collect background data before making recommendations and improvements to the systems for phase II of the project.

Reference:

Huneycutt, D., 2002, The Demonstration Project and Stormwater Management, In: Seventh Biennial Stormwater Research & Watershed Management Conference May 22-23, 2002, p. 213-222.

3.4 Vegetation Systems (Biofilters) Systems

3.4.1 Enhanced Erosion and Sediment Control Using Swale Block

Summary: Earthen cross barriers, or swale blocks, can be used to increase retention of stormwater runoff from highways in grass swales to increase retention of solids for reduction of sediment loadings to permanent watercourses. According to this report, at one site in Florida, 3 swale blocks in a long swale in Florida were effective at retaining water and solids.

Reference:

Wanielista, M.P., Yousef, Y.A., et al., 1986, Best Management Practices - Enhanced Erosion and Sediment Control Using Swale Block, Florida Department of Transportation.

3.4.2 Removal of Highway Contaminants by Roadside Swales

Summary: The removal of heavy metals, nitrogen and phosphorus species on a mass basis is directly related to infiltration losses through swales. Therefore, retention of as much water as possible on the swale area will reduce the highway pollutant loadings to receiving waters. Removal efficiency is higher for metals than for nitrogen or phosphorus. Heavy metals in highway runoff with large particulate fractions show higher removal efficiencies.

Reference:

Yousef, Y.A., Wanielista, M.P., *et al.*, 1985, Best Management Practices - Removal of Highway Contaminants by Roadside Swales, Fl-ER-30-85, Florida Department of Transportation, Tallahassee, Florida; FDOT-ER-34-86.

3.4.3 Maitland Swale Biofilter - Grass Swale Orlando, Florida

Summary: The site for this investigation is located at the intersection of Interstate 4 and Maitland Blvd., north of the City of Orlando in Orange County, Florida. Maitland Blvd. crosses over Interstate 4 by means of a bridge overpass created during the construction of the interchange in 1976. The traffic lanes on the interstate are separated by a 6 meter grassy median which widens to 13.5 meters through the interchange. The Maitland Blvd. Bridge consists of two sections: one carrying two lanes of east bound traffic plus one exit lane and the other carrying two lanes of west bound traffic plus one exit lane. The section carrying west bound traffic spans 168 meters with a 16 meter roadway and a 16 meter horizontal clearance. The section carrying east bound traffic spans 163 meters and also with a 16 meter roadway and 16 meter horizontal clearance. The average annual daily traffic volume on Maitland Blvd is 15,000 vehicles per day. Interstate 4 has three lanes of traffic east and west bound through the Maitland Interchange. The traffic volume on Interstate 4 through the Maitland Interchange is approximately 45,000 ADT in each direction. A grassy swale along the eastern side of Ramp A was selected for this investigation. This swale was used because of its accessibility and the availability of a continuous source of runoff water from a drain located at the bottom of the swale. The drain connects to the west pond via a 36 inch diameter RCP. The experiments conducted at this site used a submersible pump placed at the downstream stormwater inlet. The water was spiked with a concentration of heavy metal (Pb, Cd, Zn, Cr, Cu, Ni, and Fe) and nutrients (P and N) in concentrations typical of highway runoff. The spiked water traveled a distance of 175 ft. From the results obtained, it appears that ionic species of metals, nitrogen and phosphorous species may be retained on the swale site by sorption, precipitation, co-precipitation and biological uptake processes. These processes can reduce pollutant concentration in highway runoff flowing over swales. Occasional increases in dissolved highway contaminants were observed at intermediate stations during swale experiments particularly close to the inflow point. This may result from the initial flow resuspension and resolubilization of loosely bound contaminants. The removal of heavy metals, nitrogen, and phosphorous species on a mass basis was directly related to the infiltration losses through swales.

Therefore, retention of as much water as possible on the swale area will reduce the highway contaminant loadings to adjacent receiving waters. Recommendations for the construction of roadside swales are presented. The information in the document is limited to a small number of storms and, thus, may provide only minimal data for the efficiency analysis of the swale in question.

Reference: International Stormwater BMP Database Basic Database

Yousef, Y.A., Hvitved-Jacobsen, T., Wanielista, M.P., Harper, H.H., Hamilton, R.S., Harrison, R.M., (eds), 1987, Removal of Contaminants in Highway Runoff Flowing through Swales, Special Issue: Highways Pollution Proceedings of the Second International Symposium, London, United Kingdom, 7-11 July 1986, 1987, pp. 391-399, Sci. Total Environ, vol. 59, Dep. Civ. Eng., Univ. Central Florida, Orlando, Florida 32816-0093, USA

3.4.4 EPCOT Swale Biofilter - Grass Swale Orlando, Florida

Summary: The EPCOT interchange was constructed during 1982-83 as a 0.8 mile multilane connector between the EPCOT entrance and SR 535. The interchange is approximately 1.5 miles southwest of the I-4/SR535 interchange and 2.4 miles northeast of the I-4/US 192 interchange, near Lake Buena Vistas in Orange County, Florida. Watershed size is unknown. The swale area selected for this study was a newly constructed swale along ramp A which connected the EPCOT Center Exit to the westbound lanes of I-4. Two experiments were conducted at this site, one in a predominately earthen state before the establishment of vegetation in the swale, and the other after vegetation had become established. The experiments conducted at this site used a submersible pump placed at the downstream stormwater inlet. The water was spiked with a concentration of heavy metals (Pb, Cd, Zn, Cr, Cu, Ni, and

Fe) and nutrients (P and N) in concentrations typical of highway runoff. Occasional increases in dissolved highway contaminants were observed at intermediate stations during swale experiments particularly close to the inflow point. This may result from the initial flow resuspension and resolubilization of loosely bound contaminants. The removal of heavy metals, nitrogen, and phosphorous species on a mass basis was directly related to the infiltration losses through swales. Therefore, retention of as much water as possible on the swale area will reduce the highway contaminant loadings to adjacent receiving waters. Recommendations for the construction of roadside swales are presented. The information in the document is limited to a small number of storms and, thus, may provide only minimal data for the efficiency analysis of the swale in question.

Reference: International Stormwater BMP Database Basic Database

Yousef, Y.A., Hvitved-Jacobsen, T., Wanielista, M.P., Harper, H.H., Hamilton, R.S., Harrison, R.M., (eds), 1987, Removal of Contaminants in Highway Runoff Flowing through Swales, Special Issue: Highways Pollution Proceedings of the Second International Symposium, London, United Kingdom, 7-11 July 1986, 1987, pp. 391-399, Sci. Total Environ, vol. 59, Dep. Civ. Eng., Univ. Central Florida, Orlando, Florida 32816-0093, USA

3.5 Infiltration Systems

3.5.1 Oleander Avenue Stormwater Exfiltration Trench System, City of Daytona Beach, Florida

Summary: The Oleander Avenue watershed historically discharged untreated runoff to storm sewers that ultimately discharged to the Halifax River. The area was also subject to periodic local flooding due to the inadequate capacity of the conveyances. The primary objective of this project is to demonstrate the cost-effectiveness of using exfiltration systems as a method of retrofitting stormwater problem areas for future use within the city's beachside community. To alleviate the flooding problem and to reduce pollutant loading to the river, a perforated pipe exfiltration trench treatment system was constructed. Site constraints limited the treatment volume to 0.75 inches over the DCIA which translates into a storage volume of 30,700 cubic feet. The 294 feet of exfiltration system is designed to accept the runoff from a 5 year, 24 hour storm representing flows of from 1.5 to 17.5 cfs from the drainage area subbasins. Actual pipe sizes varied from 19" x 30" to 29" x 45" to meet the design storm flow conditions. The rock filled trench measures 16 feet in width and 2 feet in depth. The exfiltration trench appears to be functioning very well as water quality monitoring efforts have failed to find any discharge from the system. Since exfiltration systems provide 100% treatment for all water which is retained and exfiltated, this system will reduce the stormwater pollutant loadings discharged to surface waters by at least 80%, since the trenches will eliminate the discharge from over 80% of the storms that occur. The project allowed the city to identify the design and construction constraints associated with this type of treatment system as well as installation costs for these systems. This knowledge will be used as the city retrofits other basins.

Reference:

Bateman, M., Livingston, E.H., Cox, J., 1998, Overview of Urban Retrofit Opportunities in Florida, in National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments Proceedings Chicago, IL, February 9-12, 1998, p. 166.

3.6 Minimizing Directly Connected Impervious Surfaces

3.6.1 Evaluation of Green Roof Technology in Central Florida

Summary: The objective of this project is to design, construct, and monitor a green roof at the UCF Student Union to determine: 1) the appropriate plants for green roofs under Florida climatic conditions, 2) the stormwater management benefits of green roofs, and 3) the energy benefits of green roofs.

Reference: Ongoing (January 15, 2004 until January 14, 2007), Dr. Marty Wanielista, Stormwater Management Academy University of Central Florida.

3.7 Miscellaneous and Vendor-Supplied Systems

3.7.1 Evaluation of Pollutant Removal Effectiveness of Proprietary BMPs

Summary: To test and provide technical data and cost evaluation associated with different levels of three proprietary BMP systems (CDS, Stormceptor, BaySaver). To accomplish the stated objective, the selected systems will be evaluated based on the following parameters: 1) initial cost (equipment and installation costs), 2) applicability to perform under varied flow rates, 3) percentages of removal for different pollutants, 4) validate the manufacturers maintenance plans, and 5) develop a cost/pollutant removal rate.

Reference: Ongoing (July 4, 2003 until March 3, 2005), Dr. Fidelia (Ola) N. Nnadi, Stormwater Management Academy University of Central Florida.

3.7.2 Stormwater Treatment Using Alum

Summary: Innovative and cost-effective stormwater treatment systems using alum have been constructed in Florida to meet the challenge of reducing pollutant concentrations in nonpoint source discharges to surface waters without committing large amounts of land to the treatment process. In 1986, a prototype system was introduced in a lake restoration project on Lake Ella in Tallahassee, Florida, based on the flow-weighted injection of liquid aluminum sulfate, commonly called alum, into the runoff flow inside storm sewer lines before discharge into the lake. The Lake Ella project constituted the first use of alum for treatment of stormwater inputs into a receiving water body. Lake Ella is a shallow, 13-acre lake that received stormwater input through 18 separate storm sewers from 160 acres of a highly impervious urban watershed. Lake Ella has a volume of only 30 million gallons, but receives 137 million gallons annually. A second, similar treatment system was constructed at Lake Dot and others are planned for Lake Lucerne, Lake Osceola, and Lake Cannon. Alum stormwater treatment combines an extremely cost-effective method of retrofitting direct discharge stormwater systems with unequaled removal rates of nutrients, heavy metals, and bacteria.

Reference:

Harper, H.H., Herr, J.L., 1992, Stormwater Treatment Using Alum, Public Works Magazine PUWOAH, Vol. 123, No. 10, p 47-49, 89-90, September 1992. 1 fig, 1 tab.

3.7.3 An Assessment of an In-line Alum Injection Facility Used to Treat Stormwater Runoff in Pinellas County, Florida

Summary: This study was conducted to determine the feasibility of using an in-line alum injection facility for a stormwater treatment retrofit. Alum treatment is primarily used to remove phosphorus (usually the limiting nutrient in fresh water). Other alum treatment facilities constructed in Florida inject alum into the stormwater flow in storm sewers located upstream of receiving water bodies (*e.g.*, a lake) with the alum floc allowed to settle in the water body.

The purpose of this study is to determine the effectiveness of alum technology for an in-line system with limited storage volume for alum floc containment, and to conduct an environmental impact assessment. This study also afforded the District an opportunity to characterize the water quality of an older urban ditched system. Data collection included flow-weighted storm event samples, monthly water quality samples, and hydrologic data collection. Event based load reductions were calculated, comparisons were made of pre- and post-treatment data, and event and monthly water quality were compared to State surface water quality Class III standards. Additionally, a comparison to event mean concentration (EMC) pollutant reduction was performed between predicted reductions estimated in the permit application and load reductions measured during this study. The water quality constituents analyzed included various forms of phosphorus and nitrogen, and several metals. To some degree, portions of these data were likely biased due to a backflow of alum in the inflow station samples. A detailed analysis of the potential for aluminum toxicity to various fish and benthic species was also conducted. Event load reduction calculations were performed on inflow and outflow data collected during seven storm events that were successfully treated with alum. Mean total phosphorus and ortho phosphorus load reductions were 37 and 42 percent respectively. Mean percent load reductions of ammonia and nitrate+nitrite were 24.5 and 52.2 percent respectively while, event total Kjeldahl nitrogen loads increased on average by 5 percent. Zinc loads were reduced in most events (despite the alum solution being contaminated with zinc) and when a single outlier was excluded, mean zinc removal was 41 percent. Iron and lead load reductions were variable with the mean load increasing (export). Dissolved monomeric aluminum event loads were mostly reduced with a mean 56 percent reduction. However, total aluminum mean loads revealed an increase of 36 percent. This large increase in total aluminum was attributed to inadequate storage volume for the alum floc. Generally, the load reductions outlined above are good considering the settling ponds small size. Lead and iron EMCs were in noncompliance less at the outflow than inflow. Copper and zinc EMCs, on the other hand exhibited higher percent noncompliance at the outflow than inflow. The increase in copper and zinc standard noncompliance at the outflow were attributed to these metals being a contaminant in the alum solution. Reductions in pH values were mirrored by peaks in aluminum concentrations. This relationship exemplifies the environmental chemistry of aluminum where pH is the driving force in aluminum solubility. Zinc was the sole metal to consistently show concentrations within detectable levels and seemed unaffected by facility operations. Generally, phosphorus concentrations measured downstream of the alum facility were lower and less variable after facility installation. The data suggest that alum residual in the sediment pond tempered phosphorus concentration increases during periods when the injection facility was inoperable. TSS concentration peaks at the outflow were lower after installation. TKN concentrations at all stations showed little change throughout the study due to alum facility installation and operation. Inflow and outflow event mean concentration (EMC) data were compared to predicted EMC reductions calculated in the MSSW permit application. Predictions for ammonia and nitrate+nitrite agreed with measured data. Measured changes in pollutant EMCs were a 32 percent *increase* in total nitrogen, a seven percent *decrease* in total phosphorus and a 184 percent *increase* in total suspended solids. EMC predicted percent reduction should not be confused with actual percent load reduction also presented in the report. The importance of operation and maintenance cannot be over emphasized. The regulatory agencies should require the permittee of an alum injection system to: a) assure sufficient funds are available for repair/replacement of inoperable equipment, b) submit semi-annual operation and inspection reports, and c) require operators to have some level of expertise appropriate for facility operations. It is important to maximize alum floc containment volume to minimize potential adverse environmental impacts downstream. The containment volume at this study site was inadequate. Despite the operation and maintenance problems experienced, event mean concentration and loads of phosphorus were reduced during alum facility operations. The data indicate the alum facility could be effective in reducing phosphorus if properly maintained. Monthly samples showed that phosphorus concentrations measured downstream from the alum injection facility were generally lower and less variable after facility installation. Potentially toxic concentrations of aluminum to aquatic wildlife were measured at stations immediately upstream and downstream of the alum facility. Aluminum concentrations at stations further downstream were below these potentially harmful levels.

<u>Reference</u>:

Carr, D. W., 1998, An Assessment of an In-line Alum Injection Facility Used to Treat Stormwater Runoff in Pinellas County, Florida, Southwest Florida Water Management District, 36 pages.

Carr, D.W., 1999, An Assessment of an In-Line Alum Injection Facility Used to Treat Stormwater Runoff in Pinellas

County, Florida, Proceedings of the Sixth Biennial Stormwater Research and Watershed Management Conference, September 14-17, 1999, p. 68-79.

3.7.4 Lake Ella Alum Injection System

Summary: In 1985, a lake restoration project was initiated in Lake Ella, a shallow, 13.3 acre hypereutrophic "lake" which receives stormwater runoff from a 157 acre highly impervious watershed. Due to its highly developed and urban watershed, and because of the low permeability of the watershed's clay soils, it was determined that traditional stormwater treatment BMPs could not be used. Instead, chemical treatment of runoff was evaluated using various chemical coagulants including aluminum sulfate (alum), ferric salts, and polymers. Jar tests determined that alum consistently provided the highest removal efficiencies and produced the most stable end product. Consequently, a prototype alum injection system was designed where liquid alum was injected within storm sewers on a flow weighted basis. Standard triplex metering pumps are used as the injection pumps, each individually regulated by sonic flow meters attached to the storm sewer lines to be treated. Many of the smaller storm sewers were combined to reduce the points of discharge into the lake from 17 to ten. Six of these ten inputs, representing 95% of the average flow, are equipped with alum injectors. Alum is pumped from a 6000 gallon alum storage tank into individual one inch PVC underground carrier lines to the point of injection. The alum mixes with stormwater as it travels through the storm sewers, passes through a fine mesh trash trap, and is discharged into Lake Ella. The restoration project also included the removal of 50,000 yds^3 of accumulated sand, debris, and muck from the bottom of Lake Ella and the recontouring of the lake's bottom with a gradual slope toward the outfall control structure. Pre- and post-alum injection monitoring is summarized below:

Parameter	Before	After	Parameter	Before	After
pH	7.41	6.43	DO	3.5 mg/l	7.4 mg/l
T N	1876 ug/l	417 ug/l	Total P	232 ug/l	26 ug/l
BOD	41 mg/l	3.0 mg/l	Chlorophyll-a	180mg/m^3	5.1 mg/m^3
Secchi Depth	0.5 m	2.2 m	Florida TSI	98	47

Alum sludge accumulation rate: 0.33 cm/yr. Pollutants in sediments are much more tightly bound after alum injection system.

Reference:

Harper, H., 1990, Final Report on the Long Term Performance of the Alum Stormwater Treatment System at Lake Ella, Florida, Submitted to Florida Department of Environmental Regulation, Stormwater/NPS Management Section, Tallahassee, Florida.

3.7.5 Indian River Lagoon Baffle Boxes, Brevard County Surface Water Management

Summary: The Indian River Lagoon National Estuary Program identified stormwater discharges as the major factor in the decline in the lagoon's health. In particular, reductions in the stormwater loadings of total suspended solids, nutrients, and freshwater are needed to restore the lagoon. The county developed an innovative BMP, the baffle box, which can be installed within existing rights-of-way as a way of retrofitting stormwater discharges where land is unavailable for traditional BMPs. Baffle boxes are large sediment traps that require regular maintenance. Sediment accumulation rates vary depending on site characteristics such as drainage area, land use, soil type, slope, mowing frequency, and base flow. The box accumulates from 500 to 50,000 pounds per month, and requires monthly cleaning in the wet season and cleaning every two to three months in the dry season. By the end of 1997, the county had installed 31 baffle boxes, with others under construction. As part of the implementation of the Indialantic area stormwater master plan, 11 baffle boxes currently are being installed and monitored. Three different designs are being evaluated to determine their effectiveness including: (1) a two-chamber box for small pipes and drainage areas; (2) a three-chamber box for larger pipes; and (3) two boxes in series, where one box currently exists and collects large amounts of sediment. The monitoring program for the 11 new baffle boxes will not begin until the spring of 1998. However, previous assessments of the effectiveness of baffle boxes on 22 existing systems is shown below: The county has also installed a continuous deflective separation unit, a new BMP from CDS Technologies of Australia. This unit cost $55,000 to install and treats the runoff from a 40 acre watershed. This unit captures 100% of floatables and has been cleaned out twice resulting in the removal of 8,013 pounds of sediment.

Reference:

Bateman, M., Livingston, E.H., Cox, J., 1998, Overview of Urban Retrofit Opportunities in Florida, in National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments Proceedings Chicago, IL, February 9-12, 1998, p. 166.

3.7.6 Oil and Grease Removal BMP Demonstration, City of Oakland Park, Florida

Summary: The City of Oakland Park received one of the state's Stormwater Demonstration Grants to develop and monitor a prototype BMP for in-line removal of oil and grease from stormwater using oil absorbent material. The Northeast 40th Court site was chosen because inspection of the storm sewer system revealed substantial amounts of oil and grease. These were attributed to the large number of automobile repair shops, paint shops, plating shops, and similar businesses in the drainage area. The project consisted of characterizing the concentrations of oil and grease in the stormwater, a review of the material safety data sheets of three different oil sorbent materials, a laboratory bench scale study of one of the oil sorbent materials, construction of the BMP system, and effectiveness monitoring. The final BMP system included diversion box with a weir to direct runoff into the treatment system. As stormwater enters the treatment unit, flow is directed against an aluminum baffle imparting a slight rolling motion which causes floatables and trash to be trapped against the baffle wall for easy removal. Upon entering the treatment chamber, velocity slows greatly, allowing grit, sludge, and oil particulate matter to settle to the sloping bottom. The stormwater is then redirected upward through two cross-layers of the absorbent media, which are secured by being sandwiched between two aluminum grates, where free oil and grease are removed via absorption into the material. The absorbent media chosen was custom made by NewPig Corporation of Tipton, Pennsylvania. The product, called the Spaghetti Pillow, consists of shredded strips of polypropylene packaged in tough, UV resistant mesh skin in the shape of a rectangular bag or pillow. The two layers of media are placed perpendicular to each other to avoid short circuiting. Inflow and outflow sampling of the system was conducted for ten storms between July 1994, and April 1995. Storm event oil and grease concentrations ranged from 0 to 261 mg/l, with mean pollutant concentrations ranging from 1.41 to 85.58 mg/l. Oil and grease mass removal efficiencies ranged from 71% to 95%, while flows ranged from 0 to 1.75 cfs. The absorption efficiency of the filter media bags were measured twice. The amount of oil and grease absorbed ranged from 1.7 pounds to 62.5 pounds, which represents an absorption efficiency of 110% to 470%.

Reference:

Camp, Dresser, and McKee, 1995, Final Report on the City of Oakland Park Stormwater Demonstration Grant Project, Submitted to Florida Department of Environmental Protection, Stormwater/NPS Management Section, Tallahassee, Florida.

3.7.7 Pollutant Removal Testing for a Suntree Technologies Grate Inlet Skimmer Box

Summary: Over the last several years, a number of BMPs have been developed to provide stormwater treatment by trapping pollutants and debris in inlets. Inlet trap BMPs are quasi source controls, being inexpensive, requiring no roadway construction or utility relocation, and keeping pollutants out of the water bodies, rather than trying to remove the pollutants from the water once it is contaminated. Suntree Technologies, of Cape Canaveral, Florida, commissioned Creech Engineers, Inc. and Universal Engineering to perform testing on a Grate Inlet Skimmer Box (GISB) to determine its pollutant removal effectiveness for sediment and grass clippings. The testing was performed on September 26, 2001. The GISB is designed to trap sediment, grass, leaves, organic debris, floating trash, and hydrocarbons as they enter a grated inlet, thereby preventing these pollutants from entering the stormdrain system where they would cause detrimental impacts on downstream waterbodies. The GISB is a 3/16” thick fiberglass device custom made to fit most types of grated inlets. The overflow capacity of the GISB is designed to be greater than the curb grate capacity, thereby insuring that there will be no loss of hydraulic capacity due to the device being inside the inlet. The bottom of the GISB is designed to be above any pipes entering or leaving the inlet so that flow through the inlet is not blocked. Water flowing through the grate first encounters a hydrocarbon absorbing cellulose. This boom also serves to trap large debris between the boom and the body of the GISB. At the bottom of the trap are a series of stainless steel filter screens covering 3.5 inch wide cutouts in the fiberglass body. These screens trap debris while allowing water to pass through the bottom of the body and out to the storm drain system. The screens in the floor and first vertical row of the GISB are fine mesh. The second vertical row of screens are medium mesh and the highest row are coarse mesh. On the outside of the cutouts the screens are backed by stainless diamond plate to provide support to the screens since heavy loads of debris build up in the box. If the flow rate through the inlet exceeds the capacity of the filter screens there is another row of overflow holes cut out with no screens. These overflow holes allow water to pass through the GISB even if it becomes full of debris. The level of the holes is above the bottom of the top tray, enabling the tray to act as a skimmer to prevent floating trash from escaping through the overflow holes. About halfway down the box is a diffuser plate to minimize resuspension of trapped sediment. Inlet traps such as these are generally designed to capture hydrocarbons, sediment, and floating debris. There is generally a large build up of grass, leaves, and yard debris in the GISBs; which represent a source of nutrients, which do not enter the waterbodies. Royal and England, 1999, determined that leaves and grass leach most of their nutrients into the water within 24-72 hours after being submerged in water. GISBs are designed to keep captured debris in a dry state, off the bottom of the inlet, thus preventing phosphates and nitrates from leaching into the stormdrain system, where much more expensive BMPs would be required to remove the dissolved nutrients.

Reference:

Creech Engineers, Inc., 2001, Pollutant Removal Testing for a Suntree Technologies

3.7.8 Sedimentation Control Using Two Baffle Boxes in Series

Summary: For the last 8 years, the Brevard County Surface Water Improvement Program has used baffle boxes for stormwater sedimentation control at over 34 locations. As part of a Florida Department of Environmental Protection Demonstration Project for Indialantic Area Baffle Boxes, two baffle boxes were constructed in series on a 9.75 ha (24.1 ac) drainage basin in Sunset Park, near Indialantic. The first baffle box was installed in 1992 and long-term cleanout records have been documented on the performance of this baffle box. A second baffle box was installed in 1998 immediately upstream of the first baffle box to create a series configuration. Autosampler monitoring results for TSS, Total Phosphorus, COD, and BOD removal efficiencies are presented in this report for the second baffle box. In addition, the effectiveness of two baffle boxes in series is examined.

Reference:

England, G., and Royal, J, (date not specified) Sedimentation Control Using Two Baffle Boxes in Series, Creech Engineers and Brevard County Surface Water Improvement

3.7.9 Site Evaluation of Suntree Technologies, Inc. Grate Inlet Skimmer Boxes for Debris, Sediment, and Oil & Grease Removal

JOHNSON ENGINEERING

Summary: Stormwater is now recognized as the leading source of pollution to our remaining natural water bodies in the United States. Development and urbanization have removed most of the natural filtration and sediment trapping systems provided by the environment. Current development must address this need through the implementation of stormwater treatments systems in the project design. Most of these systems perform reasonably well, if properly designed, constructed, and maintained. Retrofit of older urban areas lacking these modern stormwater systems is a continually expensive challenge. The Downtown Disney complex, formerly the Lake Buena Vista Shopping Village, has several drainage basins with 1970's stormwater systems. These older systems discharge directly into the adjacent drainage canal with no pollutant treatment. Over time the accumulation of sediments, nutrients, intensive development, and recreational/entertainment pressures are contributing to water quality degradation. Whenever new development or redevelopment occurs, the stormwater system is brought to current code/permit requirements. In the interim, several areas are in need for rapid, effective, and economical improvement in the quality of its stormwater discharge. Suntree Technologies Incorporated, located in Cape Canaveral, Florida, manufactures stormwater grate inlet skimmer boxes. They are made of a high quality fiberglass frame, with stainless steel filter screens backed by heavy-duty aluminum grating. Each unit is custom made to accommodate various inlet sizes. A hydrocarbon absorption boom is attached to the top of the skimmer box for petroleum, oil, and grease removal. These devices fit below the grate and catch sediment, debris, and petroleums, oils & greases.

Clean-out, maintenance, and performance reporting is provided by Suntree on a scheduled basis.

Reference:

Snell, E., Site Evaluation of Suntree Technologies, Inc. Grate Inlet Skimmer Boxes for Debris, Sediment, and Oil & Grease Removal, Reedy Creek Improvement District Planning & Engineering Department, 4 p.

3.7.10 The Evaluation and Design of an Alum Stormwater Treatment System to Improve Water Quality in Lake Maggiore in St. Petersburg, Florida

Summary: Lake Maggiore is a 156-hectare hypereutrophic lake located adjacent to Tampa Bay in the City of St. Petersburg, Florida. Since virtually all watershed development occurred prior to implementation of current stormwater management regulations, Lake Maggiore receives untreated stormwater runoff from a 927-hectare watershed area. The lake also receives significant quantities of baseflow, partially a result of reclaimed wastewater used for irrigation in the watershed. Documentation of water quality problems such as algal blooms, fish kills, nuisance macrophyte growth, and high bacteria levels date back as far as the early 1950s. An environmental assessment of Lake Maggiore was conducted from 1989-1991 which concluded that an acceptable improvement in the trophic status could be achieved by an 80% reduction in annual loadings of total phosphorus from stormwater runoff and baseflow. The study recommended that alum treatment of stormwater and baseflow be implemented due to the low cost and high removal efficiencies. Five separate alum stormwater treatment systems were designed during 1995, including one on-line system with direct floc input into the lake and four off-line systems using adjacent golf course and park ponds, to provide an

80% reduction of stormwater and baseflow loadings of total phosphorus into Lake Maggiore. Construction began in August 1996 and was completed in October 1997. Start-up and testing of the systems are ongoing, with full operation scheduled for late November 1997. The Lake Maggiore Restoration Project demonstrates alum stormwater treatment systems are extremely effective in removing nutrients, heavy metals, and bacteria from lake inputs and are routinely the most cost-effective lake restoration alternative. Alum treatment systems consistently provide the highest removal efficiencies of any retrofit alternative and typically require no land acquisition.

Reference:

Herr, J.L., Harper, H.H., 1997, The Evaluation and Design of an Alum Stormwater Treatment System to Improve Water Quality in Lake Maggiore in St. Petersburg, Florida, In: Fifth Biennial Stormwater Research Conference, November 5- 7, 1997.

3.7.11 Continuous Deflection Separation (CDS) Unit for Sediment Control In Brevard County, Florida

Summary: In July 1997, Brevard County's Stormwater Utility Program installed a new type of trash and sedimentation control device called a continuous deflection separation (CDS) unit. This was the first American installation to use the CDS technology, which was developed in Australia. This location served a drainage basin of 24.87 hectares (62.45 acres) of mixed industrial, commercial, and vacant land. Over an 18 month period 5 storm events were monitored for 6 parameters: pH, TSS, BOD, COD, turbidity, and Total Phosphorus. In addition, sediment samples were collected and tested for 61 parameters. Sampling was accomplished using autosamplers placed upstream and downstream of the CDS unit. The first three storms were monitored using flow weighted composite samples and the last two used discrete samples. This sampling program proved to be quite a challenge for the personnel relatively inexperienced in the use of autosamplers and stormwater sampling techniques. The lessons learned in monitoring techniques are discussed in detail and illustrate the difficulty in evaluating new technologies.

Sediment sampling showed no significant accumulations of hydrocarbons or heavy metals. In fact, few of the sampled parameters were above detectable limits. The stormwater samples showed a wide range of removal efficiencies; most of which could be explained by problems with equipment failure or improper equipment set up. It is estimated that the CDS unit provided an average of 52% removal efficiency for total suspended solids and 31% removal efficiency for phosphorus.

Reference:

Strynchuk, J., Royal, J., England, G., 2000, Continuous Deflection Separation (CDS) Unit for Sediment Control In Brevard County, Florida, Brevard County Surface Water Improvement, 35 p.

3.7.12 Baffle Boxes and Inlet Devices for Stormwater BMPs

Summary: With the advent of NPDES Stormwater Permits and increased environmental awareness, many municipalities are confronted with the daunting task of retrofitting existing developed areas, which provide little or no water quality treatment for stormwater runoff. While retention ponds are the traditional method used for treating stormwater, they are often not feasible for retrofit projects due to available land constraints. This study will present several new types of treatment methods utilizing existing inlets and manholes. There are no universal fixes for stormwater pollution control. Each outfall and drainage basin must be analyzed to determine types of pollutant loadings, size of drainage basin, type of conveyance system, and pollutants targeted for removal. Then the appropriate BMP or series of BMP's should be selected. Baffle boxes are effective BMP's for sediment removal in small to medium size drainage basins. They are installed inline with existing pipes, requiring minimal easements and utility relocations. For small flows and drainage basins, grate inlet baskets, and curb inlet baskets are affordable alternatives for providing stormwater treatment. Installation into existing inlets and manholes avoids disruptive and expensive conventional construction. Inlet devices trap small amounts of sediment and larger volumes of yard debris and trash. Research is being continued to quantify nutrient loading rates from grass clippings captured by these units. The tradeoff for these low cost treatment methods is the perpetual maintenance expense. It is important to note that if the devices are not going to be frequently maintained they will not be effective. A dedicated source of manpower and equipment is needed to remove the pollutants from these BMP's.

Reference:
England, G., 1999, Baffle Boxes and Inlet Devices for Stormwater BMPs, 6 p.

3.8 Treatment Train Systems

3.8.1 The Effectiveness of a Detention Pond and Wetlands System in Reducing the Amounts of Lead Transported by Urban Stormwater Runoff

Summary: The construction of different types of in-line temporary storage devices to reduce constituent loads carried by urban stormwater runoff is becoming more prevalent. The results of a study to determine the effectiveness of a detention pond-wetlands system to reduce the amount of lead in urban stormwater runoff are presented. The detention pond and wetlands receive drainage from a 42 acre urban area. The pond area is 9,000 square feet and the depth of water is about 8 feet during rainstorm periods. The wetlands are about 34,000 square feet in size and the depth of water ranges from 0 to 2 feet during nonstorm periods. Total lead loads entering the system ranged from 0.021 to 1.7 pounds. Data were collected for the pond and wetlands for nine storms, and the pond only for an additional three storms. System inlet data only were collected for one storm. The detention pond and wetlands are generally effective in reducing the amount of lead being transported by the urban runoff. In 8 of 12 storms, the detention pond reduced the amount of total lead in the runoff. The maximum reduction observed in the pond was 73 percent. For four storms, an increase of total lead load, ranging from 26 to 190 percent, was observed through the pond. This increase may be due to short circuiting (flow moving directly from pond inlet to outlet), scouring, resuspension of pond bottom materials, high concentrations of lead in the pond water before the storm, analytical error, or other factors. The wetlands reduced the total lead load for each of the nine storms an average of about 75 percent. The combined system (pond and wetlands in series) reduced total lead loads for each of the monitored storms. The system retained an average of 72 percent of the total lead load that was introduced.

Reference:

Martin, E.H., 1985, The effectiveness of a detention pond and wetlands system in reducing the amounts of lead transported by urban stormwater runoff: Environmental Systems Engineering Institute Publication 85-1, University of Central Florida, p. 133-143.

3.8.2 Evaluation of the Stormwater Treatment Facilities at the Lake Angel Detention Pond, Orange County, Florida

Summary: This is the final report on the use of Granulated Active Carbon (GAC) beds of Filtrasorb 400 in series to reduce the Trihalomethane Formation Potential (THMFP) concentrations at the Lake Angel detention pond, Orange County, Florida. The detention pond accepts runoff from an interstate highway and a commercial area. Breakthrough time was estimated from laboratory analyses and used to design two beds in series at the detention pond. Breakthrough occurred in the first bed after treating 138,000 liters of water. Exhaustion of the first bed was reached after treating 1270 bed volumes with a sorption zone length of 1.70 feet. The TOC adsorbed per gram of GAC was 6.3 mg. The liquid flow rate averaged 0.0011 cfs. Similar breakthrough curves for Total Organic Carbon (TOC) and color were also reported. The used GAC can be disposed of by substituting it for sand in concrete mixes. An economic evaluation of the GAC system at Lake Angel demonstrated an annual cost of $4.39/1000 gallons to treat the stormwater runoff after detention and before discharge into a drainage well. The cost could be further reduced by using the stormwater to irrigate right-of-way sections of the watershed. An alternative method of pumping to another drainage basin was estimated to be more expensive. The underdrain network for the GAC system initially became clogged with the iron- and sulfur-precipitation bacteria Leptothrix, Gallionella and Thiothrix. These bacteria were substantially

reduced by altering the influent GAC system pipeline to take water directly from the lake. An alternate pipe system used a clay layer to reduce ground water inputs and did not exhibit substantial bacterial growth.

Reference:

Wanielista, M., Charba, J., Dietz, J., Russell, B., 1991, Evaluation of the Stormwater Treatment Facilities at the Lake Angel Detention Pond, Orange County, Florida, Final report, 2 Jan 90-1 Jul 91.

3.8.3 Nonpoint Source Phosphorus Control by a Combination Wet Detention/Filtration Facility in Kissimmee, Florida

Summary: Water quality investigations were conducted to assess the treatment potential (concentration reduction) of a dual component wet detention/filtration-berm stormwater management system, located in Kissimmee, Florida. Phosphorus concentrations are indicative of nonpoint source pollution in urban and commercial stormwater runoff. Therefore, orthophosphorus and total phosphorus concentrations were monitored at three different sampling stations within the system: 1) surface runoff influent channel; 2) wet detention basin standing pool; and 3) filtration-berm effluent collection box. Routine monthly data were collected to characterize prevalent ambient conditions. In addition, six distinct storm events were monitored with automatic samplers to characterize episodic phosphorus variations during the period November, 1985 to November, 1986. Statistical analyses (t-test) of routine monthly concentration data showed significant differences (p less than or equal to 0.05) between the stormwater influent and the wet detention basin standing pool samples for both orthophosphorus and total phosphorus. However, similar analyses between detention basin standing pool and filtration-berm effluent

samples showed no significant differences. These results suggest positive treatment potential attained through wet detention, but significant additional treatment was not realized through berm filtration. Storm event results reinforced these conclusions, indicating wet detention treatment potential far superior to filtration-berm treatment potential. The average storm event treatment potential realized by wet detention during six events for orthophosphorus and total phosphorus was 77%. The average treatment potentials realized by filtration for orthophosphorus and total phosphorus were -91% and 16%, respectively. The average treatment potentials realized by the overall combined system for orthophosphorus and total phosphorus were 55% and 85%, respectively.

Reference:

Holler, J.D., 1990, Nonpoint Source Phosphorus Control by a Combination Wet Detention/Filtration Facility in Kissimmee, Florida, FLA. SCI., vol. 53, no. 1, pp. 28-37.

3.8.4 An Evaluation of the Lake Jackson (Florida) Filter System and Artificial Marsh on Nutrient and Particulate Removal from Stormwater Runoff

Summary: Concern over pollution caused by stormwater runoff entering Lake Jackson from the city of Tallahassee culminated in the construction of a sediment filtration plant and artificial marsh to remove suspended solids and nutrients from the runoff prior to its discharge into the lake. Water samples collected during storm events were analyzed for a wide range of particulate and dissolved parameters, including suspended solids and various N and P species. Gauging stations, located at key points in the system, provided an accurate determination of water flow during sampling periods. Accurate flow data, rarely available in natural systems, permitted mass balance and removal efficiency calculations to be made. Results from the first year of study indicate that the system is capable of removing a large fraction of both suspended solids and dissolved and particulate nutrient material.

Reference:

Tuovila, B.J., Outland, J.B., Esry, D.H., and Franklin, M., 1987, An Evaluation of the Lake Jackson (Florida) Filter system and Artificial Marsh on Nutrient and Particulate Removal from Stormwater Runoff, p. 271-278, *In:* K.R. Reddy and W. H. Smith (eds.) 1987, Aquatic Plants for Water Treatment and Resource Recovery, Magnolia Publishing, Inc.

3.8.5 Removal of Microbial Indicators from Stormwater Using Sand Filtration, Wet Detention, and Alum Treatment Best Management Practices

Summary: The Environmental Protection Agency has determined that nearly 90% of fecal coliform pollution to surface waters originated from non-point sources such as urban and agricultural stormwater runoff. In the Tampa Bay watershed, several tributaries, which receive agricultural, industrial, and urban runoff exhibit consistent, elevated total and fecal coliform bacteria concentrations which often exceed State standards for shellfish harvesting and recreational exposure. Based on State water quality standards, 45% of these tributaries did not meet their intended use for recreation and the propagation and maintenance of a healthy, well-balanced population of fish and wildlife. In urbanized areas, contaminated stormwater can impact recreational beaches in both marine and freshwater environments and can cause a number of bathing-related illnesses including eye, ear, nose, and upper respiratory ailments, skin irritation, and gastrointestinal infections. Very few studies have been conducted to determine how well

stormwater management systems reduce microbial indicators from stormwater. In this study, indicators and surrogates of microbial pathogens were used to determine how well three types of stormwater systems reduced microbes using simulated storm events. The indicators used were total and fecal coliform bacteria, MS2 coliphage, and fluorescent beads representing a pathogenic protozoa. The three types of systems were: sand filtration, wet detention and alum coagulation. Samples were taken before the introduction of the surrogate or indicator organisms, right after the introduction and then ten samples at timed intervals were collected to observe die-off effects. Heavy metals, turbidity and total suspended solids were also measured using the same experimental design. Additionally, gram-negative bacteria already in the water were identified during each of the sampling steps. Significant ($p < 0.05$) reductions in total and fecal coliform bacteria, MS2, and bead concentrations were observed between inflow and outflow samples for each of the three stormwater treatment systems. On a few occasions, however, greater concentrations of total coliform bacteria, turbidity and total suspended solids were found in outflow samples than at the inflow. Using flow-weighted sampling techniques the following reductions were measured at all three systems. For beads, the reduction was greater than 90% and for MS2 coliphage, greater than 80%. Efficiencies for total and fecal coliform varied widely with total coliform removal values consistently less than 70% while fecal coliform reductions ranged from 65 to 100%. Overall, alum coagulation (dose = 10 mg/L) provided the greatest removal efficiencies under controlled laboratory conditions using jar tests. Removal efficiencies using sand filtration were generally high for turbidity, MS2, and beads but not for total or fecal coliforms. Wet detention using the current regulatory standard of a 5-day bleed-down period provided consistently high removal efficiencies for fecal coliform bacteria, MS2 and beads, and had the greatest TSS removal of the three treatment systems. Water quality standards for total coliform bacteria were exceeded more often during the 14-day trials than the 5-day trials which may have been caused by heavier than normal rainfall. A number of gram-negative bacteria were also identified in both the inflow and outflow samples taken from the wet detention ponds including several which are capable of causing human disease. Most of the bacteria were present in both the inflow and outflow samples. A small proportion of bacterial removal may have occurred as a result of heavy metal toxicity. Each of the three stormwater treatment systems evaluated in this study were capable of reducing microbial pollution and each had specific attributes that would make it more advantageous than the other for specific applications or site constraints. The use of a multiple treatment system in which several different BMPs are joined in series may offer greater reductions for a broader collection of parameters than any single BMP. Since no single BMP evaluated during this study had consistently greater removals of all the parameters, this approach would be more effective. The consistent presence of pathogenic strains of bacteria in both inflow and outflow samples from all of the three sites evaluated further stresses the importance of stormwater treatment to reduce potential public health risks. Methods commonly used for wastewater such as chlorine disinfection, ozonation, and UV light irradiation have been suggested for the removal of microbial pathogens from stormwater. Since resuspension of sediments can reduce the effectiveness of wet detention ponds, reducing flow rates at the inflow can be critical to achieving sanitary water at the outflow.

Reference:

Kurz, R. C., 1998, Removal of Microbial Indicators form Stormwater Using Sand Filtration, Wet Detention, and Alum Treatment Best Management Practices, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609, 169 pages.

3.8.6 Florida Aquarium Parking Lot: A Treatment Train Approach for Stormwater Management

Summary: Impervious surfaces such as parking lots and roof tops cause more stormwater runoff and pollutant loads than any other type of land use. Low Impact Development (LID) design criteria provide alternatives that have successfully reduced runoff and pollution loads by reducing imperviousness, conserving ecosystems, maintaining natural drainage courses, reducing the use of pipes and minimizing clearing and grading. Providing rainfall runoff storage throughout the entire drainage basin disperses runoff uniformly throughout a site's landscape by using a variety of detention, retention, and other practices. A parking lot at the Florida Aquarium in Tampa is being used as a research site and demonstration project to quantify how small alterations to parking lot designs can dramatically decrease runoff and pollutant loads. An innovative parking lot design using LID techniques has been implemented for the Florida Aquarium and utilizes the entire drainage basin for stormwater treatment. The study site is an 11.5 ac parking lot serving 700,000 visitors annually. Automatic instruments collect flow weighted water quality sample and measure flow and rainfall during storm events. The research is designed to determine pollutant load reductions measured from three elements in the treatment train: different pavement types in the parking lot, a planted strand with native wetland trees and a small wet-detention pond used for final treatment. (In this study swales are small depressions between parking rows and strands are larger swales). The parking lot research involved testing three paving surfaces as well as testing basins with and without swales. This makes four treatment types with two replicates of each type. The paving surfaces are asphalt, concrete and porous paving. A total of 59 rain events are included in the data set and represent storms that produced as little as 0.37 inches of rain to a maximum amount of 2.91 inches. The monitoring effort also investigated other processes taking place by measuring rainfall, sediments, as well as variations in pH, dissolved oxygen, temperature, turbidity, and weather conditions. The runoff coefficient is a ratio that can be converted to a percentage and for traditional parking lots a typical range is 70 to 90 percent of rain falling on the site would run off. At the Florida Aquarium site even the basins with only small garden areas and no swales measured the yearly average runoff at about 55 percent. The basins with swales and paved in asphalt or concrete reduced runoff to 30 percent and porous paving, to about 16 percent. The basins with larger garden areas reduced runoff by an additional 50 percent. When the volume of water discharged from all the different elements in the treatment train (the swales, the strand and the pond) are compared, calculations showed almost all the runoff was retained on site. Although the year sampled was during an extreme drought, it is estimated that even during a normal year, discharge would have taken place only about four or five times and the amount would have been greatly reduced. For larger storms, permeable paving did not reduce runoff much more than the other basins with swales. Phosphorus concentrations are highest in the basins with vegetated swales and phosphorus loads were actually increased in basins with swales, although porous paving and larger garden areas ameliorated this effect somewhat. Most metals (iron, lead, zinc, manganese, copper) have higher concentrations in basins paved with asphalt. Nitrate and ammonia most often enter the system directly in rainfall with a correlation coefficient of 0.84 for nitrates and 0.48 for ammonia measured at the basins with no swale. Nitrate-nitrogen and total nitrogen appear to be measured in fairly similar concentrations in all basins while ammonia concentrations are variable. Regression equations show increased concentrations of nitrate in rainfall result in increased concentrations in runoff for all basins. Sediment samples indicate that metal pollutants are not contaminating the water table and that most metals are sequestered in the surface soils. The whole basin approach for the parking lot was an excellent design alternative with no discharge off site. By flexibly interpreting stormwater regulations and taking two feet from the end of each parking space, land was provided for the swales without reducing the number of spaces. This design also did not compromise parking since the front end of the car extends over the swale rather than impermeable paving. Other sensible innovative strategies need to be implemented where land is at a premium. Permeable paving reduces runoff from small rain events, but swales are more effective for reducing runoff from all events.

Reference:

Rushton, B.T., and Hastings, R., 2001, Florida Aquarium Parking Lot: A Treatment Train Approach For Stormwater

Management, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609.

3.8.7 Stormwater Management Alternatives Demonstration Project

Summary: Better maintenance procedures and retrofits designed to improve the discharge water quality from stormwater systems are necessary if these systems are to meet State water quality goals. A demonstration project to educate the public about stormwater systems and provide professionals with innovative ideas that can be used for stormwater management will result from the project. Additionally, a monitoring program will measure pollutant loads discharged to the bay from an effluent filtration system and a modified wet detention pond. Also the water quality and flow discharged through the underground filter system on a daily basis will be quantified. A literature summary will provide concise information about stormwater management alternatives. The site is part of a low impact parking lot design, which has already demonstrated its ability to reduce runoff and pollution. During the first year of the study background data has been collected from the existing ponds. During the second year, pond improvements and maintenance alternatives will be implemented and the ponds monitored to quantify the results. The exact methods will depend on the results of the literature review but might include bubblers, pre-treatment devices, vegetation changes or minor pond alterations such as excavating a deeper permanent pool. Sediment samples and an invertebrate study have provided additional information. Chemical treatment of floating algae with copper is usually unsuccessful and often results in discharges of toxic levels of copper and higher levels of nitrate as the algae die. Phosphorus is released from the sediments into ponds at low dissolved oxygen levels (below 2-3 mg/L). The under drains in the effluent filtration system discharged constantly and indicate that on a yearly basis this runoff was a greater amount than discharged over the weir during storm events. Nitrates, ammonia and phosphorus were measured at the highest levels in the under drain pipes of the effluent filtration system. Metals and to a lesser extent phosphorus increase when total suspended solids increase. Phosphorus concentrations were highest in the pond with the highest concentrations of phosphorus in the sediments, especially when dissolved oxygen levels were low. The three ponds surveyed showed wide variations in the number of invertebrates collected. The well-oxygenated pond with no chemicals added had the greatest diversity, the anaerobic pond with only a thin layer of sediments over a cement bottom had about half as many invertebrates, and the pond treated once a month with algicide had only one invertebrate species. Fluctuating salinity levels may have also influenced these results. Ponds with nuisance plant problems need remedial solutions other than chemical treatment with copper. Some suggestions for improving the pond after cleaning out the muck include: a) maintaining a deep water permanent pool, b) planting submerged macrophytes which pump oxygen into the water, c) installing a bubbler or fountain, d) using a pre-treatment device such as a bioretention garden or sediment sump. Appropriate fish and other aquatic species stocked in the ponds might improve the ecological balance, provide a way to estimate pond health, and help control nuisance species such as mosquitoes. Effluent filtration systems should not be permitted except under exceptional conditions. They are usually not properly maintained and export higher levels of dissolved nutrients than other stormwater systems.

Reference:

Rushton, B.T., 1998, Sources and Sinks for Stormwater Pollutants, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609.

3.8.8 Broadway Outfall Stormwater Retrofit Monitoring Project (Phase 2)

Summary: The Broadway Outfall drainage basin is approximately 132.4 acres in size and includes a 30.6 acre high intensity commercial district. The entire commercial district, which is 100% impervious, was constructed prior to the implementation of the state's stormwater discharge rule. All rainfall incident on these 30.6 acres discharges directly into the Hillsborough River reservoir untreated, resulting in virtually all the contaminants accumulated between inter-event dry periods being conveyed directly to the river. In addition to the commercial district, the Broadway Outfall drainage basin includes residential, multi-family, institutional, recreational land uses including a golf course. The retrofit project has installed a Model PSW70XX (26 cfd capacity) CDS unit in series with an excavated sediment sump immediately downstream, followed by a shallow linear marsh system extending approximately 500 feet downstream. Phase 2 of the project will collect two years of data, including most storm events, to determine the efficiency of the system to remove pollutants. The monitoring of the Broadway Outfall project includes collecting flow weighted samples before stormwater enters the CDS unit, again after it leaves the system and finally as it leaves the marsh system. Rain water will also be collected for chemical analysis.

Flow will be measured before stormwater enters the system and at the outfall structure. It is assumed that the same amount of water will leave the CDS unit as enters the sealed tank. The amount of flow that bypasses the CDS unit will also be estimated. Base flow will be collected on a consistent schedule. In addition, wells surrounding the site will analyze water table interactions, sediment samples will determine pollutants retained on site and macroinvertebrate sampling will also be conducted. The major goal of the project is to assess the efficiency (pollutant removal) of the various treatment elements. The primary constituents monitored include nutrients, metals, ions, pesticides, and priority pollutants. Since the monitoring project will not begin until March 2002 there are no results. However, some pre-construction sediment and water quality grab samples have been collected and they indicate some of the potential problems. The concentrations of semi-volatile organic pollutants in the sediments where stormwater was first discharged from the pipe into the ditch were high and some exceeded toxic standards. For example, concentrations (ug/kg) were: Fluoranthene 41,000, Benzo(a)anthracene 24,000, Chrysene 26,000, pyrene 35,000. These were reduced to undetectable levels in the middle section of the ditch and increased, but at lower levels, as the ditch receives runoff from more commercial development. Five PAHs were also detected in the water column at the inflow of the ditch, but not after water traveled further down the water course. No pesticides were detected in the sediments, but atrazine and hexazinone were measured in the water column. Anoxic conditions (low dissolved oxygen) were measured in the ditch.

References: Ongoing

3.8.9 Lake Jackson Megginnis Arm Regional Stormwater System

Summary: Studies in the mid-1970s of Lake Jackson in Leon County, Florida, determined that stormwater from the rapidly urbanizing Megginnis Arm watershed and from the construction of Interstate 10 were responsible for the lake's water quality degradation. In 1983, the NWFWMD and the FDER cooperatively designed and constructed, using EPA Clean Lakes grant and state funds, an experimental regional stormwater treatment system. The system consists of a 20 acre wet detention pond with a heavy sediment basin at the inflow, a 4.2 acre sand filter system, and a 5.7 acre, three cell constructed wetland. The pond originally was sized for 150 acre-feet of storage, representing the runoff from a 2.5 inch storm in the watershed. Continued urbanization of the watershed resulted in greater volumes of stormwater, thereby reducing the system's effectiveness. Therefore, the system was enlarged in 1989-90 to increase the storage volume by 31.7% thus providing 173.8 acre-feet of storage, or storage for 1.02 inches of runoff from the watershed. In 1992, the sand filter system was completely renovated, including new distribution pipes and sand filter media. Finally, in 1990-92, over 112,000 cubic yards of sediments which had accumulated in the bottom of Megginnis Arm were removed and the littoral areas of the arm were replanted with native macrophytes and trees. About 6,000 cubic yards of materials were dredged from the heavy sediment basin after three years of operation with additional material removed during the system's expansion. Monitoring data shows that in normal operation, the system can reduce total volume by 30% and reduce loadings by over 90% for solids, 70% for total nitrogen, 80% for total phosphorus, and 50% for orthophosphorus.

References:

Northwest Florida Water Management District, 1984, Final Construction Report – Lake Jackson Clean Lakes Restoration Project, Submitted to Florida Department of Environmental Regulation, Bureau of Operations, Tallahassee, Florida.

Northwest Florida Water Management District, 1990, Final Report on the Expansion of the Lake Jackson Stormwater Treatment Facility, Submitted to Florida Department of Environmental Regulation, Stormwater/NPS Management Section, Tallahassee, Florida.

Northwest Florida Water Management District, 1992, Lake Jackson Regional Stormwater Retrofit Plan, Water Resources Special Report 92-1, Havana, Florida.

3.8.10 Lake Greenwood Urban Wetland City of Orlando Stormwater Utility

Summary: The Greenwood Urban Wetland was built to alleviate flooding and to treat stormwater runoff prior to discharge to drainage wells which flow to the Floridan Aquifer. The system is designed to detain the runoff from 2.5 inches of rainfall. Approximately 300,000 cubic yards of material was removed to create the system which enlarged the surface area of the "lake" from four to thirteen acres. Weirs were constructed to control water levels and establish three ponds to maximize stormwater detention. The average water depth is 5.1 feet, the storage volume is 66 acre feet, and the hydraulic residence time is 22.7 days. The lakes have a 25 to 30-foot-wide littoral shelf which was planted with over 82,000 plants of ten species of native macrophytes. The lakes are connected by marsh flowways and the system also includes a "riverine floodway" that allows large storms to bypass the lake system. The floodway is planted with seven species of hardwood swamp trees. An upstream sediment/debris basin, pond aeration, and an irrigation system reusing stormwater are incorporated into the design to increase pollutant removal effectiveness. The reuse system allows the City to irrigate the park and the adjacent city-owned cemetery with stormwater instead of potable water, saving the city $25,000 per year. In addition to providing flood protection and stormwater treatment, the 26 acre Lake Greenwood Urban Wetland park includes sidewalks, bridges, and green space passive recreation which is widely used by nearby residents. Preconstruction monitoring was conducted from May 19, 1987 through October 13, 1988 to determine the trophic state of Lake Greenwood and to determine the potential loadings discharged to the lake's five drainage wells. The preconstruction Trophic State Index averaged 64 and was highly variable ranging from 12. 5 to 80.8 with five months above 70. After construction, TSI values averaged 57 but no months had values above 66 and variability was less with a range of 36.2 to 66.3. Treatment effectiveness of the system is summarized below:

	TN	NO2	NO3	NH4	TP	OP	Cd	Cu	Pb	Zn
Sed Trap	4%	-76%	4%	-100%	11%	7%	26%	19%	10%	6%
Wetland	11%	8%	-13%	10%	62%	77%	0%	59%	60%	69%

Reference:

McCann, K. and L. Olson, Orlando Stormwater Utility, 1994, Final report on Greenwood Urban Wetland Treatment Effectiveness, Submitted to Florida Department of Environmental Protection, Stormwater/NPS Management Section, Tallahassee, Florida.

3.8.11 Packed Bed Wetland Filter System

Summary: Clear Lake is 360 acres in size and stormwater loadings from its three square mile watershed have led to serious water quality problems. An innovative stormwater treatment system was needed for this basin to both reduce pollutant load and function within a limited area where multiple demands are placed on the use of land. The constructed experimental stormwater treatment train consists of: A 3.3 acre off-line wet detention pond with a sediment trap at the inlet. Construction of diversion weirs to shunt the first flush to the wet detention pond while allowing the remaining stormwater to bypass the system. Construction of 10 packed beds consisting of five crushed concrete and five granite media beds, vegetated with four differing combinations of wetland plants. Installation of two pumps to supply water to the packed beds from both the wet detention system during storms and from Clear Lake during dry periods. Control valving to allow for varied water flow rates through the packed beds. Automated flow meters and composite samplers to allow storm event sampling. Monitoring was performed on the effectiveness of the overall system, the performance of the individual beds, and the best flow rate at which to operate the system (30, 60, or 120 gal/min). Analysis of the individual beds showed consistent removal across all beds for cadmium, copper, lead, zinc, total nitrogen, TKN, nitrite, total phosphorus, TSS, VSS, and fecal coliform. Among the remaining parameters, chromium, ammonia, nitrate, orthophosphorus, TDS, and TOC, pollutant removals within bed 6 were consistently low at all three flow rates. Conversely, bed 5 exhibited consistently high removals for the same parameters. The high flow rate was determined to be the best operating rate for the system. Overall pollutant load reduction is presented below:

Parameter	% Removal	Parameter	% Removal	Parameter	%Removal
Cadmium	80	Total Nitrogen	63	Total phosphorus	82
Chromium	38	TKN	62	Orthophosphorus	14
Copper	21	Ammonia	6	TDS	8
Lead	73	Nitrate	75	TSS	81
Zinc	55	Nitrite	-9	VSS	80
Fecal Coliform	78	TOC	38		

Reference:

City of Orlando Stormwater Utility Bureau, 1995, Final Report on the Packed Bed Wetland Stormwater Treatment System, Submitted to Florida Department of Environmental Regulation, Stormwater/NPS Management Section, Tallahassee, Florida.

3.8.12 Bath Club Concourse Stormwater Rehabilitation Project Town of North Redington Beach, Pinellas County, Florida

Summary: The Bath Club Concourse is a combination roadway and parking lot connecting Bath Club Circle and Gulf Boulevard. Before the project, the Bath Club Concourse was totally impervious consisting of asphaltic pavement. Untreated runoff from the Concourse and its associated drainage area was directed by sheet flow into a single storm sewer inlet and discharged offsite, and ultimately to Boca Ciega Bay. The objectives of this project were: (1) to maximize the amount of stormwater runoff that could be infiltrated on-site, thereby reducing the annual volume that is discharged off-site without any treatment; and (2) to demonstrate innovative alternative approaches to treating stormwater in highly urbanized areas where land for traditional BMPs is scarce and very expensive. Drainage was redirected toward two new pervious concrete parking areas located in the center of the Concourse. These are separated by an unpaved landscaping island that also provides infiltration. To maximize infiltration of the pervious concrete parking areas, two 150-feet-long underdrains were installed in the eastern half of the project to facilitate the drainage of the subsurface soils immediately beneath the pervious concrete. The project improvements resulted in a significant reduction of direct discharge of stormwater runoff from the site. Calculations accounting for average annual rainfall and runoff, as well as pore space volume and subsurface water flow, indicate that the improvements caused a 33% reduction in total on-site runoff volume between the pre- and post-project conditions. Further, the volume of surface runoff discharging directly to Boca Ciega Bay was reduced by about 75%. Calculated overall removal efficiencies for the project are based on the efficiency of the underdrain/filter system to remove pollutants and are indicated as follows:

Parameter	Lead	Zinc	TSS	BOD	TP	OrthoP	TN
% Removal	73	72	73	61	49	26	65

Reference:
Bateman, M., Livingston, E.H., Cox, J., 1998, Overview of Urban Retrofit Opportunities in Florida, in National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments Proceedings Chicago, IL, February 9-12, 1998, p. 166.

3.8.13 Sunset Drive Outfall Stormwater Rehabilitation Project, City of South Pasadena, Pinellas County, Florida

Summary: The Sunset Drive drainage basin is nearly fully developed and consists of approximately 55% impervious area. Historically, stormwater was collected and discharged untreated to a local storm sewer which connects to a City of St. Petersburg storm sewer main. This storm sewer main ultimately discharges to Boca Ciega Bay. The objectives of this project were: (1) to reduce stormwater pollutant loading to Boca Ciega Bay by incorporating an inline sediment sump/oil and grease skimmer in the Sunset Drive storm sewer system before its junction with the larger storm sewer main; and (2) to demonstrate innovative alternative approaches to treating stormwater in highly urbanized areas where land for traditional BMPs is scarce and very expensive. The sump was designed, to the extent possible, to meet the current rule requirements for this type of system. Due to physical limitations, the design provided for the storm sewer flow to be diverted to the area of an existing greenspace for treatment, prior to being diverted back to the main flow path of the storm sewer. The greenspace, which is adjacent to the bay, was modified into an open, linear wet-sump, which included energy dissipaters and a skimmer baffle. The project also included an attractive boardwalk around and over the facility as well as plantings of salt marsh vegetation in the sump's littoral zone. The project provides an opportunity to trap and retain sediment and other suspended materials as small as 0.1 mm in diameter. A corresponding reduction in other urban pollutants typically associated with suspended solids such as heavy metals, bacteria, and oxygen demanding substances can also be expected. The sediment load reduction to Boca Ciega Bay is estimated to be approximately 24.5 cubic yards per year.

Reference:
Bateman, M., Livingston, E.H., Cox, J., 1998, Overview of Urban Retrofit Opportunities in Florida, in National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments Proceedings Chicago, IL, February 9-12, 1998, p. 166.

3.8.14 Jungle Lake Water Quality and Habitat Enhancement, Southwest Florida Water Management District

Summary: Walter Fuller Park is a highly used recreational/athletic park located in the western part of the city of St. Petersburg, approximately 2.5 miles east of Boca Ciega Bay. Jungle Lake was excavated about 75 years ago to provide fill for the construction of local roads. The 11.2 acre kidney-shaped lake received untreated stormwater from five inflows and discharges to the bay via a single outflow. During most storms, runoff bypassed Jungle Lake and was discharged directly to the bay. To improve the quality of water in the lake and that which is discharged to the bay, a BMP treatment train was constructed. The system includes: A diversion weir so that most stormwater is routed into the lake for treatment instead of directly into the bay, Modification of the inflow ditches to create shallow sloughs vegetated with native aquatic macrophytes. Expansion of the lake to create littoral zones vegetated with macrophytes. Two partially submerged berms which produce a longer flow path, increase residence time, provide natural habitat, and replace park uplands resulting from the lake perimeter modifications. Sediment sumps at the northeastern and southeastern inflows. An oil and grease skimmer on the outfall structure. Over 15,000 herbaceous plants consisting of 11 species, 170 trees, and 700 shrubs.

Reference:

Macrina, J. J. and D. M. Vickstorm, 1985, Jungle Lake Water Quality and Habitat Enhancement, Proceedings of the Fourth Biennial Stormwater Research Conference, SWFWMD, Brooksville, Florida.

3.8.15 BMP Treatment Train in the Florida Keys, City of Key Colony Beach, Florida

Summary: Recognizing the importance of reducing stormwater pollution in protecting its sensitive natural resources, the City included in its comprehensive plan policies requiring the retrofitting of its existing drainage system. With technical assistance from the DEP and the SFWMD, the City's consultant developed a stormwater master plan in 1993. The plan included plugging 28 existing stormwater outfalls and constructing a retention basin and swales with raised inlets and exfiltration trenches which overflow into injection wells. Implementation of the master plan began in 1995, and is scheduled for completion by the year 2000. Phase 1 has been completed and Phase 2 will be completed by the fall of 1998. The stormwater master plan calls for the construction of 82,146 linear feet of swales, 9 modified raised swale inlets, about 60,000 linear feet of exfiltration trench, 35 inlet baffle systems to direct the first flush into the exfiltration trenches, and 22 injection wells. Actual stormwater monitoring will not begin until the completion of Phase 2. By plugging the direct stormwater discharges to surface waters and providing storage and treatment for the first 1.5 inches of runoff, the stormwater volume and pollutant loadings will be substantially reduced. Modeling indicates that these will be reduced by up to 75% from pre-project conditions.

Reference:

Greiner Engineering, 1993, City of Key Colony Beach Stormwater Master Plan (Stormwater Retrofit Project).

3.8.16 Silver Star Road Detention Pond, Orlando, Florida

Summary: The study examines the efficiency of a detention pond/wetland system for temporary storage of urban stormwater runoff from a Florida Department of Transportation roadway. The system is an online temporary storage pond-wetland system in series. The study documents the regression efficiency for 22 constituents. Thirteen storms were monitored. The author concludes that the pond generally reduced suspended constituent loads (TSS, 65%, suspended Pb, 41%, suspended Zn, 37%, Suspended N, 17%, and suspended P, 21%). Additionally, the wetland was generally effective in reducing suspended constituent loads. (TSS, 66%, Pb 75%, Zn, 50%, N, 30%, P, 19%), and dissolved loads (TDS, 38%, Pb, 54%, Zn, 75%, N, 13%, P, 0%). The system was quite effective at reducing pollutant loads. One of the most interesting aspects of the article is the use of an efficiency calculation method termed the "regression efficiency". This method is carried out by regressing loads-out as a function of loads-in with the intercept of the regression constrained to the origin. The regression efficiency is thus defined as unity minus the regression slope. The regression efficiency assumes that the efficiency is the same for all storms and that the storms monitored are representative of all storms for the BMP.

Reference: International Stormwater BMP Database Basic Database

3.8.17 Lake Munson Retention Pond (Wet) - Surface Pond with a Permanent Pool Tallahassee, Florida

Summary: The study examines the long term performance of a wetland/lake system for stormwater discharge and wastewater effluent discharge. This paper studies a 255-acre wetland/lake system which has received wastewater effluent and stormwater discharges for over 30 years. Six storms were sampled upstream and three storms downstream of the lake. The study documents the constituent removal efficiency for 25 parameters. Lake Munson displays removal rates that would be commonly expected from relatively new wet detention ponds having similar dimensions and stormwater loading rates. The lake system was effective at retaining particulate material from incoming stormwaters (turbidity 87% removal, suspended solids 95% removal, total P 64% removal, total N 31% removal, BOD 20% removal, TOC 24% removal, total Cr 78% removal, total Cu 72% removal, total Pb 91% removal). Dissolved organic nitrogen and orthophosphate had negative removal rates of -15% and -50%, respectively. The following general conclusions were also made. The author suggests a design criteria to provide twice the volume of the average storm event in order to reduce the impact of any one storm on pond water quality. The Lake Munson performance was surprising because the system has received heavy nutrient loads from wastewater and stormwater discharges for over 30 years and has never been maintained. Removal efficiencies increased rapidly with increasing pond surface area up to a point of diminishing returns beyond which efficiencies improved little with increasing pond area. Removal of suspended material was insensitive to pond depths. Phosphorous removal rates were sensitive to increasing pond depths versus pond area, particularly for pond areas larger than 1.5 to 2.0 percent of the watershed.

Reference: International Stormwater BMP Database Basic Database,

3.8.18 Application of Stormwater Best Management Practices on Constrained Sites – Hunter's Spring Park Case Study

Summary: The Southwest Florida Water Management District (District) and the City of Crystal River jointly funded a stormwater Best Management Practice (BMP) demonstration project at the City's Hunter's Spring Park. Hunter's Spring Park is the only public swimming facility on Kings Bay, an Outstanding Florida Waters (OFW). Due to this limited access to the bay this small park, heavily used by local residents, provides a good opportunity for public education. The park also provides a good opportunity to carry out stormwater BMPs which will reduce sediment and trash loading to the bay. Prior to construction of the BMPs, stormwater runoff from the park parking lot and a portion of Northeast I st Ave. discharged directly into Hunter's Spring Cove. Oils and greases, sediment and trash readily washed into the cove following storm events. In addition, a portion of the parking lot and road were subject to tidal inundation at times of extreme high tides. This provided a unique challenge to the design and construction of a stormwater treatment system. The project improvements consisted of the implementation of a *treatment* train: reduction of impervious cover, vegetative conveyance swale and vegetative filter area.

Reference:

Stevens, S.E., and Flint, M.J., (date not specified) Southwest Florida Water Management District, Surface Water Improvement and Management Department, 7601 Highway 301 North, Tampa Florida 33637.

3.8.19 Infiltration Opportunities in Parking Lot Designs Reduce Runoff and Pollution

Summary: 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.

Reference:

Rushton, B., 2002, Infiltration Opportunities in Parking Lot Designs Reduce Runoff and Pollution, In: Seventh Biennial Stormwater Research & Watershed Management Conference May 22-23, 2002, p. 146-155.

3.8.20 Stormwater Management and Implementation of BMPs at Miami International Airport

Summary: Miami-Dade Aviation Department (MDAD) began a $5.4 billion capital improvement program (CIP) at Miami International Airport (MIA) in 1990. A key element in the planning and environmental permitting is the Stormwater Master Plan (SWMP, CDM 1992) for the 5 square mile airport in urban Miami. The SWMP included comprehensive evaluations of hydrology, hydraulics, water quality, Best Management Practices (BMPs), and facility planning in phases to allow cost-effective implementation of the CIP while aircraft operations continued and increased to serve growing air traffic demands. A variety of constraints were identified including the protection of aircraft passenger safety (no fog or bird attractants) and the environment (water quality, manatees, and hazardous material cleanups). Aircraft passenger safety issues regulated by the Federal Aviation

Administration (FAA) had to be balanced versus the environmental requirements of the United States Environmental Protection Agency (USEPA), South Florida Water Management District (SFWMD), and Miami-Dade Department of Environmental Resource Management (DERM). MDAD has proactively implemented a BMP Treatment Train, which includes a series of activities to reduce nonpoint source pollutant load generation and to remove pollutants from the runoff prior to discharge. The BMP Treatment Train has been shown by water quality monitoring to cost-effectively treat runoff from the airport to meet federal, state, and local standards and permit requirements. Implementation has been coordinated with a $5.4 billion CIP to allow timely and appropriate retrofits to the system. This paper presents an overview of the MIA Stormwater Management Program and a summary of the successful implementation of the BMP Treatment Train.

Reference:

Schmidt, P.E., Pantoja, N.B., Lopez-Blazquez, L., 2002, Stormwater Management and Implementation of BMPs at Miami International Airport, Camp Dresser & McKee, Inc., Miami - Dade Aviation Department, Dade Aviation Consultants

3.8.21 Stormwater Quality Management Using a Combined Wet-Detention Sand-Filter Stormwater Facility

Summary: Due to the extent of clay soils throughout the City of Tallahassee, stormwater quality treatment has been limited to wet detention. A stormwater quality facility which combines wet detention with side-bank sand-filtration was constructed to treat stormwater in conjunction with storage and attenuation. The facility consists of a 1.21 ha (3.0 A) wet-detention facility and a 48.14 rn3 (1,700 ft) side-bank sand filter. Stormwater samples were collected during a two-year permit period to evaluate the ability of the pond and sand filter to treat selected pollutants. Mass balance sampling was conducted during the winter and summer seasons to evaluate the ability of the combined facility to retain pollutants. Attenuation event sampling was conducted throughout the period in an attempt to differentiate between pollutant concentrations from the combined treatment versus no treatment associated with flow-through discharge which occurs during excessive rainfall events. Preliminary findings of the mass balance sampling reveal that pollutants are retained to varying degrees and that retention of some pollutants is seasonal. Removal efficiency of Total Phosphorus averaged 67 percent, and maximum removal efficiency for metals ranged from 75 to 96 per cent. Preliminary findings from the attenuation sampling reveal sand filtration was effective in reducing the concentrations of most pollutants examined. Findings of project may be used in the development and calibration of pollutant loading models and establishment of realistic goals for pollution load reduction.

<u>Reference</u>:

Gowan, T.D., and Watkins, C.E., 1997, Stormwater Quality Management Using a Combined Wet-Detention Sand-Filter Stormwater Facility, *In*: Fifth Biennial Stormwater Research Conference November 5- 7, 1997, p. 98-106.

3.8.21 <u>Greenwood Urban Wetland Treatment Effectiveness</u>

<u>Summary</u>: The Greenwood Urban Wetland treats stormwater runoff from a 527 acre sub-basin in downtown Orlando Florida. Thirteen acres of ponds with a sediment control basin, pond aeration and an irrigation system reusing stormwater were incorporated into the design for pollutant removal efficiencies. The City of Orlando conducted a study on the Greenwood Urban

Wetland to determine the pollutant removal efficiency of the sediment basin and wetland system in removing pollutants associated with stormwater runoff. Results of the study indicated that the sediment basin removed total phosphorus and ortho phosphate at a removal efficiency of 11.4% and 7.4% respectively. The sediment basin removed total nitrogen and nitrate at removal efficiencies of 3.7% and 16.0% but exported ammonia and nitrite with removals of -100.5% and -76.2% respectively. Removal efficiencies for cadmium, copper, lead and zinc were 25.8%, 18.6%, 9.6% and -5.9% respectively. Pollutant removal efficiency of the wetland system was reduced due to high groundwater inflows. Total phosphorus and ortho phosphate had removal efficiencies in the wetland of 61.5% and 76.7% respectively. The wetland system performed poorly at removing nitrogen. Data indicated removal efficiencies for total nitrogen, ammonia, nitrate and nitrite at 11.0%, 10.2%, -13.2% and 8.1% respectively. Cadmium, copper, lead and zinc were removed in the wetland at removal efficiencies of 0.0%, 58.9%, 59.7% and 68.9% respectively.

Reference:

McCann, K., and Olson, L., 1994, Final Report on Greenwood Urban Wetland Treatment Effectiveness, Prepared by City of Orlando Stormwater Utility Bureau for the Florida Department of Environmental Protection, 18 p.

Palmer, C.N. and Hunt, J.D., 1989, Greenwood Urban Wetland: A man-made Stormwater Treatment Facility, p. 205-214, In: D.W. Fisk (*ed*); Wetlands: Concerns and Successes. Proceedings, American Water Resources Association Symposium in Tampa, Florida, Sept. 17-22, 1989.

3.9 Non-Structural BMPs

3.9.1 Integration of the Florida Yards and Neighborhoods Program into Stormwater Planning for Nutrient Removal

Summary: Stormwater from residential areas is estimated to contribute more than one-third (33%) of the total nitrogen load to Sarasota Bay. The Florida Yards and Neighborhoods Program (FYN) was developed in 1993 to promote environmentally friendly landscaping with plants suited to the Southwest Florida Climate, natural conditions, and wildlife. Using the FYN principles, homeowners can reduce fertilizer and pesticide use, possibly improving the quality of stormwater runoff. West-central Florida has been under severe drought conditions for over two years, and landscape irrigation can account for more than 40% of a homeowner's water usage. Research being conducted by the University of Florida/IFAS will provide information that demonstrates the value of the Florida Yards and Neighborhoods Program as an aid in the improvement of water quality. Current research consists of two projects: 1) a set of replicated plots at the Ft. Lauderdale IFAS center, and 2) examination of the effects of Florida Yards and Neighborhoods in actual residential communities. The FYN program is presented directly to the general public as a tool that, if implemented at large enough scale, may help improve water quality in local streams and estuarine waters. To this end, the Sarasota County (Florida) Board of County Commissioners recently approved a bill requiring FYN-type landscapes be used in any new developments built within County limits.

Reference:

Raulerson, G.E., Alderson, M., Cisar, J.L., Snyder, G.H., 2002, Integration of the Florida Yards and Neighborhoods Program into Stormwater Planning for Nutrient Removal, In: Seventh Biennial Stormwater Research & Watershed Management Conference May 22-23, 2002, p. 204-212.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Existing and ongoing studies of stormwater treatment BMPs in southwest Florida is limited at this time. Based on this literature review, BMP research is primarily being performed on detention systems, which is the most common stormwater treatment system in southwest Florida. The studies of detention system concentrate on the impact of littoral plantings, evaluation of different depths with aeration, and roadway pollutant removal efficiency. Other stormwater treatment BMP research in southwest Florida includes infiltration (*e.g.*, porous pavement evaluation), minimizing directly connected impervious surfaces (*e.g.*, green roof), and miscellaneous/vendor-supplied systems (e.g., Leitner Creek By-Pass).

A fair amount of research of stormwater treatment BMPs has been performed in other areas of Florida. The majority of the existing research has focused on detention systems and treatment trains that utilize a combination of structural BMPs. In addition, some research has been performed on the pollutant removal efficiency of wetlands and vendor-supplied systems. Very little research has been performed on non-structural BMPs in Florida. This is likely due to the inherent difficulties in measuring the success of such systems without controllable boundaries (*e.g.,* inlets and outlets).

Based on the paucity of data from existing stormwater treatment BMPs in southwest Florida, Johnson Engineering recommends that research be performed on those BMPs most commonly permitted and installed (*e.g.*, wet detention).

JOHNSON ENGINEERING

5.0 REFERENCES

American Society of Civil Engineers (ASCE), 2002, Urban Stormwater BMP Performance Monitoring, A Guidance Manual for Meeting the National Stormwater BMP Database Requirements, Prepared by GeoSyntec Consultants, Urban Drainage and Flood Control District, EPA, EPA-821-B-02-001, April 25, 002.

Bahk, B., and Kehoe, M., 1997, A Survey of Outflow Water Quality from Detention Ponds in Agriculture, Southwest Florida Water Management District, 42 pages.

Bateman, M., Livingston, E.H., and Cox, J., 1998, Overview of Urban Retrofit Opportunities in Florida, National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments, Proceedings Chicago, IL February 9-12, 1998, EPA/625/R-99/002, July 1999.

Camp, Dresser, and McKee, 1995, Final Report on the City of Oakland Park Stormwater Demonstration Grant Project, Submitted to Florida Department of Environmental Protection, Stormwater/NPS Management Section, Tallahassee, Florida.

Carr, D.W., 1999, An Assessment of an In-Line Alum Injection Facility Used to Treat Stormwater Runoff in Pinellas County, Florida, Proceedings of the Sixth Biennial Stormwater Research and Watershed Management Conference, September 14-17, 1999, p. 68-79.

Carr, D. W., 1998, An Assessment of an In-line Alum Injection Facility Used to Treat Stormwater Runoff in Pinellas County, Florida, Southwest Florida Water Management District, 36 pages.

Carr, D.W., and Kehoe, M.J., 1997, Outfall Water Quality from Wet-Detention Systems, Southwest Florida Water Management District, 36 pages.

Carr, D.W., and Rushton, B.T., 1995, Integrating a Native Herbaceous Wetland into Stormwater Management, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609, 131 pages.

Carr, D.W., 1994, Management of stormwater runoff for water quality using an isolated natural wetland, Lake Reserv. Manage., vol. 9, no. 2, p. 63, 1994.

Creech Engineers, Inc., 2001, Pollutant Removal Testing for Suntree Technologies

Cunningham, J., 1993, Comparative water quality data of a deep and a shallow wet detention pond, In Proceedings of the 3rd Biennial Stormwater Research

Conference, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609.

Dierberg, F.E., Cullum, M.G., 1988, Evaluation of Dry Detention/Filtration Stormwater Management System Receiving Runoff from a Mixed Urban Land Use, 8th Annual International Symposiun on Lake and Watershed Management, p. 29.

England, G., and Royal, J, Sedimentation Control Using Two Baffle Boxes in Series, Creech Engineers and Brevard County Surface Water Improvement

England, G., 1999, Baffle Boxes and Inlet Devices for Stormwater BMPs, 6 p.

Esry, D.H., and Cairns, D.J., 1989, Overview of the Lake Jackson Restoration Project with Artificially Created Wetlands for Treatment of Urban Runoff, p. 247-257, in: D.W. Fisk (ed.), Wetlands, Concerns and Successes. Proceedings, American Water Resources Association Symposium in Tampa, Florida, Sept. 17-22, 1989.

Fries, B.M., 1986, Fate of Phosphorus from Residential Stormwater Runoff in a Southern Hardwood Wetland, Thesis, Master of Science in Engineering, University of Central Florida, Orlando, Florida.

Goldstein, A.L., 1982, Utilization of a Freshwater Marsh to Treat Rainfall Runoff From Upland Pasturelands, Presented at Univ. of Florida et al, Nonpoint Pollution Control Technology in Florida Symposium, Gainesville, Florida, March 9-10, 1982, page 106-126.

Gowan, T.D., and Watkins, C.E., 1997, Stormwater Quality Management Using a Combined Wet-Detention Sand-Filter Stormwater Facility, *In*: Fifth Biennial Stormwater Research Conference November 5- 7, 1997, p. 98-106.

Greiner Engineering, 1993, City of Key Colony Beach Stormwater Master Plan (Stormwater Retrofit Project).

Hampson, P.S., 1986, Effects of Detention on Water Quality of Two Stormwater Detention Ponds Receiving Highway Surface Runoff in Jacksonville, Florida, USGS Water Resources Investigations Report 86-4151, 69 p, 20 fig, 16 tab, 34 ref, 2 append.

Harper, H.H., Herr, J.L., Baker, D., Livingston, E.H., 1999, Performance Evaluation of Dry Detention Stormwater Management Systems, Proceedings of the Sixth Biennial Stormwater Research and Watershed Management Conference, September 14-17, 1999, p. 162-178.

Harper, H.H., Herr, J.L., 1992, Stormwater Treatment Using Alum, Public Works Magazine PUWOAH, Vol. 123, No. 10, p 47-49, 89-90, September 1992. 1 fig, 1 tab.

Harper, H.H., 1990, Final Report on the Long Term Performance of the Alum Stormwater Treatment System at Lake Ella, Florida, Submitted to Florida Department of Environmental Regulation, Stormwater/NPS Management Section, Tallahassee, Florida.

Harper, H.H., Wanielista, M.P., Fries, B.M., and Baker, D.M., 1986, Stormwater Treatment by Natural Systems, Florida Department of Environmental Regulation, Star Project number 84-026, 331 pages.

Harper, H.H., Pollutant Removal Efficiencies for Typical Stormwater Systems in Florida, Environmental Research & Design, Inc., 3419 Trentwood Blvd., Suite 102, Orlando, Florida 32812-4863, 11 p.

Herr, J.L., Harper, H.H., 1997, The Evaluation and Design of an Alum Stormwater Treatment System to Improve Water Quality in Lake Maggiore in St. Petersburg, Florida, In: Fifth Biennial Stormwater Research Conference, November 5- 7, 1997.

Holler, J.D., 1990, Nonpoint Source Phosphorus Control by a Combination Wet Detention/Filtration Facility in Kissimmee, Florida, FLA. SCI., vol. 53, no. 1, pp. 28-37.

Holler, J.D., 1989, Water Quality Efficiency of an Urban Commercial Wet Detention Stormwater Management System at Boynton Beach Mall in south Palm Beach County, Florida, Florida Scientist. Orlando Florida, vol.52, no.1, pp.48-57.

Howard, R.M., 1994, Packed bed filter system, Lake Reserv. Manage, vol. 9, no. 2, p. 83.

International Stormwater BMP Database Basic Database, http://www.bmpdatabase.org/

Kehoe, M.J., Dye, C.W., and Rushton, B.T., 1994, A Survey of the Water-Quality of Wetlands-Treatment Stormwater Ponds, Southwest Florida Water Management District, 42p.

Kehoe, M.J., 1993, Water Quality Survey of Twenty-Four Stormwater Wet-Detention Ponds, Southwest Florida Water Management District, 84 pages.

Knight, R.L., Winchester, B.H., and Higman, J.C., 1985, Ecology, Hydrology, and Advanced Wastewater Treatment Potential of an Artificial Wetland in North-Central Florida, Wetlands 5: 167-180 (Journal of the SWS).

Kollinger, R.J., 1999, Stormwater Retrofit of the Abandoned Jan-Phyl Wastewater Treatment Plant Site, Proceedings of the Sixth Biennial Stormwater Research and Watershed Management Conference, September 14-17, 1999, p. 238-247.

Kurz, R. C., 1998, Removal of Microbial Indicators form Stormwater Using Sand Filtration, Wet Detention, and Alum Treatment Best Management Practices, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609, 169 pages.

Macrina, J. J. and D. M. Vickstorm, 1985, Jungle Lake Water Quality and Habitat Enhancement, Proceedings of the Fourth Biennial Stormwater Research Conference, SWFWMD, Brooksville, Florida.

Maristany, A.E.; Bartel, R.L., 1989, Wetlands and Stormwater Management: A Case Study of Lake Munson, Part I: Long-Term Treatment Efficiencies, In: Wetlands: Concerns and Successes, Proceedings of a Symposium held September 17-22, 1989, Tampa, Florida, American Water Resources Association, Bethesda, Maryland, p. 215-229, 7 fig, 6 tab, 8 ref.

Martin, E.H., The Effectiveness of a Detention Pond and Wetlands System in Reducing the Amounts of Lead Transported by Urban Stormwater Runoff, U.S. Geological Survey, Orlando, Florida.

Martin, E. H., 1988, Effectiveness of an Urban Runoff Detention Pond - Wetlands System, Journal of Environmental Engineering (ASCE) JOEDDU, Vol. 114, No. 4, p 810-827, August 1988, 4 fig, 5 tab, 11 ref.

McCann, K. and L. Olson, Orlando Stormwater Utility, 1994, Final report on Greenwood Urban Wetland Treatment Effectiveness, Submitted to Florida Department of Environmental Protection, Stormwater/NPS Management Section, Tallahassee, Florida.

Nepshinsky, J., Dewey, C., Victor, P., and Brown R., 1995, Water Quality Assessment of Permitted Stormwater Management Systems, St. Johns River Water Management District, 12 p.

Northwest Florida Water Management District, 1992, Lake Jackson Regional Stormwater Retrofit Plan, Water Resources Special Report 92-1, Havana, Florida.

Northwest Florida Water Management District, 1990, Final Report on the Expansion of the Lake Jackson Stormwater Treatment Facility, Submitted to Florida Department of Environmental Regulation, Stormwater/NPS Management Section, Tallahassee, Florida

Northwest Florida Water Management District, 1984, Final Construction Report - Lake Jackson Clean Lakes Restoration Project, Submitted to Florida Department of Environmental Regulation, Bureau of Operations, Tallahassee, Florida.

City of Orlando Stormwater Utility Bureau, 1995, Final Report on the Packed Bed Wetland Stormwater Treatment System, Submitted to Florida Department of Environmental Regulation, Stormwater/NPS Management Section, Tallahassee, Florida.

Palmer, C.N. and Hunt, J.D., 1989, Greenwood Urban Wetland: A man-made Stormwater Treatment Facility, p. 205-214, In: D.W. Fisk (ed); Wetlands: Concerns and Successes. Proceedings, American Water Resources Association Symposium in Tampa, Florida, Sept. 17-22, 1989.

Raulerson, G.E., Alderson, M., Cisar, J.L., Snyder, G.H., 2002, Integration of the Florida Yards and Neighborhoods Program into Stormwater Planning for Nutrient Removal, In: Seventh Biennial Stormwater Research & Watershed Management Conference May 22-23, 2002, p. 204 --212.

Rushton, B., 2002, Infiltration Opportunities in Parking Lot Designs Reduce Runoff and Pollution, In: Seventh Biennial Stormwater Research & Watershed Management Conference May 22-23, 2002, p. 146-155.

Rushton, B. T., 2001, Treatment of Stormwater Runoff from an Agricultural Basin by a Wet-Detention Pond in Ruskin, Florida, DEP Contract Number WM 539, Southwest Florida Water Management District.

Rushton, B.T., and Hastings, R., 2001, Florida Aquarium Parking Lot: A Treatment Train Approach For Stormwater Management, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609

Rushton, B.T., 1998, Sources and Sinks for Stormwater Pollutants, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609.

Rushton, B.T., Miller, C., Hull, C., and Cunningham, J., 1997, Three Design Alternatives for Stormwater Detention Ponds, Southwest Florida Water Management District, 2379 Broad Street, Brooksville, Florida 34609, 59 pages.

Rushton, B.T. and Dye, C.W., 1993, An In-Depth Analysis of a Wet Detention Stormwater System, Southwest Florida Water Management District, 2379 Broad Street, Brooksville,Florida 34609, 121 pages.

Small, M.M., 1978, Artificial Wetlands as Nonpoint Source Wastewater Treatment Systems, In: Environmental Quality Through Wetlands Utilization, Proceedings from a Symposium Sponsored by the Coordinating Council on the Restoration of the Kissimmee River, Feb 28, Tallahassee, Florida.

Schmidt, P.E., Pantoja, N.B., Lopez-Blazquez, L., 2002, Stormwater Management and Implementation of BMPs at Miami International Airport, Camp Dresser & McKee, Inc., Miami - Dade Aviation Department, Dade Aviation Consultants

Snell, E., Site Evaluation of Suntree Technologies, Inc. Grate Inlet Skimmer Boxes for Debris, Sediment, and Oil & Grease Removal, Reedy Creek Improvement District Planning & Engineering Department, 4 p.

Stoker, Y.E., 1996, Effectiveness of a Stormwater Collection and Detention System for Reducing Constituent Loads from Bridge Runoff in Pinellas County, Florida, U.S. Geological Survey, Open-File Report 96-484.

Strecker, E., Quigley, M, Urbonas, B., and Jones, J., 2004, Stormwater Management, State-of-the-Art in Comprehensive Approaches to Stormwater., The Water Report, Issue #6, August 15, 2004.

Stormwater Authority, Stormwater Library, http://www.stormwater-resources.com

Strynchuk, J., Royal, J., England, G., 2000, Continuous Deflection Separation (CDS) Unit for Sediment Control In Brevard County, Florida, Brevard County Surface Water Improvement, 35 p.

Stevens, S.E., and Flint, M.J., Southwest Florida Water Management District, Surface Water Improvement and Management Department, 7601 Highway 301 North, Tampa Florida 33637.

Tuovila, B.J., Outland, J.B., Esry, D.H., and Franklin, M., 1987, An Evaluation of the Lake Jackson (Florida) Filter system and Artificial Marsh on Nutrient and Particulate Removal from Stormwater Runoff, p. 271-278, In: K.R. Reddy and W. H. Smith (eds.) 1987, Aquatic Plants for Water Treatment and Resource Recovery, Magnolia Publishing, Inc.

Urban Drainage and Flood Control District (UDFCD), 1992, Urban Storm Drainage Criteria Manual, Volume 3 – Best Management Practices, Urban Drainage and Flood Control District, Denver, Colorado.

United States Environmental Protection Agency (EPA), 1999, Preliminary Data Summary of Urban Storm Water Best Management Practices, EPA-821-R-99-012.

Wanielista, M., Charba, J., Dietz, J., Russell, B., 1991, Evaluation of the Stormwater Treatment Facilities at the Lake Angel Detention Pond, Orange County, Florida, Final report, 2 Jan 90-1 Jul 91.

Wanielista, M.P., Yousef, Y.A., et al., 1986, Best Management Practices - Enhanced Erosion and Sediment Control Using Swale Block, Florida Department of Transportation

Wanielista, M.P., et al., 1978, Shallow-Water Roadside Ditches for Stormwater Purification, Florida Department of Transportation

Yousef, Y.A., Wanielista, M.P., et al., 1985, Best Management Practices - Removal of Highway Contaminants by Roadside Swales, Fl-ER-30-85, Florida Department of Transportation, Tallahassee, Florida; FDOT-ER-34-86.