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Water Quality Division
Resource Planning Department
South Florida Water Management District

EXECUTIVE SUMMARY

Stormwater runoff has long been recognized as a major pollution source. This assessment was initiated to address two objectives relative to stormwater runoff and its treatment. The first objective was to assess reported stormwater runoff quality for differing land uses throughout the United States, with a focus on data collected within the state of Florida. Stormwater runoff quality is believed to vary with the land use generating the runoff. The second objective of this publication was to evaluate the data reported in the literature concerning the treatment efficiencies associated with the various stormwater management systems. Treatment of stormwater runoff has been accomplished through the use of various water management systems and is permitted under regulatory requirements by the South Florida Water Management District (SFWMD).

Fortunately, a large body of information on stormwater runoff exists, and was partially summarized in the National Urban Runoff Program study (United States Environmental Protection Agency, 1983). In addition, the state of Florida contains several agencies and organizations that have conducted extensive studies in the area of stormwater runoff and treatment. Among those that should be noted are the Florida Department of Environmental Regulation, the University of Florida, the University of Central Florida, the United States Geological Survey, and the consulting firm of Camp, Dresser and McKee, along with the staff of the Resource Planning Department of the SFWMD. Reports from these agencies and organizations form the backbone of data available in the state of Florida for stormwater runoff and are referenced extensively in this publication. Studies that are on going or planned for the near future will add to the knowledge available in the field of stormwater research and will aid in understanding the benefits, and more importantly, the constraints associated with the treatment of this nonpoint source of pollution.

One conclusion of this report that can be stated is that for selected constituents, runoff water quality varies with land use. The land use types that were evaluated and compared in this assessment include residential, commercial, light industrial, roadway, and mixed urban. Statistical differences between runoff water quality parameters and land use classification were evaluated by using the Duncan's multiple-range test. Higher nutrient loads are generated by residential land uses than commercial, mixed urban, light industrial, or roadways. Metal contamination is more widespread from commercial and roadway projects than from residential, light industrial, or mixed urban land uses. Residential and roadway areas demonstrated higher export potential for chemical oxygen demand. There are no discernable trends for suspended solids export as a function of land use. Urban roadway projects generally have higher overall pollutant loadings than rural roadway projects. Limited data indicates that organic contamination in the form of polycyclic aromatic hydrocarbons are comparable for residential, commercial, and highway sites, although significantly higher levels were found at a heavy industrial site. Any monitoring program designed for a specific land use should utilize the above information when designing the parameter listing.

Treatment for the pollution generated by stormwater runoff is required in the state of Florida through the regulatory process. There are several treatment methods that are suggested. Wet detention is the most commonly used mechanism, with approximately 70 percent of the water management systems permitted in south Florida being wet detention systems. Dry detention, and/or retention and some form of infiltration filtration are the other types of treatment mechanisms that are commonly used.

There is sufficient information in the literature to form general conclusions about the efficiencies associated with different water management system types. These conclusions are given with the assumption that the guidelines for proper construction of water management systems were followed and that operation and maintenance procedures for the systems are followed post construction. These conclusions are founded on results from multiple studies where there is a general consensus.

Retention systems, which include grassed swales, achieve upwards of a 90 percent reduction for nutrients and solids. The calculations for treatment efficiencies for retention systems usually did not consider sub-surface flow, and the impacts on local ground water from these systems have not been fully determined. The issue of ground water impacts from all water management systems has become one of the most significant questions to stormwater researchers and will be addressed in the near future by on-going studies.

Wet detention basins provide good to excellent pollutant removal efficiencies for suspended solids, metals, and nutrients. The standing water column provides for several physicochemical processes to achieve pollutant removal (sedimentation, degradation, and vegetative up-take). However, the majority of studies concentrated on pollutant removals from surface water only. Ground water transport of pollutants is a potential threat. The total system must be evaluated, surface water and ground water, to determine an accurate treatment efficiency for the stormwater system.

Treatment of stormwater by use of dry detention basins is generally considered to be inferior to that achieved by wet detention. There is limited data available on dry detention basin treatment efficiencies. However one study, which was performed in the northeast United States, showed negative removals for total nitrogen and NO_x, as well as lower total phosphorus removals. The reason for the low removals was probably due to the absence of a standing water column, which provides a means for more extensive biological treatment.

Swale systems permitted in south Florida usually act as retention systems or have higher exposure to filtration mechanisms such as surface area of grass/volume of water. Swale systems have shown high pollutant removal efficiencies, similar to retention systems. More data is needed on swale systems to determine ground water contamination pollution potential.

Stormwater treatment levels associated with wetlands vary with the type of wetland in question and the age of the wetland. Some studies have shown wetlands to produce a net export of nutrients due to seasonality of vegetation. Further studies should be performed on the possible detrimental effects of concentrated urban runoff routed to different wetland type areas.

Porous pavement does not appear to be viable stormwater management alternative. These systems have limited life hydrologically and are questionable at best at providing water quality treatment. Sweeping shows potential as a supplemental practice, which may aide in lowering the amount of pollutants available to stormwater runoff.

Stormwater runoff is highly variable from different land use areas. Thus, prescribing one stormwater treatment system as a cure-all is not practical. Stormwater treatment systems should be chosen on a site specific basis. A combination of treatment methods (e.g., sweeping, pretreatment with swales, detention) may prove to be the most successful schemes.

Based upon this assessment of urban stormwater runoff and treatment, several recommendations are proposed.

1. This assessment should be used as a reference guide when the SFWMD's Resource Control Department commences reevaluation of stormwater management regulations for <u>Permit Information Volume IV</u>, Basis of Review.

2. Roadway stormwater runoff, both in perception and in fact, contains pollutants at levels equal to commercial and industrial land use areas. Concurrent planning for water resources and transportation is strongly recommended to allow sufficient right-of-way for the construction of these improved water management systems.

3. Based on limited data from studies outside of Florida, dry detention basins may not provide a level of stormwater treatment which warrants the allowance of credits. Elimination of these credits should be considered if studies within the District substantiate these findings.

4. Future research should include the examination of ground water contamination potential from retention/detention facilities and provide recommendations to rule changes if ground waters are being affected.

5. Little information exists on stormwater runoff quality from golf courses and golf course communities in south Florida. This urban land use type has the potential for contributing significant nutrient and pesticide loadings to the receiving waters and should be the focus of a future monitoring study.

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ABSTRACT

The South Florida Water Management District (SFWMD) has been permitting surface water management systems since 1977 through the requirement of specific design criteria. The development of these design criteria, presented as the Basis of Review in the SFWMD's Permit Information Manual Volume IV, has been an evolutionary process. Since its inception in 1977, the Basis of Review has undergone nine revisions, expanding and including additional guidelines on water quality, ground water, and wetlands protection. The SFWMD was further delegated the sole responsibility for permitting the design and installation of stormwater management systems in 1982 by the Florida Department of Environmental Regulation.

Stormwater runoff has long been recognized as a major pollution source, and subsequently numerous books, papers, and reports have been published on the topic. The objectives of this assessment are twofold. First, assess reported stormwater runoff quality for differing land uses throughout Florida and compare to studies across the country. Second, evaluate the data reported in the literature concerning the treatment efficiencies associated with the various stormwater management systems. This information will assist with the continued development and review of stormwater management design criteria by the SFWMD.

Urban land uses evaluated and compared include residential, commercial, light industrial, roadway, and mixed urban. Data evaluation showed that for selected constituents, runoff water quality varies widely with land use. Nutrient levels were present in higher concentrations from residential sites than from commercial, mixed urban, light industrial, or roadways. Reported urban roadway runoff quality demonstrated generally higher overall pollutant loadings than rural roadway sites. Data from one study, which investigated organic contamination in the form of polycyclic aromatic hydrocarbons (PAH), indicated that residential, commercial, and roadway sites exported comparable amounts of the compounds. However, a heavy industrial site showed significantly higher PAH levels were being exported by stormwater runoff.

Data from several stormwater treatment systems were analyzed and compared. Retention systems, (e.g. grassed swales, basins) achieve upwards of a 90 percent reduction for nutrients and suspended solids. Wet detention basins were shown to provide good to excellent pollutant removal efficiencies for suspended solids, metals, and nutrients. Dry detention basins are generally considered to be inferior to that achieved by wet detention. Stormwater treatment levels associated with wetlands seems to be moderate at best. Several studies have shown that although wetlands appeared to provide good pollutant removals on an individual storm basis, long term effects such as seasonality of vegetation may actually produce a net export of nutrients. Information reported on other treatment systems such as porous pavement and exfiltration trenches disclosed that operation and maintenance problems may exist for these alternatives.

Although stormwater treatment systems have been reported to provide a varying range of protection to receiving waters, data on potential ground water impact is sparse in the literature. This issue has become one of the most significant questions which will be addressed by stormwater researchers in the near future.

KEY WORDS

Detention

Exfiltration

Urban Land Use

Retention

Stormwater Management

Stormwater Runoff

Swales

Treatment Efficiency

Water Quality

DEFINITIONS

EMC:	abbreviation of event mean concentration. It indicates the total mass of pollutants washed off divided by the total volume of runoff for an individual storm event.
ha:	hectare or hectares, one hectare equals 2.47 acres
lb/acre/year:	pounds per acre per year
mg/L:	milligrams per liter
µg/L:	micrograms per liter

PREFACE

A primary role of the Water Quality Division's Stormwater Research Section is to provide support to the South Florida Water Management District's regulatory arm, Resource Control Department (RCD), particularly in design criteria evaluation. One of the methods by which support is being provided is the formation of basin-wide water quality criteria. This work requires the development of a computer model to predict quality criteria from selected land use types, developments, and watersheds to predict basin-wide impacts. This assessment of published stormwater management data is the first step in the calibration of such a model.

Although the development of a basin-wide water quality criteria model is a long term project, this report will provide current information to the staff of RCD for the evaluation of regulatory criteria for urban land uses.

PART I
OVERVIEW

Introduction

Stormwater runoff, as seen in current literature trends, has become recognized as a major source of water pollution in urban as well as rural land areas. Stormwater runoff may contain significant levels of various constituents and pollutants, including oxygen demand, solids, nutrients, priority pollutants, and heavy metals (Field and Szeely, 1974). The extent of stormwater runoff as an avenue of nonpoint source pollution will vary greatly with land use, geographic location, and management practices.

Due to the increasing concern over stormwater runoff being a significant pollution source in south Florida, the South Florida Water Management District (SFWMD) has taken an active role in stormwater quality research. The evaluation of a stormwater management system at a single family residential site was initiated in 1981 by the Water Quality and Water Resources Divisions of the Resource Planning Department. Stormwater research activities were expanded to a section within the Water Quality Division in January, 1987. The Stormwater Research Section's objective is to simultaneously evaluate multiple stormwater management systems and to commence watershed level modeling of nonpoint source pollution occurrence and control. These efforts are designed to provide direct support for the SFWMD's regulatory arm, the Resource Control Department.

A major step in the modeling process is to assess available published data for use as possible model input. This report fulfills that purpose for urban land uses. In addition, this report provides a concise summary of land use related water quality information and treatment efficiencies for various stormwater management systems that will assist in making regulatory decisions.

History

National

Stormwater management has gone through several major transitional changes during the past twenty years. Historical philosophies concerning stormwater runoff dealt in terms of quantity only (United States Environmental Protection Agency (USEPA), 1983). Typical practices were to route runoff into stormwater sewer systems as quickly as possible. Construction and installation of low resistance drainage channels, culverts, and conveyances, which quickly route stormwater runoff away from residential areas, parking lots, businesses, etc., also increases runoff velocities which causes downstream flooding (Rossmiller, 1981).

Urban stormwater runoff began receiving a renewed, nationwide interest during the middle 1960's when combined sewer overflows were first reported to contain suspended solids and oxygen-demanding organics at amounts comparable to untreated sanitary sewage (Sonnen, 1983). Thus, urban stormwater runoff began to be identified as a source of pollution.

Public Law 92-500, the Federal Water Pollution Control Act (FWPCA), was passed in 1972. Public Law 92-500 called for achieving "fishable" and "swimmable" water quality in surface waters throughout the United States by 1983. The FWPCA called for meeting this goal by controlling both point and nonpoint pollution discharges (Section 208, FWPCA). Initially, the emphasis was to design and build new treatment facilities to manage pollution from point sources. These actions resulted in very little progress on control of nonpoint sources (e.g. stormwater runoff). By the 1970's, the major pollution problems from point sources have been identified and considerable progress had been made in controlling and cleaning up these discharges. However, it was evident that the FWPCA's goal of achieving all inclusive "fishable" and "swimmable" water quality would not be met unless further attention was given to the control of nonpoint pollution sources. Thus, the FWPCA's Section 208 was further scrutinized, and the emphasis of controlling pollution discharge was shifted to nonpoint sources (Schad, 1984).

One of the outcomes from re-prioritizing pollution discharge research towards nonpoint source was the creation of the USEPA's National Urban Runoff Program (NURP). NURP was the largest coordination of projects ever undertaken to examine nonpoint source pollution from various urban land uses. The overall goal of NURP was to "develop information that would help provide local decision makers, states, USEPA, and other interested parties with a rational basis for determining whether or not urban runoff is causing water quality problems and, in the event that it is, for postulating realistic control options and developing water quality management plans, consistent with local needs, that would lead to implementation of least cost solutions" (USEPA, 1983). Twenty-eight cities throughout the United States were selected as NURP study sites. Most cities conducted multiple stormwater runoff studies with varying land uses (residential, commercial, open and nonurban, industrial, and mixed).

Although studies such as NURP have shown stormwater runoff is a significant nationwide contributor to nonpoint source pollution, most regulatory mandates controlling stormwater runoff are at local levels. These directives are largely accomplished through drainage and flood control rules (Sonnen, 1983). However several states, particularly Florida and Maryland, are taking an active role in providing legislation and the means to enforce rules regarding the control of hydraulic and quality aspects of stormwater runoff.

SFWMD Basis Of Review

Part IV of the Florida Water Resources Act (Act) of 1972 (Chapter 373, Florida Statutes) expanded the role of the SFWMD (then the Central and Southern Florida Flood Control District) to include a full range of water management activities in addition to flood control. The Act gave the SFWMD responsibility for permitting the construction and operation of surface water management systems (including stormwater management systems). The permitting rules, published as Chapters 40E-4 and 40E-40 Florida Administrative Code (FAC), establish guidelines for obtaining an individual or general construction/operation permit (SFWMD, 1987). In addition, the SFWMD was delegated responsibility for the regulation of stormwater discharge by the Florida Department of Environmental Regulation under Chapter 17-25.090 FAC in 1982.

The SFWMD's explanation of criteria for each construction or operation permit is presented as the Basis of Review found in the Permit Information Manual Volume IV (SFWMD, 1987). The Basis of Review was originally adopted in May, 1977. Since that time there have been nine revisions with the latest modification in April, 1987. The Basis of Review specifies requirements for both water quantity and water quality, as well as environmentally related criteria.

The Basis of Review's guideline for water quantity requires off-site discharge be limited to amounts which will not cause adverse off-site impacts, essentially pre- versus post-development discharge. This guideline expands and provides specifications for flood protection, floodplain encroachment, minimum drainage, and other conditions. A thorough explanation of water quantity requirements is presented in the Basis of Review.

The Basis of Review begins defining requirements for water quality with the statement, "Projects shall be designed so that discharges will meet state water quality standards, as set forth in Chapter 17-3 FAC". (SFWMD, 1987). Comprehensive water quality monitoring and consequently extensive agency manpower to maintain such records and enforce compliance of the literally thousands of stormwater management systems in south Florida was not deemed a feasible or effective administrative practice. Therefore, water quality standards are assumed to be achieved with "reasonable assurance" by mandating design criteria in the construction of stormwater management systems.

The primary volumetric standard for water quality treatment is calculated using a wet detention system. Wet detention systems are designed to detain the first inch of runoff from a project or 2.5 inches times the percentage of imperviousness, whichever is greater. The total volume, which must be maintained by a stormwater management system for water quality purposes, may be reduced for systems using dry detention or retention. "Credits" allowing for a reduction in required volumes are given if certain additional criteria are met. These credits may be allowed for features such as dry detention pretreatment. Complete explanations of the various stormwater management alternatives are given in the Basis of Review.

PART II
URBAN LAND USE AND STORMWATER RUNOFF QUALITY RELATIONSHIPS

Introduction

Objective

The water quality characteristics of stormwater runoff can be extremely diverse for various land uses as well as being influenced by regional conditions (i.e. rainfall patterns, seasonal temperatures, population, etc.). This part's objective is to condense and present information from studies reported in literature concerning the relationship between land use activity and stormwater runoff water quality. A literature survey of studies conducted throughout the United States has been performed. Selected studies have been summarized and runoff water quality characteristics are reported. Studies which have been performed in Florida, particularly south Florida, are duly noted.

Stormwater runoff monitoring studies reported in the literature were grouped into five major categories as follows:

a) residential
b) commercial
c) roadway
d) industrial, and
e) mixed urban

Stormwater runoff water quality parameters reported in the literature typically fall into four classes as follows:

a) nutrients,
b) heavy metals,
c) oxygen demand and total suspended solids, and
d) organics.

Each land use, and its associated stormwater runoff quality, is discussed individually. A comparison of all land use types and related stormwater runoff quality is presented at the conclusion of Part II. Statistical analyses were performed to determine if significant differences exist between pollutants measured and land use classification. The Duncan's multiple-range test (Middlebrooks, 1983) was used to evaluate differences (at 95 percent confidence interval) between land use groups. Because of the sparse reported data concerning priority pollutant organics (priority compounds identified by theUSEPA), this topic will be covered collectively for all land uses in the comparison of land uses section.

Pollutant Build-up and Stormwater Runoff

As mentioned, stormwater runoff can vary drastically from one land use to another. These differences are usually in terms of water quantity as well as water quality. Urbanization is one of the major factors which may cause differences in stormwater runoff. Urbanization causes changes in the runoff process primarily in two ways.

First, as more land area becomes covered with impervious surfaces (e.g. roads, roof tops, parking lots), the infiltration capacity for an area is lowered causing an increased percentage of stormwater to become runoff. Urbanization often results in natural channels being straightened, deepened, and lined as well as the installation of gutters, storm sewers, and drains. All of these modifications lead to increases in runoff volumes, peak flow rates, and runoff velocities. Thus, the runoff accumulates downstream faster and in greater amounts, which may lead to increased flooding as well as bank erosion. The hydrologic effect of urbanization is illustrated by comparative hydrographs (urban versus rural) presented in Figure 2-1.

The second effect urbanization has on the stormwater runoff process is in terms of quality. Large amounts of diverse pollutants generated by urban activities are deposited directly or by atmospheric fallout throughout the developed watershed. The amount of contaminant material existing on a given site is largely dependent on the particular land use activity and the length of time since the site was last cleaned (either by sweeping or substantial rainfall). Factors influencing material build-up include surrounding land use, local traffic volume and character, traffic surface type and condition, public works practices, and season (Sartor et al., 1974). Evaluation of field sampling data suggested the quantity and rate of pollutant build-up varies for different land use activities. The results of this evaluation is displayed graphically in Figure 2-2.

Pollutants which are deposited on impervious surfaces are easily washed off by stormwater runoff. However, areas not covered by impervious material are usually changed by landscaping, covered with grass and vegetation, and treated with a variety of fertilizers and pesticides. These pervious areas will also contribute to the pollutant loads contained in stormwater runoff.

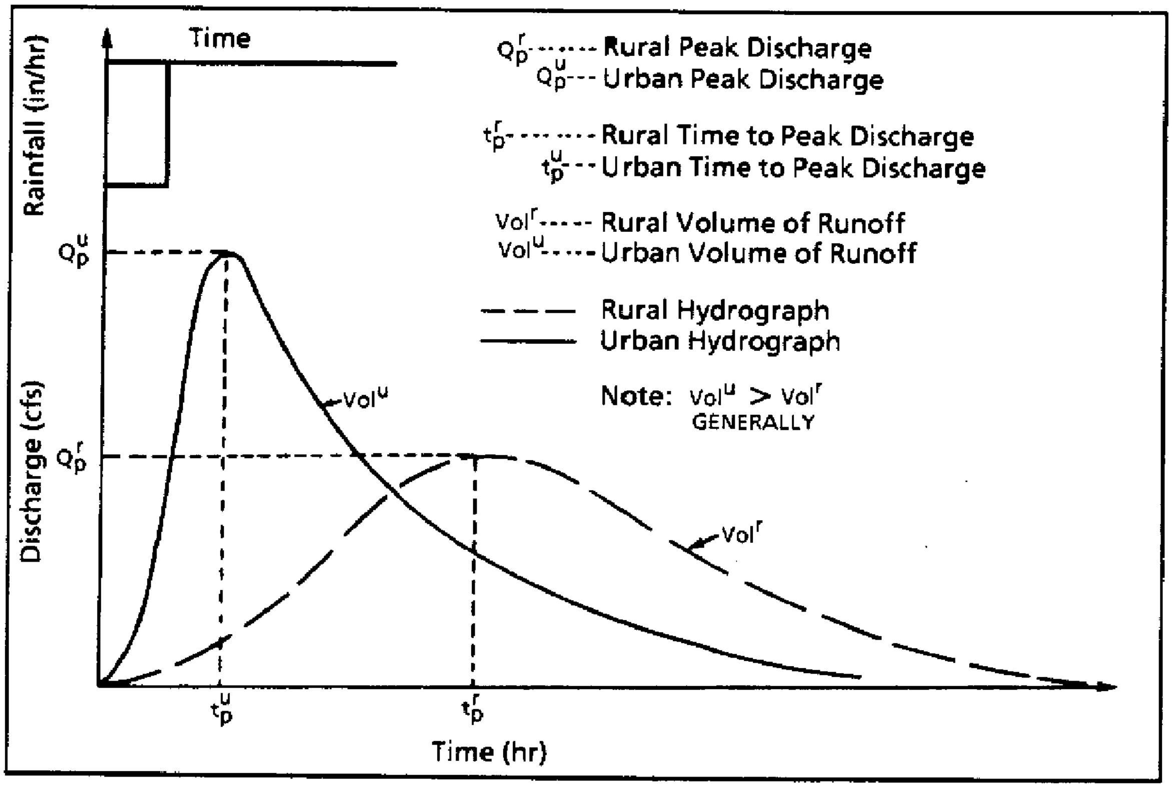

FIGURE 2.1 URBANIZATION IMPACTS ON BASIN RESPONSE WITHOUT INCREASED DETENTION STORAGE (American Geophysical Union, 1982)

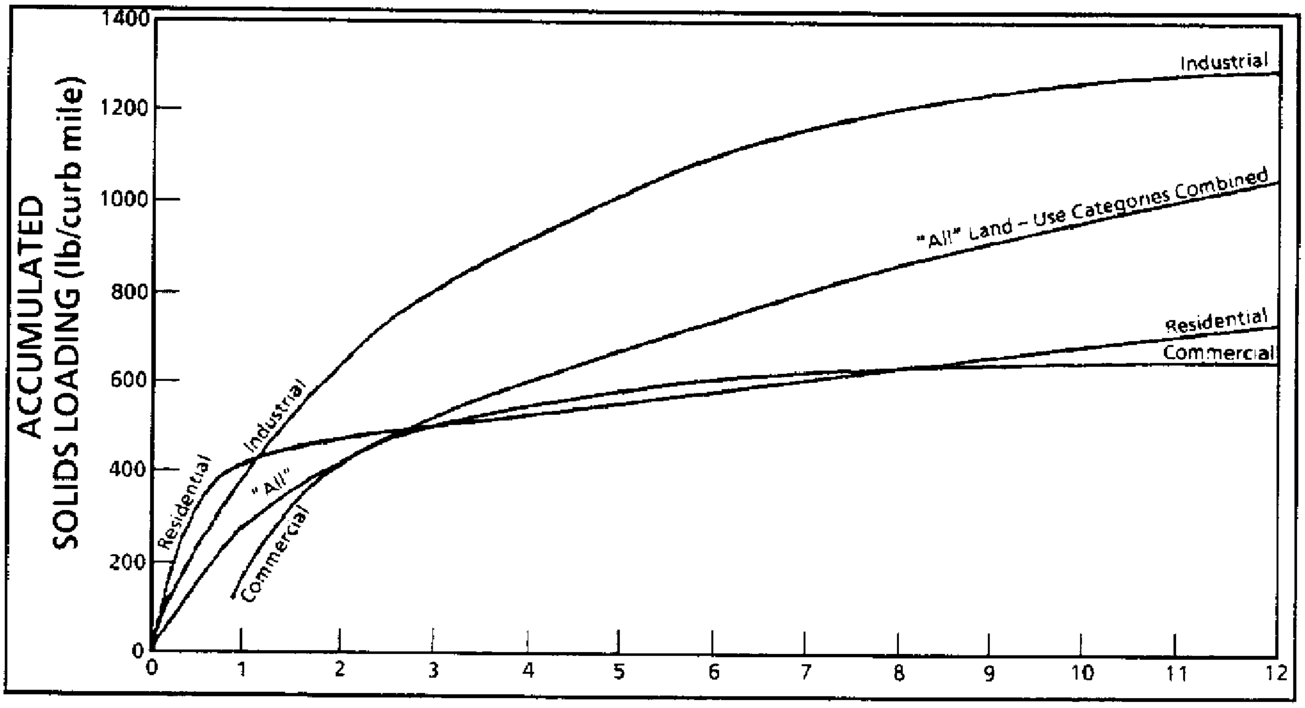

FIGURE 2-2 POLLUTANT BUILD-UP BY VARIOUS LAND USE ACTIVITIES (Sartor et al., 1974)

The amount of pollutants transported by stormwater runoff usually varies vastly during each runoff event. Typically, as rain begins to fall, a "scouring" of pollutants and surface debris occurs (this is especially evident for areas with a high percentage of impervious ground cover). When the initial abstraction and surface storage requirements are met, the runoff contains a "first flush" of pollutants. This "first flush" generally peaks prior to the hydrologic peak. A simplified version of the "first flush" concept is illustrated in Figure 2-3. Several studies have observed the "first-flush" occurrence (Post, Buckley, Shuh, and Jernigan, 1982; Cullum, 1984; Livingston, 1985(a); Lakatos and McNemar, 1986)

Figure 2-3 shows large differences between maximum and minimum concentrations. This demonstrates how it may be misleading to report a concentration range or an average concentration of pollutants from a runoff event. Rather, reporting the total pollutant mass discharged divided by the total discharge volume (<u>e</u>vent <u>m</u>ean <u>c</u>oncentration or EMC) from runoff provides a method for comparing the characteristics of individual runoff events and/or sites.

The methods by which stormwater runoff contaminants are reported in the following sections (i.e. mass per event, average concentration, concentration range, EMC) are dictated by the information and data available in the referenced literature.

Pollutant Sources

There are a multitude of sources for the constituents found in stormwater runoff. Pollutants may consist of solid waste litter, vehicle pollutants, chemicals, direct surface applied substances (i.e. fertilizers), or atmospheric deposition (i.e. dust, dirt) as well as many others.

The sources of nutrients (nitrogen and phosphorus) as an example, are largely considered to be agricultural areas. However, residential land use sites in the state of Florida are believed to contribute

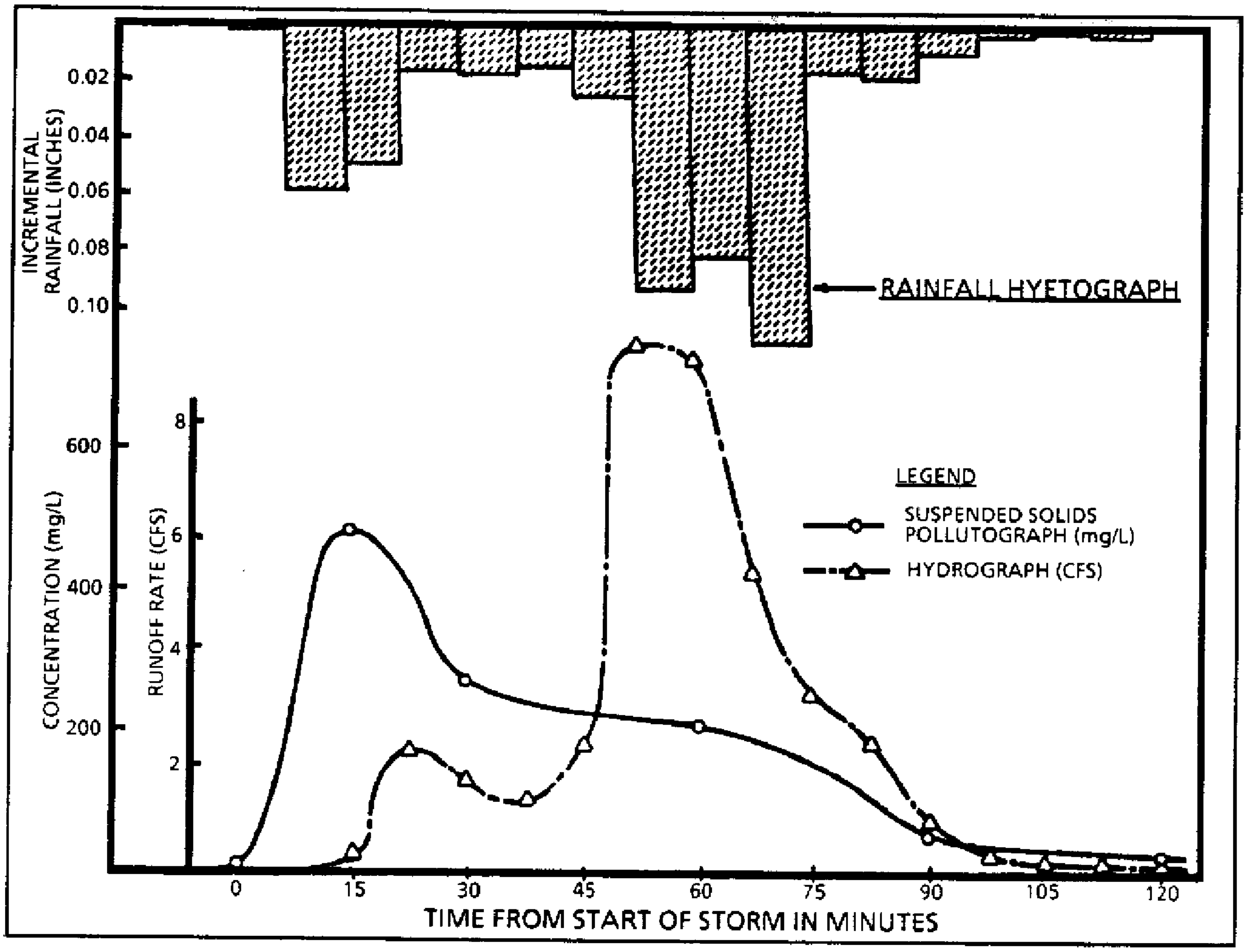

FIGURE 2-3. TYPICAL STORMWATER RUNOFF QUANTITY/QUALITY RELATIONSHIPS

substantial amounts of nitrogen and phosphorus in stormwater runoff. Nutrient concentrations applied as lawn fertilization may not be as high as agricultural sites, but the sheer number of residential sites (and golf courses) located in south Florida may cause a significant cumulative effect of nutrient loading to receiving waters (Synder, 1982).

Solids are an important and commonly monitored parameter in stormwater runoff studies. Emphasis is placed on solids loadings not just for concerns of sediment loadings to receiving waters, but because several studies have shown solids to have high correlations with nutrients, oxygen demand constituents, metals, and organic priority pollutants (Sartor et al., 1974; USEPA, 1983; Hoffman et al., 1984).

A biological oxygen demand in receiving waters can be produced by organic material collected in stormwater runoff. Greases and oils from vehicle operations are the most common source of these organics. Grease and oil loadings range depending on land use types, vehicles, and traffic patterns. Wanielista (1978) recounts a study which reported grease and oil loadings of 32.8 lb/curb mile/day for industrial areas, 4.90 lb\curb mile\day for commercial areas, and 18.6 lb\curb mile\day for residential areas. The chemical oxygen demand (COD) test may be a better indicator of oxygen demand produced by stormwater runoff than the biochemical oxygen demand (BOD) test. Stormwater runoff may contain several potential sources of toxins, which may interfere with the BOD test (USEPA, 1983).

Heavy metals are a concern in stormwater runoff because several are known to be toxic to a wide variety of aquatic plants and animals. Heavy metals found in urban runoff are 10-1,000 times the concentration of metals found in sanitary sewage (Wanielista, 1978). Heavy metal sources are largely associated with the operation of motor vehicles, atmospheric fallout, and road surface materials (Harper, 1985). Some sources of heavy metals are displayed in Table 2-1.

Metals found in stormwater runoff include dissolved and particulate forms. A study by Yousef et al. (1985) found the dissolved fraction for selected heavy metals varied greatly. Some examples include dissolved lead measuring 6 - 13 percent of total lead, zinc 35 - 57 percent, and copper 60 percent. The removal of dissolved versus particulate forms of metals by various stormwater treatment systems will be discussed in Chapter 3.

Among the toxic heavy metals detected in stormwater runoff, lead, zinc, and copper appear to be the most abundant and detected most frequently (Nightingale, 1975; USEPA, 1983; Harper, 1985). Thus, to keep within the scope of this report, published monitoring results of lead, zinc, and copper will be presented as representative of heavy metals found in stormwater runoff.

Organics such as pesticides, petroleum based hydrocarbons, and other complex organic compounds have been present in stormwater runoff for a very long time. Only in recent years has the presence of these organic compounds become an issue because of relatively new developments in sophisticated detection technology and medical advancements showing correlations between these organics and potential harm to human health. The source list for organic pollutants is long and vast ranging from

TABLE 2-1. SOURCES OF HEAVY METALS FOUND IN STORMWATER RUNOFF (HARPER, 1985; WIGINGTON ET AL., 1986)

Source	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Gasoline	X			X				X	X
Exhaust Emissions							X	X	
Motor Oil and Grease	X			X			X	X	X
Antifreeze				X					X
Undercoating								X	X
Brake Linings			X	X			X	X	X
Rubber	X			X				X	X
Asphalt				X			X		X
Concrete				X				X	X
Diesel Oil	X								
Engine Wear		X	X	X	X	X			

common household items, to industrially produced by-products. In depth reporting of all the organic pollutants found in stormwater runoff is beyond the scope of this report. However, a summary of the compounds reported in the literature will be presented.

Residential

There have been relatively few stormwater monitoring studies which have singled out residential areas; most urban stormwater runoff studies were conducted in mixed land use areas which will be discussed in a further section. Studies involving residential areas referenced in this section and brief site descriptions are presented in Table 2-2.

Nutrients

Nutrient quantities reported in the residential monitoring studies are displayed in Table 2-3. Nutrient EMC values for each constituent reported for the Florida NURP (J.L. Young Apts. and Charter and Harding) and Pompano studies are consistent. The nationwide NURP average study mean EMCs are substantially lower for TKN and higher for $NO_2 + NO_3$ and Total-P. This is explained by the fact that the nationwide NURP study results are a compilation of several studies under various geographic, urban, atmospheric, as well as other conditions. The data presented for the nationwide NURP study should be taken into context, realizing the variability of each of the distinct study sites.

Timbercreek nutrient EMC data are significantly lower for all nutrients reported. Water samples collected during the Timbercreek evaluation were taken after stormwater runoff had passed through vegetated swales, thus providing pre-treatment.

TABLE 2-2. SELECTED RESIDENTIAL STORMWATER RUNOFF MONITORING STUDY SITES

Reference	Site Description
USEPA, 1983	NURP. Nationwide Urban Runoff Program (NURP) consisted of stormwater runoff monitoring projects in 28 cities across the United States; 39 residential monitoring sites.
USEPA, 1983	J. L. YOUNG APTS., FLORIDA. NURP residential study site, Tampa, Florida; 8.7 acres, high-density, multi-family; drainage system is 100 percent curbs, gutters, and sewers, 61 percent impervious. Data also included in NURP results.
USEPA, 1983	CHARTER AND HARDING STREETS, FLORIDA. NURP residential study, Tampa, Florida; 42 acres, low-density; drainage system - 100 percent sewered, collection system - ditches (13 percent), curb-gutter (12 percent), grass swales (75 percent), impervious (14 percent). Data also included in NURP results.
Cullum, 1984; Cullum, 1985	TIMBERCREEK, FLORIDA. Low density residential community, southern Palm Beach County, Florida; 122 acres, 2.5 units/ acre, 311 residences; drainage system - grass swales, catch basins, storm sewers, and 7.9 acres of interconnected lakes.
Mattraw and Sherwood, 1977; Mattraw et al., 1978; Mattraw and Miller, 1981	POMPANO, FLORIDA. Single family residential community, northeast Broward County, Florida; 41 acres, 219 residences; drainage system - grass swales.
Weinberg et al., 1980	LOCH LOMOND, FLORIDA. Residential community, northeast Broward County, Florida; 26 acres, medium-density (duplexes, fourplexes, etc), 18 units/ acre, 550 residences; drainage system - grates and sewers.
ECFRPC, 1983	LAKE HOURGLASS, FLORIDA. Residential community in Orange County, southeast of Orlando, Florida; 78 acres; drainage system is drop inlets and sewers.

TABLE 2-3. NUTRIENT EMCs AND CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED RESIDENTIAL LAND USE MONITORING STUDIES

Study	TKN (mg/L)	$NO_2 + NO_3$ (mg/L)	Total-P (mg/L)	Ortho-P (mg/L)
NURP				
Average Study Mean EMC	0.23*	1.8*	0.62*	0.21*
Mean EMC Range	0.48 - 11	0.31 - 9.5	0.22 - 4.1	0.07 - 0.45
Number of Sites	(36)	(26)	(39)	(18)
Number of Events	(898)	(583)	(1,029)	(344)
J. L. YOUNG APTS., FLORIDA**				
Mean EMC	1.3	0.31	0.33	--
90 Percent Confidence	0.79 - 1.5	0.19 - 0.36	0.21 - 0.38	--
Number of Events	(12)	(12)	(12)	--
CHARTER AND HARDING, FLORIDA**				
Mean EMC	1.7	0.61	0.40	--
90 Percent Confidence	0.90 - 1.9	0.34 - 0.69	0.12 - 0.37	--
Number of Events	(12)	(12)	(12)	--
TIMBERCREEK, FLORIDA				
Mean EMC	0.75	0.18	0.14	0.08
Number of Events	(9)	(9)	(9)	(9)
POMPANO, FLORIDA				
Mean EMC	--	--	0.30*	--
EMC Range	--	--	0.02 - 1.3*	--
Mean Concentration	1.6	0.54	0.32	0.31
Concentration Range	0.19 - 12	BD - 3.6	0.06 - 2.4	0.03 - 1.8
Number of Events	(33)	(33)	(33)	(33)
LOCH LOMOND, FLORIDA				
Mean Concentration	1.6*	0.31*	0.73*	0.39*
Concentration Range	BD - 2.6	BD - 1.1	0.16 - 2.0	0.002 - 1.8
Number of Events	(1)	(1)	(1)	(1)
LAKE HOURGLASS, FLORIDA				
Mean Concentration	3.6*	--	0.78*	0.26*
Concentration Range	0.75 - 20	--	0.29 - 1.8	0.12 - 0.49
Number of Events	(7)	--	(7)	(7)

* CALCULATED FROM REPORTED DATA
** DATA ALSO INCLUDED UNDER NURP
BD - BELOW DETECTION

Mean concentrations and concentrations for the selected nutrient ranges are presented for Pompano, Florida; Loch Lomond, Florida and Lake Hourglass, Florida. The mean concentrations are not easily comparable because the calculated mean value is dependent on sampling frequency and does not indicate a total nutrient loading.

Heavy Metals

Reported heavy metal quantities are presented in Table 2-4. Metal measurements have historically been considered insignificant in residential areas and settings because of the relatively low source occurrence (e.g. automobile traffic is lower than a highway or commercial parking lot). The nationwide NURP study results show significantly higher heavy metal EMCs than the other investigations. As mentioned, this may be due to the high variability between each nationwide study site. The NURP results identify the large irregularities associated with stormwater runoff quality. EMCs presented for the remaining studies agree quite well with the exception of a somewhat higher lead EMC value calculated for Pompano, Florida.

Oxygen Demand and Total Suspended Solids

BOD, COD, and total suspended solids (TSS) are three commonly monitored parameters in stormwater runoff studies. Summarized results are presented in Table 2-5. As noted with the nutrients, EMC values of BOD, COD and TSS values are comparable between the J.L. Young Apts., Charter and Harding, and Pompano study sites. The nationwide NURP study results for COD and TSS are again significantly higher due the site variabilities.

TABLE 2-4. HEAVY METAL EMCs AND CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED RESIDENTIAL LAND USE MONITORING STUDIES

Study	Total Copper (µg/L)	Total Zinc (µg/L)	Total Lead (µg/L)
NURP			
Average Study Mean EMC	56*	254*	293*
Mean EMC Range	26 - 312	54 - 1,390	34 - 2,750
Number of Sites	(26)	(29)	(31)
Number of Events	(468)	(797)	(802)
J. L. YOUNG APTS., FLORIDA**			
Mean EMC	6	60	76
90 Percent Confidence	5 - 7	44 - 69	34 - 82
Number of Events	(12)	(12)	(12)
CHARTER AND HARDING, FLORIDA**			
Mean EMC	10	53	49
90 Percent Confidence	5 - 11	25 - 59	14 - 47
Number of Events	(12)	(12)	(12)
POMPANO, FLORIDA			
Mean EMC	--	80*	166*
EMC Range	--	7- 233*	14 - 613*
Mean Concentration	8	86	167
Concentration Range	BD - 41	10 - 560	30 - 1,100
Number of Events	(8)	(8)	(8)

* CALCULATED FROM REPORTED DATA
** DATA ALSO INCLUDED UNDER NURP
BD - BELOW DETECTION

TABLE 2-5. OXYGEN DEMAND AND TOTAL SUSPENDED SOLIDS EMCs AND CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED RESIDENTIAL LAND USE MONITORING STUDIES

Study	BOD (mg/L)	COD (mg/L)	TSS (mg/L)
NURP			
Average Study Mean EMC	13*	102*	228*
Mean EMC Range	5 - 28	39 - 234	25 - 2,166
Number of Sites	(11)	(36)	(39)
Number of Events	(124)	(902)	(1,102)
J. L. YOUNG APTS., FLORIDA**			
Mean EMC	16	73	53
90 Percent Confidence	7 - 17	34 - 79	21 - 56
Number of Events	(12)	(12)	(12)
CHARTER AND HARDING, FLORIDA**			
Mean EMC	13	55	33
90 Percent Confidence	5 - 13	35 - 64	9 - 30
Number of Events	(12)	(12)	(12)
TIMBERCREEK, FLORIDA			
Mean EMC	--	--	21
Number of Events	--	--	(9)
POMPANO, FLORIDA			
Mean EMC	--	39*	--
EMC Range	--	2.3 - 153*	--
Mean Concentration	8.3	44	28
Concentration Range	1.9 - >100	4.0 - 289	ND - 249
Number of Events	(8)	(31)	(33)
LOCH LOMOND, FLORIDA			
Mean Concentration	--	227*	--
Concentration Range	--	35 - 268	--
Number of Events	--	(1)	--
LAKE HOURGLASS, FLORIDA			
Mean Concentration	10*	86*	108*
Concentration Range	4.6 - 24	45 - 198	10 - 184
Number of Events	(7)	(7)	(7)

* CALCULATED FROM REPORTED DATA
** DATA ALSO INCLUDED UNDER NURP
ND - NONE DETECTED

Commercial

Selected monitoring studies involving commercial land use areas (largely malls) which are referenced in this section are briefly described in Table 2-6.

Nutrients

A summary of nutrient measurements reported for selected commercial stormwater monitoring studies are presented in Table 2-7. Nutrient EMC values reported for the Florida based study sites (Norma Park, Coral Ridge Mall, and Altamonte Springs Mall) are in agreement.

The mass of nutrients available for export from any commercial land use area varies depending on the amount of fertilizers and extent of maintained green areas on-site and on adjacent projects. However, commercial land use projects with relatively little or no maintained green areas still exhibit nutrients in stormwater runoff. These nutrient exports can be attributable largely to precipitation and atmospheric deposition.

Heavy Metals

Metals are typically one of the primary concerns with stormwater runoff from commercial land use areas. The most predominate metals found in commercial runoff are lead, zinc, and copper. Table 2-8 summarizes copper, zinc, and lead EMCs and concentrations found in commercial land use stormwater runoff as reported in the various studies. The data appears to be site specific and somewhat variable, with lead and zinc being dominant as expected. The variability in heavy metal measurements are probably due to factors such as parking availability, traffic density, seasonal traffic patterns, as well as others.

TABLE 2-6. SELECTED COMMERCIAL STORMWATER RUNOFF STUDY SITES

Reference	Site Description
USEPA, 1983	NURP. Nationwide Urban Runoff Program (NURP) consisted of stormwater runoff monitoring projects in 28 cities across the United States.
USEPA, 1983	NORMA PARK, FLORIDA. NURP commercial study site, Tampa, Florida; 46.6 acres, of which 90.7 percent is commercial (42.3 acre); drainage system is 21.7 percent curb and gutters, 5.8 percent grass gutters, and 72.5 percent ditches and swales; 90.3 percent impervious
Mattraw, Jr. and Miller, 1981; Miller and Mattraw, Jr., 1982	CORAL RIDGE MALL, FLORIDA. USGS commercial study, downtown Fort Lauderdale, Florida; 20.4 acre mall (roof and parking lot); drainage system is grates and culverts.
ECFRPC, 1977(a); ECFRPC, 1977(b)	ALTAMONTE SPRINGS, FLORIDA. Study site is a 21.8 acre portion of a shopping mall complex, north of Orlando, Florida; asphalt parking lot is drained by curb and culverts.
Black, 1980; Owe et al., 1982	SYRACUSE, NEW YORK. Study site is a parking lot of a large suburban shopping mall in Syracuse, New York; 40 acre asphalt mall parking lot; drainage system is curbs, channelized sheetflow and sewered.
Oakland, 1983	DURHAM, NEW HAMPSHIRE. Study site is a commercial supermarket parking lot in Durham, New Hampshire; 0.77 acre asphalt parking lot is drained by curbs and slotted drains.
Hoffman et al., 1982 and 1984	WARWICK, RHODE ISLAND. Study iste is a 30.9 acre section of a shopping center complex in Warwick, Rhode Island; study area is asphalt parking lot and mall rooftop drained by curb and culvert.

TABLE 2-7. NUTRIENT EMCs AND CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED COMMERCIAL LAND USE MONITORING STUDIES

Study	TKN (mg/L)	NO_2+NO_3 (mg/L)	Total-P (mg/L)	Ortho-P (mg/L)
NURP				
Average Study Mean EMC	1.5*	0.8*	0.29*	0.15*
Mean EMC Range	0.6 - 3.7	0.36 - 1.2	0.11 - 0.7	0.05 - 0.29
Number of Sites	(10)	(8)	(10)	(3)
Number of Events	(223)	(209)	(307)	(62)
NORMA PARK, FLORIDA				
Mean EMC	0.83	0.36	0.15	--
90 Percent Confidence	0.43 - 0.93	0.26 - 0.41	0.11 - 0.17	--
Number of Events	(12)	(12)	(12)	--
CORAL RIDGE MALL, FLORIDA				
Mean EMC	--	--	0.08*	--
EMC Range	--	--	0.02 - 0.26*	--
Number of Events	--	--	(31)	--
Mean Concentrations	2.0	0.23	0.10	0.05
Concentration Range	0.29 - 11.5	ND - 1.7	0.01 - 1.0	ND - 0.73
Observations	(380)	(320)	(320)	93
ALTAMONTE SPRINGS, FLORIDA				
Mean EMC	0.97*	--	0.17*	--
Mean EMC Range	0.23 - 2.3*	--	0.06 - 0.25*	--
Number of Events	(6)	--	(6)	--
DURHAM, NEW HAMPSHIRE				
Mean Concentrations	1.0	0.76	0.15	--
Concentration Range	0.36 - 1.84	0.22 - 1.43	0.04 - 0.27	--
Number of Events	(11)	(11)	(11)	--

* CALCULATED FROM REPORTED DATA
ND - NONE DETECTED

Oxygen Demand and Total Suspended Solids

BOD, COD, and TSS measurements are presented in Table 2-9. BOD and COD measurements are consistent for the studies reported. Suspended solids levels are also relatively consistent between studies, except for the NURP study which is three to seven times higher than the other EMCs reported.

Roadway

Within the past decade several monitoring studies have been performed with the objective of assessing and quantifying the contribution which automobile operations have towards nonpoint source water pollution. Table 2-10 provides a brief description of each roadway study site included in this report.

Nutrients

Nutrient data for the selected roadway study sites are presented in Table 2-11. Nutrients exported via stormwater runoff from roadway land use areas are largely dependent on the site's settings. Well groomed and landscaped medians and surrounding areas will likely contribute to the nutrient loads.

Sample Road, Florida and Dixie Plant, Florida have slightly lower Total-P mean concentrations than the other study sites. The drainage system for these

TABLE 2-8. HEAVY METAL EMCs AND CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED COMMERCIAL LAND USE MONITORING STUDIES

Study	Total Copper (µg/L)	Total Zinc (µg/L)	Total Lead (µg/L)
NURP			
Average Study Mean EMC	50*	418*	203*
Mean EMC Range	11 - 104	37 - 1,416	46 - 409
Number of Sites	(6)	(10)	(9)
Number of Events	(152)	(221)	(209)
NORMA PARK, FLORIDA			
Mean EMC	12	37	46
90 Percent Confidence	8 - 13	19 - 41	21 - 49
Number of Events	(12)	(12)	(12)
CORAL RIDGE MALL, FLORIDA			
Mean EMC	--	121*	383*
EMC Range	--	38 - 301*	72 - 1,085*
Number of Events	--	(29)	(29)
Mean Concentration	15	128	387
Concentration Range	0 - 500	ND - 1,900	6 - 7,000
Observations	(96)	(295)	(295)
ALTAMONTE SPRINGS, FLORIDA			
Mean EMC	--	--	303*
Mean EMC Range	--	--	160 - 491*
Number of Events	--	--	(5)
SYRACUSE, NEW YORK			
Average Mean Concentration	570*	2,240*	1,720*
Concentration Range	10 - 280	890 - 4,740	730 - 2,970
Number of Events	(12)	(13)	(12)
DURHAM, NEW HAMPSHIRE			
Mean Concentration	60	340	122
Concentration Range	BD - 110	90 - 800	25 - 200
Number of Events	(11)	(11)	(11)

*CALCULATED FROM REPORTED DATA
BD -BELOW DETECTION

TABLE 2-9. OXYGEN DEMAND AND TOTAL SUSPENDED SOLIDS EMCs AND CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED COMMERCIAL LAND USE MONITORING STUDIES

Study	BOD (mg/L)	COD (mg/L)	TSS (mg/L)
NURP			
Average Study Mean EMC	14*	84*	169*
Mean EMC Range	8 - 19	40 - 184	22 - 412
Number of Sites	(8)	(10)	(10)
Number of Events	(171)	(243)	(309)
NORMA PARK, FLORIDA			
Mean EMC	12	41	22
90 Percent Confidence	6 - 13	29 - 47	9 - 22
Number of Events	(12)	(12)	(12)
CORAL RIDGE MALL, FLORIDA			
Mean EMC	--	63*	--
EMC Range	--	8 - 218*	--
Number of Events	--	(31)	--
Average Concentration	5.4	71	26
Concentration Range	1.4 - 11	10 - 2,200	0 - 249
Observations	(69)	(380)	(367)
ALTAMONTE SPRINGS, FLORIDA			
Mean EMC	--	--	42*
EMC Range	--	--	7 - 90*
Number of Events	--	--	(6)
DURHAM, NEW HAMPSHIRE			
Mean Concentration	5.9	77	24
Concentration Range	2.5 - 8.7	16 - 168	1 - 115
Number of Events	(11)	(11)	(11)
WARWICK, RHODE ISLAND			
Mean EMC	--	--	56
EMC Range	--	--	21 - 113
Concentration Range	--	--	1.6 - 252
Number of Events	--	--	(6)

*CALCULATED FROM REPORTED DATA

TABLE 2-10. SELECTED ROADWAY STORMWATER RUNOFF STUDY SITES

Reference	Site Description
Mattraw, Jr. and Miller 1981; Miller and Mattraw, Jr., 1982	SAMPLE ROAD, FLORIDA. Highway study site located in Broward County, Florida; 3,000 foot section, 58.3 acres, 6-lane divided highway, moderate traffic (approximately 20,000 vehicles per day); drained curb and gutters.
Yousef et al., 1985; Yousef et al., 1986; Hvitved-Jacobsen et al., 1984; Harper et al., 1986	MAITLAND, FLORIDA. Highway study site is a major Federal Interstate (I-4) interchange located north of Orlando, Florida; 48.9 acre drainage, total traffic volume of approximately 65,000 vehicles per day.
Yousef et al., 1985; Yousef et al., 1986; Hvitved-Jacobsen et al., 1984; Harper et al., 1986	EPCOT, FLORIDA. Highway study site is a major interchange connecting Walt Disney World's Epcot Center with Federal Interstate I-4; 20.5 acre drainage.
Howie and Waller, 1986	DIXIE PLANT, FLORIDA. Highway study site is a heavily travelled roadway (approximately 39,000 vehicles per day) in southeastern Broward County, Florida; drainage system is partially vegetated swales.
Howie and Waller, 1986	PEMBROKE ROAD, FLORIDA. Highway study site is a major east/ west artery (approximately 20,000 vehicles per day) in south Broward County, Florida; 219 residences; drainage system is vegetated swales.
Clark et. al., 1981	SEATTLE, WASHINGTON. Highway study site is 1.22 acre section of Federal Interstate I-5; 4 lanes with approximately 50,000 vehicles per day; drainage system is a culvert.
Shelly and Gaboury, 1986	FHwA. Twelve highway study sites across the United States; 8 sites classified as "urban" and 4 sites classified as "rural".

projects was largely curb and gutter rather than vegetated swales and ditches. This may indicate that nutrient export is influenced by contiguous vegetation and landscaping practices.

It appears that EMC values for TKN and Total-P reported by the Federal Highway Administration (FHwA) studies are significantly higher for urban sites than for rural sites.

Heavy Metals

Similar to commercial and industrial land use areas, heavy metals exported from roadway areas are a primary concern based on their potential aquatic toxicity. Selected metal concentrations reported by monitoring studies are presented in Table 2-12. Lead appears to be the dominant heavy metal exported from the roadway land use sites. Heavy metals exported via stormwater runoff from roadway sites appears to be variable as indicated by EMC and concentration ranges presented in Table 2-12. Zinc and lead EMC are higher for the FHwA urban than the rural monitoring projects.

Oxygen Demand and Total Suspended Solids

Table 2-13 tabulates measurements of BOD, COD, and TSS reported in the selected stormwater runoff monitoring studies. Limited oxygen demand and solids data was available in current published studies. Consequently, few conclusive statements can be made. However, the FHwA studies again showed that the urban roadway sections to contribute higher amounts of COD and TSS than the rural sites.

Urban vs. Rural

The FHwA has been engaged in an extensive stormwater monitoring study at several highway sites across the United States for over a decade. In a paper by Shelley and Gaboury (1986), some of the water quality data collected during the FHwA projects were reported. The data, reported as EMCs, are presented

TABLE 2-11. NUTRIENT EMCs AND CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED ROADWAY LAND USE MONITORING STUDIES

Study	TKN (mg/L)	NO_2+NO_3 (mg/L)	Total - P (mg/L)	Ortho - P (mg/L)
SAMPLE ROAD, FLORIDA				
Mean EMC	--	--	0.08*	--
EMC Range	--	--	0.03 - 0.31*	--
Number of Events	--	--	(40)	--
Mean Concentration	0.66	0.30	0.08	0.04
Concentration Range	0.05 - 6.0	ND - 2.0	ND - 0.80	ND - 0.31
Observations	(441)	(441)	(440)	(44)
MAITLAND, FLORIDA				
Mean EMC	--	--	0.53	--
Number of Events	--	--	(15)	--
EPCOT, FLORIDA				
Mean EMC	--	--	0.22	--
Number of Events	--	--	(18)	--
DIXIE PLANT, FLORIDA				
Mean Concentration	0.82*	0.25*	0.11*	0.06*
Concentration Range	BD - 2.5	0.01 - 0.65	0.02 - 0.30	BD - 0.15
Number of Events	(9)	(8)	(9)	(8)
PEMBROKE ROAD, FLORIDA				
Mean Concentration	1.62*	0.53*	0.34*	0.05*
Concentration Range	0.22 - 5.1	0.1 - 0.65	0.02 - 0.56	0.01 - 0.11
Number of Events	(7)	(7)	(7)	(7)
SEATTLE, WASHINGTON				
Mean Concentration	1.1	0.82	0.34	
Concentration Range	0.64 - 2.0	0.52 - 1.7	0.02 - 0.55	
FHwA - URBAN				
Average Study Mean EMC	2.8	--	0.70	--
Mean EMC Range	1.9 - 4.2	--	0.30 - 1.7	--
Number of Sites	(8)	--	(8)	--
FHwA - RURAL				
Average Study Mean EMC	1.65	--	0.16	--
Mean EMC Range	0.68 - 2.5	--	0.06 - 0.29	--
Number of Sites	(4)	--	(4)	--

* CALCULATED FROM REPORTED DATA
BD - BELOW DETECTION
ND - NONE DETECTED

TABLE 2-12. HEAVY METAL EMCs AND CONCENTRATIONS FOUND IN STORM-WATER RUNOFF FROM SELECTED ROADWAY LAND USE MONITORING STUDIES

Study	Total Copper (µg/L)	Total Zinc (µg/L)	Total Lead (µg/L)
SAMPLE ROAD, FLORIDA			
Mean EMC	--	98*	270*
EMC Range	--	25 - 366*	41 - 757*
Number of Events	--	(39)	(40)
Mean Concentration	6.5	90	282
Concentration Range	ND - 51	ND - 1,000	18 - 2,700
Observations	(428)	(428)	(428)
MAITLAND, FLORIDA			
Mean EMC	39	74	181
Number of Events	(15)	(15)	(15)
EPCOT, FLORIDA			
Mean EMC	24	35	38
Number of Events	(22)	(21)	(22)
DIXIE PLANT, FLORIDA			
Mean Concentration	20*	82*	240*
Concentration Range	BD - 100	4 - 580	BD - 2,100
Number of Events	(9)	(9)	(9)
PEMBROKE ROAD, FLORIDA			
Mean Concentration	15*	162*	239*
Concentration Range	BD - 50	BD - 780	BD - 1,800
Number of Events	(8)	(8)	(8)
SEATTLE, WASHINGTON			
Mean Concentration	30	400	800
Concentration Range	BD - 70	200 - 1,000	200 - 1,500
FHwA - URBAN			
Average Study Mean EMC	--	420	1,310
Mean EMC Range	--	170 - 620	30 - 2,030
Number of Sites	--	(8)	(8)
FHwA - RURAL			
Average Study Mean EMC	--	120	260
Mean EMC Range	--	70 - 270	10 - 280
Number of Sites	--	(4)	(4)

*CALCULATED FROM REPORTED DATA

BD - BELOW DETECTION

ND - NONE DETECTED

TABLE 2-13. OXYGEN DEMAND AND TOTAL SUSPENDED SOLIDS EMCs AND CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED ROADWAY LAND USE MONITORING STUDIES

Study	BOD (mg/L)	COD (mg/L)	TSS (mg/L)
SAMPLE ROAD, FLORIDA			
Mean EMC	--	61*	--
EMC Range	--	9 - 277*	--
Number of Events	--	40	--
Mean Concentration	9.0	55	15
Concentration Range	1.3 - 36	ND - 440	ND - 241
Observations	(84)	(435)	(430)
SEATTLE, WASHINGTON			
Mean Concentration	--	137	145
Concentration Range	--	75 - 211	43 - 320
FHwA - URBAN			
Average Study Mean EMC	--	149	234
Mean EMC Range	--	34 - 289	161 - 410
Number of Sites	--	(8)	(8)
FHwA - RURAL			
Average Study Mean EMC	--	43	42
Mean EMC Range	--	31 - 51	9 - 90
Number of Sites	--	(4)	(4)

*CALCULATED FROM REPORTED DATA
ND - NONE DETECTED

in Table 2-14. Site classification (urban vs. rural) was determined based on three general categories.

a) site data:
configuration (elevated, ground level, depressed), pavement condition, design, right-of-way vegetation, drainage features.

b) operations:
traffic (density, speed, braking), vehicle characteristics (type, age, repair), maintenance sweeping, mowing, weed control), institutional (litter laws, speed limit enforcement, emission regulations).

c) surrounding land use:
type (residential, commercial, industrial, agricultural.), geology (relief, soil, ground water), agriculture (tillage, irrigation, cropping practices).

Comparison of data from urban and rural highway sites in Table 2-14 shows a significant difference in pollutant EMCs reported. The rural highway sites export significantly less pollutants than the urban locations for all constituents measured.

Industrial

The category of "industrial" land use areas may hold a wide variety of classifications from light industrial parks to heavy manufacturing. Thus, stormwater runoff quality is largely site specific.

Relatively few monitoring studies have focused on industrial land use areas (100 percent of land use). The NURP (USEPA, 1983) presented industrial monitoring data on four sites. However, the NURP study further stated the sites listed under this category typically reflected light industrial parks (e.g. small manufacture) rather than heavy industrial (e.g. steel mills, refineries, etc).

TABLE 2-14. REPORTED STORMWATER RUNOFF EVENT MEAN CONCENTRATIONS (EMCs) FROM TWELVE FEDERAL HIGHWAY ADMINISTRATION HIGHWAY LAND USE MONITORING STUDIES (SHELLEY AND GABOURY, 1986)

Site		TKN	TPO_4	TSS	Zn	Pb	COD
URBAN							
Denver		3.38	0.82	410	0.62	0.68	289
Milwaukee Highway 795		2.52	0.38	183	0.46	2.03	130
Los Angeles		4.22	0.45	172	0.55	0.99	196
Milwaukee Highway 45		2.76	0.45	343	0.44	0.88	134
Nashville		1.90	1.69	190	0.26	0.41	113
Milwaukee Highway 94		3.20	0.30	161	0.52	0.90	122
Walnut Creek		2.24	0.41	224	0.30	0.75	120
Harrisburg (a)		2.20	1.08	184	0.17	0.03	34
	Mean	2.81	0.70	234	0.42	1.31	149
	Median	2.72	0.59	220	0.38	0.55	124
	COV	0.27	0.66	0.36	0.47	2.14	0.67
RURAL							
Sacramento		1.90	0.12	90	0.27	0.28	51
Harrisburg (b)		1.20	0.29	31	0.06	0.10	31
Efland		2.50	0.13	19	0.06	0.01	49
Broward County		0.68	0.06	9	0.07	0.23	38
	Mean	1.65	0.16	42	0.12	0.26	43
	Median	1.40	0.13	26	0.09	0.09	41
	COV	0.62	0.71	1.24	0.85	2.64	0.23

Table 2-15 summarizes the EMC values reported for the four monitoring sites classified "industrial" during the NURP project. The four sites were located in or near Boston, Massachusetts; Lansing, Michigan (2 sites);and Kansas City, Kansas.

Mixed Urban

A wide variety of mixed land use stormwater runoff studies have been conducted throughout the United States. Project sites have included combinations of virtually all types of land uses; agricultural, industrial, roadway, commercial, and residential. Stormwater runoff quality varies from site to site with respect to the size and combination of land use areas involved, thus comparison between particular monitoring studies is difficult. Due to the considerable number of mixed land use stormwater runoff studies which have been performed, a summary of selected studies focused in south Florida will be addressed.

The United States Geological Survey (USGS) has conducted a stormwater runoff water quality monitoring study on several mixed land use areas near Tampa, Florida (Lopez and Giovannelli, 1984). The project report analyzes rainfall, runoff, and water quality data collected from 1975-1980 at nine mixed land use urban watersheds. The areas ranged in size from 0.34 to 3.45 acres and included combinations of high- and low-density residential, commercial, roadway, industrial, institutional, recreational, and open spaces. The percentage of land use mixtures differed appreciably for the nine drainages (Table 2-16). The study presents flow-weighted concentrations (EMC) and loading measurements for the constituents monitored as well as projections of future loadings based on basin development. Tables 2-17 to 2-19 summarize the

TABLE 2-15. SUMMARY OF CONSTITUENTS FOUND IN STORMWATER RUNOFF FROM NURP INDUSTRIAL LAND USE MONITORING STUDIES

Parameter	Average Study Mean EMC	EMC Range	Number of Sites
TKN, mg/L	1.6	0.62 - 3.7	4
NO_2+NO_3, mg/L	0.93	0.67 - 1.4	3
Total-P, mg/L	0.42	0.11 - 0.60	4
Ortho-P, mg/L	0.15	0.06 - 0.35	4
Total-Cu, µg/L	32	25 - 36	3
Total-Zn, µg/L	1,063	223 - 2,721	3
Total-Pb, µg/L	115	115 - 116	2
BOD, mg/L	10	5 - 14	3
COD, mg/L	62	58 - 67	3
TSS, mg/L	108	48 - 188	4

An additional monitoring effort conducted by the USGS (Martin, 1985; Martin and Smoot, 1986) reported on runoff quality from a 42 acre urban drainage located near Orlando, Florida. The percentage of mixed land uses are as follows: Forest - 33 percent; Roadway - 27 percent; High-Density Residential - 27 percent; and Low-Density Residential - 13 percent. The study reported lead and zinc concentration ranges as 8-910 µg/L and 10-530 µg/L, respectively. These ranges generally agree with ranges found in residential (Table 2-4) and roadway monitoring (Table 2-12). Total phosphorus and total nitrogen concentration ranges were reported as 0.02-0.50 mg/L and 0.50-3.32 mg/L, respectively. Again, these values agree with ranges reported.

Another study site in which stormwater runoff monitoring has been conducted was Lake Eola, located in downtown Orlando, Florida (Harper et al., 1982; Wanielista, 1978). Lake Eola receives direct stormwater runoff via sewers from a 160 acre watershed of dense commercial, roadway, and residential areas. Stormwater runoff was determined to be the primary source of pollution entering Lake Eola. Table 2-20 gives a summary of stormwater average concentrations and loading rates into Lake Eola for various parameters.

The amount of pollutants exported by any particular mixed land use area is dependent on the diversity, percentage, and proximity of the assorted individual land use sections. One may expect an area with large tracts of well maintained residential areas (low density), recreation areas (i.e. golf courses), and small sections of commercial land uses to export higher amounts of nutrients and lower concentrations of metals. Yet a mixed land use area, which is largely commercial and industrial, will probably generate higher quantities of heavy metals and priority pollutants.

Comparison of Land Uses

The question often arises "which land use area contributes the most constituents to stormwater runoff?" This is difficult to answer concisely because of the wide variety of constituents found in stormwater runoff. Variation exists between different land uses (e.g. residential versus commercial) as well as individual sites within the same classification (commercial$_a$ versus commercial$_b$).

Nutrients

Figure 2-4 illustrates the range of TKN values reported for residential, commercial, roadway, industrial, and mixed urban land use sites. Although data analysis showed no statistically significant difference between land uses, commercial sites graphically appeared to exhibit slightly lower TKN EMCs as compared to reported ranges for residential, roadway, industrial, and mixed urban land use areas.

One reason for similar TKN measurements from the different land use types is chemical constituents in precipitation. Several studies have reported that precipitation may contribute 10 - 45 percent of the nitrogren loads exported from a site (Irwin and Kirkland, 1980; Halverson et al., 1984; Miller 1985; Ebbert and Wagner, 1987).

TABLE 2-16. CHARACTERISTICS OF URBAN WATERSHEDS MONITORED DURING A MIXED URBAN LAND USE STORMWATER RUNOFF QUALITY STUDY (FROM LOPEZ AND GIOVANNELLI, 1984)

			LAND USE, IN PERCENTAGE OF TOTAL AREA							
Station Name	Drainage Area, in Square Miles	Population Density, in Persons Per Acre	Roads	Single-Family Residential	Multifamily Residential	Commercial	Industrial	Institutional	Recreational	Open Space
Artic Street Storm Drain at Tampa, Florida	0.34	6.6	14.7	46.2	0	36.5	0	1.5	0	1.1
Kirby Street Drainage Ditch at Tampa, Florida	1.40	6.8	4.4	69.0	3.3	4.5	0	2.2	1.0	15.6
St. Louis Street Drainage Ditch at Tampa, Florida	.51	8.2	11.8	68.1	0	3.3	0	6.5	2.3	8.0
Gandy Boulevard Drainage Ditch at Tampa, Florida	1.29	5.7	8.5	31.6	5.1	21.0	0	3.9	5.6	24.3
Allen Creek near Largo, Florida	1.79	6.9	10.3	59.0	3.9	7.0	0	7.9	.5	11.4
Booker Creek at St. Petersburg, Florida	3.45	5.8	12.3	48.8	1.7	18.1	4.4	3.0	2.7	9.0
Bear Creek at St. Petersburg, Florida	1.89	6.9	12.8	66.1	4.3	5.8	0	5.5	1.0	4.5
Saint Joes Creek at St. Petersburg, Florida	1.72	5.3	12.0	47.7	.1	16.2	7.7	1.8	1.9	12.6
Turner Street Storm at Clearwater, Florida	.45	6.9	12.7	37.4	1.4	28.0	20.0	.4	0	.1

TABLE 2-17. NUTRIENTS FOUND IN STORMWATER RUNOFF FROM SELECTED MIXED URBAN LAND USE MONITORING STUDIES (ALL VALUES ARE EMCs WITH NUMBER OF EVENTS IN PARENTHESES) (STUDY SITES ARE RANKED ACCORDING TO PERCENTAGE OF EACH LAND USE TYPE: R = RESIDENTIAL, C = COMMERCIAL, RD = ROADWAY, I = INDUSTRIAL)

Study Site	TKN (mg/L)	$NO_2 + NO_3$ (mg/L)	Total-P (mg/L)	Ortho-P (mg/L)
Arctic Street (R>C>RD)	1.4* 0.58 - 3.7* (17)	0.27* 0.09 - 1.4* (17)	0.28 0.12 - 0.61 (17)	0.14 0.21 - 0.92 (17)
Gandy Blvd (R>C>RD)	1.6* 0.24 - 2.8* (20)	0.24* 0.07 - 0.50* (20)	0.30 0.20 - 0.44 (20)	0.18 0.11 - 0.28 (20)
Booker Creek (R>C>RD>I)	2.2* 0.85 - 6.5 (11)	0.16* 0.05 - 0.35* (20)	0.50 0.24 - 1.0 (11)	0.21 0.10-0.32 (11)
Saint Joes Creek (R>C>RD>I)	1.2* 0.65 - 3.3* (7)	1.2* 0.83-1.4* (7)	0.30 0.20 - 1.0 (13)	0.12 0.08 - 0.20 (7)
Kirby Street (R>C=RD)	1.7* 0.90 - 3.7* (20)	0.51* 0.20 - 1.8* (20)	0.25 0.08 - 0.50 (20)	0.12 0.04 - 0.27 (20)
Turner Street (R>C>I>RD)	0.94* 0.37 - 7.4 (13)	0.58* 0.07 - 1.2* (13)	0.52 0.13 - 0.97 (13)	0.19 0.10 - 0.35 (13)
St. Louis Street (R>RD>C)	2.4* 0.39 - 14* (24)	0.33* 0.01 - 0.68* (24)	0.45 0.12 - 1.7 (41)	0.14 0.10 - 0.23 (24)
Allen Creek (R>RD>C)	2.0* 0.31 - 4.8* (28)	0.41* 0.07 - 1.6* (28)	0.52 0.12 - 1.4 (34)	0.16 0.08 - 0.25 (28)
Bear Creek (R>RD>C)	0.63* 0.09 - 1.4* (15)	0.11* 0.04 - 0.35* (15)	0.20 0.06 - 0.30 (21)	0.08 0.03 - 0.10 (15)

* CALCULATED FROM REPORTED DATA

TABLE 2-18. HEAVY METALS FOUND IN STORMWATER RUNOFF FROM SELECTED MIXED URBAN LAND USE MONITORING STUDIES (LOPEZ AND GIOVANNELLI, 1984). (ALL VALUES ARE EMCs WITH NUMBER OF EVENTS IN PARENTHESES). (STUDY SITES ARE RANKED ACCORDING TO PERCENTAGE OF EACH LAND USE TYPE: R = RESIDENTIAL, C = COMMERCIAL, RD = ROADWAY, I = INDUSTRIAL)

Study Site	Total Copper (µg/L)	Total Zinc (µg/L)	Total Lead (µg/L)
Arctic Street	16	172	743
(R>C>RD)	6 - 70	100 - 310	43 - 1,600
	(12)	(12)	(12)
Gandy Blvd.	7	103	154
(R>C>RD)	2 - 27	50 - 300	20 - 590
	(19)	(19)	(19)
Booker Creek	21	115	219
(R>C>RD>I)	12 - 38	100 - 150	190 - 270
	(11)	(11)	(11)
Saint Jose Creek	51	182	349
(R>C>RD>I)	12 - 100	90 - 300	72 - 1,100
	(6)	(6)	(11)
Kirby Street	--	--	50
(R>C=RD)	--	--	5 - 190
	--	--	(20)
Turner Street	18	255	405
(R>C>I>RD)	8 - 69	110 - 400	130 - 740
	(9)	(9)	(9)
St. Louis Street	16	133	213
(R>RD>C)	5 - 28	60 - 200	24 - 580
	(40)	(25)	(18)
Allen Creek	15	97	156
(R>RD>C)	3 - 28	20 - 170	6 - 300
	(27)	(27)	(34)
Bear Creek	2	83	128
(R>RD>C)	2 - 20	7 - 160	15 - 220
	(21)	(21)	(21)

TABLE 2-19. OXYGEN DEMAND AND TOTAL SUSPENDED SOLIDS CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM SELECTED MIXED URBAN LAND USE MONITORING STUDIES (LOPEZ AND GIOVANNELLI, 1984) (ALL VALUES ARE EMCs WITH NUMBER OF EVENTS IN PARENTHESES) (STUDY SITES ARE RANKED ACCORDING TO PERCENTAGE OF EACH LAND USE TYPE: R=RESIDENTIAL, C=COMMERCIAL, RD=ROADWAY, I=INDUSTRIAL

Study Site	BOD (mg/L)	COD (mg/L)	TSS (mg/L)
Arctic Street	6.2	57	--
(R>C>RD)	4.4 - 8.6	10 - 170	--
	(16)	(12)	--
Gandy Blvd.	5.0	32	--
(R>C>R)	2.0 - 12	14 - 64	--
	(20)	(20)	--
Booker Creek	4.9	83	--
(R>C>RD>I)	3.4 - 8.3	39 - 160	--
	(11)	(11)	--
Saint Joes Creek	8.1	77	--
(R>C>RD>I)	5.2 - 10	38 - 210	--
	(9)	(9)	--
Kirby Street	4.5	64	--
(R>C=RD)	1.4 - 8.6	5 - 120	--
	(20)	(20)	--
Turner Street	10	89	--
(R>C>I>RD)	1.4 - 28	25 - 170	--
	(13)	(13)	--
St. Louis Street	6.1	55	--
(R>RD>C)	2.0 - 11	11 - 130	--
	(40)	(40)	--
Allen Creek	5.6	54	--
(R>RD>C)	0.70 - 11	15 - 130	--
	(34)	(19)	--
Bear Creek	4.7	56	--
(R>RD>C)	0.70 - 6.0	10 - 210	--
	(14)	(18)	--

* CALCULATED FROM REPORTED DATA

TABLE 2-20. AVERAGE CONCENTRATIONS AND LOADING RATES FOR SELECTED STORMWATER RUNOFF PARAMETERS INTO LAKE EOLA

Parameter	Average Stormwater Concentration	Average Loading (kg/yr)
TKN, mg/L	3.3	1,760
Total-P, mg/L	0.48	264
TSS, mg/L	131	54,505
Total Copper, µg/L	0.07	37.4
Total Zinc, µg/L	0.38	204
Total Lead, µg/L	0.44	234
BOD, mg/L	13	5,390
COD, mg/L	74	39,105

Figure 2-5 compares total phosphorus ranges reported for each of the five land use types. Residential land use areas exported significantly {95% Confidence Interval (C. I.)} higher total phosphorus EMCs than the other land use classifications. Conversely, the EMCs reported from commercial sites were significantly (95% C. I.) lower than the other land use types.

Heavy Metals

Based on the literature assessed for this report, lead, which is the most predominant heavy metal in stormwater runoff, appeared to be significantly (90% C. I.) more prevalent in runoff from commercial and roadway land use areas than residential, industrial, and mixed urban areas reported as illustrated in Figure 2-6. However, little differences can be seen between commercial and roadway land use areas.

Oxygen Demand

As mentioned, COD is probably a more accurate test for oxygen demand in stormwater runoff because of the sensitivity of the BOD test to toxins. Reported COD values show residential and roadway areas to have a much higher variability and potential (95% C. I.) to export COD to receiving waters than the other land use groups (Figure 2-7).

Total Suspended Solids

Total suspended solids EMC range comparison is presented in Figure 2-8. There did not appear to be any clear pattern as to which land use group showed a higher potential to export TSS quantities in stormwater runoff.

Organics

Organic priority pollutants have become of more interest during recent years due to their possible

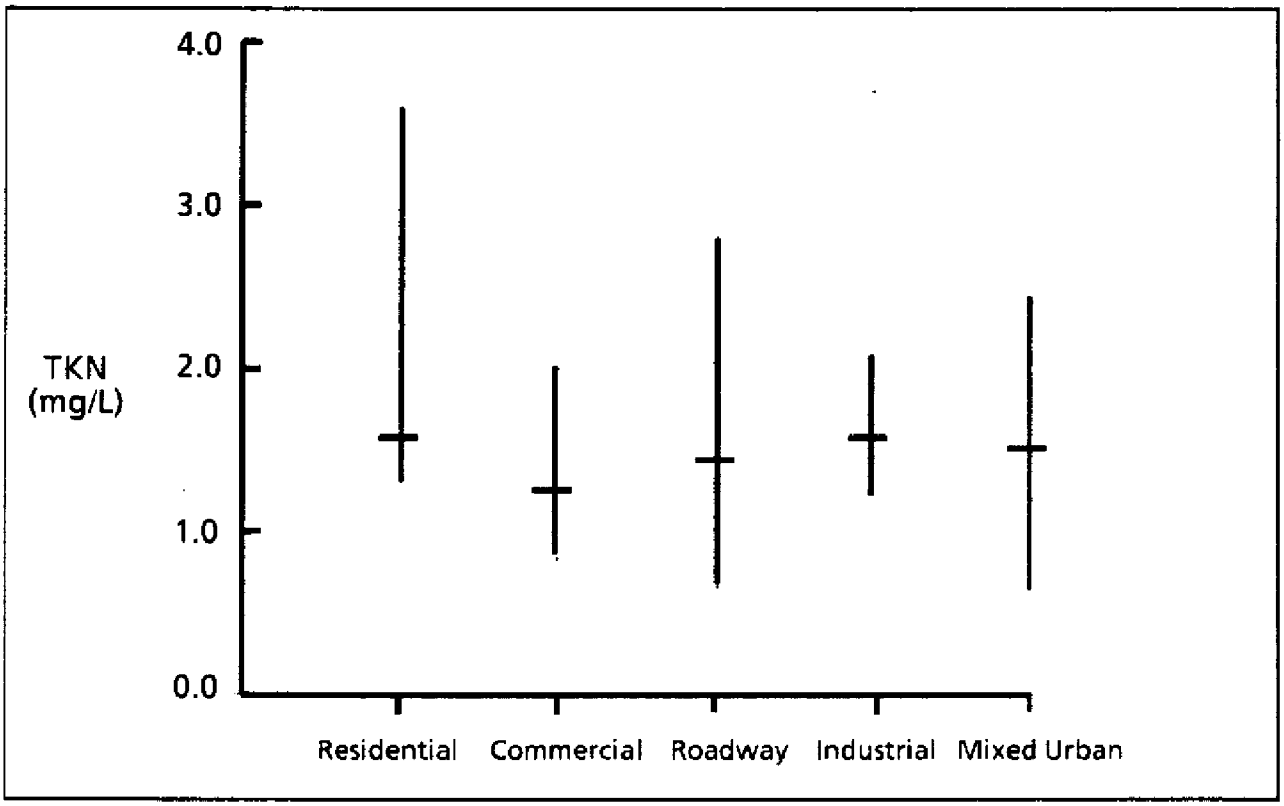

FIGURE 2-4. COMPARISON OF TOTAL KJELDAHL NITROGEN (TKN) EMC RANGES AND MEANS

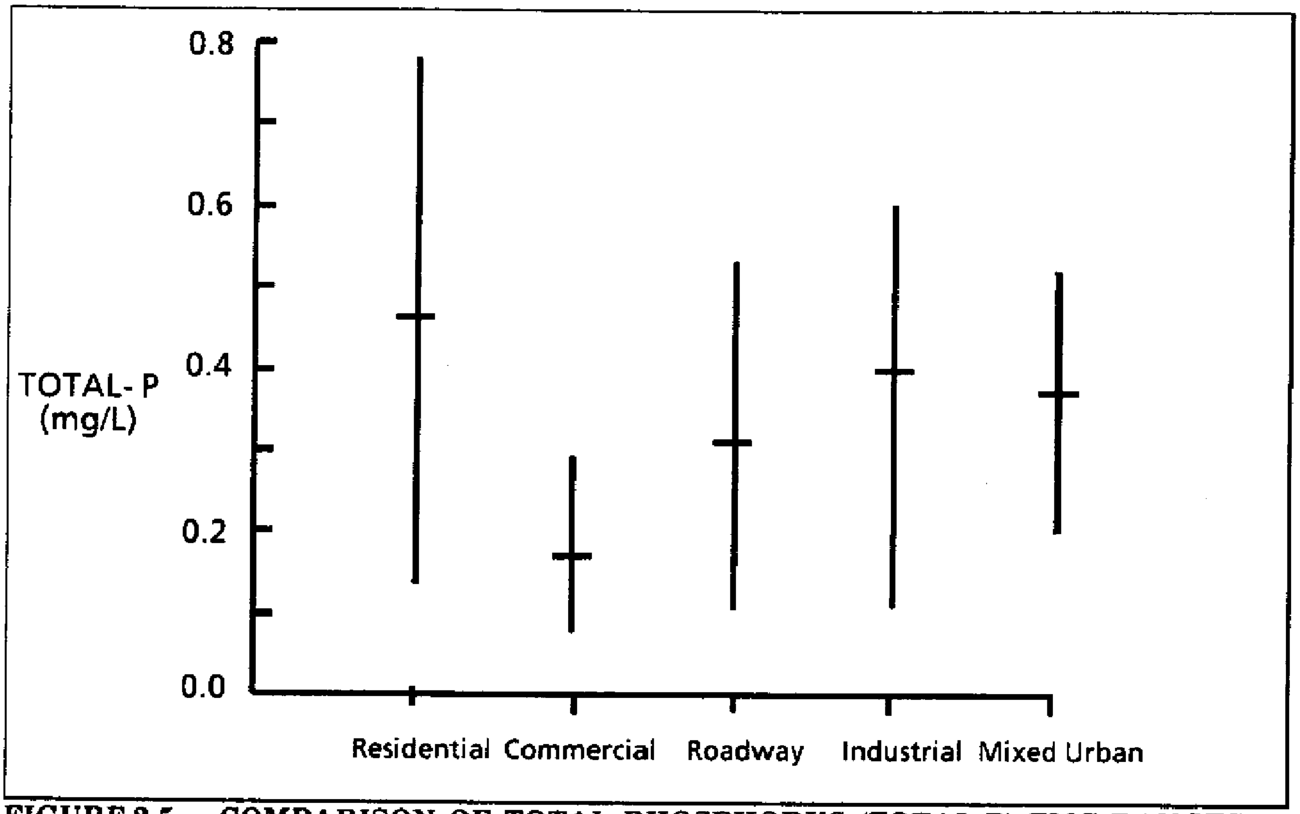

FIGURE 2-5. COMPARISON OF TOTAL PHOSPHORUS (TOTAL-P) EMC RANGES AND MEANS

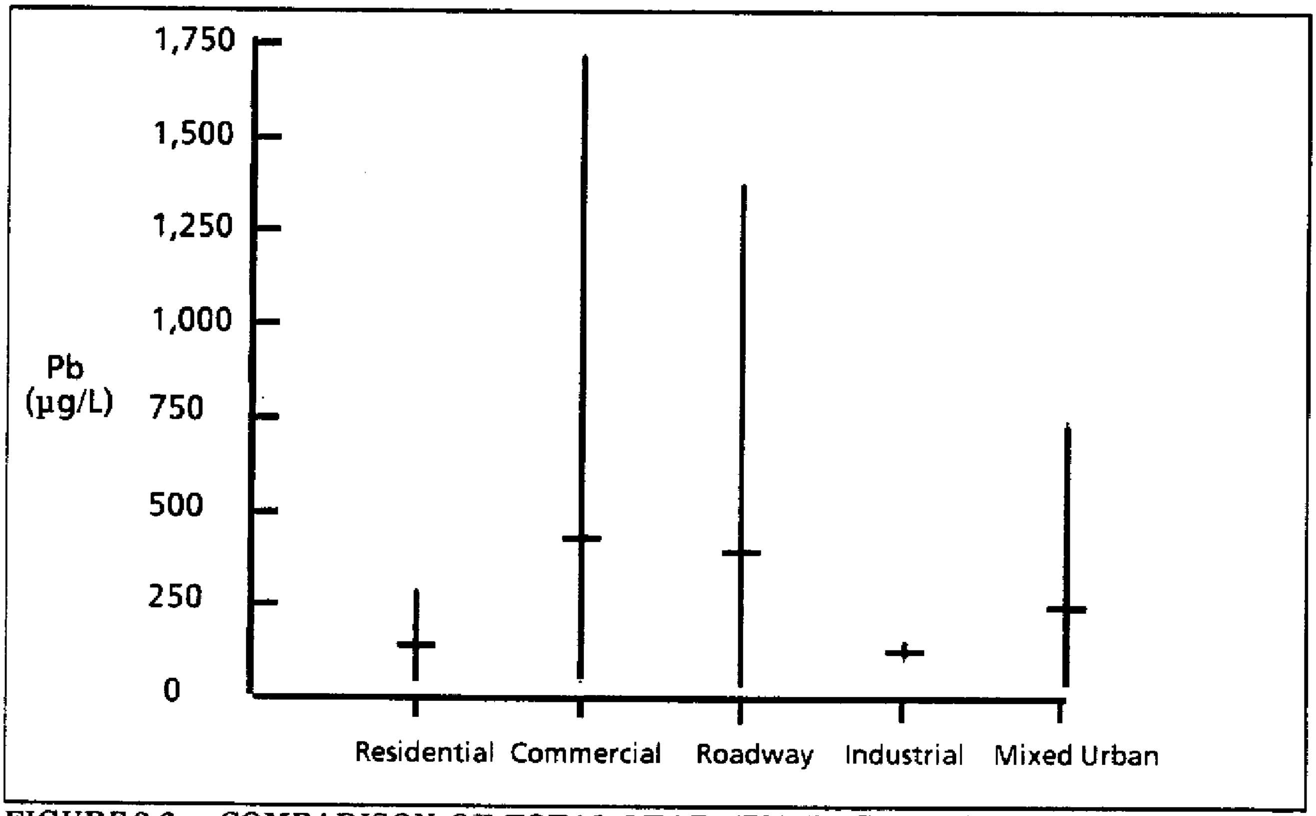

FIGURE 2-6. COMPARISON OF TOTAL LEAD (Pb) EMC RANGES AND MEANS

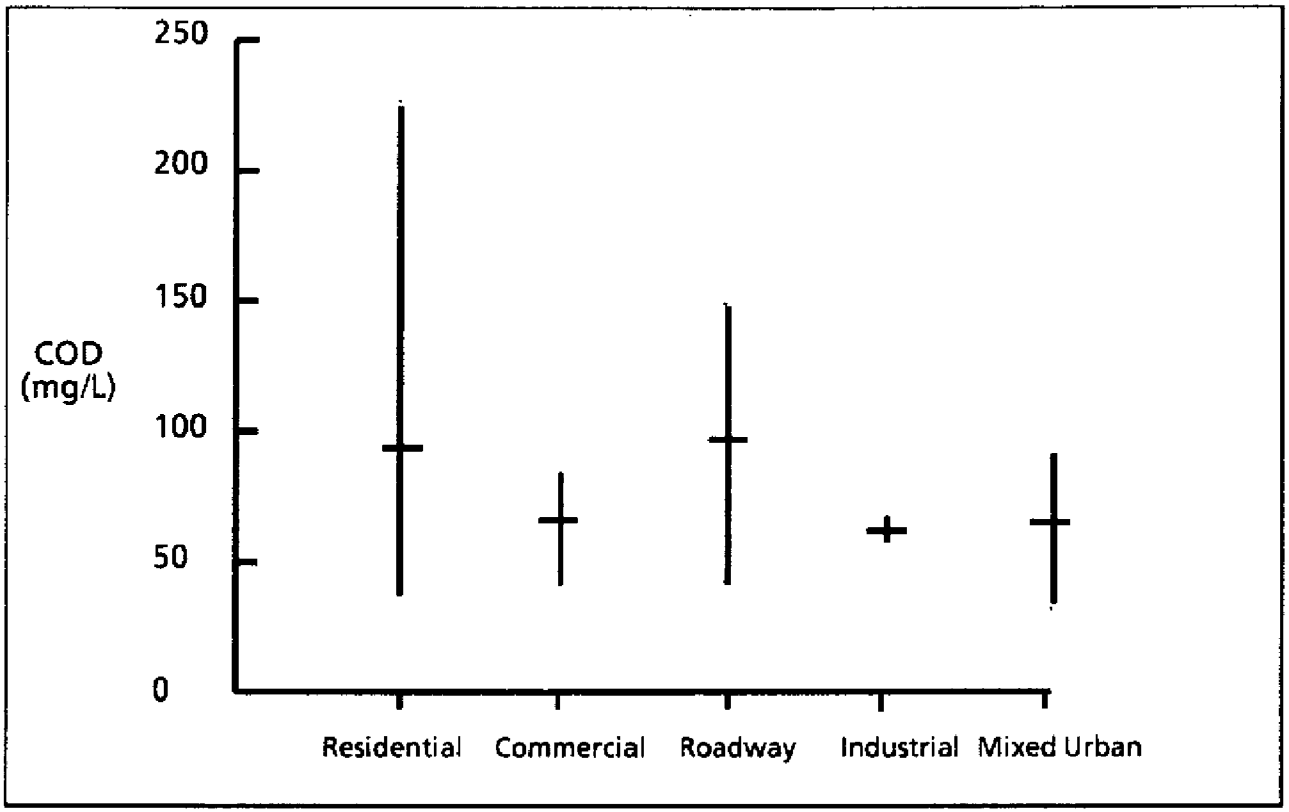

FIGURE 2-7. COMPARISON OF CHEMICAL OXYGEN DEMAND (COD) EMC RANGES AND MEANS

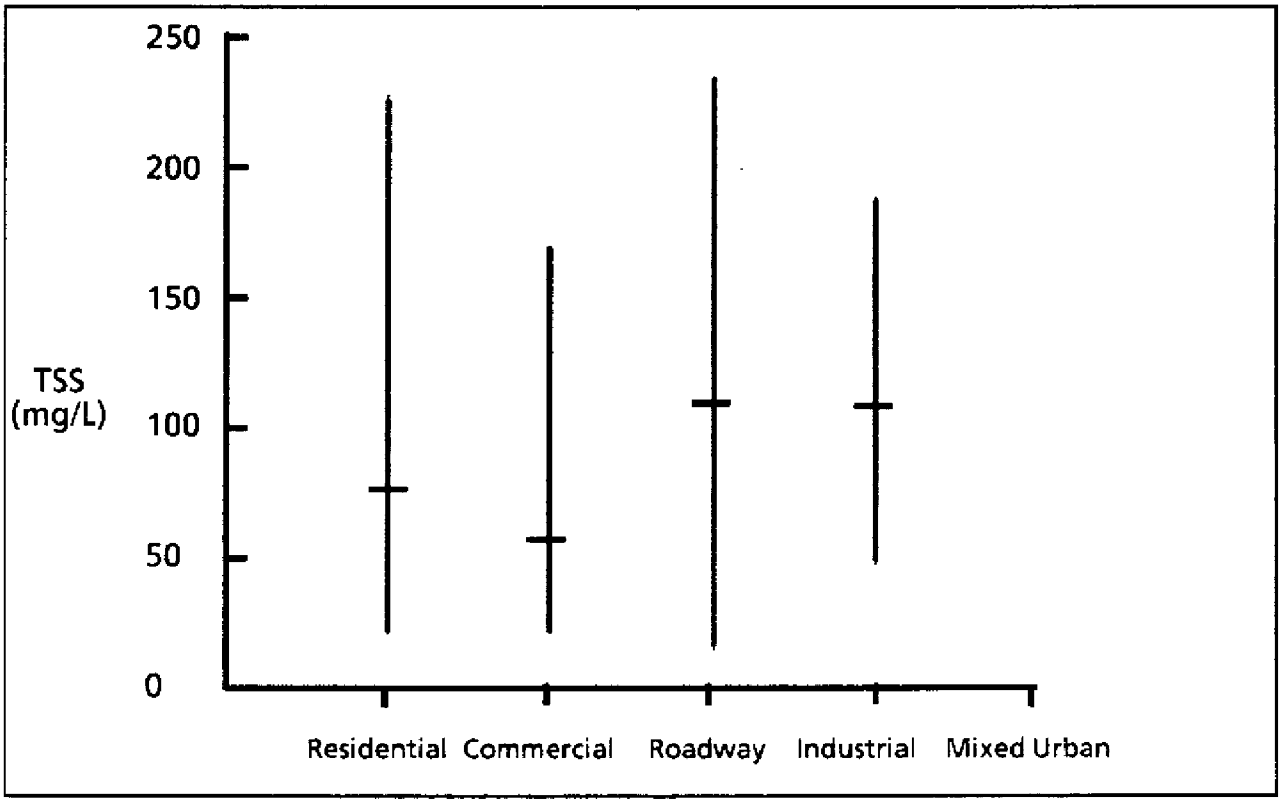

FIGURE 2-8. COMPARISON OF TOTAL SUSPENDED SOLIDS (TSS) EMC RANGES AND MEANS

impact on human health. However, stormwater runoff monitoring studies focusing on priority pollutant organics are limited.

One such study was conducted in and near Warwick, Rhode Island, (Hoffman et al., 1982: Hoffman et al. 1984) in which the potential for urban runoff to be a source of Polynuclear Aromatic Hydrocarbons (PAHs) in receiving waters was evaluated. This particular investigation involved a series of comparative monitoring projects under four different land uses, residential, commercial (shopping center), heavy industrial, and highway. The studies investigated the effect the land uses had on contributing to the presence of polycyclic aromatic hydrocarbons (PAHs - largely petroleum by-products) in stormwater runoff. The summarized PAH EMC results of the Warwick, Rhode Island, study are presented in Table 2-21.

Examination of Table 2-21 shows the residential, commercial, and highway sites to exhibit comparable levels of PAH. However, the heavy industrial site monitored shows a significantly higher PAH export.

Twenty eight NURP study sites were also utilized to provide data for 114 organic pollutants. Table 2-22 lists the pollutants, cities where detected, frequency of detection, and concentration range. Table 2-22 may be reduced and put in perspective by evaluating the data in two ways. First, ranking the organic pollutants by detection frequency allows for categorization of constituents which are most prevalent. No organic pollutants were detected in greater than 25 percent of the samples analyzed. Thirteen organic compounds were detected in 10 percent or greater of the samples and are ranked in Table 2-23. The most commonly found organic was the plasticizer bis(2-ethylhexyl) phthalate (22 percent) followed by the pesticide α-hexachlorocyclohexane (20 percent). The same plasticizer was also commonly detected in surface and ground water samples analyzed during a stormwater management evaluation on a South Florida commercial land use site (SFWMD (b)).

The second method for evaluating the organic priority pollutants detected during the NURP study is by water quality criteria exceedance. There are several water quality criteria ranging from taste and odor to drinking water standards. Table 2-24 displays the organic pollutants detected in greater than 10 percent of the NURP samples analyzed. The most serious criteria exceedance in the human carcinogen category (HC) were α-hexachlorocyclohexane, γ-hexachlorocyclohexane (lindane), chlordane, phenanthrene, pyrene, and chrysene.

Summary

Table 2-25 illustrates a cursory summary of statistical analyses performed on the stormwater runoff water quality data presented in Figures 2-4 through 2-8. The matrix in Table 2-25 identifies the land use classifications which were shown to be statistically higher pollutant exporters. The matrix reveals that no individual land use category was shown to be a dominant exporter for all pollutants.

Industrial and commercial land use areas are generally perceived to have a higher potential for catastrophic events (e.g. spills). Such perceptions have led to SFWMD permit monitoring requirements for industrial sites and additional pre-treatment for industrial and commercial sites. These same perceptions hold for the possibility of isolated spills occurring on roadways. However, roadways do not have pre-treatment or monitoring requirements.

Analysis of typical storm events show that roadway runoff appears to export pollutants at levels equal to commercial and industrial land use areas, and in fact may export higher levels of lead and COD. This fact, along with the potential for isolated spills, places roadways at the same priority level as industrial and commercial sites in terms of water quality concerns. Consideration should be given to increasing the requirements of water management systems associated with roadways to provide equivalence with present criteria required for industrial and commercial land use areas.

TABLE 2-21. SUMMARY OF POLYCYCLIC AROMATIC HYDROCARBONS (PAH) CONCENTRATIONS FOUND IN STORMWATER RUNOFF FROM FOUR LAND USE AREAS IN WARWICK, RHODE ISLAND (HOFFMAN ET AL., 1984)

Land Use Type	Mean EMC (μg/L)	EMC Range (μg/L)	Number of Events
Residential	1.86	1.29 - 2.53	3
Commercial	2.34	0.29 - 7.80	6
Multilane Highway	4.50	1.67 - 8.36	3
Heavy Industrial	17.70	3.51 - 49.1	5

TABLE 2-22. SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES[1] (FROM USEPA, 1983)

Pollutant	Cities Where Detected[2]	Frequency of Detection[3]	Range of Detected Concentrations (µg/l)[4]
I. PESTICIDES			
1. Acrolein	Holding Times Exceeded		
2. Aldrin	4,7,26	6	0.002T - 0.1M
3. α-Hexachlorocyclohexane (α-BHC) (Alpha)	7,8,22,26	20	0.0027 - 0.1M
4. β-Hexachlorocyclohexane (β-BHC) (Beta)	7,8	5	0.018 - 0.1M
5. γ-Hexachlorocyclohexane (γ-BHC) (Gamma) (Lindane)	7,8,22,26	15	0.007 - 0.1M
6. δ-Hexachlorocyclohexane (δ-BHC) (Delta)	7,26	6	0.004 - 0.1M
7. Chlordane	2,8,21,26	17	0.01L - 10
8. DDD	Not Detected		
9. DDE	26	6	0.007 - 0.027
10. DDT	7	1	0.1M
11. Dieldrin	26,27	6	0.007 - 0.1
12. α-Endosulfan (Alpha)	7,26,27	19	0.008 - 0.2
13. β-Endosulfan (Beta)	Not Detected		
14. Endosulfan Sulfate	Not Detected		
15. Endrin	Not Detected		
16. Endrin Aldehyde	Not Detected		
17. Heptachlor	7,8,27	6	0.01 - 0.1M
18. Heptachlor Epoxide	7,26	2	0.003T - 0.1M
19. Isophorone	7	3	10M
20. TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin)	Not Included in NURP Program		
21. Toxaphene	Not Detected		
II. METALS AND INORGANICS			
22. Antimony	7,24,26	13	2.6 - 23A
23. Arsenic	2,3,7,12,19,20,21,22,26,27	52	1 - 50.5
24. Asbestos	Not Included in NURP Program		
25. Beryllium	7,12,20,21	12	1 - 49
26. Cadmium	1,2,3,7,12,20,21,27	48	0.1M - 14
27. Chromium	1,2,7,8,12,17,19,20,21,22,26,27,28	58	1 - 190
28. Copper	1,2,3,4,7,8,12,17,19,20,21,22,23,26,27,28	91	1L - 100
29. Cyanides	4,8,19,22,26,27	23	2 - 300
30. Lead	1,2,3,4,7,8,12,17,19,20,21,22,26,28	94	6 - 460
31. Mercury	7,20,28	9	0.6 - 1.2
32. Nickel	2,3,7,12,20,21,26,27	43	1 - 182
33. Selenium	7,19,23	11	2 - 77
34. Silver	3,17,27	7	0.2M - 0.8
35. Thallium	7	6	1 - 14
36. Zinc	1,2,3,7,12,17,19,20,21,22,23,27,28	94	10 - 2,400

TABLE2-22 CONTINUED. SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES (FROM USEPA, 1983)

Pollutant	Cities Where Detected[2]	Frequency of Detection[3]	Range of Detected Concentrations (µg/l)[4]
III. PCBS AND RELATED COMPOUNDS			
37. PBC - 1016 (Aroclor 1016)	Not Detected		
38. PCB - 1221 (Aroclor 1221)	Not Detected		
39. PCB - 1232 (Aroclor 1232)	Not Detected		
40. PCB - 1242 (Aroclor 1242)	Not Detected		
41. PCB - 1248 (Aroclor 1248)	Not Detected		
42. PCB - 1254 (Aroclor 1254)	Not Detected		
43. PCB - 1260 (Aroclor 1260)	2	1	0.03
44. 2-Chloronaphthalene	Not Detected		
IV. HALOGENATED ALIPHATICS			
45. Methane, Bromo- (Methyl Bromide)	Not Detected		
46. Methane, Chloro- (Methyl Chloride)	Not Detected		
47. Methane, Dichloro - (Methylene Chloride)	4,17,22	11	5-14,5A
48. Methane, Chlorodibromo-	28	1	2
49. Methane, Dichlorobromo-	28	1	2
50. Methane, Tribromo - (Bromoform)	28	1	1
51. Methane, Trichloro - (Chloroform)	4,17,20,22,23,27,28	9	0.2T-12L
52. Methane, Tetrachloro - (Carbon Tetrachloride)	4,28	3	1-2
53. Methane, Trichlorofluoro-[5]	2,4,24,28	5	0.6T-27
54. Methane, Dichlorodifluoro- (Freon-12)[5]	Not Detected		
55. Ethane, Chloro-	Not Detected		
56. Ethane, 1,1-Dichloro-	4,28	3	1.5A-3
57. Ethane, 1,2-Dichloro-	28	1	4
58. Ethane, 1,1,1-Trichloro-	4,2,7,22,24	6	1.6-10M
59. Ethane, 1,1,2-Trichloro-	28	2	2-3
60. Ethane, 1,1,2,2-Tetrachloro-	4	2	2G-3
61. Ethane, Hexachloro-	Not Detected		
62. Ethene, Chloro- (Vinyl Chloride)	Not Detected		
63. Ethene, 1,1-Dichloro-	28	2	1.5-4
64. Ethene, 1,2-Trans-Dichloro-	20,28	4	1-3
65. Ethene, Trichloro-	2,4,8,24,28	6	0.3T-12
66. Ethene, Tetrachloro-	8,17,22,28	5	1M-43
67. Propane, 1,2-Dichloro-	28	1	3
68. Propene, 1,3-Dichloro-	28	2	1-2
69. Butadiene, Hexachloro-	Not Detected		
70. Cyclopentadine, Hexachloro-	Standard Methods Inappropriate		

TABLE 2-22 CONTINUED. SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES (FROM USEPA, 1983)

Pollutant	Cities Where Detected[2]	Frequency of Detection[3]	Range of Detected Concentrations (µg/l)[4]
V. ETHERS			
71. Ether, Bis (Chloromethyl)5	Not Detected		
72. Ether, Bis (2-Chloroethyl)	Not Detected		
73. Ether, Bis (2-Chloroisopropyl)	Not Detected		
74. Ether, 2-Chloroethyl Vinyl	Not Detected		
75. Ether, 4-Bromophenyl Phenyl	Not Detected		
76. Ether, 4-Chlorophenyl Phenyl	Not Detected		
77. Bis (2-Chloroethoxy) Methane	Not Detected		
VI. MONOCYCLIC AROMATICS (EXCLUDING PHENOLS, CRESOLS, PHTHALATES)			
78. Benzene	4,17,27	5	1-13
79. Benzene, Chloro-	7,20,26,28	5	1G-10M
80. Benzene, 1,2-Dichloro-	Not Detected		
81. Benzene, 1,3-Dichloro-	Not Detected		
82. Benzene, 1,4-Dichloro-	Not Detected		
83. Benzene, 1,2,4-Trichloro-	Not Detected		
84. Benzene, Hexachloro-	Not Detected		
85. Benzene, Ethyl-	4,8,17,20,26,28	6	1 - 2
86. Benzene, Nitro-	Not Detected		
87. Toluene	4,17	3	3 - 9
88. Tolune, 2,4-Dinitro	Not Detected		
89. Toluene, 2,6-Dinitro	Not Detected		
VII. PHENOLS AND CRESOLS			
90. Phenol	4,7,26	14	1L - 13T
91. Phenol, 2-Chloro-	28	1	2
92. Phenol, 2,4-Dichloro-	Not Detected		
93. Phenol, 2,4,6-Trichloro-	Not Detected		
94. Phenol, Pentachloro-	4,8,19,20,26,27,28	19	1T - 115
95. Phenol, 2-Nitro-	8	1	1M
96. Phenol, 4-Nitro-	4,7,8,20,26,28	10	1T - 37
97. Phenol, 2,4-Dinitro-	Not Detected		
98. Phenol, 2,4-Dimethyl-	4,7,8,26	8	1T - 10M
99. m-Cresol, p-Chloro-	4	1	1.5A
100. o-Cresol 4,6-Dinitro-	Not Detected		

TABLE 2-22 CONTINUED. SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES (FROM USEPA, 1983)

Pollutant	Cities Where Detected[2]	Frequency of Detection[3]	Range of Detected Concentrations (µg/l)[4]
VIII. PHTHALATE ESTERS			
101. Phthalate, Dimethyl	8	1	1L
102. Phthalate, Diethyl	3,4,17,20,21	6	1 - 10M
103. Phthalate, Di-N-Butyl	4,22,24	6	0.5T - 11
104. Phthalate, Di-N-Octyl	8,20,26,27,28	6	0.4T - 2G
105. Phthalate, Bis (2-Ethylhexyl)	4,12,19,22,21,26	22	4T - 62
106. Phthalate, Butyl Benzyl	2,8,26	6	1 - 10M
IX. POLYCYCLIC AROMATIC HYDROCARBONS			
107. Acenaphthene	Not Detected		
108. Acenaphthylene	Not Detected		
109. Anthracene	2,17,20,21,26,28	7	1 - 10M
110. Benzo (a) Anthracene	2,21,27	4	1 - 10M
111. Benzo (b) Fluoranthene	26,27	5	1 - 5
112. Benzo (k) Fluoranthene	2,21,27	3	4 - 14
113. Benzo (g,h,i) Perylene	21	1	5
114. Benzo (a) Pyrene	2,21,26,27	6	1 - 10M
115. Chrysene	2,7,17,21,26,27	10	0.6T - 10M
116. Dibenzo (a,h) Anthracene	21	1	1T
117. Fluoranthene	2,8,12,17,21,26,27,28	16	0.3T - 21
118. Fluorene	28	1	1
119. Indeno (1,2,3-c,d) Pyrene	21	1	4
120. Naphthalene	4,24,26,28	9	0.8T - 2.3
121. Phenanthrene	2,8,17,20,21,26,27,28	12	0.3T - 10M
122. Pyrene	2,3,8,12,17,21,26,27,28	15	0.3T - 16
X. NITROSAMINES AND OTHER NITROGEN-CONTAINING COMPOUNDS			
123. Nitrosamine, Dimethyl (DMN)	Standard Methods Inappropriate		
124. Nitrosamine, Diphenyl	Standard Methods Inappropriate		
125. Nitrosamine, Di-N-Propyl	Not Detected		
126. Benzidine	Standard Methods Inappropriate		
127. Benzidine, 3,3'-Dichloro-	Not Detected		
128. Hydrazine, 1,2-Diphenyl-	Standard Methods Inappropriate		
129. Acrylonitrile	Holding Times Exceeded		

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[1] BASED ON 121 SAMPLE RESULTS RECEIVED AS OF SEPTEMBER 30, 1983, ADJUSTED FOR QUALITY CONTROL REVIEW

[2] CITIES FROM WHICH DATA ARE AVAILABLE:

1. DURHAM, NJ 2. LAKE QUNISIGAMOND, MA 3, MYSTIC RIVER, MA 4. LONG ISLAND, NY 7. WASHINGTON, DC
8. BALTIMORE, MD 12 KNOXVILLE, TN 17. GLEN ELLYN, IL 19. AUSTIN, TX 20 LITTLE ROCK, AR
21. KANSAS CITY, KS 22. DENVER, CO 23 SALT LAKE CITY, UT 24 RAPID CITY, SD 26. FRESNO, CA
27. BELEVUE, WA 28. EUGENE, OR

[3] PERCENTAGES ROUNDED TO NEAREST WHOLE NUMBER

[4] SOME REPORTED CONCENTRATIONS ARE QUALIFIED BY STORET QUALITY CONTROL REMARK CODES, TO WIT: A=VALUE REPORTED IS THE MEAN OF TWO OR MORE DETERMINATIONS; G=VALUE REPORTED IS THE MAXIMUM OF TWO OR MORE DETERMINATIONS; L=ACTUAL VALUE IS KNOWN TO BE GREATER THAN VALUE GIVEN; M-PRESENCE OF MATERIAL VERIFIED BUT NOT QUANTIFIED; T=VALUE REPORTED IS LESS THAN CRITERIA OF DETECTION. ONE VALUE IN THIS COLUMN INDICATES ONE POSITIVE OBSERVATION OR THAT ALL OBSERVATIONS WERE EQUAL

[5] NO LONGER INCLUDED AS A PRIORITY POLLUTANT

TABLE 2-23. MOST FREQUENTLY DETECTED ORGANIC PRIORITY POLLUTANTS IN NURP URBAN RUNOFF SAMPLES (USEPA, 1983)

	Organic Compound	Detection Frequency	Concentration Range µg/L
VIII.	PHTHALATE ESTERS		
105.	Bis (2-Ethylhexyl) Phthalate	22%	4T - 62
I.	PESTICIDES		
3.	α- Hexachlorocyclohexane	20%	0.0027 - 0.1M
12.	α - Endosulfan	19%	0.008 - 0.2
7.	Chlordane	17%	0.01L - 10
5.	γ - Hexachlorocyclohexane (Lindane)	15%	0.007 - 0.1M
VII.	PHENOLS AND CRESOLS		
94.	Pentachlorophenol	19%	1T - 115
90.	Phenol	14%	1L - 13T
96.	4 - Nitrophenol	10%	1T - 37
IX.	POLYCYCLIC AROMATIC HYDROCARBONS		
117.	Fluoranthene		
122.	Pyrene	16%	0.3T - 21
121.	Phenanthrene	15%	0.3T - 16
115.	Chrysene	12%	0.3T - 10M
		10%	0.6T - 10M
IV.	HALOGENATED ALIPHATICS		
47.	Dichloromethane (Methylene Chloride)	11%	5 - 14.5A

STORET QUALITY CONTROL INDEX MARKS:

A = VALUE REPORTED IS THE MEAN OF TWO OR MORE DETERMINATIONS
L = ACTUAL VALUE IS KNOWN TO BE GREATER THAN VALUE GIVEN
M = PRESENCE OF MATERIAL VERIFIED BUT NOT QUANTIFIED
T = VALUE REPORTED IS LESS THAN CRITERIA OF DETECTION

NOTE: Table 2-24 on following 2 pages.

TABLE 2-25. RESULT MATRIX OF STATISTICAL ANALYSES BETWEEN LAND USE CATEGORIES AND POLLUTANT EMC'S

(X IDENTIFIES THE LAND USE CLASSIFICATIONS WHICH WERE STATISTICALLY SHOWN TO EXPORT THE HIGHEST EMC'S)

Pollutant	Land Use Classifications				
	Residential	Commercial	Light Industrial	Roadway	Mixed Urban
TKN	--	--	--	--	--
Total-P	X	--	--	--	--
Lead (Pb)	--	X	--	X	--
COD	X	--	--	X	--
TSS	--	--	--	--	--

TABLE 2-24. SUMMARY OF WATER QUALITY CRITERIA EXCEEDANCES FOR POLLUTANTS DETECTED IN AT LEAST TEN PERCENT OF NURP SAMPLES (USEPA, 1983)[1]

Pollutant	Frequency of Detection (%)	Detections/ Samples[2]	CRITERIA EXCEEDANCES (%)[3]						
			None	FA	FC	OL	HH	HC[4]	DW
I. PESTICIDES									
3. α-Hexachlorocyclohexane	20	21/106						8,18,20	
5. γ-Hexachlorocyclohexane (Lindane)	15	15/100			8			0,10,15	
7. Chlordane	17	7/42		2	17			17,17,17	
12. α-Endosulfan	19	9/49			10				
II. METALS AND INORGANICS									
22. Antimony	13	14/106	X						
23. Arsenic	52	45/87						52,52,52	1
25. Beryllium	12	11/94			6*			12,12,12	
26. Cadmium[5]	48	44/91		8	48		1		1
27. Chromium[5,6]	58	47/81			1*				1
28. Copper[5]	91	79/87		47	82				
29. Cyanides	23	16/71		3	22		4		
30. Lead[5]	94	75/80		23	94		73		
32 Nickel[5]	43	39/91			5		21		73
33. Selenium	11	10/88			5		10		
36. Zinc[5]	94	88/94		14	77				10
IV. HALOGENATED ALIPHATICS									
47. Methane, Dichloro-	11	3/28						0,0,11	
VII. PHENOLS AND CRESOLS									
90. Phenol	14	13/91	X						
94. Phenol, Pentachloro-	19	21/111		1*	11*	1			
96. Penol, 4-Nitro-	10	11/107	X						

TABLE 2-24 CONTINUED. SUMMARY OF WATER QUALITY CRITERIA EXCEEDANCES FOR POLLUTANTS DETECTED IN AT LEAST TEN PERCENT OF NURP SAMPLES (USEPA, 1983)

Pollutant	Frequency of Detection (%)	Detections/ Samples[2]	CRITERIA EXCEEDANCES (%)[3] None	FAC	FC	OL	HH	HC[4]	DW
VIII. PHTHALATE ESTERS									
105. Phthalate, Bis (2-Ethylhexyl)	22	15/69			22*				
IX. POLYCYCLIC AROMATIC HYDROCARBONS									
115. Chrysene	10	11/109						10,10,10	
117. Fluoranthene	16	17/109	x						
121. Phenanthrene	12	13/110						12,12,12	
122. Pyrene	15	16/110						15,15,15	

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* INDICATES FTA OR FTC VALUE SUBSTITUTED WHERE FA OR FC CRITERION NOT AVAILABLE (SEE BELOW)

[1] BASED ON 121 SAMPLE RESULTS RECEIVED AS OF SEPTEMBER 30, 1983, ADJUSTED FOR QUALITY CONTROL REVIEW

[2] NUMBER OF TIMES DETECTED/ NUMBER OF ACCEPTABLE SAMPLES

[3] FA = FRESHWATER AMBIENT 24-HOUR INSTANTANEOUS MAXIMUM CRITERION ("ACUTE" CRITERION)
FC = FRESHWATER AMBIENT 24-HOUR AVERAGE CRITERION ("CHRONIC" CRITERION).
FTA = LOWEST REPORTED FRESHWATER ACUTE TOXIC CONCENTRATION. (USED ONLY WHEN FA IS NOT AVAILABLE).
FTC = LOWEST REPORTED FRESHWATER CHRONIC TOXIC CONCENTRATION. (USED ONLY WHEN FC IS NOT AVAILABLE).
OL = TASTE AND ODOR (ORGANOLEPTIC) CRITERION.
HH = NON-CARCINOGENIC HUMAN HEALTH CRITERION FOR INGESTION OF CONTAMINATED WATER AND ORGANISMS.
HC = PROTECTION OF HUMAN HEALTH FROM CARCINOGENIC EFFECTS FOR INGESTION OF CONTAMINATED WATER AND ORGANISMS.
DW = PRIMARY DRINKING WATER CRITERION.

[4] ENTRIES IN THIS COLUMN INDICATE EXCEEDANCES OF THE HUMAN CARCINOGEN VALUE AT THE 10^{-5}, 10^{-6}, AND 10^{-7} RISK LEVEL, RESPECTIVELY. THE NUMBERS ARE CUMULATIVE, I.E., ALL 10^{-5} EXCEEDANCES ARE INCLUDED IN 10^{-6} EXCEEDANCES, AND ALL 10^{-6} EXCEEDANCES ARE INCLUDED IN 10^{-7} EXCEEDANCES.

[5] WHERE HARDNESS DEPENDENT, HARDNESS OF 100 MG/L $CACO_3$ EQUIVALENT ASSUMED

[6] DIFFERENT CRITERIA ARE WRITTEN FOR THE TRIVALENT AND HEXAVALENT FORMS OF CHROMIUM. FOR PURPOSES OF THIS ANALYSIS, ALL CHROMIUM IS ASSUMED TO BE IN THE LESS TOXIC TRIVALENT FORM.

PART III
TREATMENT EFFICIENCIES ASSOCIATED WITH SELECTED STORMWATER MANAGEMENT SYSTEMS

Introduction

Objective

Controlling the quantity and quality of stormwater runoff must be accomplished in order to protect sensitive receiving waters. Control measures may be provided via several types of treatment schemes. The objective of this section is to present and compare several selected stormwater management systems as reported in the literature.

Treatment Efficiency Concepts

Several different approaches have been used for the management of stormwater runoff. There are basically two types of strategies used in stormwater runoff treatment: a) source control prior to runoff, and b) runoff treatment. Source control examples are sweeping, responsible property maintenance, controlled fertilization, dust and dirt control, etc. Runoff treatment methods vary depending on factors such as location, property availability, local regulations, and additional considerations. The most common stormwater runoff treatment strategies involve the concept of detention/retention. The SFWMD's Basis of Review (SFWMD, 1987) gives the following definitions for detention and retention:

> **DETENTION:** "The delay of storm runoff prior to discharge into receiving waters".
>
> **RETENTION:** "The prevention of storm runoff from direct discharge into receiving waters; included as examples are systems which discharge through percolation, exfiltration, filtered bleed-down and evaporation processes".

Presented in Figure 3-1 are four schematic drawings showing the basic differences between wet and dry detention/retention systems.

The effectiveness of any stormwater treatment system is usually measured in terms of efficiency. Efficiency is generally presented as a percentage and is calculated using the following relationship:

$$\frac{\underset{\text{(Inflow)}}{\text{Mass of Pollutant}} - \underset{\text{(Outflow)}}{\text{Mass of Pollutant}}}{\underset{\text{(Inflow)}}{\text{Mass of Pollutant}}} \times 100\ \%$$

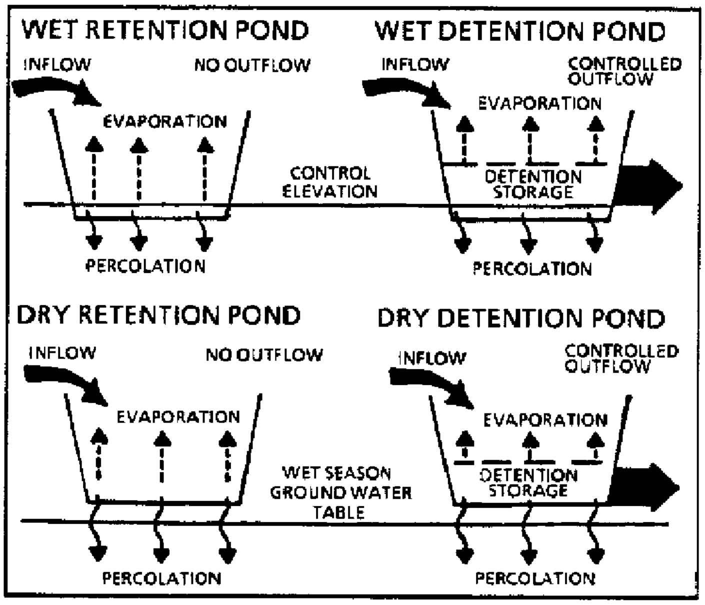

FIGURE 3.1 **SCHEMATICS OF FOUR BASIC DETENTION/RETENTION STORMWATER RUNOFF MANAGEMENT SYSTEMS (Adapted from Post, Buckley, Schuh and Jernigan, 1982)**

Treatment efficiencies may be calculated for surface waters or the total system, which includes ground water fluxes and associated water quality. A vast difference in calculated treatment results may occur when the ground water component is taken into consideration. Caution must be taken when comparing treatment efficiencies of different systems to ensure consistent calculation methods are being used.

The following sections will present data and discussions on selected management approaches to the control and treatment of stormwater runoff.

Detention

The concept of retaining or detaining stormwater runoff is not new. Since 1971 some areas of the country, particulary parts of Maryland, have required each new development to provide detention for purposes of preventing accelerated erosion and downstream flooding (Benner, 1985). Subsequently, there have been numerous evaluations of detention/ retention facilities.

Wet Detention Basins

Wet detention basins are fundamentally designed to slowly release collected stormwater runoff so that the peak discharge from the developed runoff area is reduced. Hydraulic holding times are relatively short, on the order of hours to days. Water quality treatment may be achieved by several physicochemical processes. Studies have concurred that one of the principal mechanisms of stormwater runoff treatment by detention basins is sedimentation (Driscoll, 1982; McCuen, 1980).

Table 3-1 presents reported pollutant removal efficiencies for several selected wet detention basin studies. The Boca Raton, Florida, (Cullum, 1984) results clearly show the differences between calculating the treatment efficiencies for the surface water and total system. TKN percentages rose dramatically when the entire system was evaluated.

The Orlando, Florida, (Martin and Smoot, 1986; Martin and Miller, 1987) study is unique in that a wet detention pond and cypress wetland are connected in series to provide stormwater treatment for a mixed urban area. The two processes, wet detention pond and wetlands, exhibited different removal characteristics for given parameters. The wet detention pond system showed low removals for lead and suspended solids loads while the wetlands portion seemed to actually export ortho-phosphorus. Discussion of wetland treatment efficiency will continue in another section.

Based on the treatment efficiencies displayed in Table 3-1, wet detention systems appear to provide good to excellent water quality treatment. The reported wet detention treatment ponds showed good removal for phosphorus (total and ortho-), lead, COD, and TSS. TKN removal seems to be low, particularly at the residential and mixed urban study sites. This may be due to elevated TKN loads from the open green areas associated with these land uses. However, NO_x removals were reported as quite high (70-85 percent). This, along with high ortho-phosphorus removals, shows dissolved nutrient uptake within the water column by biota. Reports from these studies also hypothesize that there are nutrient removal processes in addition to sedimentation (e.g. dissolved nutrient uptake in the water column; anaerobic sediment release).

Dry Detention Basins

There is limited data available concerning the treatment efficiency for large or centralized dry detention pond systems. However, one study which

TABLE 3-1. REPORTED TREATMENT EFFICIENCIES FROM SELECTED WET DETENTION MONITORING STUDIES

Site		MEAN TREATMENT EFFICIENCIES (%)						
		TKN	NO_x	T-P	O-P	T-Pb	COD	TSS
Boca Raton, Florida[1] (Residential)	Surface	-34*	77*	60*	90*	--	--	54*
	System	-1*	85*	56*	80*	--	--	45*
Orlando, Florida[2] (Mixed Urban)	Pond	15*	--	38	57	40	-1	66
	Wetlands	23*	--	17	2	73	18	66
	Total	40*	--	43	28	83	17	68
Brevard Co., Florida[3] (Commercial)	Surface	76	--	69	--	96	--	94
Washington, D.C.[4] (Residential)	Surface	37	84	59	56	--	--	37
	Surface	46	71	70	51	--	--	87
Somerset Co., New Jersey[5] (Mixed Urban)	Surface	-13*	--	23*	--	--	24*	37

* CALCULATED FROM REPORTED DATA

[1] CULLUM, 1984; CULLUM, 1985

[2] MARTIN AND MILLER, 1987

[3] POST, BUCKLEY, SHUH, AND JERNIGAN, 1982

[4] RANDALL, 1982

[5] FERRARA AND WITKOWSKI, 1983

investigated a comparison of wet and dry detention basins performed during the USEPA's NURP program showed that the dry system did not perform as adequately as the wet basins monitored (Table 3-2). Treatment efficiencies were based on the surface component only. The dry detention basin (Stedwick pond), located near the greater Washington, D.C. area, showed good removal of TSS (77 percent) yet produced negative removals of nitrogen (-37 percent TKN, -69 percent NO_X) and low treatment efficiency for total phosphorus (26 percent) (Randall,1982). The study surmised that although both wet and dry detention systems sufficiently removed solids, higher nutrient removals within the wet system were attributable to biological activity in both the standing water column and the emergent vegetation.

A similar dry detention basin treatment efficiency study was performed in northern Virginia (reported by Camp, Dresser, and McKee, 1985). The study results also showed negative removals by the dry detention basin (Table 3-2).

The Camp, Dresser, and McKee (1985) report, which examined stormwater management criteria in south Florida, recommended the use of dry detention ponds or basins only as a last resort for water quality management or as a pretreatment practice before wet detention. This recommendation was based on the Washington, D.C. and Virginia treatment efficiency studies (Table 3-2) and settling column tests.

Detention with Filtration

Laboratory and field scale pilot studies on dry detention with effluent filtration which have been performed in south Florida gave mixed results. A laboratory scale study was performed by the University of Central Florida (Wanielista et al., 1981) using two filtration media, which showed that pollutant removals may be dependent on media composition (Table 3-3). A field scale wet detention with effluent filtration study was performed near Lake Jackson, Florida. The Lake Jackson study showed that the filter media possessed a high solids removal efficiency. Although the report states that nutrient and solids removals were good, the system was prone to clogging during stormwater runoff events which contained high sediment loads.

A field demonstration project (Lake Tohopekaliga Demonstration Project) conducted by the SFWMD found logistical problems with filter media clogging. The SFWMD technical publication is currently under review (SFWMD(a)).

Retention

Swales

Swales are a common method of stormwater runoff management and treatment in south Florida, and combine aspects of both detention and retention. Swales are vegetated open channels designed and located to directly receive stormwater runoff. Swales are primarily used as pretreatment systems and to convey stormwater runoff to a central stormwater treatment structure or receiving water. The swale slows the runoff flow, thus providing a large surface area for natural percolation and infiltration. The vegetated sides and bottoms of swales also filter and trap some of the solids and pollutants associated with stormwater runoff.

Swales have been found to be effective in the removal of pollutants from stormwater runoff from a surface water perspective. Table 3-4 summarizes surface treatment efficiencies from four monitoring studies of different land uses: residential (Post, Buckley, Shuh, and Jernigan, 1982), highway/roadway (Harper et al., 1984), commercial (Oakland, 1983) and agricultural (Dickey and Vanderholm, 1981).

TABLE 3-2. REPORTED TREATMENT EFFICIENCIES FROM SELECTED DRY DETENTION BASIN MONITORING STUDIES

Site		MEAN TREATMENT EFFICIENCIES (%)					
		TKN	NO_X	T-P	O-P	T-Pb	TSS
Washington, D.C.[1] (Residential)	Dry	-37	-69	26	27	--	77
	Wet	37	84	59	56	--	37
	Wet	46	71	70	51	--	87
Annadale, Virginia[2]	Dry	0*	--	0*	0*	--	0*

*NEGATIVE REMOVAL DOCUMENTED FOR SEVERAL STORMS

[1] RANDALL, 1982

[2] REPORTED IN CAMP, DRESSER, AND McKEE, 1985

TABLE 3-3. REPORTED TREATMENT EFFICIENCIES FROM LABORATORY SCALE AND FIELD DETENTION BASIN WITH EFFLUENT FILTRATION MONITORING STUDIES (WANIELISTA ET AL., 1981)

Filtration Media Composition		MEAN TREATMENT EFFICIENCIES (%)				
		TKN	T-P	O-P	BOD	TSS
Laboratory Studies						
Varying Limestone, Rock, Sand, and Flow	a)	63	32	-66	69	93
	b)	68	37	-71	71	93
50/50 Mix Sand and Alum Sludge		--	88	89	--	--
Field Study						
Lake Jackson, Florida	a)	--	19	--	--	95
	b)	--	97	--	--	99

Removal efficiencies for the commercial site (Oakland, 1983) reported in Table 3-4 are significantly lower than removal percentages for the residential and highway/roadway monitoring sites. The swale was designed to provide surface detention, with a clay layer placed below the topsoil layer to prevent infiltration of runoff.

The fate of constituents removed from stormwater runoff by swale systems is a topic of concern within the literature. Heavy metals have been shown to accumulate in the sediments beneath the swales (Harper, 1985; Wigington et al., 1986). While surface water treatment efficiencies appear to be excellent, the impacts on shallow ground water resulting from grassed swale treatment systems need to be further documented. Additional discussion on

TABLE 3-4. SWALE TREATMENT EFFICIENCIES OF STORMWATER RUNOFF CONSTITUENTS AS REPORTED BY SELECTED STORMWATER RUNOFF MONITORING STUDIES

Site	MEAN TREATMENT EFFICIENCIES (%)						
	TKN	T-P	TSS	BOD_5	T-Cu	T-Zn	T-Pb
Brevard County, Florida[1] (Low Density Residential)	99+	99+	99+	99	--	--	99+
Orlando, Florida[2] (Highway/ Roadway)	--	--	--	--	41	90	91
Durham, New Hampshire[3] (Commercial)	28*	--	--	11	48	51	65
University of Illinois[4] (Agricultural)	97	96	95	--	--	--	--

* CALCULATED FROM REPORTED DATA

[1] POST, BUCKLEY, SHUH, AND JERNIGAN, 1982

[2] HARPER ET AL., 1984 (MAITLAND INTERCHANGE NORTH OF ORLANDO, FLORIDA)

[3] OAKLAND, 1983 (DETENTION SWALE - CLAY LAYER PREVENTED ANY INFILTRATION)

[4] DICKEY AND VANDERHOLD, 1981 (FEEDLOT EFFLUENT)

ground water contamination potential is provided in the off-line retention section.

Off-Line Retention

Off-line retention basins (diversion of stormwater runoff into a holding area) are generally designed as percolation areas. Since treatment efficiencies are determined by monitoring surface discharge and retention basins are designed to allow none, such calculations are not valid. Although direct discharge of pollutants is minimized, fate of pollutants and indirect discharge of pollutants into surface waters by means of ground water transmission are issues of concern (Wanielista and Yousef, 1978).

Several investigations have been conducted to determine the fate of pollutants within retention pond systems (Nightingale, 1975; Wigington et al., 1983; Hvited-Jacobsen et al., 1984; Harper, 1985; Yousef et al., 1985; Nightingale, 1987). Most of these studies have focused on the ability of bottom sediments to perform as "pollutant sinks". The results of these studies suggest that the sediments do act as pollutant sinks, particularly for heavy metals. However these studies further agree that there is a potential for ground water contamination from retained urban runoff, particularly in areas of high water tables and porous soils such as south Florida. To date, few monitoring studies have included extensive monitoring to determine the potential impact stormwater retention may have on ground water quality. Harper (1985) conducted ground water monitoring as part of a swale and retention basin investigation. Harper found that heavy metal concentrations were higher in ground water beneath the retention pond than in the overlying water column. However, area ground water movement was slow, so the effects of increased metal concentrations within surface aquifers was considered very localized.

On-Line Retention

On-line retention systems are basins usually built in existing flow routes of stormwater runoff (i.e. stream channels , canals, etc.). The basins allow structured discharge but differ from detention treatment by having long holding times (weeks to months) with the location of the inlet and outlet structures such that short circuiting is prevented (Wanielista and Yousef, 1985). Treatment efficiencies reported for selected on-line retention systems are presented in Table 3-5.

Exfiltration

Exfiltration trenches have become a common method of on-site stormwater runoff treatment/disposal in south Florida. The design most used in south Florida is a buried perforated culvert, which is backfilled with sand and/or graded aggregate. A filter cloth surrounds the backfill to prevent the natural soils from clogging the backfill. Water is routed to the pipe, which has a larger storage volume than a simple rock filled trench. Water then exfiltrates through the perforations into the surrounding backfill and eventually the natural soil profile.

Few studies have thoroughly evaluated the ability of the exfiltration trench to effectively accept and treat stormwater runoff. Studies by McQueen (1980) and Branscome and Tomasello (1987) have investigated the quantity aspects of exfiltration trenches in Dade and Palm Beach Counties, respectively. McQueen's (1980) review of a trench system in Dade County reported that the system performed well from a quantity aspect. The study by Branscome and Tomasello (1987) concentrated on defining the hydraulic characteristics of a properly designed exfiltration system.

Two south Florida exfiltration monitoring studies have been performed by the USGS in Dade and Orange Counties. These studies, which are currently under review, examined the water quality treatment aspects of two exfiltration systems. The study conducted in Dade County indicated that monitoring of the water quality of shallow ground water near the exfiltration trench was not greatly different than local area ground water quality.

TABLE 3-5. REPORTED TREATMENT EFFICIENCIES FROM SELECTED ON-LINE RETENTION MONITORING STUDIES

Site	TKN	T-P	TSS	T-Pb	BOD_5	COD
Lansing, Michigan[1] (Mixed Urban)	30 - 50	50 - 80	50 - 80	80 - 95	50 - 80	--
Ann Arbor, Michigan[2] (Mixed Urban)	0 - 28	40 - 62	45 - 93	34 - 87	--	--

[1] LUZKOW AND SCHERGER, 1981 (WET RETENTION)

[2] SCHERGER AND DAVIS, 1982 (WET RETENTION)

A roadway runoff/exfiltration monitoring project is presently being conducted by the SFWMD in Palm Beach County (SFWMD(d)). The project goal is to determine the effectiveness of the treatment scheme to handle the required volume of stormwater runoff, by exfiltration and storage, as well as the reduction of pollutant concentrations.

One major unanswered question is the life expectancy of a properly designed exfiltration system. High sediment loads may lead to the filter fabric and backfill becoming clogged over time. An exfiltration trench must be sealed from accepting inflow during construction of areas which will eventually discharge to the system (i.e. roads, parking lots). If the trench is open during construction, premature sediment loadings may reduce or completely inhibit exfiltration of stormwater runoff prior to the systems completion. Also, as a good portion of exfiltration trenches are constructed under paved areas, the maintenance problem of un-clogging these systems is of concern.

Porous Pavement

Porous pavement has been used at the local level for over two decades to alleviate drainage problems in flood prone areas (e.g. road sections, aircraft runways). However, in recent years with the realization of the need for stormwater runoff management in urban areas, porous pavement is being considered and used as a supplement and/or an alternative to detention/ retention facilities (Field et al., 1982; Field, 1985; Medico, 1985).

Research demonstration projects have been conducted to evaluate the effectiveness of porous pavement for stormwater runoff control. Porous pavement installations in Delaware, Pennsylvania, Texas, and New York have proved successful on a structural and drainage basis (Field et al., 1982). Some clogging did result during runoff events, which were heavily laden with sediment, but the problem was relieved through flushing.

These reported examples of effective porous pavement operation did not give details as to the system's construction, which may influence the system's ability to remove stormwater runoff. For example, the SFWMD recognizes that pavement specifications require that sub-grade needs to be placed at 90 percent compaction. Such practices would render the porous pavement system to be ultimately impervious.

One major concern, which seems to revolve around the porous pavement issue, is water quality. There is a deficiency in the evaluations of the water quality treatment effectiveness of the porous pavement, and under drain designs. In particular, questions on potential ground water contamination have not been answered.

Wetlands

One of the most recent alternative suggestion for stormwater runoff storage and treatment is the use of existing or constructed wetlands. Although some wetlands have received stormwater runoff either directly or indirectly for years, questions associated with vegetative impact and treatment efficiencies are now being asked. Throughout the literature, a concern about the ability of wetlands to effectively treat stormwater runoff appears prevalent.

There are basically three physicochemical processes by which pollutants may be removed by a wetland system. The processes are loss to the atmosphere by volatilization, incorporation into the sediments and uptake by vegetation, and by degradation (Harper et al., 1985). Another process, which is indirectly associated with incorporation into sediments, is sedimentation under low velocity flows.

Wetlands treatment of stormwater runoff has been documented by several investigators to be moderate (Ammon et al., 1981; Oberts, 1982; Scherger, 1982; Kutash, 1985; Harper et al., 1986; Lakatos and McNemar, 1986; Martin and Smoot, 1986; Bowmer, 1987; SFWMD and East Central Florida Regional Planning Council (ECFRPC), 1987).

Variability exists in data reported for distinct wetland monitoring projects. The inconsistency within the data is probably due to difficulties in collecting vital information. First, low flows often encountered with wetland systems may aid in settling solids but constrain accurate hydrologic measurements, thus reliable calculations of mass loadings and exports are difficult. Further, pollutant utilization and entrapment by a wetland may be affected by factors such as seasonality in light of limited growing seasons. Although the monitoring of an individual storm event may show that a particular wetland is capable of high removals, long term annual wetland monitoring may show a much lower removal or even a net export of pollutants due to seasonal vegetation die-off and nutrient recycling (Federico et al., 1978; Davis, 1982; Davis et al., 1985; Goldstein, 1986).

Another complicating factor to the applicability and effectiveness of using wetlands as part of stormwater management systems is the wide variety of different wetland types. Wet prairie, broad-leaf emergent marsh, open water slough, willow/shrub marsh, cypress swamp, mixed hardwood swamp, are all defined as "wetlands", yet each has its own unique ecosystems which may provide different treatment efficiency thresholds.

Long term monitoring results (annual means) of phosphorus treatment efficiencies from several south Florida marshes are presented in Table 3-6. The data presented in Table 3-6 were collected from wetland areas which received runoff from predominantly agricultural lands. In contrast, Table 3-7 introduces data collected from monitoring studies on wetlands which received stormwater runoff largely from combined urban areas.

An issue which remains to be resolved is to determine what affect, if any, adding stormwater will have on the natural ecosystem of wetland areas. Presently, there are studies being conducted by the SFWMD to assess any adverse impacts (quantity, quality, and vegetative) stormwater diversion may have on wetlands.

Harper et al. (1986) makes several recommendations based on an extensive stormwater runoff - wetlands treatment monitoring project. The study states that wetland systems which are best suited as stormwater management systems, are those which already exhibit relatively long hydroperiods (e.g., hardwood hammocks, cypress domes, and marshes). Further, hardwood wetlands have the ability to evapotranspire much larger quantities of hydrologic inputs. Thus, smaller hardwood wetland areas may be able to accept relatively larger volumetric inputs than other wetland types.

Other Stormwater Treatment Methods

Sweeping

Urban runoff pollutants are a result of primarily two co-factors, surface build-up of contaminants and rainfall/runoff washoff. The hypothesis of street sweeping was to remove contaminants (or a portion of them) before they could be washed off. Several studies have investigated and commented on the effectiveness of sweeping operations to reduce contaminant loads and concentrations found in stormwater runoff (Sartor et al., 1974; ECFRPC(b), 1977; Pitt, 1979; Bender and Rice, 1982; USEPA, 1983; Field, 1985; Heaney, 1986).

Sartor et al. (1974) was one of the first studies to characterize street surface contaminants and street sweeping efficiency. The study reported that although "fines" accounted for approximately 6 percent of the total solids, they comprised 25 to 50 percent of the BOD_5, nitrogen, and phosphorus. Later monitoring studies by ECFRPC (b) (1977), Pitt (1979), and Bender and Rice (1982) reported similar results of solids and heavy metals removals of up to 50 percent, while overall BOD_5, nitrogen, and phosphorus removals were less than 10 percent. The common conclusion presented by these studies is that vacuum street and parking lot sweeping is effective in removing larger particles and thus some pollutant load. However, the sweepers' mechanical inadequacies limit the removal of fine particles (<50 microns), with which the bulk of pollutants are associated.

Based on literature information and data, it appears sweeping may remove a considerable portion of potential stormwater runoff pollutants if a comprehensive and thorough sweeping program is conducted.

TABLE 3-6. MEAN ANNUAL TOTAL PHOSPHORUS BUDGETS BASED ON MONITORING OF SELECTED SOUTH FLORIDA WETLANDS (FROM DAVIS ET AL., 1985 AND GOLDSTEIN, 1986)

		TOTAL PHOSPHORUS				
	Marsh Area	Loading		Export		Treatment Efficiency
Study Site	(ha)	mg/l	$g/m^2/yr$	mg/l	$g/m^2/yr$	(%)
Boney Marsh	49	0.042	0.61	0.02	0.19	69
Armstrong Slough	12	0.172	16.3	0.13	11.3	31
Ash Slough	8	0.88	6.2	0.76	3.7	40
Chandler Slough	380	0.31	4.4	0.22	3.4	23
WCA 1	57,250	0.097	0.22	0.10	0.11	50
WCA 2A	44,830	0.070	0.20	0.025	0.04	80
WCA 3A	203,660	0.051	0.09	0.01	0.004	96

TABLE 3-7. MEAN TREATMENT EFFICIENCIES OF SELECTED WETLANDS RECEIVING STORMWATER RUNOFF FROM URBAN AREAS

Study Site	MEAN TREATMENT EFFICIENCIES (%)						
	TKN	TSS	T-P	O-P	T-Zn	T-Pb	COD
CYPRESS SWAMP							
Orlando, Florida[1]							
Pond	15*	66	38	57	39	40	-1
Wetlands	23*	66	17	2	56	73	18
Total	40*	68	43	28	70	83	17
MIXED HARDWOOD SWAMP	--**						
Orlando, Florida[2]		83	7	-109	41	55	--
WET PRAIRIE							
Ann Arbor, Michigan[3]	21*	82*	53*	--	--	75*	--

* CALCULATED FROM REPORTED DATA

** ORGANIC N AND TOTAL N SHOWED -24 PERCENT AND -2 PERCENT TREATMENT EFFICIENCIES RESPECTIVELY

[1] MARTIN AND SMOOT, 1986; MARTIN AND MILLER, 1987 (MIXED URBAN)

[2] HARPER ET AL., 1986 (HIDDEN LAKE)

[3] SCHERGER, 1982 (FOUR OR FIVE EVENTS) (SWIFT RUN)

However, sweeping should be considered and used as a supplementary method of runoff contaminant control due to operational and maintenance constraints.

Miscellaneous

There are several schools of thought as to additional methods for controlling stormwater runoff from both the quantity and quality point of views. One popular concept is water reuse. Water reuse utilizes stormwater runoff prior to discharge thus protecting the receiving waters. Several studies and papers have been conducted and written on the subject. Examples include using stormwater runoff for industrial purposes, agricultural and urban irrigation, indirect potable, as well as implementation of economic incentives to reuse water (Field and Fan, 1981; Thompson, 1982; Handley and Ekern, 1984; Deis et al., 1986; Shannon et al., 1986). Efficient fertilization through the addition of nutrients to irrigation water has been offered as one of many source control alternatives (Synder, 1982; Ferguson, 1987).

Summary

Stormwater runoff contributes a significant amount of pollution to receiving waters, as was inferred in Part 1 of this report. Protection of receiving waters from this pollution source is possible, however, by utilizing a number of stormwater treatment practices. The question which remains, however, is which treatment scheme should be used to achieve the desired stormwater treatment levels.

Retention systems showed the highest pollutant removal efficiencies. Nutrient, heavy metal, and oxygen demand surface water pollutant removals of 60 percent and greater are common from retention basins. Swale systems have shown excellent surface water pollutant removals on the order of 90+ percent. These removals protect surface receiving waters from highly concentration discharges. Removal of the pollutants is generally by vegetation up-take, degradation, and sediment binding. However, some pollutants may reach ground waters and discharge indirectly to the same receiving waters which the treatment system was designed to protect. Potential conditions such as these should carefully be considered when placing a retention system.

Wet detention basins are less effective stormwater treatment systems than retention basin or swale systems, but they still exhibit good to excellent pollutant removal efficiencies for suspended solids, metals, and nutrients. Pollutant removal takes place largely in the water column by sedimentation, degradation, and vegetative up-take. The total system, including surface and ground water components, should be evaluated to ensure the feasibility of a wet detention treatment system in a particular area.

Limited information is available on dry detention basins. However, two studies which were reported showed the dry detention basins were dramatically inferior in pollutant removal compared to wet detention systems. This may be due to the absence of a water column which lends to the biological treatment of stormwater runoff.

Utilizing wetland areas as natural components of stormwater treatment has come under closer examination during recent years. Data presented in this report indicates that wetlands are moderate stormwater treatment systems for the removal of nutrients. Some long term investigations have shown net export of nutrients on a seasonal basis. An issue which remains unanswered and should be addressed by future monitoring projects, is how well different types of wetland systems (i.e., marsh, cypress swamp, etc.) will treat stormwater runoff.

Porous pavement does not appear to be a useful scheme in stormwater treatment. Maintenance and prevention from clogging make the hydrologic capabilities of porous pavement on the long term basis highly questionable. In addition, the questions of water quality treatment and potential ground water impacts need to be addressed before porous pavement can be considered a viable alternative.

Modern exfiltration systems are relatively new in south Florida with little track record on long-term performance. Studies are presently exploring the water quality treatability aspects of the exfiltration trench. Construction runoff must be prevented from entering the exfiltration system so sediment loadings will not clog the pipe, backfill, and filter cloth thus limiting the system's lifespan.

Each particular stormwater treatment scheme has its advantages and disadvantages and must be chosen on a site specific basis depending on factors such as availability of land, site layout, cost effectiveness, etc. However, to achieve the best treatment efficiencies, thus protecting receiving waters, a combination of treatment systems should be incorporated into any land use plan. For example, a large mall area might consider using a wet detention basin as its primary treatment facility with pretreatment using grassed swales, inlets in grassed areas, or raised inlets. Additional methods should be considered as supplemental such as sweeping, efficient irrigation of green areas, water reuse, etc. A comprehensive plan of source control as well as stormwater runoff collection and treatment will provide the most effective water quality and quantity management.

LITERATURE CITED* AND ADDITIONAL BIBLIOGRAPHY

Alberts, E.E. and R.G. Spomer. 1985. Dissolved Nitrogen and Phosphorus in Runoff from Watersheds in Conservation and Conventional Tillage. J. Soil Water Conserv. 40(1):153-157.

*American Geophysical Union. 1982. Urban Stormwater Hydrology. Water Resources Monograph Series No. 7, D.F. Kibler, Ed. Washington, D.C. 271p.

American Society of Civil Engineers (ASCE). 1982. Proceedings of the Conference on Stormwater Detention Facilities. William DeGroot, Ed. 431 p.

*Ammon, D.C., W.C. Huber, J.P. Heaney. 1981. Wetlands Use for Water Management in Florida. J. Water Res. Planning Mgmt. Div. Proceedings of ASCE 107(WR2):315-327.

Baca, E., P.B. Bedient, and R. Olsen. 1982. Urban Impacts of Water Supply Reservoir. J. Environ. Engr. Div. Proceedings of ASCE 108(EE1):73-87.

Baldwin, L.B. 1975. Agricultural Practices to Reduce Non-point Pollution in the Okeechobee-Kissimmee Basin. State of Florida Dept. of Environ. Reg., Tech. Series 1(4), 62 p.

Bausano, J.C., P.A. Stevens, J.A. Pounds, and P.B. Kelman. 1982. Design and Evaluation of Alternative Stormwater Management Systems. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 209-215.

Beaulac, M.N. and K.H. Reckhow. 1982. An Examination of Land Use - Nutrient Export Relationships. Water Res. Bull. 18(6):1013-1024.

Bender, G.M., D.C. Noel, M.L. Terstriep. 1983. Final Report -Nationwide Urban Runoff Project, Champaign, Illinois, Assessment of the Impact of Urban Storm Runoff on an Agricultural Receiving Stream. Illinois Dept. of Energy and Natural Resources. 153 p.

*Bender, G.M. and W.W. Rice. 1982. Effects of Municipal Street Sweeping on Urban Storm Runoff Quality. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 217-223.

*Benner, R.E. 1985. Urban Sediment and Stormwater Control: The Maryland Experience. J. Soil Water Conserv. 40(1):72-75.

Bennett, E.R., L.E. Leach, C.G. Enfield, and D.M. Walters. 1985. Optimization of Nitrogen Removal by Rapid Infiltration. Project Summary - EPA/600/S2-85/016, Ada, OK.

Bedient, P.B., J.L. Lambert, and N.K. Springer. 1980. Stormwater Pollutant Load-Runoff Relationships. Jour. Water Poll. Control Fed. 52(9):2396-2404.

Berdine, S.P. and J.S. Kutzman. 1975. Stormwater Management and the 208 Program. In the Proceedings: Stormwater Management Workshop, Gainesville, FL, M.P. Wanielista ed. Florida Technological University, Orlando, FL. pp. 5-20.

Bergstrom, L. 1987. Nitrate Leaching and Drainage from Annual and Perennial Crops in Tile-Drained Plots and Lysimeters. J. Environ. Qual. 16(1):11-18.

Beukeboom, T.J. 1982. A Dry-Well System for Excess Rainwater Discharge. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 205-207.

*Black, P.E. 1980. Water Quality Patterns During a Storm on a Mall Parking Lot. Water Res. Bull. 16(4):615-620.

*Bowmer, K.H. 1987. Nutrient Removal from Effluents by an Artificial Wetland: Influence of Rhizosphere Aeration and Preferential Flow Studied Using Bromide and Dye Tracers. Water Res. (G.B.) 21(5):591-599.

Braden J.B. and D.L. Uchtmann. 1985. Agricultural Nonpoint Pollution Control: An Assessment. J. Soil Water Conserv. 40(1):23-26.

*Branscome, J. and R.S. Tomasello. 1988. Field Testing of Exfiltration Systems. South Florida Water Management District, Tech. Pub. 87-5, West Palm Beach, Florida. 50 p.

Campbell, K.L. 1982. Nutrient Transport from North Florida Agricultural Fields and Watersheds. The Proceedings of the IFAS Conference on

Nonpoint Pollution Control Technology in Florida. Gainesville, Florida. pp. 14-27.

*Camp, Dresser, and McKee, Inc. 1985(a). An Assessment of Stormwater Management Programs. J.P. Hartigan, S.V. Plante, and L.A. Rosner, Maitland, Florida.

Camp, Dresser, and McKee, Inc. 1985(b). Feasibility Study for a Roanoke Valley Comprehensive Stormwater Management Program. CDM, Annandale, Virginia.

Carter, K.B. 1985. Protecting our Investment in Clean Waters. Journal of Water Poll. Control Fed. 57(2):104-108.

Celauro, F.P. and M.W. Haque. 1981. Detention Ponds - A Practical Look at the Cost of the Concept: A Case Study. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 289-295.

Chadderton, R.A. 1983. Discussion: "Farmers' Attitudes Toward Government Involvement in Preventing Agricultural Nonpoint Source Water Pollution," by F. Dale Parent and Stephen B. Lovejoy. Water Res. Bull. 19(4):673-675

Chesters, G. and L.J. Schierow. 1985. A Primer on Nonpoint Pollution. Journal of Soil Water Conserv. 40(1):9-13.

CH_2M Hill. 1978. Water Quality Studies in the Everglades Agricultural Area of Florida. Submitted to the Florida Surgar Cane League. CH_2M Hill, Gainesville, FL.

*Clark, D.L., R. Asplund, J. Ferguson., and B.W. Mar. 1981. Composite Sampling of Highway Runoff. J. Environ. Engr. Div. Proceed. of ASCE 107(EE5):1067-1081.

Clark II, E.H. and J.A. Haverkamp. 1984. Policies Controlling Agricultural Nonpoint-Source Pollution. Conference on Options for Reaching Water Quality Goals, American Water Res. Assoc.

Cole, R.H., R.E. Frederick, R.P. Healy, and R.G. Rolan. 1984. Preliminary Findings of the Priority Pollutant Monitoring Project of the Nationwide Urban Runoff Program. J. Water Poll. Control Fed. 56(7):898-908.

Cox, J.H. 1982. Sources of Watershed Data. The Proceedings of the IFAS Conference on Nonpoint Pollution Control Technology in Florida. Gainesville, Florida. pp. 291-317.

Cox, J.H. 1985. Overview of BMP's and Urban Stormwater Management. Proceedings: Stormwater Management - "An Update", M.P. Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

*Cullum, M.G. 1984. Evaluation of the Water Management System at a Single Family Residential Site: Water Quality Analysis for Selected Storm Events at Timbercreek Subdivision in Boca Raton, Florida. South Florida Water Management District, Tech. Pub. 84-11 Volume II, West Palm Beach, Florida. 116 p.

*Cullum, M.G. 1985. Stormwater Runoff Analysis at a Single Family Residential Site. Proceedings: Stormwater Management - "An Update", M.P. Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

Daniel, T.C., R.C. Wendt, P.E. McGuire, and D. Stoffel. 1982. Nonpoint-Source Loading Rates from Selected Land Uses. Water Res. Bull. 18(1):117-120.

*Davis, F.D., A.C. Federico, A.L. Goldstein, and S.M. Davis. 1985. Use of Wetlands for Water Quality Improvements. Proceedings: Stormwater Management - "An Update", M.P.Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, FL.

Davis, L.R. (a) 1982. The Effects of Deicing Salt Usage on Surface and Ground Water Quality. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 239-248.

*Davis, S.M. (b) 1982. A Review of Phosphorus Uptake by Freshwater Wetlands in Comparison to the Boney Marsh, Kissimmee River. The Proceedings of the IFAS Conference on Nonpoint Pollution Control Technology in Florida. Gainesville, Florida. pp. 180-189.

*Deis, G.C., D. Scherzinger, and J.R. Thornton. 1986. Reclaimed Water Irrigation to Eliminate Summer Discharge. J. Water Poll. Control. Fed. 58(11):1034-1038.

*Dickey, E.C. and D.A. Vanderholm. 1981. Vegetative Filter Treatment of Livestock Feedlot Runoff. J. Environ. Qual. 10(3):279-284.

Dickson, K.G., A.C. Federico, and J.R. Lutz. 1978. Water Quality in the Everglades Agricultural Area and its Impact on Lake Okeechobee. South Florida Water Management District Tech. Pub. 78-3, West Palm Beach, FL. 132 p.

Dinchak, W.G. 1981. Soil-Cement for Storm Water Control Facilities. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 303-307.

Dowd, R.M. 1987. New Clean Water Provisions. Environ. Sci. Technol. 21(5):427.

Dowling, A. 1975. 208 Program Design. In the Proceedings: Stormwater Management Workshop, Gainesville, FL, M.P. Wanielista ed. Florida Technological University, Orlando, FL. pp. 5-20.

*Driscoll, E.D. 1982. Analysis of Detention Basins in EPA NURP Program. In Proceedings of the Conference on Stormwater Detention Facilities, ASCE, William DeGroot, Ed. pp. 21-31.

Driscoll, E.D. 1986. Lognormality of Point and Nonpoint Source Pollutant Concentrations. In Proceedings of Stormwater and Water Quality Model Users Group Meeting, T.O. Barnwell, Jr. and W.C. Huber, Eds. EPA/600/9-86/023.

Duda, A.M. 1985. Environmental and Economic Damage Caused by Sediment from Agricultural Nonpoint Sources. Water Res. Bull. 21(2):225-234.

Duncan, S.H., R.E. Bilby, J.W. Ward, and J.T. Heffner. 1987. Transport of Road-Surface Sediment Through Ephemeral Stream Channels. Water Res. Bull. 23(1):113-119.

Duru, J.O. 1981. On-Site Detention: A Storm Water Management or Mismanagement Technique? In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 297-302.

*East Central Florida Regional Planning Council (ECFRPC(a)). 1977. Water Quality Data for Natural and Cultural Areas and Abatement Facilities. CH_2M Hill, July.

*East Central Florida Regional Planning Council (ECFRPC(b)). 1977. An Assessment of Parking Lot Sweeping at the Altamonte Springs Mall. CH_2M Hill Technical Memorandum, August.

*East Central Florida Regional Planning Council (ECFRPC). 1983. Best Management Practices, Stormwater Management Report, 208 Areawide Water Quality Management Planning Program. Winter Park, Florida. 82 p.

*Ebbert, J.C. and R.J. Wagner. 1987. Contributions of Rainfall to Constituent Loads in Storm Runoff from Urban Catchments. Water Res. Bull. 23(5): 867-871.

Eganhouse, R.P. and I.R. Kaplan. 1981. Extractable Organic Matter in Urban Stormwater Runoff: 1. Transport Dynamics and Mass Emission Rates. Environ. Sci. Technol. 15(3):310-315.

Eganhouse, R.P., B.R.T. Simonelt, and I.R. Kaplan. 1981. Extractable Organic Matter in Urban Syormwater Runoff: 2. Molecular Characterization. Environ. Sci. Technol. 15(3):315-326.

Fam, S., M.K. Stenstrom, and G. Silverman. 1987. Hydrocarbons in Urban Runoff. J. Environ. Engr. ASCE 113(5):1032-1046.

Federico, A.C. 1977. Investigations of the Relationship Between Land Use, Rainfall, and Runoff Quality in the Taylor Creek Watershed. South Florida Water Management District, Tech. Pub. 77-3, West Palm Beach, Florida. 59 p.

*Federico, A.C., J.F. Milleson, P.S. Millar, and M. Rosen. 1978. Environmental Studies in the Chandler Slough Watershed. South Florida Water Management District, Tech. Pub. 78-2, West Palm Beach, Florida. 220 p.

*Federico, A.C., K.G. Dickson, C.R. Kratzer, and F.E. Davis. 1981. Lake Okeechobee Water Quality Studies and Eutrophication Assessment. South Florida Water Management District, Tech. Pub. 81-2, West Palm Beach Florida. 380 p.

Fellows, C.R. and P.L. Brezonik. 1981. Fertilizer Flux into two Florida Lakes via Seepage. J. Environ. Qual. 10(2):174-177.

*Ferguson, B.K. 1987. Water Conservation Methods in Urban Landscape Irrigation: An Exploratory Overview. Water Res. Bull. 23(1):147-152.

Ferrara, R.A. 1982. Stormwater Detention and Nonpoint Source Pollution Control. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 91-97.

*Ferrara, R.A. and P. Witkowski. 1983. Stormwater Quality Characteristics in Detention Basins. J. Environ. Engr. ASCE 109(2):428-447.

*Field, R. 1985. Urban Runoff: Pollution Sources, Control and Treatment. Water Res. Bull. 21(2): 197-206.

*Field, R. and C.Y. Fan. 1981. Industrial Reuse of Urban Stormwater. J. Environ. Engr. Div. Proceed. of ASCE 107(EE1):171-189.

*Field, R., H. Masters, and M. Singer. 1982. An Overview of Porous Pavement Research. Water Res. Bull. 18(2):

*Field, R. and P.J. Szeeley. 1974. Urban Runoff and Combined Sewer Overflow. J. Water Poll. Control Fed. 46(6):1209-1226.

Field, R. and R. Turkeltaub. 1981. Urban Runoff Receiving Water Impacts: Program Overview. J. Environ. Engr. Div. Proceed. of ASCE 107(EE1): 83-100.

Finnemore, E.J. 1982. Stormwater Pollution Control: Best Management Practices. J. Environ. Engr. Div. Proceed. of ASCE 108(EE5):835-851.

Finnemore, E.J. and W.G. Lynard. 1982. Management and Control Technology for Urban Stormwater Pollution. J. Water Poll. Control Fed. 54(7):1099-1111.

Fok, A.T.K. 1981. Some Considerations of Detention Lake Design. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 323-331.

Gaggiani, N.G. and A.G. Lamonds. 1978. Chemical and Biological Quality of Lakes Faith, Hope, and Charity, at Maitland, Florida, with Emphasis on the Effects on Storm Runoff and Bulk Precipitation, 1971-74. U.S. Geological Survey Open-File Report 77-491, Tallahassee, Florida. 94 p.

Gianessi, L.P., H.M. Peskin, P. Crosson, and C. Puffer. 1986. Nonpoint-Source Pollution: Are Cropland Controls the Answer? J. Soil Water Conserv. 41(4):215-218.

Gjessing, E., E. Lygren, L. Berglind, T. Gulbrandsen, R. Skaane. 1984. Effect of Highway Runoff on Lake Water Quality. Sci. Total Environ. 33:245-257.

Glandon, R.P., R.C. Payne, C.D. McNabb, and T.R. Batterson. 1981. A Comparison of Rain-Related Phosphorus and Nitrogen Loading from Urban, Wetland, and Agricultural Sources, Water Res. (G.B.) 15:881-887.

Glenne, B. 1984. Simulation of Water Pollution Generation and Abatement on Suburban Watersheds. Water Res. Bull. 20(2):211-217.

Goff, J.D. and F.E. Goldman. 1981. Urban Recreational Lakes Serving as Storm Water Retention Basins and Effluent Disposal. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 315-321.

*Goldstein, A.L. 1982. Utilization of a Freshwater Marsh to Treat Rainfall Runoff from Pasturelands. The Proceedings of the IFAS Conference on Nonpoint Pollution Control Technology in Florida. Gainesville, Florida. pp. 106-125.

*Goldstein, A.L. 1986. Upland Detention/Retention Demonstration Project - Final Report. South Florida Water Management District, Tech. Pub. 86-2, West Palm Beach, Florida. 374 p.

Goldstein, A.L. and R.J. Ulevich. 1981. Engineering, Hydrology and Water Quality Analysis of Detention/Retention Sites. Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin.

Guitjens, J.C. and W.W. Miller. 1980. Irrigation Water and Surface Runoff Quality and Quantity in Carson Valley, Nevada. Water Res. Bull. 16(3):459-462.

Hallberg, G.R. 1986. From Hoes to Herbicides: Agriculture and Ground Water Quality. J. Soil Water Conserv. Nov.-Dec. pp. 357-364.

*Halverson, H.G., D.R. DeWalle, and W.E. Sharpe. 1984. Contribution of Precipitation to Quality of Urban Storm Runoff. Water Res. Bull. 20(6): 859-864.

Halverson, H.G., D.R. DeWalle, W.E. Sharpe, and D.L. Wirries. 1982. Runoff Contaminants from Natural and Manmade Surfaces in a Nonindustrial Urban Area. International Symposium on Urban

Hydrology, Hydraulics and Sediment Control. Univ. of Kentucky, Lexington, Kentucky.

Hampson, P.S. 1986. Effects of Detention on Water Quality of two Stormwater Detention Ponds Receiving Highway Surface Runoff in Jacksonville, Florida. U.S. Geological Survey Water-Resources Investigations Report 86-4151, Tallahassee, Florida.

*Handley, L.L. and P.C. Ekern. 1984. Effluent Irrigation of Para Grass: Water, Nitrogen, and Biomass Budgets. Water Res. Bull. 20(5):669-677.

*Harper, H.H. 1985. Fate of Heavy Metals from Highway Runoff in Stormwater Management Systems. PhD. Dissertation, Univ. of Central Florida, Orlando, Florida.

*Harper, H.H., M.P. Wanielista, B.M. Fries, and D.M. Baker. 1986. Stormwater Treatment by Natural Systems. Star Project #84-026 - Final Report, Florida Dept. of Environ. Regulation, Tallahassee, Florida.

*Harper, H.H., Y.A. Yousef, and M.P. Wanielista. 1982. Restoration of Lake Eola. Second Annual Conference of the North American Lake Management Society. Vancouver, British Columbia, Canada.

*Harper, H.H., Y.A. Yousef, and M.P. Wanielista. 1984. Efficiency of Roadside Swales in Removing Heavy Metals from Highway Associated Nonpoint Source runoff. Conference on Options for Reaching Water Quality Goals, American Water Res. Assoc.

*Harper, H.H., Y.A. Yousef, and M.P. Wanielista. 1986. Effectiveness of Detention/Retention Basins for Removal of Heavy Metals in Highway Runoff. In Proceedings of Stormwater and Water Quality Model Users Group Meeting, T.O. Barnwell, Jr. and W.C. Huber, Eds. EPA/600/9-86/023.

Harrington, W., A.J. Krupnick, and H.M. Peskin. 1985. Policies for Nonpoint-Source Water Pollution Control. J. Soil Water Conserv. 40(1):27-32.

Hartigan, J.P. 1985. Urban Nonpoint Pollution Management for Water Supply Protection: Regional Versus On-site BMP Plans. In the International Symposium on Urban Hydrology, Hydraulics Infrastructures and Water Quality Control, University of Kentucky, Lexington, Kentucky, pp. 121-130.

Hawkins, R.H. 1976. Salt Storage and Runoff in Urban Watershed. J. Environ. Engr. Div. Proceed. ASCE 102(EE4):737-743.

Hawley, M.E. and R.H. McCuen. 1987. Elements of Comprehensive Stormwater Management Program. J. Water Res. Planning Manage. ASCE 113(6): 793-809.

Heaney, J.P. 1986. Research Needs in Urban Stormwater Pollution. J. Water Res. Planning Manage. ASCE 112(1):36-47.

Heaney, J.P. 1987. Urban Stormwater Runoff. Presented at the 1987 Water Quality Conference, Miami, Florida.

Heaney, J.P. and W.C. Huber. 1984. Nationwide Assessment of Urban Runoff Impact on Receiving Water Quality. Water Res. Bull. 20(1):35-42.

Heimbuch, R.J. and P.F. Martecchini. 1981. Rock Filled Detention Reservoirs. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 465-468.

Hendry, C.D. and P.L. Brezonik. 1980. Chemistry of Precipitation at Gainesville, Florida. Environ. Sci. Technol. 14(7):843-849.

*Hoffman, E.J., J.S. Latimer, G.L. Mills, and J.G. Quinn. 1982. Petroleum Hydrocarbons in Urban Runoff from a Commercial Land Use Area. J. Water Poll. Control Fed. 54(11):1517-1525.

*Hoffman, E.J., G.L. Mills, J.S. Latimer, and J.G. Quinn. 1984. Urban Runoff as a Source of Polycyclic Aromatic Hydrocarbons to Coastal Water. Environ. Sci. Technol. 18(8):580-587.

Hopkinson, Jr., C.S. and J.W. Day, Jr. Modeling the Relationships Between Development and Storm Water and Nutrient Runoff. Environ. Manage. 4(4):315-324.

*Howie, B. and B.G. Waller. 1986. Chemical Effects of Highway Runoff on the Surficial Aquifer, Broward, County, Florida. U.S. Geological Survey Water-Resources Investigations Report 86-4200, Tallahassee, Florida.

Huber, W.C., J.P. Heaney, D.A. Aggidis, R.E. Dickinson, K.J. Smolenyak, and R.W. Wallace. Urban Rainfall-Runoff-Quality Data Base. Project Summary EPA-600/S2-81-238, Cincinnati, OH.

Hunter, J.V., T. Sabatino, R. Gomperts, and M.J. MacKenzie. 1979. Contribution of Urban Runoff to Hydrocarbon Pollution. J. Water Poll. Control 51(8): 2129-2138.

*Hvitved-Jacobsen, T., Y.A. Yousef, M.P. Wanielista, and D.B. Pearce. 1984. Fate of Phosphorus and Nitrogen in Ponds Receiving Highway Runoff. Sci. Total Environ. 33:259-270.

*Irwin, G.A. and R.T. Kirkland. 1981. Chemical and Physical Characteristics of Precipitation at Selected Sites in Florida. U.S. Geological Survey Water-Resources Investigations Report 80-81, Tallahassee, Florida.

Jacobs, E.L. 1984. Gabions: Flexible Solutions for Urban Erosion. In the International Symposium on Urban Hydrology, Hydraulics and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 121-128.

James, W.P., J.F. Bell, and D.L. Leslie. 1987. Size and Location of Detention Storage. J. Water Res. Planning Manage. ASCE 113(1):15-28.

Jones, J.E. and D.E. Jones, Jr. 1984. Essential Urban Detention Ponding Considerations. J. Water Res. Planning Manage. ASCE 110(4):418-433.

Jones, R.L., A.G. Hornsby, P.S.C. Rao, and M.P. Anderson. 1987. Movement and Degradation of Aldicarb Residues in the Saturated Zone under Citrus Groves in the Florida Ridge. J. Contaminant Hydro. 1(3):265-285.

Kanwar, R.S., J.L. Baker, and S.W. Melvin. 1986. Alternatives to the use of Agricultural Drainage Wells. Water Res. Bull. 22(4):573-579.

Kent, E.J., Dr.R. Burke III, and Dr.S.L. Yu. 1981. Source Control of Storm Water Through Joint use of Constructed Storage and Soil Management. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 453-464.

Khanal, N. 1975. Hydrologic Aspects of On-Site Retention Systems for Urban Storm Runoff. Central and Southern Florida Flood Control District, West Palm Beach, Florida. 71 p.

Korpics, J.J. 1988. Regualtion of Storm Water Point Source Discharges. J. Water Poll. Control Fed. 60(1):50-56.

Kramer, R.A., W.T. McSweeny, W.R. Kerns, and R.W. Stavros. 1984. An Evaluation of Alternative Policies for Controlling Agricultural Nonpoint Source Pollution. Water Res. Bull. 20(6):841-846.

Krishma, J.H., G.F. Arkin, and J.R. Martin. 1987. Runoff Impoundment for Supplemental Irrigation in Texas. Water Res. Bull. 23(6):1057-1061.

Kutash, W. 1985. Effectiveness of Wetland Stormwater Treatment: Some Examples. Proceedings: Stormwater Management - "An Update", M.P. Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

*Lakatos, D.F. and L.J. McNemar. 1986. Storm Quality Management Using Wetlands. Presented at the University of Georgia's Ninth Symposium on Freshwater Wetlands and Wildlife, Charleston, South Carolina.

Lakatos, D.F. and W.B. Satterthwaite. 1985. Current Trends in Urban Watershed Management. In the International Symposium on Urban Hydrology, Hydraulic Infrastructures and Water Quality, University of Kentucky, Lexington, Kentucky, pp. 103-108.

*LaRock, P.A., B. Tuovila, T. Johengen, and S. Boutelle. 1986. The Use of an Artificial Marsh and Filter System to Treat Urban Stormwater Runoff. Dept. of Oceanography, Florida State Univ., Tallahassee, Florida.

Lauwaert, A.J. 1985. Water Quality and Regional Water Supply Planning. J. Water Res. Planning Manage. ASCE 111(3):253-267.

*Livingston, E.H. 1985(a). Overview of Stormwater Management. Florida Depart. of Envrion. Reg., Tallahassee, Florida.

Livingston, E.H. 1985(b). The Stormwater Rule: Past, Present, and Future. Proceedings: Stormwater Management - "An Update", M.P.Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

Loganathan, G.V. and J.W. Delleur. 1984. Effects of Urbanization on Frequencies of Overflows and Pollutant Loadings from Storm Sewer Overflows: A Derived Distribution Approach. Water Resources Res. (G.B.) 20(7):857-865.

*Lopez, M.A. and R.F. Giovannelli. 1984. Water-Quality Characteristics of Urban Runoff and Estimates of Annual Loads in the Tampa Bay area, Florida, 1975-80. U. S. Geological Survey Water-Resources Investigations Report 83-4181, Tallahassee, Florida.

Lutz, J.R. 1977. Water Quality and Nutrient Loadings of the Major Inflows from the Everglades Agricultural Area to the Conservation Areas, Southeast Florida. South Florida Water Management District. Tech. Pub. 77-6. 69 p.

*Luzkow, S.M., D.A. Scherger, and J.A. Davis. 1981. Effectiveness of two in-line Urban Storm Water Best Management Practices (BMP's). In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 193-206.

Maas, R.P., M.D. Smolen, and S.A. Dressing. 1985. Selecting Critical Areas for Nonpoint-Source Pollution Control. J. Soil Water Conserv. 40(1): 68-71.

MacKenzie, M.J. and J.V. Hunter. 1979. Sources and Fates of Aromatic Compounds in Urban Stormwater Runoff. Environ. Sci. Technol. 13(2): 179-183.

*Martin, E.H. 1985. The Effectiveness of a Detention Pond and Wetlands System in Reducing the Amounts of Lead Transported by Urban Stormwater Runoff. Proceedings: Stormwater Management - "An Update", M.P.Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

*Martin, E.H. and R.A. Miller. 1987. Efficiency of an Urban Stormwater Detention System. Proceedings: Fourth International Conference on Urban Storm Drainage. To be published.

*Martin, E.H. and J.L. Smoot. 1986. Constituent-Load Changes in Urban Stormwater Runoff Routed Through a Detention Pond-Wetlands System in Central Florida. U.S. Geological Survey, Water-Resources Investigations Report 85-4310, Tallahassee, Florida. 74 p.

Mason, Jr., J.M. 1984. Multistaged Outlet Control for Small On-Site Detention. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 431-437.

Mason, Jr., J.M. 1984. Development of a Stormwater Management Plan. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 201-205.

*Mattraw, Jr., H.C., and C.B. Sherwood. 1977. Quality of Stormwater Runoff from a Residential Area, Broward County, Florida. J. Res. U.S. Geological Survey 5(6):823-834.

*Mattraw, Jr., H.C., J. Hardee, and R.A. Miller. 1978. Urban Stormwater Runoff Data for a Residential Area, Pompano Beach, Florida. U.S. Geological Survey Open-File Report 78-324, Tallahassee, Florida.

*Mattraw, Jr., H.C. and R.A. Miller. 1981. Stormwater Quality Processes for Three Land-Use Areas in Broward County, Florida. U.S. Geological Survey Water-Resources Investigations Report 81-23, Tallahassee, Florida.

*McCuen, R.H. 1980. Water Quality Trap Efficiency of Storm Water Management Basins. Water Res. Bull. 16(1):15-21.

*McQueen, D.E. 1980. Underground Disposal of Storm Water Runoff at Miami International Airport. Prepared for Dade County Aviation Department. Lloyd and Associates, Inc, Vero Beach, FL. 83 p.

McTernan, W.F., B.L. Weand, and T.J. Grizzard. 1987. Evaluation of Management Practices to Control Agricultural Pollutants. Water Res. Bull. 23(4):691-700.

*Medico, Jr., J.J. 1985. The Design of Porous Pavement Stormwater Management Systems and their Comparison with Asphalt Pavement Aystems. Proceedings: Stormwater Management - "An Update", M.P.Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

Meister, J.F. and S. Kefer. 1981. A Comparison Between Urban and Nonurban Storm Water Runoff Water Quality in an Urbanized Watershed. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 211-217.

*Middlebrooks, E.J. 1983. Statistical Calculations. Ann Arbor Sciences Publishers, Ann Arbor, Michigan. 120 pp.

*Miller, R.A. 1985. Using Bulk-Precipitation Data to Analyze the Movement of Chemical Constituents in Urban Stormwater. Proceedings: Stormwater Management - "An Update", M.P.Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

*Miller, R.A. and H.C. Mattraw, Jr. 1982. Storm Water Runoff Quality from Three Land Use Areas in South Florida. Water Res. Bull. 18(3):513-519.

Myers, C.F., J. Meek, S. Tuller, and A. Weinberg. 1985. Nonpoint Sources of Water Pollution. J. Soil Water Conserv. 40(1):14-18.

NATO Advanced Science Institutes Series (NATO). 1986. Urban Runoff Pollution. H.C. Torno, J. Marsalek, M. Desbordes, eds. Springer-Verlag Publishers, Berlin, West Germany.

Nelson, J.O. 1987. Water Conserving Landscapes Show Impressive Savings. J. American Water Works Assoc. 79(3):35-42.

*Nightingale, H.I. 1975. Lead, Zinc, and Copper in Soils of Urban Storm-Runoff Retention Basins. J. American Water Works Assoc. 67(8):443-446.

*Nightingale, H.I. 1987. Accumulation of As, Ni, Cu, and Pb in Retention and Recharge Basins Soils from Urban Runoff. Water Res. Bull. 23(4):663-672.

Novotny, V., H.M. Sung, R. Bannerman, and K. Baum. 1985. Estimating Nonpoint Pollution from Small Urban Watersheds. J. Water Poll. Control Fed. 57(4):339-348.

*Oakland, P.H. 1983. An Evaluation of Urban Storm Water Pollutant Removal Through Grassed Swale Treatment. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 183-185.

Oberts, G.L. 1982. Impact of Wetlands on Nonpoint Source Pollution. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 225-232.

Odum, E.P. 1987. Reduced-Input Agriculture Reduces Nonpoint Pollution. J. Soil Water Conserv. 42(6):412-414.

Ormsbee, E.L. 1984. Systematic planning of dual purpose detention basins. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Quality Control, University of Kentucky, Lexington, Kentucky, pp. 143-151.

Ostry, R.C. 1982. Relationship of water quality and pollutant loads to land uses in adjoining watersheds. Water Res. Bull. 18(1):99-104.

*Owe M., P.J. Craul, and H.G. Halverson. 1982. Contaminant levels in precipitation and urban surface runoff. Water Res. Bull. 18(5):863-868.

Parent, F.D. and S.B. Lovejoy. 1982. Farmer's attitudes toward government involvement in preventing agricultural nonpoint-source water pollution. Water Res. Bull. 18(4):502-506.

*Pitt, R. 1979. Demonstration of nonpoint pollution abatement through improved street cleaning practices. EPA Grant No. S-804432, Cincinnati, OH, EPA-600/2-79-161.

*Post, Buckley, Schuh, and Jernigan, Inc. 1982. Evaluation of two best management practices: a grassy swale and a retention/detention pond, Brevard 208 Continuing Planning Process. EPA Grant 067-301.00.

Raasch, G.E. 1982. Urban stormwater control project in an ecologically sensitive area. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 187-192.

*Randall, C.W. 1982. Stormwater dentention ponds for water quality control. In proceedings of the Conference on Stormwater Detention Facilities, ASCE, William DeGroot, Ed. pp. 200-204.

Randall, C.W., K. Ellis, T.J. Grizzard, and W.R. Knocke. 1982. Urban runoff pollutant removal by sedimentation. In proceedings of the Conference on Stormwater Detention Facilities, ASCE, William DeGroot, Ed. pp. 205-219.

Rausch, D.L. and J.D. Schreiber. 1981. Sediment and nutrient trap efficiency of a small flood-detention reservoir. J. Environ. Qual. 10(3):288-293.

Reddy, G.B. and K.R. Reddy. 1987. Nitrogen transformation in ponds receiving polluted water from nonpoint sources. J. Environ. Quality. 16(1):1-5.

Richman, C.J. 1984. Designing detention form stream bank protection. In the International Symposium on Urban Hydrology, Hydraulics, and

Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 129-131.

Riekerk, H. 1982. Forest Runoff Water Quality. The Proceedings of the IFAS Conference on Nonpoint Pollution Control Technology in Florida. Gainesville, Florida. pp. 28-47.

Ritter, G. and A.L. Goldstein. 1985. BMP's for South Florida's Dairy Lands. Proceedings: Stormwater Management - "An Update", M.P.Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

*Ritter, G.J. and L.H. Allen, Jr. 1982. Taylor Creek Headwaters Project Phase I Report; Water Quality. South Florida Water Management District Tech. Pub. 82-2, West Palm Beach, FL. 186 p.

Ritter, W.F and J.R. Harris. 1984. Nonpoint Source Nitrogen Loads to Delaware Lakes and Streams. Agricultural Wastes 9:35-50.

*Rossmiller, Ronald L., P.E. 1981. A Philosophy for Urban Storm Water Management. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 273-280.

Rutledge, A.T. 1987. Effects of Land Use on Ground Water Quality in Central Florida - - Preliminary Results: U.S. Geological Survey Toxic Waste - - Ground Water Contamination Program. U.S. Geological Survey Water Resources Investigations Report 88-4163, Tallahassee, Florida.

*Sartor, J.D., G.B. Boyd, and F.J. Agardy. 1974. Water Pollution Aspects of Street Surface Contaminants. J. Water Poll. Control Fed. 46(3):458-467.

*Schad, T.M. 1984. Twenthieth Annual Conference - Introduction. Proceedings of Options for Reaching Water Quality Goals, Washington, D.C. American Water Resources Association, Bethesda, MD.

Schaefer, G.C. and D.L. Hey. 1983. Source Control as a Management Strategy for Urban Stormwater Pollution. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 207-219.

*Scherger, D.A. and J.A. Davis. 1982. Control of Stormwater Runoff Pollutant Loads by a Wetland and Retention Basin. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 109-123.

Schillinger, J.E. and J.J. Gannon. 1985. Bacterial Adsorption and Suspended Particles in Urban Stormwater. J. Water Pollut. Control Fed. 57(5): 384-389.

Schlosser, I.J. and J.R. Karr. 1981. Water Quality in Agricultural Watersheds: Impact of Riparian Vegetation During Base Flow. Water Res. Bull. 17(2):233-240.

Schmidt, S.D. and D.R. Spencer. 1986. The Magnitude of Improper Waste Discharges in an Urban Stormwater System. J. Water Pollut. Control Fed. 58(7):744-748.

Schreiber, J.D. and E.E. Neumaier. 1987. Biochemical Oxygen Demand of Agricultural Runoff. J. Environ. Qual. 16(1):6-10.

Shahane, A.N. 1982. Estimation of Pre- and Post-Development Nonpoint Water Quality Loadings. Water Res. Bull. 18(2):231-237.

*Shannon, J.D., B. Derrington, and A. Varma. 1986. Multipurpose Wastewater Reuse. J. Water Poll. Control Fed. 58(11):1039-1042.

*Shelley, P.E., and D.R. Gaboury. 1986. Pollution from Highway Runoff - Preliminary Results. In Proceedings of Stormwater and Water Quality Model Users Group Meeting, T.O. Barnwell, Jr. and W.C. Huber, Eds. EPA/600/9-86/023.

Shih, S.F. 1984. Impact of Water Cutback on Sugarcane Production in the Florida Everglades. Water Res. Bull. 20(2):187-191.

Smith, W.G. 1982. Water Quality Enhancement Through Stormwater Detention. In Proceedings of the Conference on Stormwater Detention Facilities, ASCE, William DeGroot, Ed. pp. 236-244.

*Sonnen, Michael B. 1983. Guidelines for the Monitoring of Urban Runoff Quality. USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio. 119 p.

South Florida Water Management District (SFWMD(a)). In review. Evaluation of a Dry Detention with Filtration Stormwater Management System for a Mixed Land Use Area: Lake Tohopekaliga Demonstration Project. Resource Planning Department, West Palm Beach, FL.

South Florida Water Management District (SFWMD(b)). In review. Evaluation of a Wet Detention Stormwater Management System for a Commercial Area: Boynton Beach Mall. Resource Planning Department, West Palm Beach, FL.

South Florida Water Management District (SFWMD(c)). In review. Evaluation of a Wet Detention Stormwater Management System for a Single Family Residential Area: Springhill Subdivision. Resource Planning Department, West Palm Beach, FL.

South Florida Water Management District (SFWMD(d)). In progress. Evaluation of an Exfiltration Stormwater Management System for a Roadway Area: Summit Avenue. Resource Planning Department, West Palm Beach, FL.

South Florida Water Management District (SFWMD(e)). In progress. Evaluation of a Wet Detention Water Management System for a Citrus Area. West Palm Beach, FL.

*South Florida Water Management District (SFWMD(f)). In review. Environmental Criteria Manual. Resource Control Department, West Palm Beach, FL.

*South Florida Water Management District (SFWMD). 1987. Management and Storage of Surface Waters, Permit Information Manual, volume IV. West Palm Beach, Florida.

*South Florida Water Management District and East Central Florida Regional Planning Council (SFWMD and ECFRPC). 1987. Boggy Creek Water Quality Management Study. Produced by South Florida Water Management District, West Palm Beach, FL. 150 p.

Spangenberg, N.E. 1987. Implementation Strategies for Agricultural and Silvicultural Nonpoint-Source Pollution Control in California and Wisconsin. Water Res. Bull. 23(1):133-137.

Stenstrom, M.K., G.S. Silverman, and T.A. Bursztynsky. 1984. Oil and Grease in Urban Stormwaters. J. Environ. Engr. 110(1):58-72.

Straub, C.P., V.M. Goppers, and R.D. Singer. 1982. Effect of Land Use on Municipal Water Systems. International Symposium on Urban Hydrology, Hydraulics and Sediment Control. Univ. of Kentucky, Lexington, Kentucky.

Striegl, R.G. 1987. Suspended Sediment and Metals Removal from Urban Runoff by a Small Lake. Water Res. Bull. 23(6):985-996.

*Snyder, G.H. 1982. Nutrient Losses from Turfgrass. The Proceedings of the IFAS Conference on Nonpoint Pollution Control Technology in Florida. Gainesville, Florida. pp. 220-233.

Snyder, G.H. and S.F. Shih. 1982. Management Alternatives in the Everglades Agricultural Area. The Proceedings of the IFAS Conference on Nonpoint Pollution Control Technology in Florida. Gainesville, Florida. pp. 355-367.

Thomas, L.M. 1985. Viewpoint - Management of Nonpoint-Source Pollution: What Priority? J. Soil Water Conserv. 40(1):8.

*Thompson, S.A. 1982. Reduction of Urban Runoff Through Economic Incentives: Boulder, Colorado. Water Res. Bull. 18(1):125-127.

Thornley, S. and A.W. Bos. 1985. Effects of Livestock Wastes and Agricultural Drainage on Water Quality: An Ontario Case Study. J. Soil Water Conserv. 40(1):173-175.

Tai, C.C. 1975. Agricultural Reservoir Study. Central and Southern Florida Flood Control District, Tech. Pub. #75-3. 43 p.

*United States Environmental Protection Agency (USEPA). 1983. Results of the National Urban Runoff Program (NURP). Executive Summary; Volume I - Final Report; Volume II - Appendices; Vol. III - Data Appendix. USEPA, Washington D.C.

Van Haveren, B.P. 1986. Management of Instream Flows Through Runoff Detention and Retention. Water Res. Bull. 22(3):399-404.

Vatagodakumbura, S. 1982. Application of Stormwater Management Criteria to New Development Planning. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 193-204.

Verhoff, F.M. and S.M. Yaksich. 1982. Storm Sediment Concentrations as Affected by Land Use, Hydrology, and Weather. J. Environ. Qual. 11(1):72-78.

Vigon, B.W. 1985. The Status of Nonpoint Source Pollution: Its Nature, Extent, and Control. Water Res. Bull. 21(2):179-184.

Wakeham, S.G. A Characterization of the Sources of Petroleum Hydrocarbons in Lake Washington. Jour. Water Poll. Control Fed. 49(7):1680-1687.

Waller, D.H. and E. Locke. 1981. Storm Water Detention Facilities in the Halifax-Dartmouth Region. In the International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, Kentucky, pp. 309-313.

*Wanielista, M.P. 1978. Stormwater Management: Quantity and Quality. Ann Arbor Science, Ann Arbor, MI. 383 p.

*Wanielista, M.P. and Y.A. Yousef. 1978. Designs and Analysis of Stormwater Retention Basins Using Quality and Quantity Criteria. International Conference on Urban Storm Drainage, University of Southampton, Southampton, United Kingdom.

*Wanielista, M.P. and Y.A. Yousef. 1985. Overview of Stormwater Management Practices. Proceedings: Stormwater Management - "An Update", M.P. Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

Wanielista, M.P., Y.A. Yousef, and W.M. McLellon. 1977. Nonpoint Source Effects on Water Quality. J. Water Poll. Control Fed. 49(3):441-451.

Wanielista, M.P., Y.A. Yousef., B.L. Golding, and C.L. Cassagnol. 1981(a). Stormwater Management Manual. Univ. of Central Florida, Dept. Civil Engr. and Environ. Sci. 141 p.

*Wanielista, M.P., Y.A. Yousef, H.H. Harper, and C.L. Cassagnol. 1981(b). Detention with Effluent Filtration for Stormwater Management. 2nd International Conference on Urban Storm Drainage, Urbana, IL, USA.

Wanielista, M.P., Y.A. Yousef, and J.S. Taylor. 1982. Stormwater Management to Improve Lake Water Quality. EPA Grant 600/S2-82-048.

Wanielista, M.P., Y.A. Yousef, and H.H. Harper. 1985(a). Swale Hydraulics. Proceedings: Stormwater Management - "An Update", M.P.Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

Wanielista, M.P., Y.A. Yousef, L.M. Van DeGraaff, and S.H. Rehamann-Koo. 1985(b). Best Management Practices - Enhanced Erosion and Sediment Control Using Swale Blocks. Univ. of Central Florida submitted to Florida Depart. of Transportation, Contract No. 99700-7271, Tallahassee, FL.

Wauchope, R.D. 1987. Tilted-Bed Simulation of Erosion and Chemical Runoff from Agricultural Fields: I. Runoff of Sediment and Sediment-Associated Copper and Zinc. J. Environ. Qual. 16(3):206-211.

Wauchope, R.D. 1987. Tilted-Bed Simulation of Erosion and Chemical Runoff from Agricultural Fields: II. Effects of Formulation on Atrazine Runoff. J. Environ. Qual. 16(3):212-216.

Weibel, S.R., R.J. Anderson, and R.L. Woodward. 1964. Urban Land Runoff as a Factor in Stream Pollution. J. Water Poll. Control Fed. 36(7):914-924.

*Weinberg, M., D. Reece, and D. Allman. 1980. Effect of Urban Stormwater Runoff to a Man-Made Lake on Ground Water Quality. South Florida Water Management District, Tech. Pub. 80-4, West Palm Beach, Florida. 112 p.

Whipple, Jr., W. and J.V. Hunter. 1977. Effects of Storm Frequency on Pollution from Urban Runoff. Jour. Water Poll. Control Fed. 49(11):2243-2248.

Whipple, Jr., W. and J.V. Hunter. 1979. Petroleum Hydrocarbons in Urban Runoff. Water Res. Bull. 15(4):1096-1105.

Whipple, Jr., W. and J.V. Hunter. 1981. Settleability of Urban Runoff Pollution. Jour. Water Poll. Cont. 53(12):1726-1731.

White, E.M. 1983. Factors Controlling Runoff Nutrient Loss from Cultivated Land in Eastern South Dakota. Water Res. Bull. 19(5):649-653.

*Wigington, Jr., P.J., C.W. Randall, and T.J. Gizzard. 1983. Accumulation of Selected Trace Metals in Soils of Urban Runoff Detention Basins. Water Res. Bull. 19(5):709-718.

*Wigington, Jr., P.J., C.W. Randall, and T.J. Gizzard. 1986. Accumulation of Selected Trace Metals in Soils of Urban Runoff Swale Drains. Water Res. Bull. 22(1):73-79.

Williams, L.H. 1982. Effectiveness of Stormwater Detention. In Proceedings of the Conference on Stormwater Detention Facilities, ASCE, William DeGroot, Ed. pp. 121-134

Wilson, J.T., C.G. Enfield, W.J. Dunlap, R.L. Cosby, D.A. Foster, and L.B. Baskin. 1981. Transport and Fate of Selected Organic Pollutants in a Sandy Soil. J. Environ. Qual. 10(4):501-506.

Yates, P., R.S. Mansell, D.V. Calvert, and J.S. Rogers. Flatwoods Citrus Drainage. The Proceedings of the IFAS Conference on Nonpoint Pollution Control Technology in Florida. Gainesville, Florida. pp. 48-62.

Young, C.E. and R.S. Magleby. 1987. Agricultural Pollution Control: Implications from the Rural Clean Water Program. Water Res. Bull. 23(4): 701-707.

*Yousef, Y.A., T. Hvitved-Jacobsen, L. Wiseman, and J.M. Bateman. 1986. Detoxification of Heavy Metals in Highway Runoff by Retention/Detention. Proceedings of the International Conference on Chemicals in the Environment, Lisbon, Portugal. pp. 70-76.

*Yousef, Y.A., M.P. Wanielista, and H.H. Harper. 1985(a). Fate of Pollutants in Retention/Detention Ponds. Proceedings: Stormwater Management - "An Update", M.P.Wanielista and Y.A. Yousef, Eds. Univ. of Central Florida, Environ. Systems Engr. Institute, Pub. #85-1, Orlando, Florida.

*Yousef, Y.A., M.P. Wanielista, H.H. Harper, D.B. Pearce, R.D. Tolbert. 1985. Best Management Practices - Removal of Highway Contaminants by Roadside Swales. Univ. of Central Florida submitted to Florida Dept. of Transportation, Contract No. 99700-7271, Tallahassee, FL.