Evaluation of Current Stormwater Design Criteria within the State of Florida

Final Report

Prepared for:

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

FDEP Contract No. SO108

June 2007

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ACKNOWLEDGEMENTS

The authors wish to thank the Bureau of Watershed Management/Nonpoint Source Management of the Florida Department of Environmental Protection for their assistance in funding and administration of this project. A special thank you is also given to the FDEP Project Manager, Mr. Eric Livingston, for his invaluable support throughout this project. His guidance, technical expertise, and wisdom contributed heavily to the success of this project. The authors also wish to thank the talented personnel from the various water management districts who reviewed the Draft Final Report and provided valuable comments and input.

Funding for this project was provided by a TMDL Water Quality Grant from the Bureau of Watershed Management, Florida Department of Environmental Protection, Tallahassee, Florida.

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SECTION 4

STORMWATER RUNOFF – QUALITY AND QUANTITY

The performance efficiency and effectiveness of stormwater treatment systems are closely linked to the quantity and quality of the generated stormwater stream. Issues related to the quantity and quality of stormwater runoff form the basis of existing stormwater treatment design criteria. A discussion of the quality and quantity of stormwater runoff generated by various land use categories is given in the following sections.

4.1 Water Quality Characteristics

4.1.1 Data Availability

A multitude of stormwater characterization studies have been conducted within the State of Florida as part of research projects, permit monitoring requirements, retrofit projects, and NPDES permitting. Land use categories included in runoff characterization studies can typically be grouped into one of 12 general land use designations which are commonly used in pollutant loading evaluations. A summary of these general land use categories is given in Table 4-1.

When performing pollutant loading studies for large watershed areas, land use information is often obtained as FLUCCS codes (Florida Land Use Code and Classification System). This system typically provides multiple sub-categories for each of the 12 general land use categories summarized in Table 4-1 based upon differences in percentage imperviousness, vegetative cover, and development density. Unfortunately, detailed runoff characterization data are not available for most of these sub-categories. As a result, when performing pollutant loading studies, detailed land use categories represented by FLUCCS codes must often be assigned to one of the 12 general land use categories summarized in Table 4-1 for estimation of pollutant loadings. This assignment is typically performed based upon anticipated similarities in hydrologic and pollutant loading characteristics between the detailed FLUCCS code designations and the general land use categories.

A summary of the availability of runoff characterization data for various pollutant categories and land use types is given in Table 4-2. Good runoff characterization data is generally available for suspended solids in each of the land use categories summarized in Table 4-1. A similar level of characterization data availability is present for total nitrogen and total phosphorus in virtually all land use categories. However, information on dissolved species of nitrogen and phosphorus is relatively limited in the existing literature.

TABLE 4-1

GENERAL LAND USE CATEGORIES FOR RUNOFF CHARACTERIZATION DATA

GENERAL CATEGORY	DESCRIPTION
Low-Density Residential	Rural areas with lot sizes greater than 1 acre or less than one dwelling unit per acre; internal roadways associated with the homes are also included
Single-Family Residential	Typical detached home community with lot sizes generally less than 1 acre and dwelling densities greater than one dwelling unit per acre; duplexes constructed on one-third to one-half acre lots are also included in this category; internal roadways associated with the homes are also included
Multi-Family Residential	Residential land use consisting primarily of apartments, condominiums, and cluster-homes; internal roadways associated with the homes are also included
Low-Intensity Commercial	Areas which receive only a moderate amount of traffic volume where cars are parked during the day for extended periods of time; these areas include universities, schools, professional office sites, and small shopping centers; internal roadways associated with the development are also included
High-Intensity Commercial	Land use consisting of commercial areas with high levels of traffic volume and constant traffic moving in and out of the area; includes downtown areas, commercial sites, regional malls, and associated parking lots; internal roadways associated with the development are also included
Industrial	Land uses include manufacturing, shipping and transportation services, sewage treatment facilities, water supply plants, and solid waste disposal; internal roadways associated with the development are also included
Highway	Includes major road systems, such as interstate highways and major arteries and thoroughfares; roadway areas associated with residential, commercial, and industrial land use categories are already included in loading rates for these categories
Agriculture	Includes cattle, grazing, row crops, citrus, and related activities
Open/ Undeveloped	Includes open space, barren land, undeveloped land which may be occupied by native vegetation, rangeland, and power lines; this land does not include golf course areas which are heavily fertilized and managed; golf course areas have runoff characteristics most similar to single-family residential areas
Mining/ Extractive	Includes a wide variety of mining activities for resources such as phosphate, sand, gravel, clay, shell, etc.
Wetlands	Include a wide range of diverse wetland types, such as hardwood wetlands, cypress stands, grassed wetlands, freshwater marsh, and mixed wetland associations
Open Water/ Lakes	Land use consists of open water and lakes, rivers, reservoirs, and other open waterbodies

TABLE 4-2

RUNOFF CHARACTERIZATION DATA AVAILABILITY

PARAMETER GROUP	SPECIES	DATA AVAILABILITY	LAND USES
Suspended Solids	TSS	Good	All
Nutrients	Total N Total P	Good	All
	NH_3 NO_x TKN Ortho-P	Limited	Limited
Metals	Zinc Lead Copper	Fair to Good	Commercial, Residential, and Highway
	Cadmium Nickel Diss. Metals	Poor to Fair	Commercial, Residential, and Highway
Oxygen Demanding Substances	BOD	Fair to Good	Commercial, Residential, and Highway
	COD	Poor to Fair	Commercial, Residential, and Highway
Oils, Greases, and Hydrocarbons	Oil and Grease TRPH	Poor	Commercial, Residential, and Highway
	Specific Compounds	Extremely Poor	Commercial, Residential, and Highway
Pathogens	Total Coliform Fecal Coliform	Poor	Commercial, Residential, and Highway
	E. Coli	Extremely Poor	Commercial, Residential, and Highway

Runoff characterization data for zinc, lead, and copper are most commonly available for commercial, residential, and highway land uses. However, even in these categories, the availability of the data is only considered to be fair to good. Information on other heavy metals, such as cadmium, chromium, and nickel, as well as dissolved metal species, is poor in virtually all land use categories. The only studies which include these latter parameters appear to be research-related projects.

Runoff characterization data for biochemical oxygen demand (BOD) is fair to good in commercial, residential, and highway land use categories. A limited amount of information for this parameter is also present in agricultural studies. However, chemical oxygen demand (COD) is measured relatively infrequently, and the data availability for this parameter is considered poor to fair.

Oils, greases, and hydrocarbons are measured on an infrequent basis in stormwater characterization studies. Most of the studies including these parameters are research projects, many of which are designed specifically to address these compounds. Oils, greases, and hydrocarbons are generally evaluated through the generic oil and grease or TRPH (total recoverable petroleum hydrocarbon) lab tests. Testing for specific compounds is extremely rare within the literature.

Information on pathogens, such as total and fecal coliform, is poor in the available literature, with the majority of information addressing commercial, residential, and highway land uses. Information on more specific pathogens, such as E. coli, is extremely poor for virtually all land use categories.

A literature review was conducted by Harper during 1992-93 to identify significant stormwater characterization studies performed within the State of Florida. Basic information for many of the evaluated land uses was obtained from the document by Harper (1994) titled "Stormwater Loading Rate Parameters for Central and South Florida". This report presents the results of an extensive literature search and analysis of runoff characteristics for selected parameters and land use types within Central and South Florida. The runoff characteristics provided in this document include publications and studies conducted specifically within the State of Florida by a variety of state, federal, and local governments, along with private consultants.

Each study was reviewed for adequacy of the database, with special attention to factors such as length of study, number of runoff events monitored, monitoring methodology, as well as completeness and accuracy of the work. In general, it is preferred that selected studies present at least a one-year period of data collection representing a wide range of rainfall and antecedent dry period conditions. Unfortunately, in a number of cases, the only available data base for a given land use category or loading parameter represented a relatively small and limited data collection process. These studies were carefully examined on a case-by-case basis and a decision was made as to whether or not to include the data in loading rate estimates. No studies with less than five storm sample events were used. An important requirement for inclusion of stormwater monitoring data is that the study measures only a homogeneous watershed area. This requirement is necessary since input into most loading rate models is based upon homogeneous land use types. Unfortunately, this requirement limited the usefulness of several thorough stormwater studies by the USGS which evaluated mixed land use areas.

Approximately 120 reports and publications of stormwater research conducted within the State of Florida were initially reviewed as a part of the literature search process. During the initial review process, studies which contain an insufficient number of sample events or address mixed land use areas were removed from further consideration, leaving approximately 40 reports with potential pollutant loading information.

The Harper (1994) report includes all significant stormwater characterization studies performed in Florida prior to the early 1990s. However, a limited number of additional runoff characterization studies have been performed since the publication date for this report. Therefore, a supplemental literature search was performed by ERD to identify additional resources for characterization data. Additional land use characterization studies were obtained for single-family residential areas, low-intensity commercial, highway/transportation land use, agriculture-citrus, agriculture-row crop, and open space/undeveloped/rangeland/forest areas. The supplemental characterization data were combined with the data provided by Harper (1994) to generate a database reflecting all significant characterization studies performed in Florida. A brief summary of information contained within selected characterization studies from the combined database is given in Table 4-3. A listing of hydrologic and general characteristics for studies included in the combined database is given in Appendix B.

TABLE 4-3

SUMMARY OF SELECTED STORMWATER CHARACTERIZATION STUDIES PERFORMED IN THE STATE OF FLORIDA

REFERENCE	LOCATION OF STUDY AREA	LAND USE TYPE	PARAMETERS MEASURED	COMMENTS
Federico (1977)	Taylor Creek Drainage Basin, FL	1. Pasture 2. Dairy 3. Citrus	General Parameters, Nutrients	An average of 43 daily composite samples collected in drainage ditches from July to September 1975. Data presented as concentration only with no hydrologic data for direct conversion to loading rates.
East Central Florida Regional Planning Council (ECFRPC) (1978)	Central Florida Area	1. Residential 2. Commercial 3. Pasture 4. Well-drained 5. Flatwoods 6. Range 7. Lake 8. Swamp	Nutrients, BOD, Solids	Presents summaries of studies conducted in Central Florida with results expressed in concentration and loading rate forms.
Gaggiani, et al. (1978)	Maitland, FL	Primarily residential	Nutrients, Major Ions, Heavy Metals	Bulk precipitation and runoff samples were collected from 3 adjacent watersheds from April 1971 to June 1974. A total of 46 storm events were monitored. Data includes event mean concentration and mass loading for storm events.
Miller (1979)	Southeast Florida Coastal Area	1. 17.9 acres low-density residential 2. 58.3 acres highway basin 3. 20.4 acres commercial 4. 14.7 acres high-density residential	None	Report gives detailed hydrologic information on the four drainage basins. Results of runoff sampling programs are given in other publications by the author.
Weinberg, et al. (1980)	Broward County, FL	26 acres of high-density residential	General Parameters, Nutrients	Grab samples and timed samples collected from 2 rain events during 1975. Insufficient data base.
Mattraw, et al. (1981)	Broward County	3 separate areas: 1. 40.8-acre single-family residential (43.9% imp.) 2. 58.3-acre 6-lane highway (36.2% imp.) 3. 28.4-acre commercial (regional shopping mall, 98% imp.)	General Parameters, Nutrients, Metals, Bacteria	More than 30 flow-weighted samples collected from 1974-1977. Data presented as concentration and loadings. Detailed hydrology provided for each basin.

TABLE 4-3 -- CONTINUED

SUMMARY OF SELECTED STORMWATER CHARACTERIZATION STUDIES PERFORMED IN THE STATE OF FLORIDA

REFERENCE	LOCATION OF STUDY AREA	LAND USE TYPE	PARAMETERS MEASURED	COMMENTS
Harper, et al. (1982)	Orlando, FL	160 acres of high-density commercial and residential	General Parameters, Solids, BOD, Metals, Nutrients	Runoff collected from mixed residential and commercial watersheds during 1978 using manual and automatic techniques. Data presented in both concentration and loading rate forms but represents mixed land use.
Waller (1982)	Dade County, FL	1. Commercial 2. State Park 3. Residential 4. Row Crops 5. Agricultural	General Parameters, Nutrients, Heavy Metals	Runoff samples collected from June to October 1978 only for storms of intensity equal to or exceeding 1.0 inch/hour. Data cannot be used for loading rate estimation since typical less intense storm events were not monitored.
Wanielista, et al. (1982)	Orlando, FL	1. Residential 2. Commercial	General Parameters, Nutrients, Metals	Four runoff events were collected from separate residential and commercial watersheds from July to November 1978 using manual flow-weighted collection techniques. Data presented in both concentration and loading rate forms. However, the data base is small and covers only a portion of the year. Residential area receives heavy traffic volume from adjacent downtown area.
Yousef, et al. (1982)	Orlando, FL	Interstate Highway (I-4)	General Parameters, Nutrients, Metals	Runoff from highway bridges was collected from 11 storm events during August 1975. Data presented in concentration form only. Sampling program and hydrologic information sufficient to generate annual loadings, but data is specific to bridge or highway runoff only.
German (1983)	Maitland, FL	2 Sub-basins: Residential and Highway	General Parameters, Nutrients, Metals	39 runoff events sampled in residential areas and 17 samples in highway areas from 1975-1979.
McKenzie, et al. (1983)	Miami, FL	1.43 acre Interstate Highway (I-95)	General Parameters, Nutrients, Metals	Runoff collected during 5 storm events from November 1979 to May 1981 using automated instrumentation. Data presented as both concentration and loading rates, but is specific only to highway systems.
Cullum (1984) Greg (1984)	Boca Raton, FL	122 acres single-family residential	General Parameters, Nutrients	Detailed hydrologic concentration and mass loading data. However, only rain events in excess of 1 inch were sampled.
ECFRPC (1984)	Central Florida	11 land use types	Nutrients, BOD, Solids	Presents concentration and loading rate information for expanded land use categories not presented in earlier 1978 publication. Data generated from Central Florida studies funded by ECFRPC. Hydrologic information is also provided.

TABLE 4-3 -- CONTINUED

SUMMARY OF SELECTED STORMWATER CHARACTERIZATION STUDIES PERFORMED IN THE STATE OF FLORIDA

REFERENCE	LOCATION OF STUDY AREA	LAND USE TYPE	PARAMETERS MEASURED	COMMENTS
Lopez, et al. (1984)	Tampa Bay, FL	A mixed-use urban watershed	General Parameters, Nutrients, Heavy Metals	Detailed study from 1975-1980 including streamflow, climate, physiographic and water quality data. Extremely detailed discussion of watershed characteristics. Data presented in both concentration and loading rate formats. Although land use is mixed, 3 of the 9 sites are approximately 70% residential which may be useful for single land use estimates.
Waller, et al. (1984)	Coral Gables, FL	1. Commercial, Residential, Highway 2. Residential	Nutrients, Metals	Sampled 3 runoff events during March and April 1982 using ponded water collected in a low area. Insufficient data for estimation of loading rates. Data given as concentrations only.
Miller (1985)	Broward/Dade Counties, FL	1. Residential 2. Highway 3. Commercial 4. Apartment	Nutrients, Suspended Solids, Lead	Gives percent entrainment curves for various rain events. No actual concentration data or loading rate information supplied.
Yousef, et al. (1985)	Orlando, FL	Interstate Highway (I-4)	General Parameters, Nutrients, Metals	Runoff collected from roadside swales during 17 storm events from 1982-1983 using automatic collection equipment. Data presented as both concentration and loading rates. Limited to highway land use only. Presents data on pollutant removal efficiencies of swales.
Harper, et al. (1985)	Sanford, FL	54 acres low-density residential area	General Parameters, Nutrients, Metals	Flow-weighted composite runoff samples collected for 22 storm events during 1984. Grass swales with raised inlets used for conveyance and treatment. Data presented as both concentration and loading rates. Detailed hydrologic and watershed information. Presence of swale drainage/treatment system limits usefulness for characterization data.
Harper (1985)	Orlando, FL	Highway runoff (ADT = 16,000) 4.0-acre watershed	Heavy Metals	Flow-weighted runoff samples collected at inlet to wet detention pond during 16 storm events from April 1983-May 1984 with a wide range of total rainfall and antecedent rainfall conditions. No pre-treatment. Data presented as concentration only. Detailed hydrologic and rain event characteristics provided. Data used to evaluate fate of heavy metals.
Martin, et al. (1985)	Orange County, FL	Mixed use basin: 33% forest, 27% urban roadway, 27% high-density residential, and 13% low-density residential	General Parameters, Nutrients, Metals	Study provides evaluation of performance efficiency of a detention pond-wetlands system. No actual characterization data provided.

TABLE 4-3 -- CONTINUED

SUMMARY OF SELECTED STORMWATER CHARACTERIZATION STUDIES PERFORMED IN THE STATE OF FLORIDA

REFERENCE	LOCATION OF STUDY AREA	LAND USE TYPE	PARAMETERS MEASURED	COMMENTS
Howie, et al. (1986)	Broward County, FL	Highway	Nutrients, Metals	A total of 12 storm events were sampled from May to November 1983. Samples were collected from swale flow and do not reflect direct runoff. Surficial aquifer also sampled.
Yousef, et al. (1986)	Orlando, FL	Interstate Highway (I-4)	General Parameters, Nutrients, Metals	Flow-weighted composite runoff samples collected over 13-month period in 1982-1983 using automatic equipment. Event mean concentrations given for measured parameters. Hydrologic data provided could be used to generate loading rates. Study limited to highway use only.
Fall (1987)	Upper St. Johns River Basin	222,486 acres of primarily agriculture (70% pasture, 5% row crops)	General Parameters, Nutrients, Metals	Collection of 58 pumped discharge samples from 9 pumps from 1982-1987. Pumped discharges were not necessarily related to storm events. Data summarized by concentration only. No hydrologic data given for direct conversion to loading rates.
Fall, et al. (1987)	Indian River County, FL	27,720 acres agricultural basin (22,000 acres of citrus, remainder in pasture and drainage works)	General Parameters, Nutrients, Pesticides	Samples of pumped agricultural discharge collected monthly from November 1984 to November 1985. Results given in terms of concentration only. No hydrologic data provided.
Hendrickson (1987)	Brevard County, FL	5681 acres agricultural area, row crops and rangeland	General Parameters, Nutrients, Pesticides	A total of 87 samples of pumped agricultural discharge were collected during August to December 1986. Data given as concentration only. Loading rates may be determined using hydrologic data given. This represents a ditched agricultural area.
Harper (1988)	Central Florida Area	1. Interstate Highway 2. Residential 3. Commercial	General Parameters, Nutrients, BOD, Solids, Metals	Runoff collected from 5 watersheds during 8-12 storm events per watershed in 1987. Data presented in concentration form with hydrologic information on each watershed. Also gives removal efficiencies for stormwater management systems associated with each watershed along with groundwater effects.
Whalen, et al. (1988)	Various Locations Around U.S.	All General Types	General Parameters, Nutrients, BOD, Heavy Metals, Organics	Excellent summary report of runoff studies conducted primarily in Florida. Also presents data on effectiveness of stormwater management systems for pollutant removal.
Greg, et al. (1989)	Boca Raton, FL	Medium-density, residential (32.4 acres with 37% impervious)	Nutrients, Suspended Solids	Six runoff events were collected from 1985 to January 1986 using automatic equipment. Study includes detailed hydrologic information. Data given as concentration only, but could be converted to loading rate with information provided.

TABLE 4-3 -- CONTINUED

SUMMARY OF SELECTED STORMWATER CHARACTERIZATION STUDIES PERFORMED IN THE STATE OF FLORIDA

REFERENCE	LOCATION OF STUDY AREA	LAND USE TYPE	PARAMETERS MEASURED	COMMENTS
Harper and Herr (1993)	DeBary, FL	Low-intensity commercial, 50.7-acre watershed	General Parameters, Nutrients, Metals	
Harper and Herr (1994)	Orange County, FL	Single-family homes on one-acre lots	General Parameters, Nutrients, BOD, Suspended Solids, Metals	Four runoff events were collected from October 1993 to February 1994. Study includes hydrologic information. Data given as both concentration and areal loading rates.
Bahk (1997)	Ruskin, FL	Agriculture – row crops 210-acre watershed	General Parameters, Nutrients, Metals	Total of 18 grab samples collected from drainage ditch from Feb. 1992-Sept. 1995. Data as concentration only. Even though collected as grab samples, large sample size gives data usefulness. No hydrologic data provided.
Rushton, et al. (1997)	Tampa, FL	Mixed land use; 30% rooftops and asphalt parking; 6% limestone storage; and 64% grassed storage	General Parameters, Nutrients, Metals	Flow-weighted samples of pond inflow collected during 1993-1994.
ERD (2000)	Bradfordville – Tallahassee, FL	Low-intensity commercial; asphalt parking areas; inlets and stormsewers; 8-acre drainage basin	General Parameters, Nutrients, Demand Parameters	Flow-weighted composite samples collected during 12 storm events from Feb.-May 1999. Detailed hydrologic evaluation.
ERD (2000)	Bradfordville – Tallahassee, FL	Evaluated 3 separate areas: 1. 1.0-acre highway site on 6-lane divided highway 2. 16.8-acre single-family residential 3. 7.5-acre rural residential	General Parameters, Nutrients, Demand Parameters	Flow-weighted composite samples collected during 11 events at highway site, 5 events at rural residential site, and 7 events at single-family residential site. Good hydrologic data provided.
City of Tallahassee and ERD (2002)	Tallahassee, FL	1. High-intensity commercial 2. Light industrial 3. Recreation/open space 4. Multi-family residential 5. Low-density residential 6. Single-family residential	Nutrients, Demand Parameters, Metals	Flow-weighted composite samples collected at six land use characterization sites during 73 events from May 1999-March 2002. Data used to develop and calibrate area-wide pollutant loading model.
Rushton (2002)	Cockroach Bay - Tampa, FL	210-acre row crop area	General Parameters, Nutrients, Metals	Total of 85 runoff samples collected from 1998-2001 using automatic refrigerated samplers. Also contains extensive rainfall quality data.

TABLE 4-3 -- CONTINUED

SUMMARY OF SELECTED STORMWATER CHARACTERIZATION STUDIES PERFORMED IN THE STATE OF FLORIDA

REFERENCE	LOCATION OF STUDY AREA	LAND USE TYPE	PARAMETERS MEASURED	COMMENTS
ERD (2004)	Orlando, FL	Single-family residential; 2 separate sub-basins: 52.9-acre and 19.4 acre	General Parameters, Nutrients, Demand Parameters	Flow-weighted composite samples collected during 25 storm events at one site and 8 events at the other site from June-Sept. 2003.
Rushton (2004)	Temple Terrace, FL	132.4-acre mixed use basin including high-intensity commercial, multi-family residential, and golf course	General Parameters, Nutrients, Metals, Bacteria	Data collected as part of performance evaluation for a CDS unit. Excellent hydrologic data. Extensive water quality data for both inflow and outflow.
Teague, et al. (2005)	Florida Aquarium – Tampa, FL	11.25-acre parking lot; combination of asphalt, cement, and pervious pavement	Nutrients, Metals	Flow-weighted samples collected during 56 storm events using refrigerated auto-sampler from 2000-2003.
ERD (2005) Unpublished Data	Orlando, FL	6.5-acre watershed centered along U.S. 441, 6-8 lane asphalt highway	General Parameters, Nutrients, Metals	Flow-weighted samples collected during 23 storm events using refrigerated auto-sampler from April-August 2004.
ERD (2007)	Winter Haven	43.9-acre basin with light industrial and warehouse land use	General Parameters, Nutrients	Flow-weighted samples collected during 10 storm events using auto-sampler from October 2005-March 2006.
ERD (2007)	Windermere	95.4-acre basin, single-family, dirt roads with grassed swales	General Parameters, Nutrients	Flow-weighted samples collected during 14 storm events using auto-sampler from October 2005-March 2006.

A large number of stormwater monitoring studies have been conducted within the State of Florida as part of the NPDES Program. Stormwater samples collected as part of this program are restricted to a well defined range of rainfall depths and antecedent dry period conditions. Although this information may be useful in comparing runoff characteristics between major metropolitan areas, the sampling protocols required by this program do not necessarily provide accurate estimates of the average annual runoff concentrations for a given pollutant discharging from various land use categories. These values can only be estimated by monitoring a wide range of rainfall depths and antecedent dry period conditions. As a result, data collected as part of the NPDES Program are not utilized to estimate runoff characteristics for the purposes of this evaluation.

Studies included in development of stormwater characterization data cover the period from 1977-2005. Runoff concentrations of many parameters appear to be relatively consistent for a particular land use over this period with the exception of lead. Concentrations of lead in studies conducted prior to 1980-1990 are generally much greater than post 1980-1990 studies, presumably due to reductions of lead content in gasoline over this same period. Recent research conducted by ERD indicates that concentrations of total lead in stormwater runoff measured since 1990 are substantially lower than values measured prior to 1990. Therefore, it is assumed that lead concentrations presented in pre-1990 studies are not representative of current conditions and are not included in estimation of mean runoff characteristics of lead.

In general, the objective of the literature review is to provide estimates of event mean concentrations (emc) for each study included in the stormwater characterization database. When applied on an annual basis, the event mean concentration is defined as follows:

$$emc = \frac{total\ \ annual\ \ pollutant\ \ load\ \ for\ a\ \ given\ \ parameter}{total\ \ annual\ \ runoff\ \ volume}$$

In essence, this value reflects a flow-weighted average concentration for a given parameter over an annual cycle. When the emc is multiplied by the estimated total annual runoff volume, it provides an estimate of the annual mass loading discharging from the evaluated land use category for a given pollutant.

4.1.2 Single-Family Residential

Single-family residential land use is defined as a typical detached home with lot sizes generally less than 1 acre and dwelling densities greater than 1 dwelling unit per acre. Duplexes constructed on one-third to one-half acre lots are also included in this category. This type of land use is characterized by a moderate degree of impervious area, generally ranging from approximately 20-40%. Hydrologic characteristics for the identified single-family residential stormwater characterization studies are given in Table B.1 (Appendix B). Watershed areas for the identified characterization studies range from 7.39-897 acres, with impervious percentages ranging from 6.1-65.0%.

A summary of mean stormwater characteristics from single-family residential stormwater studies is given in Table 4-4. Each of the studies included in Table 4-4 provide characterization data for total nitrogen and total phosphorus. However, nutrient concentrations measured at the Orlando Duplex site by Harper (1988) appear to be substantially elevated, particularly when compared with total phosphorus values measured at the remaining sites. The measured emc of 1.69 mg/l for total phosphorus at this site is a clear outlier in the data set and is not included in estimation of the mean emc values for total phosphorus. The total nitrogen emc of 4.62 mg/l at this site also appears to be elevated but is not a clear outlier value. Therefore, this value is retained for estimation of the mean emc for total nitrogen. Total nitrogen emc values range from 1.02-4.62 mg/l, with an overall mean of 2.07 mg/l. Total phosphorus emc values range from 0.102-0.510 mg/l, with an overall mean of 0.327 mg/l. All but one of the listed studies provides characterization data for BOD, with 13 of the 17 studies including information for TSS.

TABLE 4-4

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM SINGLE-FAMILY RESIDENTIAL STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	**TP**	**BOD**	**TSS**	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**
Pompano Beach	Mattraw, et al. (1981)	2.00	0.310	7.9	26.0	--	--	0.008	0.298	--	0.167[1]	0.086
Tampa - Charter Street	U.S. EPA (1983)	2.31	0.400	13.0	33.0	--	--	--	--	--	0.49[1]	0.053
Maitland (3 basins)	German (1983)	2.20	0.340	7.1	43.0	--	--	0.014	0.350	0.008	0.230[1]	0.016
St. Pete - Bear Creek	Lopez, et al. (1984)	1.50	0.200	4.7	--	--	--	0.009	--	--	0.128[1]	0.083
Tampa - Kirby Street	Lopez, et al. (1984)	2.20	0.250	4.5	--	--	--	--	--	--	0.050[1]	--
Tampa - St. Louis Street Ditch	Lopez, et al. (1984)	3.00	0.450	6.1	--	--	--	0.016	--	--	0.213[1]	0.133
Orlando Duplex	Harper (1988)	4.62	1.69[1]	9.5	63.2	0.005	0.015	0.033	0.464	0.020	0.058[1]	0.089
Orlando - Essex Pointe	Harper (1988)	1.85	0.20	6.5	30.1	0.002	0.017	0.027	0.420	0.029	0.132[1]	0.045
Springhill Subdivision, Palm Beach	Greg, et al. (1989)	1.18	0.307	--	3.5	--	--	--	--	--	--	--
Tampa - 102nd Avenue	Holtkamp (1998)	2.62	0.510	13.4	36.8	--	--	0.019	--	--	0.005	0.060
Bradfordville, FL	ERD (2000)	1.30	0.280	2.7	57.1	--	--	--	--	--	--	--
Key Colony, Florida Keys	ERD (2002)	1.20	0.281	2.0	26.9	0.0015	0.0025	0.010	0.067	--	0.001	0.020
Tallahassee - Woodgate Subdivision	COT and ERD (2002)	1.29	0.505	15.0	76.0	--	--	0.007	--	--	0.007	0.039
Sarasota County	ERD (2004)	1.17	0.506	4.4	10.1	--	--	--	--	--	--	--
Orlando - Krueger St.	ERD (2004)	3.99	0.182	17.1	41.8	--	--	--	--	--	--	--
Orlando - Paseo Street	ERD (2004)	1.02	0.102	4.0	12.0	--	--	--	--	--	--	--
Windermere	ERD (2007)	1.69	0.402	--	65.0	--	--	--	--	--	--	--
Overall Mean Value		**2.07**	**0.327**	**7.9**	**37.5**	**0.003**	**0.012**	**0.016**	**0.320**	**0.019**	**0.004**	**0.062**

1. Data not included in calculation of mean value

Heavy metal characterization data from the residential land use studies is relatively limited, with the greatest amount of data available for copper, lead, and zinc. However, as discussed in Section 4.1.1, lead concentrations measured prior to 1990 are excluded from estimation of overall mean concentrations, substantially reducing the available data set for this parameter.

As seen in Table B.1, five of the 17 stormwater characterization sites utilize grassed swales exclusively for conveyance of stormwater runoff, while seven of the stormwater characterization sites use curb and gutter systems exclusively. The remaining sites use a combination of swale and curb and gutter systems. A comparison of runoff characteristics for residential sites utilizing grassed swales and curb/gutter drainage systems is given in Table 4-5. With the exception of total phosphorus, runoff characteristics collected from residential areas utilizing grassed swales appear to be substantially lower in value than observed for characterization sites utilizing curb and gutter systems. Overall, runoff collected from grassed swale drainage systems was approximately 38% lower for concentrations of total nitrogen, 48% lower for BOD, 46% lower for TSS, 47% lower for copper, and 23% lower for zinc than mean values measured at monitoring sites which utilized curb and gutter systems.

An analysis of variance comparison was conducted between the two data sets to determine if the observed differences in runoff concentrations between grassed swales and curb/gutter sites are statistically significant. This analysis was conducted only for total nitrogen, total phosphorus, BOD, TSS, copper, and zinc due to the limited data sets available for the other parameters. None of the differences in concentrations were found to be significant at a 95% probability level. However, the observed differences in total nitrogen concentrations were found to be statistically different at a 91% probability level, with a 77% probability level for significant differences in BOD concentrations, a 86% probability level for significant differences in TSS concentrations, and a 75% probability level for significant differences in copper concentrations. However, the overall number of data points available for this analysis is limited which makes detection of significant differences between the data sets more difficult.

TABLE 4-5

COMPARISON OF RUNOFF CHARACTERISTICS FOR RESIDENTIAL AREAS UTILIZING GRASSED SWALES AND CURB / GUTTER DRAINAGE SYSTEMS

a. Grassed Swales

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	TP	BOD	TSS	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Pompano Beach	Mattraw, et al. (1981)	2.00	0.310	7.9	26.0	--	--	0.008	0.298	--	0.167[1]	0.086
Palm Beach -Springhill Subdivision	Greg, et al. (1989)	1.18	0.307	--	3.5	--	--	--	--	--	--	--
Florida Keys- Key Colony	ERD (2002)	1.20	0.281	2.0	26.9	0.002	0.003	0.010	0.067	--	0.001	0.020
Sarasota County	ERD (2004)	1.17	0.506	4.4	10.1	--	--	--	--	--	--	--
Windermere	ERD (2007)	1.69	0.402	--	65.0	--	--	--	--	--	--	--
Overall Mean Value		**1.45**	**0.361**	**4.8**	**26.3**	**0.002**	**0.003**	**0.009**	**0.183**	**--**	**0.001**	**0.053**

b. Curb and Gutter

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	TP	BOD	TSS	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Tampa - Kirby Street	Lopez, et al. (1984)	2.20	0.250	4.5	--	--	--	--	--	--	0.050[1]	--
Tampa - St. Louis Street Ditch	Lopez, et al. (1984)	3.00	0.450	6.1	--	--	--	0.016	--	--	0.213[1]	0.133
Orlando - Essex Pointe	Harper (1988)	1.85	0.200	6.5	30.1	0.002	0.017	0.027	0.420	0.029	0.132[1]	0.045
Tampa - 102nd Avenue	Holtkamp (1998)	2.62	0.510	13.4	36.8	--	--	0.019	--	--	0.005	0.060
Bradfordville, FL	ERD (2000)	1.30	0.280	2.7	57.1	--	--	--	--	--	--	--
Tallahassee - Woodgate Subdivision	COT and ERD (2002)	1.29	0.505	15.0	76.0	--	--	0.007	--	--	0.007	0.039
Orlando - Krueger St.	ERD (2004)	3.99	0.182	17.1	41.8	--	--	--	--	--	--	--
Overall Mean Value		**2.32**	**0.340**	**9.3**	**48.4**	**0.002**	**0.017**	**0.017**	**0.420**	**0.029**	**0.006**	**0.069**

1. Value not included in calculation of mean value

4.1.3 Multi-Family Residential

Multi-family residential land use consists primarily of apartments, condominiums, and cluster homes. In general, this land use contains a large degree of impervious surface, with impervious percentages often in excess of 50%. A summary of hydrologic parameters from the six identified multi-family residential stormwater characterization studies is given in Table B.2. Watershed areas for the selected studies range from 8.7-73.3 acres, with impervious percentages ranging from 61-74%. Each of these monitoring sites utilizes underground stormsewer systems.

A summary of mean stormwater emc values from multi-family residential stormwater studies is given in Table 4-6. Each of the six listed studies provides characterization data for total nitrogen and total phosphorus, with five of the studies also providing information on BOD and TSS. Information on heavy metals is extremely limited for this land use category, with mean values provided only for copper, lead, and zinc. Studies performed prior to 1990 are not included in estimation of mean values for lead concentrations.

In general, mean concentrations for total nitrogen, total phosphorus, BOD, and TSS from the multi-family studies are higher in concentration than mean values obtained from the single-family residential studies. The increases in runoff characteristics observed in multi-family residential areas are expected due to the larger degree of impervious area and the higher level of activity.

TABLE 4-6

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM MULTI-FAMILY RESIDENTIAL STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	TP	BOD	TSS	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Orlando - Shoals Apartments	ECFRPC (1978)	1.91	0.51	7.8	143	--	--	--	--	--	0.341[1]	--
Miami - Kings Creek Apartments	Miller (1979)	2.57	0.45	14.5	36.8	--	--	--	--	--	0.054[1]	0.059
Loch Lomond	Weinburg, et al. (1980)	1.91	0.73	--	--	--	--	--	--	--	--	--
Orlando - Downtown	Wanielista, et al. (1982)	4.68	0.72	10.1	95.6	--	--	--	--	--	--	--
Tampa - Young Apartments	U.S. EPA (1983)	1.61	0.33	16.0	53.0	--	--	--	--	--	0.076[1]	0.060
Tallahassee - Royal Pavilion Apartments	COT and ERD (2002)	1.22	0.380	8.0	61.0	--	--	0.009	--	--	0.006	0.138
Overall Mean Value		**2.32**	**0.52**	**11.3**	**77.8**	--	--	**0.009**	--	--	**0.006**	**0.086**

1. Data not included in calculation of mean value

4.1.4 Low-Density Residential (Rural)

Low-density residential land use is defined as a rural type community with lot sizes generally greater than one acre and less than one dwelling unit per acre. These areas are typically characterized by low traffic volumes and runoff coefficients along with relatively low pollutant loading rates. The majority of these land areas are pervious surfaces covered by grass or wooded areas with only a small percentage of impervious area.

Low-density rural residential land use is the only general land use category for which specific loading rate studies were not found during the literature search. However, this type of land use is basically a mixture of the categories of single-family residential and open space since vegetated areas in the low-density category are often left in a natural condition typical of open spaces. Therefore, for purposes of this evaluation, runoff characteristics for low-density residential areas are estimated as the arithmetic mean of the mean values for single family residential (Table 4-4 and open space (Table 4-12).

4.1.5 Low-Intensity Commercial Areas

For the purposes of this evaluation, the term intensity refers to the level of use of the commercial area rather than an indication of the type of business or density of development. Low-intensity commercial areas are defined as areas which receive only a moderate amount of traffic volume and where cars may be parked during the day for extended periods of time. Since most commercial activities themselves generate relatively little pollutant loading, the majority of pollutant deposition occurs as a result of automobiles and trucks operating within the commercial area. Low-intensity commercial areas include schools, churches, professional office sites, and small shopping centers. High-intensity commercial areas include downtown business districts and large regional shopping areas.

A summary of hydrologic characteristics from low-intensity commercial stormwater characterization studies is given in Table B.3. Nine separate studies were identified in the available literature, with watershed areas ranging from 2.17-50.70 acres. Percentage imperviousness for the commercial sites range from 60% to approximately 100%. Eight of the nine studies utilize curb and gutter stormsewer systems, with swales utilized for drainage conveyance at the Florida Aquarium site.

A summary of mean stormwater emc values from low-intensity commercial stormwater studies is given in Table 4-7. Characterization data for total nitrogen, total phosphorus, and TSS are provided for each of the nine studies, with eight of the nine studies providing characterization data for BOD. As observed in previous land use categories, characterization data for heavy metals is somewhat limited. In general, low-intensity commercial areas are characterized by relatively low levels of total nitrogen, total phosphorus, and BOD, although TSS concentrations are somewhat elevated. Runoff characteristics reported by Harper and Herr (1993) are not included in calculation of the mean value since the runoff in this study received pre-treatment in a vegetated swale prior to collection.

TABLE 4-7

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM LOW-INTENSITY COMMERCIAL STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	TP	BOD	TSS	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Orlando Areawide Study[1]	ECFRPC (1978)	0.89	0.16	3.6	146	--	--	--	--	--	0.068[2]	--
Ft. Lauderdale - Coral Ridge Mall	Miller (1979)	1.10	0.10	5.4	45.0	--	--	0.015	--	--	0.387[2]	0.128
Tampa - Norma Park	U.S. EPA (1983)	1.19	0.15	12.0	22.0	--	--	--	--	--	0.046[2]	0.037
Orlando - International Market Place	Harper (1988)	1.53	0.19	11.6	111	0.008	0.013	0.031	1.10	0.028	0.136[2]	0.168
DeBary[3]	Harper and Herr (1993)	0.761	0.260	6.9	79.1	0.0005	0.003	0.010	0.582	--	0.009	0.028
Bradfordville	ERD (2000)	2.14	0.160	9.0	38.3	--	--	--	--	--	--	--
Tallahassee - Cross Creek Shopping Center	COT and ERD (2002)	0.925	0.15	8.0	15.0	--	--	0.008	--	--	0.002	0.045
Sarasota County	ERD (2004)	0.88	0.31	4.3	39.9	--	--	--	--	--	--	--
Florida Aquarium - Tampa	Teague, et al. (2005)	0.761	0.215	--	42.4	0.003	--	0.019	1.17	--	0.008	0.090
Overall Mean Value		**1.18**	**0.179**	**7.7**	**57.5**	**0.006**	**0.013**	**0.018**	**1.14**	**0.028**	**0.005**	**0.094**

1. Average of studies performed on a parking lot, motel complex, and commercial strip development
2. Data not included in calculation of mean value
3. Values excluded from means due to swale pre-treatment

4.1.6 High-Intensity Commercial Areas

High-intensity commercial land use consists of commercial areas with high traffic volume and relatively constant traffic moving into and out of the area. For purposes of this evaluation, high-intensity commercial areas include downtown business districts and large regional shopping areas. This land use category is typically characterized by a high degree of imperviousness, with values often in excess of 90%.

A summary of hydrologic characteristics from high-intensity commercial stormwater studies in Florida is given in Table B.4. Watershed sizes for the characterization studies range from 28-83 acres, with impervious percentages ranging from 96.4-98%. Four separate studies were obtained from the literature search which includes a regional shopping mall, a downtown commercial area, and commercial areas with heavy traffic volume.

A summary of mean stormwater emc values from high-intensity commercial stormwater studies is given in Table 4-8. Each of the four studies provides characterization data for total nitrogen and total phosphorus, while only half of the studies provide characterization data for BOD and TSS. Each of the studies also provides characterization information for lead and zinc, although all of the studies which provide data for lead were performed prior to 1990 and not useful for estimating current lead characteristics in runoff. As seen in Table 4-8, runoff characteristics from high-intensity commercial areas are substantially higher for virtually all evaluated parameters than observed in the low-density commercial studies.

TABLE 4-8

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM HIGH-INTENSITY COMMERCIAL STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	TP	BOD	TSS	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Broward County	Mattraw, et al. (1981)	1.10	0.10	5.4	45.0	0.009	--	0.015	0.334	--	0.387[1]	0.128
Orlando - Downtown Area	Wanielista (1982)	2.81	0.31	17.2	94.3	--	--	--	--	--	0.560[1]	0.165
Dade County	Waller (1984)	3.53	0.82	--	--	--	--	--	--	--	0.187[1]	0.183
Broward County	Howie, et al. (1986)	2.15	0.15	--	--	--	--	--	--	--	0.241[1]	0.162
Overall Mean Value		**2.40**	**0.345**	**11.3**	**69.7**	**0.009**	**--**	**0.015**	**0.334**	**--**	**--**	**0.160**

1. Data not included in the calculation of mean value

4.1.7 Light Industrial

Information concerning stormwater characterization data from light industrial areas is very limited in the existing literature. Only three studies could be identified which specified industrial park land use. Two of these studies were performed during the 1980s, with the final study performed during 2002.

A summary of hydrologic characteristics from the industrial stormwater studies is given in Table B.5. Watershed area and percent impervious area are not available for two of the three studies, with only impervious percentage provided for the final study.

A summary of emc values from industrial land use areas is given in Table 4-9. In general, industrial areas are characterized by relatively low concentrations of total nitrogen and BOD, with more elevated concentrations of total phosphorus and TSS.

TABLE 4-9

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM LIGHT INDUSTRIAL STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	TP	BOD	TSS	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Orlando Areawide Study	ECFRPC (1985)	1.42	0.31	9.1	102	--	--	--	--	--	--	--
Manatee County Southeast Area Study	CDM (1985)	1.18	0.15	--	--	--	--	--	--	--	--	--
Tallahassee	COT and ERD (2002)	1.09	0.090	6.0	18.0	--	--	0.003	--	--	0.002	0.057
Winter Haven	ERD (2007)	1.10	0.488	5.3	75.7	--	--	--	--	--	--	--
Overall Mean Value		**1.20**	**0.260**	**6.8**	**65.2**	**--**	**--**	**0.003**	**--**	**--**	**0.002**	**0.057**

1. Data not included in the calculation of mean value

4.1.8 Highway/Transportation

Highway/transportation land use consists primarily of major highway systems, such as interstate highways, expressways, and major state and federal highway systems. In general, highway systems included under this category are considered to be heavily traveled, with constant traffic movement throughout the day. This land use category is typically characterized by a high degree of imperviousness.

A summary of hydrologic information from highway/transportation stormwater characterization studies is given in Table B.6. Eleven runoff characterization studies were identified in the literature review, with watershed areas ranging from 1.3-58.3 acres and impervious percentages ranging from 36-100%. Approximately half of the studies represent interstate highway systems, with the remaining studies reflecting major 4- or 6-lane highways. All of the systems provide drainage by curb and gutter systems.

A summary of emc values from highway/transportation stormwater studies is given in Table 4-10. Each of the 11 studies provides information for total nitrogen and total phosphorus, with five studies providing information for BOD and eight studies providing information for TSS. A relatively large number of the studies also included measurements of heavy metals, including cadmium, chromium, copper, iron, nickel, lead, and zinc. In general, highway/ transportation stormwater appears to have moderate levels of total nitrogen, total phosphorus, and TSS, with a relatively low level for BOD. Stormwater concentrations of copper and zinc appear to be somewhat elevated compared with concentrations measured in other land use categories.

TABLE 4-10

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM HIGHWAY / TRANSPORTATION STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	TP	BOD	TSS	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Broward County (6-lane)	Mattraw, et al. (1981)	0.96	0.08	9.0	15.0	0.007	--	0.007	0.207	--	0.282[1]	0.090
I-95 Miami (Bridge)	McKenzie, et al. (1983)	3.20	0.16	--	42.0	0.001	0.010	0.040	--	--	0.590[1]	0.330
Maitland	German (1983)	1.30	0.240	--	27.0	--	--	0.012	0.350	0.009	0.092[1]	0.055
I-4 Maitland Interchange	Harper (1985)	1.40	0.17	--	--	0.0025	0.004	0.038	0.341	0.003	0.163[1]	0.071
Maitland Blvd.	Yousef, et al. (1986)	1.40	0.17	--	--	0.0022	0.004	0.039	0.354	0.004	0.181[1]	0.074
I-4 EPCOT Interchange	Yousef, et al. (1986)	3.16	0.42	--	--	0.0016	0.003	0.024	0.205	0.003	0.026[1]	0.024
Winter Park I-4	Harper (1988)	1.60	0.23	6.9	34.0	0.008	0.013	0.050	1.120	0.046	0.224[1]	0.170
Orlando I-4	Harper (1988)	2.15	0.550	4.2	66.5	0.008	0.014	0.067	1.450	0.020	0.343[1]	0.272
Bayside Bridge - Tampa	Stoker (1996)	1.10	0.10	--	20.0	0.0001	0.003	0.008	0.530	0.003	0.011	0.050
Tallahassee	ERD (2000)	1.10	0.166	1.9	70.6	--	--	--	--	--	--	--
Orlando - U.S. 441	ERD (2005) - unpublished data	0.683	0.085	4.2	23.1	--	--	--	--	--	--	--
Overall Mean Value		**1.64**	**0.22**	**5.2**	**37.3**	**0.004**	**0.007**	**0.032**	**0.570**	**0.013**	**0.011**	**0.126**

1. Data not included in calculation of mean value

The mean stormwater characteristics summarized in Table 4-10 are intended for use only where highway/transportation is the dominant land use category in a particular area. As indicated previously, stormwater characteristics summarized in this table are most appropriate for expressways, interstate highway systems, and heavily traveled roadways. Roadways associated with other land use categories, such as residential, commercial, industrial, agriculture, open space, and mining/extractive, are included in the stormwater characteristics presented for each of these categories. Therefore, roadway areas for these land use types should not be evaluated separately since runoff generated on the roadway surfaces is mixed with runoff generated from the dominant land use category.

4.1.9 Agricultural Areas

Agricultural land use within Florida is extremely varied, both in terms of agricultural activities and soil types. Agricultural activities such as cattle grazing and row crops are commonly conducted on poorly drained soils which are characterized by a relatively high runoff potential. Citrus, however, requires well drained soils with a much lower runoff potential than those typically associated with grazing or row crop activities. For these reasons, a wide range of agricultural uses and characteristics must be considered to obtain representative emc values appropriate for specific agricultural activities. For purposes of this analysis, agricultural activities in Florida are divided into three primary categories, including pasture land, citrus, and row crops. Sufficient characterization data currently exists within the literature to provide separate runoff characteristics for each of these three categories.

4.1.9.1 Pasture Land Use

Three separate studies were identified in the literature review which provide runoff characterization data for pasture land use. A summary of hydrologic characteristics from these pasture land use studies is given in Table B.7. Watershed sizes for the evaluated areas range from 21.6-155,741 acres. Each of the three study sites occurred on relatively poorly drained soils.

A summary of emc values from pasture land use studies is given in Table 4-11. Runoff characterization data is provided in each of the three studies for total nitrogen and total phosphorus, with BOD and TSS provided in two of the three studies. Measurement of heavy metal concentrations was not conducted in any of the studies. In general, pasture land use appears to have runoff concentrations for total nitrogen, total phosphorus, and TSS which are substantially greater than concentrations observed in residential or commercial areas.

TABLE 4-11

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM PASTURE LAND USE STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)			
		TN	TP	BOD	TSS
St. Cloud	CH2M Hill (1977)	5.57	0.88	7.0	180
St. Johns River Basin	Fall (1987)	2.48	0.27	3.2	8.6
Ash Slough	Hendrickson (1987)	2.37	0.697	--	--
Overall Mean Values		**3.47**	**0.616**	**5.1**	**94.3**

A relatively large degree of variability appears to exist between runoff concentrations from the three pasture land use areas. These differences are particularly apparent in the measured runoff concentrations for total nitrogen, total phosphorus, and TSS in the St. Cloud study. The studies performed in the St. Johns River Basin and in Ash Slough present hydrologic and water quality data at the farm boundaries after transport through conveyance systems to the point of discharge from the farm. These measured values reflect the effects of pollutant uptake and attenuation during travel through conveyance systems such as canals or on-site detention ponds. This type of value is more representative of runoff characteristics which actually discharge from large farm basin areas.

However, the St. Cloud study represents water quality data measured directly as runoff from the field area prior to entering adjacent canals and ditches and, as a result, does not include pollutant uptake and deposition of suspended solids and nutrients within conveyance systems located within the farm. As a result, the total nitrogen, total phosphorus, and TSS values obtained at this site are substantially greater than those obtained at the other sites. Nevertheless, this value is included in estimation of mean values for pasture land use to account for pasture areas that discharge rapidly into off-site drainage systems.

4.1.9.2 Citrus Land Use

Seven runoff characterization studies involving citrus land use were identified during the literature review. Soil types represented in these studies are generally poorly drained soils, consisting of fine grain sands, peat, or muck. The water table elevations in most of these studies was controlled by furrows and lateral ditches to keep the root zone of the plants dry. A summary of hydrologic characteristics from the citrus land use studies is given in Table B.8. Watershed sizes included in the land use characterization studies range from 184-56,868 acres. Studies included in this category were conducted from 1987-1997.

A summary of emc values from the citrus land use studies is given in Table 4-12. Each of the seven studies provides characterization data for total nitrogen and total phosphorus, with two studies providing data for BOD, and five studies providing studies for TSS. Information on heavy metal characteristics from citrus land uses is extremely limited. In general, citrus land use appears to have moderate concentrations for total nitrogen and total phosphorus, with relatively low concentrations for BOD, TSS, and heavy metals.

TABLE 4-12

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM CITRUS LAND USE STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)								
		TN	TP	BOD	TSS	Cd	Cr	Cu	Pb	Zn
St. Johns River Basin (Citrus/Row)	Fall (1987)	3.26	0.24	3.0	28.0	--	--	--	--	--
St. Johns Water Control District (Citrus/Pasture)	Fall, et al. (1987)	1.33	0.09	2.1	4.6	--	--	--	--	--
Armstrong Slough (Citrus/Pasture)	Hendrickson (1987)	1.57	0.09	--	--	--	--	--	--	--
Upper St. Johns River Basin	Fall (1990)	2.72	0.16	--	23.3	--	--	0.004	--	--
Gator Slough (Hendry/Collier Counties)	Sawka and Black (1993)	3.32	0.170	--	--	--	--	0.002	--	--
Upper St. Johns River Basin	Fall (1995)	2.31	0.45	--	20.1	--	--	--	--	--
Charlotte/DeSoto Counties (4 sites)	Bahk and Kehoe (1997)	1.15	0.08	--	1.69	0.0004	0.001	--	0.001	0.012
Overall Mean Values		**2.24**	**0.183**	**2.55**	**15.5**	**0.0004**	**0.001**	**0.003**	**0.001**	**0.012**

4.1.9.3 Row Crops Land Use

Eight separate studies were identified in the literature which provide stormwater characterization data for row crop activities. A summary of hydrologic characteristics from row crop stormwater studies in Florida is given in Table B.9. Watershed areas included in these studies range from 12-5680 acres, although half of the sites did not include information on the watershed area. Soil types included in the areas are a combination of sand and muck soils. Studies included for characterization of row crops were performed from 1987-2002.

A summary of emc values from row crop stormwater studies is given in Table 4-13. Each of the eight studies provide characterization data for total nitrogen and total phosphorus, with five of the studies providing information for TSS, and none of the studies providing information for BOD. Information on heavy metal characteristics is included in three of the eight studies. In general, nutrient concentrations measured in row crop areas appear to be similar to those observed in pasture land use areas, although measured TSS concentrations in row crop areas appear to be substantially lower than those observed in pasture areas.

TABLE 4-13

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM ROW CROP STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)										
		TN	TP	BOD	TSS	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Willowbrook Farms	Hendrickson (1987)	2.68	0.562	--	--	--	--	--	--	--	--	--
Upper St. Johns River Basin	Fall (1987)	3.26	0.24	--	--	--	--	--	--	--	--	--
Upper St. Johns River Basin	Fall (1990)	4.73	0.43	--	37.4	--	--	--	--	--	--	--
Upper St. Johns River Basin	Fall (1995)	3.36	1.07	--	32.4	--	--	--	--		--	
Manatee County (5 sites)	Bahk, et al. (1997)	1.45	0.500	--	7.0	0.0001	0.001	0.011	--	--	0.0008	0.017
Cockroach Bay (Ruskin, FL)	Bahk (1997)	1.57	0.51	--	--	0.0003	0.004	0.035	0.160	BDL	0.008	0.052
Upper St. Johns River Basin (3 sites)	Hendrickson (unpublished data)	2.26	0.163	--	4.9	--	--	--	--	--	--	--
Cockroach Bay (Ruskin, FL)	Rushton (2002)	1.85	1.265	--	17.4	0.0003	--	0.019	0.934	--	0.002	0.020
Overall Mean Values		**2.65**	**0.593**	**--**	**19.8**	**0.0002**	**0.003**	**0.022**	**0.547**	**BDL**	**0.004**	**0.030**

4.1.9.4 Comparison of Agricultural Characteristics

A comparison of emc values from pasture, citrus, and row crop agricultural activities is given in Table 4-14. Pasture land use appears to have the largest mean concentration for total nitrogen, total phosphorus, and TSS. The lowest concentrations for these parameters occur for citrus land use.

A category of general agriculture is also included in the final row of Table 4-14. This category simply reflects the arithmetic mean of the listed characteristics for pasture, citrus, and row crop activities and is intended as a generic representation of agricultural activities for use in studies where information on specific agricultural activities is not known.

TABLE 4-14

COMPARISON OF STORMWATER CONCENTRATIONS FROM AGRICULTURAL ACTIVITIES IN FLORIDA

LAND USE	MEAN emc VALUE (mg/l)			
	TN	TP	BOD	TSS
Pasture	3.47	0.616	5.1	94.3
Citrus	2.24	0.183	2.55	15.5
Row Crops	2.65	0.593	--	19.8
General Agriculture[1]	2.79	0.431	3.8	43.2

1. Mean of pasture, citrus, and row crop land uses

4.1.10 <u>Undeveloped/Rangeland/Forest Land Use</u>

The category of undeveloped/rangeland/forest land use includes open spaces and undeveloped land occupied by native vegetation, forests, and rangeland. These areas are typically characterized by little or no impervious area and a relatively low runoff potential throughout most of the year.

Five separate runoff characterization studies were identified which measured undeveloped, rangeland, or forest land use areas. A summary of hydrologic characteristics from these studies is given in Table B.10. The evaluated studies range from Tallahassee to Miami. However, information on watershed area is not provided for any of the studies since delineation of watersheds for natural areas is often difficult. Land use in the evaluated studies includes flatwood, rangeland, open spaces, and forests, and studies were conducted over the years from 1977-2004.

A summary of emc values from the undeveloped, rangeland, and forest stormwater studies is given in Table 4-15. Each of the five studies provides characterization data for total nitrogen and total phosphorus, with three studies providing data for BOD, and four studies providing data for TSS. Heavy metal characteristics for copper, lead, and zinc are included in only one study. In general, undeveloped, rangeland, and forest land uses are characterized by relatively low concentrations for each of the available parameters summarized in Table 4-15.

TABLE 4-15

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM UNDEVELOPED / RANGELAND / FOREST STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)						
		TN	TP	BOD	TSS	Cu	Pb	Zn
Orlando ECFRPC	CH2M Hill (1977)	1.52	0.10	1.7	18.5	--	--	--
Miami	Waller (1982)	0.90	0.02	--	4.8	--	--	--
Boggy Creek Study	ECFRPC (1988)	1.47	0.07	--	--	--	--	--
Sarasota/Charlotte Counties	ERD (2004)	0.703	0.031	1.0	1.9	--	--	--
Overall Mean Value		**1.15**	**0.055**	**1.4**	**8.4**	**--**	**--**	**--**

1. Data not included in calculation of mean value

4.1.11 Mining/Extractive Land Use

The category of mining/extractive land use includes a wide variety of mining activities for resources such as phosphate, sand, gravel, clay, and shell. Very little information is available in the current literature concerning the runoff characteristics of this land use type with the exception of site-specific studies generated as a result of water quality violations and enforcement actions. The only reference which provides runoff characterization data for mining/extractive land use is the Boggy Creek Study by the East Central Florida Regional Planning Council (ECFRPC) in 1988. This study assumes that very little pollution is generated from the actual mining operation, and runoff characteristics primarily reflect contributions from access roads, parking areas, and office sites. This assumption appears reasonable for many types of mining activities which generally extract materials from isolated pit areas. A summary of hydrologic data from the ECFRPC study is given in Table B.11. Although the watershed size is not presented in the study, the percentage of impervious area is estimated to be 23%.

A summary of stormwater emc values from mining/extractive land use studies is given in Table 4-16. Information is provided in the Boggy Creek study only for total nitrogen and total phosphorus, with a mean total nitrogen concentration of 1.18 mg/l and a mean total phosphorus concentration of 0.15 mg/l.

TABLE 4-16

SUMMARY OF MEAN STORMWATER CHARACTERISTICS FROM MINING / EXTRACTIVE STORMWATER STUDIES

LOCATION	REFERENCE	MEAN emc VALUE (mg/l)						
		TN	TP	BOD	TSS	Cu	Pb	Zn
Boggy Creek Study	ECFRPC (1988)	1.18	0.15	--	--	--	--	--
Overall Mean Value		**1.18**	**0.15**	--	--	--	--	--

1. Data not included in calculation of mean value

4.1.12 Wetlands

Land uses assigned to the category of wetlands include a wide range of diverse wetland types, such as hardwood wetlands, cypress stands, grassed wetlands, and mixed wetland associations. Wetland systems are routinely included in ongoing monitoring efforts, and wetland characterization data is available throughout the State of Florida for a variety of wetland types.

When wetland characterization data is required, it is best to obtain regionally-specific data for the type of wetland system being evaluated. Wetland characterization is available through STORET, water management districts, FDEP, and local governmental monitoring agencies.

The hydrology of wetlands can be extremely complex, varying from flow-through wetlands which discharge throughout much of the year, to depressional wetlands which discharge infrequently. When including wetlands in pollutant loading evaluations, the site-specific hydrologic characteristics of the wetlands under evaluation must be considered. As a result of the complexities of wetland systems, guidelines concerning representative concentrations and hydrologic characteristics of wetlands are not included in this analysis.

4.1.13 Open Water/Lakes

The final land use category, open water/lakes, consists of open waterbodies such as lakes, reservoirs, streams, and rivers. Pollutant concentrations from these sources are a result of discharges from the waterbody during and following rain events. The discharge from the waterbody is a mixture of runoff contributed from the surrounding watershed and the ambient water quality characteristics of the waterbody. Waterbodies often provide pollutant attenuation for watershed areas which are tributary to the waterbody.

Characterization data is currently available for a large number of waterbodies located within the State of Florida. These data are easily available through STORET, the LAKEWATCH Program at the University of Florida, water management districts, FDEP, and local governmental agencies. In many cases, specific water quality data may be available for larger waterbodies which may be included in a pollutant loading analysis. Due to the abundant availability of site-specific data, recommendations on representative water quality characteristics for open water/lake land uses are not provided in this analysis.

4.1.14 Recommended Characterization Data

A summary of literature-based runoff characterization data for general land use categories in Florida is given in Table 4-17 based upon the information provided in the previous sections. The values summarized in this table represent the mean emc values for each of the general land use categories discussed previously.

In general, the data summarized in Table 4-17 reflect a pattern of increasing runoff concentrations with increasing land use intensity. Of the three types of residential land uses summarized in Table 4-17, the lowest emc values are associated with low-density residential. Increases in emc values occur when the land use intensity is increased to single-family residential, and further increases occur as the intensity is increased to multi-family. A similar pattern is apparent between low- and high-intensity commercial areas, with higher emc values reflected for high-intensity commercial areas for each of the listed parameters. Land use categories which are not expected to be a significant source of nitrogen or phosphorus loadings, such as industrial and highway areas, are characterized by relatively low concentrations for these parameters. In contrast, agricultural areas, which would be expected to have elevated concentrations of nutrients, are characterized by higher concentrations of nutrients, particularly for total phosphorus.

TABLE 4-17

SUMMARY OF LITERATURE-BASED RUNOFF CHARACTERIZATION DATA FOR GENERAL LAND USE CATEGORIES IN FLORIDA

LAND USE CATEGORY	TYPICAL RUNOFF CONCENTRATION (mg/l)						
	TOTAL N	TOTAL P	BOD	TSS	COPPER	LEAD	ZINC
Low-Density Residential[1]	1.61	0.191	4.7	23.0	0.008[4]	0.002[4]	0.031[4]
Single-Family	2.07	0.327	7.9	37.5	0.016	0.004	0.062
Multi-Family	2.32	0.520	11.3	77.8	0.009	0.006	0.086
Low-Intensity Commercial	1.18	0.179	7.7	57.5	0.018	0.005	0.094
High-Intensity Commercial	2.40	0.345	11.3	69.7	0.015	--	0.160
Light Industrial	1.20	0.260	7.6	60.0	0.003	0.002	0.057
Highway	1.64	0.220	5.2	37.3	0.032	0.011	0.126
Agricultural							
Pasture	3.47	0.616	5.1	94.3	--	--	--
Citrus	2.24	0.183	2.55	15.5	0.003	0.001	0.012
Row Crops	2.65	0.593	--	19.8	0.022	0.004	0.030
General Agriculture[2]	2.79	0.431	3.8	43.2	0.013	0.003	0.021
Undeveloped / Rangeland / Forest	1.15	0.055	1.4	8.4	--	--	--
Mining / Extractive	1.18	0.15	7.6[3]	60.0[3]	0.003[3]	0.002[3]	0.057[3]

1. Average of single-family and undeveloped loading rates
2. Mean of pasture, citrus, and row crop land uses
3. Runoff concentrations assumed equal to industrial values for these parameters
4. Value assumed to be equal to 50% of single-family concentration

The mean runoff characteristics summarized in Table 4-17 are recommended for use in general runoff characterization and loading studies within the State of Florida. However, in areas where more site-specific runoff characterization information is available, the site-specific data should be used instead of the generalized data summarized in Table 4-17.

Several assumptions were made in assigning runoff concentrations to provide a more complete database for the general land use categories. First, runoff characterization data was not available for copper, lead, or zinc in low-density residential land uses in the literature. Therefore, to provide estimates of runoff characteristics for these parameters, typical concentrations of copper, lead, and zinc in low-density residential areas are assumed to be equal to 50% of the mean values listed for single-family residential. Heavy metal concentrations were also not available for copper, lead, or zinc for mining/extractive land uses. As a result, runoff concentrations for these parameters in mining/extractive areas are assumed to be similar to concentrations observed in industrial areas. Pollutant contributions from mining activities are generated primarily from the movement of trucks and automobiles along access roads into and out of the site, as well as parking lots and garages. These activities are very similar to those occurring in industrial areas.

4.2 Estimation of Runoff Quantities

Estimates of annual and event-based runoff volumes were calculated to evaluate variability in regional runoff generation and the performance efficiencies of dry retention systems. These calculations were performed using the SCS (Soil Conservation Service) Curve Number Methodology and the historical rainfall data sets for meteorological sites discussed in Section 4.1. A discussion of the methodology and results of this modeling is given in the following sections.

4.2.1 Methodology

The SCS curve number methodology utilizes separate calculations for the runoff volume generated from directly connected impervious areas (DCIA) and non-DCIA areas. An impervious area is considered to be directly connected if runoff from the area flows directly into the drainage conveyance system, such as a gutter or stormsewer. Areas are also considered to be directly connected if runoff from the area occurs as a concentrated shallow flow that is conveyed through a pervious area, such as a roadside swale, and then into a drainage system. The SCS curve number method assumes that after allotting for initial abstraction, all rainfall which occurs on directly connected impervious areas becomes stormwater runoff.

Non-directly connected impervious areas (non-DCIA) include all pervious areas and portions of impervious areas which are not considered to be directly connected. The SCS model assumes that runoff generated in these areas has the opportunity to infiltrate into the soil, depending upon the soil types and land cover characteristics, before significant runoff volumes begin to be generated within the area. The runoff generating characteristics of non-DCIA areas are quantified through the use of a curve number (CN). A curve number is a hydrologic factor which is used to reflect the runoff potential of a particular land use and soil type. Theoretical values for curve numbers range from 0-100, with low values reflecting a low runoff potential and higher values reflecting a high runoff potential. Representative curve numbers can be obtained from a variety of sources, although the original source of these data was published by the Natural Resources Conservation Service (NRCS) as Technical Release 55 titled “Urban Hydrology for Small Watersheds” dated June 1986. This reference provides an extensive listing of curve numbers for different hydrologic soil groups and land use covers.

The TR 55 document divides soil groups within the United States into Hydrologic Soil Groups (HSG) which groups general soil types with respect to runoff-producing characteristics. A summary of the characteristics of the designated hydrologic soil groups, identified as A, B, C, and D, is given in Table 4-18. The primary consideration in assigning soils to the general soil group types is the inherent capacity of the bare soil to permit infiltration. Soils classified in HSG A consist primarily of deep sandy soils, with a high infiltration rate and a low runoff potential. The vast majority of rainfall which occurs in these areas is absorbed by infiltration and does not become stormwater runoff. Soils classified in HSG D consist of clayey-type soils or soils with a high organic content which exhibit a low infiltration rate and a high runoff potential. A large portion of the rainfall which occurs on soils in this classification ultimately becomes stormwater runoff.

TABLE 4-18

CHARACTERISTICS OF SCS HYDROLOGIC SOIL GROUP CLASSIFICATIONS

SOIL GROUP	DESCRIPTION	RUNOFF POTENTIAL	MINIMUM INFILTRATION RATE (inches/hour)
A	Deep sandy soils	very low	0.30-0.45
B	Shallow sandy soils	low	0.15-0.30
C	Sandy soil with high clay or organic content	medium to high	0.05-0.15
D	Clayey soils	very high	0.00-0.05

The SCS method calculates the runoff volume for a given rainfall event by adding the rainfall excess (runoff) from the non-DCIA portion to the rainfall excess created from the DCIA portion of the land use. Rainfall excess from the non-DCIA areas is calculated using the following set of equations:

$$nDCIA\ CN = \frac{CN * (100 - Imp) + 98\ (Imp - DCIA)}{(100 - DCIA)}$$

$$Soil\ \ Storage,\ S = \left(\frac{1000}{nDCIA\ CN} - 10\right)$$

$$Q_{nDCIA_i} = \frac{(P_i - 0.2S)^2}{(P_i + 0.8S)}$$

where:

CN	=	curve number for pervious area
Imp	=	percent impervious area
$DCIA$	=	percent directly connected impervious area
$nDCIA\ CN$	=	curve number for non-DCIA area
P_i	=	event rainfall
Q_{nDCIAi}	=	rainfall excess for non-DCIA for rainfall event

For the DCIA portion, rainfall excess is calculated using the following equation:

$$Q_{DCIA_i} = (P_i - 0.1)$$

When P_i is less than 0.1, Q_{DCIAi} is equal to zero. This factor reflects the initial abstraction for the impervious areas which assumes that the first 0.1 inch of rainfall is stored within the irregularities in the impervious surfaces and does not become stormwater runoff. After these surfaces become filled with the initial 0.1 inch of rainfall, additional rainfall begins to generate runoff on these surfaces.

One of the primary objectives of the hydrologic modeling efforts conducted by ERD is to evaluate the impact of the variability in probability distributions of individual rain events throughout the State of Florida, as discussed in Section 3.2, on rainfall/runoff relationships, as characterized by variabilities in modeled runoff coefficients. The impacts of variability in the sizes of individual rain events can best be evaluated using a continuous simulation hydrologic model which evaluates rainfall/runoff relationships over an extended period of time. However, this type of continuous modeling cannot be adequately conducted using rainfall data summarized on a daily basis. A portion of the 111 NCDC meteorological stations within the State of Florida also provide precipitation records which are summarized on an hourly basis. A listing of NCDC hourly precipitation monitoring stations in Florida is given in Table 4-19. Hourly precipitation data is available from 45 separate monitoring stations, with a period of hourly rainfall data ranging from 13-64 years.

All available hourly precipitation data was obtained for each of the 45 monitoring stations listed in Table 4-19. For each site, a continuous simulation was conducted of rainfall/runoff relationships using the entire record of hourly precipitation data for each site based on the SCS curve number method. This modeling included a mean of approximately 4685 individual rain events for each of the 45 monitoring stations. A location map for the 45 hourly precipitation monitoring sites is given on Figure 4-1.

The pervious area curve number values listed in engineering texts and reference manuals, used to estimate the amount of runoff lost due to infiltration into the soil during a rain event, reflect a "normal" antecedent moisture condition at the time of the rain event. These curve number values are commonly used for modeling design storm events (25- or 100-year storms) for developed areas where soil infiltration is a relatively insignificant loss in comparison with the overall volume of runoff generated during these design storm events. However, when performing continuous simulation modeling, the soil moisture condition at the time of the rain event can have a significant impact on the runoff volume generated from pervious areas. The Soil Conservation Service (SCS) has developed three antecedent soil moisture conditions to account for variability in runoff generation as a function of antecedent rainfall conditions. These three antecedent soil moisture conditions are labeled I, II, and III and are identified as follows:

Condition I:	Little significant rainfall during previous 5-day period; soils are dry
Condition II:	Average conditions
Condition III:	Heavy rainfall, or light rainfall and low temperatures have occurred within the past 5 days; soils are saturated

TABLE 4-19

LISTING OF NCDC HOURLY PRECIPITATION MONITORING STATIONS IN FLORIDA

STATION	NUMBER OF YEARS	NUMBER OF EVENTS	MEAN ANNUAL RAINFALL (inches)	MAXIMUM EVENT (inches)	MEAN EVENT (inches)
Apalachicola Municipal Airport (211)	49	5630	55.79	10.06	0.49
Crestview Radio WJSB (1984)	21	2700	64.16	11.20	0.50
Niceville (6240)	20	2112	62.74	12.00	0.59
Panacea 3 S (6828)	32	3137	58.62	12.19	0.60
Panama City 5 NE (6842)	35	3607	58.72	11.10	0.57
Pensacola Regional Airport (6997)	33	4165	62.17	13.93	0.49
Tallahassee Municipal Airport (8758)	45	5570	64.55	13.41	0.52
Avon Park 2 W (369)	27	2985	48.71	9.73	0.44
Branford (3543)	53	5644	52.27	11.89	0.49
Clewiston (1649)	35	3679	46.26	9.60	0.44
Deland 1 SSE (2229)	13	1527	53.95	11.30	0.46
Dowling Park 1 W (2391)	35	3468	51.42	9.00	0.52
Gainesville-Univ. of Florida (3316)	49	5162	50.04	8.69	0.48
Graceville 1 SW (3538)	32	3250	55.31	10.30	0.54
Kissimmee 2 (4625)	25	2747	45.85	15.62	0.42
Lakeland (4797)	53	6413	49.92	10.80	0.41
Leesburg (4980)	48	5071	48.03	8.77	0.45
Lynne (5237)	28	2936	48.97	7.80	0.47
Marineland (5391)	52	5336	47.04	10.85	0.46
Melbourne Regional Airport (5612)	47	5073	47.52	9.89	0.44
Moore Haven Lock 1 (5895)	43	4885	45.89	9.60	0.40
Orlando International Airport (6628)	62	7855	50.03	13.75	0.39
Raiford State Prison (7440)	30	3076	48.94	10.10	0.48
Tamiami Trail 40 mi (8780)	26	2968	52.13	9.20	0.46
Venus (9184)	39	4260	47.26	11.75	0.43
Woodruff Dam (9795)	27	2794	52.63	9.50	0.51
Key West WB City (4575)	63	8035	39.07	24.39	0.31
Lignumvitae Key (5035)	26	2521	40.92	8.30	0.42
Brooksville Chin Hil (1046)	50	5211	54.03	12.90	0.52
Cross City (2006)	47	4965	55.14	11.10	0.52
Daytona Beach Regional Airport (2158)	63	8019	49.61	11.46	0.39
Fort Myers-Page Field (3186)	28	3051	53.13	10.15	0.49
Inglis 3 E (4273)	48	4698	51.05	11.43	0.52
Jacksonville (4371)	64	8148	52.96	15.05	0.42
Lamont 6 WNW (4892)	45	4523	54.05	9.73	0.54
Parrish (6880)	44	4349	52.06	10.60	0.53
St. Leo (7851)	54	5619	52.90	11.84	0.51
St. Petersburg Whittd (7886)	45	4607	50.68	11.84	0.50
Tampa International Airport (8788)	47	5253	46.07	13.96	0.41
Vernon (9206)	16	1716	59.89	6.90	0.56
Boca Raton (845)	40	5527	60.10	14.00	0.43
Homestead Exp Stn (4091)	27	3687	58.39	18.00	0.43
Miami WSO City (5668)	64	10119	56.92	15.30	0.36
St. Lucie New Lock 1 (7859)	35	4688	54.82	10.66	0.41
West Palm Beach Intl Airport (9525)	64	10040	60.61	15.23	0.39
Mean:	**40.6**	**4685**	**52.70**	**11.66**	**0.47**

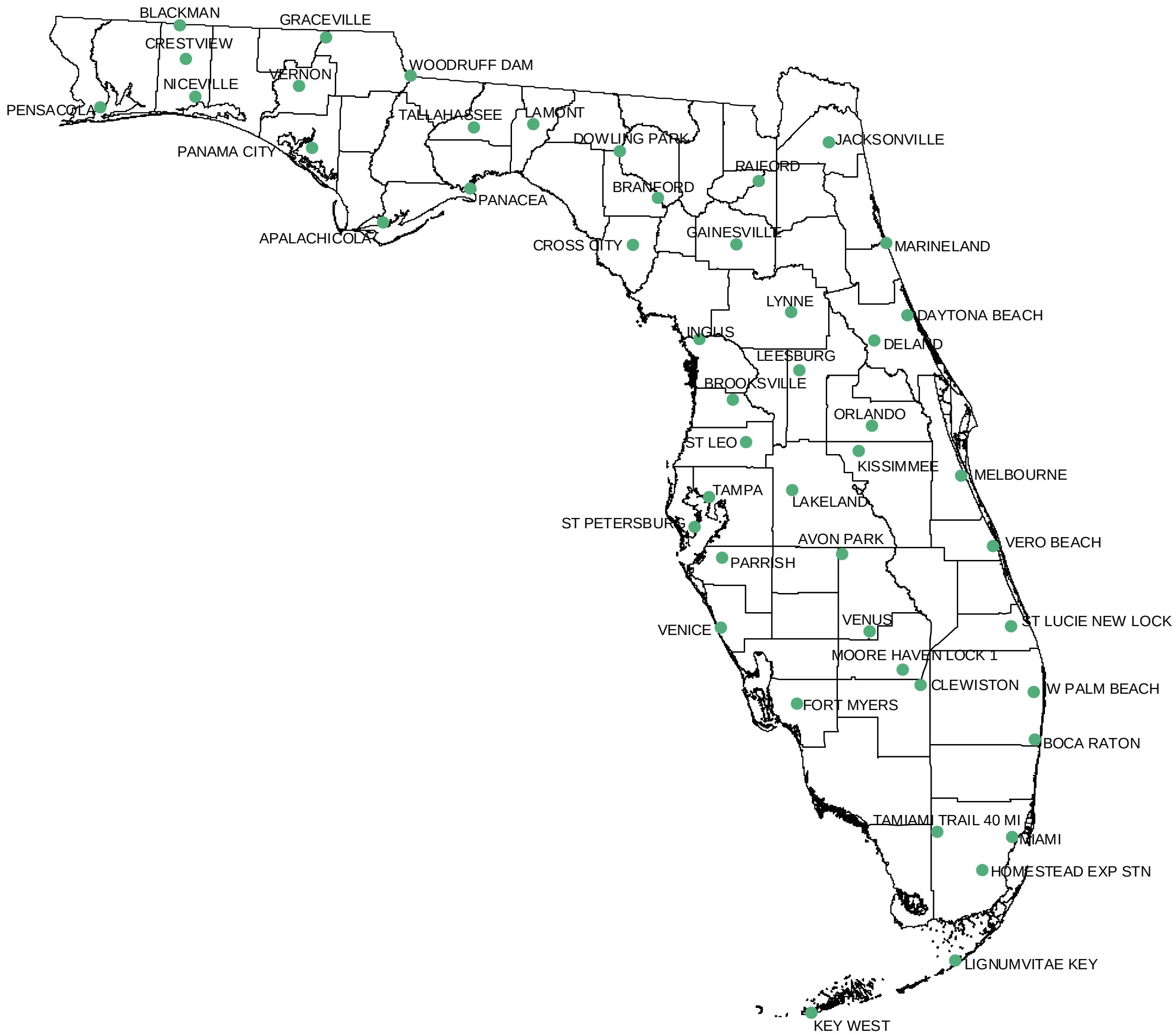

Figure 4-1. Locations of Hourly Meteorological Monitoring Sites.

The antecedent rainfall necessary to trigger AMC I or III conditions is based upon the rate at which the soil storage is recovered following a rain event. Loss of soil moisture occurs as a result of several processes, one of which is evapotranspiration. Evapotranspiration increases during the "growing" season and decreases during the "dormant" season. For Florida, the growing season is commonly assumed to be from March-September, and the dormant season from October-February.

Recommended rainfall depths corresponding to the three antecedent moisture conditions (AMC) are summarized in Table 4-20 (USDA, 1986) for both dormant and growing season conditions. Antecedent moisture conditions are determined by evaluating the total cumulative rainfall in the 5-day period prior to a selected rainfall event. During dormant season conditions, occurring from October-February, a cumulative antecedent 5-day rainfall less than 0.5 inches would indicate a shift to antecedent moisture Condition I for the new rain event. During growing season conditions, this value increases to 1.4 inches. However, if the total antecedent 5-day rainfall exceeds 1.1 inches during dormant season conditions, an antecedent moisture Condition III is assigned to the next rain event. Under growing season conditions, this value increases to 2.1 inches. When performing continuous simulations, the SCS recommends that the standard curve number value assumed for modeling purposes be modified to consider antecedent rainfall conditions.

TABLE 4-20

RECOMMENDED SEASONAL RAINFALL DEPTHS FOR THE THREE ANTECEDENT MOISTURE CONDITIONS (AMC)

AMC	TOTAL ANTECEDENT 5-DAY RAINFALL (inches)	
	DORMANT SEASON (October-February)	GROWING SEASON (March-September)
I	< 0.5	< 1.4
II	0.5-1.1	1.4-2.1
III	> 1.1	> 2.1

The tabular curve number values presented in textbooks and handbooks generally reflect antecedent moisture Condition II. These values can be modified to reflect either antecedent moisture Condition I or III, based upon the antecedent cumulative 5-day rainfall using the relationships summarized in Table 4-21 (McCuen, 1982). Mathematical expressions for these relationships have been developed by Chow, et al. (1988) as follows:

$$CN\,(I) = \frac{4.2\,CN\,(II)}{10 - 0.058\,CN\,(II)}$$

and

$$CN\,(III) = \frac{23\,CN\,(II)}{10 + 0.13\,CN\,(II)}$$

TABLE 4-21

RECOMMENDED CURVE NUMBER ADJUSTMENTS BASED ON ANTECEDENT MOISTURE CONTENTS

CN FOR CONDITION II	CORRESPONDING CN FOR CONDITION	
	I	III
100	100	100
95	87	99
90	78	98
85	70	97
80	63	94
75	57	91
70	51	87
65	45	83
60	40	79
55	35	75
50	31	70
45	27	65
40	23	60
35	19	55
30	15	50
25	12	45
20	9	39
15	7	33
10	4	26
5	2	17
0	0	0

Estimates of runoff depths were generated for each of the 45 hourly meteorological sites for a wide variety of directly connected impervious area (DCIA) and non-DCIA curve numbers. Runoff calculations were performed for combinations of DCIA values ranging from 0-100%, in 5% increments, and for non-DCIA curve numbers ranging from 30-95, in 5-unit increments, along with a non-DCIA curve number of 98. The calculated runoff depth for each combination of DCIA and non-DCIA curve number represents the total runoff generated for the assumed hydrologic characteristics over the entire period of record for a given site. The total runoff depth is then divided by the total rainfall depth which occurred over the entire period of record to generate a runoff C value for each combination of DCIA and curve number.

The runoff coefficient ranges from 0-1 and represents the ratio of runoff depth to the precipitation depth. The rated C Value is calculated using the following equation:

$$\text{C Value} = \frac{\text{Generated Runoff (depth or volume)}}{\text{Total Rainfall (depth or volume)}}$$

Runoff C values can be calculated on either an event basis or for an annual period. The calculated C value for each combination of DCIA and curve number reflects the average runoff/rainfall ratio for a given meteorological monitoring site over the entire available period of record. The calculated runoff C value does not represent anticipated rainfall/runoff relationships for any given year, but does reflect anticipated runoff/rainfall relationships over an extended period of time for each site.

4.2.2 Impacts of Rainfall Distributions on Runoff Depth

The variability in frequency distributions of individual rain events, discussed in the previous section, has the potential to impact rainfall/runoff relationships for individual rain events as well as on an annual basis. Areas which have a large number of small rain events which generate little measurable runoff may have a lower annual runoff coefficient than a similar area in a different portion of the State which is characterized by a high frequency of large rain events which generate significant runoff.

The potential impacts of rainfall frequency distributions on runoff volumes were evaluated by conducting simulations of the annual runoff depth generated by typical residential and commercial developments constructed at various locations throughout the State. Eight separate undeveloped and developed land use categories were assumed to evaluate the impacts of rainfall distributions on annual runoff coefficients. A summary of hydrologic assumptions used for the developed land use categories is given in Table 4-22. The low-density residential areas are assumed to have approximately 15% impervious area, with 5% of the area as DCIA. Hydrologic characteristics are provided for single-family residential developments based on 25% impervious and 40% impervious conditions. High-density residential areas are assumed to be 65% impervious, with 80% impervious assumed for commercial activities. Curve numbers for pervious areas are also included based on soil types and assumptions regarding landscaped conditions. Highway land use categories are also included, based upon 50% and 75% impervious assumptions. Curve number values for pervious areas are provided for each of the four major hydrologic soil groups.

Estimates of the annual runoff depths generated by the land use categories summarized in Table 4-22 were calculated using the continuous simulation methodology outlined in Section 4.2.1 and the hydrologic characteristics summarized in Table 4-22. These estimates were calculated for each of the 45 NCDC hourly precipitation monitoring stations summarized in Table 4-19. This process resulted in a total of 1440 separate long-term continuous simulations by modeling annual long-term runoff coefficients for each of the eight land use types, four individual soil groups, and 45 monitoring stations. The calculated runoff coefficients for each combination of monitoring site, land use, and curve number reflect the average annual runoff coefficient for the modeled monitoring sites over the entire available period of record.

The runoff C values generated as a result of the process outlined above were evaluated using a K-means clustering algorithm to identify similarities and differences in annual runoff coefficients for each of the eight land use types and four soil groups across the State of Florida. The clustering algorithm attempts to minimize the squared error objective function, representing the distance measured between a data point and the center of a chosen cluster. Clustering is simply a method of partitioning a data set into sub-sets (clusters) so that the data in each sub-set are statistically similar for the evaluated common trait.

TABLE 4-22

SUMMARY OF HYDROLOGIC ASSUMPTIONS USED FOR DEVELOPED LAND USE CATEGORIES

TYPICAL LAND USE	PERCENT TOTAL IMPERVIOUS AREA	% DCIA[1]	CURVE NUMBER (CN) FOR PERVIOUS AREAS			
			HSG A	**HSG B**	**HSG C**	**HSG D**
Low-Density Residential	15	5	49[2]	69[2]	79[2]	84[2]
Single-Family Residential						
a. 25% impervious	25	15	39[3]	61[3]	74[3]	80[3]
b. 40% impervious	40	25	39[3]	61[3]	74[3]	80[3]
High-Density Residential	65	50	39[3]	61[3]	74[3]	80[3]
Commercial	80	75	39[3]	61[3]	74[3]	80[3]
Highway[4]						
a. 50% impervious	50	50	49[2]	69[2]	79[2]	84[2]
b. 75% impervious	75	75	49[2]	69[2]	79[2]	84[2]

1. Percentage of total project area
2. Assumes open space, lawns, or landscaping in fair condition
3. Assumes open space, lawns, or landscaping in good condition
4. Includes area within right-of-way

For this evaluation, cluster analysis was conducted for 2, 3, 4, 5, 6, 7, and 8 clusters. There is no standard technique to determine the optimum number of clusters which should be chosen to represent a particular data set. However, the elbow criterion is a common rule of thumb which is often used to determine the appropriate number of clusters to be selected. The elbow criterion indicates that you should select a number of clusters so that adding an additional cluster does not provide a significant amount of additional information in the model. This criterion is typically evaluated using the percentage of variance explained for each cluster model. A graph of the percentage of variance and annual runoff coefficients explained as a function of the number of clusters is given in Figure 4-2. As the curve begins to approach the 4- or 5-cluster models, the additional variance explained by adding an additional cluster to the model becomes incrementally small. Therefore, an appropriate number of clusters for the annual runoff coefficients model appears to be approximately 4 or 5. The 5-cluster analysis was selected as the final model because this model identified the Florida Keys as unique in terms of annual runoff coefficients compared with other areas throughout the State of Florida. ERD has conducted stormwater and meteorological monitoring throughout the State of Florida, including the Florida Keys, and has firsthand knowledge of the substantially different meteorological processes which occur within the Florida Keys compared with other areas within the State of Florida. As a result of this firsthand experience, the 5-cluster model was selected.

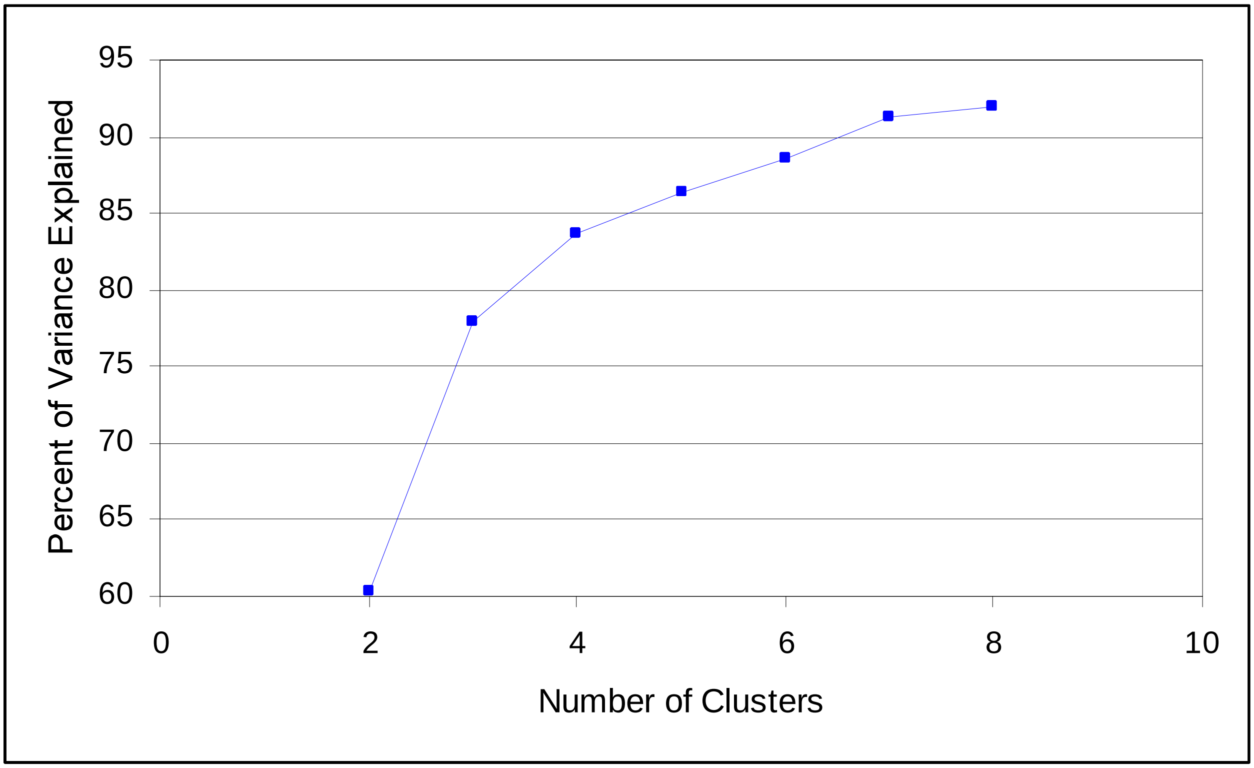

Figure 4-2. Percentage of Variance in Annual Runoff Coefficients Explained as a Function of the Number of Clusters.

A graphical summary of the results of the cluster analysis is given in Figure 4-3. Meteorological monitoring sites with similar runoff generating characteristics are grouped together by color on this figure. Approximate areas represented by the clustered meteorological monitoring sites are shaded in similar colors, generally on a County-wide basis. The majority of the indicated zones appear to be intuitive with respect to variability in rainfall events throughout the State. Portions of the Panhandle have been clustered together in an area which is impacted by a high number of large frontal events. Portions of the State along the Gulf Coast also appear to be similar runoff generating characteristics. Central and Central-Coastal portions of Florida also appear to have similar runoff characteristics. Runoff patterns in Southeast Florida appear to be dissimilar to rainfall patterns in other areas of the State. The Florida Keys are also identified on Figure 4-3 as a unique meteorological zone. The meteorological zones indicated on Figure 4-3 are utilized throughout the remainder of this report for evaluating runoff generation, pollutant loadings, and stormwater management system performance.

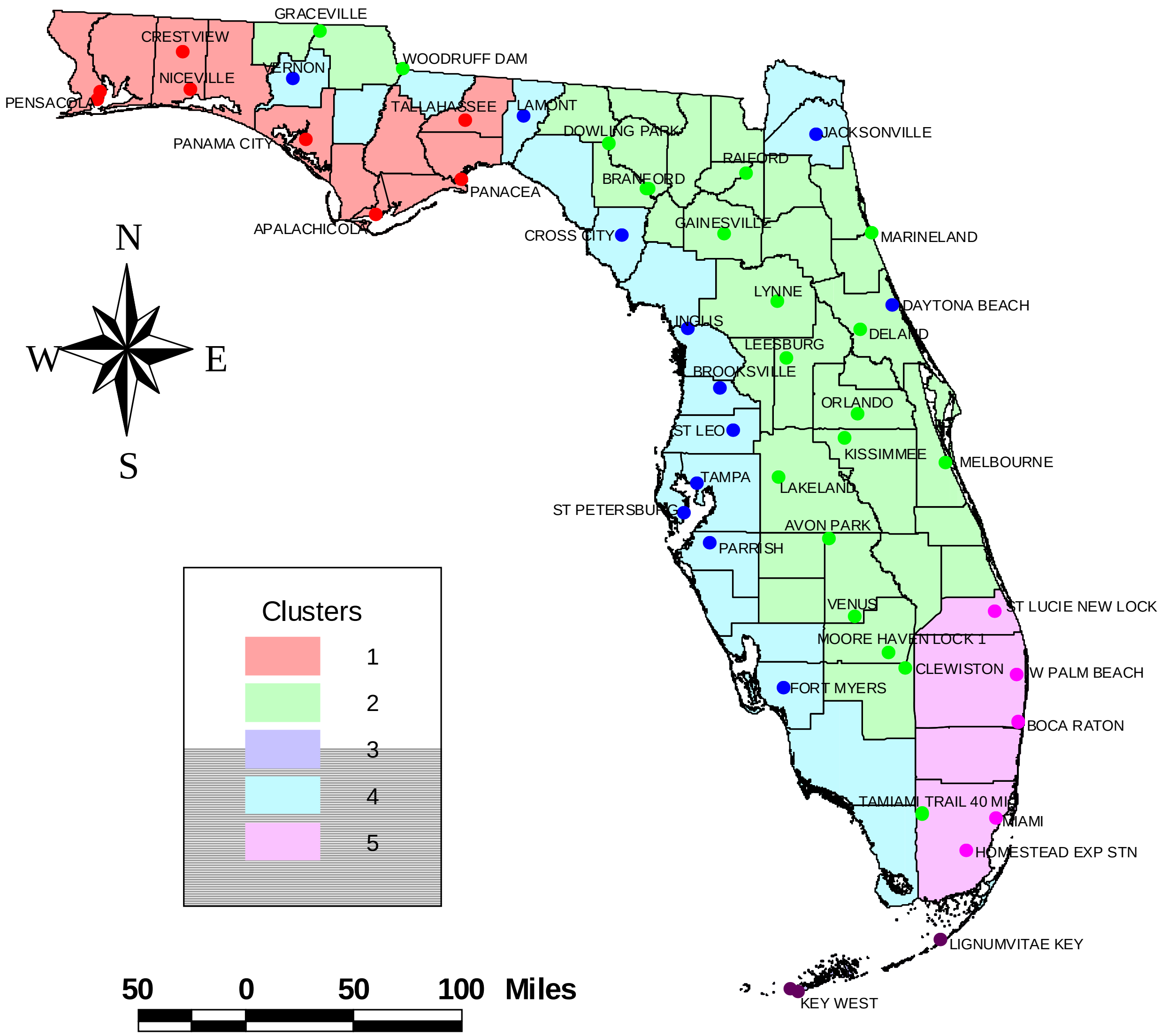

Figure 4-3. Meteorological Zones Identified Using Cluster Analysis.

Unfortunately, not all counties in Florida have long-term meteorological monitoring sites with hourly data. For purposes of designating meteorological zones, counties without a monitoring site were grouped according to the meteorological characteristics of adjacent counties with monitoring sites. The resulting zones appear to be relatively intuitive with respect to meteorological processes. The cluster groupings only have two apparent outliers, Daytona Beach and Tamiami Trail, which appear out of place. However, in a data set containing 45 points, an analysis conducted at a 95% probability level would be expected to have approximately 2-3 outlier values. A listing of counties included in each meteorological zone is given in Table 4-23.

TABLE 4-23

COUNTIES INCLUDED IN THE DESIGNATED METEORLOGICAL ZONES

ZONE				
1	2	3	4	5
Okaloosa	St. Lucie	Monroe	Washington	Martin
Liberty	Columbia		Manatee	Broward
Bay	DeSoto		Levy	Miami-Dade
Wakulla	St. Johns		Pasco	Palm Beach
Leon	Seminole		Pinellas	
Santarosa	Sumter		Lee	
Gulf	Flagler		Hillsborough	
Franklin	Suwannee		Hernando	
Escambia	Gadsden		Sarasota	
Walton	Gilchrist		Duval	
	Glades		Dixie	
	Calhoun		Collier	
	Hamilton		Citrus	
	Hardee		Charlotte	
	Hendry		Taylor	
	Union		Nassau	
	Highlands		Jefferson	
	Putnam		Monroe	
	Holmes			
	Indian River			
	Jackson			
	Volusia			
	Lafayette			
	Lake			
	Polk			
	Brevard			
	Bradford			
	Baker			
	Madison			
	Osceola			
	Marion			
	Orange			
	Clay			
	Okeechobee			
	Alachua			

A summary of mean runoff coefficients for each cluster as a function of land use and hydrologic soil group is given in Table 4-24. The values summarized in this table reflect the mean runoff coefficients for each land use and hydrologic soil group and each meteorological monitoring site included in each of the five clusters. The values summarized in Table 4-24 reflect differences in runoff coefficients as a result of frequency distributions of common rain events only. This analysis does not include variability in rainfall depth throughout the State which must be multiplied times the mean runoff coefficients to obtain an estimate of annual runoff volume.

TABLE 4-24

SUMMARY OF MEAN RUNOFF COEFFICIENTS FOR EACH CLUSTER AS A FUNCTION OF LAND USE AND HYDROLOGIC SOIL GROUP

LAND USE	HYDROLOGIC SOIL GROUP	CLUSTER				
		1	2	3	4	5
Undeveloped Land	A	0.015	0.007	0.013	0.011	0.018
	B	0.064	0.039	0.052	0.050	0.067
	C	0.126	0.087	0.103	0.105	0.127
	D	0.176	0.128	0.143	0.149	0.173
Low-Density Residential Areas	A	0.092	0.069	0.081	0.079	0.093
	B	0.166	0.126	0.140	0.144	0.164
	C	0.238	0.187	0.200	0.210	0.232
	D	0.294	0.237	0.248	0.262	0.284
Single-Family Residential Areas (25% Impervious)	A	0.155	0.136	0.143	0.144	0.151
	B	0.206	0.173	0.184	0.188	0.202
	C	0.268	0.223	0.235	0.243	0.260
	D	0.313	0.262	0.272	0.285	0.302
Single-Family Residential Areas (40% Impervious)	A	0.245	0.220	0.227	0.231	0.237
	B	0.294	0.257	0.266	0.273	0.284
	C	0.350	0.303	0.312	0.324	0.337
	D	0.391	0.339	0.347	0.362	0.375
High-Density Residential Areas	A	0.455	0.423	0.424	0.436	0.435
	B	0.490	0.450	0.453	0.467	0.469
	C	0.529	0.483	0.485	0.503	0.506
	D	0.556	0.508	0.509	0.529	0.531
Commercial Areas	A	0.648	0.613	0.609	0.628	0.618
	B	0.664	0.625	0.622	0.642	0.633
	C	0.683	0.641	0.637	0.658	0.651
	D	0.697	0.653	0.649	0.671	0.664
Highway Areas (50% Impervious)	A	0.444	0.415	0.416	0.427	0.425
	B	0.481	0.442	0.445	0.459	0.460
	C	0.517	0.473	0.476	0.492	0.495
	D	0.546	0.498	0.500	0.519	0.522
Highway Areas (75% Impervious)	A	0.647	0.612	0.608	0.627	0.616
	B	0.665	0.626	0.623	0.642	0.634
	C	0.683	0.641	0.638	0.659	0.651
	D	0.698	0.654	0.650	0.672	0.665

4.2.3 Annual Runoff Generation

A summary of calculated mean annual runoff coefficients as a function of curve number and DCIA is given in Appendix C for each of the five designated meteorological zones. The values presented in these tables reflect the proportion of annual rainfall which becomes stormwater runoff in each meteorological zone for 315 DCIA and non-DCIA curve number combinations. Continuous simulations of runoff generation were conducted over the period of record for each of the 45 hourly meteorological monitoring stations in Florida. Runoff calculations were performed for combinations of DCIA values ranging from 0-100%, in 5% increments, and for non-DCIA curve numbers ranging from 30-95, in 5 unit increments. A non-DCIA curve number of 98 was also included in this analysis. The mean runoff C value for each combination of DCIA and curve number value was calculated using values from each of the meteorological monitoring sites within a given zone. The values summarized in Appendix C reflect the average long-term runoff coefficients for each of the five designated zones over a wide range of DCIA and curve number combinations. The data summarized in Appendix C reflect a total of 14,175 separate long-term continuous simulations of runoff coefficients based upon the 21 DCIA intervals, 15 curve number intervals, and 45 meteorological monitoring sites. This information is used in subsequent sections for evaluation of existing stormwater design criteria and to evaluate the performance efficiency of proposed alternative regulations.

The information contained in Appendix C can be used to estimate the annual runoff volume for a given parcel under either pre- or post-development conditions by multiplying the mean annual rainfall depth for the given area, obtained from the Figures in Appendix A.3, times the appropriate runoff coefficient based upon the DCIA and curve number characteristics for the meteorological zone in which the parcel is located, listed in Appendix C. This estimate is calculated as follows:

$$\text{Annual Runoff Volume (ac-ft)} =$$

$$\text{Area (acres)} \times \text{Mean Annual Rainfall (inches)} \times \text{C Value} \times \frac{1\ \text{ft}}{12\ \text{in}}$$

Linear interpolation can be used to estimate annual runoff coefficients for combinations of DCIA and curve number which fall between the values included in Appendix C.

As seen in Appendix C, a wide degree of variability is present in calculated annual runoff coefficients for various combinations of DCIA and non-DCIA curve numbers between the five meteorological zones in Florida. Increases in DCIA as well as increases in the non-DCIA curve number both result in significant increases in the calculated annual runoff coefficients. To illustrate the general relative relationships between DCIA, curve number, and annual runoff volumes, a set of average annual runoff coefficients was generated by calculating the mean runoff coefficient for each combination of DCIA and non-DCIA curve number for the five meteorological zones in Florida. A graphical summary of this relationship is given in Figure 4-4. This graph indicates a linear relationship between runoff coefficients and percent DCIA, with an exponential relationship between runoff coefficient and curve number. Increases in curve numbers, particularly at curve number values in excess of 80, result in substantial increases in the estimated annual runoff coefficient and corresponding annual runoff volume.

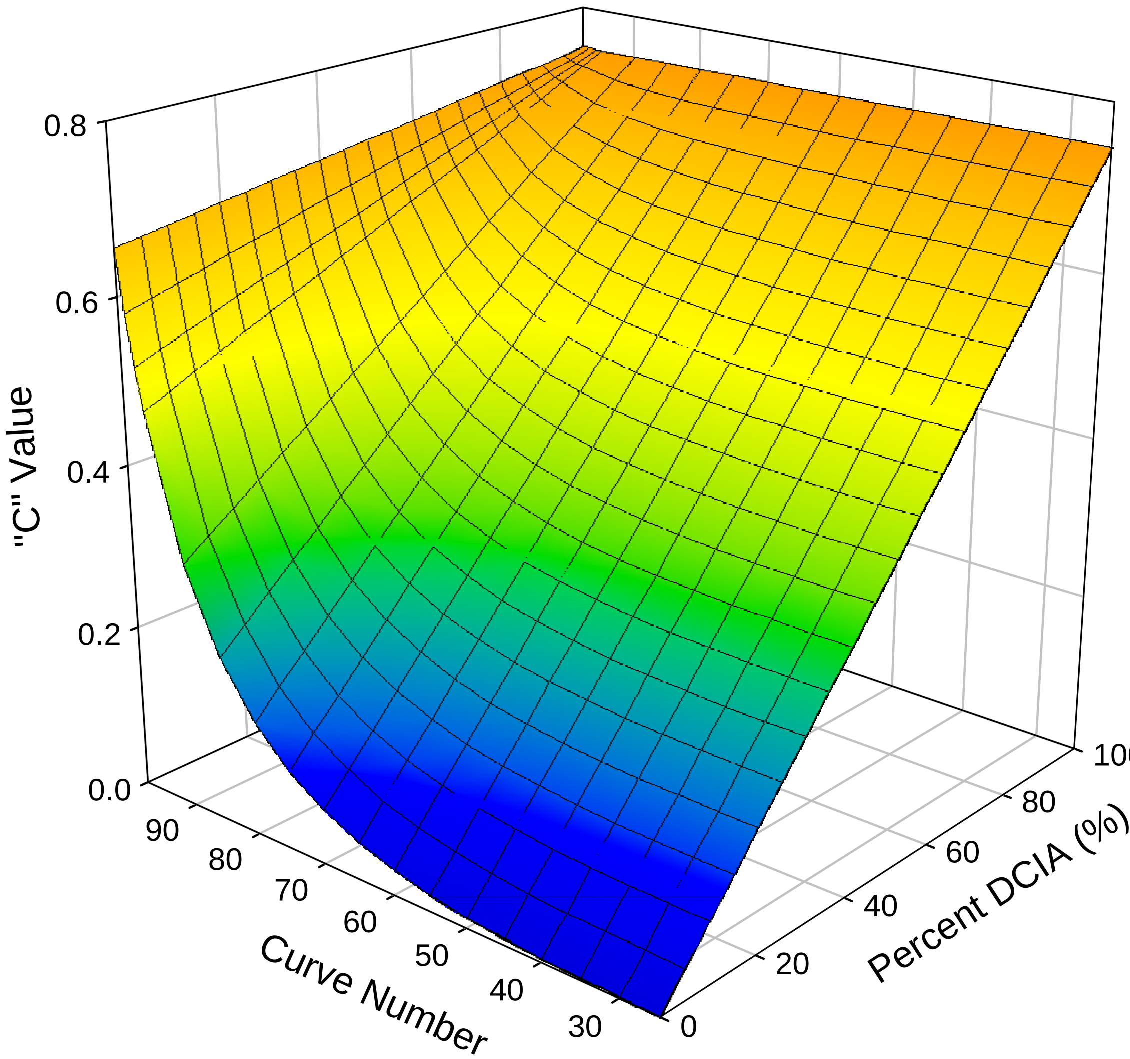

Figure 4-4. General Relationships Between Percent DCIA, Curve Number, and C Value.

A graphical illustration of the distribution of runoff coefficients as a function of DCIA and curve number for the Panhandle (Zone 1) rainfall distribution is given in Figure 4-5. In this meteorological region, DCIA appears to have a relatively small impact on runoff coefficient at DCIA percentages of 40 or less. However, at percentages above 40, the runoff coefficient appears to increase rapidly. Changes in curve number appear to have a minimal impact on runoff coefficients until the curve number begins to exceed approximately 85. Above this value, subsequent increases in curve number result in large increases in runoff coefficient.

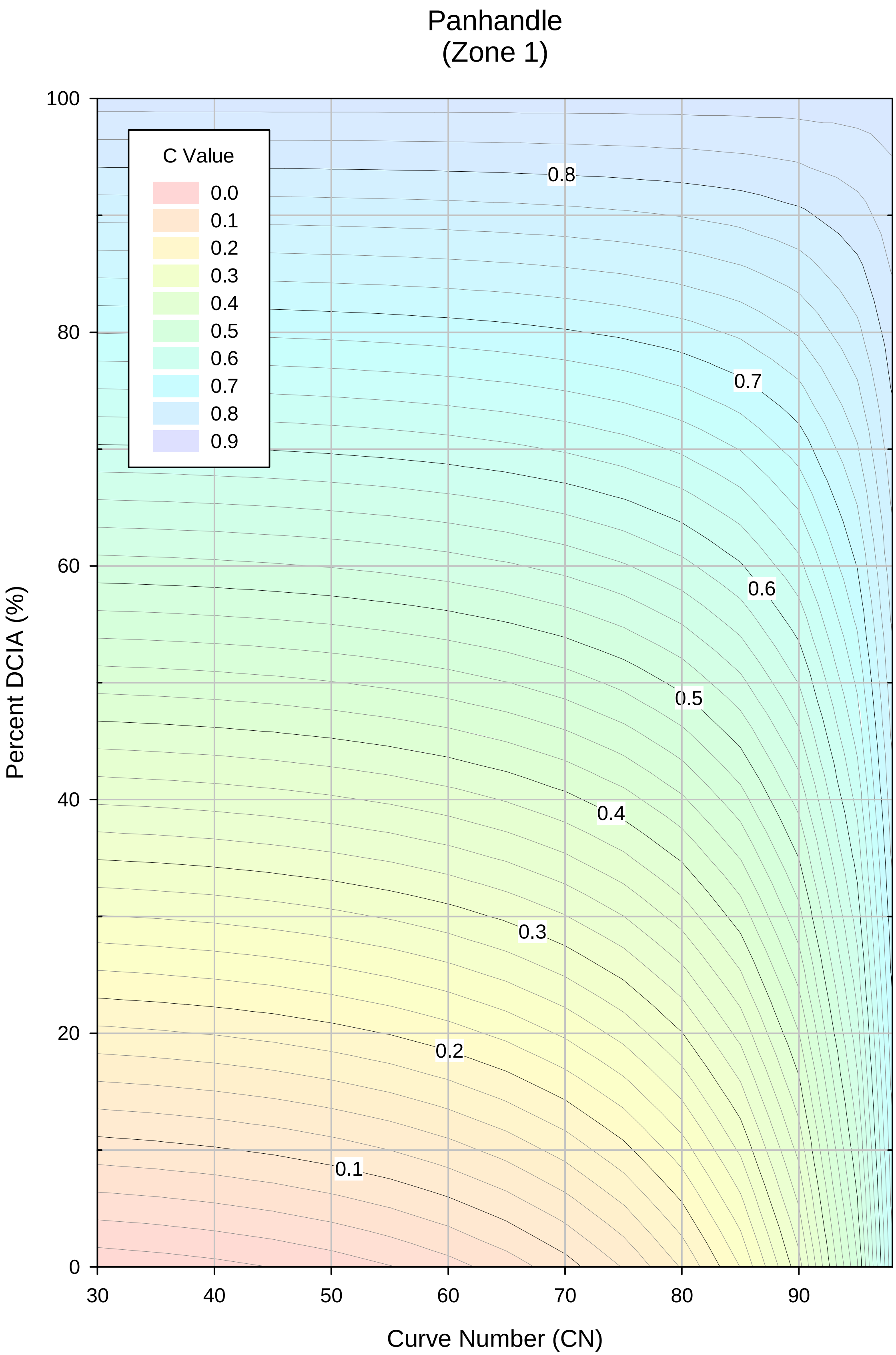

Figure 4-5. Distribution of C Values as a Function of DCIA and Curve Number for the Panhandle Area (Zone 1).

A graphical representation of the distribution of runoff coefficients as a function of DCIA and curve number for the Florida Keys meteorological zone is given in Figure 4-6. For this rainfall distribution, DCIA appears to have a relatively minimal impact on runoff coefficients until the DCIA begins to exceed a value of approximately 70. Above this value, subsequent increases in DCIA result in relatively large increases in runoff coefficients. Changes in curve number appear to have a relatively small impact on runoff coefficient until the curve number begins to exceed a value of approximately 95. Above this value, runoff coefficients begin to increase rapidly. The data presented in Figure 4-6 suggest that, for a given combination of DCIA and curve number, the runoff coefficient for the Florida Keys zone is substantially lower than the runoff coefficient which would occur in the Panhandle region.

A graphical representation of the state-wide mean distribution of runoff coefficients as a function of DCIA and curve number is given in Figure 4-7. This diagram represents the average of the five designated meteorological zones within the State. On a state-wide basis, significant changes in runoff volume do not occur until the DCIA value exceeds approximately 45-50 and the curve number exceeds 90.

For comparison purposes, modeled annual runoff coefficients for a hypothetical development with a DCIA of 40% and a non-DCIA curve number of 70 are given in Figure 4-8. If this development were to be constructed in the Florida Keys (Zone 3) or Central (Zone 2) portions of the State, approximately 36% of the annual rainfall would become stormwater runoff. However, if this development were to be constructed in the Panhandle area, approximately 39-40% of the annual rainfall would become stormwater runoff. On a state-wide average, approximately 37.5% of the rainfall which occurs on the hypothetical development would become stormwater runoff. Lower than average annual runoff coefficients would be observed in the Florida Keys (Zone 3), Central Area (Zone 2), and Gulf Coast Area (Zone 4), with higher runoff coefficients observed in the Panhandle (Zone 1) and Southeast Coastal (Zone 5).

The differences in annual runoff coefficients between the meteorological regions summarized in Figure 4-8 are due primarily to differences in the distribution of rain events which occur at each of these sites. For example, the Key West and Melbourne regional sites are characterized by a high percentage of annual events with a relatively low rainfall depth which generate little or no measurable runoff volume. Since a large portion of the annual rainfall in these areas is generated by small events, the net effect is to substantially decrease the annual runoff coefficient associated with these areas. On the other hand, the Pensacola and Tallahassee areas are characterized by a high percentage of larger storm events, commonly associated with frontal boundaries which move through the area. Since larger rain events typically generate a larger proportion of stormwater runoff than smaller events, the annual runoff coefficients for these areas tend to be more elevated.

The results summarized in Figure 4-8 have significant implications with respect to the performance efficiency of stormwater management systems, particularly systems that have design criteria based on providing treatment for the runoff generated by a stated rainfall event. Based on the information summarized in Figure 4-8, a 1-inch rain event in the Panhandle area will generate more runoff than a 1-inch rain event which occurs in the Florida Keys or Central areas. This would create a substantial difference, not only in the required treatment volume, but also in the performance efficiency of a stormwater system designed for the same hypothetical development in the Panhandle and Florida Keys.

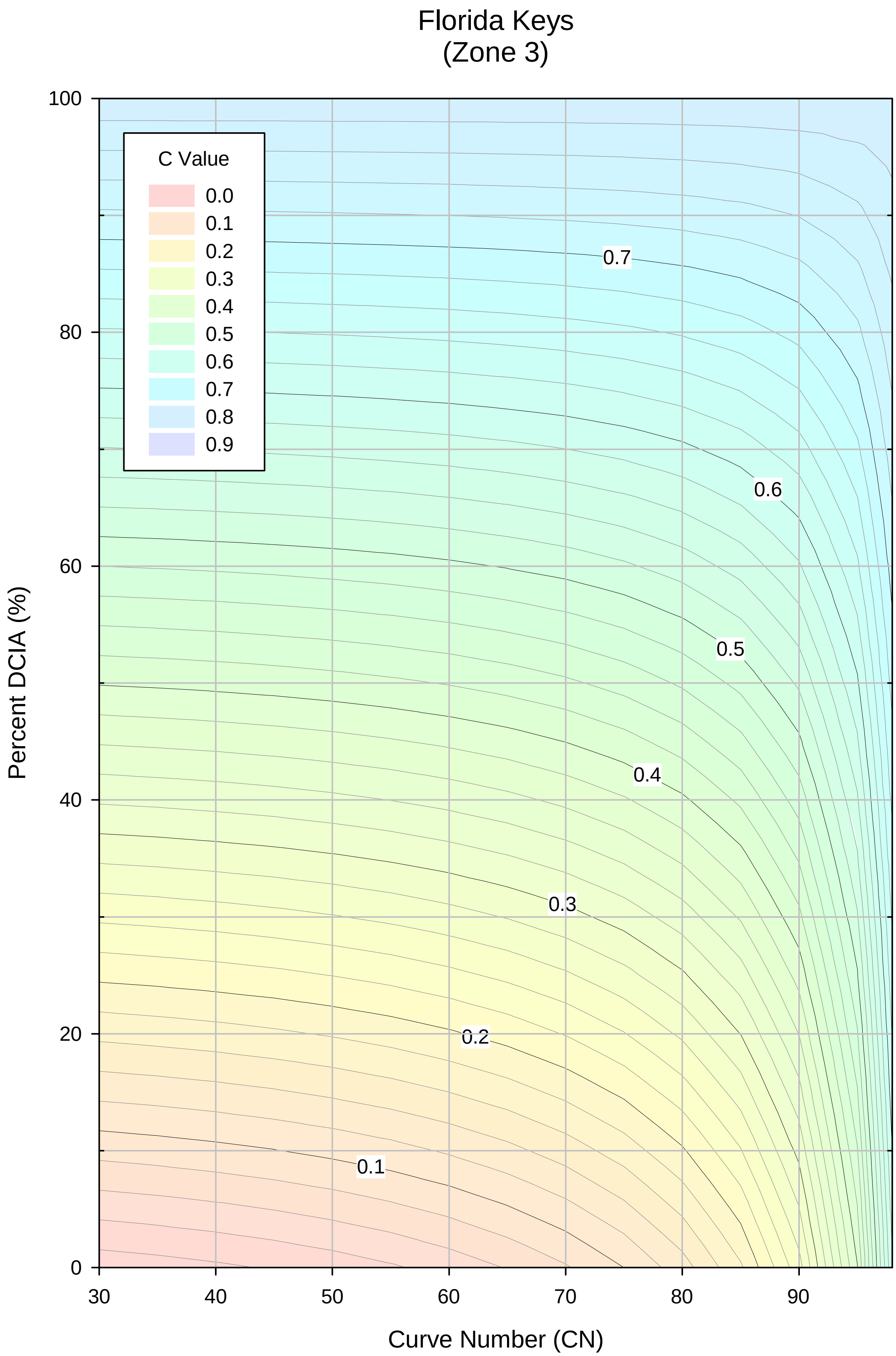

Figure 4-6. Distribution of C Values as a Function of DCIA and Curve Number for the Florida Keys (Zone 3).

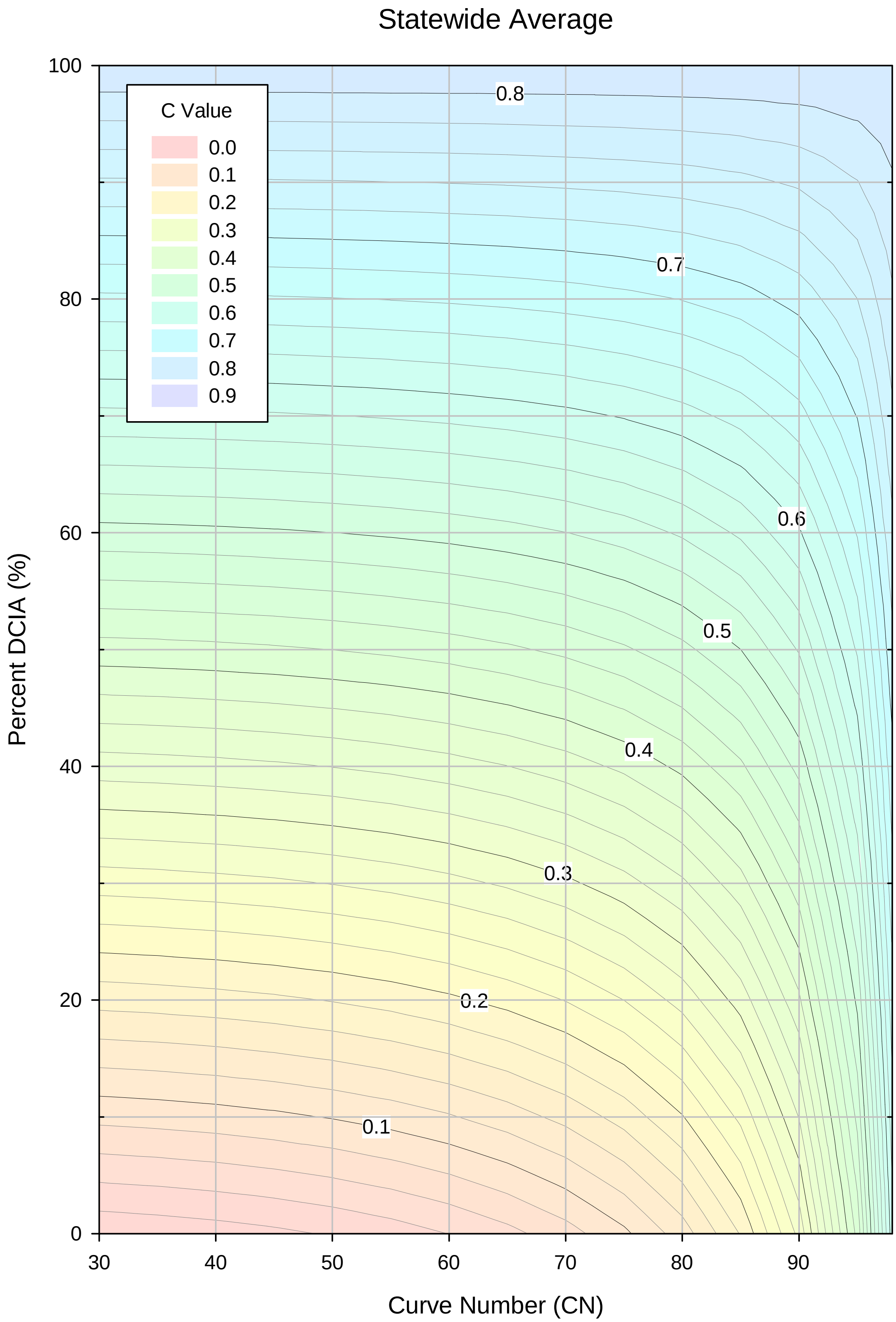

Figure 4-7. State-wide Mean Distribution of C Values as a Function of DCIA and Curve Number.

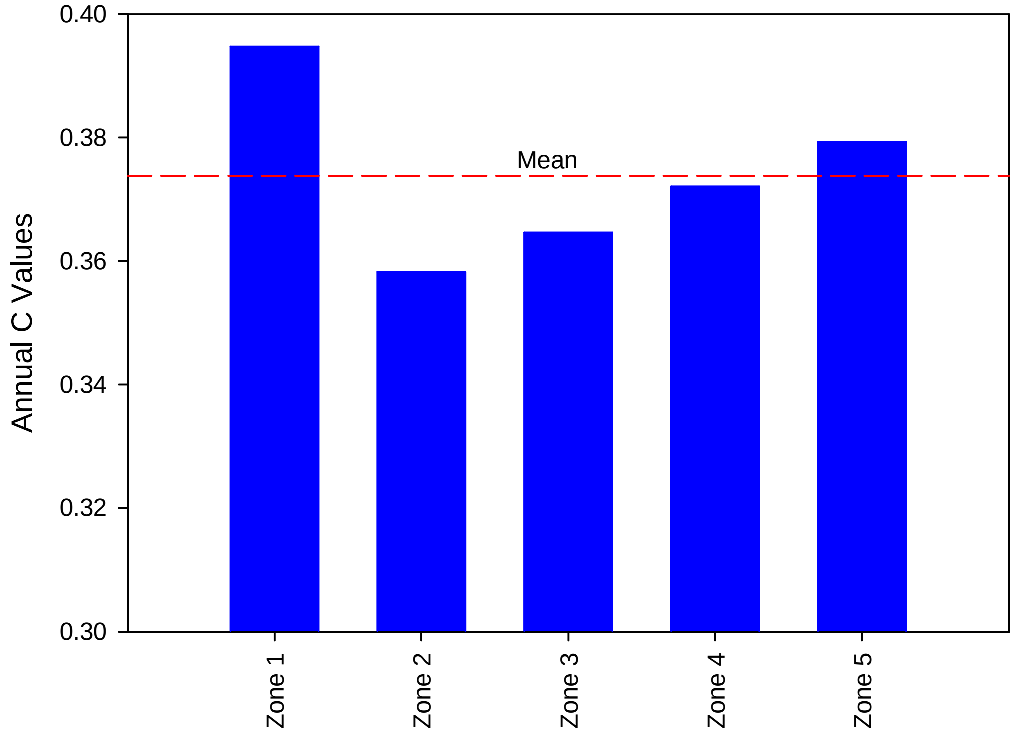

Figure 4-8. Modeled Annual Runoff Coefficients (C Values) for a Hypothetical Development with a DCIA of 40% and a non-DCIA Curve Number of 70.

The phenomenon illustrated in Figure 4-8 is explained primarily by the relative number of small and large rain events associated with the different meteorological regions within the State. For example, a comparison of the percentage of annual rainfall volume generated by rain events less than 0.1 inch at the designated meteorological regions is given in Figure 4-9. For the Florida Keys (Zone 3) sites, approximately 5-8% of the annual rainfall volume is contributed by rain events less than 0.1 inch in depth. Based upon the assumption that impervious surfaces provide an initial abstraction of approximately 0.1 inch, no measurable runoff would be measured by rain events of this size. In contrast, only approximately 3-6% of the annual rainfall volume in the Panhandle zone is contributed by rain events less than 0.1 inch in depth.

A comparison of the percentage of annual rainfall volume generated by rain events greater than 1 inch is given in Figure 4-10. Only approximately 49% of the annual rainfall volume which occurs in the Florida Keys (Zone 3) is generated by rain events greater than 1 inch. However, at the Panhandle sites (Zone 1), approximately 62% of the annual rainfall volume occurs as a result of events greater than 1 inch. Since larger rain events generate a proportionately larger runoff volume due to the lessening impact of initial abstraction, areas which have a higher proportion of large rain events can be expected to have a larger annual runoff coefficient.

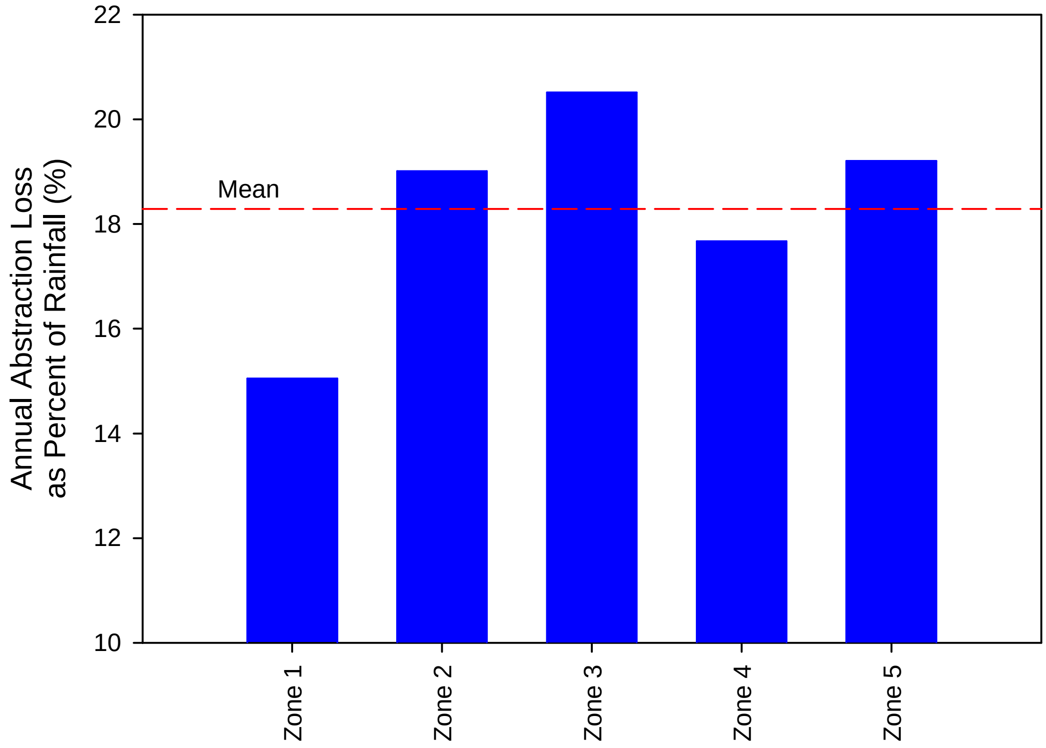

Figure 4-9. Percentage of Annual Rainfall Volume Generated by Rain Events < 0.1 Inch.

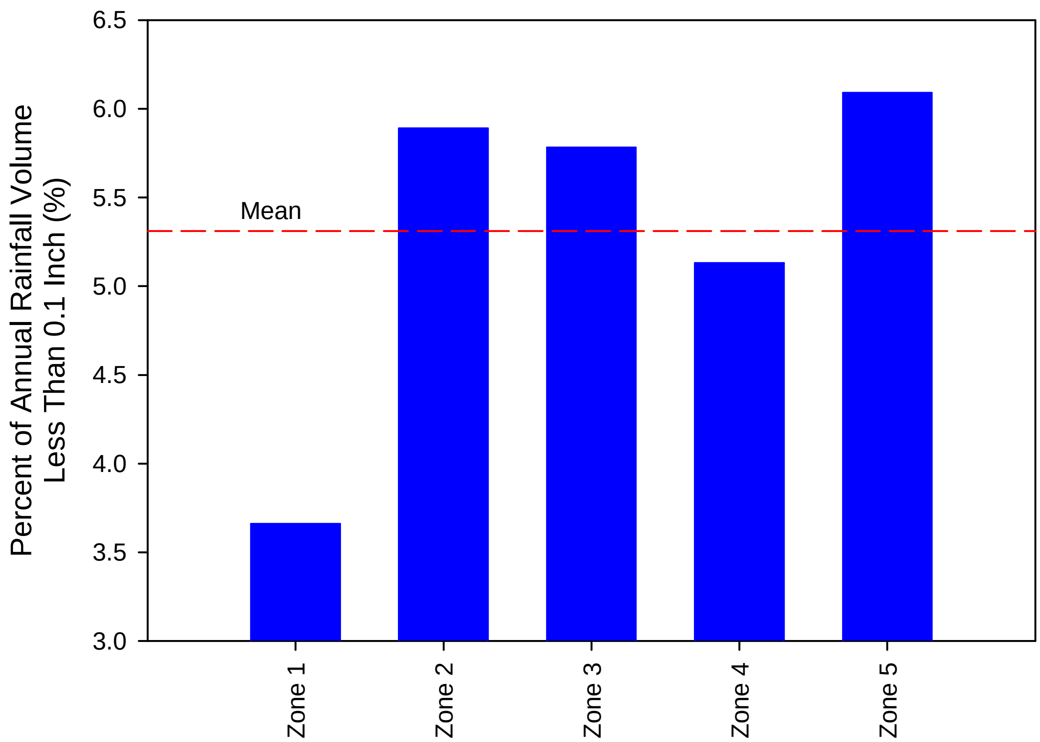

Figure 4-10. Percentage of Annual Rainfall Volume Generated by Rain Events >1 Inch.

A comparison of the percentage of annual rainfall depth lost to abstraction on impervious surfaces for each of the meteorological zones is given in Figure 4-11. In the Florida Keys (Zone 3) area, approximately 21% of the total annual rainfall which occurs on impervious surfaces is lost as a result of initial abstraction. This rainfall, which is stored on the surface of the impervious areas, is removed by evaporation processes between storm events. However, in the Panhandle (Zone 1) area, only 15% of the annual rainfall depth is lost to initial abstraction on impervious surfaces due to the higher percentage of large rain events in this portion of the State.

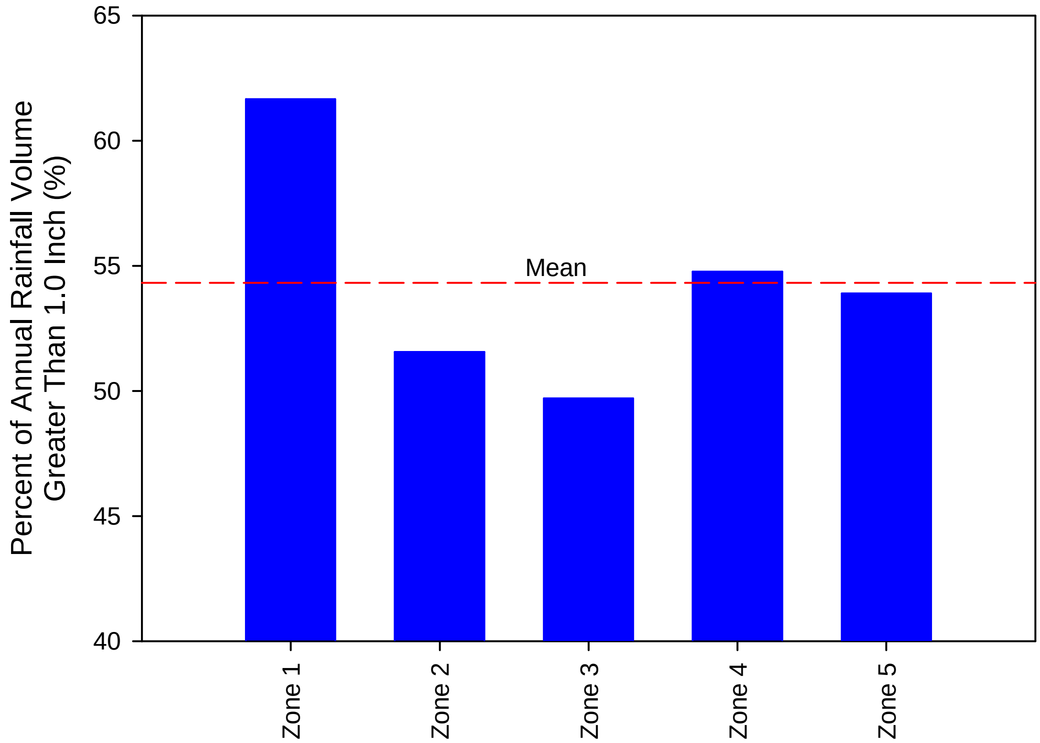

Figure 4-11. Percentage of Annual Rainfall Depth Lost to Initial Abstraction on Impervious Surfaces.