POLLUTANT REMOVAL EFFICIENCIES FOR TYPICAL STORMWATER MANAGEMENT SYSTEMS IN FLORIDA

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ABSTRACT

A literature review was conducted of previous research performed within the State of Florida which quantifies pollutant removal efficiencies associated with various stormwater management systems. Comparative removal efficiencies were obtained and summarized for dry retention, wet retention, off-line retention/detention systems, wet detention, wet detention with filtration, dry detention with filtration, and dry detention. Estimated pollutant removal efficiencies were generally available for total nitrogen, orthophosphorus, total phosphorus, TSS, BOD, copper, lead and zinc.

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

INTRODUCTION

A substantial amount of research has been conducted over the past several decades which demonstrates that some commonly used stormwater management techniques are much more efficient in removing and retaining pollutant loadings than others. However, in spite of this research, many stormwater management facilities are selected or designed based upon the ability of the system to function hydraulically rather than with regards to pollutant removal effectiveness. A literature review was performed which quantifies pollutant removal efficiencies associated with common stormwater management systems. The results of this literature review may be useful in modifying existing stormwater management regulations to emphasize the use of techniques which are most effective in terms of removing and retaining stormwater pollutants.

EVALUATION METHODOLOGY

A literature review was conducted by Harper (1995) of previous research performed within the State of Florida which quantifies pollutant removal efficiencies associated with various stormwater management systems used within the State. Each study which was obtained was evaluated 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 work. It was preferred that selected studies contain at

least a 3-month period of data collection, representing a wide range of rainfall and antecedent dry weather conditions. Studies with less than four monitored storm events were not included.

Only stormwater management facilities constructed within the State of Florida, according to applicable stormwater regulations, were included in this evaluation. Pollutant removal efficiencies were obtained and summarized for the following types of stormwater management facilities: (1) dry retention (on-line); (2) wet detention (on-line); (3) off-line retention/detention; (4) wet detention; (5) wet detention with filtration; (6) dry detention; and (7) dry detention with filtration.

The terms "detention" and "retention" are often used interchangeably by engineers, even those who have been designing stormwater management facilities for many years. For purposes of this discussion, the following definitions shall apply:

Detention:	The collection and temporary storage of stormwater, generally for a period of time ranging from 24-72 hours, in such a manner as to provide for treatment through physical, biological or chemical processes with subsequent gradual release of stormwater to downstream receiving waters.
Retention:	On-site storage of stormwater with subsequent disposal by infiltration into the ground or evaporation in such a manner as to prevent direct discharge of stormwater runoff into receiving waters.

REMOVAL EFFICIENCIES FOR COMMON STORMWATER MANAGEMENT FACILITIES

A summary of literature references and estimated pollutant removal efficiencies was prepared for each type of stormwater system evaluated. The results of these evaluations are summarized in the following sections.

Dry Retention Systems (On-Line)

In spite of the fact that on-line dry retention systems are used extensively throughout the Sate of Florida, relatively little research has been conducted to evaluate the pollutant removal effectiveness of these systems. Only two references were identified during the literature search on dry retention systems, both of which were conducted as part of the Orlando Areawide 208 Assessment during the late 1970s. A summary of treatment efficiencies for dry retention systems, based on selected research studies in Florida, is given in Table 1.

TABLE I

TREATMENT EFFICIENCIES FOR DRY RETENTION SYSTEMS BASED ON SELECTED RESEARCH STUDIES IN FLORIDA

STUDY SITE LAND USE	TYPE OF EFFICIENCIES REPORTED	MEAN REMOVAL EFFICIENCIES									
		N%	TKN	Total N	Ortho -P	Total P	TSS	BOD	Total Cu	Total Pb	Total Zn
Orlando/ Commercial	Concentration	-92	-91	-91		-61	-85	-92			
Orlando/ Urban	Calculated										
	a. 0.25" ret.	-80	-80	-80	-80	-80	-80	-80	-80	-80	-80
	b. 0.50" ret.	-90	-90	-90	-90	-90	-90	-90	-90	-90	-90
	c. 0.75" ret.	-95	-95	-95	-95	-95	-95	-95	-95	-95	-95
	d. 1.00" ret.	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99

e. 1.25" rec.	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9

1. ECFRPC (1978)
2. Wanielista (1978)

The first study, published in 1978 by the East Central Florida Regional Planning Council (ECFRPC), was conducted on a commercial watershed in Orlando. Concentration-based removal efficiencies for the dry retention system reported in this study ranged from approximately 61 % for total phosphorus to more than 90 % for species of nitrogen. Information on the amount of retention storage available within the system is not presented as part of this study.

The second study was conducted by Wanielista (1978) and was also part of the Orlando Areawide 208 Assessment. This study presents calculated estimates for the efficiency of retention systems based upon simulations of yearly rainfall/runoff events. Removal efficiencies are presented as a function of retention volume with increasing removal efficiencies associated with increasing runoff volumes retained. This simulation assumes that the retention pond drains completely between rain events so that the design retention volume is available for the next storm event. Removal efficiencies of approximately 80% are associated with retention of 0.64 cm (0.25 in) of runoff, 90% for 1.27 cm (0.50 in) of runoff, and 95% for a retention volume of 1.91 cm (0.75 in) of runoff. Even though these removal estimates are only calculated and are not based upon actual field measurements, these removal efficiencies are used extensively throughout the State of Florida.

It is obvious that removal efficiencies achieved in retention systems are regulated to a large degree by the amount of runoff volume retained. In general, the annual pollutant removal effectiveness of a retention system should increase as the retention volume increases. However, since dry retention systems do not always recover the entire pollution abatement volume before the next storm event, the actual observed pollutant removal efficiencies for dry retention systems are probably somewhat less than the values presented by Wanielista. Based on experience by ERD in evaluating stormwater management systems, recommended removal efficiencies for on-line dry retention facilities are summarized in Table 2.

TABLE 2

RECOMMENDED REMOVAL EFFICIENCIES FOR ON-LINE DRY RETENTION FACILITIES

TREATMENT VOLUME		PERCENT REMOVAL OF TP, TN, TSS
cm	inches	TOTAL Cu, Pb AND Zn
0.64	0.25	-60
1.27	0.50	-80
1.91	0.75	-90
2.54	1.00	-95
3.18	1.25	-98

Wet Retention Systems (On-Line)

Similar to dry retention systems, relatively little research has been conducted within the State of Florida on treatment efficiencies for wet retention systems. Only two studies were identified during the literature search which evaluate the effectiveness of wet retention systems. A summary of removal efficiencies achieved in these two investigations is given in Table 3.

TABLE 3

TREATMENT EFFICIENCIES FOR WET RETENTION SYSTEMS BASED ON SELECTED RESEARCH STUDIES IN FLORIDA

STUDY SITE/ LAND USE	TYPE OF EFFICIENCIES REPORTED	MEAN REMOVAL EFFICIENCIES (%) NO~	TKN	Total N	Orth o-P	Total P	TSS	BOD	Total Cu	Total Pb	Total Zn
Orlando/ Residential.	Mass	-93	45	-62	+20	-29	-76	-20	-23	-51	-59
Orlando/ Commercial'	Mass	-95	+16	-19	44	-73	-93	-60	-25	-49	-77
		-94	-15	-41	-12	-51	-85	-40	-24	-50	

1. Harper (1988)

Both of the studies identified in the literature search were conducted by Harper (1988) as part of a two-year study for the Florida Department of Environmental Protection. These studies were conducted in the Orlando area, with one site representing residential land use and one site representing commercial land use. Both wet retention systems were designed to provide a pollutant abatement volume of 1.3 cm (0.50 in) of runoff over the watershed area. Neither of the two systems were observed to drain completely between storm events, with a permanent pool depth of approximately 15-60 cm (6-24 in). With the exceptions of NO, TSS and the measured heavy metals, considerable variability was observed in the treatment performance for these two systems. Measured treatment efficiencies ranged from approximately 10- 15 % for orthophosphorus and TKN; 40-50 % for total nitrogen, total phosphorus and BOD; and more than 85 % for TSS and NO,

In general, treatment efficiencies for wet retention systems are substantially lower for many parameters than removal efficiencies estimated for dry retention systems.

These differences are probably related to several factors. First, wet retention systems typically regain the pollution abatement volume by infiltration of the runoff into the groundwater at a slower rate than dry retention systems due to the differences in effective percolation area. As a result, subsequent storm events may occur prior to evacuation of the required treatment volume, thereby reducing the overall efficiency of the system. Second, particulate forms of nitrogen and phosphorus which settle upon the pond bottom can resolubilize in the wet environment into the water column of the pond. Material that was trapped into the sediments at one time may then be transported from the pond with the next storm event which exceeds the available pollution abatement volume. However, this phenomenon of resolubilization can be minimized by increasing the permanent pool depth to approximately 1.8 m (6 ft) or greater to isolate settled sediment material.

A summary of mean removal efficiencies for the two wet retention systems is given in at the bottom of Table 3. On an average annual basis, wet retention systems provide approximately 40% removal for total nitrogen, 50% for total phosphorus, 85% removal for TSS, and 40% removal for BOD. Removal efficiencies for heavy metals average 25% for total copper, 50% for total lead and 68% for total zinc.

Off-Line Retention/Detention (Dual Pond) Systems

Off-line retention/detention systems, often called dual pond systems, are commonly used within the City of Orlando and other urban areas. These systems provide an off-fine retention pond with a pollution abatement volume generally equivalent to 1.3 cm (0.50 in) of runoff over the contributing watershed area. After the retention pond reaches the design storage level, a diversion weir then diverts the remaining stormwater runoff into a separate detention pond for flood control purposes.

Off-line retention/detention systems provide pollutant removal mechanisms in both the retention system as well as the detention portions of the pond. The initial first-flush pollutants are diverted into the retention facility. Stormwater runoff entering the separate detention pond is generally cleaner than the stormwater runoff

which enters the off-line retention ponds. Removal processes such as settling, adsorption, and precipitation reactions can also occur within the detention facility during the drawdown period.

A summary of treatment efficiencies for off-line retention/detention systems based on studies conducted within the State of Florida is given in Table 4. Only two studies were identified in the State of Florida which provide pollutant removal efficiencies for off-line retention/detention systems. These studies were conducted by Harper (1988) in the Orlando area on residential and commercial watersheds. Each system was constructed according to applicable regulations of the City of Orlando at the time of construction and provided a permanent pollution abatement volume of 1.27 cm. (0.50 in) over the contributing watershed area within the retention pond portion of the system.

TABLE 4

TREATMENT EFFICIENCIES FOR OFF-LINE RETENTION/DETENTION SYSTEMS (DUAL POND) BASED ON SELECTED RESEARCH STUDIES IN FLORIDA

STUDY SITE/ LAND USE	TYPE OF EFFICIENCIES REPORTED	MEAN REMOVAL EFFICIENCIES									
		NO~	TKN	Total N	Ortho-P	Total P	TSS	BOD	Total Cu	Total Pb	Total Zn
Orlando/ Residential'	Mass	-88	-83	-85	-;6	--92	-95	-90	-85	-71	-91
Orlando/ Commercial'	Mass	-95	-	-30	-61	-76	-89	-64	-47	-80	-81
		-92	-83	-58	-79	-84	-92	-77	-66	-76	-86

1. Harper (1988)

Excellent removal efficiencies were achieved in the study reported by Harper (1988) in the Orlando residential watershed. Measured removal efficiencies for total nitrogen, total phosphorus, TSS, BOD, total copper and total zinc were equal to 85 % or greater. Removal efficiencies measured in the commercial watershed studied are somewhat lower than those reported in the residential watershed. Removal efficiencies for total nitrogen, total phosphorus, TSS and BOD measured in this study were 30%, 76%, 89% and 64%, respectively. Removal efficiencies for the measured heavy metals ranged from 47 % for copper to 81 % for zinc.

Mean values for the two studies are reported at the bottom of Table 4. On an average basis, off-line retention/detention facilities provide good removal efficiencies for total nitrogen, total phosphorus, TSS, BOD and heavy metals. Annual removal efficiencies for this type of system can be expected to be approximately 55-65 % for total nitrogen and total copper; 75-85% for total phosphorus and total lead; and 80-90% for TSS, BOD and total zinc.

Wet Detention Systems

Of the stormwater management facilities investigated during this research, probably the most amount of research within the State of Florida has been conducted on wet detention systems. Unfortunately, much of the existing research was conducted on wet detention systems which were not constructed according to current regulations regarding mean detention time, pond configuration and depth. Many of the available studies do not present information regarding the pollution abatement volume or residence time within the system.

A summary of treatment efficiencies for wet detention systems based on selected research studies in Florida is given in Table 5. Measured removal efficiencies for NOX, orthophosphorus, total phosphorus, TSS

and heavy metals are relatively consistent between the studies presented within the table. In contrast, a high degree of variability in measured removal efficiencies is present for TKN and total nitrogen. Removal efficiencies for total nitrogen range from -12% to -44% for the studies presented in Table 3-22. Wet detention systems provide mean removal efficiencies of 60% or greater for NOX, orthophosphorus, total phosphorus, TSS and copper. Removal efficiencies for orthophosphorus, TSS, lead and zinc approach or exceed 75%.

TABLE 5

TREATMENT EFFICIENCIES FOR WET DETENTION SYSTEMS BASED ON SELECTED RESEARCH STUDIES IN FLORIDA

STUDY SITE/ LAND USE'	TYPE OF EFFICIENCIES REPORTED	MEAN REMOVAL EFFICIENCIES (%) NO~	TKN	Total N	Ortho-P	Total P	TSS	BOD	Total --Cu	Total Pb
Brevard County/ Commercial'	Concentration	-	-76	-	-	-69	-94	-	-	-96
Boca Raton/ Residential2	Concentration	-93	+31	-12	-93	-55	-68	-	-	-
	Mass	-87	0	-15	-82	-60	-64		-	-
Maitland/ Highway'	Concentration	-85	-22	-35	-94	-81	-		-56	-88
EPCOT/ Highway'	Concentration	-79	-35	-44	-92	-62	-		0	0
Orlando/ Urban'	Concentration	-	-15		57	-38	-66	-	-	-40
Orlando/ Residential'	Mass	-95	-90	-	-	-91	-82	-90	-90	-90
DeBary/ Commercial-ResidentiaI6	Mass a. td 7 days	-50	-	-20	-40	-60	-85	-50	-40	-60
	b. 14 days	-70	-	-30	-60	-70	-85	-60	-50	-85
Tampa/light Commercial'	Mass	-65	-49	-	-67	-65	-55	-	-	-
MEAN VALUES		-80	-37	-26	-73	-6S	-75	-67	-59	-77

1. Post, Buckley, Schuh & Jernigan (1982)
2. Cullum (1984)
3. Yousef, et al. (1986)
4. Martin and Miller (1987)
5. Harper (1988)
6. Harper and Herr (1993)
7. Rushton and Dye (1993)

In many of the studies the ability of the system to remove total nitrogen is heavily dependent upon the fraction of total nitrogen present as organic nitrogen. Organic nitrogen is not readily available through biological or chemical processes, and there are relatively few mechanisms for removal of this species in a wet detention system. In contrast, both NO, and ammonia are readily taken up in biological processes which accounts for the relatively good removal efficiencies achieved for these species in wet ponds. In systems where organic nitrogen represents a dominant proportion of the total nitrogen in the incoming stormwater flow, removal of total nitrogen can be expected to be relatively poor. If inorganic species of NO,, and ammonia represent the dominant nitrogen species found, then removal efficiencies for total nitrogen can be expected to increase.

On an average basis, wet detention systems can be expected to provide a net removal of approximately 20-30% for total nitrogen; 60-70% for total phosphorus and copper; and 75 % or more for total suspended

solids, total lead and total zinc. The report by Harper and Herr (1993) presents separate removal efficiencies for pond detention times of approximately 7 days, along with detention times of 14 days or more. With the exception of TSS, increasing the pond detention time results in a slight improvement in removal efficiencies for the listed parameters. At a detention time of 7 days, removal of total nitrogen, total phosphorus and TSS is estimated to be approximately 20%, 50% and 85 %, respectively. Heavy metal removal is estimated at 40 %, 60 % and 85 % for copper, lead and zinc, respectively. At a detention time of 14 days, removal of total nitrogen, total phosphorus and TSS increases slightly to approximately 30%, 70% and 85%, respectively. Heavy metal removal at a detention time of 14 days increases to 50%, 85% and 95% for copper, lead and zinc, respectively.

Wet Detention with Filtration Systems

Wet detention with filtration systems are commonly used throughout the State of Florida. However, prior to 1993, no specific research had been conducted to evaluate the pollutant removal effectiveness of these systems. In 1993, a study was performed by Harper and Herr over a 6-month period at a research site in DeBary, Florida. A detailed hydrologic budget was calculated for the pond and filter system combined and separately, and flow-weighted composite samples were collected of stormwater runoff, underdrain outflow, bulk precipitation and groundwater inputs to allow calculation of a detailed mass balance for the overall system.

A summary of treatment efficiencies measured by Harper and Herr ~1993) for wet detention with filtration systems is given in Table 6. On an annual mass basis, the wet detention with filtration system was found to remove approximately 60% of the total phosphorus and 98% of the TSS. However, no net removal of total nitrogen was measured at the site. Removal efficiencies for heavy metals were variable, ranging from 37% for total copper to 89% for total zinc.

TABLE 6

TREATMENT EFFICIENCIES FOR WET DETENTION WITH FILTRATION SYSTEMS BASED ON SELECTED RESEARCH STUDIES IN FLORIDA

STUDY	TYPE OF			MEAN REMOVAL EFFICIENCIES (%)							
SITE/ LAND USE	EFFICIENCIES REPORTED	NO.	T"	Total N	Ortho-P	Total P	TSS	BOD	Total Cu	Total Pb	Total Zn
DeBary/ Commercial & Residential	Overall	-27	0	0	-37	-61	-98	-99	-37	-71	-89

1. Harper and Herr (1993)

Harper and Herr (1993) concluded that the majority of removal processes occurred within the open water portions of the pond and not within the filter media. Particles of nitrogen, phosphorus and heavy metals which became trapped on the filter media were found to solubilize over time, resulting in increased concentrations of dissolved species in the underdrain flow compared with concentrations measured in the pond. No long-term effectiveness or affinity of the filter media was observed to retain inputs of nitrogen, phosphorus and heavy metals.

The poor removal efficiencies for total nitrogen exhibited by the system were found to be related to entrapment of particulate nitrogen on the filter surface with later subsequent decomposition and solubilization of particulate forms into dissolved forms of nitrogen which could then pass through the filter media and into the outflow. The effectiveness of the system would probably have been greater if the filter system had been removed since the* particulate forms of phosphorus and nitrogen would have settled into the bottom sediments where solubilization into the water column would have been of less concern. The study concluded that filter

systems remove relatively little pollution present in the stormwater flow on a long-term permanent basis, and the operation of wet detention ponds could probably be enhanced by elimination of the filter system and substitution with an orifice that allowed a slow drawdown over a period of several days.

Dry Detention Systems (Without Filtration)

Dry detention facilities are used commonly within the South Florida Water Management District. Although these systems are commonly used, the literature review did not find any studies conducted within the State of Florida which identified the pollutant removal effectiveness of these systems. Dry detention systems remove pollutants primarily through sedimentation processes with a limited amount of biological and chemical activity occurring in addition to settling. Since dry detention facilities are designed to regain the pollution abatement volume within a period of several days, opportunities for biological activity is severely limited.

Due to the function of dry detention systems, pollutant removal efficiencies are dictated primarily by settling processes. Removal of suspended solids in these systems between the inflow and outflow is generally relatively good. Removal of particulate forms of nitrogen, phosphorus and heavy metals may also occur due to sedimentation during travel through the pond. However, few removal mechanisms are available for dissolved forms of nutrients, heavy metals or other parameters other than losses due to infiltration into the pond bottom.

Estimated treatment efficiencies for dry detention systems are presented in Table 7 based on extensive previous research conducted by ERD on stormwater management facilities. Assuming a detention time of 1-3 days within the system, removal of suspended solids can be expected to range from approximately 60-80%. In general, approximately half of the total phosphorus measured in runoff is present in a particulate form. Much of this particulate matter can be expected to settle out within the detention facility. However, resolubilization. of some settled particulate matter may increase dissolved phosphorus concentrations within the water column, reducing the effective removal efficiency of the system. Therefore, removal of total phosphorus within the system is estimated to be approximately 20-40%.

TABLE 7

ESTIMATED TREATMENT EFFICIENCIES FOR DRY DETENTION SYSTEMS

PARAMETER	RANGE OF ESTIMATED REMOVAL EFFICIENCIES	RECOMMENDED REMOVAL EFFICIENCY
Total N	-10 to -20	-15
Total P	-10 to -40	-25
TSS	60 to -80	-70
BOD	-30 to -50	-40
Total Cu	-20 to -50	-35
Total Pb	-40 to -80	-60
Total Zn	-50 to -90	-70

Particulate forms of total nitrogen generally comprise approximately one-third of the total nitrogen measured in stormwater runoff. Much of this particulate matter can be expected to settle out within the pond. However, some resolubilization may occur, reducing the observed treatment effectiveness. Annual removal of total nitrogen within a dry detention system is estimated to be approximately 10-20%.

Lead and zinc are typically characterized by significant particulate fractions which account for the majority of the metal species measured in stormwater runoff. As a result, mass removal for these metals should be good due to settling of particulate matter within the pond. In contrast, copper is primarily in a dissolved form in runoff, and removal efficiencies of this metal should be substantially less than for lead or zinc. Annual removal in dry detention ponds is estimated to be 20-50% for total copper, 40-80% for total lead, and 50-90% for total zinc.

Significant decomposition of oxygen demanding wastes may also occur within detention facilities with a detention time of 1-3 days. Some BOD is also present in stormwater as particulate matter which may settle out onto the pond bottom. As a result, treatment efficiency for BOD in a dry detention system is estimated to be approximately 30-50%.

Comparison of Treatment Efficiencies for Stormwater Management Systems

A comparison of treatment efficiencies for typical stormwater management systems used in the State of Florida is given in Table 8 based on information obtained in the literature review. In cases where a range of removal efficiencies are presented in technical reports related to a particular stormwater management technique, the mid-point of the range is given in Table 8 for comparison purposes.

The Florida State Water Policy, outlined in Chapter 17-40 of the Florida Administrative Code, establishes a goal of 80% annual reduction of stormwater pollutant loadings by stormwater management systems. Of the stormwater management systems listed in Table 8, only dry retention systems, with 0.5-inch of runoff retained, meet the State Water Policy goal of 80% reduction in annual pollutant loadings to the system. Off-line retention/detention facilities meet the 80% reduction goal for total phosphorus, TSS, BOD and total zinc, but provide only a 60-75 % annual pollutant reduction for total nitrogen, copper and lead. Wet detention systems can meet the 80% reduction goal for TSS only, with removal efficiencies from 40-50% for total nitrogen, total phosphorus and BOD. Dry detention with filtration systems meet the 80% reduction goal for total lead only and provide virtually no pollutant removal for total nitrogen, total phosphorus and BOD. Based on the available literature, dry detention with filtration systems were found to exhibit a high degree of variability in estimated removal efficiencies. The actual removal efficiencies achieved by dry detention with filtration systems are a function of the relationship between the underdrain system and the seasonal high groundwater table.

TABLE 8

COMPARISON OF TREATMENT EFFICIENCIES FOR TYPICAL STORMWATER MANAGEMENT SYSTEMS USED IN FLORIDA

TYPE OF SYSTEM	ESTIMATED REMOVAL EFFICIENCIES (%)						
	TOTAL N	TOTAL P	TSS	BOD	TOTAL Cu	TOTAL Pb	TOT Zn
Dry Retention							
a. 0.25-inch retention	-60	-60	-60	-60	-60	-60	-60
b. 0.50-inch retention	-80	-80	-80	-80	-80	-80	-80
c. 0.75-inch retention	-90	-90	-90	-90	-90	-90	-90
d. 1.00-inch retention	-95	-95	-95	-95	-95	-95	-95
e. 1.25-inch retention	-98	-98	-98	-98	-98	-98	-98
Off-Line Retention/Detention	-60	-85	-90	-80	-65	-75	-85
Wet Retention	-40	-50	-85	-40	-25	-50	-70
Wet Detention	-25	-65	-85	-55	-60	-75	-85
Wet Detention with Filtration	0	-60	-98	-99	-35	-70	-90
Dry Detention	-15	-25	-70	-40	-35	-60	-70
Dry Detention with Filtration							
a. Type A or B soils	0	0	-75	0	-65	-90	-25
b. Type C or D sods	0	0	-60	0	-45	-90	-10
Alum Treatment	-50	-90	-90	-75	-80	-90	-80

Based on the information provided in Table 8, the most effective stormwater management systems in terms of retaining stormwater pollutants appear to be dry retention, off-line retention/detention ponds, wet retention, and wet detention systems. The use of these types of systems should be emphasized to maximize the pollutant removal effectiveness for stormwater management systems.

Based upon the literature review, there is little evidence to indicate that filter systems improve the operational performance of stormwater management systems. In fact, much of the research indicates that filter systems may actually degrade the pollutant removal effectiveness of either a wet detention or dry detention system. In addition, filter systems must be routinely maintained to continue the proper hydraulic performance of the system. In view of the poor pollutant removal effectiveness of filter systems, and the continuing maintenance problems associated with these systems, the use of filter systems with wet detention or dry detention ponds should be discouraged.

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