PERFORMANCE EVALUATION OF DRY DETENTION STORMWATER MANAGEMENT SYSTEMS

Harvey H. Harper, Ph.D., P.E., *Jeffrey L. Herr*, P.E., and *David Baker*, E.I.
Environmental Research & Design, Inc.
3419 Trentwood Blvd, Suite 102, Orlando, Florida 32812

Eric H. Livingston
Florida Department of Environmental Protection
Bureau of Water Resource Protection/Nonpoint Source Management
Twin Towers Office Building, MS 3570;
2600 Blair Stone Road, Tallahassee, Florida 32399-2400

ABSTRACT

Field and laboratory investigations were conducted from August 1997 to March 1998 at a project site in DeBary, Florida to evaluate the hydraulic and water quality characteristics of a dry detention pond system constructed with a perforated pipe vertical filter system as an outlet control structure and anti-clogging device. The dry detention pond was constructed in 1996 to provide stormwater treatment for a 9.66 ha (23.86 ac) single-family residential watershed. Field instrumentation was installed at the dry detention pond site to conduct a complete hydrologic budget for the pond, including water level recorder, rainfall recorder, Class A pan evaporimeter, and groundwater piezometers. Automatic sequential samplers with integral flow meters were installed to provide continuous records of inflow and outflow from the pond and to collect stormwater and outflow samples on a flow-weighted basis.

On a mass basis, the dry detention pond was extremely effective in retaining mass inputs for all measured parameters. Overall mass removal for total nitrogen within the system was approximately 86%, with 84% removal of total phosphorus, 99% removal of TSS, 82% removal of BOD, and 88-96% removal for heavy metals. However, the magnitude of the mass removal efficiencies are due to the fact that more than 70% of the inputs into the pond were lost as a result of groundwater seepage through the pond bottom. On a concentration basis, the water column of the dry detention pond was capable of providing removal efficiencies of 30-90% for all input parameters with the exception of dissolved organic nitrogen, particulate nitrogen, total nitrogen, and BOD. Migration through the filter system provided little additional removal for most parameters.

The filter underdrain system was observed to exhibit highly variable hydraulic characteristics and was prone to clogging after only a few weeks of operation. Routine backwashing was necessary to maintain the filter system in an operational manner. In the absence of the substantial losses observed as a result of groundwater seepage from the pond, it appears that the filter underdrain system would be incapable of maintaining the pond in a near-dry condition.

INTRODUCTION

One of the most common stormwater treatment methodologies used in Central and South Florida today for pollution abatement is dry detention. Stormwater inputs into a dry detention system are typically evacuated within 24-72 hours through an outlet structure, leaving the system in a "dry" condition between storm events. Dry detention systems are commonly used in high groundwater table areas where the normal groundwater level will not allow the use of a retention-type facility. Removal of particulates and associated pollutants by sedimentation within the pond is the primary physical removal process occurring in dry detention systems.

A common problem associated with the use of dry detention systems has been clogging of the outfall structure orifice used to regulate the discharge of water from the storage basin. In response to this persistent problem, the St. Johns River Water Management District (SJRWMD) published new criteria in 1994, as outlined in Chapter 40C-42 F.A.C., which requires that outlet structures for dry detention basins contain a device to prevent the discharge of accumulated sediment, minimize exit velocities, and reduce clogging. Examples of such devices, provided by SJRWMD, include a perforated riser enclosed in a gravel jacket, along with perforated pipes enclosed in either sand or gravel. However, the performance efficiency of these new systems has not been evaluated.

Study Site

Field and laboratory investigations were conducted from August 1997 to March 1998 at a dry detention pond site in DeBary, Florida. The dry detention pond was constructed in 1996 to provide stormwater treatment for a 9.66 ha (23.86 ac) single-family residential watershed with approximately 37% impervious coverage. Soils within the drainage basin are classified in Hydrologic Soil Group A.

The detention pond is constructed with a small vertical bottom filter system adjacent to the outfall structure according to criteria outlined by the SJRWMD in Chapter 40C-42 FAC. The filter system consists of a 10 cm (4 in) perforated PVC pipe covered with a filter fabric sock. The perforated pipe is approximately 3.3 m (10 ft) in length, with a 30 cm (12 in) layer of 20-30 silica sand on all sides of the perforated pipe covered by a 10 cm (4 in) top layer of FDOT coarse aggregate. Filter media used in the filter system met all applicable criteria for filter systems outlined in Chapter 62-25 FAC. Based on a total filter length of approximately 3.3 m (10 ft) and a width of 0.6 m (2 ft), the filter system provides a vertical filter area of approximately 2.0 m^2 (20 ft^2). The filter is the only drawdown mechanism provided for the detention pond other than an overflow weir designed at a 100-year flood elevation. The detention pond is designed to be maintained in a dry condition except during the drawdown period immediately following rain events. At the mean pond bottom elevation of 50 ft (MSL), the pond surface area is approximately 1515 m^2 (16,299 ft^2). Discharges from the underdrain system flow to an adjacent final retention pond which is constructed in a depressional area with no direct off-site discharge. A schematic of the outfall structure with bottom filter system is given in Figure 1.

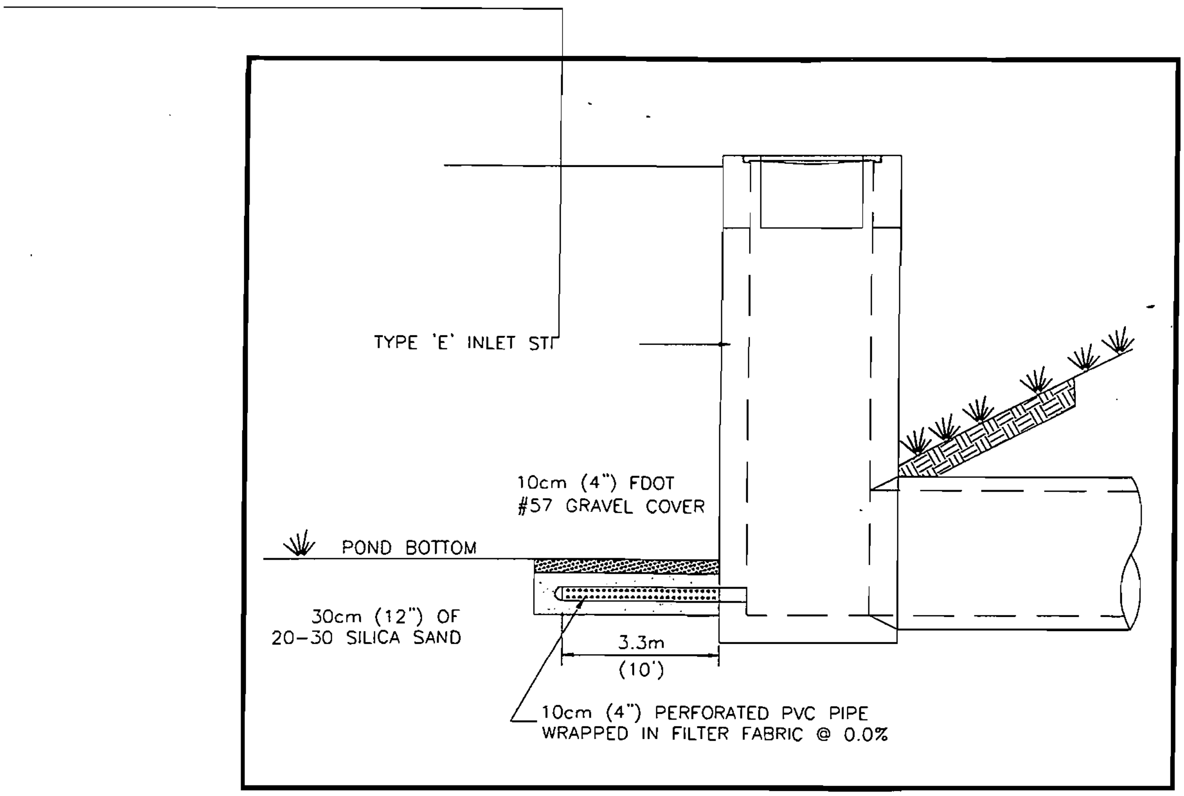

Figure 1. Schematic of dry detention pond outfall structure with anti-clogging device.

MATERIALS AND METHODS

Field instrumentation was installed at the dry detention pond site to conduct a complete hydrologic budget for the pond, including a water level recorder, rainfall recorder, Class A pan evaporimeter, and groundwater piezometers. Automatic sequential samplers with integral flow meters were installed to provide continuous records of inflow and outflow from the pond and to collect stormwater and outflow samples on a flow-weighted basis. A total of 21 groundwater piezometers were installed along seven transects around the perimeter of the detention pond to

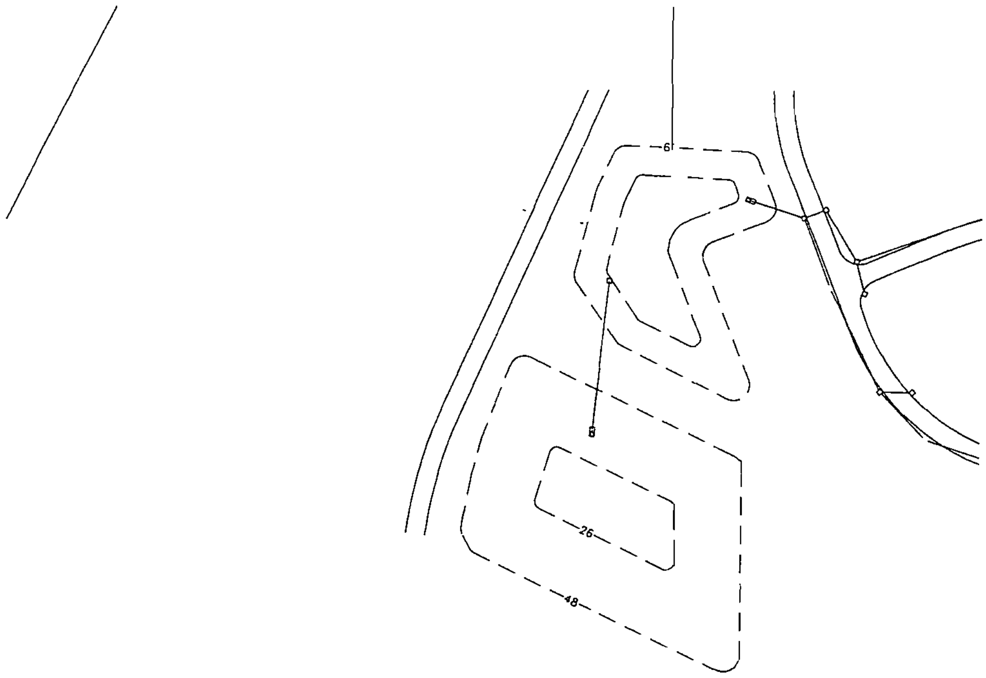

Figure 2. Field instrumentation.

provide information on horizontal groundwater gradients in the vicinity of the pond site. A schematic of field instrumentation used at the dry detention pond site is given in Figure 2.

Laboratory analyses were conducted on collected samples of stormwater runoff, dry weather baseflow, outflow, surface water, and bulk precipitation. Analyses performed included nutrients, general inorganic parameters, demand parameters, chlorophyll-a, oil and grease, TRPH, fecal coliform, and dissolved and total heavy metals. In excess of 80,000 separate field and laboratory measurements were generated during the course of this project.

RESULTS

A continuous record of rainfall characteristics was collected at the DeBary site from August 10, 1997 to March 1, 1998 using a tipping bucket rainfall collector with a digital data logging recorder. Individual rainfall events ranged from 0.03-4.70 cm (0.01-1.85 in), with a mean of 0.9 cm (0.36 in) per rain event. A total of 64.4 cm (25.35 in) of rainfall was measured at the site from August 1997 through February 1998. Total daily evaporative losses at the site ranged from a high of 0.42 cm/day in September to a low of 0.18 cm/day during December.

Pond water surface elevations had a maximum fluctuation of approximately 0.8 m (2.75 ft) during the project period. Typical water depths in the pond throughout the project period ranged from approximately 15-30 cm (6-12 inches). The maximum measured water level in the pond of 51.85 ft (MSL) resulted in a maximum water depth of 0.72 m (2.35 ft). Although the pond is designed as a dry detention pond, areas of standing water were present within the pond at all times throughout the 6-month assessment period. Based on piezometric elevations measured at the project site from September 1997 to February 1998, no significant evidence of migration of groundwater into the pond was observed during the project period.

Continuous inflow hydrographs were recorded for inputs of stormwater and baseflow into the detention pond at 10-minute intervals from August 16, 1997 to March 1, 1998. Calculated runoff coefficients at the pond site ranged from a low of 0.102 in October to a high of 0.167 in February, with a weighted average runoff coefficient of 0.128.

During the 6-month sampling period, stormwater runoff contributed approximately 85% of the hydrologic inputs into the system, with approximately 12% contributed by direct rainfall and 3% contributed by dry weather baseflow. Based upon the results of piezometric measurements, no direct groundwater inflow into the pond is assumed. The dominant loss from the pond appears to be groundwater seepage which accounted for approximately 71% of the total pond losses. Underdrain outflow appears to account for approximately 20% of the pond losses, with evaporation comprising the remaining 9%. A comparison of overall hydrologic inputs and losses at the dry detention pond site is given in Figure 3. Average detention time within the pond ranged from a low of 4.3 days in February to a maximum of 60 days in November.

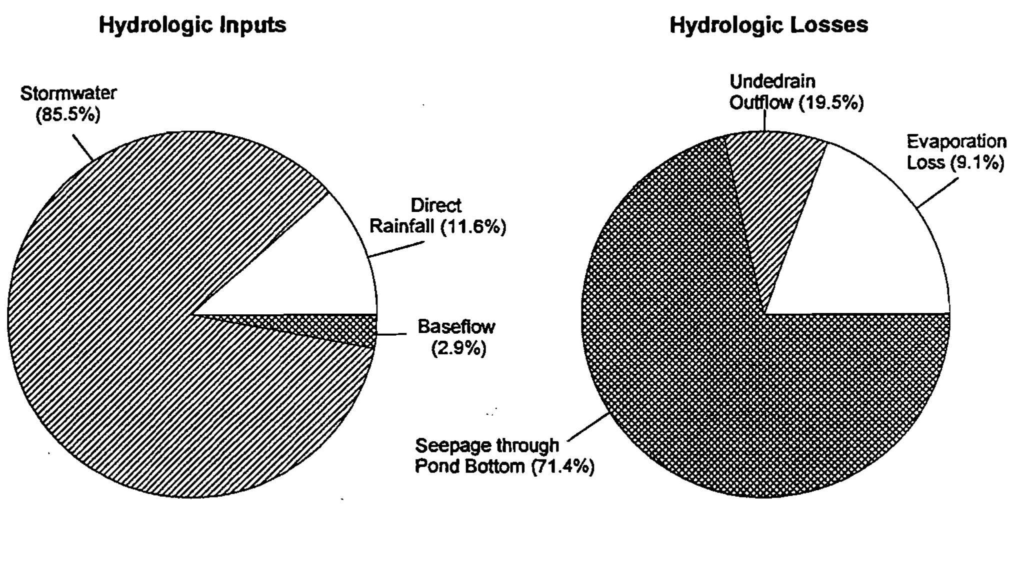

Figure 3. Comparison of hydrologic inputs and losses.

Characteristics of Stormwater and Dry Weather Baseflow

A total of 35 separate storm event composite samples were collected and analyzed over the 6-month sampling period, representing more than 64% of the total storm events which generated measurable runoff into the detention pond. Six composite baseflow samples were also collected at the inflow to the detention pond. A summary of chemical characteristics of runoff and baseflow measured at the site is given in Table 1.

TABLE 1

MEAN CHARACTERISTICS OF STORMWATER RUNOFF AND DRY WEATHER BASEFLOW MEASURED AT THE DRY DETENTION POND SITE

PARAMETER	UNITS	STORMWATER RUNOFF MEAN[1]	BASEFLOW MEAN[2]	PARAMETER	UNITS	STORMWATER RUNOFF MEAN[1]	BASEFLOW MEAN[2]
pH	s.u.	7.73	7.75	Oil and Grease	mg/l	< 0.5	< 0.5
Spec. Conductivity	µmho/cm	122	222	TRPH	mg/l	< 0.5	< 0.5
Alkalinity	mg/l	70.5	100	Fecal Coliform	#/100 ml	3412	372
NH_3	µg/l	1374	615	Cd - Diss.	µg/l	< 0.5	0.6
NO_x	µg/l	283	601	Cd - Total	µg/l	0.6	2.3
Diss. Organic N	µg/l	1042	564	Cr - Diss.	µg/l	3	3
Particulate N	µg/l	1204	460	Cr - Total	µg/l	12	7
Total N	µg/l	3905	2240	Cu - Diss.	µg/l	2	3
Ortho-P	µg/l	153	316	Cu - Total	µg/l	4	5
Particulate P	µg/l	212	131	Pb - Diss.	µg/l	< 2	< 2
Total P	µg/l	383	467	Pb - Total	µg/l	6	< 2
Turbidity	NTU	412	8.7	Fe - Diss.	µg/l	212	69
Chloride	mg/l	9.5	21	Fe - Total	µg/l	2985	686
TSS	mg/l	299	9.7	Zn - Diss.	µg/l	6	13
BOD	mg/l	5.8	2.4	Zn - Total	µg/l	35	28

1. n = 35 samples
2. n = 6 samples

The mean concentration of total nitrogen in stormwater runoff at the DeBary site is higher than concentrations of total nitrogen typically found in residential runoff in Central Florida, although this value was influenced substantially by elevated levels of total nitrogen measured during one or two individual storm events. In contrast, the mean total phosphorus concentration in stormwater runoff measured at the site is more typical of total phosphorus values normally measured in urban runoff, although substantially elevated total phosphorus concentrations were observed during several individual events. Stormwater runoff at the site was found to have elevated levels of turbidity and TSS. Measured concentrations of oil and grease and TRPH were found at or below minimum detection limits in all monitored stormwater samples. In general, measured concentrations of all heavy metals in stormwater runoff, with the exception of iron, were found to be extremely low in value. Each of the measured heavy metals was found to exist primarily in a particulate form.

Dry weather baseflow was found to have lower concentrations of both total nitrogen and total phosphorus than observed in stormwater runoff. Measured concentrations of heavy metals in baseflow samples collected at the site were found to be extremely low in value for virtually all measured metals. The majority of heavy metals in baseflow inputs were present as particulate metal species.

Characteristics of Bulk Precipitation

A summary of measured characteristics of bulk precipitation is given in Table 2. In general, bulk precipitation was found to be acidic, low in ionic strength, and poorly buffered. Elevated levels of ammonia, organic nitrogen, nitrate, and total phosphorus were measured on several occasions, presumably impacted by clearing and burning activities on property adjacent to the site. Periods of elevated phosphorus concentrations appear to correspond with elevated levels of nitrogen, turbidity, and TSS, suggesting a significant influence from the burning and clearing activities. Relatively low levels of heavy metals were measured in bulk precipitation, although evidence of elevated concentrations during specific events are apparent for both total iron and total zinc. These elevated levels also appear to be related to the clearing activities observed at the adjacent site.

TABLE 2

MEAN CHARACTERISTICS OF BULK PRECIPITATION MEASURED AT THE DEBARY DRY DETENTION POND SITE FROM AUGUST 1997-FEBRUARY 1998[1]

PARAMETER	UNITS	MEAN	PARAMETER	UNITS	MEAN
pH	s.u.	6.72	Turbidity	NTU	6.7
Spec. Conductivity	µmho/cm	20	Chloride	mg/l	2
Alkalinity	mg/l	19.2	TSS	mg/l	13.2
NH_3	µg/l	450	Total Cadmium	µg/l	0.5
NO_x	µg/l	184	Total Chromium	µg/l	3
Diss. Organic N	µg/l	876	Total Copper	µg/l	1
Total N	µg/l	1510	Total Lead	µg/l	<2
Ortho-P	µg/l	113	Total Iron	µg/l	94
Total P	µg/l	191	Total Zinc	µg/l	12

1. n = 15 samples

Characteristics of Pond Surface Water

A summary of mean chemical characteristics of pond surface water is given in Table 3. Visually, the detention pond was characterized by a green water column, presumably resulting from excess algal growth, and a relatively turbid appearance. The pond water column was well oxygenated on all monitoring dates, with field measured values of ORP indicating oxidized conditions within the pond for all monitoring events.

TABLE 3

MEAN CHARACTERISTICS OF DETENTION POND SURFACE WATER MEASURED AT THE DEBARY DRY DETENTION POND SITE FROM AUGUST 1997-FEBRUARY 1998[1]

PARAMETER	UNITS	MEAN	PARAMETER	UNITS	MEAN
pH[2]	s.u.	7.14	Chlorophyll-a	mg/m^3	16.3
Spec. Conductivity[2]	µmho/cm	121	BOD	mg/l	12.2
Diss. Oxygen[2]	mg/l	9.3	Oil and Grease	mg/l	< 0.5
Oxygen Saturation	%	107	TRPH	mg/l	< 0.5
ORP[2]	mV	560	Fecal Coliform	#/100 ml	115
Alkalinity	mg/l	52.5	Cd - Diss.	µg/l	< 0.5
NH_3	µg/l	97	Cd - Total	µg/l	0.5
NO_x	µg/l	52	Cr - Diss.	µg/l	3
Diss. Organic N	µg/l	921	Cr - Total	µg/l	4
Particulate N	µg/l	1859	Cu - Diss.	µg/l	1.2
Total N	µg/l	2929	Cu - Total	µg/l	1.2
Ortho-P	µg/l	15	Pb - Diss.	µg/l	3
Particulate P	µg/l	220	Pb - Total	µg/l	3
Total P	µg/l	257	Fe - Diss.	µg/l	225
Turbidity	NTU	56.7	Fe - Total	µg/l	1407
Chloride	mg/l	4	Zn - Diss.	µg/l	3
TSS	mg/l	42.6	Zn - Total	µg/l	6

1. n = 27 samples
2. Field measured value

Measured concentrations of total nitrogen and total phosphorus in the pond water were elevated on many monitoring dates due to a high percentage of particulate species. Surface water within the pond typically exhibited low concentrations of fecal coliform bacteria. Measured concentrations of chlorophyll-a within the pond were highly variable throughout the monitoring period, ranging from 0.2-70.2 mg/m^3. In general, measured concentrations of heavy metals in pond surface water were found to be extremely low in value and substantially lower than input concentrations measured in stormwater runoff.

Characteristics of Underdrain Outflow

Mean chemical characteristics of underdrain outflow are summarized in Table 4. In general, chemical characteristics of underdrain outflow appear to be similar to those found in pond surface water. Migration through the underdrain appears to result in a slight reduction in measured concentrations of total nitrogen. Measured concentrations of dissolved organic nitrogen and particulate nitrogen appear to decrease during migration through the filter media, while substantial increases are observed in measured concentrations of ammonia and nitrate. A slight reduction in particulate phosphorus is apparent during migration through the filter media, with a corresponding increase in soluble orthophosphorus in the underdrain outflow compared with the pond surface water. Measured concentrations of total phosphorus remain unchanged during migration through the filter.

TABLE 4

MEAN CHARACTERISTICS OF UNDERDRAIN OUTFLOW MEASURED AT THE DEBARY DRY DETENTION POND SITE FROM AUGUST 1997-FEBRUARY 1998[1]

PARAMETER	UNITS	MEAN	PARAMETER	UNITS	MEAN
pH	s.u.	7.28	TRPH	mg/l	< 0.5
Spec. Conductivity	µmho/cm	114	Fecal Coliform	#/100 ml	724
Alkalinity	mg/l	53.4	Chlorophyll-a	mg/m^3	11.9
NH_3	µg/l	149	Cd - Diss.	µg/l	< 0.5
NO_x	µg/l	174	Cd - Total	µg/l	< 0.5
Diss. Organic N	µg/l	832	Cr - Diss.	µg/l	3
Particulate N	µg/l	1566	Cr - Total	µg/l	3
Total N	µg/l	2721	Cu - Diss.	µg/l	1.1
Ortho-P	µg/l	31	Cu - Total	µg/l	1.1
Particulate P	µg/l	208	Pb - Diss.	µg/l	3
Total P	µg/l	260	Pb - Total	µg/l	3
Turbidity	NTU	41.3	Fe - Diss.	µg/l	149
Chloride	mg/l	3	Fe - Total	µg/l	1113
TSS	mg/l	31.0	Zn - Diss.	µg/l	4
BOD	mg/l	9.8	Zn - Total	µg/l	7
Oil and Grease	mg/l	< 0.5			

1. n = 48 samples

Underdrain discharges from the dry detention pond were found to exhibit chronic violations of Class III surface water quality criteria for turbidity, fecal coliform bacteria and total iron. Approximately one out of three measured outflow samples exceeded applicable Class III criteria for turbidity and total iron, with one out of five outflow samples exceeding applicable Class III criteria for fecal coliform bacteria.

Estimated Removal Efficiencies for System Components

System Mass Removal Efficiencies

Overall system removal efficiencies for the dry detention pond over the 6-month period are summarized in Table 5. On an overall mass basis, removal efficiencies for measured parameters ranged from approximately 82-99%, with an overall mass removal of 86% for total nitrogen, 84% removal of total phosphorus, 99% removal of TSS, 82% removal of BOD, and 88-96% removal for heavy metals.

TABLE 5

ESTIMATED MASS REMOVAL EFFICIENCIES FOR THE DEBARY DRY DETENTION POND FROM SEPTEMBER 1997-FEBRUARY 1998

PARAMETER	UNITS	TOTAL INPUTS[1]	OUTFALL LOSSES[2]	SYSTEM REMOVAL (%)	PARAMETER	UNITS	TOTAL INPUTS[1]	OUTFALL LOSSES[2]	SYSTEM REMOVAL (%)
NH_3-N	g	3,236	407	87	TSS	kg	3,368	41	99
NO_x-N	g	2,016	184	91	BOD	kg	37	6.8	82
Diss. Org. N	g	4,875	842	83	Cadmium	g	6.1	0.74	88
Particulate N	g	10,063	1,311	87	Chromium	g	119	5.7	95
Total N	g	20,123	2,745	86	Copper	g	37	1.5	96
Ortho-P	g	929	127	86	Iron	g	26,962	1,744	94
Particulate P	g	2,007	336	83	Lead	g	52	4.1	92
Total P	g	3,167	498	84	Zinc	g	207	10	95
Chloride	kg	37	3.9	89					

1. Sum of inputs from stormwater, baseflow, and bulk precipitation
2. Measured mass losses through the outfall structure

The extremely high mass removal efficiencies observed within the system are primarily due to the fact that only a small portion of the hydraulic inputs into the pond system left the pond through the underdrain outflow. More than 70% of the inputs into the pond were lost as a result of groundwater seepage through the pond bottom which carried a corresponding mass of pollutants as the water migrated through the bottom sediments and into adjacent groundwater. Although the dry detention pond appears to exhibit excellent mass removal efficiencies for all measured constituents, this assessment does not indicate that similar removal efficiencies can be achieved in a dry detention pond which does not have a significant loss component due to groundwater seepage.

Concentration-Based Removal Efficiencies

Pond Water Column

Concentration-based removal efficiencies were calculated to estimate pollutant attenuation which occurred only within the water column of the detention pond. These efficiencies were calculated by comparing the estimated weighted inflow concentrations for all measured inputs from stormwater runoff, dry weather baseflow, and bulk precipitation, with the calculated mean pond concentrations. A summary of concentration-based removal efficiencies for the pond water column is given in Table 6.

TABLE 6

CONCENTRATION-BASED REMOVAL EFFICIENCIES FOR SYSTEM COMPONENTS

PARAMETER	UNITS	POND REMOVAL (%)	FILTER REMOVAL (%)	OVERALL SYSTEM REMOVAL (%)	PARAMETER	UNITS	POND REMOVAL (%)	FILTER REMOVAL (%)	OVERALL SYSTEM REMOVAL (%)
NH_3-N	μg/l	76	-182	31	TSS	mg/l	90	37	93
NO_x-N	μg/l	79	-138	50	BOD	mg/l	-171	62	-2
Dis. Org. N	μg/l	-54	38	5	F. Coliform	#/100 ml	97	27	98
Part. N	μg/l	-51	53	28	Cadmium	μg/l	33	0	33
Total N	μg/l	-19	37	25	Chromium	μg/l	73	14	75
Ortho-P	μg/l	87	-473	25	Copper	μg/l	73	17	78
Part. P	μg/l	11	-3	8	Iron	μg/l	57	17	64
Total P	μg/l	34	-31	13	Lead	μg/l	52	-7	56
Turbidity	NTU	90	-8	89	Zinc	μg/l	76	-17	72
Chloride	mg/l	0	25	42					

The pond water column appears to provide good removal efficiencies for inorganic nitrogen species, although increases in measured concentrations were observed for dissolved organic nitrogen, particulate nitrogen, and total nitrogen. Unlike the trend observed for species of nitrogen, measured phosphorus species exhibited consistent removals within the water column of the pond. On an overall basis, the pond water column appeared to be capable of removing approximately one-third of the total phosphorus input. The water column of the pond was also found to be capable of providing significant removal efficiencies for both turbidity and TSS, with an estimated removal efficiency of 90% for each parameter. Increases in measured BOD concentrations within the pond may be related to the use of the pond by waterfowl on a periodic basis. The pond provided excellent removal efficiencies for fecal coliform. The detention pond water column provided good removal efficiencies for all heavy metals, largely due to settling of particulate metal forms.

Filter System

Removal efficiencies were also calculated for changes in concentration during migration through the underdrain outflow system. Migration through the underdrain system appeared to reduce measured concentrations of dissolved organic nitrogen and particulate nitrogen, while increasing measured concentrations of ammonia and nitrate. On an overall basis, total nitrogen concentrations were reduced by approximately 37% within the filter underdrain system. Although the filter system appears capable of removing total nitrogen, the long-term fate of these pollutants in the filter system is uncertain. However, migration through the filter media did not result in a measured reduction in phosphorus species. Measured concentrations of orthophosphorus, particulate phosphorus, and total phosphorus were found to increase in concentration during migration through the underdrain filter system.

Measured concentrations of turbidity were relatively unchanged during migration through the filter media. Turbidity within the water column of the pond appears to be a result of colloidal particles which are capable of migrating through the sand filter media. In contrast to the trends observed for turbidity, however, measured concentrations of TSS decreased by 37% during migration through the filter. The filter underdrain system is also approximately 62% effective in reducing concentrations of BOD. Migration through the filter underdrain system also reduced measured concentrations of fecal coliform bacteria and chlorophyll-a. However, migration through the filter underdrain system was relatively ineffective in reducing measured concentrations of either dissolved or total heavy metals.

Overall System Removal Efficiencies

Concentration-based removal efficiencies were calculated for the overall detention pond system as the change between the weighted input concentration and the weighted output concentration discharging through the underdrain system. On an overall basis, the dry detention system was found to exhibit positive removal efficiencies for all measured parameters with the exception of BOD. An overall removal efficiency of 25% was observed for total nitrogen, with an overall removal of 13% for total phosphorus. The dry detention pond system appears to be highly effective in reducing concentrations of certain particulate species, as evidenced by an 89% removal efficiency for turbidity, 93% removal efficiency for suspended solids, and 98% removal efficiency for fecal coliform. Measured removal efficiencies ranged from 56-78% for heavy metals.

Performance Characteristics of the Filter Underdrain System

Field Maintenance Activities

When field monitoring activities at the dry detention pond site first began in August 1997, it was discovered that the original filter underdrain system was inoperable. As a result, the original filter underdrain system was removed and reconstructed according to the original pond design details. After reconstructing the filter underdrain system, the hydraulic performance of the filter media was restored for a period of approximately two weeks. After this time, the hydraulic conductivity of the filter media decreased rapidly, becoming virtually totally clogged after a period of four weeks.

During September 1997, a backwash of the filter system was performed at a rate of approximately 15 gpm/ft^2 of filter area to fluidize the silica sand media, allowing trapped particles to escape. After completion of the backwash procedure, the original hydraulic performance of the filter media was restored for approximately 2-3 weeks, followed by a rapid decrease in conductivity of the filter media. Backwash attempts were again performed during October and November 1997 to maintain the hydraulic performance of the filter system. During the backwash procedures in November, it appears that the media became channelized, allowing water to migrate directly to the perforated pipe system, bypassing the filter media entirely.

Hydraulic Characteristics of the Filter System

In general, recovery within the pond following rain events appeared to be relatively slow due to the poor hydraulic performance of the filter underdrain system. If the large groundwater loss component had not been present, the hydraulic function of the underdrain system would have been insufficient for maintaining the pond in a dry condition, and the pond would have rapidly filled to the 100-year weir overflow elevation.

Over the 6-month monitoring period, the filter system was found to exhibit a high degree of variability in calculated permeability (K) values. Normal operation of the underdrain filter system using clean filter media resulted in measured permeability values ranging from approximately 3-4 ft/day. Field measured permeability values began to approach zero as the filter became clogged between backwash events. When channelization of the filter system occurred, field measured permeability increased substantially to values ranging from approximately 5-12 ft/day.

CONCLUSIONS

Based upon the results obtained during this project, the following specific conclusions were reached:

1. On a mass basis, the dry detention pond was extremely effective in retaining mass inputs for all measured parameters. Overall mass removal for total nitrogen within the system was approximately 86%, with 84% removal of total phosphorus, 99% removal of TSS, 82% removal

of BOD, and 88-96% removal for heavy metals. However, the magnitude of the mass removal efficiencies obtained in this assessment are largely a function of the fact that more than 70% of the inputs into the pond were lost as a result of groundwater seepage through the pond bottom which carried a corresponding mass of pollutants as the water migrated through the sediments and into the adjacent groundwater. Similar removal efficiencies could not be achieved in a dry detention pond which did not have a significant loss component due to groundwater seepage.

2. The water column of the dry detention pond was capable of reducing input concentrations of all input parameters with the exception of dissolved organic nitrogen, particulate nitrogen, total nitrogen, and BOD. Measured increases in concentrations of these parameters within the pond may be related to the presence of waterfowl which were observed to utilize the pond on a periodic basis. Although the pond water column provided no net removal for total nitrogen, the pond was capable of reducing concentrations of total phosphorus by 34%, turbidity by 90%, TSS by 90%, fecal coliform by 97%, cadmium by 33%, chromium and copper by 73%, iron by 57%, lead by 52%, and zinc by 76%.

3. Migration through the filter media was capable of reducing measured concentrations of dissolved organic nitrogen, particulate nitrogen, total nitrogen, TSS, BOD, fecal coliform, and chlorophyll-a. The filter media appeared to exhibit poor removal efficiencies for phosphorus species and heavy metals. Conversion of trapped particulate matter in the filter media into dissolved forms was observed for several parameters, such as ammonia, nitrate, and orthophosphorus.

4. The filter underdrain system was observed to exhibit highly variable hydraulic characteristics and was prone to clogging after only a few weeks of operation. Routine backwashing was necessary to maintain the filter system in an operational manner. In the absence of the substantial losses observed as a result of groundwater seepage from the pond, it appears that the filter underdrain system would have been incapable of maintaining the pond in a near-dry condition.

RECOMMENDATIONS

Based on the results obtained during this project, and the specific conclusions presented previously, the following recommendations are made for improving the performance of dry detention systems:

1. Further use of orifice anti-clogging devices which are similar in design to the anti-clogging device investigated during this project, should be discontinued. Evidence gathered during this project indicates that these vertical filer systems exhibit extremely variable hydraulic characteristics and are subject to clogging after relatively short run times. Continual maintenance will be required for these systems to maintain the filter media in an operational

mode. In addition, these anti-clogging devices provide little additional pollutant attenuation for the overall stormwater system.

2. Due to the rapid potential for clogging, dry detention systems constructed according to current SJRWMD criteria should be inspected and maintained at a frequency not to exceed once each month. Field maintenance activities may include filter backwashing, replacement of filter media, or other options necessary to maintain the hydraulic performance of the system.

ACKNOWLEDGMENTS

The project was funded by the Florida Department of Environmental Protection as part of a Section 319 grant from the U.S. Environmental Protection Agency. The authors wish to thank these organizations for their assistance and cooperation in this effort.