Treatment Efficiencies of Detention with Filtration Systems

Final Report

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CHAPTER 1

INTRODUCTION

As a means of protecting Florida's surface waters from the effects of nonpoint source pollution, regulations have been established which require new developments or projects to provide pollution abatement for a specified volume of stormwater runoff on-site. One of the most common stormwater treatment methodologies utilized in the State of Florida today for pollution abatement is the filter system. These filter systems incorporate either a wet or dry detention basin to attenuate and provide temporary storage for runoff inputs during rain events. Detained runoff then passes through a minimum of 2 feet of filter media and is collected in an underdrain system for ultimate discharge to the receiving waterbody. It is commonly thought that this filtration process attenuates many common stormwater pollutants, particularly those associated with particulate matter.

Although side bank filter systems are one of the most popular stormwater treatment technologies utilized in the State of Florida today, little previous research has been done to demonstrate the effectiveness of these systems for attenuating stormwater pollutants. Recently, concern has been expressed that suspended matter trapped by the filter system may be subject to decomposition and solubilization processes over time, resulting in a gradual release of the particulate matter originally trapped within the system. Questions have also been raised concerning the hydraulic effectiveness of various filter media and filter configurations. The effectiveness of various sod media in improving the pollutant attenuation capabilities of filter systems have also been questioned.

In 1990, the St. Johns River Water Management District (District), as part of the Surface Water Improvement and Management (SWIM) Program, selected Environmental Research & Design, Inc. (ERD) to study the effectiveness of a wet detention pond with side bank filters in the lower St. Johns River Basin. This study included field instrumentation of a wet detention with filtration site and a six-month period of monitoring to define water quality and hydrologic characteristics of the system. In addition, pilot scale studies were conducted to evaluate the hydraulic efficiency and pollutant removal effectiveness of various filter media and sod cover for use with side bank filter systems. The results of this study will be used to refine design, operation and maintenance practices for filter systems and to support future District rule revisions.

1.1 Scope of Research Efforts Described in this Report

The research efforts described in this report present a detailed investigation of the hydrology, hydraulic performance and water quality characteristics of a wet detention with filtration system located in DeBary, Florida. In addition, the results of pilot studies are also presented which evaluate the hydraulic and pollutant removal effectiveness of various filter media and sod configurations. Field investigations and laboratory studies began in April 1992 and continued through January 1993. In excess of 48,000 separate field and laboratory measurements were generated during the course of this project.

This report is divided into two separate volumes. This volume is titled "Treatment Efficiency for Detention with Filtration - Volume I" and consists of a literature review of previous work efforts conducted on filter systems, a discussion of field and laboratory procedures, a presentation of the experimental results and conclusions, along with Appendices A through Z with the exception of Appendix E and Appendix F. Appendix E and Appendix F are contained in Volume II which is titled "Treatment Efficiency for Detention with Filtration - Volume II - Appendix E and Appendix F". These appendices contain a complete listing of inflow and outflow hydrographs at the detention with filtration pond site from June through November 1992. The size of this information necessitated that these appendices be bound in a separate volume.

1.2 Units of Measurement

Research efforts described in this report are presented almost exclusively using metric units of measurement. In general, all data, measurements and descriptions given in this report are presented in metric form with English equivalent units given in parentheses for measurements of length, area and volume. However, elevation data referenced to mean sea level (MSL) is given in terms of English units (i.e., feet) with metric equivalents listed in parentheses. Units of measurement for evaluation of hydraulic characteristics of underdrains are given in English units since this is the common form of units used in design of filter systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of Previous Research on Filter Systems

A literature review was conducted to identify previous studies, research efforts, publications or other information dealing with the design and operation of filtration systems. References evaluated during this research were limited to studies conducted within the State of Florida. Emphasis was placed on information pertaining to hydraulic performance, water quality and pollutant removal efficiencies.

During the literature review process, available information on research pertaining to filtration systems was requested from water management districts within the State of Florida which permit detention with filtration systems, the Florida Department of Environmental Regulation, the U.S. Geological Survey, state universities and local governments within the Lower St. Johns River Basin, including Orange and Seminole Counties. In addition, a computerized literature search was conducted for any published articles or summary reports on filtration systems evaluated within the State of Florida.

In spite of the fact that filtration systems are used extensively throughout the State of Florida for management of stormwater runoff, only a few significant research projects have been conducted to evaluate the hydraulic or water quality performance of these systems under actual field conditions. Several studies were reviewed which evaluated filter performance under lab type conditions and attempted to extrapolate a rather limited data base to long-term performance evaluations for filter systems constructed in the field. These studies are not included as part of this literature survey. Only two previous studies were identified which presented actual measurements of inflow and outflow from an operational filter system. A summary of these two studies in given in the following sections. Unfortunately, neither of the two filter systems were constructed using design criteria and parameters typically used in current filtration systems.

2.1.1 Lake Tohopekaliga Demonstration Project

The Lake Tohopekaliga Demonstration Project was constructed in 1985 as a dry detention with filtration facility to provide stormwater treatment for 49 ha (122 ac) of mixed commercial and residential land use. Details of the operation, hydraulic performance and water quality benefits achieved by this system are presented by Cullum and Dierberg (1990) and Holler (1990). The detention basin was constructed adjacent to Lake Tohopekaliga with a bottom invert elevation approximately 0.15 m (0.5 ft) below the regulated wet season elevation for the lake. The system was originally designed as a dry detention basin which provided a storage volume equivalent to 1.07 cm (0.42 in) of runoff for the entire 49 ha watershed. An emergency overflow spillway was provided so that rainfall in excess of the design storage volume could discharge directly into an existing canal connected to Lake Tohopekaliga.

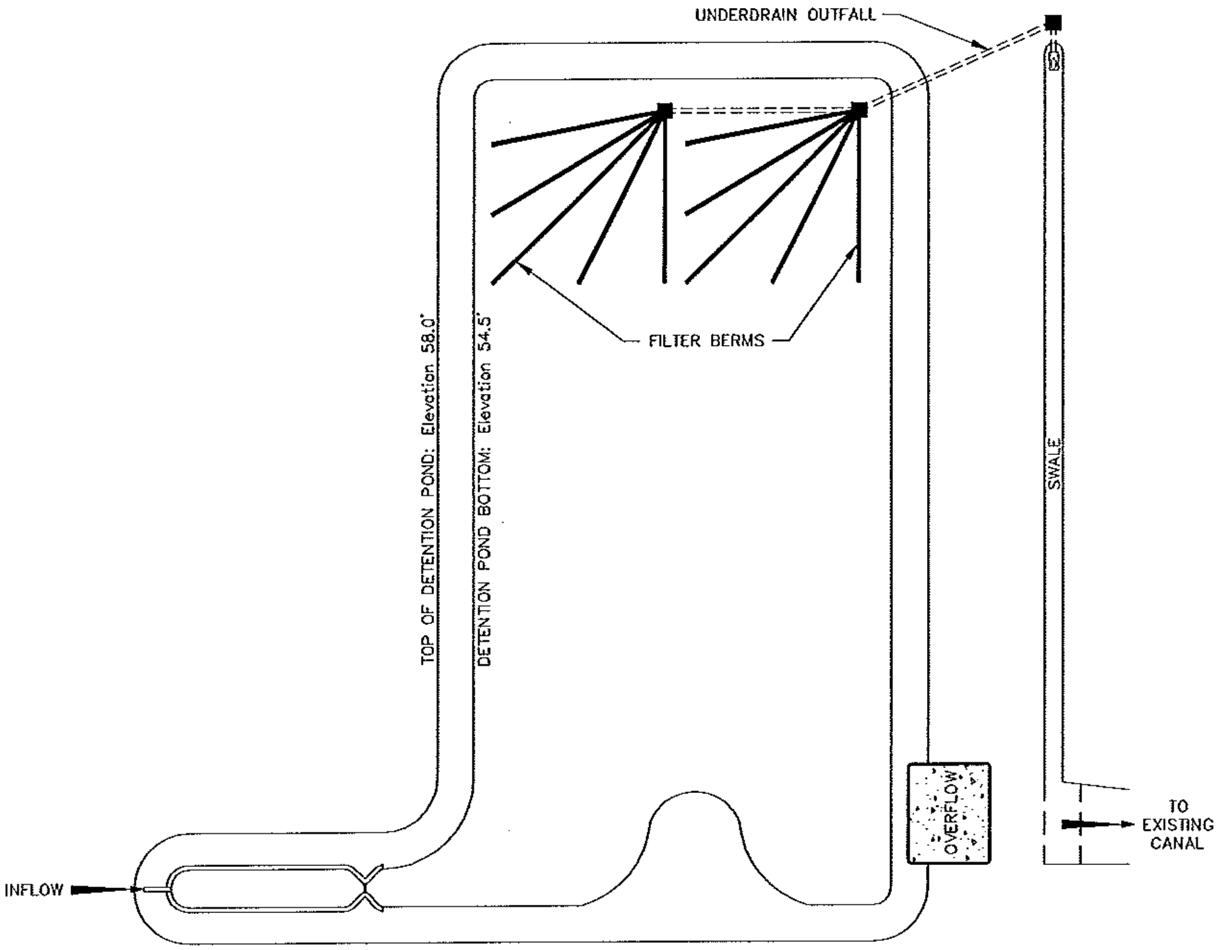
Two sets of filtration berms were constructed within the detention pond as indicated in Figure 2-1. Each set of filter berms consisted of five arms arranged radially and joined at a common collection box. A total of 305 m (100 ft) of filter berm was constructed within the basin.

A cross-section for a typical filter berm is given in Figure 2-1. The filter berm was constructed of a composite filter material consisting of 1/3 sand, 1/3 clay and 1/3 topsoil from the area used for construction of the detention facility. A 15 cm (6 in) perforated underdrain was constructed in the bottom of each filter berm with a 0.3 m (1 ft) thick layer of FDOT No. 57 gravel surrounding the perforated pipe. The system was designed to maximize phosphorus removal in stormwater by adsorption and attenuation onto clay and topsoil particles within the filter media based upon the results of limited laboratory investigations. This filter media did not conform to the requirements outlined in Chapter 17-25 of the Florida Administrative Code which limits the percentage of silt, clay and organic matter within filter media to less than 1%. In addition, the effective grain size of the composite filter media was probably substantially less than the grain size of 0.20-0.55 mm specified in Chapter 17-25.

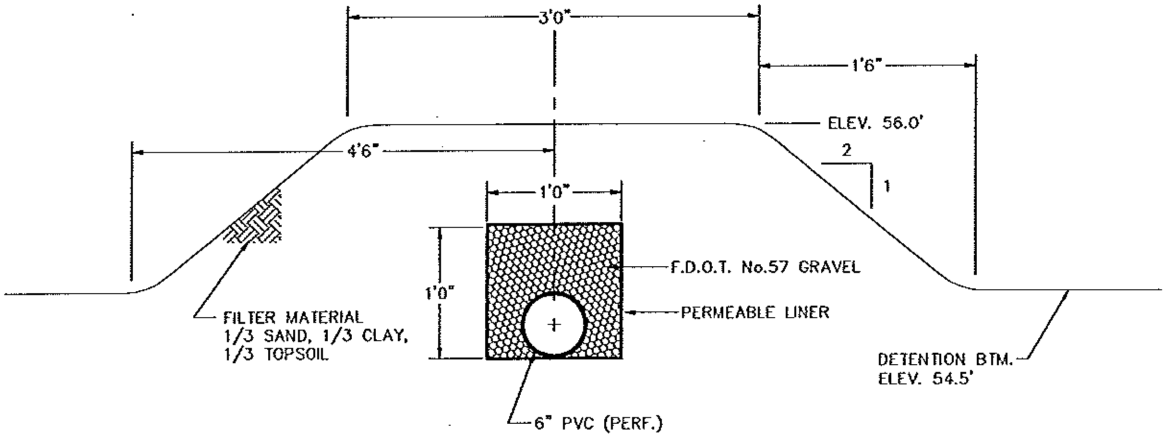
Shortly after construction was completed on the system, the filter berms became clogged with fine particles from the surrounding watershed, substantially restricting the flow through the filter media (Cullum and Dierberg, 1990). The inability to drawdown standing water from the basin altered the stormwater management system from a dry detention with filtration system to a shallow wet retention marsh dominated by Typha species.

Storm event monitoring was conducted during six storm events from November 1985 to November 1986 at three locations within the pond. One monitoring location was established at the inflow to the system to evaluate characteristics of raw stormwater runoff entering the basin. A second sampling location was established within the water column of the pond adjacent to the filter berms to evaluate removal efficiencies obtained by the system during migration of stormwater runoff through the water column of the detention facility. A final sampling location was established at the outfall from the underdrain system to monitor water quality characteristics of underdrain outflow. Measurements of flow rate were not computed at either the inflow or outflow locations.

A summary of the results of storm event monitoring at the filtration site is given in Table 2-1. Input concentrations of soluble reactive phosphorus and total phosphorus decreased approximately 77-78% during migration through the pond prior to reaching the



PLAN VIEW OF FILTRATION BASIN



CROSS-SECTION OF FILTER BERM

Figure 2-1. Details of the Lake Tohopekaliga Demonstration Project Filtration Basin.

TABLE 2-1

RESULTS OF STORM EVENT MONITORING FROM NOVEMBER 1985 TO NOVEMBER 1986 AT LAKE TOHOPEKALIGA DEMONSTRATION PROJECT

(Mean of 6 Storm Events)

PARAMETER	UNITS	MEAN INFLOW (I)	MEAN POND CONCENTRATION (B)	PERCENT CHANGE IN POND	MEAN OUTFLOW (O)	PERCENT CHANGE IN FILTER	TOTAL PERCENT CHANGE IN SYSTEM
pH	s.u.	7.56	7.33	NA	7.24	NA	NA
Spec. Conductance	µmhos/cm	189	236	+25	257	+9	+36
Soluble Reactive P (first 3 events)	mg/l	0.082	0.018	-78	0.051	+183	-38
Soluble Reactive P (last 3 events)	mg/l	0.087	0.020	-77	0.013	-35	-85
Soluble Reactive P (6 events)	mg/l	0.084	0.019	-77	0.032	+68	-62
Total P	mg/l	0.80	0.18	-78	0.12	-33	-85
Turbidity	NTU	132	16.3	-88	24.5	+50	-81

NA: Not Applicable

1. Adapted from Cullum and Dierberg (1990)

filter berms. Cullum and Dierberg (1990) attributed this attenuation to uptake of nutrients by the standing crop of Typha species within the marsh pond. Turbidity was also reduced approximately 88% during migration through the pond. In contrast, an increase of approximately 25% was observed for specific conductivity.

Although discharge through the filter berms were substantially reduced by clogging from fine particles within the watershed, migration through the filter media reduced concentrations of total phosphorus by 33% compared with mean total phosphorus concentrations measured within the pond. However, on an average basis, soluble reactive phosphorus increased approximately 68% during travel through the filter, with a corresponding increase of 9% for specific conductivity and 50% for turbidity. Holler (1990) observed that filter performance for removal of orthophosphorus improved substantially during the final three monitored storm events compared to the initial three events, possibly indicating stabilization of the filtration media as the system aged.

Water quality monitoring was also conducted on a monthly basis from March 1984 to November 1986 within the detention system. Grab samples were collected of inflow pond water and outflow during each monthly sampling event. A summary of mean water quality characteristics from March 1984 to November 1986 is given in Table 2-2. Measured concentrations of both total phosphorus and total nitrogen were lower in pond water than in stormwater inflow entering the pond. A small additional removal in total phosphorus was observed during migration through the filter media but not for total nitrogen. Measured concentrations of ammonia, NO_x and soluble reactive phosphorus decreased substantially during migration through the pond. However, measured concentrations of each of these parameters were found to be higher in the underdrain outflows than in water within the pond. This behavior suggests that particles of total phosphorus and total nitrogen trapped within the filter media may be undergoing decomposition with subsequent release of soluble inorganic species of each nutrient through the filter media. Increases in concentration during migration through the filter media were also observed for specific conductivity, color, calcium, magnesium, sodium, potassium, iron, chloride and silicate.

Both Cullum and Dierberg (1990) as well as Holler (1990) concluded that the demonstration study site exhibited poor hydraulic performance and failed as a detention with filtration experiment. Holler suggested that the poor hydraulic performance of the filter was due to clogging of the filter system with sediment fines and an insufficient head on the filter media to drive water through the filter against tailwater conditions within the lake. Both studies concluded that the primary mechanism responsible for pollutant removals observed within the system was the wet detention component of the system rather than the filter media.

2.1.2 Lake Jackson Stormwater Treatment Facility

The Lake Jackson stormwater treatment facility was constructed in 1982 to provide stormwater treatment for a highly urbanized watershed within the City of Tallahassee. Untreated stormwater runoff from the urbanized area flows to Lake Jackson

TABLE 2-2

SUMMARY OF MONTHLY ROUTINE WATER QUALITY MONITORING AT THE LAKE TOHOPEKALIGA DEMONSTRATION PROJECT FROM MARCH 1984 TO NOVEMBER 1986[1]

(All Concentrations in mg/l Unless Otherwise Noted)

PARAMETER	INFLOW	POND NEAR FILTER BERMS	OUTFLOW
pH (units)	6.7	7.0	6.6
Alkalinity	2.07	2.03	2.43
Spec. Cond. (μmhos/cm)	285	262	293
Dissolved Oxygen	4.8	5.1	1.9
Ammonium	0.12	0.03	0.11
Nitrite plus Nitrate	0.018	0.008	0.010
Organic N	1.22	1.10	1.03
Total N	1.36	1.14	1.15
Soluble Reactive P	0.07	0.02	0.03
Total P	0.21	0.09	0.07
Color (units)	62	56	58
Turbidity (NTU)	15.0	14.6	11.9
Total Suspended Solids	6.5	4.7	4.1
Sulfate	11.5	7.5	6.8
Chloride	16.8	13.7	14.5
Calcium	39.3	43.5	46.8
Magnesium	4.31	2.57	2.59
Sodium	15.6	13.3	13.4
Potassium	2.40	1.96	2.24
Iron	1.01	0.39	0.58
Silicate	9.0	2.8	3.8

1. Adapted from Cullum and Dierberg (1990)

by way of a natural channel called Megginnis Creek. Details of the operation, hydraulic performance and water quality benefits achieved by this system are presented by LaRock (1988).

The stormwater treatment facility was constructed in-line with Megginnis Creek and consists of two primary parts, a 163,000 m^3 (5,750,000 ft^3) impoundment basin with a 1.8 ha (4.48 ac) intermittent sand filter for removal of particulate matter, followed by a 2.5 ha (6.17 ac) artificial marsh to remove dissolved nutrients. A schematic of the stormwater treatment facility is given in Figure 2-2. A sediment basin was constructed near the point of inflow to provide an area for collection of heavy sediment and sand. The average depth of the impoundment is approximately 2 m (6.5 ft) below the surface of the filter bed.

The filter system consists of a 0.3-0.64 m (1.0-2.1 ft) layer of graded coarse sand, with a diameter of 0.4-0.8 mm, over a layer of filter fabric. Filtered stormwater runoff is collected in a 0.61 m (2.0 ft) thick layer of FDOT No. 57 limestone. A series of 8" corrugated perforated drain pipes was placed at the bottom of the limestone layer to collect the stormwater runoff and transport it from the filter bed to the point of exit from the impoundment.

During normal rain events, the impoundment begins to fill with incoming stormwater runoff until it reaches the level of the filter media. Infiltration of stormwater runoff then begins through the filter media with effluent exiting through the underdrain pipe. An overflow spillway was also constructed to provide an outlet for excess runoff during extreme storm events which exceed the capacity of the filtration system. The sides of the filter media were not sealed, and lateral inflow of water from the impoundment was common.

A pumping system was constructed to allow water from the impoundment to be sprayed onto the surface of the filter between storm events to further lower the water level in the impoundment prior to the next rain event. According to LaRock (1988), the pumping system was used for only several weeks and then discontinued because of excessive operational costs. Subsequent to discontinuing the automatic irrigation system, the impoundment storage capacity was regulated by manually opening and closing a drain valve in the spillway. However, this method of operation did not provide adequate drawdown of storage volume for subsequent storm events, and over 60% of all storm events experienced some degree of bypass through the system rather than infiltration through the filter media (LaRock, 1988).

Outflow from the filter impoundment is directed into the artificial marsh system for subsequent filtration and removal of dissolved constituents. Under extreme storm events which exceed capacity of the marsh system, a bypass canal is provided to direct the stormwater runoff around the marsh system.

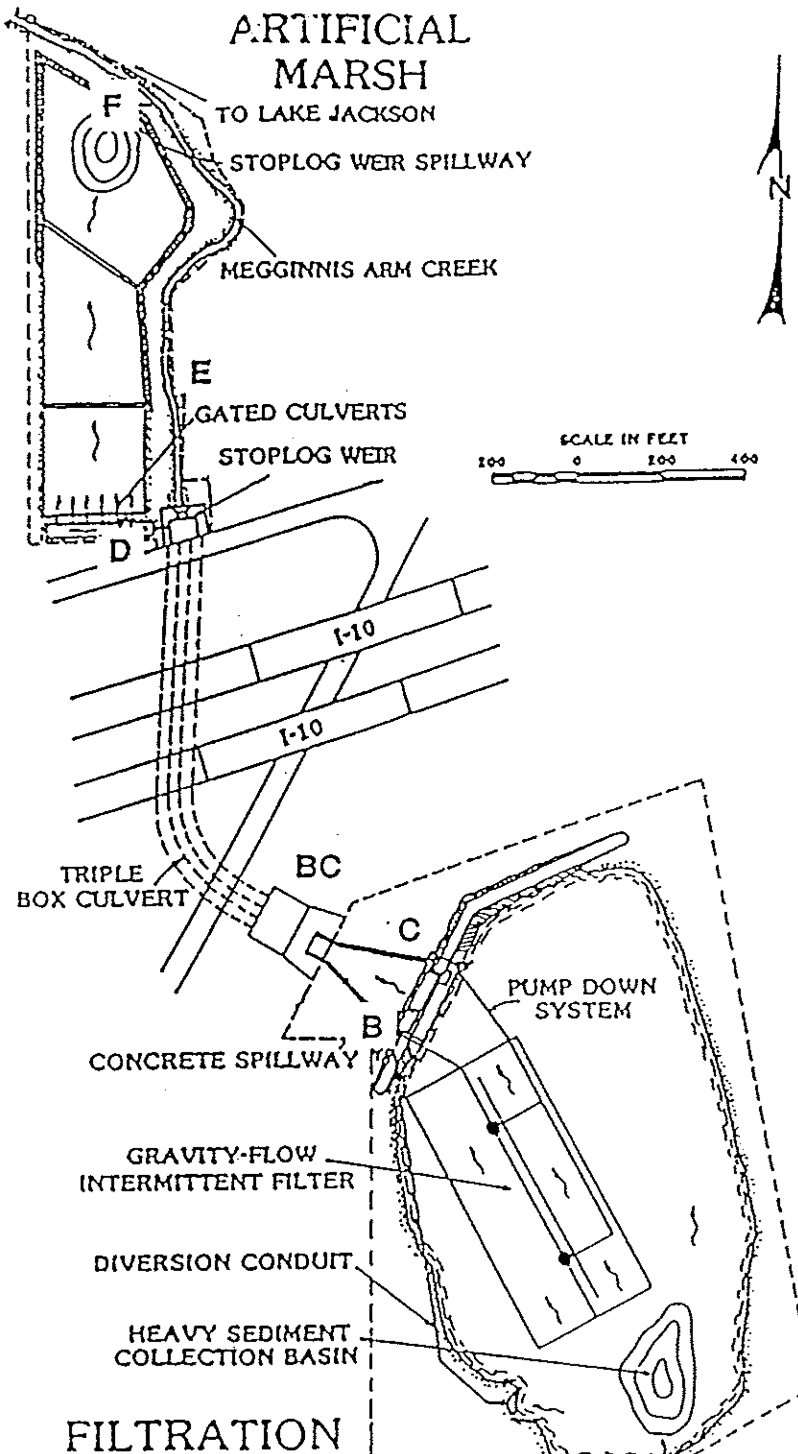


Figure 2-2. Plan of the Lake Jackson Filtration Impoundment and Artificial Marsh.

Water quality monitoring was conducted at the sample locations indicated in Figure 2-2 from 1983 to 1986 using automatic stormwater samplers and gaging stations for estimation of flow. Mass loadings rates and removal efficiencies were estimated for both the filtration impoundment and artificial marsh system for a number of storm events during this period.

A summary of percent changes in mass loadings between inflow and outflow in the impoundment/filter pond system, based upon a total of five storm events measured from 1983 to 1986, is given in Table 2-3. Removal efficiencies presented in this table reflect the combined removal effectiveness of the detention basin impoundment and the filtration system. Removal efficiencies were not estimated separately for the filtration system alone. The removal efficiencies presented in Table 2-3 represent changes in total mass loadings from the inflow, measured at point A indicated on Figure 2-2, to the point of outflow, measured at point B as indicated on Figure 2-2.

An extreme degree of variability is present in changes in mass loadings between storm events for many of the parameters listed in Table 2-3. According to LaRock (1988), removal efficiencies are artificially enhanced for many parameters due to the fact that several of the monitored storm events resulted in little or no outflow from the impoundment, thus retaining the majority of the input mass within the system. These events result in removal efficiencies for many parameters which appear extraordinarily high during several monitored events. Similarly, other storm events produced significant amounts of rainfall which resulted in substantial bypass through the spillway structure, creating low removal efficiencies for these monitored events.

On an overall basis, the combined impoundment/filtration system resulted in excellent removals of both inorganic and organic suspended solids, with removal efficiencies in excess of 96% for each of these parameters. Removal of total nitrogen and total phosphorus was also good through the system, with an average of approximately 60% removal for these parameters. Nitrogen species of ammonia and nitrite decreased during migration through the system, while mass loadings of nitrate increased. LaRock attributed the increases in nitrate to ammonia oxidizing bacteria which were present within the filter media and were responsible for dissolution of portions of the calcium and magnesium present within the dolomite underdrain media. Unfortunately, sampling was not conducted which would allow an estimation of removal efficiencies achieved within the filter system only separate from the combined impoundment/filtration pond.

Shortly after the filter system was placed in service, problems with filter clogging began to occur. Backwashing capabilities were not provided with the filter system. Within the first three years of operation, estimates indicate that the flow through the filter was reduced by approximately 70% (LaRock, 1988). LaRock conducted further evaluations of filter performance during storm events when filter performance was minimal. It was concluded that the filter was primarily responsible for removing suspended matter, but had little effect on the removal of nitrogen or phosphorus. In conclusion, LaRock suggested that the filter, as it is currently operated, does not afford a significant benefit to water quality due to the substantial bypass which occurs through the spillway overflow structure during most storm events.

TABLE 2-3

SUMMARY OF PERCENT CHANGES IN MASS LOADINGS BETWEEN INFLOW AND OUTFLOW IN THE LAKE JACKSON IMPOUNDMENT/ FILTER POND FROM 1983-1986[1]
(n = 5 Storm Events)

PARAMETER	RANGE OF VALUES (%)	MEAN VALUE (%)
Ammonia	-37 to -82	-59
Nitrite	-66 to -91	-79
Nitrate	+141 to -93	+17
Total N	-21 to -97	-59
Filtered P	+16 to -69	-25
Total P	-19 to -98	-62
Inorganic Suspended Solids	-97 to -99	-98
Organic Suspended Solids	-93 to -98	-96
Chloride	+161 to -67	+6
Calcium	+105 to -67	+28
Magnesium	+458 to -55	+202

[1] Adapted from LaRock (1988)

2.2 Design and Performance Criteria for Filter Systems

Specific design and performance criteria for filtration systems used in the lower St. Johns River Basin area have been developed by both the Florida Department of Environmental Regulation (FDER) and the St. Johns River Water Management District (SJRWMD). Filter criteria developed by FDER are listed in Chapter 17-25 of the Florida Administrative Code, titled "Regulation of Stormwater Discharge". Design and performance standards for filtration systems are outlined in Chapter 17-25.025 which provides specific standards for particle size, particle gradation, organic matter content, effective grain size and design drawdown periods for filtration systems. Filter criteria developed by the St. Johns River Water Management District are outlined in Chapter 40C-42.

The St. Johns River Water Management District has promulgated a detailed set of specific design and performance criteria for filtration systems which are based upon the general outline provided in Chapter 17-25.025. These performance criteria provide additional details for treatment volumes required for off-line or on-line detention with filtration systems as well as additional requirements for clean-out ports, restrictions on installations in high groundwater table areas, and additional volume requirements when discharging to Outstanding Florida Waters (OFW). Design and performance criteria developed by the St. Johns River Water Management District are contained in Chapter 40C-42.026 of the Florida Administrative Code and included as part of the publication titled Applicant's Handbook - Management and Storage of Surface Waters.

Current design and performance criteria for filtration systems emphasize primarily the hydraulic operation and structural integrity of the filter. The St. Johns River Water Management District requires that media used in filter systems have a permeability equal to or greater than that of the surrounding soil, with a low percentage of silt, clay and organic matter which could potentially clog the filter system. Filter fabric or other similar barriers are typically used to prevent movement of the filter media and to prevent the filter media from being washed into the perforated underdrain pipe. The hydraulic capacity of the filter system is typically designed with a safety factor of at least 2 to insure that the required pollution abatement volume can be drawn down within a minimum of 72 hours following a storm event. The excerpt from Chapter 40C-42 which addresses filtration systems is given below:

> Chapter 40C-42.026 Specific Design and Performance Criteria
>
> Filtration systems shall:
>
> A. Provide detention with filtration for the greater of the following:
>
> 1. Off-line detention with filtration of the first one inch of runoff or 2.5 inches of runoff from the impervious area, whichever is greater; or

   2. On-line detention with filtration of an additional one-half inch of runoff from the drainage area over that volume specified in subparagraph 1, above, whichever is greater.

B. Provide detention with filtration in accordance with either of the following for those systems which have direct discharge to Class I, Class II or Outstanding Florida Waters:

   1. At least an additional fifty percent of the applicable treatment volume specified in subparagraph 1, above. Off-line detention with filtration must be provided for at least the first one inch of runoff or 2.5 inches of runoff from the impervious area, whichever is greater, of the total amount of runoff required to be treated; or

   2. On-line detention with filtration of the runoff from the 3-year, 1-hour storm or an additional fifty percent of the treatment volume specified in subparagraph 2, above, whichever is greater.

C. Provide the capacity for the appropriate treatment volume of stormwater specified in paragraphs A or B, above, within 72 hours following a storm event.

D. Have pore spaces large enough to provide sufficient flow capacity so that the permeability of the filter is equal to or greater than the surrounding soil. The design shall ensure that the particles within the filter do not move. When sand or other fine textured aggregate other than natural soil is used for filtration, the filter media should be of quality sufficient to satisfy the following requirements:

   1. Washed (less than 1 percent silt, clay and organic matter) unless filter cloth is used which is suitable to retain the silt, clay and organic matter within the filter. Calcium carbonate aggregate is not an acceptable filter media;

   2. Uniformity coefficient of 1.5 or greater; and

   3. Effective grain size of 0.20 to 0.55 millimeters in diameter. These criteria are not intended to preclude the use of multilayered filters nor the use of materials to increase ion exchange, precipitation or the pollutant absorption capacity of the filter.

E. Include, at a minimum, capped and sealed inspection and clean-out ports which extend to the surface of the ground at the following locations for each drainage pipe:

1. The terminus; and

2. Every 400 feet or every bend of 45 or more degrees, whichever is less.

F. Utilize filter fabric or other means to prevent the filter material from moving or being washed out through the perforated pipe.

G. Be designed with a safety factor of at least 2 unless the applicant affirmatively demonstrates based on plans, test results, calculations or other information that a lower safety factor is appropriate for the specific site conditions. Examples of how to apply this factor include, but are not limited to, the following:

1. Reducing the design percolation rate by half,

2. Doubling the length of the filtration system, or

3. Designing for the required drawdown within 36 hours instead of 72 hours.

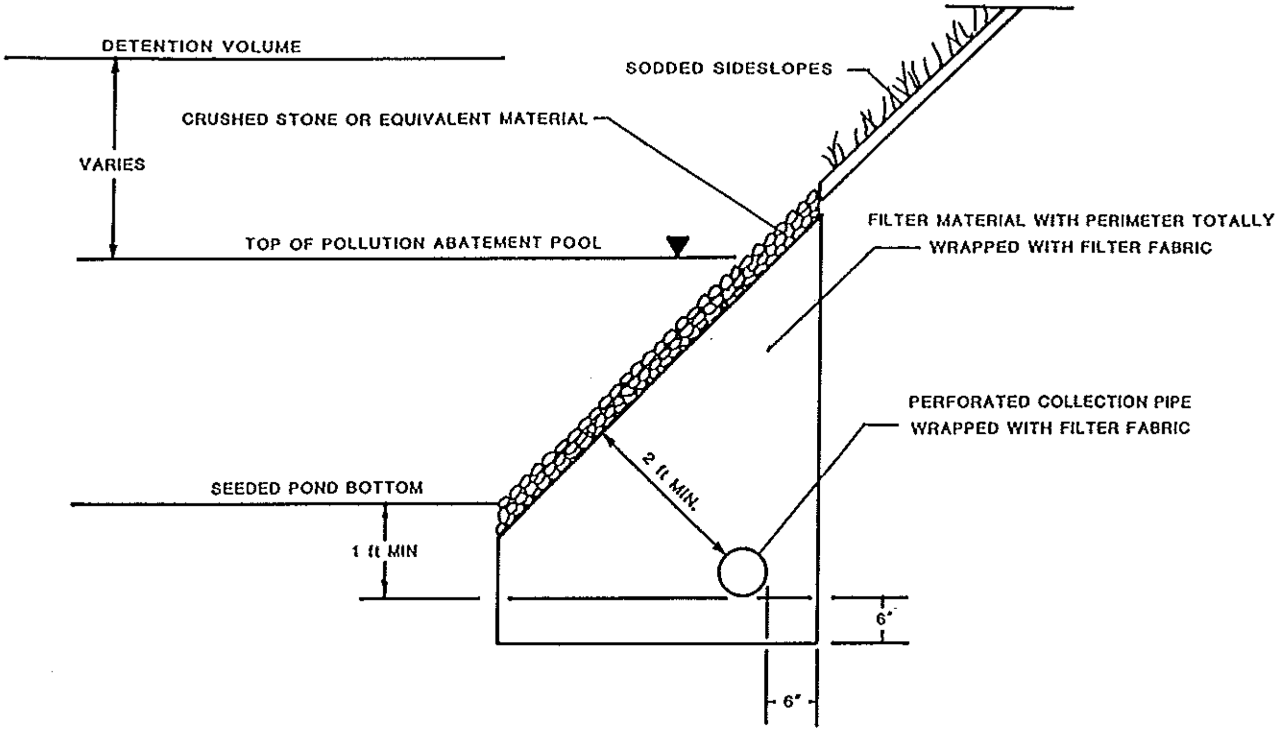
H. Be designed so that the invert elevation of the perforated pipe is above the seasonal high groundwater table elevation. If the pipe is proposed to be set below this elevation, the pipe should be separated by structural means from the hydraulic contribution of the surrounding water table or groundwater inflow must be considered in the drawdown calculations.

2.3 Typical Filter System Configurations

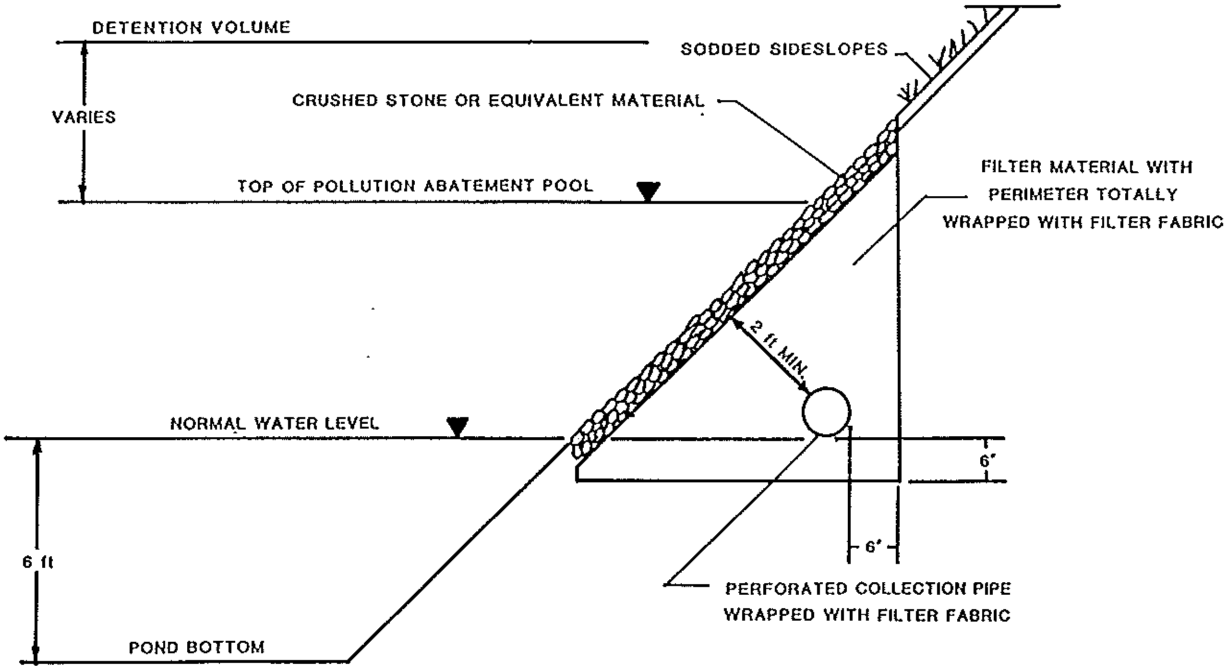
The majority of filter systems constructed within the State of Florida are built in a side bank type configuration, with a filter system constructed along all or portions of the perimeter of the pond. The length of required filter is sized to provide a drawdown for the pollution abatement volume within a specified period, generally 72 hours. Side bank filter systems may be constructed in either a "dry bottom" or "wet bottom" type configuration. Details for each of these two configurations are provided in Figure 2-3.

2.3.1 "Dry Bottom" Pond Filter Configurations

A "dry bottom" filter pond is designed to contain standing water only during rain events and for a maximum period of 72 hours following the rain event during the drawdown period for the filter. The bottom of a "dry bottom" filter pond is typically constructed a minimum distance of 0.3-0.9 m (1-3 ft) above the estimated seasonal high water table. This design is intended to insure that the bottom of the pond will maintain the "dry bottom" conditions.



"DRY BOTTOM" POND CONDITION



"WET BOTTOM" POND CONDITION

Figure 2-3. Typical Details of "Dry Bottom" and "Wet Bottom" Side Bank Filter Pond Configurations.

In addition to side bank filters, other types of dry bottom filters and underdrain systems include mounded or elevated sand filters and bottom vertical sand filters. A schematic of a typical mounded or elevated sand filter system is given in Figure 2-4. Bottom vertical sand filters are discussed in more detail in Section 2.3.3.

Where high water tables prohibit the installation of ponds with a bottom elevation or underdrain above the seasonal high water table, either design is often ineffective in maintaining "dry bottom" pond conditions throughout the year. In addition, groundwater seepage into the underdrain pipe creates a continuous baseflow in the underdrain system throughout the year, increasing mass loadings to receiving waterbodies. The bottom of these systems is generally seeded with grasses or sodded to minimize erosion along the pond bottom.

"Dry bottom" pond configurations rely primarily on the filter media itself for pollutant attenuation within the basin. Settling processes can also occur within the standing pool of water within the stormwater basin during the drawdown period which causes suspended solids and other material to be deposited onto the bottom of the filter pond. However, these processes are limited primarily to chemical and physical processes since biological activity within the variable pool of water in a "dry bottom" pond is negligible. As a result, "dry bottom" filter ponds often provide poor removal efficiencies for dissolved constituents, since these parameters generally require biologically mediated processes for effective removal.

2.3.2 "Wet Bottom" Pond Filter Configurations

"Wet bottom" filter ponds are typically constructed with a permanent pool of water at a minimum depth of approximately 2 m (6 ft) below the invert elevation for the underdrain pipe. These filter systems enhance the physical removal capabilities of the filter media with an opportunity for biological and chemical processes within the permanent pool volume. Uptake of dissolved nutrients such as ammonia, nitrate and orthophosphorus is generally improved by biological processes within the water column of the pond. These processes are substantially lacking in a "dry bottom" pond configuration. Therefore, a "wet bottom" pond can be expected to achieve a higher pollutant removal efficiency than a "dry bottom" pond due to the enhanced opportunity for biological processes in addition to chemical and physical processes within the system.

2.3.3 Bottom Vertical Filters

A variation of typical filter designs which is used sporadically throughout the State of Florida is a bottom vertical filter. In this filter configuration, the filter is constructed into the bottom of the stormwater pond with the face of the filter level with the pond bottom. The filter system is typically installed in a trench with a depth of 0.9 m (3 ft) and a width of 1.2 m (4 ft) with vertical sides and a horizontal bottom. Vertical bottom filters are constructed to allow a minimum travel path of 0.6 m (2 ft)

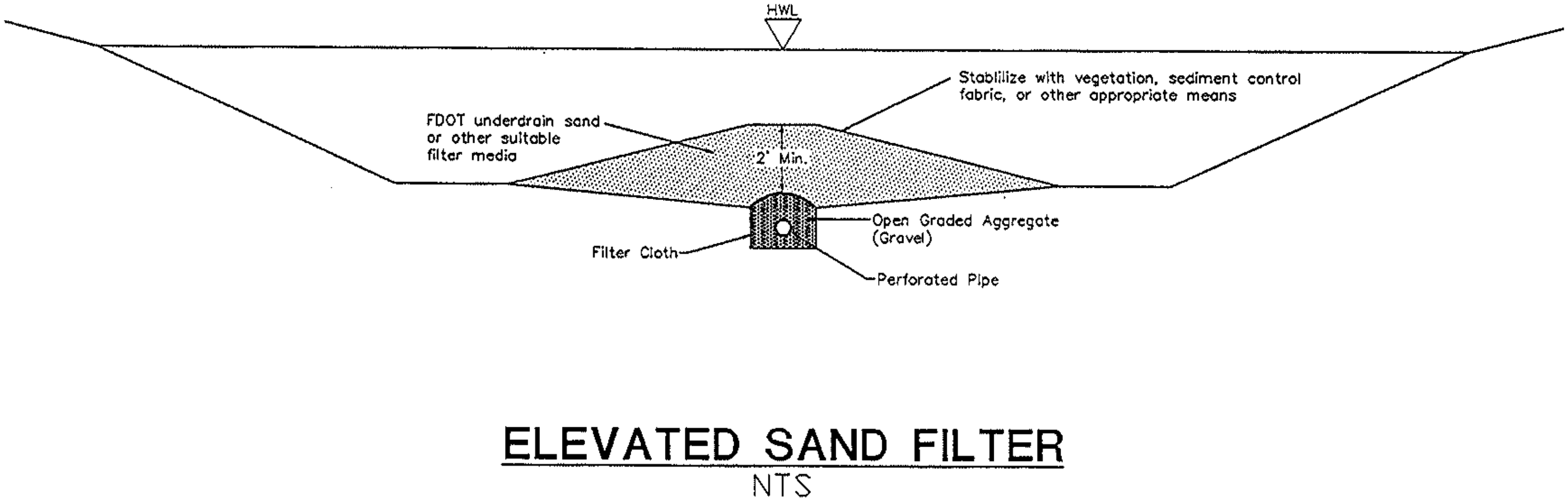


Figure 2-4. Schematic of a Typical Mounded or Elevated Sand Filter.

through the filter media for stormwater inputs into the pond prior to entering the underdrain pipe. The entire perimeter of the filter media is usually wrapped with a filter fabric.

It seems intuitive that bottom vertical filters would be more susceptible to clogging than side bank filters since many of the suspended solids entering the stormwater basin settle onto the bottom of the pond which may eventually clog or limit the infiltration capacity along the surface of the vertical filter. Bottom vertical filters may also be more susceptible to clogging from erosion and sediment transport within the detention pond itself than side bank filters. The Florida Department of Environmental Regulation and the St. Johns River Water Management District have found that the mechanical action provided by the growth of grass is particularly adept at breaking up the sealing caused by the deposition of oil, grease and sediment associated with stormwater runoff. For this reason, and in an attempt to provide some uptake of dissolved nutrients, sod is often required as a ground cover for these systems.

2.3.4 Filter System Details

Both the "dry bottom" and "wet bottom" pond configurations require filtration of all stormwater inputs through a minimum of 0.6 m (2 ft) of filter media with the characteristics outlined in Section 2.2. At low water levels, the actual flow path through the filter media often substantially exceeds the 0.6 m (2 ft) minimum travel path. The filter face for both filter configurations is typically covered with a material designed to prevent erosion and damage to the filter media. Crushed stone or equivalent material is commonly used for this purpose. As previously mentioned, some filter faces may also be sodded to minimize erosion and increase the opportunity for adsorption and entrapment of pollutants within the filter system. The perimeter of the trench containing the filter material is typically wrapped with filter fabric to isolate the filter media from the surrounding soils.

A wide variety of filter media is currently used in filter designs. Typical media includes FDOT equivalent sand, 20-30 silica sand, concrete wash and composite filter materials consisting of filter sand and native soils to enhance adsorption capacity. Little previous research has been conducted on the hydraulic or water quality benefits achieved by each of the different media types under actual field conditions.

2.4 Typical Design Equations for Filtration Systems

A number of theoretical and empirical design equations are currently used within the State of Florida to predict drawdown in vertical bottom and side bank filter systems as well as to calculate the length of filter pipe necessary to discharge a certain volume of water within the 72-hour required time period. Representatives of the St. Johns River Water Management District and the Florida Department of Environmental Regulation were contacted to develop a list of the most commonly used filter design equations for design of filtration systems. As a result of these discussions, a total of seven filter system design equations were identified as commonly used in design processes for filter systems. Four of these design equations are commonly used for bottom vertical filter systems, and three equations are commonly used for side bank filter analyses. Each of these design equations are discussed in the following sections.

2.4.1 Design Equations for Bottom Vertical Filter Systems

The following four design equations were identified for use with bottom vertical filter systems:

1. **Darcy's Equation** (Reference: Florida Land Development Manual, p. 6-265)

2. **Modified Falling Head Equation** (Reference: Florida Land Development Manual, p. 6-268)

3. **Incremental Darcy's Equation** (Reference: Same as Incremental Darcy's Equation for Side Bank Filters with modified hydraulic gradient analysis for vertical filters)

4. **Incremental Darcy's Equation Utilizing the Effective Area** (Reference: Draft St. Johns River Water Management District Stormwater Applicant's Handbook)

Many of the filter system design equations are based on Darcy's Equation for saturated flow through porous media which is written as:

$$Q = K\,i\,A$$

where:

Q = flow through underdrain pipe (ft^3/hr)

K = permeability rate of filter media (ft/hr)

i = hydraulic gradient (ft/ft)

A = area of flow (ft^2)

Darcy's Equation is used to estimate the quantity of flow in filtration systems for varying conditions of the hydraulic gradient (i) and the area of flow (A). Since the hydraulic gradient and the area of flow vary over time as the filter system continues the drawdown process, flow through filter media using Darcy's Equation is often calculated incrementally with respect to pond stage elevations. Flow rates predicted through the underdrain pipe at various time intervals can be used to calculate a corresponding decrease in pond stage elevation which then becomes the starting point for the next incremental analysis. This incremental process is continued until the desired treatment volume is evacuated through the underdrain pipe or the desired recovery time is achieved.

An important, but often misunderstood, portion of Darcy's Equation is the hydraulic gradient (i) term. The hydraulic gradient between two points is defined as the difference in hydraulic head or water surface elevation between the two points divided by the distance between the points. The hydraulic gradient can be expressed as:

$$i = \frac{\Delta H}{\Delta L}$$

The hydraulic gradient (i) is often obtained from scale drawings of the filtration system.

The coefficient of permeability (K) in Darcy's Equation is a function of the permeability of the filter media used within the filter system. With all other factors equal, the permeability of the filter media used in the filter system directly determines the underdrain flow rates and drawdown characteristics of the filter system. Over time, inputs of suspended solids from the surrounding watershed may clog the surface layers of filter systems. As soils begin to clog the filter media, the permeability of the media begins to become characteristic of the watershed soils which have clogged the filter rather than the permeability of the filter media. The St. Johns River Water Management District recommends that permeability values used in design of filtration systems be limited to permeability (K) values for soils within the surrounding watershed. Recommended permeability (K) values by the St. Johns River Water Management District for use in design of filtration systems based on types of soils in which the filter pond is constructed are summarized in Table 2-4.

TABLE 2-4

RECOMMENDED PERMEABILITY (K) VALUES BY SJRWMD

SOIL TYPE	K (ft/hr)
A	2.5
B	2.0
C	1.0
D	0.5
A/D	2.5
B/D	1.5
C/D	0.5

2.4.1.1 Darcy's Equation

Darcy's Equation for bottom vertical filters is the most simplistic application for estimation of drawdown. The velocity of flow through the filter media is assumed proportional to the media hydraulic conductivity (K), and the hydraulic gradient is commonly assumed to be 1. This equation assumes that the velocity of travel through the media is constant regardless of the head on the filter. The filter area intersected (A) is equal to the width of the bottom vertical filter (W) times the length of the bottom vertical filter (L). This is represented as:

$$A = L\,W$$

and therefore

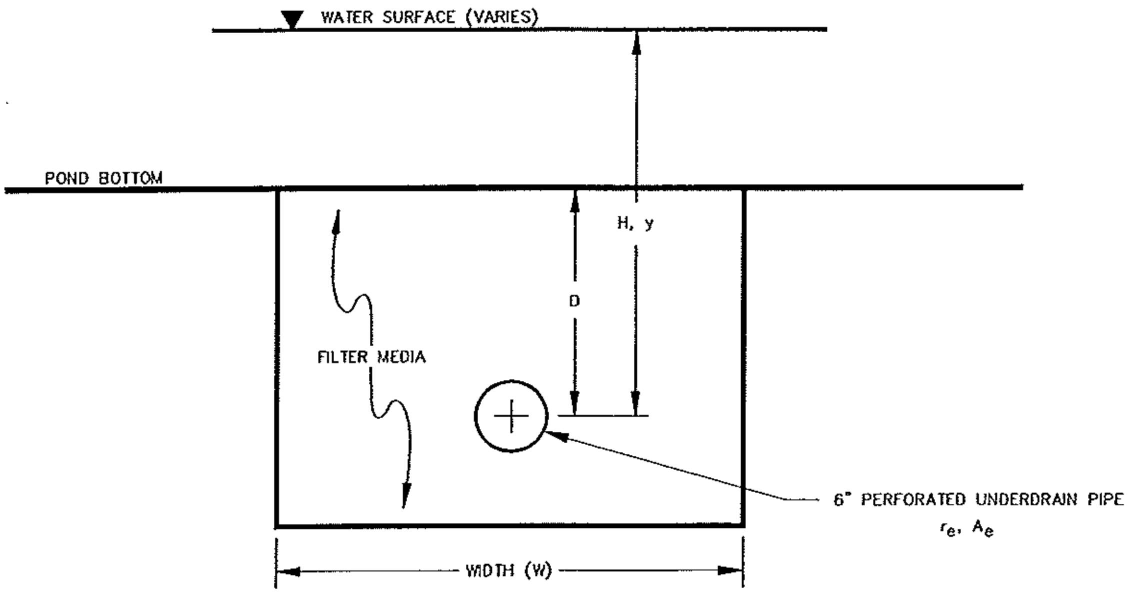
$$Q = K\,W\,L$$

The length of underdrain required can be calculated by L = Q/KW where Q is equal to the volume of water which must be evacuated over a given time interval. A schematic of a bottom vertical filter indicating typical design variables is given in Figure 2-5.

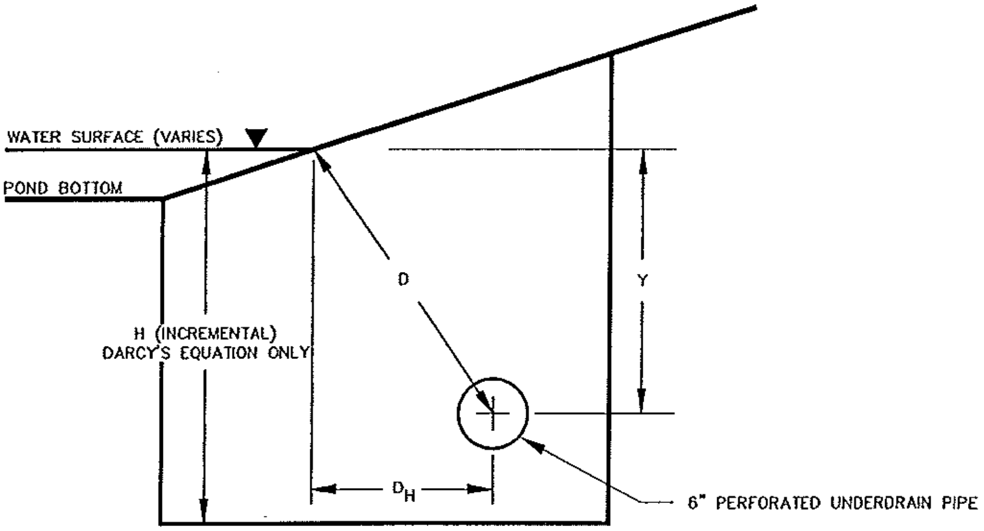
There are several assumptions in the use of Darcy's Equation as described previously which appear to be theoretically incorrect. First, it is unlikely that the hydraulic gradient will remain constant for all values of head on the filter. More likely, the value of "i" will vary as the water level in the facility varies. With bottom filters, "i" is commonly greater than 1 for most situations. Therefore, the use of this equation with i = 1 is conservative and, in many cases, will indicate longer underdrains than actually necessary. Second, this equation, along with all other design equations presented in this section, does not consider effects from other contributions such as groundwater which may also contribute to flow through the underdrain pipe. It is, therefore, imperative that the underdrain be installed above the highest anticipated groundwater levels.

2.4.1.2 Modified Falling Head Equation

The Modified Falling Head Equation for bottom vertical filters combines Darcy's Equation and the Falling Head Equation into an empirical formula commonly used to determine the hydraulic conductivity (K) of soils from falling head permeability testing. The equation can be rearranged to solve for either drawdown time (t) or filter area (A) as follows:



TYPICAL BOTTOM VERTICAL FILTER



SIDE BANK FILTER

Figure 2-5. Schematic of Typical Vertical Bottom and Side Bank Filter Systems, Indicating Design Variables.

$$dt = \frac{2.3\, a\, D}{A}\, K \log\left(H_o / H_i\right)$$

where:

a = horizontal average cross-sectional area of the treatment volume of the pond (ft^2)

A = horizontal cross-sectional area of the bottom vertical filter (ft^2)

D = average distance through the filter media through which the water must travel until it reaches the gravel envelope if present, or otherwise to the top of the underdrain

dt = time interval it takes for the water elevation to drop from its initial level (H_O) to some lower value (H_i) as the water surface draws down towards the pond bottom (hours)

This equation can be rearranged to solve directly for the area of filter needed for a drawdown from H_o to H_i in a time equal to dt by:

$$A = \frac{2.3\, a\, D}{K\, dt} \log\left(H_O / H_i\right)$$

The value of D in the above equations is the actual length of flow through the media to its outflow point. When the underdrain pipe is embedded in a horizontal gravel envelope, the value of D is simply the vertical distance from the top of the filter sand to the top of the gravel envelope. When a gravel envelope is not used, D represents the average distance from the top of the filter sand to the top of the underdrain pipe. In these cases, an average D value can be calculated based upon the maximum travel path, from the edge of the filter sand to the top of the underdrain, and a minimum travel path, calculated as the vertical distance from the top of the filter sand to the top of the underdrain pipe. However, many designers simply use either the maximum length of flow path from the top of the underdrain to the edge of the filter media, or the minimum travel path from the top of the filter media to the top of the underdrain pipe.

The Modified Falling Head Equation does not assume that the hydraulic gradient is equal to 1 and, therefore, is much less conservative than Darcy's Equation. Typically, the Modified Falling Head Equation will result in substantially less underdrain required than would be indicated using Darcy's Equation. This analysis also assumes that the underdrain pipe does not limit the flow through the filter system.

2.4.1.3 Incremental Darcy's Equation

The Incremental Darcy's Equation utilizes Darcy's Equation but divides it into increments to improve the accuracy of the results. Darcy's Equation, Q = KiA, is written as:

$$Q = K\frac{H}{D}A$$

where (see Figure 2-5):

H = vertical difference between the water surface and the center line of the underdrain pipe (ft)

D = vertical depth of the bottom vertical filter media (ft) (normally, this value is 2 ft)

Using this equation, the flow rate (Q) can be separated into as many increments as desired. The instantaneous flow rate can be calculated at any point in time knowing H and D. Since the area of the bottom vertical filter (A) is equal to the width of the filter (W) times the length of the filter (L), the equation can be written as follows:

$$Q = K\frac{H}{D}WL$$

The Incremental Darcy's Equation is often substantially more accurate in predicting filter drawdown characteristics than can be obtained using Darcy's Equation. The Incremental Darcy's Equation does not assume that the hydraulic gradient (i) is constant for all conditions of head above the filter media. This equation assumes that flow will increase as the head above the filter increases which appears to be more theoretically correct than the assumption of a constant hydraulic gradient used in Darcy's Equation. Also, the accuracy of the Incremental Darcy's Equation is increased by dividing flow conditions into a number of intervals rather than calculating a single interval as is often done with Darcy's Equation.

2.4.1.4. Incremental Darcy's Equation Utilizing the Effective Area

The previous design equations for bottom vertical filters were based upon the assumption that the permeability of the filter media is the limiting factor regulating the discharge through the underdrain system. The final bottom vertical design equation, called the Incremental Darcy's Equation Utilizing the Effective Area, assumes that the limiting factor in regulating flow through the underdrain system is the area of total openings within the underdrain pipe rather than the filter media itself. This equation assumes that the openings of the pipe are insufficient to convey the total water volume which passes through the filter media. In addition, head loss also occurs due to convergence of flow lines as the filtered water approaches the openings in the underdrain pipe, further limiting the flow which can enter the underdrain system.

This equation utilizes an effective radius (r_e) such that a completely open drain hole of radius (r_e) will offer the same resistance to inflow as a tube with radius (r). A summary of effective radii for various size drain tubes, as given in the SJRWMD Draft Stormwater Applicants Handbook, is given in Table 2-5. Effective areas (Ac) for drain pipes within gravel envelopes are provided in Table 25-3 of the SJRWMD Draft Stormwater Applicants Handbook.

TABLE 2-5

EFFECTIVE RADII (r_e) FOR
VARIOUS SIZED DRAIN TUBES

DRAIN	OUTSIDE DIAMETER (in)	r_e (in)
3" corrugated*	3.5	0.14
4" corrugated*	4.5	0.20
5" corrugated*	5.5	0.41
6" corrugated*	6.5	0.58

* Based on 5 rows of slots with total opening amount to 1.5 to 2% of the wall area.

Envelopes of more permeable media around the underdrain pipe increase the effective radii of the pipe by allowing a freer movement of water to the drain openings. As seen in Table 2-5, when a gravel envelope is placed around the underdrain pipe, the effective radii of the pipe increases substantially compared with values listed with no gravel envelope. However, it is important to note that the effective radius of the pipe even with the gravel envelope is still less than the actual pipe radius.

Once the effective radius of a particular underdrain pipe has been determined, the effective flow area (A_e) of the pipe can be determined from the following equation:

$$A_e = 2\pi\, r_e\, L$$

where:

A_e = effective flow area of the underdrain pipe (ft^2)

π = 3.1416

r_e = effective pipe radius (in)

L = length of underdrain pipe (ft)

Once the total effective area has been calculated for the underdrain system, the discharge rate (Q) can be calculated at various increments of drawdown using the following equation (see Figure 2-5):

$$Q = K \frac{\Delta H}{\Delta D} A_e$$

where:

Q = underdrain discharge (ft^3/hr)

K = filter media permeability (ft/hr)

H = vertical distance from water surface to center of underdrain (ft)

D = vertical distance from top of underdrain trench to the center of the underdrain (ft)

A_e = effective flow area (ft^2)
= $2\pi\, r_e\, L$

Many design engineers use D as the distance from the top of the underdrain trench to the top of the underdrain pipe. This smaller D value increases the value of "i", which increases the value of Q, and underestimates the actual drawdown time for the filter system.

2.4.2 Design Equations for Side Bank Filter Systems

With only a few exceptions, the design equations discussed previously for bottom vertical filter systems are also appropriate for estimation of drawdown characteristics in side bank filter systems. The primary difference between the methodologies involves the estimation of the cross-sectional area of the filter media intersected by the stormwater flow and calculation of the hydraulic gradient which generally decreases with time in side bank filter systems rather than remaining constant as assumed under Darcy's Equation.

As indicated by representatives of the St. Johns River Water Management District and the Florida Department of Environmental Regulation, three design equations are commonly used for design of side bank filter systems:

1. **Incremental Darcy's Equation** (Reference: Florida Land Development Manual, p. 6-271)
2. **Modified Incremental Darcy's Equation** (Reference: Common Practice)
3. **Incremental Darcy's Equation Utilizing the Effective Area** (Reference: Draft St. Johns River Water Management District Stormwater Applicant's Handbook)
4. **Flow Net** (Reference: Florida Land Development Manual, p. 6-276)

Comments on the use of each of these equations is given in the following sections.

2.4.2.1 Incremental Darcy's Equation

One of the most commonly used equations for designing side bank filters is the Incremental Darcy's Equation modified for lateral flow. This equation assumes that the velocity of water traveling through the porous media is proportional to the hydraulic conductivity of the media and the hydraulic gradient exerted on the system. This equation is written as:

$$Q = K i A$$

where (Figure 2-5):

Q = underdrain discharge (ft^3/hr)

K = media permeability (ft/hr)

i = $\Delta Y / \Delta D_H$

where:

Y = vertical distance from water surface to center of underdrain (ft)

D_H = horizontal distance from edge of water surface to center of underdrain (ft)

A = average cross-sectional area of the saturated zone (ft^2) as follows:

$$A = (H - \frac{Y}{2})\,L$$

where:

H = vertical distance from water surface to bottom of filter media (ft)

Y = vertical distance from water surface to centerline of underdrain (ft)

L = length of underdrain (ft)

A schematic of a side bank filter system indicating typical design variables is given in Figure 2-5.

2.4.2.2 Modified Incremental Darcy's Equation

The Modified Incremental Darcy's Equation involves a slight modification of the basic Incremental Darcy's Equation. The hydraulic gradient (i) is equal to the hydraulic head (Y) divided by the diagonal flow path (D). Also, the area (A) is not a vertical plane but the area of the wetted surface of the pond side bank, measured on a diagonal line. This equation can be written as (see Figure 2-5):

$$Q = KiA = K\frac{Y}{D}A$$

where:

H = vertical distance from water surface to center of underdrain (ft)

D = diagonal distance from top of water surface to center of underdrain (ft)

A = W x L (ft^2)

where: W = average width of the saturated filter media at the filter surface and at the drain pipe (ft)

L = length of filter media (ft)

The primary difference between the Modified Incremental Darcy's Equation and other design equations is the diagonal measurements of D and the calculation of A. In most other typical design equations, the flow distance is assumed to be a horizontal measurement from the water surface to the center of the underdrain, and A is assumed to be a vertical plane.

2.4.2.3 Incremental Darcy's Equation Utilizing Effective Area

The Incremental Darcy's Equation Utilizing the Effective Area for side bank filters is very similar to that discussed under the bottom vertical filters. The basic equation is written as (see Figure 2-5):

$$Q = K\frac{Y}{D}A_e$$

where:

Q = discharge (ft^3/hr)

K = permeability (ft/hr)

Y = vertical distance from water surface to center of underdrain (ft)

D = diagonal distance from water surface to center of underdrain (ft)

A_e = effective flow area (ft^2)
= $2\pi\ r_e\ L$

where:

r_e = effective radius (in)

L = length of underdrain (ft)

2.4.2.4 Flow Net Approach

Another method for evaluating seepage through a typical side bank underdrain system involves the construction of flow nets. This method is not as common as the three design equations described previously, but is sometimes used within the State of Florida to calculate required underdrain lengths. Flow lines of seepage through a typical side bank underdrain system are illustrated in Figure 2-6. The Flow Net Equation, as provided in the Florida Development Manual Guide to Sound Lake and Water Management and Stormwater Management Practices, is written as:

$$q = KH\frac{nf}{nd}$$

where:

q = seepage quantity (L^3/T/ft of filter)

K = permeability of the media (L/T)

H = net head, as illustrated in Figure 2-6 (L)

nf = number of flow channels

nd = number of equal potential drops

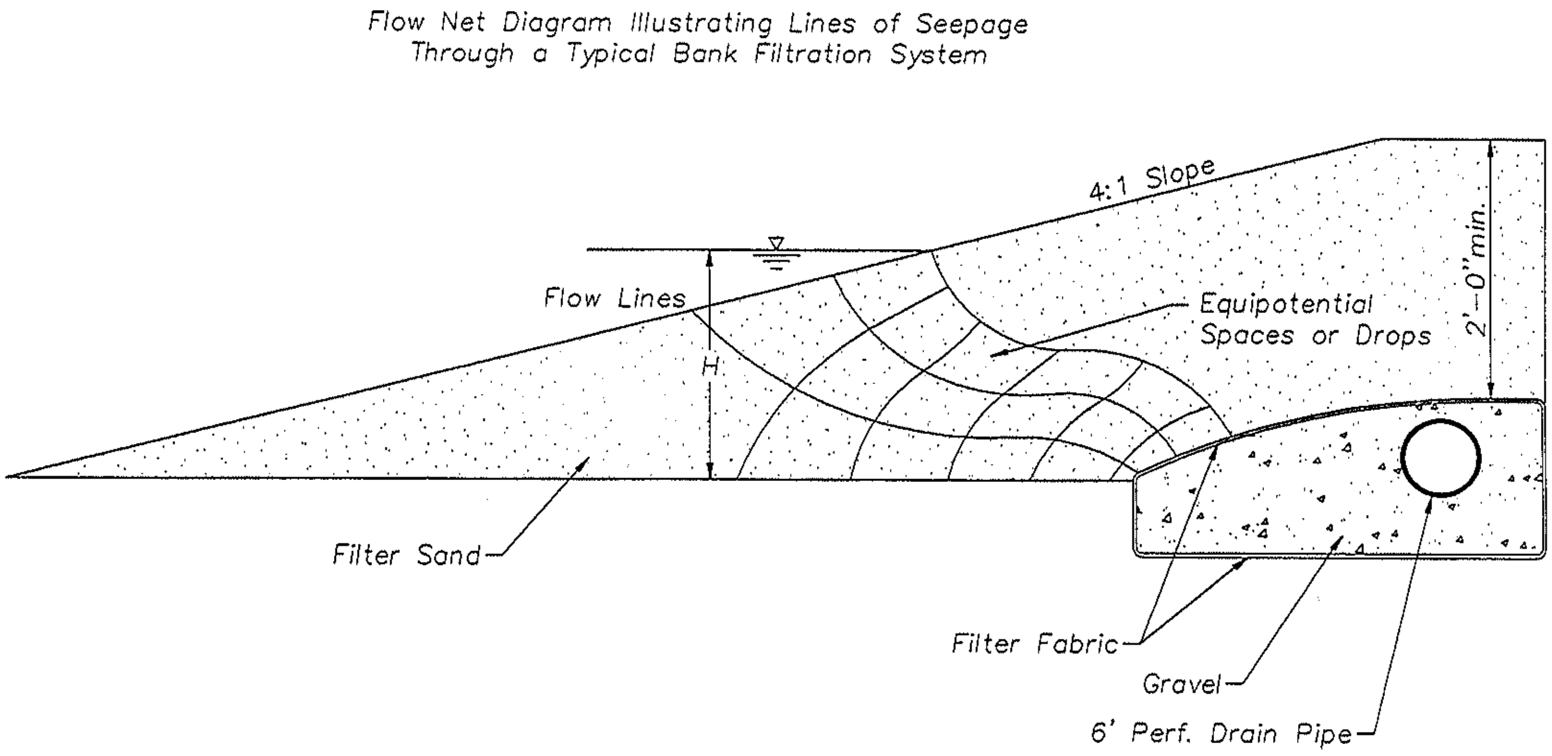


Figure 2-6. Flow Net Diagram Illustrating Lines of Seepage Through a Typical Side Bank Filtration System.

The ratio of nf/nd is known as the Shape Factor. The number of flow channels and the corresponding number of equipotential spaces depends on the shape of the cross-section and will not necessarily be a whole number. Each shape produces a different number of spaces and channels. Although flow nets are difficult to properly develop, once constructed, they will continually apply to the specific design of shape.

First, the initial rate of discharge (q) is established at each desired increment of drawdown. Once this is completed, the total stage discharge relationship for the filter is determined by multiplying the value of discharge (q) of each stage by the length of filter (L). The instantaneous discharge (q) is averaged between each increment. Based on the volume of storage for each increment, the drawdown time can be calculated by dividing the incremental volume by the average rate of outflow.

2.5 Hydraulic Evaluation of Design Equations

Virtually no practical research has been conducted to verify the applicability of the design equations presented in the previous section for predicting drawdown in either vertical bottom filters or side bank filter configurations. Much of the existing hydraulic information on filter systems was generated from laboratory investigations of permeability values for various filter media rather than actual field test conditions.

As part of the work efforts conducted during the research discussed in this report, each of the previously described design equations were evaluated under both field and pilot test conditions to compare the ability of each equation for predicting measured drawdown in both bottom vertical filters and side bank filter configurations. Design equations commonly used for prediction of drawdown in side bank filter configurations were evaluated in an existing detention with filtration facility as well as a pilot scale system of a side bank filter. Design equations commonly used for vertical bottom filters were tested only in the pilot scale configuration. The results of these analyses are presented in Chapter 4.

CHAPTER 3

FIELD AND LABORATORY PROCEDURES

3.1 Description of the Study Site

Field and laboratory investigations were conducted from April 1992 to January 1993 at a study site in DeBary, Florida to evaluate the hydraulic and water quality characteristics of a detention with filtration pond system. The location of the DeBary pond site is indicated in Figure 3-1. The pond site is located on the east side of U.S. 17 in DeBary, approximately 91 m (300 ft) south of the intersection with Highbanks Road.

The detention with filtration pond was constructed in 1988 by the Florida Department of Transportation (FDOT) to provide stormwater treatment from the widening of highway U.S. 17 through DeBary to accommodate a center turn lane. At that time, approximately 3.35 m (11 ft) of pavement were added to both sides of the roadway, including a 1.2 m (4 ft) paved shoulder. The new roadway surface is paved with asphalt and has an average width of approximately 13.7 m (45 ft).

A delineation of the drainage basin area which contributes stormwater runoff to the detention with filtration pond is indicated in Figure 3-2. This drainage basin includes primarily low density commercial areas immediately adjacent to highway U.S. 17 and a residential area on the southwest corner of the basin. Runoff within the drainage basin area moves by overland flow to a series of inlets and deep swales located along the west and east sides of highway U.S. 17. In general, these deep roadside swales are the primary conveyance mechanisms for stormwater runoff along both the west and east sides of the road. Underground stormsewer lines with contributing inlets have been constructed along some of the commercial property areas to provide access to businesses located along the roadway. The roadside stormsewer lines are not continuous and ultimately discharge into the primary swale conveyance system.

Runoff generated within the residential area located in the southwest corner of the drainage basin flows through shallow roadside swales with ultimate discharge into the primary drainage system located along highway U.S. 17. Overall, the primary drainage system along highway U.S. 17 contains approximately 1253 m (4110 ft) of underground stormsewer lines and approximately 1829 m (6000 ft) of roadside swale. The drainage basin delineation indicated in Figure 3-2 was determined by ERD based upon aerial contour photography of the study site and field verifications during rain events from May to November 1992.

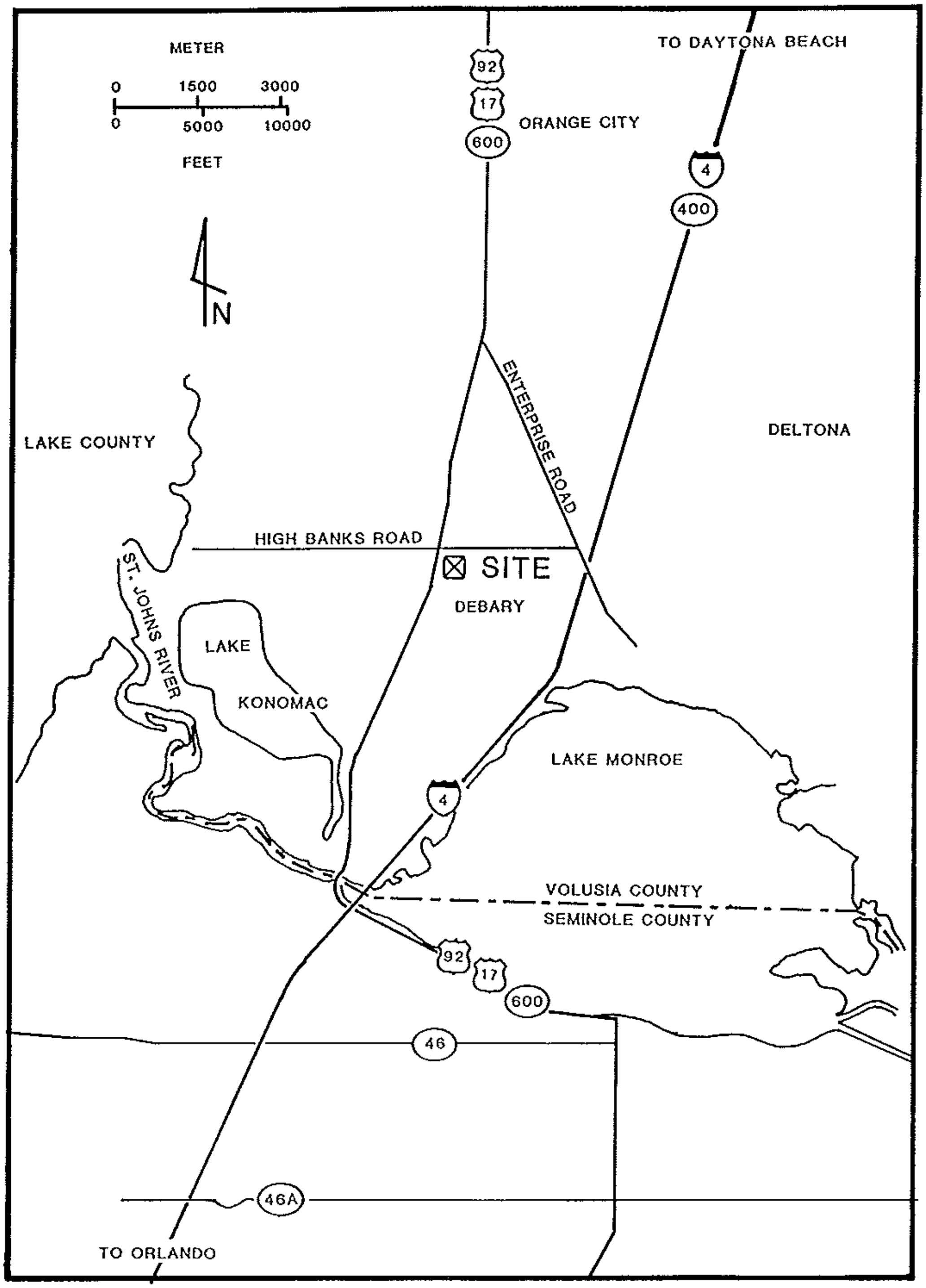


Figure 3-1. Location Map for the DeBary Detention with Filtration Pond Site.

Hydrologic characteristics of the contributing watershed area for the DeBary detention with filtration pond site are summarized in Table 3-1. The total area contained within the contributing watershed basin is approximately 20.5 ha (50.7 ac). The drainage basin is divided approximately equally between low density commercial land use immediately adjacent to highway U.S. 17 and single-family land use found in the southwest corner of the drainage basin. Overall, the drainage basin is approximately 59.6% impervious with 95% of this area consisting of directly connected pervious areas. No lakes or other waterbodies are located within the contributing watershed area.

TABLE 3-1

HYDROLOGIC CHARACTERISTICS OF THE CONTRIBUTING WATERSHED AREA FOR THE DEBARY DETENTION WITH FILTRATION POND SITE

Watershed Area:	20.5 ha (50.7 ac)
Percent in Lakes	0
Impervious Area:	59.6%
Pervious Area:	40.4%
Percent of Pervious Area Directly Connected:	95.3%[1]
CN for Pervious Areas:	49
Time of Concentration:	80 minutes

1. Percent of total impervious area.

According to the soil survey of Volusia County, Florida, published by the Soil Conservation Service, soils within the drainage basin consist of the following series:

SOILS NUMBER	SOILS NAME	HYDROLOGIC SOIL GROUP
1	Apopka Fine Sand	A
37	Orsino Fine Sand	A
42	Paola Fine Sand	A

The Apopka Fine Sands and Orsino Fine Sands constitute the majority of the soils found within the drainage basin. Paola Fine Sands are found in approximately 5% of the area. Each of these soils is classified as hydrologic soil grouping A which indicates excellent permeability and a low runoff potential. Vertical permeability of the Paola and Orsino soils exceeds 51 cm/hr (20 in/hr) to depths in excess of 203 cm (80 in). Vertical permeability of the Apopka soils ranges from 15-50.8 cm/hr (6-20 in/hr) to depths as deep as 157 cm (62 in). Pervious areas within the drainage basin consist primarily of open spaces and lawns with grass cover in fair condition on 50-75% of the area with a curve number (CN) value of 49.

Time of concentration for the drainage basin area was estimated as the time required for stormwater runoff to travel from the farthest point in the drainage basin to the point of inflow to the detention pond. This path begins in the residential area on the southwest corner of the basin. Stormwater generated in this vicinity is collected in shallow roadside swales and is transported into the primary stormsewer system along U.S. 17. Upon entering this stormsewer system, stormwater travels through a series of underground stormsewer lines and open roadside swales with final discharge into the detention pond. Travel time for each of these reaches of the stormsewer system was estimated using the Manning Equation for both open channel and pipe flow based upon the slope, geometric characteristics of the channel and an assumed depth of flow. Estimated time of concentration for the watershed is 80 minutes.

According to design calculations contained within FDOT files, the roadside swale system along U.S. 17 which discharges into the detention pond is designed primarily for conveyance. The conveyance capacities of all the swales and stormsewer systems have been designed to accommodate the runoff generated by a 10-year storm.

Drainage system and detention pond details for the DeBary detention with filtration research site are given in Figure 3-3. Three large stormsewer lines converge at the pond site from the east, west and south, into a single 74 cm x 114 cm RCP (29" x 45") which discharges into the detention with filtration pond at a single location. A grassed swale is located along the northern boundary of the pond site to intercept off-site drainage flowing onto the property from adjacent areas to the north. No off-site drainage enters the pond site from the west, east or south. A 1.8 m (6 ft) high chain-link fence surrounds the entire detention pond site.

Elevation contours for the detention pond are also indicated on Figure 3-3. This contour information is based upon field surveys conducted by ERD during February 1993. Spot elevations were collected at 3.05 m (10 ft) intervals over the entire pond site, and the contours in Figure 3-3 were generated using AUTOCAD. The sides of the pond are constructed on a 3:1 side slope down to a bottom elevation of approximately 50.5 ft (15.40 m). The average measured invert of the underdrain pipe is 54.88 ft (16.73 m), based upon field surveys conducted by ERD. The control elevation for the underdrain system is assumed to be the centerline of the 15 cm (6 in) perforated pipe at elevation

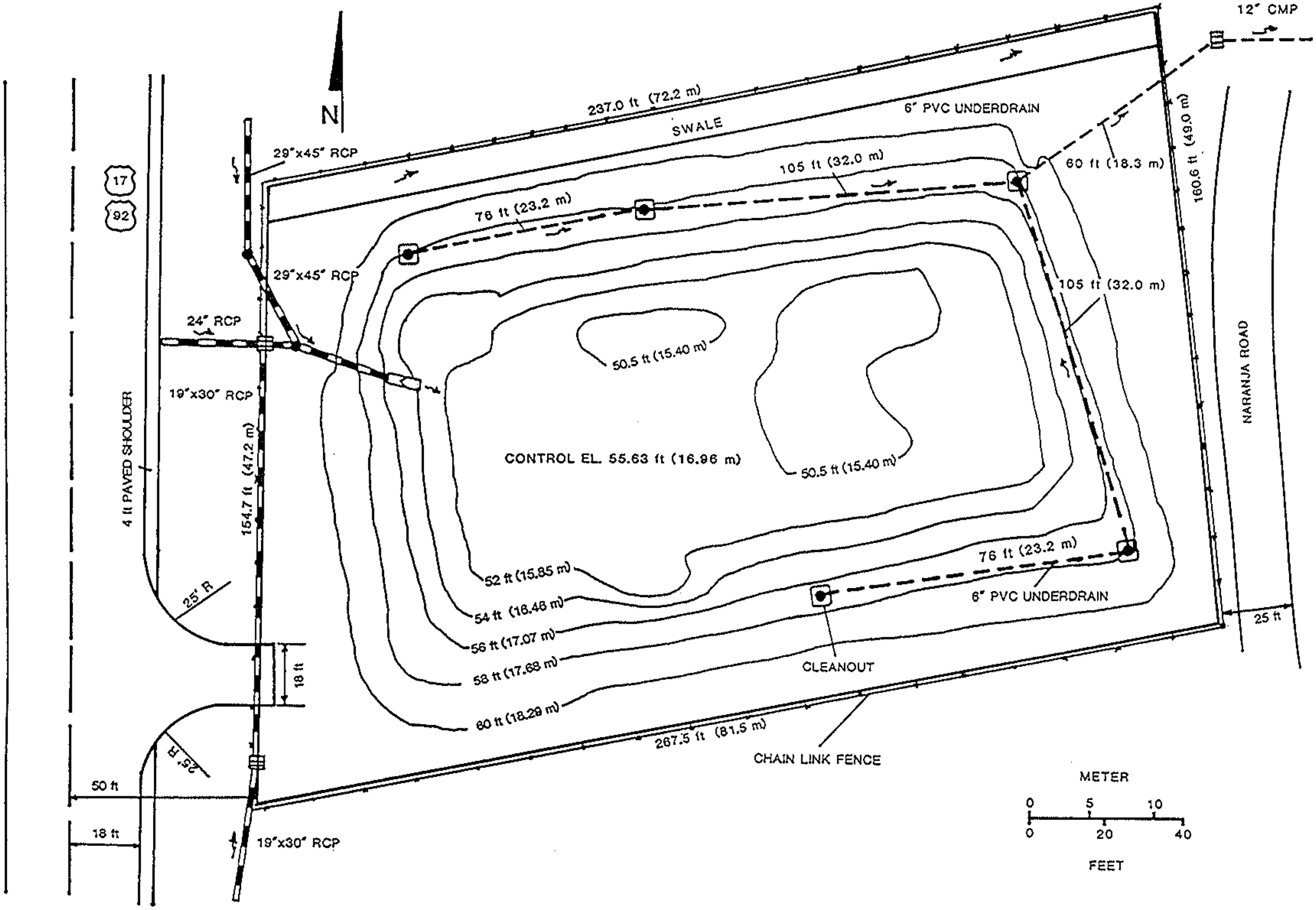


Figure 3-3. Drainage and Pond Details for the DeBary Detention with Filtration Site.

55.13 ft (16.81 m). At the control elevation of 55.13 ft (16.81 m) the water surface area is approximately 1,361 m^2 (14,645 ft^2) or approximately 0.14 ha (0.34 ac) with a cumulative volume of 1,411 m^3 or approximately 49,806 ft^3. A summary of morphological characteristics of the DeBary detention with filtration pond is given in Table 3-2.

Although not shown in Figure 3-3, elevation contours drop sharply between the east boundary of the pond site and Naranja Road, with a total change in elevation of approximately 1.2-1.5 m (4-5 ft). To prevent seepage of water from the pond through the sides of the steep embankment between the chain-link fence and Naranja Road, a clay core was constructed along the entire east property boundary and approximately half of the north property boundary.

According to the technical report submitted with the project permit to FDOT, the stormwater management system has been designed to meet the requirements outlined in Chapter 40C-42 of the Florida Administrative Code. The project does not meet the permitting thresholds as established in Chapter 40C-4 as determined by the St. Johns River Water Management District (District). A permit for the project was issued by the District on March 4, 1987. The as-built certification was submitted by FDOT on March 31, 1988 and the site was inspected on June 3, 1988 by the District and found to be in compliance with the permit.

The detention pond is constructed with an underdrain system located along the north, east and approximately half of the south side of the pond. A total of 110 m (362 ft) of perforated underdrain is installed at the pond site. Discharges from the underdrain pipe travel through a 15 cm (6 in) non-perforated PVC pipe into a small inlet manhole located outside the detention pond site at the northeast corner. This inlet is connected by a 30 cm (12 in) corrugated metal pipe which discharges into a land-locked lake, Lake Gem. Since discharges from the pond enter a waterbody with no positive outfall, the detention pond has been designed to detain the runoff from a 25-year, 24-hour storm at a peak stage of 57.98 ft (17.68 m).

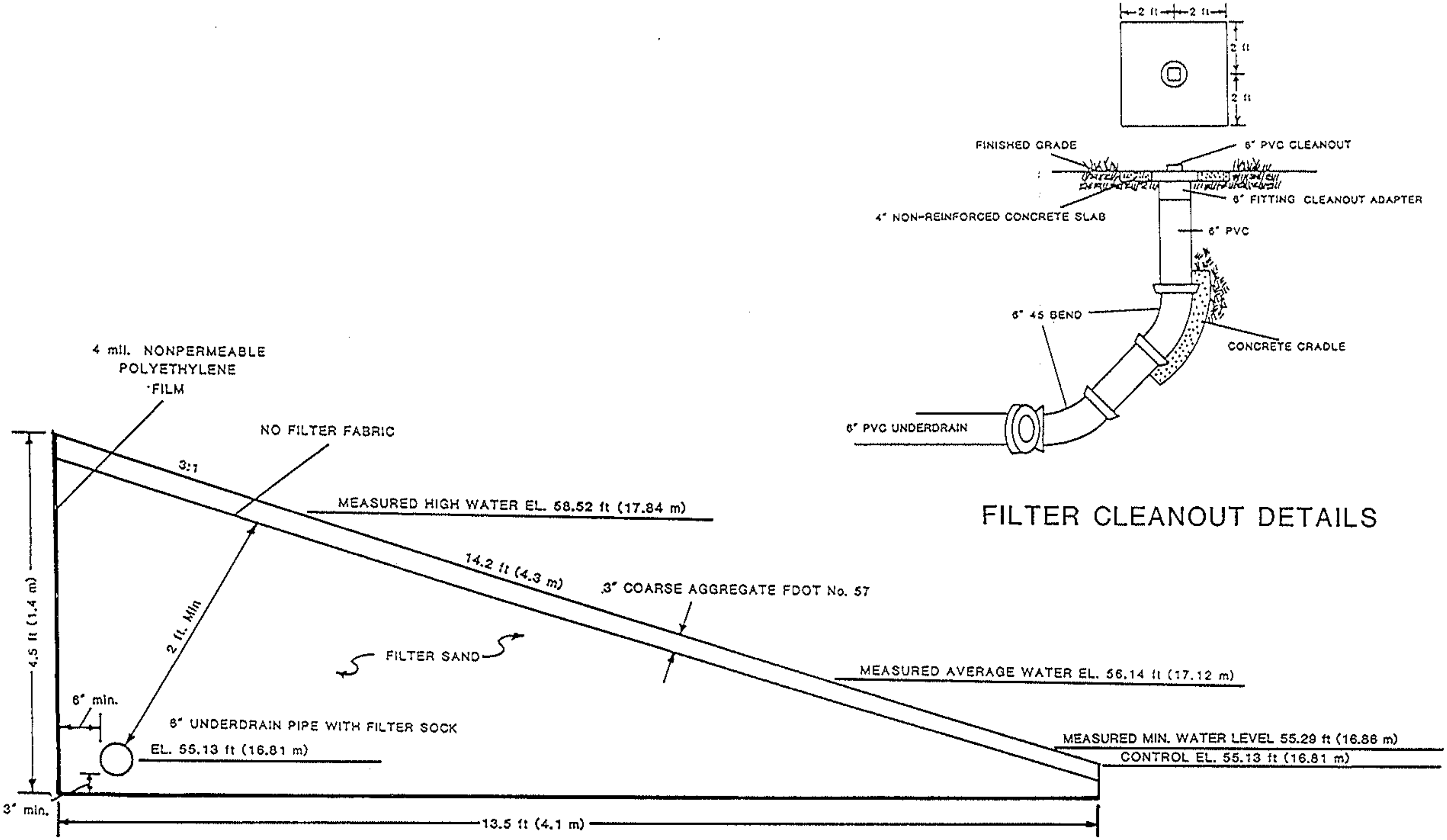
A schematic cross-section of the side bank filter system at the DeBary detention with filtration pond site is given in Figure 3-4. This typical cross-section is based upon field measurements and survey information collected by ERD. The filter system consists of a 15 cm (6 in) perforated PVC underdrain pipe covered with a filter fabric sock. The underdrain pipe is surrounded by a layer of filter sand with a minimum travel distance of 0.6 m (2 ft) for any flow path through the filter media. As seen in Figure 3-4, at the measured average water elevation of 56.14 ft (17.12 m), the travel flow path through the filter media is substantially greater than 0.6 m (2 ft). The face of the filter is constructed on a 3:1 slope with a 7.6 cm (3 in) layer of coarse aggregate (FDOT No. 57). A 4 mil non-permeable polyethylene film is located along the base and vertical side of the filter system to minimize inflow of groundwater into the underdrain pipe. Filter fabric is not used along the face of the filter to separate the filter sand from the coarse aggregate media.

TABLE 3-2

MORPHOLOGICAL CHARACTERISTICS OF THE DEBARY DETENTION WITH FILTRATION POND[1]

ELEVATION		SURFACE AREA		CUMULATIVE VOLUME	
m	ft	m^2	ft^2	m^3	ft^3
15.396	50.5	189.5	2,039	0	0
15.549	51.0	737.5	7,934	71	2,493
15.854	52.0	918	9,874	323	11,397
16.159	53.0	1,051	11,307	623	21,988
16.463	54.0	1,201	12,921	966	34,102
16.768	55.0	1,346	14,483	1,355	47,804
17.073	56.0	1,500	16,138	1,789	63,115
17.378	57.0	1,670	17,965	2,272	80,167
17.683	58.0	1,855	19,962	2,809	99,131
17.988	59.0	2,074	22,314	3,408	120,269

1. Based on field measurements conducted by ERD.



FILTER CLEANOUT DETAILS

CROSS-SECTION OF FILTER SYSTEM

Figure 3-4. Filter Details for the Side Bank Filter System at the DeBary Detention with Filtration Pond Site.

Access points for cleaning or inspecting the PVC underdrain system are located at the ends and corners of the underdrain as well as mid-way along the north underdrain pipe. Typical details for underdrain cleanouts are also shown in Figure 3-4. These cleanout and inspection ports allow access to the PVC underdrain for routine backflushing operations or to remove clogs from the underdrain lines.

FDOT maintenance practices at the detention pond site consist primarily of mowing the grass within the fenced area and control of large vegetation within the swale along the north side of the detention pond site. No backflushing or maintenance of the underdrain system has been conducted by the FDOT in the five years since construction of the pond. The filter face along the east and south side of the pond is covered with dense weeds and woody shrubs. Vegetation along the north side of the filter face is sporadic and consists primarily of small weed species. It appears that FDOT has attempted to control the growth of vegetation on the filter face by mowing the face of the filter using a large tractor. Deep ruts have been formed within the filter media along the east and south sides, as deep as 0.45 m (1.5 ft), from the tires of the tractors driving in this area. Substantial disturbances of the filter media are evident in several areas where it appears that a tractor or other vehicle had become stuck within the filter area. Disturbances caused by tractor tires has forced the coarse aggregate surface layer down into the filter media along many areas of the filter face. However, the majority of these disturbed areas are above the average water level elevation of 56.14 ft (17.12 m).

3.2 Field Procedures and Instrumentation

A schematic of field instrumentation used at the DeBary detention with filtration pond site is given in Figure 3-5. Instrumentation was installed to conduct a complete hydrologic budget for the pond site, including a water level recorder, rainfall recorder, evaporimeter and groundwater piezometers. Automatic sequential samplers 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. Details on installation and routine operation for this equipment are contained in the following sections.

3.2.1 Instrumentation for Collection of Stormwater and Baseflow

Automatic sequential samplers with integral flow meters, manufactured by Sigma (Sigma Model No. SL8000), were installed at the inflow stormsewer and underdrain outflow pipe to collect samples on a flow-weighted basis and provide a continuous hydrograph of inputs and outputs from the pond. The stormwater collector was installed inside an insulated equipment shelter adjacent to the point of inflow into the pond. The stormwater collector was operated on a 120 VAC power source from a temporary power connection installed at the site.

A small sharp-crested weir was constructed inside the oval stormsewer line to provide a control point for accurate measurement of stormwater inputs. The flow

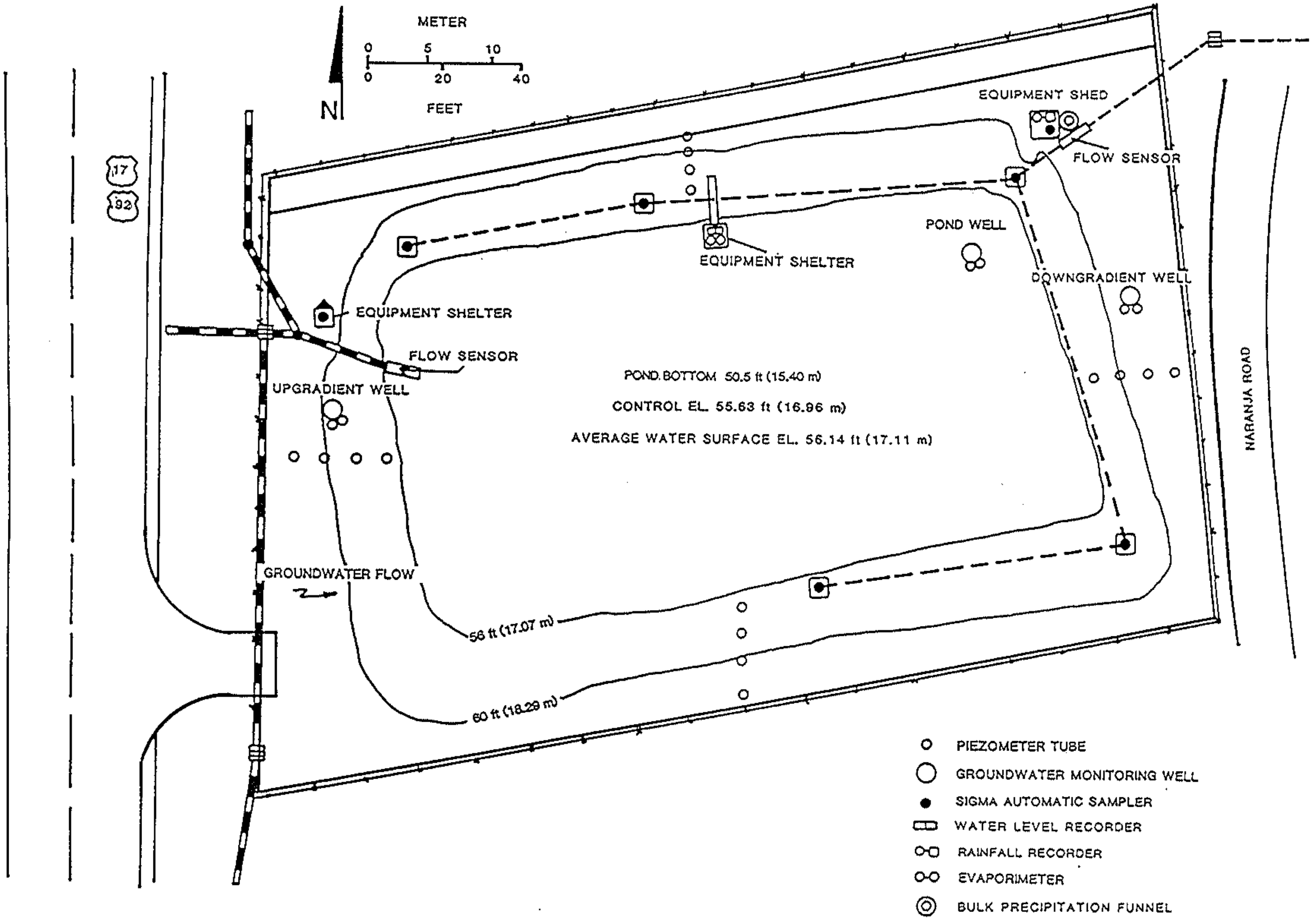


Figure 3-5. Field Instrumentation Used at the DeBary Detention with Filtration Pond Site.

recorder was programmed to provide a continuous record of hydraulic inputs into the pond with measurements stored into internal memory at 10-minute intervals. The automatic stormwater collector contained 24 one-liter polyethylene bottles and was programmed to collect stormwater samples in a flow-weighted sample mode. A single flow-weighted composite stormwater sample was generated from each rain event by combining sample bottles from the same storm event to form a composite. An average of five flow-weighted composite samples of stormwater runoff were collected and submitted for laboratory analyses each month.

Periodically, a continuous flow was recorded entering the detention pond over a period of several days which was unrelated to a particular storm event. This baseflow input was measured primarily in the days preceding large storm events during August, September, October and November. Continuous input hydrographs and flow-weighted samples were collected of baseflow during each baseflow event. A total of seven separate baseflow events were monitoring during the 6-month study period.

3.2.2 Instrumentation for Collection of Filter Underdrain Flow

Samples of underdrain outflow from the pond were also collected using a Sigma sequential automatic sampler with an integral flow recorder programmed to operate in the flow-weighted sample mode. Underdrain flow rates were monitored by placing a weir structure in-line with the underdrain pipe. The box containing the weir was constructed of 3/4" marine plywood and was 2.4 m (8 ft) long, 0.46 m (1.5 ft) wide and approximately 1.8 m (6 ft) tall. A 2.4 m (8 ft) section of the underdrain pipe was removed and replaced with the weir box structure. A 45° V-notch weir was constructed on the downstream end of the box for measurement of discharges from the underdrain pipe. The flow sensor was attached below the weir to record weir elevations which were converted into flow rates using the integral flow meter inside the sequential sampler. The Sigma unit was housed inside a small equipment shed installed adjacent to the outflow line. Outflow samples were formed into a flow-weighted composite of outflow from the detention pond collected over approximately a 72-hour period. A single composite outflow sample was formed from the individual sequential samples collected on each of the site visits. Two underdrain sample collectors were operated using a 120 VAC power source from a temporary power connection installed at the research site.

3.2.3 Routine Sample Collection Procedures

Field personnel visited the site twice each week to retrieve samples and flow data from the stormwater and outflow collectors. The center compartment of each of the two automatic samplers was filled with approximately 8-10 lb of ice on each sample visit. This amount of ice was sufficient to chill collected samples between collection dates. Data was retrieved from each storm collector unit using a Data Transfer Unit (DTU) which produced a hard copy printout of inflow and outflow hydrographs when connected to an office printer.

3.2.4 Hydrologic Instrumentation

In addition to continuous measurement of inflow and outflow from the pond, additional instrumentation was installed to complete the hydrologic budget for the pond site. A sensitive water level recorder (Stevens Model A-71) was installed inside the equipment shelter, approximately 6.1 m (20 ft) into the pond along the north shore. A walkway was installed to connect the equipment shelter with the adjacent dry land. The water level recorder provided a continuous strip chart record of changes in water surface elevation with a sensitivity of 1 mm. Strip chart records lasted approximately two months before replacement was necessary.

A recording rain gauge was installed on the roof of the equipment shed located adjacent to the underdrain outfall line. This rainfall recorder, Texas Electronics, Inc., Model 1014-P, produced a strip chart record of rainfall characteristics measured at 3 second intervals. This record was used to provide information on rainfall characteristics such as total rainfall amount, antecedent dry period, rainfall intensity and total rainfall volumes for each month of the study.

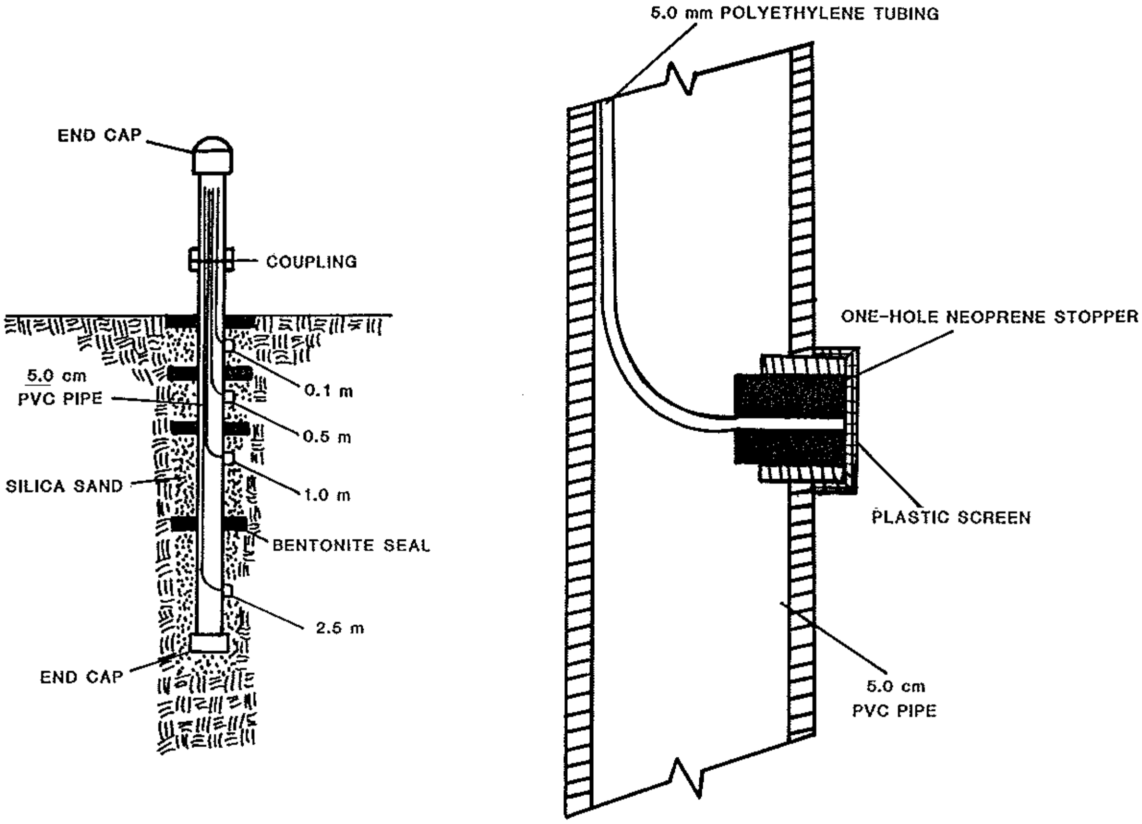
A Qualimetrics Model 6811 recording evaporimeter was installed on the top of the equipment shelter used to house the Stevens water level recorder. This recording evaporimeter provided a continuous strip chart record of evaporative losses from the pond surface on a daily basis during the six-month study period. Measurements collected by the recording evaporimeter were calibrated on-site using a Class "A" pan evaporimeter.

A series of groundwater piezometers were installed on each of the four sides of the detention pond to provide information on horizontal groundwater gradients in the vicinity of the pond site. A total of four 3.2 cm (1.25 in) diameter shallow piezometers were installed on each side of the pond to a depth of approximately 3.05 m (10 ft) below the ground surface. Piezometers were installed at distances of 2 m, 4 m, 6 m and 9 m from the pond water surface at the average water elevation of 56.14 ft (17.11 m). Piezometric measurements were collected from each of the sixteen piezometers on a weekly basis using a water level recorder manufactured by SoilTest.

Additional 1.3 cm (0.5 in) diameter piezometers were installed in each well bore hole to evaluate vertical groundwater gradients. Two piezometers were installed with each multiport monitoring well with one piezometer located adjacent to the 1 m sample port and the second piezometer located adjacent to the 2.5 m sample port. These piezometers were also monitored on a weekly basis in the manner previously described.

3.2.5 Groundwater Monitoring

Three multiport groundwater monitoring wells were installed at the site. A schematic of a typical groundwater monitoring well is given in Figure 3-6. The multiport groundwater design is such that all sample ports are housed in a single 5 cm (2 in) PVC pipe. The ports were constructed from one-hole neoprene stoppers with a



MONITORING WELL INSTALLATION

CROSS-SECTION OF SAMPLING PORT FOR GROUNDWATER

Figure 3-6. Schematic of a Typical Multiport Monitoring Well.

5 mm semi-rigid polyethylene tube inserted into the hole. This stopper was covered with a small mesh plastic screen to prevent soil particles from entering the tubing. Polyethylene tubing was extended from each sample port through the PVC casing to the surface where the ends were permanently marked for identification of sample ports during sample collection. These wells provide the ability to collect groundwater samples from precise locations within the water table. This type of monitoring well has been used on numerous previous research projects by ERD.

Bore holes for the multiport wells were formed by extending a 15 cm (6 in) stainless steel casing into the ground in 1 m (3.3 ft) sections using a portable rotary cathead and a standard 64 kg hammer. No drilling fluids or lubricants of any kind were used during drilling. Once the drilling process was completed, the hole was backwashed with clean water until the wash water was clear and free of suspended solids. A portable well pump was then inserted into the casing and any remaining wash water was pumped from the bore hole. The PVC monitoring well housing was inserted into the bore hole, and backfilling with clean silica sand (20-30 grade) was begun. After approximately 1.5 m (5 ft) of silica sand backfill had been placed, the stainless steel casing was gently raised, and a 1 m (3.3 ft) section was removed. Bentonite seals, approximately 20 cm thick, in the form of 0.64 cm (0.25 in) pellets, were placed mid-way between each of the sample ports as indicated in Figure 3-6. An additional seal was placed around the monitoring well casing at the ground surface to minimize seepage of water around the sides of the PVC pipe. A removable end cap cover was installed on each well to protect the sample tubes.

Monitoring wells were installed at the locations indicated in Figure 3-5 with one well installed upgradient in terms of groundwater movement, one well placed in a downgradient position and one well installed within the pond. The normal direction of shallow groundwater flow in the vicinity of the detention with filtration pond is from west to east. For the pond well, sample ports were installed at distances of 0.1 m, 0.5 m, 1.0 m and 2.5 m below the pond bottom. For the upgradient and downgradient monitoring wells, sample ports were installed at distances of 0.1 m, 0.5 m, 1.0 m and 2.5 m below the groundwater table at the time of well installation. All monitoring wells were installed during March and April 1992.

After installation of monitoring wells was completed, sample collection was delayed approximately 30-60 days to allow for groundwater disturbances created during the installation process to dissipate. During this period, all ports on each of the three wells were purged for 10 minutes on a weekly basis using a peristaltic pump to remove any remaining groundwater which may have been disturbed during construction. This process removed approximately 10 liters from each sample port on each weekly visit.

Groundwater samples were collected from each sample port on each of the three monitoring wells, for a total of 12 samples, on a monthly basis from May to November 1992. In general, samples were collected using a peristaltic pump operated at a low flow rate of approximately 100 ml/min. The discharge from the peristaltic pump was connected to a flow cell attached to a Hydrolab Surveyor II water quality monitor. Each sample port was purged by pumping until a stable conductivity reading was reached. After reaching a stable conductivity value, field measurements of pH, dissolved oxygen, temperature, conductivity and redox potential were recorded for each of the 12 monitoring ports. Following collection of field measurements, the sample tube was removed from the Hydrolab water quality monitor, and the pump flow was directed into appropriate sample bottles for collection. Sample collection was begun at the 0.1 m sample port and progressed downward in order to the 2.5 m sample port.

3.2.6 Collection of Surface Water

Pond surface water was collected on a weekly basis from the center of the pond using a clear acrylic Kemmerer water sampler. A single vertical composite sample was formed from the pond by combining equal aliquots of pond water from each 1 m deep layer from the surface to the bottom. On most sampling events, this resulted in two separate samples being collected, with one near the surface and one near the bottom. The individual samples were combined together to form a single composite sample for analysis. In addition, vertical depth profiles of pH, temperature, conductivity, dissolved oxygen and redox potential were collected within the pond beginning at the water surface and extending at 0.5 m intervals from the water surface to the pond bottom using a Hydrolab Surveyor II Water Quality Monitor.

3.2.7 Bulk Precipitation

Water quality characteristics of direct bulk precipitation were estimated by collection and analysis of combined wet and dry fallout. A housing was placed on top of the equipment shelter located adjacent to the outfall line which contained a 30 cm diameter polyethylene funnel. The discharge from the funnel was attached to a length of tygon tubing which was inserted into a 4-liter sample container inside a refrigerator within the equipment shelter. Combined wet and dry fallout was collected and stored inside the sample container located within the refrigerator. Bulk precipitation samples were collected on a weekly basis, and the old sample container was replaced with a new, clean bottle.

3.2.8 Sediment Collection and Analysis

Sediment sampling was conducted within the detention pond, in control areas and within the filter media to quantify the fate of stormwater pollutants within the detention with filtration system. Sample locations for collection of soils and sediments at the DeBary detention with filtration pond site are indicated in Figure 3-7. Sediment core samples were collected within the detention pond in a grid pattern of longitudinal and transverse sections. A total of 28 sediment core samples were collected within the pond. The purpose of these samples is to define the horizontal and vertical migration of runoff-related pollutants within the detention pond.

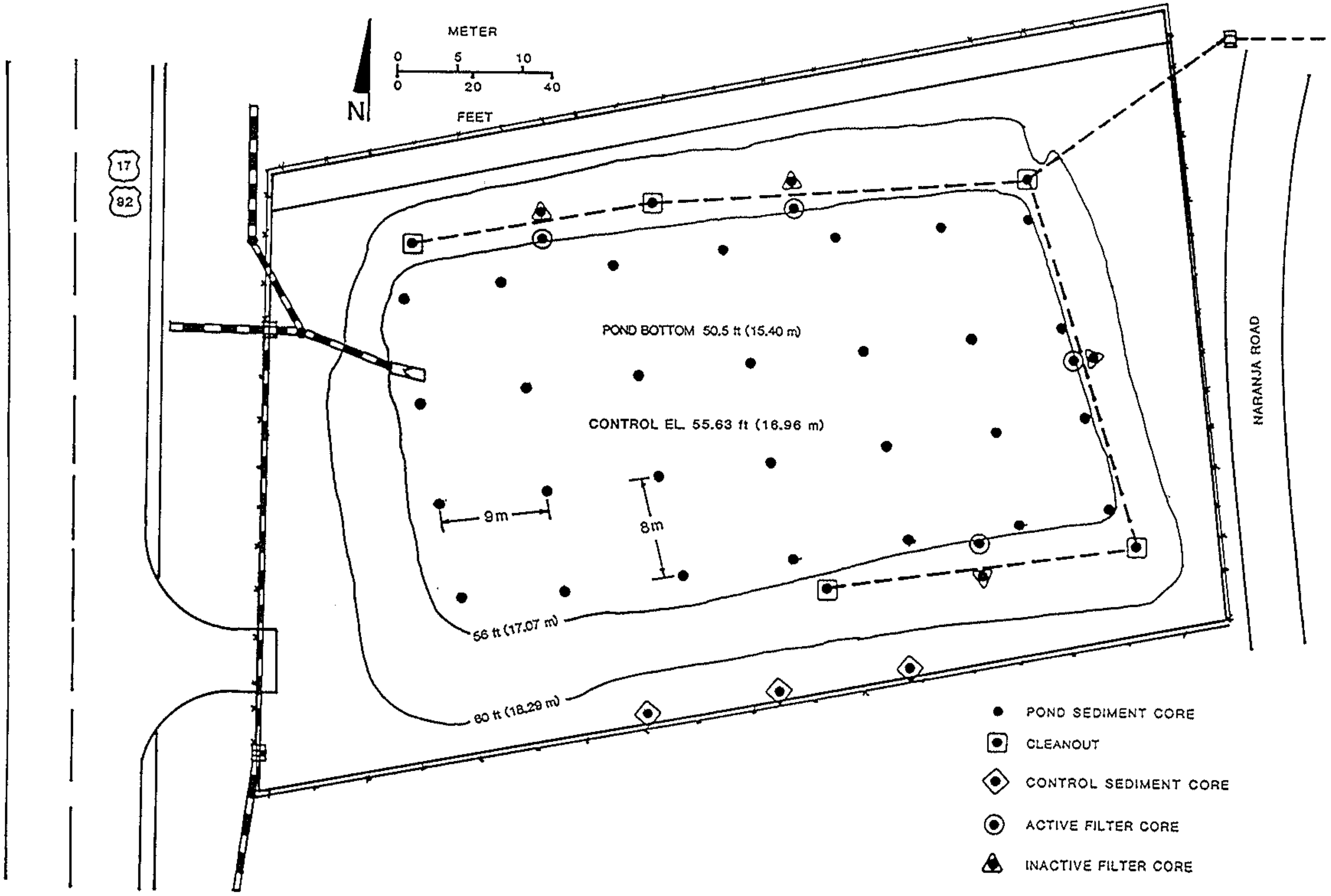


Figure 3-7. Sample Locations for Collection of Soils and Sediments at the DeBary Detention with Filtration Pond Site.

Sediment core samples were collected using a clear acrylic split-spoon type sampler. The sediment core collector was driven a minimum of 50 cm into the sediments or soil and then retrieved. The split-spoon core sampler was opened, and the sediment core sample was divided into the following layers: 0-1 cm, 1-5 cm, 5-10 cm, 10-15 cm, 15-25 cm, and 25-50 cm. Triplicate core samples were collected at each sample location and divided into each of the six sediment layers.

For samples collected within the detention pond, individual composite samples were formed for the 0-1 cm layer at each collection point by combining the triplicate samples collected at each sample location. A total of 28 composite samples were collected from the 0-1 cm layer within the pond. These samples were used to evaluate horizontal variations in sediment characteristics within the pond.

Sediment layers deeper than the 0-1 cm layer were used to evaluate vertical variations in sediment characteristics. Individual composite samples of the 1-5 cm, 5-10 cm, 10-15 cm, 15-25 cm and 25-50 cm layers were made by combining each of the individual core layer samples collected at the 28 sample locations into a single sediment container. This process produced five composite sediment core samples, one for each of the five vertical sample layers.

Sediment samples were also collected in an isolated area adjacent to the southern property boundary, in an area unaffected by runoff inputs, to serve as control samples. Triplicate samples were collected at each of the control sediment core sites and combined by layer to form one composite sediment sample for each of the six vertical core layers mentioned previously.

Sediment core samples were also collected from the filter bed at the locations indicated in Figure 3-7. Two separate series of sediment core samples were collected from the filter. One set of sediment samples was collected from the "active" filter area which was defined to be that portion of the filter area below the average water line which filters water on a continuous basis. Samples were also collected from "inactive" areas of the filter, located in portions of the filter bed above the normal high water level elevation. This portion of the filter is not actively used to filter pollutants and serves as a control to evaluate the retention of stormwater pollutants within the filter media. A single composite sample was formed for each of the six vertical layers for both active and inactive portions of the filter media.

3.3 Field and Laboratory Analyses

A summary of field and laboratory analyses conducted on water samples collected during this research is given in Table 3-3. Laboratory analyses performed on sediment samples are summarized in Table 3-4. Details on field operations, laboratory procedures and quality assurance methodologies are provided in the FDER-approved Comprehensive Quality Assurance Plan No. 870322G/S for Environmental Research & Design, Inc.. In addition, a Quality Assurance Project Plan, outlining the specific field and laboratory

TABLE 3-3

SUMMARY OF FIELD AND LABORATORY ANALYSES FOR WATER SAMPLES

PARAMETER	SCHEDULE OF ANALYSES					METHOD OF ANALYSIS
	INFLOW	OUTFLOW	SURFACE WATER	BULK PRECIPITATION	GROUND-WATER	
pH (lab/field)	lab	lab	field	lab	field	EPA-83[1], Sec. 150-1
Cond. (lab/field)	lab	lab	field	lab	field	EPA-83, Sec. 120-1
Temperature (field)	-	-	field	-	field	EPA-83, Sec. 170-1
Diss. Oxygen (field)	-	-	field	-	field	SM-16[2], Sec. 421 F
ORP (field)	-	-	field	-	field	Manf. Spec.
Alkalinity	x	x	x	x	x	EPA-83, Sec. 310.1
NH_3-N	x	x	x	x	x	SM-16, Sec. 417 E
NO_x-N	x	x	x	x	x	EPA-83, Sec. 353.3
Dissolved Organic N	x	x	x	x	x	Alk. Persulfate[3]
Particulate Organic N	x	x	x	x	-	Alk. Persulfate[3]
Orthophosphorus	x	x	x	x	x	EPA-83, Sec. 365.2
Total P	x	x	x	x	x	Alk. Persulfate[4]
Turbidity	x	x	x	x	x	EPA-83, Sec. 180.1
Chloride	x	x	x	x	x	EPA-83, Sec. 325.3
TSS	x	x	x	x	-	EPA-83, Sec. 160.2
Chlorophyll-a	-	-	x	-	-	SM-16, Sec. 1002 G
BOD	x	x	x	x	x	SM-16, Sec. 507
Fecal Coliform	-	-	x	-	-	SM-16, Sec. 909 C
Cadmium (Total/Diss.)	x	x	x	Total	Total	EPA-83, Sec. 213.1
Chromium (Total/Diss.)	x	x	x	Total	Total	EPA-83, Sec. 218.1
Copper (Total/Diss.)	x	x	x	Total	Total	EPA-83, Sec. 220.1
Lead (Total/Diss.)	x	x	x	Total	Total	EPA-83, Sec. 239.1
Iron (Total/Diss.)	x	x	x	Total	Total	EPA-83, Sec. 236.1
Zinc (Total/Diss.)	x	x	x	Total	Total	EPA-83, Sec. 289.1

1. Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, Revised March 1983.
2. Standard Methods for the Examination of Water and Wastewater, 16th Ed., 1985.
3. Alkaline Persulfate Digestion: FDER-approved alternate method for determination of TKN
4. Alkaline Persulfate Digestion: FDER-approved alternate method for determination of Total P

TABLE 3-4

SUMMARY OF LABORATORY ANALYSES FOR SEDIMENT SAMPLES

PARAMETER	SAMPLES ANALYZED	METHOD OF ANALYSIS
Moisture Content	all	EPA/CE-81-1[1]; p. 3-54, p. 3-58
Organic Content	all	EPA/CE-81-1; pp. 3-59 and 3-60
Total P	all	EPA-83[2], Sec. 365.4
Total N	all	EPA/CE-81-1; p. 3-205
Cadmium	all	EPA[3] 7130
Chromium	all	EPA 7190
Copper	all	EPA 7210
Lead	all	EPA 7420
Iron	all	EPA 7380
Zinc	all	EPA 7950
Aluminum	all	EPA 7020
Manganese	all	EPA 7400
Particle Size	Composite Samples	EPA/CE-81-1; pp. 3-33 to 3-47

1. Procedures for Handling and Chemical Analysis of Sediments and Water Samples, EPA/Corps of Engineers, EPA/CE-81-1, 1981.

2. Methods for Chemical Analysis of Water and Wastes, EPA/4-79-020, Revised March 1983.

3. Test Methods for Evaluating Solid Wastes, Physical-Chemical Methods, 3rd Ed., EPA-SW-846, Updated November 1990.

procedures to be conducted for the research efforts described in this report, was submitted for approval from FDER prior to initiation of any field and laboratory activities.

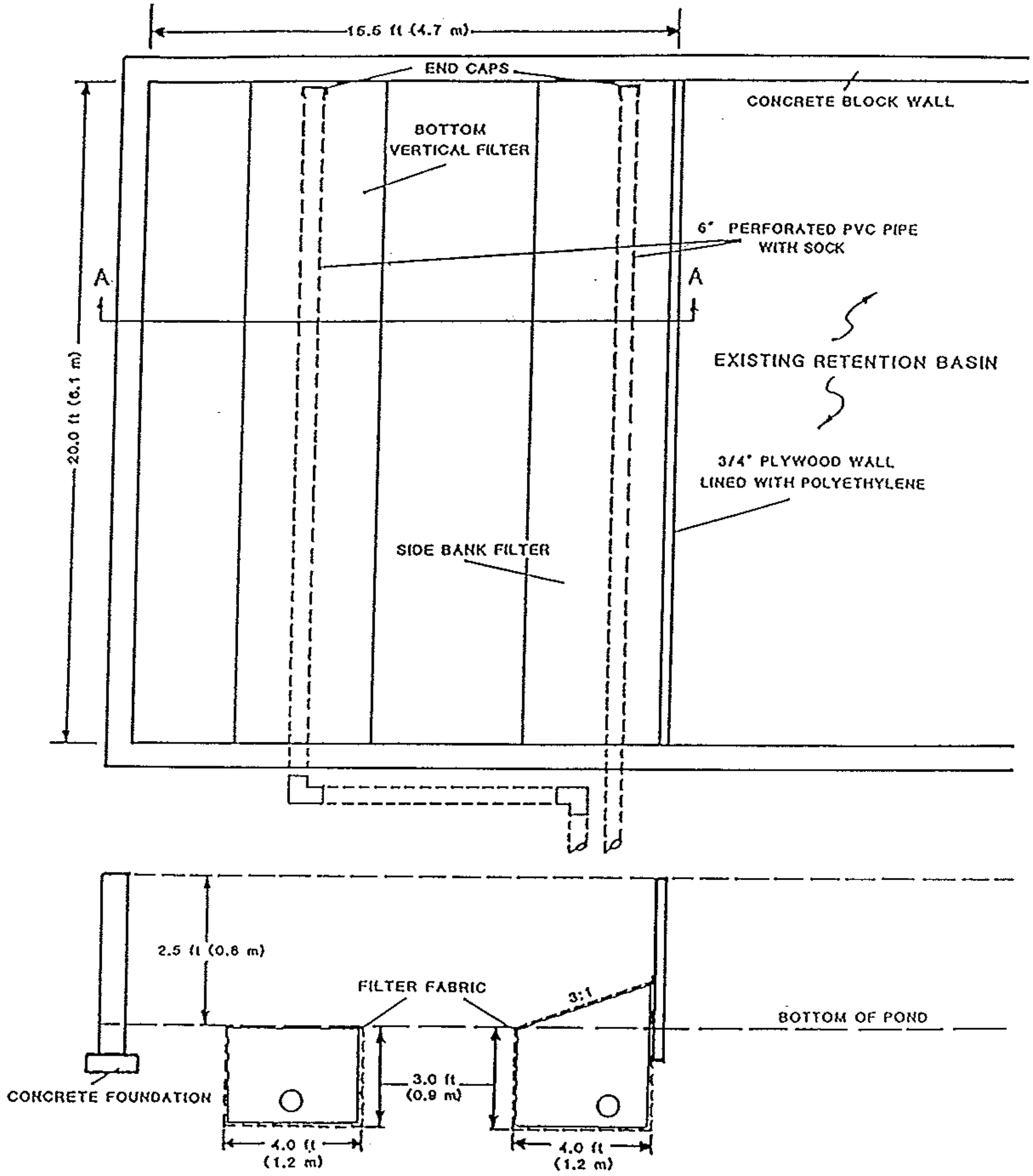
3.4 Pilot Filter Bed Testing

A series of pilot scale experiments were conducted to evaluate the effects of filter media, system configurations and sod cover on hydraulic performance and pollutant attenuation. A filter test area was constructed inside an existing retention basin adjacent to the ERD office. This retention basin is constructed with a vertical concrete block wall on all sides. A 1.9 cm (0.75 in) plywood wall was constructed across a portion of the retention basin to isolate a test area with a width of 4.7 m (15.5 ft) and a length of 6.1 m (20.0 ft). A schematic of the pilot scale filter system is given in Figure 3-8. The plywood wall was lined with polyethylene to prevent water seepage. The connections between the plywood wall and block wall were carefully sealed to provide a watertight basin.

A bottom vertical filter and a typical side bank filter were constructed in the test area as indicated in Figure 3-8. A maximum water level of 0.8 m (2.5 ft) could be applied above the face of each of the filter systems with a maximum depth of 1.45 m (4.75 ft) above the centerline of the underdrain pipes. The perforated underdrain pipes from both filter systems were connected to solid PVC pipe extending away from the test basin as indicated in Figure 3-8. Each of the two outflow lines discharged into a stilling basin, constructed from marine plywood, with a 45° V-notch weir at the end of the basin. Discharges from each filter were measured by measuring the height of water flowing through the V-notch weir. Experimentation was conducted using only one filter at a time. The discharge line from the filter not in use was capped.

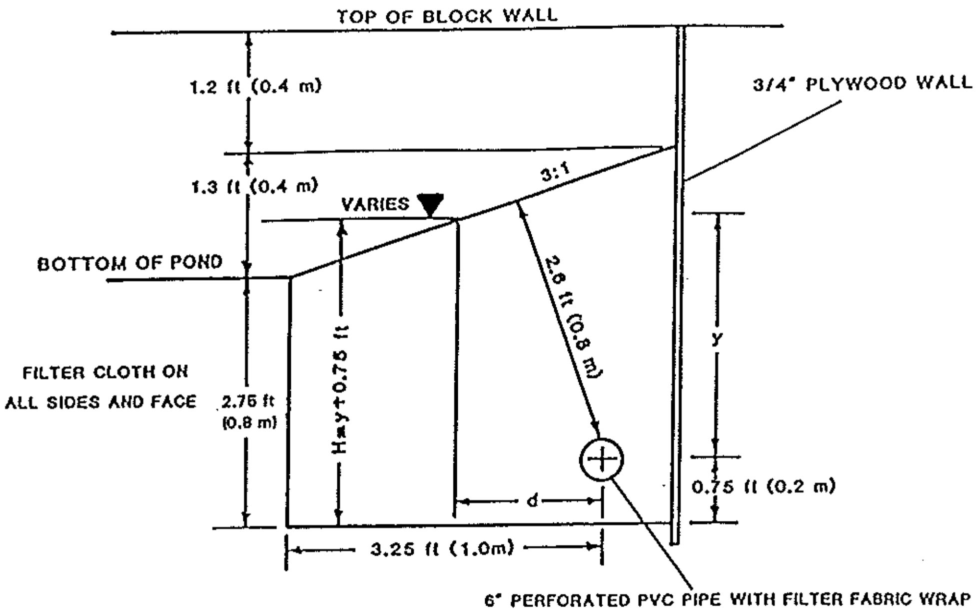
Details of the side bank and bottom vertical filters are given in Figure 3-9. Each of the two filter systems was installed in an excavated trench approximately 0.9 m (3.0 ft) deep and 1.2 m (4.0 ft) wide. The excavated trench was wrapped with filter cloth on all sides and filled with filter media to a depth of approximately 15 cm (6 in). The perforated PVC underdrain pipe was wrapped in filter cloth and placed in the appropriate location along the filter trench. The remaining filter media was then placed on top of the perforated pipe with care taken not to compact the filter media. The face of the side bank filter was constructed on a 3:1 slope, with the bottom vertical filter face constructed level with the bottom of the pond. Excess filter cloth was wrapped across the face of both filters to prevent fill material from clogging the filter media. The filter fabric used was Typar Style 3401, manufactured by DuPont.

Prior to collection of field data or samples for sample analyses, all filter media was initially rinsed to remove impurities present within the filter media. These rinse cycles were conducted by filling the pond to a maximum level of 0.8 m (2.5 ft), uncapping the underdrain for the system which had been recently constructed, and allowing the underdrain to flow in an unhindered fashion until the pond was empty. A

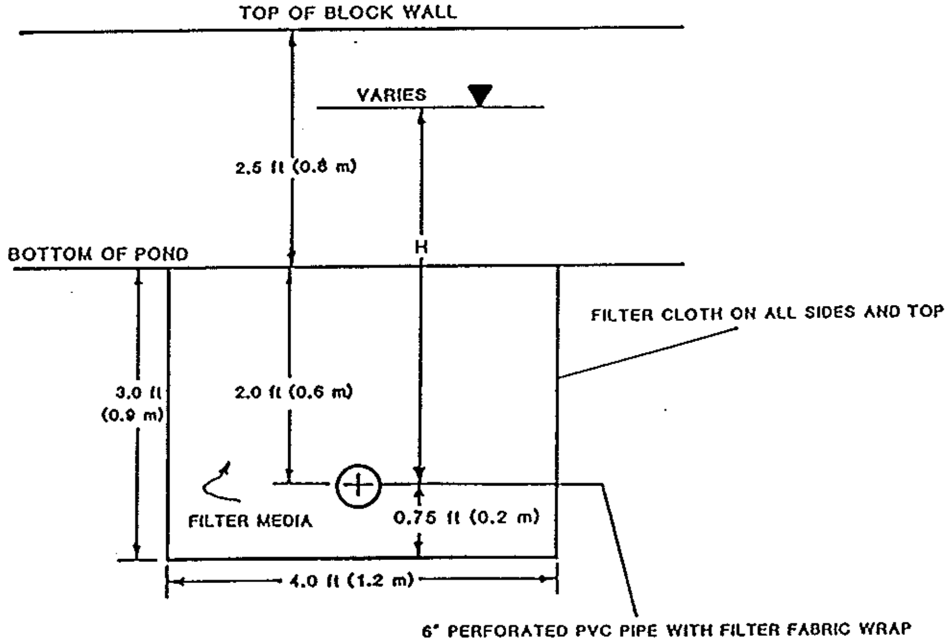


CROSS-SECTION A - A

Figure 3-8. Schematic of the Pilot Scale Filter System.



SIDE BANK FILTER



BOTTOM VERTICAL FILTER

Figure 3-9. Details of the Side Bank and Bottom Vertical Filters.

minimum of four rinse cycles were conducted on each filter media prior to initiation of experimentation.

A summary of pilot scale filter tests is given in Table 3-5. The bottom and side bank filters were initially filled with a fine coarse sand aggregate per FDOT specification 902.4 which meets the specifications outlined in Chapter 17-25 of the Florida Administrative Code for filter media. Initial hydraulic testing was conducted on each filter system to evaluate the drawdown characteristics of each filter configuration and for comparison with typically used drawdown equations. These initial hydraulic experiments were conducted by filling the pond to the maximum level of 0.8 m (2.5 ft), uncapping either the bottom filter or side bank filter underdrain pipe, and allowing the underdrain to flow in an unhindered fashion. Flow rates from the underdrain were measured using the V-notch weir constructed in the stilling basin as described previously. Water used to fill the retention basin was pumped from a nearby adjacent lake. A total of six hydraulic experiments were performed using the bottom hydraulic filter, with three hydraulic experiments conducted on the side bank filter.

At the completion of the initial hydraulic testing, all subsequent experimentation was conducted only on the side bank filter for both hydraulic evaluation and water quality. A simulated stormwater solution was prepared by injecting a concentrated solution of nutrients and heavy metals into the lake water which was pumped into the basin for testing purposes. After filling the basin with the simulated stormwater solution, the side bank underdrain cap was removed and the underdrain was allowed to flow in an unhindered fashion. Measurements of flow rates discharging from the underdrain pipe were conducted using the V-notch weir box. Flow-weighted composite samples were collected from the underdrain outflow to evaluate changes in water quality characteristics during migration through the filter media. Periodic samples were also collected within the test basin to provide an estimate of mean water quality characteristics prior to migration through the filter media. A single flow-weighted composite sample of underdrain outflow and simulated stormwater solution was submitted for laboratory analyses from each side bank filter experiment.

Hydraulic and water quality testing was conducted using the side bank filter with three different media configurations and four different sod covers. Initial hydraulic and water quality testing was conducted using the side bank filter configuration with the original filter media (FDOT 902.4) with no sod cover. The side bank filter was then modified to include a 15 cm (6 in) gravel envelope around the underdrain pipe and was used for additional hydraulic and water quality testing. A final series of tests was conducted by replacing the original filter media with 20-30 silica sand. A total of four sod types were also tested on the side bank filter using the original filter media (FDOT 902.4) without a gravel envelope. These sod types included St. Augustine sod grown in sand, St. Augustine sod grown in muck, Bahia sod grown in sand and Bermuda sod grown in muck. Hydraulic and water quality analyses were conducted for each of the four sod types.

TABLE 3-5

SUMMARY OF PILOT SCALE FILTER TESTS

TEST SERIES NO.	FILTER CONFIGURATION	NO. OF TESTS PERFORMED	ANALYSES PERFORMED	
			HYDRAULIC	WATER QUALITY
1	Bottom Vertical Filter without sod cover	6	yes	no
2	Side Bank Filter without sod cover	3	yes	no
3	Side Bank Filter without sod cover	4	yes	yes
4	Side Bank Filter with St. Augustine sod grown in sand	4	yes	yes
5	Side Bank Filter with St. Augustine sod grown in muck	4	yes	yes
6	Side Bank Filter with Bahia sod grown in sand	4	yes	yes
7	Side Bank Filter with Bermuda sod grown in muck	4	yes	yes
8	Side Bank Filter with a gravel envelope around underdrain pipe	4	yes	yes
9	Side Bank Filter using 20-30 silica sand as filter media	4	yes	yes

During each of the water quality experiments indicated in Table 3-5, a single composite sample of basin water and underdrain outflow was formed for each experiment. Composite samples were analyzed for the following parameters:

1. pH
2. Specific Conductivity
3. Ammonia
4. NO_x
5. Dissolved Organic Nitrogen
6. Particulate Organic Nitrogen
7. Total Nitrogen
8. Orthophosphorus
9. Total Phosphorus
10. Turbidity
11. TSS
12. BOD
13. Total and Dissolved Copper
14. Total and Dissolved Lead
15. Total and Dissolved Zinc

All parameters were analyzed using the laboratory procedures outlined in Table 3-3.

3.5 Statistical Treatment of Data

A large number of statistical analyses were conducted during analysis of the experimental results from this research. All statistical procedures were performed using the Statistical Analysis System (SAS) and included PROC CORR for calculation of Pearson product-moment correlation coefficients; PROC PLOT to produce scatter diagrams of the values of one variable against the values of another variable for examination of relationships and functional forms; PROC MEANS to obtain simple univariate descriptive statistics such as means, standard deviation, minimum and maximum values; PROC UNIVARIATE to evaluate data distribution and to test for normality; PROC GLM for analysis of variance procedures for unbalanced data sets; and PROC REG and PROC STEPWISE for regression analyses to provide least-square estimates to various linear regression models. All data sets were initially tested for normality of data distribution by examination of residuals. Many data sets required a log transformation to obtain a normally distributed probability distribution function. Subsequent statistical analyses were conducted using transformed data sets where appropriate.

Statistical analyses were conducted on data sets using the number of significant figures indicated in the raw data contained in the Appendices. Data indicated as less than the detection limit for a particular variable was entered into the data set as one-half of the detection limit presented.

CHAPTER 4

RESULTS

Field monitoring, sample collection and laboratory analyses for stormwater, baseflow, surface water, underdrain outflow, bulk precipitation, groundwater and sediments were conducted at the DeBary detention with filtration pond site over a six-month period from June to November 1992. Hydrologic monitoring of rainfall, evaporation, water surface elevation and piezometric levels was begun in May 1992 and continued for a period of seven months through November 1992. A discussion of experimental results of these tasks is given in the following sections.

4.1 Site Hydrology

As previously discussed, a wide range of hydrologic information was collected at the DeBary detention with filtration pond site. The purpose of this information is three-fold: (1) to provide information on hydrologic characteristics of rain events used for characterization of stormwater runoff; (2) to assist in evaluation of a hydrologic budget for the pond site; and (3) to evaluate the direction of groundwater movement at the pond site. In general, hydrologic information is presented only as it relates to understanding and quantifying these three areas.

4.1.1 Rainfall Characteristics

A continuous record of rainfall characteristics was collected at the DeBary research site from May 15, 1992 to November 30, 1992, using a tipping bucket rainfall collector with a continuous strip chart recorder. The characteristics of individual rain events measured at the DeBary research site are given in Appendix A. In general, a continuous record of rainfall characteristics was maintained throughout the study period with the exception of a power failure which occurred from August 4-6, 1992. For each individual rain event, information on total rainfall, event starting time, event ending time, event duration, average rainfall intensity, maximum rainfall intensity and antecedent dry period are included in Appendix A. Average rainfall intensity is calculated as the total rainfall divided by the total event duration. Maximum rainfall intensity is the maximum intensity occurring during any 15-minute interval for the rain event.

A summary of rainfall characteristics measured at the DeBary detention with filtration pond site during May to November 1992 is given in Table 4-1. Total event rainfall ranged from 0.05-15.01 cm (0.02 in - 5.91 in) , with a mean of 1.2 cm (0.47 in) per rain event. A total of 109.2 cm (42.99 in) of rainfall were measured at the site from May through November.

TABLE 4-1

SUMMARY OF RAINFALL CHARACTERISTICS MEASURED AT THE DEBARY DETENTION WITH FILTRATION POND SITE DURING MAY-NOVEMBER 1992

PARAMETER	UNITS	MINIMUM VALUE	MAXIMUM VALUE	MEAN VALUE
Total Rainfall	cm in	0.05 0.02	15.01 5.91	1.20 3.05
Event Duration	hr	0.08	35.75	2.67
Average Intensity	cm/hr in/hr	0.03 0.01	5.72 2.25	0.77 0.30
Maximum Intensity[1]	cm/hr in/hr	0.10 0.04	9.14 3.60	1.97 0.78
Antecedent Dry Period	days	0.20	12.92	2.15

[1] Maximum 15-minute intensity.

4.1.2 Fluctuations in Pond Water Surface Elevations

Water surface elevations in the DeBary detention with filtration pond were measured on a continuous basis using a Stevens Model A-71 water level recorder from April to November 1992. A complete listing of water surface elevations, at 3-hour intervals for each day of record, is included in Appendix B. Water surface elevations fluctuated a maximum of approximately 1 m (3.3 ft) during the study period. Relationships between total daily rainfall and pond surface elevations at the DeBary research site are indicated in Figure 4-1. In general, pond surface elevations responded rapidly to rainfall inputs with a gradual pond drawdown occurring over a period of 3-4 days.

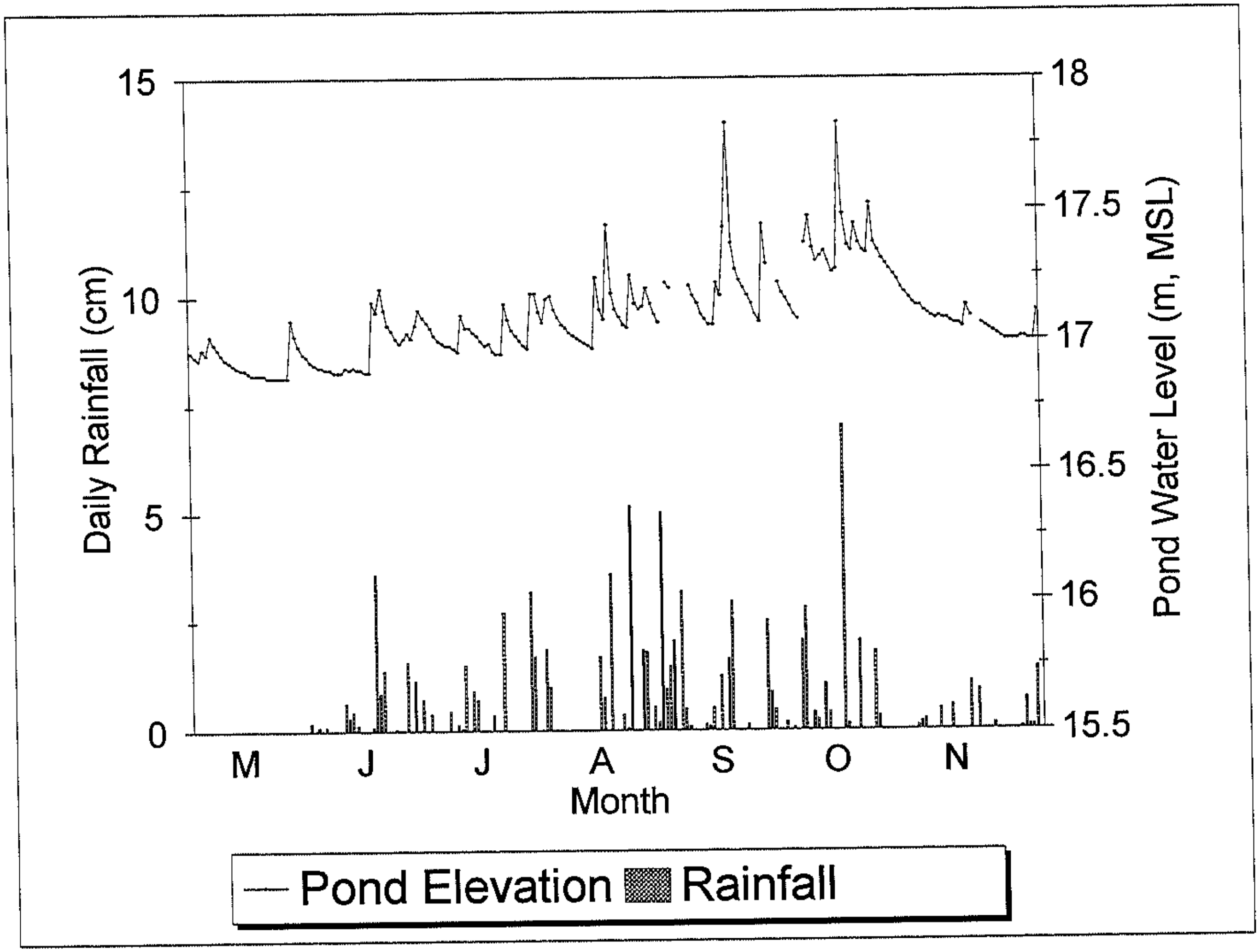


Figure 4-1. Relationships Between Rainfall and Pond Surface Elevation at the DeBary Research Site.

Measured minimum, maximum and average pond water levels during the study period are indicated on Figure 3-4 and summarized in Table 4-2. Water levels within the pond generally exceeded the control elevation throughout the study period. During several periods of prolonged hot weather with no rainfall, the pond elevation dropped below the control elevation with a measured minimum water elevation approximately 0.34 ft (0.10 m) less than the control elevation of the underdrain pipe. The pond control elevation is assumed to be equal to the centerline of the underdrain pipe. The measured maximum water level in the pond of 58.52 ft (17.84 m) exceeded the design peak stage by approximately 0.54 ft (0.16 m). The peak design stage is based upon the peak elevation reached in the pond for a 25-year, 24-hour storm based on the SCS interim Florida rainfall distribution. The peak design stage for the pond was exceeded on two occasions during the 6-month study period.

TABLE 4-2

**SUMMARY OF POND WATER LEVELS
AT THE DEBARY RESEARCH SITE**

PARAMETER	ELEVATION	
	ft (MSL)	m (MSL
Control Elevation[1]	55.63	16.960
Measured Minimum Water Level	55.29	16.86
Measured Maximum Water Level	58.52	17.84
Mean Water Level	56.14	17.12
Design Peak Stage	57.98	17.68

1. Invert elevation of the underdrain pipe.

4.1.3 Fluctuations in Piezometric Elevations

A listing of piezometric elevations measured at the DeBary research site from May to November 1992 is given in Appendix C for piezometers located along the west, east, north and south sides of the pond as well as piezometers associated with the three groundwater monitoring wells. Horizontal piezometric gradients along the west, east, north and south sides of the DeBary detention pond are summarized in Figure 4-2. In general, groundwater along the west side of the pond appears to be migrating into the

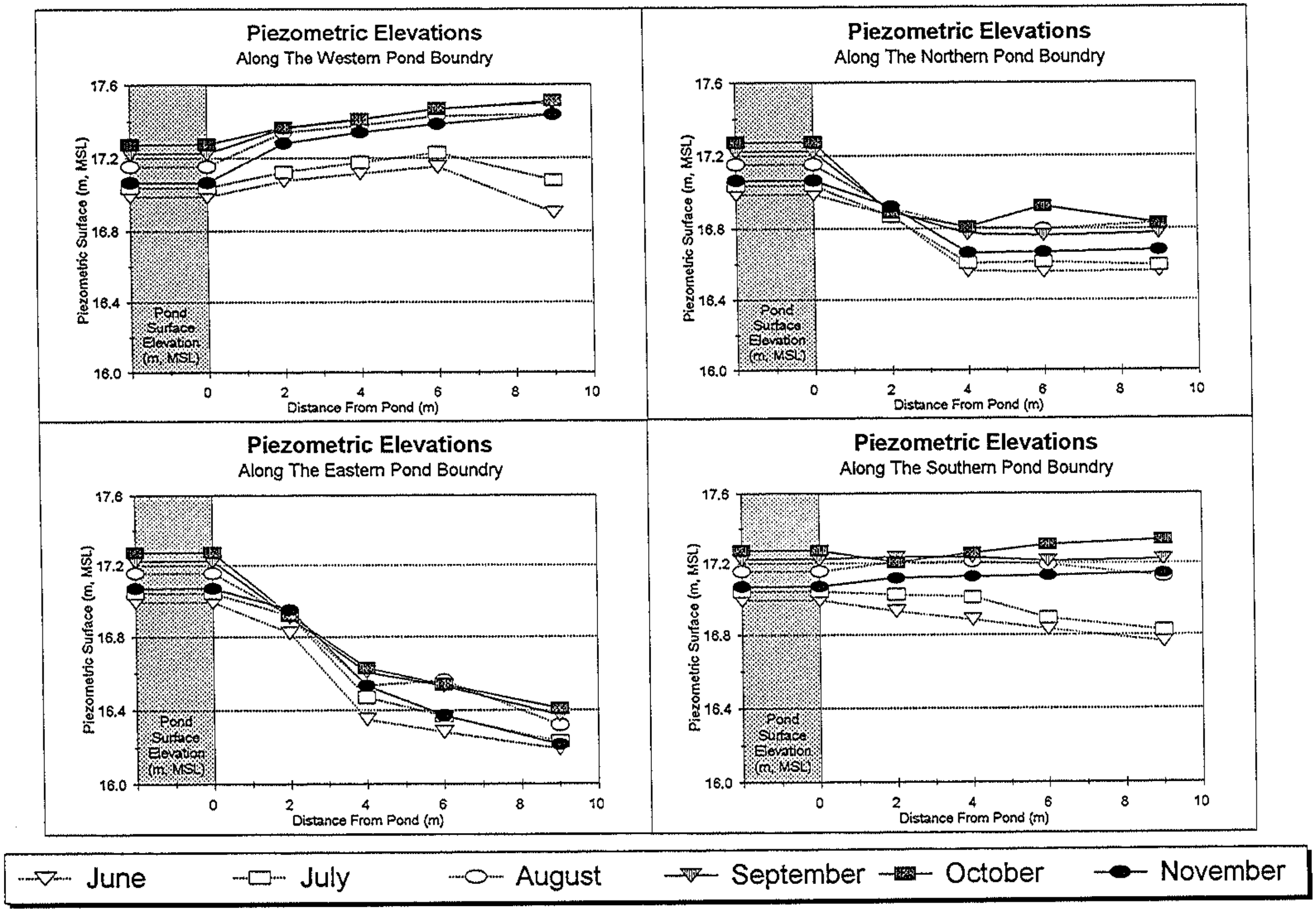


Figure 4-2. Horizontal Piezometric Gradients Along the West, East, North and South Sides of the DeBary Detention Pond.

pond throughout the 6-month study period. This tendency was more obvious during the period from August through November when groundwater levels are typically near peak elevations in Central Florida. The piezometric gradient is less steep during June and July, although it still indicates a net migration into the pond from the west side.

Piezometric gradients along the north and east sides of the pond indicate potential for migration from the pond throughout the study period. Hydraulic gradients for each of the six months are relatively similar along both the north and east sides. However, even though the hydraulic gradients presented in Figure 4-2 indicate a net migration away from the pond, the total quantity of water leaving the pond along these sides is severely restricted by the presence of the clay core located along the entire east boundary and one-half of the northern pond boundary. This clay core was inserted to minimize seepage of water along these two pond boundaries.

Piezometric gradients along the southern pond boundary are relatively small, particularly in comparison with gradients measured along the other three sides of the pond. During June and July, it appears that the primary hydraulic gradient in the south piezometers is away from the pond while during September, October and November, the primary hydraulic gradient is toward the pond. However, in view of the relatively minor gradients measured along the south, it is unlikely that substantial groundwater movement occurs in either direction along this boundary.

A summary of vertical hydraulic gradients at the three multiport monitoring wells is given in Figure 4-3. The dominant hydraulic gradient within the pond indicates a tendency for downward water movement. The pond hydraulic gradient is relatively small until September when water surface elevations within the pond begin to increase. After that time, the downward hydraulic gradient increases substantially and remains elevated throughout the remainder of the study period.

Vertical hydraulic gradients at the upgradient and downgradient groundwater monitoring wells are relatively small in value and appear to follow somewhat similar trends. From June through August, these areas indicate a slight upward hydraulic gradient with a hydraulic gradient near zero for the remainder of the study period. Based upon these relatively low vertical hydraulic gradients, it appears that the dominant direction of groundwater flow in both upgradient and downgradient areas is horizontal rather than vertical. Horizontal gradients indicated in Figure 4-2 are substantially greater than the vertical gradients indicated in Figure 4-3.

4.1.4 Estimates of Site Evaporation

As discussed in Chapter 3, a recording evapograph was installed at the DeBary research site to provide a continuous record of evaporative losses from the pond surface on a daily basis during the 6-month study period. Measurements collected by the recording evapograph were calibrated on-site using a Class A pan evaporimeter.

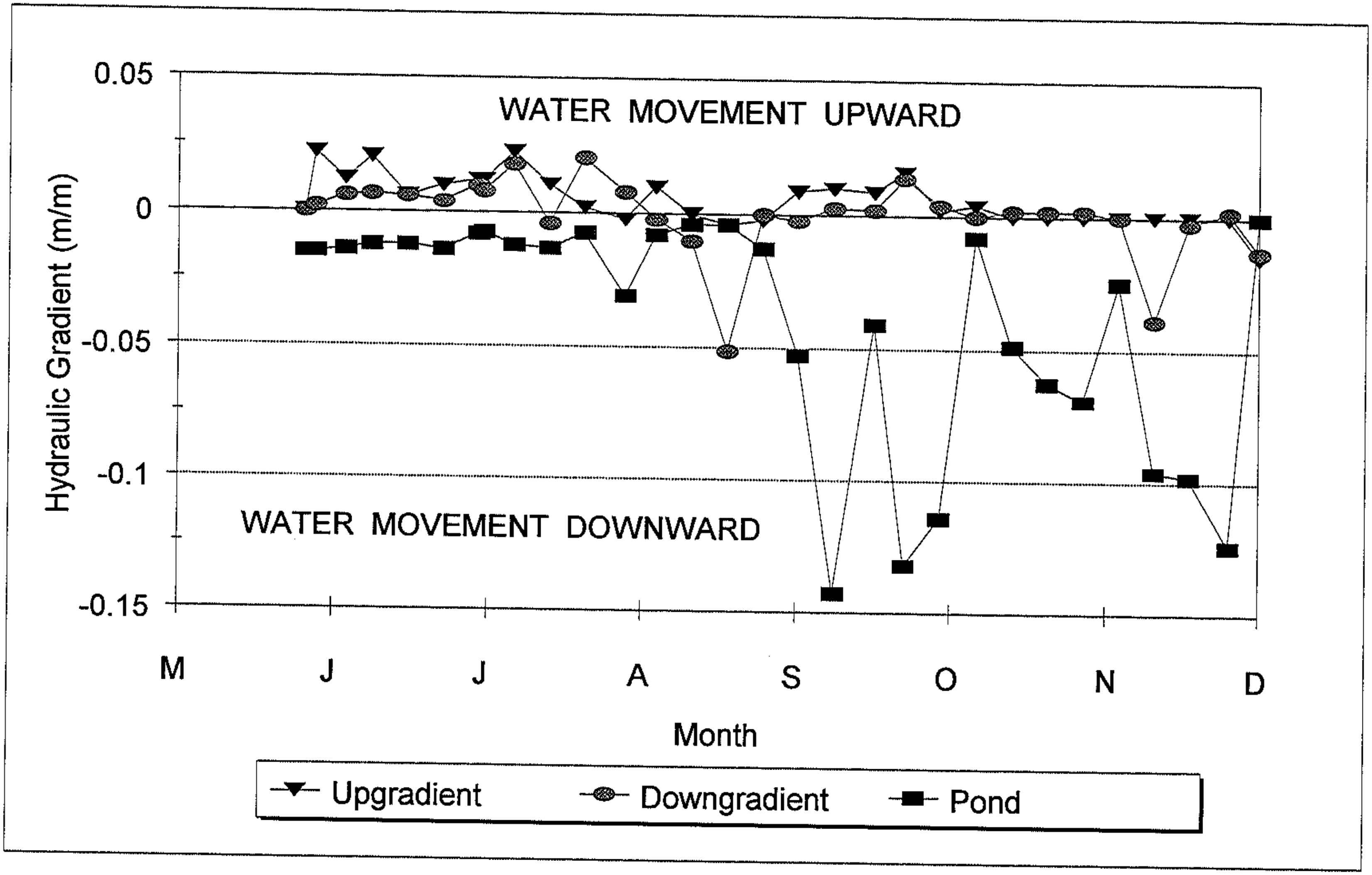


Figure 4-3. Vertical Hydraulic Gradients at the Three Multiport Monitoring Wells.

Average daily evaporation losses measured at the DeBary detention with filtration site from May to November 1992 are presented in Table 4-3 and summarized in Figure 4-4. Hourly evaporative losses increase during the day, reaching a peak value between 12 noon and 3 p.m. Evaporative losses decrease rapidly at approximately 4-6 p.m. Evaporation during night time hours was found to be approximately 10% of the maximum evaporation measured during daylight hours.

Mean daily evaporative losses measured at the DeBary research site from May to November 1992 are summarized in Figure 4-5. Total daily evaporative losses range from a low of 1.54 mm/day in November to a maximum of 10.46 mm/day in July. Total daily evaporation during June to August was similar, with an average of approximately 8.7 mm/day. Total daily evaporation decreased rapidly from September through November.

4.1.5 Estimates of Inputs and Losses from Rainfall and Evaporation

Estimates of hydraulic inputs from direct precipitation to the DeBary detention with filtration pond were performed for a 7-month period from May through November 1992. These estimates are summarized in Appendix D. For each rain event occurring during each of the seven months, the total rainfall is multiplied by the pond area to produce an estimate of the amount of water entering the pond from total rainfall for each rain event. Estimates of total rainfall from rain events are summed for each month to provide an estimate of total hydraulic inputs from rainfall into the pond on a monthly basis.

For purposes of these calculations, a linear regression was performed between pond elevation and pond area so that the area at the time of an individual rainfall event could be estimated with a reasonable degree of accuracy based upon the pond elevation at the start of the rain event. The best-fit equation relating stage to pond area was a fourth degree equation as follows:

$$Y = 1481.974 - 187.3368X + 2.07655X^2 - 0.190167X^3 + 0.041904X^4$$

where:

Y = pond area (m^2)

X = pond stage (m, MSL)

The coefficient of determination (R^2) for this equation is 0.99962. This equation was used to estimate pond area for each beginning water elevation at the start of an individual rain event.

TABLE 4-3

AVERAGE DAILY INTERVAL EVAPORATION LOSSES (in mm) AT THE DEBARY DETENTION WITH FILTRATION SITE FROM MAY-NOVEMBER 1992

MONTH	TOTAL EVAPORATION (mm) FOR EACH TIME INTERVAL								AVERAGE DAILY TOTAL
	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	
May	0.06	0.12	0.32	1.48	1.76	1.03	0.27	0.08	5.12
June	0.08	0.30	0.88	2.34	2.68	1.58	0.55	0.26	8.67
July	0.08	0.25	0.62	2.54	3.04	2.63	1.02	0.28	10.46
August	0.05	0.12	0.93	2.90	2.37	1.67	0.62	0.09	8.75
September	0.04	0.20	0.26	1.44	2.22	1.38	0.66	0.24	6.44
October	0.05	0.13	0.25	0.78	1.13	1.13	0.30	0.14	3.91
November	0.01	0.03	0.06	0.31	0.62	0.37	0.09	0.05	1.54

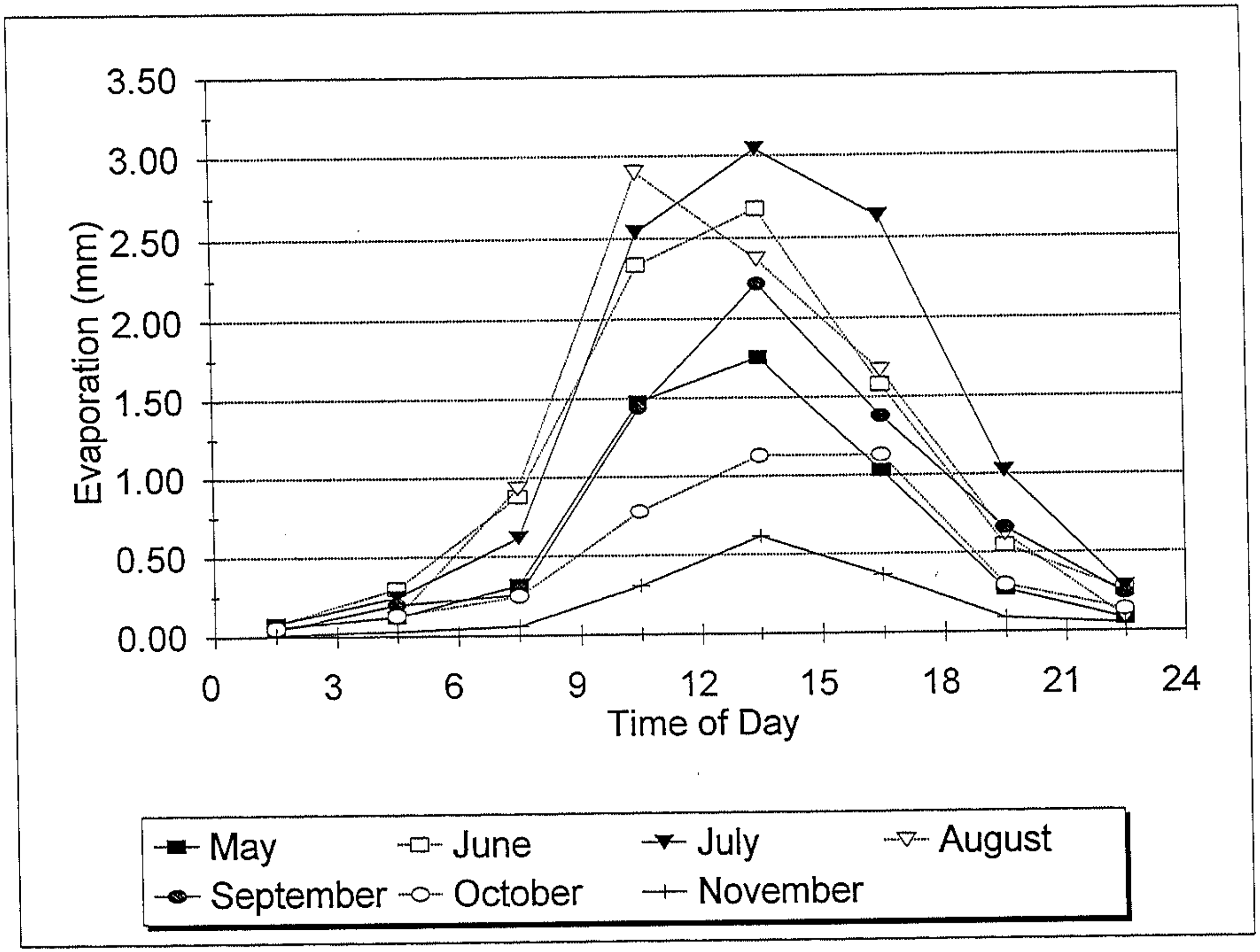


Figure 4-4. Hourly Evaporative Losses Measured at the DeBary Research Site.

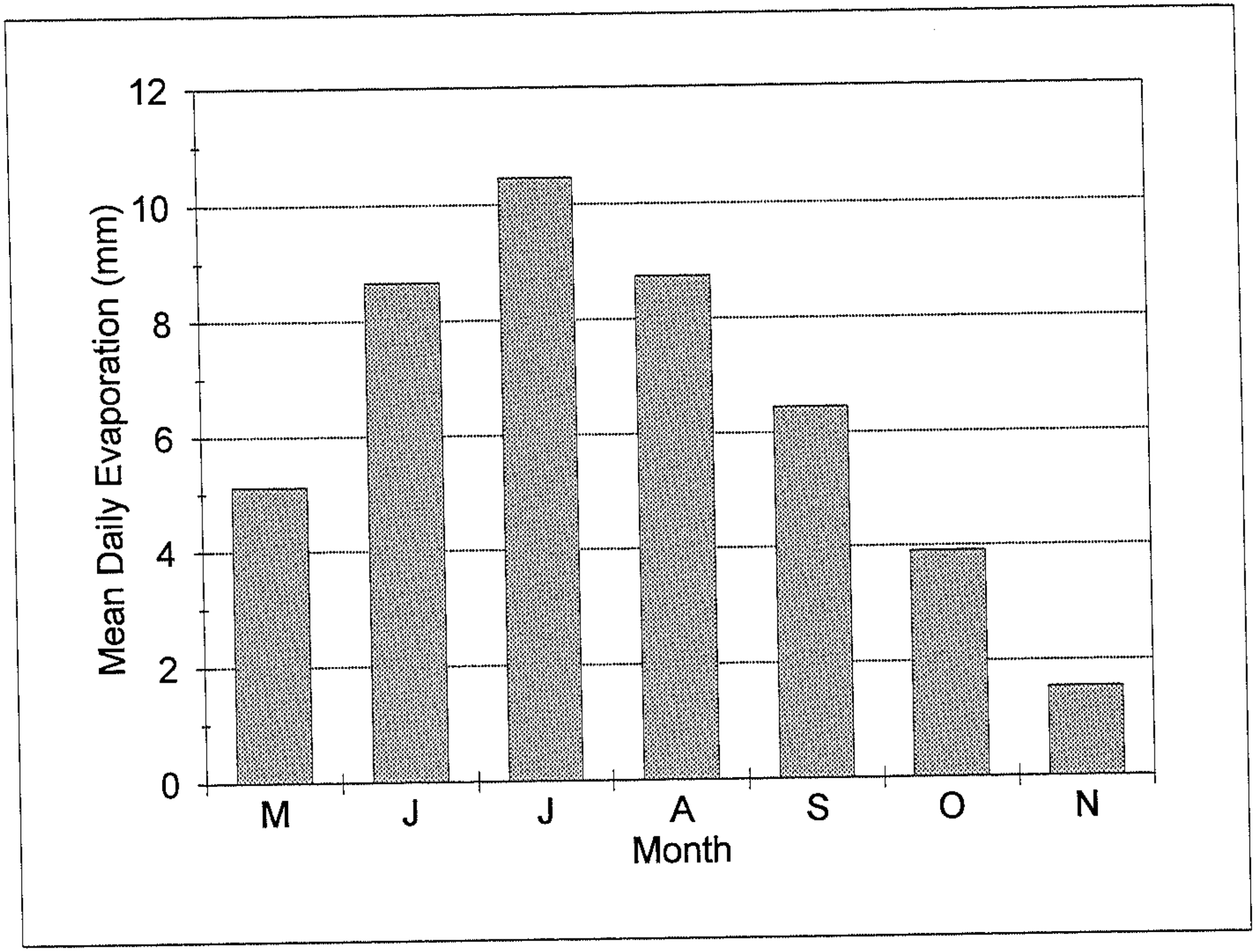


Figure 4-5. Mean Daily Evaporative Losses Measured at the DeBary Research Site from May to November 1992.

Estimates of surface water evaporation losses were also conducted on a daily basis from May through November 1992. These calculations are summarized in Appendix E. The average water surface elevation for each date was calculated and the corresponding pond surface area was estimated using the regression equation. The average monthly evaporation was multiplied times the pond surface area to produce an estimate of the daily evaporation loss in m^3. The daily evaporation losses were summed to produce a monthly estimate of evaporation losses from the detention pond. Estimates of rainfall inputs and evaporative losses are used in a subsequent section to perform a hydrologic budget for the pond.

4.1.6 Stormwater Inputs to the DeBary Detention Pond

As described in Chapter 3, continuous inflow hydrographs were recorded for inputs of stormwater and baseflow into the detention pond from June 4, 1992 to November 26, 1992. A complete listing of measured stormwater and baseflow inputs to the DeBary detention pond is given in Appendix F, located in Volume II. This appendix contains a continuous inflow hydrograph along with information on minimum daily flow rates, maximum daily flow rates, average daily flow rates, total daily volume, and cumulative total volume for the period of record.

A summary of rainfall-runoff relationships at the DeBary detention with filtration pond site from June to November 1992 is given in Table 4-4. Total rainfall measured during each of the six months is given in both centimeters and inches. Total rainfall volume is equal to the total monthly rainfall times the contributing watershed area of 20.5 ha (50.7 ac). This volume represents the total rainfall amount which fell within the watershed during each of the six months. Next, measured stormwater volumes entering the detention pond are indicated in units of cubic meters and cubic feet. Finally, an average runoff coefficient "C" value is calculated for each month by dividing the stormwater input volume by the total rainfall volume which fell within the watershed.

Calculated runoff coefficients at the DeBary research site ranged from a low of 0.036 in June to a high of 0.278 in October, with a weighted average runoff coefficient of 0.121. The runoff values given in Table 4-4 are relatively low in value for a watershed with an impervious area of approximately 60%. These values indicate that a large portion of the runoff volume is lost due to infiltration along the roadside swales adjacent to U.S. Highway 17. The substantial increases in runoff coefficients measured in September and October may reflect increasing groundwater elevations during those months and decreases in runoff lost due to infiltration. For example, a total of 13.79 cm of rainfall fell in June with an average runoff coefficient of 0.036. In October, 12.91 cm of rainfall was recorded with an average runoff coefficient of 0.278.

TABLE 4-4

SUMMARY OF RAINFALL-RUNOFF RELATIONSHIPS AT THE DEBARY DETENTION WITH FILTRATION POND SITE FROM JUNE-NOVEMBER 1992

MONTH	TOTAL RAINFALL		TOTAL RAINFALL VOLUME[1]		STORMWATER RUNOFF		AVERAGE "C" VALUE
	inches	cm	ft^3	m^3	ft^3	m^3	
June	5.43	13.79	999,343	28,320	35,958	1019	0.036
July	4.25	10.80	782,174	22,166	41,922	1188	0.054
August	11.78	29.93	2,168,003	61,438	205,444	5822	0.095
September	7.13	18.12	1,312,212	37,186	307,460	8713	0.234
October	5.08	12.91	934,928	26,495	260,175	7373	0.278
November	8.06	20.46	1,483,370	42,037	81,091	2298	0.055
TOTALS:	41.73	106.01	7,680,030	217,642	932,050	26,413	0.121 (average)

---

1. Equal to the total monthly rainfall times the contributing watershed area.

4.1.7 Underdrain Outflow from the DeBary Detention Pond

Continuous hydrographs of underdrain outflow from the detention pond were collected using a sequential automatic sampler with an integral flow recorder from June 4, 1992 to November 30, 1992. A complete listing of underdrain outflow hydrographs from the DeBary site is given in Appendix G, located in Volume II. In addition to a complete hydrograph with measurements recorded at 10-minute intervals, these records also contain information on minimum daily flow rates, maximum daily flow rates, average daily flow rates, total daily volume and cumulative total volume over the period of record. Cumulative total underdrain outflow was calculated for each of the six months and used in preparation of a monthly hydrologic budget for the site. Outflow information was also used to evaluate filter hydraulics, discussed in a later section.

4.1.8 Monthly Hydrologic Budget

A monthly hydrologic budget for the DeBary detention with filtration site is given in Table 4-5. Inputs into the pond include stormwater runoff, direct rainfall and groundwater inflow. Monthly estimates of stormwater inflow were obtained from Table 4-4. Estimates of hydraulic inputs from direct rainfall were obtained from the calculations given in Appendix D.

Outputs from the pond include underdrain outflow, loss due to evaporation and loss due to groundwater seepage from the pond. Losses from the pond due to underdrain outflow were obtained by summing daily underdrain outflow from the pond over each of the 6-month periods. Estimates of losses due to evaporation were taken from tables provided in Appendix E. Gains or losses due to either groundwater inflow or groundwater loss were determined as the difference between hydraulic inputs and outputs so that the inputs and outputs from the pond were balanced for each of the six months.

During the 6-month study period, the dominant input into the pond was stormwater runoff which contributed 78% of the average inputs into the system. Net groundwater movement in the vicinity of the pond was out of the pond from June to September, but reversed to become an input into the pond in October and November when water table elevations generally reach their highest annual levels. During November, groundwater inflow into the pond exceeded inputs from stormwater runoff. The dominant output from the pond was underdrain outflow which contributed 82% of the estimated outputs during the 6-month study period. Losses due to evaporation were approximately equal to direct inputs from rainfall.

4.1.9 Estimation of Hydraulic Detention Time

Estimates of average monthly detention times for hydraulic inputs within the DeBary detention with filtration pond are presented in Table 4-6. Total hydraulic inputs into the pond are listed for each of the six months, representing the sum of the inputs listed in Table 4-5. The average surface water elevation for each month is given as the

TABLE 4-5

MONTHLY HYDROLOGIC BUDGET FOR THE DEBARY DETENTION WITH FILTRATION SITE

MONTH	INPUTS			OUTPUTS		
	STORMWATER (m^3)	DIRECT RAINFALL (m^3)	GROUNDWATER INFLOW (m^3)	UNDERDRAIN OUTFLOW (m^3)	EVAPORATION LOSS (m^3)	GROUNDWATER LOSS (m^3)
June	1019	200	0	786	384	49
July	1188	160	0	682	483	183
August	5822	552	0	3185	421	2768
September	8713	285	0	7532	306	1160
October	7373	208	969	8354	196	0
November	2298	310	4962	7503	67	0
Totals:	26,413	1715	5931	28,042	1857	4160
Percent of Total:	78	5	17	82	6	12

TABLE 4-6

AVERAGE MONTHLY DETENTION TIME FOR HYDRAULIC INPUTS AT THE DEBARY DETENTION WITH FILTRATION POND

MONTH	TOTAL INPUTS		AVERAGE WATER SURFACE ELEVATION		AVERAGE POND VOLUME		DETENTION TIME	
	m^3	ft^3	m	ft	m^3	ft^3	MONTHS	DAYS
June	1,219	43,019	17.035	55.87	1,732	61,124	1.42	42.6
July	1,348	47,560	17.064	55.97	1,776	62,655	1.32	40.8
August	6,374	224,915	17.200	56.42	1,992	70,276	0.31	9.7
September	8,998	317,527	17.264	56.62	2,088	73,687	0.23	7.0
October	8,551	301,733	17.263	56.62	2,088	73,687	0.24	7.6
November	7,570	267,123	17.046	55.91	1,750	61,737	0.23	5.6

average of water surface elevations listed in Appendix B for each month. The average pond volume was obtained using an empirically derived relationship between surface area and cumulative volume based on the morphological characteristics contained in Table 3-2. The average monthly detention time was calculated by dividing the average pond volume by the total hydraulic inputs for each month.

Average detention time within the pond ranged from a low of 5.6 days in September to a maximum of 42.6 days in June. Hydraulic detention time within the system is regulated primarily by inputs of stormwater runoff and is directly related to the total rainfall occurring during a particular month.

4.2 Characteristics of Stormwater and Baseflow Measured at the DeBary Research Site

Flow-weighted samples of stormwater runoff were collected at the DeBary detention with filtration pond site from June to November 1992. A total of 33 separate storm event composite samples were collected and analyzed over the 6-month study period, representing more than 90% of the total storm events which generated measurable runoff into the detention pond. In addition, seven composite baseflow samples were also collected at the input to the DeBary detention with filtration pond. Baseflow samples primarily represent groundwater inflow into the detention pond through the stormsewer system during periods of high groundwater elevations. Event mean chemical characteristics of stormwater runoff and baseflow entering the DeBary pond from June to November 1992 are given in Appendix H. Concentrations of heavy metals in stormwater runoff and baseflow entering the DeBary detention pond are given in Appendix I.

Mean characteristics of stormwater runoff measured at the DeBary research site during June to November 1992 are given in Table 4-7. Stormwater characteristics were monitored over a wide range of rain event characteristics. Total event rainfall ranged from 0.41 to 15.01 cm, rain event durations ranged from 0.42 to 35.8 hours, average intensities ranged from 0.03 to 3.4 cm/hr, maximum 15-minute event intensities ranged from 0.61 to 9.14 cm/hr with antecedent dry periods ranging from 0.47 to 12.9 days.

In general, a high degree of variability was observed in event mean concentrations for general chemical parameters. Mean event concentrations of alkalinity, ammonia, particulate organic N, ortho-P, dissolved organic P, total P, chloride and TSS varied by approximately one order of magnitude between minimum and maximum event mean concentrations. Measured concentrations of nitrate, dissolved organic N, total N, particulate P, turbidity and BOD covered over two orders of magnitude between minimum and maximum values.

Stormwater runoff measured at the DeBary research site was slightly alkaline in pH, with a mean value of 7.77 and moderately buffered with a mean alkalinity of 90 mg/l. Measured event mean concentrations of turbidity and TSS were typically high in

TABLE 4-7

MEAN CHARACTERISTICS OF STORMWATER RUNOFF MEASURED AT THE DEBARY DETENTION WITH FILTRATION POND SITE DURING JUNE-NOVEMBER 1992[1]

PARAMETER		UNITS	RANGE OF VALUES		MEAN	C.V.[2]
			MINIMUM	MAXIMUM		
pH		s.u.	7.16	8.41	7.77	4
Spec. Conductivity		μmho/cm	63	339	130	47
Alkalinity		mg/l	30	272	90	56
NH_3		μg/l	< 10	239	77	62
NO_x		μg/l	< 10	772	175	93
Diss. Organic N		μg/l	< 50	976	290	76
Part. Organic N		μg/l	< 50	544	220	59
Total N		μg/l	50	1376	761	35
Ortho-P		μg/l	20	258	78	60
Diss. Organic P		μg/l	2	127	18	126
Particulate P		μg/l	< 2	557	164	91
Total P		μg/l	39	678	260	64
Turbidity		NTU	2.1	351	65	116
Chloride		mg/l	2.0	58	9.2	120
TSS		mg/l	3.5	384	79.1	116
BOD		mg/l	1.6	385	6.9	123
Cadmium	Diss.	μg/l	< 0.5	1.0	< 0.5	62
	Total	μg/l	< 0.5	1.0	0.5	60
Chromium	Diss.	μg/l	1	3	1.4	44
	Total	μg/l	1	8	3.2	53
Copper	Diss.	μg/l	5	14	7.5	24
	Total	μg/l	6	17	9.7	26
Lead	Diss.	μg/l	< 2	6	2.1	61
	Total	μg/l	< 2	25	8.5	77
Iron	Diss.	μg/l	7	87	31	64
	Total	μg/l	104	2020	582	86
Zinc	Diss.	μg/l	2	19	7.5	48
	Total	μg/l	8	57	28	51
Total Rainfall		cm	0.41	15.01	2.26	117
Duration		hours	0.42	35.75	4.21	149
Average Intensity		cm/hour	0.03	3.38	0.92	89
Maximum Intensity		cm/hour	0.61	9.14	3.21	63
Antecedent Dry Period		days	0.47	12.92	2.24	107

1. n = 33 samples
2. C.V.: Coefficient of Variation = $\sigma/\bar{x}$, expressed as a percentage

value, with a mean of 65 NTU for turbidity and 79.1 mg/l for TSS. Measured concentrations of chloride and BOD were typically low in value.

Mean event concentrations of total nitrogen found in stormwater runoff at the DeBary site were somewhat lower than concentrations of total nitrogen typically found in stormwater runoff in Central Florida. The mean total nitrogen concentration of 761 μg/l is less than one-half of typical stormwater concentrations of total nitrogen in Central Florida and may be related to the pre-treatment occurring in the roadside swale system used for conveyance of stormwater runoff to the detention pond site. The dominant nitrogen species in stormwater runoff was dissolved organic nitrogen, comprising 38% of the total nitrogen found. An additional 29% of the total nitrogen was comprised of particulate organic nitrogen. Inorganic species of ammonia and nitrate comprised only 33% of the total nitrogen measured at the site.

In contrast, the mean total phosphorus concentration in stormwater runoff of 260 μg/l is typical of total phosphorus concentrations found in stormwater runoff in Central Florida. The dominant phosphorus species found in stormwater runoff was particulate phosphorus which accounted for 63% of the total phosphorus measured at the DeBary site. Orthophosphorus, with a mean concentration of 78 μg/l, contributed 30% of the total phosphorus found with only 7% contributed by dissolved organic phosphorus.

In general, measured concentrations of all heavy metals at the DeBary research site, with the exception of iron, were extremely low in value. The mean concentration of total cadmium in stormwater runoff was less than 1 μg/l, with mean concentrations of chromium, copper and lead less than 10 μg/l. Measured concentrations of heavy metals were substantially less variable between rain events than observed with general stormwater parameters. With the exception of iron, event mean concentrations for all heavy metals covered less than one order of magnitude. The low levels of heavy metals found at the DeBary research site may be related to pre-treatment occurring in the roadside swale system during transport of stormwater runoff to the pond.

Excluding iron, the most common heavy metals found in stormwater runoff were copper, lead and zinc, together accounting for 93% of the total heavy metals measured at the site. Cadmium and copper were found primarily in a dissolved state in stormwater runoff, while chromium, lead, iron and zinc were found to be primarily particulate in nature. More than 70% of the lead, iron and zinc measured at the site was present in a particulate form.

Mean monthly characteristics of stormwater runoff measured at the DeBary research site are given in Table 4-8. In general, relatively little variability was found between monthly mean concentrations for parameters listed in Table 4-8. However, monthly mean concentrations of several parameters appeared to be lower during August, September and October, months which exhibited the highest average runoff coefficients measured during the study. Measured concentrations of total N, total P, turbidity, TSS, BOD, lead, iron and zinc appeared to be somewhat lower during these three months.

TABLE 4-8

MEAN MONTHLY CHARACTERISTICS OF STORMWATER RUNOFF MEASURED AT THE DEBARY DETENTION WITH FILTRATION SITE DURING JUNE-NOVEMBER 1992

PARAMETER	UNITS	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
pH	s.u.	7.89	7.93	7.54	7.78	7.42	7.94
Spec. Conductivity	μmho/cm	92	86	128	171	134	120
Alkalinity	mg/l	117	102	68	69	121	108
NH_3	μg/l	55	67	105	85	48	79
NO_x	μg/l	203	401	197	74	31	218
Diss. Organic N	μg/l	140	122	262	469	258	251
Part. Organic N	μg/l	329	259	206	154	110	320
Total N	μg/l	726	849	772	782	429	869
Ortho-P	μg/l	72	87	94	65	55	107
Diss. Organic P	μg/l	12	12	10	28	16	14
Particulate P	μg/l	223	317	149	73	142	183
Total P	μg/l	307	417	253	166	214	304
Turbidity	NTU	132	82.7	33.9	28.2	81.9	87.4
Chloride	mg/l	2.4	3.2	5.8	16.9	9.3	8.2
TSS	mg/l	127	94.5	50.7	31.0	101	151
BOD	mg/l	25.2	3.2	2.4	3.3	3.6	6.9
Cadmium Diss.	μg/l	< 0.5	< 0.5	0.84	0.51	< 0.5	< 0.5
Total	μg/l	< 0.5	< 0.5	0.86	0.58	< 0.5	0.85
Chromium Diss.	μg/l	1.8	1.8	1.0	1.2	1.3	1.5
Total	μg/l	4.2	4.2	3.6	2.3	3.0	2.8
Copper Diss.	μg/l	5.8	7.0	7.6	8.4	8.3	7.3
Total	μg/l	9.2	10.0	9.2	9.0	13.0	10.3
Lead Diss.	μg/l	2.4	2.2	2.2	< 2	< 2	2.5
Total	μg/l	14.6	10.2	7.8	3.9	8.0	12.5
Iron Diss.	μg/l	16	13	23	46	37	36
Total	μg/l	933	871	395	300	692	705
Zinc Diss.	μg/l	8.0	7.4	10	7.0	4.3	6.8
Total	μg/l	41	37	28	17	25	37
Total Rainfall	cm	13.79	10.80	29.93	18.12	12.91	20.46
Stormwater Inputs	m^3	1019	1188	5822	8713	7373	2298
Number of Samples		5	5	5	11	3	3

A series of correlation analyses were performed using the PROC CORR routine of the SAS statistical package to determine if significant relationships exist between measured chemical characteristics of stormwater runoff and rain event characteristics such as total rainfall, event duration, average intensity, maximum intensity and antecedent dry period. Pearson correlation coefficients, along with level of significance values, were calculated for each combination of rain event characteristic and measured stormwater chemical parameter. Chemical parameters which exhibit at least one significant correlation with a rain event characteristic are summarized in Table 4-9. Chemical parameters which do not exhibit significant relationships with rain event characteristics are not listed in Table 4-9.

Significant positive correlations were found between pH and total rainfall, average intensity and maximum intensity, indicating that pH values increase as each of these characteristics increase. Significant negative correlations were observed between particulate organic nitrogen and total nitrogen with event duration, indicating that concentrations of these nitrogen species decrease with increasing time during rain events. This behavior suggests that nitrogen species may be removed from roadway and land surfaces during early portions of rain events with decreasing loadings added to stormwater flow as rain event duration increases.

Significant positive correlations were observed for particulate organic nitrogen, total N, particulate P, total P, TSS, total lead and total zinc with rainfall intensity. These positive correlations suggest that the mobilization of each of these species into stormwater runoff increases as the intensity of rainfall increases. Each of these species is associated to a large extent with particulate matter in stormwater runoff which apparently is mobilized more readily into stormwater flow during high intensity events. Antecedent dry period was found to have significant correlations only with ortho-P, total P and dissolved zinc.

Measurable inputs of baseflow into the DeBary detention pond were observed on a sporadic basis during August, September, October and November. Baseflow inputs are considered to be water flowing through the stormsewer system and entering the detention pond unrelated to an identifiable storm event. Baseflow measured at the DeBary site is primarily groundwater seepage which enters the stormsewer system and ultimately discharges into the pond. Measurable baseflow occurred during three days in August, eight days in September, three days in October and two days in November. In general, baseflow occurred during periods following repeated heavy rain events.

A summary of chemical characteristics of baseflow measured at the DeBary research site is given in Table 4-10. Baseflow was found to be slightly alkaline in pH with a mean value of 7.68. Conductivity in baseflow was substantially greater than that found in stormwater runoff with a mean baseflow specific conductivity of 299 μmho/cm compared to a value of 130 μmho/cm for stormwater runoff.

Baseflow was also found to have substantially higher concentrations of total nitrogen than found in stormwater runoff, with a mean baseflow total nitrogen concentration of 1381 μg/l compared to 761 μg/l for stormwater runoff. The dominant

TABLE 4-9

CORRELATIONS BETWEEN CHEMICAL CHARACTERISTICS OF STORMWATER RUNOFF AND RAIN EVENT CHARACTERISTICS

PARAMETER	PEARSON CORRELATION COEFFICIENT/ (LEVEL OF SIGNIFICANCE)				
	TOTAL RAINFALL	EVENT DURATION	AVERAGE INTENSITY	MAXIMUM INTENSITY	ANTECEDENT DRY PERIOD
pH	0.357 (0.041)	N.S.C.[1]	0.469 (0.006)	0.530 (0.002)	N.S.C.
Part. Organic N	N.S.C.	-0.359 (0.040)	0.593 (0.0003)	0.504 (0.003)	N.S.C.
Total N	N.S.C.	-0.550 (0.001)	0.357 (0.042)	N.S.C.	N.S.C.
Ortho-P	N.S.C.	N.S.C.	N.S.C.	N.S.C.	0.845 (0.0001)
Particulate P	N.S.C.	N.S.C.	0.432 (0.012)	0.425 (0.014)	N.S.C.
Total P	N.S.C.	N.S.C.	0.422 (0.014)	0.393 (0.024)	0.469 (0.006)
TSS	0.381 (0.029)	N.S.C.	0.422 (0.015)	0.364 (0.038)	N.S.C.
Dissolved Cr	0.429 (0.013)	N.S.C.	N.S.C.	N.S.C.	N.S.C.
Total Pb	N.S.C.	N.S.C.	0.423 (0.014)	0.374 (0.032)	N.S.C.
Dissolved Zn	-0.372 (0.033)	N.S.C.	N.S.C.	N.S.C.	0.447 (0.009)
Total Zn	N.S.C.	N.S.C.	0.390 (0.025)	N.S.C.	N.S.C.

[1] N.S.C.: No Significant Correlation at the 0.05 level of significance

TABLE 4-10

MEAN CHARACTERISTICS OF BASEFLOW INPUTS MEASURED AT THE DEBARY DETENTION WITH FILTRATION POND SITE DURING JUNE-NOVEMBER 1992[1]

PARAMETER		UNITS	RANGE OF VALUES		MEAN	C.V.[2]
			MINIMUM	MAXIMUM		
pH		s.u.	7.48	7.86	7.68	2
Spec. Conductivity		μmho/cm	198	374	299	21
Alkalinity		mg/l	51	134	89	30
NH_3		μg/l	120	532	222	64
NO_x		μg/l	< 10	70	22	126
Diss. Organic N		μg/l	819	1176	946	12
Part. Organic N		μg/l	75	283	194	41
Total N		μg/l	1168	2022	1381	21
Ortho-P		μg/l	10	64	25	90
Diss. Organic P		μg/l	2	48	23	78
Particulate P		μg/l	4	60	31	67
Total P		μg/l	44	144	84	47
Turbidity		NTU	2.2	5.4	3.3	35
Chloride		mg/l	25	63	38	33
TSS		mg/l	2.3	9.0	4.4	53
BOD		mg/l	1.7	3.3	2.7	19
Cadmium	Diss.	μg/l	< 0.5	< 0.5	< 0.5	0
	Total	μg/l	< 0.5	0.6	< 0.5	44
Chromium	Diss.	μg/l	< 1	1	< 1	34
	Total	μg/l	< 1	4	1.5	80
Copper	Diss.	μg/l	7	10	8.7	13
	Total	μg/l	8	13	9.6	20
Lead	Diss.	μg/l	< 2	10	2.3	150
	Total	μg/l	< 2	10	2.6	129
Iron	Diss.	μg/l	24	126	85	46
	Total	μg/l	63	195	127	34
Zinc	Diss.	μg/l	5	9	7.1	21
	Total	μg/l	6	11	8.7	20

1. n = 7 samples

2. C.V.: Coefficient of Variation = $\sigma/\bar{x}$, expressed as a percentage

nitrogen species in baseflow was dissolved organic nitrogen, comprising 69% of the total nitrogen measured. Inorganic species of ammonia and nitrate comprised 18% of the total nitrogen found in baseflow.

In contrast, measured concentrations of total phosphorus in baseflow were relatively low in value and substantially lower than values measured in stormwater runoff. Measured concentrations of ortho-P, dissolved organic P and particulate P in baseflow inputs were approximately equal. Similarly, measured concentrations of turbidity, TSS and BOD were substantially lower than values for these parameters found in stormwater runoff.

Measured concentrations of heavy metals in baseflow inputs were low in value for all measured metals. Total metal concentrations for all metals in baseflow inputs were lower than total concentrations for the same species found in stormwater runoff. Measured concentrations of cadmium, chromium, and lead in baseflow inputs were less than 3 μg/l on average. Mean concentrations of copper and zinc were less than 10 μg/l.

4.3 Characteristics of Bulk Precipitation

Water quality characteristics of combined wet and dry fallout (bulk precipitation) were measured at the DeBary research site from June through November 1992. Bulk precipitation was measured by collecting all wet and dry fallout which fell into a funnel device attached to the roof of the equipment shelter located adjacent to the outfall line. In general, bulk precipitation samples were collected over periods ranging from 5 to 10 days. A total of 17 bulk precipitation samples were collected at the DeBary research site during the 6-month study period. A listing of chemical characteristics for each bulk precipitation sample collected at the DeBary research site is given in Appendix J. Concentrations of total heavy metal in bulk precipitation are listed in Appendix K.

Mean characteristics of bulk precipitation measured at the DeBary research site during June to November 1992 are summarized in Table 4-11. Bulk precipitation was found to be somewhat acidic with pH values ranging from 4.27 to 6.52 and a mean of 5.00. Bulk precipitation was also relatively low in ionic strength with a mean conductivity of only 22 μmho/cm. Buffering capacity for bulk precipitation was also extremely low with a mean alkalinity of only 1 mg/l.

Considerable variability was observed in measured concentrations of both nitrogen and phosphorus in bulk precipitation. The most dominant nitrogen species found in bulk precipitation was NO_x which comprised 37% of the mean total nitrogen concentration of 671 μg/l. Together, inorganic species of ammonia and NO_x accounted for 54% of the total nitrogen found with 46% present as organic nitrogen.

Measured concentrations of total phosphorus in bulk precipitation were extremely variable, covering a range of over two orders of magnitude, with a mean total phosphorus concentration of 45 μg/l. Approximately 60% of the total phosphorus found

TABLE 4-11

MEAN CHARACTERISTICS OF BULK PRECIPITATION MEASURED AT THE DEBARY DETENTION WITH FILTRATION POND SITE DURING JUNE-NOVEMBER 1992[1]

PARAMETER	UNITS	RANGE OF VALUES		MEAN	C.V.[2]
		MINIMUM	MAXIMUM		
pH	s.u.	4.27	6.52	5.00	11
Spec. Conductivity	µmho/cm	8	55	22	50
Alkalinity	mg/l	0	5	1	100
NH_3	µg/l	< 10	448	108	96
NO_x	µg/l	17	767	251	72
Diss. Organic N	µg/l	< 50	490	142	98
Part. Organic N	µg/l	< 50	503	174	83
Total N	µg/l	206	1764	671	63
Ortho-P	µg/l	< 2	40	7	177
Diss. Organic P	µg/l	< 2	62	11	144
Particulate P	µg/l	< 2	86	27	94
Total P	µg/l	< 2	124	45	90
Turbidity	NTU	0.6	5.1	2.1	69
Chloride	mg/l	1	8	3	82
TSS	mg/l	0.3	24.3	6.2	103
Total Cadmium	µg/l	< 0.5	3.3	0.77	91
Total Chromium	µg/l	< 1	3	1.2	61
Total Copper	µg/l	3	13	7.0	43
Total Lead	µg/l	< 2	4	1.7	58
Total Iron	µg/l	17.0	148	53	69
Total Zinc	µg/l	8	70	25	73

1. n = 17 samples

2. C.V.: Coefficient of Variation = $\sigma/\bar{x}$, expressed as a percentage

was present as particulate phosphorus with only 40% in a dissolved form. Dissolved orthophosphorus comprised only 16% of the total phosphorus measured.

Measured concentrations of turbidity and chloride exhibited relatively little variability in bulk precipitation. Mean values for both turbidity and chloride are relatively low with a mean turbidity of 2.1 NTU and a mean chloride concentration of 3 mg/l. In contrast, substantial variability was observed in concentrations of TSS with an overall mean of 6.2 mg/l.

As observed for stormwater and baseflow, variability in concentrations of heavy metals appears to be substantially less than that exhibited by general chemical parameters. Mean concentrations of cadmium, chromium and lead averaged less than 2 μg/l with a mean for total copper of only 7 μg/l. However, relatively high concentrations of zinc were present in bulk precipitation samples. Measured concentrations of total zinc in bulk precipitation samples ranged from 8-70 μg/l with a mean of 25 μg/l. This mean value for total zinc is similar to the mean of 28 μg/l for total zinc found in stormwater runoff. With the exception of iron, total zinc and total copper were clearly the dominant heavy metal species found in bulk precipitation, with zinc comprising 70% of the total heavy metals measured and copper comprising an additional 20% of the total metals measured.

Mean monthly characteristics of bulk precipitation measured at the DeBary research site are given in Table 4-12. The highest measured concentrations of total nitrogen, total phosphorus and TSS appear to occur in June, September and October. A similar pattern is present for measured concentrations of heavy metals with high concentrations also observed during August.

4.4 Characteristics of Pond Surface Water

Pond surface water was collected from the DeBary detention with filtration pond on a weekly basis from the center of the pond using a clear acrylic Kemmerer water sampler. A single vertical composite sample was formed and submitted for analysis on each weekly sampling visit. In addition, vertical depth profiles of pH, temperature, conductivity, dissolved oxygen and redox potential were collected within the pond beginning at the water surface and extending at 0.5 m intervals from the water surface to the pond bottom. In general, the average water depth within the detention pond was approximately 1.7 m (5.5 ft). Physical-chemical profiles were collected on most monitoring dates to a depth of 1.5 m (4.9 ft). A complete listing of physical-chemical profiles, Secchi disk depths and visual observations for pond surface water is given in Appendix L.

Visually, the detention pond was characterized by a green appearance, due to excessive algal growth, and a relatively turbid water column. Field observations of a turbid water column and general green appearance were recorded on 23 of the 28 monitoring dates conducted. The water column was reported as clear on only 5 of the 28 monitoring dates. The water column within the pond was also observed to exhibit a

TABLE 4-12

MEAN MONTHLY CHARACTERISTICS OF BULK PRECIPITATION MEASURED AT THE DEBARY DETENTION WITH FILTRATION SITE DURING JUNE-NOVEMBER 1992

PARAMETER	UNITS	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
pH	s.u.	5.45	4.59	4.76	5.31	5.01	4.96
Spec. Conductivity	μmho/cm	14	16	19	23	27	24
Alkalinity	mg/l	3	1	1	2	2	1
NH_3	μg/l	218	28	86	96	195	84
NO_x	μg/l	356	285	318	205	287	176
Diss. Organic N	μg/l	316	56	90	198	225	61
Part. Organic N	μg/l	150	86	98	250	307	108
Total N	μg/l	1040	464	585	743	1012	417
Ortho-P	μg/l	40	< 2	10	10	< 2	< 2
Diss. Organic P	μg/l	12	< 2	2	16	26	4
Particulate P	μg/l	23	18	14	43	51	9
Total P	μg/l	75	20	26	69	78	14
Turbidity	NTU	5.1	1.2	3.1	2.2	1.1	1.7
Chloride	mg/l	1	1	1	3	4	5
TSS	mg/l	10.4	9.0	6.0	11.7	2.2	1.2
Total Cadmium	μg/l	0.90	< 0.50	1.27	0.77	0.87	0.56
Total Chromium	μg/l	1.0	1.0	1.0	1.8	< 1	1.1
Total Copper	μg/l	10.0	6.5	9.0	8.0	7.0	4.0
Total Lead	μg/l	3.0	1.5	1.7	1.8	1.7	1.5
Total Iron	μg/l	148	55	66	38	50	37
Total Zinc	μg/l	14	24	23	20	31	32
Number of Samples		1	2	3	4	3	4

light brown color with high levels of turbidity following extreme rain events. Measurements of Secchi disk depth within the pond generally correlated with visual characteristics of the water column, ranging from 3.3 to 1.4 m with a mean value of approximately 0.7 m.

The pond water column was characterized by a sharp thermal stratification which occurred on many of the monitoring dates. For purposes of this discussion, a thermal stratification is defined as a drop in temperature of 1°C or more over a vertical distance of 1 m in the water column. This type of stratification routinely occurred within the pond at a depth of 0.5 m with a change in temperature in excess of 1°C between 0.5 m and 1.0 m. This phenomenon was present on 17 of the 28 monitoring dates. However, in spite of this frequent thermal stratification, chemical stratification for pH, dissolved oxygen, specific conductivity or redox potential was not observed on any monitoring date.

A summary of mean physical-chemical field measurements collected in the DeBary detention pond is given in Table 4-13. Thermal stratification within the pond is apparent in this data with a mean decrease of 1.18°C between 0.5 m and 1.0 m depths. Relatively little variability was observed in measured concentrations of pH, dissolved oxygen, conductivity or redox potential with depth. Mean values for pH decrease only 0.11 unit between top and bottom samples, with dissolved oxygen levels differing by only 1.6 mg/l between top and bottom samples. Measured values for conductivity and redox potential are virtually identical in top and bottom measurements.

A listing of general chemical characteristics in pond surface water for each of the 28 monitoring dates is given in Appendix M. Concentrations of heavy metals in surface water samples collected on each of the 28 monitoring dates are presented in Appendix N. A summary of mean characteristics of detention pond surface water is given in Table 4-14.

In general, with the exceptions of ammonia and NO_x, measured concentrations for all chemical parameters within the pond surface water were substantially less variable and covered a smaller range of values than measurements for the same parameters found in stormwater runoff. The dominant nitrogen species in pond surface water was organic nitrogen with approximately equal contributions from dissolved and particulate organic nitrogen species. Together, these species accounted for 96% of the total nitrogen found in pond surface water. Mean concentrations of ammonia and NO_x were extremely small within the pond, comprising only 4% of the total nitrogen found. Mean concentrations of ammonia and NO_x in pond water are substantially lower than values found in stormwater runoff, while both dissolved and particulate organic nitrogen are higher in value in pond water than in stormwater. The mean total nitrogen value of 891 μg/l in pond water is approximately 17% higher than the value of 761 μg/l found in stormwater runoff. It appears that ammonia and NO_x in stormwater runoff is being utilized by algae and converted into organic nitrogen within the pond water.

With the exception of dissolved organic phosphorus, measured concentrations of all phosphorus species in pond surface water were found to be substantially lower than

TABLE 4-13

MEAN PHYSICAL-CHEMICAL FIELD MEASUREMENTS COLLECTED IN THE DEBARY DETENTION WITH FILTRATION POND DURING MAY-NOVEMBER 1992

DEPTH	PARAMETER	UNITS	NO. OF OBSERVATIONS	MINIMUM VALUE	MAXIMUM VALUE	MEAN	CV
0.1 m	Temperature	°C	28	19.27	35.41	29.15	14.5
	pH	s.u.	28	6.28	8.76	7.58	8.5
	Diss. Oxygen	mg/l	28	6.0	11.7	8.9	15.3
	Conductivity	μmho/cm	28	146	303	240	17.7
	ORP	mv	28	259	526	423	16.9
0.5 m	Temperature	°C	28	19.21	34.87	28.36	15.0
	pH	s.u.	28	6.26	8.84	7.59	9.2
	Diss. Oxygen	mg/l	28	5.8	11.7	8.8	18.3
	Conductivity	μmho/cm	28	143	303	239	17.9
	ORP	mv	28	267	544	429	17.2
1.0 m	Temperature	°C	28	18.06	33.26	27.18	14.1
	pH	s.u.	28	6.20	8.93	7.53	9.1
	Diss. Oxygen	mg/l	28	5.6	11.6	8.2	19.3
	Conductivity	μmho/cm	28	145	303	239	18.1
	ORP	mv	28	260	548	429	17.6
1.5 m	Temperature	°C	27	17.81	33.10	26.95	14.4
	pH	s.u.	27	6.31	8.70	7.47	8.2
	Diss. Oxygen	mg/l	27	5.0	10.1	7.3	19.4
	Conductivity	μmho/cm	27	145	311	238	17.9
	ORP	mv	27	256	549	422	18.5
Secchi Disk Depth		m	28	0.3	1.4	0.68	11.8

TABLE 4-14

MEAN CHARACTERISTICS OF DETENTION POND SURFACE WATER MEASURED AT THE DEBARY DETENTION WITH FILTRATION POND SITE DURING JUNE-NOVEMBER 1992[1]

PARAMETER		UNITS	RANGE OF VALUES		MEAN	C.V.[2]
			MINIMUM	MAXIMUM		
pH		s.u.	6.26	8.81	7.54	9
Spec. Conductivity		μmho/cm	145	303	240	18
Diss. Oxygen		mg/l	5.7	10.9	8.3	17
ORP		mv	263	539	427	17
Alkalinity		mg/l	70	125	94	16
NH_3		μg/l	< 10	239	35	164
NO_x		μg/l	< 10	107	12	163
Diss. Organic N		μg/l	156	777	448	38
Part. Organic N		μg/l	81	895	410	50
Total N		μg/l	555	1365	891	21
Ortho-P		μg/l	< 2	55	16	85
Diss. Organic P		μg/l	7	62	20	72
Particulate P		μg/l	8	152	65	53
Total P		μg/l	65	209	101	30
Turbidity		NTU	1.7	41.3	8.9	89
Chloride		mg/l	5	40	16	44
TSS		mg/l	2.9	20.0	9.3	46
Chlorophyll-a		mg/m^3	8.4	48.3	19.5	44
BOD		mg/l	1.1	13.8	5.8	56
Fecal Coliform		No./100 ml	64	12,150	1695	159
Cadmium	Diss.	μg/l	< 0.5	< 0.5	< 0.5	0
	Total	μg/l	< 0.5	0.7	< 0.5	32
Chromium	Diss.	μg/l	< 1	2	< 1	30
	Total	μg/l	< 1	3	1.1	43
Copper	Diss.	μg/l	3	11	5.2	32
	Total	μg/l	3	11	5.4	31
Lead	Diss.	μg/l	< 2	8	< 2	106
	Total	μg/l	< 2	8	< 2	103
Iron	Diss.	μg/l	4	416	66	118
	Total	μg/l	115	1063	379	71
Zinc	Diss.	μg/l	1	8	3.9	40
	Total	μg/l	2	10	5.0	41

1. n = 28 samples

2. C.V.: Coefficient of Variation = $\sigma/\bar{x}$, expressed as a percentage

values measured in stormwater runoff. The dominant phosphorus species measured within the pond was particulate phosphorus which accounted for 64% of the total phosphorus found within the pond. Dissolved orthophosphorus contributed only 16% of the total phosphorus found. The mean total phosphorus concentration of 101 μg/l in pond surface water is approximately 61% lower than values of total phosphorus found in stormwater runoff. Similar to nitrogen, it appears that orthophosphorus is being utilized as a source of nutrients for algal growth which is primarily responsible for its removal from the water column.

Measured concentrations of turbidity, TSS and BOD were all substantially lower in pond surface water than measured in stormwater inputs to the pond. In addition, the range of values found for these parameters was substantially less than the range of values observed in stormwater runoff.

Concentrations of chlorophyll-a in pond surface water were typically high throughout the study period as evidenced by the apparent green color and obvious turbidity within the water column. Measured values of chlorophyll-a ranged from 8.4 to 48.3 mg/m^3, with a mean of 19.5 mg/m^3.

Measured fecal coliform counts within the pond were extremely variable during the monitoring period with a range of values of 64 to 12,150 organisms/100 ml. Fecal coliform counts in pond surface water exceeded 800 organisms/100 ml on 11 of the 28 monitoring dates. However, the source of this bacterial contamination was difficult to assess and may be related to the large population of resident water fowl which lived at the detention pond site. Water fowl populations, ranging in size from 4 to more than 20 were visible on each of the monitoring visits.

In general, measured concentrations of both total and dissolved heavy metals in pond surface water were relatively low in value and substantially lower than values measured in stormwater runoff. Measured concentrations of heavy metals throughout the study period were relatively consistent within the pond with little variability observed in individual values. With the exception of iron, mean concentrations of both total and dissolved heavy metals were equal to or less than 5 μg/l within the pond surface water.

A summary of mean monthly characteristics of detention pond surface water is given in Table 4-15. Monthly average water quality characteristics within the pond appeared to be relatively similar for each of the six months. The only exception to this generality may be for species such as total phosphorus, turbidity, TSS, BOD and fecal coliform which appear to be somewhat lower during August, September or October when stormwater inputs into the pond are maximum. As seen in Table 4-8, mean values for many parameters in stormwater runoff were substantially lower during these three months also. The combination of decreased stormwater concentrations and increased flushing apparently serves to lower measured concentrations of some chemical parameters. No monthly trends are apparent in measured concentrations of either dissolved or total heavy metals.

TABLE 4-15

MEAN MONTHLY CHARACTERISTICS OF DETENTION POND SURFACE WATER MEASURED AT THE DEBARY DETENTION WITH FILTRATION SITE DURING JUNE-NOVEMBER 1992

PARAMETER	UNITS	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
pH	s.u.	8.04	8.28	7.52	7.25	7.29	6.80
Spec. Conductivity	µmho/cm	244	216	187	244	255	290
Diss. Oxygen	mg/l	9.5	9.2	7.1	7.2	8.6	8.1
ORP	mv	379	387	370	439	486	515
Alkalinity	mg/l	107	94	79	84	89	105
NH_3	µg/l	11	11	31	11	26	110
NO_x	µg/l	10	< 10	10	< 10	< 10	34
Diss. Organic N	µg/l	388	271	345	590	606	526
Part. Organic N	µg/l	451	656	380	325	221	414
Total N	µg/l	860	943	764	924	853	1015
Ortho-P	µg/l	23	10	26	10	10	14
Diss. Organic P	µg/l	23	22	12	18	28	18
Particulate P	µg/l	37	75	91	52	54	82
Total P	µg/l	83	107	129	80	92	114
Turbidity	NTU	9.0	8.6	19.0	2.8	3.6	7.8
Chloride	mg/l	12	10	17	19	22	20
TSS	mg/l	10.6	15.0	7.9	6.8	6.2	8.9
Chlorophyll-a	mg/m^3	15.0	17.9	16.5	16.9	16.0	33.7
BOD	mg/l	10.4	4.9	4.5	3.6	3.8	5.7
Fecal Coliform	No./100 ml	2364	2692	2852	1162	481	335
Cadmium Diss.	µg/l	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Total	µg/l	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Chromium Diss.	µg/l	1.0	1.0	1.0	1.3	< 1	< 1
Total	µg/l	1.2	1.0	1.2	1.5	1.0	< 1
Copper Diss.	µg/l	5.7	4.5	5.4	6.5	4.0	4.8
Total	µg/l	6.0	4.5	5.8	6.5	4.0	5.2
Lead Diss.	µg/l	< 2	< 2	< 2	< 2	< 2	2.4
Total	µg/l	< 2	< 2	3.0	< 2	< 2	2.6
Iron Diss.	µg/l	22	10	52	87	86	146
Total	µg/l	322	273	279	210	482	684
Zinc Diss.	µg/l	4.2	3.8	5.6	3.8	3.8	2.2
Total	µg/l	5.0	5.3	6.8	4.5	4.5	3.6
Stormwater Inputs	m^3	1019	1188	5822	8713	7373	2298
Number of Samples		6	4	5	4	4	5

4.5 Characteristics of Underdrain Outflow

As discussed in Chapter 3, underdrain outflow from the pond was collected as 72-hour composite samples which were retrieved from the research site twice each week. A total of 47 underdrain outflow samples were collected and analyzed at the DeBary research site during the 6-month monitoring period. A complete listing of chemical characteristics of each of the 47 monitored outflow events is given in Appendix O. Concentrations of heavy metals in underdrain outflow samples are given in Appendix P.

Mean characteristics of underdrain outflow measured at the DeBary research site are summarized in Table 4-16. With the exceptions of specific conductivity, NO_x, orthophosphorus, chloride, lead and iron, chemical characteristics of individual underdrain outflow samples exhibited substantially more variability in value than observed in detention pond surface water samples.

The mean total nitrogen concentration of 707 μg/l in underdrain outflow is somewhat less than the mean of 891 μg/l in pond surface water and approximately equal to the mean of 761 μg/l found in stormwater runoff. It appears that the underdrain filter system is removing substantial quantities of particulate organic nitrogen since the mean value of 86 μg/l in underdrain outflow is substantially less than the mean of 410 μg/l in detention pond surface water. However, it also appears that a portion of the trapped particulate organic nitrogen is undergoing conversion to ammonia and NO_x, possibly by microbial activity, inside the filter bed. Measured concentrations of both ammonia and NO_x increased substantially in underdrain outflow compared with concentrations found in pond surface water. The combined mean concentration of ammonia and NO_x in underdrain outflow is 274 μg/l compared with a mean of only 47 μg/l for these same parameters combined in the pond surface water. Inorganic species of nitrogen contributed 39% of the total nitrogen found in the underdrain flow, but only 5% of the total nitrogen found in the pond water.

Species of phosphorus appeared to be undergoing a conversion similar to that observed for nitrogen inside the filter media. Mean concentrations of particulate phosphorus are reduced substantially during migration through the filter, with a mean underdrain concentration of only 18 μg/l compared with a mean of 65 μg/l inside the pond. However, it appears that a portion of the trapped particulate phosphorus is being converted to dissolved orthophosphorus inside the filter media, based upon the fact that dissolved orthophosphorus concentrations in the underdrain outflow averaged 48 μg/l compared with a mean of 16 μg/l in pond surface water. However, a net retention of phosphorus appears to be occurring inside the filter media since the mean total phosphorus concentration of 77 μg/l in underdrain outflow is approximately 24% lower than the mean total phosphorus concentration of 101 μg/l in pond surface water.

Removal of turbidity, TSS and BOD is also apparently occurring within the filter media since measured concentrations for these parameters in underdrain outflow are substantially lower than mean values found in pond surface water. Mean values of turbidity decreased approximately 82% during migration through the filter, with a 90% reduction in concentrations of TSS and a 57% reduction in concentrations of BOD.

TABLE 4-16

MEAN CHARACTERISTICS OF UNDERDRAIN OUTFLOW MEASURED AT THE DEBARY DETENTION WITH FILTRATION POND SITE DURING JUNE-NOVEMBER 1992[1]

PARAMETER		UNITS	RANGE OF VALUES		MEAN	C.V.[2]
			MINIMUM	MAXIMUM		
pH		s.u.	7.40	7.93	7.71	2
Spec. Conductivity		μmho/cm	139	346	254	17
Alkalinity		mg/l	62	133	105	18
NH_3		μg/l	< 10	311	153	53
NO_x		μg/l	11	571	121	108
Diss. Organic N		μg/l	81	1013	348	56
Part. Organic N		μg/l	< 50	469	86	91
Total N		μg/l	320	1398	707	29
Ortho-P		μg/l	20	89	48	36
Diss. Organic P		μg/l	< 2	49	11	97
Particulate P		μg/l	2	195	18	161
Total P		μg/l	34	293	77	53
Turbidity		NTU	0.4	9.6	1.6	101
Chloride		mg/l	5	23	16	34
TSS		mg/l	0.1	6.0	0.9	120
BOD		mg/l	0.7	10.2	2.5	73
Cadmium	Diss.	μg/l	< 0.5	0.9	< 0.5	37
	Total	μg/l	< 0.5	0.9	< 0.5	45
Chromium	Diss.	μg/l	< 1	2	< 1	30
	Total	μg/l	< 1	5	1.3	68
Copper	Diss.	μg/l	2	10	5.5	34
	Total	μg/l	2	23	7.0	58
Lead	Diss.	μg/l	< 2	6	< 2	85
	Total	μg/l	< 2	8	< 2	74
Iron	Diss.	μg/l	25	210	113	42
	Total	μg/l	57	414	161	38
Zinc	Diss.	μg/l	< 1	6	1.9	54
	Total	μg/l	1	7	2.1	58

1. n = 47 samples

2. C.V.: Coefficient of Variation

With the exception of copper, measured concentrations of heavy metals in the underdrain outflow were equal to or less than mean concentrations measured in pond surface waters. Mean concentrations of cadmium, chromium, lead and zinc in underdrain outflow were equal to approximately 2 μg/l or less with a mean of 7 μg/l for copper.

Mean monthly characteristics of underdrain outflow measured at the DeBary research site are given in Table 4-17. In general, relatively little variability is evident in measured concentrations of most parameters for each of the six months monitored. Mean concentrations of heavy metals appear to be relatively consistent throughout the study period.

Mean monthly flow rates in underdrain outflow from the pond are also listed at the bottom of Table 4-17. Underdrain outflow was extremely variable during the 6-month study period, ranging from a minimum of 0.340 liters/sec in June to a maximum of 6.85 liter/sec in October. The overall mean flow discharged through the underdrain system at the DeBary site was 2.85 liters/sec (0.101 cfs).

Statistical correlations were conducted to determine if a relationship exists between flow rates through the filter system and the chemical characteristics of underdrain flow. A summary of correlations between underdrain filter flow rates and chemical characteristics of underdrain flow is given in Table 4-18. Filter flow rate was found to have a significant negative correlation with specific conductivity, alkalinity, ammonia, orthophosphorus, dissolved iron and total iron. Significant positive correlations were found between flow rates and dissolved organic nitrogen, dissolved organic phosphorus, total chromium, dissolved lead and total lead. Correlations between flow rate and the remaining chemical parameters were not significant at the 0.05 level.

The majority of significant correlations indicated in Table 4-18 can be explained by either a chemical or physical phenomenon. Significant positive correlations between flow rate and total chromium, total lead and dissolved lead suggests that increases in flow rate result in increased underdrain concentrations of these parameters. Total lead and chromium in pond surface water are present primarily as particulate matter. As flow rates through the filter system increase, particles containing chromium or lead may begin to pass through the filter system, resulting in higher measured concentrations in underdrain outflow under high flow conditions.

The significant negative correlations observed between flow rate and dissolved iron, total iron, orthophosphorus, ammonia, alkalinity and specific conductivity may be related to chemical processes occurring within the filter media. This relationship suggests that as flow rates decrease within the filter, concentrations of these parameters increase in the underdrain outflow. Based on field observations, anaerobic conditions exist within the filter during periods of low flow. A strong hydrogen sulfide smell was readily evident within the flow metering box attached to the underdrain outflow during periods of low flow conditions. As the filter media becomes anaerobic, particles of iron trapped within the filter media become reduced from Fe^{+3} to Fe^{+2}, resulting in a release

TABLE 4-17

MEAN MONTHLY CHARACTERISTICS OF UNDERDRAIN OUTFLOW MEASURED AT THE DEBARY DETENTION WITH FILTRATION SITE DURING JUNE-NOVEMBER 1992

PARAMETER	UNITS	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
pH	s.u.	7.57	7.75	7.64	7.79	7.73	7.74
Spec. Conductivity	µmho/cm	261	230	198	244	269	306
Alkalinity	mg/l	119	104	86	96	102	122
NH_3	µg/l	143	142	127	112	165	225
NO_x	µg/l	108	230	128	128	43	113
Diss. Organic N	µg/l	225	200	219	470	448	446
Part. Organic N	µg/l	135	144	66	47	61	71
Total N	µg/l	611	715	540	754	721	852
Ortho-P	µg/l	58	40	63	40	48	40
Diss. Organic P	µg/l	14	9	9	8	17	6
Particulate P	µg/l	42	15	10	8	19	13
Total P	µg/l	114	64	90	56	84	60
Turbidity	NTU	0.8	1.3	2.9	1.7	1.0	1.4
Chloride	mg/l	12	11	8	17	21	20
TSS	mg/l	0.6	1.0	1.6	1.0	0.3	1.3
BOD	mg/l	4.7	2.0	1.8	1.8	1.5	2.9
Cadmium Diss.	µg/l	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Total	µg/l	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Chromium Diss.	µg/l	1.0	1.0	1.0	1.1	< 1	< 1
Total	µg/l	1.1	1.4	1.2	1.4	1.4	1.1
Copper Diss.	µg/l	5.5	6.4	5.0	6.3	5.9	3.6
Total	µg/l	9.6	10.0	5.0	6.9	6.3	3.9
Lead Diss.	µg/l	< 2	< 2	< 2	< 2	2.0	< 2
Total	µg/l	< 2	< 2	< 2	< 2	2.2	< 2
Iron Diss.	µg/l	123	83	106	87	130	146
Total	µg/l	220	145	173	115	147	174
Zinc Diss.	µg/l	2.9	2.0	1.5	2.0	1.4	1.6
Total	µg/l	3.5	2.0	1.7	2.0	1.7	1.6
Underdrain Flow rate	liters/sec	0.340	0.425	1.84	5.18	6.85	2.44
	cfs	0.012	0.015	0.065	0.183	0.242	0.086
Number of Samples		8	7	6	9	9	8

TABLE 4-18

CORRELATIONS BETWEEN UNDERDRAIN FILTER FLOW RATE AND CHEMICAL CHARACTERISTICS OF UNDERDRAIN FLOW

(n = 45 Samples)

PARAMETER		PEARSON CORRELATION COEFFICIENT/ (LEVEL OF SIGNIFICANCE)
pH		N.S.C.[1]
Specific Conductivity		-0.317 (0.034)
Alkalinity		-0.503 (0.001)
NH_3		-0.401 (0.006)
NO_x		N.S.C.
Diss. Organic N		0.298 (0.047)
Part. Organic N		N.S.C.
Total N		N.S.C.
Ortho-P		-0.304 (0.042)
Diss. Organic P		0.543 (0.0001)
Particulate P		N.S.C.
Total P		N.S.C.
Turbidity		N.S.C.
Chloride		N.S.C.
TSS		N.S.C.
BOD		N.S.C.
Cadmium:	Diss.	N.S.C.
	Total	N.S.C.
Chromium:	Diss.	N.S.C.
	Total	0.453 (0.002)
Copper:	Diss.	N.S.C.
	Total	N.S.C.
Lead:	Diss.	0.665 (0.0001)
	Total	0.636 (0.0001)
Iron:	Diss.	-0.479 (0.0009)
	Total	-0.463 (0.001)
Zinc:	Diss.	N.S.C.
	Total	N.S.C.

1. N.S.C.: No significant correlation at the 0.05 level of significance

of iron into the underdrain flow. Since phosphorus is often bound with iron in a natural environment, release of iron within the filter media could also result in the release of orthophosphorus into the underdrain flow. Increases in ammonia concentrations in anaerobic soils and sediments is a commonly observed phenomenon and apparently is also occurring within the filter media. Increased levels of specific conductivity simply reflect the additional ions from ammonia, orthophosphorus and iron entering the underdrain flow.

4.6 Characteristics of Groundwater at the DeBary Research Site

Groundwater characteristics were measured using three multiport groundwater monitoring wells installed in upgradient, downgradient and pond locations at the research site. Separate water quality samples were collected from four sample ports on each of the three multiport monitoring wells at distances of 0.1 m, 0.5 m, 1.0 m and 2.5 m below the groundwater table at time of well installation. Samples were collected from each monitoring well on a monthly basis using a peristaltic pump operated at a low flow rate. General chemical characteristics of groundwater samples collected at each of the three monitoring wells for the six sample collection dates are given in Appendix Q. Concentrations of heavy metals in groundwater samples collected from the three monitoring wells over the six collection dates are given in Appendix R.

4.6.1 Groundwater Characteristics at the Upgradient Monitoring Site

A summary of mean water quality characteristics in the upgradient monitoring well is given in Table 4-19. Groundwater at the upgradient location was found to be somewhat acidic in nature with a mean pH of 5.64 at the 0.1 m sample port, decreasing steadily to a value of 4.66 at the 2.5 m sample port. Mean values of specific conductivity and temperature also decreased steadily with increasing groundwater depth. Measured values for redox potential also decreased steadily with increasing groundwater depth, indicating reduced conditions at each of the four monitoring ports. Redox potentials less than 200 mv generally indicate the presence of reduced conditions. Mean measurements of alkalinity also decreased substantially with increasing water depth, corresponding to decreases in mean pH levels.

Measured concentrations of total nitrogen also decrease rapidly with increasing groundwater depth. Ammonia nitrogen is the dominant nitrogen species found at the 0.1 and 0.5 m sample ports, with dissolved organic nitrogen becoming the dominant nitrogen species at the 1.0 and 2.5 m sample ports. Mean concentrations of NO_x are extremely low at each of the sample ports. The reducing environment within the groundwater is conducive to denitrification processes which would convert nitrate into either gaseous nitrogen or ammonia. However, a trend of decreasing concentrations with increasing groundwater depth was not observed for total phosphorus. The dominant phosphorus

TABLE 4-19

MEAN WATER QUALITY CHARACTERISTICS IN THE UPGRADIENT WELL AT THE DEBARY DETENTION WITH FILTRATION SITE FROM JUNE-NOVEMBER 1992

PARAMETER	UNITS	MEAN CONCENTRATION BY PORT			
		0.1 m	0.5 m	1.0 m	2.5 m
pH	s.u.	5.64	5.09	4.67	4.66
Spec. Conductivity	μmho/cm	192	113	76	78
Temperature	°C	27.43	27.19	26.84	26.49
ORP	mv	87	37	4	-18
Alkalinity	mg/l	46	11	4	4
NH_3-N	μg/l	1371	260	91	80
NO_x-N	μg/l	17	11	20	17
Diss. Organic N	μg/l	258	172	159	172
Total N	μg/l	1645	443	271	269
Ortho-P	μg/l	44	32	42	25
Diss. Organic P	μg/l	4	3	3	3
Total P	μg/l	48	35	45	28
Chloride	mg/l	17.7	15.7	16.8	18.3
BOD	mg/l	3.2	3.2	3.5	4.6
Cadmium	μg/l	< 0.5	< 0.5	< 0.5	< 0.5
Chromium	μg/l	1.6	1.7	1.3	1.5
Copper	μg/l	3.2	4.8	2.8	3.5
Lead	μg/l	< 2	< 2	< 2	2.2
Iron	μg/l	375	840	856	967
Zinc	μg/l	1.3	1.0	1.2	1.2
No. of Samples	--	6	6	6	6

species present was clearly orthophosphorus, contributing 90% or more of the total phosphorous measured at each sample port. Mean concentrations of both chloride and BOD were also relatively consistent at each of the four sample ports.

With the exception of iron, no tendency for increasing or decreasing concentrations of measured heavy metals was observed at the four sample ports. In general, measured concentrations of heavy metals in the upgradient groundwater well were extremely low at all sample ports, with mean concentrations of cadmium, chromium, lead and zinc equal to or less than 2 μg/l at all sample ports.

4.6.2 Groundwater Characteristics at the Pond Monitoring Site

Mean water quality characteristics in the pond monitoring well are summarized in Table 4-20. Unlike trends observed in upgradient groundwater samples, mean concentrations of pH and specific conductivity do not exhibit a tendency for rapidly decreasing values with increasing groundwater depth in groundwater beneath the pond. Mean pH levels beneath the pond at the four sample ports were approximately neutral in value and substantially greater than pH values measured at the upgradient site. Similarly, mean concentrations of specific conductivity were also substantially greater beneath the pond than in the upgradient area. Mean values of redox potential were also found to be substantially greater beneath the pond than in upgradient samples, with oxidized conditions extending to a depth of 0.5 m below the pond and mildly reduced conditions at 1.0 m and 2.5 m depths. Mean alkalinity was also relatively consistent at each of the four sample ports with values ranging from 100 mg/l to 119 mg/l, compared with mean values ranging from 4 mg/l to 46 mg/l in the upgradient area.

In contrast to the trend of decreasing concentrations of total nitrogen with increasing groundwater depth observed in the upgradient area, mean concentrations of total nitrogen beneath the pond increased slightly with increasing groundwater depth. The dominant nitrogen species at all sample depths was clearly ammonia nitrogen, contributing 64-74% of the total nitrogen measured at each sample port. Mean measured concentrations of NO_x nitrogen, however, were extremely low in groundwater beneath the pond.

Mean groundwater concentrations of total phosphorus beneath the pond did not exhibit a clear trend of either decreasing or increasing concentrations with increasing groundwater depth. At most of the sample ports, orthophosphorus was the dominant phosphorus species contributing approximately 50% or more of the total phosphorus measured. Mean concentrations of both chloride and BOD were relatively consistent in groundwater beneath the pond at the four sample ports.

Measured concentrations of all heavy metals, with the exception of iron, were found to be extremely low in value beneath the pond, although mean concentrations of copper and zinc appear to be somewhat higher beneath the pond than found in the

TABLE 4-20

MEAN WATER QUALITY CHARACTERISTICS IN THE POND WELL AT THE DEBARY DETENTION WITH FILTRATION SITE FROM JUNE-NOVEMBER 1992

PARAMETER	UNITS	MEAN CONCENTRATION BY PORT			
		0.1 m	0.5 m	1.0 m	2.5 m
pH	s.u.	6.87	6.94	6.86	6.79
Spec. Conductivity	µmho/cm	293	290	282	277
Temperature	°C	29.22	28.85	28.67	27.80
ORP	mv	222	206	174	142
Alkalinity	mg/l	119	108	110	100
NH_3-N	µg/l	623	803	845	859
NO_x-N	µg/l	46	15	11	22
Diss. Organic N	µg/l	307	374	288	348
Total N	µg/l	976	1192	1143	1228
Ortho-P	µg/l	34	17	5	29
Diss. Organic P	µg/l	12	16	7	14
Total P	µg/l	46	33	12	43
Chloride	mg/l	15.5	15.5	14.7	14.3
BOD	mg/l	5.2	5.5	5.7	8.0
Cadmium	µg/l	< 0.5	< 0.5	< 0.5	< 0.5
Chromium	µg/l	1.0	1.0	1.3	1.2
Copper	µg/l	5.5	5.7	4.3	5.8
Lead	µg/l	< 2	< 2	< 2	< 2
Iron	µg/l	241	158	305	1943
Zinc	µg/l	4.6	2.3	1.6	1.9
No. of Samples	--	6	6	6	6

upgradient area. Nevertheless, with the exception of iron, mean concentrations of cadmium, chromium, copper, lead and zinc were equal to approximately 5 μg/l or less at each of the four sample ports.

4.6.3 Groundwater Characteristics at the Downgradient Monitoring Site

A summary of mean water quality characteristics measured at the downgradient monitoring well is given in Table 4-21. Mean characteristics for many parameters in the downgradient area are similar to those measured in the pond. Mean measured values of pH and specific conductivity in the downgradient well are slightly lower than those measured in the pond well but exhibit similar trends with respect to increasing groundwater depth. Based on mean redox potentials, groundwater at the 0.1 m and 0.5 m sample ports is oxidized, but slightly reduced at the 1.0 m and 2.5 m depths. Mean values for each of these parameters are substantially higher than mean values found in the upgradient monitoring well.

Mean values for total nitrogen at the four sample ports are somewhat lower than total nitrogen found beneath the pond and exhibit a clear tendency for decreasing concentration with increasing groundwater depth. The dominant nitrogen species at each sample port is ammonia nitrogen, contributing 52-58% of the total nitrogen measured at each sample port. Groundwater concentrations of nitrate nitrogen were found to be extremely low at each sample port, with measurements below detectable limits at depths of 0.5 m and greater.

The measured concentrations of total phosphorus at the downgradient monitoring site are similar to those observed in upgradient and pond sites, although a trend for increasing concentrations of total phosphorus with increasing groundwater depth is apparent. Orthophosphorus is the dominant phosphorus species present in groundwater at the downgradient site comprising 55-86% of the total phosphorus present. Relatively little variation is present in measured concentrations of chloride and BOD at the four sample ports.

With the exception of iron, measured concentrations of heavy metals at each of the four sample ports were relatively low in the downgradient area. Mean concentrations of cadmium, chromium and zinc are equal to approximately 3 μg/l or less with copper equal to approximately 6 μg/l or less.

4.6.4 Comparison of Groundwater Characteristics in Pond, Upgradient and Downgradient Areas

An analysis of variance comparison of groundwater characteristics in the top 1 m of pond, upgradient and downgradient monitoring wells is given in Table 4-22. The 2.5 m sample ports were not included in this analysis, since several of these sample ports extended slightly into a dense clay layer. As a result, it is likely that the majority of

TABLE 4-21

MEAN WATER QUALITY CHARACTERISTICS IN THE DOWNGRADIENT WELL AT THE DEBARY DETENTION WITH FILTRATION SITE FROM JUNE-NOVEMBER 1992

PARAMETER	UNITS	MEAN CONCENTRATION BY PORT			
		0.1 m	0.5 m	1.0 m	2.5 m
pH	s.u.	6.16	6.30	6.05	6.01
Spec. Conductivity	μmho/cm	240	227	180	179
Temperature	°C	27.46	27.17	26.85	25.97
ORP	mv	312	221	182	129
Alkalinity	mg/l	90	76	60	57
NH_3-N	μg/l	395	362	375	286
NO_x-N	μg/l	47	< 10	< 10	< 10
Diss. Organic N	μg/l	291	277	255	257
Total N	μg/l	728	639	633	548
Ortho-P	μg/l	11	17	28	37
Diss. Organic P	μg/l	9	10	7	6
Total P	μg/l	20	26	35	43
Chloride	mg/l	16	14	13	13
BOD	mg/l	4.1	3.5	3.2	3.2
Cadmium	μg/l	< 0.5	< 0.5	< 0.5	< 0.5
Chromium	μg/l	1.3	1.3	1.7	1.3
Copper	μg/l	4.7	4.7	6.3	4.8
Lead	μg/l	2.0	< 2	3.8	7.2
Iron	μg/l	568	6240	4397	5662
Zinc	μg/l	1.7	3.2	3.7	2.2
No. of Samples	--	6	6	6	6

TABLE 4-22

ANOVA COMPARISON OF GROUNDWATER CHARACTERISTICS IN THE TOP 1 m OF POND, UPGRADIENT AND DOWNGRADIENT MONITORING WELLS AT THE DEBARY DETENTION WITH FILTRATION SITE

PARAMETER	UNITS	WELL SITE[1]	MEAN VALUE	TUKEY'S MULTIPLE COMPARISON	NO. OF OBS.	PROB. OF UNEQUAL MEANS
pH	s.u.	Pond	6.89	A	18	99.9
		Down	6.17	B	15	
		Up	5.13	C	18	
Spec. Cond.	μmho/cm	Pond	288	A	18	99.9
		Down	211	B	15	
		Up	127	C	18	
Temperature	°C	Pond	28.91	A	18	99.9
		Up	27.15	B	18	
		Down	27.10	B	15	
ORP	mv	Down	223	A	15	99.9
		Pond	201	A	18	
		Up	42	B	18	
Alkalinity	mg/l	Pond	112	A	18	99.9
		Down	72.3	B	15	
		Up	20.4	C	18	
NH_3-N	μg/l	Pond	757	NSD[2]	18	89.4
		Up	574		18	
		Down	374		15	
NO_x-N	μg/l	Pond	24	NSD	18	54.3
		Up	16		18	
		Down	14		15	
Diss. Organic N	μg/l	Pond	323	A	18	98.2
		Down	271	A	15	
		Up	196	B	18	
Total N	μg/l	Pond	1104	NSD	18	94.0
		Up	786		18	
		Down	654		15	
Ortho-P	μg/l	Up	40	A	18	99.9
		Down	20	B	15	
		Pond	18	B	18	
Diss. Organic P	μg/l	Pond	12	A	18	98.7
		Down	8	A	15	
		Up	3	B	18	

TABLE 4-22

ANOVA COMPARISON OF GROUNDWATER CHARACTERISTICS IN THE TOP 1 m OF POND, UPGRADIENT AND DOWNGRADIENT MONITORING WELLS AT THE DEBARY DETENTION WITH FILTRATION SITE

-- Page Two --

PARAMETER	UNITS	WELL SITE[1]	MEAN VALUE	TUKEY'S MULTIPLE COMPARISON	NO. OF OBS.	PROB. OF UNEQUAL MEANS
Total P	µg/l	Up	43	NSD	18	94.7
		Pond	30		18	
		Down	28		15	
Turbidity	NTU	Up	105	A	18	99.9
		Down	48.6	B	15	
		Pond	6.4	B	18	
Chloride	mg/l	Up	16.7	NSD	18	66.2
		Pond	15.2		18	
		Down	13.9		15	
BOD	mg/l	Pond	5.5	A	18	97.7
		Down	3.5	B	15	
		Up	3.3	B	18	
Cadmium	µg/l	Pond	0.29	NSD	18	70.4
		Down	0.27		15	
		Up	0.25		18	
Chromium	µg/l	Up	1.5	NSD	18	94.4
		Down	1.5		15	
		Pond	1.1		18	
Copper	µg/l	Down	5.3	NSD	15	86.4
		Pond	5.2		18	
		Up	3.6		18	
Iron	µg/l	Down	4368	A	15	99.9
		Up	690	B	18	
		Pond	234	B	18	
Lead	µg/l	Down	2.6	A	15	98.9
		Pond	1.6	A	18	
		Up	1.2	B	18	
Zinc	µg/l	Down	3.1	NSD	15	92.9
		Pond	2.8		18	
		Up	1.2		18	

1. Monitoring Well Designations:

UP -	Upgradient monitoring well
DOWN -	Downgradient monitoring well
POND -	Pond monitoring well

2. NSD - No significant difference in mean values at the 0.05 level of significance

groundwater movement in the vicinity of the research site is reflected in groundwater samples monitored at the 0.1, 0.5 and 1.0 m sample depths.

The comparison presented in Table 4-22 consists of an analysis of variance test, conducted using PROC GLM of SAS, to evaluate if significant differences exist between measured groundwater concentrations in upgradient, downgradient and pond areas. If significant differences are found to exist, then Tukey's multiple comparison technique is used to evaluate where the significant differences may exist. This multiple comparison technique computes the mean values for each of the three well sites and groups the sites according to statistically significant differences. Mean values are represented by different letters under the column titled "Tukey's Multiple Comparison" in Table 4-22 were found to be statistically different at the 0.05 level of significance. The probability of unequal means is also listed in the final column of Table 4-22 to provide an indication of the strength of differences between the mean values.

Multiple comparisons presented in Table 4-22 suggest that the pond is having a significant effect on groundwater characteristics in the downgradient area compared with characteristics found in upgradient areas. Mean values for pH, specific conductivity and alkalinity are significantly higher in pond and downgradient areas than found in upgradient groundwater. In addition, groundwater in pond and downgradient areas was found to have significantly higher levels of dissolved organic nitrogen, dissolved organic phosphorus and total lead than found in upgradient areas. In contrast, pond and downgradient areas were found to have significantly lower levels of orthophosphorus and turbidity than measured in upgradient groundwater. No significant differences were found between groundwater concentrations of ammonia, nitrate, total nitrogen, total phosphorus, chloride, cadmium, chromium, copper or zinc at the 0.05 level of significance.

In summary, groundwater characteristics in downgradient areas is similar to groundwater measured beneath the pond. It appears that the pond is causing increases in groundwater concentrations of pH, specific conductivity, redox potential, dissolved organic nitrogen, dissolved organic phosphorus and lead in groundwater compared with characteristics found in upgradient monitoring wells.

4.6.5 Effects of Detention Pond Characteristics on Underlying Groundwater Quality

An analysis of variance comparison was also conducted to evaluate the effects of the detention pond on groundwater immediately beneath the pond. The analysis of variance procedure compared mean characteristics for each of the measured parameters at each of the four sample depths beneath the pond. A summary of the results from the analysis of variance procedure is given in Table 4-23. No significant differences were detected at the 0.05 level of significance for mean groundwater concentrations measured at the four sample port depths beneath the detention pond. This comparison provides

TABLE 4-23

ANOVA COMPARISON OF WATER QUALITY CHARACTERISTICS IN THE POND MULTIPORT MONITORING WELL AT THE DEBARY DETENTION WITH FILTRATION SITE

PARAMETER	UNITS	SAMPLE PORT DEPTH (m)	MEAN VALUE	TUKEY'S MULTIPLE COMPARISON	PROBABILITY OF UNEQUAL MEANS
pH	s.u.	0.5	6.94	NSD[1]	5.6
		0.1	6.87		
		1.0	6.83		
		2.5	6.79		
Spec. Cond.	μmho/cm	0.1	293	NSD	15.5
		0.5	290		
		1.0	282		
		2.5	277		
Temperature	°C	0.1	29.22	NSD	33.1
		0.5	28.85		
		1.0	28.67		
		2.5	27.80		
ORP	mv	0.1	222	NSD	46.3
		0.5	206		
		1.0	174		
		2.5	142		
Alkalinity	mg/l	0.1	119	NSD	49.7
		1.0	110		
		0.5	108		
		2.5	100		
NH_3-N	μg/l	2.5	859	NSD	8.4
		1.0	845		
		0.5	803		
		0.1	623		
NO_x-N	μg/l	0.1	46	NSD	82.9
		2.5	22		
		0.5	15		
		1.0	11		

TABLE 4-23

ANOVA COMPARISON OF WATER QUALITY CHARACTERISTICS IN THE POND MULTIPORT MONITORING WELL AT THE DEBARY DETENTION WITH FILTRATION SITE

--Page Two--

PARAMETER	UNITS	SAMPLE PORT DEPTH (m)	MEAN VALUE	TUKEY'S MULTIPLE COMPARISON	PROBABILITY OF UNEQUAL MEANS
Diss. Organic N	µg/l	0.5 2.5 0.1 1.0	374 348 307 288	NSD	42.7
Total N	µg/l	2.5 0.5 1.0 0.1	1228 1192 1143 976	NSD	8.0
Ortho-P	µg/l	0.1 2.5 0.5 1.0	34 29 17 5	NSD	70.4
Diss. Organic P	µg/l	0.5 2.5 0.1 1.0	16 14 2 7	NSD	37.6
Total P	µg/l	0.1 2.5 0.5 1.0	46 43 33 12	NSD	79.6
Turbidity	NTU	2.5 0.1 0.5 1.0	9.0 8.9 5.6 4.7	NSD	49.4
Chloride	mg/l	0.1 0.5 1.0 2.5	15.5 15.5 14.6 14.3	NSD	3.7

TABLE 4-23

ANOVA COMPARISON OF WATER QUALITY CHARACTERISTICS IN THE POND MULTIPORT MONITORING WELL AT THE DEBARY DETENTION WITH FILTRATION SITE

--Page Three--

PARAMETER	UNITS	SAMPLE PORT DEPTH (m)	MEAN VALUE	TUKEY'S MULTIPLE COMPARISON	PROBABILITY OF UNEQUAL MEANS
BOD	mg/l	2.5 1.0 0.5 0.1	8.0 5.7 5.5 5.2	NSD	28.5
Cadmium	μg/l	0.5 0.1 1.0 2.5	0.38 0.25 0.25 0.25	NSD	90.6
Chromium	μg/l	1.0 2.5 0.1 0.5	1.3 1.2 1.0 1.0	NSD	19.5
Copper	μg/l	2.5 0.5 0.1 1.0	5.8 5.7 5.5 4.3	NSD	8.2
Iron	μg/l	2.5 1.0 0.1 0.5	1943 305 241 158	NSD	91.2
Lead	μg/l	1.0 0.5 2.5 0.1	1.8 1.8 1.3 1.2	NSD	53.9
Zinc	μg/l	0.1 0.5 2.5 1.0	4.6 2.3 1.9 1.6	NSD	71.1

1. NSD: No significant difference at the 0.05 level of significance

evidence that significant vertical variability does not exist for groundwater characteristics in the vicinity of the pond, although horizontal migration of groundwater and effects on downgradient areas is apparent in the previous analysis.

4.7 Characteristics of Sediment Samples Collected at the DeBary Research Site

As discussed in Chapter 3, sediment sampling was conducted within the detention pond, in control areas and within the filter media to quantify the fate of stormwater pollutants within the detention with filtration system. Sediment sampling was conducted to define both the horizontal and vertical migration of runoff-related pollutants within the detention pond. A summary of experimental results is given in the following sections.

4.7.1 Horizontal Migration of Runoff-Related Pollutants

A total of 28 separate sediment core samples were collected within the pond in the grid pattern indicated in Figure 3-7. The 0-1 cm sediment layer for each of these sample locations was analyzed separately to evaluate the horizontal distribution of nutrients and heavy metals within the pond. A summary of physical and chemical characteristics measured in the 0-1 cm sediment core samples is given in Table 4-24. This information was entered into a SAS data file, and concentration isopleths were plotted for each of the parameters listed in Table 4-24. These isopleths illustrate the horizontal distribution for each measured parameter upon entering the detention pond. This information is valuable in evaluating depositional patterns which assist in evaluating system designs to maximize retention of pollutants within a stormwater management system.

Horizontal distributions of moisture content and organic content in the 0-1 cm layer in sediments in the DeBary detention pond are shown in Figure 4-6. The pond perimeter line indicated in this diagram represents the measured average water level of 56.14 ft (17.12 m). Sediment moisture content in the 0-1 cm layer ranged from 19.3% on the east end of the pond to a maximum of 90.5% near the center of the pond. Sediment moisture content in the sediments is highest in value near the center of the pond with rapidly decreasing concentrations toward each side of the pond.

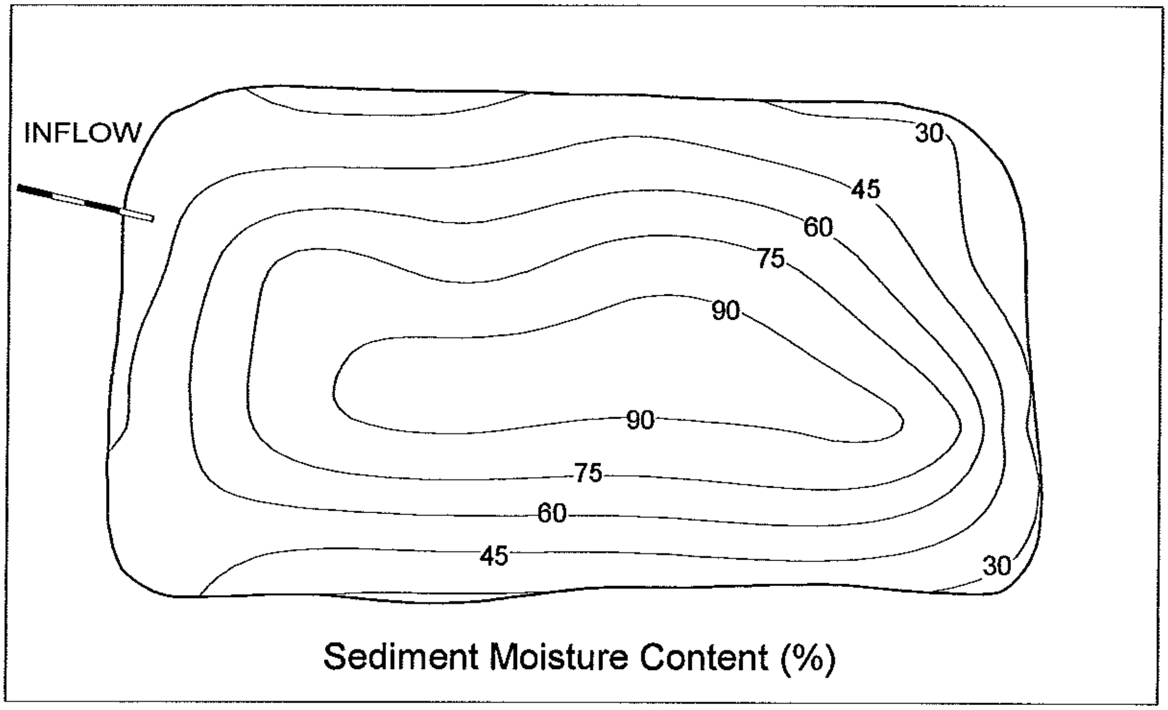
Sediment organic content within the pond ranged from a low of 0.4% on the east end of the pond to a maximum of 23.3% near the center. Accumulation patterns for organic content in the sediments are similar to those observed for moisture content with highest concentrations located near the center and rapidly decreasing concentrations located near the edges.

Horizontal distributions for total nitrogen and total phosphorus in the 0-1 cm sediment layer are indicated in Figure 4-7. Attenuation patterns for both nitrogen and phosphorus appear to be very similar within the detention pond. Sediment concentrations

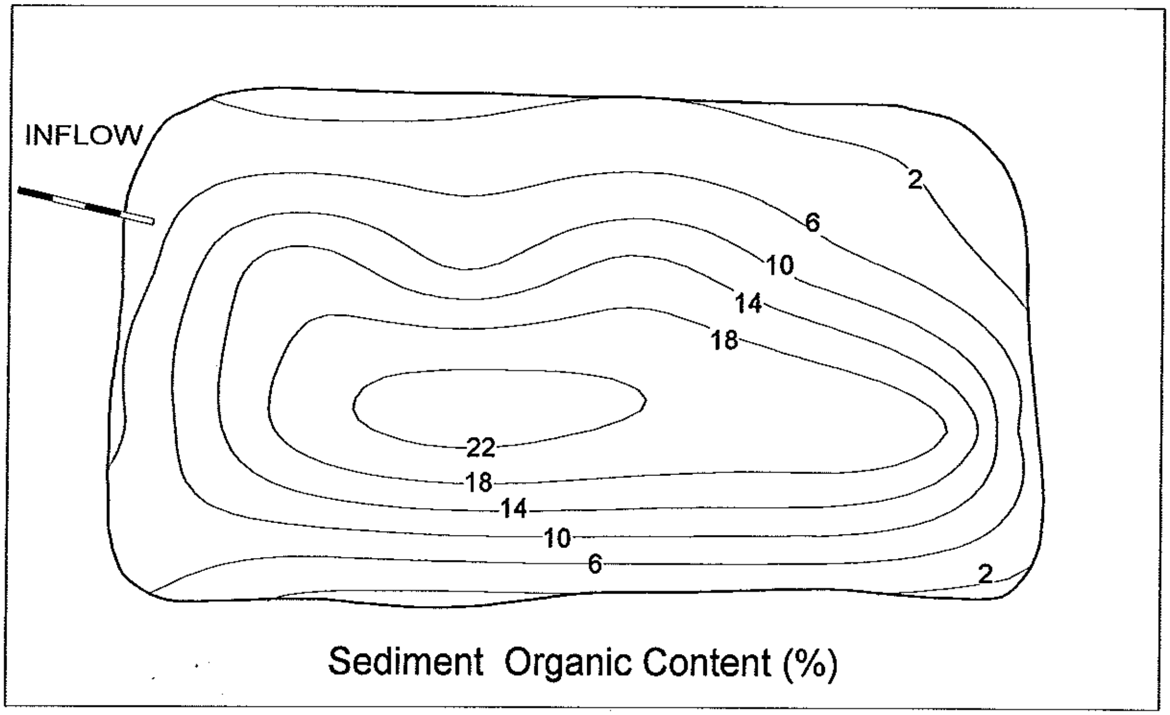
TABLE 4-24

CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED FROM THE 0-1 cm LAYER IN THE DEBARY DETENTION WITH FILTRATION POND

SAMPLE LOCATION	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	SEDIMENT CONCENTRATION (μg/g Wet Weight)									
			N	P	Al	Cu	Cd	Cr	Fe	Mn	Pb	Zn
1-1	55.8	6.8	771	88	2.01	1.58	0.16	0.69	193	0.79	7.69	8.08
1-2	40.9	4.4	668	79	1.76	1.49	0.08	1.49	250	0.68	5.95	4.74
1-3	29.8	1.7	322	49	1.00	1.66	0.00	2.27	141	0.61	4.24	2.42
1-4	36.9	2.5	427	149	1.30	2.29	0.11	2.90	326	2.14	9.93	12.80
2-1	28.8	1.5	200	42	1.16	1.21	0.02	0.00	134	0.69	4.86	1.55
2-2	83.7	19.2	1009	323	3.34	3.21	0.29	5.32	649	3.50	16.20	33.10
2-3	81.6	17.2	988	323	2.89	3.59	0.33	6.01	648	4.98	15.40	39.00
2-4	27.4	0.9	197	166	1.16	2.42	0.40	0.69	295	3.63	5.53	4.67
3-1	30.0	1.6	286	72	1.74	1.33	0.10	0.00	239	0.66	3.98	1.99
3-2	90.5	23.3	644	196	3.58	2.18	0.17	4.42	548	1.69	10.10	20.90
3-3	63.9	7.4	842	339	3.36	4.74	0.47	8.61	754	6.00	18.10	38.80
3-4	28.0	1.4	212	146	6.05	2.09	0.10	4.99	573	3.70	4.99	4.67
4-1	28.3	1.8	217	69	3.27	1.53	0.10	3.05	408	1.36	2.04	2.71
4-2	85.9	21.2	912	278	3.52	3.20	0.28	5.68	573	3.79	14.00	33.20
4-3	83.3	15.7	825	313	3.78	3.71	0.31	6.62	594	4.65	15.60	36.00
4-4	40.0	2.7	402	125	6.44	2.02	0.09	6.06	732	3.46	7.07	6.93
5-1	31.6	1.7	266	117	4.23	1.70	0.12	3.56	787	2.94	5.73	6.20
5-2	87.6	19.5	733	282	3.60	3.15	0.28	5.80	535	3.49	16.30	31.90
5-3	72.7	7.6	672	285	3.26	2.91	0.24	5.75	570	4.48	12.10	24.60
5-4	28.0	1.0	176	53	1.23	1.41	0.14	1.58	271	1.41	2.99	1.94
6-1	24.8	0.4	67	31	0.77	1.10	0.22	0.18	197	1.48	2.92	0.00
6-2	89.7	20.4	671	278	2.98	2.79	0.24	4.98	460	3.24	12.80	27.40
6-3	72.7	7.6	987	313	9.51	11.30	1.00	19.20	1853	16.50	43.10	119.00
6-4	27.7	0.7	223	51	0.43	1.12	0.30	0.48	130	1.28	4.33	1.60
7-1	25.2	1.0	133	47	0.65	1.23	0.26	1.58	194	1.06	4.58	0.53
7-2	21.5	1.4	337	77	1.18	2.37	0.20	1.46	299	2.37	7.29	4.37
7-3	19.3	0.9	183	73	0.89	1.89	0.15	0.52	182	1.55	4.99	1.35
7-4	24.5	0.5	152	37	0.36	1.42	0.20	0.12	90	0.71	4.80	0.53

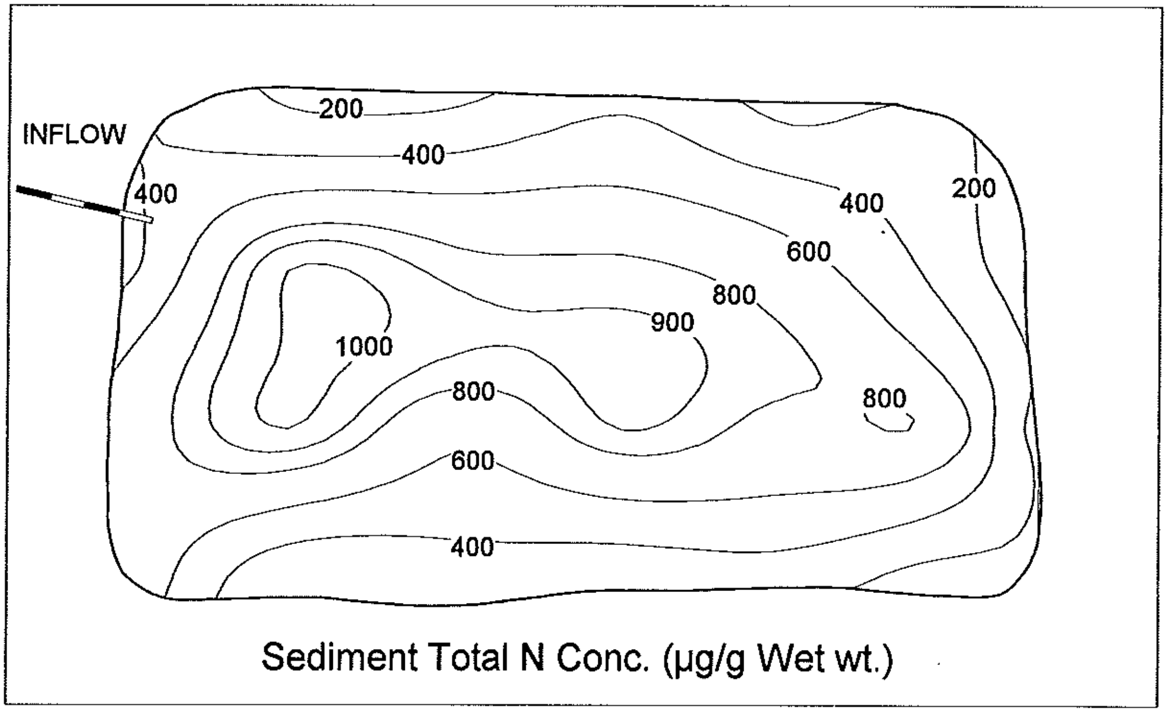


Sediment Moisture Content (%)



Sediment Organic Content (%)

Figure 4-6. Horizontal Distribution of Moisture and Organic Content in the 0-1 cm Layer of Sediment in the DeBary Detention with Filtration Pond.



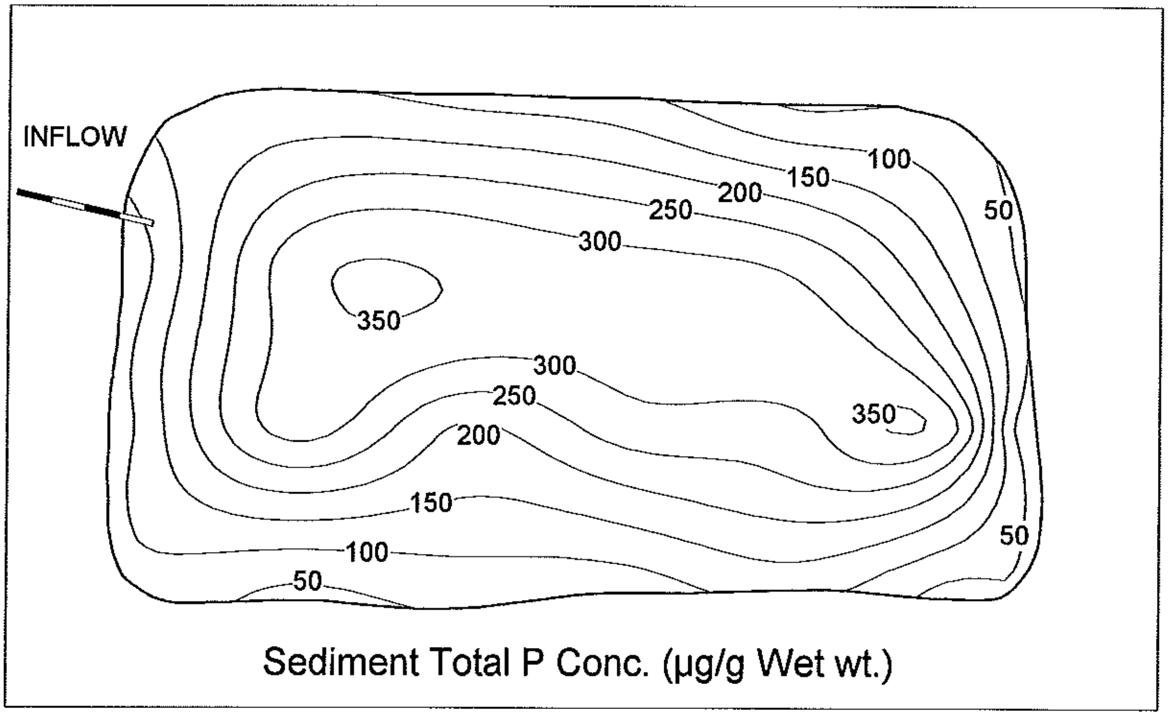


Figure 4-7. Horizontal Distribution of Total Nitrogen and Total Phosphorus in the 0-1 cm Layer of Sediment in the DeBary Detention with Filtration Pond.

of both parameters increase rapidly upon entering the detention pond with maximum sediment concentrations reached at a distance of approximately 15 m (50 ft) from the point of inflow into the pond. Sediment concentrations decrease after this maximum point with continued gradual settling occurring over much of the detention basin bottom.

Horizontal distributions of cadmium and chromium in the 0-1 cm layer are indicated in Figure 4-8. Sediment concentrations of both parameters reach a peak at a distance of approximately 20-25 m (55-80 ft) from the point of inflow. A gradual continued deposition of both parameters is evident throughout other portions of the pond.

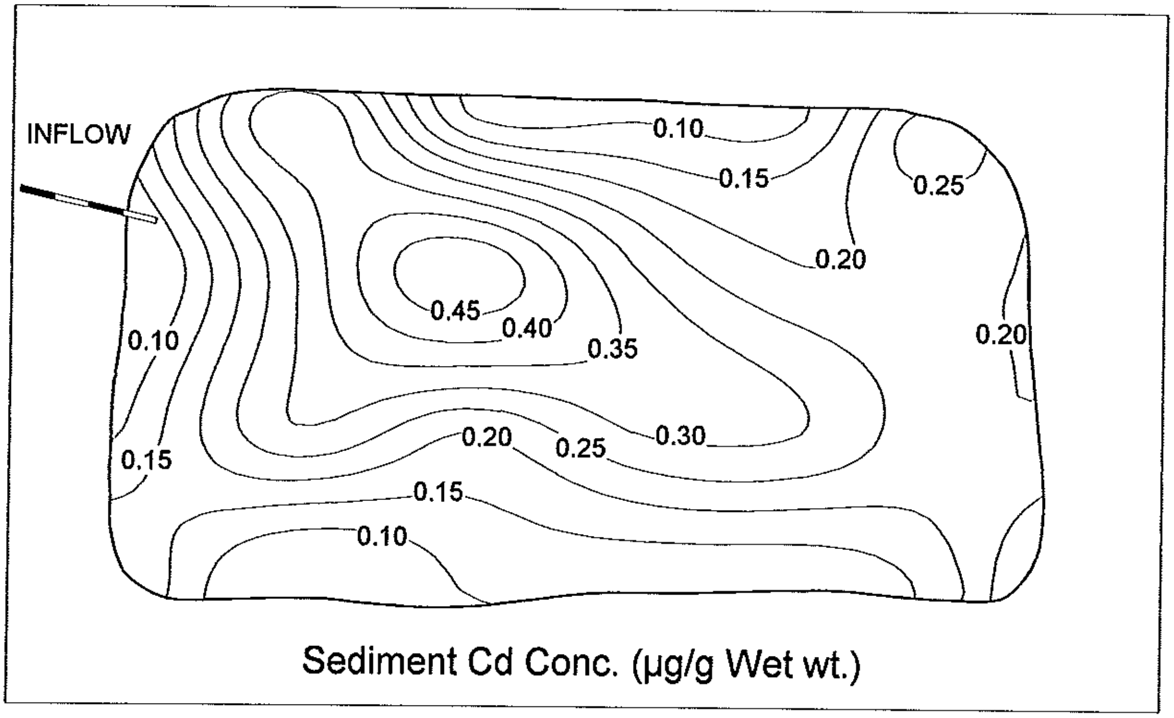
Distributions of lead and zinc in the 0-1 cm sediment layer are given in Figure 4-9. Settling patterns for lead and zinc in the detention pond are similar to those observed for cadmium and chromium with maximum deposition occurring at a distance of approximately 20 m (65 ft) from the point of inflow. A continued gradual deposition is apparent for each of these parameters throughout other portions of the pond.

Horizontal depositional patterns for copper and manganese in the 0-1 cm layer are shown in Figure 4-10. Depositional patterns for copper and manganese are similar to those for other heavy metals. The maximum point of sediment accumulation for both metals appeared to occur at a distance of 20-25 m (55-80 ft) from the point of inflow. Continued gradual sediment deposition is apparent into other areas of the pond.

Horizontal distributions of aluminum and iron in the 0-1 cm layer are shown in Figure 4-11. Depositional patterns for sediment aluminum appear to be somewhat different than those exhibited by other heavy metals. Highest sediment aluminum concentrations appear to occur along the north pond boundary near the shoreline. However, since aluminum is a major constituent of soils and sediments, this apparent depositional pattern may not be related to inputs from stormwater runoff. The distribution of sediment iron concentrations appears to be more similar to that exhibited by other heavy metals. However, the area of highest sediment concentrations for iron also appear to extend upward toward the north pond boundary. A second small area of elevated iron concentrations is also apparent in the southeast corner of the pond. Similar to aluminum, sediment iron concentrations may also be affected by characteristics of the soils used for construction of the detention pond.

Correlations between sediment characteristics and concentrations of nutrients and heavy metals in the 0-1 cm layer are given in Table 4-25. Pearson correlation coefficients are presented for each correlation pair along with the level of significance associated with each correlation coefficient.

All of the measured heavy metals and nutrients exhibited strong positive significant correlations at the 0.05 level with sediment moisture content. This relationship was particularly strong for total nitrogen and total phosphorus. These relationships indicate that heavy metals and nutrients within the pond sediments are associated with soils that retain high levels of moisture, such as fine grained soils. Sediment organic content was found to be significantly correlated with sediment



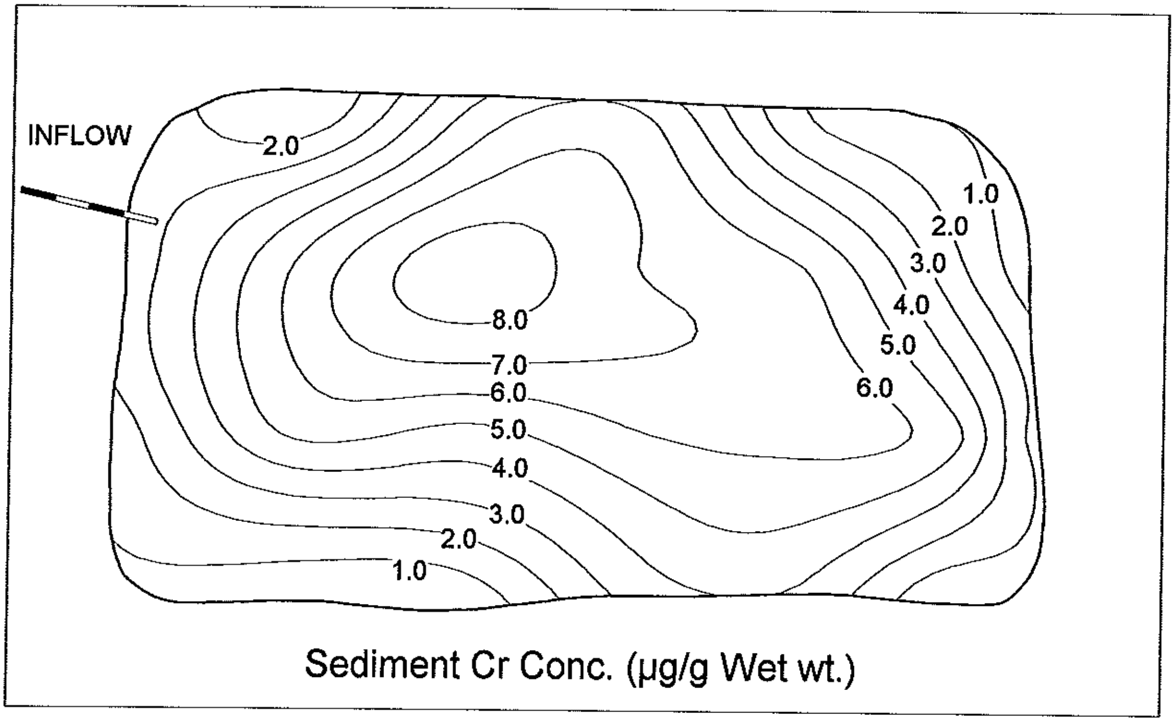
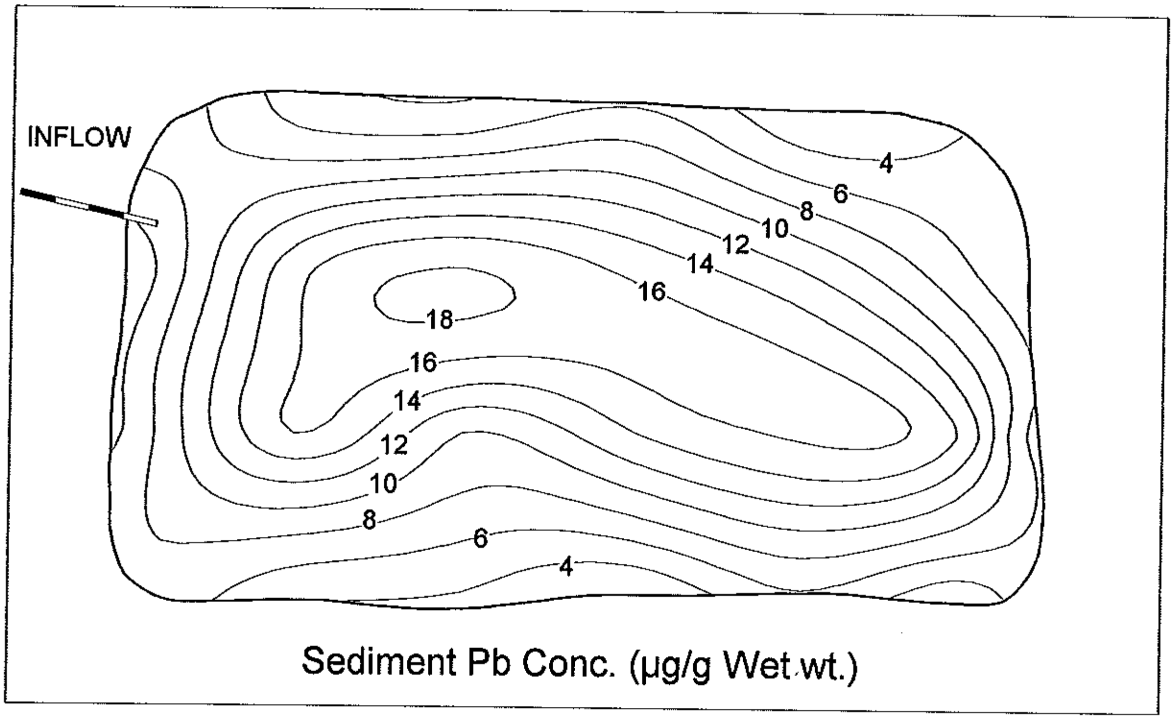
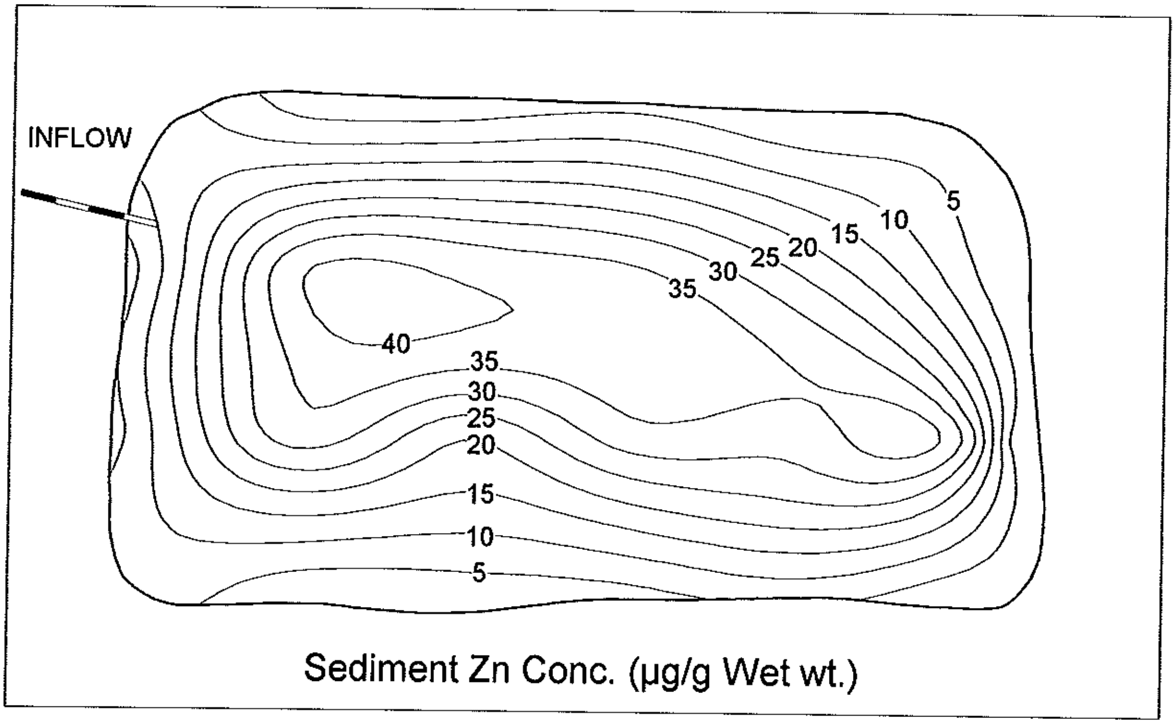


Figure 4-8. Horizontal Distribution of Cadmium and Chromium in the 0-1 cm Layer of Sediment in the DeBary Detention with Filtration Pond.

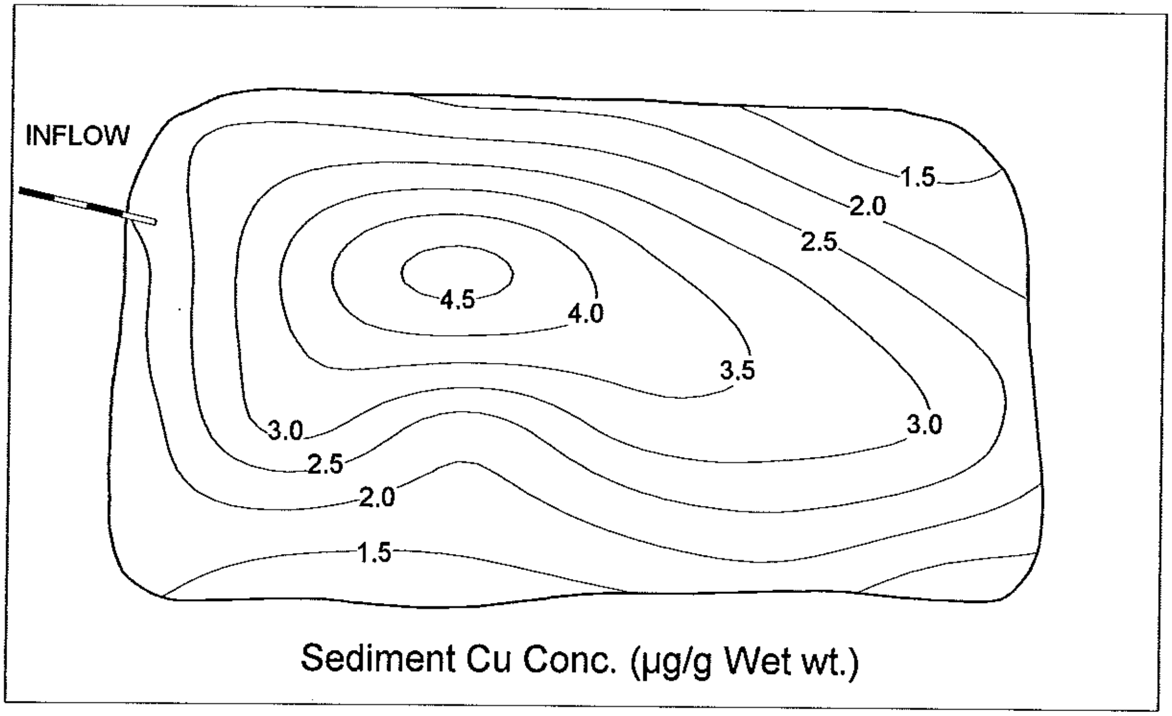


Sediment Pb Conc. (µg/g Wet wt.)



Sediment Zn Conc. (µg/g Wet wt.)

Figure 4-9. Horizontal Distribution of Lead and Zinc in the 0-1 cm Layer of Sediment in the DeBary Detention with Filtration Pond.



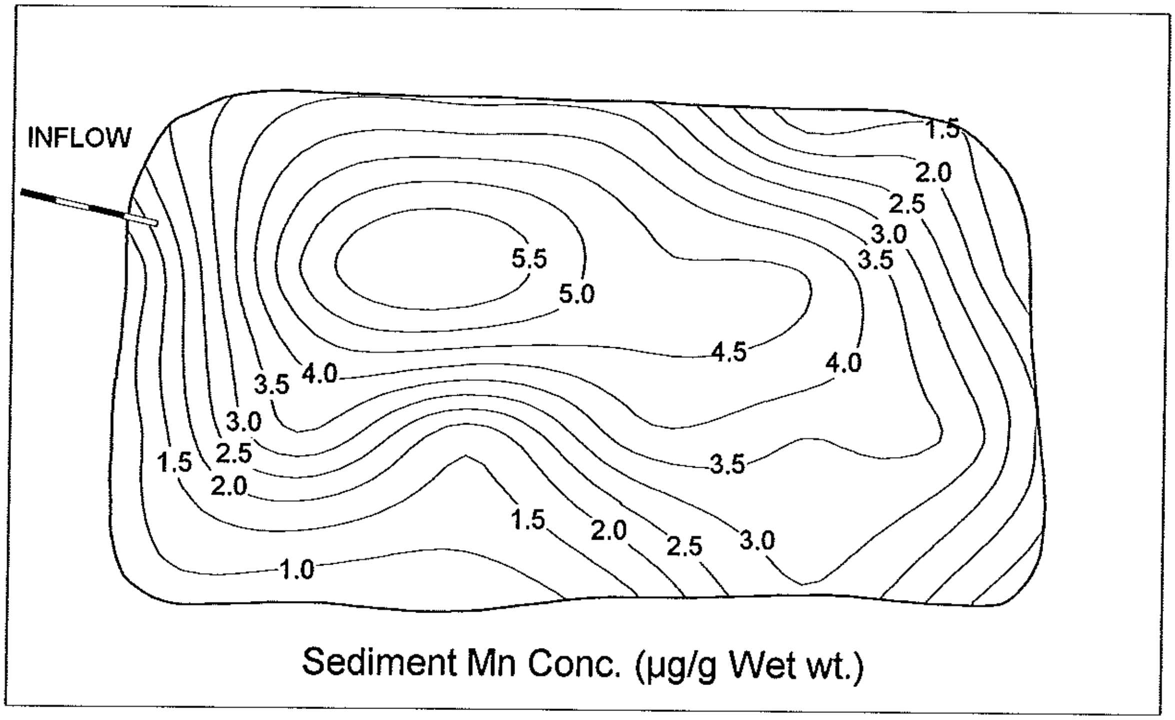
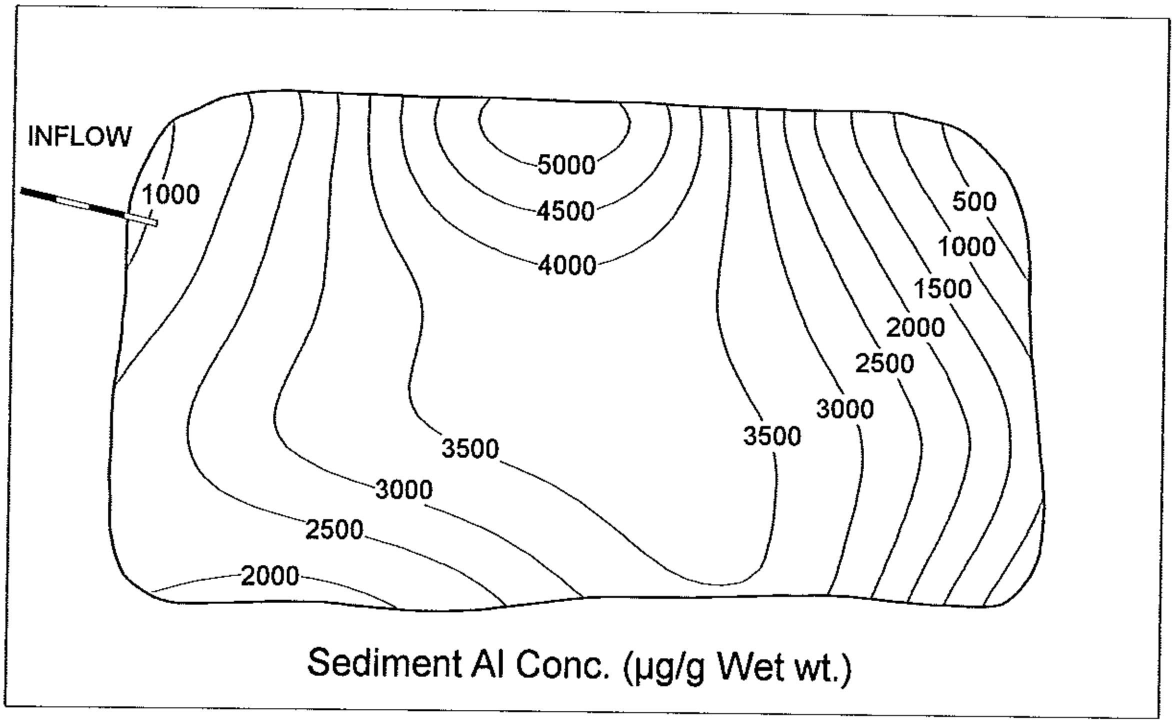


Figure 4-10. Horizontal Distribution of Copper and Manganese in the 0-1 cm Layer of Sediment in the DeBary Detention with Filtration Pond.



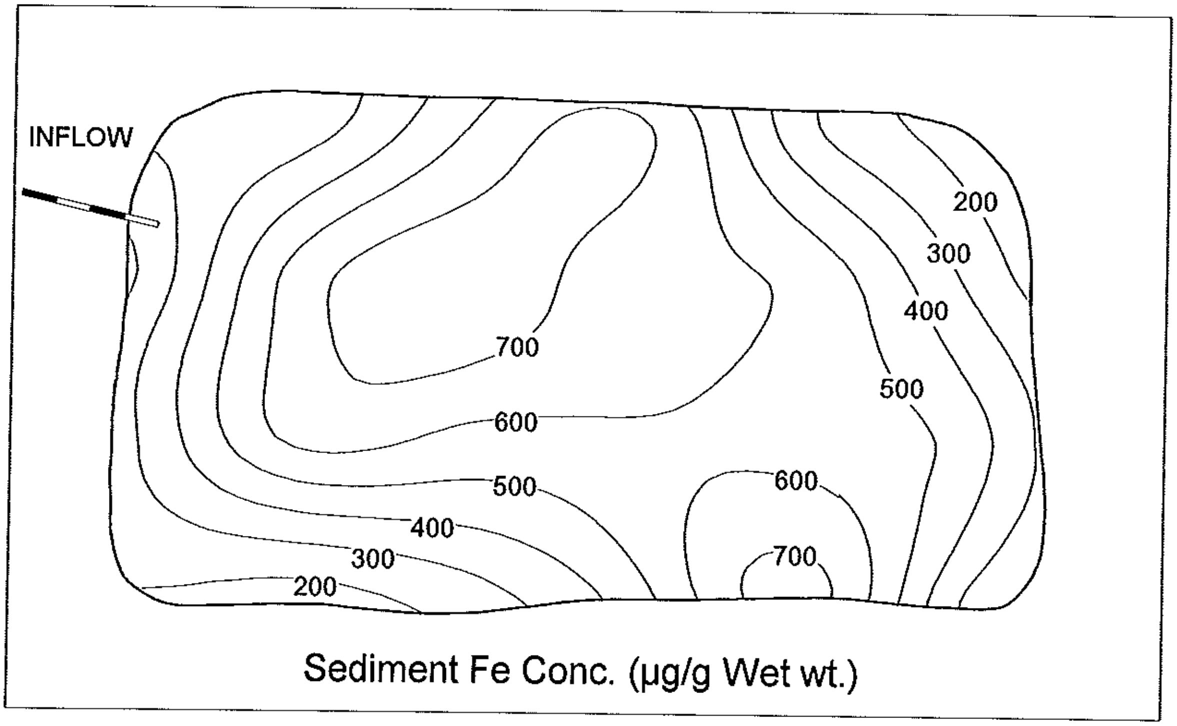


Figure 4-11. Horizontal Distribution of Aluminum and Iron in the 0-1 cm Layer of Sediment in the DeBary Detention with Filtration Pond.

TABLE 4-25

CORRELATIONS BETWEEN SEDIMENT CHARACTERISTICS AND SEDIMENT CONCENTRATIONS OF NUTRIENTS AND HEAVY METALS IN THE 0-1 cm LAYER OF THE DEBARY DETENTION POND

PARAMETER	PEARSON CORRELATION COEFFICIENT/ (LEVEL OF SIGNIFICANCE)	
	MOISTURE CONTENT	ORGANIC CONTENT
Aluminum	0.471 (0.011)	N.S.C.[1]
Copper	0.500 (0.007)	N.S.C.
Cadmium	0.430 (0.023)	N.S.C.
Chromium	0.608 (0.001)	0.405 (0.033)
Iron	0.522 (0.004)	N.S.C.
Manganese	0.453 (0.015)	N.S.C.
Lead	0.648 (0.002)	0.482 (0.009)
Zinc	0.654 (0.002)	0.488 (0.009)
Total Nitrogen	0.885 (0.001)	0.776 (0.001)
Total Phosphorus	0.878 (0.001)	0.755 (0.001)

1. N.S.C.: No significant correlation at the 0.05 level of significance

concentrations of chromium, lead, zinc, nitrogen and phosphorus. These relationships were particularly strong for total nitrogen and total phosphorus. These strong correlations suggest that organic complexes may be largely responsible for retaining sediment concentrations of heavy metals and nutrients within the pond sediments.

4.7.2 Vertical Characteristics of Soils and Sediments at the DeBary Research Site

Composite samples of soils and sediments were collected at the DeBary research site at the locations indicated in Figure 3-7 to evaluate the vertical attenuation of nutrients and heavy metals within the detention pond. Composite sediment samples were collected for the following six layers: 0-1 cm, 1-5 cm, 5-10 cm, 10-15 cm, 15-25 cm and 25-50 cm. Composite samples within the pond were formed by combining triplicate samples collected at each of the 28 sample locations indicated in Figure 3-7 by layer to form the six composite samples indicated previously. Control sediment core samples were collected along the south boundary of the detention pond site in an area undisturbed by construction activities for the pond. Triplicate soil samples were collected at each of the three sample sites and combined together by layer to form a composite sample for each of the six sediment layers. Each of the pond and control sediment layers were analyzed for moisture content, organic content, nutrients and heavy metals as well as grain size distribution. Chemical characteristics of vertical composite core samples collected in pond and control areas at the DeBary research site are summarized in Table 4-26.

A comparison of sediment concentrations of moisture content, organic content, total nitrogen and total phosphorus in the top 50 cm of pond and control areas at the DeBary research site is given in Figure 4-12. In general, sediment concentrations of these parameters appear to be highest in value near the surface with decreasing concentrations with increasing sediment or soil depth. The general pattern of decreasing concentrations with increasing depth appears to be logarithmic in nature for most parameters.

Measured sediment concentrations for moisture content and total phosphorus appear to be greater at all depths in pond sediments than found in the control area. It appears that the pond sediments are retaining total phosphorus in concentrations in excess of that present in undisturbed soils at the pond site. In contrast, measured concentrations for organic content and total nitrogen were found to be higher in value in the top 10 cm of the control area than within the pond. Measured concentrations of these parameters at depths in excess of 10 cm are similar in pond and control areas. This behavior suggests that, particularly for total nitrogen, retention within the pond sediments may be low.

A comparison of sediment concentrations of cadmium, copper, lead and zinc in pond and control sediments is given in Figure 4-13. With the possible exception of zinc, sediment concentrations of cadmium, copper and lead are higher in value at all measured depths than found in the control area. Sediment concentrations of zinc in the 0-1 cm layer appear to be substantially higher in the control area than within the pond. This

TABLE 4-26

CHARACTERISTICS OF VERTICAL COMPOSITE CORE SAMPLES COLLECTED IN POND AND CONTROL AREAS AT THE DEBARY RESEARCH SITE

SITE	SAMPLE LAYER (cm)	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	SEDIMENT CONCENTRATION (μg/g Wet Weight)									
				N	P	Al	Cu	Cd	Cr	Fe	Mn	Pb	Zn
Pond	0-1	48.6	6.8	483	157	2694	2.52	0.23	3.71	451	2.96	9.56	16.8
	1-5	34.4	2.5	337	131	4030	2.05	0.24	3.93	641	2.87	9.60	7.08
	5-10	26.7	2.7	211	104	5260	2.38	0.19	4.77	664	2.21	8.51	3.41
	10-15	20.0	1.8	97	77	8220	2.05	0.17	7.27	732	1.49	6.90	0.50
	15-25	18.4	2.0	70	67	11400	2.10	0.19	8.00	803	1.14	7.05	0.38
	25-50	19.9	1.9	56	58	10900	2.09	0.23	7.40	714	1.14	7.59	0.19
Control	0-1	12.2	9.0	1839	118	1510	2.56	0.14	0.08	388	9.28	3.09	64.00
	1-5	2.8	17.6	501	79	2080	1.49	0.13	0.78	519	2.55	2.48	10.60
	5-10	9.0	1.8	0	80	3210	1.85	0.04	1.50	561	2.20	2.29	2.64
	10-15	7.6	1.1	186	70	2610	1.63	0.04	1.63	423	2.83	1.97	1.63
	15-25	8.5	1.1	0	59	2070	1.06	0.23	1.44	343	2.42	1.82	1.97
	25-50	6.9	1.0	0	28	1120	1.07	0.08	0.87	268	2.00	1.26	3.73

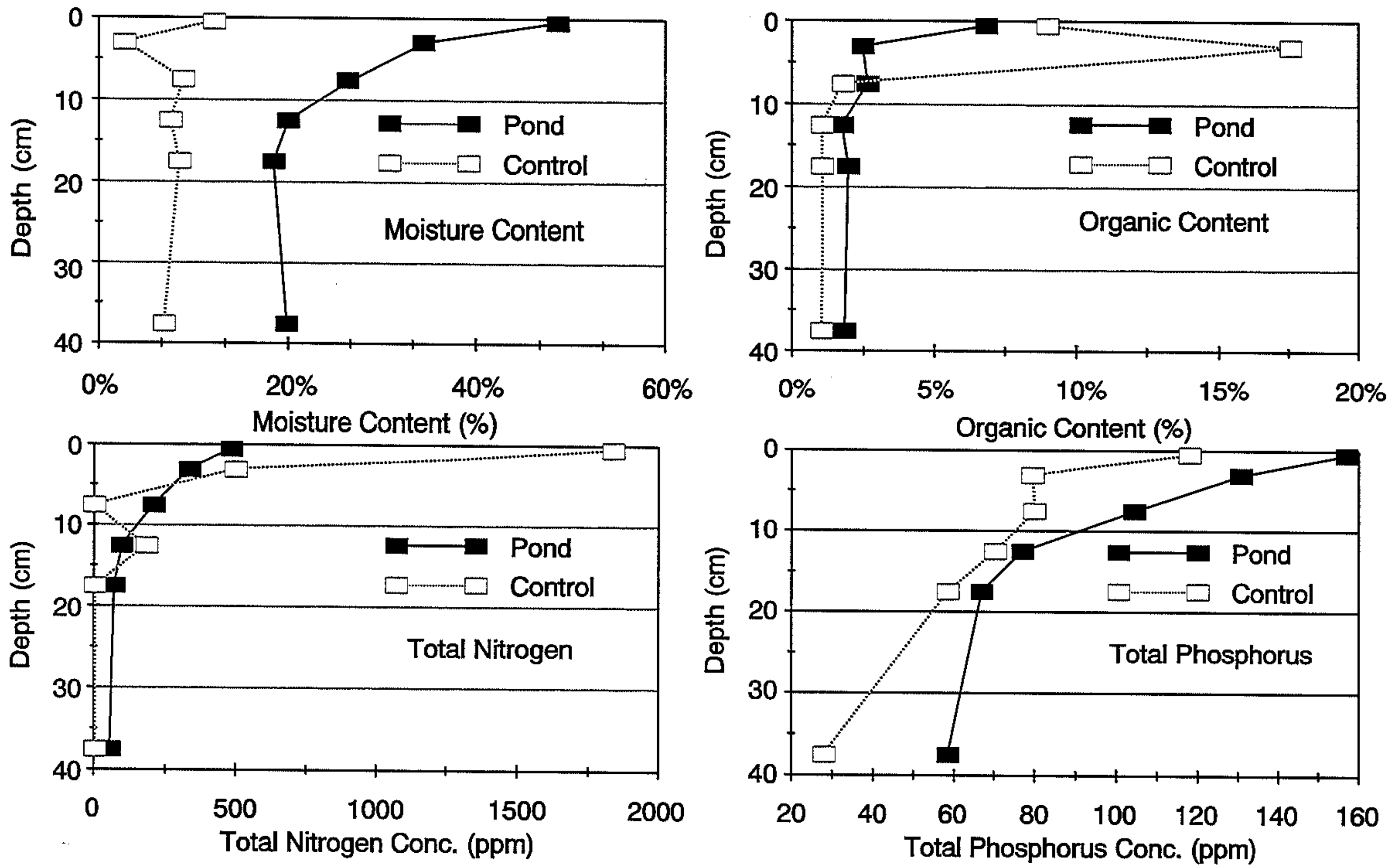


Figure 4-12. Comparison of Sediment Concentrations of Moisture Content, Organic Content, Total Nitrogen, and Total Phosphorus in the Top 50 cm of Pond and Control Areas at the DeBary Detention with Filtration Site.

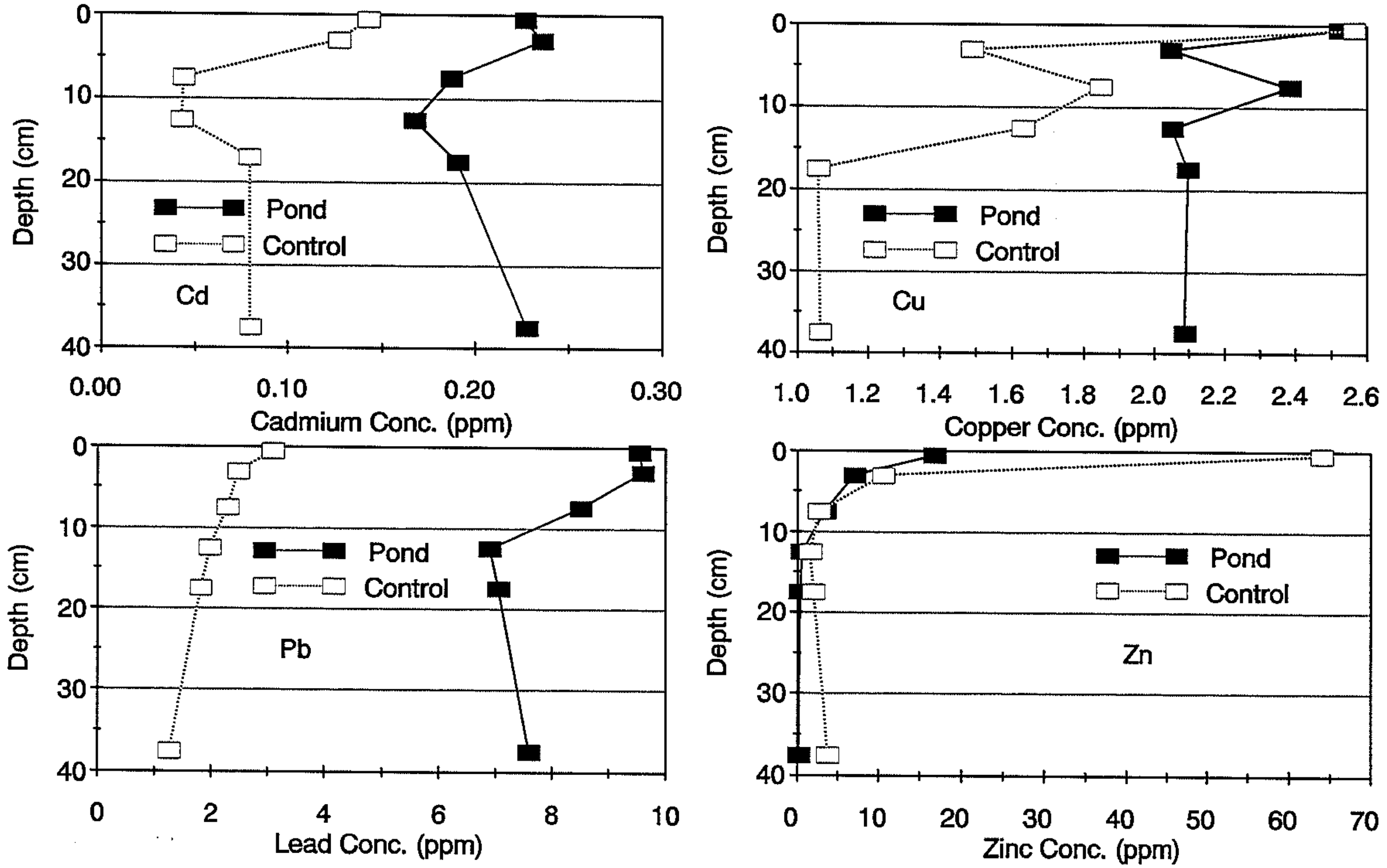


Figure 4-13. Comparison of Sediment Concentrations of Cadmium, Copper, Lead and Zinc in the Top 50 cm of Pond and Control Areas at the DeBary Detention with Filtration Site.

significant difference may be due to the fact that the control sediment samples were collected near the perimeter galvanized chain-link fence. Zinc is a common metal used for galvanizing and rust-protection purposes on chain-link fence material, and leaching of this material into nearby soils may be responsible for the higher zinc levels found in this area. At depths in excess of 1 cm, sediment concentrations of zinc in pond and control areas appear to be relatively similar.

Although sediment concentrations of all metals presented in Figure 4-13 decrease with increasing sediment depth in both pond and control areas, the patterns of decreasing sediment concentrations do not exhibit the typical logarithmic relationships exhibited by moisture content, total nitrogen and total phosphorus in Figure 4-12. However, measured concentrations for all metals presented in Figure 4-13 are highest at the sediment surface and decrease with increasing sediment depth.

A comparison of sediment concentrations of chromium, iron, manganese and aluminum in the top 50 cm of pond and control area sediments is presented in Figure 4-14. Sediment concentrations of chromium, iron and aluminum appear to be substantially greater in pond areas than in control areas. However, sediment concentrations of chromium, iron and aluminum appear to increase with increasing sediment depth rather than the typical patterns for decreasing concentrations exhibited for the other heavy metals. Sediment concentrations for these parameters in the control area also increase with increasing depth to depths ranging from approximately 20-30 cm, with decreasing concentrations at deeper depths. Similar to the trend observed with zinc, surface sediment concentrations of manganese are substantially higher in the control area than in the pond area. At depths in excess of 1 cm, sediment concentrations of manganese are relatively similar between pond and control areas.

In summary, with the possible exceptions of zinc and manganese, it is evident that each of the heavy metals measured are accumulating within the sediments of the pond at concentrations higher than in undisturbed control areas. Sediment concentrations of total nitrogen, total phosphorus, cadmium, copper, lead, zinc and manganese were found to be highest at the surface with decreasing concentrations at increasing sediment depths. In contrast, sediment concentrations of chromium, iron and aluminum appear to increase with increasing sediment depth. However, it is apparent that the detention pond is attenuating and retaining inputs of heavy metals and total phosphorus within the pond sediments in concentrations substantially greater than found in undisturbed control sediments.

As described in Chapter 3, laboratory sieve analyses were conducted on each of the vertical composite core samples collected in pond and control areas at the DeBary research site. Standard sieve sizes of 20, 40, 60, 80, 100 and 200 mesh were used in each analysis. Laboratory data generated during sieve analyses on the vertical composite core samples are given in Appendix S.

A summary of the sieve analyses conducted on core samples collected in pond and control areas is given in Table 4-27. In general, grain size distribution in pond and control areas appears to be relatively similar with pond areas retaining a slightly larger

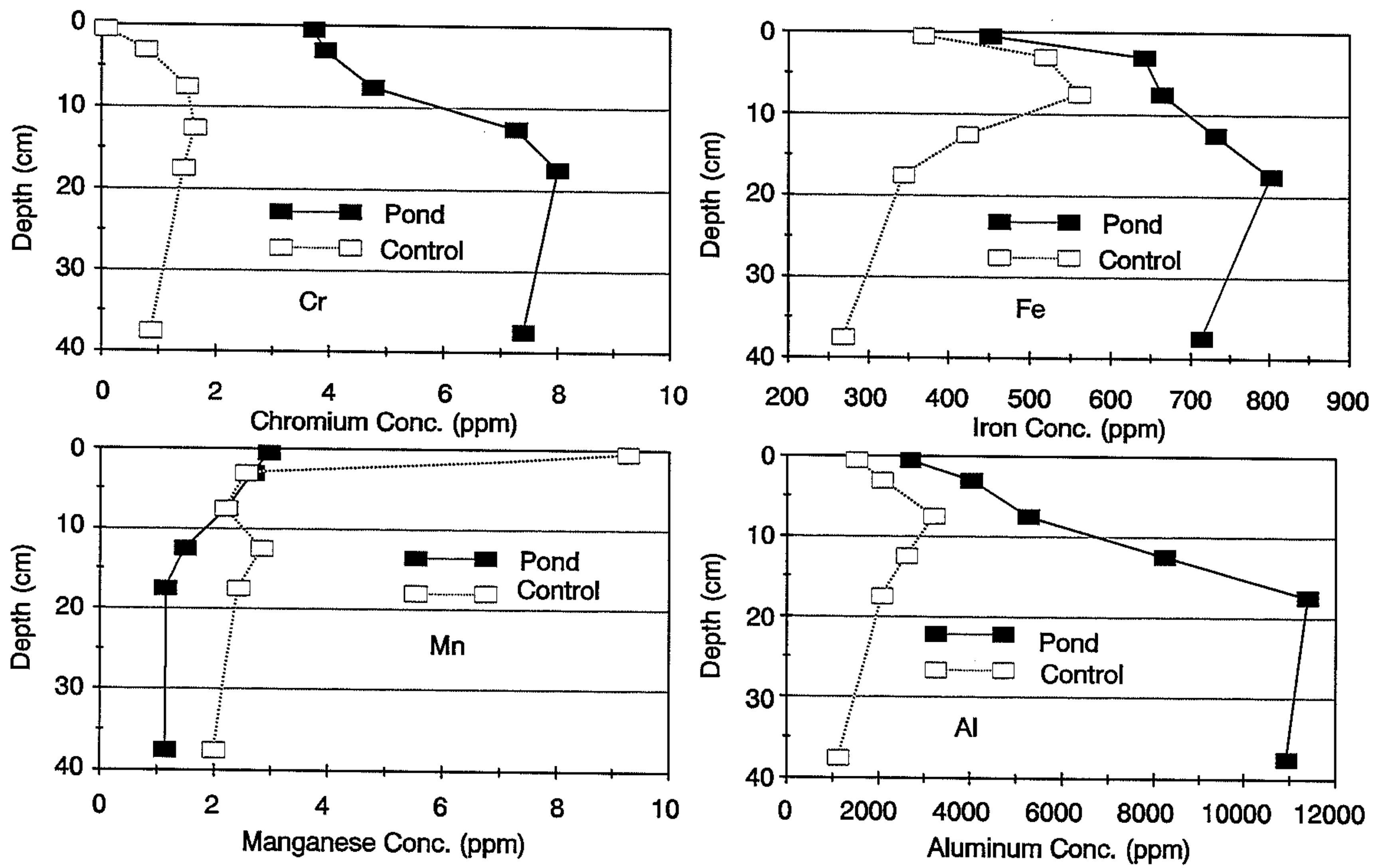


Figure 4-14. Comparison of Sediment Concentrations of Chromium, Iron, Manganese and Aluminum in the Top 50 cm of Pond and Control Areas at the DeBary Detention with Filtration Site.

TABLE 4-27

SUMMARY OF SIEVE ANALYSES CONDUCTED ON CORE SAMPLES COLLECTED AT THE DEBARY DETENTION WITH FILTRATION POND SITE

SITE	SAMPLE LAYER	PERCENT RETAINED ON EACH SIEVE SIZE (U.S. Standard Sizes)						
		20	40	60	80	100	200	PAN
Pond	0-1	5.81	3.02	12.08	39.24	11.37	25.39	3.09
	1-5	0.85	4.29	9.23	29.06	16.60	32.31	7.66
	5-10	2.69	4.04	12.03	38.36	13.75	24.36	4.77
	10-15	2.16	3.24	12.44	42.20	14.56	21.55	3.85
	15-25	1.64	2.63	16.43	42.27	12.88	19.80	4.35
	25-50	2.55	1.74	15.16	39.33	13.60	23.37	4.25
	Average	2.62	3.16	12.90	38.41	13.79	24.46	4.66
Control	0-1	7.00	5.90	12.40	29.30	15.50	27.60	2.30
	1-5	6.56	7.91	12.28	26.32	14.17	30.43	2.33
	5-10	6.71	4.63	8.33	30.38	17.07	29.78	3.10
	10-15	3.45	2.32	8.57	35.97	18.32	28.58	2.79
	15-25	1.61	1.42	8.34	36.00	18.83	31.07	2.73
	25-50	0.99	1.41	6.62	33.22	19.09	35.51	3.16
	Average	4.39	3.93	9.42	31.87	17.16	38.50	2.73
Filter Bed	Active Filter Composite	21.07	38.53	25.49	12.06	1.88	0.92	0.05
	Inactive Filter Composite	22.63	38.21	25.25	11.25	1.83	0.77	0.06

percentage on the 80 mesh screen and within the pan, while control areas exhibited higher retention on the 20 mesh screen and the 200 mesh screen. In general, the percentage of soil particles trapped by 80, 100 and 200 mesh screens as well as within the pan appear to increase with increasing vertical depth.

Statistical correlations were conducted between chemical characteristics of sediments and sediment grain size to evaluate the effects of grain size on sediment concentrations of nutrients and heavy metals. A summary of these correlations is given in Table 4-28, including Pearson correlation coefficients and level of significance for each significant correlation at the 0.05 level. Sediment concentrations of many nutrients and heavy metals appear to be correlated both with large diameter particles as well as small diameter particles. Sediment concentrations of nitrogen, phosphorus, aluminum, chromium, iron, manganese and zinc were found to be positively correlated with relatively large 40 and 60 mesh size particles. Sediment concentrations for moisture content, nitrogen, phosphorus, manganese, lead and zinc were found to be positively correlated with 200 mesh size particles or smaller. No significant correlations were observed between grain size and organic content, copper or cadmium.

4.7.3 Vertical Characteristics of Core Samples from Active and Inactive Filter Areas

Composite vertical core samples were also collected from active and inactive filter areas of the DeBary research site to evaluate attenuation mechanisms for pollutants within the filter media. Active filter areas were defined as filter media located below the average water level within the pond which filters pond water on a fairly continuous basis. Inactive portions of the filter were selected in areas above the measured high water level for the pond in areas which have rarely been used for filtration of pond water in the underdrain system.

Chemical characteristics of vertical composite core samples collected in active and inactive filter areas are summarized in Table 4-29. In general, active filter media was found to have higher measured concentrations for moisture content, nitrogen, phosphorus, and several of the measured heavy metals.

A comparison of sediment concentrations of moisture content, organic content, total nitrogen and total phosphorus in the top 50 cm of active and inactive filter areas is given in Figure 4-15. With the exception of organic content, measured concentrations for each parameter are higher in value within the active portion of the filter than in inactive areas. For total nitrogen and total phosphorus, sediment concentrations are highest near the filter surface and increase in a logarithmic manner with increasing sediment depth. Measured concentrations of moisture content, organic content, total nitrogen and total phosphorus in the active filter media are substantially less at all measured depths than concentrations found in sediment samples collected within the pond. Although it is apparent that the filter media is retaining at least nitrogen and phosphorus within the filter media, the retention rate is substantially less than that exhibited by the pond system.

TABLE 4-28

CORRELATIONS BETWEEN SEDIMENT CHARACTERISTICS AND POND SEDIMENT GRAIN SIZE

PARAMETER	PEARSON CORRELATION COEFFICIENT/ (LEVEL OF SIGNIFICANCE)						
	20	40	60	80	100	200	PAN
Moisture Content	N.S.C.[1]	N.S.C.	N.S.C.	N.S.C.	N.S.C.	0.951 (0.004)	0.812 (0.050)
Organic Content	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.
N	N.S.C.	0.876 (0.022)	N.S.C.	N.S.C.	N.S.C.	0.909 (0.012)	N.S.C.
P	N.S.C.	0.926 (0.008)	N.S.C.	N.S.C.	N.S.C.	0.860 (0.028)	N.S.C.
Al	N.S.C.	N.S.C.	0.942 (0.005)	N.S.C.	N.S.C.	N.S.C.	N.S.C.
Cu	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.
Cd	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.
Cr	N.S.C.	N.S.C.	0.878 (0.021)	0.854 (0.031)	N.S.C.	N.S.C.	N.S.C.
Fe	N.S.C.	N.S.C.	0.856 (0.030)	N.S.C.	N.S.C.	N.S.C.	N.S.C.
Mn	N.S.C.	0.899 (0.015)	N.S.C.	N.S.C.	N.S.C.	0.891 (0.017)	N.S.C.
Pb	N.S.C.	N.S.C.	N.S.C.	N.S.C.	N.S.C.	0.940 (0.005)	N.S.C.
Zn	N.S.C.	0.825 (0.043)	N.S.C.	N.S.C.	N.S.C.	0.934 (0.006)	0.828 (0.042)

1. N.S.C.: No Significant Correlation

TABLE 4-29

CHARACTERISTICS OF VERTICAL COMPOSITE CORE SAMPLES COLLECTED IN ACTIVE AND INACTIVE FILTER AREAS AT THE DEBARY RESEARCH SITE

SITE	SAMPLE LAYER (cm)	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	SEDIMENT CONCENTRATION (μg/g Wet Weight)									
				N	P	Al	Cu	Cd	Cr	Fe	Mn	Pb	Zn
Active Filter	0-1	14.8	0.5	176	58	710	1.60	0.07	0.73	196	2.53	2.93	4.99
	1-5	15.4	0.3	108	35	510	1.72	0.16	0.23	125	0.86	1.49	3.13
	5-10	15.0	0.2	58	19	440	2.10	0.16	0.08	67.1	0.45	1.43	2.85
	10-15	14.8	0.2	45	12	350	0.83	0.07	0.07	45.9	0.42	1.45	1.38
	15-25	14.8	0.1	46	8	330	0.95	0.09	0.09	28.7	0.23	0.82	1.95
	25-50	15.1	0.1	33	7	310	0.95	0.03	0.00	28.6	0.22	0.50	0.67
Inactive Filter	0-1	0.1	10.6	85	60	570	1.15	0.10	0.51	159	9.38	1.59	4.02
	1-5	1.0	0.1	29	22	400	1.08	0.10	0.26	104	3.95	1.21	1.85
	5-10	1.6	0.1	26	10	360	1.50	0.09	0.00	62.6	1.50	1.08	2.08
	10-15	2.0	0.1	9	7	290	0.86	0.05	0.07	51.7	0.72	0.50	1.87
	15-25	2.2	0.1	12	8	330	0.83	0.06	0.06	32.3	0.47	0.59	0.30
	25-50	3.1	0.1	5	6	370	1.04	0.10	0.06	47.3	0.43	0.61	0.37

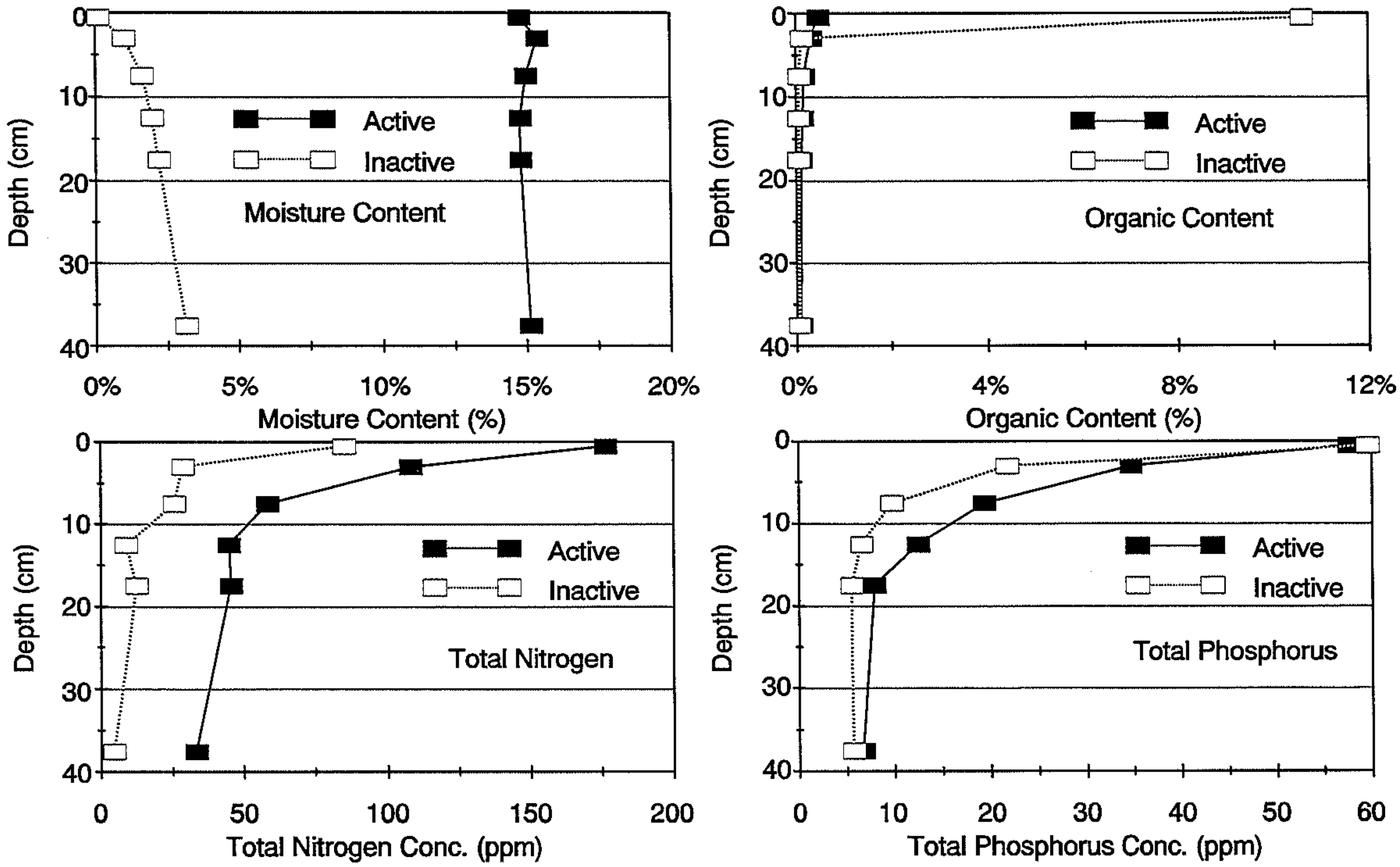


Figure 4-15. Comparison of Sediment Concentrations of Moisture Content, Organic Content, Total Nitrogen and Total Phosphorus in the Top 50 cm of Active and Inactive Filter Areas at the DeBary Detention with Filtration Site.

A comparison of sediment concentrations of cadmium, copper, lead and zinc in active and inactive filter media is given in Figure 4-16. In general, measured concentrations for each of these heavy metals appear to be higher within the active filter media than found in the inactive portion. However, differences in concentrations between active and inactive areas appears to be relatively small. In contrast, measured concentrations of cadmium, copper, lead and zinc in pond sediments are substantially greater in value than concentrations measured in the active portions of the filter. It appears from the results presented in Figure 4-16 that the filter media has a limited ability to retain these heavy metals based upon the relatively low concentration of heavy metals found in the active portions of the filter media and also the fact that little difference appears to exist between measured concentrations of heavy metals in the active and inactive areas.

A comparison of sediment concentrations of chromium, iron, manganese and aluminum in active and inactive filter media is given in Figure 4-17. There appears to be little difference in measured sediment concentrations for these parameters between active and inactive areas. In addition, measured concentrations of these parameters in filter media are substantially lower than values measured within the pond sediments. Measured concentrations for these metals in both active and inactive areas are highest near the surface and decrease with increasing vertical depth. Although it is obvious these metals are being retained near the surface of the filter media, the ability of the filter media itself to retain heavy metals is limited.

4.8 Pilot Filter Bed Testing

A series of pilot scale experiments were conducted to evaluate the effects of filter media, system configurations and sod cover on pollutant attenuation and hydraulic performance of filter systems. Experimentation was conducted as described in Chapter 3 using three different filter media and four sod covers. The results of water quality and hydraulic evaluations are presented in the following sections.

4.8.1 Pollutant Attenuation by Various Filter Media

An initial series of water quality experiments were conducted using typical sand filter media in a side bank configuration as indicated in Figures 3-8 and 3-9. The media used in the side bank filter was a coarse sand aggregate per FDOT Specification 902.4 which meets the specifications outlined in Chapter 17-25 of the Florida Administrative Code for filter media. A total of four separate experiments were conducted by using the side bank filter with typical sand filter media by filling the test basin with a simulated stormwater solution and monitoring pond water and underdrain outflow during the drawdown period. These experiments covered a relatively wide range of concentrations for the parameters measured to evaluate filter performance under a variety of input conditions. Individual results of the four pilot studies conducted using this media are presented in Appendix T (pages T-1 to T-4).

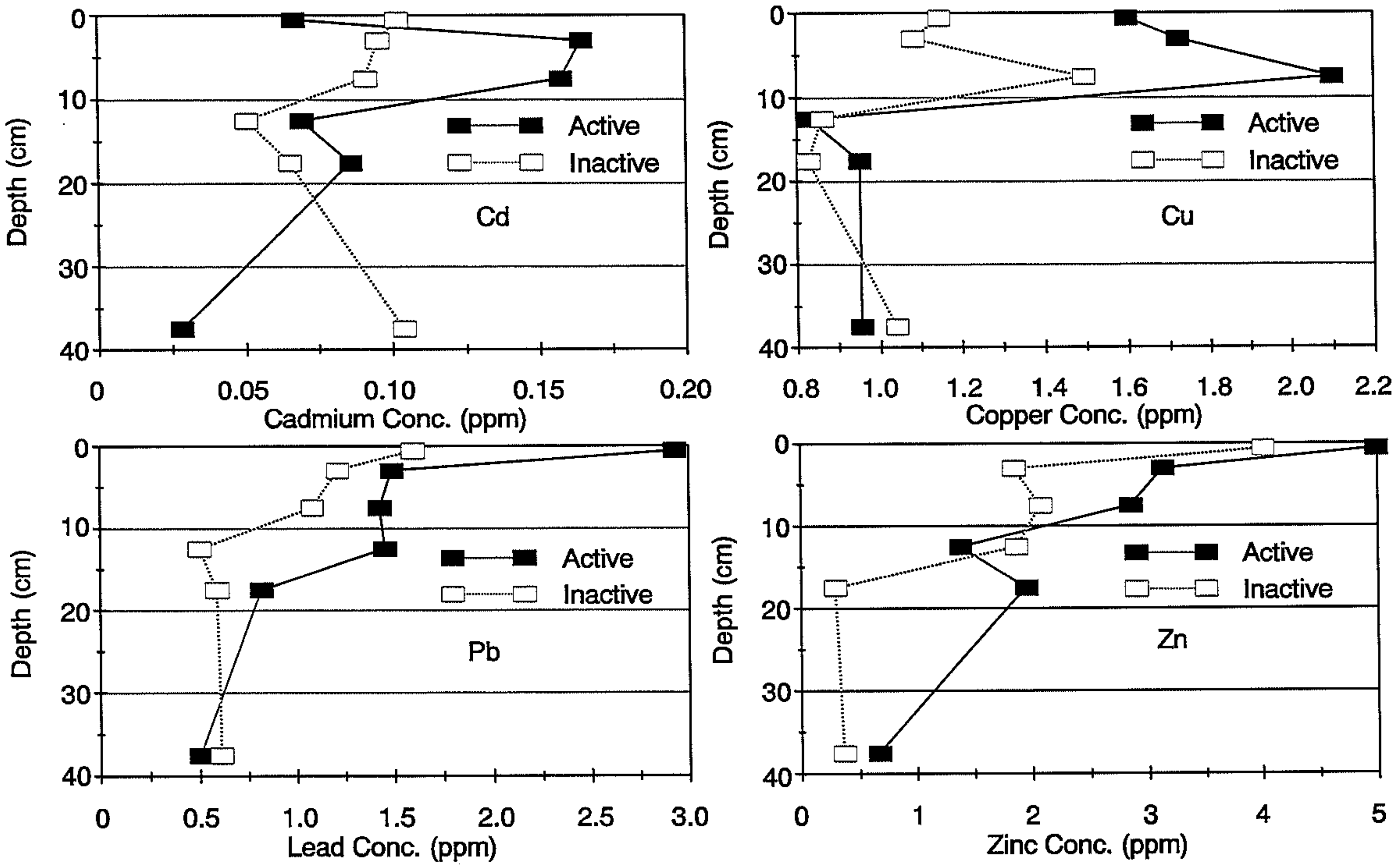


Figure 4-16. Comparison of Sediment Concentrations of Cadmium, Copper, Lead and Zinc in the Top 50 cm of Active and Inactive Filter Areas at the DeBary Detention with Filtration Site.

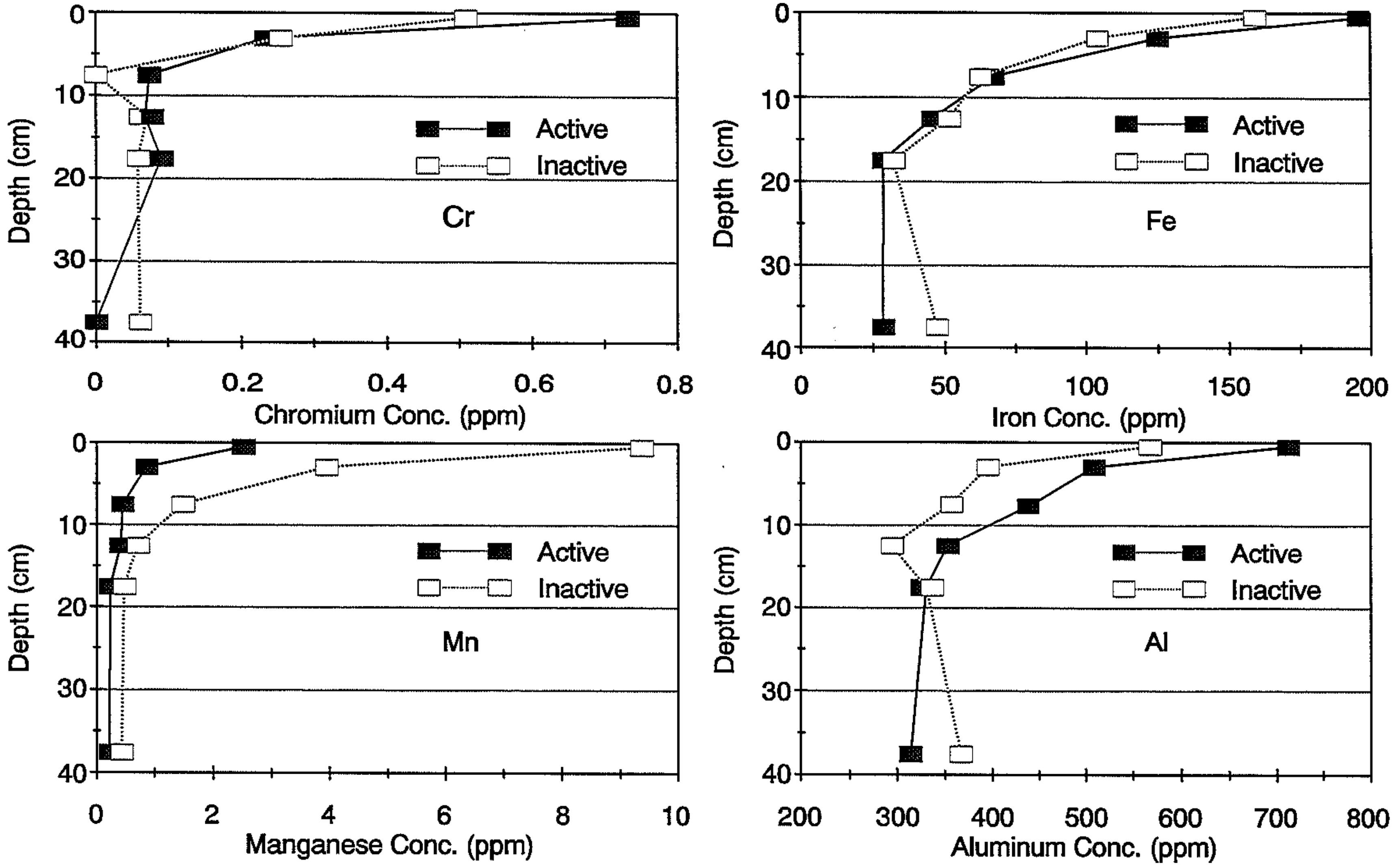


Figure 4-17. Comparison of Sediment Concentrations of Chromium, Iron, Manganese and Aluminum in the Top 50 cm of Active and Inactive Filter Areas at the DeBary Detention with Filtration Site.

Mean results from the four pilot studies conducted using the typical sand filter media in a side bank configuration are summarized in Table 4-30. Migration through the filter media removed relatively little total nitrogen from the simulated stormwater solution with a mean removal of only 5%. Nitrogen species of ammonia, dissolved organic nitrogen and particulate organic nitrogen exhibited removals from 12-19% within the filter media while concentrations of NO_x increased 46%. Total phosphorus was removed an average of 41% by the filter media with the majority of this removal accounted for by attenuation of particulate phosphorus species. Removal of turbidity was also fairly good within the filter media with a mean removal of 56%. Mean removal of lead and zinc in the filter media was extremely good with an average removal of 90% for total lead and total zinc. On the other hand, total copper was not effectively removed by the filter media with a net removal of less than 30%.

A second series of pilot studies were conducted using a side bank filter with a 15 cm (6 in) gravel envelope around the underdrain pipe. The same typical sand filter media (FDOT Spec. 902.4) used in the initial experiments were used as the filtration media for these experiments as well. The purpose of the gravel envelope around the underdrain pipe was to enhance the hydraulic performance of the filter system. A total of four separate water quality experiments were conducted using the gravel envelope configuration. Water quality results from each of the four pilot studies conducted with the gravel envelope are given in Appendix T (pages T-5 to T-8).

Mean results of the four pilot studies using the gravel envelope are summarized in Table 4-31. Removal of total nitrogen and total phosphorus was similar to that exhibited using the typical sand filter media with a net removal of 6% for total nitrogen and 37% for total phosphorus. As observed in the previous experiments, removal of total nitrogen was achieved primarily by removal of ammonia and organic nitrogen, while concentrations of NO_x increased. Similarly, removal of total phosphorus was primarily associated with removal of particulate forms. Removal of BOD within the filter media averaged approximately 2%.

The side bank filter with the gravel envelope was capable of removing substantial amounts of lead and zinc from the stormwater solution with removals in excess of 90% for total species of both metals. Removal of total copper by the gravel envelope system averaged approximately 50%.

A final series of filter media experiments were conducted by reconfiguring the side bank filter media using 20-30 silica sand as the underdrain media with no gravel envelope. A total of four water quality experiments were conducted using this media. This media is substantially more coarse than the typical filter media, and exhibited a much higher flow rate through the underdrain system. Results of each of the four pilot studies conducted using the 20-30 silica sand media are given in Appendix T (pages T-9 to T-12).

Mean results of the four pilot studies using the 20-30 silica sand are summarized in Table 4-32. Removal of total nitrogen and total phosphorus is similar to that observed with the previous media configurations. Reduction in concentrations of total nitrogen

TABLE 4-30

MEAN RESULTS OF PILOT STUDIES CONDUCTED USING TYPICAL SAND FILTER MEDIA IN A SIDE BANK CONFIGURATION

(Summary of 4 Experiments)

PARAMETER		UNITS	MEAN POND WATER CONCENTRATION	MEAN UNDERDRAIN CONCENTRATION	PERCENT CHANGE
pH		s.u.	7.08	7.36	4
Conductivity		μS/cm	253	271	7
NH_3-N		μg/l	199	175	-12
NO_x-N		μg/l	190	278	46
Diss. Organic N		μg/l	775	669	-14
Part. Organic N		μg/l	98	79	-19
Total N		μg/l	1261	1200	-5
Ortho-P		μg/l	149	141	-5
Particulate P		μg/l	36	21	-42
Total P		μg/l	279	166	-41
BOD		mg/l	4.6	4.4	-4
Copper:	Diss.	μg/l	13	7	-46
	Total	μg/l	14	10	-29
Lead:	Diss.	μg/l	10	2	-80
	Total	μg/l	24	3	-88
Zinc.:	Diss.	μg/l	48	2	-96
	Total	μg/l	51	4	-92

TABLE 4-31

MEAN RESULTS OF PILOT STUDIES CONDUCTED USING A SIDE BANK FILTER WITH A GRAVEL ENVELOPE AROUND THE UNDERDRAIN PIPE

(Summary of 4 Experiments)

PARAMETER		UNITS	MEAN POND WATER CONCENTRATION	MEAN UNDERDRAIN CONCENTRATION	PERCENT CHANGE
pH		s.u.	6.98	7.24	4
Conductivity		μS/cm	244	265	9
NH_3-N		μg/l	256	191	-25
NO_x-N		μg/l	217	301	39
Diss. Organic N		μg/l	631	556	-12
Part. Organic N		μg/l	62	44	-29
Total N		μg/l	1165	1094	-6
Ortho-P		μg/l	145	150	3
Particulate P		μg/l	18	9	-50
Total P		μg/l	255	160	-37
BOD		mg/l	4.7	4.6	-2
Copper:	Diss.	μg/l	13	5	-62
	Total	μg/l	14	7	-50
Lead:	Diss.	μg/l	33	< 2	-97
	Total	μg/l	44	< 2	-98
Zinc.:	Diss.	μg/l	54	3	-94
	Total	μg/l	55	4	-93

TABLE 4-32

MEAN RESULTS OF PILOT STUDIES CONDUCTED USING A SIDE BANK FILTER WITH 20-30 SILICA SAND MEDIA

(Summary of 4 Experiments)

PARAMETER		UNITS	MEAN POND WATER CONCENTRATION	MEAN UNDERDRAIN CONCENTRATION	PERCENT CHANGE
pH		s.u.	6.96	6.93	0
Conductivity		$\mu S/cm$	246	252	2.4
NH_3-N		$\mu g/l$	220	174	-21
NO_x-N		$\mu g/l$	330	323	-2
Diss. Organic N		$\mu g/l$	941	832	-12
Part. Organic N		$\mu g/l$	65	111	71
Total N		$\mu g/l$	1556	1440	-7
Ortho-P		$\mu g/l$	214	140	-35
Total P		$\mu g/l$	395	177	-55
BOD		mg/l	2.0	2.0	0
Copper:	Diss.	$\mu g/l$	16	6	-63
	Total	$\mu g/l$	17	8	-53
Lead:	Diss.	$\mu g/l$	55	< 2	-98
	Total	$\mu g/l$	84	< 2	-99
Zinc.:	Diss.	$\mu g/l$	82	< 1	-99
	Total	$\mu g/l$	85	< 1	-99

through the filter averaged approximately 7% with 55% removal of total phosphorus. Removal of heavy metals was also good using the 20-30 silica sand with 99% removal for total lead and zinc and 53% removal for total copper.

A comparison of mean removal efficiencies for various filter media is given in Table 4-33. Overall removal of total nitrogen and total phosphorus was similar between the three filter media. Removal of total nitrogen ranged from 5-7% with total phosphorus removal ranging from 37-55%. Removal of heavy metals appears to be somewhat greater with the gravel envelope modification and with the 20-30 silica sand than observed using standard filter media. Removal of heavy metals using the gravel envelope and the 20-30 silica sand exceeded 90% for total lead and zinc and 50% for total copper.

4.8.2 Attenuation of Pollutants by Various Sod Covers

A series of experiments were conducted using four separate sod covers on the side bank filter system constructed using the original filter media (FDOT Specification 902.4) to evaluate pollutant attenuation by various sod media. A total of four sod types were investigated during this research, including: St. Augustine sod grown in sand, St. Augustine sod grown in muck, Bahia sod grown in sand and Bermuda sod grown in muck. Individual water quality results from experimentation using each of the four sod covers are presented in Appendix U.

Initial testing using sod cover was conducted using St. Augustine sod grown in sand. A total of four separate experiments were conducted to evaluate pollutant attenuation through the side bank filter covered with the St. Augustine sod. Individual results from each of the four experiments using St. Augustine sod are given in Appendix U (pages U-1 to U-4). A wide range of concentrations were used in the simulated stormwater solution to evaluate system performance under a variety of pollutant concentrations.

Mean results of pilot studies conducted using a side bank filter covered with St. Augustine sod grown in sand are summarized in Table 4-34. Mean removal of total nitrogen and total phosphorus using the sod cover was relatively low with an average removal of 11% for total nitrogen and 13% for total phosphorus. Removal of total nitrogen within the filter system was achieved primarily by removal of ammonia and organic nitrogen with concentrations of NO_x increasing through the filter system. Similarly, concentrations of orthophosphorus increased during migration through the sod and filter combination. Removal of heavy metals by the St. Augustine sod was similar to that exhibited by the filter media alone with an average removal of 90% for lead and zinc and approximately 50% for total copper.

A second series of pilot studies were conducted using a St. Augustine sod grown in muck over the same side bank filter system as used in the initial experimentation. A total of four separate experiments were conducted, covering a wide range of water

TABLE 4-33

COMPARISON OF MEAN REMOVAL EFFICIENCIES FOR VARIOUS FILTER MEDIA WITH NO SOD COVER

PARAMETER		PERCENT CHANGE DURING FLOW THROUGH MEDIA		
		STANDARD FILTER MEDIA	STANDARD FILTER WITH GRAVEL ENVELOPE	20-30 SILICA SAND
pH		4	4	0
Conductivity		7	9	2.4
NH_3-N		-12	-25	-21
NO_x-N		46	39	-2
Diss. Organic N		-14	-12	-12
Part. Organic N		-19	-29	71
Total N		-5	-6	-7
Ortho-P		-5	3	-35
Particulate P		-42	-50	39
Total P		-41	-37	-55
BOD		-4	-2	0
Copper:	Diss.	-46	-62	-63
	Total	-29	-50	-53
Lead:	Diss.	-80	-97	-98
	Total	-88	-98	-99
Zinc.	Diss.	-96	-94	-99
	Total	-92	-93	-99

TABLE 4-34

MEAN RESULTS OF PILOT STUDIES CONDUCTED USING A SIDE BANK FILTER COVERED WITH ST. AUGUSTINE SOD GROWN IN SAND

(Summary of 4 Experiments)

PARAMETER		UNITS	MEAN POND WATER CONCENTRATION	MEAN UNDERDRAIN CONCENTRATION	PERCENT CHANGE
pH		s.u.	7.18	7.23	1
Conductivity		μS/cm	249	261	5
NH_3-N		μg/l	207	130	-37
NO_x-N		μg/l	233	344	48
Diss. Organic N		μg/l	813	635	-22
Part. Organic N		μg/l	98	95	-3
Total N		μg/l	1351	1203	-11
Ortho-P		μg/l	198	246	24
Particulate P		μg/l	23	24	4
Total P		μg/l	309	270	-13
BOD		mg/l	1.6	1.4	-13
Copper:	Diss.	μg/l	14	6	-57
	Total	μg/l	15	7	-53
Lead:	Diss.	μg/l	18	< 2	-94
	Total	μg/l	32	4	-88
Zinc.:	Diss.	μg/l	51	2	-96
	Total	μg/l	53	4	-92

quality characteristics. Individual results of pilot studies using the typical sand filter media covered with the St. Augustine sod grown in muck are given in Appendix U (pages U-5 to U-8).

Mean results of pilot studies conducted using a side bank filter covered with St. Augustine sod grown in muck are given in Table 4-35. Removal of total nitrogen and total phosphorus by the muck grown sod was similar to that exhibited by the sod grown in sand with an average removal of 11% for total nitrogen and 19% for total phosphorus. Measured concentrations of ammonia and organic nitrogen decreased during migration through the filter while concentrations of NO_x increased. Similarly, particulate phosphorus decreased approximately 44% during migration through the filter, while orthophosphorus increased 39%. Removal of heavy metals by the muck grown sod appears to be slightly greater than that exhibited by sod grown in sand with removal of lead and zinc exceeding 95% and copper removal exceeding 55%.

A third set of experiments was conducted using Bahia sod grown in sand. A total of four separate experiments were conducted, covering a wide range of water quality characteristics. The results of the four pilot studies conducted using the Bahia sod grown in sand are given in Appendix U (pages U-9 to U-12).

Mean results of pilot studies conducted using a side bank filter covered with Bahia sod grown in sand are given in Table 4-36. Removal of total nitrogen, total phosphorus and heavy metals using the Bahia sod was similar to that exhibited by the St. Augustine sods. Removal of total nitrogen and total phosphorus in the filter system averaged 9% and 41%, respectively. Removal of total lead and total zinc by the Bahia sod was extremely good with an average of 87% for total lead and 98% for total zinc.

The final pilot study was conducted using the side bank filter covered with Bermuda-419 sod grown in muck. A total of four separate experiments were conducted, covering a wide range of water quality characteristics. Individual results of the four pilot studies conducted using the Bermuda-419 sod grown in muck are given in Appendix U (pages U-13 to U-16).

Mean results of pilot studies conducted using the Bermuda sod grown in muck are summarized in Table 4-37. Removal of total nitrogen, total phosphorus and BOD using the Bermuda sod is substantially less than that exhibited by the St. Augustine or Bahia sods. Removal of total nitrogen averaged only 3% using the Bermuda sod, with a net increase of 3% for total phosphorus and a BOD removal of only 4%. Concentrations of lead and zinc were removed well with the Bermuda sod, with removals of approximately 95%. However, the removal of copper with the Bermuda sod was somewhat less than that exhibited with the other sod types, with a removal of only 41%.

A comparison of mean removal efficiencies for the four sod covers over a side bank filter is given in Table 4-38. Removal of total phosphorus and BOD appears to be greater with the Bahia sod grown in sand than with either the St. Augustine or Bermuda sod types. The Bahia sod also resulted in a net removal for orthophosphorus, while

TABLE 4-35

MEAN RESULTS OF PILOT STUDIES CONDUCTED USING A SIDE BANK FILTER COVERED WITH ST. AUGUSTINE SOD GROWN IN MUCK

(Summary of 4 Experiments)

PARAMETER		UNITS	MEAN POND WATER CONCENTRATION	MEAN UNDERDRAIN CONCENTRATION	PERCENT CHANGE
pH		s.u.	7.09	7.02	-1
Conductivity		μS/cm	244	249	2
NH_3-N		μg/l	260	160	-38
NO_x-N		μg/l	215	307	43
Diss. Organic N		μg/l	800	716	-11
Part. Organic N		μg/l	88	32	-64
Total N		μg/l	1363	1214	-11
Ortho-P		μg/l	166	231	39
Particulate P		μg/l	25	14	-44
Total P		μg/l	318	257	-19
BOD		mg/l	2.0	1.5	-25
Copper:	Diss.	μg/l	14	6	-57
	Total	μg/l	16	7	-56
Lead:	Diss.	μg/l	32	< 2	-97
	Total	μg/l	46	2	-96
Zinc.:	Diss.	μg/l	62	1	-98
	Total	μg/l	63	2	-97

TABLE 4-36

MEAN RESULTS OF PILOT STUDIES CONDUCTED USING A SIDE BANK FILTER COVERED WITH BAHIA SOD GROWN IN SAND

(Summary of 4 Experiments)

PARAMETER		UNITS	MEAN POND WATER CONCENTRATION	MEAN UNDERDRAIN CONCENTRATION	PERCENT CHANGE
pH		s.u.	7.29	7.23	-1
Conductivity		µS/cm	247	254	3
NH_3-N		µg/l	239	118	-51
NO_x-N		µg/l	234	245	5
Diss. Organic N		µg/l	638	614	-4
Part. Organic N		µg/l	107	130	21
Total N		µg/l	1218	1106	-9
Ortho-P		µg/l	156	137	-12
Particulate P		µg/l	26	12	-54
Total P		µg/l	300	176	-41
BOD		mg/l	2.6	1.7	-35
Copper:	Diss.	µg/l	14	6	-57
	Total	µg/l	15	7	-53
Lead:	Diss.	µg/l	18	2	-89
	Total	µg/l	45	6	-87
Zinc.:	Diss.	µg/l	56	1	-98
	Total	µg/l	59	1	-98

TABLE 4-37

MEAN RESULTS OF PILOT STUDIES CONDUCTED USING A SIDE BANK FILTER COVERED WITH BERMUDA-419 SOD GROWN IN MUCK

(Summary of 4 Experiments)

PARAMETER		UNITS	MEAN POND WATER CONCENTRATION	MEAN UNDERDRAIN CONCENTRATION	PERCENT CHANGE
pH		s.u.	7.06	7.26	3
Conductivity		μS/cm	246	261	6
NH_3-N		μg/l	315	200	-37
NO_x-N		μg/l	250	467	87
Diss. Organic N		μg/l	815	719	-12
Part. Organic N		μg/l	159	132	-17
Total N		μg/l	1569	1518	-3
Ortho-P		μg/l	209	301	44
Particulate P		μg/l	30	34	13
Total P		μg/l	346	358	3
BOD		mg/l	2.7	2.6	-4
Copper:	Diss.	μg/l	25	13	-48
	Total	μg/l	27	16	-41
Lead:	Diss.	μg/l	37	< 2	-99
	Total	μg/l	65	4	-94
Zinc.:	Diss.	μg/l	119	6	-95
	Total	μg/l	134	6	-96

TABLE 4-38

COMPARISON OF MEAN REMOVAL EFFICIENCIES FOR VARIOUS SOD COVERS OVER A SIDE BANK FILTER

PARAMETER		PERCENT CHANGE DURING FLOW THROUGH MEDIA			
		ST. AUGUSTINE GROWN IN SAND	ST. AUGUSTINE GROWN IN MUCK	BAHIA GROWN IN SAND	BERMUDA GROWN IN MUCK
pH		1	-1	-1	3
Conductivity		5	2	3	6
NH_3-N		-37	-38	-51	-37
NO_x-N		48	43	5	87
Diss. Organic N		-22	-11	-4	-12
Part. Organic N		-3	-64	21	-17
Total N		-11	-11	-9	-3
Ortho-P		24	39	-12	44
Particulate P		4	-44	-54	13
Total P		-13	-19	-41	3
BOD		-13	-25	-35	-4
Copper:	Diss.	-57	-57	-57	-48
	Total	-53	-56	-53	-41
Lead:	Diss.	-94	-97	-89	-99
	Total	-88	-96	-87	-94
Zinc.	Diss.	-96	-98	-98	-95
	Total	-92	-97	-98	-96

orthophosphorus concentrations increased using the other sod types. The Bermuda sod grown in muck appears to exhibit the poorest removal efficiencies, particularly for total nitrogen, total phosphorus, BOD and total copper. Removal of total lead and total zinc is relatively similar between the four sod types.

Although removal efficiencies for the four sod types are similar on many parameters, it appears that maximum removal efficiencies may be achieved for certain parameters using the Bahia sod grown in sand. This sod type appears to exhibit superior removal of total phosphorus and BOD compared with the other sod types. Bermuda sod grown in muck apparently exhibits the poorest removal efficiency among the four sods tested. However, differences in removal efficiencies may be related more to differences in soil types than the type of grass tested.

4.9 Hydraulic Characteristics of the Filter System at the DeBary Research Site

As discussed in Chapter 3, detailed hydraulic information was collected on the filter system at the DeBary research site. The purpose of this analysis was three-fold: (1) to evaluate drawdown characteristics of the filter system during measured rain events at the research site; (2) to evaluate field measured permeability values (K values) for the detention with filtration system during actual operation; and (3) to investigate the applicability of commonly used design equations for predicting measured drawdowns observed at the research site. Each of these evaluations are discussed in the following sections.

4.9.1 Physical Characteristics of Filter Media at the DeBary Detention with Filtration Site

Physical characteristics of the filter media at the DeBary research site are summarized in Table 4-39 based upon sieve analyses of composite filter media samples collected in active and inactive portions of the filter bank. Grain size distributions for active and inactive filter media are contained in Appendix S (page S-18).

Based upon the sieve analyses given in Appendix S, the filter media at the DeBary research site had a D_{10} (particle diameter at which 10% of all particles are finer) of 0.225 mm for both active and inactive portions of the filter. The D_{10} particle diameter is also called the effective particle diameter, and is required to be between values of 0.20 and 0.55 mm according to criteria listed in Chapter 17-25.025 of the Florida Administrative Code. The filter sand used at the DeBary research site falls within this range of diameters for the effective particle diameter.

TABLE 4-39

PHYSICAL CHARACTERISTICS OF FILTER MEDIA AT THE DEBARY RESEARCH SITE

PARAMETER	FILTER MATERIAL		CHAPTER 17-25.025 FILTER MEDIA REQUIREMENTS
	DEBARY: ACTIVE AREA MEDIA	DEBARY: INACTIVE AREA MEDIA	
D_{10}[1] (mm)	0.225	0.225	--
D_{60}[2] (mm)	0.610	0.600	--
Uniformity Coefficient[3]	2.71	2.67	> 1.5
Effective Diameter[4]	0.225	0.225	0.20-0.55
Organic Matter (%)	0.2	1.9	< 1

1. D_{10} = Particle diameter (mm) at which 10% of all particles are finer
2. D_{60} = Particle diameter (mm) at which 60% of all particles are finer
3. Uniformity Coefficient = D_{60}/D_{10}
4. Effective Diameter = D_{10}

A second particle characteristic, D_{60} (particle diameter at which 60% of all particles are finer) is also included in Table 4-39. This diameter ranged from 0.600 to 0.610 mm for active and inactive areas at the DeBary site. The uniformity coefficient is defined as the ratio of D_{60}/D_{10} and is required to be in excess of 1.5 according to requirements outlined in Chapter 17-25. The uniformity coefficient of 2.71 for the active filter media and 2.67 for the inactive media also meet this media requirement.

Chapter 17-25 also requires that organic matter within the filter media be less than 1% by weight of the media itself. The measured organic content within the active portions of the filter was 0.2% which clearly meets the requirements of Chapter 17-25. The organic matter content in the inactive portions of the filter media was 1.9% which exceeds the required value of 1%. However, adjacent upland soils had been washed onto the face of the filter in many of the inactive filter areas. The organic content of 1.9% probably reflects an input of natural soils onto the filter media along these portions of the filter.

In summary, filter media in the active portions of the filter at the DeBary research site met all applicable criteria for filter systems listed in Chapter 17-25. Inactive portions of the filter media met requirements for the uniformity coefficient and the effective diameter, but slightly exceeded the maximum allowable value for organic matter. However, this organic matter is likely due to external inputs onto the filter surface rather than organic material present within the actual filter media.

4.9.2 Drawdown Characteristics of the Filter Underdrain System

Drawdown characteristics of the filter underdrain system at the DeBary research site were evaluated using a combination of available data. Water surface elevations were obtained from information included in Appendix B. Runoff inflow hydrographs into the pond were obtained from hydrograph information listed in Appendix F. Outflow hydrographs were obtained from information listed in Appendix G. Finally, information on the characteristics of rain events was obtained from rainfall characteristics given in Appendix A. Drawdown characteristics of the filter system for typical rain events measured at the DeBary research site are presented in the following paragraphs.

Relationships between inflow, outflow and pond stage for a 0.71 cm (0.28 in) rain event on June 16, 1992 are given in Figure 4-18. This figure contains an inflow hydrograph for stormwater inputs into the pond, an underdrain outflow hydrograph over a period of 72 hours, and changes in pond elevation over the same period. As seen in Figure 4-18, the water surface elevation within the pond responded rapidly to this rain event, increasing from an initial elevation of 55.88 ft (17.038 m) to a high of 56.23 ft (17.142 m) over a period of six hours.

Underdrain outflow from the pond also increased rapidly in response to the increase in pond elevation, increasing from a low of 0.008 cfs prior to the start of the rain event to a maximum of 0.031 cfs approximately 2 hours after the start of the rain event. Underdrain outflow from the pond declined steadily with increasing time to a discharge rate of 0.018 cfs 24 hours after the storm event, a discharge of 0.010 cfs at 48 hours following the storm event, and a discharge of 0.07 cfs 72 hours following the beginning of the storm event. After a period of 72 hours, discharge flow rates from the filter were slightly less than flow rates measured prior to the rain event. A similar trend was observed for water surface elevations within the pond. The beginning pond elevation prior to the rain event was 55.89 ft (17.038 m). After a period of 72 hours, pond elevation had decreased to a level of 55.92 ft (17.048 m) or within 0.01 m (0.03 ft) of the initial starting elevation. In terms of both underdrain discharge rates and pond surface elevations, the detention pond met the requirements for drawdown within a period of 72 hours.

Relationships between inflow, outflow and pond stage for a 1.37 cm (0.54 in) rain event on June 6, 1992 are given in Figure 4-19. This monitored rain event began at 16:00 with a duration of 0.67 hours. Similar to the trend observed in the June 16, 1992 storm event, both the pond surface elevation and underdrain outflow rates increased rapidly in response to stormwater inputs from the rain event. Peak values for both pond stage and underdrain outflow rates appear to occur approximately 2 hours after the start of the rain event.

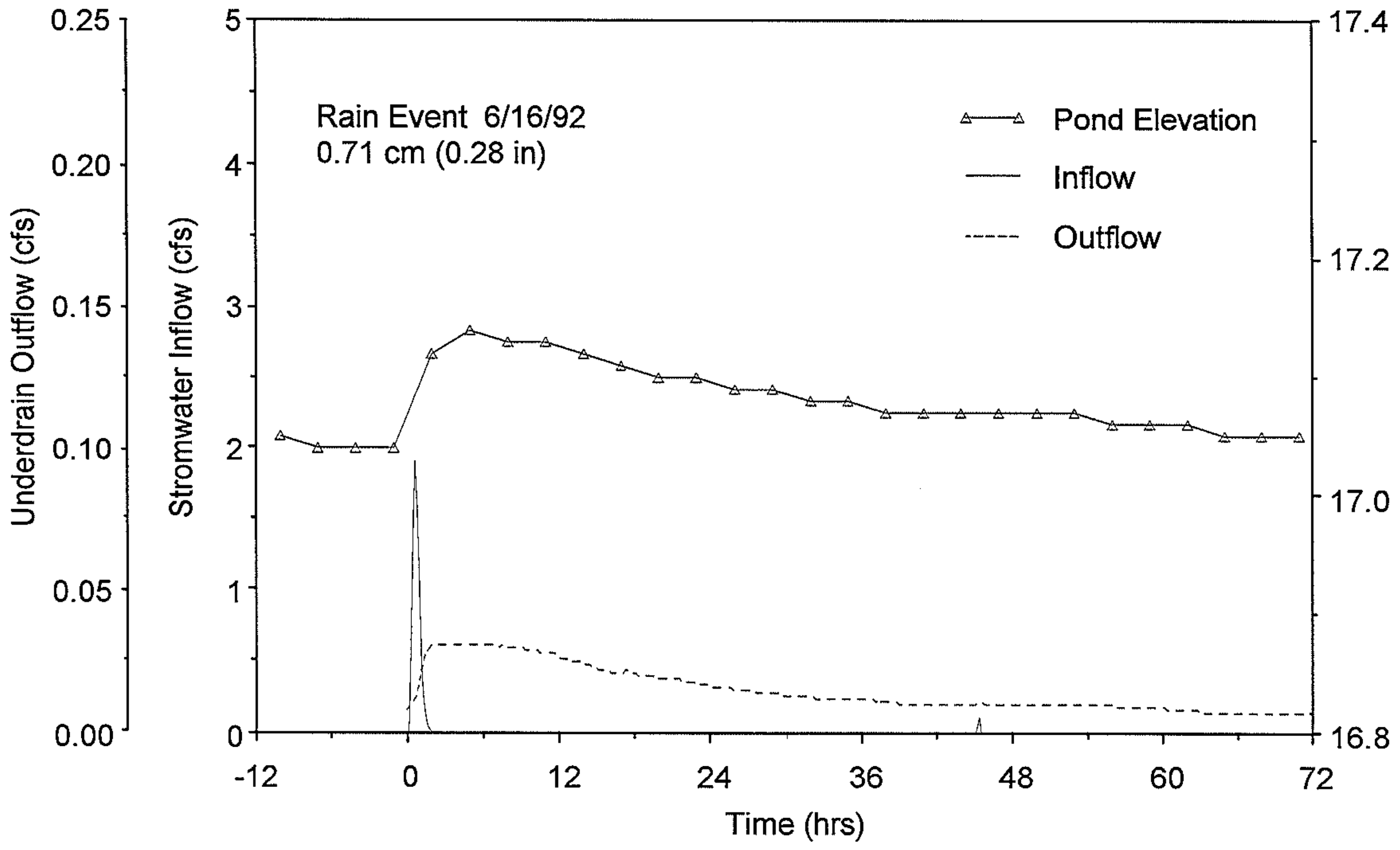


Figure 4-18. Relationships Between Inflow, Outflow and Pond Stage for a 0.71 cm (0.28 in) Rain Event on June 16, 1992.

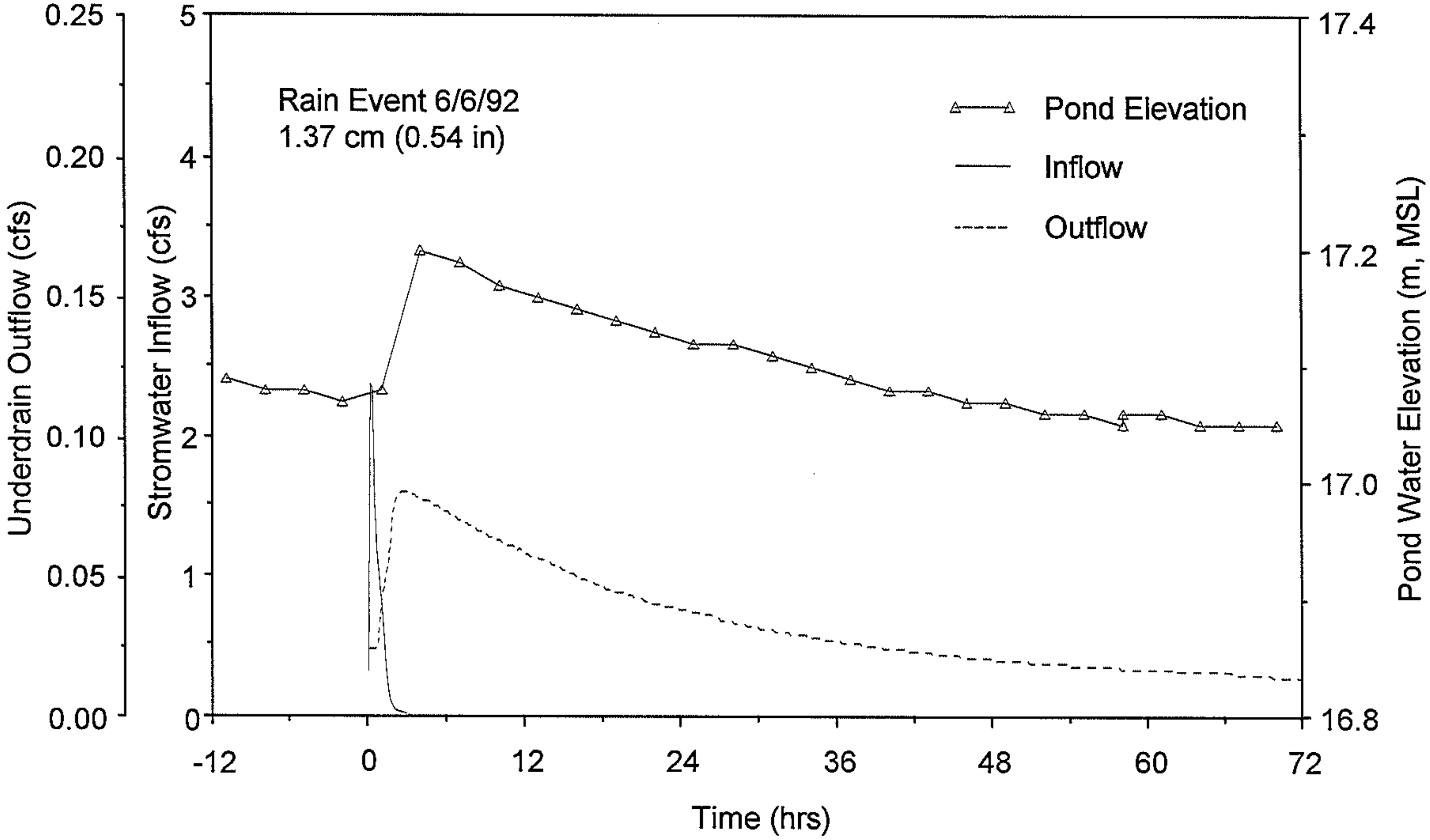


Figure 4-19. Relationships Between Inflow, Outflow and Pond Stage for a 1.37 cm (0.54 in) Rain Event on June 6, 1992.

Prior to the start of the rain event, the pond surface elevation was 56.00 ft (17.072 m). Following the rain event, the pond peaked at a stage of 56.43 ft (17.204 m), with a gradual decline in pond surface elevation to a value of 17.042 m (55.90 ft) after 72 hours. This value is 0.026 m (0.09 ft) lower than the initial starting elevation prior to the storm event. Underdrain outflow rates prior to the start of the rain event averaged approximately 0.024 cfs, with a peak value of 0.080 cfs reached approximately 1 hour after the beginning of the storm event. Underdrain outflow from the pond decreased steadily with increasing time to a discharge rate of 0.037 cfs after 24 hours and 0.013 cfs after 72 hours. This underdrain outflow value is approximately 46% less than outflow measured prior to the start of the rain event. It appears that the detention pond easily met the 72-hour drawdown requirement for both pond elevation and underdrain discharge rates for this storm event of 1.37 cm (0.54 in).

Relationships between inflow, outflow and pond stage for a 2.72 cm (1.07 in) storm event on July 7, 1992 are given in Figure 4-20. This storm event was a relatively intense event, beginning at 20:50 and lasting for 1.17 hours. The pond elevation increased from a level of 55.58 ft (16.944 m) to a maximum of 56.50 ft (17.226 m) approximately 5 hours after initiation of the rain event. The pond surface elevation began a gradual slow decline following the rain event. However, after 72 hours, the pond water surface elevation was still 0.099 m (0.33 ft) higher than the initial elevation prior to the rain event. After 7 days of drawdown, the pond was still approximately 0.29 m (0.10 ft) greater than the surface elevation prior to the rain event in spite of no measured rainfall or runoff during this period.

Underdrain outflow rates responded rapidly to increases in water surface elevation during this rain event. Prior to the start of the rain event, underdrain discharge was measured at 0.00 cfs. This flow rate increased to a maximum of 0.085 cfs approximately 2 hours after the start of the rain event. Discharge rates declined slowly over a period of days with a discharge value of 0.22 cfs after 24 hours, 0.10 cfs after 48 hours, and 0.05 cfs after 72 hours. The pond did not meet the required 72-hour drawdown for either water surface or underdrain discharge rates for this somewhat intense rain event.

Relationships between inflow, outflow and pond stage for multiple rain events occurring on July 14-15, 1992 with a combined rainfall of 4.88 cm (1.92 in) are given in Figure 4-21. Pond surface elevations and underdrain outflow rates responded rapidly to inflow from stormwater runoff during each of the two events. Drawdown in pond surface elevation and decreases in underdrain outflow rates occurred steadily over a period of several days following the final rain event. After a period of 72 hours following the second rain event, water surface elevation and underdrain outflow rates had declined to values lower than those present prior to the start of the second event but were still greater than original values measured prior to the first rain event on July 14, 1992. The occurrence of multiple rain events apparently has a significant effect on the ability of the detention pond to recover the available storage volume within the required 72-hour period.

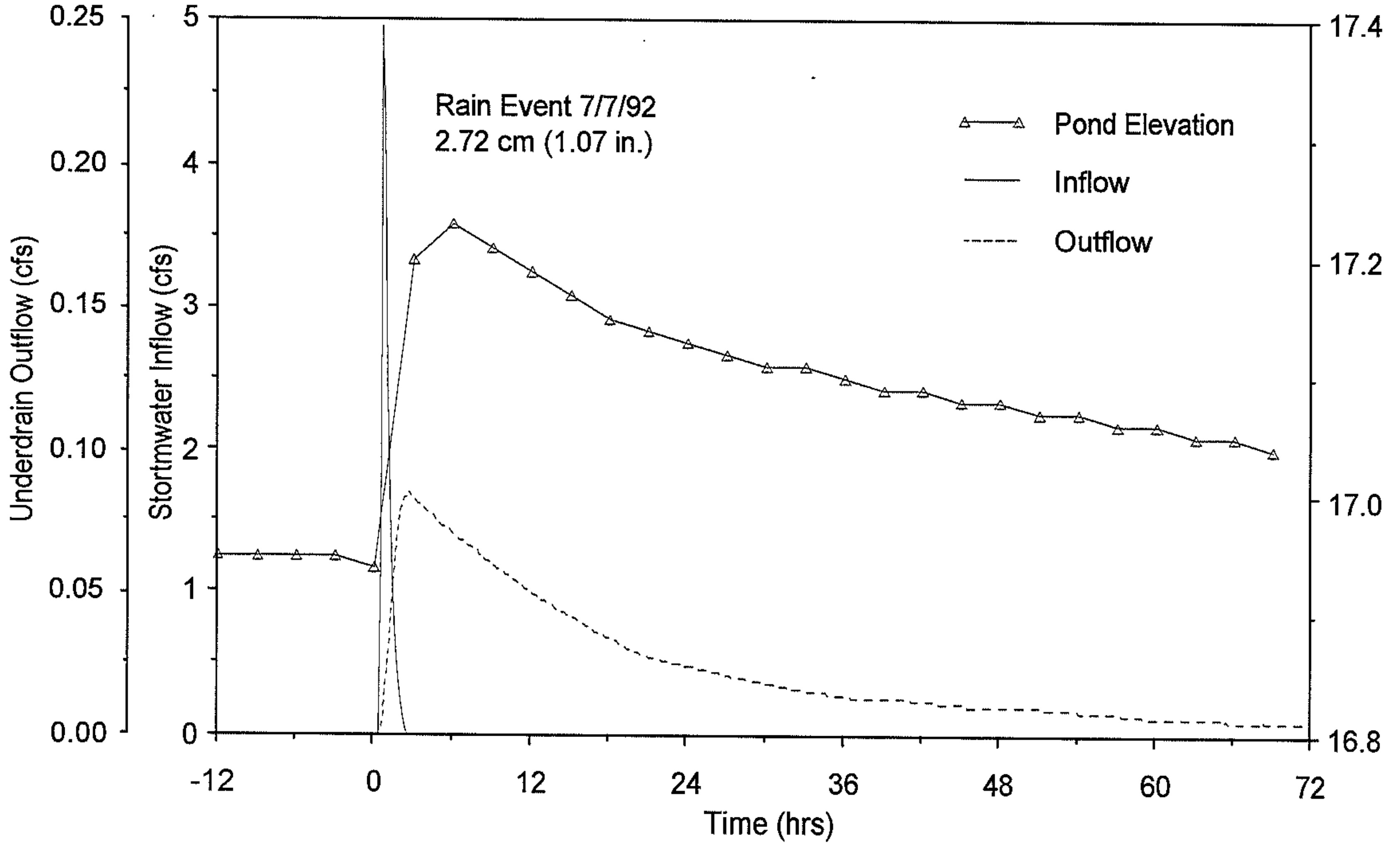


Figure 4-20. Relationships Between Inflow, Outflow and Pond Stage for a 2.72 cm (1.07 in) Rain Event on July 7, 1992.

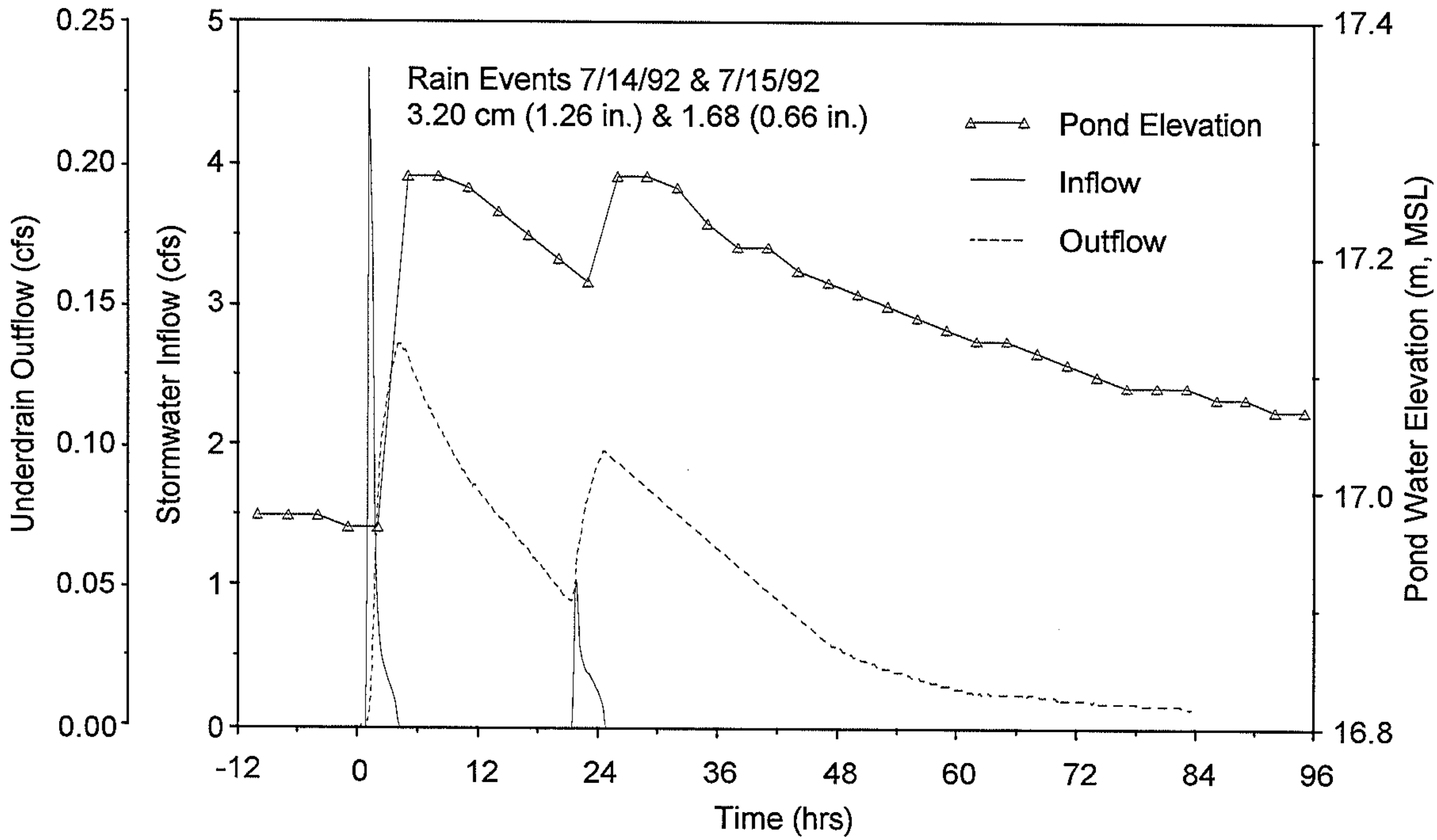


Figure 4-21. Relationships Between Inflow, Outflow and Pond Stage for Sequential Rain Events of 3.20 cm (1.26 in) and 1.68 cm (0.66 in) on July 14-15, 1992.

In summary, for rain events less than approximately 1.3 cm (0.5 in), the detention pond was able to recover both pond elevation and outflow discharge rates to levels equal to or less than those measured in the pond prior to rain events during a drawdown period of 72 hours. However, the pond was unable to recover either pond elevation or outflow discharge rates for rain events substantially in excess of 1.3 cm (0.5 in) or during multiple rain events such as those occurring on July 14-15, 1992.

Drawdown characteristics of the previously discussed storm events on June 6, June 16, July 7, and July 14-15, 1992 are summarized in Figure 4-22. In this figure, underdrain flow rates are plotted versus the hydraulic head above the center of the underdrain pipe based upon pond surface elevations given in Appendix B. References to head above the underdrain pipe in this figure refer to the vertical distance above the centerline of the underdrain pipe.

Drawdown curves for each of the rain events shown in Figure 4-22 appear to reflect exponential type relationships with increasing underdrain flow rates at increasing head elevations. The general shape of each drawdown curve appears to be very similar between the rain events. However, it is interesting to note that the underdrain flow rate for a given head above the underdrain pipe decreases steadily for each of the four rain events. For example, at a head of 0.4 m (1.3 ft) above the underdrain, the underdrain outflow rate during drawdown from the rain event occurring June 6, 1992 is approximately 0.04 cfs. However, by the time of the rain event occurring on July 14, 1992 the underdrain rate through the filter has decreased to approximately 0.01 cfs at the same head of 0.4 m (1.3 ft). This behavior suggests that the filter may trap and accumulate particles during periods of frequent rainfall with gradual decomposition and removal of these particles over time.

Drawdown characteristics for eight storm events from June to November 1992 are indicated in Figure 4-23. Underdrain outflow rates appear to exhibit an exponential relationship as a function of head above the underdrain with rapidly increasing underdrain outflow rates with increasing underdrain head. Underdrain outflow discharge rates appear to approach zero as the distance above the centerline of the underdrain approaches a value of 0.076 m (0.25 ft) which is equal to the elevation at the top of the underdrain pipe. It appears that friction head losses through the filter media may limit the effective drawdown capacity of the underdrain to an elevation of 55.38 ft (16.88 m) which is equal to the top flow line of the pipe. This apparent limit of drawdown is very close to the minimum measured water level of 55.29 ft (16.86 m).

4.9.3 Evaluation of Field Measured Permeability (K) Values

Instantaneous permeability (K) values for the detention with filtration system at the DeBary research site were calculated on a daily basis over the 6-month study period from June through November 1992. Permeability values were calculated for all days when the underdrain outflow was greater than 0.0 cfs using the Incremental Darcy's Equation based upon water surface elevation presented in Appendix D and underdrain

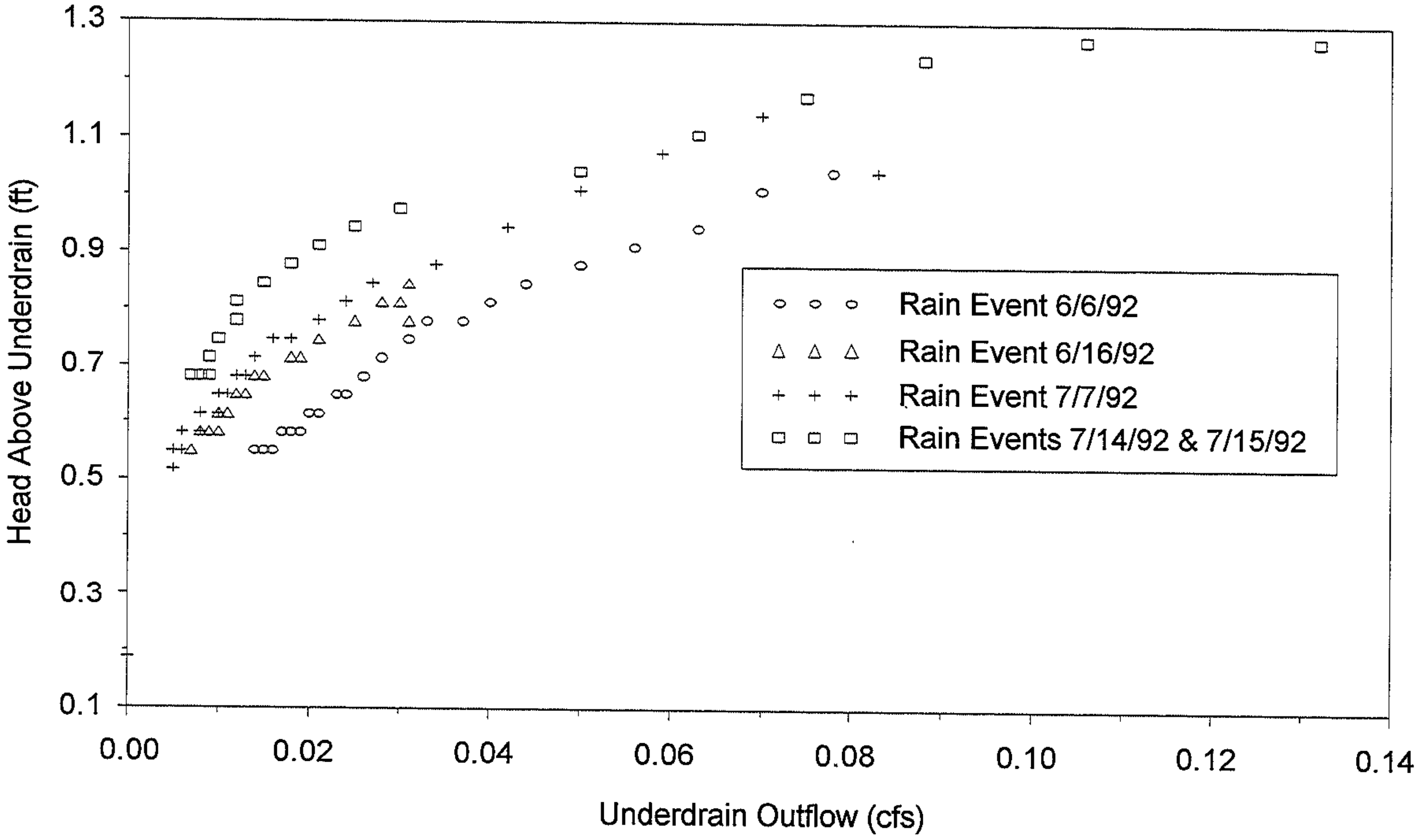


Figure 4-22. Filter Drawdown Characteristics of Selected Storm Events in June-July at the DeBary Research Site.

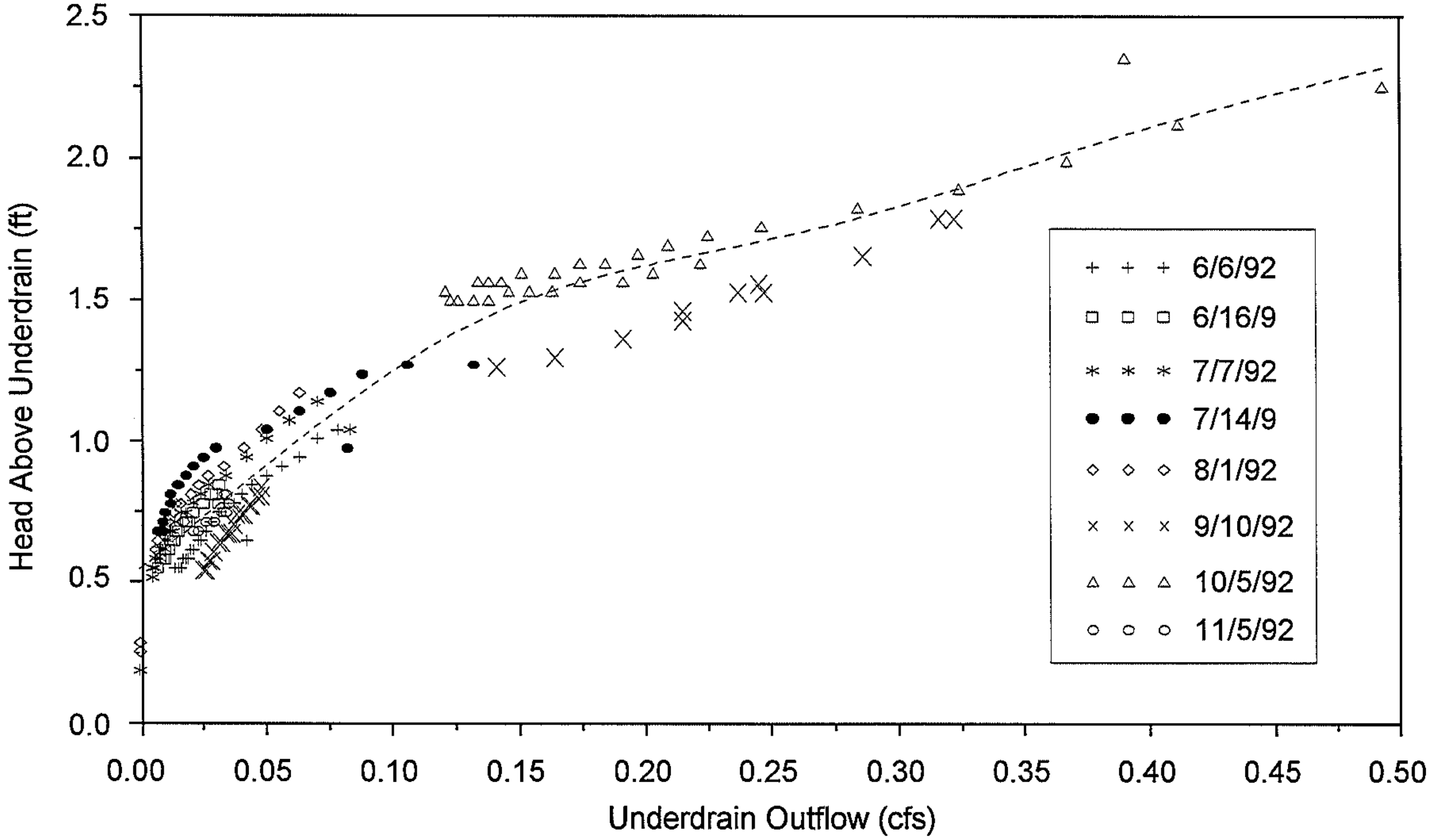


Figure 4-23. Filter Drawdown Characteristics of Selected Storm Events in June-November at the DeBary Research Site.

outflow data given in Appendix G. Instantaneous measurements of water surface elevations and underdrain outflow were collected on a daily basis at an arbitrarily chosen time of 6 p.m. The coefficient of permeability (K) was calculated using the Incremental Darcy's Equation as described in Section 2.4.2.1.

A summary of monthly variations in the calculated coefficient of permeability (K) for the detention with filtration system at the DeBary research site is given in Table 4-40. Calculated minimum and maximum values of K during each month are presented along with the overall mean monthly value. Daily variations in calculated permeability values are extremely high during June and July when the head above the underdrain ranged from 0.2 to 0.3 ft. Calculated permeability values for these months covered more than one order of magnitude between minimum and maximum values. The monthly mean values of 1.91 ft/hr for June and 1.12 ft/hr for July are the lowest values measured during the 6-month study period.

TABLE 4-40

MONTHLY VARIATIONS IN THE CALCULATED COEFFICIENT OF PERMEABILITY (K) FOR THE DETENTION WITH FILTRATION SYSTEM AT THE DEBARY RESEARCH SITE

MONTH	VALUE OF K (ft/hr)			MEAN POND ELEVATION (m)	AVERAGE HEAD ABOVE UNDERDRAIN (ft)
	MINIMUM	MAXIMUM	MEAN		
June	0.44	5.26	1.91	17.021	0.20
July	0.47	6.43	1.12	17.048	0.29
August	0.88	4.87	3.42	17.158	0.65
September	2.90	5.97	3.86	17.221	0.86
October	1.18	5.99	2.22	17.273	1.03
November	1.78	3.07	2.37	17.068	0.35
Mean Values	1.28	5.27	2.34	17.132	0.56

Variability in measured permeability values becomes substantially less during August through November as the average head above the underdrain increases. In addition, the minimum measured permeability values for any given month increased substantially during this period, while the maximum measured values remained relatively constant. Monthly mean values during the period from August through November were substantially higher than those found in June and July, with permeability values ranging from 2.2 to 3.8. The overall mean permeability value for the side bank filter system from June through November was 2.34 ft/hr.

4.9.4 Evaluation of Common Design Equations

Measured drawdown characteristics of the detention with filtration system at the DeBary research site were compared with commonly used design equations for side bank filter systems to evaluate the ability of these equations to predict drawdown characteristics actually measured at the research site. The following common design equations were used in this evaluation:

1. Incremental Darcy's Equation
2. Modified Incremental Darcy's Equation
3. Incremental Darcy's Equation Utilizing the Effective Area

Relationships between underdrain outflow and head above the underdrain for the side bank filter system at the DeBary research site are given in Figure 4-24. Predicted drawdown curves for the previously listed design equations are also indicated on Figure 4-24. Two separate values were assumed for the coefficient of permeability (K) in the design equations. The first K value, 2.34 ft/hr, represents the actual measured permeability value at the DeBary research site determined using Darcy's Equation. The second permeability value, 2.5 ft/hr, represents the allowable permeability (K) values for use in design of filtration systems based on types of soil in which the filter will be placed as recommended by the St. Johns River Water Management District in the Draft Stormwater Handbook. Based upon a soil type in Hydrologic Group A, the allowable permeability value recommended by the District is 2.5 ft/hr.

Both the Incremental Darcy's Equation and the Incremental Darcy's Equation Utilizing the Effective Area appear to provide good fits to the actual measured outflow at the DeBary detention with filtration pond at heads less than 0.75 ft above the centerline of the underdrain pipe. Between a head of 0.75 and 1.0 ft, the Incremental Darcy's Equation Utilizing the Effective Area begins to underestimate flow, while the Incremental Darcy's Equation provides a good fit to the field measured data. From approximately 1.0-1.75 ft, the Modified Incremental Darcy's Equation provides the best fit. At heads above 1.75 ft, all three equations underestimate outflow, however, the Modified Incremental Darcy's Equation provides the closest fit to the actual data. The shape of the curve produced by the Incremental Darcy's Equation is very similar to that observed with the Modified Incremental Darcy's Equation.

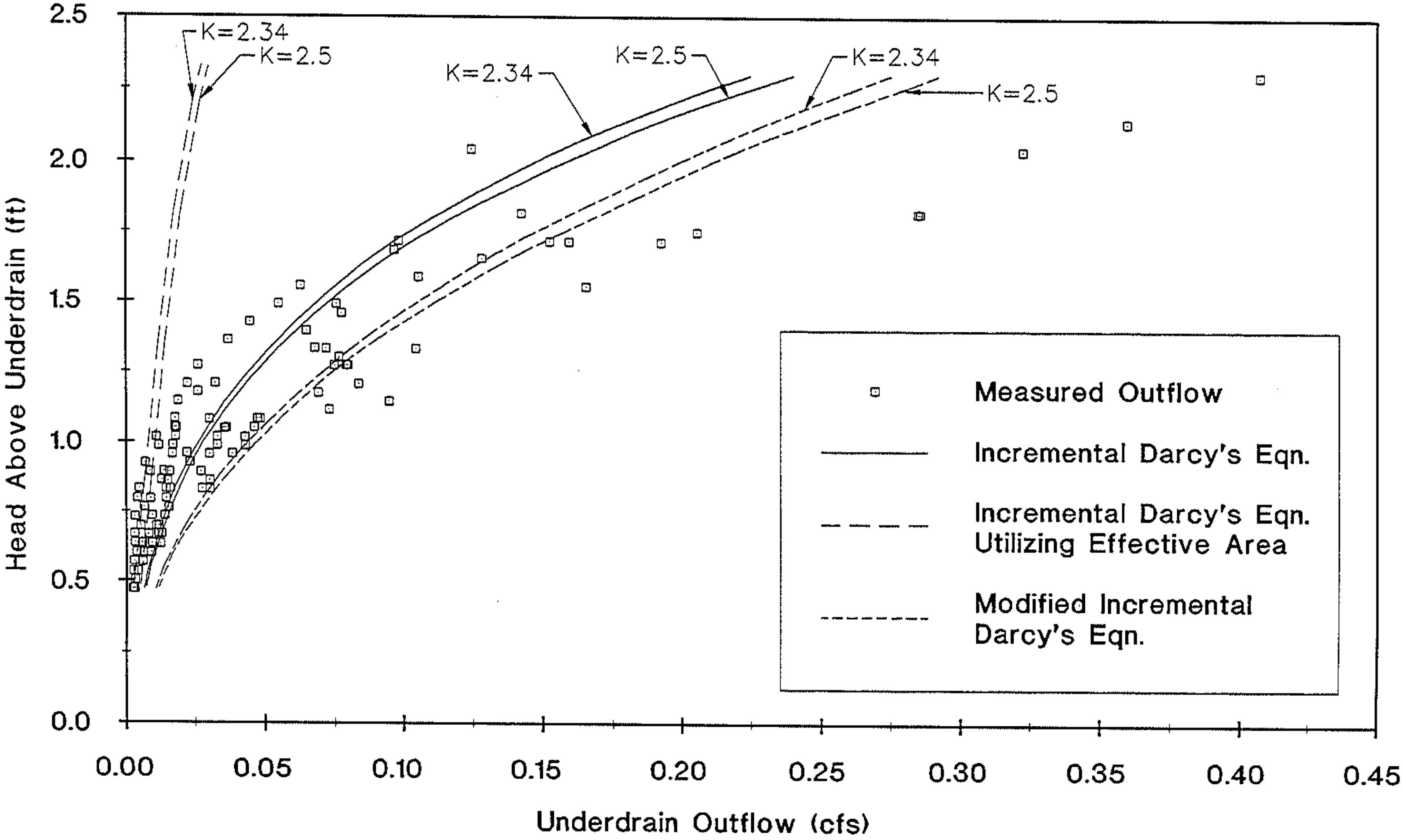


Figure 4-24. Comparison of Measured Drawdown at the DeBary Detention with Filtration Site and Calculated Drawdown Using Common Design Equations.

It appears that either the Incremental Darcy's Equation or the Incremental Darcy's Equation Utilizing the Effective Area are accurate equations under low head conditions (below 0.75 ft), the Incremental Darcy's Equation is the best fit in the medium head ranges (0.75-1.50 ft), and the Modified Incremental Darcy's Equation provides the best fit at the highest head conditions observed in the field (greater than 1.5 ft). As mentioned previously, the Incremental Darcy's Equation Utilizing the Effective Area provides the lowest underdrain outflows for any given head. However, the fact that the equation appears to provide a good fit to actual conditions at very low head elevations may be coincidental. Low underdrain discharge rates during low head conditions are probably a result of the reduced filter surface area rather than a result of the orifice size.

4.10 Hydraulic Characteristics of the Pilot Scale Filter Systems

As described in Chapter 3, a number of hydraulic experiments were conducted using both vertical and side bank filter systems in various configurations to evaluate the hydraulic characteristics of these common filter systems. The purpose of these hydraulic evaluations were to: (1) evaluate the drawdown characteristics of vertical bottom filters as well as side bank filters constructed in a "dry bottom" type configuration, using various filter configurations, filter media and sod covers; (2) evaluate field measured permeability values for various filter media, filter configurations and sod covers; and (3) investigate commonly used design equations for applicability in predicting measured drawdown using the side bank and vertical bottom filter systems. A summary of hydraulic results from pilot studies conducted using vertical and side bank filter configurations is given in Appendix V. The results of these investigations are discussed in the following sections.

4.10.1 Physical Characteristics of Filter Media

Two separate filter media were evaluated in the pilot test experiments. First, FDOT 902.4 media, a commonly specified filter media, was used in both vertical and side bank filter experiments as well as experiments which utilized sod cover. Second, a 20-30 silica sand media was also tested. Sieve analyses were conducted on each of these two filter media to evaluate the physical properties of the media. The results of the grain size distribution conducted on the pilot test filter media are summarized in Appendix S (pages S-15 to S-17).

A summary of physical characteristics of the two filter media used in pilot testing is given in Table 4-41. The D_{10} diameters for the two media were substantially different with a value of 0.154 mm for the FDOT 902.4 media and 0.395 mm for the 20-30 silica sand. Similarly, measured values for D_{60} were also substantially different between the two media with a value of 0.354 for the FDOT media and an estimated value of 1.00 for the 20-30 silica sand. However, uniformity coefficients for the two media were similar, ranging from 2.3 to 2.5. Both media exceeded the minimum value of 1.5 for the uniformity coefficient required by Chapter 17-25. The effective diameter of 0.395 mm for the 20-30 silica sand met the range of 0.20-0.55 mm required in Chapter 17-25. However, the effective diameter of 0.154 for the FDOT media was slightly less than the minimum value of 0.20 recommended in Chapter 17-25. Both filter media met the requirement for organic content to be less than 1%.

TABLE 4-41

PHYSICAL CHARACTERISTICS OF FILTER MEDIA USED IN PILOT TESTING

PARAMETER	FILTER MATERIAL		CHAPTER 17-25 FILTER MEDIA REQUIREMENTS
	PILOT TESTS: FDOT 902.4 MEDIA[1]	PILOT TESTS: 20-30 SILICA SAND	
D_{10}[2] (mm)	0.154	0.395	--
D_{60}[3] (mm)	0.354	1.00 (est.)	--
Uniformity Coefficient[4]	2.30	2.53	> 1.5
Effective Diameter[5]	0.154	0.395	0.20-0.55
Organic Matter (%)	0.3	0.2	< 1

1. Used in both vertical and side bank filter experiments
2. D_{10} = Particle diameter (mm) at which 10% of all particles are finer
3. D_{60} = Particle diameter (mm) at which 60% of all particles are finer
4. Uniformity Coefficient = D_{60}/D_{10}
5. Effective Diameter = D_{10}

The two filter media used in pilot testing appear to fall on either side of the media found at the DeBary research site based upon a comparison of physical characteristics given in Table 4-41 and Table 4-39. The FDOT 902.4 media appears to be somewhat smaller in average grain size than the filter media found at the DeBary research site, while the 20-30 silica sand appears to have an average particle size somewhat larger than that found at the DeBary site.

4.10.2 Drawdown Characteristics of Pilot Filter Configurations

A comparison of drawdown characteristics for various side bank configurations with no sod cover is given in Figure 4-25. This figure includes mean drawdown curves

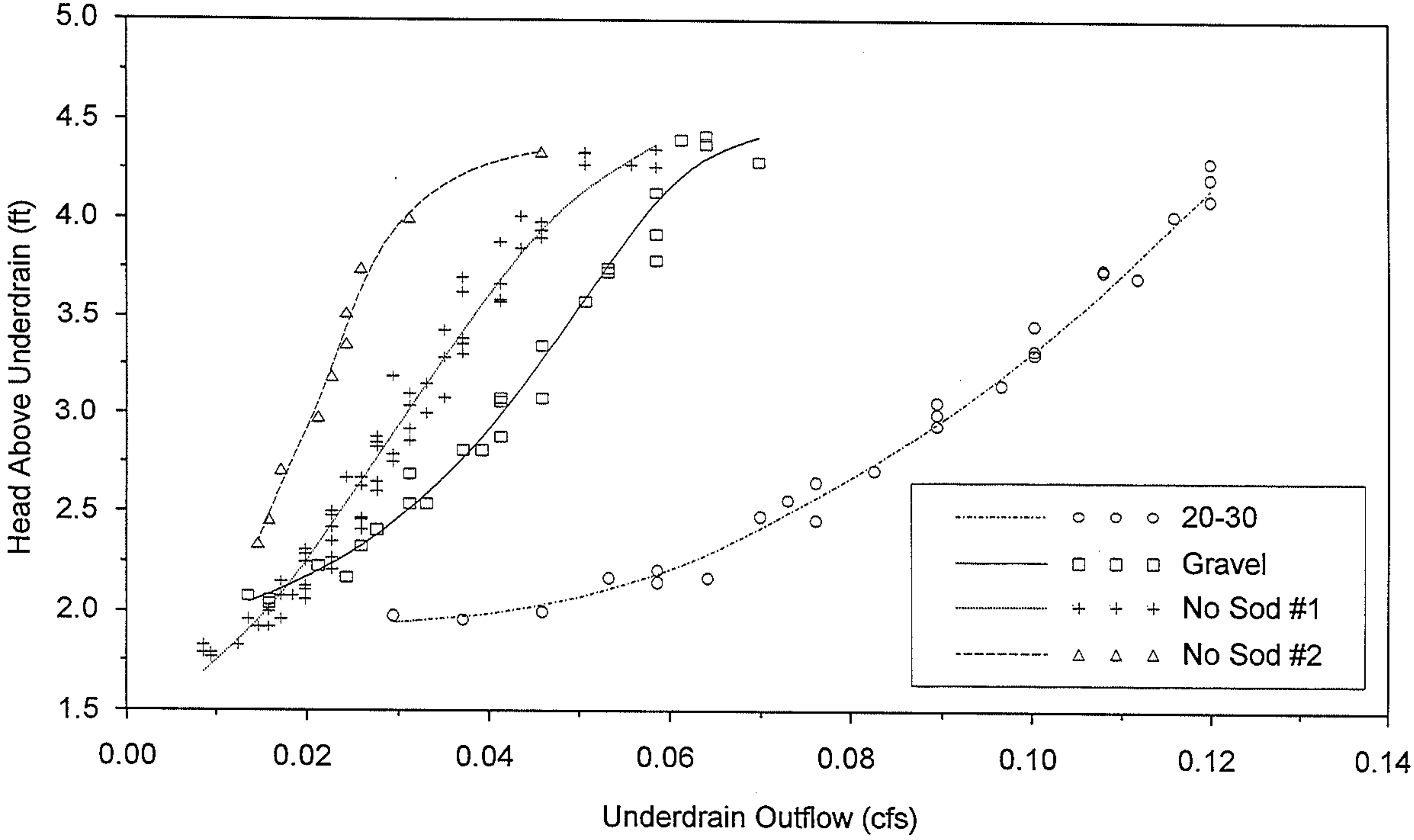


Figure 4-25. Measured Drawdown Characteristics of Various Side Bank Filter Configurations with No Sod Cover.

for the side bank filter constructed using FDOT 902.4 media with no sod cover, the side bank filter configuration using FDOT 902.4 media with a gravel envelope around the underdrain pipe, and a side bank filter using 20-30 silica sand. Data points indicated on Figure 4-25 represent all data collected from a minimum of three separate hydraulic experiments with each media configuration.

Two separate curves are shown in Figure 4-25 for the side bank filter constructed using FDOT 902.4 media with no sod cover. The curve designated as "No Sod #1" represents the average drawdown characteristics of the filter media based upon six hydraulic experiments conducted from May 21 to June 1, 1992, immediately after completion of construction of the filter system. This curve appears to exhibit a logarithmic type curve with underdrain flow rates appearing to level off at head elevations in excess of 4 ft above the filter underdrain. The second curve, indicated as "No Sod #2", represents the hydraulic performance for a single drawdown experiment conducted on December 22, 1992 after the side bank filter had been used for approximately 6 months for experimentation using various types of sod cover. Underdrain flow rates measured during this second experiment were substantially less than those found with the newly constructed filter media. At a head of 4 ft above the underdrain, the flow rate during the second experiments were approximately 40% lower than measured during the first experiment, with a 30% reduction in flow rates at a height of 3 ft above the underdrain pipe.

Drawdown characteristics of a side bank filter constructed with a gravel envelope around the underdrain pipe are also shown in Figure 4-25. This filter configuration provided increased underdrain outflow rates, compared to a side bank filter constructed without an envelope, at head elevations of 2.0 ft or more above the underdrain pipe. At an elevation of 4 ft of head above the underdrain pipe, outflow discharge rates were increased by approximately 20% using the gravel envelope, with an increase of approximately 25% at a head of 3 ft above the underdrain pipe. The drawdown curve for the gravel envelope also appears to exhibit a logarithmic or "S" shaped curve.

Substitution of the 20-30 silica sand for the FDOT 902.4 sand media substantially improved the hydraulic performance of the filter system. The drawdown curve for the 20-30 silica sand appears to exhibit an exponential type relationship. At a head of 4 ft above the underdrain pipe, the measured flow rate through the 20-30 sand was approximately 130% greater than the filter system constructed using the FDOT 902.4 media. At an elevation of 3 ft above the underdrain pipe, the flow rate through the 20-30 silica sand was approximately 180% greater than flow using the typical filter media. At a head of approximately 2.2 ft above the underdrain pipe, the flow using the 20-30 sand was approximately 150% greater.

Drawdown characteristics of a side bank filter system constructed using FDOT 902.4 filter media, covered with various sod types, are shown in Figure 4-26. Drawdown characteristics are included in this figure for four different sod types including Bahia grown in sand, St. Augustine (Floritam) grown in sand, St. Augustine (Floritam) grown in muck, and Bermuda sod grown in muck. Drawdown curves for each of the

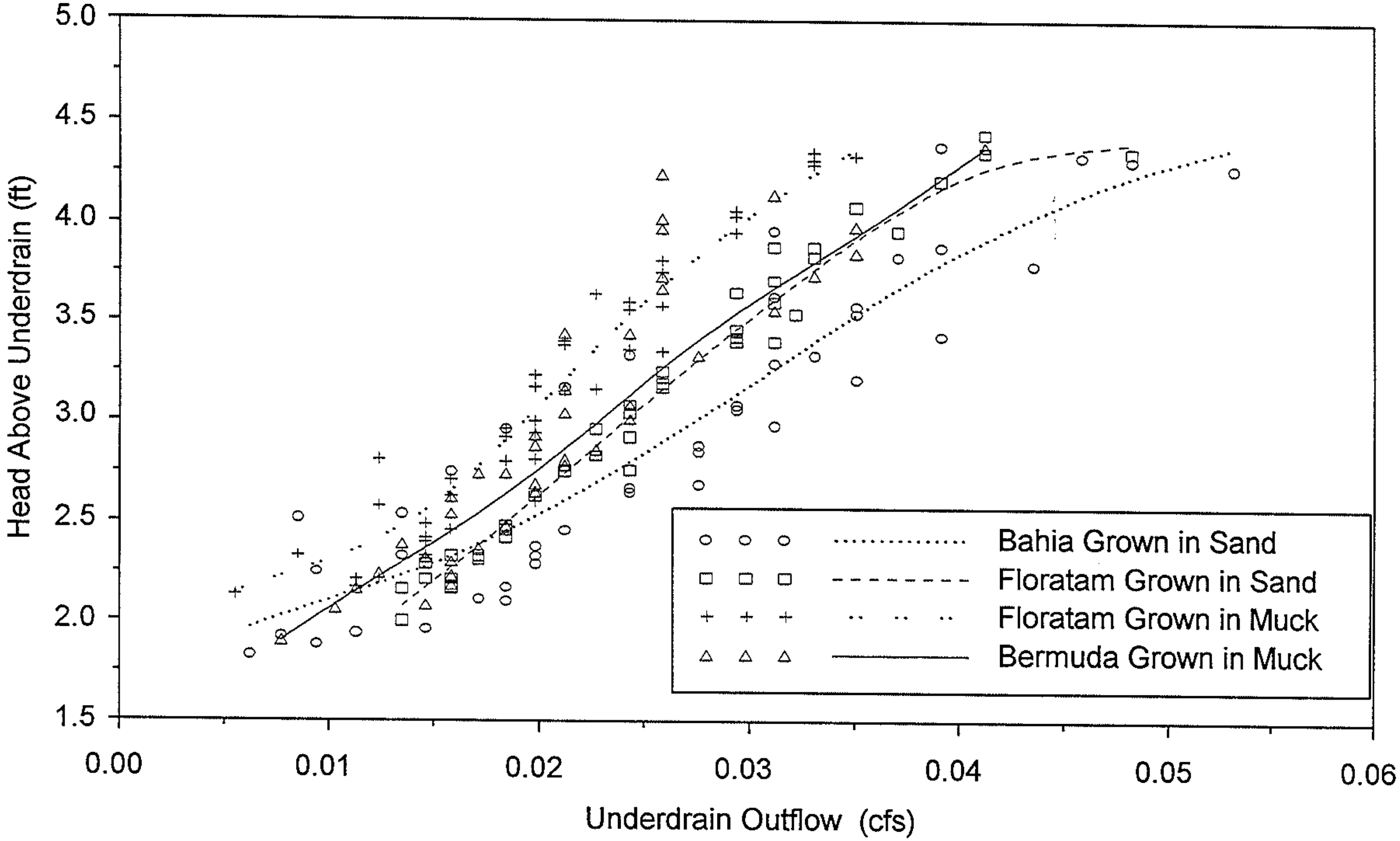


Figure 4-26. Measured Drawdown Characteristics of a Side Bank Filter Covered with Various Sod Types.

four sod types appear to exhibit a logarithmic type relationship, with flow rates beginning to level off slightly at head elevations above 4.0-4.5 ft.

Sod grown in sand appears to exhibit enhanced hydraulic performance compared to sod grown in muck. The best hydraulic performance of the four sod types was achieved using Bahia sod grown in sand, followed by St. Augustine grown in sand. However, the hydraulic characteristics of St. Augustine grown in muck were very similar to that obtained with the St. Augustine grown in sand. The worst hydraulic performance was achieved using Bermuda sod grown in muck. The hydraulic performance exhibited by Bahia sod grown in sand was only approximately 5-10% less than underdrain outflow rates exhibited by the sand filter with no sod cover. The hydraulic performance of St. Augustine sod, for both sand and muck, was approximately 20% less than that exhibited by the filter system with no sod cover. Addition of Bermuda sod grown in muck decreased hydraulic performance approximately 30-35%.

4.10.3 Evaluation of Field Measured Permeability (K) Values

4.10.3.1 Bottom Vertical Filter

Field measured permeability (K) values for the vertical bottom filter were determined using Darcy's Equation for Saturated Flow:

$$Q = KiA$$

where:

Q = the underdrain discharge flow rate (ft^3/hr)

K = permeability of the filter media (ft/hr)

i = hydraulic gradient (ft/ft)

A = filter surface area intersected by the flow (ft^2)

For a vertical filter system, the velocity of flow is assumed to be proportional to the hydraulic conductivity of the soil, and the hydraulic gradient is assumed to be equal to 1. As discussed in Chapter 3, the vertical filter was constructed with a width of 4 ft and a length of 20 ft with an approximate surface area of 80 ft^2. Since underdrain outflow rates were known, K was determined by solving Darcy's Equation with K as an unknown.

Determination of field measured permeability values for the vertical bottom filter are summarized in Table 4-42. A permeability (K) value has been determined for each of the six hydraulic experiments using the bottom vertical filter. Hydraulic conductivity values appear to approach equilibrium values in experiments 4 through 6 at somewhat lower permeability values than measured during the first three experiments. Since the filter sand was installed by hand and was very loose initially, the higher permeability values obtained during the first three runs are probably due to loose filter media conditions. It appears that the filter media compacts over time with equilibrium K values achieved for the last three experiments. The mean permeability value during the last three experiments was 2.01 ft/hr.

TABLE 4-42

DETERMINATION OF FIELD MEASURED PERMEABILITY (K) VALUES FOR THE VERTICAL BOTTOM FILTER
(Based on the assumption that i = 1)

DATE	TOTAL UNDERDRAIN OUTFLOW (ft^3)	DRAWDOWN TIME (hrs)	AVERAGE UNDERDRAIN FLOW (ft^3/hr)	CALCULATED K VALUE (ft/hr)
5/30/92	725	3.78	192	2.40
6/2/92	708	3.50	202	2.53
6/3/92	702	4.00	176	2.20
6/4/92	702	4.38	160	2.00
6/4/92	708	4.42	160	2.00
6/5/92	773	4.75	163	2.04

4.10.3.2 Side Bank Filter Configurations

Determinations of field measured permeability (K) values for various side bank configurations were also determined using Darcy's Equation for saturated flow. However, for a side bank filter, the hydraulic gradient "i" is not assumed to be 1 but varies with pond water level. At any instantaneous moment:

$$i = y/d$$

where:

y = vertical distance between the pond water surface and the center of the underdrain (ft)

d = horizontal distance between the pond water surface and the center of the underdrain (ft)

Calculations of permeability coefficients for each of the pilot scale side bank configurations are given in Appendix W.

A summary of calculated permeability values for various filter configurations and sod covers is given in Table 4-43. The K values presented were determined based upon calculated "i" values from approximately five or six different water levels. The values presented in Table 4-43 are average values for the calculated data points. Please note that a majority of the water levels yielded an i value greater than or equal to 1 due to the configuration of the side bank filter. For filter configurations with an "i" value less than 1, calculated K values may be different. The K values shown in Table 4-43 give an indication of the K value which would most accurately represent the hydraulic capacity of the different media based on the common array of assumptions used to determine the K values shown.

As seen in Table 4-43, the permeability of the side bank filter using the FDOT 902.4 sand was 2.01 ft/hr. This permeability increased to a value of 2.48 ft/hr when a gravel envelope was placed around the underdrain pipe. Substitution of 20-30 silica sand for the FDOT 902.4 media increased the calculated permeability to a value of 5.3 ft/hr. This value was the highest permeability measured in any of the pilot scale tests.

Field measured permeabilities of the side bank filter system covered with various sod types are also summarized in Table 4-43. Calculated permeability values range from a high of 1.89 for the Bahia sod grown in sand to a low of 1.27 for the Bermuda sod grown in muck. The permeability of the filter configuration with a Bahia sod cover grown in sand was only 6% less than the permeability of the filter media with no sod cover. The presence of sod covers, particularly the Bahia sod grown in sand, does not appear to have a significant effect on the calculated permeability of the filter system.

4.10.3.3 Evaluation of Common Design Equations for Predicting Underdrain Flow in Pilot Test Configurations

As discussed in Chapter 3, hydraulic experiments were conducted using a bottom vertical filter with no sod cover and a side bank filter system with various configurations of media and sod cover to evaluate the applicability of commonly used design equations for predicting drawdown for the tested filter configurations. The results of these evaluations are presented in the following sections.

TABLE 4-43

SUMMARY OF CALCULATED K VALUES FOR VARIOUS FILTER CONFIGURATIONS AND SOD COVERS

FILTER MEDIA	FILTER CONFIGURATION	GROUND COVER	AVERAGE CALCULATED K VALUE (ft/hr)
902.4 Sand	Side Bank	None	2.01
902.4 Sand	Side Bank	Bahia grown in sand	1.89
902.4 Sand	Side Bank	St. Augustine grown in sand	1.57
902.4 Sand	Side Bank	St. Augustine grown in muck	1.42
902.4 Sand	Side Bank	Bermuda grown in muck	1.27
902.4 Sand	Side Bank with Gravel Envelope	None	2.48
20-30 Sand	Side Bank	None	5.30

4.10.3.3.1 Vertical Bottom Filter

The predicted drawdown characteristics of the vertical bottom filter were compared using the following design equations:

1. Darcy's Equation (Reference: Florida Development Manual; p. 6-265)
2. Falling Head Equation (Reference: Florida Development Manual; p. 6-268)
3. Incremental Darcy's Equation (Reference: Same as Darcy's Equation with the hydraulic gradient calculated as indicated in Figure 2-5)
4. Incremental Darcy's Equation Utilizing the Effective Area (Reference: SJRWMD Stormwater Applicant's Handbook)

A comparison of measured and calculated drawdown curves using Darcy's Equation, Incremental Darcy's Equation and the Incremental Darcy's Equation Utilizing the Effective Area for the vertical bottom filter with no sod cover is given in Figure 4-27. Drawdown curves for these design equations have been calculated using two separate permeability (K) values. The first K value, 2.01 ft/hr is the mean measured permeability for the FDOT 902.4 media as determined in pilot test experiments. The second permeability value, 2.5 ft/hr, is the maximum permeability value recommended by SJRWMD for filter systems constructed in areas with Type A soils.

Predicted drawdown curves for the vertical bottom filter using Darcy's Equation are essentially vertical lines which assume a constant underdrain outflow for all values of head above the underdrain. Darcy's Equation assumes that the value of $i = 1$, and since K and the filter area are constant, the calculated Q value is essentially the same for all values of head above the underdrain. As seen in Figure 4-27, Darcy's Equation underpredicts flow at head values of 4 ft or more above the centerline of the filter, while this equation overpredicts flow at head elevations less than 3 ft. However, Darcy's Equation can be used to provide an estimate of the average underdrain outflow and, therefore, could be used to quickly estimate required vertical bottom filter size requirements.

Curves representing the calculated values of underdrain outflow versus head above the underdrain for the Incremental Darcy's Equation Utilizing the Effective Area were substantially lower than either the observed values or the calculated values using the other design equations and are too low in value to illustrate on Figure 4-27. The calculated underdrain outflow for a K value of 2.01 ft/hr ranged from 0.003 to 0.007 cfs for head values between 2 and 4.5 feet above the underdrain values. Using a K value of 2.5 ft/hr and a head between 2 and 4.5 feet above the underdrain, the underdrain outflow was calculated to range from 0.004 to 0.009 cfs. The calculations using the Incremental Darcy's Equation Utilizing the Effective Area underestimated observed underdrain outflow by a factor of approximately 10. This equation does not appear to be appropriate for calculating the length of vertical bottom filter required for the filter configuration used in this study.

As seen in Figure 4-27, the Incremental Darcy's Equation overpredicts flow for virtually all conditions of head above the underdrain. This overprediction is increased substantially when a higher K value of 2.5 is used. One method of increasing the accuracy of calculations performed using the Incremental Darcy's Equation is to utilize an average length of flow through the media to its outflow point. Given the filter configuration shown in Figure 2-5, the maximum travel length through the media to the underdrain pipe would be approximately 3.75 ft at the edge of the underdrain trench versus 1.75 ft at the mid-point. Utilizing an average D value of 2.75 ft and calculating Q with a variable "i", the dashed line, as illustrated on Figure 4-27, is obtained. This method, while overestimating underdrain outflow for heads below approximately 3.5 ft, is relatively accurate for head values above 3.5 ft and was the most accurate calculation performed for vertical bottom filters in this study.

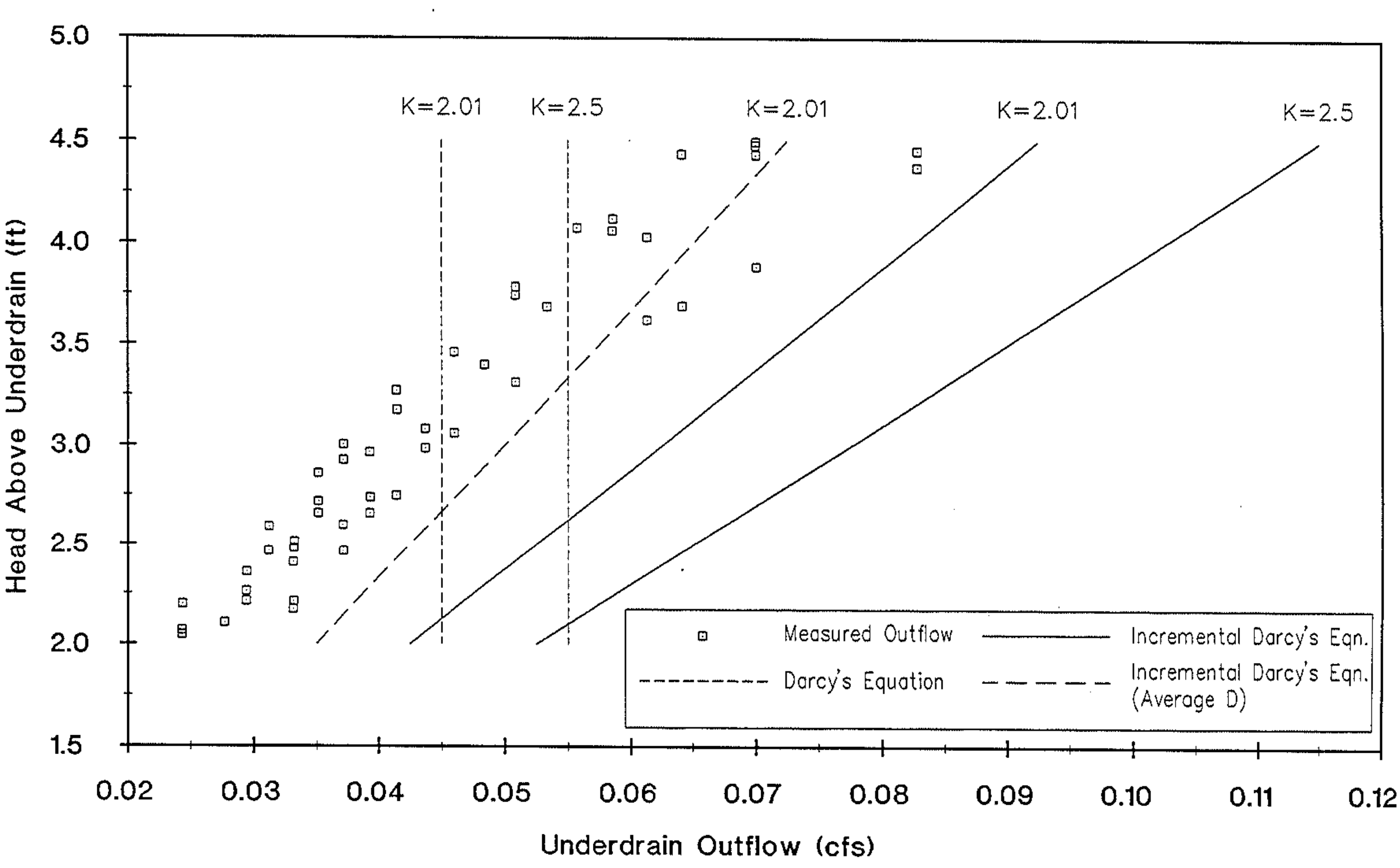


Figure 4-27. Comparison of Measured and Calculated Drawdown Curves for the Vertical Bottom Filter with No Sod Cover.

The Falling Head Equation is primarily used to determine drawdown time required for a filter to drop from an initial water level to some lower level as the water surface draws down toward the pond bottom. A comparison of measured and calculated drawdown times using the Falling Head Equation for pilot studies using the bottom vertical filter is given in Table 4-44. Both calculated and actual drawdown times represent the length of time required for the water elevation to drop from the initial pond level to an elevation equal to the pond bottom. Using the measured permeability of 2.01 ft/hr, a filter area (A) of 80 ft^2 , an average surface area of 280 ft^2 and an average length of flow (D) of 2.75 ft, the Falling Head Equation underestimated the length of time required to drawdown the water level within the pilot test basin. At this permeability, the Falling Head Equation underpredicted drawdown time by an average of 13%. The Falling Head Equation substantially underpredicted the actual drawdown time at a permeability of 2.5 ft/hr, with an average error of 31% for the higher permeability value.

In summary, it appears that, when field measured permeabilities are used, the Incremental Darcy's Equation with an average D and calculated "i" most accurately predicts observed drawdown for vertical bottom filters, although this equation results in overestimates of underdrain outflow under low to medium head conditions. The maximum permeability of 2.5 ft/hr allowed by SJRWMD for use in Type A soils results in a substantial overestimation of underdrain outflow under all head conditions.

4.10.3.3.2 Side Bank Filter Configuration with No Sod Cover

Hydraulic evaluations were conducted using the side bank filter system constructed as a "dry bottom" pond configuration to evaluate the ability of various design equations to predict measured drawdown characteristics for each filter type. Side bank experiments using no sod cover were conducted for the following configurations: (1) a traditional "dry bottom" type filter system constructed using FDOT 902.4 media; (2) a "dry bottom" type filter system constructed using FDOT 902.4 media with a gravel envelope around the underdrain; and (3) a "dry bottom" type filter configuration using 20-30 silica sand as the filter media. Each of these filter configurations were tested using the following design equations:

1. Incremental Darcy's Equation (Reference: Florida Development Manual, p. 6-271)
2. Incremental Darcy's Equation Utilizing the Effective Area (Reference: SJRWMD Stormwater Applicant's Handbook)
3. Modified Incremental Darcy's Equation (Reference: SJRWMD Stormwater Applicant's Handbook, Figure 25-1)

TABLE 4-44

COMPARISON OF MEASURED AND CALCULATED DRAWDOWN TIMES USING THE FALLING HEAD EQUATION FOR THE BOTTOM VERTICAL FILTER

EXPERIMENT NUMBER	HEAD CONDITIONS (ft)		K = 2.01 ft/hr			K = 2.5 ft/hr		
	INITIAL (h_o)	FINAL (h_i)	ACTUAL DRAWDOWN TIME (hr)	CALCULATED DRAWDOWN TIME (hr)	PERCENT ERROR (%)	ACTUAL DRAWDOWN TIME (hr)	CALCULATED DRAWDOWN TIME (hr)	PERCENT ERROR (%)
1	4.46	2.17	3.5	3.4	- 3	3.5	2.8	- 20
2	4.38	2.20	3.5	3.3	- 6	3.5	2.6	- 26
3	4.50	2.10	4.0	3.6	- 10	4.0	2.9	- 28
4	4.44	2.21	4.1	3.3	- 20	4.1	2.6	- 37
5	4.48	2.25	4.0	3.3	- 18	4.0	2.6	- 35
6	4.44	2.19	4.3	3.4	- 21	4.3	2.7	- 37
Average	--	--	--	--	- 13	--	--	- 31

Experimental Conditions:

D = 2.75 ft
a = 280 ft^2
A = 80 ft^2

A comparison of measured and calculated drawdown curves for a side bank filter with no sod cover is given in Figure 4-28. Similar to the approach used for the vertical bottom filter, two separate K values are indicated in this figure, with a value of 2.01 ft/hr as representative of the measured field permeability and a maximum value of 2.5 ft/hr as recommended by SJRWMD.

As seen in Figure 4-28, the best fit to the observed measured outflow values, below a head of approximately 3.5 feet, is attained using the Incremental Darcy's Equation with the K value of 2.50 ft/hr. In this equation, $i = 1$ for all values of $Y \geq 2.31$ ft, representing the upper straight line portion of the curve. For values of $Y \leq 2.31$ ft, the hydraulic gradient i is < 1 and produces the lower portion of the curve. Above a head of 3.5 ft, the Modified Incremental Darcy's Equation produces values closest to actual measurements but the slopes of the calculated and measured data points are substantially different.

The Incremental Darcy's Equation Utilizing Effective Area does not produce a good fit to the observed outflow data for either the field measured K value or the maximum K value. This plot exhibits an inflection point where $Y = 2.97$ ft. Values of $Y \geq 2.97$ ft result in a hydraulic gradient equal to 1 which produces the vertical portions of the equation. For all head conditions, this equation underestimates outflow by over a factor of 10.

As observed with the DeBary research site, the Incremental Darcy's Equation is most accurate at lower heads, with the Modified Incremental Darcy's Equation becoming the most accurate at higher heads. In general, the Incremental Darcy's Equation Utilizing the Effective Area underestimates flow under all head conditions.

A comparison of calculated and measured drawdown curves for a side bank filter constructed with a gravel envelope around the underdrain pipe is given in Figure 4-29. As observed in the side bank filter using the FDOT 902.4 media without a gravel envelope, the Incremental Darcy's Equation is the most applicable equation when a gravel envelope is included with the filter at low heads. As head above the underdrain increases, the Modified Incremental Darcy's Equation becomes more valid.

Interestingly, the Incremental Darcy's Equation Utilizing the Effective Area is reasonably accurate at higher head conditions. The gravel envelope increases the effective radius value by a factor of approximately 20, thus increasing the calculated outflow by the same factor.

A comparison of measured and calculated drawdown characteristics for a side bank filter constructed using the 20-30 silica sand media is given in Figure 4-30. The Incremental Darcy's Equation, while underestimating outflow, is closest to the measured outflow data under low head conditions when the field measured permeability value of 5.3 ft/hr is used as the value of K. At higher heads, the Modified Incremental Darcy's Equation becomes the most accurate estimate. The use of different K values substantially alters the ability of the equation to predict observed outflow values.

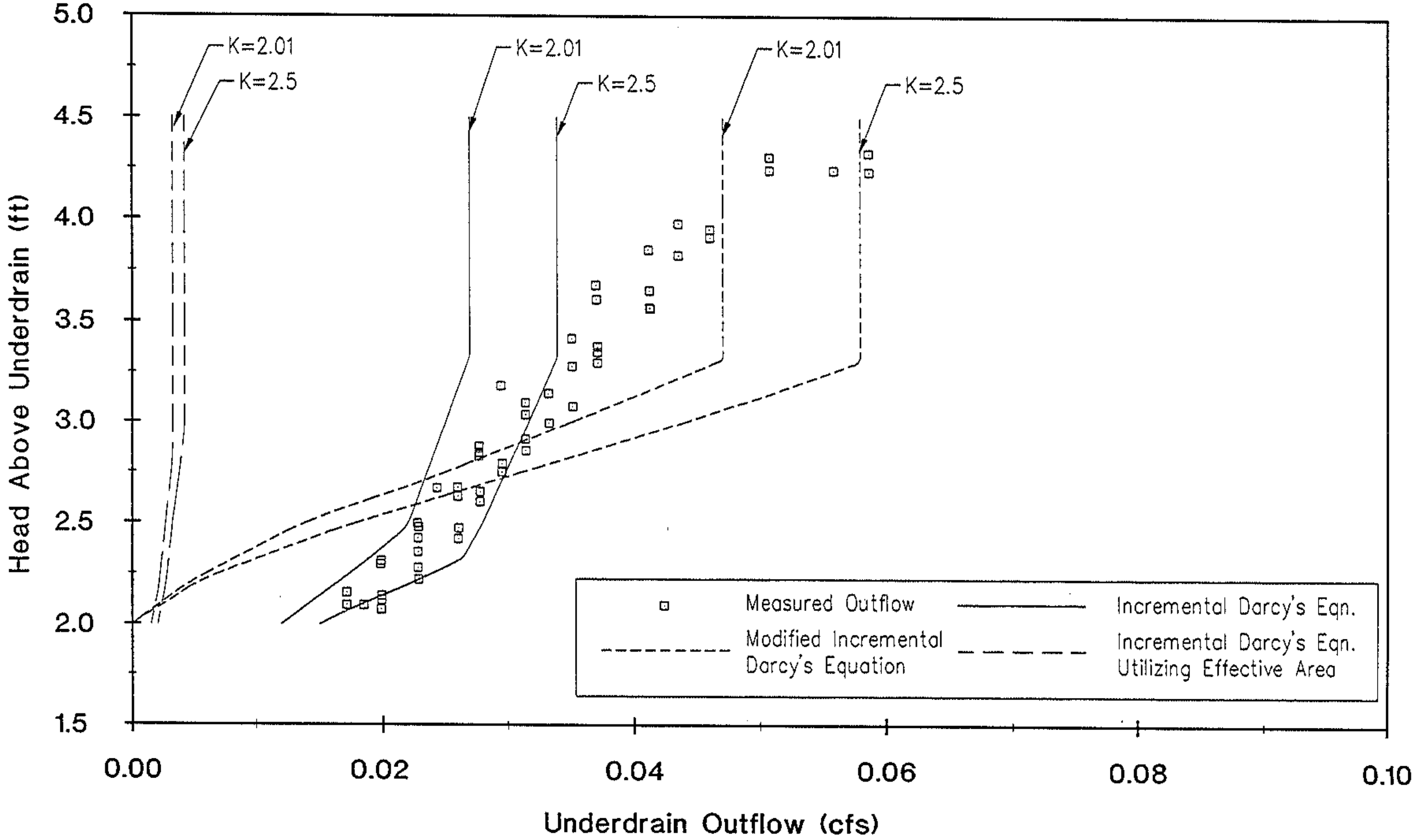


Figure 4-28. Comparison of Measured and Calculated Drawdown Curves for a Side Bank Filter with No Sod Cover.

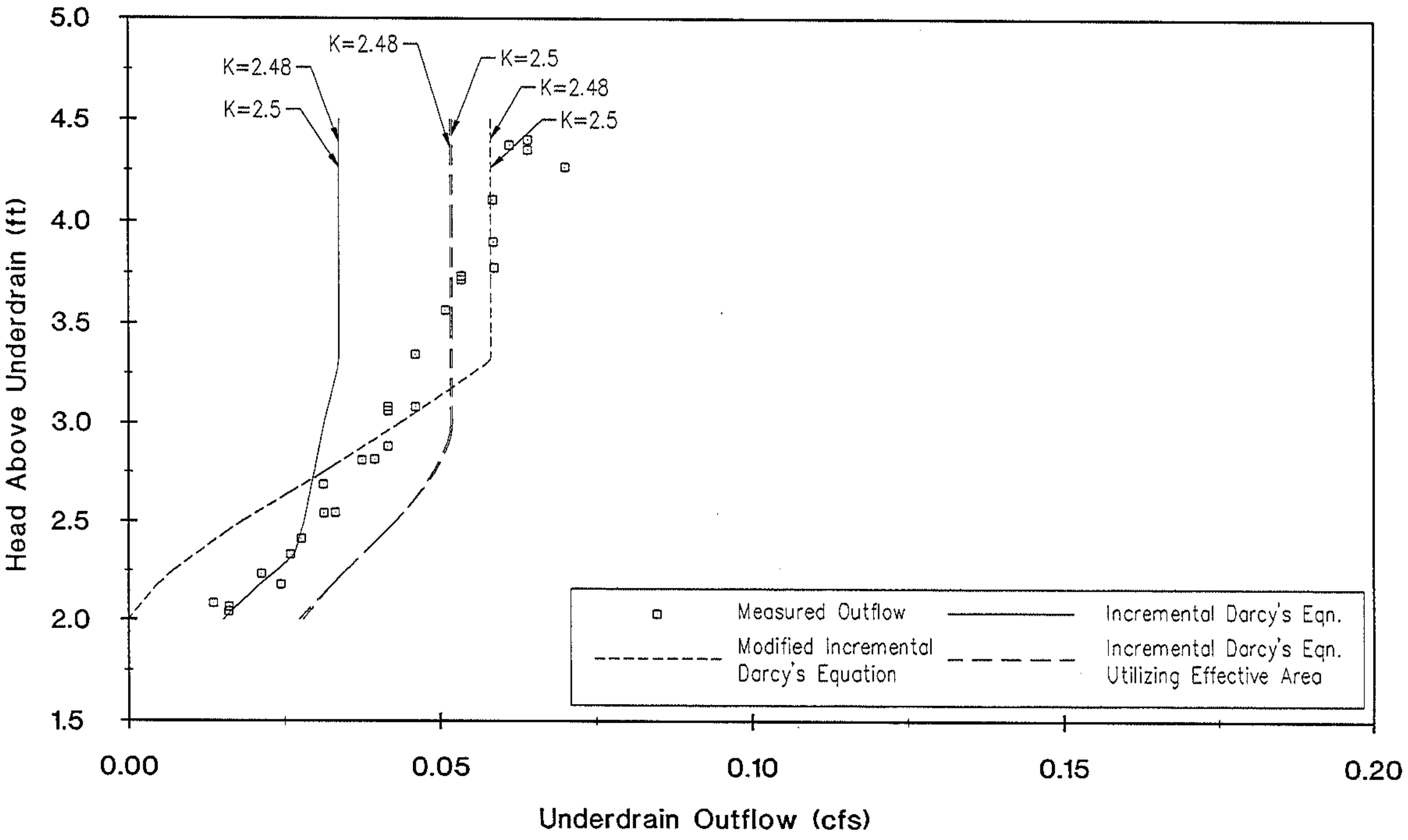


Figure 4-29. Comparison of Measured and Calculated Drawdown Curves for a Side Bank Filter with a Gravel Envelope Around the Underdrain Pipe.

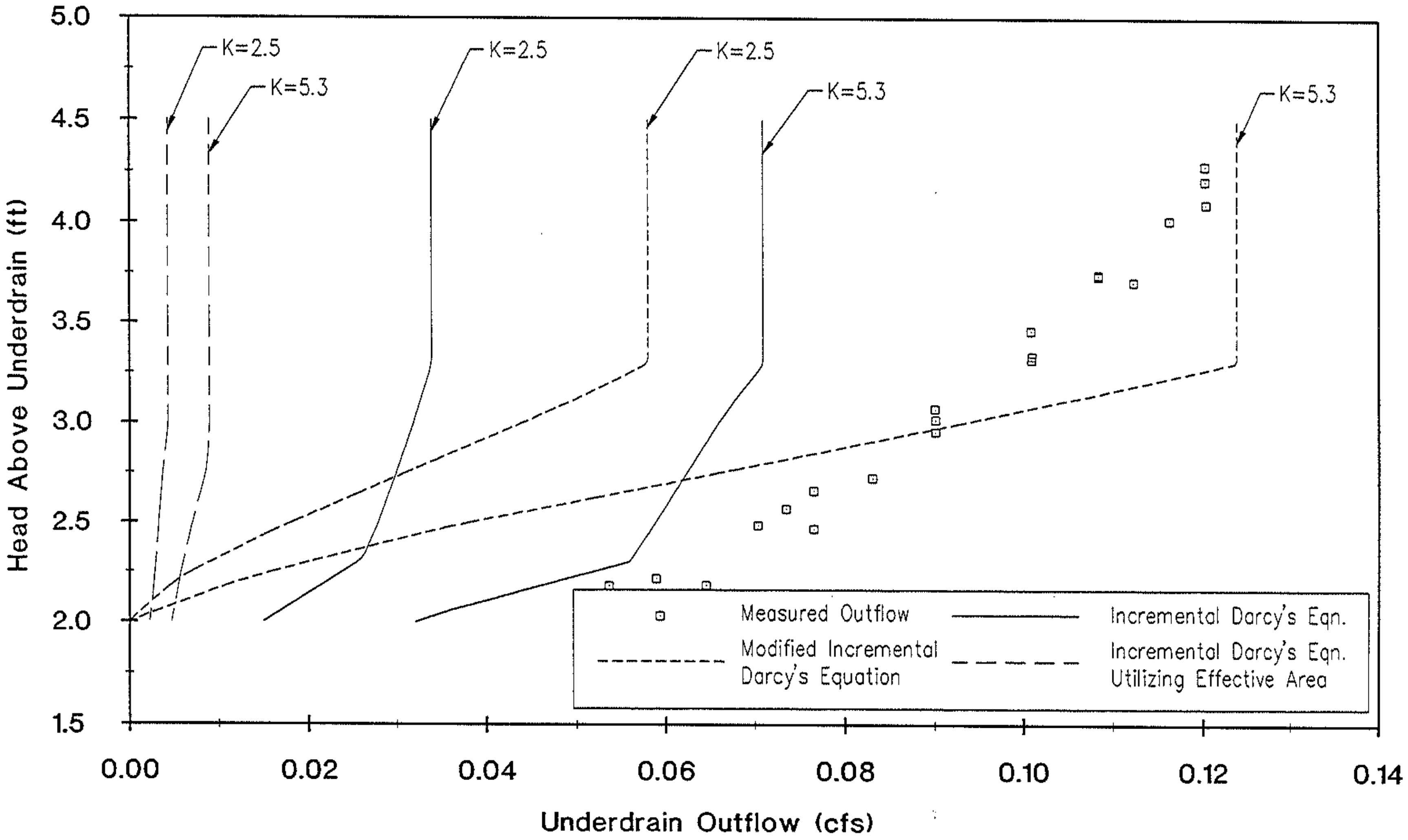


Figure 4-30. Comparison of Measured and Calculated Drawdown Curves for a Side Bank Filter with 20-30 Silica Sand Media.

As observed with the previous filter configurations, except with gravel envelopes, the Incremental Darcy's Equation Utilizing the Effective Area significantly underestimates outflow at all head conditions.

4.10.3.3.3 Effects of Various Sod Types on Design Equations

As described in Chapter 3, hydraulic evaluations were conducted using the side bank filter configuration with FDOT 902.4 media and several sod covers to evaluate the applicability of various design equations for use in filter systems covered with sod. The same design equations used to evaluate the effects of various filter configurations, discussed in the previous section, were used to evaluate the effects of sod cover. A total of four sod cover types were tested, including: (1) Bahia sod grown in sand; (2) St. Augustine (Floritam) grown in sand; (3) St. Augustine (Floritam) grown in muck; and (4) Bermuda-419 sod grown in muck.

A comparison of measured and calculated drawdown curves for a side bank filter covered with Bahia sod grown in sand is given in Figure 4-31. Similar to the trend exhibited by the various filter configurations, the Incremental Darcy's Equation appears to be the best predictor of actual measured outflows from the underdrain system, particularly when the field measured permeability value of 1.89 ft/hr is used for the value of K at low heads. At higher heads, the Modified Incremental Darcy's Equation is more accurate. Increasing the permeability to a value of 2.5 ft/hr results in a substantial overestimate in underdrain flow rates from the pond with the Modified Incremental Darcy's Equation. The Incremental Darcy's Equation Utilizing Effective Area again underestimates outflow discharge substantially.

A comparison of measured and calculated drawdown curves for a side bank filter covered with St. Augustine (Floritam) sod grown in sand is given in Figure 4-32. The Incremental Darcy's Equation provides a better fit to the measured outflow data under low head conditions when the field measured permeability of 1.57 ft/hr is used. At higher heads, the Modified Incremental Darcy's Equation provides a better fit. Substituting a higher value of 2.5 ft/hr for K results in an overestimation of underdrain outflow rates for both equations. Similar to the results observed for the Bahia sod, the Incremental Darcy's Equation Utilizing Effective Area underestimates flow at all heads.

A comparison of measured and calculated drawdown curves for a side bank filter covered with St. Augustine (Floritam) sod grown in muck is given in Figure 4-33. The Incremental Darcy's Equation fits the experimental data well under low head conditions with the field measured permeability of 1.27 ft/hr. At higher heads, the Modified Incremental Darcy's Equation provides a better fit. The Incremental Darcy's Equation Utilizing Effective Area again underestimates outflow at all head conditions. Extremely poor modeling capabilities are achieved using permeability values of 2.5 ft/hr for both equations.

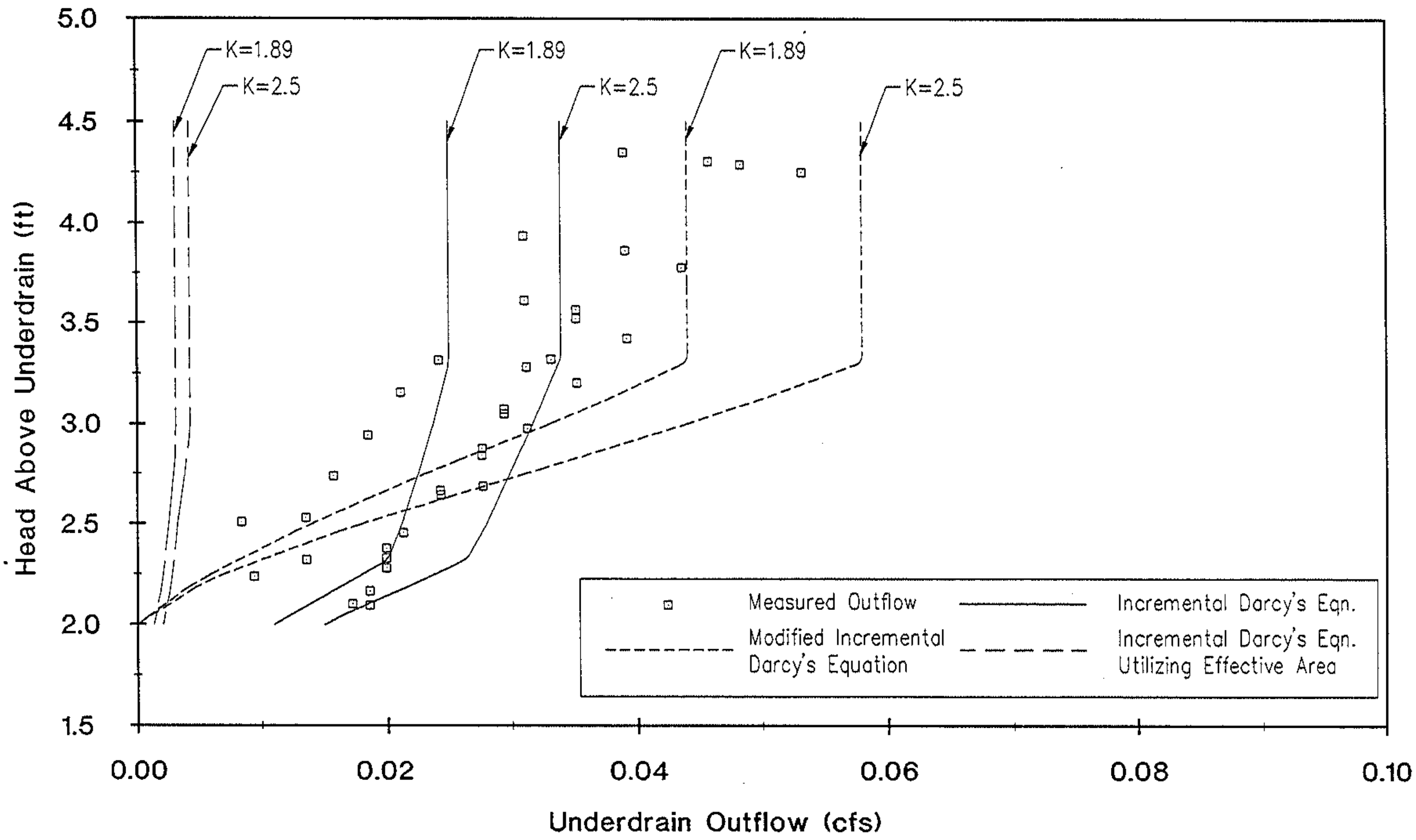


Figure 4-31. Comparison of Measured and Calculated Drawdown Curves for a Side Bank Filter Covered with Bahia Sod Grown in Sand.

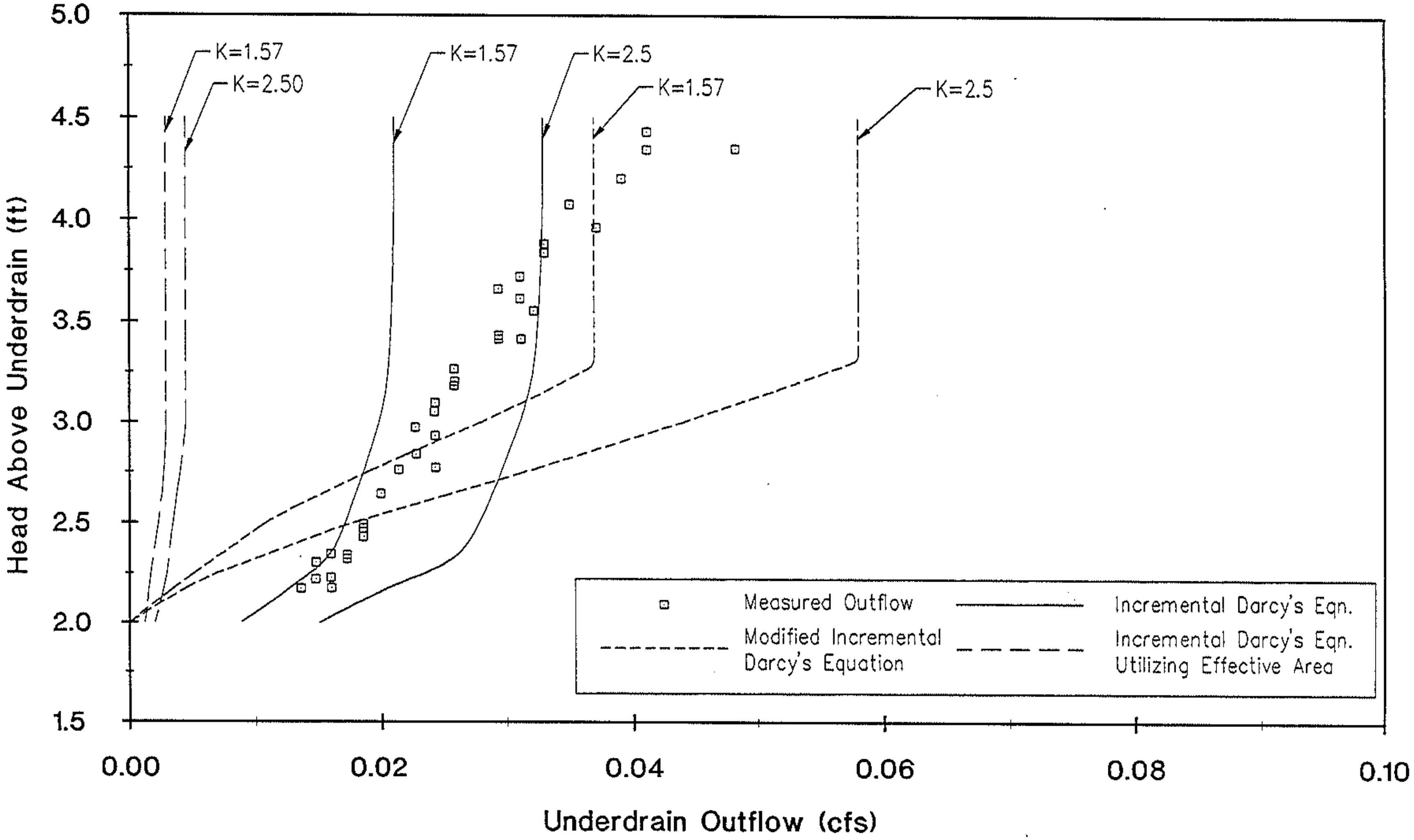


Figure 4-32. Comparison of Measured and Calculated Drawdown Curves for a Side Bank Filter Covered with St. Augustine Sod Grown in Sand.

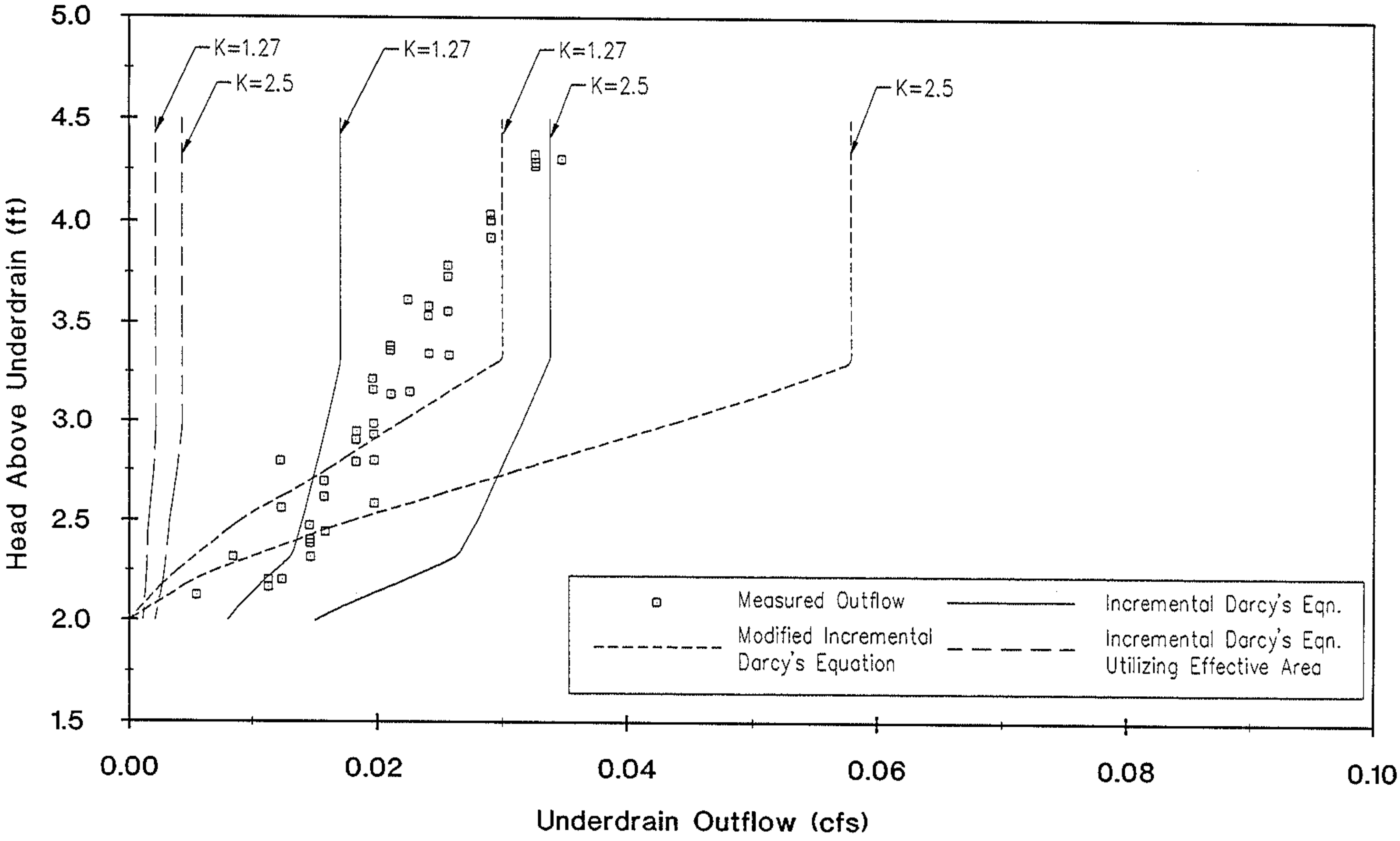


Figure 4-33. Comparison of Measured and Calculated Drawdown Curves for a Side Bank Filter Covered with St. Augustine Sod Grown in Muck.

A comparison of measured and calculated drawdown curves for a side bank filter covered with Bermuda-319 sod grown in muck is given in Figure 4-34. The Incremental Darcy's Equation again provides the best fit to the observed outflow data at low heads using the field measured permeability value of 1.42 ft/hr. As seen with the previous sods, the Modified Incremental Darcy's Equation provides a reasonable fit to the data at higher heads. Poor predictive capabilities are exhibited by both models utilizing K values higher than the measured field value of 1.42 ft/hr. The Incremental Darcy's Equation Utilizing the Effective Area provides an extremely poor fit for all values of head for the Bermuda sod grown in muck.

In summary, it appears that the Incremental Darcy's Equation is the most suitable equation for predicting drawdown characteristics in side bank filter systems for low head conditions. As head increases, the Modified Incremental Darcy's Equation appears to be most appropriate for use in predicting drawdown characteristics of side bank filter systems. The Incremental Darcy's Equation Utilizing the Effective Area provided substantial underestimations of outflow except at very low heads (0.5-0.75 ft) and does not appear to be generally useful for design of side bank filter systems.

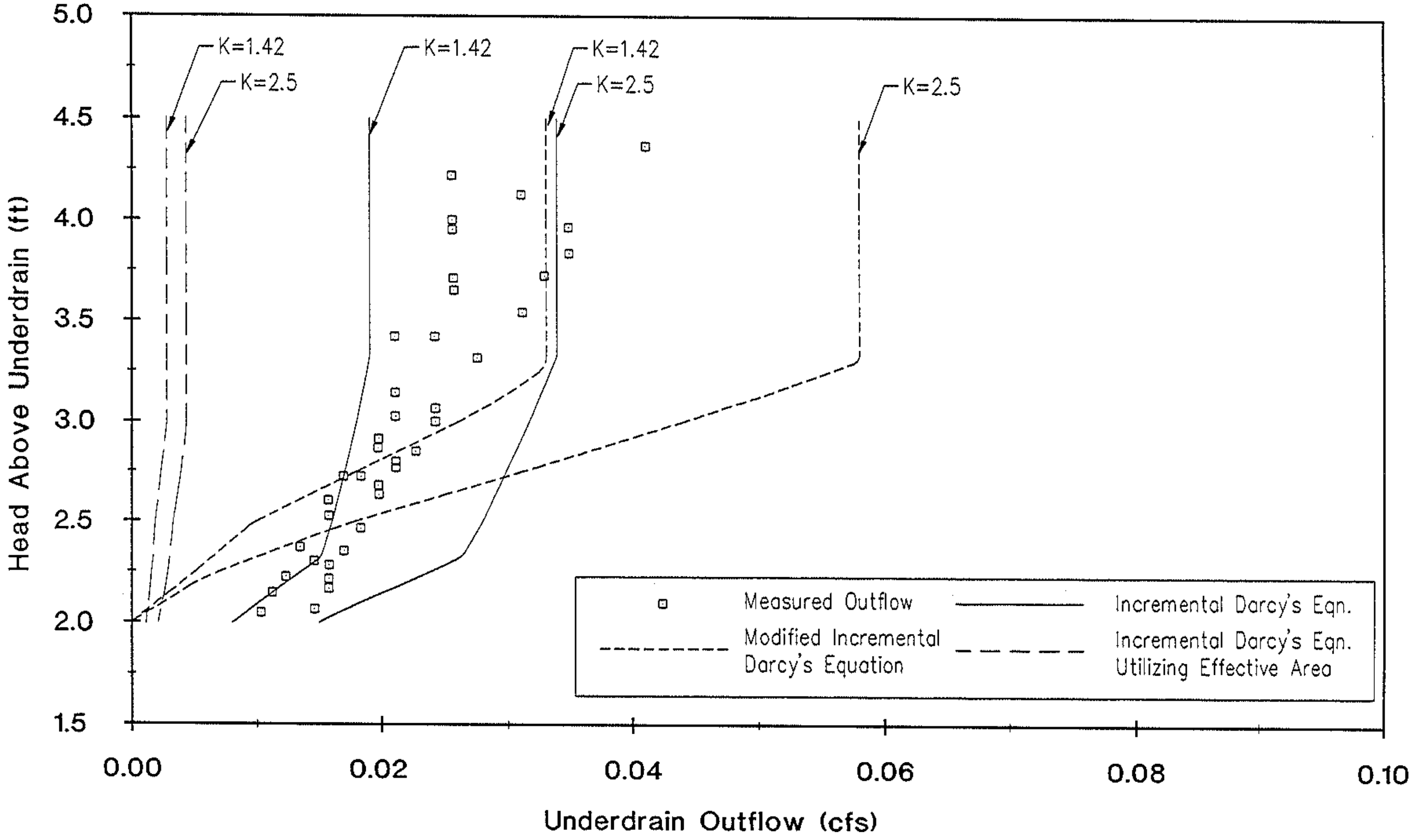


Figure 4-34. Comparison of Measured and Calculated Drawdown Curves for a Side Bank Filter Covered with Bermuda Sod Grown in Muck.

CHAPTER 5

DISCUSSION

The discussion of experimental results contained in this chapter will provide an evaluation of pollutant removal efficiencies achieved by the DeBary detention with filtration pond, with emphasis on the mechanisms responsible for removal of pollutants within the system. The appropriateness of commonly used design equations for predicting hydraulic drawdown in typical filter systems will also be discussed along with a consideration of maintenance procedures for wet and dry filter systems. A review is presented of the characteristics of stormwater runoff collected at the DeBary research site, along with comparisons from other published runoff studies in Central Florida. The potential for migration of stormwater related pollutants into groundwaters at the DeBary site will also be discussed.

5.1 Characterization of Stormwater Runoff at the DeBary Research Site

A comparison of stormwater characteristics measured at the DeBary research site with characteristics found at other Central Florida sites is given in Table 5-1. Data for five other Central Florida sites was obtained from a research project by Harper (1988) which presented event mean runoff characteristics for highway, residential and commercial land use based upon a 12-month monitoring period conducted during 1986 and 1987. Runoff generated at each of the five study sites was transported to the point of measurement by either a curb and gutter stormsewer system or an underground stormsewer.

Stormwater measured at the DeBary research site was found to be slightly more alkaline, with a mean pH of 7.77, and more well buffered, with a mean alkalinity of 90 mg/l, than with runoff measured at the other five Central Florida sites. In contrast, measured concentrations of NO_x and organic nitrogen at the DeBary research site were substantially lower than values measured at any of the other five Central Florida sites. The mean total nitrogen concentration of 761 μg/l is only 17-50% of total nitrogen values measured at other Central Florida locations. In addition, measured concentrations of both dissolved and total heavy metals found at the DeBary research site are substantially lower than values measured at other Central Florida locations, particularly for cadmium, copper, lead and zinc.

TABLE 5-1

COMPARISON OF STORMWATER CHARACTERISTICS MEASURED AT THE DEBARY RESEARCH SITE WITH CHARACTERISTICS AT OTHER CENTRAL FLORIDA SITES

PARAMETER		UNITS	CENTRAL FLORIDA RUNOFF CHARACTERISTICS[1]					DEBARY RESEARCH SITE
			HIGHWAY SITE #1	HIGHWAY SITE #2	RESIDENTIAL SITE #1	RESIDENTIAL SITE #2	COMMERCIAL SITE	
pH		s.u.	6.51	6.78	7.15	7.22	6.96	7.77
Spec. Cond.		µmhos/cm	150	111	83	109	131	130
Alkalinity		mg/l	42	42	50	58	69	90
NH_3-N		µg/l	88	131	34	202	90	77
NO_x		µg/l	400	542	628	262	484	175
Diss. Organic N		µg/l	543	807	841	2880	639	290
Part. Organic N		µg/l	570	672	342	1280	314	220
Total N		µg/l	1601	2152	1845	4624	1527	761
Ortho-P		µg/l	64	159	49	106	18	78
Diss. Organic P		µg/l	34	126	59	822	28	18
Particulate P		µg/l	131	265	90	770	143	164
Total P		µg/l	229	550	198	1698	189	260
Chlorides		mg/l	10	8	11	20	16	9
BOD		mg/l	6.9	4.2	6.5	9.5	11.6	6.9
Turbidity		NTU	21.8	29.2	9.6	13.1	30.3	65
SS		mg/l	34.0	66.5	30.1	63.2	111.4	79.1
Cadmium	Diss.	µg/l	5.99	5.55	1.86	3.06	4.49	< 0.5
	Total	µg/l	8.45	8.35	2.17	5.02	8.15	0.5
Chromium	Diss.	µg/l	8.71	5.35	11.7	9.00	5.55	1.4
	Total	µg/l	13.1	13.6	16.5	15.3	13.0	3.2
Copper	Diss.	µg/l	25.1	25.4	21.8	22.1	18.4	7.5
	Total	µg/l	49.8	66.9	27.4	32.9	31.3	9.7
Lead	Diss.	µg/l	129	74.6	93.1	100	62.1	2.1
	Total	µg/l	224	343	132	158	136	8.5
Iron	Diss.	µg/l	105	95.4	55.8	31.8	115	31
	Total	µg/l	1120	1450	420	464	1100	582
Zinc	Diss.	µg/l	83.7	107	19.2	29.9	46.9	7.5
	Total	µg/l	170	272	44.9	88.9	168	28

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[1] Harper, Harvey H. Effects of Stormwater Management Systems on Groundwater Quality, Final Report to the Florida Department of Environmental Regulation, Project WM190, September 1988.

The somewhat dilute concentrations of nitrogen and heavy metals found in stormwater runoff at the DeBary site may be due to the pre-treatment effects occurring in the roadside swale conveyance system along both sides of U.S. 17. Previous research by Yousef, et al. (1985) on removal of stormwater contaminants by roadside swales, indicates that roadside swales have the potential to remove as much as 30% of the total nitrogen loading and 60-80% of the total metals loading in stormwater runoff during migration through the swale conveyance system. This study concluded that the primary mechanism responsible for uptake of nutrients and heavy metals within swales is contact with the soil surface rather than uptake by vegetation.

At the same time, erosion processes may also be occurring within the swale system which increase the transport of suspended matter. Measured values for turbidity and suspended solids appear to be relatively high at the DeBary research site. It is possible that some of this suspended matter may be generated due to erosion of the swale channel during intense rain events. Nevertheless, the roadside swale system appears to be an extremely effective pre-treatment mechanism for reducing input loadings into the detention pond.

5.2 Characteristics of Pond Surface Water at the DeBary Detention with Filtration Site

As discussed in Chapter 4, chemical characteristics of pond surface water were generally lower in value and substantially less variable than observed for inputs of stormwater runoff. In general, measured variability of chemical parameters within the pond water was relatively small with the possible exceptions of ammonia, NO_x and fecal coliform bacteria. Inputs of stormwater runoff are apparently diluted rapidly into the permanent pool of the detention pond. This dilution process and mixing with existing water within the pond minimizes fluctuations in water quality within the pond water compared to that observed in the stormwater runoff.

The depth of the permanent pool within the pond ranged from approximately 1.5 m (5 ft) to 2.0 m (6.5 ft) during the study period. However, in spite of periodic inputs of stormwater runoff containing elevated levels of BOD, the pond maintained a well aerated and oxidized water column from the water surface to the bottom on all monitoring dates. The minimum dissolved oxygen measured within the pond at a depth of 1.5 m was 5.0 mg/l. Measured values of redox potential indicated a well oxidized water column at all depths on all monitoring occasions. The maximum pond depth of approximately 2.0 m (6.5 ft) appears adequate to maintain these well oxygenated conditions within the pond. However, the fact that well oxygenated conditions were maintained in a pond with a maximum depth of 2.0 m (6.5 ft) does not indicate that ponds deeper than 2.0 m (6.5 ft) will exhibit areas of low dissolved oxygen. Unfortunately, research conducted at the DeBary detention pond does not allow extrapolation of oxygen regimes that may occur in deeper ponds.

5.3 Estimated Mass Removal Efficiencies Achieved at the DeBary Detention with Filtration Pond

5.3.1 Monthly Mass Balances at the DeBary Detention with Filtration Site

Monthly mass balances were calculated for the DeBary detention with filtration pond for each of the six months during the study period from June to November 1992. A summary of monthly mass balance calculations is given in Appendix X. Inputs into the detention with filtration system were assumed to occur from stormwater, bulk precipitation and groundwater inflow. For each month, mass inputs due to stormwater runoff were calculated by multiplying the mean monthly concentration in stormwater runoff for each measured parameter times the monthly hydraulic inputs into the pond as a result of storm events. Inputs from bulk precipitation were estimated as the mean bulk precipitation concentration for each month times the total rainfall volume falling upon the pond surface during each particular month.

Groundwater inputs into the pond were assumed to occur primarily along the western boundary of the pond, with inflow groundwater characteristics represented by the upgradient monitoring well. Mass input from groundwater was calculated as the mean groundwater concentration in the 0-1 m interval of the upgradient monitoring well times the estimated hydraulic inputs from groundwater for each particular month. As seen in Table 4-5, groundwater inflow into the pond was determined to occur only during October and November. The sum of mass inputs from stormwater, bulk precipitation and groundwater equal the total mass input into the pond system for each parameter during a given month.

Mass outputs from the pond occur through the underdrain outflow and by groundwater losses to downgradient areas, primarily on the east end of the pond. Mass loss through the underdrain outflow was calculated by multiplying the mean monthly concentration for each parameter in the underdrain outflow times the estimated hydraulic discharge through the outflow during each month. Losses due to groundwater seepage out of the pond were estimated by multiplying a mean surface water concentration times the estimated hydraulic loss from the pond system into groundwater for each month. The representative concentration of water lost into groundwater was assumed to be equivalent to the concentration within the pond itself since pond water seeping through the sides of the basin represents losses from the system due to groundwater. The sum of the total mass lost by the underdrain outflow and from groundwater is equal to the total mass output from the system. Mass retention within the detention with filtration system is calculated as follows:

$$\frac{\textit{Total Mass Output} - \textit{Total Mass Input}}{\textit{Total Mass Input}} \times 100 = \textit{Mass Retention}$$

A summary of monthly mass removal efficiencies measured at the DeBary detention with filtration pond site is given in Table 5-2. Considerable variability is present in monthly mass removal efficiencies for species of nitrogen as well as dissolved organic phosphorus. A net mass removal by the system was achieved for ammonia and dissolved organic nitrogen during only one of the six monitored months. Net mass removals for NO_x were achieved during three of the six months, with a net removal for particulate organic nitrogen during five of the six months. A net mass removal for total nitrogen was achieved on four of the six months with mass removal efficiencies ranging from -45% to +47% over the study period. Removal efficiencies for some of the nitrogen species appears to be related to the average monthly detention time indicated at the bottom of Table 5-2 with removal efficiencies increasing with increasing detention time within the system.

In contrast, consistently high mass removal rates were achieved for the remaining chemical parameters listed in Table 5-2 during each of the six months monitored. Excellent consistent removal efficiencies were achieved for particulate phosphorus and total phosphorus, with removal efficiencies for total phosphorus ranging from 49-87%. Excellent mass removals were also achieved for suspended solids and BOD with an average removal of approximately 98-99% for these parameters.

Consistent mass removals were also achieved for total heavy metal during each of the six months monitored. Mass removal of chromium, lead, iron and zinc appears to be particularly good within the detention with filtration system.

The effects of detention time on overall mass removal of selected parameters in the DeBary detention with filtration pond are summarized in Figure 5-1. With the exception of total copper, removal efficiencies for each of the listed parameters appears to increase with increasing detention time within the pond. Mass removal of total zinc within the detention with filtration system exceeds 80% for all measured detention times. Mass removal of total phosphorus, total lead and total chromium within the detention with filtration system appears to approach an efficiency of 80% after approximately 30 days of detention time within the pond. Mass removal of total nitrogen within the pond system appears to be extremely variable with a net removal of only 30% achieved after a detention time of 30 days.

Unfortunately, average monthly detention times during the monitoring period were either greater than 40 days or less than 10 days with no values for detention time between 10 and 40 days. This makes extrapolation of the data presented in Figure 5-1 difficult. However, it appears that a net mass removal of 80% can be achieved for total phosphorus, total chromium, total lead and total zinc within the detention with filtration pond system with detention times in excess of 30 days. It appears that removal efficiencies of 80% for total nitrogen or total copper cannot be achieved within the detention with filtration system at detention times as high as 40-45 days.

TABLE 5-2

SUMMARY OF MONTHLY MASS REMOVAL EFFICIENCIES MEASURED AT THE DEBARY DETENTION WITH FILTRATION POND SITE

PARAMETER	AVERAGE MASS REMOVAL EFFICIENCY					
	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
NH_3-N	13	18	26	11	54	-24
NO_x-N	-69	-70	-67	38	21	5
Diss. Organic N	-5	21	5	2	74	109
Part. Organic N	-66	-32	1	-48	-42	-31
Total N	-45	-39	-20	-4	47	18
Ortho-P	-41	-72	-51	-45	-10	-26
Diss. Organic P	-18	-29	4	-67	11	3
Part. P	-85	-94	-68	-81	-85	-77
Total P	-71	-87	-57	-65	-57	-49
TSS	-100	-99	-98	-98	-99	-98
BOD	-97	-98	-99	-100	-99	-96
Total Cadmium	-52	-40	-67	-37	-27	-44
Total Chromium	-79	-78	-67	-39	-52	-24
Total Copper	-31	-41	-45	-26	-48	-12
Total Lead	-91	-90	-74	-60	-70	-64
Total Iron	-81	-86	-43	-60	-79	-70
Total Zinc	-93	-95	-86	-87	-93	-88
Avg. Detention Time (Days)	42.6	40.8	9.7	7.0	7.6	5.6

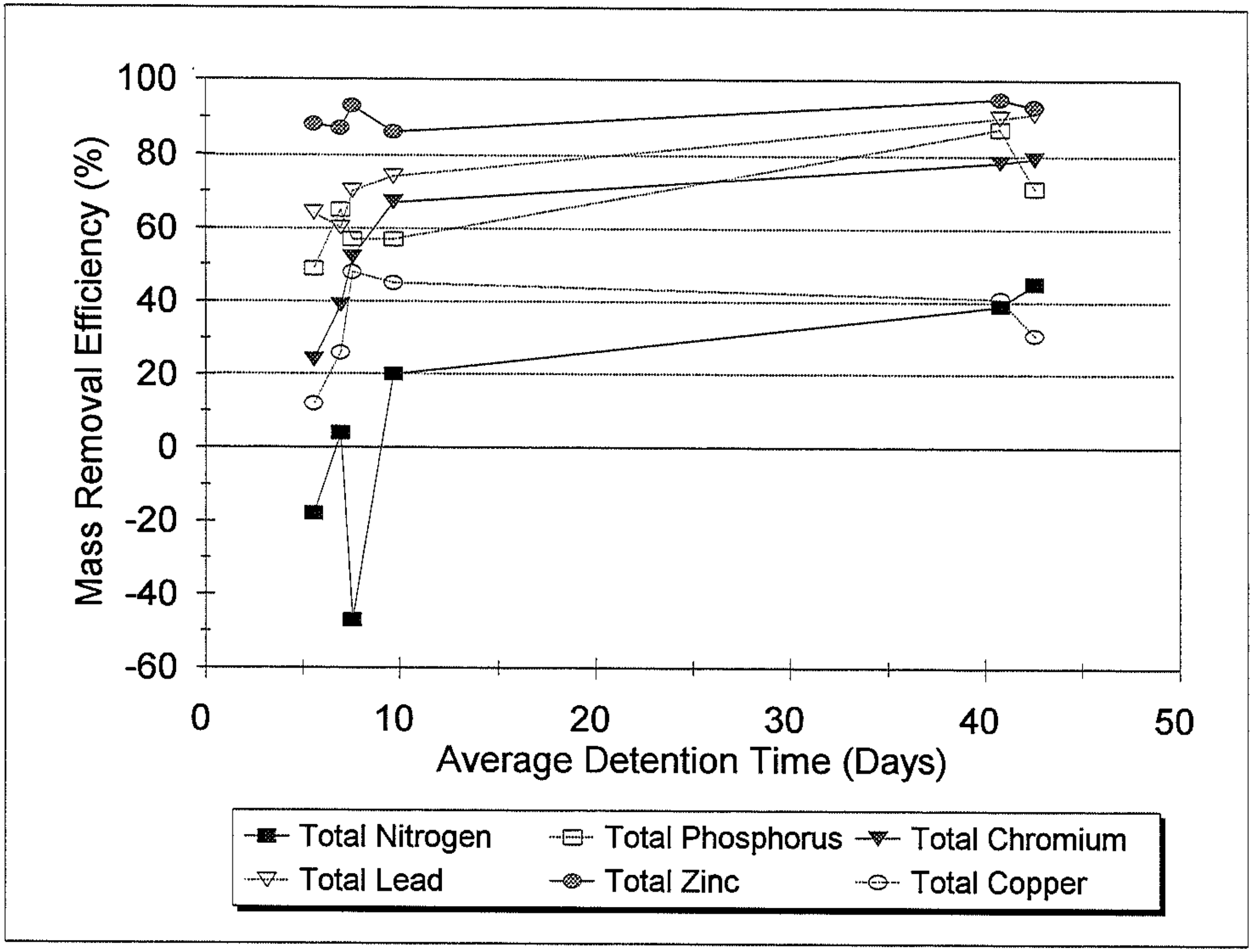

Figure 5-1. Effects of Detention Time on Overall Mass Removal of Selected Parameters in the DeBary Detention with Filtration Pond.

5.3.2 Overall Mass Balance for the DeBary Detention with Filtration Site

An overall mass balance for the DeBary detention with filtration site for the 6-month monitoring period from June to November 1992 is given in Table 5-3. Total inputs into the pond were calculated as previously described including inputs for stormwater runoff, bulk precipitation and groundwater inflow. Total outputs from the pond are also summarized in Table 5-3 and include losses due to underdrain outflow and groundwater lost from the pond. These outputs are calculated in the same manner as described previously for the monthly calculations. The sum of these two output values is equal to the total mass lost from the system during the 6-month monitoring period.

The overall mass retention within the DeBary detention with filtration pond over the 6-month study period is shown in the final column of Table 5-3. In general, mass retention for all nitrogen species was relatively poor within the pond system. Net removal of ammonia within the pond system was only 2%, with a net removal of approximately 30% for NO_x and particulate organic nitrogen. Dissolved organic nitrogen increased in mass during migration through the pond with approximately 36% more mass leaving the pond than entering the pond. This behavior suggests that the removal observed for ammonia and NO_x may simply be a conversion process occurring in the pond where these compounds are converted through microbial activity into dissolved organic nitrogen. Overall, no net removal was observed for total nitrogen within the detention with filtration system with a net export of 3% calculated for total nitrogen.

In contrast, consistent removals were observed for all measured species of phosphorus. Net removal for orthophosphorus within the detention with filtration system was approximately 37% with a 31% retention for dissolved organic phosphorus. Particulate phosphorus appears to be retained extremely well within the pond system, presumably due to settling and adsorption processes occurring within the water column, with a net retention of 80% within the pond. Overall, removal of total phosphorus within the pond averaged 61% during the 6-month study period.

Mass retention for TSS and BOD within the pond was excellent, with an average retention of 98% for TSS and 99% for BOD. Removal for each of these species is enhanced by allowing adequate time for settling and decomposition processes to occur. The minimum detention time of approximately 5 days within the pond system is apparently adequate to remove the majority of the constituents from the water column.

Consistent mass removals were observed for each of the measured heavy metals. In general, a removal of approximately 40% was observed for total copper, with a 50% removal for total cadmium and total chromium, a 70% removal for total lead and total iron, and a 90% removal for total zinc. It is interesting to note that metal species which exhibited high percentages of dissolved fractions in stormwater runoff, including cadmium, chromium and copper, typically had removal efficiencies ranging from approximately 40-50% within the pond. Metal species such as lead, iron and zinc, which are primarily particulate in nature in stormwater runoff, exhibited removal efficiencies

TABLE 5-3

OVERALL MASS BALANCE FOR THE DEBARY DETENTION WITH FILTRATION POND FROM JUNE-NOVEMBER 1992

PARAMETER	TOTAL INPUTS (kg)				TOTAL OUTPUTS (kg)			OVERALL MASS RETENTION (%)
	STORM-WATER	BULK PRECIPITATION	GROUND-WATER	TOTAL MASS INPUT	OUTFLOW MASS	GROUND-WATER	TOTAL MASS OUTPUT	
NH_3	2.023	0.190	2.523	4.736	4.524	0.101	4.625	-2
NO_x	3.204	0.465	0.261	3.930	2.820	0.035	2.855	-27
Diss. Organic N	8.378	0.244	1.215	9.837	11.64	1.709	13.349	36
Part. Organic N	4.730	0.267	0.000	4.997	1.811	1.567	3.378	-32
Total N	18.22	1.157	3.998	23.37	20.79	3.398	24.19	3
Ortho-P	1.942	0.017	0.207	2.167	1.284	0.088	1.372	-37
Diss. Organic P	0.479	0.015	0.015	0.509	0.293	0.059	0.352	-31
Particulate P	3.575	0.041	0.000	3.616	0.392	0.328	0.720	-80
Total P	6.004	0.073	0.217	6.294	1.994	0.474	2.467	-61
TSS	3204	11.03	0.000	3215	26.04	33.15	59.19	-98
BOD	8378	0.000	12.6	8391	58.64	18.01	76.65	-99
Total Cadmium	0.015	0.002	0.001	0.018	0.008	0.001	0.010	-47
Total Chromium	0.079	0.002	0.006	0.087	0.036	0.005	0.041	-52
Total Copper	0.273	0.013	0.013	0.298	0.164	0.025	0.189	-37
Total Lead	0.194	0.003	0011	0.208	0.052	0.010	0.061	-71
Total Iron	13.62	0.108	3.350	17.08	4.170	1.081	5.251	-69
Total Zinc	0.664	0.041	0.005	0.710	0.051	0.025	0.076	-89

from 70-90%. This suggests that a primary mechanism for removal of heavy metals within the detention with filtration pond may be settling processes which occur within the water column allowing particulate forms of heavy metals to settle out into the bottom sediments. This same process is also responsible for the excellent removal exhibited by TSS within the system.

5.4 Evaluation of Removal Mechanisms Within the Detention with Filtration System

A series of analyses were conducted to evaluate mechanisms responsible for removal of pollutants within the detention with filtration system. First, monthly concentration-based removal efficiencies were calculated for the wet detention basin portion of the system only to evaluate removal achieved within the permanent pool of the basin without consideration of the filter system. These removal efficiencies were calculated as the percent change in concentration between inflow stormwater concentrations and average monthly detention basin surface water concentrations for the 6-month study period. Concentration-based removal efficiencies were calculated for each of the measured parameters on a monthly basis for each of the six months monitored.

A second set of removal efficiencies were calculated to evaluate removal occurring through the filter media only. These removal efficiencies were calculated as the percent change between mean monthly pond water concentrations and monthly mean concentrations measured in the underdrain outflow and reflect the percent reductions achieved by the filter media only. Calculations for concentration-based removal efficiencies within the DeBary detention with filtration system for both pond water and the filter system during June through November 1992 are given in Appendix Y.

5.4.1 Pond-Based Removal Efficiencies

A summary of monthly concentration-based pond removal efficiencies during June to November 1992 is given in Table 5-4. A considerable degree of variability is evident in the monthly concentration-based pond removal efficiencies presented in Table 5-4. This variability is particularly apparent for species of nitrogen, dissolved organic phosphorus, BOD and dissolved species of most heavy metals.

During the 6-month monitoring period, excellent removals were obtained for both ammonia and NO_x within the water column of the pond with a net average removal of 62% for ammonia and 92% for NO_x. In contrast, concentrations of both dissolved and particulate organic nitrogen increased by more than 100% within the pond compared with inputs of stormwater runoff. Total nitrogen concentrations within the pond increased an average of 26% compared with stormwater inputs. It appears that the abundant growth of algae within the detention pond may be at least partly responsible for the trend in nitrogen values observed within the pond. Removal of ammonia and NO_x within the

TABLE 5-4

SUMMARY OF MONTHLY CONCENTRATION-BASED POND REMOVAL EFFICIENCIES DURING JUNE-NOVEMBER 1992

PARAMETER		AVERAGE MONTHLY REMOVAL EFFICIENCY						OVERALL AVERAGE
		JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	
pH		8	14	14	-1	-1	-10	4
Spec. Cond.		200	160	54	51	95	165	121
Alkalinity		12	15	59	37	-24	10	18
NH_3		-89	-92	-88	-93	-48	38	-62
NO_x		-95	-99	-93	-93	-87	-84	-92
Diss. Organic N		134	146	44	31	136	130	104
Part. Organic N		57	212	177	134	91	40	119
Total N		11	19	-1	13	92	24	26
Ortho-P		-65	-86	-66	-82	-81	-85	-78
Diss. Organic P		97	128	44	-27	78	39	60
Particulate P		-80	-70	-5	-19	-61	-49	-47
Total P		-68	-68	-28	-46	-56	-58	-54
Turbidity		-92	-89	-46	-93	-95	-90	-84
TSS		-90	-80	-76	-74	-94	-93	-85
BOD		-49	74	66	12	11	-6	18
Cadmium	Diss.	25	29	-53	-43	3	-8	-8
	Total	-29	-18	-52	-54	-28	-69	-42
Chromium	Diss.	-31	-28	57	26	-29	-55	-10
	Total	-67	-72	-58	-30	-66	-69	-60
Copper	Diss.	22	-17	12	-10	-50	-25	-11
	Total	-34	-49	-27	-22	-69	-48	-42
Lead	Diss.	-48	-41	-29	-39	-21	9	-28
	Total	-89	-78	-44	-72	-87	-77	-75
Iron	Diss.	69	-1	255	121	139	360	157
	Total	-60	-65	-40	-38	-29	9	-37
Zinc	Diss.	-35	-34	-15	-37	-9	-63	-32
	Total	-86	-83	-65	-70	-82	-90	-51
Detention Time		42.6	40.8	9.7	7.0	7.6	5.6	18.9

pond water is likely due to uptake by algae which utilize these organic sources of nitrogen for growth. These inorganic nitrogen species become incorporated into algal biomass which increases particulate organic nitrogen as well as total nitrogen within the pond.

Orthophosphorus was removed consistently over the 6-month period with a mean removal of 78% within the water column. Orthophosphorus is apparently utilized as a nutrient source by algae within the pond and incorporated into algal biomass. Concentrations of dissolved organic phosphorus increased within the pond which may be due to byproducts resulting from algal production and decomposition processes. Relatively good removals were achieved for both particulate and total phosphorus within the pond with an average removal of 50% for each of these parameters.

Removal of both turbidity and TSS within the pond were relatively consistent over the 6-month study period with an average removal of approximately 85% for these parameters. The relatively quiescent water column within the pond provides an optimum opportunity for settling of particulate matter after entering the pond system, resulting in the excellent removal efficiencies observed for these parameters. In contrast, removal of BOD within the pond water was found to be extremely variable with a net removal occurring in the water column on only two of the six monitoring dates. Overall, BOD concentrations increased 18% within the pond compared to stormwater inputs. However, these increases in BOD may not be purely related to stormwater inputs entering the pond. As described in Chapter 3, the pond contained a relatively large population of water fowl which could contribute heavily to BOD loadings and may mask removal efficiencies achieved for stormwater runoff within the pond system.

Removal of dissolved metal species within the pond was extremely variable over the 6-month monitoring period. All of the measured heavy metals, with the exception of zinc, exhibited months with both positive and negative removal efficiencies within the water column of the pond. However, on an overall average basis, dissolved concentrations of all heavy metals were reduced within the water column of the pond with the exception of dissolved iron which increased an average of 157%. In general, removal of dissolved cadmium, chromium and copper averaged approximately 10% within the pond, with removals for dissolved lead and zinc of approximately 30%.

The effects of pond detention time on the removal of total nitrogen, total phosphorus, TSS and BOD within the water column of the pond are illustrated in Figure 5-2. The removal of total phosphorus and TSS within the water column of the pond appears to have reached near maximum levels at the minimum detention time of 5.6 days. Removal efficiencies for these parameters increased only slightly by increasing the average detention time to 40 days.

In contrast, removal efficiencies observed for total nitrogen and BOD are extremely variable and do not appear to exhibit a strong relationship with average detention time. Negative removal efficiencies are exhibited for total nitrogen and BOD for many of the monthly averages. It does not appear that increasing the average

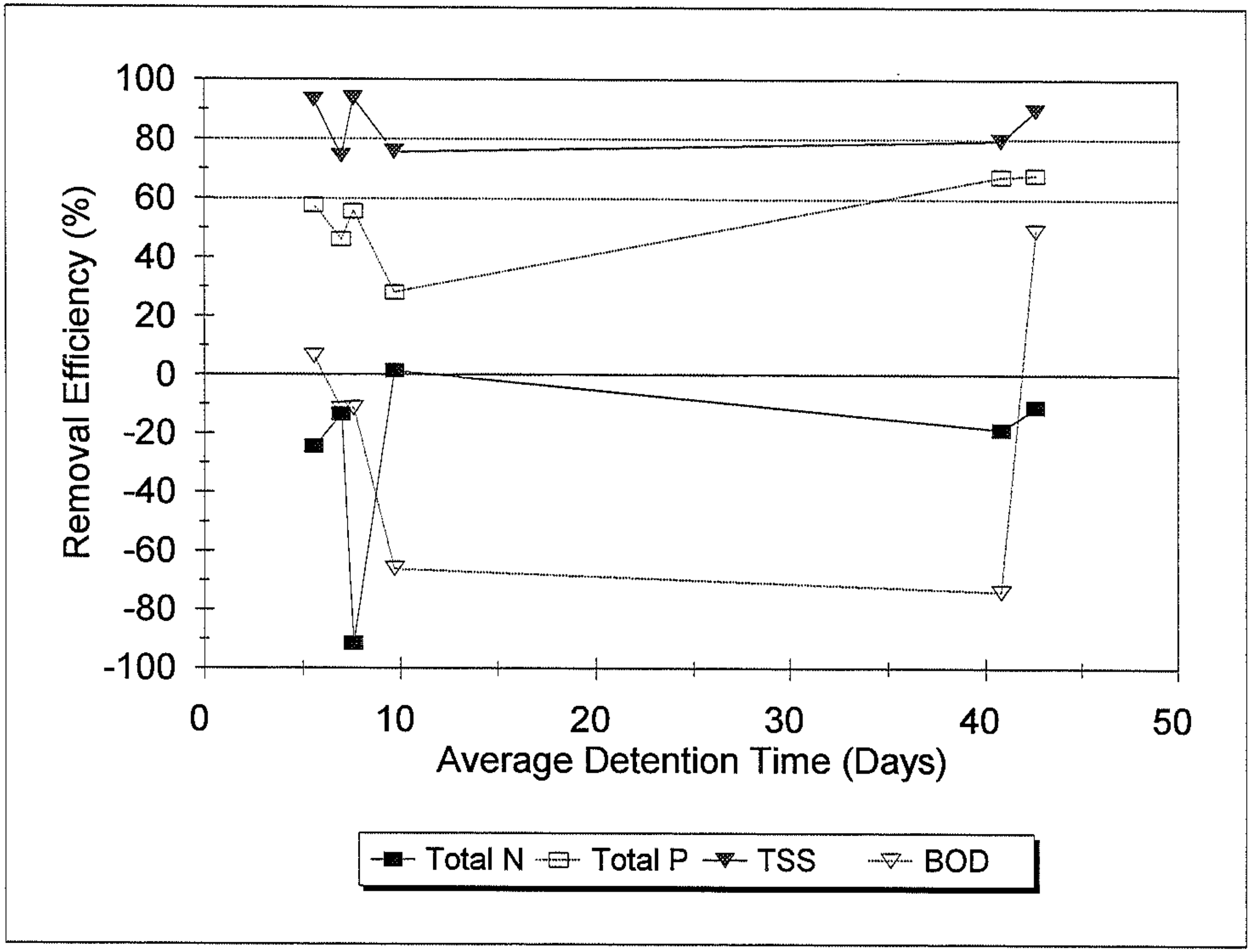

Figure 5-2. Effects of Pond Detention Time on Removal of Total Nitrogen, Total Phosphorus, TSS and BOD within the Pond.

detention time within the pond above the minimum measured value of 5.6 days will significantly improve the overall removal efficiencies exhibited for the parameters shown in Figure 5.2.

The effects of pond detention time on removal of total chromium, lead, zinc and copper within the pond are illustrated in Figure 5-3. Water column removal efficiencies exhibited for these parameters appear to be extremely variable particularly at average detention times of 10 days or less. Removal efficiencies become more consistent as the average detention time increases with net removals for total lead and total zinc within the water column of 80% or more at average detention times in excess of 40 days. The removal of total chromium and total copper did not appear to be substantially enhanced by increasing the average detention time within the pond.

5.4.2 Removal Efficiencies Achieved Within the Filter System

Concentration-based removal efficiencies for the side bank filter only during the period from June through November 1992 are summarized on a monthly basis in Table 5-5. In general, changes in concentration during migration through the filter media appear to be substantially more consistent than observed for concentration changes within the pond.

In contrast to the trends observed within the detention pond water column, concentrations of both ammonia and NO_x increased substantially during migration through the filter media, while concentrations of organic nitrogen species decreased during migration through the media. Net removal of total nitrogen within the filter averaged 22%. This behavior suggests that particulate organic nitrogen is being trapped within the filter media on a consistent basis. However, organic nitrogen trapped by the filter is apparently decomposing through microbial activity into ammonia and NO_x, resulting in substantially increased concentrations for these parameters in the underdrain outflow. The removal of particulate nitrogen within the filter, therefore, is only temporary in nature with subsequent breakdown and decomposition into soluble inorganic species of nitrogen which then pass through the filter media.

A similar pattern is exhibited for species of phosphorus within the filter media. During migration through the filter, approximately 65% of the particulate phosphorus is removed and retained within the filter. However, increases of over 200% were measured for outflow concentrations of orthophosphorus through the filter media. It is apparent that particulate phosphorus trapped upon the filter media is slowly decomposing and leaching through the media as soluble orthophosphorus. Net retention on the filter media for total phosphorus was approximately 20%.

The filter media appears to be relatively efficient in trapping and retaining both turbidity and TSS within the media, with an average removal of 76% for turbidity and 89% for TSS over the 6-month period. BOD is also removed by the filter media with

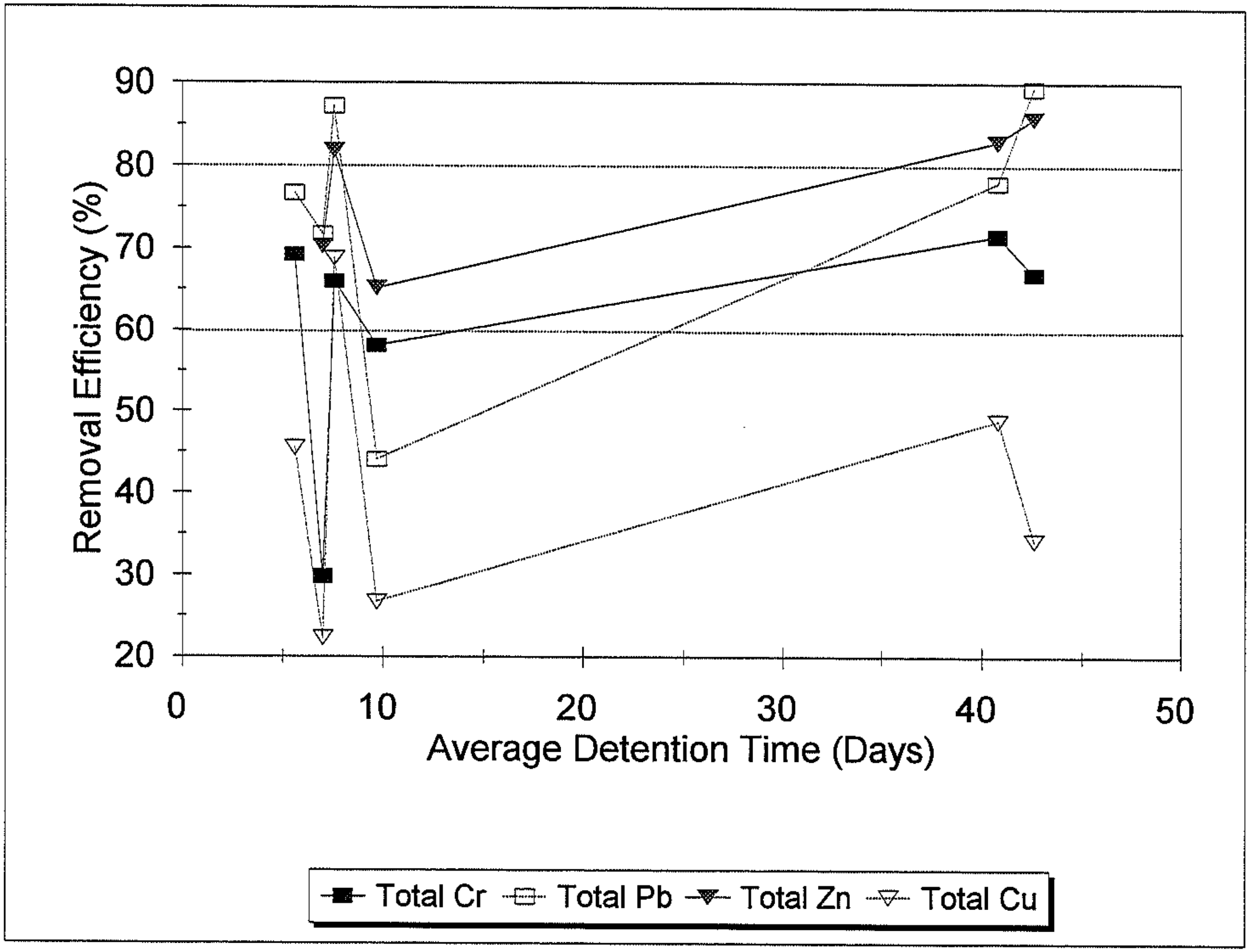

Figure 5-3. Effects of Pond Detention Time on Removal of Total Chromium, Lead, Zinc and Copper within the Pond.

TABLE 5-5

CONCENTRATION-BASED REMOVAL EFFICIENCIES FOR THE SIDE BANK FILTER ONLY DURING JUNE-NOVEMBER 1992

PARAMETER		AVERAGE MONTHLY REMOVAL EFFICIENCY						AVERAGE REMOVAL
		JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	
pH		-6	-6	2	7	6	14	3
Spec. Cond.		7	6	6	0	5	6	5
Alkalinity		11	10	8	15	14	16	12
NH_3		1200	1191	310	918	511	105	706
NO_x		980	4500	1180	2460	760	232	1685
Diss. Organic N		-41	-26	-37	-20	-26	-15	-28
Part. Organic N		-70	-78	-83	-86	-72	-83	-79
Total N		-29	-24	-29	-18	-15	-16	-22
Ortho-P		157	300	142	264	380	193	239
Diss. Organic P		-39	-59	-25	-56	-41	-67	-48
Particulate P		14	-80	-89	-85	-65	-84	-65
Total P		37	-40	-30	-30	-10	-47	-20
Turbidity		-92	-85	-85	-39	-72	-82	-76
TSS		-94	-93	-80	-86	-95	-85	-89
BOD		-55	-59	-60	-50	-62	-49	-56
Cadmium	Diss.	0	0	16	28	0	0	7
	Total	0	20	-15	48	0	0	9
Chromium	Diss.	0	0	0	-15	-22	0	-6
	Total	-8	40	0	-7	40	38	17
Copper	Diss.	-4	42	-7	-3	48	-25	9
	Total	60	122	-14	6	57	-25	34
Lead	Diss.	50	30	20	60	100	-21	40
	Total	38	-22	-60	70	120	-38	18
Iron	Diss.	459	706	104	0	51	0	220
	Total	-32	-47	-38	-45	-70	-75	-51
Zinc	Diss.	-31	-47	-73	-47	-63	-27	-48
	Total	-30	-62	-75	-56	-62	-58	-57

a relatively consistent removal of approximately 56%. However, much of this apparent reduction in BOD concentrations is likely due to the trapping of algal cells within the filter media since algal populations within the pond water column were extremely high throughout much of the monitoring period. In standard laboratory BOD tests on pond water, these algal populations will be included inside the BOD bottles and would exert an artificial oxygen demand due to respiration by the algal cells within the bottle. As a result, a portion of the BOD measured within the water column of the pond may be due to respiration activities by algal cells rather than the presence of decomposable organic matter within the water column. BOD reductions during migration through the filter, therefore, may be partially due to removal of algae from the water column rather than an actual oxidation of organic matter within the filter.

Removal of both dissolved and total metal species was extremely poor within the filter media for all measured heavy metals except iron and zinc. Increases in concentrations through the filter media were observed for total cadmium, chromium, copper and lead with increases in concentration ranging from 9-34% for these metal species. Net removals were observed for only total iron and total zinc, with a mean removal of approximately 51-57% for these species. Long-term decomposition and breakdown of trapped particulate metal species, with subsequent conversion to dissolved species, may be responsible for observed increases in dissolved metal species. With the exceptions of iron and zinc, the filter is apparently incapable of retaining trapped heavy metals on a long-term basis within the filter media.

5.4.3 Comparison of Concentration-Based Pond and Filter Removal Efficiencies

A comparison of concentration-based removal efficiencies achieved within the pond water column and within the side bank filter system at the DeBary detention pond is given in Table 5-6. It is apparent that chemical, physical and biological processes within the water column of the detention pond are the primary mechanisms responsible for removal of orthophosphorus, total phosphorus, turbidity and heavy metals for the detention with filtration system. The presence of the side bank filter system appears to enhance the removal efficiency of only a few parameters, including total nitrogen, TSS, total iron and total zinc. The primary mechanisms for removal of pollutants within the system occur within the water column of the detention pond with the filter system acting as a final polishing mechanism for selected constituents. As discussed previously, even though the filter system may trap particles of organic nitrogen or particulate phosphorus, subsequent decomposition processes result in increased outflow concentrations of soluble inorganic species of nitrogen and phosphorus as the trapped particles slowly decompose within the filter media.

As indicated in Figures 4-12, 4-13 and 4-14, the sediments are clearly the primary depository for species of nitrogen, phosphorus and heavy metals removed from the water column of the pond. Sediment concentrations of total phosphorus, cadmium, copper, lead, chromium, iron and aluminum were substantially greater in pond sediments than

TABLE 5-6

COMPARISON OF CONCENTRATION-BASED REMOVAL EFFICIENCIES ACHIEVED IN POND AND FILTER PORTIONS OF THE DEBARY DETENTION WITH FILTRATION POND

PARAMETER		REMOVAL AVERAGE IN POND	AVERAGE REMOVAL IN FILTER
pH		4	3
Spec. Cond.		121	5
Alkalinity		18	12
NH_3		-62	706
NO_x		-92	1685
Diss. Organic N		104	-28
Part. Organic N		119	-79
Total N		26	-22
Ortho-P		-78	239
Diss. Organic P		60	-48
Particulate P		-47	-65
Total P		-54	-20
Turbidity		-84	-76
TSS		-85	-89
Cadmium	Diss.	-8	7
	Total	-42	9
Chromium	Diss.	-10	-6
	Total	-60	17
Copper	Diss.	-11	9
	Total	-42	34
Lead	Diss.	-28	40
	Total	-75	18
Iron	Diss.	157	220
	Total	-37	-51
Zinc	Diss.	-32	-48
	Total	-51	-57

in an isolated control area. This behavior suggests that the pond is accumulating and storing heavy metals and phosphorus on a long-term basis within the pond sediments. In contrast, sediment concentrations of total nitrogen were virtually identical in pond and control areas, indicating a lack of long-term accumulation for nitrogen within the pond sediments. This trend is consistent with the poor removal efficiencies observed for nitrogen within the detention system.

Based on information provided in Figures 4-12, 4-13 and 4-14, it appears that the majority of inputs of total phosphorus and heavy metals in the detention pond are retained near the sediment surface with decreasing sediment concentrations with increasing depth for most heavy metals. The primary exceptions to this generality appear to be iron and aluminum which increase in concentration with increasing sediment depth. However, iron and aluminum are common constituents of the sediments in detention basins, and vertical attenuation patterns exhibited in Figure 4-14 may not be a result of stormwater related phenomena.

In contrast to the trends observed within the sediments of the pond, the filter media does not appear to have a long-term ability to retain phosphorus or heavy metals. The comparison of filter core samples collected from active and inactive filter areas given in Figures 4-15, 4-16 and 4-17 indicates that concentrations of phosphorus and heavy metals are very similar in active and inactive portions of the filter. Only slight increases in concentrations were observed in the active portions of the filter media for total phosphorus, cadmium, copper, lead and zinc. No measurable increases in concentrations were observed in active portions of the filter for chromium, iron or manganese. Clearly, the ability of the filter to trap and retain heavy metals and phosphorus on a long-term basis is severely limited.

In contrast, concentrations of total nitrogen in the active portions of the filter media appear to be somewhat higher than those found in inactive portions. This trend suggests that the filter media may have some affinity for long-term retention of total nitrogen which is also reflected in the net removal of 22% for total nitrogen achieved within the filter media as shown in Table 5-6.

In summary, although the filter media may provide enhanced removal for total nitrogen, TSS, total iron and total zinc, it does not provide substantial enhancement for removal of the remaining measured chemical parameters. The ability of the filter media to retain pollutants on a long-term basis is severely limited due to the lack of adsorption or exchange sites on the silica particles which comprise the filter media. The primary mechanism for retaining particles within the filter media is likely a purely physical phenomenon of entrapment within the media. The process of entrapment can only provide long-term removal efficiencies for particulate matter which is not subject to rapid decomposition.

Based upon the strong hydrogen sulfide odor present within the filter underdrain outflow on most monitoring occasions, it is apparent that anaerobic conditions existed within the filter media throughout much of the study period. These anaerobic conditions reduced the ability of the filter to retain redox-sensitive species within the filter media such as iron, manganese and phosphorus. Although not measured as part of this study, it is also likely the discharges from the underdrain are extremely low in dissolved oxygen and exist, at least initially, in a reduced condition.

5.4.4 Comparison with Chapter 17-302 Class III Water Quality Criteria

A comparison of mean water quality characteristics in the detention pond water column and underdrain outflow with Class III Surface Water Quality Standards as outlined in Chapter 17-302 of the Florida Administrative Code is given in Table 5-7. Mean water quality characteristics within the detention pond water column met all applicable Class III criteria for the parameters measured, including heavy metals. Discharges from the detention pond without the additional filtration by the filter media would not have resulted in violations of Class III criteria.

Similarly, with the possible exception of dissolved oxygen, underdrain outflow also met all applicable Class III criteria for surface waters, including heavy metals. Treated discharges from the underdrain system did not create any violations of surface water quality.

5.5 Effects of Filter Configuration and Sod Covers on Removal Efficiencies for Side Bank Filter Systems

5.5.1 Effects of Filter Configurations

A comparison of mean concentration-based removal efficiencies for various filter configurations and sod covers is given in Table 5-8. As discussed in Section 4.8, enhanced removal for total nitrogen, total phosphorus and heavy metals were achieved using the 20-30 silica sand media compared with the standard FDOT 902.4 media and the standard media with a gravel envelope. However, as seen in Figure 4-25, the hydraulic capacity of the 20-30 silica sand was substantially greater than that for either the standard filter media or the filter media with a gravel envelope. Flow velocities were obviously higher through the 20-30 silica sand, resulting in lower detention times within the filter media. Both the FDOT 902.4 media and the 20-30 silica sand media are primarily comprised of silica particles with different mean grain size diameters.

Ignoring any potential contaminants within the filter media, the raw affinity of the two medias for uptake by adsorption and ion exchange are both relatively low. In fact, the greater flow velocity through the 20-30 silica sand media should reduce the opportunity for adsorption and exchange reactions to occur during migration through this media. The additional removal apparently achieved using this filter media may be related to the presence of some contaminants within the filter media which have an affinity for nitrogen, phosphorus and heavy metals. It is unlikely that these enhanced removal

TABLE 5-7

COMPARISON OF MEAN WATER QUALITY CHARACTERISTICS IN THE DETENTION POND WATER AND UNDERDRAIN OUTFLOW WITH CLASS III WATER QUALITY STANDARDS

PARAMETER		UNITS	MEAN POND CONCENTRATION	MEAN UNDERDRAIN OUTFLOW	CHAPTER 17-302 CRITERIA - CLASS III WATER
pH		s.u.	7.54	7.71	6.0-8.5
Spec. Conductivity		μmho/cm	240	254	< 1275
Alkalinity		mg/l	94	105	≥ 20
NH_3		μg/l	35	153	N.N.S.[1]
NO_x		μg/l	12	121	N.N.S.
Diss. Organic N		μg/l	448	348	N.N.S.
Part. Organic N		μg/l	410	86	N.N.S.
Total N		μg/l	891	707	N.N.S.
Ortho-P		μg/l	16	48	N.N.S.
Diss. Organic P		μg/l	20	11	N.N.S.
Particulate P		μg/l	65	18	N.N.S.
Total P		μg/l	101	77	N.N.S.
Turbidity		NTU	8.9	1.6	≤ 29
Chloride		mg/l	16	16	N.N.S.
TSS		mg/l	9.3	0.9	N.N.S.
BOD		mg/l	5.8	2.5	N.N.S.
Cadmium	Diss.	μg/l	< 0.5	< 0.5	--
	Total	μg/l	< 0.5	< 0.5	< 1.1[2]
Chromium	Diss.	μg/l	< 1	< 1	--
	Total	μg/l	1.1	1.3	< 207[2]
Copper	Diss.	μg/l	5.2	5.5	--
	Total	μg/l	5.4	7.0	< 11.8[2]
Lead	Diss.	μg/l	< 2	< 2	--
	Total	μg/l	< 2	< 2	< 3.2[2]
Iron	Diss.	μg/l	66	113	--
	Total	μg/l	379	161	< 1000
Zinc	Diss.	μg/l	3.9	1.9	--
	Total	μg/l	5.0	2.1	< 106[2]

1. N.S.S.: No numerical standard

2. Hardness dependent criterion - values listed assumes a typical hardness of 100 mg/l

TABLE 5-8

COMPARISON OF MEAN CONCENTRATION-BASED REMOVAL EFFICIENCIES FOR VARIOUS FILTER CONFIGURATIONS AND SOD COVERS

PARAMETER	PERCENT CHANGE DURING FLOW THROUGH MEDIA						
	FILTER CONFIGURATIONS			SOD COVERS			
	STANDARD FILTER MEDIA	STANDARD FILTER WITH GRAVEL ENVELOPE	20-30 SILICA SAND	ST. AUGUSTINE GROWN IN SAND	ST. AUGUSTINE GROWN IN MUCH	BAHIA GROWN IN SAND	BERMUDA GROWN IN MUCK
pH	4	4	0	1	-1	-1	3
Conductivity	7	9	2.4	5	2	3	6
NH_3-N	-12	-25	-21	-37	-38	-51	-37
NO_x-N	46	39	-2	48	43	5	87
Diss. Organic N	-14	-12	-12	-22	-11	-4	-12
Part. Organic N	-19	-29	71	-3	-64	21	-17
Total N	-5	-6	-7	-11	-11	-9	-3
Ortho-P	-5	3	-35	24	39	-12	44
Particulate P	-42	-50	39	4	-44	-54	13
Total P	-41	-37	-55	-13	-19	-41	3
BOD	-4	-2	0	-13	-25	-35	-4
Copper Diss.	-46	-62	-63	-57	-57	-57	-48
Total	-29	-50	-53	-53	-56	-53	-41
Lead Diss.	-80	-97	-98	-94	-97	-89	-99
Total	-88	-98	-99	-88	-95	-87	-94
Zinc Diss.	-96	-94	-99	-96	-98	-98	-95
Total	-92	-93	-99	-92	-97	-98	-96

efficiencies measured during the somewhat limited side bank experiments would continue for a prolonged period of time. As a result, it is difficult to conclude that significant differences exist between the various filter media and their ability to attenuate and trap pollutants within the filter media. However, based upon hydraulics alone, it would be expected that the standard filter media would retain a larger pollutant mass on a long-term basis due to a relatively fine particle size and a slower flow velocity through the filter media. The opportunity for long-term removal should decrease with the gravel envelope configuration and decrease even further using the 20-30 silica sand.

5.5.2 Effects of Various Sod Covers

A comparison of mean concentration-based removal efficiencies for various sod covers is also presented in Table 5-8. As discussed in Section 4.8, maximum removal for total nitrogen, total phosphorus and heavy metal species was obtained primarily using the Bahia sod grown in sand and the St. Augustine sod grown in muck. The addition of the Bahia sod to the filter face reduced the hydraulic performance of the filter system by approximately 5-10% compared with underdrain outflow rates exhibited by the underdrain sand filter with no sod cover. The addition of St. Augustine sod, grown in either sand or muck, reduced the hydraulic performance of the filter system approximately 20%.

As seen in Table 5-8, removal of total phosphorus and BOD appears to be somewhat greater with Bahia sod grown in sand and St. Augustine sod grown in muck than with the other two sands. Removal of heavy metals appears to be approximately equal for the four sod types. However, removal efficiencies exhibited by the various sod covers are more likely related to the soil types in which the sod was grown rather than the type of sod itself.

As seen in Appendix V, the duration of side bank filter experiments utilizing the various sod covers was approximately 4-6 hours. The amount of actual plant uptake which could potentially occur during this time is extremely small. The pollutant removals observed for parameters listed in Table 5-8 are probably a result of adsorption or exchange reactions within the soil rather than from vegetative uptake. Therefore, differences in pollutant removals shown in Table 5-8 are more likely due to differences in soil characteristics rather than differences in sod types. This situation would probably also occur in a permanent filter installation utilizing sod cover. Initial uptake of nitrogen, phosphorus and heavy metals would occur due to adsorption and exchange reactions with the soil media. Plant uptake occurs on a slower and more continuous rate. Nutrients adsorbed onto soil particles may be slowly taken up by plant material over time and stored into plant biomass. Therefore, from the perspective of pollutant uptake, it probably makes little difference which type of grass cover is selected since most of the initial uptake occurs within the soil layer.

As discussed previously, the majority of pollutant removal achieved within a filter system constructed with a permanent pool volume, similar to the DeBary research site, occurs within the water column of the detention pond rather than within the filter media. It is unlikely that the addition of a sod cover to the filter bank in this type of system would substantially increase the pollutant attenuation capabilities of the system. The addition of a sod cover over the filter media would reduce the hydraulic flow through the filter media and substantially complicate future maintenance practices such as backflushing of the filter media to maintain the hydraulic capacity of the system. The potential hydraulic problems which would likely be caused by the addition of a sod cover do not appear to be worth the minimal additional water quality benefits which may be achieved by using a sod cover over a "wet bottom" type filter system.

In contrast, the addition of a sod cover to a "dry bottom" side bank filter configuration may substantially enhance the long-term pollutant attenuation capabilities of the system. In this type of system, the primary mechanism responsible for attenuation of pollutants, other than settling processes which may occur within the detention basin, is entrapment of pollutants within the filter media. As discussed previously, the evidence generated during this research suggests that the filter media itself has almost no ability to retain pollutants on a long-term basis. The addition of a sod cover to this type of filter system, although reducing the hydraulic performance of the system, would provide active sites for pollutant uptake and attenuation and may enhance the pollutant attenuation capabilities of the systems.

If sod covers are used in "dry bottom" type filter configurations, then care should be exercised in selection of the appropriate permeability (K) value for use in design of the underdrain system. The K values presented in this research should be viewed as maximum K values for the various types of sod covers investigated. Permeability values are likely to decrease in value with time as particles begin to accumulate on top of the soil surface. Nevertheless, it appears that the addition of a sod cover to a "dry bottom" type pond configuration will provide enhanced pollutant attenuation for systems which currently provide poor removal efficiencies for nutrients and heavy metals. Additional long-term research is recommended to evaluate the changes in hydraulic permeability for various sod covers over extended periods of time as well as maintenance practices which may be necessary to maintain the hydraulic performance of filter systems used with sod cover.

5.6 Groundwater Impacts of the DeBary Detention with Filtration System

As discussed in Section 4.1, piezometric elevations measured at the DeBary research site from May to November 1992 indicate that groundwater seepage enters the DeBary detention pond along the west side with seepage leaving the pond along the east side. Relatively little groundwater movement was found to occur along the north and south sides of the pond.

Groundwater seepage from the pond along the east side appears to be having a substantial impact on groundwater characteristics measured at the downgradient monitoring well. Groundwater at the downgradient monitoring site was similar for many parameters to groundwater measured beneath the pond and substantially different from groundwater measured in the upgradient monitoring well.

Land elevations along the east side of the pond drop rapidly, approximately 5-6 m (15-20 ft), to Lake Gem over a horizontal distance of only 90 m (300 ft). This drop in land surface elevation produces a sharp hydraulic groundwater gradient which increases the movement of groundwater along the east side of the pond in spite of the clay key constructed adjacent to the pond.

The conclusion that measurable changes in groundwater characteristics may be caused by an adjacent stormwater pond is contrary to conclusions reached by Harper (1985) during investigations on groundwater impacts of a wet detention system receiving highway runoff as well as conclusions reached by Harper (1988) during a 1-year study on the effects of various stormwater management systems on groundwater quality in the Central Florida area. However, none of these previous studies were conducted on stormwater management systems with steep groundwater gradients along the one side of the pond. The enhanced movement of groundwater at the DeBary research site caused by the strong groundwater gradient is responsible for the measurable impacts on groundwater quality measured in downgradient areas at this site.

Even though measurable impacts in groundwater quality were detected at the DeBary site, this does not indicate that a deterioration of groundwater quality has occurred. For some constituents such as pH, redox potential, turbidity and orthophosphorus, groundwater characteristics in downgradient areas have improved in water quality compared with conditions found in upgradient areas. In spite of the enhanced movement of groundwater found at this site, measured concentrations of heavy metals in downgradient areas, with the exception of iron, were found to be extremely low in spite of accumulations of metals and nutrients within the sediments of the pond. These findings support conclusions reached by Harper (1985, 1988) that accumulations of heavy metals in pond sediments do not appear to exhibit significant impacts on groundwater quality even with enhanced groundwater gradients and groundwater movement.

5.7 Evaluation of Design Equations

Commonly used design equations were evaluated for applicability in predicting measured drawdown in a vertical bottom filter, a side bank filter constructed in a "wet bottom" configuration, and a side bank filter constructed in a "dry bottom" configuration. The results of each of these analyses are discussed in the following sections.

5.7.1 Recommended Design Equations for a "Wet Bottom" Side Bank Filter Configuration

As discussed in previous sections, the side bank filter system at the DeBary research site is constructed in a "wet bottom" configuration in which the filter is constructed along the side of a permanent detention basin pool. The majority of pollutant removal processes within this type of pond configuration occur within the water column of the pond rather than within the filter media. The filter media acts primarily as a drawdown mechanism which limits the discharge flow rates from the pond.

Estimates of percent error between measured and calculated underdrain discharge flow rates for the DeBary detention with filtration pond using common design equations are given in Table 5-9. As seen in Table 5-9 and in Figure 4-24, all design equations except the Effective Area Equation overestimate underdrain discharge rates at low head conditions for head elevations of 1 ft or less above the centerline of the underdrain pipe. Using the Modified Darcy's Equation, the percent error could be as high as 171%. Substantial underestimates of underdrain discharge rates are obtained under all head conditions using the Effective Area Equation. At higher head conditions (> 2.0 ft), the three design equations underestimate outflow.

From the information provided in Table 5-9, it appears that the Modified Darcy's Equation and the Incremental Darcy's Equation could both be used for estimation of drawdown in a "wet bottom" filter configuration. At head elevations greater than 1.5 ft, the Modified Darcy's Equation provides the best fit. However, even this equation begins to underestimate flow at head elevations of 2.0 ft or more above the center of the underdrain. For the Incremental Darcy's Equation, underestimation of flow begins at a head of 1.0 ft and increases as head increases. It appears that the Incremental Darcy's Equation may be more appropriate for modeling flow regimes under low conditions of head, less than 1.25-1.50 ft above the underdrain, while the Modified Darcy's Equation may be most appropriate for modeling flow rates at higher head conditions. If the Modified Darcy's Equation is used as a design equation to estimate drawdown curves for "wet bottom" filter configurations, it may be appropriate to switch to the Incremental Darcy's Equation whenever the head above the filter approaches a value of 1 to 1.5 ft. This will result in a better estimate of underdrain flow rates under low head conditions.

5.7.2 Design Equations for Vertical Bottom Filters

As discussed in Chapter 4, four design equations were evaluated for predicting drawdown in vertical bottom filters. These equations included: (1) Darcy's Equation; (2) Falling Head Equation; (3) Incremental Darcy's Equation; and (4) Incremental Darcy's Equation Utilizing the Effective Area.

Estimates of percent error between measured and calculated underdrain discharge rates for the vertical bottom filter using common design equations are given in Table 5-10. The best fit to the field measured data is achieved using the Incremental Darcy's Equation with an averaged D or the Falling Head Equation at the field measured permeability values. Both equations slightly overestimate flow rates by approximately 13-26% depending upon the head above the underdrain. The percent error obtained using the Incremental Darcy's Equation ranges from approximately 26-55% at the same K value. At the same K value, Darcy's Equation overestimates flow at low head conditions and underestimates flow at high head conditions, even though the mean absolute error is only 24%.

TABLE 5-9

ESTIMATES OF PERCENT ERROR BETWEEN MEASURED AND CALCULATED UNDERDRAIN DISCHARGE RATES FOR THE DEBARY DETENTION WITH FILTRATION POND USING COMMON DESIGN EQUATIONS

HEAD ABOVE UNDERDRAIN CENTERLINE (ft)	PERCENT ERROR IN ESTIMATION (%)					
	MODIFIED DARCY'S EQUATION		INCREMENTAL DARCY'S EQUATION		DARCY'S EQUATION UTILIZING EFFECTIVE AREA	
	K = 2.34	K = 2.5	K = 2.34	K = 2.5	K = 2.34	K = 2.5
0.5-0.75	157	171	57	71	-43	-14
0.75-1.0	84	95	11	16	-63	-53
1.0-1.25	36	43	-17	-12	-79	-74
1.25-1.50	12	18	-28	-24	-85	-82
1.50-1.75	2	9	-31	-27	-88	-86
1.75-2.00	-7	-1	-35	-28	-90	-89
2.00-2.25	-23	-18	-42	-36	-92	-91
2.25-2.50	-34	-30	-47	-43	-94	-93
Mean Error[1]	44	48	34	32	79	73

[1] Absolute Error

TABLE 5-10

ESTIMATES OF PERCENT ERROR BETWEEN MEASURED AND CALCULATED UNDERDRAIN DISCHARGE RATES FOR THE VERTICAL BOTTOM FILTER USING COMMON DESIGN EQUATIONS

HEAD ABOVE UNDERDRAIN CENTERLINE (ft)	PERCENT ERROR IN ESTIMATION (%)								
	INCREMENTAL DARCY'S EQUATION			DARCY'S EQUATION UTILIZING EFFECTIVE AREA		DARCY'S EQUATION		FALLING HEAD EQUATION	
	K = 2.01	K = 2.01 AVER. D	K = 2.5	K = 2.01	K = 2.5	K = 2.01	K = 2.5	K = 2.01	K = 2.5
2.0-2.5	55	26	90	-90	-87	45	77	13	31
2.5-3.0	53	21	87	-89	-87	18	45		
3.0-3.5	48	17	83	-89	-87	-2	20		
3.5-4.0	39	9	71	-89	-88	-20	-2		
4.0-4.5	26	-1	57	-90	-89	-36	-21		
Mean Error[1]	44	15	78	89	88	24	33	13	31

1. Absolute Error

It is important to note that the calculation of underdrain discharge rates is extremely sensitive to changes in the value of K. Increasing the value of K from the field measured value of 2.01 ft/hr to 2.5 ft/hr using Darcy's Equation and the Incremental Darcy's Equation increases the percent error under most conditions of head by a factor of 1.5 to 2. Therefore, it is extremely important that a representative K value be utilized for the type of media used in any filter design. The calculated outflows for the Effective Area method were underestimated so greatly (an average of -89%) that a change in K had little effect on the percent error.

Percent error for the Falling Head Equation is generally not used to predict underdrain outflow rates but is used to calculate the length of time required for the filter to drawdown from one elevation to another elevation. This equation underestimated the actual time required for drawdown of the pilot test system by approximately 13% at a K value of 2.01, indicating an overestimation by this same amount for average flow. However, this error is substantially less than the error obtained using either the Darcy's Equation or Darcy's Equation Utilizing the Effective Area. It appears that the Falling Head Equation or Incremental Darcy's Equation with an average D may be a suitable design equation for use in estimating drawdown time for vertical bottom filters, provided that the overestimation of flow inherent in these equations is considered.

5.7.3 Evaluation of Design Equations for Various Side Bank Filter Configurations

Estimates of percent error between measured and calculated underdrain discharge rates for various side bank configurations using three common design equations are given in Table 5-11. Design equations included in this analysis are: (1) the Modified Darcy's Equation; (2) the Incremental Darcy's Equation; and (3) Darcy's Equation Utilizing Effective Area.

As seen in Table 5-11, the Incremental Darcy's Equation, using the field measured permeability values, provides a relatively close estimation, under low head conditions (< 3.0 feet), of actual measured flow rates from the side bank filter system for each of the three filter configurations tested, including the FDOT 902.4 media, the FDOT 902.4 media with a gravel envelope around the underdrain pipe, and the 20-30 silica sand. The Modified Incremental Darcy's Equation is more accurate at higher heads in the range of 3.0-4.5 feet. Substantial error was obtained using the other design equations in this range. It should be noted that the percent error in estimation for all three equations increases as K values other than the field measured K values are substituted into the design equations, particularly for the 20-30 silica sand media. Therefore, selection of an appropriate K value is extremely important for insuring a good fit between predicted and measured underdrain flow rates.

Darcy's Equation Utilizing the Effective Area is clearly not suitable for predicting drawdown for the side bank configuration using either the FDOT 902.4 media or the 20-30 silica sand. Percent errors obtained using Darcy's Equation Utilizing Effective

TABLE 5-11

ESTIMATES OF PERCENT ERROR BETWEEN MEASURED AND CALCULATED UNDERDRAIN DISCHARGE RATES FOR VARIOUS SIDE BANK FILTER CONFIGURATIONS USING COMMON DESIGN EQUATIONS

FILTER CONFIGURATION	HEAD ABOVE UNDERDRAIN CENTERLINE (ft)	PERCENT ERROR IN ESTIMATION (%)					
		MODIFIED INCREMENTAL DARCY'S EQUATION		INCREMENTAL DARCY'S EQUATION		DARCY'S EQUATION UTILIZING EFFECTIVE AREA	
FDOT 902.4 Media		K = 2.01	K = 2.5	K = 2.01	K = 2.5	K = 2.01	K = 2.5
	2.0-2.5	-67	-62	-19	5	-89	-87
	2.5-3.0	-11	11	-14	7	-89	-86
	3.0-3.5	21	50	-24	-3	-90	-88
	3.5-4.0	15	41	-34	-17	-92	-90
	4.0-4.5	-16	4	-52	-39	-94	-93
	Mean Error[1]	26	34	29	14	91	89
FDOT 902.4 Media and a Gravel Envelope Around Underdrain Pipe		K = 2.48	K = 2.5	K = 2.48	K = 2.5	K = 2.48	K = 2.5
	2.0-2.5	-65	-65	-4	-4	52	52
	2.5-3.0	-14	-14	-17	-17	33	33
	3.0-3.5	9	9	-30	-30	11	11
	3.5-4.0	5	5	-38	-38	-5	-5
	4.0-4.5	-9	-9	-47	-47	-19	-19
	Mean Error[1]	20	20	27	27	24	24
20-30 Silica Sand		K = 5.30	K = 2.5	K = 5.30	K = 2.5	K = 5.30	K = 2.5
	2.0-2.5	-69	-87	-26	-65	-90	-95
	2.5-3.0	-20	-62	-23	-63	-90	-95
	3.0-3.5	12	-47	-29	-66	-91	-96
	3.5-4.0	12	-48	-36	-69	-92	-96
	4.0-4.5	3	-52	-41	-72	-93	-97
	Mean Error[1]	23	59	31	67	91	96

1. Absolute Error

Area for these filter configurations ranged between 86-97%. It is interesting to note the error in flow estimation using this equation reduced to 5-52% with the gravel envelope. This appears to indicate that the Effective Area method may be useful with a gravel envelope, particularly at higher heads (> 3.0 feet).

5.7.4 Evaluation of Design Equations for Use with Sod Covers in Side Bank Filter Systems

Estimates of percent error between measured and calculated underdrain discharge rates for a side bank filter covered with various sod types for three common design equations is given in Table 5-12. Similar to the results obtained with the various filter configurations without sod cover, the Incremental Darcy's Equation is clearly the most appropriate equation for use in predicting underdrain discharge rates for "dry bottom" type systems with various sod covers at low head conditions (< 3.0 feet). At higher head conditions, the Modified Incremental Darcy's Equation provides the best fit (3.0-4.5 feet). It should also be noted that selection of an appropriate permeability (K) value is also necessary to insure a close fit between the calculated and measured underdrain flow rates. Substantial errors in estimation will be obtained by using Darcy's Equation Utilizing Effective Area for a "dry bottom" type filter configuration.

5.7.5 Summary of Recommended Design Equations

A summary of recommended design equations for filter systems is given in Table 5-13. In general, the Incremental Darcy's Equation is appropriate for modeling drawdown in side bank filters designed in both the "wet bottom" and "dry bottom" configuration with low head conditions. The Modified Incremental Darcy's Equation will provide a good fit for predicting drawdown using the "wet bottom" and "dry bottom" configurations at higher heads.

For vertical bottom configurations, either the Incremental Darcy's Equation with an average D or the Falling Head Equation is recommended. Each of these equations will result in an overestimation of flow rate by approximately 13-15% and are sensitive to changes in K values. However, these equations provide the best fit of the commonly used design equations.

5.8 Selection of Permeability (K) Values

The importance of carefully selecting appropriate permeability (K) values for particular filter systems, filter configurations and sod types is evident in the plots of measured versus calculated drawdowns presented at the end of Chapter 4. Even utilizing equations determined to be "best fit" equations for a particular filter type, substantial errors can be achieved in estimates of underdrain discharge rates by improper selection

TABLE 5-12

ESTIMATES OF PERCENT ERROR BETWEEN MEASURED AND CALCULATED UNDERDRAIN DISCHARGE RATES FOR A SIDE BANK FILTER COVERED WITH VARIOUS SOD TYPES USING COMMON DESIGN EQUATIONS

FILTER CONFIGURATION	HEAD ABOVE UNDERDRAIN (ft)	PERCENT ERROR IN ESTIMATION (%)					
		MODIFIED INCREMENTAL DARCY'S EQUATION		INCREMENTAL DARCY'S EQUATION		DARCY'S EQUATION UTILIZING EFFECTIVE AREA	
Bahia Sod Grown in Sand		K = 1.89	K = 2.5	K = 1.89	K = 2.5	K = 1.89	K = 2.5
	2.0-2.5	-50	-43	14	57	-84	-80
	2.5-3.0	9	41	5	36	-87	-83
	3.0-3.5	30	70	-17	10	-89	-86
	3.5-4.0	16	53	-34	-11	-92	-89
	4.0-4.5	-4	26	-46	-26	-93	-91
	Mean Error[1]	22	47	23	28	89	86
St. Augustine (Floritam) Sod Grown in Sand		K =1.57	K = 2.5	K = 1.57	K = 2.5	K = 1.57	K = 2.5
	2.0-2.5	-63	-50	-19	38	-89	-83
	2.5-3.0	-5	48	-10	43	-89	-82
	3.0-3.5	22	89	-22	22	-90	-84
	3.5-4.0	12	76	-36	3	-92	-87
	4.0-4.5	-5	49	-46	-13	-93	-89
	Mean Error[1]	21	62	27	24	91	85

1. Absolute Error

TABLE 5-12

ESTIMATES OF PERCENT ERROR BETWEEN MEASURED AND CALCULATED UNDERDRAIN DISCHARGE RATES FOR A SIDE BANK FILTER COVERED WITH VARIOUS SOD TYPES USING COMMON DESIGN EQUATIONS

-- Page Two --

FILTER CONFIGURATION	HEAD ABOVE UNDERDRAIN (ft)	PERCENT ERROR IN ESTIMATION (%)					
		MODIFIED INCREMENTAL DARCY'S EQUATION		INCREMENTAL DARCY'S EQUATION		DARCY'S EQUATION UTILIZING EFFECTIVE AREA	
St. Augustine (Floritam) Sod Grown in Muck		K = 1.27	K = 2.5	K = 1.27	K = 2.5	K = 1.27	K = 2.5
	2.0-2.5	-58	-33	-8	83	-88	-77
	2.5-3.0	-6	82	-13	76	-89	-78
	3.0-3.5	18	132	-23	50	-90	-81
	3.5-4.0	11	115	-37	26	-92	-84
	4.0-4.5	-7	81	-47	6	-93	-87
	Mean Error[1]	20	89	26	48	90	81
Bermuda Sod Grown in Muck Sod Grown in Sand		K =1.42	K = 2.5	K = 1.42	K = 2.5	K = 1.42	K = 2.5
	2.0-2.5	-67	-47	-20	47	-89	-81
	2.5-3.0	-10	55	-15	50	-89	-81
	3.0-3.5	20	104	-24	32	-89	-83
	3.5-4.0	10	93	-37	13	-91	-86
	4.0-4.5	-6	66	-46	-3	-92	-88
	Mean Error[1]	23	73	28	29	90	84

1. Absolute Error

TABLE 5-13

SUMMARY OF RECOMMENDED DESIGN EQUATIONS FOR FILTRATION SYSTEMS

FILTER TYPE	RECOMMENDED DESIGN EQUATION	COMMENTS
Vertical Bottom Filter	Incremental Darcy's Equation Using Average D	a. overestimates flow rates at field measured K values b. sensitive to changes in K values
	Falling Head Equation	a. error similar to Incremental Darcy's Equation Using Average D b. used for estimation of drawdown time only
Side Bank Filter: "Wet Bottom" Configuration	Incremental Darcy's Equation	a. best fit equations for $Y \leq 1.5$ ft b. robust to changes in K
	Modified Incremental Darcy's Equation	a. best fit equations for $Y > 1.5$ ft b. sensitive to changes in K
Side Bank Filter: "Dry Bottom" Configuration	Incremental Darcy's Equation	a. best fit equations for $Y \leq 3.0$ ft b. robust to changes in K
	Modified Incremental Darcy's Equation	a. best fit equations for $Y > 3.0$ ft b. sensitive to changes in K

of K values. It is important that permeability values used in design be based upon actual measured permeabilities for the particular filter media and filter configuration to be used for a particular project.

Vertical bottom filter systems and side bank filters constructed in the "dry bottom" configuration appear to be similar with respect to potential for clogging by sediment material entering the stormwater basin from the surrounding watershed. Each of these filter configurations provide ample opportunity for surrounding soils, mobilized by stormwater flow, to become trapped onto the face of the filter system. The St. Johns River Water Management District currently recommends that allowable design permeabilities for filter systems be selected to correspond with the permeabilities of the surrounding soils within the drainage basin which contributes runoff to the stormwater facility. This design procedure assumes that soils within the surrounding watershed will eventually become mobilized by stormwater flow, enter the stormwater facility, and become trapped onto the face of the filter media, thereby limiting the percolation rate of the filter system to that exhibited by soils within the watershed basin. This design approach seems reasonable for vertical bottom filters and side bank filters constructed in the "dry bottom" configuration since the potential for entrapment of soil particles within the filter media appears to be high for these type systems.

However, one potential problem which may occur utilizing this design approach is selection of the initial permeability value. Field measurements conducted by ERD indicate that the initial permeability of the commonly used FDOT 902.4 media is less than the allowable permeability value of 2.5 ft/hr which could be used for design purposes if the filter system were to be constructed in an area with Type A soils. Therefore, initial permeabilities may need to be reviewed based upon the characteristics of the media actually placed within the filter system. Final long-term permeability may then approach the permeability of on-site soils within the watershed basin for "dry bottom" or vertical filters.

Filter systems constructed as side bank filters in a "wet bottom" configuration may respond differently to potential clogging situations than observed for vertical bottom filters or side bank filters constructed in a "dry bottom" configuration. Unless the watershed is comprised of extremely fine-grained soils, suspended solids inputs into a filter system constructed with a permanent pool will settle out within the pond and not be trapped within the filter media. These systems are much less likely for clogging over the long-term. Since the potential for filter clogging by soils from the watershed area appears to be substantially less for this type of system, the use of permeability values based upon characteristics of watershed soils may not be appropriate for the design of this type filter system.

Particles which become trapped within the filter media in a wet detention pond system are primarily particles such as algal cells which form within the basin rather than particles entering the basin through direct inputs of stormwater runoff. Evidence generated during this research indicates, that although these particles may be initially trapped by the filter media, the trapped matter is apparently degraded over time, based upon substantially enhanced levels of dissolved nitrogen and phosphorus in the underdrain outflow, presumably from decomposition processes. This type of filter arrangement is substantially less likely to become clogged than one which is subject to receiving and collecting inputs of soils from the watershed area.

Unfortunately, the period of research involved in this research did not allow a long-term evaluation of the clogging potential for a wet detention system. However, the DeBary detention with filtration system had been in operation approximately 5 years prior to the study described within this research. There are no records of any maintenance activities conducted on this filter system by FDOT during that time. Even after 5 years of continuous filtration, the field measured permeability of the filter system was still found to be approximately 2.34 ft/hr. Although the initial permeability of this filter media is not known, it appears that little clogging of the filter system has occurred over the 5 years of continuous operation.

5.9 Hydraulic Versus Water Quality Conditions

Currently, the overall design of filter systems is dictated primarily by hydraulic considerations. The primary hydraulic concern in designing filter systems is to insure that the filter system recovers the required pollution abatement volume within the specified period of time, generally 72 hours. During the design process, conservative permeability values and safety factors are incorporated into the design of the filter bed to insure drawdown within the required period of time. In many instances, particularly in newly constructed filter systems, the design process results in a filter system which recovers in a length of time substantially less than the required 72-hour period. Although this design approach is appropriate from a hydraulic standpoint, it reduces the detention time within the filter facility and decreases the pollutant attenuation capacity of the system.

It is apparent from research discussed in this report that the filter system itself provides only a small amount of the total pollutant attenuation achieved by a filtration system. In both a "wet pond" and "dry pond" configuration, the primary mechanisms responsible for attenuation of pollutants are physical, chemical and biological processes which occur in either the permanent pool or the detained water pool prior to filtration through the filter media. Hydraulic designs which decrease the detention time within the stormwater basin will also reduce the pollutant attenuation capacity of the system.

Therefore, extreme care should be taken in selection of design equations and appropriate permeability (K) values used in design of filter systems to insure that the filter system does not drawdown too rapidly and reduce the pollutant attenuation achieved within the system. Virtually all design equations tested during this research already overestimate the actual observed flow rates through filter systems. Incorporation of low permeability values and excessive safety factors should be carefully reviewed to insure that drawdown will not occur too rapidly so as to substantially hinder the ability of the system to retain pollutants.

5.10 Observations on Maintenance Practices

Unfortunately, the duration of research conducted at the DeBary research site and in the pilot test studies did not allow evaluation of the long-term potential for filter clogging and the need for appropriate maintenance activities to minimize clogging. However, general observations on maintenance practices conducted at the DeBary research site will be briefly discussed.

The primary maintenance activity conducted at the DeBary research site consists of vegetation maintenance along the filter face as well as areas upland from the detention pond. Presently, a tractor-powered mower is used to mow vegetation growing along the filter surface and upland areas twice each year. Deep ruts are present along many areas of the filter face where it appears that a tractor-type mower has attempted to drive over the unconsolidated sand filter media. In many areas, these ruts are more than 0.3 m (1 ft) deep. These ruts create an opportunity for water to short-circuit and pass through a substantially reduced travel path prior to entering the underdrain system.

Because of these apparent difficulties, it appears that active mowing of the filter face was stopped at some point in the past, and natural vegetation, such as tall weeds and woody shrubs, have been allowed to colonize along more than 50% of the filter face. Much of this vegetation is over 2 m (6.5 ft) tall. The long-term effects of this extensive vegetative growth on hydraulic performance of the filter system are not known. However, it seems logical that vegetation growth along the face of the filter media should be maintained at reasonable levels.

Improved control of vegetation along the filter face at the DeBary research site may be as simple as changing the type of mowing device used. It appears that previous mowers have consisted of tractors which pulled the mower attachment directly behind the tractor. A side-arm type mower which extends away from the tractor is more appropriate for vegetation control on filter surfaces since the tractor itself does not have to drive on the filter media. This type of mower would be substantially easier to operate and more efficient and would not result in damage to the filter face.

Maintenance procedures for vegetation on "dry bottom" type filter configurations may be similar to those just discussed for "wet bottom" configurations. It seems reasonable that vegetative growth should be controlled and that heavy equipment should not drive on the face of the filter media regardless of whether the system is constructed as a "dry bottom" or "wet bottom" system.

Since "dry bottom" configurations are more susceptible to clogging due to deposition from soils and sediments within the watershed area, backflushing of "dry bottom" type filters may need to be performed on a regular basis to maintain system performance. It is beyond the scope of work efforts conducted in this project to evaluate the interval at which this type of maintenance activity is required. However, a number of experiments were conducted to evaluate the effectiveness of sod covers for enhancing the pollutant removal effectiveness of these systems. Application of a sod cover to the face of a filter system may restrict the ability to backflush the system for maintenance purposes. The reduced permeability exhibited by the sod cover may make backwashing efforts ineffective and difficult to perform. Substantially higher pressure may be necessary to force water back up through the sod cover once it has become established. For this reason, additional research is recommended on maintenance practices for sod covered filter banks.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

6.1.1 Description of Study Site

Field and laboratory investigations were conducted from April 1992 to January 1993 at a study site in DeBary, Florida to evaluate the hydraulic and water quality characteristics of a detention with filtration pond system. The detention with filtration pond was constructed in 1988 by the Florida Department of Transportation (FDOT) to provide stormwater treatment for a 20.5 ha (50.7 ac) watershed which is divided equally between low density commercial land use and single-family land use. Runoff generated within the drainage basin for the detention pond system is collected in deep roadside swales which are used for conveyance of stormwater runoff entering the detention pond. Soils within the drainage basin are classified in Hydrologic Soil Group A.

The detention pond is constructed with a side bank filter system for recovery of pollution abatement volumes. The filter system consists of a 15 cm (6 in) perforated PVC underdrain pipe covered with a filter fabric sock. The face of the filter is constructed on a 3:1 slope with a 7.6 cm (3 in) layer of coarse aggregate (FDOT No. 57). A 4 mil non-permeable polyethylene film is located along the base and vertical side of the filter system to minimize inflow of groundwater into the underdrain pipe. The filter system is the only drawdown mechanism provided for the detention pond. No overflow weirs or other outflow structures were constructed within the pond. Discharges from the underdrain flow to Lake Gem, a land-locked waterbody. At the normal water elevation, the detention pond has an area of approximately 0.15 ha (0.36 ac) with a maximum depth of 2.0 m (6.6 ft).

6.1.2 Field and Laboratory Procedures

Field instrumentation was installed to conduct a complete hydrologic budget for the pond site, including a water level recorder, rainfall recorder, evaporimeter and groundwater piezometers. Automatic sequential samplers 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. Field personnel visited the research site twice each week to retrieve samples and flow data from the stormwater and outflow collectors.

Three multiport groundwater monitoring wells were also installed at the site. The monitoring wells were installed so that one well was upgradient from the pond in terms of groundwater movement, one well in a downgradient position and one well installed within the pond. Sample ports were installed at depths of 0.1 m, 0.5 m, 1.0 m and 2.5 m below the water table elevation at the time of installation. Polyethylene tubing was extended from each sample port through the well casing to the surface for collection of groundwater samples. Groundwater samples were collected using a peristaltic pump operated at a low flow rate. All sample ports were purged on a weekly basis for a period of approximately 30-60 days prior to sample collection. Field measurements of pH, dissolved oxygen, temperature, conductivity and redox potential were recorded during sample collection.

Pond surface water was collected on a weekly basis from the center of the pond as a single vertical composite sample. Vertical depth profiles of pH, temperature, conductivity, dissolved oxygen and redox potential were also collected within the pond. Water quality characteristics of bulk precipitation were estimated by collection and analysis of combined wet and dry fallout. Bulk precipitation samples were also collected on a weekly basis.

Sediment core samples were collected within the detention pond, in control areas and within the filter media to quantify the fate of stormwater pollutants within the detention with filtration system. A total of 28 sediment core samples were collected within the pond and divided into the following layers: 0-1 cm, 1-5 cm, 5-10 cm, 10-15 cm, 15-25 cm and 25-50 cm. Triplicate core samples were collected at each sample location and divided into each of the six sediment layers. A total of 28 separate sediment core samples were collected within the detention pond to define the horizontal and vertical migration of runoff related pollutants within the detention pond. Composite samples were also collected from an isolated control area and from active and inactive portions of the filter bed.

Detailed laboratory analyses were conducted on collected samples of inflow, outflow, surface water, bulk precipitation and groundwater. Analyses included nutrients, general inorganic parameters, demand parameters, chlorophyll-a, fecal coliform and dissolved and total heavy metals. Extensive testing was also conducted on sediment samples including nutrients, heavy metals and particle size. In excess of 48,000 separate field and laboratory measurements were generated during the course of this project.

6.1.3 Pilot Testing

A series of pilot scale experiments were conducted to evaluate the effects of filter media, filter configurations and sod cover on hydraulic performance and pollutant attenuation in filter systems. A filter test area was constructed inside an existing retention pond with a width of 4.7 m (15.5 ft) and a length of 6.1 m (20.0 ft). A bottom vertical filter and a typical side bank filter in a "dry bottom" configuration were constructed within the test area. The vertical bottom filter and side bank filters were initially filled with a fine coarse sand aggregate per FDOT Specification 902.4.

Hydraulic testing was conducted on each filter system to evaluate drawdown characteristics of vertical bottom and side bank filters for comparison with typically used design equations.

Additional hydraulic and water quality testing was conducted using the side bank filter with three different media configurations and four different sod covers. Initial testing was conducted using the side bank filter configuration with the original filter media (FDOT 902.4) with no sod cover. The side bank filter was then modified to include a 15 cm (6 in) gravel envelope around the underdrain pipe. A final series of tests was conducted by replacing the original filter media with 20-30 silica sand.

A total of four sod types were also tested on the side bank filter using the original filter media (FDOT 902.4) without a gravel envelope. These sod types included St. Augustine sod grown in sand, St. Augustine sod grown in muck, Bahia sod grown in sand, and Bermuda sod grown in muck. Hydraulic and water quality analyses were conducted for each of the four sod types.

6.1.4 Site Hydrology

A continuous record of rainfall characteristics was collected at the DeBary research site from May 15, 1992 to November 30, 1992 using a tipping bucket rainfall collector with a continuous strip chart recorder. Total event rainfall ranged from 0.05 to 15.01 cm (0.02 to 5.91 in) with a mean of 1.2 cm (0.47 in) per rain event. A total of 109.2 cm (42.99 in) of rainfall were measured at the site from May through November.

Water surface elevations at the DeBary research site were measured on a continuous basis using a water level recorder from April to November 1992. Water surface elevations fluctuated a maximum of approximately 1 m (3.3 ft) during the study period. The peak design stage for the pond was exceeded on two occasions during this 6-month study period.

Piezometric elevations were measured at the DeBary research site from May to November 1992 with piezometers located along the west, east, north and south sides of the pond as well as piezometers installed with the three groundwater monitoring wells. In general, groundwater was found to be migrating into the pond along the west side of the pond and seeping out of the pond along the east side. Piezometric gradients along the north and south sides of the pond were relatively small. Vertical groundwater gradients at the research site were found to be extremely small, particularly in comparison with the horizontal gradients.

Average daily evaporation losses were measured at the DeBary research site from May to November 1992. Hourly evaporative losses increased during the day, reaching a peak value between 12 noon and 3 p.m., with rapid decreases in evaporation between 4 p.m. and 6 p.m. Evaporation during night-time hours was found to be approximately

10% of the maximum evaporation measured during day-light hours. Total daily evaporative losses ranged from a low of 1.54 mm/day in November to a maximum of 10.46 mm/day in July.

Estimates of hydraulic inputs from direct precipitation onto the pond surface were performed on a daily basis for a 7-month period from May through November 1992. These estimates were performed by multiplying the total rainfall for each rain event times the estimated pond area at the time of the rain event. Estimates of surface water evaporative losses were also conducted on a daily basis through May to November.

Continuous inflow hydrographs were recorded for inputs of stormwater and baseflow into the detention pond from June 4, 1992 to November 26, 1992. Calculated runoff coefficients at the DeBary research site ranged from a low of 0.036 in June to a high of 0.278 in October, with a weighted average runoff coefficient of 0.121. These relatively low values are presumably due to infiltration of runoff within the roadside swales during conveyance to the detention pond.

During the 6-month study period, stormwater contributed 78% of the inputs into the pond, with 17% contributed by groundwater inflow and 5% by direct rainfall. Groundwater inflow into the pond was found to occur only during October and November, with groundwater losses from the pond during June through September. The dominant output from the pond was underdrain outflow which contributed 82% of the estimated outputs during the 6-month study period. Groundwater losses contributed an additional 12%, with 6% of the hydraulic losses due to evaporation.

Average detention time within the pond ranged from a low of 5.6 days in November to a maximum of 42.6 days in June. Hydraulic detention time within the pond system is regulated primarily by inputs of stormwater runoff and is directly related to the total rainfall occurring during a particular month.

6.1.5 Characteristics of Stormwater and Baseflow

Flow-weighted samples of stormwater runoff were collected at the DeBary detention with filtration site from June to November 1992. A total of 33 separate storm event composite samples were collected and analyzed over the 6-month study period, representing more than 90% of the total storm events which generated measurable runoff into the detention pond. In addition, seven composite baseflow samples were also collected at the input to the DeBary detention pond. Stormwater characteristics were monitored over a wide range of rain event characteristics.

In general, a high degree of variability was observed in event mean runoff concentrations for general chemical parameters. Measured concentrations of several parameters covered over two orders of magnitude between minimum and maximum values. The mean concentration of total nitrogen in stormwater runoff at the DeBary site was 761 μg/l. This value is less than one-half of typical stormwater concentrations of total nitrogen in Central Florida and may be related to the pre-treatment occurring the roadside swale system used for conveyance of stormwater runoff to the detention pond site. The dominant nitrogen species in stormwater runoff was organic nitrogen, comprising 67% of the total nitrogen found.

In contrast, the mean total phosphorus concentration of 260 µg/l in stormwater runoff is typical of total phosphorus concentrations found in stormwater runoff in Central Florida. The dominant phosphorus species present in stormwater runoff was particulate phosphorus, with accounted for 63% of the total phosphorus measured.

In general, measured concentrations of all heavy metals at the DeBary research site, with the exception of iron, were extremely low in value. The mean concentration of total cadmium in stormwater runoff was less than 1 µg/l, with mean concentrations of chromium, copper and lead less than 10 µg/l. Excluding iron, the most common heavy metals found in stormwater runoff were copper, lead and zinc, which together accounted for 93% of the total heavy metals measured at the site. Cadmium and copper were found primarily in a dissolved state in stormwater runoff, while chromium, lead, iron and zinc were found to be primarily particulate in nature.

Rainfall intensity was found to exhibit significant positive correlations with particulate organic nitrogen, total nitrogen, particulate phosphorus, total phosphorus, TSS, total lead and total zinc. These positive correlations suggest that the mobilization of each of these species into stormwater runoff increases as the intensity of rainfall increases. Event duration was found to exhibit significant negative correlations between particulate organic nitrogen and total nitrogen, indicating that concentrations of these species decrease with increasing time during rain events.

Baseflow at the DeBary research site was found to have substantially higher concentrations of total nitrogen than found in stormwater runoff, with a mean baseflow total nitrogen of 1381 µg/l compared to 761 µg/l for stormwater runoff. The dominant nitrogen species in baseflow was dissolved organic nitrogen. In contrast, measured concentrations of total phosphorus and heavy metals were relatively low in value in baseflow inputs. Measured concentrations of cadmium, chromium and lead in baseflow inputs were less than 3 µg/l on average. Average concentrations of copper and zinc were less than 10 µg/l.

6.1.6 Characteristics of Bulk Precipitation

A total of 17 bulk precipitation samples were collected at the DeBary research site during the 6-month study period. Bulk precipitation was found to be acidic with pH values ranging from 4.27 to 6.52. Bulk precipitation was also low in ionic strength with an extremely low buffering capacity.

The most dominant nitrogen species found in bulk precipitation was NO_x which comprised 37% of the mean total nitrogen concentration of 671 µg/l. Measured concentrations of total phosphorus in bulk precipitation were extremely variable with a mean total phosphorus concentration of 45 μg/l. Approximately 60% of the total phosphorus was in a particulate form with 40% in a dissolved form. With the exception of zinc, measured concentrations of heavy metals in bulk precipitation were relatively low, with average concentrations less than 2 μg/l for cadmium, chromium and lead. Measured concentrations of zinc ranged from 8-70 μg/l with a mean of 25 μg/l. This mean value for total zinc is similar to the mean for total zinc found in stormwater runoff.

6.1.7 Characteristics of Pond Surface Water

Visually, the detention pond was characterized by a green appearance due to excessive algal growth and a relatively turbid water column. The pond water column was characterized by a sharp thermal stratification which occurred on many of the monitoring dates at a depth of 0.5 m. However, in spite of this frequent thermal stratification, chemical stratification for pH, dissolved oxygen, specific conductivity or redox potential was not observed on any monitoring date. Measured dissolved oxygen levels exceeded 5 mg/l at all locations within the pond on all monitoring dates.

The dominant nitrogen species in pond surface water was organic nitrogen which accounted for 96% of the total nitrogen found. Mean concentrations of ammonia and NO_x were extremely small within the pond. The mean total nitrogen value of 891 μg/l within the pond is approximately 17% higher than the value of 761 μg/l found in stormwater runoff. Measured concentrations of all phosphorus species in the pond surface water were found to be substantially lower than values measured in stormwater runoff. The dominant phosphorus species measured within the pond was particulate phosphorus which accounted for 64% of the total phosphorus found within the pond. Measured values of chlorophyll-a ranged from 8.4 to 48.3 mg/m^3. Measured fecal coliform counts within the pond were also extremely variable during the monitoring period, with a range of values of 64 to 12,150 organisms/100 ml. However, much of this bacterial contamination may be due to the large population of resident water fowl at the site.

In general, measured concentrations of both total and dissolved heavy metals in pond surface water were relatively low in value and substantially lower than values measured in stormwater runoff. With the exception of iron, mean concentrations of both total and dissolved heavy metals were equal to or less than 5 μg/l within the pond surface water.

6.1.8 Characteristics of Underdrain Outflow

A total of 47 underdrain outflow samples were collected and analyzed at the DeBary research site during the 6-month monitoring period. The mean total nitrogen concentration of 707 μg/l in underdrain outflow is less than the mean of 891 μg/l in pond surface water and approximately equal to the mean of 761 μg/l found in stormwater runoff. Measured concentrations of both ammonia and NO_x increased substantially in underdrain outflow compared with concentrations found in the pond surface water. The combined mean concentration of ammonia and NO_x in underdrain outflow was 274 μg/l compared with a mean of only 47 μg/l within the pond surface water. These inorganic species of nitrogen comprised 39% of the total nitrogen found in the underdrain flow, but only 5% of the nitrogen found in the pond water.

Mean concentrations of particulate phosphorus were reduced from 65 μg/l inside the pond to only 18 μg/l after migration through the filter. However, a portion of the trapped particulate phosphorus is apparently being converted to dissolved orthophosphorus inside the filter media since orthophosphorus concentrations in the underdrain outflow average 48 μg/l compared with a mean of only 16 μg/l in pond surface water. However, mean concentrations of total phosphorus and underdrain outflow were approximately 24% lower than mean total phosphorus concentrations in the pond surface water. Similarly, mean values of turbidity decreased approximately 82% during migration through the filter, with a 90% reduction in TSS and a 57% reduction in BOD.

With the exception of copper, measured concentrations of heavy metals in the underdrain outflow were equal to or less than mean concentrations measured in pond surface waters. Mean concentrations of cadmium, chromium, lead and zinc in underdrain outflow were equal to approximately 2 μg/l or less, with a mean of 7 μg/l for copper. Decreases in filter flow rates were found to result in significantly higher concentrations of specific conductivity, alkalinity, ammonia, orthophosphorus, dissolved iron and total iron. Significant positive correlations were found between flow rate and dissolved organic nitrogen, dissolved organic phosphorus, total chromium, dissolved lead and total lead.

6.1.9 Characteristics of Groundwater

Groundwater characteristics were measured using three multiport groundwater monitoring wells installed in upgradient, downgradient and pond locations at the research site. Separate water quality samples were collected from four sample ports on each of the multiport monitoring wells at distances of 0.1 m, 0.5 m, 1.0 m and 2.5 m below the groundwater table at the time of well installation. Samples were collected from each monitoring well on a monthly basis using a peristaltic pump operated at a low flow rate.

Groundwater at upgradient locations was found to be somewhat acidic in nature, with pH values ranging from 5.64 at the 0.1 m sample port to 4.66 at the 2.5 m sample port. Measured values for redox potential indicated reduced conditions at each of the four monitoring ports. A general trend was observed for decreasing concentration of all nitrogen species with increasing groundwater depth. This trend was not observed for species of total phosphorus. The dominant phosphorus species present in groundwater at the upgradient monitoring site was orthophosphorus which contributed 90% or more of the total phosphorus measured at each sample port. In general, measured concentrations of heavy metals were extremely low at all sample ports, with mean concentrations of cadmium, chromium, lead and zinc equal to or less than 2 μg/l at all sample ports.

Groundwater beneath the detention pond was found to be higher in pH and redox potential than measured in the upgradient monitoring area. In general, oxidized conditions extended to a depth of 0.5 m below the pond with mildly reduced conditions at 1.0 m and 2.5 m.

In contrast to the trend of decreasing concentrations of total nitrogen with increasing groundwater depth observed in the upgradient area, mean concentrations of total nitrogen beneath the pond increased slightly with increasing groundwater depth. The dominant nitrogen species at all sample depths was ammonia nitrogen, with extremely low measured concentrations of NO_x.

Mean groundwater concentrations of total phosphorus beneath the pond did not exhibit a clear trend of either increasing or decreasing concentrations with increasing groundwater depth. Orthophosphorus was the dominant phosphorus species found in groundwater beneath the pond, contributing 50% or more of the total phosphorus measured.

Measured concentrations of all heavy metals, with the exception of iron, were found to be extremely low in value beneath the pond, although mean concentrations of copper and zinc were somewhat higher beneath the pond than found in the upgradient area. Mean concentrations of cadmium, chromium, copper, lead and zinc were equal to approximately 5 μg/l or less.

Mean groundwater characteristics measured at the downgradient monitoring well were similar to characteristics found beneath the pond. Based on measured redox potentials, groundwater at the 0.1 m and 0.5 m sample ports was generally oxidized with slightly reduced conditions at the 1.0 m and 2.5 m depths.

Mean values for total nitrogen in the downgradient well were somewhat lower than total nitrogen found beneath the pond and exhibited a clear tendency for decreasing concentration with increasing groundwater depth. The dominant nitrogen species at each sample port was ammonia nitrogen. Measured concentrations of total phosphorus were similar to those observed in upgradient and pond sites, with orthophosphorus as the dominant phosphorus species present. With the exception of iron, measured concentrations of heavy metals at each of the four sample ports were relatively low in the downgradient area.

An analysis of variance comparison was conducted to evaluate if significant differences exist between measured groundwater concentrations in upgradient, downgradient and pond areas. Multiple comparisons suggest that the pond is having a significant effect on groundwater characteristics in the downgradient area compared with characteristics found in upgradient areas. Mean values of pH, specific conductivity and alkalinity were significantly higher in pond and downgradient areas. Pond and downgradient areas were found to have significantly lower levels of orthophosphorus and turbidity compared with upgradient groundwater. Even though measurable impacts on groundwater quality were detected at the DeBary site, this does not indicate that a deterioration of groundwater quality has occurred. For some constituents such as pH, redox potential, turbidity and orthophosphorus, groundwater characteristics in downgradient areas have improved compared with conditions found in upgradient areas.

An analysis of variance comparison was also conducted to evaluate the effects of the detention pond on groundwater immediately beneath the pond. No significant differences were detected at the 0.05 level of significance for mean groundwater concentrations measured at the four sample ports beneath the detention pond. This evidence suggests that significant vertical variability does not exist for groundwater characteristics in the vicinity of the pond, although horizontal migration of groundwater and effects on downgradient areas is apparent.

6.1.10 Characteristics of Sediments

6.1.10.1 Horizontal Migration of Pollutants

In general, both nutrients and heavy metals appear to settle rapidly into the sediments upon entering the detention pond. Peak sediment concentrations of most measured parameters appear to occur at a distance of approximately 20-25 m (55-80 ft) from the point of inflow. Gradual continued deposition is apparent for all parameters throughout other portions of the pond.

Each of the measured heavy metals and nutrients were found to exhibit strong positive significant correlations at the 0.05 level with sediment moisture content. This relationship was particularly strong for total nitrogen and total phosphorus. These relationships indicate that heavy metals and nutrients within the pond sediments are associated with soils that retain high levels of moisture, such as fine grained soils.

6.1.10.2 Vertical Characteristics of Soils and Sediments

With the possible exceptions of zinc and manganese, it is evident that each of the heavy metals measured are accumulating within the sediments of the pond at concentrations higher than in undisbursed control areas. Sediment concentrations of total nitrogen, total phosphorus, cadmium, copper, lead, zinc and manganese were found to be highest at the surface, with decreasing concentrations at increasing sediment depths. Patterns of decreasing sediment concentrations with increasing sediment depth exhibited typical logarithmic relationships for most metals. In contrast, sediment concentrations of chromium, iron and aluminum appear to increase with increasing sediment depth. However, it is apparent that the detention pond is attenuating and retaining inputs of heavy metals and total phosphorus within the pond sediments in concentrations substantially greater than found in undisbursed control sediments.

Composite vertical core samples were also collected from active and inactive portions of the filter bed to evaluate attenuation mechanisms for pollutants within the filter media. Concentrations of nutrients and heavy metals in both active and inactive portions of the filter media were found to be highest in concentration near the surface and decrease with increasing sediment depth. However, in general, measured concentrations of all parameters within the filter media were substantially less than that found within the sediments of the pond. With the exception of manganese, all measured parameters were found in higher concentrations within the active portion of the filter media than in inactive areas. The filter media is clearly retaining pollutants within the media, although the retention rate is substantially less than that exhibited within the sediments of the pond. It appears that the filter media has a limited capacity to retain nutrients and heavy metals based upon the relatively low concentrations found in active portions of the filter media and also due to the fact that little difference is found between measured concentrations of heavy metals in active and inactive areas.

6.1.11 Pilot Filter Bed Testing

6.1.11.1 Pollutant Attenuation by Various Filter Media

A series of pilot scale experiments were conducted to evaluate the effects of filter media and filter configurations on pollutant attenuation in a side bank filter system. Three separate media and system configurations were tested, including a side bank filter system constructed using FDOT 902.4 media, a side bank filter system constructed using FDOT 902.4 media with a gravel envelope around the underdrain pipe, and a side bank filter system constructed using 20-30 silica sand as the filter media. A total of four separate experiments were conducted with each media and filter configuration using a simulated stormwater solution with continuous monitoring of pond water and underdrain outflow during the drawdown period.

Removal of total nitrogen and total phosphorus were similar for each of the three filter media configurations tested. Removal of total nitrogen ranged from 5-7% with a removal for total phosphorus from 37-55%. In general, removal of heavy metals was typically good for each of the three filter configurations. Removal of total copper ranged from 30-50%, with a removal for total lead of 88-99% and removal of zinc between 92-99%. Removal efficiencies for total nitrogen, total phosphorus and heavy metals appear to be somewhat higher using the 20-30 silica sand media than with the other configurations, although removal efficiencies were relatively similar for each of the three configurations.

6.1.11.2 Attenuation of Pollutants by Various Sod Covers

A series of experiments were conducted using four separate sod covers on the side bank filter system constructed using the FDOT 902.4 media to evaluate pollutant attenuation by various sod covers. A total of four sod types were investigated during this research, including: St. Augustine sod grown in sand, St. Augustine sod grown in muck, Bahia sod grown in sand and Bermuda sod grown in muck. A total of four separate experiments were conducted using each sod cover with a simulated stormwater solution.

Removal of total nitrogen and heavy metals by the four sod media appear to be relatively similar. Removal of total nitrogen ranged from 3-11%, with copper removal ranging from 41-56%, removal of lead ranging from 87-96% and removal of zinc ranging from 92-98%. Substantially higher removals for total phosphorus were obtained with the Bahia sod grown in sand with an average removal of 41% for this sod type compared with removals of less than 20% for the other sod types.

Due to the relatively short contact time between the simulated stormwater solution and the plant material, it is unlikely that plant uptake contributes a large portion of the removal efficiencies observed during these experiments. The majority of removal efficiencies observed are likely to occur within the sod media rather than by plant uptake. Therefore, the type of soil used is probably more important in determining pollutant attenuation than the type of sod grown within the soil.

6.1.12 Hydraulic Evaluations

6.1.12.1 Hydraulic Characteristics of the Filter System at the DeBary Research Site

Sieve analyses were conducted on composite filter media samples collected in active and inactive portions of the filter bank at the DeBary research site. Based upon these sieve analyses, the filter media in active portions of the filter bank at the DeBary site met all applicable criteria for filter systems outlined in Chapter 17-25.025 of the Florida Administrative Code.

Drawdown characteristics of the filter underdrain system at the DeBary research site were evaluated based upon information on water surface elevations, runoff inflow hydrographs, outflow hydrographs and characteristics of rain events. For rain events less than approximately 1.3 cm (0.5 in), the detention pond was able to recover both pond elevation and outflow discharge rates to levels equal to or less than those measured in the pond prior to rain events during a drawdown period of 72 hours. However, the pond was unable to recover either pond elevation or outflow discharge rates for rain events substantially in excess of 1.3 cm (0.5 in) or during multiple rain events on consecutive days.

Underdrain outflow rates appear to exhibit an exponential relationship as a function of head above the underdrain, with rapidly increasing underdrain outflow rates with increasing underdrain heads. Underdrain outflow discharge rates appear to approach zero as the distance above the centerline of the underdrain approaches a value of 0.076 m (0.25 ft) which is equal to the elevation at the top of the underdrain pipe. Friction losses through the filter media appear to limit the effective drawdown capacity of the underdrain to an elevation equal to the top flow line of the pipe.

Instantaneous permeability (K) values were measured for the detention with filtration system at the DeBary research site and were calculated on a daily basis for the 6-month study period from June through November 1992. Permeability values were calculated for all days when the underdrain outflow was greater than 0.0 cfs using the Incremental Darcy's Equations based upon water surface elevations and underdrain outflow data.

Daily variations in calculated permeability values were extremely high during June and July when the head above the underdrain ranged from 0.2-0.3 ft. Calculated permeability values for these months covered more than one order of magnitude between minimum and maximum values. Variability in measured permeability values became substantially less during August through November when the average head above the underdrain increased. The overall mean permeability value for the side bank filter system from June through November was 2.34 ft/hr.

Measured drawdown characteristics of the detention with filtration system at the DeBary research site were compared with commonly used design equations for side bank filter systems to evaluate the ability of these equations to predict drawdown characteristics actually measured at the research site. Both the Incremental Darcy's Equation and the Modified Incremental Darcy's Equation appear to provide good fits to the actual measured outflow at the DeBary research site, although both equations tended to underestimate underdrain outflow at head values greater than 1.5 feet. Changes in predicted drawdown characteristics due to changes in the value of K are relatively small for both equations.

6.1.12.2 Pilot Scale Filter Systems

A number of hydraulic experiments were conducted using both vertical and side bank filter system in various configurations to evaluate the hydraulic characteristics of these common filter systems. Two separate filter media were evaluated, including the FDOT 902.4 media and 20-30 silica sand.

Sieve analyses were conducted on each of the two filter media to evaluate the physical properties of each media. The 20-30 silica sand was found to have a relatively large grain size with an effective diameter of 0.395 mm. The 20-30 silica sand met the requirements for filter media outlined in Chapter 17-25.025 of the Florida Administrative Code. The FDOT 902.4 media was found to have a substantially smaller effective diameter of only 0.154 mm which is slightly less than the minimum value of 0.20 mm recommended in Chapter 17-25.

Drawdown characteristics of the side bank filter system constructed using FDOT 902.4 media and the side bank system constructed using FDOT 902.4 media with a gravel envelope were relatively similar, although the gravel envelope configuration resulted in enhanced flow rates through the underdrain system. At an elevation of 4 ft of head above the underdrain pipe, outflow discharge rates were increased by approximately 20% using the gravel envelope. Substitution of the 20-30 silica sand for the FDOT 902.4 media substantially improved the hydraulic performance of the filter system. At a head of 4 ft above the underdrain pipe, the measured flow rate through the 20-30 silica sand was approximately 130% greater than the filter system constructed using the FDOT 902.4 media. The flow rate through the 20-30 silica sand was approximately 180% greater at a head of 3 ft and 150% greater at a head of 2.2 ft.

Filter drawdown characteristics were also evaluated using the typical side bank filter system constructed using FDOT 902.4 filter media covered with the four sod types. Drawdown curves for each of the four sod types appear to exhibit a logarithmic type relationship with flow rates beginning to level off slightly at head elevations above 4.0-4.5 ft. Sod grown in sand was found to exhibit enhanced hydraulic performance compared to sod grown in muck. The best hydraulic performance of the four sod types was achieved using the Bahia sod grown in sand, followed by St. Augustine sod grown in sand. The hydraulic performance exhibited by Bahia sod grown in sand was only approximately 5-10% less than underdrain outflow rates exhibited by the sand filter with no sod cover. The addition of a sod cover to the filter media does not appear to substantially decrease the hydraulic performance of the filter system.

Field measured permeability values were determined for the vertical bottom filter and each of the side bank configurations including sod covers. The calculated permeability of the FDOT 902.4 media was found to be 2.01 ft/hr. This permeability increased to a value of 2.48 ft/hr when a gravel envelope was placed around the underdrain pipe. Substitution of 20-30 silica sand for the FDOT 902.4 media increased the calculated permeability to a value of 5.3 ft/hr which was the highest permeability measured in any of the pilot scale tests.

Field permeabilities with the side bank filter system covered with various sod types ranged from a high of 1.89 ft/hr for the Bahia sod grown in sand to a low of 1.27 ft/hr for the Bermuda sod grown in muck. The permeability of the filter configuration with a Bahia sod cover grown in sand was only 6% less than the permeability of the filter media with no sod cover. The presence of sod covers, particularly the Bahia sod grown in sand, does not appear to have a significant effect on the calculated permeability of the filter system. The configuration of the pilot scale filter system resulted in many of the tests being conducted with an "i" value ≥ 1.

Hydraulic experiments were conducted using a bottom vertical filter with no sod cover and a side bank filter with various configurations of media and sod cover to evaluate the applicability of commonly used design equations for predicting drawdown for the tested configurations. When field measured permeabilities are used, the Incremental Darcy's Equation using an average D more accurately predicts observed drawdown for vertical bottom filters, although this equation results in overestimates of underdrain outflow under most head conditions. Use of the maximum permeability of 2.5 ft/hr allowed by SJRWMD for use in Type A soils results in a substantial overestimation of underdrain outflow for all head conditions.

The Falling Head Equation may also be a suitable design equation for use in estimating drawdown time for vertical bottom filters. This equation is generally not used to predict underdrain outflow rates but is used to calculate the length of time required for the filter to drawdown from one elevation to another. This equation underpredicted the actual time required for drawdown of the pilot test system by approximately 13% at the field measured K value.

The Incremental Darcy's Equation, using field measured permeability values, provides a close estimation of actual measured flow rates from the side bank filter system constructed in the "dry bottom" type configurations for each of the three filter configurations and four sod types tested at low head conditions. At higher head conditions, the Modified Incremental Darcy's Equation provided the best fit. Substantial error was obtained using the other design equations. The percent error in estimation for the Incremental Darcy's Equation and the Modified Incremental Darcy's Equation increases substantially as K values other than the field measured K values are substituted into the design equations. Therefore, selection of an appropriate K value is extremely important for insuring a good fit between predicted and measured underdrain flow rates.

6.1.13 Estimated Mass Removal Efficiencies for the DeBary Detention with Filtration Pond

Monthly mass balances were calculated for the DeBary detention with filtration pond for each of the six months during the study period from June through November 1992 along with an overall mass balance for the 6-month period. Inputs into the detention with filtration system were assumed to occur from stormwater, bulk precipitation and groundwater inflow. Mass outputs from the pond occur through the underdrain outflow and by groundwater losses to downgradient areas, primarily on the east side of the pond.

Considerable variability was observed in monthly mass removal efficiencies for species of nitrogen as well as dissolved organic phosphorus. A net mass removal by the system was achieved for ammonia and dissolved organic nitrogen during only one of the six monitoring months. Net mass removals for NO_x were achieved during three of the six months, with a net removal for particulate organic nitrogen during five of the six months. A net mass removal for total nitrogen was achieved during four of the 6 months.

In contrast, consistently high mass removal rates were achieved for orthophosphorus, particulate phosphorus, total phosphorus, TSS, BOD and heavy metals during each of the six months monitored. Monthly mass removal efficiencies for total phosphorus ranged from 49-87%, with removal efficiencies for TSS and BOD ranging from 97-100%.

With the exception of total copper, removal efficiencies for each of these measured parameters appears to increase with increasing detention time within the pond.

Mass removal of total zinc within the detention with filtration system exceeded 80% for all measured detention times. Mass removal for total phosphorus, total lead and total chromium appears to approach an efficiency of 80% after approximately 30 days of detention time within the pond. Mass removal of total nitrogen within the pond was extremely variable with a net removal of only 30% achieved after a detention time of 30 days.

An overall mass balance for the DeBary detention with filtration facility for the 6-month monitoring period was also calculated. In general, mass detention for all nitrogen species was relatively poor within the pond system. Net removal of ammonia within the pond system was only 2% with a net removal of approximately 30% for NO_x and particulate organic nitrogen. Organic nitrogen increased substantially within the pond. No net removal was observed for total nitrogen within the detention with filtration system.

In contrast, consistent removals were observed for all measured species of phosphorus. Net removal for orthophosphorus within the detention with filtration system was approximately 37%. Particulate phosphorus was retained extremely well within the pond with a net retention of 80%. Overall, removal of total phosphorus within the pond averaged 61% during the 6-month study period.

Mass retention for TSS and BOD within the pond was excellent with an average retention of 98% for TSS and 99% for BOD. Consistent mass removals were also observed for each of the measured heavy metals. In general, a removal of approximately 40% was observed for total copper, with a 50% removal for total cadmium and total chromium, a 70% removal for total lead and total iron, and 90% removal for total zinc. A primary mechanism for removal of heavy metals and TSS within the detention pond appears to be settling processes which occur within the water column, allowing particulate forms of heavy metals to settle out into the bottom sediments.

Concentration-based removal efficiencies were calculated for both the detention pond and the filter media to evaluate mechanisms responsible for removal of pollutants within the detention with filtration system. Chemical, physical and biological processes within the water column of the detention pond are the primary mechanisms responsible for removal of orthophosphorus, total phosphorus, turbidity and heavy metals for the detention with filtration system. The presence of the side bank filter system appears to enhance the removal efficiency of only a few parameters including total nitrogen, TSS, total iron and total zinc. The primary mechanisms for removal of pollutants within the system occur within the water column of the detention pond with the filter system acting as a final polishing mechanism for selected constituents. Even though the filter system may trap particles of organic nitrogen or particulate phosphorus, subsequent decomposition processes result in increased outflow concentrations of soluble inorganic species of nitrogen and phosphorus as the trapped particles slowly decompose within the filter media.

Although the filter media may provide enhanced removal for selected species such as total nitrogen, TSS, total iron and total zinc, it did not provide substantial enhancement for removal of the remaining measured chemical parameters. The ability of the filter media to retain pollutants on a long-term basis is severely limited due to a lack of adsorption or exchange sites on the silica particles which comprise the filter media. The primary mechanism for retaining particles within the filter media is likely a purely physical phenomenon of entrapment within the filter media. The process of entrapment can only provide long-term removal efficiencies for particulate matter which is not subject to subsequent decomposition.

Mean water quality characteristics within the detention pond water column met all applicable Class III criteria outlined in Chapter 17-302 of the Florida Administrative Code for the parameters measured, including heavy metals. Discharges from the detention pond without the additional filtration by the filter media would not have resulted in violations of the Class III criteria. Similarly, with the possible exception of dissolved oxygen, underdrain outflow also met all applicable Class III criteria for surface waters, including heavy metals. Treated discharges from the underdrain system would not create any violations of surface water quality.

6.2 Conclusions

From the results obtained during this research, the following specific conclusions were reached:

1. Infiltration and runoff within the roadside swales during conveyance to the detention pond resulted in extremely low values for runoff coefficients measured at the DeBary research site. Calculated runoff coefficients ranged from a low of 0.036 in June to a high of 0.278 in October, with a weighted average runoff coefficient of 0.121.

2. Stormwater contributed 78% of the inputs into the pond, with 17% contributed by groundwater inflow and 5% by direct rainfall. Groundwater inflow into the pond occurred only during October and November, with groundwater losses to the pond during June through September.

3. The dominant output from the pond was underdrain outflow which accounted for 82% of the estimated outputs. Groundwater losses contributed an additional 12%, with 6% of hydraulic losses due to evaporation.

4. Groundwater movement at the site was primarily from west to east along a horizontal gradient. Vertical groundwater gradients at the research site were extremely small, particularly in comparison with horizontal gradients.

5. Average detention time within the pond was extremely variable from month to month, with a low of 5.6 days in November to a maximum of 42.6 days in June. Hydraulic detention time was regulated primarily by inputs of stormwater runoff and the amount of total rainfall occurring during a particular month.

6. Measured concentrations of most parameters in stormwater runoff were substantially lower than concentrations typically found in stormwater measured in Central Florida. The lower values found at the DeBary site are thought to be related to pre-treatment occurring within the roadside swale system used for conveyance of stormwater runoff to the detention pond site.

7. Excluding iron, the most common heavy metals found in stormwater runoff were copper, lead and zinc, which together accounted for 93% of the total heavy metals measured at the site. Cadmium and copper were found primarily in a dissolved state in stormwater runoff, while chromium, lead, iron and zinc were found to be primarily particulate in nature.

8. The water column within the detention pond was characterized by a sharp thermal stratification at a depth of 0.5 m. However, in spite of this frequent thermal stratification, chemical stratification for pH, dissolved oxygen, specific conductivity or redox potential was not observed on any monitoring date. Measured dissolved oxygen levels equaled or exceeded 5 mg/l at all locations on all monitoring dates.

9. With the exception of nitrogen species, mean concentrations of all measured parameters were substantially lower within the pond than found in stormwater runoff. Variability of measured concentrations was also lower within the pond than found in stormwater runoff. Measured concentrations of both total and dissolved heavy metals in pond surface water were extremely low in value with mean concentrations of both total and dissolved heavy metals equal to or less than 5 μg/l, with the exception of iron.

10. The filter system at the DeBary research site was extremely effective in removing water column concentrations of particulate nitrogen and phosphorus. However, it is apparent that these trapped particles are undergoing decomposition processes within the filter media since underdrain outflow concentrations of ammonia, NO_x and orthophosphorus were substantially higher than values measured within the pond.

11. With the exception of copper, measured concentrations of heavy metals in the underdrain outflow were equal to or less than mean concentrations measured in pond surface waters.

12. Analysis of variance comparisons indicate that the pond is having a significant effect on groundwater characteristics in the downgradient area compared with characteristics found in upgradient areas. However, even though measurable impacts on groundwater quality were detected at the DeBary site, this does not indicate that a deterioration of groundwater quality has occurred. For some constituents such as pH, redox potential, turbidity and orthophosphorus, groundwater characteristics in downgradient areas have improved compared with conditions found in upgradient areas.

13. Both nutrients and heavy metals appear to settle rapidly into the sediments upon entering the detention pond. Peak sediment concentrations in the 0-1 cm layer for most measured parameters appear to occur at a distance of approximately 20-25 m from the point of inflow. Gradual continued deposition is apparent for all parameters throughout other portions of the pond.

14. Sediment concentrations of total nitrogen, total phosphorus, cadmium, copper, lead, zinc and manganese were found to be highest at the surface, with decreasing concentrations at increasing sediment depths. It is apparent that the detention pond is attenuating and retaining inputs of heavy metals and total phosphorus within the pond sediments in concentrations substantially greater than found in undisturbed control sediments.

15. Sediment core samples collected from active and inactive portions of the filter bed indicate that the filter media has an ability to retain pollutants within the media, although the retention rate is substantially less than that exhibited within the sediments of the pond. The ability of the filter media to retain pollutants appears to be limited.

16. Removal of total nitrogen, total phosphorus and heavy metals appears to be similar in pilot scale tests conducted using a side bank filter constructed with FDOT 902.4 media, FDOT 902.4 media with a gravel envelope around the underdrain pipe, and 20-30 silica sand as filter media.

17. The addition of sod cover to the side bank filter system resulted in a small enhancement of removal efficiencies for total nitrogen, total phosphorus and heavy metals compared to the filter system with no sod cover. Due to the relatively short contact time between the stormwater solution and the plant material, it is likely that much of the additional removal observed is due to contact with the sod media rather than by plant uptake. The type of soil used is probably more important in determining pollutant attenuation than the type of sod grown within the soil.

18. For rain events less than approximately 1.3 cm (0.5 in), the detention pond was able to recover both pond elevation and outflow discharge rates to levels equal to or less than those measured in the pond prior to rain events over the drawdown period of 72 hours. However, the DeBary pond was unable to recover either pond elevation or outflow discharge rates for rain events substantially in excess of 1.3 cm (0.5 in) or during multiple rain events on consecutive days.

19. Underdrain outflow rates at the DeBary pond appear to exhibit an exponential relationship as a function of head above the underdrain with rapidly increasing underdrain flow rates with increasing underdrain heads. Friction losses through the filter media appear to limit the effective drawdown capacity of the underdrain to an elevation equal to the top flow line of the pipe.

20. Both the Incremental Darcy's Equation and the Modified Incremental Darcy's Equation appear to provide good fits to the actual measured outflow for "wet bottom" type filter systems such as the one at the DeBary research site. However, both equations tend to underestimate underdrain outflow at head values greater than 1.5 feet. Changes in predicted drawdown characteristics due to changes in the value of K are relatively small for both equations.

21. Modification of a standard side bank filter system with a gravel envelope around the underdrain pipe increased discharge outflow rates by approximately 20% at a head of 4 ft above the underdrain pipe. Substitution of 20-30 silica sand for the standard filter media improved measured flow rates through the underdrain system by approximately 130% at a head of 4 ft above the underdrain pipe.

22. The addition of a sod cover to the filter media does not appear to substantially decrease the hydraulic performance of the filter system. The hydraulic performance exhibited by Bahia sod grown in sand was only approximately 5-10% less than underdrain outflow rates exhibited by the sand filter with no sod cover.

23. When field measured permeabilities are used, both the Incremental Darcy's Equation Using an Average D and the Falling Head Equation fairly accurately predict observed drawdown for vertical bottom filters, although both equations result in overestimates of underdrain flow under most head conditions. Underdrain discharge rates predicted by both equations are extremely sensitive to changes in permeability values for the filter media.

24. The Incremental Darcy's Equation, using field measured permeability values, provides a close estimation of actual measured flow rates from side bank filter systems constructed in a "dry bottom" type configuration under low head conditions for each of the three filter configurations and four sod types tested. At higher head conditions, the Modified Incremental Darcy's Equation provides the best fit. Substantial errors are obtained using the other design equations. Selection of an appropriate K value is extremely important for insuring a good fit between predicted and measured underdrain flow rates.

25. Monthly mass removal efficiencies were extremely variable at the DeBary detention with filtration pond for most species of nitrogen as well as dissolved organic phosphorus. In contrast, consistently high mass removal rates were achieved for orthophosphorus, particulate phosphorus, total phosphorus, TSS, BOD and heavy metals during each of the six months monitored.

26. Removal efficiencies for most measured parameters appear to increase with increasing detention time within the pond with peak removal efficiencies achieved after a detention time of 10 days. However, mass removal of total nitrogen is extremely variable, with a net removal of only 30% achieved after a detention time of 30 days.

27. Overall mass retention for all nitrogen species was extremely poor within the detention pond system with a net increase of 3% for total nitrogen. In contrast, consistent removals were observed for all measured species of phosphorus, with a net removal of 37% for orthophosphorus and 61% for total phosphorus. Mass retention for TSS and BOD within the system was excellent with an average retention of 98% for TSS and 99% for BOD.

28. Consistent mass removals were observed for each of the measured heavy metals within the DeBary detention with filtration system. In general, an overall mass removal of approximately 40% was observed for total copper, 50% for total cadmium and total chromium, 70% for total lead and total iron, and 90% removal for total zinc. The primary mechanism for removal of heavy metals and TSS within the detention pond appears to be settling processes which occur within the detention pond water column.

29. Chemical, physical and biological processes within the water column of the detention pond are the primary mechanisms responsible for removal of orthophosphorus, total phosphorus, turbidity and heavy metals for the detention with filtration system. The presence of a side bank filter system appears to enhance the removal efficiency of only a few parameters including total nitrogen, TSS, total iron and total zinc.

30. The detention with filtration system does not appear to meet the 80% pollutant removal goal outlined in Chapter 17-40 of the Florida Administrative Code. A net mass removal of 80% was achieved only for TSS, BOD and total zinc within the detention with filtration system.

6.3 Recommendations

Based upon the experimental results obtained during this research and the specific conclusions presented previously, the following recommendations are made for improving the performance and design of filtration systems:

1. The use of wet detention with filtration systems is strongly recommended over vertical filter systems or "dry bottom" pond configurations. Evidence gathered during this research indicates that the filter portion of the system provides a relatively small portion of the pollutant attenuation capabilities of the system. The majority of the removal processes occur within the permanent pool of the filter system. Therefore, wet detention with filtration systems provide substantially enhanced pollutant removal than can potentially occur within a dry filtration system.

2. Removal efficiencies for many of the measured parameters within the wet detention with filtration system at the DeBary research site appear to reach a plateau after a detention time of 10 days within the detention pond. Additional removals achieved after a detention time of 10 days appear to be minimal. Therefore, it is recommended that wet detention with filtration systems incorporate a minimum average detention time of 10 days within the permanent pool of the system for stormwater inputs.

3. Many of the commonly used design equations for predicting underdrain outflow and drawdown in filter systems do not accurately predict measured drawdown characteristics. Many of these equations overestimate actual underdrain outflow rates, resulting in insufficient designs which do not evacuate within the required drawdown period. It is recommended that the design equations summarized in Table 5-13 for vertical bottom filters, side bank filters constructed in the "wet bottom" configuration, and side bank filters constructed in the "dry bottom" configuration be used. Many of these design equations are sensitive to changes in permeability values, and selection of appropriate K values is critical to accurately predict drawdown characteristics.

4. The current design procedure of selecting permeability values based on soil characteristics within the watershed basin appears to be appropriate for filter systems constructed in the "dry bottom" configuration and vertical bottom filters since these filters are subject to potential clogging by soils from the surrounding watershed. This methodology for selection of K is not recommended for ponds constructed with a permanent wet pool. Chemical, physical and biological processes which occur within the permanent pool will result in deposition of the majority of the suspended solids entering the pond into the sediments. The potential for clogging of filter media in wet ponds by watershed soils appears to be remote.

5. The design of filter systems is currently dictated primarily by hydraulic considerations to insure that the pollution abatement volume is evacuated from the system within the required drawdown period. In many instances, this design process incorporates a safety factor and utilizes restrictive permeabilities of watershed soils. This combination results in a design which provides rapid drawdown and a reduced detention time within the permanent pool. Since the majority of the pollutant removal processes occur within the permanent pool of a "wet bottom" configuration or the detained pool in a "dry bottom" configuration, decreasing the detention time within these systems only serves to decrease the pollutant removal potential of the system. Current design practices should be reviewed to insure that the use of safety factors or restrictive watershed soil permeabilities does not unnecessarily reduce the detention time for pollutants within a filter system.

6. Since the majority of pollutant removal processes occur within the permanent pool of a wet detention with filtration facility, a sod cover is not recommended on the face of the filter media in wet detention systems. However, a sod cover may enhance the pollutant attenuation capabilities of a system constructed in a "dry bottom" configuration. The addition of a sod cover, particularly one grown in sand, will result in only a minor restriction to the hydraulic performance of the system, yet provide sites for adsorption and exchange of pollutants onto the soil within the sod media.

7. Maintenance guidelines need to be established to protect the integrity of the filter system from maintenance practices, particularly those which involve driving heavy machinery upon the face of the filter media. It appears that maintenance of vegetation is necessary on the filter face, but techniques should be used which minimize disturbance of the filter media. Applications of herbicides may an alternative for vegetation control to eliminate the possibility of damage to the filter by heavy machinery.

REFERENCES

Cullum, Michael G. and Dierberg, Forrest E. (1990). "Evaluation of a Dry Detention with Filtration Stormwater Management System Which Receives Runoff from a Mixed Urban Lake Use." South Florida Water Management District.

Harper, Harvey H. (1985). "Fate of Heavy Metals from Highway Runoff in Stormwater Management Systems." Ph.D. Dissertation, University of Central Florida, Orlando, FL.

Harper, Harvey H. (1988) "Effects of Stormwater Management Systems on Groundwater Quality." Final Report for DER Project WM190.

Holler, Jeffrey D. (1990). "Nonpoint Source Phosphorus Control by a Combination Wet Detention/Filtration Facility in Kissimmee, Florida." <u>Environmental Chemistry 1</u>, pp. 28-37.

LaRock, Paul. (1988) "Evaluation of the Lake Jackson Stormwater Treatment Facility." Final Report, Contract No. LR70(A), Florida Department of Environmental Regulation.

Livingston, Eric; McCarron, Ellen; Cox, John; and Sanzone, Patricia. (1988). "The Florida Development Manual: A Guide to Sound Land and Water Management." Florida Department of Environmental Regulation, Nonpoint Source Management Section.

Whalen, Paul J. and Cullum, Michael G. (1988) "An Assessment of Urban Land Use/Stormwater Runoff Quality Relationships and Treatment Efficiencies of Selected Stormwater Management Systems." Technical Publication 88-9, South Florida Water Management District, Water Quality Division, Resource Planning Department.

Yousef, Yousef A.; Wanielista, Martin P.; Harper, Harvey H.; Pearce, David B.; and Tolbert, Robert D. "Best Management Practices: Removal of Highway Contaminants by Roadside Swales." Contract No. 99700-7271, Report FL-ER-30-85. Florida Department of Transportation, Bureau of Environment, Environmental Research.