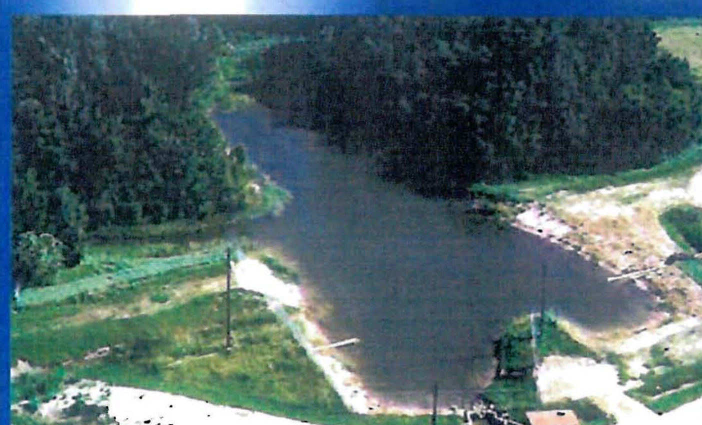
Three Design Alternatives For Stormwater Detention Ponds

1990-91

1993-94

1994-95



Southwest Florida
Water Management District

June 1997

COVER: Aerial views of the three design configurations for the pond studied during this project.

> **TOP PHOTO:** The pond as it appeared during the dry season for the first year of the study. The view is looking from north to south with the outflow instrument trailer, the white rectangle, in the foreground. Also seen in the background are experimental research ponds which are not a part of this report.
>
> **MIDDLE PHOTO:** The pond as it appeared during the second year of the study. The view is looking from south to north with the inflow instrument trailer in the foreground. Also shown is the industrial area that is part of the air shed.
>
> **BOTTOM PHOTO:** The pond as it appeared immediately after reshaping for the final year of the study. The view is from south to north with the brown wooden inflow instrument shelter in the foreground.

TITLE PAGE PHOTO: The pond during construction right before the final year of the study. The view is from north to south with the outflow instrument trailer in the foreground. It also shows part of the drainage basin which includes a parking lot, a vehicle storage compound, equipment storage areas, grassed ditches/swales and experimental ponds (not a part of this report). Some of the canal system which received the effluent from the wet detention pond is seen in the upper left hand corner.

COVER DESIGN: Mary Ann Ritter

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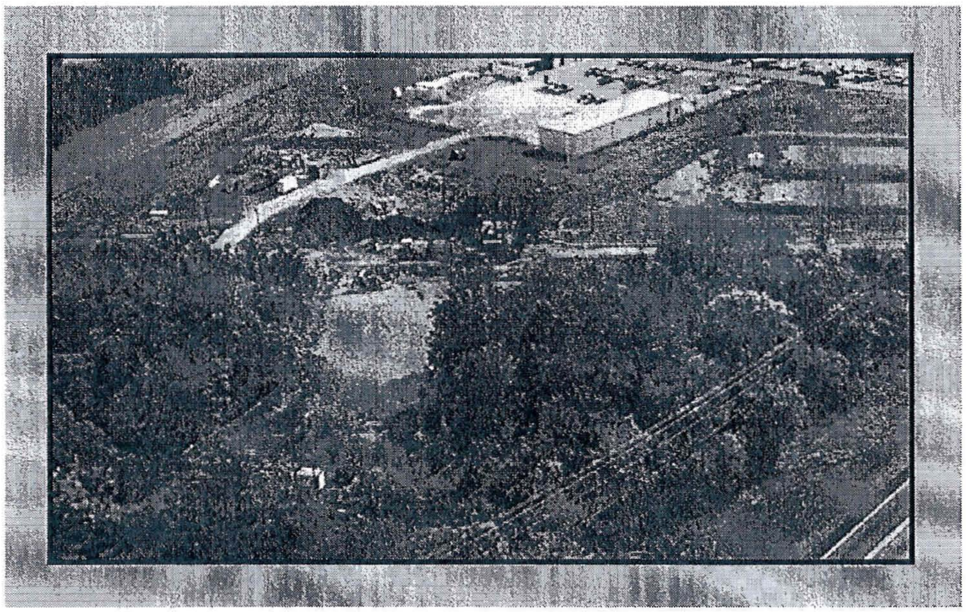

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JUNE 1997

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EXECUTIVE SUMMARY

The most common method for stormwater management in Florida is the construction of wet detention ponds. As new information has become available, senior technical staff at the Southwest Florida Water Management District (SWFWMD) has modified their Surface Water Management Rules (MSSW) to improve the performance of these systems. To determine the effect of some of these rule modifications, one wet detention pond was reshaped to replicate three configurations representing different rule criteria and each configuration was monitored for an eight month period.

In general, detention attenuation systems are designed to reduce water pollution as well as flooding. The major components of wet detention ponds consist of a permanent water pool, an overlying zone in which the stormwater fluctuating volume temporarily increases the depth, and a shallow littoral zone to act as a biological filter. The purpose of this research was to determine how much improvement in water quality can be expected by increasing residence time of the water in the permanent pool. Specifically, the Conservation Wet Detention criteria, which includes a 14-day residence time, was compared to earlier rule criteria. Other objectives included measuring the hydrologic response to rainfall, analyzing peak flow, measuring pollutant loading from rainfall, correlating relationships between constituents, determining compliance with state water quality goals, recording the reaction of field parameters to changing environmental conditions, measuring pollutants in the sediments, documenting vegetation and insect colonization, and making recommendations for improvements in stormwater systems.

Site Description

A wet detention pond located at the SWFWMD Service Office in Tampa was used to study the effectiveness of the various design alternatives. The drainage basin is 6.5 acres with about 30 percent of the watershed covered by roof tops and asphalt parking lots, 6 percent by a crushed limestone storage compound and the remaining 64 percent as a grassed storage area. The impervious surfaces discharge to ditches which provide some pre-treatment before stormwater enters the pond. During the first year of the study (1990), the pond was shallow and completely vegetated with a permanent pool less than one foot deep and an average wet season residence time of two days. In the second year (1993), the vegetated littoral zone covered 35% of the pond area and the volume of the permanent pool was increased to include a five day residence time by excavating the pond to five feet. For the final year (1994), the vegetated littoral zone was planted with desirable species, the depth of the pond was kept at five feet and the area of the permanent pool was enlarged for a calculated wet season residence time of 14 days. This final year tested the Conservation Wet Detention design.

The major emphasis of the study was to compare the pollutant removal efficiency of the pond by collecting flow-weighted composite samples for over 20 storm events occurring from June through January of each year. Automated equipment recorded rainfall amounts, measured water levels and calculated flow rates using standard formulas. For mass loading calculations, rainfall directly on the pond was included as an input. Some parameters affected by diurnal cycles were monitored *in situ* at two hour intervals.

Hydrology

Rain events were compared for the same eight month period of each year. Although equipment at the study site measured much different rainfall amounts for the three years (28" in 1990, 34" in 1993 and 44" in 1994), the averages for each storm were similar, for example, rain amount (0.53-0.57 inches), intensity (0.26-0.30 in/hr) and duration (2.61-2.72 hrs). Drought years did decrease the amount of direct discharge from the pond and increased the amount lost by exfiltration and evapotranspiration (ET). Water losses from seepage and ET were estimated as: 40 percent in 1990, 30 percent in 1993 and 18 percent in 1994. The runoff coefficient was the only significantly different rainfall characteristic between years with the rainfall deficit in 1990 reducing the coefficient to 0.19 compared to 0.36 for the other two more normal years.

Water Quality

The efficiency of the pond to remove pollutants was dramatically improved in 1994 when the Conservation Wet Detention design was in place. The percent efficiency for pollutant load removal is at least 20 percent better when 1994 is compared to 1990. The specific removal rates from 1990 to 1994 are: Total suspended solids from 71 percent to 94 percent, ammonia from 54 percent to 90 percent, nitrate+nitrite from 64 percent to 88 percent, ortho-phosphate from 69 percent to 92 percent, total phosphorus from 62 percent to 90 percent, total zinc from 56 percent to 87 percent, total iron from 40 percent to 94 percent and total cadmium from 55 percent to 87 percent. In 1994, the mass loading efficiencies always met the 80 percent reduction goal of the State Water Policy (Chapter 62-40 FAC) except for total organic nitrogen which was reduced by only 30 percent in 1990 and 51 percent in 1994. Organic nutrients will always be difficult to remove in wetlands such as this one where high primary productivity generates organic matter.

Load removal efficiency was not necessarily improved between 1990 and 1993, although the residence time had been increased from two to five days. The lower efficiencies in 1993 were caused by one extreme storm event with 3.89 inches of rain. This one storm accounted for 28 percent of the total stormwater outflow for the sampling year and an even larger percentage of total constituent loads. For example, outflow loads for this one event as a percentage of total outflow loads for all 22 events were: ammonia (77%), nitrate+nitrite (56%), organic nitrogen (44%), ortho-phosphate (45%), total phosphorus (39%) suspended solids (38%), zinc (32%), and copper (46%). Another measurement to determine if water discharged from stormwater systems meet state water quality goals is to compare the data to state water quality standards (Chapter 62-

302 FAC). In 1993 and 1994, except for iron in one sample, no metals were discharged from the wet detention pond that did not meet standards, while from 5 to 69 percent of metal concentrations at the inflow did not meet standards. This demonstrates the effectiveness of wet detention ponds in reducing pollutants to acceptable levels before discharge to our rivers, lakes and estuaries.

Although no numerical state water quality standards have been set for nitrogen and phosphorus, these constituents are of concern since excessive levels cause algal problems. Threshold levels for eutrophication suggested by some limnologists are 0.3 mg/l for inorganic nitrogen and 0.01 mg/l for ortho phosphorus. Although average concentrations in rainfall and at the inflow were high enough to cause eutrophication, the averages at the outflow for inorganic nitrogen (0.158 mg/l in 1990, 0.082 mg/l in 1993 and 0.098 mg/l in 1994) were low enough to cause no problems. Phosphorus concentrations in the Tampa Bay region are more difficult to evaluate since the region is naturally enriched in phosphate, but approach 0.01 mg/l with longer residence times. Averages for ortho-phosphorus at the outfall were 0.108 mg/l in 1990, 0.084 mg/l in 1993, and 0.027 mg/l in 1994.

Rainfall directly on the pond is a significant source for some pollutants. Depending on the area of the pond, which was increased from 0.30 acres to 0.57 acres over the course of the study, rainfall accounted for 14 to 26 percent of the hydrologic input, while 20 to 30 percent of inorganic nitrogen and 9 to 10 percent of copper entered directly in rainfall. Zinc concentrations were variable between years but perhaps as much as 38 percent entered the pond in rain during the 1993 sampling period. Much higher concentrations of inorganic nitrogen (>0.4 mg/l) were measured in storms with less than an inch of precipitation while storms greater than 1.25 inches never had levels this high, indicating that precipitation tends to contain contaminants at higher concentrations in short storms. This suggests that rainfall traps pollutants in the early part of the storm while longer duration rain events dilute samples.

Field Parameters

Measurements of dissolved oxygen (DO), pH, temperature, oxidation reduction potential (ORP) and conductivity fluctuate on a daily cycle and are perturbed by rainfall events. Rain decreased temperature and conductivity for all stations, but a much sharper drop occurred at the inflow station. Also rainfall decreased both pH and dissolved oxygen in the permanent pool where they were measured higher than at the outflow. In contrast pH and DO increased at the outflow which usually had low measurements. During quiescent periods between rain events, the wide littoral shelf concentrated at the outflow, ameliorated temperature, reduced dissolved oxygen and decreased pH in the water flowing through the vegetation. The different conditions in the permanent pool compared to the littoral shelf allow pollution removal using both aerobic and anaerobic processes as well as different pH regimes. A circumneutral pH helps immobilize metals and improves nitrification-denitrification while alternating oxidizing and reducing conditions enhance nitrogen removal.

Discrete Samples

To determine some of the processes taking place, three individual storm events were evaluated by taking up to 24 individual samples. These were composited together to represent the rising limb, the top, the falling limb and the tail of the hydrograph. Almost all constituents demonstrated a reduction after the peak of the storm had passed, although there were considerable differences between storms. The most consistent results were demonstrated by a storm with an intense opening burst of high intensity rain which also had high initial pollutant concentrations.

Sediments

The sediments were classified as mineral soils and generally had a sand content between 75 and 95 percent. Organic content showed a reduced percentage with depth, and the surface layer generally ranged between 2 and 5 percent organic matter except for the east ditch and an area on the littoral shelf, both of these areas were vegetated with cattails and measured over 7 percent. Nitrogen concentrations (TKN) were much lower in the permanent pool and the grassed pre-treatment swale than in the vegetated east ditch and outflow littoral shelf. Also, the concentration of both inorganic nitrogen and TKN in the water column exhibited the same pattern as that in the sediments indicating an exchange between the sediment water interface during quiescent no flow conditions. Phosphorus concentrations showed more accumulation in the pond sediments and the vegetated east ditch than at the inflow swale or the outflow of the pond. This could be the result of several processes: 1) sedimentation in the permanent pool, 2) enrichment as a result of the higher aluminum content associated with some soils, or 3) the more anaerobic conditions at the outflow. Unlike nitrogen, phosphorus concentrations in the water column exhibited no consistent pattern with concentrations in the sediments, but a negative correlation existed with dissolved oxygen during quiescent conditions. None of the metal concentrations measured in these newly constructed ponds reached toxic levels and only a few measurements were considered in the range that could potentially be associated with adverse biological effects.

Sediment samples were tested for over 100 organic pollutants at 4 to 5 locations in the pond and two locations in the ditches but only a few were detected. In 1990 the pond had been receiving stormwater runoff for four years and both the inflow and outflow had some detectable levels of organic pollutants. In 1993, four months after the newly constructed pond had been receiving runoff, no organic pollutants were detected in the pond, but measurable concentrations of polycyclic aromatic hydrocarbons (PAH) were measured in the pre-treatment swale near the parking lot. In 1995, the concentrations in the swale had increased several fold and the pond, which had been reshaped for the last time six months earlier, already showed trace levels of PAHs.

Statistical Relationships

Correlation analysis for constituents measured at the inflow and outflow demonstrated the same general patterns but relationships were much weaker at the outflow in part because of the much lower concentrations of constituents measured there. The one exception was total suspended solids compared to total phosphorus (r=0.71 at the outflow and r=0.47 at the inflow) indicating a transformation of suspended solids in the pond from inorganic particles to organic forms. A tendency also existed for more phosphorus to be measured with larger storms (r=0.48 at the inflow and r=0.45 at the outflow). The correlation analysis also emphasized the importance of iron as a controlling mechanism for pollution removal. Since it forms particles that settle easily it represents a process leading to sedimentation. Positive correlations of constituents with iron at the inflow included: lead (r=0.74), suspended solids (r=0.68), phosphorus (r=0.63), manganese (r=0.42), copper (r=0.35), and ammonia (r=0.39).

Vegetation Analysis

Shallow areas in ponds and lakes, suitable for colonization by emergent wetland plants, are referred to as littoral zones and, since they help provide for the biological assimilation of pollutants, at least 35 percent of the area of wet detention ponds constructed using SWFWMD rules must consist of a littoral shelf. The effect of planting the littoral zone with desirable species was documented in this study by making percent cover estimates right before planting and again two years later. The most striking differences in the littoral zone between the six month old pond in 1994 and two years later in 1996 included the large reduction in open water (from 62% to 30%) and the increase in plant species diversity (from 3.67 to 6.70 species per meter square). Some other trends were also noted. Factors which influenced the colonization of cattail included exposed soils after construction. Also much greater species diversity and survival of desirable planted species occurred on the large (45 x 45 sq ft) and relatively shallow (<1ft avg depth) littoral shelf which was concentrated at the outflow compared to the steeper littoral zone surrounding the edge of the rest of the pond. Planting desirable species on the wide shelf reduced the invasion of torpedo grass while the steep slopes favored the expansion of torpedo grass into deep water and may indicate that a 3.5 maximum depth for a littoral zone is too deep. Also none of the planted pickerel weed survived on the deeper part of the narrow littoral shelf surrounding the pond and none of the planted arrowhead survived anyplace except on the wide shelf.

Macroinvertebrate Sampling

The diversity and abundance of aquatic macroinvertebrates can be used as a measure of environmental quality. This limited study indicated that stormwater ponds were not dominated by an abundant number of individuals representing a few tolerant taxa, as might be expected, but instead were quite diverse including some species intolerant of pollution. More detailed studies of insects in wet detention ponds would provide useful information for making these systems better wildlife habitat, and more information is needed about the bioaccumulation of toxic pollutants in species that use these systems.

Pollutant Removal Mechanisms

The Tampa Office pond in 1994, which used the Conservation Wet Detention design, performed well for removing pollutants during the first eight months after construction. Factors which likely contributed to this result were pre-treatment opportunities in the watershed, increased residence time with good flushing characteristics, a wide vegetated littoral shelf concentrated at the outfall, aerobic conditions in the permanent pool, alternating anaerobic aerobic processes on the littoral shelf, mineral soils for the substrate, increased iron in runoff and a circumneutral pH. Features which might help the pond even more would be a better landscape design incorporating trees to lessen the impact of rain drops and reduce runoff, a sediment sump in front of the pond to collect large particle pollutants as well as aid in maintenance, plants selected specifically for their proven ability to remove stormwater pollutants by pumping oxygen to the rhizosphere, and better control of fertilizers and herbicide use. In addition, incorporating the entire drainage basin into the stormwater design would help reduce runoff to pre-developments levels.

RECOMMENDATIONS

1. The Conservation Wet Detention criteria should be encouraged for all stormwater management systems possible. In this study the effluent which resulted from using this criteria met almost all state water quality standards and this design can reduce the need for fill material and produce other economic benefits.

2. Stormwater designs that utilize the entire drainage basin and reduce discharge to pre-development levels should be encouraged and credit given to developers who use these techniques. Although stormwater ponds reduce peak flows, only a watershed approach will significantly reduce the volume of water discharged downstream. Another method to reduce flow downstream as well as improve water quality is to incorporate a stormwater reuse component into the stormwater system.

3. The impact on the receiving waters needs more study. Unlike wastewater, stormwater pollution is delivered in pulses and extreme events especially need to be assessed. During 1993 in this study, from 32 to 77 percent of all the pollutants measured during the 22 storms monitored that year were discharged during one storm.

4. Concentrations of polycyclic aromatic hydrocarbons (PAH) showed a progressive increase in the pre-treatment swale near the parking lot and they were beginning to be detected in the pond within eight months after construction. Since they are a known carcinogen their accumulation and disposal needs further study.

5. Inorganic nitrogen and some metals enter the system directly as anthropogenic air pollution. Reduction at the source is necessary to improve surface water pollution.

6. Iron appears to be a controlling mechanism for pollution removal and should be studied in more detail.

7. Vegetation in the littoral zone plays a vital role in the processes which remove pollutants. More study is needed to determine which species enhance these processes.

8. A wide littoral shelf with shallow relief is the most effective means for providing conditions to remove pollutants and increase diversity. Planting the littoral shelf proved successful for replacing torpedo grass, a nuisance species, but successful cattail removal is not as easy.

9. Wet detention ponds are suitable for a diverse macro invertebrate and fish community and more information is needed about the bioaccumulation of toxic pollutants in species that use these systems.

10. Aerobic bottom sediments and a circumneutral pH in a permanent pool with adequate residence time are necessary conditions for stormwater ponds and designs which provide these conditions should be incorporated in stormwater systems.

11. More information on maintenance of stormwater systems is an urgent need.

12. A watershed approach using a variety of techniques throughout the basin could greatly improve stormwater treatment.

INTRODUCTION

Although stormwater runoff is a natural component of the hydrologic cycle, its quality has been degraded by modern technology to the detriment of rivers, streams, lakes and coastal waters. Alteration of natural drainage patterns, the addition of man-induced pollutants and changes in hydroperiod have caused declines in fisheries, restrictions on swimming, contamination of shellfish and accelerated eutrophication of lakes and rivers. In recognition of these problems governmental agencies began to regulate surface runoff in the early 1980s. Water management systems constructed in Florida are under the jurisdiction of five water management districts. The Southwest Florida Water Management District (SWFWMD) regulates systems in new developments under Chapter 40-D4 and 40D-40 F.A.C., Rules for the Management and Storage of Surface Waters (MSSW).

With the accumulation of more data and the insight from practical experience, the MSSW rules have been modified and new technical procedures developed to try to increase pollutant removal capabilities and thereby reduce the downstream impacts. To determine the effect of some of these rule modifications, one wet-detention pond was recontoured to replicate three configurations representing different rule criteria. The purpose of this research was to determine how much improvement in water quality can be expected by increasing residence time (the average amount of time that water remains in a system before it is replaced). Specifically the Conservation Wet Detention guidelines (TP/SWP-022, alternative 3) which include a 14-day residence time were compared to earlier rule criteria. Other objectives of the study included measuring the hydrologic response to rainfall, analyzing peak flow, measuring pollutant loading from rainfall, correlating relationships between constituents, determining compliance with state water quality goals, recording the reaction of field parameters to daily cycles and rainfall events, and measuring organic priority pollutants, metals and nutrients in the sediments.

Development of the Conservation Wet Detention Criteria

Guidelines for the Conservation Wet Detention design, which were tested during the final year of this study (1994), evolved over a period of time. The original concept for wet detention was sediment entrapment and early designs were little more than sedimentation basins. As more data became available it was obvious that sedimentation alone was not sufficient to remove the pollutants present, especially those in the dissolved form. Another approach was suggested which viewed detention basins as a lake achieving a controlled level of eutrophication. It incorporated more processes for treatment and therefore more pollution removal (Hartigan 1989). The key parameter in the eutrophication model is average hydraulic residence time (the average amount of time water is detained in the pond). At SWFWMD this concept developed into a technical procedure suitable for wet detention ponds constructed in west central Florida. To be effective calculations must be based on local rainfall records. The specifications for the Conservation Wet Detention design with some examples can be found in Appendix A.

Design Components

The most common method for stormwater management in Florida is the construction of detention basins. Detention attenuation systems use ponds which discharge stormwater over a period of several days and reduce water pollution as well as flooding. Wet detention ponds consist of a permanent water pool, an overlying zone in which the stormwater fluctuating volume temporarily increases the depth, and a shallow littoral zone to act as a biological filter. Extended detention times have long been recognized as a best management practice for treating urban runoff pollution, since the longer detention times allow for increased sedimentation and biological uptake. The major components for designing wet detention ponds are described below.

Permanent Pool

The most important feature of a wet-detention basin is the permanent pool. It allows for stormwater treatment between rain events before new stormwater displaces the treated water in the pond. Therefore, the size and the shape of the permanent pool should be one of the first considerations in design development. The design should provide for good circulation, mixing and residence time. This can be accomplished by creating maximum separation between the inflow and outflow, locating inflow inverts below the control elevation, using multi-cell ponds or flow baffles and eliminating dead areas. For permanent pool storage volume, solids settling design curves usually assign more than 90 percent of the total pollutant removal to quiescent conditions between storms (Hartigan 1989). The size of the permanent pool to watershed area should be 4 to 6 percent of the drainage basin to achieve this amount of pollutant removal. Residence time in the permanent pool has to be balanced with the amount of time needed to enhance sedimentation and ensure adequate nutrient uptake without the risk of thermal stratification and anaerobic bottom waters, two weeks has been determined as an optimal residence time (Hartigan 1989). The depth of the permanent pool should be shallow enough to minimize the risk of thermal stratification, but deep enough to reduce algal blooms and prevent sediment resuspension.

Fluctuating Pool

The volume above the permanent pool that is slowly released within five days after a storm event is the fluctuating pool. This feature reduces peak flows downstream and provides some solids settling and nutrient removal. This zone assures freeboard for closely spaced rain events which enhances mixing by providing additional time for mixing to occur. The fluctuating pool was referred to in earlier design criteria as "treatment volume". The bottom of the fluctuating pool, the lowest elevation at which water can be released through the outfall structure, is referred to as the control elevation which usually coincides with seasonal high water levels.

Littoral Zone

The littoral zone is a shallow shelf around the perimeter of the pond or in some other configuration which promotes suitable conditions for plants to improve water quality by biological uptake and transformations. In turn, nutrient uptake in the littoral zone helps minimize the proliferation of free-floating algae by limiting the amount of nutrients available for phytoplankton (Hartigan 1989). Macrophytes have also been know to excrete chemicals that inhibit algal growth and thus competition for light and nutrients.

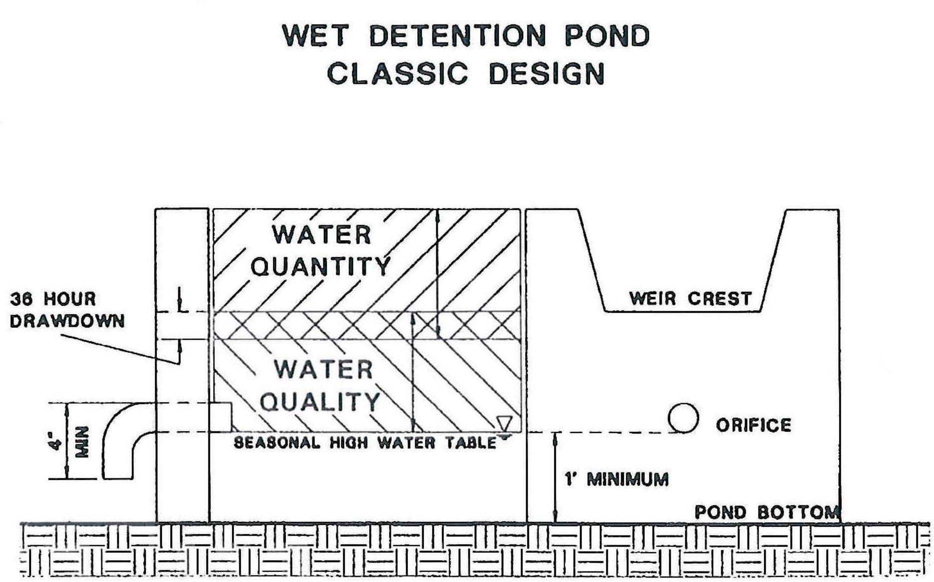
Outfall Weirs

The outflow weir configuration controls how the pond operates. Typical outfall weir configurations and some requirements for the permanent pool are shown in Figure 1 which compares the classic or older design to the Conservation Wet Detention requirements. Not only does the conservation design provide more treatment but it also can save land area. As an example, Boyer (1995) calculated the amount of pond area required for both the classic design (1.826 ac) and the Conservation Wet Detention design (1.448 ac) for a golf course and found that the conservation design saved 0.38 acres of buildable land. The smaller pond size was attributed to the conservation design's permanent wet pool that includes water quality treatment volume stored below the control elevation.

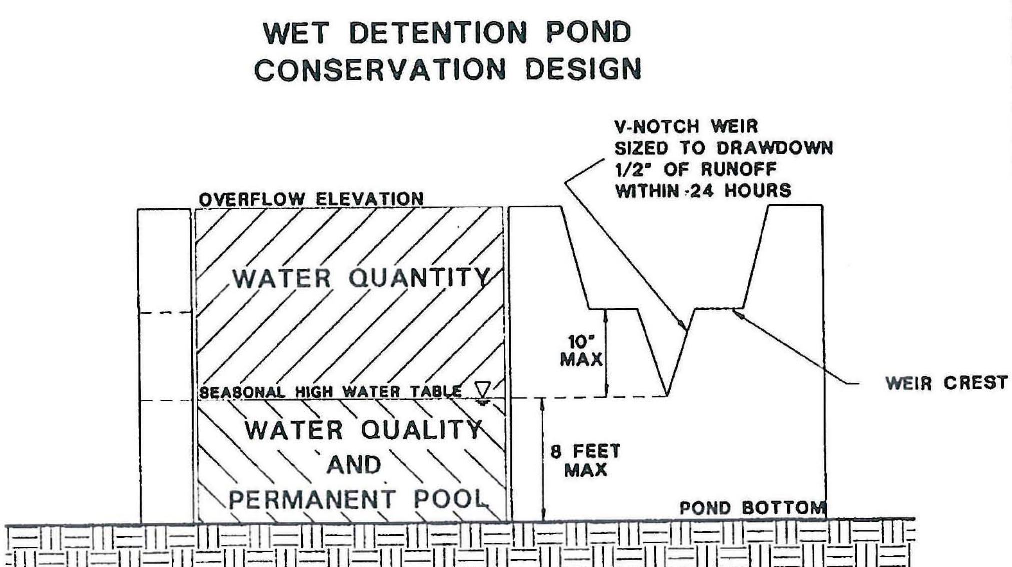
Site Description

A wet-detention pond at the SWFWMD Service Office in Tampa has been studied since 1990 to document the effectiveness of various rule criteria and design alternatives. The 6.5 acre drainage basin receives runoff from a rooftop, a parking lot, a vehicle storage compound and grassed areas which are kept mowed. About 30 percent of the site is covered by roof tops and asphalt parking lots, 6 percent by a crushed limestone storage compound, and 64 percent grassed areas. The impervious surfaces discharge to ditches which provides some pre-treatment before stormwater enters the pond. The bathymetrical contours of the pond for each year studied indicate the differences between years (Figure 2) and pertinent data for each pond configuration are compared in Table 1.

Wet detention ponds are designed to detain stormwater flow and remove pollutants prior to discharge to downstream waters. As described above, the major components for these systems consists of a design pool (permanent standing water) and a fluctuating pool in association with water-tolerant vegetation. Pollutants are primarily removed through settling, absorption by soils and nutrient uptake by vegetation and associated biota. To increase the time for these processes to take place, residence time becomes an important aspect of the design scheme.



(Source: David Boyer)



(Source: David Boyer)

Figure 1. Some differences in outflow weir design and elevations between the classic or older design and the conservation wet detention design.

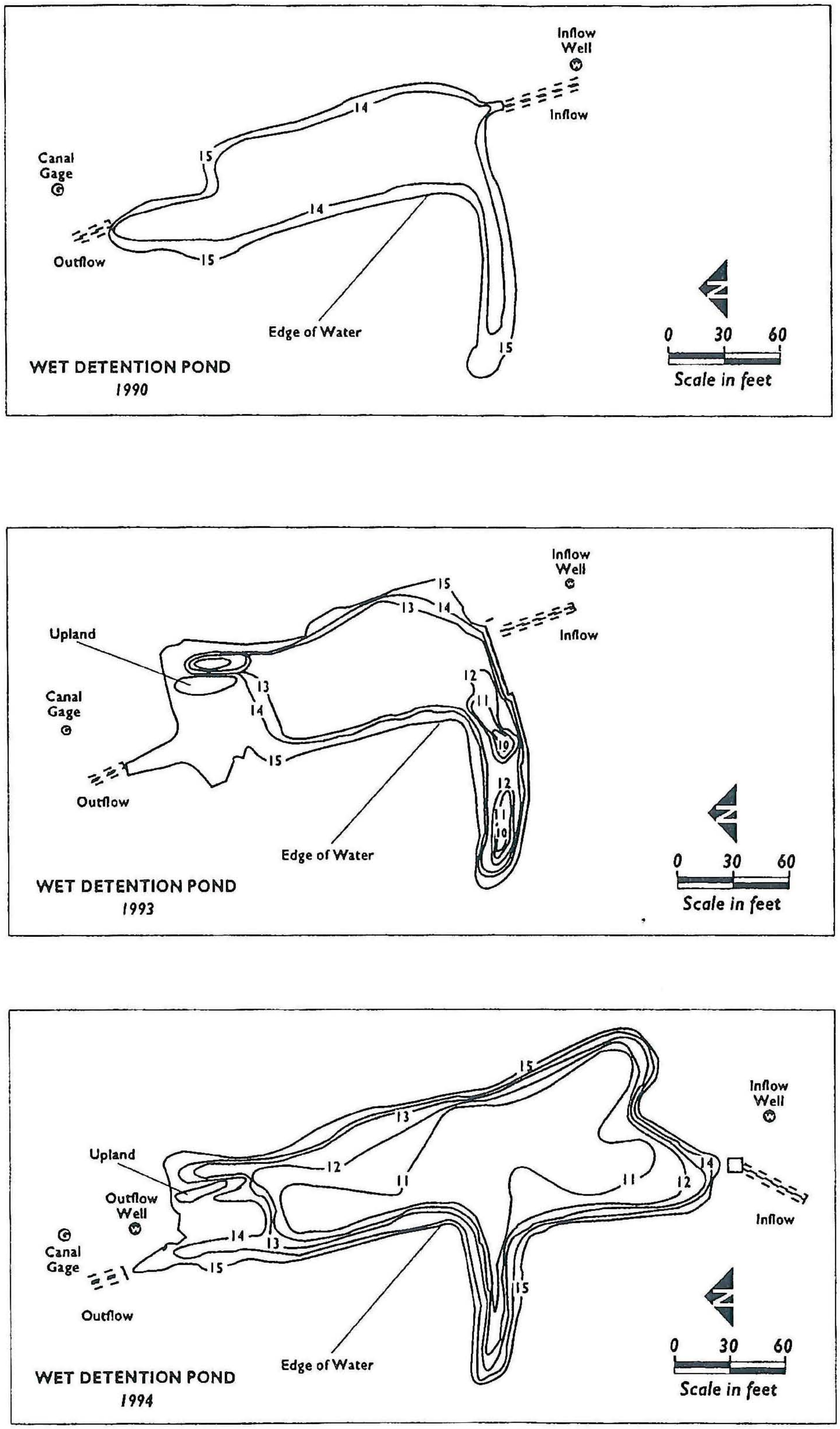


Figure 2. The bathymetric contour lines are shown for the three pond configurations. The control elevation is 15.08 (NGVD in feet) for all years and the contour intervals are one foot apart.

Table 1. Pond characteristics for the year studied.				
	Units	**1990**	**1993**	**1994**
General Information				
Construction Date	year	1986	1993	1994
Fluctuating Pool	inches	8	10	10
Bleed down Time	in/day	>0.5/5	>0.5/1	>0.5/1
Area of pond	acre	0.30	0.35	0.57
Summer Rainfall *	inches	20.36	24.50	34.12
Length of grass conveyances Swale Ditches	feet	1000 500 500	1000 500 500	1100 350 750
Residence Time	days	2	5	14
Permanent Pool (volume of water below the outflow control structure or bleeder)				
Maximum Depth	feet	1	5	5
Average Depth	feet	0.22	1.3	2.8
Volume	cu ft	2 796	19 487	70 907
Littoral Zone (shallow zone suitable for wetland plants)				
Area of Littoral Shelf	percent	100	35	35
Dominant Vegetation	scientific common	*Typha latifolia* cattail	*Chara* sps** musk-grass	*Panicum repens* torpedo grass

* Average summer rainfall is 31.04 inches for the 122 day rainy season
** This submerged alga occupied about 70% of the pond volume including the permanent pool.

During the first year of the study, 1990, the pond design represented the rules as written in 1985. The MSSW criteria at that time required that a wet detention pond be sized to detain a "fluctuating pool (treatment volume)" equal to at least one-half inch of runoff from the contributing area. It also specified that the pool include a minimum of 35 percent planted littoral zone with a depth of less than three and one half feet below the overflow elevation. The criteria further stated that the fluctuating pool not cause the pond level to rise more than eight inches above the control elevation (bleeder). Additionally the volume between the control device and the overflow elevation (fluctuating pool) should be discharged in no less than five days with no more than one-half the total volume being discharged within the first 2.5 days. In the four years since the pond was constructed vegetation had colonized the entire pond area and the permanent pool had decreased from a maximum depth of one foot to less than half a foot as decaying vegetation and sediments filled in the pond.

During the second year of the study, 1993, revised rules were used to configure the pond. Although many of the criteria remained the same, the rule changes made in 1988 allowed an 18 inch fluctuation above the control elevation (fluctuating pool) which was sized to "treat" one inch of runoff from the contributing area instead of one-half inch. The new rules also allowed an unplanted littoral zone. Not all of these criteria were incorporated in the new design excavated for this study, for example, the fluctuating pool was only ten inches instead of the eighteen allowed, but of importance for the purposes of the study, the residence time was increased from two to five days and the average depth of the pond was increased from one to two feet. The unplanted littoral zone was quickly colonized by torpedo grass (*Panicum repens*) and the volume of the pond was occupied by a submerged macroalga, a *Chara* species, typical of hard water.

For the final year of the study, 1994, the Conservation Wet Detention technical procedure, written by SWFWMD staff, was followed for the pond design (See Appendix A). The new criteria require a permanent pool with a capacity of one inch of runoff from the drainage area plus the calculated volume based on an average residence time of 14 days. The procedure allows treatment credit for residence time below the seasonal high water table in the permanent pool which by these criteria can be as deep as eight feet. It also reduces flood elevations which result from stacking flood volume on top of treatment volume and therefore makes it feasible for developers to use less fill for elevating building pads to assure flood protection.

Under normal circumstances, it would not have been necessary to increase the area of the pond to use these criteria. However, a confining layer separating a deeper artesian aquifer was close to the surface and in order not to breach this confining layer, the pond could only be excavated to a depth of five feet instead of the eight feet allowed by the guidelines. Therefore, the area of the pond had to be increased in order to provide the necessary volume for a 14-day residence time.

METHODS

Automated equipment at the site collected composite flow proportional water samples, recorded rainfall amounts, measured water levels and calculated flow rates for all storm events from June through January of 1993 and 1994. Similar instruments and methods were used in 1990 and that information is available in an earlier report (Rushton and Dye 1993). In addition rainfall water quality samples were collected, field parameters measured, and water table levels recorded.

Water Quantity

Water levels at the inflow and outflow were measured using float and pulleys connected to data loggers and also with bubbler flowmeters recording to strip charts. Flow was calculated from water levels using standard weir equations. Omnidata™ model 900 loggers scanned data at one minute intervals and reported results to a storage pack every 15 minutes. ISCO™ Model 3230 flowmeters signaled the refrigerated water quality samplers during storm events and recorded the exact time of each sample collected on a hydrograph. It was also programed to print a summary for each day.

Inflow

Flow at the inflow station was measure by a sharp-crested 90^{O} V-notch weir. The official survey drawings giving all of the dimensions are shown in Appendix B. Water levels measured by the data logger and flowmeter were compared to actual readings from the staff gauge during all site visits, but in addition, special care was taken to measure accuracy when water levels were high and rapidly changing, a much more difficult measurement. The average standard deviation using both the program written in the data logger and a calculated regression equation was 0.02 feet, about the same accuracy as reading the staff gauge in the field. See appendix B for calculations and regression graphs. The ISCO™ flowmeter which comes pre-calibrated from the factory usually agreed with the staff reading with discrepancies less than 0.01 feet. Since the accuracy of reading the staff gauge is 0.02 feet, we feel confident that the water level measurements are fairly accurate, at least for the amount of variation typical of natural systems.

The standard equation for a V-Notch weir was used to calculate flow from water levels (head) above the V-notch..

Q = 2.5 * (HEAD^2.5)

where: Q = Flow in cubic feet per second
HEAD = Water level above the bottom of the V-notch in feet.
C = 2.5 = A constant dependent on the angle of the V-notch and units of measurement.
K = 2.5 = A constant for V-notch weirs.

Several problems were encountered in trying to accurately measure flow. During 1993 it was discovered a water pipe had broken and was leaking potable water into the inflow swale during December. Storms occurring during this time period were removed from the data set, although calculations both with and without this information are included in Appendices I and J. Leaks around the inflow weir resulted in some unmeasured flow during June of 1994. For both 1993 and 1994 the water table was much closer to the surface than in 1990. In fact, during 1994, the water table was consistently measured above the inflow level indicating a substantial gradient which may have increased subsurface flow into the pond, although it was not evident by a close inspection of water level measurements. Some unmeasured flow from a low area entered the pond during large storms in 1994.

Outflow

Flow at the outfall was calculated from a two part formula using standard weir equations with some modifications. A 20° V-notch discharged water from the fluctuating pool while a rectangular weir with end contractions most accurately described the overflow discharge during large storms. Engineered drawings from the official survey show all of the dimensions (Appendix C). Trash in the narrow V-notch created a problem for measuring flow by keeping water levels artificially elevated some of the time. This potentially overestimated flow since trash was removed from the V-notch during 42 percent of site visits when flow was occurring. But since high flows almost always completely flushed the notch, this probably did not result in a serious overestimation. The V-notch was also manually calibrated and a coefficient calculated for determining flow rates (Appendix C). Field measurements and calculations were made for the outflow in a similar manner as those described for the inflow. Results showed a standard deviation between 0.01 and 0.02 feet.

The compound weir at the outflow required two equations to calculate flow. For water levels less than 0.83 feet above the V-notch, the following formula was used to measure flow.

Q=0.623*HEAD^2.5

Where: Q=Flow rate (cubic feet per second (CFS))
HEAD=Water level above the V-notch in feet.
C=0.623=Coefficient calculated from measuring flow with a bucket and stop watch (see Appendix C for calculations).
K= 2.5= A constant for V-notch weirs.

For heads greater then 0.83 feet, the maximum value of the V-notch at 0.83 feet was added to flow over an improvised rectangular weir with end contractions. The 0.83 feet was determined from actual field observations as the difference between the bottom of the V-notch and the overflow for the weir. The weir configuration is slightly different from the surveyed figure (Appendix C). The actual weir was divided in the middle to make two weir plates and posts were installed to make the overflow into a rectangular weir configuration. Since the corners of each weir served as a drag the overflow was treated as two separate weirs and flow was measured with the following formula:

$$Q = (2*C*(L-(0.2*WH))*(WH^{\wedge}1.5))$$

Where: Q = Flow rate over weir (cubic feet per second (CFS))
C=3.13=Coefficient calculated using the method of Kindsvater and Carter (1959).
L=2.47=Crest length of each weir.
WH=Head over the weir structure.

The flow through the V-notch appeared to give reasonable results, but the calculations for flow over the weir seemed to over-estimate flow unless large flows also created unmeasured flow into the pond. Also, Backwater conditions held the pond at artificially high levelsduring extreme rain events.

Rainfall

Rainfall amount was the average of two tipping bucket rain gauges located at the inflow and outflow. Precipitation was collected for water quality analysis by using an Aerochem Metics^{TM} model 301 wet/dry precipitation collector. A sensor detected precipitation and activated a motor which removed the lid from the wet bucket and transferred it to the dry bucket. When the rain stopped, the cycle was reversed. A small refrigerator was mounted under the collector to store the sample immediately until it was fixed with appropriate reagents and transported to the laboratory. Dryfall was not measured.

Water Quality

Water quality samples were collected with American Sigma ^{TM} refrigerated samplers located at the inflow and the outflow weirs. The refrigerated samplers were programmed to take samples for up to 75 specific intervals based on volume as measured by the ISCO^{TM} flow meters. All water quality samples were retrieved from the samplers, preserved as required, placed on ice and transported to the SWFWMD laboratory for analysis using standard methods (Table 2) and in accordance with SWFWMD's Comprehensive Quality Assurance Plan (SWFWMD 1993). Samples for total organic carbon cannot be collected with automatic samplers and this constituent was collected as a grab sample after storm events.

One problem encountered when analyzing the water quality data was the large number of measurements below the laboratory detection limit (left censored data). When possible the actual laboratory value was substituted as recommended by Gilbert (1987). When a value was not reported but listed as below the limit of detection (LOD) then one-half the detection limit was used. Cadmium and lead had the greatest number of censored data points (75 to 90%). Rainfall often had values below the detection limit for organic nitrogen (40%), phosphorus (50%) and hardness (40%); while the inflow and outflow stations had less than 5 percent censored data for these constituents. From 8 to 21 percent of nitrate was measured below the detection limit, most of these at the outflow. Zinc and ammonia were censored at all stations for less than 10 percent of samples. All other constituents were never censored.

Table 2. Description of laboratory analyses for parameters measured in stormwater study. Reference refers to section in Standard Methods (APHA 1985).

Parameter	Method	Det. Limit	Ref.
Total Suspended Solids	Total filterable residue dried at 103-105 oC	0.05 mg/l	209C
Total lead	Electrothermal atomic absorption spectrometry	0.01 mg/l	304
Total copper	Electrothermal atomic absorption spectrometry	0.01 mg/l	304
Total cadmium	Electrothermal atomic absorption spectrometry	0.002 mg/l	304
Total chromium	Electrothermal atomic absorption spectrometry	0.01 mg/l	304
Total zinc	Direct aspiration into air-acetylene flame	0.005 mg/l	303A
Total iron	Direct aspiration into air-acetylene flame	0.02 mg/l	303A
Ammonia-N	Automated phenate	0.01 mg/l	417G
Organic nitrogen	Macro-kjeldahl - NH_3	0.01 mg/l	420A
Nitrate-nitrite-N	Cadmium reduction	0.01 mg/l	418F
Total and ortho-phosphorus	Colorimetric automated block digester	0.01 mg/l	424
Total Organic carbon	Combustion-infrared	0.50 mg/l	505A
Calcium	AAS/Flame	0.04 mg/l	215.1
Magnesium	AAS/Flame	0.0006 mg/l	242.1
Potassium	AAS/Flame	0.07 mg/l	258.1
Chloride	Argentometric	1.0 mg/l	SM 17th Ed.
Sulfate	Turbidimetric	5.0 mg/l	375.4

For quality assurance, deionized water (D.I.) samples were taken in the same manner as stormwater samples to determine if the method of collection led to any contamination (Appendix D). Copper, iron and total Kjeldahl nitrogen appeared to be detected above the detection limit on numerous occasions. Iron could be explained by the fact that iron was measured in the D.I. water when that water was tested for another program at the District as well as for one sample in this study. The detection limit may be set too low for TKN, 0.3 mg/l appears more reasonable. None of the detections were high enough to affect the overall results of the study. The fact that the levels were above the detection limit may mean that some residual pollutant stays on the instruments even after the tubing is changed. Sample 530B in Appendix D appears to be contaminated.

Water quality concentrations were compared to State Standards for class III waters (Ch 62-302) to determine how water at this site compared to water quality goals set to protect fish and wildlife. The standards were changed in 1992 which make the results from this report different from previous reports that have been published by the District (Kehoe 1992, Rushton and Dye 1993, and Kehoe, Dye and Rushton 1994). A comparison of pre-1992 and current water quality standards shows the differences (Table 3).

Field Parameters

Some parameters affected by diurnal cycles were measured in the field. Dissolved oxygen, pH, oxidation reduction potential, temperature and conductivity were monitored *in situ* with fully submersible automated water quality DataSonde IIH samplers (manufactured by Hydrolab™) which were programmed to sense and record data at two hour intervals. Post calibration measurements were comparable to test standards for at least seven days, therefore, the units were usually deployed for a week at a time. One to three identical instruments measured conditions at up to three locations in the wet-detention pond: 1) at the inflow about five feet beyond the weir, 2) in the open water pool about ten feet before the water crossed the littoral shelf near the outflow, and 3) at the outflow right before the water was discharged from the pond. The probes were placed 4 to 6 inches above the bottom sediments and water depths varied between 0.5 and 1.0 feet. Data were summarized in graphs for each of the weekly measurements and averages for each week were calculated to compare water quality characteristics between stations and between years. Averaged values for pH data are not strictly accurate since this is the negative log of the hydrogen ion concentration, however, the differences within stations were small and the resolution of the average value seemed sufficient to describe the patterns and processes taking place. This is especially true since all the data were skewed and non-parametric statistics were used for most analyses.

Table 3. A Comparison of Class III State Surface Water Quality Standards. Standards are exceeded when pollutant concentrations were ≥ the values given below. Units in ug/l unless Indicated.

Constituent	July 1991 FAC Ch. 62-302	February 1992 FAC Ch. 62-302
Cadmium	0.8 or 1.2 Hardness dependent	$e^{(0.7852[\ln H]-3.49)}$
Copper	30	$e^{(0.8545[\ln H]-1.465)}$
Iron	1000	1000
Lead	30	$e^{(1.273[\ln H]-4.705)}$; 50 max
Manganese	100 (mg/l) (Class II)	100 (mg/l) (Class II)
Zinc	30	$e^{(0.8473[\ln H]+0.7614)}$; ≥ 1000
Dissolved oxygen (DO)	5000; Normal daily and seasonal fluctuations above these levels shall be maintained (see rules).	5000; complex, see rules
pH	6.0 min. 8.0 max; +/- 1.0 NB (standard units)	6.0 min 8.0 max; +/- 1.0 NB (standard units)
Conductivity	≤ 50% increase or 1275 umhos/cm max whichever is greater.	Shall not be increased > 50% of NB or to 1275 (umhos/cm), whichever is greater.
lnH = natural logarithm of total hardness expressed as mg/l of $CaCO_3$. NB = Natural background.		

Discrete Samples

Most water quality samples collected at the site were measured using flow-weighted composite samples. However, for three storm events up to 24 discrete samples were collected across the hydrograph. Automated refrigerated samplers linked to recording flow meters identified the exact time on the hydrograph when each sample was taken. These were then composited on a flow-weighted basis to represent the different stages of the hydrograph (rising limb, top, falling limb, the end of the falling limb and the tail). The same amount of flow was used for each stage of the hydrograph for each storm, but because of the differences in magnitude of each storm, the same amount of flow was not represented between storms.

Sediment Samples

Sediment Samples were collected at four to five locations within the wet detention pond and two locations in the inflow ditches during October of 1993 and again in January of 1995 (Figure 3). Samples were extracted intact from the sediments using a two inch diameter hand driven acrylic or stainless steel corer and analyzed for particle size, nutrient and metals. Four to six replicate cores in close proximity to each other were composited together into one sample for two depths at each location. The two strata selected for measurement represented the sediments from one to two inches and a deeper strata from four to five inches. The top organic layer, which never exceeded an inch, was discarded. Each sub-sample was deposited in a Pyrex or stainless steel mixing tray and composited with stainless steel utensils into one sample using the "four corners" method (SWFWMD 1993). Samples were placed in EPA approved ICHEM glass jars supplied by the Department of Environmental Protection (DEP) laboratory, then covered with ice in insulated coolers and transported to Tallahassee for analysis. One replicate sample was taken each year.

Particle size and organic content analyses were conducted by the marine geology laboratory at Eckerd College. The standard wet sieve and pipette methods (Folk 1965) were used for particle size analysis. The wet sieve method determined percent sand and the pipette method measured percent silt and clay. Total organic content was analyzed using the method of Dean (1974).

Priority pollutants were evaluated for all three years of the study. These samples were collected with an Ekman dredge or a hand-held stainless steel scoop, and included only the one to two inch depth. In 1990, samples were analyzed by the University of Florida's Environmental Engineering Sciences laboratory. A combination of the Environmental Protection Agency (USEPA 1986, Method 3350) and Marble and Delfino (Method Amer. Lab. 1988, 20, 265) was used to analyze samples. In 1993 and 1995, samples were analyzed using EPA approved methods in the DEP laboratory in Tallahassee.

Statistical Analysis

Statistical computations were performed using the Statistical Analysis System (SAS 1990) to determine significant differences and to analyze relationships between variables. Most statistical tests assume the variables are from an independent and normally distributed population and that the variances are homogeneous. This is rarely the case in nature, and even log transformations did not improve the distribution enough to make at least half of the samples suitable for parametric procedures according to the Shapiro-Wilk Statistic (W).

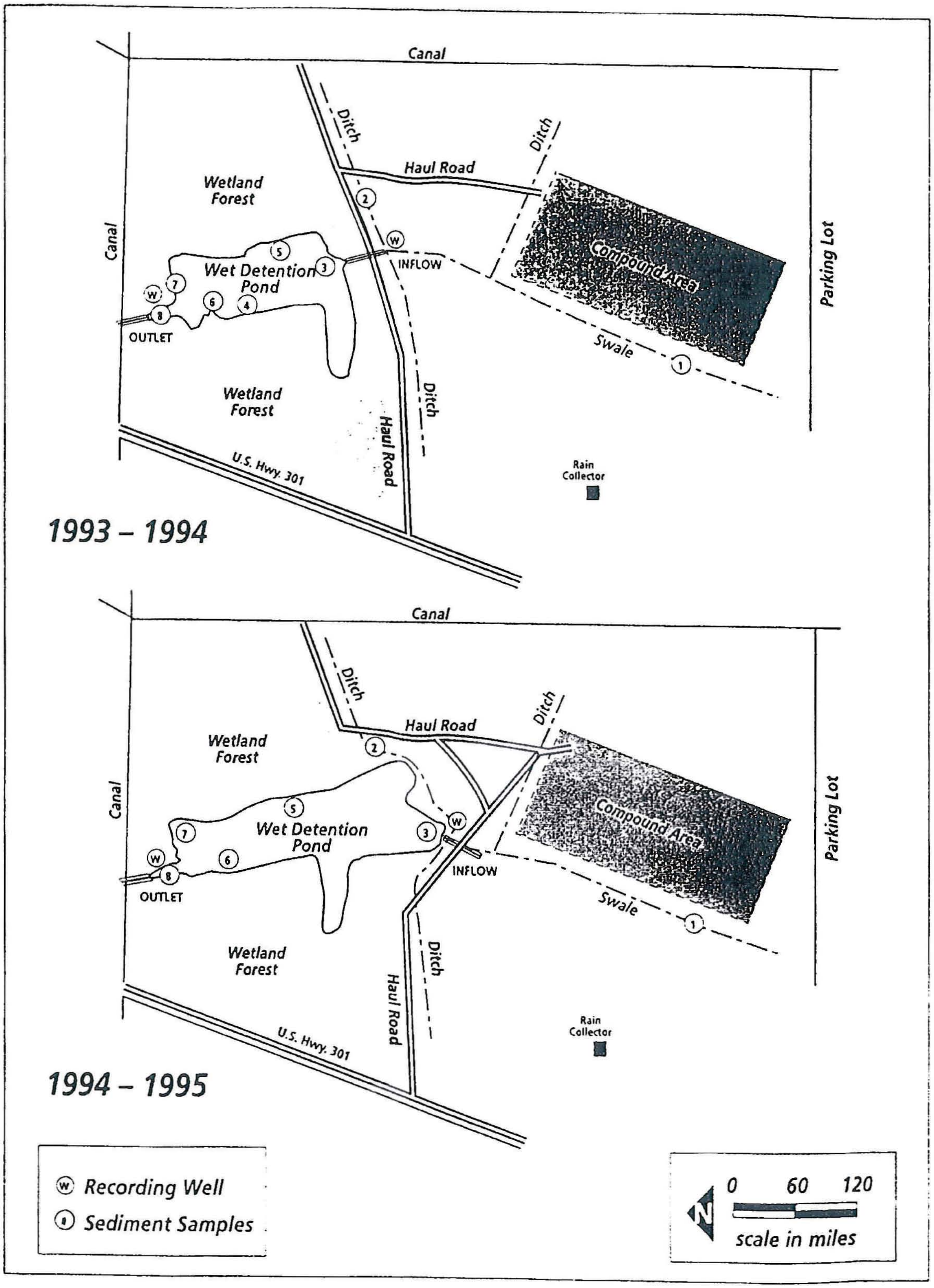


Figure 3. Site plans with location of sediment sampling sites.

To investigate the relationship between variables, nonparametric correlations were run using the Spearman rank correlation procedure. With Spearman's method differences between data values ranked further apart are given more weight, similar to the signed-rank test. It is perhaps easiest to understand as the linear correlation coefficient computed on the ranks of the data (Helsel and Hirsch 1992). Spearman's rho is best suited for large sample sizes (n>20) and the 50 to 80 data points in this study met these criteria.

To determine significant differences between years, the Wilcoxon Rank Sum Test was used to test whether concentrations of constituents in one year were consistently larger (or smaller) than those from the year before. This test has two advantages over the independent-sample t-test: a) the two data sets need not be drawn from normal distributions, and b) the test can handle a moderate number of not detected (ND) values by treating them as ties (Gilbert 1987).

Evaluation of the Data

The raw data were summarized using various mathematical and statistical techniques.

Efficiency

Efficiency of the system, i.e. the pollutant reduction from the inflow to the outflow, was calculated by two methods (concentrations and loads) using flow weighted composite samples for each storm. For load efficiency, rain falling directly on the pond was considered an input and added to the inflow data. Load efficiency gives greater weight to large storms and takes into account the reduction in pollutants retained in the pond because more water enters than leaves at the outflow. These losses are attributed to evapotranspiration and sub-surface flow.

Load efficiency (%) = ((SOL in - SOL out)/(SOL in))*100

where: SOL = the sum of loads in cubic feet for all the storms sampled from June through January of each year.
SOL in = sum of loads at the inflow plus rain falling directly on the pond.
SOL out = the sum of loads at the outfall.

For missing data (about 3%) the median value for the constituent was substituted. Loads were calculated by multiplying the constituent concentration by volume and converting to cubic feet.

The Event Mean Concentration (EMC) efficiency was calculated by averaging the inflow and outflow concentrations for each storm from June through January of each year. This method gives equal weight to both small and large storms and does not consider water volume.

EMC efficiency (%) = (conc in - conc out/conc in)*100

where: EMC = event mean concentration from flow weighted samples
Conc in = average of EMC at inflow
Conc out = average of EMC at outflow

Residence Time

Residence time was based on calculations used for permanent pool volume below the control elevation which is computed using average total wet season rainfall. The wet season is defined as the 122 day period from June through September.

$$R = (V/(A*c*P)) *(1 \text{ ft.}/12 \text{ in.})$$

where: R = Residence time (days)
V = Volume of water below the control elevation (cu.ft.)
A = Area of pond (sq.ft.)
P = Historic average wet season rainfall rate for area = (31.04 in./122 days)
c = Composite Rational runoff coefficient

Rainfall Characteristics

Rainfall conditions were calculated from the hydrology data to determine their effect on pollutant concentrations using the following formulas:

Average rainfall intensity (in/hr) = total rain / duration of storm.

Maximum 15 min intensity (in/hr) = avg. max. rain during 15 min. interval * 4

Runoff coefficient = inflow volume /(total rain * basin area)

Inter-event dry period (antecedent conditions) = days since the previous rainfall.

Vegetation Analysis

The emergent vegetation in the littoral zone was measured using percent cover in 54 systematically located 10 ft square quadrats spaced about 25 feet apart around the perimeter of the pond (Figure 4). Quadrat locations were determined from survey stakes installed during a topographic survey which identified the upper and lower boundary of the littoral zone. The stakes marked the area to be planted with pickerel weed and arrowhead later in the summer. The quadrat frame was placed parallel to the shoreline with its lower left hand corner around one of the survey stakes. When the littoral zone was wide enough (> 6ft) one quadrat was analyzed near the shore (a) and an adjacent quadrat was analyzed in deeper water (b). Percent cover of each

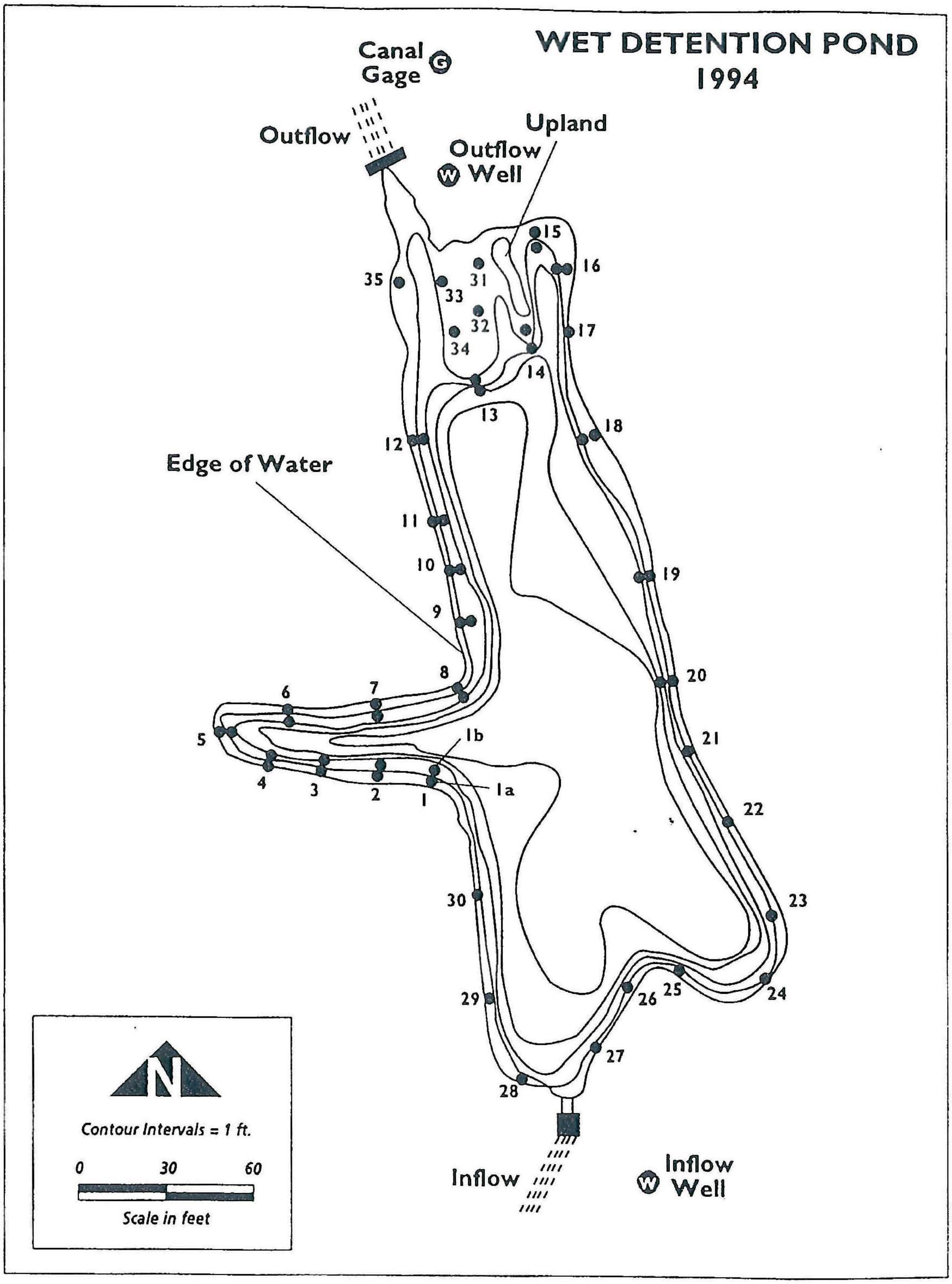


Figure 4. Location of Vegetation Quadrats. Each Dot Represents One Quadrat.

species as well as the percent of open water was estimated and recorded. Maximum and minimum water levels were also noted for each quadrat. Voucher specimens were archived and field identifications were later verified using Dressler *et al.* (1987), Godfrey and Wooten (1979) and Wunderlin (1982).

The purpose of the first survey was to document the vegetation that colonizes from natural recruitment and the later survey was made to document the competitive effect that results from planting the littoral zone. Measurements were made on June 24, 1994, about a month before the littoral zone was planted and again two years later on June 18, 1996, to document changes in species composition.

Aquatic Macroinvertebrate Measurements[1]

Macroinvertebrates were sampled using a dip net with a three foot handle for water samples and an Ekman Dredge for the sediments. Five sweeps of the dip net were taken in the littoral zone near the inflow, the outflow and the edges of the pond (Figure 5). Collections were made weekly from June 18 to August 16, 1994. Specimens were preserved in a solution of 70 percent ethanol and transported to the lab for identification. Bottom sampling was done systematically, with an Ekman Dredge along three transects. Six samples were taken with the dredge along each transect, two near the beginning of the transect, two in the middle, and two at the end, for a total of eighteen sediment samples on each date. Samples near the littoral zone were taken where the vegetation and water met, but not in the vegetation. Sediments were placed in two gallon containers and transported to the lab where they were rinsed through both an 18 gauge sieve and a 35 gauge sieve before being preserved in a 70 percent ethanol solution. Also a comparison site, a ten year old pond, was sampled on August 18, 1994. The open water and the littoral zone were sampled with equal intensity and all pond environments were lumped together and reported in one table by date.

Preliminary identification was done using McCafferty (1981) and Merritt and Cummins (1979). The bottom fauna, more specifically the chironomids and the oligochaetes, were identified with a dissecting microscope after being mounted on slides and fixed with CMC-10. For many specimens, identification was only possible to the genus level. Chironomidae identification is from Epler (1992) and oligochaetes from Brigham *et al.* (1982). The rest of the macro invertebrates were identified with a compound microscope and selected specimens were photographed. Various keys were used for species and genus identification (Berner 1950, Blatchley 1926, Young 1954) and many knowledgeable professionals provided advice with

[1] Marnie Ward, an undergraduate student in the Department of Zoology at the University of Florida, collected and identified the insects as an independent study project. The information in this section was taken from her report

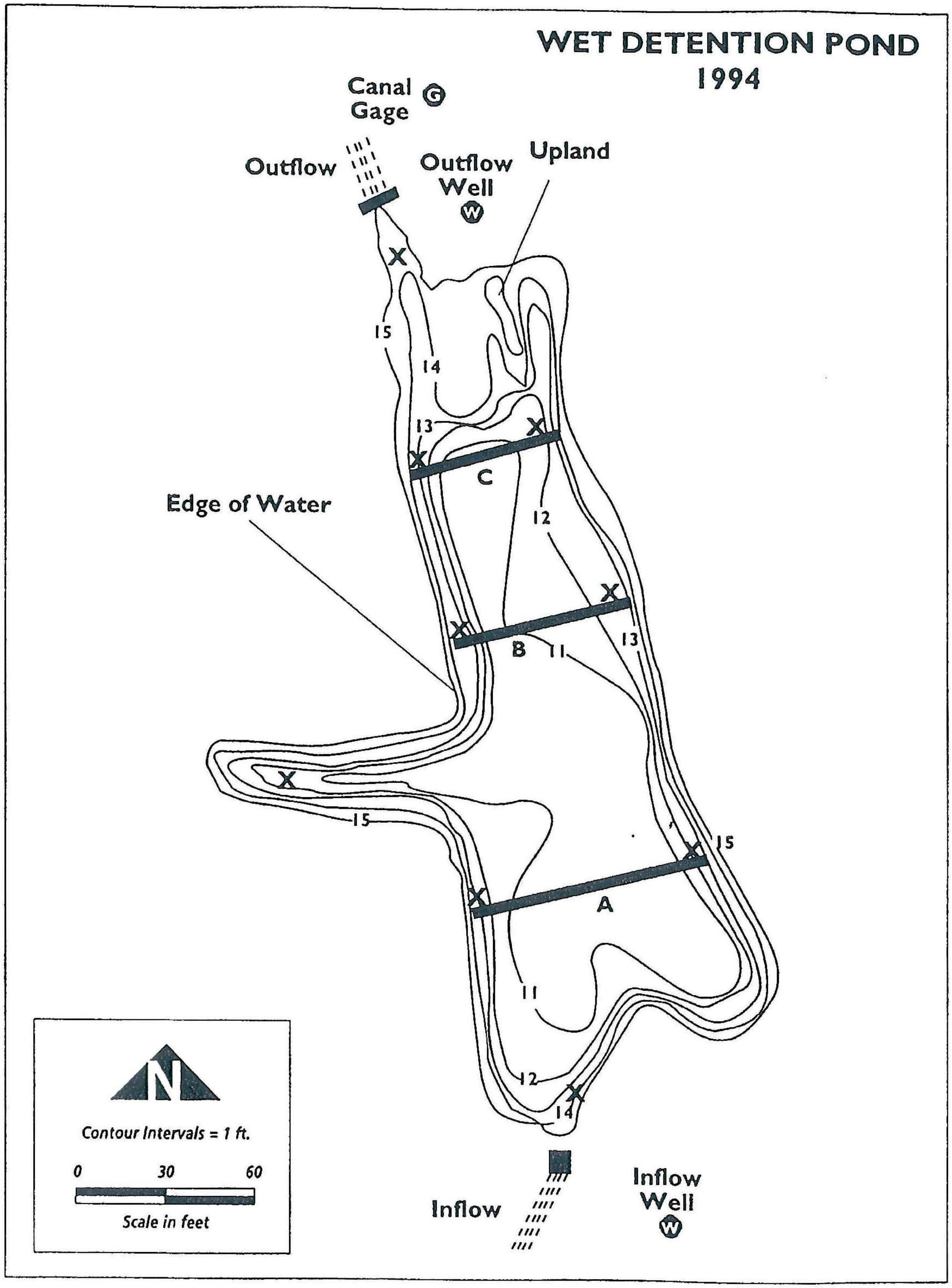


Figure 5. Location of Sediment Transects (A,B, & C) and Sweep Sampling Sites (X) Used for Insect Surveys.

problem species. Since not all individuals could be identified to the species level, the number of taxa was used for diversity measurements when species identification was not possible.

The Shannon-Weaver Diversity Index (USEPA 1973) is based on information theory and includes components of both species diversity and diversity due to the distribution of individuals among species, thereby, making species that are less common contribute more diversity:

$$\text{Diversity} = C/N\,(N \log_{10} N - \textstyle\sum n_i \log_{10} n_i)$$

Where: C=3.321928 (converts base 10 log to base 2)
N=total number of individuals
n_i=total number of individuals in the i^{th} species

The equitability measurement was devised to compare the number of species in the sample with the number of species expected (USEPA 1973). It is based on MacArthur's broken stick model which results in a distribution quite frequently observed in nature i.e. one with a few relatively abundant species and increasing numbers of species represented by only a few individuals:

$$\text{Equitability} = S'/S$$

Where S'=number of species expected (from a table using Shannon Weaver diversity to determine S').
S=number of taxa in the sample.

Many forms of stress tend to reduce diversity by making the environment unsuitable for some species or by giving other species a competitive advantage. Diversity measurements were used in this study to help evaluate these phenomena.

RESULTS AND DISCUSSION

One stormwater wet-detention pond was altered to compare its efficiency for removing pollutants using three different designs. Each pond configuration was studied for an eight month period (June through January) which covered representative conditions for both wet and dry seasons. Hydrology and water quality were analyzed for each year separately and the averaged results compared to each other. Also investigated were some of the other processes taking place such as sedimentation, groundwater interactions, vegetation colonization and insect species diversity. This section discusses the results of these measurements.

Hydrology of the System

Graphs of water levels were made to visually analyze relationships and detect problems (Appendix E and F). Continuous recorders reported rainfall, inflow, outflow and groundwater levels at 15 minute intervals. Only the 1993 and 1994 data are included for the detailed figures and tables in the appendices, but similar data are available for 1990 (Rushton and Dye 1993) and the results for the period of interest are summarized in this report. Storm numbers are placed on graphs for easy cross reference with water quality and other data.

Rainfall Characteristics

Rainfall characteristics are relevant not only to water quantity issues where they affect flooding and peak discharge but also to water quality results where they may influence constituent concentrations and removal efficiency. Antecedent conditions (inter-event dry period) and rainfall intensity increase pollutant concentrations by providing time for accumulation on land surfaces as well as the rain energy to flush pollutants through the system. Also wet and dry years affect input and output concentrations by changing subsurface flow and evapotranspiration. When conditions for the three years are compared (Table 4), the amount of rain and the number of rain events are markedly different, but for many characteristics the averaged values between years are surprisingly similar. For example, with more rainfall and more storms the number of dry days between storms are reduced, but the average amount of rain as well as intensity and storm duration are almost the same.

A key component in the study of rainfall-runoff relationships is rainfall excess, the amount of rain that runs off after depression storage and infiltration by soils. It is measured by the runoff coefficient, a ratio of rainfall excess (runoff) to precipitation volume, which ranges from 0.0 to 1.0. This coefficient represents runoff from the drainage basin and in this study ranged from 0.00 representing small storms and dry soil conditions to 0.91 measured during large storms in the wet season when soils are saturated (See Appendix G). Urban development greatly increases runoff, for example, natural woodlands and meadows with little topographic relief, typical of Florida, have coefficients that range from 0.05 to 0.20; while fully developed commercial and industrial sites range from 0.50 to 0.95 (MSSW 1988 and others).

Table 4. Comparison of rainfall characteristics between years (June through January). Abbreviations: NA=Not applicable, NS=Not significant. Values with the same letter are not statistically different.

Parameter	1990	1993	1994	significant differences
Total for each year				
Total rain (inches) *	28.00	34.21	44.38	NA
Number of rain events (>0.05 in)	53	60	83	NA
Averaged values for all storm events				
Average Rain amount (inches)	0.53	0.57	0.53	NS
Average intensity (in/hr)	0.26	0.27	0.30	NS
Inter-event dry period (days) **	4.40	3.56	2.67	NS
Duration of storm (hrs)	2.67	2.61	2.72	NS
Runoff coefficient	0.19 a	0.36 b	0.36 b	P>0.0001
Maximum values for each year				
Largest storm event (inches)	2.34	3.91	2.28	NA
Maximum duration (hrs)	15.88	16.50	13.00	NA
Maximum intensity (in/hr)	0.85	0.81	0.96	NA
Max. inter-event dry period (days)	25.77	20.45	24.89	NA
Maximum runoff coefficient	0.91	0.85	0.81	NA

* The long term average for the area from June through January is 39.95 inches. The average for an entire year is 52 inches.

** Also referred to as antecedent dry conditions.

At the study site, runoff was reduced because it was directed through ditches instead of having flow from the impervious surfaces discharging directly into the pond. This is measured by the runoff coefficient. The runoff coefficient is relevant to stormwater management systems since it is used to make estimates for pollutant loading (Harper 1994) and to make calculations for sizing systems to improve water quantity control by some methods (Wanielista and Yousef 1993, and others).

The effect caused by the amount of rainfall can be seen by comparing the runoff coefficient between years. When the pond was studied in 1990 drought conditions existed with rainfall almost 12 inches less than the long-term average of 39.95 inches. This rainfall deficit contributed to a lowered ground water level and a much reduced runoff coefficient of 0.19 compared to 0.36 for the other two more normal years. It should be noted that in 1990, a more reasonable 0.32 average coefficient is calculated when only those storms that produced flow are used. The 0.32 to 0.36 range is consistent with book values for low density developments located in flat sandy areas (MSSW 1988 and others).

Extreme events represented by maximum values have great impact on stormwater pollution. One large event, such as the 3.91 inches that fell in one day during August of 1993, can flush out the system and contribute the majority of pollutant loads measured for the entire year. This will be discussed in greater detail later. The maximum runoff coefficient for each year ranges from 0.81 to 0.91 and represents conditions when the ground is saturated caused by intense daily thunderstorms. During the summer rainy season, maximum pollutant loads can be delivered directly to the wet-detention pond with little depression storage or percolation by the drainage basin and then discharged with minimum treatment by the wet-detention pond. In contrast, it is common to have two to three weeks with no rain during the dry season in November as shown by the maximum inter-event dry period. This allows more time for pollutant accumulation on land surfaces and subsequent transport of pollutants to the wet-detention pond when it does rain.

Stage and Flow Measurements

Flow amounts calculated from stage measurements using weir and pipe equations estimated hydrologic budgets and determined pollutant loads. The amount of water entering and leaving the wet-detention pond for each storm are listed in Appendix H. The monthly rainfall volumes show the seasonal and yearly patterns of similarities and differences (Figure 6). Much more flow occurs in summer and considerably more flow was measured in 1994 than 1993. The effect of dry antecedent conditions are evident from the reduced outflow in June and December of 1993 as stormwater filled available storage space in the wet-detention pond before levels were high enough for discharge. It is also noteworthy that rainfall directly on the pond contributed a significant portion of the input. For 1993, when the pond area was 0.35 acres, 14 percent of the total input was from rainfall; in 1994, the pond surface area was increased to 0.57 acres and the total rainfall input was 26 percent.

An analysis of rainfall characteristics in Florida helps explains the variation in flow amounts. June through September is considered the rainy season in the Tampa Bay region a period when over 70 percent of annual rainfall occurs (Winsberg 1990). This is the season for convective storms which form when a parcel of air near the ground is warmed by conduction to a higher temperature than the air that surrounds it. As this heated air expands and rises it is cooled forming clouds and rain. This type of rain is highly localized and often produces short but

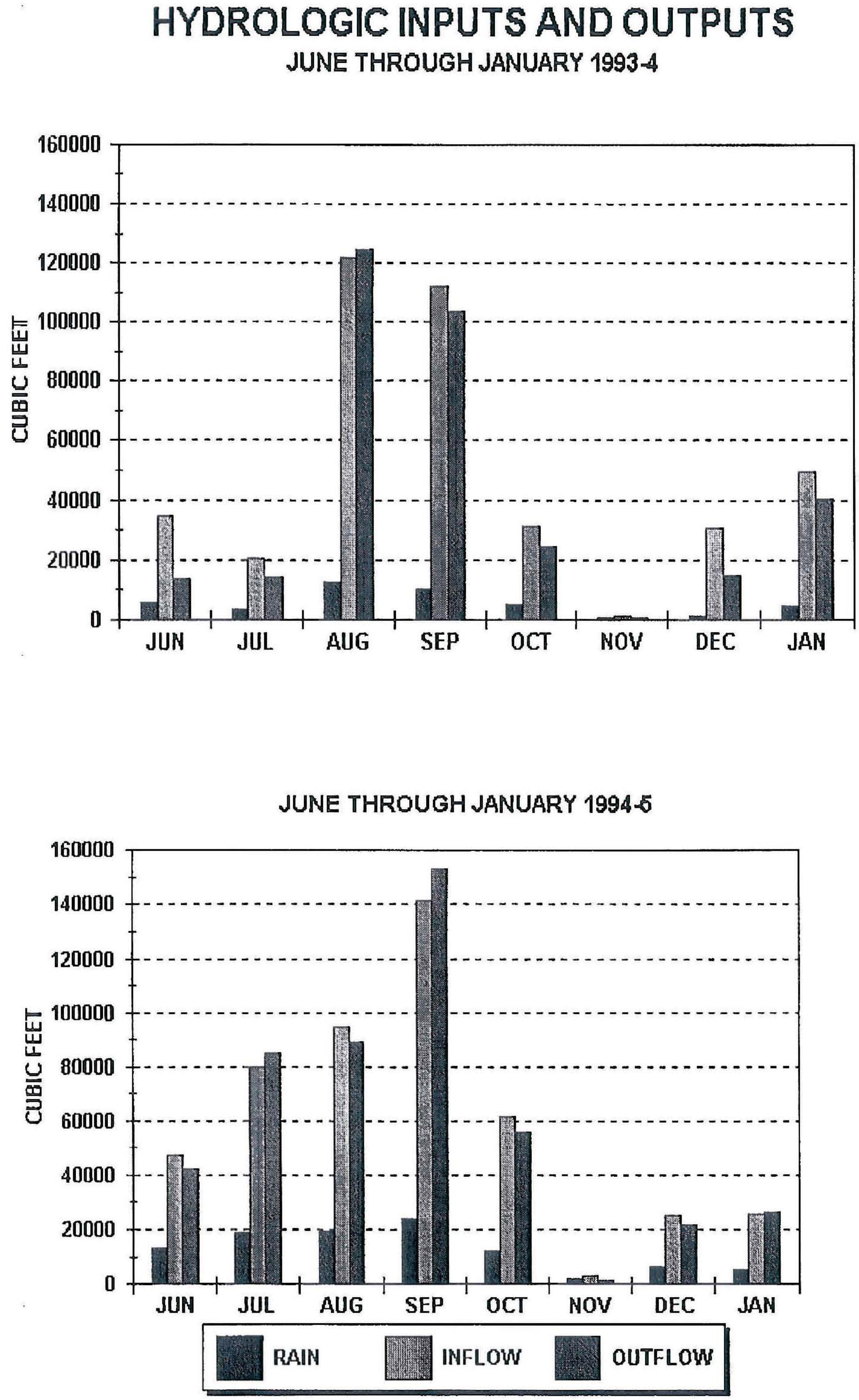


Figure 6. The monthly volumes show the seasonal and yearly patterns of similarities and differences between years for surface hydrologic inputs and outputs in rainfall on the pond, at the inflow and at the outflow.

intense storms. No other part of the nation has more thunderstorm activity than the Tampa Bay region (an average of 85 days per year). The rest of the year, October through May, is the dry season and rainfall is more dependent on cold fronts reaching the state from the north. The fall and spring have little rain since frontal systems seldom make it this far south during those seasons. About 12 percent of annual precipitation falls during December, January and February (Winsberg 1990) when storms of long duration and low intensity can produce a few large storms. Other types of precipitation which occur are caused by low pressure systems (tropical depressions) and hurricanes.

One purpose of wet-detention ponds is to reduce the peak flows and rapid runoff caused by urban development, usually to a rate no greater than the predevelopment peak discharge rate. This process is called hydrograph attenuation and is accomplished by increasing watershed time of concentration by adding water storage facilities such as detention ponds in the transport system. In this study a comparison of large storms (> 0.50 inches) showed maximum peak flow rates were greatly reduced between the inflow and outflow for both years (Table 5). The wet-detention pond reduced peak flows measured at the outflow by an average of 1.3 cfs (61%) in 1993 and 2.4 cfs (86%) in 1994. The time to peak was also lengthened with the peak flow at the outflow taking about 3 hours (67%) longer than the inflow in 1993 and 3.5 hours (75%) longer in 1994. It should be noted that the differences between years are not statistically different (P>0.05 Wilcoxon Rank Sum Test). This is not surprising since the fluctuating pool is designed to attenuate peak flows and this was about the same for both designs. The permanent pool which was made larger in 1994 is primarily used for pollution removal, however, when the permanent pool level is below the control elevation, storage is available to help reduce peak flows which accounts for slightly lower levels in 1994. The volume and timing of peak flows and the moderating influence of the wet-detention pond is obvious when seen by viewing a few of the larger storm events (Figure 7). In most cases the magnitude of the outflow is so much less, that when viewed on the same scale as the inflow, it is often difficult to detect the low outflow hydrograph even for these large storms.

Considerable attention has been directed toward detention basin designs that reduce peak flow, and although the ponds are proven effective for moderating and delaying hydrograph peaks, the additional runoff caused by urban development still increases the amount of runoff. A watershed approach needs to be implemented to increase the value of detention ponds in reducing flooded conditions. The typical detention basin will not be able to significantly reduce the volume of water by seepage and evapotranspiration (see Figure 6). Much of this excess volume is released after the peak of the discharge hydrograph, thus causing an extended period of relatively high flow (Nix and Tsay 1988). Also the extra discharge and the change in timing of release often causes a series of detention basins placed at upstream locations in the watershed to be ineffective in reducing peak flows in a downstream channel (James *et al.* 1987). It was also determined that when runoff from lower portions of the watershed are delayed they often coincide with arrival of runoff from upper portions causing peak flows higher than those for no detention conditions (Curtis and McCuen 1977). On the other hand, the gradual replacement of

Table 5. Comparison of peak flows and time to peak flow 1993 vs 1994. The data includes storms >0.50" only. Antecedent head refers to water levels when the storm began. The average maximum rainfall for 15 minute periods is also included. The delay time represents the amount of time from the beginning of the storm until the peak discharge.

MO	DA	YEAR	Total Rain (in)	Max for 15 min (in)	Inflow Ante Head (feet)	Inflow Max Head (feet)	Inflow Max Flow (cfs)	Inflow Delay Time (hours)	Outflow Ante Head (feet)	Outflow Max Head (feet)	Outflow Max Flow (feet)	Outflow Delay Time (hours)
1993 using 5 day residence time												
6	24	1993	0.94	0.4	0.02	0.78	1.34	0.5	-0.4	0.23	0.02	6.25
7	12	1993	1.05	0.34	-0.04	0.81	1.48	1.25	-0.1	0.38	0.06	3.75
7	15	1993	0.96	0.46	0.01	0.91	1.97	1	0.12	0.63	0.2	3.75
8	25	1993	2.18	0.94	-0.18	1.22	4.11	0.5	0	0.81	0.37	3.25
8	26	1993	3.95	1.04	0.05	1.47	6.55	2.25	0.94	1.49	8.22	3.25
8	29	1993	1.66	0.41	0.2	1.23	4.19	1.5	0.3	1.03	1.73	2
9	5	1993	0.94	0.62	0.02	0.79	1.39	0.75	0.12	0.56	0.15	3.75
9	6	1993	2.41	0.93	0.06	1.51	7	0.5	0.3	1.15	3.1	1.25
9	11	1993	0.92	0.4	0.05	0.84	1.62	1.25	0.17	0.74	0.29	3
9	14	1993	0.66	0.22	0.04	0.77	1.3	1.25	0.12	0.56	0.15	3.75
9	21	1993	1.49	0.71	-0.09	1.13	3.39	0.5	0.05	0.84	0.39	2.25
9	27	1993	0.8	0.39	-0.18	0.47	0.38	1	0.07	0.32	0.04	5
10	6	1993	0.82	0.13	-0.11	0.38	0.22	2.5	0.01	0.25	0.02	5.25
10	9	1993	0.5	0.07	0.09	0.17	0.03	2	0.13	0.15	0.01	5
10	30	1993	1.34	0.25	0.02	0.45	0.34	3.25	0.01	0.18	0.01	4.5
1	2	1994	0.85	0.24	0.19	0.65	0.85	0.75	0.29	0.61	0.18	4
1	13	1994	1.06	0.24	0.06	0.65	0.85	1	0.09	0.48	0.1	4.25
1	17	1994	1.18	0.39	0.07	0.95	2.2	1	0.12	0.81	0.37	4.25
Average			**1.32**	**0.45**	**0.02**	**0.84**	**2.18**	**1.26**	**0.13**	**0.62**	**0.85**	**3.81**
Std. Dev.			**0.8**	**0.28**	**0.1**	**0.36**	**2.02**	**0.75**	**0.25**	**0.35**	**1.94**	**1.19**
Variance			**0.61**	**0.61**	**6.54**	**0.42**	**0.93**	**0.6**	**1.93**	**0.56**	**2.27**	**0.31**
Maximum			**3.95**	**1.04**	**0.2**	**1.51**	**7**	**3.25**	**0.94**	**1.49**	**8.22**	**6.25**
Minimum			**0.5**	**0.07**	**-0.18**	**0.17**	**0.03**	**0.5**	**-0.4**	**0.15**	**0.01**	**1.25**
# obs			**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**
1994 using 14-day residence time												
6	14	1994	0.78	0.5	-0.18	0.71	1.06	0.5	-0.02	0.12	0	5.75
6	15	1994	1.4	0.61	0.03	1.08	3.03	0.5	0.1	0.62	0.19	6.75
6	27	1994	0.76	0.5	-0.22	0.65	0.85	1	0	0.16	0.01	2.75
7	1	1994	1.57	0.69	0	1.2	3.94	0.5	0.17	0.83	0.39	2.5
7	2	1994	0.57	0.19	-0.02	0.63	0.79	1.75	0.1	0.25	0.02	5.75
7	10	1994	0.57	0.19	-0.02	0.63	0.79	1.75	0.1	0.25	0.02	5.75
7	18	1994	0.9	0.64	0.11	0.9	1.92	0.75	0.02	0.28	0.03	2.25
7	20	1994	1.12	0.64	0.05	1.2	3.94	0.5	0.18	0.63	0.2	2.5
7	21	1994	0.51	0.26	0.18	1.1	3.17	0.5	0.38	0.57	0.15	4.25
8	10	1994	2.25	0.81	0.04	1.66	8.88	1.75	0.17	1.15	3.1	2.25
8	13	1994	0.79	0.23	0.02	0.59	0.67	1.25	0.21	0.48	0.1	5
8	24	1994	0.73	0.45	0.02	0.95	2.2	1	0.15	0.45	0.08	3.25
8	26	1994	1.17	0.34	0.25	1.15	3.55	0.5	0.24	0.83	0.39	2
9	2	1994	0.72	0.59	-0.07	0.66	0.88	0.5	0.08	0.22	0.01	2
9	15	1994	1.23	0.21	0.04	0.61	0.73	0.75	0.12	0.69	0.25	8
9	16	1994	2.03	0.52	0.06	0.96	2.26	0.5	0.42	1.01	1.53	4.25
9	17	1994	0.73	0.65	0.07	1.13	3.39	0.75	0.53	0.84	0.4	1.5
9	19	1994	1.66	0.76	0.03	1.5	6.89	0.5	0.24	0.97	1.17	1.5
9	24	1994	1.13	0.43	0	1.12	3.32	0.5	0.09	0.63	0.2	3.25
9	27	1994	0.85	0.33	0.11	1.18	3.78	0.5	0.44	0.86	0.45	2.75
10	26	1994	1.6	0.35	-0.06	1.03	2.69	0.75	-0.01	0.44	0.08	3.75
10	29	1994	1.61	0.72	0.04	1.52	7.12	0.5	0.18	0.95	1.01	1.25
11	15	1994	0.69	0.07	-0.02	0.31	0.13	5	0.01	0.14	0	13.5
12	1	1994	1.63	0.82	-0.72	1.4	5.8	0.5	0	0.68	0.24	3.25
12	20	1994	0.84	0.04	-0.1	0.24	0.07	3	0.07	0.3	0.03	15.25
1	14	1995	1.11	0.41	-0.05	1.05	2.82	1.25	0.02	0.44	0.08	3.75
1	15	1995	0.65	0.18	0.18	0.35	0.18	2.75	0.42	0.54	0.13	4
Average			**1.1**	**0.45**	**-0.01**	**0.94**	**2.77**	**1.11**	**0.16**	**0.57**	**0.38**	**4.4**
Std. Dev.			**0.46**	**0.22**	**0.17**	**0.37**	**2.25**	**1.02**	**0.15**	**0.29**	**0.65**	**3.28**
Variance			**0.42**	**0.5**	**-19.73**	**0.39**	**0.81**	**0.92**	**0.93**	**0.51**	**1.71**	**0.75**
Maximum			**2.25**	**0.82**	**0.25**	**1.66**	**8.88**	**5**	**0.53**	**1.15**	**3.1**	**15.25**
Minimum			**0.51**	**0.04**	**-0.72**	**0.24**	**0.07**	**0.5**	**-0.02**	**0.12**	**0**	**1.25**
# obs			**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**

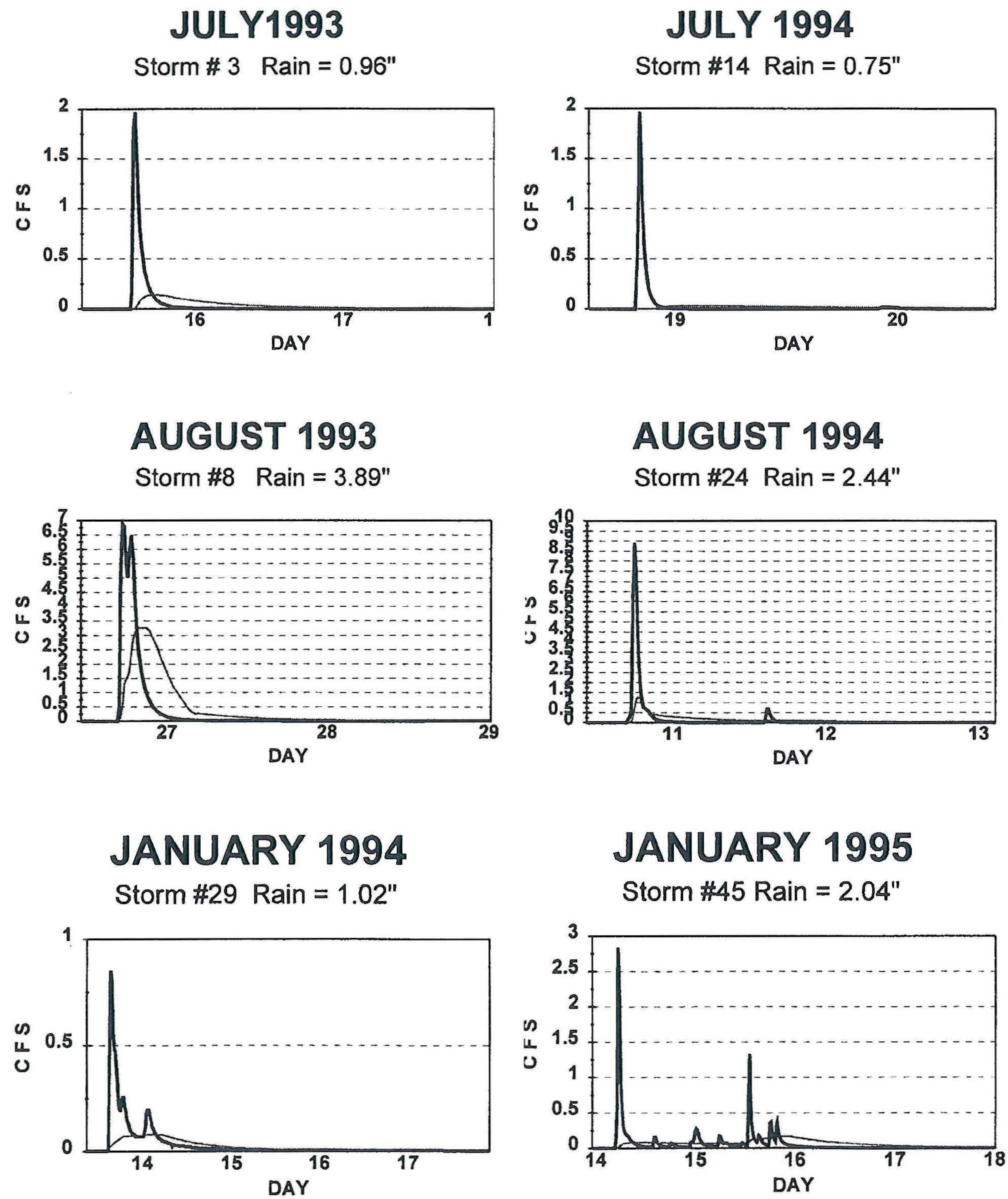


Figure 7. Some typical hydrographs showing patterns for different seasons. Inflow is represented by the dark solid line and outflow by the thin line. The July data represent the highly localized short intense convection storms typical of the rainy season. The August storms depict the largest storm measured during each year. The January hydrographs show frontal storms when rain events of longer duration and less intensity occur.

detention areas immediately upstream of culverts was shown by a computer model to reduce peak flows throughout the watershed (Malcom 1978). A watershed approach using a variety of techniques would greatly improve stormwater management.

Another method to reduce flow downstream and improve water quality is to incorporate a stormwater reuse component into the wet detention pond system. Additional benefits derived from stormwater reuse are conservation of rainfall water, reduced demand for potable water for irrigation and enhanced groundwater recharge. To help engineers develop creative designs to capture and reuse runoff, water reuse volume charts (REV) have been developed for southwest Florida (Harrison 1993) and other geographical areas (Wanielista and Yousef 1993). Another advantage of stormwater reuse is the ability to increase annual treatment efficiency to meet the 80 percent pollution removal goal of the state water policy. For example, using the REV charts a wet detention pond with 60 percent treatment would require the reuse of 50 percent of its average annual runoff to obtain a total average annual treatment efficiency of 80 percent (Harrison 1993).

Water Quality for Potential Pollutants

To compare the efficiency of the three different designs for removing pollutants, composite flow weighted water quality samples were collected at the inflow, outflow, and rainfall for almost all storms from June through January of each year. Pollution removal was calculated by two methods, one using concentrations and the other using mass loads. Concentrations for each storm were also compared to State of Florida water quality standards.

Concentrations

Concentrations of constituents for every storm sampled during the three years with summary statistics are listed in Appendix I. Average values for the three pond designs are shown in Table 6. When the average concentrations for each constituent are compared by year, there is almost always less concentration at the outflow when compared to the previous year in spite of the fact that concentrations often increased at the inflow. The increase at the inflow can be attributed to construction activities during 1993 and 1994. Other aspects which increased pollutant concentrations at the inflow were the removal of part of the ditch that provided pre-treatment before stormwater enters the pond plus fertilizer and weed control applications to the grassed areas.

Although in most cases the amount of pollution in the effluent was reduced by increasing the residence time from two to five days, the changes were not statistically significant with the possible exception of inorganic nitrogen. Nitrate plus nitrite showed a large reduction at the inflow, so this may have also improved concentrations at the outflow. The reduction at the inflow may have been caused by a leak in a water transmission line which may have diluted stormwater samples during part of the study. The significant increase in zinc measured in rainfall is attributed to the fact that the rainfall collector was moved closer to the highway in a more exposed location after 1990.

Table 6. A wet detention pond was altered to test three residence times. Water quality samples were collected on a flow weighted basis for the majority of storms that occurred from June through January of each storm year. Rain is the average concentration found in rainfall, inflow represents the average concentration measured at the inflow, and the outflow is the average concentration at the outflow.

CONSTITUENTS	UNITS	1990 2-DAY RESIDENCE TIME (1)			1993 5-DAY RESIDENCE TIME (2)			1994 14-DAY RESIDENCE TIME (3)		
		RAIN	INFLOW	OUTFLOW	RAIN	INFLOW	OUTFLOW	RAIN	INFLOW	OUTFLOW
AMMONIA-N	MG/L	0.224	0.083	0.068	0.156 --	0.077 --	0.05 *	0.202 --	0.123 *	0.035 --
NITRATE+NITRITE-N	MG/L	0.289	0.24	0.09	0.283 --	0.096 **	0.032 *	0.344 --	0.396 *	0.062 --
ORTHO-PHOSPHORUS	MG/L	0.033	0.336	0.108	0.01 --	0.248 --	0.084 --	0.01 --	0.305 --	0.027 **
TOTAL PHOSPHORUS	MG/L	0.072	0.4	0.176	0.07 --	0.651 --	0.164 --	0.012 *	0.497 --	0.053 **
ORGANIC NITROGEN	MG/L	0.305	1.025	1.002	0.341 --	1.089 --	0.823 --	0.188 --	1.09 --	0.62 *
T. SUSPENDED SOLIDS	MG/L	ND	28	11	ND n	45 --	14 --	ND n	131 **	7 **
TOTAL ZINC	uG/L	45	51	31	93 *	25 --	21 --	72 --	81 *	14 *
TOTAL IRON	uG/L	51	555	396	70 --	1517 --	463 --	71 --	3200 *	220 *
TOTAL CADMIUM	uG/L	0.3	0.5	0.6	0.44 n	BD n	BD n	BD --	BD *	BD **
TOTAL COPPER	uG/L	ND	ND	ND	1.68 n	2.59 n	2.83 n	4.01 **	6.52 **	3.96 --
TOTAL LEAD	uG/L	ND	ND	ND	BD n	BD n	BD n	BD --	5 *	BD --
TOTAL MANGANESE	uG/L	ND	ND	ND	2.2 n	33.4 n	10.2 n	2.4 --	31.1 --	10.3 --
T. ORGANIC CARBON	MG/L	ND	ND	ND	ND n	15.23 n	10.9 n	ND n	14.78 --	8.65 **
HARDNESS	MG/L	ND	ND	ND	1 n	175 n	143 n	1 --	197 --	214 **

(1) 20 to 22 storm events sampled. Below normal rainfall.
(2) 18 to 22 storm events sampled. Below normal rainfall.
(3) 37 to 42 storm events sampled. Average rainfall.
ABBREVIATIONS: Significant differences compared to the previous year.
-- = not significantly different from the year before
* = significant difference at the 0.05 level
** = significant difference at the 0.01 level
n = test not performed
BD = Below laboratory detection limit
ND = Data not available

The most impressive results were seen using the 14-day residence time criteria. Despite greater concentrations at the inflow, almost all the major pollutants at the outflow were reduced by significant levels from those measured during the previous year when the residence time was five days. The exception was nitrogen. High inflow levels of inorganic nitrogen from the fertilizer application apparently increased levels at the outflow, although concentrations are still lower than in 1990. Lead, copper and cadmium were measured at such low concentrations that differences were difficult to quantify reliably (BDL = 75 to 95% of samples).

The treatment efficiency of constituent removal was improved by the 14-day residence time design (Figure 8). Using these criteria, the reduction of pollutants from the inflow to the outflow usually met the 80 percent reduction goal specified by the State Water Policy (Chapter 62-40 FAC). These efficiencies are even better when calculated for loads which is the method recommended in the state water policy and those load reductions will be discussed below.

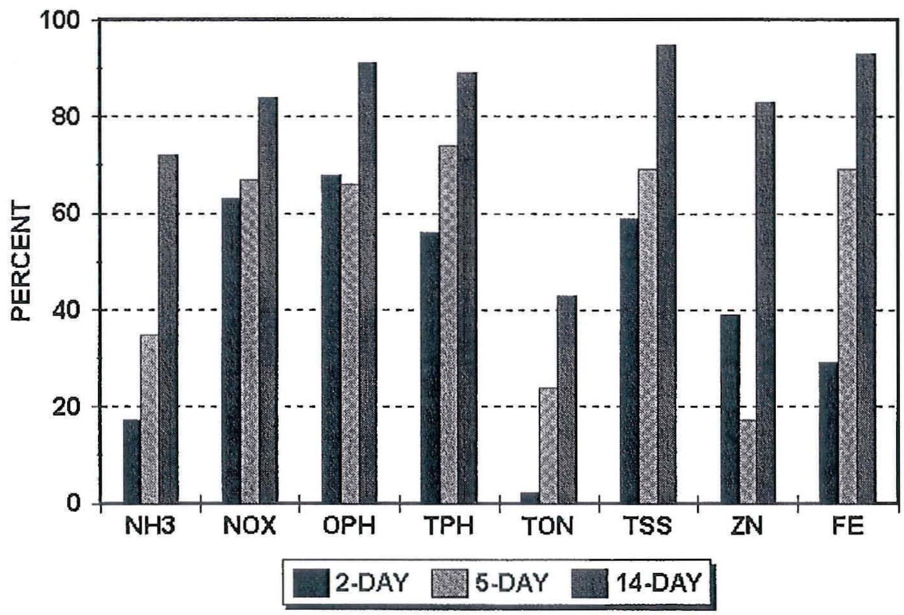


Figure 8. Comparison of percent reduction of pollutants for three residence times. Removal efficiency is calculated from event mean concentration measured at the inflow and outflow during storm events. Abbreviations are identified in Appendix R.

Mass Loading

Load removal gives greater weight to large storms as well as improvements caused by additional time for water losses through seepage and evapotranspiration; while reduction in pollutants calculated from concentrations gives equal weight to all storms and indicates the average removal of pollutants by sedimentation and physico-chemical processes. The event mean concentration is appropriate for many applications such as estimating the impact of specific storm events in rivers and lakes, but when cumulative effects are important, mass loading is more appropriate. Mass loading was calculated over the time period of this study for each year and includes stormwater volume in the calculations. Data for all the storm events sampled can be found in Appendix J and the summarized data are in Table 7. Storm volumes demonstrate the differences observed between years depending on the amount of rainfall.

Storm volumes and thus loads for each year were quite different with over twice as much flow in 1994 as in 1990. According to SWFWMD's Data Collection Department, 1990 was the third driest one-year period based on records going back to 1915. The severe drought conditions in 1990 and the below average rainfall in 1993 affected evapotranspiration and groundwater movement. The percent efficiency for storm volumes (Table 7) represents the amount lost by evapotranspiration and net seepage. The samples collected during December of 1993 were not used because of a leak in a broken water pipe which helps explain the discrepancies between total volumes and the volume for storms sampled in 1993. Some explanations for the reduction in water lost to the system from over 38 percent in 1990 to around 17 percent in 1994 include the following:

1. More vegetation in the pond in 1990 resulted in greater losses by evapotranspiration which can exceed evaporation.

2. The higher water table measured during 1993 and 1994 reduced the radial groundwater loss since this is greater when the water table is low and relatively small or reversed when the ground is saturated.

3. Two low areas contributed some unmeasured inflow to the pond during extreme events in 1994.

4. Backwater from the receiving waters (>15.08 NGVD the control elevation) may have held levels high and thus affected flow calculations for storms 8, 9 and 12 in 1993; and storms 13, 24 and 33 in 1994 (see appendices E and F). The receiving waters were never measured higher than 15.00 NGVD in 1990.

Table 7. Total loads and storm volumes for each year (June through January). RAIN=constituent load falling directly on the wet-detention pond. Percent Efficiency includes rainfall plus inflow as an input. INFL=inflow loads, OUFL=outflow loads, ND=no data. Less than (<) indicates averages below the detection limit and efficiencies are not exact.

JUNE THROUGH JANUARY CONSTITUENT LOADS	1990 (1)				1993 (2)				1994 (3)			
	RAIN	INFL	OUFL	%EFF	RAIN	INFL	OUFL	%EFF	RAIN	INFL	OUFL	%EFF
STORM VOLUMES												
Total Volume (cu ft) *	37733	222194	173657	41	52297	401359	336374	30	100727	478526	474033	18
Volume for storms used(cu ft)	24068	178628	140632	38	34755	332231	307367	17	76383	384498	386919	16
% Sampled **	64	80	81		66	83	91		76	80	82	
CONSTITUENT LOADS												
Total Suspended Solids (grms)	1701	134505	39641	71	2121	402167	133999	67	ND	2060220	130662	94
Total Organic Nitrogen (grms)	172	4738	3455	30	384	10813	9551	15	389	14169	7129	51
Ammonia Nitrogen (grms)	138	404	251	54	145	578	947	-31	373	2683	291	90
Nitrate+nitrite (grms)	154	1084	440	64	244	940	465	61	684	3262	469	88
Ortho-phosphate (grms)	15	2086	641	69	7	2230	1354	39	18	5315	437	92
Total Phosphorus (grms)	39	2465	941	62	42	4947	2121	57	31	8369	835	90
Total Zinc (grms)	29	208	104	56	76	198	186	32	127	1015	149	87
Total Iron (grms)	37	2379	1443	40	72	15017	3777	76	130	53164	3445	94
Total Cadmium (grms)	0.2	2.9	1.4	55	0.48	<1.76	<1.31	~42	<0.40	<4.21	<0.61	~87
Total Copper (grms)	ND	ND	ND	ND	2.08	23.96	25.66	1	7.85	80.32	39.6	55
Total Manganese (grms)	ND	ND	ND	ND	1.95	264.8	103.3	61	4.5	464	100	79
Total Lead (grms)	ND	ND	ND	ND	ND	ND	ND	ND	<1.15	82.96	<6.97	~92
Total Hardness (grms)	ND	ND	ND	ND	658	1255483	1139818	9	191	190079	210195	-10
Total Organic Carbon (grms)	ND	ND	ND	ND	ND	ND	ND	ND	ND	144477	83750	42

* Percent efficiency for water volumes represents the amount of rain and flow measured entering the wet-detention pond which was not measured leaving the pond at the outflow. These losses represent evapotranspiration and net seepage.

** Not all inflows and outflows were sampled caused by missed storm events and storms which didn't produce enough flow to constitute a sample. This was especially true for rainfall directly on the pond, which often didn't produce enough rain to cause flow but the amount is included here as part of the total "volume" of rainfall and accounts for including only about 60% of total rainfall during drought years.

(1) 20 to 22 storms sampled. Low rainfall. (2) 18 to 22 storms sampled. Low rainfall. (3) 37 to 42 storms sampled. Average rainfall.

The percent efficiency for pollutant removal shows at least a 20 percent improvement by using the Conservation Wet Detention criteria as shown by the 1994 data when compared to the earliest design represented by 1990 (Table 7). Load efficiency was not improved between 1990 and 1993, although the residence time had been increased from two to five days and the average depth and thus the volume of the permanent pool had been increased from 3,000 to 20,000 cubic feet. The lower efficiencies in 1993 were caused by one extreme storm event (storm #8) where 3.89 inches of rain fell during one week which had a total of 7.68 inches. At the outflow of the pond, this enormous washout effect, where stormwater had little time for treatment, produced 28 percent of the total flow for the entire study period (from June through January) and an even larger percentage of total constituent loads. For example, at the outflow, loads from this one storm compared to total loads from all 22 storms were: ammonia (77%), nitrate + nitrite (56%), organic nitrogen (44%), ortho-phosphate (45%), total phosphorus (39%), suspended solids (38%), zinc (32%), and copper (46%). The years 1990 and 1994 had no comparable extreme rain events. This indicates the need for examining stormwater impacts using extreme events which may be much more devastating to the ecosystem than is shown by using averaged values.

Mass loading efficiency using the Conservation Wet Detention criteria almost always met the 80 percent removal goal set by the State Water Policy (Chapter 62-40 FAC). Two exceptions which failed to meet the goal were total organic nitrogen (51%) and total organic carbon (42%). Total organic carbon results are not comparable since those samples were collected as a grab sample after storm events while other samples were composite samples. It will always be difficult to remove organic nutrients in wetlands such as this one where high primary productivity generates organic matter. It should be noted that the greater pollutant removal for most constituents was accomplished in spite of the fact that the volume of water lost through evaporation and seepage out of the pond decreased in 1994. Water loss is usually an important mechanism for the net reduction of pollutant loads and the fact that removal for most pollutants was still over 80 percent reflects the fact that concentrations in 1994 were usually significantly lower.

Comparison to Water Quality Standards

Another measurement to determine if water discharged from stormwater systems met state water quality goals is to compare the data to state standards. In February of 1992, the Florida Department of Environmental Protection (DEP) changed the method for determining the surface water standards considered safe for fish and wildlife. The major change incorporated the use of water hardness to compute the new standard since soft water increases the toxicity of some metals to organisms. For these metals, new rules produce a unique standard for each individual sample dependent on the natural logarithm of water hardness. The concentration of each sample (value) is listed with its unique standard in Tables 8 and 9. If a concentration is above the standard, laboratory or other tests have demonstrated it is detrimental for the propagation of aquatic species or the maintenance of a healthy, well-balanced population of fish and other aquatic organisms. All standards express the maximum

Table 8. Water quality results compared to State of Florida Class III Water Quality Standards (Chapter 62-302.530) in 1993. D.L.=Laboratory Detection Limit, na=data not available. Numbers in bold lettering exceed standards considered safe for fish and wildlife. Data are for June 1993 through January 1994. The standard for iron is <1000 ug/l.

1993	Cadmium (ug/l) D.L.=0.3				Copper (ug/l) D.L.=0.1				Lead (ug/l) D.L.=2.0				Zinc (ug/l) D.L.=10				Iron (ug/l) D.L.=30		Hardness (mg/l) D.L.=0.02	
Storm Number	inflow value	inflow std.	outflo value	outflo std.	inflow value	inflow std.	outflo value	outflo std.	inflow value	inflow std.	outflo value	outflo std.	inflow value	inflow std.	outflo value	outflo std.	inflow value	outflow value	inflow value	outflow value
1	0	1.6	0	1.4	2.3	20.5	6	16.9	0	7.2	0	5.4	24	183	5	151	**1844**	15	190	152
2	0.5	1.1	0.2	1.6	9.8	13.1	2.6	20.1	**12.6**	3.7	0	7	64	118	29	179	**6648**	792	113	186
3	0	1.2	0	1.5	4	14.9	4	18.3	0	4.5	0	6.1	39	133	22	164	**3082**	**2834**	131	167
4	0	1.5	0.3	1.2	5.6	19	2	14.9	4.6	6.4	0	4.5	46	169	21	133	**1581**	456	174	131
5	0.1	1.7	na	na	2.8	20.8	na	na	1	7.4	na	na	32	186	na	na	**1205**	na	194	na
6	0	1.7	na	na	0.7	20.8	na	na	0.6	7.4	na	na	8	186	na	na	533	na	194	na
7	0.6	1.2	0.2	0.8	3	14.2	4	8.6	**5**	4.2	1.4	2	25	127	25	77	**2569**	922	124	69
8	0.2	0.7	0.1	1.1	3	7.6	4.8	13.2	0.7	1.7	1.1	3.8	2	69	24	118	**1474**	415	60	114
9	0.2	1.1	0.2	1.3	3	12.9	2.3	16.1	**3.6**	3.6	1.7	5.1	23	116	26	144	**1898**	352	111	144
11	0.3	1.9	0.2	1.4	0	24.2	3.1	16.9	0	9.2	0.7	5.4	12	215	23	151	872	283	231	152
12	0.2	1.5	0.3	1.2	0	19.3	0.1	14.1	0	6.6	2.2	4.1	18	172	17	126	642	367	177	123
13	0.1	1.2	0	1.3	2	13.9	1.4	16	**4.6**	4.1	0.8	5	20	125	39	143	**1823**	389	121	142
14	0.1	1.2	0.2	1.3	4.3	14.4	4.8	16.1	3.4	4.3	1.4	5	34	129	34	144	**2026**	352	126	143
15	0.1	0.8	0.1	1	2.4	9.4	2.9	12.2	**2.2**	2.2	0.6	3.3	28	84	15	110	**1257**	458	76	104
16	1	1.3	0.1	1.2	3.5	16.4	1.7	14.1	2.4	5.2	0.9	4.1	36	147	15	126	905	205	147	123
17	0.1	1.6	0.1	1.1	2.2	20	0.3	13.4	1.9	7	1.1	3.8	24	179	9	120	379	177	185	116
18	0	2	0.1	1.3	0	25.8	7	15.3	1.2	10.2	2	4.7	21	230	6	137	711	117	249	135
19	0	2	0.1	1.2	2	25.5	1.3	14.9	1.4	10	1	4.5	19	227	5	133	597	165	246	131
20	0.1	1.4	0.2	1.6	2.1	17.8	1	20.5	0	5.8	0	7.2	21	159	23	183	356	149	161	190
21	0.1	3.6	0.3	1.9	1	50.2	2	23.9	0	27.4	0	9.1	20	444	68	213	213	161	543	228
22	0	2.2	na	na	1.3	28.9	na	na	0.2	12.1	na	na	28	257	na	na	166	na	285	na
23	0	1.9	na	na	2.8	24.9	na	na	0.2	9.6	na	na	14	222	na	na	112	na	239	na
24	0	1.9	0	1.5	0.1	24.1	0	18.7	0	9.2	0	6.3	20	215	10	167	82	101	230	171
25	0.1	1.9	0	1.5	0	24.9	0	19.1	0	9.6	0.2	6.5	22	222	20	170	70	95	239	175
26	0	1.9	0	1.6	0	25	0	19.8	0.1	9.7	0.2	6.9	25	223	17	177	43	93	240	183
27	0.2	2	0	1.6	0	25.2	0	19.8	0.1	9.9	0.3	6.9	19	225	15	177	50	134	243	183
28	0	2	0.1	1.7	0	26.4	0	21.5	0.5	10.5	0	7.7	26	235	16	192	98	97	256	201
29	0	1.9	0	1.6	1	24	1	20	0.8	9.1	0.2	7	17	214	4	179	417	140	229	185
30	0.1	1.1	0.1	1.4	2.3	12.7	4.4	16.7	**5.5**	3.6	1.2	5.3	28	114	14	149	**2351**	508	109	150

Table 9. Water quality results compared to Class III Water Quality Standards (Chapter 62-302.530) in 1994. D.L.= Laboratory Detection Limit. Numbers in bold lettering exceed standards considered safe for fish and wildlife. Data are for June 1994 through January 1995. The standard for iron is a constant 1000 uG/l.

1994	Cadmium (ug/l) D.L.=0.3				Copper (ug/l) D.L.=0.1				Lead (ug/l) D.L.=2.0				Zinc (ug/l) D.L.=10				Iron (ug/l) D.L.=30		Hardness (mg/l) D.L.=0.02	
Storm Number	inflow value	inflow std	outflo value	outflo std	inflow value	inflow std	outflo value	outflo std	inflow value	inflow std	outflo value	outflo std	inflow value	inflow std	outflo value	outflo std	inflow value	outflow value	inflow value	outflow value
2	0.3	3.6	0.1	2.7	4.6	41.3	1.4	39.6	0	20.5	0	19.2	25	366	12	351	723	255	432	411
3	0.3	1.3	0	2.6	3.8	14	1.2	30.8	5.9	4.1	0	13.3	37	125	12	274	4616	207	122	307
4	0.1	2.3	0.1	2.7	3.4	25.1	3.5	28.8	0.1	9.7	0	12	30	223	10	257	851	135	241	284
5	0	2.3	0	2.6	3.2	25.7	1.2	30.3	0.6	10.1	0.1	12.9	48	229	32	270	1159	185	248	301
6	0.4	1.4	0.1	2.5	3.5	14.5	1.9	29.4	3.9	4.3	0	12.3	40	130	13	261	3375	165	127	290
7	0.1	1.6	0.1	2.6	5.4	17.3	4.4	28.4	0	5.6	1.4	11.7	56	154	17	253	6511	151	156	279
9	0.2	1.5	0.1	2.3	7.7	16.1	0.5	29	2.7	5.1	1.3	12.1	40	144	15	258	253	268	144	286
12	0.1	2.4	0	2.4	2.7	26.2	3.7	25.3	1.9	10.4	1.1	9.9	39	234	20	226	820	196	254	244
13	0.2	1.6	0	2.2	4	17	4.4	26.1	2.3	5.5	0.4	10.4	43	152	19	233	1091	299	153	253
14	0.4	1.1	0.1	2.1	5.4	11.9	4.4	24.4	7.4	3.2	0	9.4	71	107	14	218	3176	156	101	234
15	0.3	1.2	0.4	2	9.1	12.6	7.4	23.3	10.5	3.5	0	8.7	68	113	25	208	5707	233	108	221
16	0.4	1.4	0	2.1	7.4	14.3	5.4	22.4	9.6	4.2	0	8.2	65	128	13	200	6358	276	125	211
17	0.2	2.3	0.05	2.1	7.3	26	6.7	23.2	0.9	10.3	0	8.7	40	231	17	207	404	347	251	220
18	0.3	1.6	0	1.9	10.1	16.7	12.6	22.7	6	5.3	0	8.4	615	149	15	202	4354	184	150	214
19	0.4	2.1	0	2.1	6.2	22.9	12.5	21.3	5.2	8.5	0	7.6	545	204	12	190	8174	148	217	199
20	0.2	1.1	0	2	11.9	11.7	3.1	23.1	3.6	3.1	0	8.6	70	105	11	206	1096	156	99	219
21	0.2	1.6	0	2	5.9	17.8	9.4	22.4	1.7	5.8	0	8.2	46	159	10	200	1539	135	161	211
22	0.1	2.4	0	2	16.9	27.2	8.1	21.7	0.9	11	0	7.8	48	242	6	193	778	101	265	203
23	0.2	1.9	0.2	1.7	7.3	20.2	2.7	21.9	4.8	7.1	0	8	7	180	3	196	3008	69	187	206
24	0.9	1	0	1.6	17.7	10	8.1	18.9	23	2.5	0.3	6.4	111	90	25	169	16175	987	82	173
25	0.3	1.8	0.1	1.7	6.8	19.4	3.4	17.3	8.3	6.6	2.5	5.6	50	173	12	154	4127	500	178	156
26	0.4	1.6	0	1.9	6.5	17.1	2.1	17.9	4.3	5.5	1	5.9	29	153	10	160	2190	258	154	162
27	0.2	3.7	0	1.9	3.4	42.8	1.4	20.3	1.8	21.6	0	7.1	41	380	4	181	718	207	451	188
29	0.1	2.1	0	1.9	2.9	23.4	2.2	20.2	2	8.8	0.1	7.1	27	208	7	180	1265	145	222	187
30	0.5	1.8	0	1.9	8.7	19	1	20.7	16.9	6.4	0	7.3	79	169	5	185	9084	150	174	193
31	0.4	1.6	0.1	1.8	3.4	16.7	4.8	20.5	10.7	5.3	0.1	7.2	37	149	17	183	4722	169	150	190
32	0.6	2.2	0.1	1.8	11.5	24.6	3.2	20.1	0.4	9.5	0.4	7	49	219	19	179	683	224	236	186
33	0	2.6	0	1.6	7.2	29.5	1.7	19.5	0	12.4	0	6.7	66	262	15	174	858	466	291	180
34	0.26	1.5	0.09	1.6	4.4	16.1	2.6	17	5.8	5	2.1	5.5	202	144	10	152	3433	29	143	153
35	0.2	1.6	0.2	1.6	4.6	16.6	3.3	16.7	4.8	5.3	0.6	5.3	29	149	9	149	2085	137	149	150
36	1.05	1.5	0.1	1.8	11.1	15.5	3.2	16.8	18.2	4.7	1.7	5.4	88	138	8	150	11127	511	137	151
37	0.2	1.9	0.1	2	4	20.6	4.7	19.7	2.5	7.3	0.8	6.8	41	184	12	176	1347	152	192	182
38	0.5	2.2	0	1.8	4.3	24.3	3.4	21.7	4.1	9.3	0.5	7.8	7	216	22	193	11189	245	232	203
39	0.1	2.3	0	1.8	3.3	26	1.9	19.9	3.2	10.3	0.3	6.9	74	232	5	178	1626	132	252	184
40	0.2	1.4	0	2	4.1	15	0.6	19.1	5.5	4.5	0.7	6.5	59	134	6	170	2104	192	132	175
41	0.2	1.8	0	2.1	7.8	19.3	2.6	22.4	2.5	6.6	0.4	8.2	32	172	12	200	229	62	177	211
42	0	3.6	0.1	2	12.5	41.1	5.4	22.9	3.3	20.4	1.5	8.5	111	365	14	204	444	104	430	217
43	0.2	2.5	0.1	2.1	1	27.6	5.2	21.8	3.6	11.3	1	7.9	90	246	31	195	4	97	270	205
44	0.2	1.9	0	1.8	12.6	21.3	4.6	23.1	3.7	7.6	0.9	8.6	87	190	21	206	336	84	199	219
45	0.34	1.3	0	1.7	3.5	13.7	2.7	19.4	8.6	4	0.3	6.6	76	123	8	173	3578	114	119	178
46	0.3	1.9	0	1.8	4.3	20.4	0.4	17.9	2.8	7.2	0.8	5.9	50	182	12	160	580	449	189	162
47	0.1	1.7	0.1	0	2.5	18.7	3.6	19.9	5.6	6.3	2.3	6.9	47	167	29	178	2521	171	171	184

concentrations which are not to be exceeded at any time (Chapter 62-302). Except for iron in one sample, no metals were discharged from the wet detention pond above the standard for 1993 or 1994, however, stormwater entering the pond exceeded standards for copper (5%), lead (33%), zinc (69%) and iron (66%) in 1994; and for lead (21%) and iron (41%) in 1993. This demonstrates the positive effect that both configurations of the wet detention pond had on downstream biota.

The result for percent exceedences of standards measured discharging from the wet detention pond is markedly different from previous studies conducted by the District which used the old state water quality standards (Kehoe 1992, Rushton and Dye 1993, and Kehoe, Dye and Rushton 1994). Using the old criteria, the zinc standard was lower at a constant 30 ug/l than the present calculated standard using hardness as part of the formula. In contrast, the lead and copper standards were higher at a constant 30 ug/l than the new calculated standard. Using the older criteria none of the water quality samples at the inflow would have exceeded standards for lead or copper in 1993 and 1994 but a higher percentage of samples would have exceeded standards for zinc. The iron standard stayed the same under both rules at 1000 ug/l, however, iron at the inflow was measured at much higher levels in 1993 and 1994 than in 1990.

Nutrient Levels and Eutrophication

Although no numerical water quality standards have been set for nitrogen and phosphorus, these constituents are of concern since excessive levels cause algal problems in receiving waters. When compared to samples collected from 781 Florida lakes (Friedemann and Hand 1989), discharge water from the wet detention pond during all three years had average values reported for total nitrogen lower than 60 to 80 percent of the monitored lakes. In contrast, phosphorus concentrations measured at the outflow of the pond in this study during 1990 and 1993 were lower than only 20 percent of the values reported for the Florida lakes measured, while during 1994, using the Conservation Wet Detention design, phosphorous levels were lower than 55 percent of the Florida lakes.

Some limnologists have tried to determine realistic concentrations for nitrogen and phosphorus that should provide acceptable water quality. According to Sawyer and Vollenweider (In Hall 1988, Daniel *et al.* 1994) nuisance blooms of algae can be expected to grow when levels of inorganic nitrogen (ammonia, nitrate and nitrite) exceed 0.3 mg/l and inorganic phosphorus (primarily ortho-phosphorus) exceeds 0.01 mg/l. For this study these values (see Table 6) were exceeded for nitrogen in rainfall for 1990 (0.513 mg/l), 1993 (0.439mg/l), and 1994 (0.546 mg/l). Although the averages in rainfall and at the inflow were higher than desired, the averages at the outflow of the pond were well below the threshold level for eutrophication of 0.30 mg/l during all three years (1990=0.158, 1993=0.116 and 1994=0.097 mg/l). Phosphorus concentrations in the Tampa Bay region are more difficult to evaluate since the region is naturally enriched in phosphate, but concentrations of ortho-phosphorus at the outflow are decreased to near the target level of 0.01 mg/l with increasing residence time. Specifically, average concentrations for each year at the outflow were 1990=0.108, 1993=0.084 and 1994=0.027 mg/l. Another way to evaluate the data is to compare the levels recommended for healthy streams by the U.S. Environmental Protection Agency (1986). The EPA suggests that a limit below 0.1 mg/l for total P should be low enough to maintain a healthy diverse ecosystem in flowing waters. This target level was achieved at the outflow for the 14-day residence time design (1990=0.176, 1993=0.164 and 1994=0.053). Nitrogen has been identified as the limiting nutrient in local waters and dilution from the better quality water discharged from permitted wet detention ponds is a good management strategy, since it reduces unacceptable nutrient levels to acceptable levels before discharge to the receiving waters and ultimately Tampa Bay.

Major Ions

In most open lake systems located in the humid regions of the world, the principal anion is carbonate. For waters with a pH range between 7 and 9, carbon is present primarily as the bicarbonate ion. This is the situation for both the inflow waters and the water in the pond in this study (Table 10). Another measure of ion concentrations is total dissolved solids (TDS) which include salts and organic residue. Livingstone (1963) suggests that the world's rivers contain an average of 120 mg/l of TDS, however, a much wider range exists for lakes. For example, oligotrophic (low nutrient) lakes average about 1.7 mg/l while eutrophic (high nutrient) lakes contain over 185 mg/l. Total dissolved solids were measured much higher than these levels in this study (Table 10) indicating highly productive eutrophic conditions which cause high levels of ions and salts. Total dissolved solids are not much affected by wetland processes and cannot be effectively reduced (Kadlec and Knight 1996) and this was the condition measured in this study with a similar range of concentrations measured at the inflow and outflow. Rainfall had low levels of TDS. In fresh water TDS can be inferred from conductivity (specific conductance) and the results of these measurements are also shown in Table 10. Although Chromium is a metal and not a major ion, it is also reported in Table 10 with its calculated standard since the results were reported from the laboratory along with the ions. It was never a problem pollutant at this particular site.

The ionic composition of inland waters is dominated by four major cations, calcium (Ca), magnesium (Mg), sodium (Na), potassium (K); and three major anions, carbonate (CO_3), sulfate (SO_4), and chlorides (Cl) (Wetzel 1975 and others). This ionic salinity is governed by runoff from parent rock material, atmospheric precipitation and the balances between evaporation and precipitation. Over large regions of the temperate zone, calcium bicarbonate dominance prevails in open lake systems, a pattern which is also consistent with the average concentrations found in the world's rivers (Wetzel 1975).

Table 10. Carbonates, dissolved solids, conductivity and chromium concentrations for selected storm events from June 1994 through January 1995. The chromium standard is given for comparison.

1994 MDL=MIN.DETECTION LIMIT=			DISSOLVED SOLIDS TDS=1.0 mg/l			HYDROXIDE mg/l as CaCO3			BICARBONATES mg/l as CaCO3			CARBONATES mg/l as CaCO3			CONDUCTIV. CND=1.0		CHROMIUM CR=4.7 ug/l value		CHROMIUM CR=ug/l Standard	
STORM NO	DATE	SAMP NO	TDSR	TDSI	TDSO	HYDR	HYDI	HYDO	BICR	BICI	BICO	CARR	CARI	CARO	CNDI	CNDO	CRIN	CROU	CRIN	CROU
2	6-14-94	40,050,406	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
3	6-15-94	40,070,809	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
4	6-16-94	40,101,112	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
5	6-17-94	40,131,415	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
6	6-20-94	40,171,816	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
7	6-21-94	40,192,021	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
9	6-29-94	10,262,527	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
12	7-06-94	10,434,241	•	•	•	•	•	0	•	•	•	•	•	•	•	•	•	•	•	•
13	7-10-94	10,454,644	25		343	•	•	•	•	•	83	•	•	0	•	•	•	•	•	•
14	7-18-94	10,504,948	75	169	346	•	0	•	0	61	81	0	0	0	•	•	•	•	•	•
15	7-20-94	10,535,152	15	148	163	•	0	0	•	79	75	•	0	0	226	230	4.4	5.8	220	396
16	7-21-94	10,545,556	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
17	7-24-94	10,575,859	•	•	343	•	•	0	•	•	94	•	•	0	•	472	•	0.0	•	•
18	7-28-94	10,636,465	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
19	7-30-94	10,686,667	100	225	305	•	0	0	•	218	76	•	0	0	320	443	44.2	1.8	390	364
20	8-03-94	10,717,069	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
21	8-06-94	10,747,372	19	236	306	•	0	0	•	117	92	•	0	0	326	432	7.9	0.6	306	382
22	8-07-94	10,777,675	•	•	•	•	0	•	•	172	•	•	0		521		1.9		460	•
23	8-08-94	10,807,879	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
24	8-10-94	10,838,182	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
25	8-11-94	10,858,486	•	206	214	•	0	0	•	172	85	•	0	0	296	326	29.5	5.6	295	307
26	8-13-94	10,898,788	•	217	217	•	0	0	•	109	89	•	0	0	312	344	•	3.7	•	347
27	8-16-94	10,909,291	•	•	245	•	•	0	•	•	103	•	•	0	•	380	•	1.6	•	•
29	8-23-94	10,969,897	•	301	269	•	0	0	•	137	103	•	0	0	442	400	6.3	1.4	326	355
30	8-24-94	10,990,001	•	240	251	•	0	0	•	239	99	•	0	0	252	383	56.1	2.8	289	350
31	8-25-94	11,040,203	•	194	225	•	0	0	•	123	94	•	0	0	200	404	27.7	3.7	418	344
32	9-16-94	11,080,709	•	325	252	•	0	0	•	104	97	•	0	0	483	388	4.9	1.5	496	335
33	9-17-94	11,111,210	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
34	9-19-94	1116,dd,dd	•	189	205	•	0	0	•	93	91	•	0	0	294	311	22.0	2.3	287	289
35	9-25-94	11,242,325	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
36	9-27-94	1129,dd,dd	•	291	212	•	0	0	•	158	100	•	0	0	429	319	10.4	3.9	353	338
37	10-02-94	11,363,435	13	247	229	•	0	0	•	138	114	•	0	0	390	366	10.9	1.7	412	370
38	10-10-94	11,414,342	•	292	343	•	0	0	•	175	74	•	0	0	470	438	11.9	1.0	441	341
39	10-12-94	11,464,544	•	•	269	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
40	10-26-94	11,484,947	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
41	11-15-94	11,545,253	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
42	12-21-94	11,565,557	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
43	12-22-94	11,605,859	•	392	268	•	0	0	•	138	71	•	0	0	545	397	10.4	1.0	467	373
44	1-07-95	11,656,364	•	285	•	•	0	•	•	66	•	•	0	•	435	•	3.7	•	364	•
45	1-14-95	1173,dd,72	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
46	1-15-95	11,767,577	•	286	•	•	0	•	•	91	•	•	0	•	429	•	3.4	•	349	•

Distribution Patterns

The proportion of the major cations of surface waters of the world tend towards Calcium > Magnesium > Sodium > Potassium (Hutchinson 1975). This pattern was usually the same as measured in this study with average concentrations (mg/l) as follows (see Appendix K for all the data):

	1993	1994
	Ca > Mg > Na > K	Ca > Mg > Na > K
Inflow:	53 > 4.4 > 3.3 > 4.4	68 > 6.7 > 4.4 > 2.4
Outflow:	46 > 4.4 > 4.1 > 2.3	76 > 5.8 > 3.9 > 1.6

The averages for 1993 removed the data for storms 21 through 28 because of a leak from a potable water source. This different water quality input is clearly identified in Appendix K by the elevated concentrations of sodium, sulfur, magnesium, calcium, chlorides and the reduction of potassium.

The major anions are usually dominated by carbonates which appear mainly as bicarbonate > sulfate > Chloride. No carbonate data was collected for 1993, but in 1994 the wet detention pond appeared to follow the norm at the inflow and it is characterized as a bicarbonate water with average concentrations as follows:

	HCO_3 > SO_4 > Cl
Inflow:	132 > 90 > 6.8
Outflow:	90 > 126 > 3.9

For 1994, the data in Appendix K and L are graphed in figures 9 and 10 to determine patterns and processes which might be taking place. Figure 9 shows the flow-weighted concentrations for each storm and Figure 10 depicts the storms on a mass loading basis. Rainfall loads directly on the pond are also graphed, but are such an insignificant input that they are impossible to detect at this scale. Concentrations (Fig 9) demonstrate the wide fluctuations at the inflow and the much more constant values at the outflow. It appears that high concentrations of calcium and sulfate measured for the pond at the beginning of the study may be caused by construction activity which resulted in the release of constituents from the sediments since values are high at the beginning of the summer in July and August but show a lower concentration with time.

When mass loading, which relates concentrations to flows, are calculated the total mass is relatively constant between the inflow and outflow except for sulfates at the beginning of the summer (Fig 10). A useful property of some ions is their conservative nature which allows them to be used as tracers for estimating the infiltration of groundwater or indicate unmeasured inflow or outflow. The concentrations of magnesium, sodium, potassium and chlorides are relatively conserved and usually undergo only minor spatial and temporal

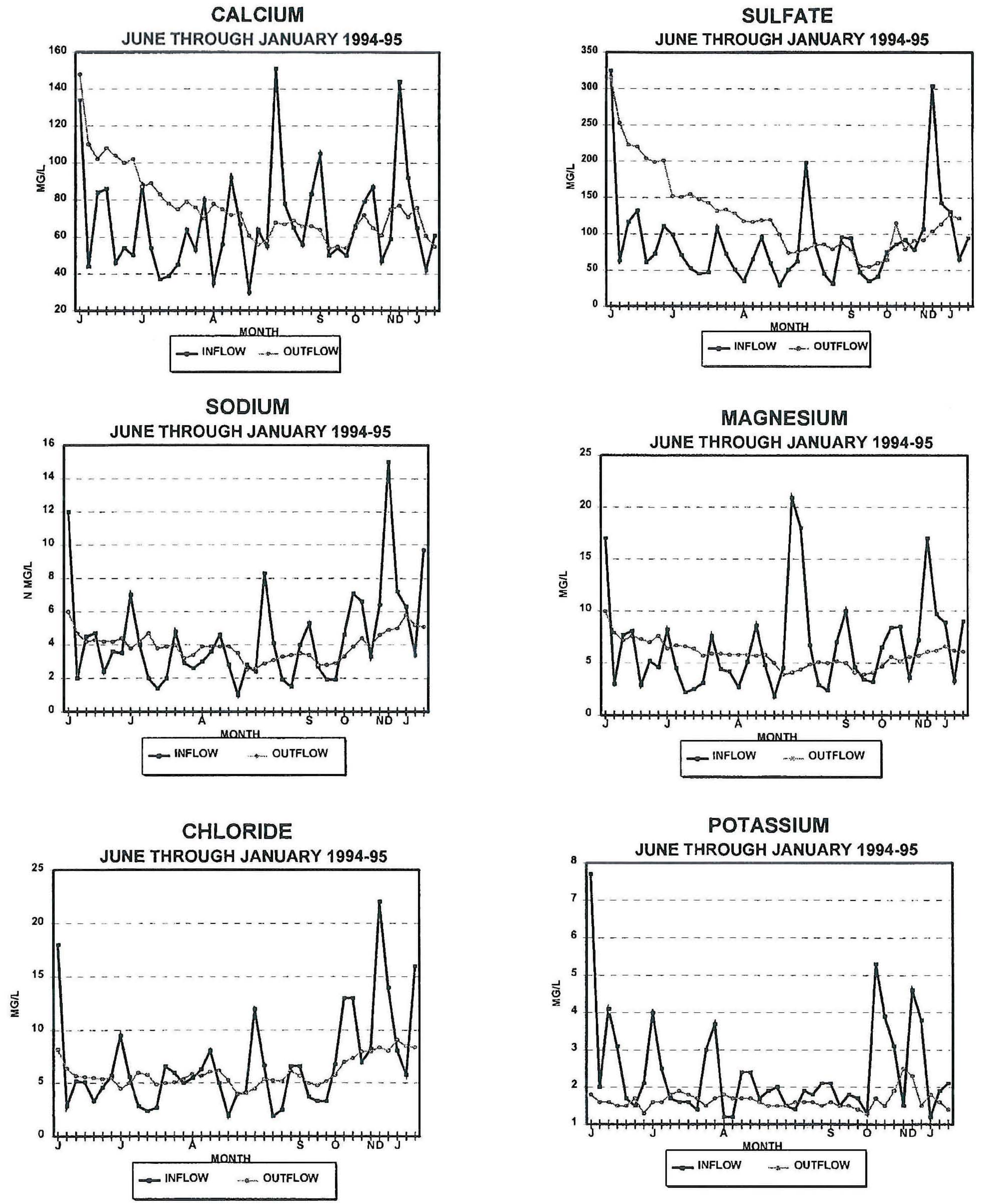


Figure 9. Comparison of flow-weighted concentrations for the major ions measured at the inflow and outflow for each storm event from June through January 1994-95.

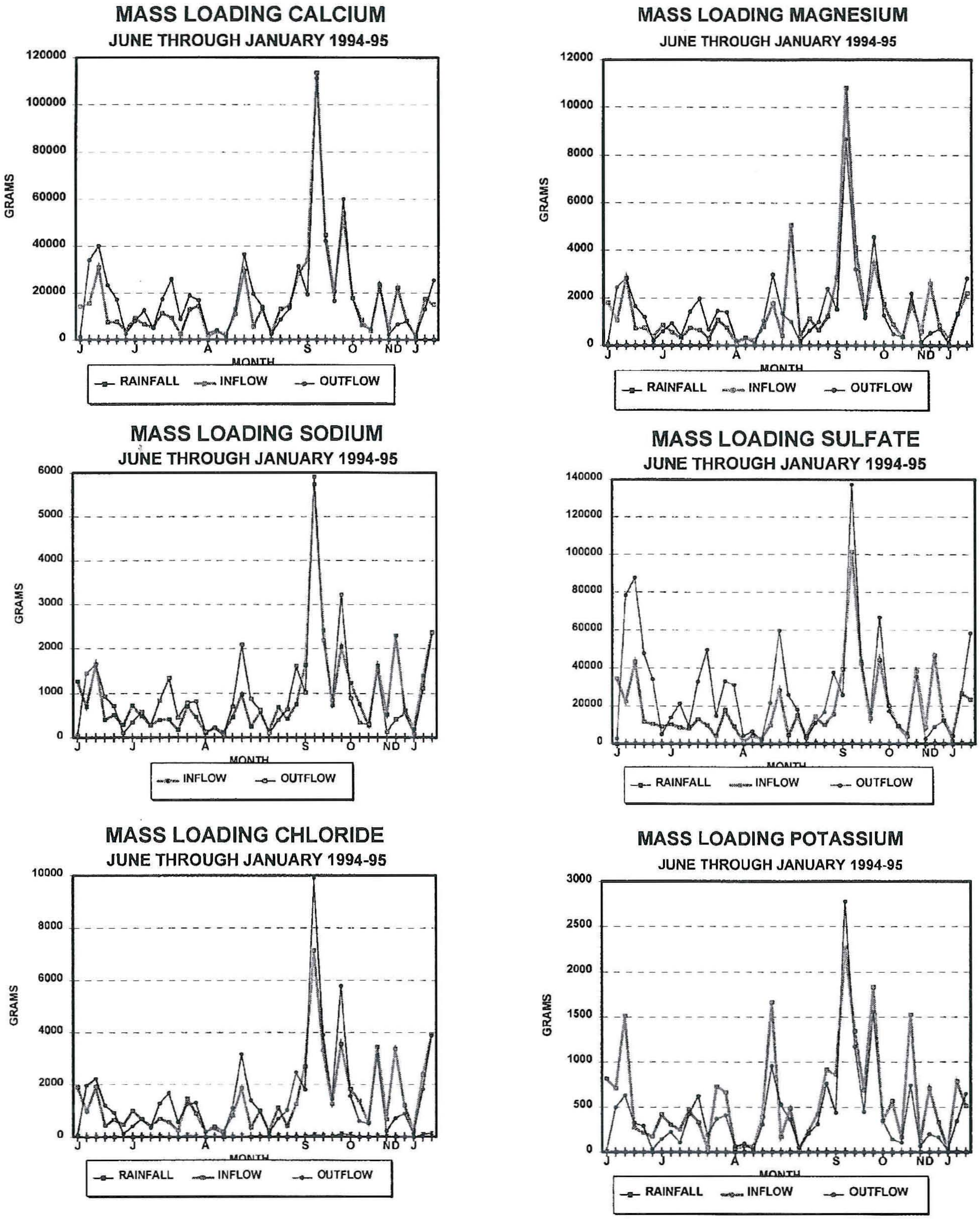


Figure 10. Comparison of mass loading for the major ions measured at the inflow, outflow, and in rainfall for each storm event from June through January 1994-95.

fluctuations (Wetzel 1975). Except for potassium, this pattern was observed in this study (Appendix L). For example when measured on a mass loading basis a variation of less than 15 percent was measured for magnesium, sodium and chloride. In contrast, potassium was reduced by about 30 percent and was apparently utilized by the rapidly colonizing plant community. These results indicate flow measurements are accurate to at least a precision of 15 percent and that groundwater inflow is not a major input to the system. A consistent discrepancy in the mass loading data for the first storm in December may indicate an error in measurement. Brief descriptions of processes affecting individual ion concentrations are discussed in the following sections.

Calcium (Ca)

Calcium and magnesium are the major ions causing water hardness. Florida hardwater lakes are calcium bicarbonate systems. These lakes (>20 mg Ca/l) undergo seasonal dynamics with lower calcium concentrations in summer as a result of the precipitation of calcium carbonate (Wetzel 1975). Calcium is biologically active providing nutrients for the biota, especially the shells of mollusks and bones of animals (Kadlec and Knight 1996). It is also important in the carbonate cycle where calcium is removed during photosynthesis along with carbon-dioxide and released during respiration in conjunction with carbonic acid. For systems in equilibrium the net effect is usually zero (Kadlec and Knight 1996). In addition calcium carbonate co-precipitates inorganic nutrients such as phosphorus and removes humic and other organic compounds by adsorption (Wetzel 1975). Calcium concentrations in inland waters range between 0.3 and 70 mg/l (Kadlec and Knight 1996). In this study the average concentrations of about 50 mg/l in 1993 and 72 mg/l in 1994 are at the high end of this range, probably explained by the unconsolidated sand laid down by high seas that once covered the area (Leighty *et al.*, 1958).

Certain algae have been correlated with differing concentrations of calcium and the relatively high levels of calcium in this system were thought responsible for the observed calcification of the alga *Chara* sp. observed in the pond during 1993. During this period calcium was reduced by 25 percent, while in 1994 with little *Chara* there was a net increase of 11 percent.

Magnesium (Mg)

Magnesium is much more soluble than calcium and rarely precipitates, as a result, the concentrations of magnesium are relatively conserved and fluctuate little (Wetzel 1975). Also since magnesium concentrations in surface water almost always exceed the requirements for plants and animals, wetlands can act as either a source or a sink. Inland surface waters have a magnesium concentration between 0.4 and 40 mg/l (Kadlec and Knight 1996). The yearly averages of 4.4 to 6.7 mg/l in this study fall near the low end of this range. Magnesium was reduced in the pond by 4 percent in 1993 and 15 percent in 1994.

Sodium (Na)

The monovalent cations sodium and potassium are involved primarily in ion transport and exchange (Wetzel 1975). Although they are functionally analogous in some of their properties, sodium is usually more important for the growth of marine organisms (Kadlec and Knight 1996). A threshold level of 4 mg Na/l is required for near optimal growth of several species, a concentration that is about the mean for numerous hard-water lakes (Wetzel 1975). The yearly averages for this study ranged from 3.3 to 4.4 mg/l which is close to the threshold level. Because most freshwater wetland species have low sodium requirements, sodium concentrations can be used as a conservative tracer for tracking groundwater discharges into wetlands. Concentration reductions of less than 11 percent and mass reductions of less than 7 percent in this study indicate very little groundwater influence.

Potassium (K)

Of the ions that are usually conserved (i.e., showing little change from the inflow to the outflow) potassium was the one exception with a reduction on a mass loading basis of 33 percent in 1993 and 27 percent in 1994. Potassium concentrations in surface waters typically range between 0.2 and 33 mg/l with an average for world rivers of about 3.4 mg/l (Kadlec and Knight 1996). This average is slightly above the 1.6 to 4.4 range found in this study.

One explanation for the reduction of potassium in the pond might be the rapid colonization of plants immediately after construction each year. Potassium ions are assimilated rapidly by plants but become available for re-solution when the plants mature and die, or when leaves and other parts are shed during the growing season (Hem 1985). Values may stabilize in future years after the pond reaches equilibrium. Also measurements in this study were made primarily during the growing season, before any massive die backs caused by freezing temperatures could have released potassium back to the water column.

Sulfate (SO_4)

The greatest difference between years as well as increases between the inflow and outflow occurred with the concentration of sulfates. The average concentration of sulfate increased from an average of 32 to 52 mg/l in 1993, to over twice that amount, an average of 90 to 126 mg/l in 1994. Also the concentrations were considerably higher than the 5 to 30 mg/l range reported as normal (Wetzel 1975). One probable source of sulfate is the sedimentary substrate which was disturbed when the pond was constructed. Often high-sulfate waters reflect the presence of old marine sediments and this is especially true when present as calcium sulfate (Cole 1979). Since both calcium and sulfate exhibit steadily declining concentrations during the first two months after construction in 1994 (Figure 9) this is a logical explanation.

Another source might be explained by the high concentrations of iron measured entering the pond at the inflow compared to the iron leaving the pond (see Table 6). This suggests the possibility of a chemical reaction producing sulfuric acid in the water column and the precipitation of ferric hydroxide. For 1994 this reaction would help explain the following differences in concentrations between the inflow and outflow: 1) Concentrations for iron were reduced 93 percent, 2) average sulfate concentrations increased 50 percent, and 3) as will be discussed later median pH at the inflow was 8.01 compared to 7.19 at the outflow.

Chloride (Cl)

Chloride ions do not enter into any significant oxidation/reduction reactions, form no important solute complexes at normal concentrations, produce few salts of low solubility, are not significantly adsorbed on mineral surfaces and play few vital biogeochemical roles (Hem 1985). The circulation of chloride ions in the hydrologic cycle are through physical processes, therefore the total mass of chloride is relatively constant, a characteristic that makes them the best ion to use as a tracer provided no significant atmospheric input from oceans or salt lakes. Since chlorides are a conservative ion they can be used to analyze some of the processes taking place in the pond (Figure 11).

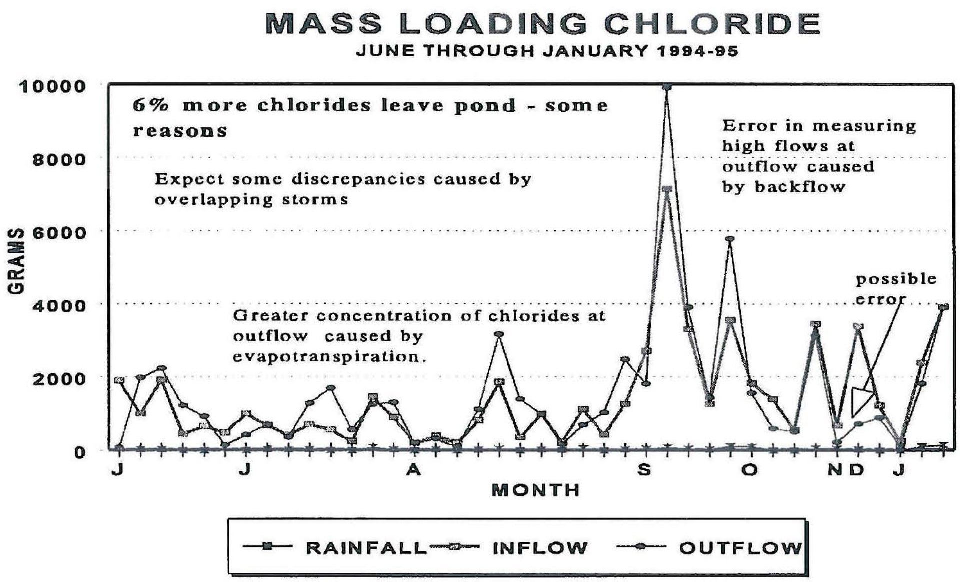


Figure 11. Comparison of chloride loads for each storm event from June through January 1994-5.

Although the study site is within 10 miles of salt water, it did not affect concentrations. Rainfall close to the ocean contains from 1 to 20 mg/l of chloride, but the concentration decreases rapidly as storms move over land. In the United States concentrations in rain are a few tenths of a milligram per liter (Junge and Werby 1958). In this study chloride in rainfall ranged from 0 to 4.0 mg/l indicating influence from the Gulf of Mexico during some storms. This small amount would explain about 2 percent of the input of chlorides to the wet-detention pond on a mass loading basis. About 6 percent more chlorides were measured leaving the wet-detention pond than entering at the inflow and in rainfall. And about 16 percent less water was measured leaving the pond. This mass balance suggests measurements for flow were fairly accurate and very little subsurface water entered the pond.

Field Parameters

Measurements of dissolved oxygen (DO), pH, temperature, oxidation reduction potential (ORP) and conductivity fluctuate on a daily cycle and are perturbed by rainfall events. These parameters were measured in this study using instruments that recorded data at two hour intervals for a week at a time. For comparison, data were collected in the wet detention pond near the inflow weir (INFLOW), in the permanent pool (MIDPOND) and immediately before water was discharged at the outflow (OUTFLOW). In the following section, an example of daily fluctuations as well as storm effects on field parameters is presented first and then individual parameters and differences between years are discussed. Graphs of all the actual measurements are shown in Appendix M.

Daily Fluctuations

The measurements for one week in September of 1994 demonstrates typical responses of field parameters to daily cycles and rainfall (Figure 12). Measurements responded to diurnal patterns by tracking the daily progress of light, temperature, respiration and related processes. In general, temperature, pH, dissolved oxygen and conductivity are similar at both the inflow station and the midpond station indicating relatively well mixed conditions in the permanent pool. During quiescent periods, before the rains began on September 24th, temperatures were measured much lower at the outflow station which is attributed to water flowing across 45 feet of littoral shelf. Dissolved oxygen is depleted and hydrogen ions increased (pH decreased) after flowing through the vegetation to the outfall station. The pH demonstrated less fluctuation at the outflow until influenced by stormwater, the former pattern is typical of areas with dense vegetation (Kadlec and Knight 1996). The data indicate two entirely different conditions in the pond which may have improved pollution removal by using both aerobic and anaerobic processes and different pH regimes. All three stations demonstrated large diurnal fluctuations for dissolved oxygen which is commonly associated with increased biological activity indicative of productive (eutrophic) systems. Some of the increased fluctuation can be attributed to the greater consumption of carbon dioxide and release of oxygen by algae.

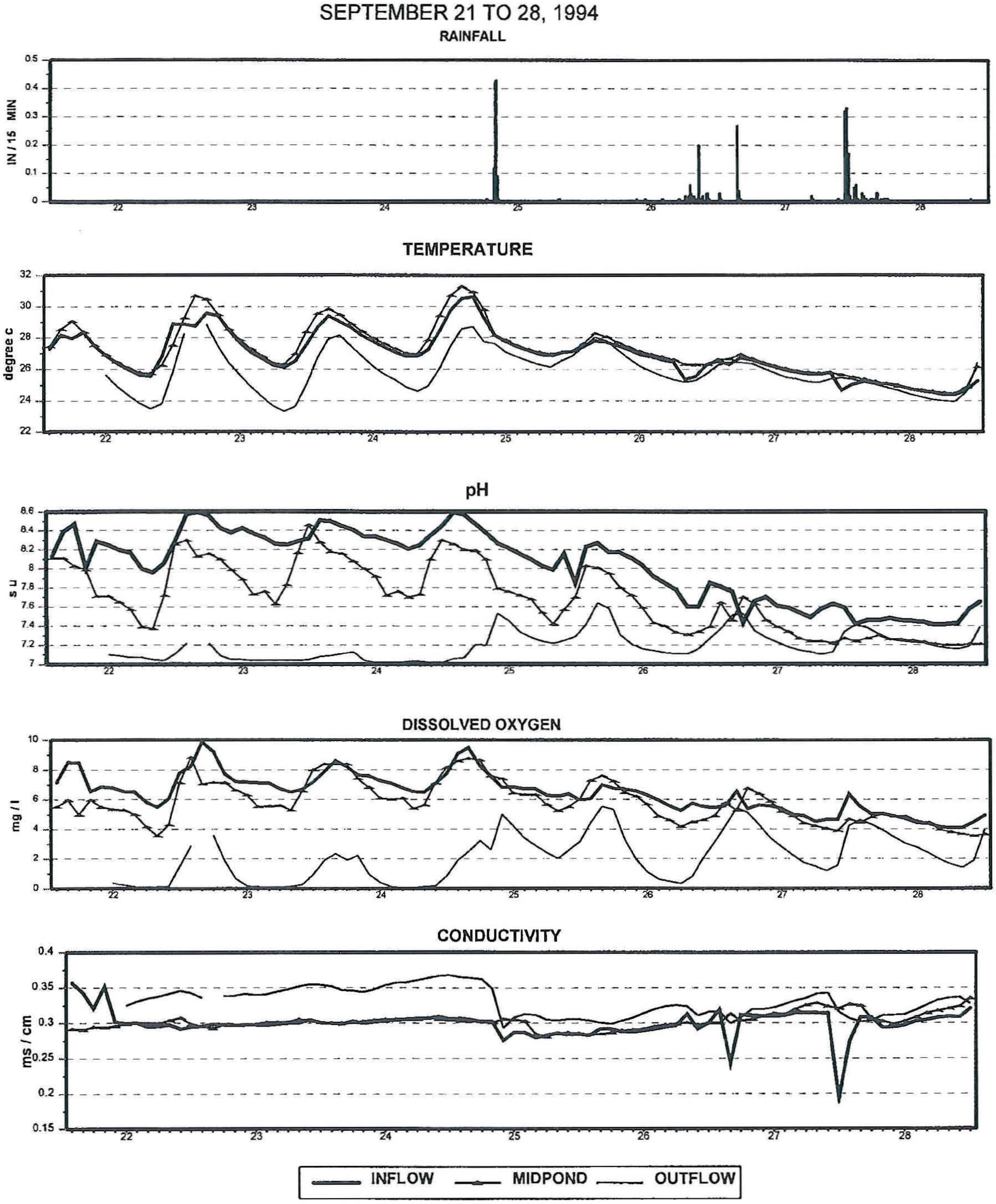


Figure 12. *In situ* measurements recorded for one week in September 1994 demonstrated typical responses to daily cycles and rainfall. Readings were made at two-hour intervals in the wet detention pond near the inflow, in the deep pool and at the outflow. See Appendix M for additional data.

Rainfall Effects

Rainfall decreased temperature and conductivity for all stations. In fact a sharp drop in conductivity is often seen during rain events, this pattern is especially apparent at the inflow station where the dilution by low conductivity rainfall is most obvious. During dry periods, the metabolism of the biota and evapotranspiration gradually raise conductivity levels. Rainfall decreased both pH and dissolved oxygen at the inflow and in the permanent pool where levels were higher; while rain events increased pH and DO at the outflow, presumably the effect of the stormwater passing through the system.

To look at individual parameters, the data for each week were summarized in Table 11 for all of the data presented in Appendix M. The averaged data compares the differences between stations and between years.

Temperature

In summer, temperatures at the outflow are two to four degrees centigrade cooler than in the pond or at the inflow but winter values appear to be higher demonstrating the moderating influence of vegetated wetlands on climate. Differences between years are caused by the fact that fewer measurements were taken during the winter in 1994.

pH

Wetland water chemistry and biology are affected by pH. For example, denitrifiers operate best in the range $6.5 < pH < 7.5$, while nitrifiers prefer $pH > 7.2$ (Kadlec and Knight 1996). This target range for denitrification was never met at the inflow or in the pond during this study, but average values between 7.0 and 7.5 were usually measured at the outflow. This indicates that most of the loss of nitrates in the system occurred on the littoral shelf. The pH values tended to be lower at the outfall station by about 0.5 pH unit (Table 11).

One strategy for improving stormwater systems may be designs which include a series of conditions featuring different pH and DO levels. Some factors to consider are those which change the concentration of dissolved carbon dioxide which affects pH. These include biological activities caused by photosynthesis and respiration, as well as physical phenomena produced by turbulence and mixing. Planted littoral zones in the flow path can accomplish the former while open water expanses with favorable wind fetches enhance the latter. These conditions were a part of the stormwater pond in this study. Chemical reactions in the pond also reduce pollutants. For example, the precipitation of iron hydroxide and the production of sulfuric acid, as mentioned earlier, may have accounted for the reduction in pH at the outflow. Other precipitation reactions which are pH dependent include aluminum phosphate ($pH = 6.3$) and iron phosphate ($pH = 5.3$) (Kadlec and Knight 1996).

Table 11. Hydrolab data. Measurements were taken at two hour intervals and the data averaged for the designated period.
Units = Degree C for Temperature, Standard units for pH, ms/cm for conductivity, mg/l for dissolved oxygen, volts for oxidation reduction potential.

1993		INFLOW					OUTFLOW					MID-POND				
START	STOP	TEMP	pH	COND	DO	ORP	TEMP	pH	COND	DO	ORP	TEMP	pH	COND	DO	ORP
30-Jul-93	06-Aug-93	32.24	7.97	0.355	8.02	0.280	28.01	6.78	0.392	1.83	0.38	•	•	•	•	•
06-Aug-93	13-Aug-93	32.20	8.06	0.375	7.20	0.307	27.64	7.90	0.379	3.96	0.32	•	•	•	•	•
27-Aug-93	03-Sep-93	27.89	7.70	0.303	5.38	0.410	27.50	7.16	0.320	3.99	0.37	•	•	•	•	•
10-Sep-93	17-Sep-93	28.98	7.73	0.291	6.24	0.413	•	•	•	•	•	•	•	•	•	•
17-Sep-93	24-Sep-93	30.02	8.09	0.261	10.74	0.376	28.45	6.75	0.308	3.34	0.39	29.75	8.17	0.24	12.10	0.22
25-Sep-93	01-Oct-93	28.42	8.46	0.243	7.94	0.342	26.37	7.81	0.282	3.24	0.43	28.02	8.86	0.19	12.73	0.24
08-Oct-93	15-Oct-93	26.42	8.21	0.311	7.51	0.326	24.19	7.27	0.289	2.81	0.44	•	•	•	•	•
22-Oct-93	29-Oct-93	25.99	8.13	0.330	9.98	0.290	23.63	7.29	0.400	2.48	0.40	•	•	•	•	•
19-Nov-93	29-Nov-93	21.48	8.52	0.320	10.36	0.290	•	•	•	•	•	•	•	•	•	•
15-Jan-94	21-Jan-94	15.49	8.04	0.426	10.62	0.309	•	•	•	•	•	15.22	8.12	0.39	8.39	0.26
21-Jan-94	28-Jan-94	17.47	8.60	0.455	13.93	0.326	18.40	•	•	3.30	0.46	•	•	•	•	•
AVERAGE		**26.05**	**8.14**	**0.33**	**8.90**	**0.33**	**25.52**	**7.28**	**0.34**	**3.12**	**0.40**	**24.33**	**8.38**	**0.27**	**11.07**	**0.24**
STD.DEV.		**5.36**	**0.28**	**0.06**	**2.35**	**0.04**	**3.16**	**0.42**	**0.05**	**0.68**	**0.04**	**6.48**	**0.34**	**0.08**	**1.91**	**0.02**
MAXIMUM		**32.24**	**8.60**	**0.46**	**13.93**	**0.41**	**28.45**	**7.90**	**0.40**	**3.99**	**0.46**	**29.75**	**8.86**	**0.39**	**12.73**	**0.26**
MINIMUM		**15.49**	**7.70**	**0.24**	**5.38**	**0.28**	**18.40**	**6.75**	**0.28**	**1.83**	**0.32**	**15.22**	**8.12**	**0.19**	**8.39**	**0.22**
MEDIAN		**25.99**	**8.21**	**0.33**	**9.98**	**0.33**	**24.19**	**7.29**	**0.31**	**3.12**	**0.43**	**24.33**	**8.38**	**0.27**	**11.07**	**0.24**
NO.OBS.		**11**	**11**	**11**	**11**	**11**	**8**	**7**	**7**	**8**	**8**	**3**	**3**	**3**	**3**	**3**

1994		INFLOW					OUTFLOW					MID-POND				
START	STOP	TEMP	pH	COND	DO	ORP	TEMP	pH	COND	DO	ORP	TEMP	pH	COND	DO	ORP
05-Jun-94	10-Jun-94	28.93	8.32	0.790	8.55	0.20	28.89	8.26	0.81	8.18	0.22	•	•	•	•	•
15-Jul-94	22-Jul-94	31.01	8.06	0.470	7.74	0.24	28.40	7.19	0.50	2.74	0.37	31.06	7.88	0.47	7.64	0.27
29-Jul-94	5-Aug-94	30.16	7.96	0.420	7.32	0.28	28.80	7.29	0.45	3.03	0.41	•	•	•	•	•
11-Aug-94	18-Aug-94	27.91	7.85	0.340	6.06	0.30	•	•	•	•	•	27.96	7.66	0.34	5.54	0.36
23-Aug-94	31-Aug-94	29.39	7.99	0.360	6.58	0.34	28.60	7.11	0.35	1.71	0.44	29.33	7.70	0.36	5.86	0.39
03-Sep-94	14-Sep-94	30.02	8.07	0.390	6.97	0.37	27.10	7.06	0.42	1.24	0.48	30.03	7.74	0.39	6.57	0.40
21-Sep-94	28-Sep-94	26.96	8.03	0.300	6.44	0.31	25.87	7.19	0.33	2.09	0.45	27.22	7.70	0.30	5.81	0.40
03-Oct-94	10-Oct-94	•	•	•	•	•	25.94	7.07	0.40	1.63	0.45	28.39	7.92	0.36	6.79	0.40
14-Dec-94	21-Dec-94	19.93	7.96	0.358	13.81	0.29	19.93	8.10	0.36	8.78	0.33	19.93	8.10	0.36	8.71	0.33
AVERAGE		**28.04**	**8.03**	**0.43**	**7.93**	**0.29**	**26.69**	**7.41**	**0.45**	**3.67**	**0.39**	**27.70**	**7.81**	**0.37**	**6.70**	**0.36**
STD.DEV.		**3.29**	**0.13**	**0.14**	**2.34**	**0.05**	**2.81**	**0.45**	**0.14**	**2.83**	**0.08**	**3.39**	**0.15**	**0.05**	**1.06**	**0.05**
MAXIMUM		**31.01**	**8.32**	**0.79**	**13.81**	**0.37**	**28.89**	**8.26**	**0.81**	**8.78**	**0.48**	**31.06**	**8.10**	**0.47**	**8.71**	**0.40**
MINIMUM		**19.93**	**7.85**	**0.3**	**6.06**	**0.20**	**19.93**	**7.06**	**0.33**	**1.24**	**0.22**	**19.93**	**7.66**	**0.30**	**5.54**	**0.27**
MEDIAN		**29.16**	**8.01**	**0.38**	**7.15**	**0.30**	**27.75**	**7.19**	**0.41**	**2.41**	**0.42**	**28.39**	**7.74**	**0.36**	**6.57**	**0.39**
NO.OBS.		**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**7**	**7**	**7**	**7**	**7**

Conductivity (Specific Conductance)

Conductivity levels were fairly consistent for all stations with readings generally between 0.3 and 0.4 ms/cm for 1993 and 0.4 and 0.5 ms/cm in 1995. Specific conductants of most natural inland surface waters range between 0.10 and 0.30 ms/cm. Above average conductivity in the pond and especially in the water table wells were also reported during previous studies at the site (Rushton and Dye 1993, Kehoe 1992) Explanations for higher levels include the fact that the substrate for the drainage basin is spoil material from constructing the adjacent canals in calcareous soils. Also a lime rock parking facility in the drainage basin increased alkalinity. Other conditions which affected the variations in conductivity was the dilution of pond water brought about by rainfall and the concentration effects of evapotranspiration between rain events. As noted in the graphs in Appendix M, a sharp drop in conductivity especially at the inflow occurs in response to rainfall.

Dissolved Oxygen (DO)

Dissolved oxygen can range from zero to more than twice the theoretical solubility in response to ecosystem variables. Wetland surface waters typically have a vertical gradient in DO, with high DO water near the surface and anoxic conditions at the sediment water interface (Kadlec and Knight 1966). Measurements in this study were taken about four inches above the sediment surface. A state standard of 5 mg/l has been set as the lowest level compatible with a healthy ecosystem. Considerable differences were seen between the permanent pool and the outflow. For example, the inflow and permanent pool measurements always met state standards, but water after flowing through the vegetated littoral zone almost never recorded readings above the 5 mg/l target level (Appendix M and Table 11). Low levels of dissolved oxygen are not unusual for vegetated wetlands where the decomposition of decaying plants and microorganisms consume oxygen.

Dissolved oxygen exhibited widely different concentrations in the pond between years caused by the differences in vegetation. Thick emergent vegetation can reduce dissolved oxygen as discussed above while heavy infestations of submerged vegetation can raise DO to high levels during the day caused by the photosynthesizing vegetation. Open water over the submerged vegetation is required for supersaturated condition since dense emergent vegetation blocks the light necessary for algae respiration (Kadlec and Knight 1966). The differences between the three vegetation regimes are exemplified in a comparison of dissolved oxygen concentrations recorded during September of each year (Figure 13). In 1990, the pond was shallow (< 1 foot deep) and was completely covered in cattails resulting in low dissolved oxygen levels (rarely measured above 5 mg/l). In 1993, the pond had a bloom of the submerged macroalga, *Chara* sp, which occupied almost the entire volume of the permanent pool resulting in the pond being supersaturated with oxygen. In 1994, the pond had a deep (about 5 feet) open water permanent pool and a well-established littoral zone and more normal DO conditions were measured.

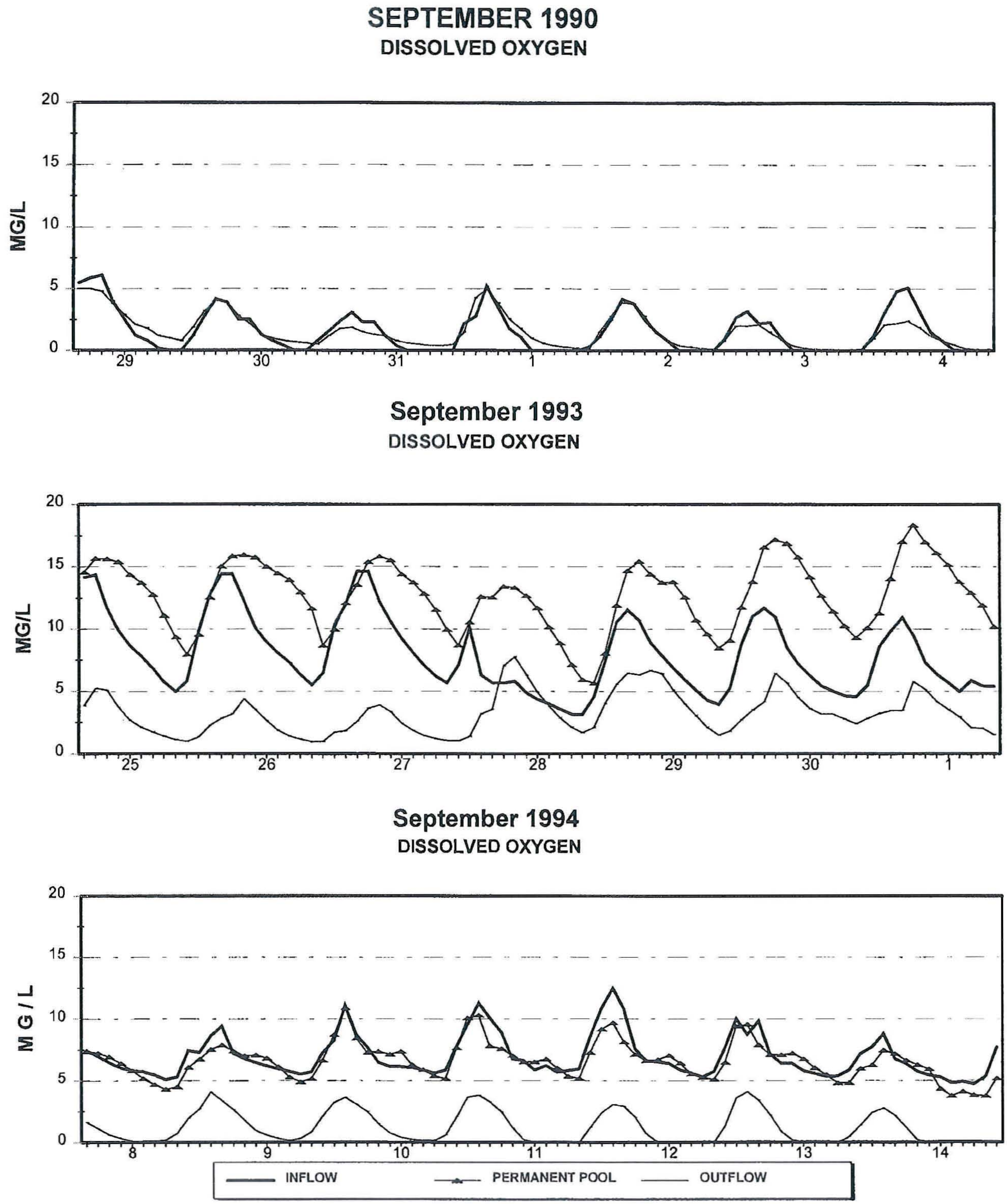


Figure 13. Comparison of dissolved oxygen measured for one week in September for each year. In 1990, the pond was less than one foot deep and covered 100% with emergent vegetation. In 1993, the pond was 2 to 5 feet deep and colonized by the submerged alga, *Chara* sp. In 1994, the pond was 5 feet deep with an open water pool and a planted littoral zone concentrated at the outflow.

Oxidation Reduction Potential (ORP)

Redox is a measure of the oxidation potential in the water or sediments. ORP measurements in natural waters show little change as long as the water contains some oxygen, enabling redox potential to remain fairly high and positive (0.3 to 0.5 volts). This was usually the condition measured in this study with average values between 0.29 and 0.40 volts. Of special interest is the fact that although low dissolved oxygen levels were measured at the outflow, the redox potential was usually measured the highest at that location with an average for both years of 0.40 volts and a range between 0.22 and 0.48 volts. When ORP falls below about 0.22 the metabolic demand of organisms use oxygen from other ions as the terminal electron acceptor in a predictable pattern (nitrate, manganese, iron, sulfate, and carbon dioxide) which leads to metal enrichment in the water column by complexing and adsorption to the acid molecule. The fact that reduced conditions were not measured near the bottom of the pond probably means an all important oxidated zone was maintained at the sediment surface which improved the pond's performance for pollution removal. Processes such as temperature, organic matter and pH also influence the rate of the redox reaction. Oxygen pumped to the root zone by vegetation also creates oxidized microsites for use by the plants and other biota. For example, Armstrong (1967) measured the oxygen flux across the roots of swamp plants and found that it is sufficient to meet the oxygen requirements of root cells, to oxidize the rhizosphere, and to ward off the entry of reduced substances.

Discrete Sampling Events

To determine some of the processes taking place, three individual storm events were evaluated using up to 24 discrete samples. Each data point for constituent concentrations included flow-weighted samples composited together to represent different stages across the hydrograph, i.e., rising limb, top, falling limb early, falling limb late and the tail (Figure 14).

First Flush Effects - The initial portion of runoff during a storm event is frequently referred to as the "first flush". Some studies have shown that pollutants are most concentrated early in the runoff process or during the rising limb of the hydrograph; as rainfall continues, the surface pollutant accumulation is depleted and pollutants are diluted (Cullum 1984, Hoffman *et.al.,* 1982, Miller 1979, Stahre and Urbonas 1990). In contrast, other studies have not found an identifiable first flush effect (DRCG 1983,USEPA 1983). In our previous studies, we have found the "first-flush" effect was most consistent for phosphorus and least consistent for nitrogen (Rushton and Dye 1993, Carr and Rushton 1995). Also "first flush" patterns depended on constituent concentrations, especially total suspended solid (TSS) which had to be greater than the 10 to 20 mg/l usually measured. In this present study with TSS always measured above 200 mg/l at the beginning of the three storms sampled, almost all constituents demonstrated a reduction across the hydrograph or at least a large reduction after the peak of the storm had passed (Figures 15 and 16). However, there were considerable differences between storms. For the 9-27-94 storm (#36) the initial peak arrived so rapidly that no samples were taken on the rising limb and the concentrations of most samples were the highest

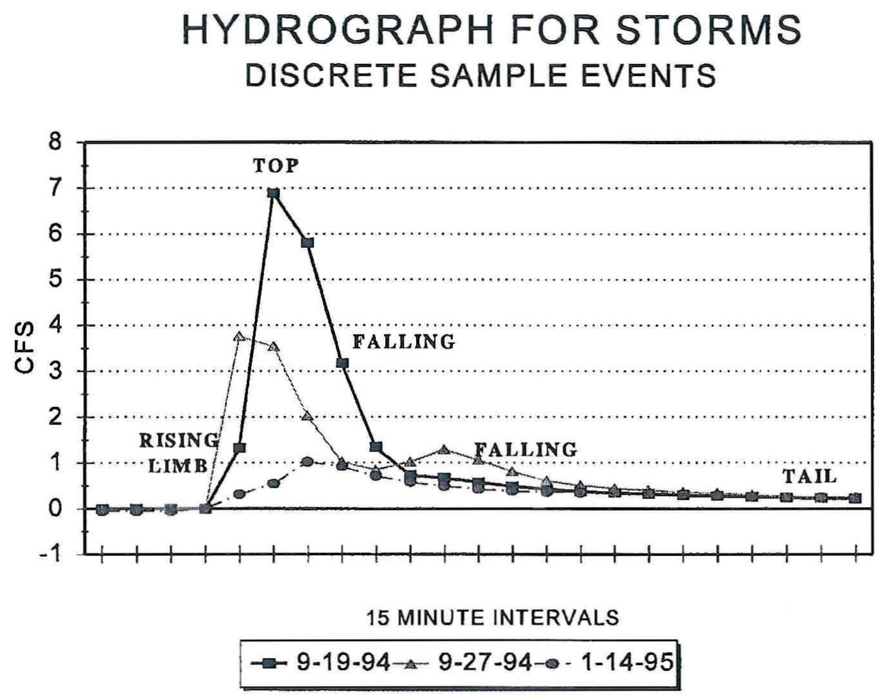


Figure 14. Individual hydrographs for the three storm events evaluated for changes in constituent concentrations indicate the different shapes depending on rainfall characteristics. Also the approximate points between which samples were composited together on a flow-weighted basis are indicated. Rainfall amounts for 9-19-94 (storm # 34) was 1.66 inches, for 9-27-94 (storm # 36) was 1.27 inches and for 1-14-95 (storm # 45) was 1.02 inches.

measured. The largest storm sampled was on 9-19-94 (#34) which usually showed the greatest concentrations at the top of the hydrograph especially for zinc and ortho phosphorus. The 1-14-95 storm (#45) begins the initial flush of a much larger winter storm system (see Figure 7) and demonstrates the least "first flush" effect.

Most constituents follow a similar pattern to that exhibited by total suspended solids, especially when TSS is measured at high concentrations such as the 9-27-94 storm with initial concentrations of 1805 mg/l. Since many pollutants are associated with TSS and large particle suspended solids are removed by sedimentation, these results support the contention that sedimentation is a major mechanism for pollution removal. The exception to the removal of constituents is water hardness which demonstrates an entirely different pattern. Since water hardness is the sum of major ion concentrations, a further analysis of ions, especially those that are conserved, provides some additional insight into patterns of removal.

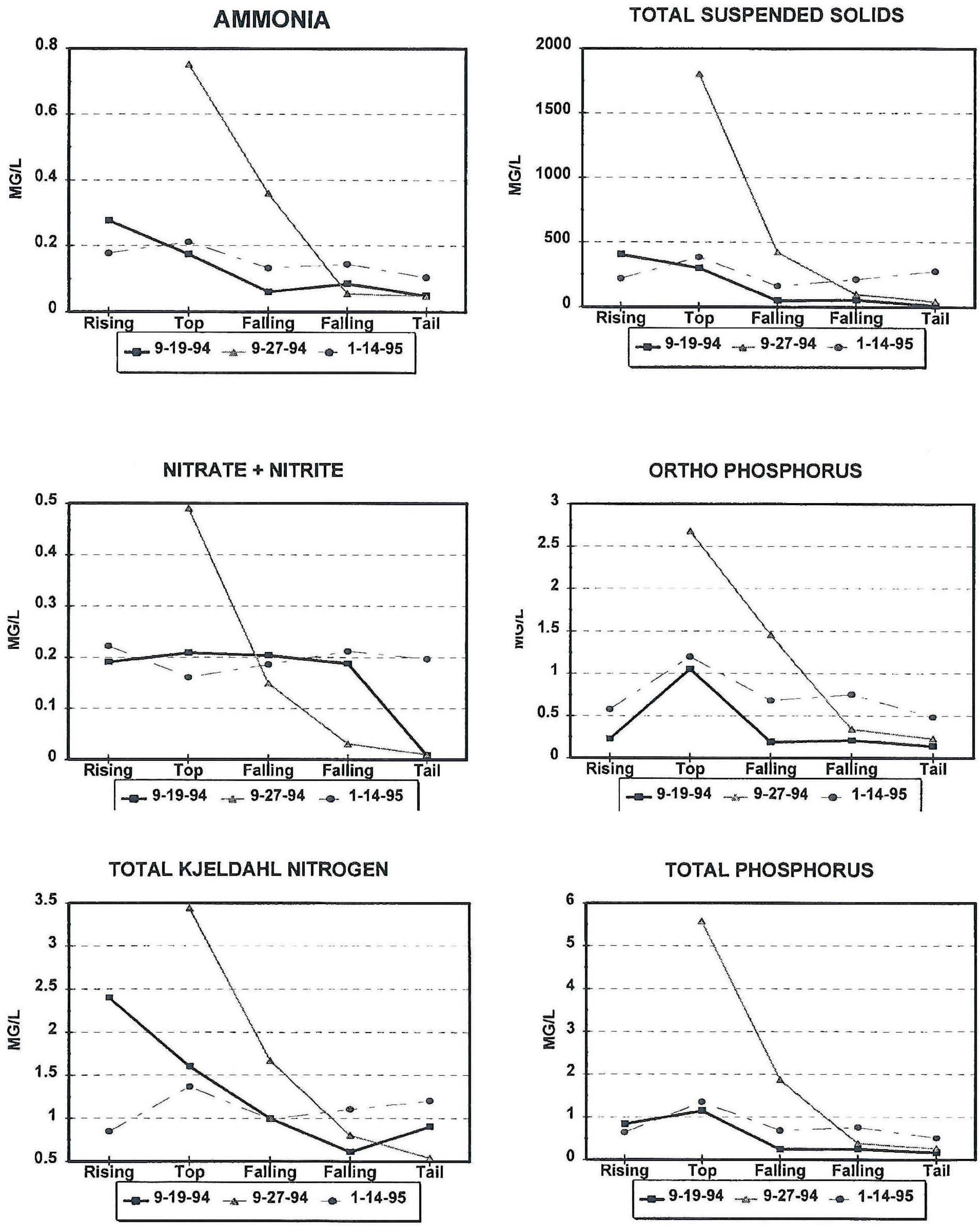


Figure 15. Concentrations of nutrients and total suspended solids measured at the inflow during different stages of the hydrograph for three rain events.

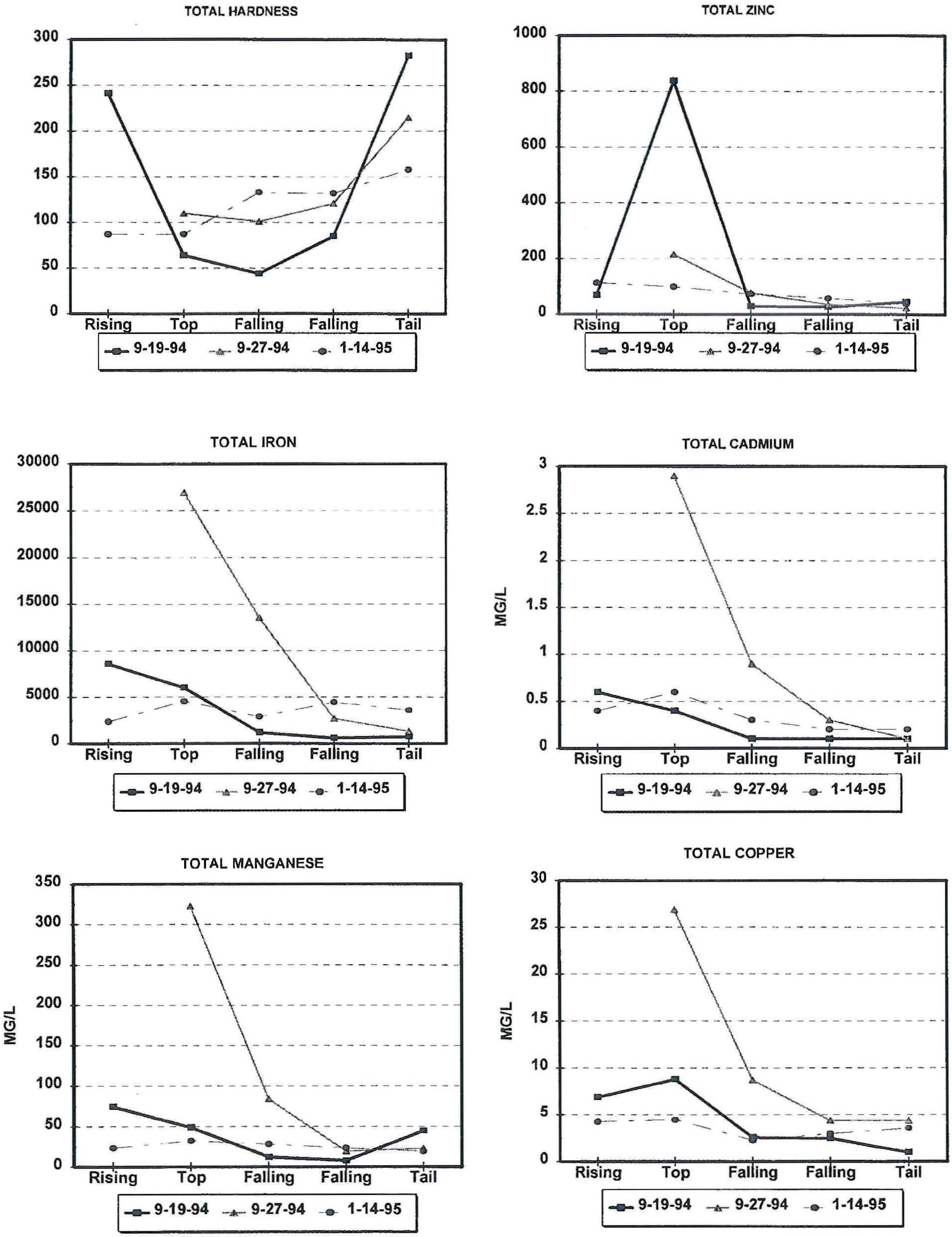


Figure 16. Concentrations of metals and total hardness measured at the inflow during different stages of the hydrograph for three rain events.

Ion Balance

As was discussed in the Major Ion Section, some ions are useful as tracers for determining the proportion of different types of waters present in solution. Sodium, chloride and magnesium were shown to be the best tracers in this study. When one compares the concentrations of these ions over the hydrograph (Figure 17), the influence of rainfall which has much lower concentrations of ions than surface water is seen. The ion concentration demonstrate almost a mirror image of the hydrograph with high flows exhibiting low concentrations and low flows, high concentrations. This is not to infer that the pollutants transported with storm flow are not dominant, but it indicates there is also a dilution effect to be considered, and it helps explain why the largest storm with the greatest intensity did not have the greatest concentration of pollutants. The comparison of ions also demonstrates that for some storms the standing water on the pad in front of the inflow weir, which had high ion concentrations, is often a major component of the samples collected on the rising limb.

Sediments

Sediment cores were collected once during each year of the study. Soils were analyzed for priority organic pollutants during all three years and for particle size, organic matter, nutrients and metals in October of 1993 and January of 1995. Cores to analyze priority pollutants were collected one to two inch deep while most of the other cores represent both the surface layer (1" to 2") and a deeper segment (4" to 5"). Results are discussed with respect to spatial relationship and in comparison to constituent concentrations in the overlying water column. They are also assessed against levels considered toxic or possibly toxic to organisms. See Figure 3 for the soil core sampling locations during 1993 and 1995.

Particle Size Analysis

The soils at the site consist of overburden material dredged up and deposited from construction of the Tampa Bypass Canal in 1981. The drainage basin was originally contoured and the first pond constructed in 1985. By 1993, differential settling was evident with the sandier soils (greater than 90% sand size particles) measured where only shallow excavations had been made such as the swale (site 1) and site 7 (Tables 12 and 13). The more deeply excavated portions of the pond consists of a greater percentage of clay (17 to 24%). This describes what is expected from the soil type in the area which was originally manatee fine sandy loam, consisting of a thin layer of loamy sand over alkaline clay materials and marl (Leighty *et al.*, 1958). Soils were well mixed during construction of the new ponds (in 1993 and again in 1994) resulting in no clear pattern between the top layer and that found 4 inches deeper, in fact particle size often measures about the same at each depth. Patches of clay were sometimes found mixed with the sandy soils explaining the discrepancies seen at site 2 and 6.

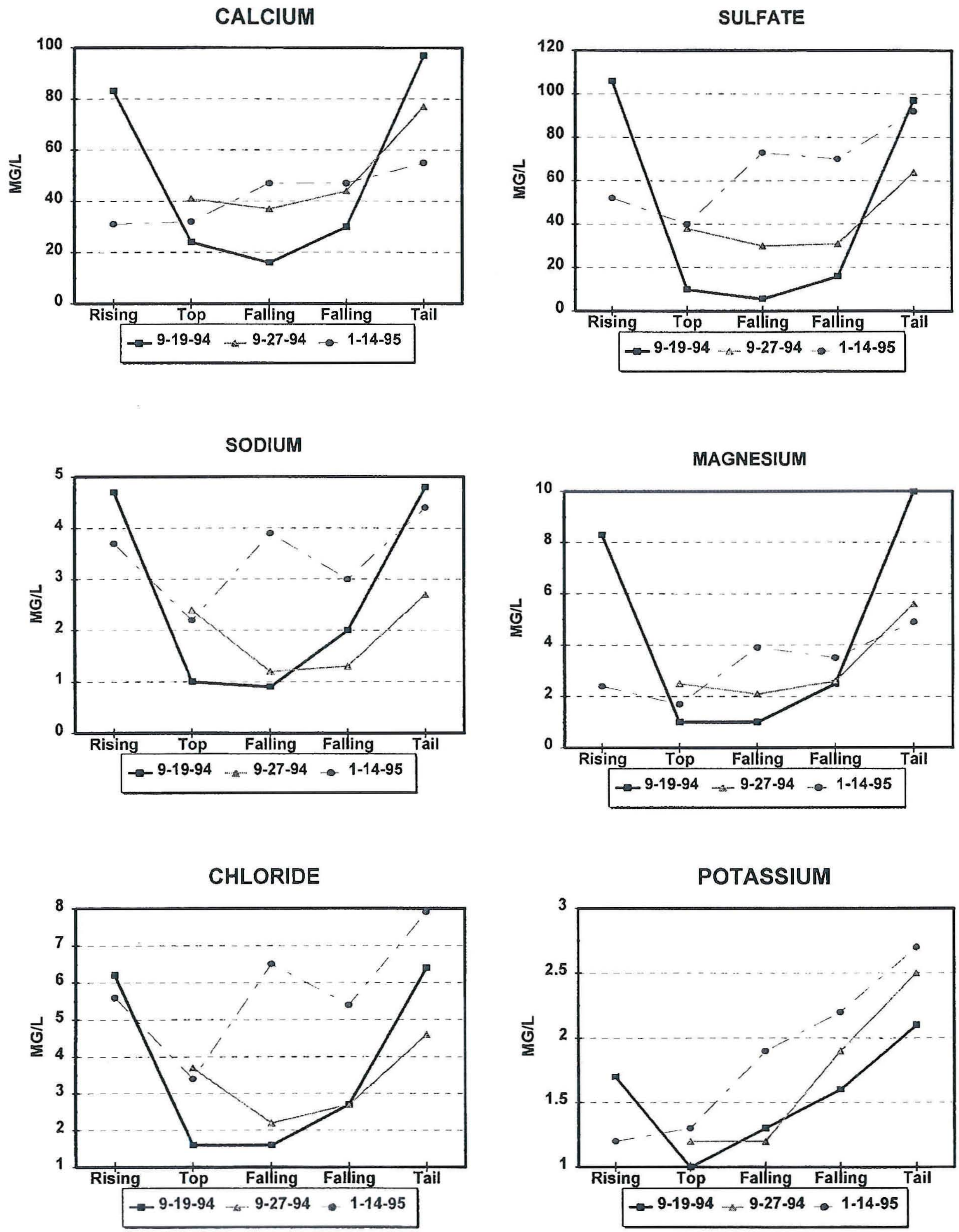


Figure 17. Concentrations of major ions measured at the inflow during different stages of the hydrograph for three rain events.