CONSTITUENT-LOAD CHANGES IN URBAN STORMWATER RUNOFF ROUTED THROUGH A DETENTION POND-WETLANDS SYSTEM IN CENTRAL FLORIDA

By Edward H. Martin and James L. Smoot

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4310

Prepared in cooperation with the

FLORIDA DEPARTMENT OF TRANSPORTATION

Tallahassee, Florida

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Suite 3015
227 North Bronough Street
Tallahassee, Florida 32301

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 236-7476)

CONTENTS

ILLUSTRATIONS

TABLES

CONSTITUENT-LOAD CHANGES IN URBAN STORMWATER RUNOFF ROUTED THROUGH A DETENTION POND-WETLANDS SYSTEM IN CENTRAL FLORIDA

By Edward H. Martin and James L. Smoot

ABSTRACT

The efficiency of a detention pond and wetlands temporary storage system to reduce constituent loads in urban runoff was determined. The reduction efficiencies for 22 constituents, including the dissolved, suspended, and total phases of many of the constituents were investigated. A new method, not previously discussed in technical literature, was developed to determine the efficiency of a temporary storage system unit such as a detention pond or wetlands. The method provides an efficiency, called the regression efficiency, determined by a regression made of loads-in against loads-out of a unit with the intercept of the regression constrained to zero. The regression efficiency of the treatment unit is defined as unity minus the regression slope.

The detention pond generally reduced suspended constituent loads. The pond had a regression efficiency of 65 percent in reducing suspended solids loads, 41 percent for suspended lead loads, 37 percent for suspended zinc loads, 17 percent for suspended nitrogen loads, and 21 percent for suspended phosphorus loads. Settling of heavier suspended particles was probably the primary process that brings about this reduction.

The wetlands was generally effective in reducing both suspended and dissolved constituent loads. Regression efficiences for suspended constituents were 66 percent for solids, 75 percent for lead, 50 percent for zinc, 30 percent for nitrogen, and 19 percent for phosphorus. Dissolved phase constituent regression efficiences were 38 percent for solids, 54 percent for lead, 75 percent for zinc, 13 percent for nitrogen, and 0 percent for phosphorus. These load reductions were probably caused by various processes such as sedimentation, coagulation, filtration, adsorption, and biological assimilation and transformation. Biochemical recycling of nutrients, such as nitrogen and phosphorus, likely account for the relatively small regression efficiencies estimated for these constituents in the wetlands.

The system (the pond and wetlands combined) achieved appreciable reductions of loads for most constituents. Significant positive regression efficiencies for the system were found for all constituents except the nutrients dissolved nitrate and dissolved orthophosphate. System regression efficiencies were 55 percent for total solids, 83 percent for total lead, 70 percent for total zinc, 36 percent for total nitrogen, and 43 percent for total phosphorus.

INTRODUCTION

One of the primary conclusions of the many urban stormwater hydrologic studies made nationwide over the last several years (prior to 1985) is that urban stormwater runoff often contains significant quantities or loads of numerous chemical and physical constituents that may adversely affect the water quality of nearby receiving waters. These constituent loads are caused by the rainfall washoff of deposited material from sources such as vehicle emissions, traffic litter, construction sites, lawns treated with fertilizers and pesticides, and atmospheric deposition. Several general categories of constituents are common in urban runoff including heavy metals, dust and soil material, nutrients, pesticides, bacteria, and natural and industrial organic compounds.

Numerous practices to mitigate the effects of stormwater runoff on water quality have been used, although their effectiveness has rarely been documented. Common practices have included predevelopment planning to preserve natural land conditions and limit embankment slopes; maintenance activies such as neighborhood cleaning and street sweeping; and use of treatment devices such as exfiltration tanks, porous pavements, swales, filtration devices, and various types of temporary storage systems such as detention or retention ponds and wetlands.

In Florida, treatment equivalent to some form of retention or detention of the first inch of rainfall is required by State law (Florida Department of Environmental Regulation, 1982). With the growing use of these costly stormwater treatment systems, there is great need for scientific documentation regarding the effectiveness and physical processes of these systems.

To provide information about the effectiveness and physical processes of these systems, a detention pond and wetlands stormwater treatment system located in an urban area of west Orlando (fig. 1) was selected for study. The study was conducted by the U.S. Geological Survey in cooperation with the Florida Department of Transportation.

Purpose and Scope

The purpose of this report is to present the results of data collection to measure the changes in constituent loads in urban stormwater runoff routed through a stormwater temporary-storage system, composed of a detention pond and shallow wetlands; to describe a new approach to estimate the efficiency of a stormwater treatment system; and to present some discussion on the factors that affect load changes and efficiencies. The scope of the study included intensive measuring and sampling of storm runoff as it passed through an in-line detention pond and shallow wetlands. Data were collected during a 2-year period from 1982 through 1984.

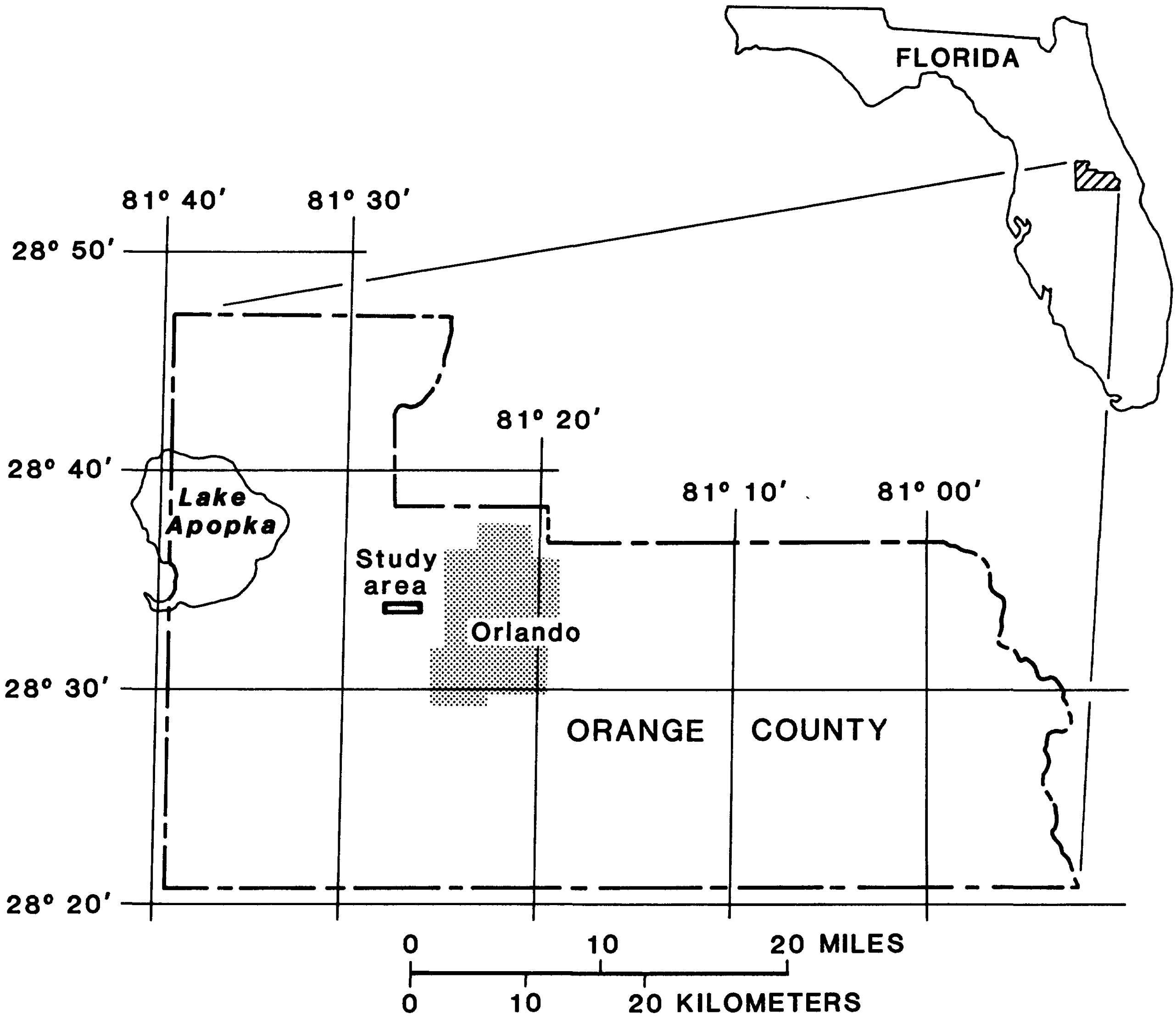

Figure 1.--Location of study area in Orange County.

Study Approach

The study approach included the installation and operation of hydrologic data-collection and sampling equipment and analysis of the collected data. Figure 2 is a sketch showing the path of water movement at the study site. Runoff delivered to the detention pond and wetlands is from a mixed roadway and low and high-density residential land use drainage basin. The pond and wetlands were instrumented to automatically collect water samples at the pond inlet, pond outlet (wetlands inlet), and the wetlands outlet (fig. 2). The instrumentation gaged flow at the three sites so that constituent mass loads passing all three points could be determined.

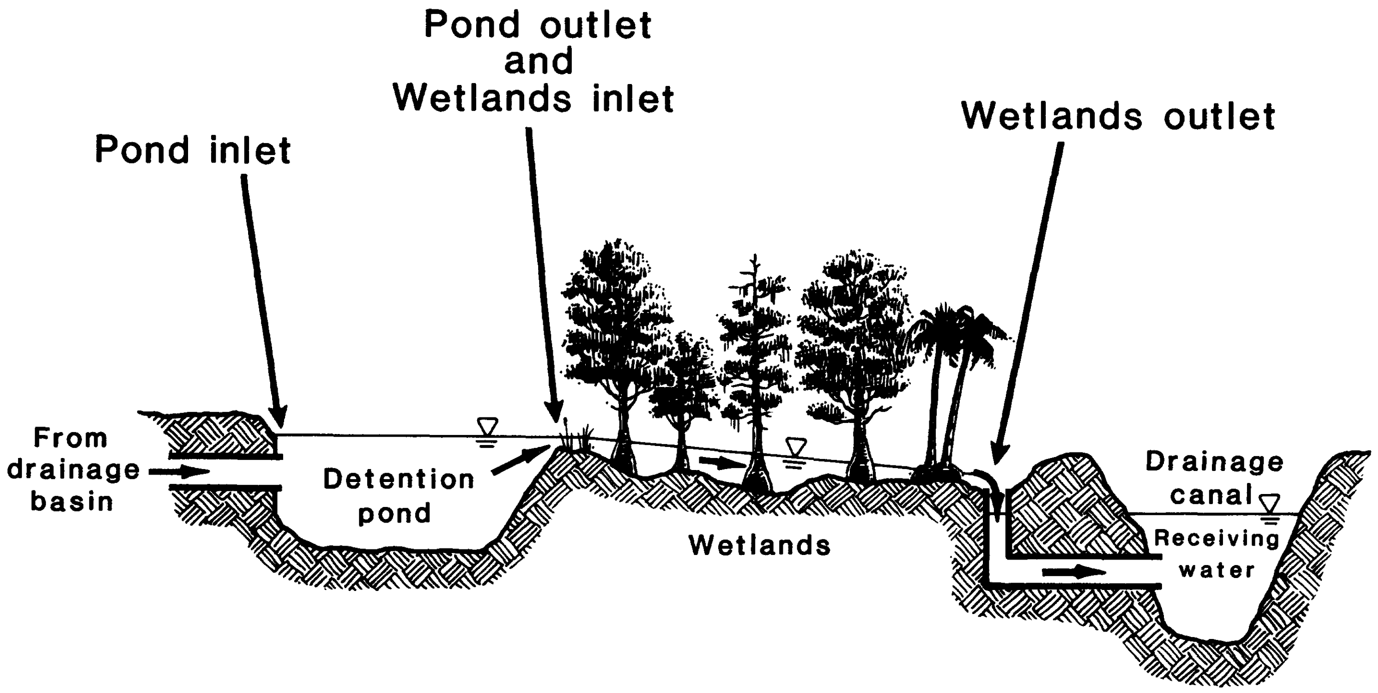

Figure 2.--Movement of water through a detention pond-wetlands system.

Rainfall measurements and precipitation samples were collected and the rainfall measurements were used to compute a rainfall-runoff relation. The bottom material in the pond and the wetlands were sampled to check for the accumulation of deposited constituents. Deposition of the suspended part of the mass load due to sedimentation was expected. Samples from the surficial aquifer were also collected to determine if constituents in the runoff were in the surficial aquifer.

Data were collected for 22 constituents found in the runoff. The constituents for which loads were calculated were grouped into four classes: (1) major ions, including chloride, sodium, sulfate, calcium, magnesium, potassium, and bicarbonate; (2) selected physical and chemical properties, including solids, suspended volatile and nonvolatile solids, and chemical oxygen demand; (3) metals, including lead and zinc; and (4) nutrients which included the nitrogen and phosphorus species, orthophosphate, and total organic carbon. Analyses for several constituents, such as cadmium, chromium, copper, and strontium, were made; no concentrations above detection limits were found.

Previous Investigations

Previous studies indicate that temporary storage systems can reduce loads of constituents associated with suspended or particulate matter in runoff. However, some constituents loads, particularly nutrients loads, were found to increase (Scherger and Davis, 1982) in runoff as it passed through a temporary storage system.

Researchers in urban hydrology use some unique classification schemes and terms. Ponds used as stormwater treatment devices are classified by their residence times or the length of time the runoff is held in temporary storage. Ponds that detain the runoff for less than 24 hours are classified as detention ponds. Ponds that retain runoff for more than one day are classified as retention ponds. This classification system is arbitrary and the characteristics and process of one are applicable with consideration to the other. Wetlands retention times are usually at least 24 hours and this classification system is not usually applied to them. Ponds are also classified by the presence or absence of water in the pond during dry periods between storms. A pond that has water stored in it between storms is a wet pond and a pond that has no between-storm storage is described as a dry pond. The volume of water in storage in a wet pond between storms is called dead storage. The storm runoff storage capacity of a pond is called live storage (Wanielista, and Yousef, 1985, p. 7).

Luzkow and others (1981) described the effectiveness of a wet retention pond in Michigan in reducing stormwater constituent loads. The pond for their study drained a 66.7-acre mixed residential, commercial, and parkland land-use area. Dead-storage volume of the pond was 233,000 ft^3, and live storage was 310,000 ft^3. Residence time of runoff in the pond was estimated to range between one and several days. Monitoring stations were established at the basin inlet and outlet to obtain flow and water-quality data. Water samples were collected using automatic samplers paced by flow recorders to provide composite flow proportional samples. Suspended sediment removal was greater than 50 percent for 11 of 14 monitored storms. Total phosphorus removals were greater than 50 percent for 8 of 14 monitored storms, and total Kjeldahl nitrogen (organic + ammonia nitrogen) removal was greater than 80 percent for 6 of 7 monitored events. A net export of total solids, total phosphorus, and total Kjeldahl nitrogen was found for rainfall depths less than about 0.3 inches. Luzkow concluded that the net export of solids and lead for small rainfall depths was due to background levels of these constituents present in the system. The net export of phosphorus and nitrogen was attributed to their incorporation and release into the system during the spring months. Luzkow found a good relation between rainfall and influent loads; the relation of effluent mass loads and rainfall was much weaker. He concluded that effluent loads are more dependent on influent loads than rainfall, and the amount of constituent load retained by a detention facility is a function of influent mass loads and basin geometry.

Scherger and Davis (1982) reported the results of two constituent loads reduction studies in Michigan; one of a wet retention pond and the other of a naturally occurring wetlands. The retention pond received drainage from 4,900 acres of mixed residential, commercial, parkland, and agricultural land uses. The dead storage of the pond was 900,000 ft^3 and live storage was 7,650,000 ft^3. Monitoring stations were established at the inlet and outlet of the basin to obtain flow and water-quality data. Discrete samples were collected at 15- to 30-minute intervals and manually composited using the flow data. Seven storms were monitored. Suspended solids removal ranged from 10 to 85 percent, and total Kjeldahl nitrogen removal ranged from none to 50 percent. About half of the Kjeldahl nitrogen was found in the dissolved form. Phosphorus removal ranged from none to 82 percent. In analyzing the reduction of constituent loads in temporary storage systems, Scherger and Davis recommended that researchers not place too much emphasis on the individual storm percentage removal of various materials, but rather consider the constituent load changes and the types of mechanisms that cause those changes (Scherger and Davis, 1982, p. 117).

The wetlands studied by Scherger and Davis received drainage from 1,200 acres of mixed residential, parkland, and agricultural land uses. The wetlands dead storage was 630,000 ft^3 and the live storage was 2,620,000 ft^3. The wetlands removed 76 to 93 percent of the solids. Total phosphorus removal ranged from 40 to 60 percent. Nitrogen removal was 20 to 30 percent. Nitrogen loads leaving the wetlands were higher than loads entering during the winter months. Dissolved nitrogen loads were reduced in the summer probably due to its uptake by plants. The authors concluded that nitrogen was removed in the summer and released in the winter. The authors also suggested that the effectiveness of detention facilities can be reduced by the unsteady turbulent nature of the inflow which is responsible for short-circuiting, disruption of smooth settling profiles, and disruption of the sludge zone.

Ferrara and Witkowski (1983) described the efficiency of a detention pond to reduce the loads of four water-quality constituents for three storms. The basin received drainage from 637 acres of mixed high and low density residential and forest land use areas. The detention pond was a wet type with an approximate depth of 8 feet in dry weather. The inlet and outlet discharge was estimated using a U.S. Geological Survey stream-gaging station immediately downstream from the pond outlet and a hydraulic routing technique. Sampling equipment was located at the inlet and outlet of the basin. Grab samples were collected at discrete time intervals. The constituent concentrations were assumed to vary linearly in time between samples. The concentrations and discharge were combined to produce constituent loads. The detention basin was shown to be effective in reducing solids, chemical oxygen demand, and total phosphorus loads. Total Kjeldahl nitrogen loads were found to generally increase through the basin. Ferrara and Witkowski attributed the increase of total Kjeldahl nitrogen to the production of this constituent from settleable organic nitrogen deposited in the pond bottom sediments during previous storms.

DESCRIPTION OF THE DETENTION POND-WETLANDS SYSTEM

The stormwater temporary storage facility selected for study is part of an urban drainage system located in an urban area west of Orlando, in east central Florida (fig. 1). Treatment facilities within the system consist of an in-line detention pond in series with a natural wetlands. The detention pond and drainage for the wetlands were built in 1980 by the Florida Department of Transportation to receive storm runoff from the urban roadway, Silver Star Road, and adjacent areas. The roadway is a four-lane, concrete thoroughfare with a posted speed limit of 45 miles per hour. The average daily traffic was counted in January 1984 as 22,000 vehicles.

The drainage basin of the detention pond and wetlands is approximately 41.6 acres. The predominant land uses are forest, urban roadway, and high-density residential with some low-density residential. The size and relative area of land uses in the basin are:

Land use	Area	
	Acres	Percent of total
Forest	11.1	33
Urban roadway	13.7	27
High-density residential	11.1	27
Low-density residential	5.7	13

The drainage system consists of a collector network beneath approximately 2 miles of urban roadway, the detention pond, the wetlands, and a drop-inlet and culvert to convey the water to a nearby canal (fig. 3). Stormwater runoff in the basin moves by overland flow to a system of curbs and gutters. The curbs and gutters direct the flow to a series of drop inlets connected to reinforced concrete drainage pipes. The size of the pipe along the main stem of the drainage system increases from 36 inches at the upstream end of the basin to 60 inches at the pond inlet. The gradient of the drainage pipe is approximately 0.8 foot per 100 feet.

Excess runoff pumped from another basin to the west is occasionally pumped into the drainage canal east of the detention pond through a 42-inch, ductile-iron pipe (fig. 3). The pipe is connected to the drainage system of the study basin by a weir in a junction box. During periods of extreme high-pressure flow in the iron pipe, discharge from the pipe can be forced over the connection weir, into the study drainage system, the detention pond, and wetlands. Stormwater diversion from the western basin into the study basin occurred during one monitored storm (table 1, storm 7).

The pond and wetlands are shown in the photograph in figure 4. Figure 5 is a map of the stormwater treatment system showing the pond, wetlands, general course of water movement, and data-collection sites. The sandy top soil and part of an underlying clay layer were excavated to form the pond. The pond is built into, and surrounded by the relatively impermeable clay layer. The excavated sand and clay were used to build a berm that extends along the east and northeast boundary of the wetlands (fig. 3). The sides of the pond are built on a 2:1 slope and are protected by sand-cement riprap. The pond area during dry weather is 8,600 ft^2. Water depths in the pond range from about 8 ft during dry weather to as much as 11 ft during storms. Storage is about 54,000 ft^3 at 8 ft depths and about 81,500 ft^3 at 11 ft depths. For the 41.6-acre drainage basin, these volumes are equal to about 0.35 inches of runoff at an 8 ft pond depth and about 0.55 inches of runoff at an 11 ft pond depth.

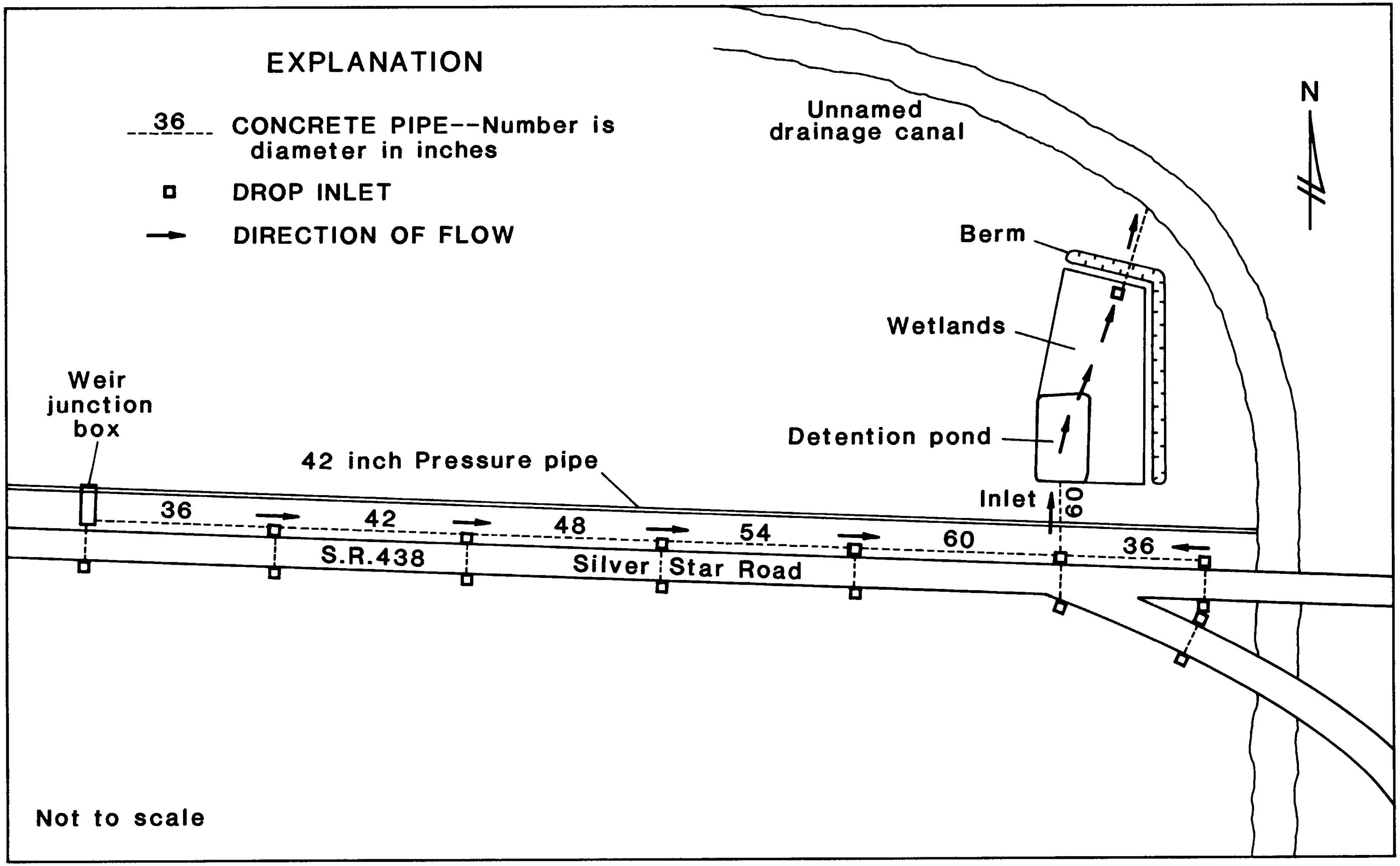

Figure 3.--Configuration of study site.

Figure 4.--Pond and wetlands in right background and equipment shelter in right foreground.

Storm runoff discharges from the pond into the wetlands by overflowing an earthen spillway at the northeast corner of the pond. The wetlands is about 32,000 ft^2 in area with dry-weather depths ranging from 0 to 3 ft and storm depths as much as 5 ft. Storage is about 20,000 ft^3 at 3 ft wetlands depths and about 122,000 ft^3, or 0.80 inches of runoff from the 41.6-acre drainage basin, at a 5 ft depth. The bed material of the wetlands is composed of sand and loamy silt. Large cypress trees grow in the slightly lower northern and eastern part of the wetlands. A heavy undergrowth of hyacinths, duckweed, cattails, and small trees occurs under the cypress stand. A thick, virtually impenetrable underbrush of wild grape, blackberry, and other running vines grows in the hardwood area in the slightly elevated western part of the wetlands. Flow leaves the wetlands through a compound weir built around a drop inlet and enters a culvert leading to the drainage canal.

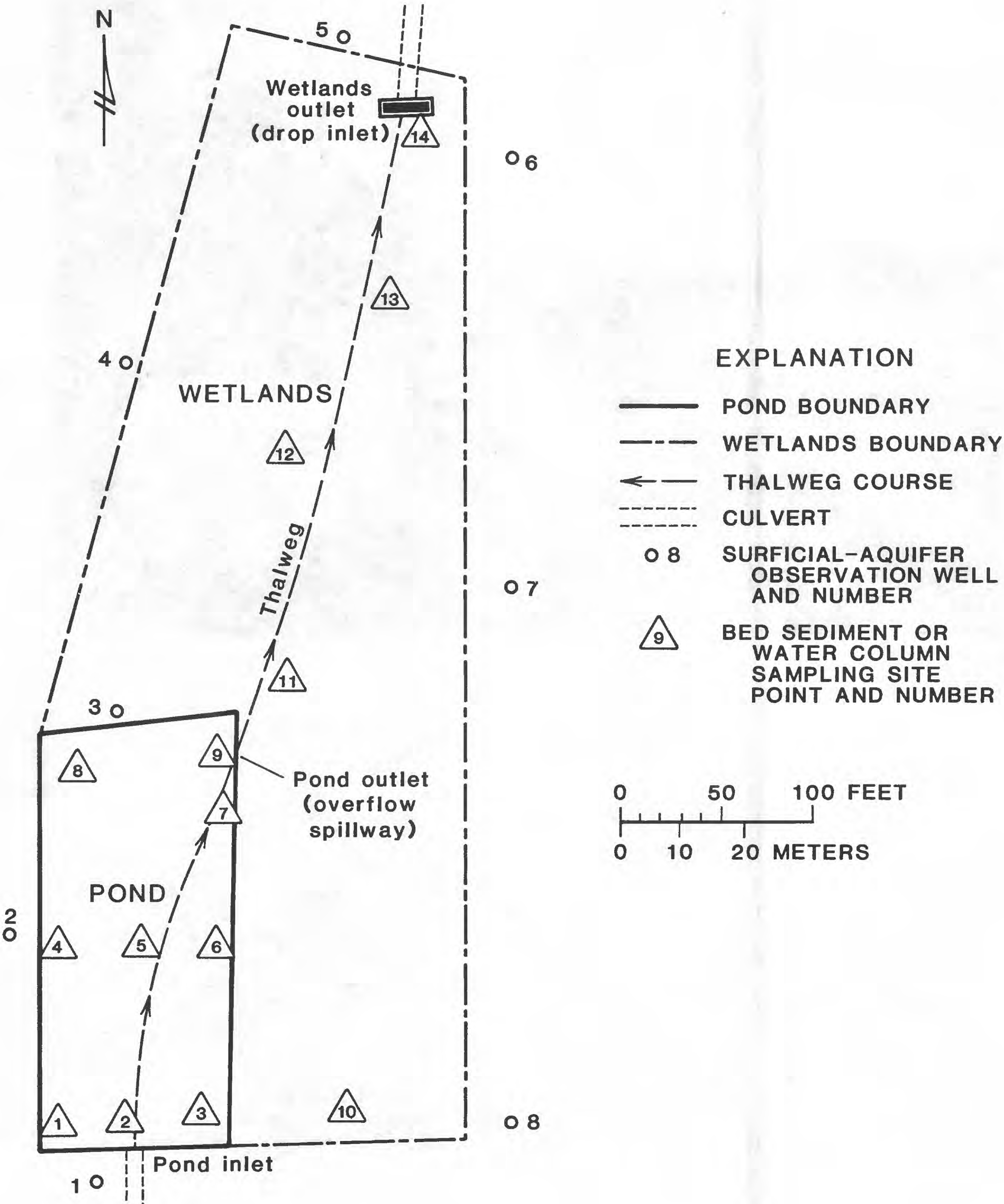

Figure 5.--Plan view of the detention pond and wetlands.

METHODS

Data Collection

A continuous record of discharge for the monitored storms was required at the three points where loads were computed--the pond inlet, the pond outlet, and the wetlands outlet. Velocities at the pond inlet were measured using an electromagnetic current meter. The current-meter probe was mounted in the center of the 60-inch diameter inlet culvert by means of a metal bracket. The sensed velocity was averaged over a 12-second period and recorded at 2-minute intervals during storms. The inlet discharge was computed by multiplying the velocity, the culvert cross-section area, and a coefficient of discharge relating point velocity to the average cross section velocity. A coefficient of 1.0 was used based upon measurements made with an "AA" Standard Price current meter. A coefficient of 1.0 is also reported by Kilpatrick and others (1985) for these conditions.

Discharge over the earthen spillway at the pond outlet was affected by backwater and submergence effects from the wetlands; therefore, it was necessary to use a numerical solution of the standard storage routing equation based on the continuity principle as given by Linsley and others (1975, p. 294) to compute the pond-outlet flow. The storage routing equation is:

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{t} \qquad (1)$$

where

I = inflow rate
O = outflow rate
S = storage volume
t = small time period, the routing period
1, 2 = beginning and end of time period.

Rearranging to solve for the outflow at the end of a time period gives

$$O_2 = I_2 + I_1 - O - \frac{2(S_2 \quad S_1)}{t} \qquad (2)$$

The inflow is measured directly as previously described. The change in storage is determined using the continuous record of pond stage and a stage-storage relation. A computer program was written to use equation (2), the record of pond inflow, and pond storage to compute pond discharge at 5-minute intervals for each monitored storm. The initial outflow for each storm was assumed to be zero.

The outlet of the wetlands consisted of a concrete drop inlet which was connected to the receiving canal by a concrete culvert. Discharge at the wetlands outlet was determined using the record of stage at the wetlands outlet and a stage-discharge relation. A compound, sharp-edged weir was constructed at the wetlands outlet to provide a stable stage-discharge relation. The discharge relation was determined using a theoretical weir rating calibrated with volumetric and current-meter discharge measurements.

The accumulated discharge was computed and plotted for each storm to check that there was never more accumulated discharge at a downstream point than at an upstream point as recommended by Linsley and others (1975, p. 294). Thus, each of the three methods of calculating discharge--electromagnetic current meter, continuity principle, and weir rating discharge--was used as a check of the other methods.

The automatic sampling equipment at the detention pond inlet and outlet was designed so that the monitored pond inlet velocity and the pond outlet stage could control the sampling frequency at those points. When the inlet velocity or pond stage exceeded preprogrammed values, sampling was initiated. Successive samples were taken at designated time intervals based upon the value of the controlling parameters, or when the controlling parameters changed more than a designated amount in a given time period. The resulting 15 to 24 samples from each collection point were drawn more frequently during time of high, rapidly changing discharge and less frequently during times of low gradually changing discharge. Samples were stored in chest freezers modified to maintain a sample temperature of 4°C.

Sampling at the wetlands outlet was performed at a constant interval of 30 minutes when a predesignated stage was exceeded. This method of sampling was adequate for the wetlands because discharges were smooth and gradually changing due to the storage capacity of the detention pond and wetlands.

Bulk-precipitation samples were collected through a plastic funnel mounted atop the equipment shelter (fig. 4). The spout of the funnel was connected to a plastic pipe that delivered the dryfall and wetfall to a bucket inside one of the modified freezers. The bulk-precipitation samples were analyzed monthly during periods of high rainfall, and bimonthly during low rainfall periods.

Rainfall depth and intensity data were collected using two tipping bucket rain gages mounted atop the equipment shelter next to the bulk-precipitation sample funnel (fig. 4). The accuracy of the tipping bucket rain gage was checked using a volumetric rain gage mounted approximately 30 ft west of the equipment shelter (30 ft to the left of the shelter in fig. 4).

Bed-sediment samples were taken at 14 sites in the pond and wetlands (fig. 5). Samples were collected in the pond using a dredge, and in the wetlands using a corer. Sediments were analyzed for pesticides and industrial organic compounds at three of the bed-sediment sites.

Samples were taken from the center of the pond at a depth of 2 ft, 1, 2, and 3 days after selected storms to provide background concentrations of constituents in the pond between storms. Eight surficial-aquifer observation wells (fig. 5) were installed to determine if urban runoff constituents had infiltrated the surficial aquifer in the detention pond and wetlands area. Well number 6 was vandalized and no samples were taken from it.

Constituent concentrations were determined by the U.S. Geological Survey Central Laboratory System according to standard methods described by

Skougstad and others (1979) and Wershaw and others (1983). Using these methods, the dissolved constituent concentration is defined as the concentration of a sample that has been filtered through a plastic membrane filter with pores 0.45 micron in diameter. The 0.45-micron diameter is about 100 times larger than the usually defined lower limit of five millimicrons for colloidal particles. The filtered samples may contain some constituent that is not dissolved in the sense of being completely surrounded by solvent molecules and having no direct contact with other particles (Hem, 1970, p. 86-88). The total constituent concentration is the concentration of an unfiltered sample, and the suspended concentration is defined as the calculated difference between the total and dissolved concentrations.

Computation of Constituent Loads

Two methods of computation can be used to determine constituent loads. They are: (1) discrete analysis, in which several discrete samples from among the samples collected are selected and individually analyzed; and (2) composite analysis, in which one flow-weighted mixture of the samples collected is analyzed. Because each method has certain advantages and disadvantages, both methods were used in this study.

The discrete method of analysis was used for 7 of the 13 storms. The selection of particular samples from among up to 24 samples collected at any collection point during a storm was done to provide an adequate description of the changes in constituent concentration with changes in the discharge. Usually one sample was chosen at the beginning of a storm, one or two on the rising limb; one at, or near, the peak; and one or two on the falling limb of the storm hydrograph.

To compute constituent loads using the discrete method of analysis, it was assumed that constituent concentrations for periods between samples vary linearly between the measured concentrations, and that concentrations prior to the first sample and after the last sample were equal to adjacent values as recommended by Doyle and Lorens (1982, p. 234) for computation of loads in urban hydrology studies.

The constituent concentration and discharge values at time steps of 2 minutes for the pond inlet, 5 minutes for the pond outlet, and 15 minutes for the wetlands outlet were multiplied to yield the constituent mass flux or the constituent mass flow rate. The mass flux was numerically integrated with time to compute the total mass or total load of constituent passing each site during the storm.

The composite method of analysis was used for six storms. Composite sampling is the formation of one sample that is the equivalent of an imaginary sample drawn from a well-mixed tank containing the total volume of water that has passed the sampling point during the storm. The total constituent load is calculated as the product of the "composite" constituent concentration and the total volume of runoff. The composite sample is formed by taking varying amounts of water from each sample taken. The amount taken from each bottle is directly proportional to the amount of runoff the sample represents.

The primary advantage of using the discrete method of analysis is the increased reliability of the loads computation from using 4 to 5 independent sample analyses. The primary advantage of the composite method is the somewhat improved accuracy gained by using some part of each of 24 samples used to form the one sample that is analyzed for constituent concentrations. The advantages of either method had to be weighed against the cost. Discrete analysis costs five to six times the cost of the composite method of analysis. The method of sampling for each storm is shown in table 1.

Table 1.--Date, method of sampling, rainfall, runoff, and duration of the monitored storms

Storm No.	Date	Method of sampling	Rainfall (inches)	Runoff (thousand feet^3)	Runoff (inches)	Duration (hours)	Intensity (inches) per hour)
1	08-20-82	Discrete	1.33	48.5	0.32	2.33	0.571
2	10-05-82	Composite	.78	32.9	.22	4.10	.190
3	12-08-82	do.	.35	15.7	.10	.40	.875
4	01-20-83	Discrete	.97	45.8	.30	7.83	.124
5	02-02-83	do.	2.49	95.5	.63	4.30	.579
6	05-30-83	Composite	1.94	93.8	.62	7.50	.259
7	06-07-83	Discrete	1.78	116.3	.77	21.67	.082
8	06-21-83	Composite	1.40	70.9	.47	5.25	.267
9	07-15-83	do.	.26	16.3	.11	2.40	.108
10	07-29-83	do.	.40	16.9	.11	10.92	.037
11	11-20-83	Discrete	.88	43.3	.29	3.25	.271
12	02-13-84	do.	.46	28.4	.19	6.50	.071
13	06-13-84	do.	1.72	80.9	.54	1.77	.972

Data Management

A SAS[1] (Statistical Analysis System) (Helwig and Council, 1979) and Fortran computer language data management system, diagrammed in figure 6, was written and used to process the large amount of data generated during this study. The data collected are of two general types--hydraulic data collected on paper tape, and water-quality constituent concentrations resulting from analyses by the U.S. Geological Survey Central Laboratory. The hydraulic data are processed, checked for errors, and readied for loads computation using SAS-based computer programs written for that purpose. The water-quality concentrations were retrieved from the national WATSTORE (National Water Data Storage and Retrieval System) computer files. The two sets of data, hydraulic and water quality, were merged in a Fortran-based program for computing loads. The loads program calculated constituent loads and output a summary of the constituent loads for each collection point in the system. Also available were plots of variables such as discharge, rainfall, concentration, accumulated discharge, accumulated loads, and mass flux versus time for each storm.

[1]Use of the trade name SAS in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

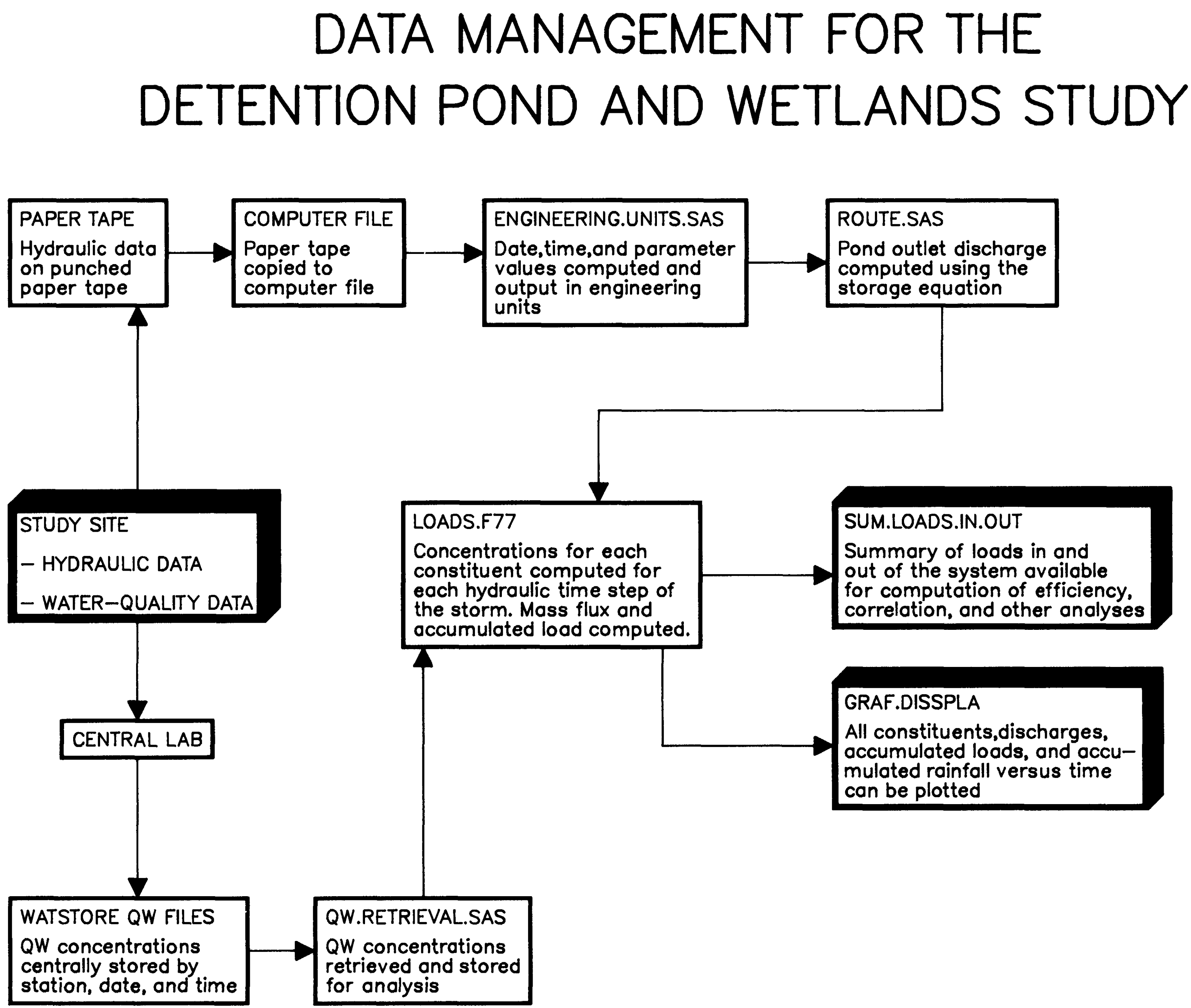

Figure 6.--The data-management system.

HYDROLOGIC ANALYSIS OF URBAN STORMWATER RUNOFF

The hydraulic characteristics measured for each storm are listed in table 1 and shown in figure 7. Rainfall for the monitored storms ranged from 0.26 to 2.49 inches. Duration (the time interval from beginning to end of flow at the pond inlet) ranged from 0.40 to 21.67 hours (table 1).

Hydrographs of 1 of the 13 monitored storms (storm 1), showing the typical instantaneous discharges at the three data-collection points, are shown in figure 8. The inlet discharge is characteristically unsteady, rapidly changing with sharp high peaks and short rising and falling limbs. The pond outlet hydrograph is similar to the pond inlet discharge, but the storage effect of the pond reduces peak discharges and allows a more gradual recession of the pond outlet discharge after the peak discharge. The relatively large storage effects of the wetlands is indicated by the much-reduced wetlands peak discharge and the smoothly changing rising and falling limbs of the wetlands discharge hydrograph.

The total runoff passing each measuring point was computed by numerically determining the area under the hydrograph for each location. The volume of runoff was then divided by the area of the drainage basin to yield a runoff in the dimension of length (inches). Runoff at the pond inlet ranged from 0.10 to 0.77 inches over the drainage basin. The runoff for the three measuring locations for each of the monitored storms is shown in table 1 and figure 7. The accumulated volume of runoff versus time for storm 2 is shown in figure 9. The volume of water in live storage in the pond or wetlands is equal to the vertical distance between the appropriate accumulated runoff curves at any given time. The wetlands is actually capable of retaining part of the runoff. For storm 2 (fig. 9), about 10,000 ft^3 or 14 percent of the initial storm runoff is retained by the wetlands. Retention in the pond is about 1,000 ft^3 or only 1.4 percent of the initial storm runoff. The runoff retained in the wetlands probably seeps slowly into the surficial aquifer, evaporates, or is retained in the wetlands. Thus, the available storage capacity of the wetlands for any storm is dependent upon antecedent conditions.

Stormwater runoff from a detention pond in another drainage basin was pumped into the study site during storm 7. The diversion flow was steady at about 2 ft^3/s for approximately 10 hours. The total duration of storm 7 (natural runoff time plus pumping time) was about 22 hours (fig. 7), which was more than twice any other storm duration. Because of this diversion, total runoff for storm 7 was greater than the storm with the largest amount of rainfall (storm 5).

Rainfall against runoff at the pond inlet, pond outlet, and wetlands outlet are plotted in figure 10. A simple linear regression of the pond inlet discharge and rainfall, excluding storm 7, yields

$$\text{RUNOFF} = 0.27\ (\text{RAINFALL}) + 0.03 \qquad (3)$$

where

RUNOFF and RAINFALL are in inches.

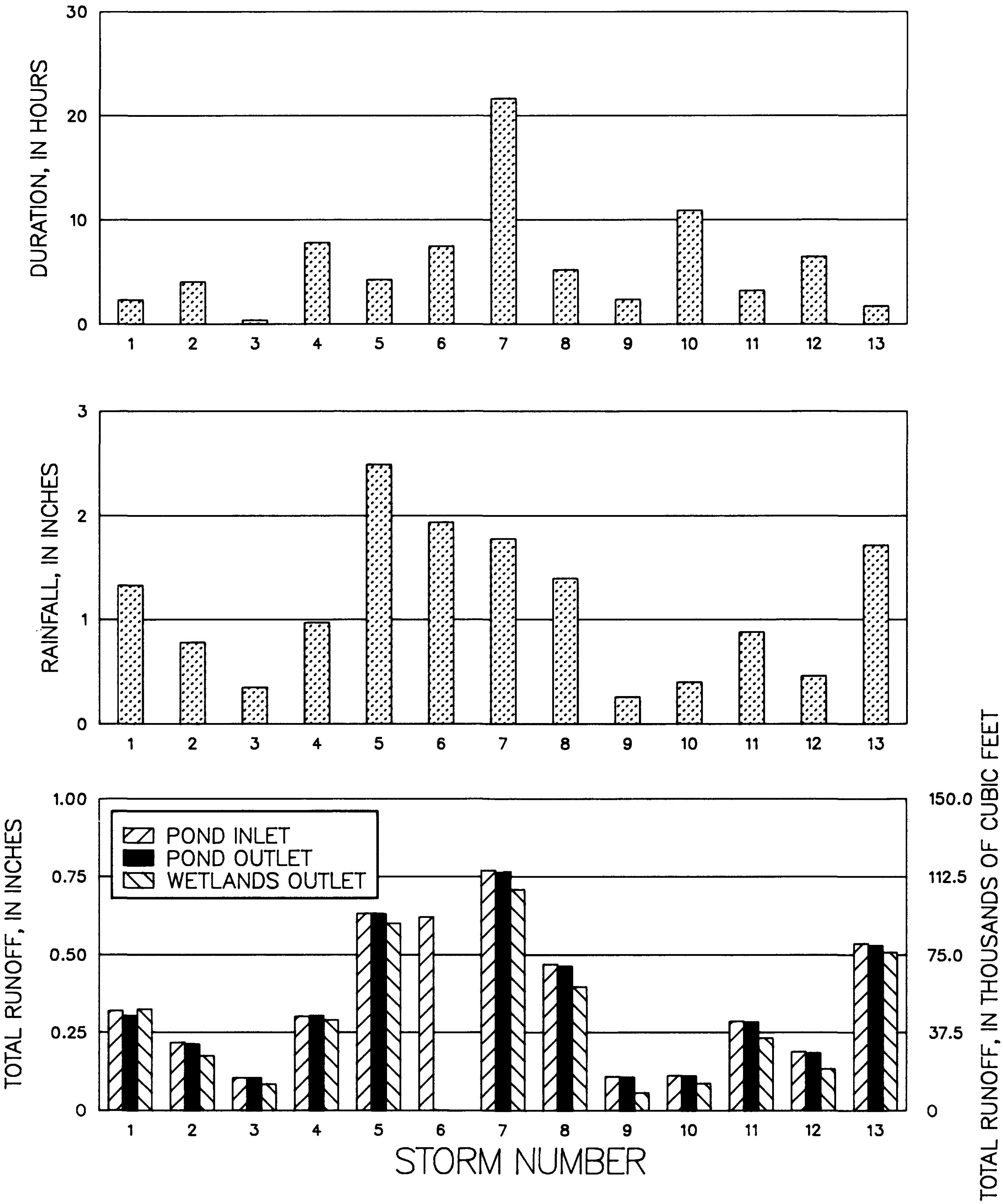

Figure 7.--Total runoff, rainfall, and duration of the monitored storms.

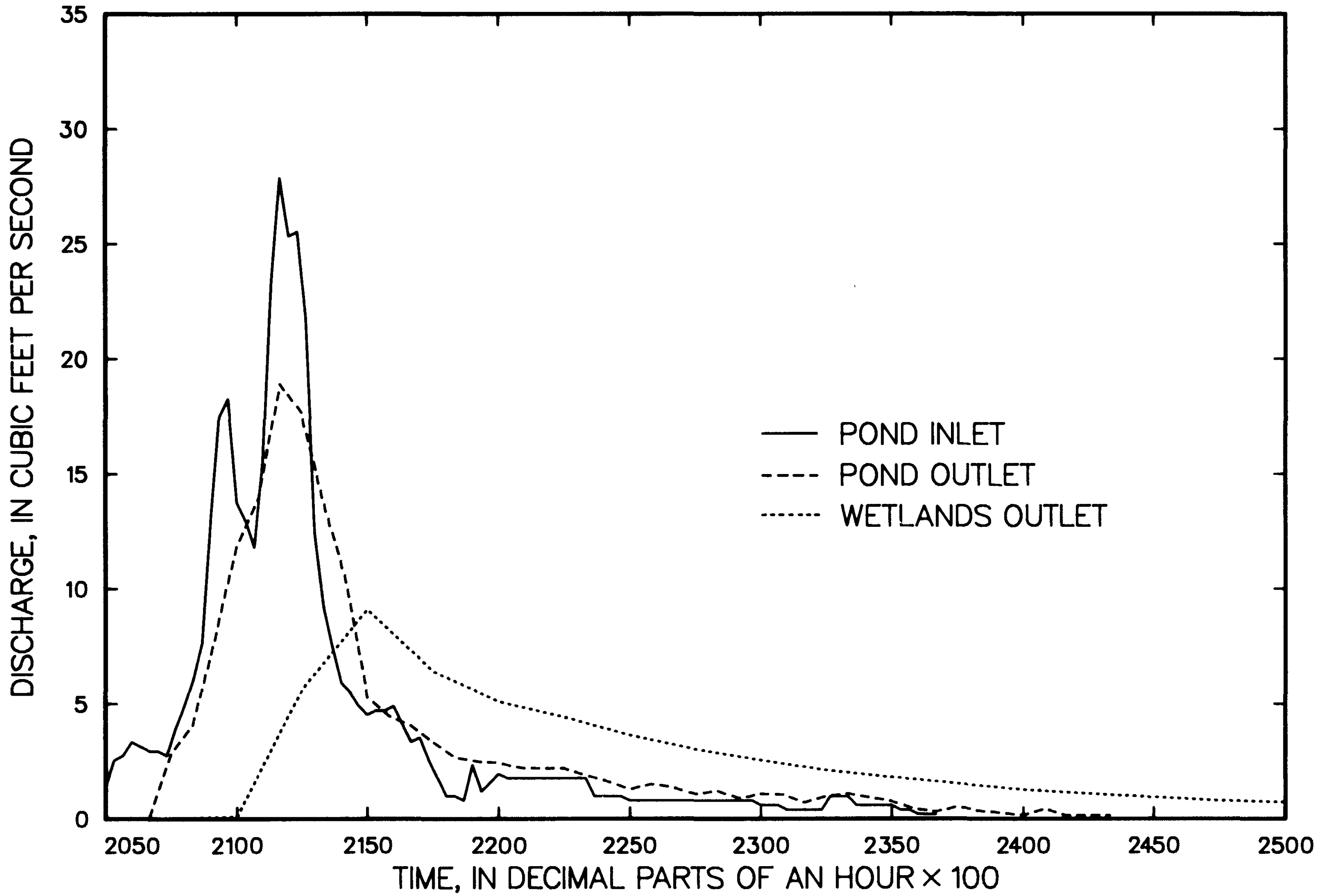

Figure 8.--Typical discharge hydrograph (storm 1).

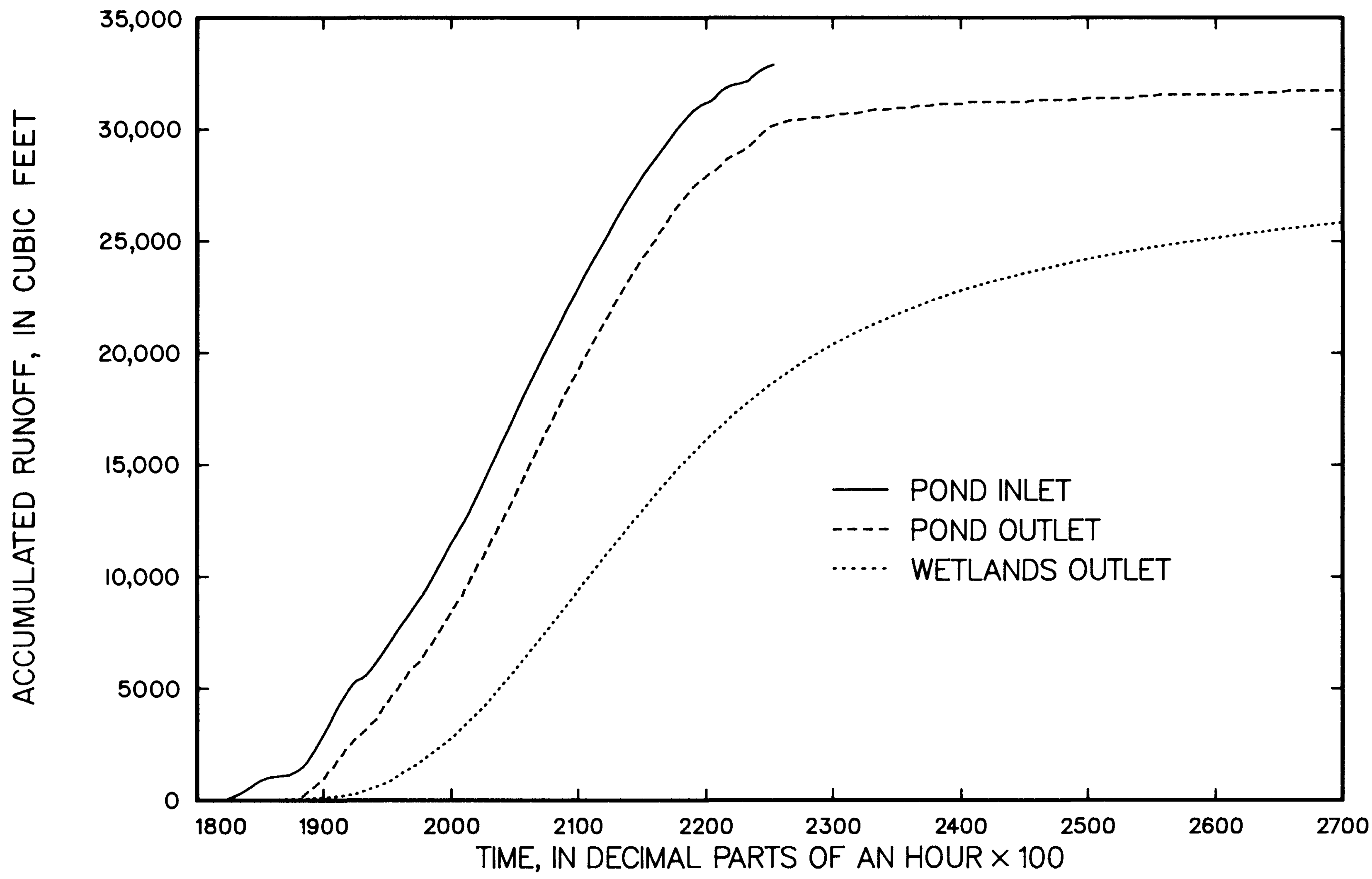

Figure 9.--Typical accumulated runoff (storm 2).

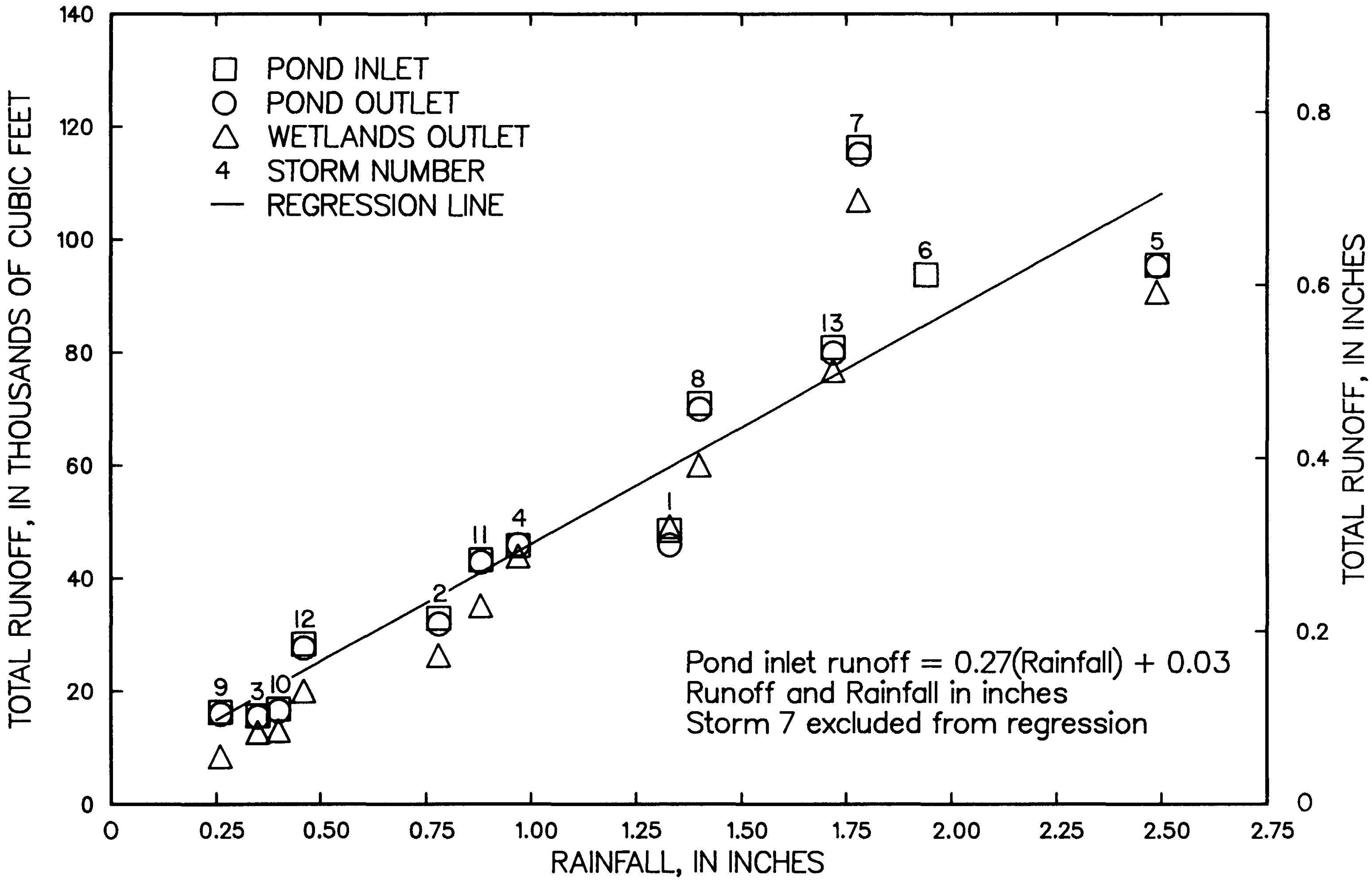

Figure 10.--Rainfall-runoff relation.

The 0.27 slope of the rainfall runoff regression is about the same as the percentage of the drainage basin that is urban roadway. Two important factors shown to influence the amount of rainfall that flows off an urbanized basin in Florida are the amount of impervious area, and its hydraulic connection to a sewer system. An impervious area that is hydraulically connected to a sewer system has been termed the hydraulically effective impervious area (Miller, 1978). The urban roadway is impervious and connected by curbs and gutters to the culvert drainage system. The area of urban paved roadway is about the same as the hydraulically effective impervious area of the basin, and, as shown by the rainfall-runoff regression, approximates that part of the rainfall that runs off the basin.

EFFICIENCY ESTIMATES OF CONSTITUENT LOAD CHANGES IN STORMWATER RUNOFF

Individual Storm Efficiency

Using the constituent loads computed as described, the individual storm efficiency of a unit such as the detention pond or wetlands is defined as the change in load divided by the initial load, given as a percentage. In equation form:

$$\text{Individual storm efficiency} = \frac{(\text{Load in} - \text{Load out})}{(\text{Load in})} \cdot 100 \qquad (4)$$

$$= \left(1 - \frac{\text{Load out}}{\text{Load in}}\right) \cdot 100$$

The loads entering and leaving, and the individual storm efficiencies of the detention pond, the wetlands, and the system (pond and wetlands) for each constituent for each storm were computed and are tabulated in the supplementary data. The pond inlet and pond outlet constituent loads were used to calculate the pond individual storm efficiencies. The pond outlet and the wetlands outlet were used to calculate the wetlands individual storm efficiencies. The pond inlet and wetlands outlet were used to calculate the system individual storm efficiencies. Increased constituent loads (loads out of the pond or wetlands greater than loads entering) were found and resulted in calculated negative efficiencies. By definition, negative individual storm efficiencies imply that loads leaving a unit are greater than loads entering.

The range of individual storm efficiencies for the study temporary storage units is quite large. Thus, the average efficiency is not indicative of the long-term performance of the system units due to the equal weight given each storm-efficiency value in computing the average. This equal weighting is a problem, particularly for storms having a small load, because small increases in net loads may result in a large negative efficiency.

For instance, the average efficiency of the pond in reducing dissolved lead was found to be -21 percent, for suspended lead -4 percent, and for total lead -3 percent (supplementary table XIV). However, most storms experienced positive efficiencies (decreased loads); average negative values were obtained because of the large negative values for storms 4 and 12. The two storms had small increases in loads that resulted in large percentage negative storm efficiencies.

Regression Efficiency

A different method of analysis than found in the literature was used in this study to determine representative efficiencies. Rather than using an average or median value to describe the overall efficiency, regression analysis is used to obtain an overall efficiency called a regression efficiency. The approach used to estimate the regression efficiency is demonstrated using data for the three phases of lead. Figure 11 shows the plots of the outlet loads versus inlet loads for the three phases of lead. Storms plotting above the line of 1:1 slope, passing through the origin, had increased loads leaving the system unit (load-out greater than load-in). Data plotting on the line of 1:1 slope had no change in loads (load-out = load-in), and storms plotting below the line had reductions (load-out less than load-in). The farther a storm plots from the 1:1 slope line, the greater the change in loads.

A simple linear, least-squares, regression was made using dissolved lead for the inlet and outlet loads and constraining the intercept to be zero. The zero intercept constraint is an engineering approximation that allows calculation of an overall efficiency and meets the general physical condition of zero loads-in (zero rainfall) yields zero loads-out. The following relation was found:

$$LEAD\_OUT = 0.71\ (LEAD\_IN) \qquad (5)$$

where

LEAD_OUT = dissolved lead loads at the pond outlet and
LEAD_IN = dissolved lead loads at the pond inlet.

Therefore, for dissolved lead, approximately 71 percent of the mass of the inlet loads is transmitted through the pond to become outlet loads, while 29 percent (unity minus the slope of the regression) is retained by the pond. Similarly, the pond retained 41 percent of suspended lead, and 39 percent of the total lead loads entering the pond (fig. 11). These efficiencies, called regression efficiencies because they were computed using the regression analysis, are considered to be more representative of the long-term efficiency of the pond for lead loads than the numerical average of the individual storm efficiencies. The standard error of estimate as a percentage of the mean dependent variable (Draper and Smith, 1966, p. 119) for these regressions was 32, 47, and 40 percent, respectively, for dissolved, suspended, and total lead (fig. 11 and supplementary data, table XIV). The standard error of estimate is a measure of the variance of the data about the regression, the smaller it is the more consistent is the regression relation. The relatively low values found for the standard error of estimate indicate consistent relations described by the regressions.

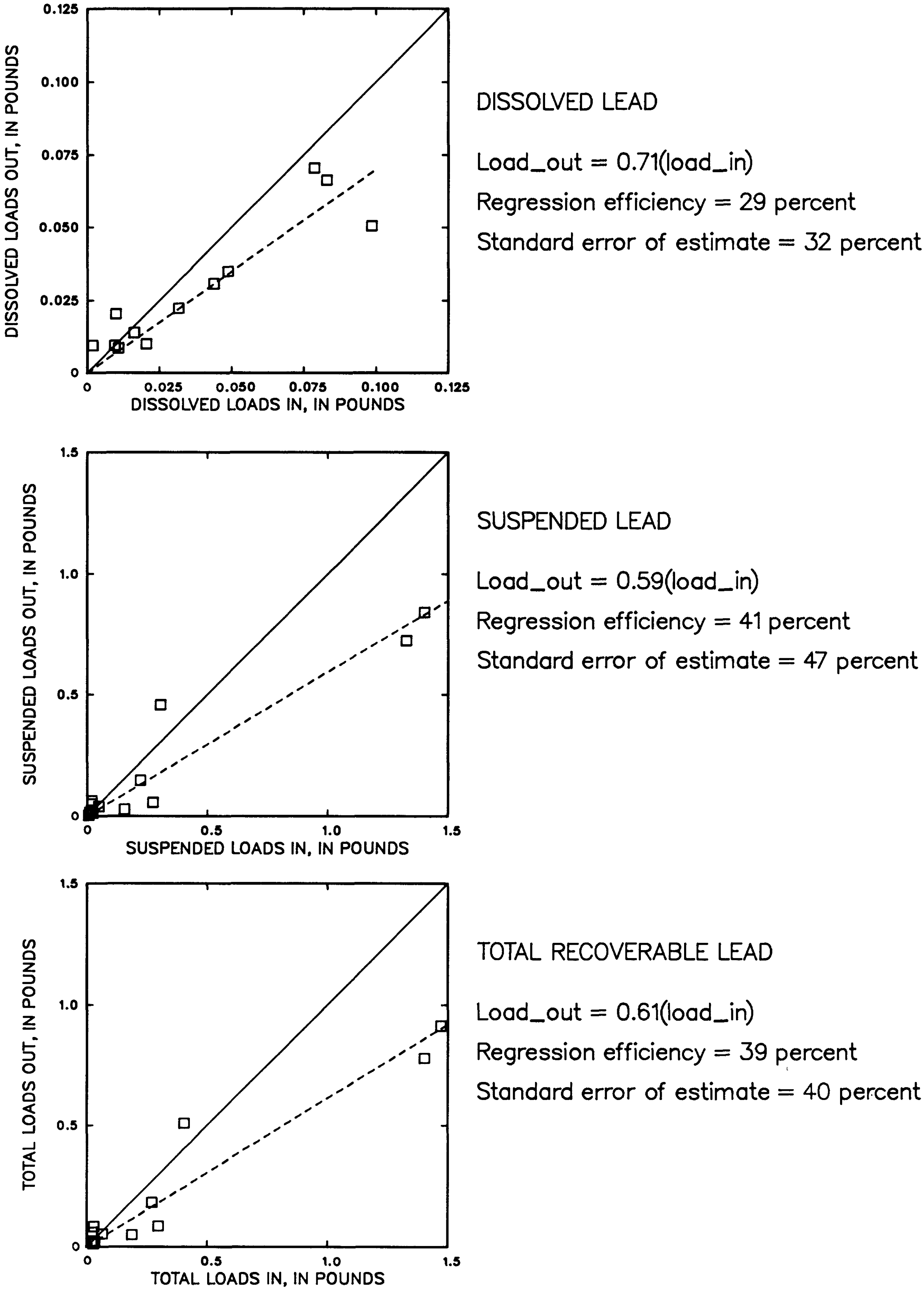

Figure 11.--Lead loads-in against lead loads-out of the detention pond.

The regression method determines the line about which the sum of the squares of the deviations of loads-out are at a minimum subject to the constraint of an origin intercept. For storms having small loads, the deviations are small though the individual storm efficiency may be relatively high. This method gives equal weights to the deviations from the regression line, not equal weight to individual storm efficiencies. Therefore, more influence is given to large storms in the regression method than in the averaging method. These large storms are probably more environmentally significant to the receiving waters because they transport larger masses of constituents. The efficiency computed using linear, least-squares regression is termed as the regression efficiency in this report.

The regression efficiency computed for each constituent is shown in tables 2, 3, 4, and 5. The slope of the regression line on which the regression efficiency is based and the standard error of estimate of the regression is shown in the tables of supplementary data. A regression analyses for the pond, the wetlands, and the entire system, were made for each constituent. Storm 7, which was not a natural rainfall-runoff event, was not used in determining the efficiencies because of its unusually long duration. The reduction of constituent loads for storm 7 was unusually high, as indicated in the supplementary data tables, and including this data in the regressions would produce higher efficiencies than those reported here. Eleven data points were used for regression analysis of the pond's efficiency and eight for the wetlands and the entire system. Because of the differences in the number of data points used for the pond and wetlands regressions, it is not possible to compute a system regression efficiency directly from the regression efficiency reported for the pond and wetlands in tables 2, 3, 4, and 5.

The standard error of estimate was used as a measure of the consistency of the regression because it is not affected by the spurious correlation that occurs when regressing loads data. Regression of loads data produces spurious correlations because the same discharge is incorporated into the independent and dependent regression variables (Benson, 1965). The standard error of estimate ranged from 10 to 60 percent, but some constituents (nutrients for example), were as high as 130 percent. Usually, coefficients less than about 50 percent indicate a consistent hydrologic relation.

CONSTITUENT-LOAD CHANGES AND REGRESSION EFFICIENCIES

The following section briefly summarizes the measured constituent-load changes and regression efficiencies for the four categories of water-quality constituents. A complete list of data and statistical summaries is given in the supplementary data tables.

Major Ions

The major ions sampled included bicarbonate, sulfate, chloride, calcium, magnesium, sodium, and potassium. The highest ion loads found in the stormwater are bicarbonate and calcium. Figures 12 and 13 show the loads of cations and anions at the measuring sites in the system for each storm. Wetlands-outlet data are not available for storms 1, 2, 3, and 6,

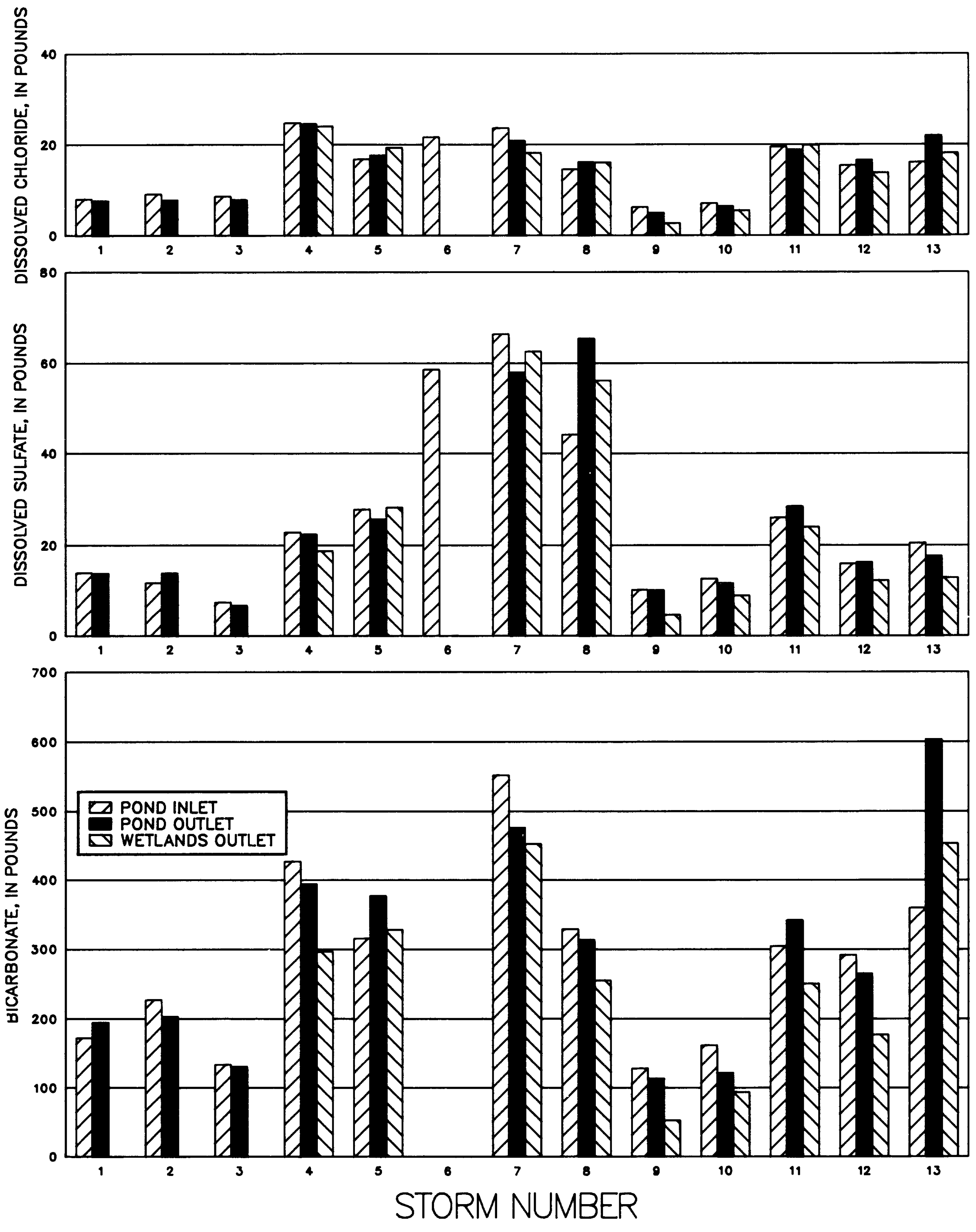

Figure 12.--Loads of cations at the pond inlet, pond outlet, and wetlands outlet.

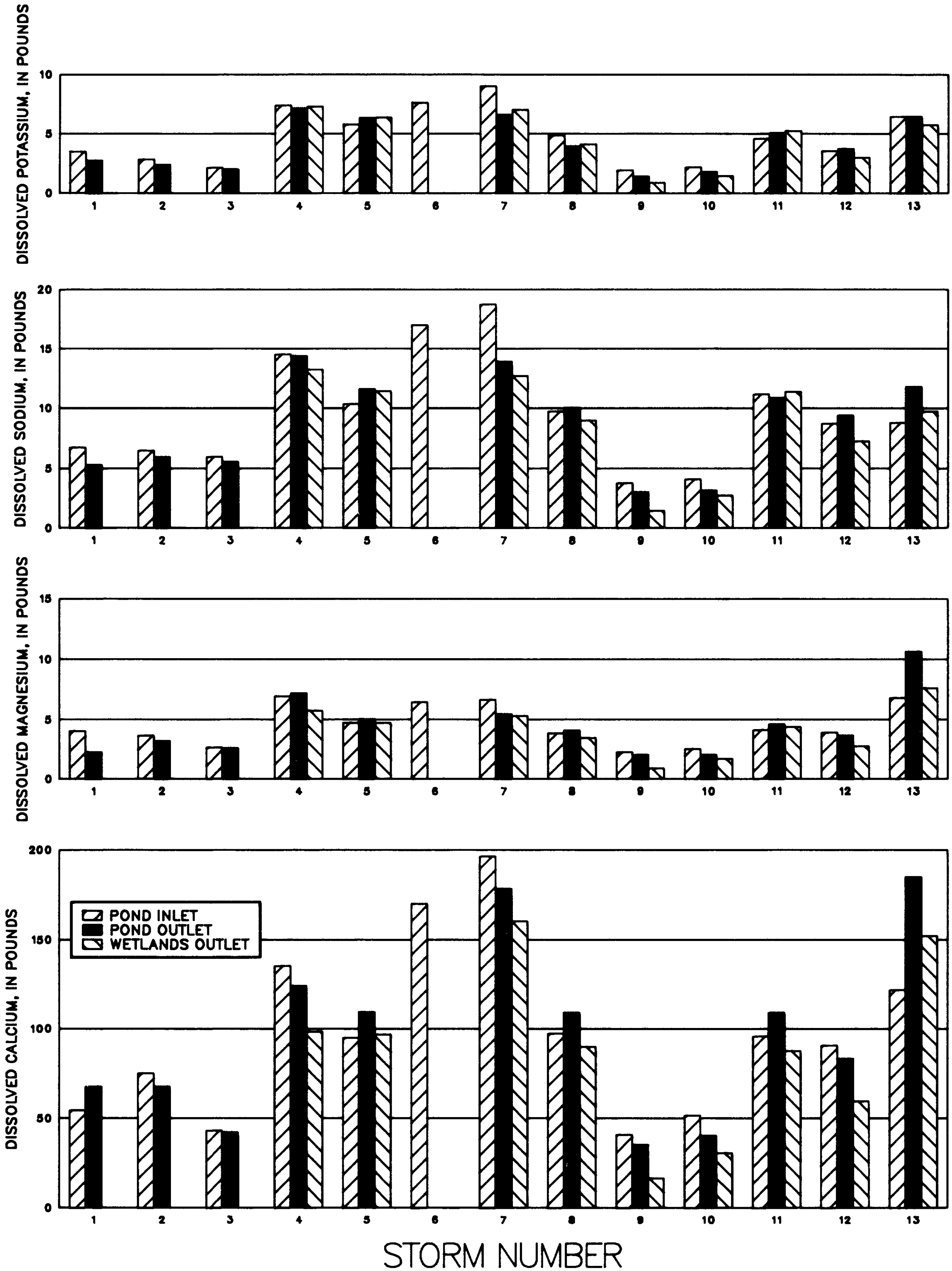

Figure 13.--Loads of anions at the pond inlet, pond outlet, and wetlands outlet.

and pond-outlet data are also not available for storm 6. For each storm, the change in loads in the pond is indicated by the difference between the pond inlet load bar and the adjacent pond outlet load bar. Changes in loads in the wetlands are indicated by the difference in the pond outlet bar and the adjacent wetlands outlet bar. The change in loads in the system for each storm is shown by the difference in the pond inlet load bar and the wetlands outlet load bar.

The regression efficiencies found for the major ion loads in the pond ranged between -5 and 9 percent (table 2). Considering the accuracy of the data, and the data collection methods used, the overall efficiency of the pond in reducing ions loads is probably close to zero.

Table 2.--Pond, wetlands, and system regression efficiencies for selected major ions

Constituent	Efficiency, in percent		
	Pond	Wetlands	System
Chloride	0	4	4
Sulfate	-3	7	2
Bicarbonate	-3	20	16
Calcium	-4	17	13
Magnesium	-5	20	10
Sodium	6	9	13
Potassium	9	1	9

The regression efficiency for ion loads in the wetlands is about 20 percent for bicarbonate, calcium, and magnesium. The wetlands regression efficiency in reducing the other ion constituent loads is 9 percent or less. The system regression efficiency for bicarbonate, calcium, magnesium, sodium, and potassium ranged from 9 to 16 percent. Chloride and sulfate were little reduced with weighted efficiencies of 4 and 2 percent, respectively.

Selected Chemical and Physical Properties

The loads of dissolved, suspended, and total solids for each part of the system are shown in bar graph form in figure 14. The total solids loads are considered large, ranging from about 1,400 pounds at the pond inlet to about 70 pounds at the wetlands outlet (fig. 14). Most of the total solids are carried in the dissolved form. At the pond inlet the dissolved solids load exceeds the suspended solids loads for all storms except storm 5.

As with ions, the detention pond had little effect on dissolved solids, with a dissolved solids loads regression efficiency of 7 percent (table 3). Suspended solids, however, were reduced significantly with a regression efficiency of 65 percent. Total solids loads (dissolved + suspended phases) were reduced at a regression efficiency of 22 percent.

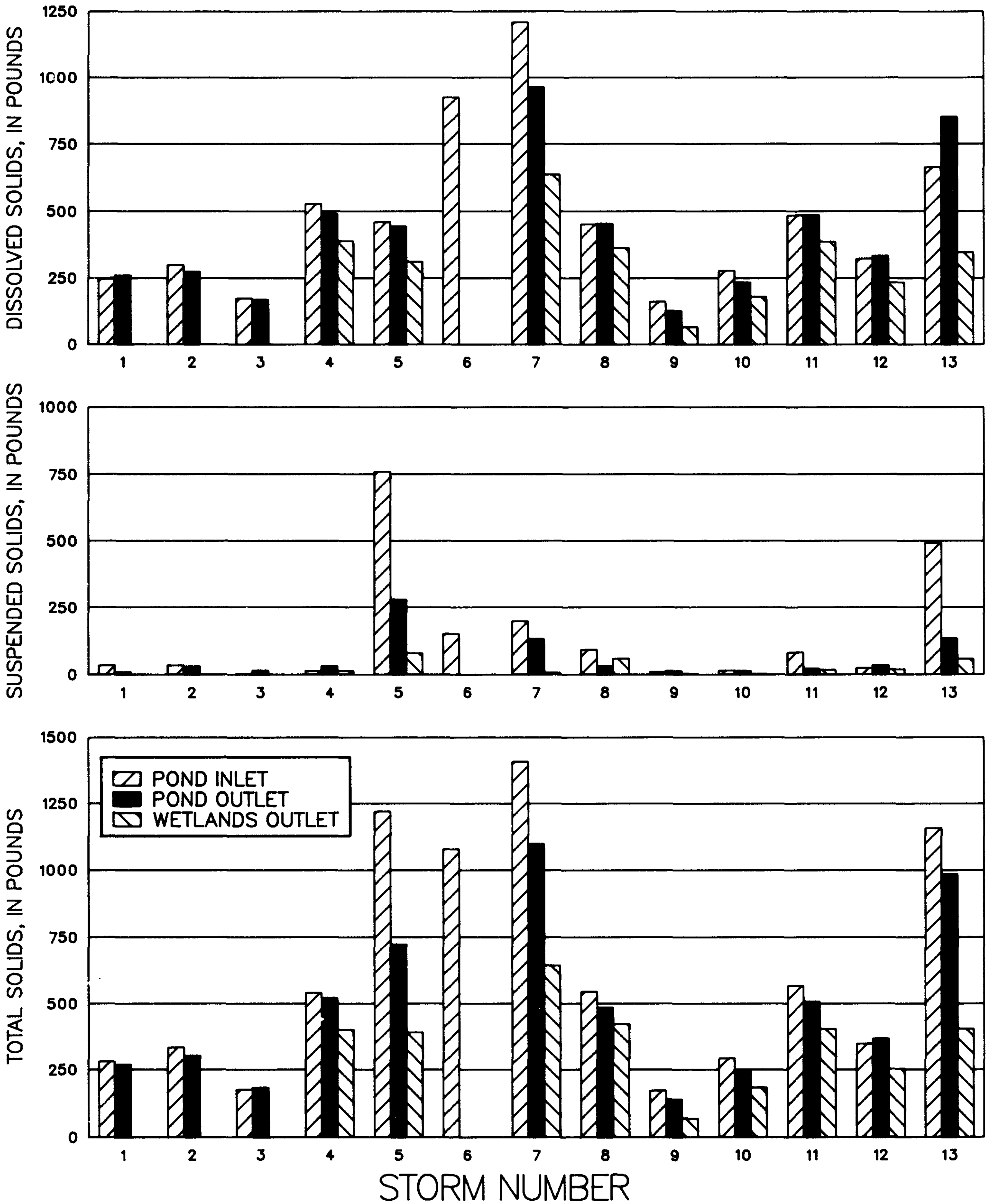

Figure 14.--Dissolved, suspended, and total solids load at the pond inlet, pond outlet, and wetlands outlet.

Table 3.--Pond, wetlands, and system regression efficiencies for selected chemical and physical characteristics

Constituent	Efficiency, in percent		
	Pond	Wetlands	System
Solids, residue at 105°C:			
Dissolved	7	38	40
Suspended	65	66	89
Total	22	41	55
Chemical oxygen demand	7	18	17
Suspended volatile solids	60	60	85
Suspended nonvolatile solids	34	-17	46

In the wetlands, the regression efficiency for dissolved solids loads was 38 percent. Suspended solids were reduced at about the same efficiency as for the pond, (66 percent). Total solids loads were reduced at a regression efficiency of 41 percent.

The pond and wetlands working together had regression efficiences of 40 percent for dissolved solids, 89 percent for suspended solids, and 55 percent for total solids.

Suspended volatile solids had a regression efficiency of 60 percent in the pond and the wetlands, and 85 percent for the system. Suspended nonvolatile solids loads were reduced by about a third in the pond, but were found to increase by 17 percent in the wetlands. The system had a regression efficiency of 46 percent for reducing suspended nonvolatile solids loads.

Chemical oxygen demand loads, ranging from 35 to 340 pounds, changed little in the pond (regression efficiency rate of 7 percent). In contrast, the wetlands reduced chemical oxygen demand loads at a regression efficiency of 18 percent. The system reduced chemical oxygen demand loads at a regression efficiency of 17 percent.

Metals

Lead and zinc were the only metals found at concentrations sufficiently above detection limits to calculate loads. Cadmium, chromium, copper, and strontium were not found above detection limits. Figures 15 and 16 are bar graphs showing the amounts of lead and zinc measured at the three measuring points. Lead was found in relatively large quantities, ranging between about 1.70 pounds of total lead at the pond inlet to almost zero total lead at the wetlands outlet (fig. 15). Lead was found to be transported primarily in the suspended form. Suspended lead loads at the pond inlet exceeded dissolved lead pond inlet loads for all monitored storms except one (storm 9).

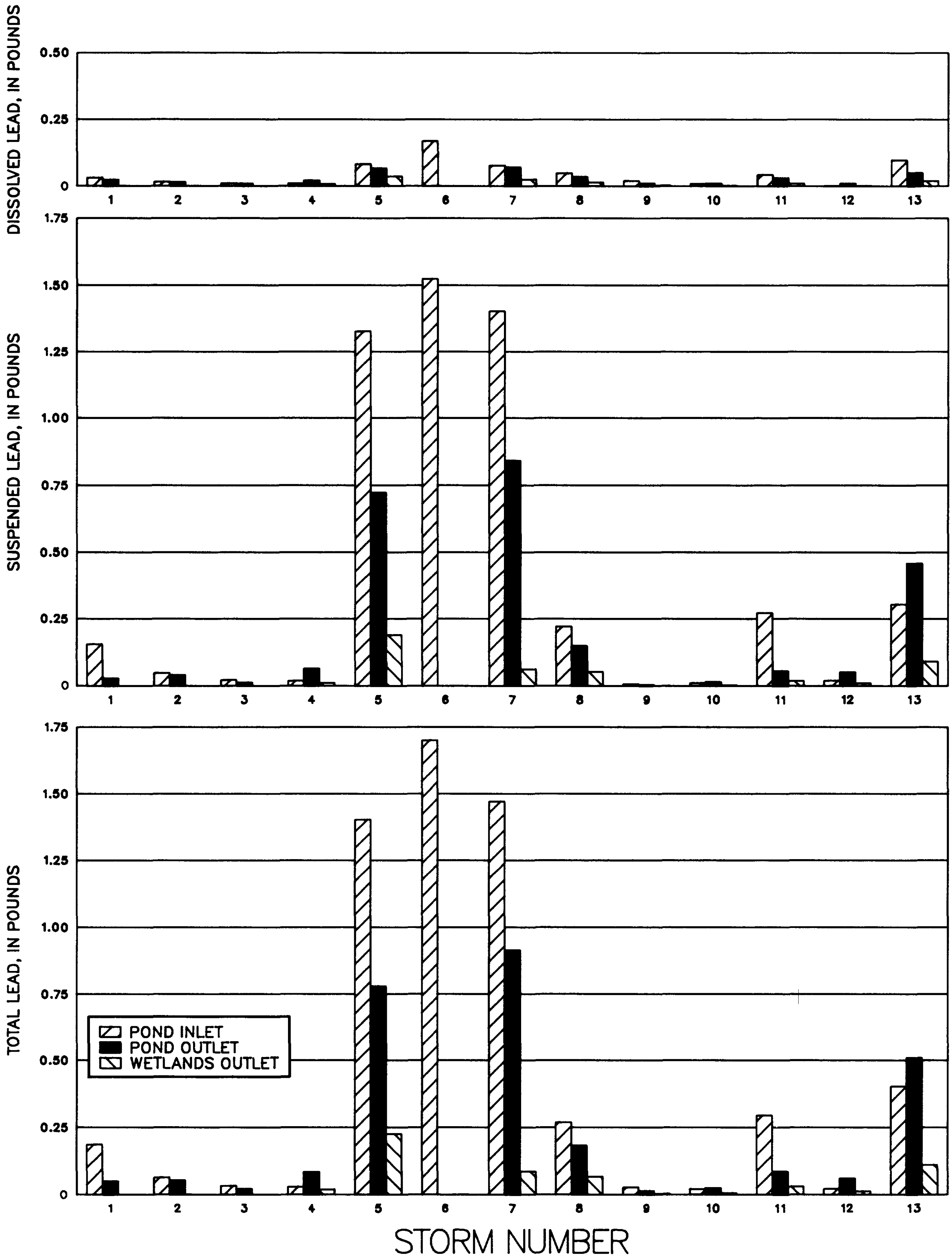

Figure 15.--Dissolved, suspended, and total recoverable lead loads at the pond inlet, pond outlet, and wetlands outlet.

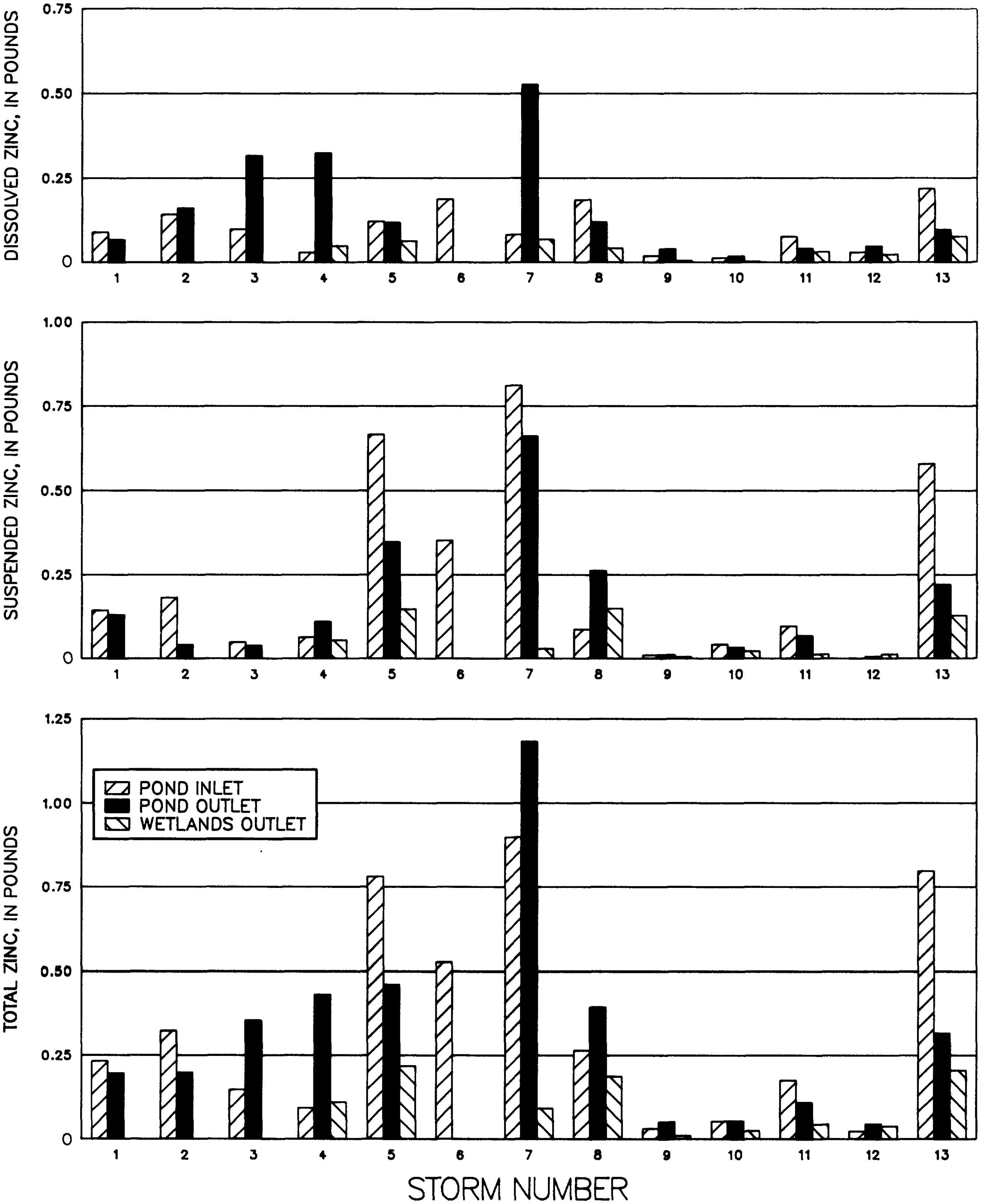

Figure 16.--Dissolved, suspended, and total recoverable zinc loads at the pond inlet, pond outlet, and wetlands outlet.

As with other constituents, the pond was moderately effective in reducing suspended lead loads (regression efficiency 41 percent, table 4). Dissolved lead loads were reduced at a regression efficiency of 29 percent. The wetlands was more effective in removing both dissolved and suspended phases lead loads than the pond. Lead loads were reduced in the wetlands at a regression efficiency of 54 percent for dissolved lead, 75 percent for suspended lead, and 73 percent for total lead. For the system dissolved loads were reduced at a weighted rate of 70 percent, suspended lead at a rate of 85 percent, and total lead at a rate of 83 percent.

Table 4.--Pond, wetlands, and system regression efficiencies for lead and zinc

Constituent	Efficiency, in percent		
	Pond	Wetlands	System
Recoverable lead:			
Dissolved	29	54	70
Suspended	41	75	85
Total	39	73	83
Recoverable zinc:			
Dissolved	-17	75	65
Suspended	37	50	76
Total	15	56	70

Suspended zinc loads were reduced in the pond at about the same rate as suspended lead loads. Dissolved zinc loads increased in the pond in 6 of the 12 storms (fig. 16); the regression efficiency rate is -17 percent. The wetlands reduced both dissolved and suspended zinc loads at a regression efficiency of 75 and 50 percent, respectively. Though the pond was apparently a source of zinc for some of the storms, the system reduced dissolved zinc loads at a regression efficiency of 65 percent, suspended loads at 76 percent efficiency, and total loads at a 70 percent efficiency.

Nutrients

The nutrient group of constituents includes the nitrogen and phosphorus species, and total organic carbon. The nitrogen species are organic nitrogen, ammonia, nitrate, and nitrite. The sum of these four species is defined as the constituent, total nitrogen. Nitrite was never found above detection limits, so for this study nitrogen is equal to the sum of organic nitrogen, ammonia, and nitrate.

Figure 17 shows the nitrogen loads at the three measuring points. Total nitrogen loads ranged from about 12 pounds at the pond inlet to about 0.5 pounds at the wetlands outlet (fig. 17). Nitrogen loads were equally proportioned in the dissolved and suspended phase. Total nitrogen was reduced at a weighted rate of 19 percent in the detention pond (table 5). Regression efficiences for dissolved and suspended forms of nitrogen are

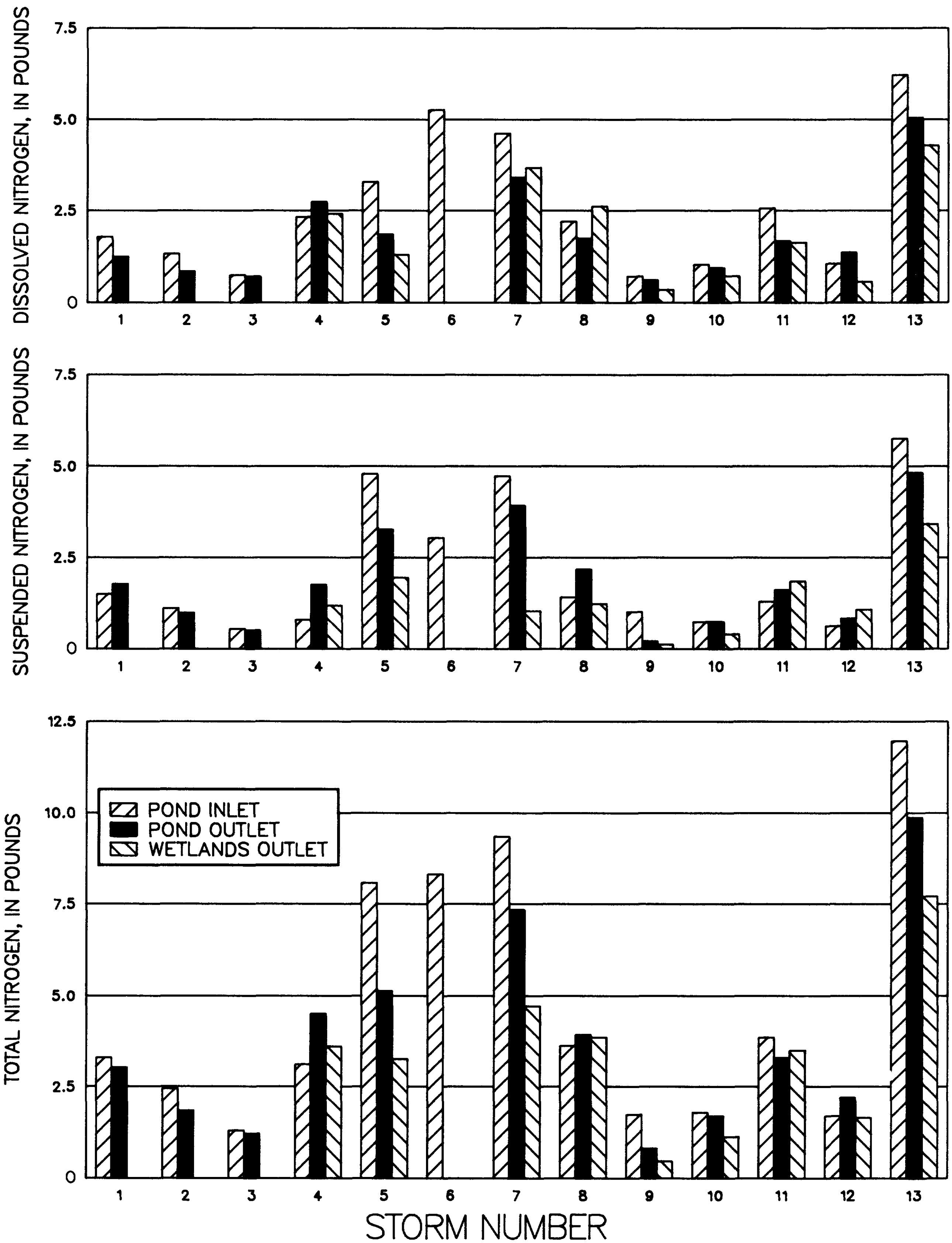

Figure 17.--Dissolved, suspended, and total nitrogen loads at the pond inlet, pond outlet, and wetlands outlet.

about the same as found for the total phase. The wetlands have a regression efficiency for dissolved nitrogen loads of 13 percent, for suspended nitrogen loads 30 percent, and for total nitrogen loads 21 percent. The system has a regression efficiency of 36 percent in reducing total nitrogen loads (table 5).

Table 5.--Pond, wetlands, and system regression efficiencies for selected nutrients

Constituent	Efficiency, in percent		
	Pond	Wetlands	System
Nitrogen:			
Dissolved	24	13	30
Suspended	17	30	43
Total	19	21	36
Organic nitrogen:			
Dissolved	19	22	39
Suspended	18	28	41
Total	17	23	39
Ammonia:			
Dissolved	72	60	80
Suspended	65	48	84
Total	60	54	61
Nitrate:			
Dissolved	24	-20	-7
Suspended	-78	90	78
Total	-17	40	9
Total organic carbon	3	18	22
Dissolved orthophosphate	76	-30	21
Phosphorus:			
Dissolved	70	0	57
Suspended	21	19	41
Total	33	17	43
Orthophosphorus:			
Dissolved	76	-30	21
Suspended	38	22	46
Total	57	2	28

Organic nitrogen makes up the largest proportion of total nitrogen. Organic nitrogen loads ranged from 9.19 pounds at the pond inlet to 0.33 pounds at the wetlands outlet (see supplementary data, table XIX). The regression efficiencies for organic nitrogen were about the same as that for total nitrogen.

Total ammonia and total nitrate loads ranged from 0.00 pounds to 1.46 pounds (supplementary data, tables XXI and XXIII). In several storms, no ammonia or nitrate were measured coming into either the pond or wetlands and a small quantity was measured leaving the system unit, resulting in an individual calculated storm efficiency using equation 5 of negative infinity.

Total ammonia was generally reduced in both the pond and the wetlands. The pond reduced total ammonia at a regression efficiency of 60 percent, the wetlands at a regression efficiency of 54 percent, and the system at a regression efficiency of 61 percent.

Total nitrate increased at a regression efficiency of 17 percent in the pond. The wetlands reduced nitrate at a regression efficiency of 40 percent. The system reduced nitrate at a regression efficiency of 9 percent.

The measured loads of phosphorus are shown in bar-chart form in figure 18. Total phosphorus and orthophosphorus were found to be reduced at a regression efficiency of 33 and 57 percent in the pond (table 5). The wetlands was found to have an efficiency of 0 and -30 for dissolved phosphorus and dissolved orthophosphorus, respectively. The system as a whole was found to have a regression efficiency of 43 and 28 percent for total phosphorus and orthophosphorus, respectively.

Total organic carbon variation in loads was found to be quite large. Total organic carbon loads ranged between 105 pounds at the pond inlet to 7 pounds at the wetlands outlet (supplementary data, table XXXI). Total organic carbon is little changed in the pond, but reduced in the wetlands and the whole system at a regression efficiency of about 20 percent (table 5).

The wetlands acts as a source of dissolved orthophosphate. The wetlands has a regression of -30 percent, whereas the pond and system achieved a reduction of 76 and 21 percent, respectively, for loads of dissolved orthophosphate.

FACTORS AFFECTING CONSTITUENT-LOAD CHANGES

Constituent loads in urban runoff are usually attributed to two processes: (1) physical deposition of materials on the surface of the basin, such as litter, trash, fertilizers from lawns, and oil and grease droppings from automobiles; and (2) atmospheric deposition on the basin of dust and dirt between storms and deposition of constituents contained in rainfall during storms. The surface deposition is a function of man's activity on the basin and is difficult to measure and is probably highly variable.

Atmospheric depositon can be measured. Table 6 shows the concentrations of bulk-precipitation samples collected at the study site. The conductance of the bulk precipitation was small, usually less than 50 microsiemens per centimeter (μS/cm) at 25°C. The concentration of solids was as much as 187 milligrams per liter (mg/L). Concentrations of total lead and zinc varied, but were as high as 88 micrograms per liter (μg/L) for lead and 400 μg/L for zinc. Lead and zinc deposition probably result from automobile emissions. Total nitrogen concentrations were never greater than about 5 mg/L.

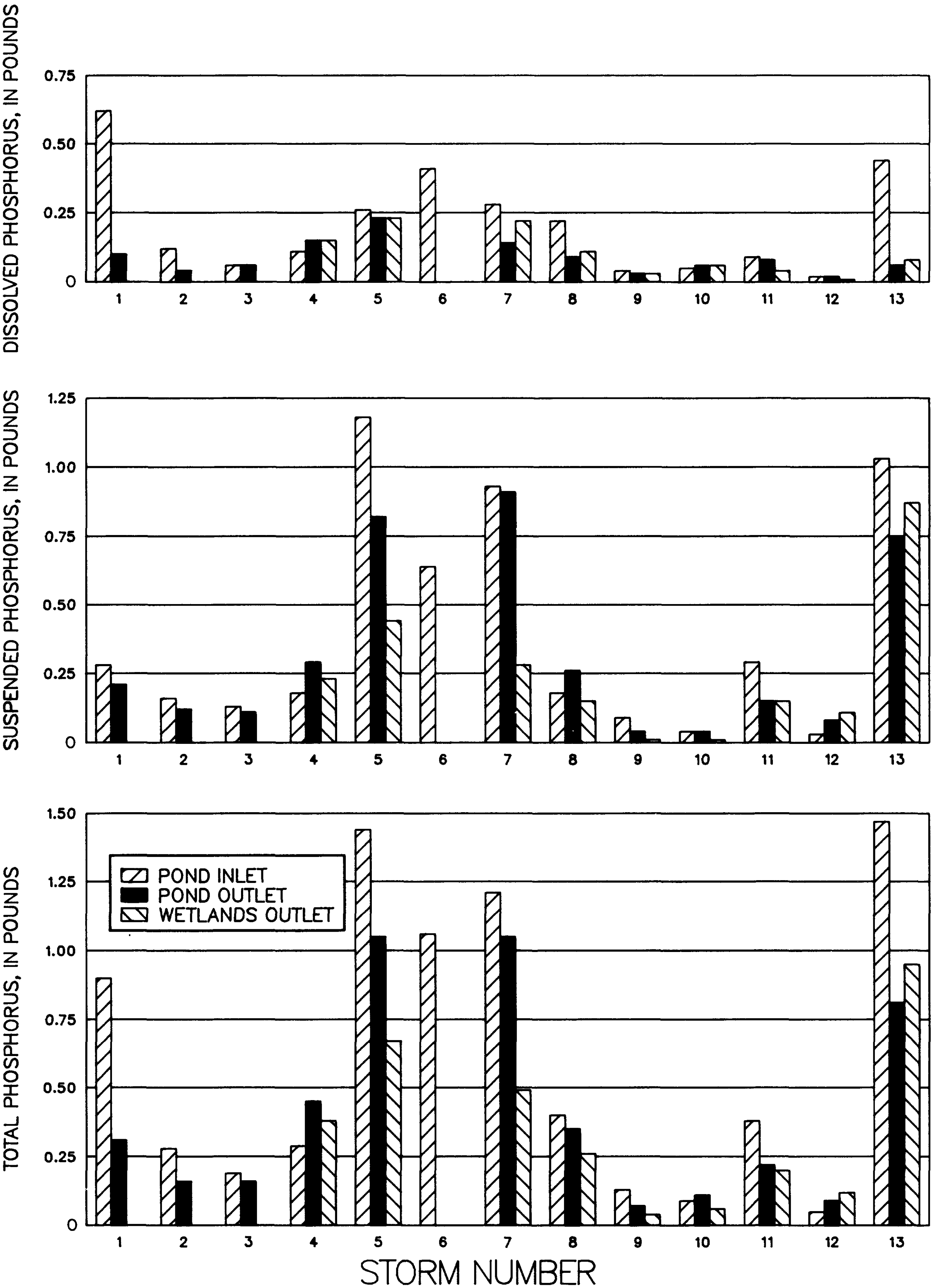

Figure 18.--Dissolved, suspended, and total phosphorus loads at the pond inlet, pond outlet, and wetlands outlet.

The deposition rate in pounds per day, for selected constituents over the 41.6-acre basin, was computed using monthly rainfall data and shown in table 6. Total solids were deposited over the basin at a rate that ranged between 11 and 146 pounds per day. The deposition rates of total zinc was higher than that found for total lead. Zinc was deposited at a maximum rate of about 0.4 pounds per day, but the maximum rate of lead was about 0.07 pounds per day. Total nitrogen deposition ranged from 0.2 to 5.6 pounds per day. These deposition rates over the basin are sufficient to account for the pond inlet constituent loads.

Table 6.--Concentrations and daily basin deposition rates of selected constituents in bulk precipitation

[μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; lbs/d, pounds per day; μg/L, micrograms per liter]

Time period	Specific conductance (μS/cm at 25°C)	Total solids (residue at 105°C)		Total lead		Total zinc		Total nitrogen	
		(mg/L)	(lbs/d)	(μg/L)	(lbs/d)	(μg/L)	(lbs/d)	(mg/L)	(lbs/d)
12/82-01/83	13	34	17	15	0.007	10	0.005	0.4	0.2
02/83-03/83	34	--	--	33	.071	50	.105	--	--
04/83-05/83	43	187	146	88	.069	90	.071	1.4	1.1
06/83	17	--	--	--	--	--	--	.6	1.5
07/83	15	50	142	17	.035	60	.122	2.2	4.5
08/83	12	7	11	13	.020	150	.227	1.0	1.5
09/83	14	16	26	8	.013	80	.130	.8	1.3
10/83	20	10	12	13	.015	40	.048	1.4	1.7
11/83-12/83	24	30	32	26	.027	400	.419	5.3	5.6
01/84-02/84	48	146	109	22	.016	90	.067	2.7	2.0
03/84	42	58	34	9	.005	100	.053	3.8	2.2

Once the constituent load reaches the detention system, the pond and wetlands in series functions somewhat like a wastewater treatment plant. Wastewater, for example, in a treatment plant is initially treated in a pretreatment or primary treatment device such as a settling basin to allow the removal of heavy and coarse suspended constituents. In this study, the detention pond functions in a similar manner by reducing suspended constituent loads. After the pretreatment or primary treatment in a wastewater plant, the effluent is treated in a secondary treatment device such as a trickling filter or activated sludge tank. The main purpose of secondary treatment is to use biological or chemical processes to change colloidal and dissolved matter into suspended solid matter. The wetlands, in this study, reduced dissolved constituent loads in a similar manner. The following is a discussion of pertinent process for each unit of the system.

Pond

Results of this study indicate the detention pond acts as a settling basin by generally reducing the suspended constituent loads. For example, the pond had a regression efficiency of 65 percent for suspended solids, 41 percent for suspended lead, 37 percent for suspended zinc, 17 percent for suspended nitrogen, and 21 percent for suspended phosphorus.

Residence time and turbulence are probably important factors that affect the settling of suspended particles. The residence time of runoff in the pond is defined as the time period for a particle to flow from the pond inlet to the pond outlet. Residence time will vary with flow rate, the mixing with water in dead storage, and the amount of available live storage in the pond. In a wastewater treatment unit, such as a settling tank, in a steady-state condition, assuming complete mixing, residence time is defined as:

$$\text{Residence time} = \frac{\text{Volume in storage } (L^3)}{\text{Discharge } (L^3/T)} \qquad (6)$$

where

L is the dimension of length and T the dimension of time.

The two conditions of steady state and complete mixing necessary for application of equation 6 to a treatment unit generally do not exist for the study detention pond. In the dynamic situation of runoff passing through the detention pond, the flow and storage change with time (fig. 8 and 9) and is, therefore, unsteady. The second condition necessary, complete mixing, is seldom achieved. When the dead and live storage capacity of the pond is exceeded, flow moves directly from the pond inlet to the pond outlet. This condition, known as short circuiting, was observed during several storms, and probably occurred for all storms in which the total runoff exceeded the total storage capacity of the pond of about 81,500 ft^3 (storms 5, 6, 7, and 13, table 1 and fig. 7).

The runoff that short circuits across the pond will have a residence time of a few minutes, and the runoff not short circuited may have a residence time of several hours. Although residence time may not be amenable to a numeric definition, the concept is still useful in that as the storage available in a treatment unit is increased and the discharge is decreased, the residence time of at least part of the runoff will increase and the removal rate of constituent loads will probably increase.

Turbulence in the pond probably varies from storm to storm depending directly on the pond inlet discharge, and indirectly on rainfall intensity. The more intense storms, such as storm 13 (table 1), with large rainfall and small durations, will have large inlet peak discharges and more turbulence than less intense storms. Unlike a waste treatment system plant, the settled material accumulating on the bottom of the pond is not generally removed as a maintenance operation. Intense high turbulence storms may scour the bottom and cause increased pond outlet loads, such as occurred for lead during storm 13 (fig. 15).

The effectiveness of the pond as a settling basin can also be seen in the accumulation of constituents in the bed sediments. The concentrations of constituents in bed sediments sampled in September 1982 and 1984 are shown in table 7. Appreciably higher metals concentrations were in the pond bed sediments than in the wetlands bed sediments, probably indicating settling in the pond.

Table 7.--Concentrations of selected constituents in bed sediments

[One sample at each site, collected during September of year noted. μg/g, microgram per gram; mg/kg, milligram per kilogram; Pb, lead; Zn, zinc; Cd, cadmium; Cr, chromium; Cu, copper; N, nitrogen; P, phosphorus]

Year	Site No.	Recoverable lead from bottom material (μg/g as Pb)	Recoverable zinc from bottom material (μg/g as Zn)	Recoverable cadmium from bottom material (μg/g as Cd)	Recoverable chromium from bottom material (μg/g as Cr)	Recoverable copper from bottom material (μg/g as Cu)	Total nitrogen in bottom material (mg/kg as N)	Total phosphorus in bottom material (mg/kg as P)
					Pond			
1982	1	620	270	6	20	41	6,900	1,600
1984	1	<10	<1	<1	3	<1	1,700	850
1982	2	220	70	3	10	26	6,900	1,000
1984	2	<10	5	<1	2	2	1,800	750
1982	3	1,200	590	9	30	73	8,600	1,400
1984	3	<10	50	<1	6	10	11,000	1,100
1982	4	410	190	5	10	26	4,000	1,800
1984	4	870	200	2	10	23	4,400	590
1982	5	340	150	5	10	27	2,900	1,100
1984	5	1,600	450	3	40	130	14,000	620
1982	6	600	240	7	10	49	14,000	720
1984	6	2,000	1,000	6	40	98	33,000	1,300
1982	7	750	360	6	10	45	4,100	1,300
1984	7	1,600	1,100	6	40	97	24,000	760
1982	8	10	4	<1	2	1	5,800	290
1984	8	10	130	<1	10	21	19,000	900
1982	9	620	250	7	20	52	6,400	1,700
1984	9	20	110	<1	20	26	23,000	760
					Wetlands			
1982	10	80	40	<1	9	3	75,000	700
1984	10	<10	2	<1	<1	<1	320	30
1982	11	10	7	<1	2	3	2,200	1,000
1984	11	30	20	<1	2	2	4,400	260
1982	12	20	10	<1	8	2	6,100	270
1984	12	<10	4	<1	1	1	520	85
1982	13	20	90	1	1	2	22,000	430
1984	13	40	10	<1	2	3	22,000	160
1982	14	10	5	<1	1	1	5,400	300
1984	14	20	7	<1	1	1	5,100	810
Median:								
Pond samples		505	195	4	10	27	7,800	950
Wetland samples		20	8	<1	2	2	5,200	280

Figure 19 is a diagram of the median concentration of lead in bed sediments from the two sampling periods. The higher concentrations of lead in the pond were generally found along or near the thalweg. The highest median concentration of lead was found in the pond along the thalweg immediately before the flow path passes over the overflow spillway at the pond outlet (fig. 19).

Concentrations of selected pesticides and industrial organic compounds in bed sediments from two sampling points in the pond and one sampling point in the wetlands are shown in table 8. The concentrations of pesticides were usually higher in the pond than in the wetlands. The highest concentration was found for chlordane, (69 micrograms per kilogram) in the pond at site 7. Site 7, near the pond outlet, usually had the highest pesticide concentrations found at the three pesticide sampling locations.

Table 8.--Concentrations of selected pesticides and industrial organic compounds in bed sediments from samples collected in September 1982

[The constituents 2,4-DP, PCN, 2,4-D, 2,4,5-T, silvex, and perthane were not found above a detection limit of 1 μg/kg at these sites. The constituents aldrin, lindane, endosulfan, endrin, ethion, heptachlor,heptachlor epoxide, methoxy-chlor, malathion, parathion diazinon, methyl parathion, mirex, trithion, and methyl trithion, were not found above detection limit of 10 μg/kg]

[Concentrations as total in bottom material, in μg/kg; <, less than]

Constituent	Site 2	Site 7	Site 14
Chlordane	4.0	69	<1.0
DDD	1.2	1.0	.2
DDE	1.9	4.3	<.1
DDT	1.0	<.1	.4
PCB	<1	15	<1
Ethion	<.1	12	<.1

As shown in table 7, the concentrations of selected constituents in the pond bed sediments can not only be high, but also variable. This variability may be caused by the random nature of the sampling technique or may indicate that intense storms create enough turbulence on the bottom of the pond to scour previously deposited constituents. The scoured constituents may either be deposited at another location in the pond or be transported out of the pond into the wetlands.

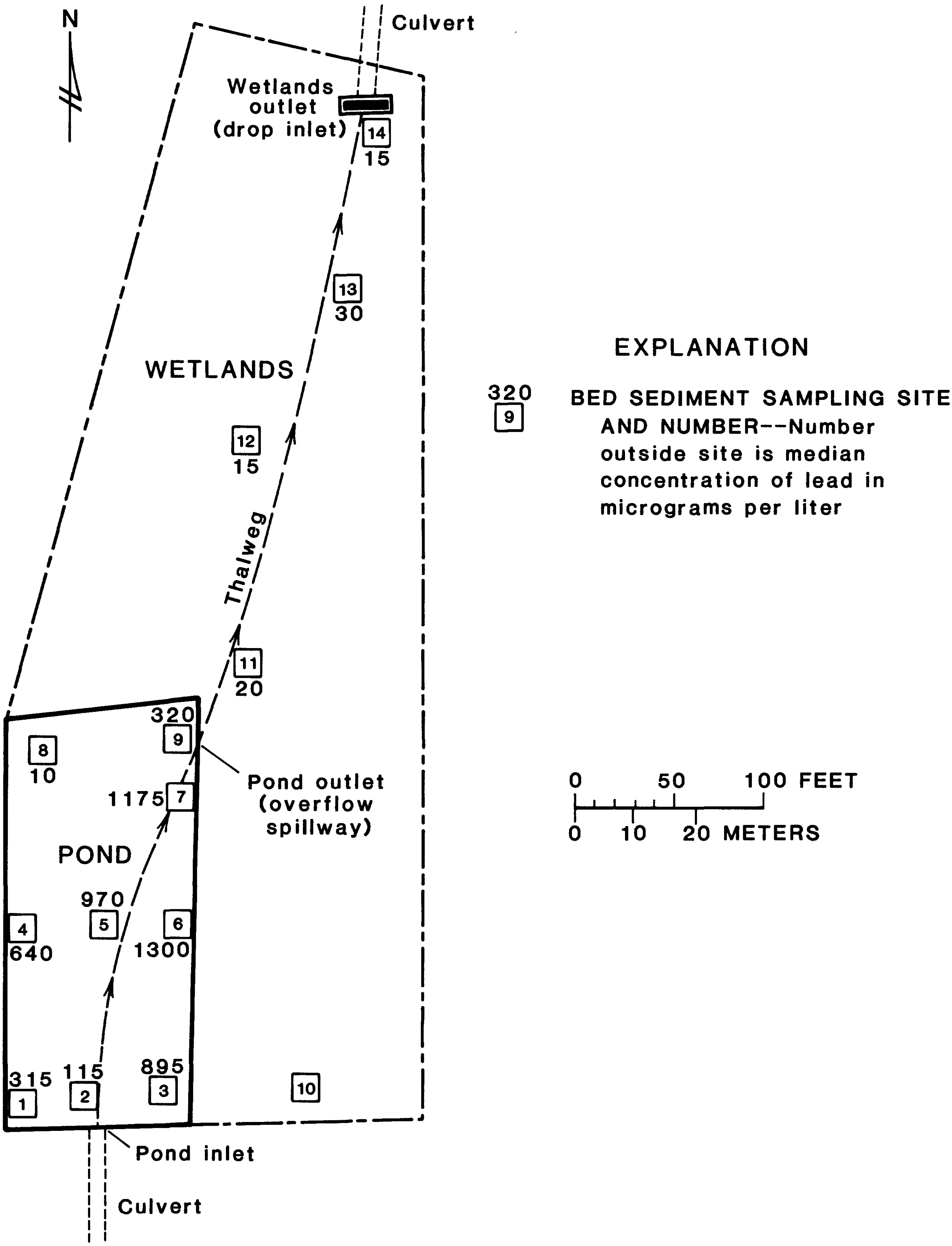

Figure 19.--Median concentrations of lead in bed sediments.

The quality and quantity of water in pond dead storage before a storm begins will influence the dissolved, and, to some extent, the suspended constituent loads at the pond outlet because the pond outlet flow is a mixture of pond inlet flow and the water in dead storage. Table 9 shows the range of concentrations of selected constituents of stormwater runoff, the pond water, and the surficial ground water. Pond samples were drawn from the center of the pond water column at a depth of 2 feet, for 1, 2, and 3 days after storms 4, 5, 7, and 11. The range of concentrations in pond water after the monitored storms is probably representative of the concentrations in the pond between storms, and thus, an indication of the pond water quality before the occurrence of the monitored storms. The dead storage volume of 54,000 ft^3 was greater than the storm runoff for 8 of the 13 monitored storms (fig. 7). The blending in the pond during storms tends to reduce the maximum runoff concentrations and increase the minimum concentrations. This equalization of maximum and minimum concentrations between the runoff and the pond water occurred for chloride, solids, lead, and phosphorus (table 9). The equalization process also occurs for the maximum concentrations of zinc and nitrogen (table 9), but is probably masked for the minimum concentrations by chemical changes that occur between storms.

Table 9.--Range of selected constituent concentrations in storm runoff, pond water, and surficial aquifer

[Storm runoff and pond water data are total concentrations for all constituents except chloride which is dissolved. Ground-water data are dissolved concentrations. Concentrations for pond water are samples from site 5, center of pond, 1, 2 and 3 days after storms 4, 5, 7 and 11. Mg/L, milligrams per liter; µg/L, micrograms per liter; Pb, lead; Zn, Zinc; N, nitrogen; P, phosphorus]

Constituent	Storm runoff		Pond water		Ground water	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Chloride (mg/L)	11.0	0.3	9.0	1.6	74	7.8
Solids (mg/L)	511	44	158	62	--	--
Lead (µg/L as Pb)	910	8	50	13	12	1
Zinc (µg/L as Zn)	530	10	80	10	56	16
Nitrogen (mg/L as N)	3.32	.50	1.3	.50	9.5	1.3
Phosphorus (mg/L as P)	.50	.02	.20	.06	.48	<.010

Chemical changes in the sediments and water column during both aerobic and anaerobic conditions and vegetative uptake in the littoral plant zone may decrease or increase constituent concentrations present in the water in pond dead storage. These biochemical transformations will affect the measured loads of constituents at the pond outlet, particularly for the smaller storms, and thus, may significantly contribute to the variability in the mass balance.

Chemical and physical processes in the pond may explain reductions in some dissolved loads of the less chemically stable constituents. The dissolved phases of lead, nitrogen, organic nitrogen, and nitrate, for instance, were removed at a regression efficiency of 20 to 30 percent (tables 4 and 5). Dissolved ammonia, orthophosphorus, phosphorus, and dissolved orthophosphate were removed in the pond at a regression efficiency of about 70 percent.

Concentrations of constituents that form soluble complexes or are part of redox systems could be increased in the pond between storms. Zinc, a common man-induced metal, is known to form relatively soluble complexes in sediments and the water column (Forstner and Wittman, 1979). This may explain the negative regression efficiency found for dissolved zinc loads in the pond (table 4). The increased suspended and total nitrate loads from the pond (table 5) may be due to nitrification in dead storage water between storms.

Wetlands

The physical and chemical processes that occur in the pond may be amplified in the wetlands. The broad shallow wetlands with its long residence times, slow velocities, high surface area to volume ratio, is environmentally conducive to physical stabilization and biological activity.

The wetlands were effective in reducing suspended constituent loads. For example, suspended solids were reduced at a regression efficiency of 66 percent, suspended lead at 75 percent, and suspended zinc at 50 percent. The processes of sedimentation, coagulation, and filtration through decomposing plant matter probably caused the reduction of suspended constituent loads in the wetlands.

The wetlands also reduces most constituent dissolved loads. For example, dissolved solids were reduced at a regression efficiency of 38 percent, dissolved lead at 54 percent, and dissolved zinc at 75 percent. These reductions are probably due to processes such as vegetative adsorption and uptake through roots, chemical transformations in plants, and chemical transformations in the sediments and water column.

The changes in dissolved and suspended nutrients loads appear to be more complex than that found for solids, lead, and zinc. The regression efficiency for total ammonia and nitrate of 54 and 40 percent, respectively, (table 5) probably indicates that ammonia and nitrate are assimilated into the wetlands vegetation or lost through denitrification in the anaerobic benthic zone (Graetz and others, 1980).

Orthophosphate is rapidly assimilated by plants, although in oxygen-rich water, orthophosphate may form insoluble complexes with some metals. Soluble phosphorus is also rapidly recycled to the water column by decaying plants and inorganic complexes in bed sediments under anaerobic conditions. Persistent anaerobic conditions in the benthic zone probably account for the -30 percent regression efficiency found for dissolved orthophosphate, the +2 percent regression efficiency for total orthophosphorus, and the relatively low 17 percent regression efficiency for total phosphorus in the wetlands. The large concentrations of nitrogen and phosphorus found in wetlands sediment (75,000 milligrams per kilogram (mg/kg) for nitrogen and 1,000 mg/kg for phosphorus, table 7), however, suggest that the wetlands is acting as an overall historical sink for some forms of nitrogen and phosphorus.

Combined System

The combined effects of the processes that occur in the system can be generally summarized by comparing the regression efficiencies of various constituents. The following ranks selected constituents according to the regression efficiencies of the system.

Constituent	Regression efficiency
Total lead	83
Total zinc	70
Total solids	55
Total phosphorus	43
Total nitrogen	36
Total orthophosphorus	28
Major ions	2-16
Dissolved nitrate	-7

The system achieved appreciable reductions in most constituent loads. For example, total solids, lead, and zinc were reduced from 55 to 83 percent, and the nutrients total nitrogen, and phosphorus, and orthophosphorus were reduced at a regression efficiency of about 30 to 40 percent. Negative regression efficiencies were estimated for dissolved nitrate. The system acts as a sink for nitrogen, but part of the retained nitrogen is exported out of the system as dissolved nitrate.

Table 10 shows the concentrations of selected constituents found in samples taken from the surficial aquifer wells. In general, the system did not seem to appreciably affect the water quality of the surficial aquifer. The high concentrations of chloride in ground water along the west border of the system probably represent typical ground water chloride concentrations (table 10). The lower concentrations of chloride on the east side of the wetlands may indicate a movement of water in the wetlands through the surficial aquifer to the drainage canal. The presence of other stormwater constituents in the surficial aquifer is not indicated by the concentrations of those constituents found in the surficial aquifer. All the wells in the surficial aquifer sampled had dissolved lead concentrations between 1 and 4 ug/L. Background dissolved lead concentrations in the pond ranged from 13 to 50 ug/L (table 9).

Table 10.--Concentrations of selected constituents in the surfical aquifer

[Samples collected April 1984. μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; μg/L, micrograms per liter; Cl, chloride; Pb, lead; Zn, zinc; N, nitrogen; P, phosphorus]

Well No.	Specific conductance (μS/cm)	Dissolved chloride (mg/L as Cl)	Dissolved lead (μg/L as Pb)	Dissolved zinc (μg/L as Zn)	Total dissolved nitrogen (mg/L as N)	Dissolved phosphorus (mg/L as P)
1	250	28	--	--	3.2	0.040
2	160	31	2	28	1.4	.480
3	210	54	2	25	1.3	<.010
4	300	74	4	56	1.4	.120
5	175	37	3	42	1.4	.150
7	170	7.8	3	21	9.5	.020
8	105	11	1	16	3.3	.020

SUMMARY

A detention pond-wetlands system that receives urban stormwater runoff was instrumented and data were collected to determine selected constituent load changes in the detention pond, wetlands, and the combined system. Data were collected to compute loads at the pond inlet, the pond outlet (wetlands inlet), and the wetlands outlet. Samples were collected and analysis made for 22 constituents contained in stormwater runoff. The constituents were grouped into 4 categories: major ions, selected physical and chemical properties, metals, and nutrients. Bulk precipitation, bed sediment, and surficial aquifer samples were collected and analyzed to aid in understanding the processes occurring in the detention pond and wetlands.

The detention pond-wetlands system receives runoff from a 41.6-acre mixed use urban basin. The detention pond has a storage volume between storms equal to about 0.35 inch of runoff from the basin and a total storage capacity of about 0.55 inch of runoff. Total storage capacity of the wetlands is about 0.80 inch of runoff.

Constituent loads, including the dissolved, suspended, and total phases for many constituents, at the pond inlet, pond outlet, and wetlands outlet, were computed for 13 storms.

A new analytical approach, not previously presented in the literature, was developed to determine a more precise estimate of the efficiency of the pond and wetlands in changing constituent loads. Rather than using a numerical average of individual storm efficiencies to determine the overall efficiency, the method linearly regresses loads into a unit, such as a detention pond or wetlands, against loads out. The intercept is constrained to be zero as an engineering approximation to allow computation of an overall efficiency and to meet the general physical condition that zero loads-in, equivalent to zero rainfall, produces zero loads-out. The efficiency of the treatment unit is unity minus the regression slope. This efficiency is called the regression efficiency.

The detention pond was found to generally reduce suspended constituent loads. The pond has a regression efficiency of 65 percent in reducing suspended solids loads, 41 percent for suspended lead loads, 37 percent for suspended zinc loads, 17 percent for suspended nitrogen loads, and 21 percent for suspended phosphorus loads. Settling of heavy suspended particles is probably the primary process controlling this reduction.

Some dissolved loads were generally reduced in the pond, but other loads were not. Major ion loads were mostly unchanged in the pond whereas dissolved lead and nitrogen regression efficiency was 29 and 24 percent, respectively. Dissolved phosphorus and dissolved orthophosphate were reduced at a regression efficiency of about 70 percent. Dissolved zinc was increased in the pond at a regression efficiency of -17 percent. Load changes of dissolved constituents commonly affected by chemical and biological transformations were generally quite variable.

The wetlands was generally effective in reducing both suspended and dissolved constituent loads. Regression efficiencies for suspended constituents include 66 percent for solids, 75 percent for lead, 50 percent for zinc, 30 percent for nitrogen, and 19 percent for phosphorus. Dissolved phase constituent regression efficiencies were 38 percent for solids, 54 percent for lead, 75 percent for zinc, 13 percent for nitrogen, and 0 percent for phosphorus. These changes are caused by the interaction of such processes as sedimentation, coagulation, filtration, adsorption, chemical transformation, and biological assimilation, and decomposition in plants.

The system achieved appreciable reductions in loads for most constituents. Significant positive regression efficiencies for the system were found for all constituents except the nutrients dissolved nitrate and dissolved orthophosphate. System regression efficiencies include 55 percent for total solids, 83 percent for total lead, and 70 percent for total zinc, 36 percent for total nitrogen, and 43 percent for total phosphorus.

REFERENCES

Benson, M. A., 1965, Spurious correlation in hydraulics and hydrology: Journal of the Hydraulics Division, ASCE, v. 91, no. HY4, July 1965, p. 35-42.

Doyle, W. H., and Lorens, J. A., 1982, Data management system for urban hydrology studies program: U.S. Geological Survey Open-File Report 82-442, 272 p.

Draper, N. R., and Smith, Harry, 1966, Applied regression analysis: New York, John Wiley, 407 p.

Ferrara, R. A., and Witkowski, Patrick, 1983, Stormwater-quality characteristics in detention basins: Journal of Environmental Engineering, ASCE, v. 109, no. 2, April 1982, paper no. 17846, p. 428-447.
Florida Department of Environmental Regulation, 1982, Regulation of stormwater discharge, Tallahassee, Florida: Chap. 17-25, in Florida Administrative Code.
Forstner, Ulrich, and Wittmann, G. T. W., 1979, Metal pollution in the aquatic environment: Springer-Verlag, New York, 486 p.
Graetz, D. A., Krohje, P. A., Erickson, N. L., Fiskell, J. G., and Rothwell, D. F., 1980, Denitrification in wetlands as a means of water-quality improvement: Florida Water Resource Center, Publication No. 48, Gainesville, Fla., 75 p.
Helwig, J. T., and Council, K. A., eds. 1979, SAS User's Guide, 1979 edition: Raleigh, N.C., SAS Institute Inc., 494 p.
Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water, 2d ed.: U.S. Geological Survey Water-Supply Paper 1473, p. 86-88.
Kilpatrick, F. A., Kaehrle, W. R., Hardee, Jack, Cordes, E. H., Landers, M. N., 1985, Development and testing of highway-sewer flow measurement and recording system: Federal Highway Administration, RD-85-050, 110 p.
Linsley, R. K., Kohler, M. A., Paulhus, J. L. H., 1975, Hydrology for engineers, 2d ed.: New York, McGraw-Hill, 182 p.
Luzkow, S. M., Scherger, D. A., and Davis, J. A., 1981, Effectiveness of two in-line urban stormwater best management practices, 1981 International symposium on urban hydrology, hydraulics, and sediment control: University of Kentucky, Lexington, Ky., July 27-30, p. 193-206.
Miller, R. A., 1978, The hydraulically effective impervious area of an urban basin, Broward County, Florida, in International symposium on urban stormwater management: Lexington, University of Kentucky, July 24-27, 1978, p. 259-261.
Scherger, D. A., and Davis, J. A., 1982, Control of stormwater runoff pollutant loads by a wetland and retention basin, 1982 International symposium on urban hydrology, hydraulics, and sediment control: University of Kentucky, Lexington, Ky., July 27-29, p. 109-123.
Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A1, 626 p.
Wanielista, M. P., and Yousef, Y. A., 1985, Overview of stormwater management practices, in Stormwater management, an update, edited by Wanielista, M. P. and Yousef, Y. A., Environmental Systems Engineering Institute, Publication no. 85-1, University of Central Florida, 315 p.
Wershaw, R. L., Fishman, M. J., Grabbe, R. R., Lowe, L. E., eds., 1983, Methods for the determination of organic substances in water and fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Laboratory Analysis, Chap. A3, Open-File Report 82-1004, 173 p.

SUPPLEMENTARY DATA I--Date, method of sampling, and computed loads of anions of the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Chloride	Sulfate	Bicarbonate	Chloride	Sulfate	Bicarbonate	Chloride	Sulfate	Bicarbonate
1	08-20-82	Discrete	8.0	14.0	172.6	7.6	13.8	194.7	--	--	--
2	10-05-82	Composite	9.1	11.8	227.5	7.7	13.9	203.2	--	--	--
3	12-08-82	do.	8.6	7.4	133.8	7.8	6.7	130.6	--	--	--
4	01-20-83	Discrete	24.8	22.9	427.8	24.6	22.4	394.2	24.0	18.8	296.9
5	02-02-83	do.	16.8	27.9	315.9	17.6	25.7	376.7	19.3	28.3	328.2
6	05-30-83	Composite	21.7	58.6	--	--	--	--	--	--	--
7	06-07-83	Discrete	23.7	66.4	552.5	20.8	57.9	476.3	18.2	62.6	453.1
8	06-21-83	Composite	14.6	44.2	329.0	16.2	65.5	314.0	16.1	56.2	255.8
9	07-15-83	do.	6.2	10.2	128.3	4.9	10.1	113.1	2.7	4.7	52.4
10	07-29-83	do.	7.1	12.6	162.0	6.4	11.6	121.3	5.5	8.9	93.7
11	11-20-83	Discrete	19.5	26.1	304.5	18.8	28.5	341.3	19.9	24.1	250.9
12	02-13-84	do.	15.5	16.0	291.9	16.5	16.3	265.0	13.8	12.3	177.0
13	06-13-84	do.	16.1	20.5	360.2	21.9	17.7	603.3	18.2	12.9	453.8
Maximum			24.8	66.4	552.5	24.6	65.5	603.3	24.0	62.6	453.8
Minimum			6.2	7.4	128.3	4.9	6.7	113.1	2.7	4.7	52.4
Mean			14.7	26.0	283.8	14.2	24.2	294.5	15.3	25.4	262.4

SUPPLEMENTARY DATA II--Individual storm efficiencies and regression slope for anions for the pond, wetlands, and the pond and wetlands system

Storm	Pond			Wetlands			System		
No.	Chloride	Sulfate	Bicarbonate	Chloride	Sulfate	Bicarbonate	Chloride	Sulfate	Bicarbonate
1	6	1	-13	--	--	--	--	--	--
2	15	-18	11	--	--	--	--	--	--
3	9	10	2	--	--	--	--	--	--
4	1	2	8	2	16	25	3	18	31
5	-5	8	-19	-10	-10	13	-15	-1	-4
7	12	13	14	12	-8	5	23	6	18
8	-11	-48	5	0	14	19	-10	-27	22
9	21	1	12	46	54	54	57	54	59
10	10	8	25	13	24	23	22	30	42
11	4	-9	-12	-6	16	26	-2	8	18
12	-7	-1	9	17	24	33	11	23	39
13	-36	14	-67	17	27	25	-13	37	-26
Maximum	21	14	25	46	54	54	57	54	59
Minimum	-36	-48	-67	-10	-10	5	-15	-27	-26
Mean	2	-2	-2	10	17	25	9	16	22
Median	5	2	6	12	16	25	3	18	22
Regression slope[1/]	100	103	103	96	93	80	96	98	84
Standard error of estimate	15	29	28	17	18	14	17	24	27

1/ Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA III--Date, method of sampling, and computed loads of cations of the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet				Load, in pounds, at pond outlet				Load, in pounds, at wetlands outlet			
			Calcium	Magnesium	Sodium	Potassium	Calcium	Magnesium	Sodium	Potassium	Calcium	Magnesium	Sodium	Potassium
1	08-20-82	Discrete	54.4	4.0	6.7	3.5	67.4	2.2	5.3	2.7	--	--	--	--
2	10-05-82	Composite	75.0	3.7	6.5	2.8	67.4	3.2	5.9	2.4	--	--	--	--
3	12-08-82	do.	43.1	2.7	6.0	2.2	42.1	2.6	5.6	2.0	--	--	--	--
4	01-20-83	Discrete	135.4	6.9	14.5	7.4	124.2	7.2	14.4	7.1	98.4	5.7	13.3	7.3
5	02-02-83	do.	94.8	4.7	10.3	5.8	109.4	5.0	11.6	6.3	96.8	4.7	11.4	6.4
6	05-30-83	Composite	170.0	6.4	17.0	7.6	--	--	--	--	--	--	--	--
7	06-07-83	Discrete	196.4	6.6	18.7	9.0	178.3	5.4	13.9	6.6	160.4	5.3	12.7	7.0
8	06-21-83	Composite	97.3	3.8	9.7	4.9	109.1	4.1	10.0	3.9	89.9	3.4	9.0	4.1
9	07-15-83	do.	40.9	2.3	3.8	1.9	35.3	2.0	3.0	1.4	16.8	.9	1.5	.9
10	07-29-83	do.	51.7	2.5	4.1	2.2	40.2	2.0	3.2	1.8	30.8	1.7	2.8	1.5
11	11-20-83	Discrete	95.8	4.1	11.2	4.6	109.1	4.6	10.9	5.1	87.5	4.4	11.4	5.3
12	02-13-84	do.	90.7	3.9	8.7	3.6	83.1	3.6	9.4	3.7	59.4	2.8	7.3	3.0
13	06-13-84	do.	121.9	6.8	8.8	6.4	184.9	10.6	11.8	6.4	152.1	7.6	9.7	5.8
Maximum			196.4	6.9	18.7	9.0	184.9	10.6	14.4	7.1	160.4	7.6	13.3	7.3
Minimum			40.9	2.3	3.8	1.9	35.3	2.0	3.0	1.4	16.8	.9	1.5	.9
Mean			97.5	4.5	9.7	4.8	95.9	4.4	8.7	4.1	88.0	4.1	8.8	4.6

SUPPLEMENTARY DATA IV--Individual storm efficiencies and regression slope for cations for the pond, wetlands, and the pond and wetlands system

Storm	Pond				Wetlands				System			
No.	Calcium	Magnesium	Sodium	Potassium	Calcium	Magnesium	Sodium	Potassium	Calcium	Magnesium	Sodium	Potassium
1	-24	45	22	21	--	--	--	--	--	--	--	--
2	10	13	8	16	--	--	--	--	--	--	--	--
3	2	3	7	7	--	--	--	--	--	--	--	--
4	8	-3	1	4	21	20	8	-2	27	17	9	1
5	-15	-6	-12	-10	12	6	1	-1	-2	0	-11	-11
7	9	18	26	27	10	2	9	-7	18	20	32	22
8	-12	-5	-3	19	18	15	10	-5	8	10	8	15
9	14	10	20	27	53	56	51	37	59	60	61	54
10	22	21	23	19	24	15	13	19	40	33	33	34
11	-14	-11	3	-10	20	5	-5	-4	9	-6	-2	-14
12	8	7	-8	-5	28	24	23	19	34	29	17	15
13	-52	-56	-34	0	18	29	17	11	-25	-12	-11	11
Maximum	22	45	26	27	53	56	51	37	59	60	61	54
Minimum	-52	-56	-34	-10	10	2	-5	-7	-25	-12	-11	-14
Mean	-4	3	4	10	22	19	14	8	19	17	15	14
Median	5	5	5	12	20	15	10	-1	18	17	9	15
Regression slope[1/]	104	105	94	91	83	80	91	99	87	90	87	91
Standard error of estimate	23	31	20	18	9	16	11	10	25	21	22	18

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA V--Date, method of sampling, and computed loads of solids of the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	247.9	34.6	282.5	259.9	7.7	267.7	--	--	--
2	10-05-82	Composite	300.1	34.5	334.6	273.8	29.8	303.5	--	--	--
3	12-08-82	do.	174.4	2.1	176.3	168.3	14.3	182.7	--	--	--
4	01-20-83	Discrete	528.3	13.0	541.3	490.4	30.0	520.4	389.1	13.1	402.2
5	02-02-83	do.	460.3	759.9	1,220.3	444.3	278.7	722.9	312.3	80.1	392.4
6	05-30-83	Composite	926.3	152.4	1,078.7	--	--	--	--	--	--
7	06-07-83	Discrete	1,209.0	198.4	1,407.4	964.4	133.0	1,097.4	637.1	7.0	644.0
8	06-21-83	Composite	452.2	93.1	545.3	453.8	30.5	484.4	363.3	59.9	423.2
9	07-15-83	do.	162.4	10.2	172.6	126.1	12.1	138.2	66.0	3.1	69.1
10	07-29-83	do.	279.3	14.8	294.1	233.8	12.7	246.5	180.4	3.2	183.7
11	11-20-83	Discrete	485.5	82.7	568.3	486.3	21.3	507.6	387.4	17.5	404.9
12	02-13-84	do.	323.9	25.0	348.9	333.4	34.5	367.9	234.0	19.4	253.4
13	06-13-84	do.	664.1	493.1	1,157.2	851.7	133.8	985.6	347.3	58.4	405.7
Maximum			1,209.0	759.9	1,407.4	964.4	278.7	1,097.4	637.1	80.1	644.0
Minimum			162.4	2.1	172.6	126.1	7.7	138.2	66.0	3.1	69.1
Mean			478.0	147.2	625.2	423.9	61.5	485.4	324.1	29.1	353.2

SUPPLEMENTARY DATA VI--Individual storm efficiencies and regression slope for dissolved, suspended, and total solids for the pond, wetlands, and the pond and wetlands system

Storm No.	Pond			Wetlands			System		
	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	-5	78	5	--	--	--	--	--	--
2	9	14	9	--	--	--	--	--	--
3	3	-581	-4	--	--	--	--	--	--
4	7	-131	4	21	56	23	26	-1	26
5	3	63	41	30	71	46	32	89	68
7	20	33	22	34	95	41	47	96	54
8	-0	67	11	20	-96	13	20	36	22
9	22	-19	20	48	74	50	59	70	60
10	16	14	16	23	75	25	35	78	38
11	-0	74	11	20	18	20	20	79	29
12	-3	-38	-5	30	44	31	28	22	27
13	-28	73	15	59	56	59	48	88	65
Maximum	22	78	41	59	95	59	59	96	68
Minimum	-28	-581	-5	20	-96	13	20	-1	22
Mean	4	-29	12	32	44	34	35	62	43
Median	3	24	11	30	56	31	32	78	38
Regression slope[1/]	93	35	78	62	34	59	60	11	45
Standard error of estimate	21	43	19	32	65	32	21	65	43

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA VII--Date, method of sampling, and computed loads of suspended volatile solids for the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet	Load, in pounds, at pond outlet	Load, in pounds, at wetlands outlet
6	05-30-83	Composite	82.1	--	--
7	06-07-83	Discrete	75.3	48.9	7.0
8	06-21-83	Composite	35.5	8.7	18.7
9	07-15-83	do.	9.2	12.1	3.1
10	07-29-83	do.	2.1	1.1	.8
11	11-20-83	Discrete	38.2	16.1	10.9
12	02-13-84	do.	2.3	6.7	1.9
13	06-13-84	do.	262.4	98.8	37.4
Maximum			262.4	98.8	37.4
Minimum			2.1	1.1	.8
Mean			63.4	27.5	11.4

SUPPLEMENTARY DATA VIII--Individual storm efficiencies and regression slope for suspended volatile solids for the pond, wetlands, and the pond and wetlands system

Storm No.	Pond	Wetlands	System
7	35	86	91
8	76	-115	47
9	-32	74	66
10	48	27	62
11	58	32	72
12	-191	72	17
13	62	62	86
Maximum	76	86	91
Minimum	-191	-115	17
Mean	8	34	63
Median	48	62	66
Regression slope[1/]	40	40	15
Standard error of estimate	34	59	54

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA IX--Date, method of sampling, and computed loads of suspended nonvolatile solids loads for the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet	Load, in pounds, at pond outlet	Load, in pounds, at wetlands outlet
6	05-30-83	Composite	70.4	--	--
7	06-07-83	Discrete	135.3	102.9	--
8	06-21-83	do.	57.6	21.8	41.2
9	07-15-83	do.	1.0	--	--
10	07-29-83	do.	12.6	--	--
11	11-20-83	Discrete	44.6	5.2	6.6
12	02-13-84	do.	19.3	27.7	20.0
13	06-13-84	do.	--	--	--
Maximum			135.3	102.9	41.2
Minimum			1.0	5.2	6.6
Mean			48.7	39.4	22.6

SUPPLEMENTARY DATA X--Individual storm efficiencies and regression slope for suspended nonvolatile solids for the pond, wetlands, and the pond and wetlands system

Storm No.	Pond	Wetlands	System
7	24	--	--
8	62	-89	29
11	88	-27	85
12	-44	28	-4
Maximum	88	28	85
Minimum	-44	-89	-4
Mean	33	-29	37
Median	43	-27	29
Regression slope 1/	66	117	54
Standard error of estimate	52	63	70

1/ Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XI--Date, method of sampling, and computed loads of chemical oxygen demand for the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet	Load, in pounds, at pond outlet	Load, in pounds, at wetlands outlet
1	08-20-82	Discrete	98.1	98.9	--
2	10-05-82	Composite	81.1	89.3	--
3	12-08-82	do.	71.5	52.6	--
4	01-20-83	Discrete	152.4	172.6	141.5
5	02-02-83	do.	195.4	190.3	152.9
6	05-30-83	Composite	58.6	--	--
7	06-07-83	Discrete	340.0	293.8	174.9
8	06-21-83	do	88.7	91.6	82.4
9	07-15-83	do	61.3	52.4	34.6
Maximum			340.0	293.8	174.9
Minimum			58.6	52.4	34.6
Mean			127.4	130.2	117.3

SUPPLEMENTARY DATA XII--Individual storm efficiencies and regression slope for chemical oxygen demand for the pond, wetlands, and the pond and wetlands system

Storm No.	Pond	Wetlands	System
1	-1	--	--
2	-10	--	--
3	26	--	--
4	-13	18	7
5	3	20	22
7	14	40	49
8	-3	10	7
9	15	34	44
Maximum	26	40	49
Minimum	-13	10	7
Mean	4	24	26
Median	1	20	22
Regression slope [1/]	93	82	83
Standard error of estimate	13	6	14

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XIII--Date, method of samp[illegible] and computed loads of lead for the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	0.032	0.155	0.188	0.022	0.028	0.050	--	--	--
2	10-05-82	Composite	.016	.049	.065	.014	.040	.054	--	--	--
3	12-08-82	do.	.011	.023	.033	.009	.012	.021	--	--	--
4	01-20-83	Discrete	.010	.020	.029	.021	.064	.084	0.008	0.012	0.019
5	02-02-83	do.	.083	1.327	1.403	.066	.723	.779	.037	.189	.226
6	05-30-83	Composite	.170	1.524	1.700	--	--	--	--	--	--
7	06-07-83	Discrete	.079	1.402	1.472	.071	.842	.914	.025	.062	.087
8	06-21-83	Composite	.049	.221	.270	.035	.148	.183	.015	.052	.067
9	07-15-83	do.	.020	.007	.028	.010	.003	.013	.003	.001	.003
10	07-29-83	do.	.010	.012	.021	.010	.015	.024	.002	.003	.006
11	11-20-83	Discrete	.044	.272	.296	.031	.056	.087	.011	.020	.031
12	02-13-84	do.	.002	.021	.022	.010	.051	.060	.002	.011	.013
13	06-13-84	do.	.098	.305	.403	.050	.458	.509	.020	.091	.111
Maximum			.170	1.524	1.700	.071	.842	.914	.037	.189	.226
Minimum			.002	.007	.021	.009	.003	.013	.002	.001	.003
Mean			.048	.411	.456	.029	.203	.232	.014	.049	.063

SUPPLEMENTARY DATA XIV--Individual storm efficiencies and regression slope for dissolved, suspended, and total lead for the pond, wetlands, and the pond and wetlands system

Storm	Pond			Wetlands			System		
No.	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	29	82	73	--	--	--	--	--	--
2	14	18	17	--	--	--	--	--	--
3	20	45	37	--	--	--	--	--	--
4	-109	-226	-186	62	82	77	20	40	34
5	20	46	44	45	74	71	56	86	84
7	10	40	38	65	93	90	68	96	94
8	28	33	32	57	65	63	69	76	75
9	50	58	53	74	83	76	87	93	89
10	0	-28	-15	75	78	77	75	72	73
11	30	79	71	64	65	65	75	93	90
12	-400	-148	-169	80	78	78	0	45	42
13	49	-50	-26	60	80	78	79	70	72
Maximum	50	82	73	80	93	90	87	96	94
Minimum	-400	-226	-186	45	65	63	0	40	34
Mean	-21	-4	-3	65	77	75	59	75	72
Median	20	36	35	65	78	77	69	76	75
Regression slope[1/]	71	59	61	46	25	27	30	15	17
Standard error of estimate	32	47	40	2[illegible]	24	23	51	46	36

[1/] Regression efficiency (percent) = 100 - regression s

SUPPLEMENTARY DATA XV--Date, method of sampling, and computed loads of zinc for the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	0.089	0.144	0.233	0.066	0.130	0.196	--	--	--
2	10-05-82	Composite	.142	.183	.324	.159	.040	.198	--	--	--
3	12-08-82	do.	.098	.049	.147	.316	.038	.354	--	--	--
4	01-20-83	Discrete	.028	.064	.092	.324	.110	.430	0.048	0.055	0.109
5	02-02-83	do.	.121	.664	.781	.117	.348	.460	.063	.148	.218
6	05-30-83	Composite	.188	.352	.528	--	--	--	--	--	--
7	06-07-83	Discrete	.082	.812	.901	.526	.660	1.183	.067	.024	.091
8	06-21-83	Composite	.186	.088	.265	.118	.262	.393	.041	.150	.187
9	07-15-83	do.	.019	.010	.031	.038	.010	.050	.005	.005	.011
10	07-29-83	do.	.013	.042	.053	.017	.032	.053	.002	.022	.024
11	11-20-83	Discrete	.076	.097	.175	.040	.068	.107	.031	.013	.044
12	02-13-84	do.	.029	.000	.023	.046	.005	.043	.023	.012	.038
13	06-13-84	do.	.219	.579	.798	.095	.221	.316	.076	.129	.205
Maximum			.219	.812	.901	.526	.660	1.183	.076	.150	.218
Minimum			.013	.000	.023	.017	.005	.043	.002	.005	.011
Mean			.099	.237	.335	.155	.160	.315	.040	.063	.103

SUPPLEMENTARY DATA XVI--Individual storm efficiencies and regression slope for dissolved, suspended, and total zinc for the pond, wetlands, and the pond and wetlands system

Storm	Pond			Wetlands			System		
No.	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	25	10	16	--	--	--	--	--	--
2	-12	78	39	--	--	--	--	--	--
3	-222	22	-141	--	--	--	--	--	--
4	-1,038	-74	-369	85	50	75	-69	14	-19
5	3	48	41	46	57	53	48	78	72
7	-538	19	-31	87	96	92	18	97	90
8	37	-196	-48	65	43	52	78	-69	29
9	-97	1	-65	88	49	79	76	49	66
10	-34	25	-0	86	31	54	81	48	54
11	48	30	39	23	81	59	60	87	75
12	-58	0	-92	51	-172	13	22	0	-66
13	56	62	60	20	41	35	65	78	74
Maximum	56	78	60	88	96	92	81	97	90
Minimum	-1,038	-196	-369	20	-172	13	-69	-69	-66
Mean	-151	2	-45	61	31	57	43	42	42
Median	-23	22	-16	65	49	54	60	49	66
Regression slope[1/]	117	63	85	25	50	44	35	24	30
Standard error of estimate	115	58	72	78	25	39	54	75	52

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XVII--Date, method of sampling, and computed loads of nitrogen of the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	1.79	1.51	3.31	1.25	1.78	3.03	--	--	--
2	10-05-82	Composite	1.34	1.12	2.45	.85	.99	1.84	--	--	--
3	12-08-82	do.	.75	.55	1.30	.71	.51	1.21	--	--	--
4	01-20-83	Discrete	2.33	.80	3.12	2.74	1.76	4.50	2.41	1.19	3.61
5	02-02-83	do.	3.29	4.79	8.08	1.86	3.27	5.13	1.31	1.96	3.27
6	05-30-83	Composite	5.28	3.05	8.32	--	--	--	--	--	--
7	06-07-83	Discrete	4.63	4.73	9.36	3.41	3.93	7.35	3.68	1.04	4.73
8	06-21-83	Composite	2.21	1.42	3.63	1.75	2.18	3.93	2.62	1.24	3.86
9	07-15-83	do.	.72	1.02	1.74	.61	.20	.81	.35	.12	.47
10	07-29-83	do.	1.05	.74	1.79	.95	.74	1.69	.73	.40	1.13
11	11-20-83	Discrete	2.57	1.30	3.86	1.68	1.62	3.30	1.64	1.86	3.50
12	02-13-84	do.	1.07	.63	1.70	1.37	0.83	2.20	.57	1.08	1.65
13	06-13-84	do.	6.22	5.75	11.97	5.05	4.82	9.87	4.29	3.42	7.71
Maximum			6.22	5.75	11.97	5.05	4.82	9.87	4.29	3.42	7.71
Minimum			.72	.55	1.30	.61	.20	.81	.35	.12	.47
Mean			2.56	2.11	4.66	1.85	1.89	3.74	1.96	1.37	3.33

SUPPLEMENTARY DATA XVIII--Individual storm efficiencies and regression slope for dissolved, suspended, and total nitrogen for the pond, wetlands, and the pond and wetlands system

Storm	Pond			Wetlands			System		
No.	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	30	-18	8	--	--	--	--	--	--
2	37	12	25	--	--	--	--	--	--
3	5	7	7	--	--	--	--	--	--
4	-18	-120	-44	12	32	20	-3	-49	-16
5	43	32	37	30	40	36	60	59	60
7	26	17	21	-8	74	36	21	78	49
8	21	-54	-8	-50	43	2	-19	13	-6
9	15	80	53	43	40	42	51	88	73
10	10	0	6	23	46	33	30	46	37
11	35	-25	15	2	-15	-6	36	-43	9
12	-28	-32	-29	58	-30	25	47	-71	3
13	19	16	18	15	29	22	31	41	36
Maximum	43	80	53	58	74	42	60	88	73
Minimum	-28	-120	-44	-50	-30	-6	-19	-71	-16
Mean	16	-7	9	14	29	23	28	18	27
Median	20	4	12	15	40	25	31	41	36
Regression slope[1/]	76	83	81	87	70	79	70	57	64
Standard error of estimate	23	31	23	29	27	17	37	49	39

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XIX--Date, method of sampling, and computed loads of organic nitrogen of the monitored storms

Storm		Method of	Load, in pounds at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
No.	Date	sampling	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	.89	1.50	2.39	1.09	1.74	2.83	--	--	--
2	10-05-82	Composite	.79	1.07	1.87	.83	.93	1.77	--	--	--
3	12-08-82	do.	.63	.55	1.18	.64	.51	1.15	--	--	--
4	01-20-83	Discrete	2.30	.80	3.09	2.41	1.73	4.14	2.23	1.19	3.43
5	02-02-83	do.	2.65	4.68	7.33	1.64	3.27	4.90	.87	1.89	2.76
6	05-30-83	Composite	3.17	2.87	6.04	--	--	--	--	--	--
7	06-07-83	Discrete	2.62	4.52	7.15	2.42	3.69	6.11	2.59	.68	3.26
8	06-21-83	Composite	1.46	1.33	2.79	1.27	2.14	3.40	1.46	1.05	2.51
9	07-15-83	do.	.48	1.01	1.49	.49	.20	.70	.23	.10	.33
10	07-29-83	do.	.78	.73	1.51	.81	.73	1.54	.31	.39	.70
11	11-20-83	Discrete	1.79	1.17	2.96	.84	1.51	2.35	1.20	.88	2.08
12	02-13-84	do.	.84	.52	1.36	1.16	.79	1.95	.43	1.05	1.48
13	06-13-84	do.	5.35	3.83	9.19	4.15	3.04	7.19	3.15	3.08	6.23
Maximum			5.35	4.68	9.19	4.15	3.69	7.19	3.15	3.08	6.23
Minimum			.48	.52	1.18	.49	.20	.70	.23	.10	.33
Mean			1.83	1.89	3.72	1.48	1.69	3.17	1.39	1.15	2.53

SUPPLEMENTARY DATA XX--Individual storm efficiencies and regression slope for dissolved, suspended, and total organic nitrogen for the pond, wetlands, and the pond and wetlands system

Storm	Pond			Wetlands			System		
No.	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	-22	-16	-18	--	--	--	--	--	--
2	-5	13	5	--	--	--	--	--	--
3	-2	7	3	--	--	--	--	--	--
4	-5	-116	-34	7	31	17	3	-49	-11
5	38	30	33	47	42	44	67	60	62
6	--	--	--	--	--	--	--	--	--
7	8	18	15	-7	82	47	1	85	54
8	13	-61	-22	-15	51	26	0	21	10
9	-2	80	53	53	50	53	52	90	78
10	-4	0	-2	62	47	55	60	47	54
11	53	-29	21	-43	42	11	33	25	30
12	-38	-52	-43	63	-33	24	49	-102	-9
13	22	21	22	24	-1	13	41	20	32
Maximum	53	80	53	63	82	55	67	90	78
Minimum	-38	-116	-43	-43	-33	11	0	-102	-11
Mean	5	-9	3	21	34	32	34	22	33
Median	-2	4	4	24	42	26	41	25	32
Regression slope[1]	81	82	83	78	72	77	61	59	61
Standard error of estimate	25	34	25	33	39	22	39	53	42

[1] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XXI--Date, method of sampling, and computed loads of ammonia of the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	0.36	0.01	0.37	0.06	0.00	0.06	--	--	--
2	10-05-82	Composite	.45	.04	.49	.02	.00	.02	--	--	--
3	12-08-82	do.	.10	.00	.10	.05	.00	.05	--	--	--
4	01-20-83	Discrete	.03	.00	.03	.11	.01	.12	0.05	0.00	0.05
5	02-02-83	do.	.18	.09	.27	.09	.00	.09	.21	.00	.21
6	05-30-83	Composite	.94	.06	1.00	--	--	--	--	--	--
7	06-07-83	Discrete	1.28	.18	1.46	.24	.24	.48	.29	.28	.58
8	06-21-83	Composite	.31	.00	.31	.04	.04	.09	.79	.07	.86
9	07-15-83	do.	.13	.01	.14	.01	.00	.01	.03	.01	.04
10	07-29-83	do.	.17	.01	.18	.03	.01	.04	.34	.02	.36
11	11-20-83	Discrete	.41	.09	.50	.58	.12	.69	.11	.00	.11
12	02-13-84	do.	.05	.12	.17	.04	.05	.08	.01	.01	.02
13	06-13-84	do.	.21	1.12	1.33	.20	.35	.55	.15	.18	.33
Maximum			1.28	1.12	1.46	.58	.35	.69	.79	.28	.86
Minimum			.03	.00	.03	.01	.00	.01	.01	.00	.02
Mean			.36	.13	.49	.12	.07	.19	.22	.06	.28

SUPPLEMENTARY DATA XXII--Individual storm efficiencies and regression slope for dissolved, suspended, and total ammonia for the pond, wetlands, and the pond and wetlands system

[*** = calculated efficiency of negative infinity]

Storm	Pond			Wetlands			System		
No.	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	83	100	84	--	--	--	--	--	--
2	96	100	96	--	--	--	--	--	--
3	50	0	50	--	--	--	--	--	--
4	-267	***	-300	55	100	58	-67	0	-67
5	50	100	67	-133	0	-133	-17	100	22
7	81	-33	67	-21	-17	-21	77	-56	60
8	87	***	71	-1,875	-75	-856	-155	***	-177
9	92	100	93	-200	***	-300	77	0	71
10	-82	0	78	-1,033	-100	-800	-100	-100	-100
11	-41	-33	-38	81	100	84	73	100	78
12	20	58	53	75	80	75	80	92	88
13	5	69	59	25	49	40	29	84	75
Maximum	96	100	96	81	100	84	80	100	88
Minimum	-267	***	-300	-1,875	***	-856	-155	***	-177
Mean	28	--	32	-337	--	-206	0	--	6
Median	66	29	67	-21	0	-21	29	0	60
Regression slope[1]	28	35	40	40	52	46	20	16	39
Standard error of estimate	130	66	88	156	44	142	108	23	127

[1] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XXIII--Date, method of sampling, and computed loads of nitrate of the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	0.50	0.00	0.50	0.09	0.04	0.13	--	--	--
2	10-05-82	Composite	.08	.00	.08	.00	.04	.04	--	--	--
3	12-08-82	do.	.02	.00	.02	.01	.00	.01	--	--	--
4	01-20-83	Discrete	.00	.00	.00	.20	.01	.21	0.13	0.00	0.13
5	02-02-83	do.	.38	.00	.38	.07	.00	.07	.18	.00	.18
6	05-30-83	Composite	1.11	.06	1.17	--	--	--	--	--	--
7	06-07-83	Discrete	.64	.01	.65	.61	.00	.61	.73	.09	.82
8	06-21-83	Composite	.35	.04	.40	.35	.00	.35	.15	.11	.26
9	07-15-83	do.	.09	.00	.09	.09	.00	.09	.08	.02	.09
10	07-29-83	do.	.09	.00	.09	.10	.00	.10	.07	.00	.07
11	11-20-83	Discrete	.33	.02	.34	.22	.00	.22	.31	.98	1.29
12	02-13-84	do.	.15	.00	.15	.13	.01	.14	.11	.01	.12
13	06-13-84	do.	.59	.78	1.37	.65	1.39	2.04	.95	.14	1.09
Maximum			1.11	.78	1.37	.65	1.39	2.04	.95	.98	1.29
Minimum			.00	.00	.00	.00	.00	.01	.07	.00	.07
Mean			.33	.07	.40	.21	.12	.33	.30	.15	.45

SUPPLEMENTARY DATA XXIV--Individual storm efficiencies and regression slope for dissolved, suspended, and total nitrate for the pond, wetlands, and the pond and wetlands system

[*** = calculated efficiency of negative infinity]

Storm	Pond			Wetlands			System		
No.	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	82	***	74	--	--	--	--	--	--
2	100	***	50	--	--	--	--	--	--
3	50	0	50	--	--	--	--	--	--
4	***	***	***	35	100	38	***	0	***
5	82	0	82	-157	0	-157	53	0	53
7	5	100	6	-20	***	-34	-14	-800	-26
8	0	100	12	57	***	26	57	-175	35
9	0	0	0	11	***	0	11	***	0
10	-11	0	-11	30	0	30	22	0	22
11	33	100	35	-41	***	-486	6	-4,800	-279
12	13	***	7	15	0	14	27	***	20
13	-10	-78	-49	-46	90	47	-61	82	20
Maximum	100	100	82	57	100	47	57	82	53
Minimum	***	***	***	-157	***	-486	***	***	***
Median	9	0	6	-20	0	14	11	-175	20
Regression slope[1/]	76	178	117	120	10	60	107	22	91
Standard error of estimate	64	0	72	55	12	110	71	169	93

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XXV--Date, method of sampling, and computed loads of phosphorus of the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	0.62	0.28	0.90	0.10	0.21	0.31	--	--	--
2	10-05-82	Composite	.12	.16	.28	.04	.12	.16	--	--	--
3	12-08-82	do.	.06	.13	.19	.06	.11	.16	--	--	--
4	01-20-83	Discrete	.11	.18	.29	.15	.29	.45	0.15	0.23	0.38
5	02-02-83	do.	.26	1.18	1.44	.23	.82	1.05	.23	.44	.67
6	05-30-83	Composite	.41	.64	1.06	--	--	--	--	--	--
7	06-07-83	Discrete	.28	.93	1.21	.14	.91	1.05	.22	.28	.49
8	06-21-83	Composite	.22	.18	.40	.09	.26	.35	.11	.15	.26
9	07-15-83	do.	.04	.09	.13	.03	.04	.07	.03	.01	.04
10	07-29-83	do.	.05	.04	.09	.06	.04	.11	.06	.01	.06
11	11-20-83	Discrete	.09	.29	.38	.08	.15	.22	.04	.15	.20
12	02-13-84	do.	.02	.03	.05	.02	.08	.09	.01	.11	.12
13	06-13-84	do.	.44	1.03	1.47	.06	.75	.81	.08	.87	.95
Maximum			.62	1.18	1.47	.23	.91	1.05	.23	.87	.95
Minimum			.02	.03	.05	.02	.04	.07	.01	.01	.04
Mean			.21	.40	.61	.09	.32	.40	.10	.25	.35

SUPPLEMENTARY DATA XXVI--Individual storm efficiencies and regression slope for dissolved, suspended, and total phosphorus for the pond, wetlands, and the pond and wetlands system

Storm	Pond			Wetlands			System		
No.	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	84	25	66	--	--	--	--	--	--
2	67	25	43	--	--	--	--	--	--
3	0	15	16	--	--	--	--	--	--
4	-36	-61	-55	0	21	16	-36	-28	-31
5	12	31	27	0	46	36	12	63	53
7	50	2	13	-57	69	53	21	70	60
8	59	-44	12	-22	42	26	50	17	35
9	25	56	46	0	75	43	25	89	69
10	-20	0	-22	0	75	45	-20	75	33
11	11	48	42	50	0	9	56	48	47
12	0	-167	-80	50	-38	-33	50	-267	-140
13	86	27	45	-33	-16	-17	82	16	35
Maximum	86	56	66	50	75	53	82	89	69
Minimum	-36	-167	-80	-57	-38	-33	-36	-267	-140
Mean	28	-4	13	-1	30	20	27	9	18
Median	18	20	22	0	42	26	25	48	35
Regression slope[1/]	30	79	67	100	81	83	43	59	57
Standard error of estimate	84	29	38	21	55	39	83	62	34

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XXVII--Date, method of sampling, and computed loads of orthophosphorus of the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet			Load, in pounds, at pond outlet			Load, in pounds, at wetlands outlet		
			Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	08-20-82	Discrete	0.53	0.08	0.61	0.07	0.07	0.15	--	--	--
2	10-05-82	Composite	.20	.00	.20	.02	.08	.10	--	--	--
3	12-08-82	do.	.05	.04	.09	.05	.03	.08	--	--	--
4	01-20-83	Discrete	.06	.04	.10	.09	.11	.20	0.10	0.07	0.17
5	02-02-83	do.	.16	.31	.47	.15	.19	.34	.21	.17	.38
6	05-30-83	Composite	.18	.23	.41	--	--	--	--	--	--
7	06-07-83	Discrete	.18	.27	.45	.08	.13	.21	.09	.11	.20
8	06-21-83	Composite	.18	.00	.18	.04	.04	.09	.07	.07	.15
9	07-15-83	do.	.01	.02	.03	.01	.00	.01	.01	.02	.03
10	07-29-83	do.	.01	.03	.04	.01	.02	.03	.02	.01	.03
11	11-20-83	Discrete	.06	.08	.13	.03	.13	.16	.02	.07	.09
12	02-13-84	do.	.02	.02	.02	.02	.02	.02	.02	.01	.03
13	06-13-84	do.	.12	.31	.43	.07	.19	.26	.08	.15	.23
Maximum			.53	.31	.61	.15	.19	.34	.21	.17	.38
Minimum			.01	.00	.02	.01	.00	.01	.01	.01	.03
Mean			.14	.11	.24	.05	.08	.14	.07	.08	.15

SUPPLEMENTARY DATA XXVIII--Individual storm efficiencies and regression slope for dissolved, suspended, and total orthophosphorus for the pond, wetlands, and the pond and wetlands system

[*** = calculated efficiency of negative infinity]

Storm	Pond			Wetlands			System		
No.	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total
1	87	13	75	--	--	--	--	--	--
2	90	***	50	--	--	--	--	--	--
3	0	25	11	--	--	--	--	--	--
4	-50	-175	-100	-11	36	15	-67	-75	-70
5	6	39	28	-40	11	-12	-31	45	19
6	--	--	--	--	--	--	--	--	--
7	56	52	53	-13	15	5	50	59	56
8	78	***	50	-75	-75	-67	61	***	17
9	0	100	67	0	***	-200	0	0	0
10	0	33	25	-100	50	0	-100	67	25
11	50	-63	-23	33	46	44	67	13	31
12	0	0	0	0	50	-50	0	50	-50
13	42	39	40	-14	21	12	33	52	47
Maximum	90	100	75	33	50	44	67	67	56
Minimum	-50	***	-100	-100	***	-200	-100	***	-70
Mean	30	--	23	-24	--	-28	1	--	8
Median	24	19	34	-13	21	0	0	45	19
Regression slope[1/]	24	62	43	130	78	98	79	54	72
Standard error of estimate	93	45	74	21	30	30	72	34	37

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XXIX--Date, method of sampling, and computed loads of dissolved orthophosphate for the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet	Load, in pounds, at pond outlet	Load, in pounds, at wetlands outlet
1	08-20-82	Discrete	1.63	0.22	--
2	10-05-82	Composite	.63	.06	--
3	12-08-82	do.	.15	.14	--
4	01-20-83	Discrete	.17	.26	0.31
5	02-02-83	do.	.48	.44	.64
6	05-30-83	Composite	.53	--	--
7	06-07-83	Discrete	.55	.24	.21
8	06-21-83	Composite	.53	.13	.45
9	07-15-83	do.	.03	.03	.03
10	07-29-83	do.	.03	.03	.07
11	11-20-83	Discrete	.18	.09	.07
12	02-13-84	do.	.06	.06	.06
13	06-13-84	do.	.37	.21	.24
Maximum			1.63	.44	.64
Minimum			.03	.03	.03
Mean			.41	.16	.23

SUPPLEMENTARY DATA XXX--Individual storm efficiencies and regression slope for dissolved orthophosphate for the pond, wetlands, and the pond and wetlands system

Storm No.	Pond	Wetlands	System
1	87	--	--
2	90	--	--
3	7	--	--
4	-53	-19	-82
5	8	-45	-33
7	56	-17	49
8	75	-62	60
9	0	0	0
10	0	-57	-57
11	50	22	61
12	0	0	0
13	43	-14	35
Maximum	90	22	61
Minimum	-53	-62	-82
Mean	30	-21	4
Median	26	-17	0
Regression slope[1/]	24	130	79
Standard error of estimate	96	21	72

[1/] Regression efficiency (percent) = 100 - regression slope.

SUPPLEMENTARY DATA XXXI--Date, method of sampling, and computed loads of total organic carbon for the monitored storms

Storm No.	Date	Method of sampling	Load, in pounds, at pond inlet	Load, in pounds, at pond outlet	Load, in pounds, at wetlands outlet
1	08-20-82	Discrete	37.4	39.0	--
2	10-05-82	Composite	30.4	41.7	--
3	12-08-82	do.	24.5	23.9	--
4	01-20-83	Discrete	73.1	80.4	60.0
5	02-02-83	do.	46.3	46.2	34.8
6	05-30-83	Composite	105.5	--	--
8	06-21-83	do.	57.5	42.8	44.9
9	07-15-83	do.	20.4	13.1	7.3
10	07-29-83	do.	23.2	21.2	17.8
11	11-20-83	Discrete	52.1	44.9	39.4
12	02-13-84	do.	27.0	27.4	23.8
13	06-13-84	do.	74.3	70.8	59.3
Maximum			105.5	80.4	60.0
Minimum			20.4	13.1	7.3
Mean			47.6	41.0	35.9

SUPPLEMENTARY DATA XXXII--Individual storm efficiencies and regression slope for total organic carbon for the pond, wetlands, and the pond and wetlands system

Storm No.	Pond	Wetlands	System
1	-4	--	--
2	-37	--	--
3	2	--	--
4	-10	25	18
5	--	25	25
8	26	-5	22
9	36	44	64
10	9	16	23
11	14	12	24
12	-2	13	12
13	5	16	20
Maximum	36	44	64
Minimum	-37	-5	12
Mean	4	18	26
Median	7	16	22
Regression slope[1/]	97	82	78
Standard error of estimate	17	13	10

[1/]Regression efficiency (percent) = 100 - regression slope.

*U.S. GOVERNMENT PRINTING OFFICE: 1986-631-135/20017 Region 4.