EFFECTS OF STORMWATER DETENTION ON THE CHEMICAL QUALITY OF RUNOFF FROM A SMALL RESIDENTIAL DEVELOPMENT, MONROE COUNTY, NEW YORK

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To Obtain*
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
	Area	
acre	0.4047	hectare
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch per year (in/yr)	25.4	millimeter per year
inch per hour (in/h)	25.4	millimeter per hour
	Volume	
acre per foot	1233.619	cubic meter
	Weight	
Pound (lb)	453.5924	gram
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)

Other Abbreviations

milligrams per liter (mg/L) = parts per million
micrograms per liter (µg/L) = parts per billion
milligrams per kilogram (mg/kg) = parts per million
micrograms per kilogram (µg/kg) = parts per billion

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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Abstract

Streamflow and water-quality data were collected at a normally dry 0.90-acre-foot-capacity flow-detention basin from August 1986 through September 1989 to assess the basin's effectiveness in removing chemical constituents in runoff from a 27-acre, moderate-density residential development. Data were collected at the inlet and outlet of the basin during three periods—from June 1986 through April 1988 with the original outlet, from May 1988 through December 1988 after an outlet modification to double the detention time, and from January 1988 through September 1989 after a second outlet modification to increase detention time 10-fold over that of the first modification.

Mass flux and trap efficiencies of 22 chemical constituents were calculated for each of the three outlet configurations. Three different methods of calculating trap efficiency were examined: (1) event mean concentration (EMC), (2) summation of loads (SOL), and (3) regression of loads (ROL). Each method incorporates slightly different features of the data. All methods generally yielded similar results, but the EMC method typically indicated slightly lower efficiency, and the ROL method slightly higher efficiency, than the SOL method. The EMC method was used to compare outlet-modification efficiency because it is more widely used than the other methods.

Trap efficiencies differed among constituents and outlet configurations. The unmodified outlet yielded a wide range of values; trap efficiency for most nutrients and solids was small or negative (suspended solids, -14 percent; suspended volatile solids, -40 percent; total phosphorus, -2.6 percent; total orthophosphorus, 6.8 percent; total organic carbon, -15 percent), whereas trap efficiency for metals, which occur largely in suspension, was relatively high, 35 and 42 percent for total lead and zinc, respectively.

The first modification substantially improved trap efficiency for most constituents, but the second modification caused only slight further improvement. Trap efficiencies for configurations 2 and 3 were, respectively, suspended solids, 79 and 84 percent; total volatile solids, 70 and 71 percent; total phosphorus, 12 and 32 percent; total orthophosphorus, 54 and 29 percent; total organic carbon, 31 and 47 percent; total lead, 61 and 38 percent; and zinc, 54 and 66 percent. Although trap efficiency for most constituents improved after both outlet modifications, the differences were significant only with respect to total solids and total organic carbon at the 95-percent confidence level and total phosphorus and total orthophosphorus at the 90-percent confidence level.

This study indicates that the original design of the detention basin for stormflow control is not highly effective in decreasing chemical loads in stormwater, but simple modifications to the outlet to increase retention time improved constituent removal.

INTRODUCTION

Irondequoit Bay, on Lake Ontario, near Rochester, N.Y. (fig. 1), has undergone extensive study and restoration to remove sediment and associated chemical constituents that have adversely affected its quality and use as a recreational resource for the surrounding communities. One of the principal water-quality studies of the bay's watershed was conducted in the 1980's under the aegis of the National Urban Runoff Program (NURP). That study, as well as others, showed that water-quality degradation associated with urbanization contributes substantially to the highly eutrophic condition of the bay (O'Brien and Gere, 1983; Kappel and others, 1986). To mitigate the effects of urbanization on receiving waters, the use of detention basins was recommended (O'Brien and Gere, 1983; Athayde and others, 1983). Such basins could serve to decrease sediment and associated constituent loads as well as excess storm runoff from impervious surfaces, but their effectiveness as a tool for water-quality control remains largely undocumented (Huber, 1988).

Detention basins have been widely used in urban watersheds to control the rate and volume of runoff from impervious surfaces. Most com-

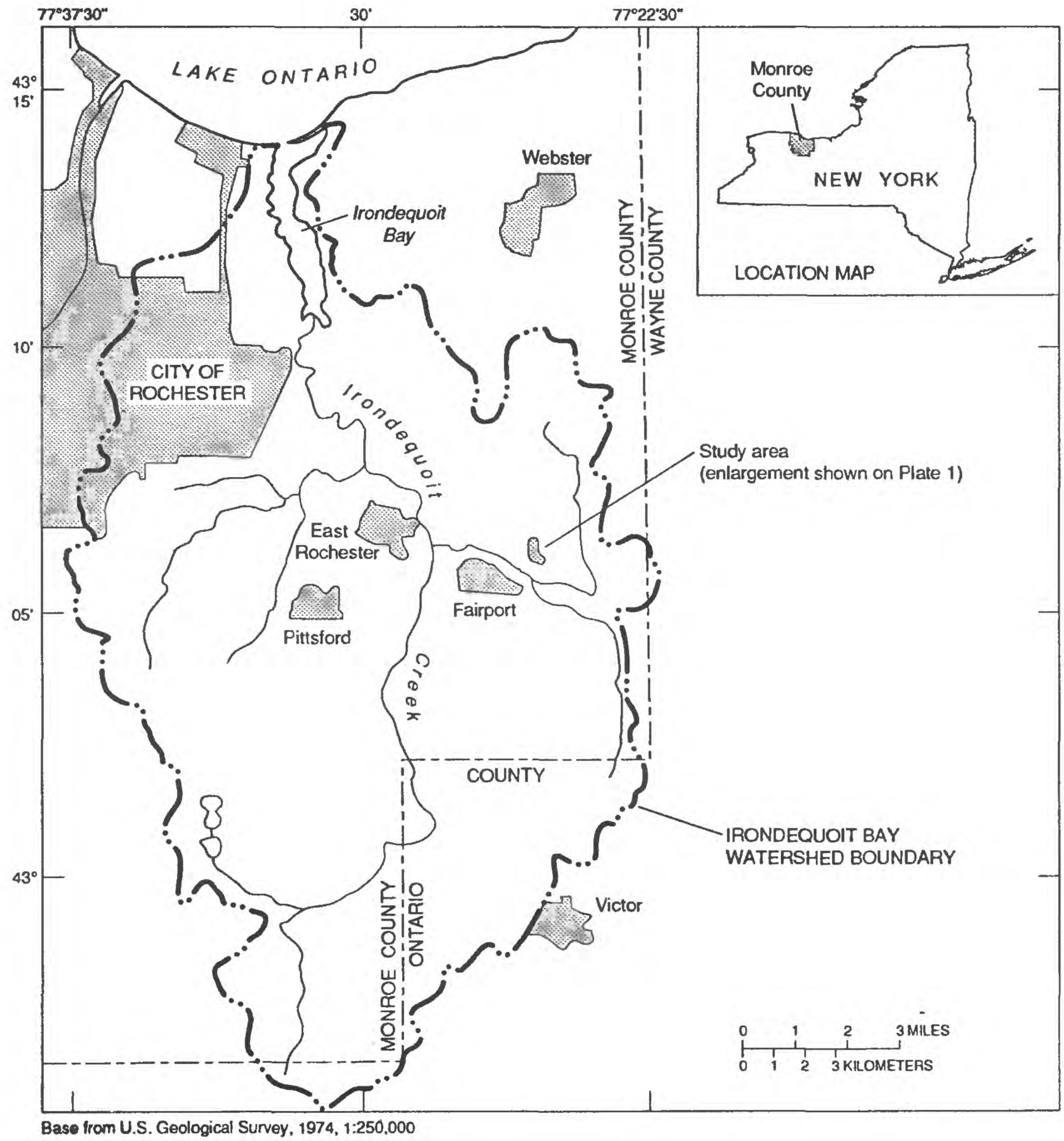

Figure 1.--Location of study area. (Modified from Kappel and others, 1986, fig. 1.)

munities in the Irondequoit Creek basin (fig. 1) have been required to control runoff in new developments since the early 1970's. This typically entails the construction of a detention basin to provide sufficient storage to prevent the post-development peak flow from exceeding the pre-development peak flow for a design storm, typically a 25-year event. The Irondequoit Creek watershed contains about 100 such basins (Richard Cortina, town planner of Brighton; Martin Brewster, town planner of Pittsford; Joseph Carr, town planner of Perinton; Jeffrey Benway, engineer for town of Penfield; oral commun., 1990).

As the deterioration in quality of storm runoff became increasingly evident, emphasis was placed on controlling its chemical quality in urban areas, as reflected in the 1987 amendments to the Federal Clean Water Act (FCWA), which set forth a national objective to reduce the contaminant loads in urban runoff to the extent practicable (Gallup and Weiss, 1988). As a result, detention basins are likely to become an important water-quality-management technique for meeting the FCWA objectives. Detention basins that have been constructed to control runoff quantity could also improve its quality through constituent settling and biological activity. Furthermore, even though these basins, as originally designed, might not significantly decrease the amount of contaminants in storm runoff, modification of the outlet to increase the storage time for biological activity and settling of suspended matter could increase their effectiveness. In the Irondequoit Creek watershed, such modification of stormwater-detention facilities could help decrease the loads of contaminants that contribute to the eutrophication of Irondequoit Bay.

Because information on the effectiveness of basin designs also could help State and local governments meet the water-quality objectives and requirements of the 1987 FCWA amendments, the U.S. Geological Survey (USGS), in cooperation with the Monroe County Department of Environmental Health (MCEHL), began a 3-year study in 1987 to assess (1) the effectiveness of a detention basin in removing contaminants from storm runoff in the Irondequoit Creek basin, and (2) the effect of subsequent modifications to its outlet to increase water-retention time. This study was part of several detention-basin studies being conducted nationally by the USGS and others in conjunction with the American Society of Civil Engineers Urban Water Resources Research Council (ASCE-UWRRC). Results of these studies are to be used by the ASCE-UWRRC to improve design criteria for managing urban storm-runoff quality.

Study Area

The watershed draining to the detention basin encompasses 26.9 acres of moderate-density residential development in the Town of Perinton, southeast of Rochester (fig. 1). Physiographic characteristics of the detention basin and the contributing watershed are summarized in table 1. Photos in figures 2A and 2B show typical land use, and plate 1 shows land use, elevations, and the storm-sewer drainage system.

Climate in this area is humid continental; average temperatures are below freezing several months each year. Precipitation during the summer results mainly from convective-type storms, which are generally of shorter duration and higher intensity than the frontal systems that are common in other seasons. Frontal systems from the north and west are often locally influenced by the Great Lakes, which moderate temperatures and result in even distribution of precipitation throughout the year. Precipitation averages 30 to 35 in/yr (Dethier, 1966).

Soils and Drainage System

Soils in the watershed are derived mainly from till—an unsorted mix of clay, silt, sand, and boulders—and are associated with the Ontario-Hilton series. Soil permeability is mostly poor to moderate; percolation rates range from 0.63 to 2.0 in/h (Heffner and Goodman, 1973). The underlying till is less weathered than the soils and is therefore less permeable. Bedrock is generally within 10 ft of land surface and could be capable of transmitting greater quantities of water than till and soils, depending on the degree of fracturing. Percolation of water to the bedrock surface is limited by the low permeability of the overlying till and soils; thus, infiltration is probably not significant in the study area (Yager and others, 1985).

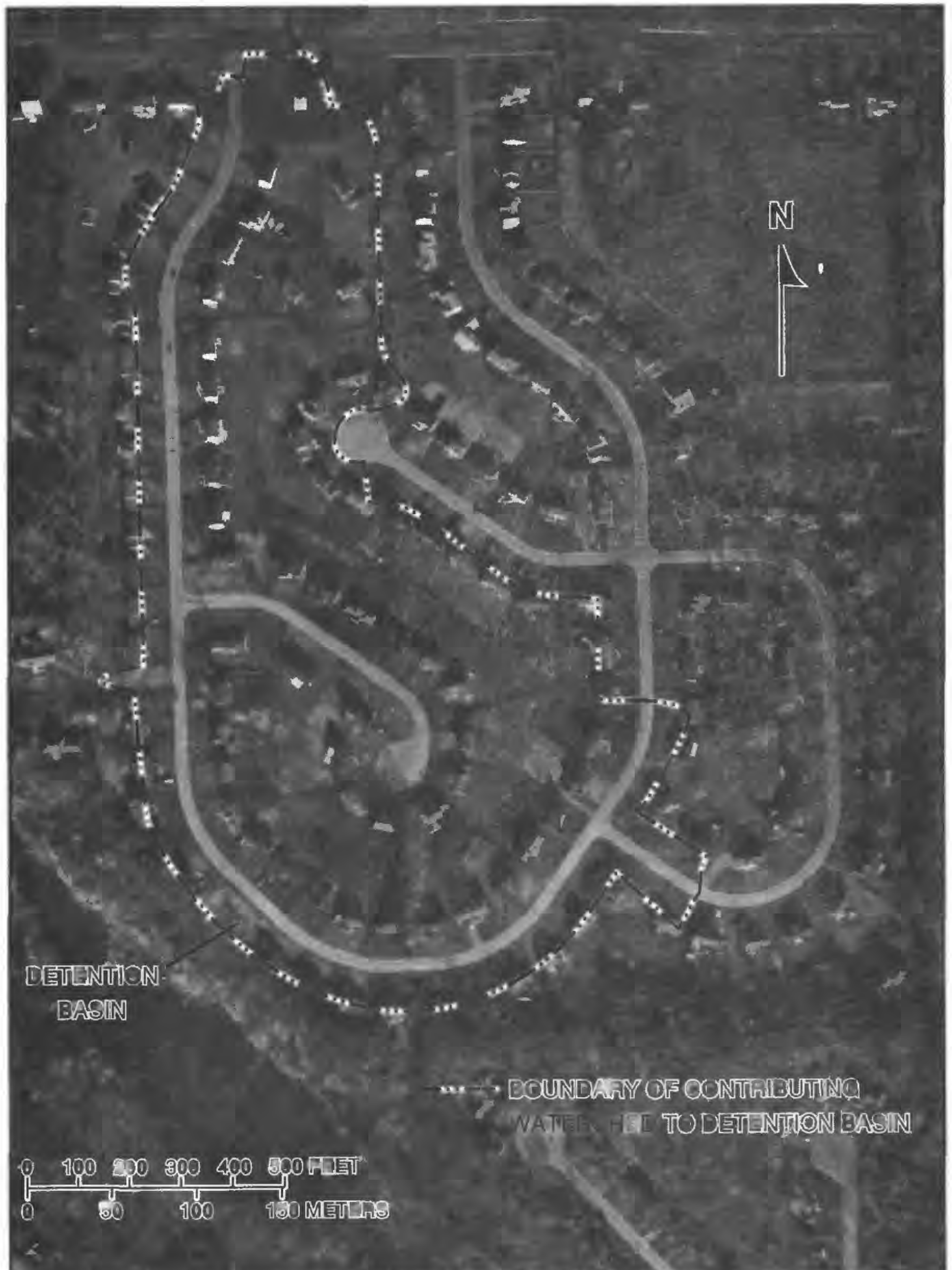

Figure 2A.--Aerial view of moderate-density residential development that drains into the detention basin.

Figure 2B.--Typical street with gutter system that drains into the detention basin.

Table 1.--Physiographic and land-use characteristics of the detention basin and its tributary watershed

[Location is shown in fig. 1, details shown on pl. 1]

Watershed	
Contributing drainage area	26.9 acres
Land use	Medium-density residential
Impervious area	5.50 acres (20 percent)
Driveways	0.82 acre
Roadways	2.25 acres
Roofs	2.43 acres
*Effective impervious area (driveways and roads)	3.07 acres (11 percent)
Noneffective impervious area (roofs and driveways)	2.43 acres (9 percent)
Average watershed slope	5 to 6 percent
Main conveyance slope for storm sewers	0.76 to 2.5 percent
Permeability of the soil A horizon	0.63 to 2.0 inches per hour
Available water capacity of soil A, B, and C horizon	0.10 to 0.15 inches per inch of soil
Percentage of drainage area served by storm sewers	100 percent
Percentage of streets with curbs and gutters	100 percent
Detention Basin	
Available storage capacity to emergency spillway	0.905 acre-foot
Depth to emergency spillway	6.8 feet
Depth to top of trickle tube	4.3 feet
Surface area	0.24 acre

* Impervious area connected directly to the storm-sewer system.

Runoff to the detention basin originates from "hydraulically effective" impervious surfaces (impervious surfaces that drain directly to the storm-sewer system [pl. 1]), and runoff from pervious surfaces when precipitation exceeds the infiltration capacity of the soil and depression storage is filled. Hydraulically effective impervious surfaces represent 11 percent of the watershed area and include street surfaces and driveways that slope toward the street (pl. 1). Other impervious surfaces not directly connected to the storm-sewer system represent 9 percent of the watershed area and consist primarily of roofs that drain onto surrounding lawns.

Runoff from excess precipitation on pervious surfaces flows onto impervious surfaces and, at three locations in the watershed (pl. 1), into swales that drain into the storm-sewer system. Several field drains that appear to be tile drains for lawns were observed in drop inlets in the street drains. These drains probably account for the small amount of base flow through the detention basin that was observed during periods of low precipitation.

Detention Basin

The detention basin occupies a residential lot (pl. 1) and was constructed at the time the subdivision was built in the early 1980's. Storage capacity of the basin at the elevation of the emergency spillway is 0.905 acre-ft. This volume is equivalent to 0.43 in. of runoff from the watershed, but because some rainfall infiltrates the soil and some evaporates, the storage capacity of the detention basin is equivalent to 1.71 in. of precipitation, as calculated from the mean runoff coefficients of storms measured during the 3-year study period. Inflow is routed to the detention basin by a single 30-in. concrete culvert pipe from the storm-sewer drainage system (pl. 1). Direct overland runoff to the basin is negligible and is limited to the sides of the basin, which have a relatively steep (30- to 40-percent) slope (fig. 3A).

The basin outlet is an 18-in.-diameter corrugated pipe that is positioned about 100 ft diagonally across from the inlet (fig. 3A). Outflow is controlled by a trickle tube made of 24-in. corrugated steel pipe placed upright over the outflow culvert (figs. 3B and 4) with 2-in. holes spaced at 6-in. intervals both horizontally and vertically.

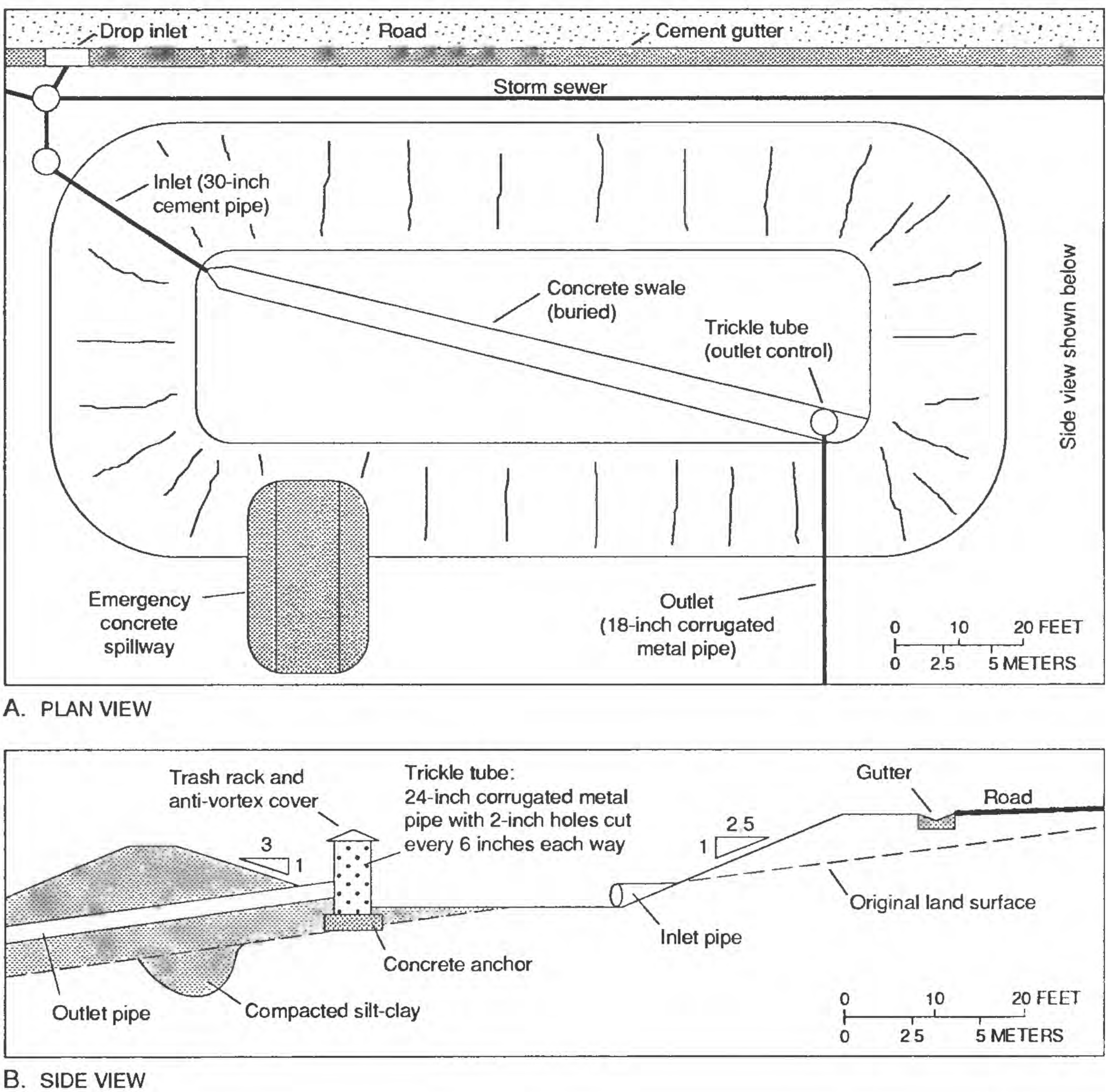

Figure 3.--Engineering drawings of the detention basin. (A) Plan view. (B) Side view.

An 8-in.-diameter opening at the base of the trickle tube allows the basin to drain unrestricted during small storms and base-flow conditions. The trickle tube is capped with a steel mesh trash rack and an antivortex plate. An emergency concrete spillway, 2.5 ft above the top of the trickle tube, releases excess stormflow from the basin.

The detention basin is an unlined excavation in clayey till. Infiltration of stormwater from the basin into the subsurface was therefore considered insignificant in relation to the volume of water associated with a storm. Vegetation in the basin consists of grasses and weeds along the sides and bottom and woody shrubs and wetland species along the swale between the inlet and outlet (fig. 4).

Purpose and Scope

This report describes the effects of stormwater detention on the chemical quality of storm runoff from the 26.9-acre development during 46 storms from August 1986 through September 1989. It includes (1) information on the hydrologic and land-use characteristics of the contributing watershed, (2) a comparison of loads of 22 constituents entering the basin with those leaving the basin and removal efficiencies for these constituents, and (3) a discussion of the efficiency of the original basin design and of two outlet modifications to increase water-retention time. An oversize map (pl. 1) of the watershed showing the housing development, streets, and storm-drainage system, is included.

Acknowledgments

The authors thank Richard Burton, Chief Chemist, and his staff at the Monroe County Environmental Health Department (MCEHD) for collecting and analyzing water samples used in this study. The authors extend special appreciation to Lisa Spittal of the MCEHD for her assistance and efforts, which ensured the successful collection and analysis of the water-quality data. The American Society of Civil Engineers Urban Water Resource Research Council provided recommendations for data collection.

Figure 4.--View of detention basin showing inlet (upper right) and trickle tube outlet (lower left corner).

METHODS OF INVESTIGATION

The following paragraphs describe (1) the instrumentation used in data collection, (2) the data-management system, and (3) the quality-assurance and control procedures.

Instrumentation

Instrumentation was installed to measure flow and monitor water quality at the inlet and outlet of the detention basin and to record water levels in the basin and the amounts of precipitation. The data were then used to calculate constituent loads into and out of the basin, which were then used to calculate trap efficiencies.

Inflow to the detention basin was calculated through techniques developed for storm-sewer flow measurement by Kilpatrick and others (1985). A trapezoidal Palmer-Bowlus flume was installed in the 30-in.-diameter concrete inlet pipe to constrict flow and thereby create a transition in flow from which a theoretical determination of discharge could be made. The flume causes flow to change from subcritical to critical at its approach and from critical to supercritical in its throat. Discharge could then be calculated from stage measurements at either the approach or throat of the flume. Stage was monitored in both locations with Schaevitz[1] pressure transducers to determine whether the flume provided sufficient fall to create the transition in flow needed to calculate discharge and to determine the best method for calculating discharge from flow characteristics. If fall through the flume was insufficient (no transition through critical flow), the theoretical discharge calculations were not applicable. During these conditions, an electromagnetic velocity sensor near the approach was used to calculate discharge. The velocity sensor was also used in the transition to full-pipe flow before the flow became pressurized. Once flow became pressurized, the Palmer-Bowlus flume operated as a venturi meter.

Outflow from the basin was initially calculated from a stage-to-discharge relation based on computed discharge for type I and type V flow at culverts (Bodhaine, 1968). This method produced unreliable results, however, because turbulence in the trickle tube caused erratic flow at the culvert entrance. Subsequently, a Parshall flume was installed below the basin outlet to provide accurate measurement of discharges of 0.35 to 16 ft^3/s. Stage at the flume was measured with a Schaevitz pressure transducer.

Water samples were collected automatically at the inflow and outflow of the flume with Manning samplers mounted inside refrigeration units to minimize chemical or biological changes in the samples before analysis. Sampler intakes were placed in the inlet and outlet culverts, which are confined; therefore, flow within the culverts is relatively well mixed. The maximum time allowed between sample collection and removal from the sampler and preparation for analysis was 25 hours, but MCEHL staff usually removed the samples and prepared them for analysis during or immediately after a storm.

During the first year of the study, water-sample collection was based on stage-activated sampling intervals or on a rate of change in stage selected through the water-sample control program developed for the Cambell CR21 data logger. After the first outlet modification, detention time increased sufficiently to cause backwater at the inflow so that stage and time activation of the inflow sampler no longer yielded representative samples of discharge. The CR21 data logger was therefore replaced, when the outlet was modified, with a CR21x data logger programmed to activate the sampler at incremental flow volumes rather than according to time and stage. The data loggers also recorded and processed data from each of the pressure transducers, the velocity sensor, and the tipping-bucket rain gage.

In addition to collecting water samples, the MCEHL analyzed them for nutrients, common ions, and metals through methods identified in table 2. Discrete water samples were often composited, depending on the appearance of the storm hydrograph and the frequency of sampling. Before flow-activated sampling was instituted, composites were made in a flow-weighted mix-

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

ture in proportion to the amount of runoff the sample represented; this was done primarily to decrease the cost of analysis while maintaining adequate sample coverage. Samples of bottom material were analyzed by the USGS National Water Quality Laboratory in Denver, Colo., by methods described in Wershaw and others (1983) and Fishman and Friedman (1989).

Table 2.--Analytical methods used by the Monroe County Environmental Health Laboratory for constituent analysis

[°C = degrees Celsius, < = less than, µg/L = micrograms per liter, mg/L = milligrams per liter, mL = milliliter, µm = micrometer]

Constituent	Preservation[1]	Holding time[2]	Detention limit[3]	Method[4]
[5]Suspended solids	P, RU	7 days	25 mg/L	209C†
[5]Dissolved solids	P, RU	7 days	25 mg/L	209B†
[5]Suspended volatile solids	P, RU	7 days	25 mg/L	209D†
[6]Total organic carbon	P, RC	28 days	0.2 mg/L	505A, B†
Chemical oxygen demand	P, RC	28 days	10 mg/L	508[1]†
Total ammonia plus organic nitrogen	P, RC	28 days	100 ug/L	351.2*
Nitrate-nitrite	P, RC	28 days	10 µg/L	353.2*
Ammonia	P, RC	28 days	10 µg/L	I-4523-84††
Phosphorus, total	P, RC	28 days	5 µg/L	424C†, 424F†
Phosphorus, dissolved	P, FC	48 hours	5 µg/L	424C†, 424F†
Orthophosphorus, total	P, RU	48 hours	5 µg/L	424F†
Orthophosphorus, dissolved	P, FC	48 hours	2 µg/L	424F†
Chloride	P, FC	28 days	0.1 mg/L	407B†
Sodium, dissolved	P, FA	6 months	0.5 mg/L	303A†
Lead, total	P, RA	6 months	5 µg/L	4.1.4*, 304†
Lead, dissolved	P, FA	6 months	5 µg/L	304†
Zinc, total	P, RA	6 months	20 µg/L	4.1.4*, 303A†
Zinc, dissolved	P, FA	6 months	20 µg/L	303A†

1 P Polyethylene bottle
RU Raw sample, stored at 4°C.
RC Raw sample, acidified with H_2SO_4 to pH<2, stored at 4°C.
RA Raw sample, acidified with HNO_3 to pH<2.
FC Sample filtered through 0.45-µm membrane, stored at 4°C.
FA Sample filtered through 0.45-µm membrane, acidified with HNO_3 to pH<2.

2 Maximum holding time per New York state Environmental Laboratory Approval Program or as specified by the method; actual holding times are generally less.

3 Routine reportable detection limit; actual reporting limit may vary with analytical run and(or) sample matrix.

4 † American Public Health Association, 1985.
* U.S. Environmental Protection Agency, 1979.
†† Fishman, M. J., and Friedman, L. C., 1989.

5 Solids detection limits are based on volume of sample filtered: 25 mg/L assumes a 100-mL sample volume.

6 For samples with high turbidity or other matrix effects requiring use of the furnace method, the detection limit is 5 mg/L.

Note: Concentrations of suspended phosphorus, orthophosphorus, lead, and zinc are calculated as difference between total and dissolved concentrations.

Data Management

Data management for the study is depicted in the flow chart shown in figure 5. Data (stage, velocity, precipitation, and timing of water samplers) recorded on the logger were also recorded onto data-storage modules to extend the memory capacity of the data logger and provide a backup memory. Data could be retrieved from the site for processing by remote communication through the telephone system or by alternating storage modules. Remote communication was used extensively during stormflows by the USGS and the MCEHL to check the instrumentation and to aid in compositing water samples. The communications link also enabled remote programming of the data logger. This capability was sometimes used to change threshold values for sampler activation.

Data from the storage module or retrieved by telephone were downloaded as ASCII files on the USGS computer. Postprocessing programs then (1) converted the raw data into engineering units, formatted by date, time, and values; (2) calculated discharge at the inlet and outlet and the storm volumes; and (3) provided graphical displays. Before computation of constituent loads and final storage of data, inflow and outflow volumes for each storm were balanced. Because outflow values before installation of the Parshall flume were unreliable, outflows for that period were recalculated through a reservoir-routing

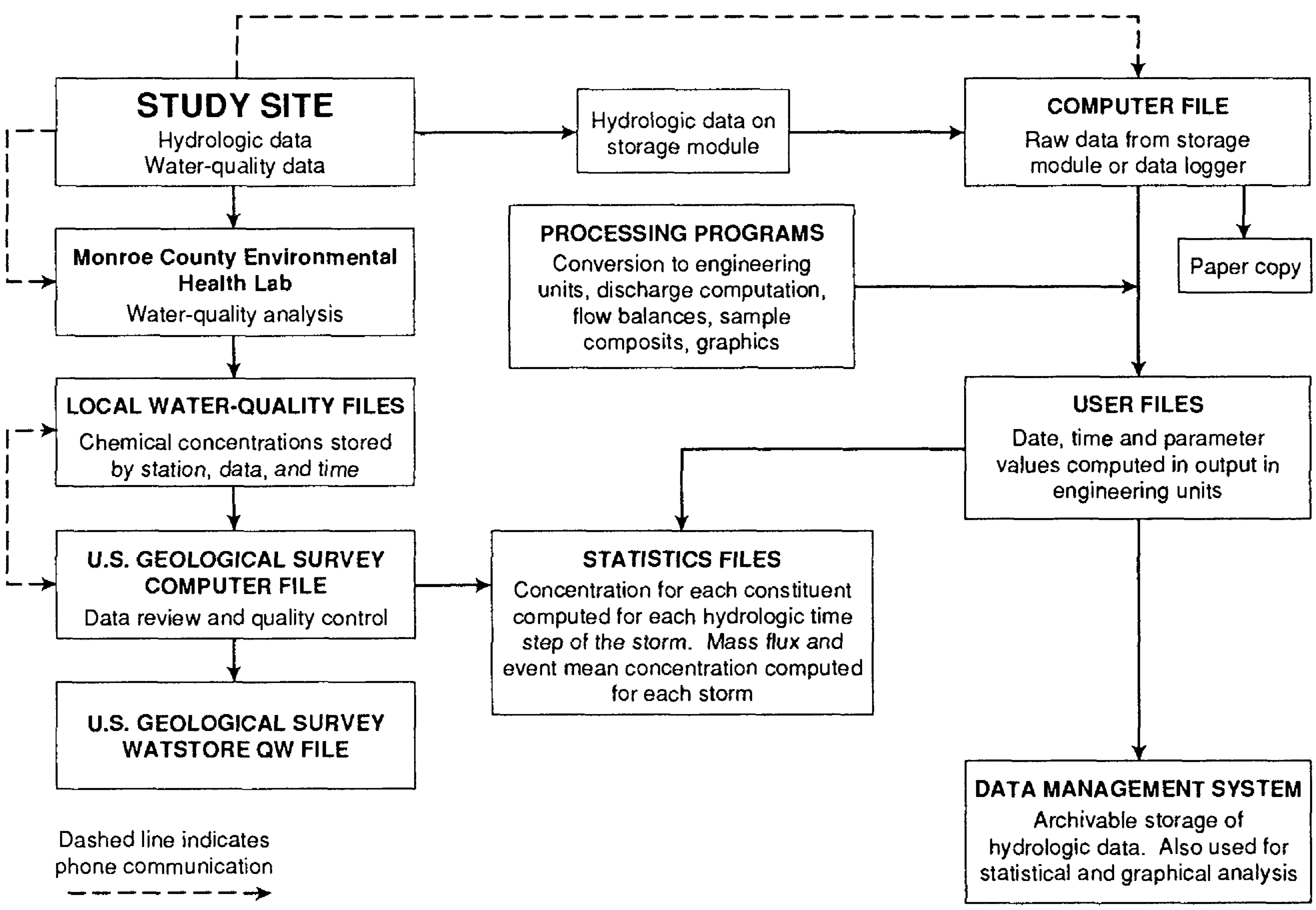

Figure 5.--Data-management flow chart.

program (Jennings, 1977) that is based on the modified-Puls method, which calculates an outflow hydrograph from the inflow hydrograph and a storage-to-outflow relation. The storage-to-discharge relation was developed from data collected after installation of the Parshall flume. Thereafter, when inflow volume did not equal outflow volume, inflow was adjusted because the modification made at the outlet control often caused submergence of the Palmer-Bowlus flume. When this occurred, inflow was adjusted proportionally to the outflow and the change in contents in the basin. Data were then entered into an interactive hydrologic analysis and data-management system known as WDMS (Lumb and others, 1989).

Water samples were catalogued by MCEHL staff upon receipt. Once analyses were performed and approved by the laboratory's internal quality control (discussed below), the data were transferred electronically to the USGS, where they were rechecked and entered into the USGS water-quality file.

Quality Assurance and Control

The quality-assurance/quality-control (QA/QC) program entailed verification of discharge data and of the accuracy of the chemical analyses performed by the MCEHL. Discharge verification included periodic calibration checks of pressure transducers and current-meter measurements to verify the theoretical ratings. Current-meter measurements were generally discarded, however, because the measuring conditions were poor, such as when flow changed rapidly and(or) was relatively small. To ensure comparability of data, therefore, the inflow volume was balanced against the outflow volume plus or minus any change in pond content. This technique revealed errors in the discharge calculations, such as through the unreliability of the outflow culvert rating, previously mentioned. During the period in which the reservoir-routing program was used to calculate outflow (before the installation of the Parshall flume), predicted pond stages were checked against measured pond stage.

The accuracy of chemical analyses was ensured by an internal QA/QC program at the MCEHL. This program entailed cation-anion balances, duplicate analyses, reanalysis to verify anomalous values, and blind-sample analysis. The MCEHL also participated in the USGS Standard Reference Water Sample Program (SRWS). MCEHL has participated in the SRWS program for several years as part of other USGS cooperative programs and has consistently performed well in the SWRS program (D. E. Erdman, USGS, written commun., 1990). The MCEHL also periodically splits samples for analysis in their laboratory and the USGS National Water Quality Laboratory as part of other cooperative programs.

Computation of Constituent Loads and Mean Concentrations in Stormflow

Constituent loads and event mean concentrations (EMC's) at the inlet and outlet during selected storms were calculated from the results of the water-quality analysis and the runoff volume that each water sample represented. Effects of the detention basin on chemical quality were evaluated in relation to each of 22 constituents. (Table 2 excludes suspended phosphorus, orthophosphorus, lead, and zinc; concentrations of these constituents are calculated from total and dissolved concentrations.) The constituents were grouped into four broad classes: (1) physical properties (solids, chemical oxygen demand), (2) nutrients (phosphorus and nitrogen compounds), (3) metals (lead and zinc), and (4) common ions (chloride and sodium).

Calculation of constituent loads entailed dividing the storm hydrograph into sections representing the water sample (or sample composite) midway between the intervals representing adjacent samples (fig. 6). The first and last samples were assigned flow increments corresponding to the start and end of the storm and the midpoint to the next sample or sample composite. Runoff volume was then calculated for each increment and multiplied by the constituent concentration measured in that sample(s) to obtain the incremental load for each constituent. The incremental loads were summed to obtain the constituent storm load. The EMC for each constituent was a quotient of the total constituent load, divided by the total runoff volume for each storm.

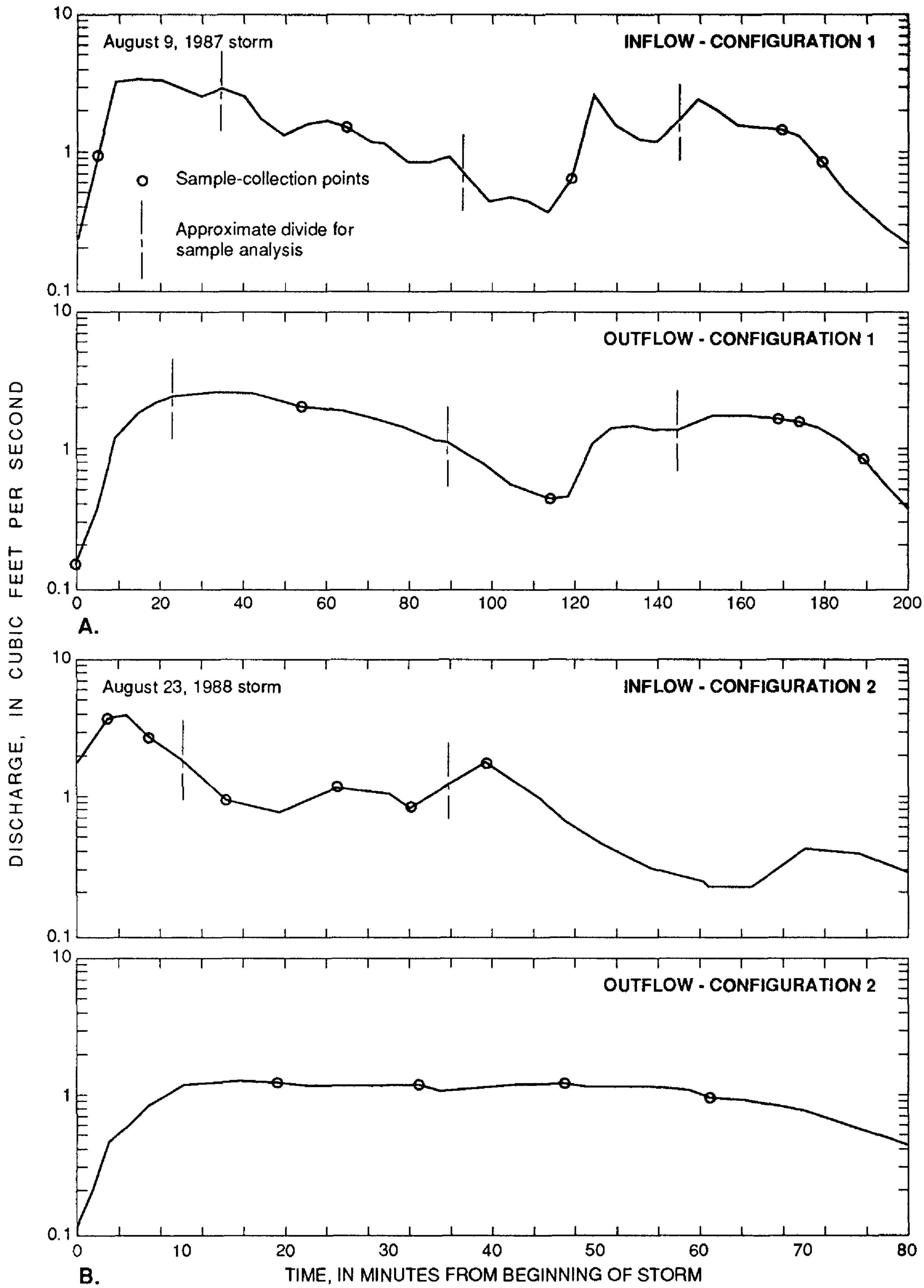

Figure 6.--Inflow and outflow hydrograph showing representative sample-collection times for configurations 1 and 2.

Calculation of Basin Trap Efficiency

Data collection during this study focused on stormflows to assess the effect of detention on chemical concentrations in runoff as it passed through the basin. The basin outlet was modified twice to increase retention times, as explained earlier. The performance of each configuration was quantified in terms of trap efficiency (percent removal) and by statistical test of differences between the inlet and outlet loads and among outlet configurations.

Trap efficiency, usually expressed as a percentage, is an indication of the relative change in constituent load after detention. Three different methods of calculating trap efficiency were compared among each other and among the three outlet configurations. One method compares event-mean concentrations at the inflow with those at the outflow, and the other two methods—summation of loads and regression of loads—compare constituent loads at the inflow with those at the outflow.

Event mean concentration. The event mean concentration (EMC) method provides a measure of the relative change in concentration between the basin inflow and outflow. The EMC's for all storms during a particular modification are averaged, and the trap efficiency is calculated as follows:

$$\text{EMC efficiency} = \frac{\text{EMC in} - \text{EMC out}}{\text{EMC in}} \times 100 ,$$

where EMC = Average event mean concentration for all storms.

The EMC method gives equal weight to all storms because flow is factored out. Thus, small storms of minor load are analyzed equally with large storms of greater load, which could cause an efficiency bias toward smaller storms. Trap efficiencies for individual storms were also calculated through the storm EMC.

Summation of loads. The summation of loads (SOL) is a measure of the average change in constituent loads within the basin. Sums of paired constituent input and output loads for all monitored storms after each modification were used to calculate an overall efficiency by the following equation:

$$\text{SOL efficiency} = \left(\frac{\text{input load} - \text{output load}}{\text{input load}}\right) \times 100 ,$$

where loads are summed for all storms.

This method provides a gross measure of the overall performance of the detention basin and gives proportional weight to large storms. The method does not provide an assessment of efficiency for individual storms, however, because loads are summed, but individual storm loads can be computed as with EMC efficiencies. Because inflow and outflow are balanced, the individual storm efficiency will be equivalent to the individual EMC efficiency.

Regression of loads. The regression of loads (ROL) is based on the linear relation between constituent loads at the inflow and those at the outflow. The slope of the regression line represents the net transport of a constituent through the basin; thus, 1 minus the slope represents the removal rate. A slope of 1.0 indicates no net change of a constituent load through the basin; slopes less than 1.0 indicates constituent retention, and a slope greater than 1.0 indicates a constituent discharge from the basin. The difference between the slope of the regression line for one outlet configuration and that for another is a measure of the difference in basin performance.

The principal difference between the efficiency computed by ROL and those computed by the other two methods is that storms are weighted about the regression line, which is a function of the inflow concentration and the square of the storm volume (inflow and outflow volumes are assumed to be equal). Thus, the larger the storm, the greater its effect on the overall performance of the basin (Martin and Smoot, 1986). This characteristic can also create a bias, however, if the regression line is based on a few outlier storms that exert undue leverage on the slope computation. This differs from the SOL efficiency, which weights the efficiency calculation only by storm volume (again, assuming equal inflow and outflow). Thus, the SOL methods give less weight to storms with high concentrations and large runoff than the ROL method. In the EMC method, flow is factored out to give equal weight to all storms.

Limitations of Efficiency Estimates

All methods used to calculate the performance of the detention basin are affected by the reliability of flow records and water-quality data. Quality assurance and control help minimize errors in discharge calculations and water-quality analytical procedures, but accurate measurement of water-quality changes also requires continuous measurement of flow and constituent concentrations. Flow can be measured nearly continuously for an extended period, but continuous measurement of constituent concentration is impractical; thus, the assessment of basin performance must be based on discrete or composite samples. Although instrumentation and sampling protocol were designed to obtain samples that are representative of the runoff, uncertainties as to their representativeness is inevitable; for instance, the sample coverage could be insufficient to define the accumulation and release patterns of a constituent during a storm. Also, because the detention basin is normally dry, data collection focused on individual storms; therefore the constituents retained in the basin during a storm could be released during subsequent minor storms or at the beginning of a large storm before discharge increases sufficiently to activate the monitoring equipment. Despite these uncertainties, the methods used were consistent among the outlet configurations and thus provided a uniform basis for comparison of basin performance.

Statistical Comparisons

Water-quality changes in the basin were tested statistically to compare differences between inflow and outflow loads and to compare the load retention among the three outlet configurations. Statistical tests were also used to examine seasonal differences in constituent retention and the relation between detention time and decreases in constituent loads.

Inflow and outflow statistics are displayed in side-by-side box plots of storm loads at the inflow and outflow of the detention basin, for each of the outlet configurations, in figures 16 through 18 (further on). The standard box plots illustrate differences between inflow and outflow loads and provide comparative information on medians, upper and lower quartiles (approximate variation in data), skewness, and outlier values in each of the data sets (Chambers and others, 1983). The scatter of the data about the median is also useful for determining whether the data fit the assumptions of the statistical test used to identify significant differences between the inflow and outflow load.

Because variance of the data was unequal, differences between the inflow and outflow constituent loads were tested through the Wilcoxon signed rank test (a nonparametric test), which is similar to a paired T-test, except that it is applied to rank-transformed data and thus makes the assumptions of the test easier to justify (Conover, 1971). A significant difference is indicated if the null hypothesis (no difference between inflow and outflow) is rejected at the 95-percent confidence level ($\alpha = 0.05$).

Differences among the three outlet configurations are also compared through the Kruskal-Wallis test to determine whether the loads retained differed significantly among the three outlet configurations. Similar to the Wilcoxon test, the Kruskal-Wallis test is applied to ranked-transformed data to relax the assumptions of normality and equal variance. Significant differences are indicated when the null hypothesis (no difference between the inflow and outflow) is rejected at the 95-percent confidence level ($\alpha = 0.05$). Seasonal differences in the performance of the detention basin were examined by the Wilcoxon test of ranked differences between inflow and outflow in periods representing the growing period (May through September) and the nongrowing period (October through April). Significant differences between inflow and outflow load for seasonal periods are indicated at the 95-percent confidence level.

DATA USED IN ANALYSIS

Precipitation and runoff were measured during 92 storms between August 1986 and September 1989. Of these storms, 46 had sufficient water-quality data for use in determining constituent retention in the basin. The number of storms sampled for each of the outlet configurations are summarized in table 3. Precipitation and flow data were collected at 5-minute intervals during storms, when stage at the inlet or outlet exceeded a predetermined threshold value. Data used to calculate the effects of detention represent about 300 analyses for 22 constituents. Because the amount of data is large, pertinent precipitation, runoff, water-quality and bottom-sediment data are summarized in the following sections and in the appendixes (at end of report).

Precipitation

Precipitation in the Rochester area during 1948-83 (National Oceanic and Atmospheric Administration, 1983) averaged slightly more than 31 in/yr. Precipitation during the 40-month study period (June 1986 through September 1989) was above normal (+4.51 in.), and monthly deviations from the norm varied significantly (fig. 7). Precipitation during the growing seasons (May through September) was above normal in all years except 1988, when it was below normal (table 4). Precipitation during the nongrowing season (October to April) was below normal in all years except 1986-87, when it was about normal (National Oceanic and Atmospheric Administration, monthly climatic data).

The intensity, duration, and antecedent conditions of storms sampled for the constituent-load calculations are summarized in appendix I. Storm precipitation during the initial period of the unmodified control averaged 0.39 in. and about 4 hours in duration. Storms were distributed evenly throughout the year and represent periods when runoff was generated from precipitation and from snowmelt. Storms during the second outlet configuration occurred primarily during the growing season, which is characterized by rapidly moving frontal systems or convective storms that are of higher intensity and shorter duration than those at other times of the year. Storm precipitation during this phase of the study averaged 0.20 in. and 1.1 hours in duration. Storms during the third outlet configuration also occurred primarily during the growing season and averaged 0.46 in. of precipitation and almost 12 hours in duration. The longer duration results from a sequence of storms that were analyzed as a single event.

Records of long-term precipitation at Rochester (1948-83) indicate that storm precipitation averaged 0.27 in., lasted 10.6 hours, and occurred about every 2.7 days. The intensity and duration of storms used in this study are similar in volume and duration to the long-term average, except for the period representing the second configuration (April through November 1988). The volume and duration of these storms, on average, were considerably below the average long-term volume and duration because they occurred predominantly during the summer, when drought conditions prevailed (National Oceanic and Atmospheric Administration, monthly climatic data).

Table 3.--Summary of storm data collected for each outlet modification

Outlet configuration	Sampling period	Number of storms	Number of storms with water-quality analysis
1	August 1986 through March 1988	52	21
2	April 1988 through November 1988	16	13
3	December 1988 through September 1989	24	12

Table 4.--Seasonal precipitation at Rochester and totals for period of study

[Values are in inches]

Season	Precip-itation	Normal*	Departure
June to Sept. 1986 (growing)	15.8	11.12	+ 4.68
Oct. 1986 to April 1987 (nongrowing)	17.26	17.58	- .32
May to Sept. 1987 (growing)	19.50	13.70	+ 5.80
Oct. 1987 to April 1988 (nongrowing)	13.21	17.58	- 4.37
May to Sept. 1988 (growing)	12.63	13.70	- 1.07
Oct. 1988 to April 1989 (nongrowing)	13.17	17.58	- 4.41
May to Sept. 1989 (growing)	17.90	13.70	+ 4.20
Totals	109.47	104.96	+ 4.51

*Average seasonal totals from 1951 to 1980 from National Oceanic and Atmospheric Administration monthly climatic data.

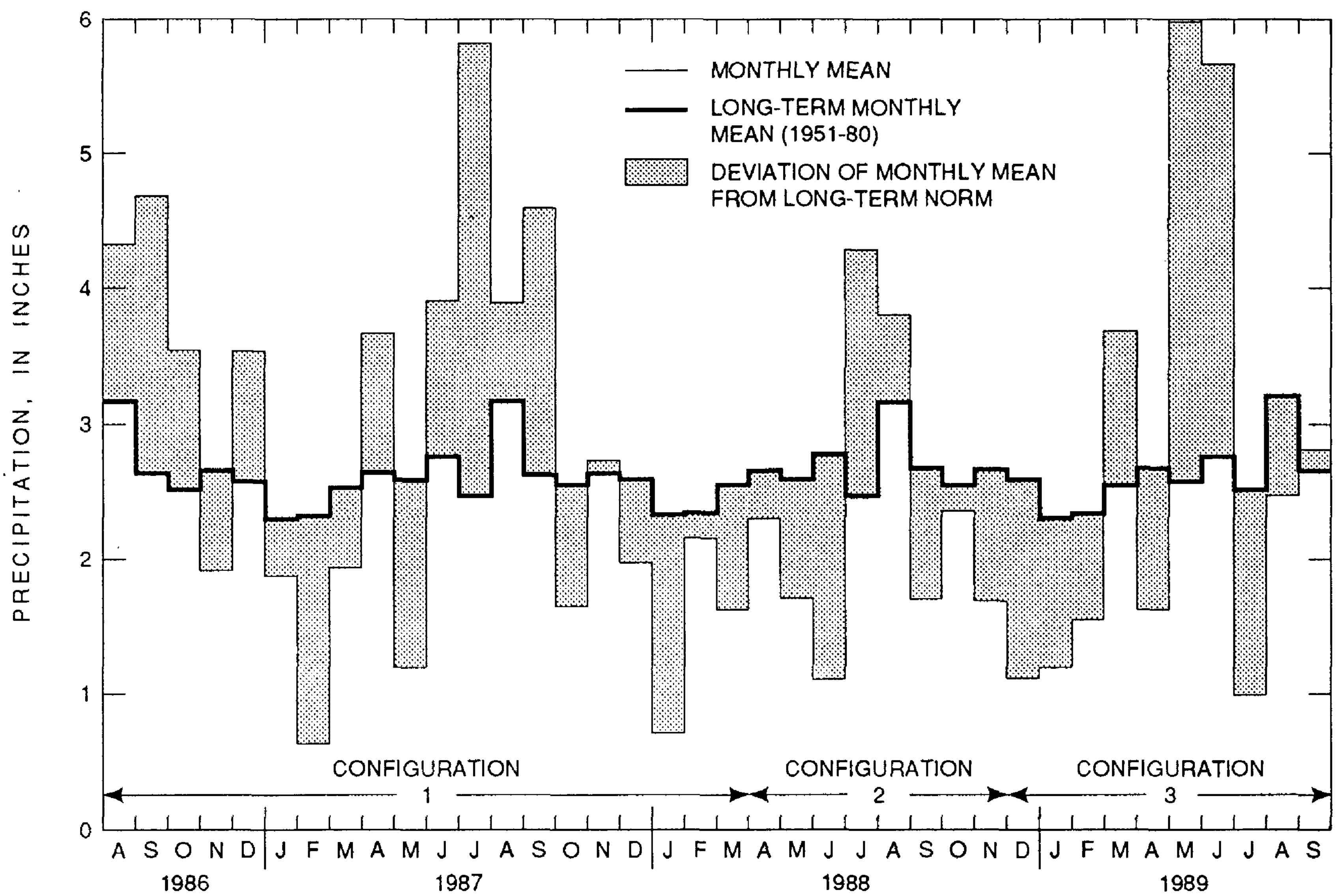

Figure 7.--Monthly precipitation totals and normals for period of study. (From National Oceanic and Atmospheric Administration monthly climatic data, National Weather Service station at Rochester, N.Y.

Runoff

Runoff characteristics of storms used for the constituent-load calculations are summarized in appendix II, which includes runoff volume, rainfall-runoff coefficients, peak flows, maximum basin stage, and average "plug" detention time. Plug concepts are explained in the section "detention time" (p. 21).

Average runoff volumes were greatest during the third configuration and lowest during the second configuration. The low runoff during the second configuration reflects drought conditions, as mentioned previously.

Rainfall-runoff relations for 33 storms that occurred during the growing season are plotted in figure 8A, and those for 13 storms that occurred in the nongrowing season are plotted in figure 8B. Regressions of runoff as a function of rainfall in the growing season had a much higher coefficient of determination (r^2 = 0.69) than storms in the nongrowing season (r^2 = 0.38). The resultant equations for the two seasons are:

Growing season:

Runoff = 0.133 (Precipitation) + .0019

Nongrowing season:

Runoff = 0.450 (Precipitation) + .025

The standard error of estimate (the measure of variance about a regression line) is 0.027 for the growing season and 0.185 for the nongrowing season.

The rainfall-runoff relations indicate that runoff from a given storm is smaller during the growing season than during the nongrowing season, mainly because the increased evapotranspiration during the growing season increases the storage capacity of soils. During the winter, freezing decreases the infiltration capacity of soils, and snowmelt or rain on snow complicate the runoff patterns.

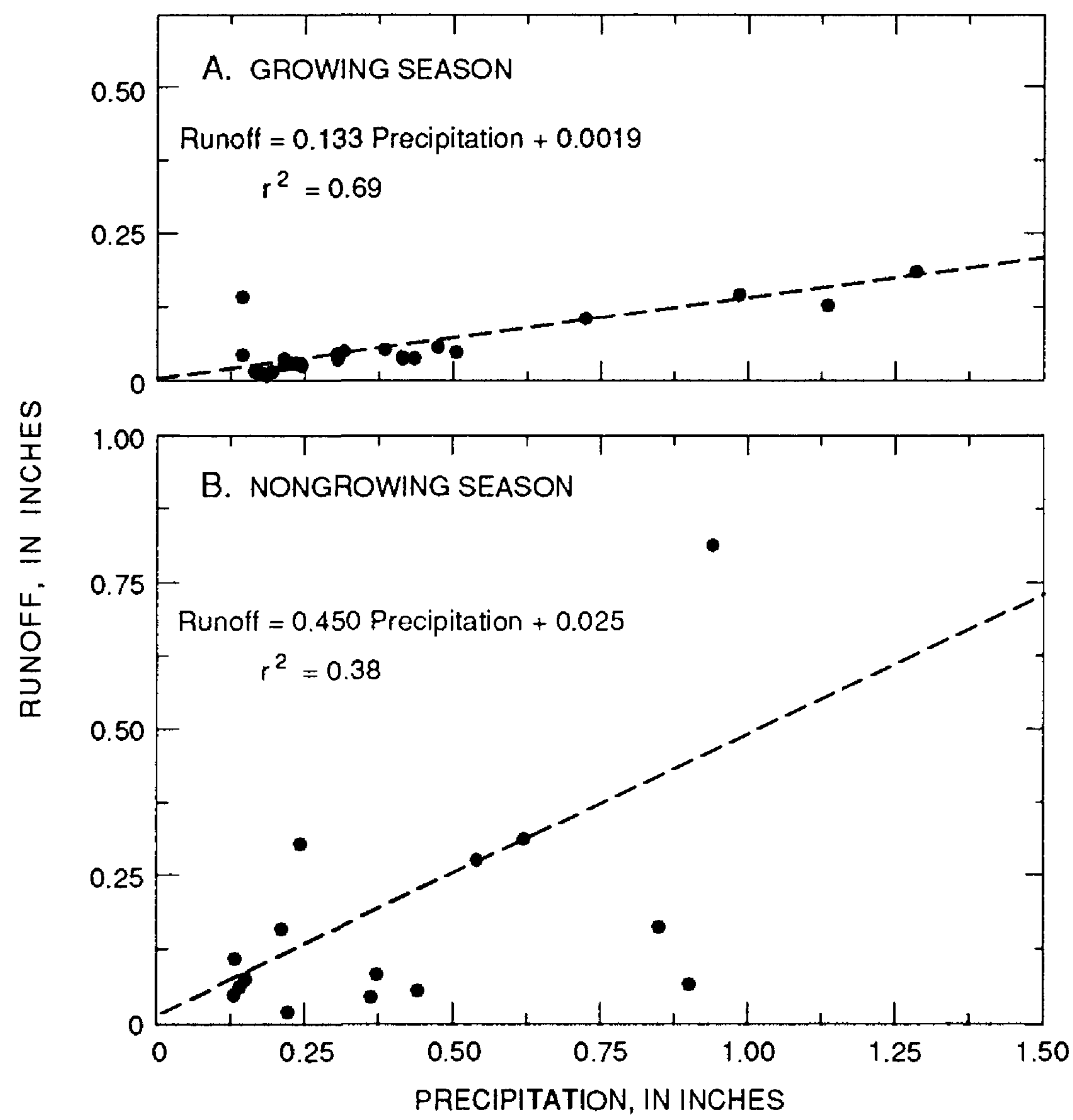

Figure 8.--Rainfall-runoff relation for storms: (A) During growing season. (B) During nongrowing season.

The slope of the rainfall-runoff regression line (13.3 percent) during the growing season is comparable to the hydraulically effective impervious area (HEIA) of the watershed (11 percent). Analytically, this relation was developed by Betsen (1964), who showed that runoff is equal to rainfall minus infiltration within the pervious area plus rainfall on the HEIA. For small storms, when runoff originates only from the HEIA,

$$RO = RN(HEIA/DA) \ ,$$

where RO = runoff,

RN = rainfall,

HEIA = hydrologically effective impervious area, and

DA = drainage area.

Rearranging the equation makes the slope of the linear part of the rainfall-to-runoff curve equal to the fractional part of HEIA:

$$RO/RN = HEIA/DA \ .$$

A few storms with rainfall greater than 0.5 in. deviate from the rainfall-runoff line, which indicates that areas outside the HEIA contribute runoff during storms with rainfall in excess of 0.5 in. Betsen (1964) refers to this as the variable-source area, whose size is proportional to antecedent conditions and duration and intensity of the storm, as well as other factors. The point at which runoff is generated from areas outside the HEIA and the size of the area could have a significant effect on water-quality characteristics of the stormflow.

Chemical Quality of Runoff

Constituent loads measured at the inflow and outflow of the detention basin during individual storms are presented in appendix III. Physical properties include suspended solids, dissolved solids, suspended volatile solids, chemical oxygen demand, and total organic carbon. These constituents are a measure of the material dissolved or suspended in runoff that are indicative of the turbidity of runoff. Suspended volatile solids, chemical oxygen demand, and total organic carbon are also a measure of the organic matter present. Detention basins are likely to have an effect on the suspended-solids content in runoff because they can settle. In contrast, basins have little effect on dissolved solids because dissolved substances do not settle and because time is insufficient for chemical or biologic reactions to precipitate them from solution.

Nutrients include various compounds of phosphorus and nitrogen. The forms of nitrogen that were measured are ammonia plus organic nitrogen (total Kjeldahl nitrogen), dissolved ammonia, and nitrite plus nitrate. Sources of nitrogen include decomposing organic matter that is introduced to the soil by nitrogen-fixing plants and bacteria, human and animal wastes, organic and inorganic fertilizers, and atmospheric deposition. Phosphorus was measured in both the total and dissolved forms as total phosphorus and orthophosphorus. Phosphorus, like nitrogen, is an essential plant nutrient that causes undesirable blooms of aquatic plants and algae and, in temperate lakes, is usually the limiting nutrient. Water-quality-management strategies, therefore, commonly emphasize the control of phosphorus, rather than of nitrogen, which is relatively more prevalent in the environment (Hem, 1970).

Phosphorus in natural waters is commonly bound to colloidal particulates (Hem, 1970; White, 1981; Raush and Schreiber, 1981); the log-transformed mean suspended phosphorus load at the inlet to the detention basin was 58 percent of the total phosphorus load, and the suspended orthophosphorus load was 35 percent of the total orthophosphorus load. The detention basin could, therefore, retain some fraction of the phosphorus load if settling time were adequate. Dissolved phosphorus can be removed through vegetative uptake (Hey and Schaefer, 1983) and(or) through adsorption of phosphate ions by metal oxides, such as ferric hydroxide (Hem, 1970); its concentration can increase within a basin, however, through the dissolution of solids (Hey and Schaefer, 1983).

Sodium and chloride compounds are widely used as a road deicers in areas affected by snow and ice and consequently are common in urban storm runoff from such regions. Sodium and chloride ions tend to remain in solution because they are highly soluble, stable, and unreactive;

therefore, detention will likely have little effect on the concentration of these ions.

Metal analyses were limited to lead and zinc, which are elevated in streams of Irondequoit Creek basin (Kappel and others, 1986). Lead and zinc are probably derived mostly from manmade sources through atmospheric deposition (Elder, 1988), although zinc also is released in this area through weathering of dolomite and soils derived from it, which typically contain a significant percentage of sphalerite, a zinc sulfide.

Partitioning of metals between dissolved or suspended phases is controlled almost entirely by pH (Elder, 1988). In the slightly acidic pH range common in this area (5 to 7), metals tend toward the suspended phase. At the inlet to the detention basin, the log-transformed mean suspended load in relation to the total load was 69 percent for lead and 60 percent for zinc.

Bottom-Sediment Chemistry

The chemical quality of sediments retained in the basin is an important consideration in assessing the health risk and disposal of the sediments removed as part of maintenance operations. To provide background information on constituents that accumulate in the basin sediments, a one-time analysis for concentrations of nutrients, metals, organic compounds in bottom sediments, and for particle-size distribution of these sediments was made at the beginning of the study in the summer of 1986.

Bottom-sediment samples were composited from groups of five samples from the top 5 in. of material at four locations in the basin—the channel between the inlet and outlet (sample 1), the normally wet, organically rich soil adjacent to the main channel (sample 2), and relative dry soil at either end of the basin (samples 3 and 4). Results of the analysis are presented in appendix IV.

Many factors affect the concentration and toxicity of constituents in bottom sediments, including moisture, organic content, temperature, aeration, redox potential, and grain-size distribution (Luoma, in press; Nightingale, 1987). Susceptibility of biological communities to contamination by trace elements, therefore, is controlled by sediment geochemistry, which is poorly documented (Luoma, 1989). Processes that affect the susceptibility of biota to organic compounds in sediments are even less known. As a consequence, quality criteria for estimating concentrations of metals and organic compounds in bottom sediments are lacking.

Concentrations of most organic compounds in the basin bottom sediments that were analyzed, including most of the organochlorine compounds used as insecticides and pesticides that are highly toxic and persist in the environment, were at or below detection limits. Diazinon, heptachlor, and DDT were detected at concentrations slightly above their detection limit in several samples (appendix IV). Diazinon is commonly used in pellet form by lawn care companies to kill grubs; heptachlor is used as an insecticide for termite control, and DDT was widely used as an insecticide until it was banned in 1973.

Concentrations of the trace metals arsenic, cadmium, and lead in the bottom sediments (appendix IV) were at or below the guidelines set forth in the Great Lakes Near Shore Index (Schierow and others, 1981). Quality criteria for the other trace metals analyzed could not be found.

HYDROLOGIC EFFECTS OF OUTLET CONFIGURATIONS

The three outlet configurations examined in this study consisted of the original design and two successive modifications to increase detention time in an attempt to improve constituent removal by extending settling time. The original outlet configuration consisted of a 4-ft-high, 24-in.-diameter corrugated metal pipe (trickle tube) with 2-in.-diameter holes every 6 in. on center and a 8-in.-diameter hole at the base to allow the pond to drain completely (fig. 4 and 9). In this configuration, the basin drained from full to empty in about 45 minutes.

The first outlet modification (second configuration) consisted of a 20-in.-diameter PVC pipe inserted into the original trickle tube outlet (fig. 9). This pipe had fewer and smaller holes (1.5-in.-diameter holes cut in four rows and four columns) and a 4-in.-diameter hole at the base, which doubled the time required for the basin to drain from full to empty (about 1.5 hours). The second modification (third configuration) eliminated the 4-in. hole at the base and increased the drainage time to 11 hours. This modification also created a small pool of standing water that was intended to promote wetland vegetation, but this was only partly successful because the bottom of the PVC insert pipe could not be sealed tightly to the bottom of the original outlet. The stage-to-discharge relations for the three outlet configurations are plotted in figure 10A, and the times required for the three outlet configurations to drain the basin from a given stage with no inflow are plotted in figure 10B.

Figure 9.--Insert pipe used to modify outlet control.

Outflow and Basin Stage

Changes in the outlet-discharge and basin-stage hydrograph that resulted from the three outlet configurations during two storms of differing duration and intensity are plotted in figures 11A and 11B. The storm of April 4, 1987 (fig. 11A) was a typical storm of low intensity and long duration, whereas that of September 17, 1988 (fig. 11B) was a typical storm of high intensity and short duration. The discharge and basin-stage hydrographs are derived from values measured during the original outlet configuration in the April 4, 1987 storm and the first modification in the September 17, 1988 storm. The plotted data for configurations other than those measured were simulated (through the reservoir-routing program by Jennings, 1977) from measured inflows and the stage-to-discharge relation for each outlet configuration.

Figures 11A and 11B show that the unmodified outlet had little effect on the shape and magnitude of the outflow hydrograph in relation to the inflow hydrograph, particularly during the April 4, 1987 storm. Basin stage during this configuration usually did not exceed a 1.0-ft rise. The modified outlets, particularly the second modification (configuration 3), attenuated the outflow and prolonged the ponding.

Peak-Discharge Attenuation

Peak outflow decreased on average about 30 percent in relation to inflow in storms that occurred during the original configuration, 60 percent during the second configuration, and 85 percent for the third configuration. Plots of peak outflow in relation to peak inflow for the three control configurations are shown in figure 12. In all configurations, peak flows were increasingly attenuated as discharge increased. Thus, modifications of detention basins to increase constituent settling will also affect their response to stormflow. For a small basin such as this, the response to modifications will likely have a negligible effect on the regional flow system, but modifications to multiple basins or basins with large contributing watersheds could result in downstream flooding. Usually the attenuation of peak discharge in multiple basins is additive, but if delayed peak discharges were to coincide with peaks from other contributing areas, the peak discharge downstream could possibly increase (Hawley and others, 1981).

Detention Time

The average detention time of water in the basin was calculated through "plug-flow" concepts, in which a "plug" represents the volume of water entering the basin in one time step. Detention time of a plug is defined as the difference in time between the centroid of a cumulative volume of water entering the basin and the centroid of the corresponding volume of water leaving of the basin (fig. 13, p. 23). The calculation of detention time was derived from the concepts described by Alley and Smith (1982) and Ward and others (1979).

Detention times for a plug of water in the unmodified basin averaged 3.4 minutes for the April 4, 1987 storm and 1.7 minutes for the September 17, 1988 storm. After the first modification, average detention times for storms of similar magnitude would be 11 minutes and 5.2 minutes, respectively, and after the second modification would be 83 minutes and 57 minutes, respectively. The plug-detention time in relation to time since storm onset is shown for each of those two storms in figures 14A and 14B (p. 24).

The averages of the mean and maximum detention time of plugs for measured storms used in the analysis of the detention basin are summarized in table 5 (p. 24). Mean detention time for plug flows averaged 4.7 minutes for the original configuration, 7.0 minutes for the first modification, and 81 minutes for the second modification. The first modification increased detention time 49 percent over the original configuration, and the second modification increased detention time by a factor of about 10 over that for the second modification.

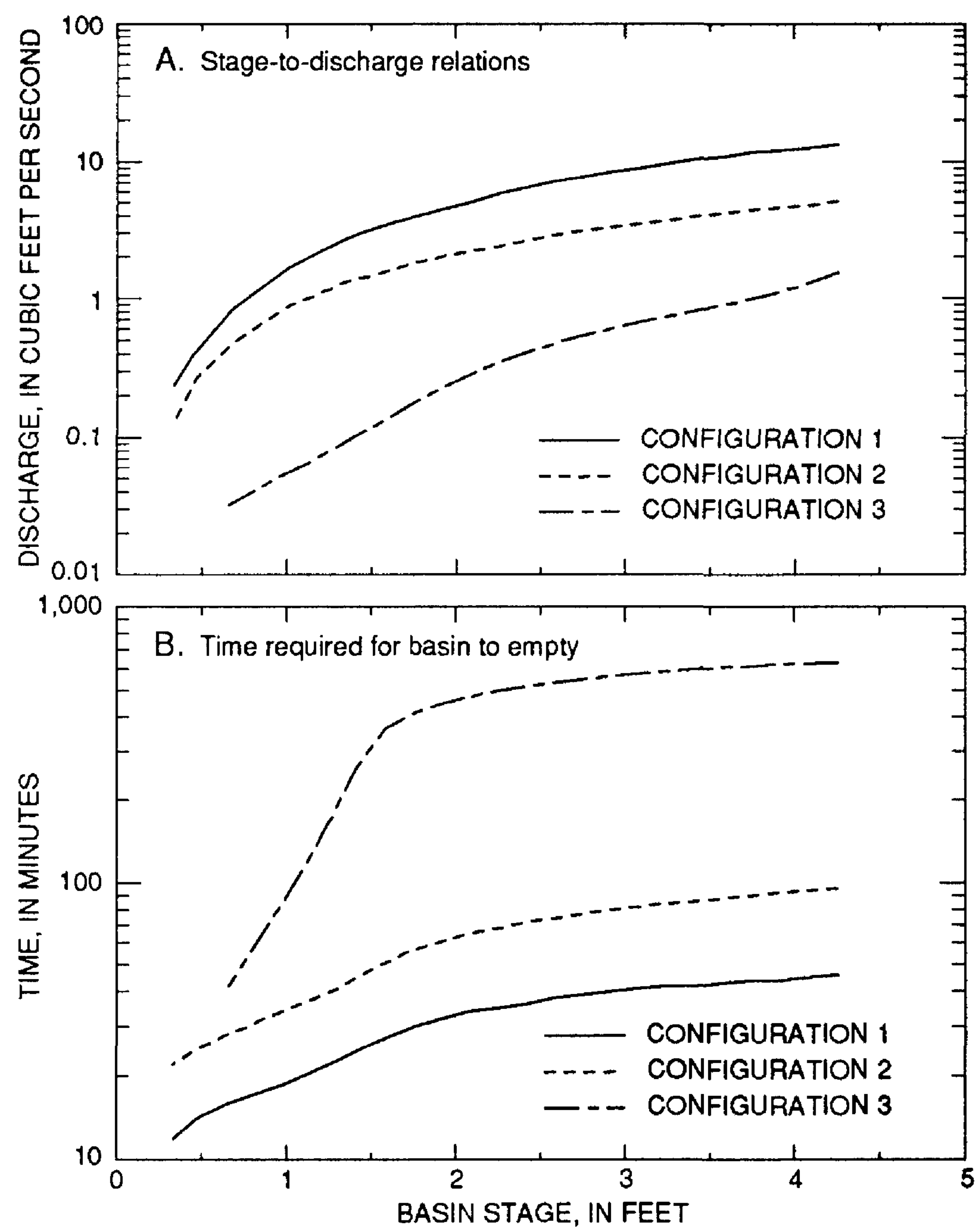

Figure 10.

Hydraulic factors for the three outlet configurations:

A. Stage-to-discharge relation.

B Time required for basin to empty.

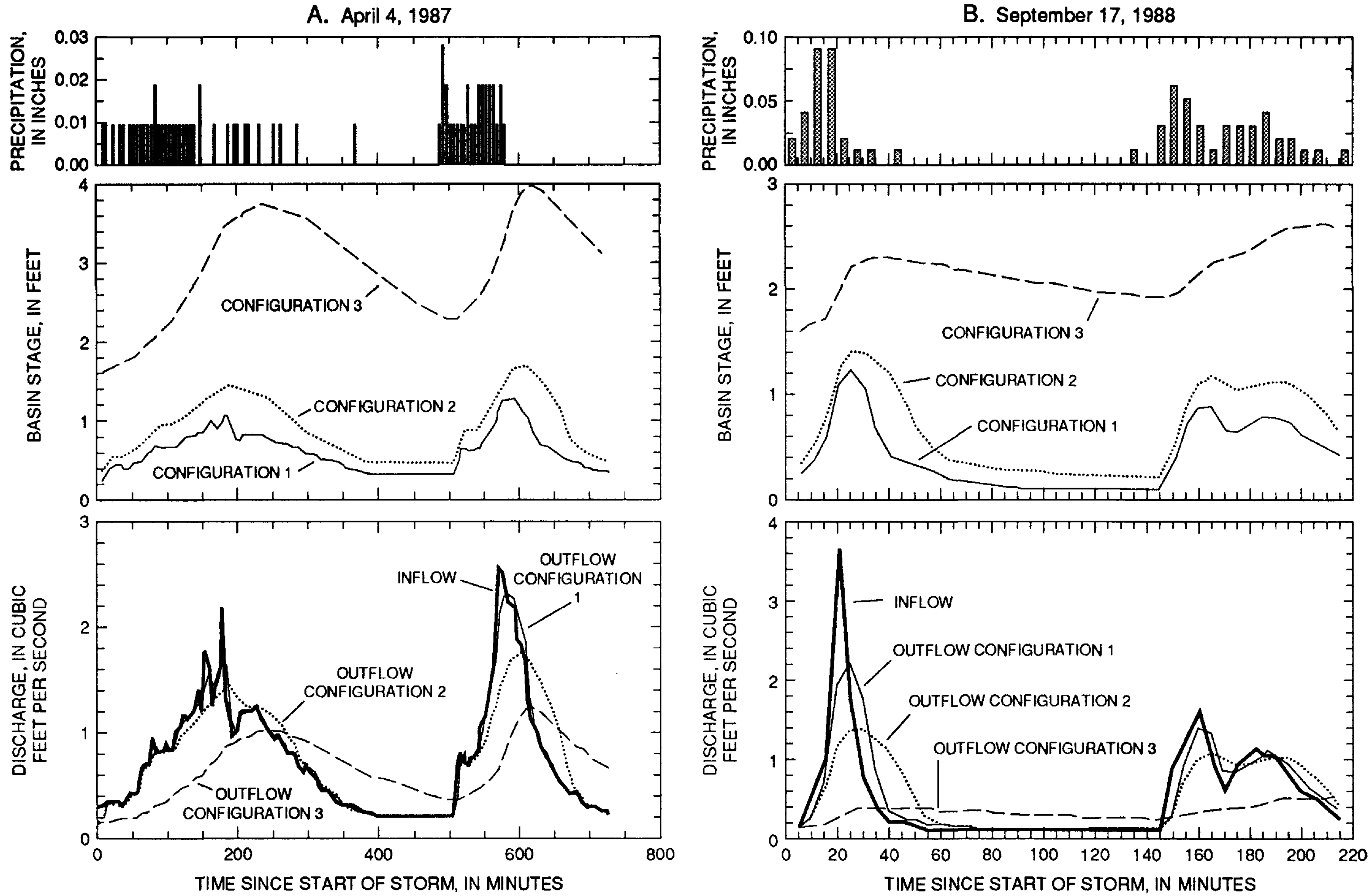

Figure 11.--Precipitation volume, basin stage, and discharge for the three outlet configurations during representative storms:
A. Long, low-intensity storm of April 4, 1987.
B. Short, high-intensity storm of September 17, 1988.

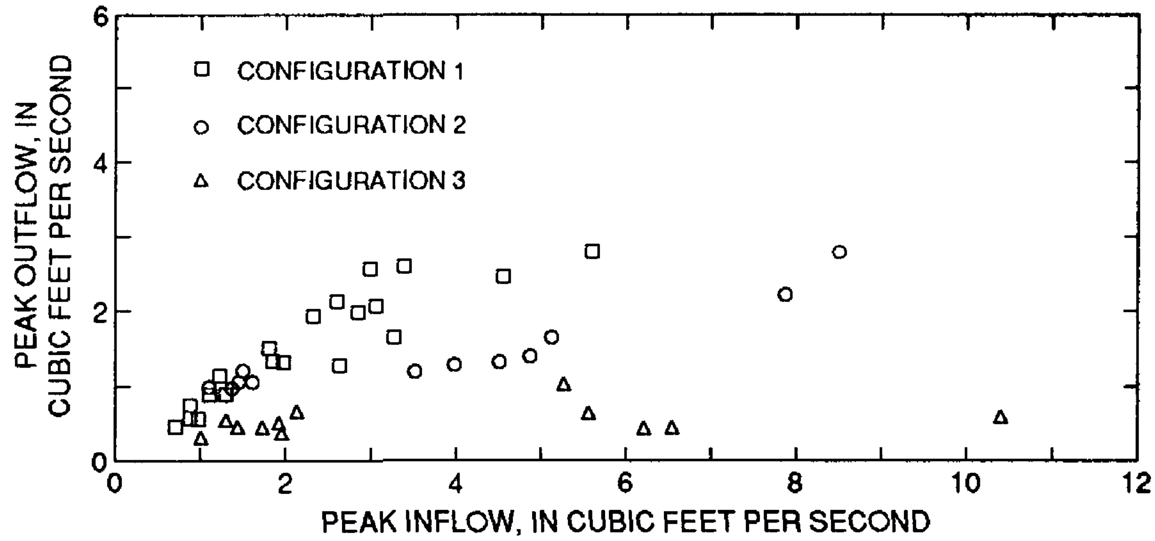

Figure 12.--Relation of peak outflow to peak inflow during the three outlet configurations.

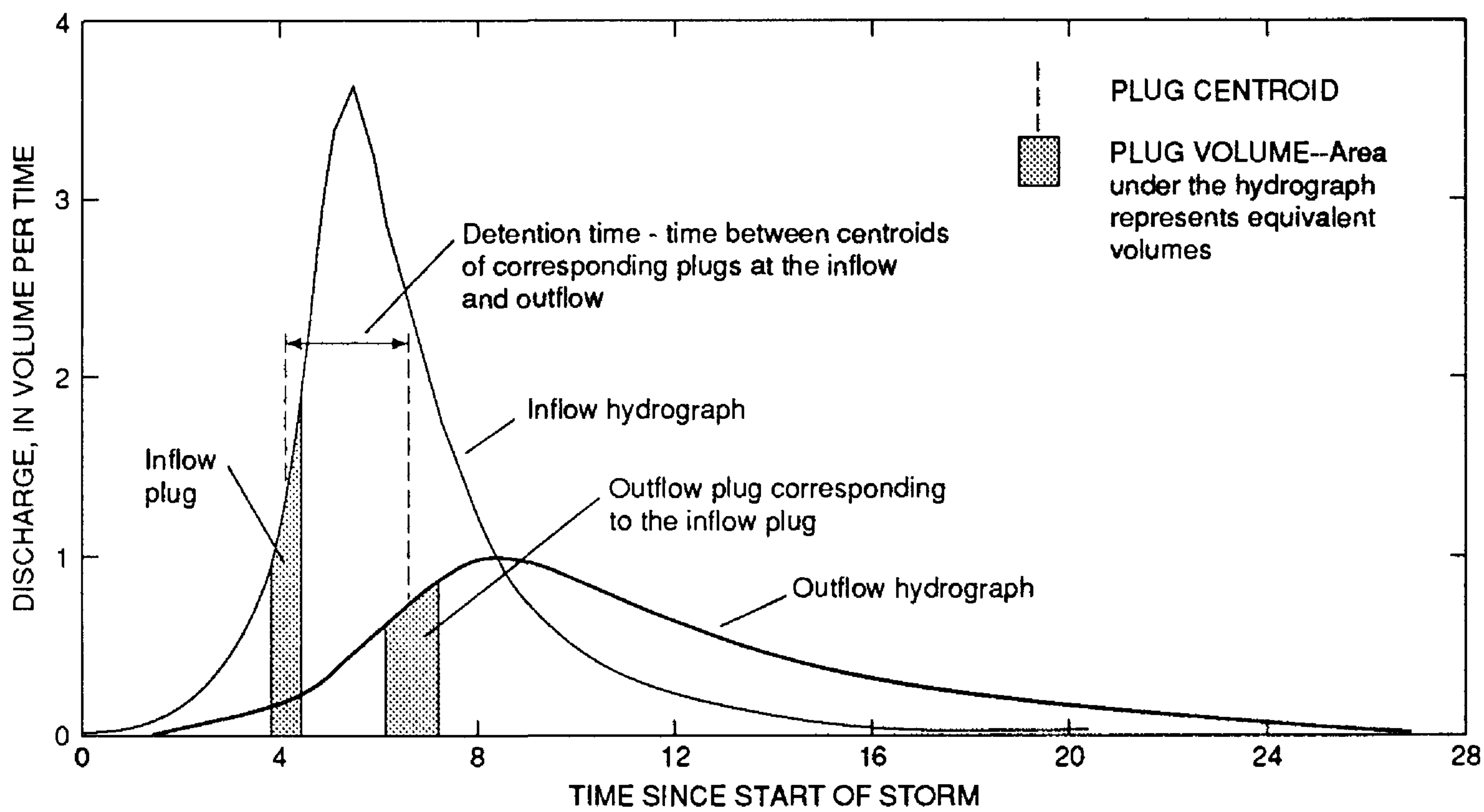

Figure 13.--Detention time between corresponding flow plugs at inflow and outflow of the detention basin, used to calculate detention times. (Modified from Alley and Smith, 1982, and Ward and others, 1979.)

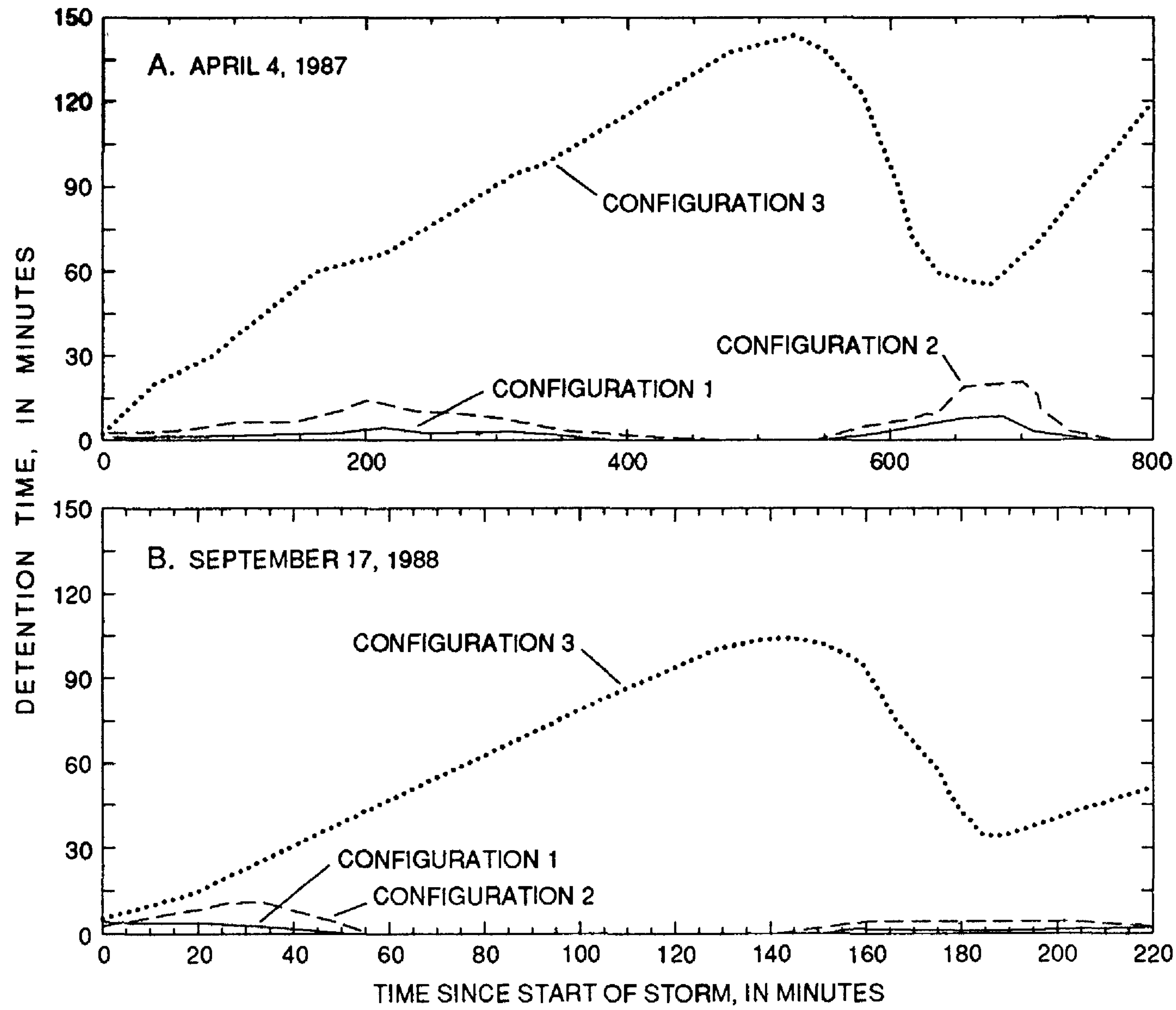

Figure 14.--Average plug-detention time for each outlet configuration during storms of April 4, 1987 and September 17, 1988.

Table 5.--Average of mean and maximum plug-detention time
[Values are in minutes]

Configuration	Number of storms	Mean detention time: Average	Mean detention time: Standard deviation	Maximum detention time: Average	Maximum detention time: Standard deviation
1	21	4.7	1.8	8.0	3.7
2	13	7.0	4.5	13	7.6
3	12	81	33	134	50

EFFECTS OF STORMWATER DETENTION ON THE CHEMICAL QUALITY OF RUNOFF

The effects of stormwater detention on constituent loads varied among constituents, storms, outlet configurations, and methods of analysis. The following sections summarize the detention basin's effects on constituent loads and examines the effects of seasonal factors and differences among methods and outlet modifications.

Changes in Constituent Loads, by Outlet Configuration

Changes in constituent loads are presented in four classes: physical properties, nutrients, common ions, and metals. Box plots for selected constituents within each class portray the characteristics (median, skewness, upper and lower quantities, and outlier values) of the inflow and outflow loads for each outlet configuration (figs. 15A, 16A, 17A). A common feature of all constituents is the relatively small median loads and small variation about the median loads during the second configuration, probably a reflection of the dry conditions that prevailed during much of that sampling period.

Bar graphs (figs. 15B, 16B, 17B) indicate the change in selected constituent loads between the inflow and outflow for individual storms during each outlet configuration. The amount of constituent load retained is indicated by the value of the bar above the zero line. The absence of a bar indicates no change in constituent load, and a bar below the zero line indicates a net increase in constituent load. Most negative loads (net increases) are balanced by a change in the partitioning of the constituent between the suspended and dissolved phase. Some storms show a negative load for all phases of a constituent, however; probably because the sampling procedures failed to detect part of the inflow load, as discussed previously. For example, a large percentage of a storm load could have occurred during the initial part of the storm—the "first flush" effect. When this occurs, sampling at the inflow could miss the initial concentrated plug of water, but sampling at the outflow could detect it after it has mixed with other stormflow. This would give the appearance of a net gain in constituent load at the outlet of the detention basin. Similarly, constituents retained from previous storms could be discharged from the basin as a result of resuspension, chemical changes, and(or) the decomposition of organic matter and give the appearance of an increase. Water-quality sampling was not adequate, however, to determine whether the long-term mass balance of constituent loads would give results similar to those reported.

Physical Properties

Suspended-solids loads were larger and more variable during the initial configuration than during the other configurations (fig. 15A), probably because the runoff during the initial period was generally greater and more variable (appendix table A2). Median loads and the variability of the loads were less at the outflow than at the inflow during all configurations (fig. 15A). Results of the Wilcoxon sign rank test indicate that the median outflow loads differ significantly from the median inflow loads at the 95-percent confidence interval for all outlet configurations. Suspended solids loads (fig. 15B) decreased during most storms during the initial configuration and for all storms after the first control modification. The largest negative load occurred during the storm of May 13, 1987, which followed one of the driest antecedent periods (appendix I), although other storms in which loads were negative do not show patterns that correlate retention with antecedent conditions (fig. 15A). A similar pattern was observed among total and volatile suspended solids (not shown in fig. 15A).

In general, dissolved solids loads were more variable in inflows than in outflows throughout the study. The median inflow loads were similar to the median outflow loads during the first and second configurations but were less than the median outflow loads during the third configuration. The Wilcoxon test indicated that this difference is not significant at the 95-percent confidence level, however.

The changes in total organic carbon loads and chemical oxygen demand, in general, were similar to the changes of dissolved solids loads except during the initial configuration, when the total organic carbon load did not change appreciably, and the chemical oxygen demand load increased. The median total organic carbon load increased during the initial configuration, possibly because the basin had been used for disposal of leaves and grass clippings, which were still being flushed out during the first storms sampled. Storm-to-storm variations in the outflow loads decreased in relation to those in the inflow load after the first modification (fig. 15B) and again after the second modification (fig. 15A). Loads of all four constituents decreased during most storms after the control modifications. The Wilcoxon signed rank test indicates a significant difference (at the 95-percent level) between the inflow and outflow loads of these constituents during the third configuration.

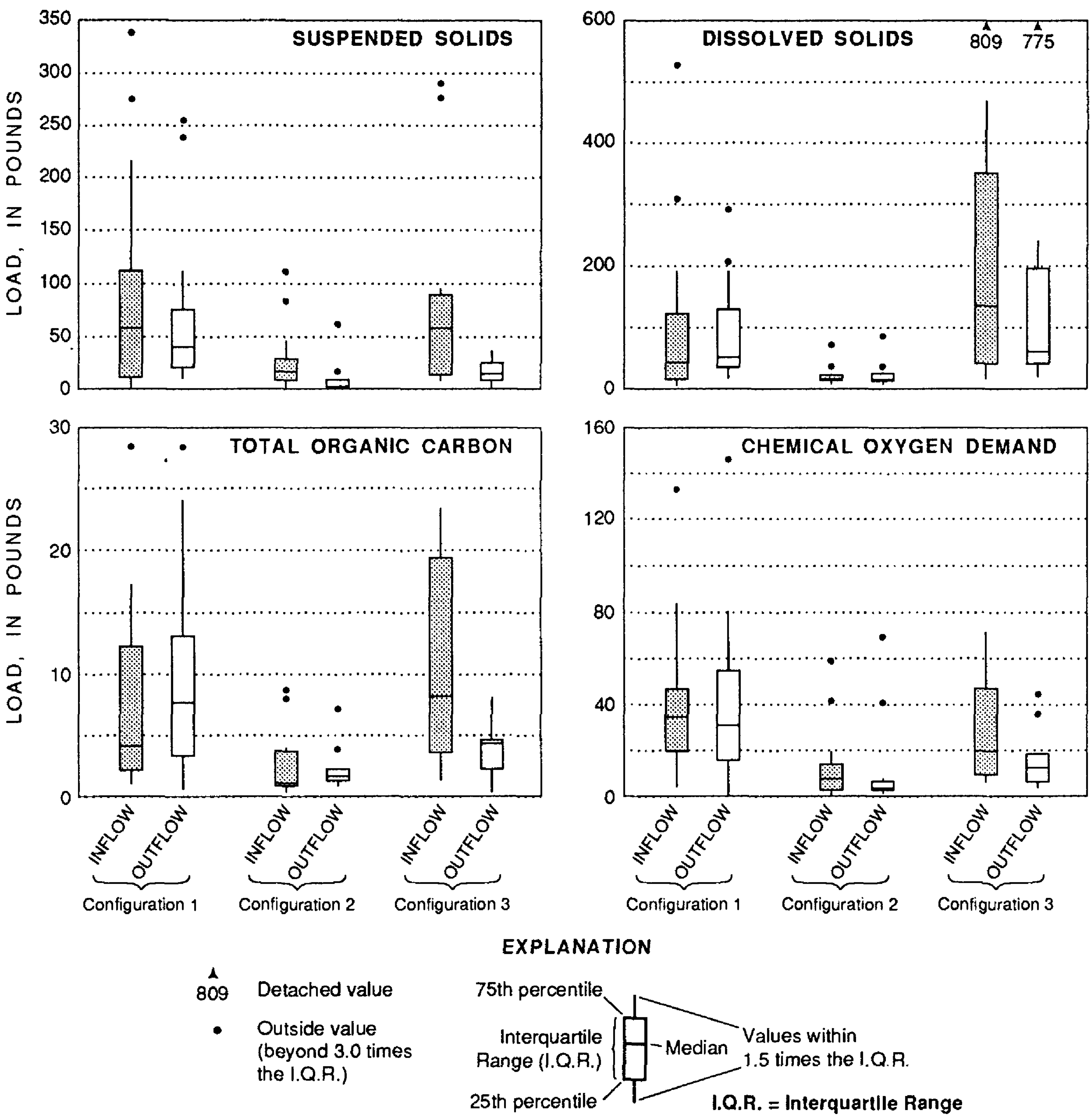

Figure 15A.--Box plots showing loads of physical-properties at inflow and outflow, by outlet configuration.

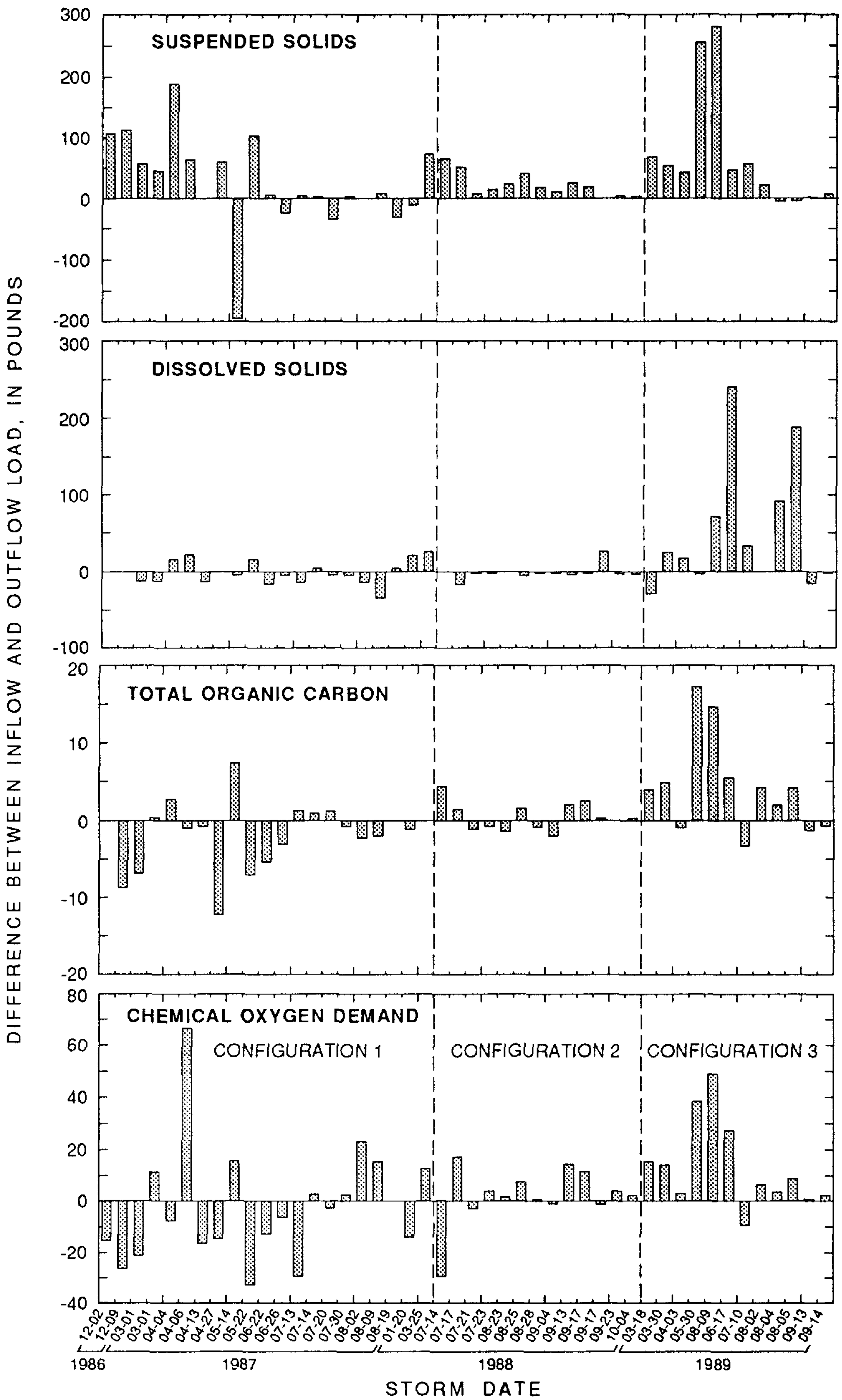

Figure 15B.--Difference between inflow and outflow load of physical properties, by storm and outlet configuration.

Nutrients

The inflow- and outflow-load characteristics of total phosphorus, total orthophosphorus, total ammonia plus organic nitrogen, and nitrite plus nitrate are depicted in box plots in figure 16A; the differences between inflow and outflow loads for individual storms are shown in figure 16B. Loads of total phosphorus and total orthophosphorus decreased during all outlet configurations and were generally more variable in the inflow than in the outflow (fig. 16A). The Wilcoxon test indicated that the difference between total phosphorus inflow loads and outflow loads was significant during only the second and third configurations. Decreases in loads of total phosphorus, which was mostly in the suspended phase (58 percent), were more consistent and larger

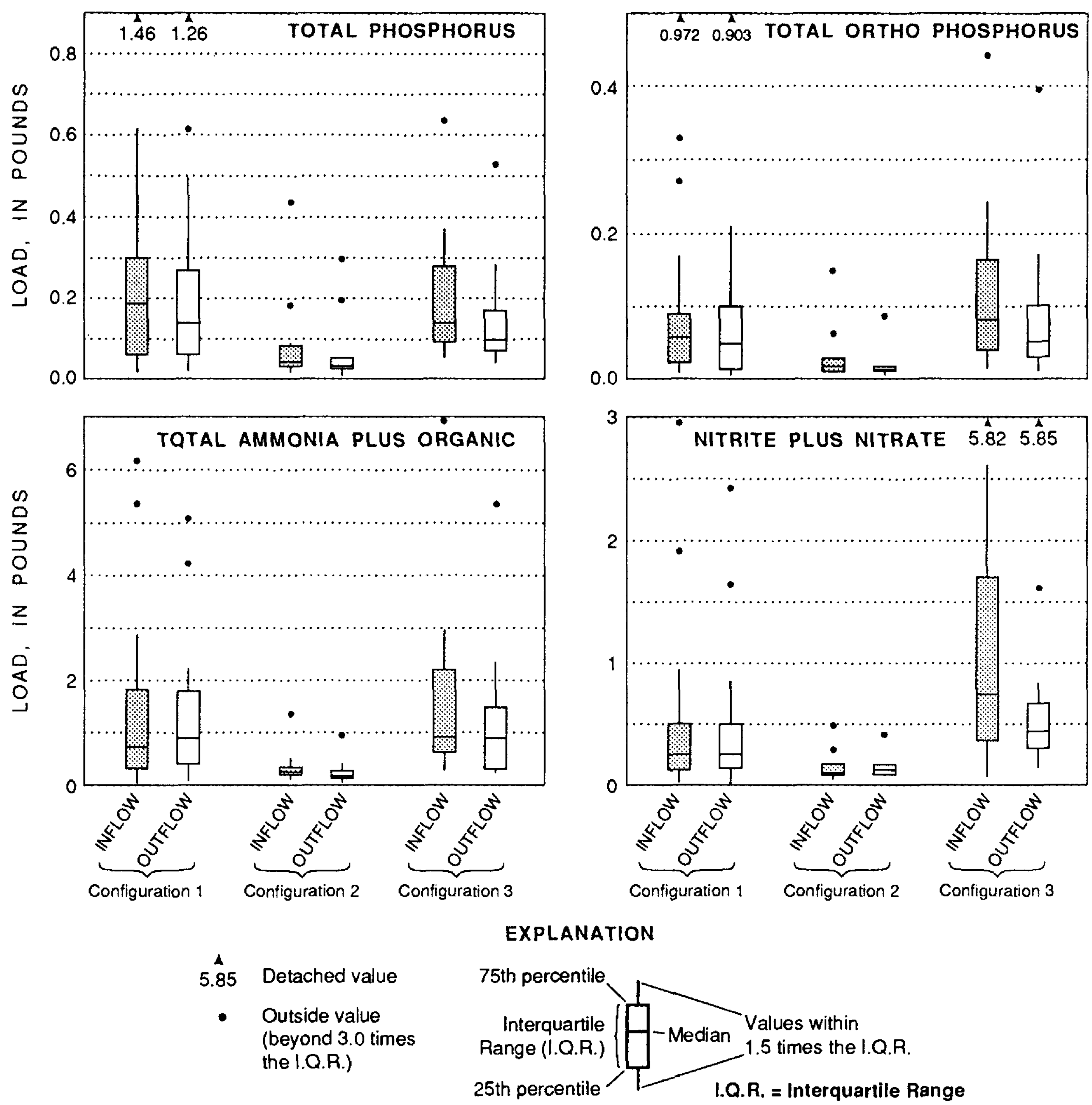

Figure 16A.--Box plots of showing loads of selected nutrients at inflow and outflow, by outlet configuration.

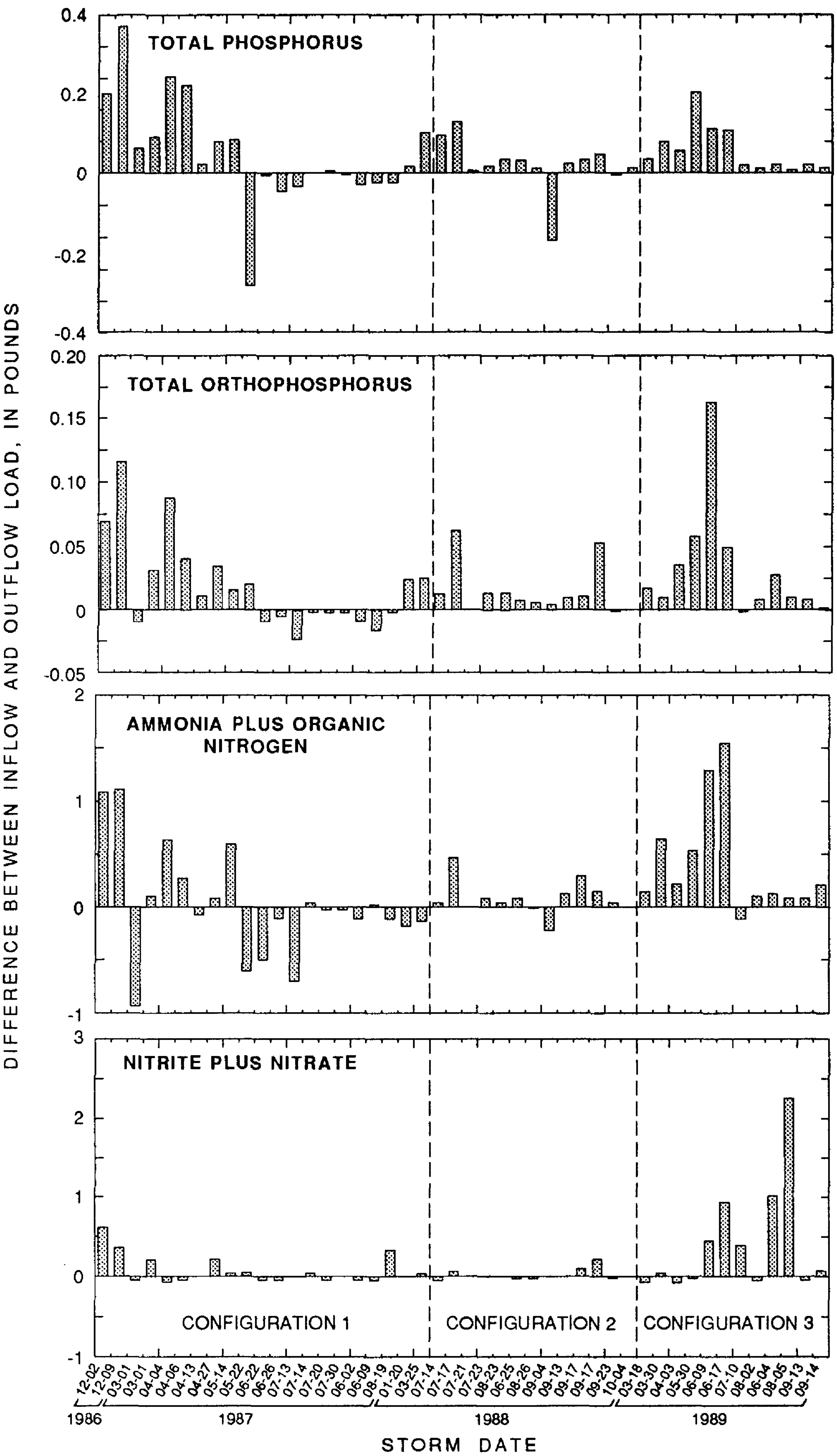

Figure 16B.--Difference between inflow and outflow load of selected nutrients, by storm and outlet configuration.

during all the storms (fig. 16B) than were those for orthophosphorus, of which only about 30 percent was in suspension. Differences in total phosphorus and total orthophosphorus loads were both negative and positive during the first configuration, indicating alternating retention and release, but became consistently positive (retention) after the outlet was modified. The improved retention for orthophosphorus could reflect the increase in suspended orthophosphorus as a fraction of total orthophosphorus in inflow during the second and third configurations. The suspended orthophosphorus load represented, on average, 20 percent of the total orthophosphorus load in storms during the first configuration, then increased to 34 percent during the second configuration and to 39 percent during the third configuration. The retention of dissolved-phosphorus species fluctuated around zero and was thus inconclusive.

Nitrogen loads in inflow and outflow generally differed little except during the third configuration, which indicated retention (fig. 16A). The Wilcoxon test indicates significant differences between inflow and outflow only for total ammonia plus organic nitrogen during the second and third configurations.

Metals

Median total lead and zinc inflow loads were greater and more variable than the corresponding outflow loads during all configurations. The Wilcoxon test indicates these differences to be significant for total zinc under all configurations, and for lead under the first configuration. Changes in the total load from inflow to outflow for both constituents during individual storms (fig. 17B) mimic the changes in the suspended forms (not shown) because these constituents are transported mainly in the suspended phase (64 percent for lead and 68 percent for zinc). Little difference in the dissolved phase of these constituents was noted between the inflow and outflow. Storms that caused a net increase in lead and zinc loads through the basin generally occurred near the end of the growing season (late September through early October). The largest net increase in the lead load occurred during early March storms that represented wintry conditions during the third configuration.

Common Ions

The box plots for sodium and chloride loads are similar among all outlet configurations (fig. 17A). The median and variability of the ion loads did not change appreciably from inflow to outflow during the first and second configurations, but decreased at the outflow during the third configuration. The Wilcoxon test indicates this difference is not significant, however. Changes in the sodium and chloride load were both positive and negative during all configurations, but the third configuration increased retention of both ions, possibly because a small volume of ponded water was available to mix with the stormwater. A large retention of sodium and chloride load occurred during the December storms of the first configuration (fig. 17B), possibly from deicing salts that are believed to have been applied in the watershed at the onset of the storm. The inflow sample could have contained salt granules that, upon dissolving, increased the concentration of these ions in the inflow sample. Salt granules that flowed into the basin would have time to dissolve during flow retention, thus, the concentrations of these ions would be diluted at the outflow and give the appearance of a large retention.

Seasonal Trends

Seasonal variations in the performance of the detention basin, although not a primary consideration of this study, were examined even though only the first configuration had a sufficient distribution of storm data throughout the year to enable valid statistical comparison. Storms were grouped as either nongrowing season (October through April, with 10 storms) or growing season (May through September, with 11 storms), and were compared by means of the Wilcoxon test of ranked differences between inflow and outflow loads, by season. A significant difference (at the 95-percent confidence level) was indicated for all species of phosphorus except suspended orthophosphorus, and for suspended solids, total solids, total volatile solids, and chloride. These differences indicate that the basin removes solids more effectively during the nongrowing season than during the growing season, possibly because most peak inflows from storms sampled during the growing season were larger (2.52 ft^3/s on average) than those during the nongrowing season (1.52 ft^3/s on average).

Typically, the effectiveness of a basin might be expected to increase during the growing period, when concentrations of dissolved constituent would be affected by increased biological activity, and would decrease during the nongrowing season, particularly during snowmelt, when the large volume of runoff decreased the time available for particulate matter to settle. Although the first part of the study indicates that basin effectiveness decreases with increased runoff, additional information would be needed to determine the effect of seasonal factors on detention-basin performance.

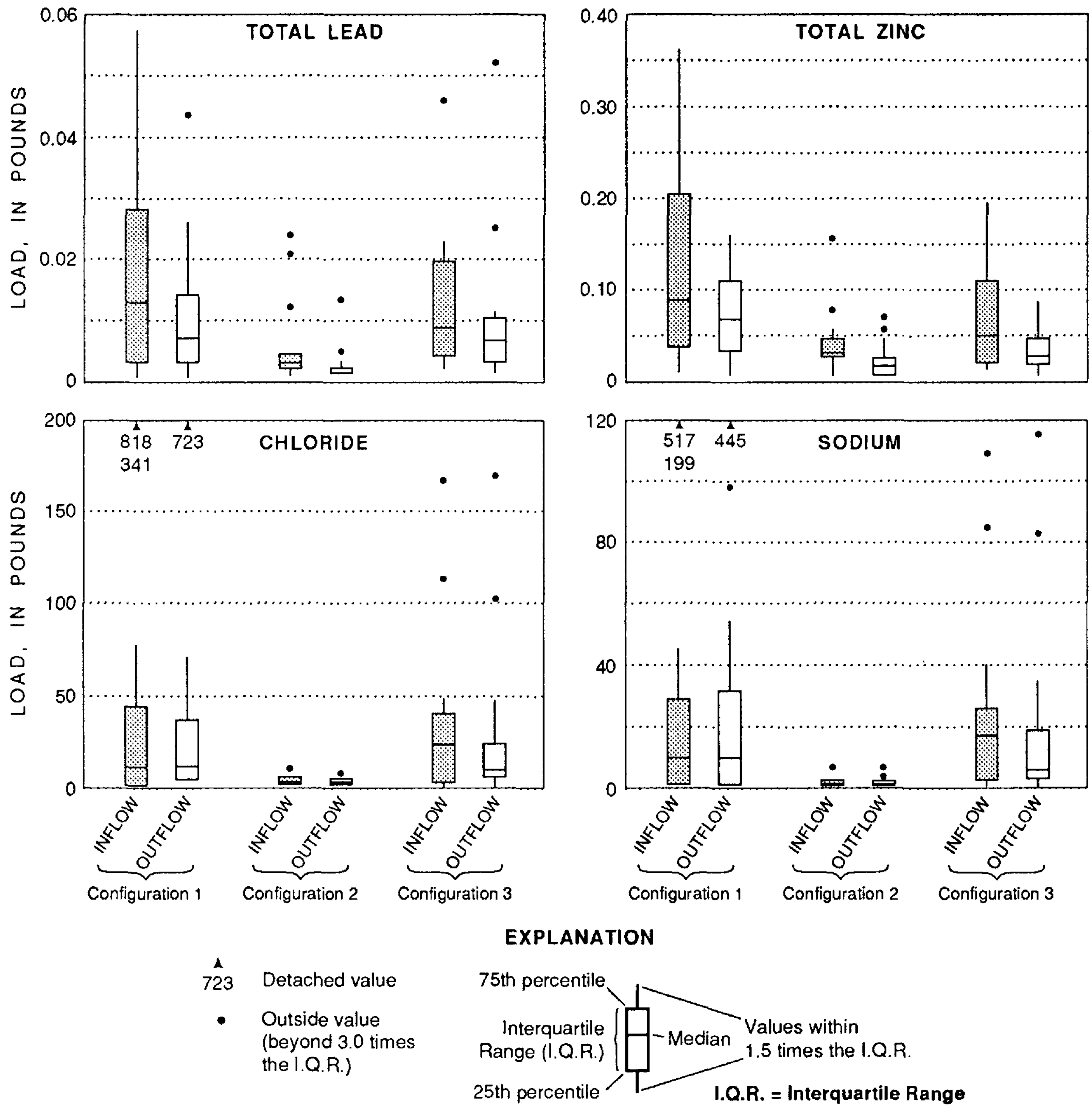

Figure 17A.--Box plots showing loads of selected metals and ions at inflow and outflow by outflow configuration.

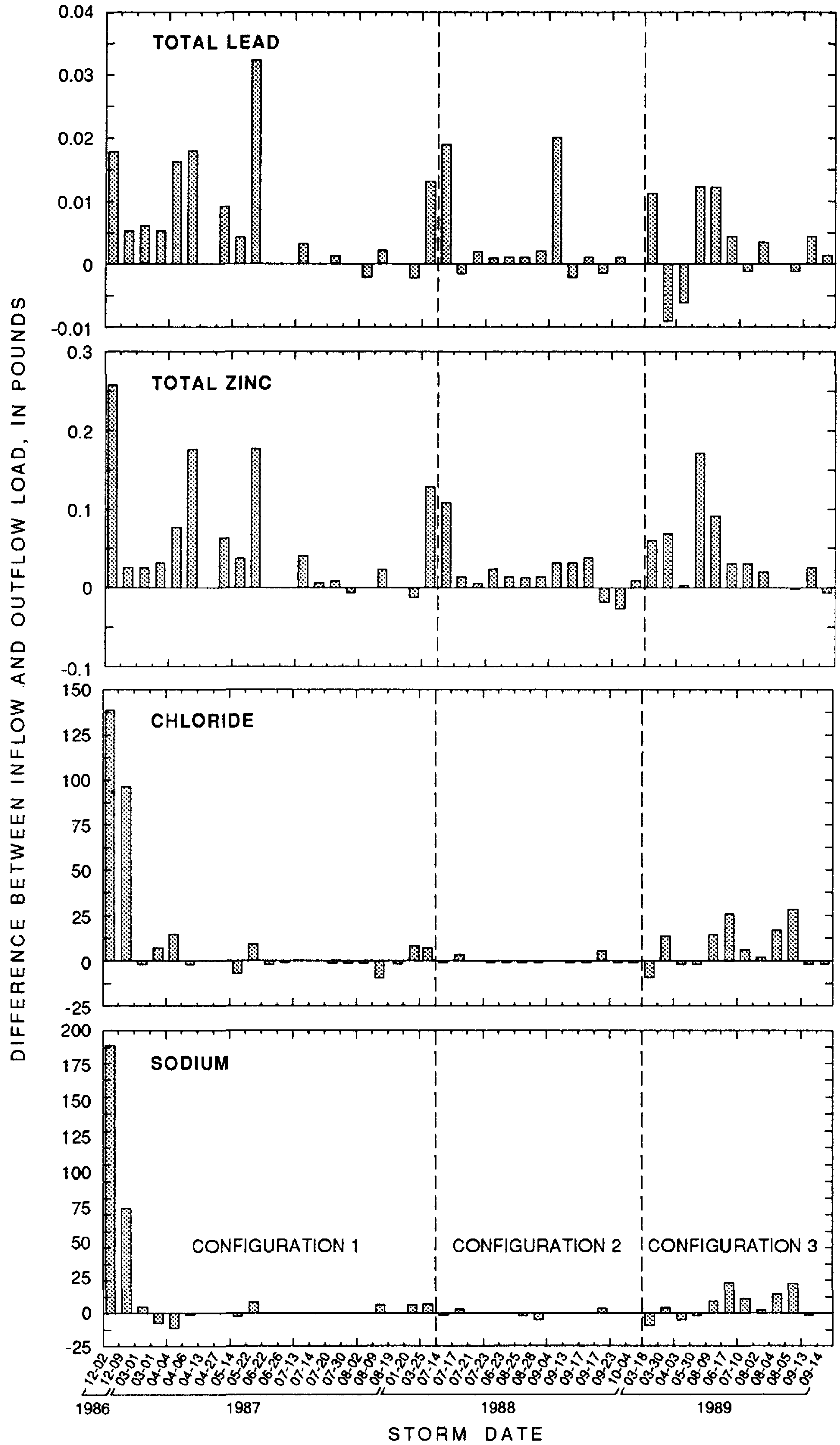

Figure 17B.--Differences between inflow and outflow load of selected metals and ions loads, by storm and outlet configuration.

Comparison of Methods for Calculating Basin Trap Efficiencies

Average efficiencies for each of the three methods of calculation—event mean concentration (EMC), summary of loads (SOL), and regression of loads (ROL)—for each of the outlet configurations are summarized in table 6 and plotted in histograms showing trap efficiency with respect to physical properties, phosphorus, and metals in figure 18. Negative efficiencies indicate increases in concentration or load between inflow and outflow.

Although basin trap efficiencies differed among constituents and outlet configurations, results of the three methods of calculation were generally similar. The EMC method typically produced the lowest trap efficiencies, the ROL method produced the highest efficiencies, and the SOL method produced intermediate efficiencies. The unmodified control produced a larger range in efficiency among methods for physical properties and some species of nutrients than the two modifications (figs. 18A and 18B). For example, the EMC method produced negative efficiencies for several physical properties and some species

Table 6.--Event mean concentration (EMC), summation of loads (SOL), and regression of loads (ROL) efficiency estimates for selected constituents, by outlet configuration

Constituent	Configuration 1 EMC	Configuration 1 SOL	Configuration 1 ROL	Configuration 2 EMC	Configuration 2 SOL	Configuration 2 ROL	Configuration 3 EMC	Configuration 3 SOL	Configuration 3 ROL
Physical properties									
Suspended solids	-13.9	29.5	42.9	78.6	70.4	62.5	83.8	82.7	90.6
Dissolved solids	-3.8	28.4	2.5	-7.8	-8.5	-6.0	25.2	22.8	16.0
Suspended volatile solids	-39.7	8.3	22.8	69.9	61.7	56.6	71.1	70.1	82.4
Total organic carbon	-15.0	-19.1	-5.0	30.6	24.8	36.1	47.4	39.0	45.0
Chemical oxygen demand	- .2	-4.1	5.8	26.4	14.4	6.0	45.3	43.3	49.8
Nutrients									
Total ammonia plus organic nitrogen	-23.2	1.2	14.6	18.9	20.4	29.3	21.5	22.8	22.9
Nitrite plus nitrate	19.8	13.4	17.8	14.8	12.7	19.8	35.2	28.9	17.9
Dissolved ammonia	16.7	2.1	15.8	22.2	17.1	22.3	6.5	15.2	19.5
Total phosphorus	-2.6	19.3	21.5	11.5	22.7	33.0	32.0	26.9	25.4
Suspended phosphorus	-1.5	24.8	32.5	3.4	18.9	32.7	44.4	38.8	48.7
Dissolved phosphorus	0.0	11.2	19.0	22.2	30.9	44.7	11.1	13.8	16.6
Total orthophosphorus	6.8	15.4	11.3	54.5	47.3	47.6	28.6	25.1	22.1
Suspended orthophosphorus	10.2	31.6	33.6	72.2	64.6	60.6	60.0	52.3	77.7
Dissolved orthophosphorus	-7.7	7.6	27.8	37.5	38.5	47.5	12.5	11.9	14.3
Common ions									
Sodium	7.8	17.3	18.2	-7.2	1.8	20.1	22.5	16.7	5.9
Chloride	2.6	17.0	15.9	-19.7	-5.5	19.4	18.2	17.1	7.5
Metals									
Total lead	35.4	39.1	41.2	60.8	55.0	72.4	37.6	18.5	9.0
Dissolved lead	4.7	16.5	31.7	-13.2	-16.7	-16.7	28.2	23.4	45.0
Suspended lead	45.4	48.3	47.5	80.4	75.8	88.9	40.1	17.1	6.0
Total zinc	42.3	44.9	52.2	53.7	43.8	55.7	66.1	54.9	64.4
Dissolved zinc	13.2	25.8	46.0	3.6	-6.2	.1	13.0	- .4	-3.4
Suspended zinc	51.6	55.8	60.0	79.8	71.9	73.3	76.2	69.4	80.2

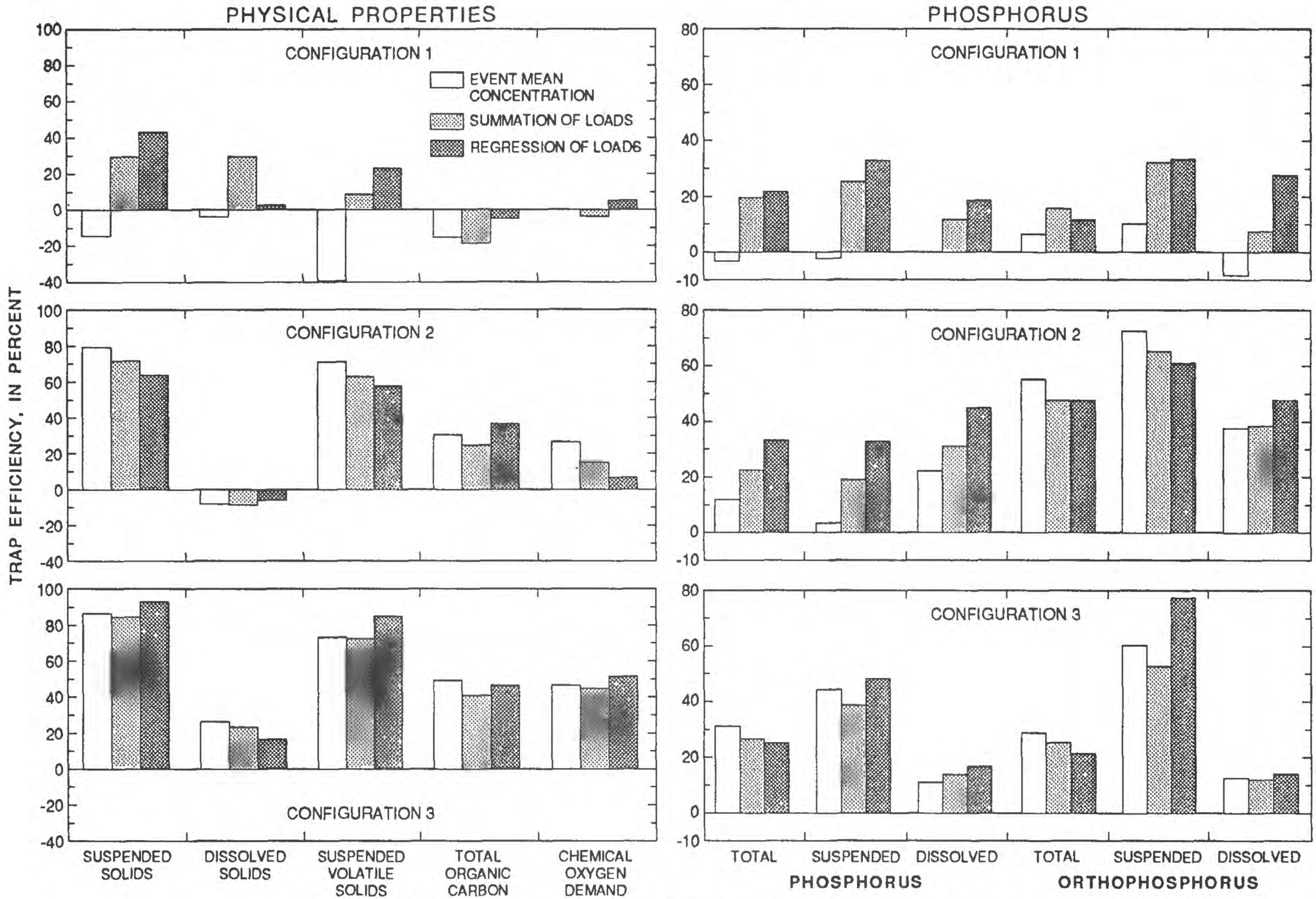

Figure 18.--Trap efficiency, by outlet configuration and calculation method:
A. Physical properties. B. Phosphorus.

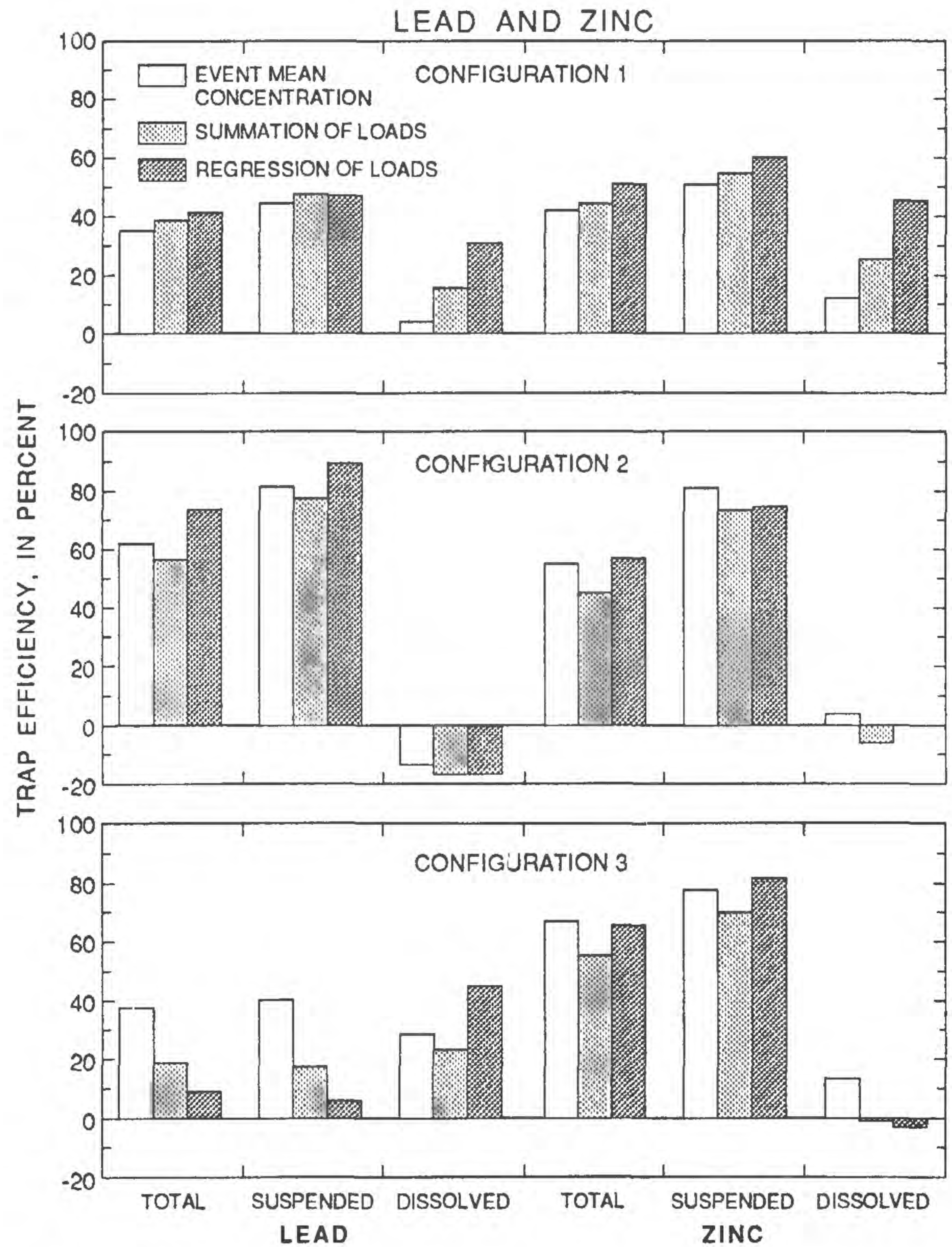

Figure 18.--(continued) Trap efficiency, by outlet configuration and calculation method: C. Lead and zinc.

of nutrients, whereas the ROL method produced negative efficiencies only for chemical oxygen demand and total organic carbon. The relatively wide range of results for the unmodified control are attributed to storm-to-storm differences in the characteristics of runoff and in the way that storms are weighted in each method. The EMC's assignment of equal weight to each storm makes the effect of large storms smaller than that in the other methods, whereas the ROL method adds weight to large storms. ROL efficiencies for total ammonia plus organic nitrogen, suspended solids, total orthophosphorus, and total lead for each of the control configurations are plotted in figure 19; these examples show the extent to which outlier storms affect the regression slope.

Results of chloride analyses were used as the basis for assessment of the three methods because chloride is unreactive and is almost always in the dissolved form and does not settle; therefore, the estimated basin efficiency for chloride should be close to zero. The three methods of analysis indicate no particular bias; the trap efficiencies for chloride ranged from 2.6 percent (EMC) to 17 percent (SOL) for the unmodified control, -19.7 percent (EMC) to 19.4 percent (ROL) for the first modification, and 7.5 percent (ROL) to 18.2 percent (EMC) for the second modification. If chloride is assumed to be representative of the uncertainty of data collection and analysis, efficiencies obtained by all methods are probably accurate to within ±20 percent.

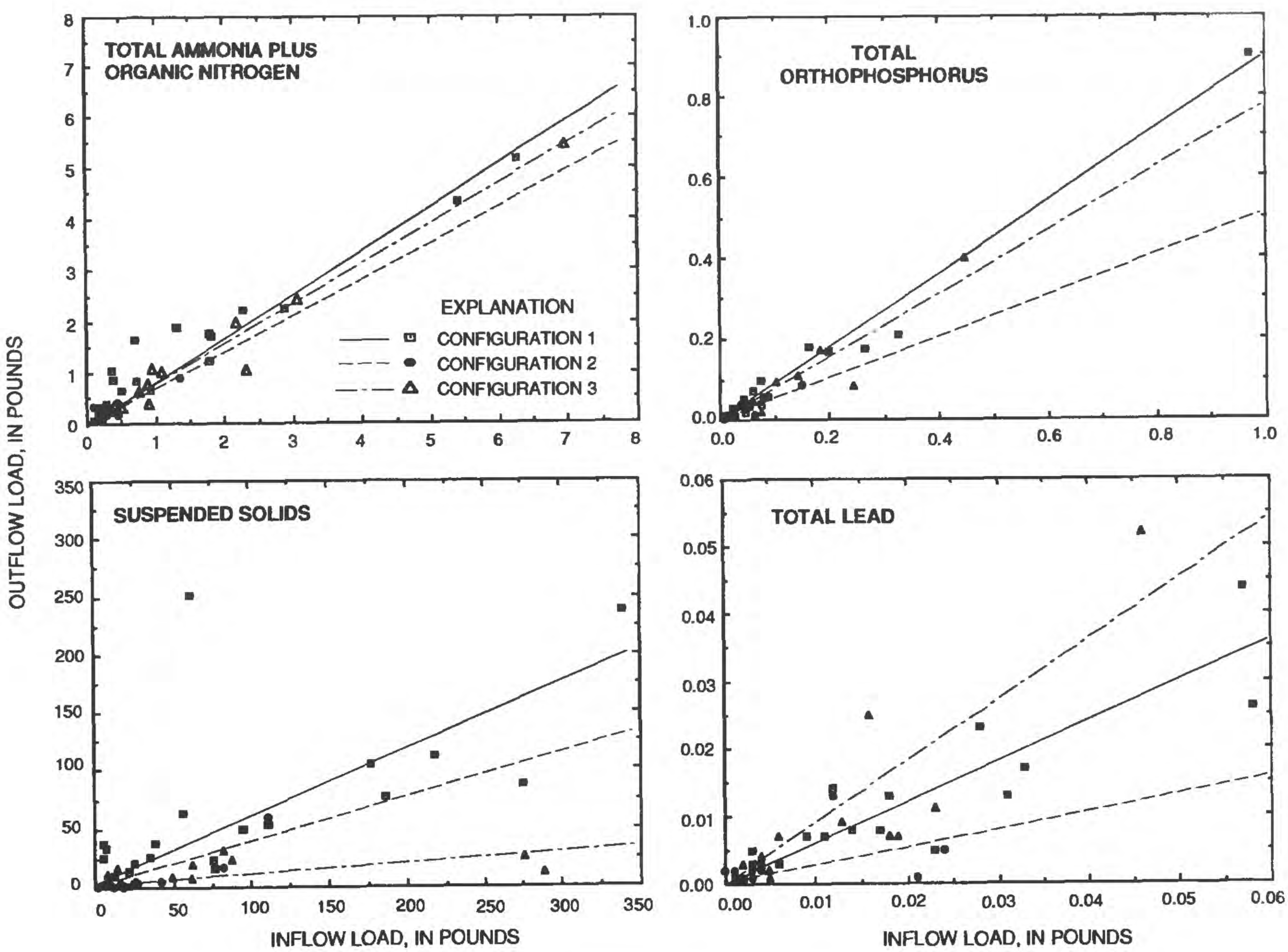

Figure 19.--Outflow loads of selected constituents in relation to inflow loads, by outlet configuration.

The EMC method for calculating trap efficiency is used in the following discussion of the effects of the outlet modifications on constituent removal because it is the most commonly used method. Some studies have reported the mean or median trap efficiency for individual storms, which differs somewhat from the EMC trap-efficiency average among all storms. Typically, the median trap efficiency for individual storms during the first configuration was in fairly close agreement with the SOL and ROL efficiencies, but less so during the two modifications. This difference could also result from storm-to-storm differences in runoff characteristics and the way that storms are weighted in each method, as described previously.

Effects of Basin-Outlet Modifications

Data collected during this study indicate that EMC efficiency was inconsistent (negative and positive) during the first outlet configuration but improved with each modification. For most constituents, the largest improvement in EMC efficiency occurred after the first modification; the second modification, with greater retention times and development of a small pool of standing water, increased efficiency only slightly over efficiencies noted after the first modification.

The large increase in trap efficiency after the first modification and the relatively small increase in trap efficiency after the second modification may be partly due to the characteristics of precipitation and runoff during the respective periods of data collection. As previously discussed, dry conditions prevailed during much of the second-configuration period in the summer of 1988, whereas normal conditions prevailed during the first and third configurations. Other factors, too, affect the performance of the detention basin, such as biological activity and the partitioning of suspended contaminants among different particle sizes. The performance of each outlet configuration, therefore, could have been different had climatic conditions been uniform throughout the study. Specifically, the expected difference would be a smaller increase in efficiency than observed after the first modification and a greater increase in efficiency than observed after the second modification. Regressions of average plug-detention times against EMC efficiency did not correlate well with trap efficiency or increased retention time, possibly because climatic conditions were not uniform throughout the study.

The following sections summarize the trap efficiencies for physical properties, nutrients, and metals among the three outlet configurations. Common ions are omitted from the discussion because they are dissolved and therefore unaffected by changes in the outlet controls. Trap efficiencies for selected constituents for each of the outlet configurations (from table 6) are compared in figure 20.

Physical Properties

Efficiencies for physical properties (suspended solids, dissolved solids, suspended volatile solids, total organic carbon, and chemical oxygen demand) were all negative (fig. 20) during the first outlet configuration (-14, -3.8, -40, -15, and -0.2 percent, respectively) because one or two storms produced large negative efficiencies that, when averaged with other storms, yielded overall negative values. For most storms (about 75 percent), however, efficiency was positive. The individual trap efficiency with respect to suspended solids, for example, ranged from -580 to 80 percent, and efficiencies of only 5 out of the 21 storms were negative.

Negative efficiency could also result from turbulence, which inhibits settling and causes resuspension. In a study of a Florida detention basin, high-intensity storms created a larger peak inflow and more turbulence than did less intense storms and thus resulted in decreased trap efficiency (Martin and Smoot, 1986). In this study, constituent retention could be similarly decreased by turbulence, particularly during the short, high-intensity storms during the first configuration, when stormflow passed more rapidly through the basin than it did during the other configurations. Efficiencies with respect to suspended solids were negative only in the growing season during the first configuration. Efficiency was negative about every third or fourth storm; these storms were below average in duration (1.22 hours as opposed to 3.56 hours for all storms) and intensity (appendix I). Because ante-

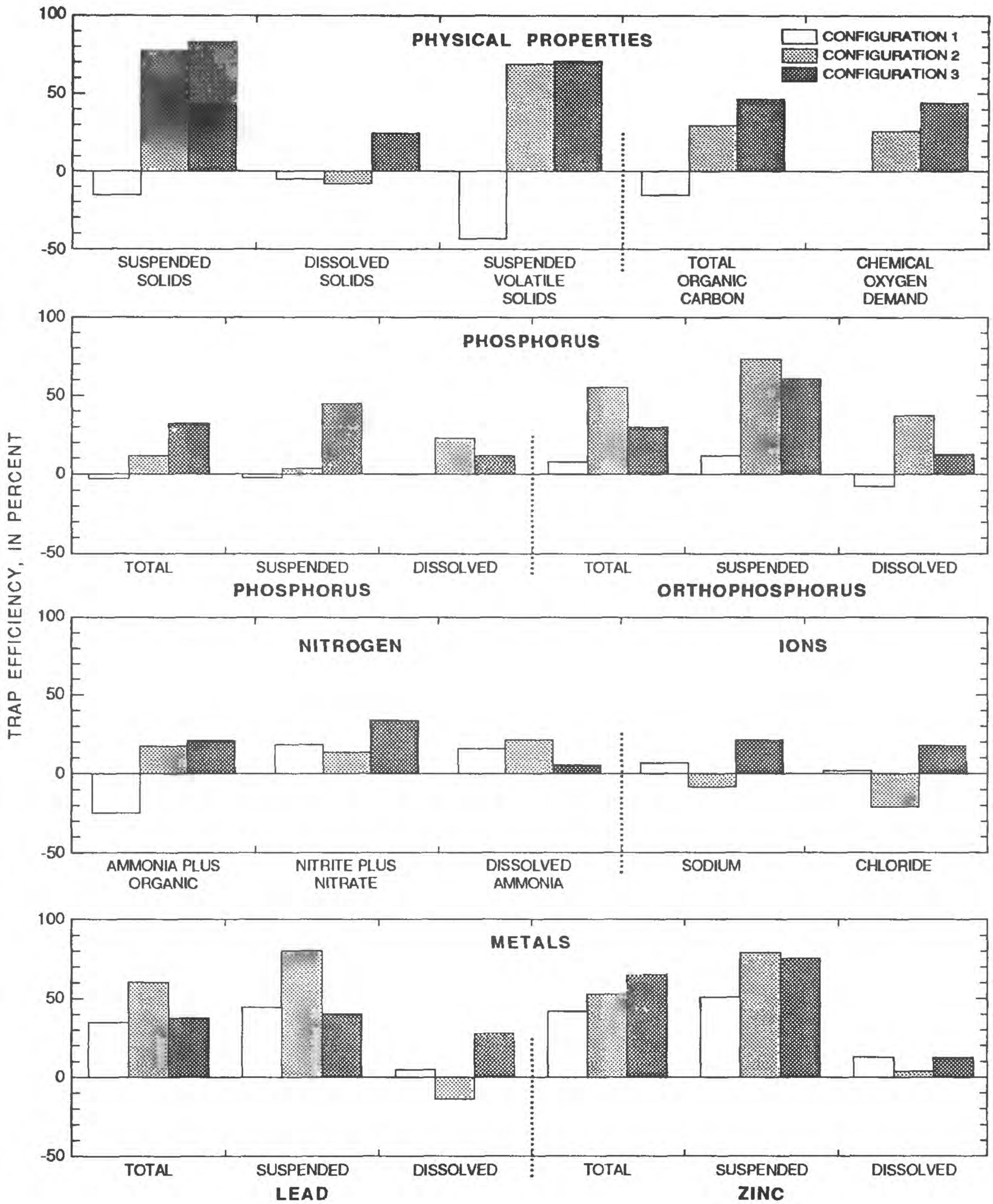

Figure 20.--Trap efficiency for selected constituents by outlet configuration, as calculated by event-mean-concentration method.

cedent conditions were close to normal, other factors probably diminished the efficiency achieved with the initial configuration, such as a period of constituent buildup in the basin followed by a washout.

The second configuration produced a substantial improvement in trap efficiency for suspended solids (79 percent), suspended volatile solids (70 percent), total organic carbon (31 percent), and chemical oxygen demand (26 percent). Efficiencies during individual storms were consistently positive for suspended solids but were both negative and positive for the other constituents. Efficiency for physical constituents improved slightly during the third configuration—suspended solids (84 percent); suspended volatile solids (71 percent); total organic carbon (47 percent); and chemical oxygen demand (45 percent).

The doubling of retention time after the first control modification, which substantially improved the removal of all physical constituents except dissolved solids, and the increase in retention time after the second modification, which improved trap efficiencies only slightly (fig. 21A), indicates that a small increase in retention time over that provided by the initial configuration produces the largest increase in efficiency, if storm characteristics are assumed to be similar among the configurations. The second configuration was characterized by dry conditions, however, which complicates direct comparison of trap efficiency because the storm characteristics influence factors such as turbulence that decrease efficiency and are difficult to quantify. Dissolved solids show a more linear efficiency increase with prolonged retention time than suspended solids, although this increase is relatively small. The Kruskal-Wallis test showed significant improvement in trap efficiency for suspended solids and total organic carbon at the 95-percent confidence level, and for suspended volatile solids, dissolved solids, and chemical oxygen demand at the 90-percent confidence level, among the three configurations.

Nutrients

Trap efficiencies for nutrients were also predominantly negative during the original configuration but improved after both modifications (fig. 20). Efficiency ranged widely among species of nitrogen during the original configuration (total ammonia plus organic nitrogen, -23 percent; nitrate plus nitrite, 20 percent; and dissolved ammonia, 17 percent) but was relatively consistent among phosphorus species (total, 2.6 percent; suspended, -1.5 percent; and dissolved, 0.0 percent), except for orthophosphorus, for which it was variable (total, 6.8 percent; suspended, 10 percent; and dissolved, -7.7 percent). Efficiencies for each of the above constituents for individual storms were similar to those for the physical properties, except that the range of efficiencies with respect to the nutrients was smaller. For instance, individual-storm trap efficiency for total phosphorus ranged from -280 to 62 percent, and efficiency was negative for only 7 out of 21 storms.

Efficiency of retention also tended to increase as retention time increased (figs. 21B, 21C). Trap efficiency for total ammonia plus organic nitrogen increased from -23 percent during the initial configuration to 19 and 22 percent after the two modifications, respectively. Efficiencies for ammonia and nitrate plus nitrite were fairly similar after the two modifications, except that the trap efficiency with the third configuration for dissolved ammonia decreased and for nitrate plus nitrite nitrogen increased. This suggests an uptake of nitrate, the form of nitrogen most readily used by green plants, and decay of plant material and formation of ammonia by bacteria.

Trap efficiency increased considerably for all phosphorus species during the second configuration, except for suspended phosphorus, for which the increase was small. The third configuration decreased the efficiency for dissolved phosphorus and all fractions of orthophosphorus, but increased the efficiency for total and suspended phosphorus. The relatively high trap efficiency for orthophosphorus during the second configuration, and its slight decrease during the third modification, could reflect a seasonal effect, in that all storms during the second configuration occurred from July through early October, when biological uptake of phosphorus was at its maximum.

Although some differences in efficiency were noted among three outlet configurations, some of which appeared substantial, the Kriskal-Wallis test indicates that they were not significant at the 95-percent confidence level.

Metals

Lead and zinc were retained more in the suspended phases than in the dissolved phase during all configurations, as expected, and retention of the dissolved phase generally improved as retention time increased (fig. 21D). During the first configuration, efficiency for suspended lead and zinc was 45 and 52 percent, respectively, but during the second configuration, it increased to 80 percent for both constituents. The efficiency during the third configuration remained about the same for suspended zinc (76 percent), but decreased for suspended lead (40 percent).

Efficiencies for total lead and zinc were similar to that of their suspended fractions because most of the lead and zinc are in the suspended phase, 69 and 60 percent, respectively. Efficiencies for the dissolved fractions of lead and zinc

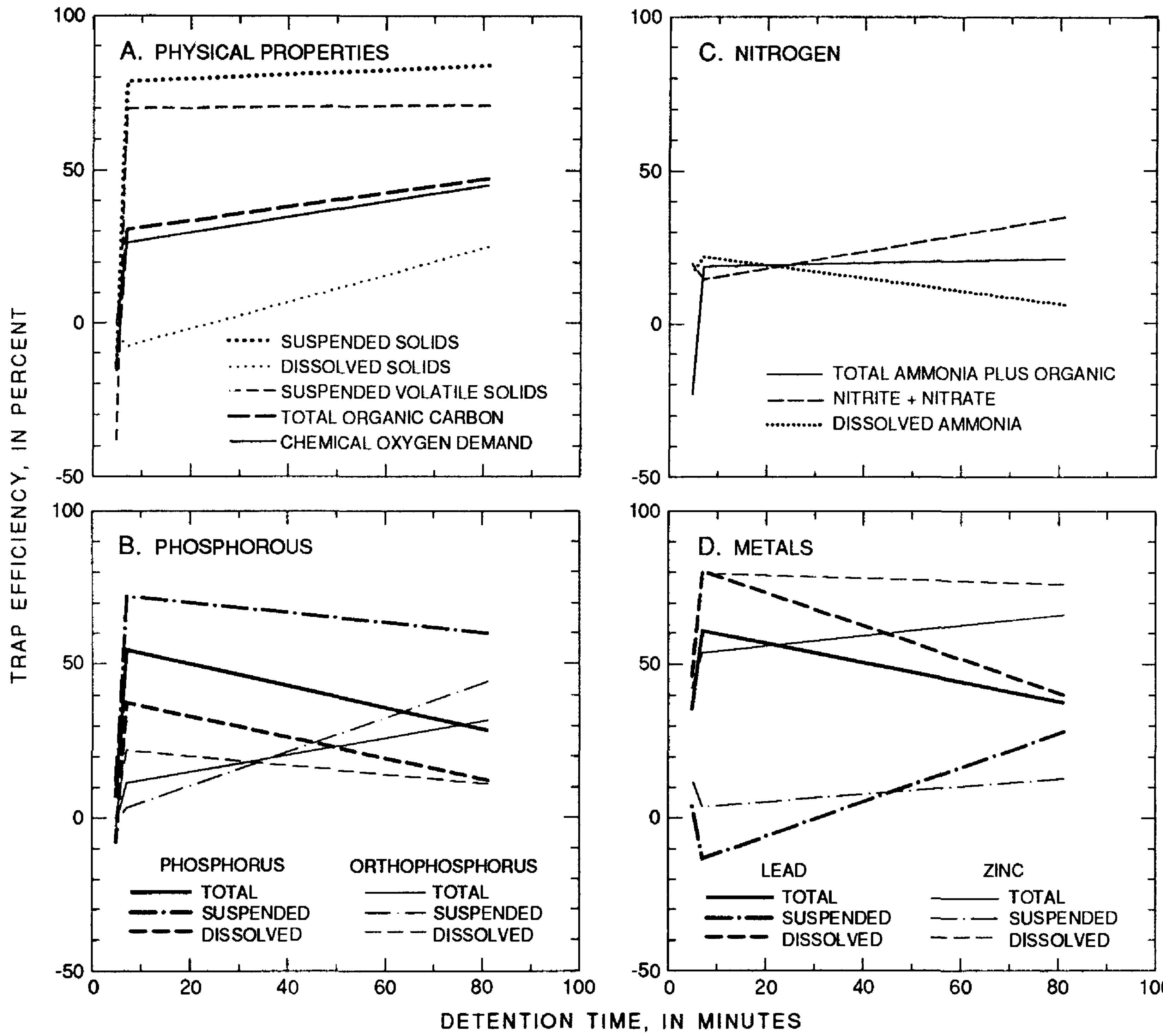

Figure 21.--Relation of trap efficiency to detention time: A. Physical properties. B. Phosphorus. C. Nitrogen. D. Metals.

were relatively low (less than 13 percent), except for dissolved lead during the third configuration, in which it was 28 percent. The increase in retention of dissolved lead during the third configuration is offset by the decrease in suspended lead, however. The reason for this change in retention of the dissolved and suspended fractions after the second modification is unknown, but changes in speciation and subsequent availability for biological uptake are highly pH dependent (Elder, 1988).

The ratio of dissolved to total EMC's for lead and zinc indicates the net change in the partitioning of the constituent as it moved through the basin. The higher ratios of dissolved lead and zinc to total lead and zinc at the basin outlet than the basin inlet with every configuration (table 7) indicates retention of the suspended forms. This ratio was greatest, by far, during the second configuration, possibly because the storms sampled during that predominantly dry period caused less turbulence of suspended material and thus enabled retention. Although the data show differences among loads retained during the respective control configurations, results of the Kriskal-Wallis test indicate that these differences are not significant at the 95-percent confidence level.

Table 7.--Ratio of dissolved total event mean concentrations for lead and zinc at the basin inlet and outlet

Outlet configuration	Lead		Zinc	
	inflow	outflow	inflow	outflow
1	0.16	0.24	0.26	0.40
2	.21	.60	.35	.71
3	.22	.25	.16	.41

SUMMARY AND CONCLUSIONS

Although stormwater-detention basins are widely recognized as an effective means for controlling storm-runoff quantity, little is known about their effect on runoff quality or on the optimum basin design for this purpose. Recent emphasis on improving runoff quality prompted a 3-year study of (1) basin effectiveness in decreasing chemical and sediment loads in urban runoff through settling, and (2) the modification of an existing basin to increase the detention time and thereby improve the quality of storm runoff.

Stormflow and water-quality data were collected at a detention basin near Rochester, N.Y. from August 1986 through September 1989 to assess the removal of chemical constituents in the basin's original configuration and with two subsequent modifications of the outflow structure to increase retention time. The basin was originally designed to control peak runoff from a 27-acre moderate-density residential development and to drain completely in about 45 minutes. Flow rates and chemical quality of stormwater at the inflow and outflow under the original design (first configuration) were monitored for 10 months (August 1986 through March 1988). The first outlet modification (second configuration) entailed inserting into the 24-in. corrugated metal trickle tube a 20-in. PVC pipe that had fewer and smaller holes than the trickle tube; this approximately doubled the retention time and allowed the basin to drain completely in about 1.5 hours. This configuration was monitored for 7 months (April 1988 through November 1988). The second modification (third configuration) entailed sealing a 4-in.-diameter hole at the base of the insert pipe to further increase retention time and create a shallow pool of standing water to favor growth of wetland-type vegetation. This modification, which allowed the basin to drain completely in about 11 hours, was monitored for 10 months (December 1988 through September 1989).

Loads of 22 constituents at the inflow and the outflow of the detention basin were calculated and trap efficiencies were computed for each of the three outlet configurations by three methods—event mean concentration (EMC), summation of loads (SOL), and regression of loads (ROL). In general, the methods yielded similar results, but each treats the data slightly differently. The ROL method provides an indication of the variance in the data but can be biased by large outlier storms, which exert undue leverage in the regression line; this method yielded slightly higher trap efficiencies than did the other two methods. The SOL method weights efficiency estimates towards large-load storms but to a lesser degree than the ROL method; efficiencies computed by this method were intermediate between those of the other two methods. The EMC method weights storms equally, regardless of their magnitude, and was chosen for comparison of the effects of the three outlet configurations on constituent retention because this method is more widely used than the other two methods.

Trap efficiencies differed among constituents and outlet configurations. The original outlet configuration produced, on average, the widest range in efficiencies with respect to most constituents, particularly those of interest to water-quality managers in the Irondequoit basin (suspended sediment and phosphorus). Removal efficiencies were small or negative (negative efficiencies indicate a net increase in constituent load at the basin outlet); the negative efficiencies for some constituents is attributed to a repartitioning of the constituent from the suspended to the dissolved phase but might also result from resuspension of previously deposited material by turbulent flow through the basin. Trap efficiencies for the first configuration averaged -14 percent for suspended solids, -2.6 percent for total phosphorus, 6.8 percent for total orthophosphorus, and -15 percent for total organic carbon. Trap efficiencies for lead and zinc, which are present mainly in suspension (60 to 70 percent of the total lead and zinc), were substantially lower (35 and 42 percent, respectively).

The first outlet modification, which doubled the settling time, substantially improved trap efficiency for most constituents but the second modification, which increased settling time 10-fold over the previous modification, improved trap efficiency only slightly. Trap efficiency for the two modified configurations (configurations 2 and 3), respectively, was as follows: suspended solids, 79 and 84 percent; total phosphorus, 12 and 32 percent; total orthophosphorus, 54 and 29 percent; total organic carbon, 31 and 47 percent; total lead, 61 and 38 percent; and total zinc, 54 and 66 percent. Although the modifications improved trap efficiency for most constituents, the improvement was significant (Kreskal-Wallis test) only for total solids and total organic carbon at the 95-percent confidence interval (both modifications). Improvements in efficiency for total phosphorus and total orthophosphorus were significant at the 90-percent confidence interval. The large increase in efficiency after the first modification and the relatively small increase in efficiency after the second modification are attributed, in part, to differences in climatic conditions among the configurations.

Results of this study indicate that even though the detention basin, as originally designed, was not particularly effective in decreasing stormwater constituent loads, simple modifications of the outlet to increase retention time improved the efficiency of constituent removal and suggest that retrofits to other detention basins in the Irondequoit Creek basin could help improve stormwater runoff to Irondequoit Bay. The results of the study may also be applicable to other areas where stormwater-discharge permits are required to meet the water-quality objectives set forth in the 1987 amendments to the Federal Clean Water Act.

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APPENDIX

The following appendix tables summarize precipitation, runoff, and water-quality data used in the analysis of the detention basin. All data are available through the USGS office in Ithaca, N.Y.

Appendix I.--Precipitation characteristics of sampled storms

[Precipitation values are in inches; > = greater than]

Storm date		Time	Duration	Precipitation	Maximum precipitation intensity (minutes)			Antecedent precipitation (days)				Time since specified inches of precipitation (hours)			
		Begin-End	(hr:min)	volume	5	15	60	1	3	7	14	0	0.25	0.50	1.0
A. Configuration 1 (original)															
1986	DEC 02-03	11:40-02:00	14:20	0.95	0.04	0.10	0.29	0.26	0.26	1.11	1.63	0.1	3.8	139.8	146.8
1986	DEC 09	09:15-16:15	07:35	.25	.02	.03	.09	.12	.25	1.63	2.50	4.6	125.9	155.3	164.0
1987	MAR 01	03:45-07:10	03:25	.15	.03	.05	.09	.23	.23	.26	.26	.0	137.7	> 720	> 720
1987	MAR 01	08:45-13:30	04:45	.22	.04	.10	.20	.40	.40	.43	.43	.0	6.0	711.8	> 720
1987	APR 04	06:10-16:35	10:25	.63	.03	.06	.19	.21	.43	1.19	1.77	.1	48.7	87.7	106.0
1987	APR 06	04:15-08:55	04:40	.14	.01	.03	.08	.46	1.36	2.34	2.92	.1	4.1	30.0	44.8
1987	APR 13	02:05-04:20	02:15	.14	.01	.03	.10	.53	.54	.96	3.23	.1	9.5	12.1	168.5
1987	APR 27-28	22:05-07:15	09:10	.86	.04	.10	.23	.04	.04	.47	.47	.0	100.0	354.8	367.1
1987	MAY14-15	23:15-01:15	02:00	.37	.04	.12	.28	.03	.03	.03	.03	.0	401.3	405.5	409.0
1987	MAY 22	15:25-16:20	00:55	.45	.15	.31	.45	.00	.00	.09	.51	96.3	183.3	184.3	589.8
1987	JUNE 22	11:30-12:25	00:55	.40	.09	.20	.40	.18	.18	.18	.18	.0	489.1	> 720	> 720
1987	JUNE 26	11:00-11:25	00:25	.18	.08	.17	.18	.13	.13	.89	.89	.0	92.8	95.1	585.3
1987	JULY 13	16:20-16:50	00:30	.42	.17	.38	.42	.00	.00	1.39	1.73	127.5	164.5	164.9	165.3
1987	JULY 14	10:30-11:25	00:55	.16	.04	.07	.16	.47	.47	.67	2.13	.1	18.0	159.0	183.1
1987	JULY 20	04:30-05:10	00:40	.18	.07	.10	.18	.07	.07	.86	2.25	.1	137.4	155.9	298.0
1987	JULY 30	04:10-04:30	00:20	.17	.06	.08	.10	.01	.01	.04	.36	.1	239.6	376.5	395.8
1987	AUG 02	20:15-20:50	00:35	.40	.13	.38	.40	.10	.10	.48	.83	.0	83.4	182.6	465.1
1987	AUG 09	13:05-16:25	03:20	.27	.10	.28	.71	.19	.19	.70	1.08	.1	160.6	160.8	248.8
1987	AUG 19	18:40-19:55	01:15	.15	.06	.10	.14	.03	.06	.06	1.55	.1	243.2	243.9	245.2
1988	JAN 20	02:05-04:35	02:30	.16	.03	.07	.15	.18	.34	.34	.34	.0	40.2	527.2	> 744
1988	MAR 25-26	20:10-00:25	04:15	.61	.06	.14	.37	.11	.28	.28	.28	.1	34.3	> 720	> 720
	Average		03:56	0.39	0.06	0.14	0.25	0.18	0.26	0.68	1.21	10.9	130	300	391

Appendix I.--Precipitation characteristics of sampled storms--(continued)

[Precipitation values are in inches; > = greater than]

Storm date		Time Begin- End	Dur-ation (hr:min)	Precipi-tation volume	Maximum precipitation intensity (minutes) 5	15	60	Antecedent precipitation (days) 1	3	7	14	Time since specified inches of precipitation (hours) 0	0.25	0.50	1.0
							B. Configuration 2								
1988	JULY 14	14:20-15:00	00:40	0.13	0.01	0.02	0.05	0.06	0.06	0.06	0.07	0.0	519.1	> 720	> 720
1988	JULY 17	10:45-12:40	01:55	.13	.01	.02	.06	.21	.38	.38	.38	.0	66.3	519.2	> 720
1988	JULY 21	04:10-05:00	00:50	.21	.04	.10	.21	.43	.55	1.07	1.07	.1	13.0	49.5	157.8
1988	JULY 23	21:10-21:50	00:40	.22	.15	.19	.22	.14	.85	1.63	1.80	.1	60.8	63.6	78.0
1988	AUG 23	20:10-21:30	01:20	.37	.08	.13	.34	.55	.55	.77	.77	.0	1.5	5.8	> 720
1988	AUG 25	20:30-22:00	01:30	.29	.09	.12	.23	.31	1.30	1.30	1.52	.1	1.0	47.8	49.8
1988	AUG 28	09:50-10:40	00:50	.20	.10	.18	.20	.39	.99	1.98	2.20	.1	4.3	60.7	103.9
1988	SEPT 04	07:15-08:05	00:50	.20	.04	.10	.20	.20	.20	2.07	3.85	.1	136.9	140.1	150.4
1988	SEPT 13	08:40-09:05	00:25	.16	.01	.03	.03	.10	.10	.11	.66	.0	213.8	217.6	357.9
1988	SEPT 17	05:55-06:40	00:45	.23	.09	.20	.23	.09	.09	.22	.78	.0	284.6	310.4	450.2
1988	SEPT 17	08:15-09:20	01:05	.29	.05	.10	.28	.42	.42	.55	1.11	.1	2.3	95.6	313.4
1988	SEPT 23	02:20-04:15	01:55	.49	.04	.09	.29	.10	.13	.85	.98	.0	137.6	138.2	424.6
1988	OCT 04	20:00-20:55	00:55	.23	.04	.11	.23	.11	.32	.32	.95	.0	52.1	280.4	418.8
	Average		01:08	0.20	0.06	0.10	0.19	0.26	0.52	0.93	1.31	0.05	90	200	344
							C. Configuration 3								
1989	MAR 18	04:50-14:15	09:25	0.32	0.04	0.10	0.25	0.20	0.20	0.20	0.80	0.0	304.3	331.0	598.0
1989	MAR 30-31	06:00-03:40	21:40	.55	.03	.06	.13	.14	.27	.27	.85	.0	35.8	288.7	595.6
1989	APR 03-04	08:05-07:00	22:55	--	--	--	--	--	--	--	--	--	--	--	--
1989	MAY 30	07:30-13:55	06:25	--	--	--	--	--	--	--	--	--	--	--	--
1989	JUNE 09-10	19:10-06:50	11:40	--	--	--	--	--	--	--	--	--	--	--	--
1989	JUNE 17	00:15-13:00	12:45	--	--	--	--	--	--	--	--	--	--	--	--
1989	JULY 10	16:30-21:10	04:40	.46	.28	.46	.46	.07	.07	.07	.43	.0	302.9	> 720	> 720
1989	AUG 02	15:25-18:15	02:50	.23	.02	.04	.04	.28	.28	.35	.35	.0	2.6	550.8	> 720
1989	AUG 04-05	16:30-00:55	08:25	1.12	.13	.25	.30	.35	.67	.67	.74	.0	.0	49.2	599.8
1989	AUG 05	15:50-23:35	07:45	.71	.26	.51	.56	1.13	1.13	1.45	1.52	.1	20.8	22.8	23.3
1989	SEPT 13-14	22:45-03:45	05:00	.30	.03	.08	.20	.11	.11	.20	.64	.0	286.6	294.0	> 720
1989	SEPT 14-15	19:05-05:50	10:45	.97	.03	.08	.22	.47	.47	.56	1.00	.0	19.0	99.8	391.4
	Average		11.37	0.46	0.10	0.20	0.03	0.34	0.40	0.47	0.79	0.01	121	294	546

Appendix II.--Runoff characteristics of sampled storms.

[ft^3 = cubic feet; ft^3/s = cubic feet per second. Dashes indicate missing record.]

Storm date		Time Begin-End	Runoff (ft^3)	Runoff (inches)	Rainfall/ runoff coefficient	Peak Flow Inflow (ft^3/s)	Peak Flow Outflow (ft^3/s)	Maximum basin stage (feet)	Mean plug detention (minutes)
				A. Configuration 1 (original)					
1986	DEC 02-03	11:40-02:00	79,200	0.811	0.854	2.93	2.56	1.16	6.68
1986	DEC 09	09:15-16:15	29,400	.301	1.204	2.24	1.94	.94	5.12
1987	MAR 01	03:45-07:10	5,980	.061	.408	1.08	.92	1.84	3.02
1987	MAR 01	08:45-13:30	15,300	.157	.712	2.70	1.99	2.34	2.66
1987	APR 04	06:10-1635	30,300	.310	.493	2.53	2.13	2.37	3.37
1987	APR 06	04:15-08:55	10,600	.109	.775	1.22	1.13	1.87	2.58
1987	APR 13	02:05-04:20	4,600	.047	.336	.83	.77	.63	3.51
1987	APR 27-28	22:05-07:15	15,600	.160	.186	1.18	1.13	.79	3.57
1987	MAY 14-15	23:15-01:15	4,400	.045	.122	1.80	1.35	.88	4.25
1987	MAY 22	15:25-16:20	5,400	.055	.123	5.55	2.83	1.43	8.37
1987	JUNE 22	11:30-12:25	3,200	.036	.090	3.20	1.65	1.01	4.60
1987	JUNE 26	11:00-11:25	1,340	.014	.078	2.61	1.31	.86	4.73
1987	JULY 13	16:20-16:50	3,500	.036	.085	3.02	2.09	1.18	6.13
1987	JULY 14	10:30-11:25	1,170	.012	.075	.66	.48	.49	2.79
1987	JULY 20	04:30-05:10	1,340	.015	.083	1.28	.89	.69	3.59
1987	JULY 30	04:10-04:35	670	.007	.041	.82	.58	.54	3.12
1987	AUG 02	20:15-20:50	3,780	.039	.097	4.50	2.50	--	7.43
1987	AUG 09	13:05-16:25	17,900	.183	.144	3.35	2.63	1.36	7.52
1987	AUG 19	18:40-19:55	1,400	.015	.100	.92	.59	--	2.29
1988	JAN 20	02:05-04:35	7,200	.074	.463	1.75	1.51	.95	3.87
1988	MAR 25-26	20:10-00:25	6,400	.066	.108	1.94	1.36	1.12	6.89
Average			11,840	0.122	0.313	2.20	1.54	1.18	4.58
				B. Configuration 2					
1988	JULY 14	14:20-15:00	4,230	0.043	0.331	7.85	2.24	1.87	6.08
1988	JULY 17	10:45-12:40	13,700	.140	1.077	8.50	2.81	2.48	15.4
1988	JULY /21	04:10-05:00	2,840	.029	.138	1.47	1.24	1.10	3.69
1988	JULY 23	21:10-21:50	2,700	.028	.127	5.12	1.68	1.49	5.61
1988	AUG 23	20:10-21:30	5,000	.051	.138	3.95	1.28	1.58	8.81
1988	AUG 25	20:30-22:00	4,330	.044	.152	4.48	1.34	1.45	4.21
1988	AUG 28	09:50-10:40	3,430	.035	.175	4.84	1.43	1.66	15.5
1988	SEPT 04	07:15-08:05	2,420	.025	.125	1.36	1.04	1.24	4.19
1988	SEPT 13	08:40-09:05	1,310	.013	.081	1.58	1.07	1.21	.93
1988	SEPT 17	05:55-06:40	2,380	.024	.104	3.49	1.20	1.48	10.08
1988	SEPT 17	08:15-09:20	3,280	.034	.117	1.34	.97	1.21	7.17
1988	SEPT 23	02:20-04:15	4,570	.047	.096	1.05	.94	1.02	4.52
1988	OCT 04	20:00-20:55	1,850	.019	.083	1.28	1.07	1.20	3.24
Average			4,000	0.041	0.211	3.56	1.41	1.46	6.98

Appendix II.--Runoff characteristics of sampled storms--(continued)

[ft^3 = cubic feet; ft^3/s = cubic feet per second. Dashes indicate missing record.]

	Date	Time Begin-End	Runoff (ft³)	Runoff (inches)	Rainfall/ runoff coefficient	Peak Flow Inflow (ft³/s)	Peak Flow Outflow (ft³/s)	Maximum basin stage (feet)	Mean plug detention (minutes)
				C. Configuration 3					
1989	MAR 18-19	04:50-14:15	8,000	0.082	0.216	1.69	0.41	2.32	67.7
1989	MAR 30-31	06:00-03:40	26,800	.274	.498	1.27	.57	2.56	143
1989	APR 03-04	08:05-07:00	30,900	.657	--	1.38	.49	2.64	71.4
1989	MAY 30	07:30-13:55	6,610	.057	--	6.20	.41	2.50	103
1989	JUNE 09-10	19:10-06:50	16,600	.165	--	2.11	.69	3.06	76.3
1989	JUNE 17	00:15-13:00	26,400	.267	--	5.24	1.05	3.72	91.7
1989	JULY 10	16:30-21:10	5,390	.055	.119	6.53	.43	2.39	81.3
1989	AUG 02	15:25-181:5	2,570	.026	.113	.97	.34	1.52	36.6
1989	AUG 04-05	16:30-00:55	12,300	.126	.114	10.36	.63	2.69	82.4
1989	AUG 05	15:50-23:35	10,100	.103	.145	5.51	.66	2.87	122
1989	SEPT 13-14	22:45-03:45	4,730	.048	.160	1.93	.36	1.61	25.3
1989	SEPT 14-15	19:05-05:50	14,000	.143	.147	1.90	.51	2.18	61.4
	Average		13,700	0.167	0.189	3.76	0.55	2.51	80.6

Appendix III.--Storm loads of chemical constituents at the basin inflow and outflow

[Dashes indicate no data. All values are in pounds. EMC = event mean concentration EMC values in milligrams per liter except metals, which are in microgram per liter.]

CONFIGURATION 1 (original)

Physical Properties

Date	Suspended solids		Dissolved solids		Suspended volatile solids		Chemical oxygen demand		Total organic carbon	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
12-2-86	218	112	--	--	38.1	23.9	132	146	28.4	28.3
12-9-86	186	76.7	523	--	16.4	17.4	30.9	55.8	7.42	15.3
3-1-87	76.4	23.0	116	127	4.20	3.35	28.0	48.8	2.41	8.54
3-1-87	95.5	50.1	193	203	8.42	6.45	45.9	34.1	9.24	8.96
4-4-87	276	87.5	303	289	25.5	8.79	48.6	54.5	15.0	12.2
4-6-87	76.9	15.8	117	96.6	9.12	1.98	85.4	17.7	3.14	3.76
4-13-87	7.85	6.93	33.5	45.6	3.09	5.77	36.7	51.9	2.54	2.65
4-27-87	111	53.6	125	125	17.8	16.0	44.6	57.9	5.34	16.9
5-14-87	62.2	253	43.5	48.4	24.7	16.7	36.5	20.6	14.1	6.58
5-22-87	339	238	46.1	31.2	43.5	46.8	49.5	81.4	17.7	24.1
6-22-87	24.9	20.5	14.5	27.3	3.51	7.63	15.9	28.1	2.33	7.23
6-26-87	5.07	26.5	8.18	9.38	2.45	6.87	9.81	14.2	2.21	4.61
7-13-87	21.5	15.0	12.7	24.2	5.15	12.4	--	28.3	10.5	9.14
7-14-87	4.30	2.56	5.48	4.16	1.60	.868	5.06	2.17	1.69	0.740
7-20-87	5.79	38.5	4.37	9.01	2.69	21.3	6.64	7.69	3.45	2.07
7-30-87	12.5	10.6	3.79	8.98	3.38	2.99	9.89	7.48	1.11	1.54
8-2-87	38.8	37.8	10.9	22.2	10.9	10.9	40.2	16.1	1.73	3.31
8-9-87	35.3	26.2	44.7	75.2	14.4	8.33	41.4	25.7	8.33	9.68
8-19-87	7.61	33.5	25.3	22.1	3.22	7.65	--	--	--	--
1-20-88	56.3	63.9	89.5	71.1	6.98	11.7	24.7	37.8	3.55	4.18
3-25-88	176	105	54.7	31.2	36.8	20.8	69.4	56.1	14.1	14.0
EMC	174	198	142	147	34.4	48.1	94.5	94.7	19.6	22.6

Appendix III.--Storm loads of chemical constituents at the basin inflow and outflow--(continued)

CONFIGURATION 1 (continued)

Nutrients

Date	Total phosphorus		Dissolved phosphorus		Total orthophosphorus		Dissolved orthophosphorus		Total ammonia plus organic nitrogen		Dissolved ammonia		Total nitrite plus nitrate	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
12-2-86	1.46	1.26	1.04	0.813	0.972	0.903	0.799	0.718	5.40	4.32	4.90	3.84	3.01	2.41
12-9-86	.872	.496	.249	.240	.325	.210	.178	.162	6.28	5.16	6.21	5.16	1.94	1.59
3-1-87	.188	.126	.035	.050	.060	.070	.032	.038	.705	1.66	.665	1.60	.210	.246
3-1-87	.419	.324	.146	.143	.200	.169	.143	.125	1.80	1.72	1.45	1.40	.659	.457
4-4-87	.615	.367	.156	.150	.266	.178	.113	.114	2.88	2.25	2.66	2.05	.773	.837
4-6-87	.304	.079	.052	.050	.077	.038	.043	.027	.922	.661	.835	.597	.497	.546
4-13-87	.056	.036	.023	.020	.022	.012	.017	.012	.293	.375	.221	.346	.178	.182
4-27-87	.266	.186	.114	.085	.089	.055	.067	.047	2.27	2.22	1.87	1.85	.911	.722
5-14-87	.141	.054	.024	.013	.023	.007	.005	.001	1.80	1.22	1.64	1.14	.328	.303
5-22-87	.341	.617	.039	.031	.053	.034	.024	.020	1.31	1.90	1.20	1.76	.279	.258
6-22-87	.074	.077	.025	.029	.023	.032	.007	.011	.394	.883	.341	.823	.054	.088
6-26-87	.015	.058	.007	.010	.005	.010	.002	.003	.196	.318	.147	.276	.098	.126
7-13-87	.123	.152	.089	.116	.075	.099	.065	.096	.365	1.07	.165	.958	.236	.239
7-14-87	.015	.013	.010	.005	.005	.006	.004	.003	.096	.065	.089	.058	.061	.033
7-20-87	.025	.021	.006	.008	.010	.011	.004	.006	.160	.182	.143	.165	.027	.047
7-30-87	.010	.013	.006	.013	.008	.009	.004	.003	.169	.187	.148	.170	.049	.058
8-2-87	.059	.084	.011	.014	.043	.052	.004	.008	.284	.402	--	--	.057	.080
8-9-87	.234	.256	.157	.187	.165	.181	.137	.158	1.79	1.78	--	--	.469	.514
8-19-87	.027	.051	.010	.007	.010	.011	.008	.005	.194	.307	--	--	.419	.107
1-20-88	.210	.193	.093	.054	.082	.058	.058	.033	.516	.675	--	--	.159	.153
3-25-88	.234	.134	.023	.016	.045	.020	.019	.011	.712	.841	--	--	.210	.196
EMC	0.390	0.395	0.128	0.132	0.145	0.138	0.128	0.084	2.20	2.71	0.298	0.247	0.901	0.729

Appendix III.--Storm loads of chemical constituents at the basin inflow and outflow--(continued)

CONFIGURATION 1 (continued)

Common Ions and Metals

Date	Sodium		Total chloride		Total lead		Dissolved lead		Total zinc		Dissolved zinc	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
12-2-86	199	99.4	341	202	0.031	0.013	0.025	0.013	0.364	0.108	0.262	0.108
12-9-86	517	445	818	723	.028	.023	.009	.009	.184	.162	.106	.055
3-1-87	33.0	32.1	47.8	50.8	.014	.008	.004	.002	.086	.065	.033	.021
3-1-87	46.1	54.9	76.6	70.8	.018	.013	.005	.005	.124	.097	.057	.059
4-4-87	28.8	41.5	49.7	36.6	.033	.017	.009	.011	.208	.135	.067	.086
4-6-87	12.3	13.3	18.0	19.6	.023	.005	.004	.004	.208	.033	.032	.031
4-13-87	5.00	4.62	7.49	7.21	.003	.003	.001	.001	.012	.012	.012	.012
4-27-87	10.6	10.6	15.3	15.0	.017	.008	.010	.007	.129	.067	.056	.057
5-14-87	5.94	9.06	10.9	17.9	.011	.007	.002	.002	.065	.031	.021	.023
5-22-87	8.89	3.73	14.3	5.76	.058	.026	.003	.003	.281	.142	.017	.017
6-22-87	--	--	1.59	3.81	--	--	--	--	--	--	--	--
6-26-87	-	--	1.64	2.26	--	--	--	--	--	--	--	--
7-13-87	1.35	1.46	1.91	2.39	.006	.003	.001	.002	.088	.050	.024	.022
7-14-87	.596	.489	.930	.725	.001	.001	.001	.001	.009	.006	.009	.005
7-20-87	.420	.760	.303	1.32	.002	.001	*0	0	.013	.007	.003	.003
7-30-87	.206	.457	.169	.915	.001	.001	0	0	.011	.007	.002	.002
8-2-87	.568	.992	.781	1.87	.003	.005	.001	.001	.033	.033	.014	.014
8-9-87	4.83	6.76	6.57	10.5	.009	.007	.006	.006	.089	.069	.056	.048
8-19-87	--	--	.384	2.67	--	--	--	--	--	--	--	--
1-20-88	26.8	22.5	42.0	34.6	.012	.014	.002	.002	.064	.076	.018	.018
3-25-88	16.8	12.8	22.4	16.4	.057	.044	.002	.002	.246	.120	.016	.016
EMC	38.9	35.9	53.3	51.9	36.1	23.3	5.77	5.49	230	132	59.7	51.9

* Zero lead indicates samples had concentrations less than 5 micrograms per liter.

Appendix III.--Storm loads of chemical constituents at the basin inflow and outflow--(continued)

CONFIGURATION 2

Physical Properties

Date	Suspended solids		Dissolved solids		Suspended volatile solids		Chemical oxygen demand		Total organic carbon	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
7-14-88	82.4	16.9	31.2	31.2	15.3	4.75	42.3	71.3	8.19	3.96
7-17-88	111	60.5	65.2	80.8	18.8	11.7	59.6	42.1	8.67	7.11
7-21-88	9.51	2.58	9.08	11.1	1.08	.709	2.60	4.43	1.09	1.60
7-23-88	15.8	3.72	5.39	6.77	2.02	1.35	7.58	3.89	.842	1.22
8-23-88	25.8	5.51	15.5	16.1	5.88	1.89	10.5	8.93	1.22	2.13
8-25-88	42.2	5.71	11.6	18.4	7.30	1.77	14.6	7.51	3.51	1.84
8-28-88	18.2	3.22	7.47	10.3	4.96	1.34	5.33	4.78	1.06	1.46
9-4-88	11.3	1.81	5.28	8.25	2.41	.790	3.02	3.66	.513	2.21
9-13-88	26.8	3.41	8.52	12.1	6.56	1.14	19.7	5.44	3.52	1.46
9-17-88	17.8	1.49	9.79	11.0	5.64	.665	14.1	3.03	3.71	1.11
9-17-88	1.64	.679	35.4	13.0	1.23	.679	2.25	2.93	1.25	.769
9-23-88	6.63	2.86	12.9	14.9	2.30	1.49	6.90	3.88	1.03	1.29
10-4-88	6.71	2.86	4.17	6.57	1.65	.523	3.29	2.09	1.19	.759
EMC	116	24.9	66.1	71.1	25.2	7.59	62.8	46.1	12.6	8.78

Nutrients

Date	Total phosphorus		Dissolved phosphorus		Total orthophosphorus		Dissolved orthophosphorus		Total ammonia plus organic nitrogen		Dissolved ammonia		Total nitrite plus nitrate	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
7-14-88	0.169	0.077	0.012	0.017	0.026	0.013	0.009	0.013	0.449	0.423	0.048	0.095	0.087	0.122
7-17-88	.429	.300	.134	.079	.151	.088	.096	.063	1.36	.916	.122	.090	.482	.416
7-21-88	.023	.020	.007	.007	.012	.012	.007	.005	.160	.156	.048	.034	.097	.094
7-23-88	.033	.018	.006	.007	.022	.010	.005	.006	.185	.122	.030	.034	.059	.068
8-23-88	.070	.038	.019	.024	.027	.013	.015	.009	.287	.278	.036	.060	.160	.160
8-25-88	.054	.025	.011	.014	.017	.012	.009	.011	.351	.299	.105	.072	.151	.175
8-28-88	.027	.020	.009	.009	.008	.004	.006	.004	.184	.207	.070	.058	.110	.136
9-4-88	.022	.189	.005	.007	.007	.005	.005	.004	.107	.332	.017	.011	.038	.038
9-13-88	.033	.015	.014	.013	.018	.009	.011	.009	.295	.187	.036	.023	.074	.076
9-17-88	.044	.015	.018	.010	.018	.009	.015	.009	.445	.166	.059	.026	.154	.071
9-17-88	.078	.035	.066	.015	.063	.010	.062	.008	.225	.097	.059	.023	.281	.083
9-23-88	.023	.027	.015	.014	.011	.012	.011	.010	.178	.155	.040	.035	.127	.150
10-4-88	.016	.010	.008	.008	.007	.007	.006	.007	.158	.157	.065	.048	.076	.067
EMC	0.265	0.234	0.091	0.066	0.111	0.056	0.075	0.046	1.43	1.16	0.268	0.209	0.613	0.521

Appendix III.--Storm loads of chemical constituents at the basin inflow and outflow--(continued)

CONFIGURATION 2 (continued)

Common Ions and Metals

Date	Sodium		Total chloride		Total lead		Dissolved lead		Total zinc		Dissolved zinc	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
7-14-88	2.64	3.43	4.75	5.55	0.024	0.005	0.001	0.003	0.156	0.048	0.021	0.016
7-17-88	6.70	5.43	9.02	7.02	.012	.013	.004	.005	.078	.067	.035	.035
7-21-88	1.04	.984	1.11	1.27	.004	.002	.001	.001	.009	.007	.007	.007
7-23-88	.269	.592	.354	.914	.004	.003	.002	.003	.027	.007	.017	.007
8-23-88	1.47	1.73	2.39	2.94	.003	.002	.002	.002	.026	.013	.013	.013
8-25-88	.865	1.61	1.19	2.66	.002	.001	.001	.001	.027	.017	.014	.012
8-28-88	.513	.534	.767	1.30	.003	.001	.002	.001	.028	.015	.009	.010
9-4-88	.452	.545	.633	.830	.021	.001	.001	.001	.045	.015	.006	.006
9-13-88	.615	1.06	1.07	2.03	0	.002	0	0	.035	.006	.006	.003
9-17-88	.415	.747	.594	1.36	.002	.001	.001	.001	.055	.020	.031	.019
9-17-88	3.69	1.01	5.53	1.67	.001	.002	.001	.001	.008	.024	.008	.023
9-23-88	.923	1.29	1.37	2.28	.003	.002	.001	.001	.029	.056	.020	.048
10-4-88	.318	.569	.446	0.991	.001	.001	.001	.001	.011	.005	.005	.005
EMC	5.58	5.98	8.38	10.0	27.5	10.8	5.75	6.51	194	90.0	66.6	64.1

Appendix III.--Storm loads of chemical constituents at the basin inflow and outflow--(continued)

CONFIGURATION 3

Physical Properties

Date	Suspended solids		Dissolved solids		Suspended volatile solids		Chemical oxygen demand		Total organic carbon	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
3-18-89	88.3	23.2	116	144	17.8	4.98	29.1	14.4	8.27	4.45
3-30-89	82.7	31.5	458	435	17.2	7.79	51.5	37.3	19.1	14.3
4-3-89	49.1	8.90	809	795	5.29	3.75	22.0	19.3	9.36	10.0
5-30-89	277	24.7	26.2	29.8	32.9	6.70	44.3	5.75	19.4	2.61
6-9-89	289	11.6	174	107	52.3	2.40	66.4	18.0	21.8	7.65
6-17-89	62.7	20.0	462	232	21.3	10.5	72.5	46.1	23.2	18.0
7-10-89	61.5	8.15	72.3	41.7	9.38	4.78	9.56	18.3	3.51	6.37
8-2-89	23.5	4.18	15.9	15.4	6.91	1.45	10.4	4.66	6.41	2.09
8-4-89	14.1	16.6	141	55.0	3.86	4.00	16.2	13.3	6.50	4.47
8-5-89	8.03	11.6	228	46.2	1.47	2.26	19.1	10.3	8.37	4.32
9-13-89	7.75	5.39	12.5	26.5	3.01	2.04	7.14	7.02	1.11	2.05
9-14-89	8.60	2.39	51.2	52.6	2.73	1.35	9.75	8.70	1.92	2.33
EMC	136	22.0	199	149	23.6	6.83	41.3	22.6	16.1	8.46

Nutrients

Date	Total phosphorus		Dissolved phosphorus		Total orthophosphorus		Dissolved orthophosphorus		Total ammonia plus organic nitrogen		Dissolved ammonia		Total nitrite plus nitrate	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
3-18-89	0.112	0.080	0.024	0.023	0.060	0.045	0.021	0.019	0.764	0.634	0.075	0.066	0.299	0.388
3-30-89	.364	.291	.200	.162	.184	.174	.161	.134	3.07	2.45	.247	.184	1.67	1.64
4-3-89	.217	.170	.108	.096	.144	.111	.101	.088	2.18	1.99	.128	.104	5.81	5.88
5-30-89	.276	.073	.021	.020	.077	.020	.018	.018	.897	.376	.095	.105	.179	.207
6-9-89	.265	.154	.064	.078	.246	.083	.054	.062	2.32	1.04	.277	.142	.897	.475
6-17-89	.637	.526	.456	.379	.447	.399	.399	.342	6.96	5.43	1.75	1.40	1.73	.819
7-10-89	.093	.080	.027	.019	.036	.038	.026	.019	.955	1.07	.226	.292	.597	.240
8-2-89	.042	.032	.009	.012	.016	.010	.007	.010	.337	.257	.050	.043	.066	.119
8-4-89	.128	.110	.079	.047	.088	.061	.069	.044	.891	.784	.091	.068	1.34	.340
8--5-89	.138	.133	.099	.086	.104	.096	.089	.080	1.09	1.04	.069	.169	2.63	.404
9-13-89	.055	.039	.016	.020	.026	.021	.014	.018	.409	.346	.122	.103	.409	.482
9-14-89	.071	.064	.039	.043	.043	.042	.032	.038	.518	.331	.133	.086	.527	.489
EMC	0.254	0.172	0.092	0.083	0.135	0.096	0.080	0.074	1.91	1.50	0.308	0.290	1.42	0.918

Appendix III.--Storm loads of chemical constituents at the basin inflow and outflow--(continued)

CONFIGURATION 3 (continued)

Common Ions and Metals

Date	Sodium		Total chloride		Total lead		Dissolved lead		Total zinc		Dissolved zinc	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
3-18-89	26.6	35.6	38.6	47.8	0.018	0.007	0.004	0.001	0.095	0.038	0.020	0.011
3-30-89	87.0	84.6	115	102	.016	.025	.006	.006	.147	.082	.051	.057
4-3-89	112	117	168	170	.046	.052	.011	.006	.055	.054	.036	.039
5-30-89	1.93	3.13	2.49	4.73	.019	.007	.007	0	.199	.029	.001	.004
6-9-89	19.0	12.0	27.6	14.3	.023	.011	0	.004	.124	.036	.008	.026
6-17-89	41.2	19.5	47.8	23.0	.013	.009	.005	.003	.085	.058	.010	.012
7-10-89	13.4	4.00	13.0	8.96	.006	.007	.002	.004	.044	.017	.007	.009
8-2-89	2.73	1.77	3.69	3.16	.005	.002	0	0	.021	.005	.005	.003
8-4-89	17.9	5.71	24.6	8.91	.004	.004	0	0	.020	.021	.012	.002
8-5-89	24.8	3.52	34.1	5.93	.002	.003	0	.001	.017	.019	.011	.003
9-13-89	.945	2.30	1.46	3.48	.005	.001	.001	.001	.025	.004	.006	.003
9-14-89	7.00	6.57	6.47	6.99	.004	.003	.002	.002	.013	.019	.009	.009
EMC	28.4	22.0	37.9	31.0	18.7	11.7	4.04	2.90	114	38.9	18.4	16.0

Appendix IV.--Results of bottom-material analysis

[Values are in micrograms per kilogram except as noted. mg/kg = milligram per kilogram; µg/g = microgram per kilogram; µg/g = microgram per gram; < = less than; > = greater than; mm = millimeters. Dashes indicate missing data.]

Constituent	Sample			
	1	2	3	4
Chemical Content				
Nitrogen, ammonia plus organic as N (mg/kg)	--	1,600	720	540
Nitrogen, nitrite plus nitrate as N (mg/kg)	--	8.0	12	10
Phosphorus as P (mg/kg)	790	710	800	400
Carbon, inorganic (mg/kg)	35,000	9,300	12,000	14,000
Carbon, inorganic plus organic (mg/kg)	43,000	14,000	17,000	22,000
Arsenic as As (µg/g)	--	3	5	3
Cadmium as Cd (µg/g)	1	1	< 1	< 1
Chromium as Cr (µg/g)	6	9	7	6
Copper as Cu (µg/g)	10	20	10	10
Lead as Pb (µg/g)	90	10	10	20
Zinc as Zn (µg/g)	219	60	60	40
Iron as Fe (µg/g)	6,200	12,000	9,800	7,800
Polychlorinated naphthalenes, dry weight (PCN)	< 1.0	< 1.0	< 1.0	< 1.0
Aldrin	< .1	< .1	< .1	< .1
Lindane	< .1	< .1	< .1	< .4
Chlordane	< 1.0	< 1.0	< 1.0	< 1.0
DDD	< .1	< .1	< .8	< .1
DDE	.4	.4	1.4	.2
DDT	6.9	.8	2.8	.1
Dieldrin	.2	.1	.2	.1
Endosulfane	< .1	< .1	< .1	< .1
Endrin	< .1	< .1	< .1	< .1
Ethion	< .1	< .1	< .1	< .1
Toxaphene	< 10	< 10	< 10	< 10
Heptachlor	4.0	.1	.1	.3
Heptachlor epoxide	2.3	.2	.1	.4
Methoxychlor	< .1	< .1	< .1	< .1
Polychlorinated biphenyl (PCB)	< 1	< 1	< 1	< 1
Malathion	< .1	< .1	< .1	< .1
Parathion	< .1	< .1	< .1	< .1
Diazinon	11	.3	1.7	.2
Methyl parathion	< .1	< .1	< .1	< .1
Mirex	< .1	< .1	< .1	< .1
Trithion	< .1	< .1	< .1	< .1
Methyl trithion	< .1	< .1	< .1	< .1
Perthane	< 1.00	< 1.00	< 1.00	<1.00
Particle-Size Distribution (in percent)				
Sand (>0.063 mm)	99	47	63	61
Silt (0.063-0.004 mm)	< 1	40	30	32
Clay (<0.004 mm)	< 1	13	7	7