EFFECTS OF HIGHWAY RUNOFF ON THE QUALITY OF WATER AND BED SEDIMENTS OF TWO WETLANDS IN CENTRAL FLORIDA

By Donna M. Schiffer

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CONTENTS

Abstract 1
Introduction 1
  Purpose and scope 2
  Previous studies........ 2
  Wetland processes 2
Study areas and approach 4
  Silver Star Road wetland........ 4
  Island Lake wetland 7
  Water-quality sampling and laboratory analysis 11
Analysis of effects of highway runoff on wetlands........ 11
  Silver Star Road wetland........ 11
    Surface-water relations 13
    Water quality 13
      Water-quality monitoring at the inlet and outlet 13
      Comparison of water-quality data to State water-quality standards for Class III waters........ 19
      Ground-water quality near the pond and wetland........ 21
      Major ions in surface waters and ground waters 21
      Qualitative analysis of organic compounds 24
    Spatial variation of constituents in bed sediments........ 24
    Distribution of constituents by sampling medium........ 26
  Island Lake wetland 32
    Water quality 32
      Water-quality monitoring at the inlet and outlet 33
      Spatial variation in water quality in the wetland 38
      Statistical analysis of water-quality data........ 43
      Comparison of water-quality data to State water-quality standards for Class III waters........ 50
      Qualitative analysis of organic compounds 51
    Spatial variation of constituents in bed sediments........ 51
    Distribution of constituents by sampling medium........ 52
  Comparison between the two wetlands........ 57
Summary and conclusions........ 59
Selected references........ 62

ILLUSTRATIONS

Figure 1-3. Maps showing Page
  1. Location of study areas........ 5
  2. Silver Star Road study area and sampling sites........ 6
  3. Island Lake and the Grace Lake drainage basin........ 9

ILLUSTRATIONS--Continued

Page

Figure 4. Aerial photograph of the Island Lake study area 10
5. Map showing Island Lake wetland and sampling sites 12
6. Discharge hydrographs for three storms at the inlet and outlet of the Silver Star Road wetland 14

7-10. Plots showing:
7. Lead concentrations during three storms at the inlet and outlet of the Silver Star Road wetland 15
8. Lead loads during three storms at the inlet and outlet of the Silver Star Road wetland 16
9. Zinc concentrations during three storms at the inlet and outlet of the Silver Star Road wetland 17
10. Zinc loads during three storms at the inlet and outlet of the Silver Star Road wetland 18

11-12. Graphs showing:
11. Distribution of selected metals and nutrients at the inlet and outlet of the Silver Star Road wetland 20
12. Distribution of dissolved Kjeldahl nitrogen (ammonia plus organic), orthophosphorus, and zinc in ground water near the Silver Star Road wetland and detention pond, for two sample dates 22
13. Stiff diagrams of major dissolved ions in water from the Silver Star Road pond, wetland, and surficial aquifer system 23
14. Piper diagram of ionic composition of ground water near the Silver Star Road detention pond and wetland, and surface water entering and leaving the wetland 25

15-18. Maps showing distribution of median values of:
15. Total Kjeldahl nitrogen in bed sediments at the Silver Star Road study area 27
16. Lead in bed sediments at the Silver Star Road study area 28
17. Zinc in bed sediments at the Silver Star Road study area 29
18. Chromium in bed sediments at the Silver Star Road study area 30

19-22. Plots showing stage and selected water-quality data at the Island Lake wetland for the storm periods:
19. February 11-12, 1986 34
20. August 28 through September 3, 1986 35
21. September 1-30, 1986 36
22. October 1-21, 1986 37

ILLUSTRATIONS--Continued

Page

Figure 23-27. Plots showing:
- 23. Total ammonia and total Kjeldahl (ammonia plus organic) nitrogen at sampling sites at the Island Lake wetland 39
- 24. Total phosphorus and total orthophosphorus concentrations at sampling sites at the Island Lake wetland 40
- 25. Specific conductance and turbidity of water from sampling sites at the Island Lake wetland 41
- 26. Dissolved calcium and alkalinity at sampling sites at the Island Lake wetland 42
- 27. Total zinc and total chromium concentrations in water at sampling sites at the Island Lake wetland 44
- 28. Stiff diagrams of major dissolved ions in water at sites at the Island Lake wetland 45
- 29. Piper diagram of major ions in water from sites at the Island Lake wetland 46

30-32. Maps showing distribution of:
- 30. Kjeldahl nitrogen and volatile solids in bed sediments at the Island Lake wetland, May 1985 53
- 31. Lead and zinc in bed sediments at the Island Lake wetland, May 1985 54
- 32. Chromium and copper in bed sediments at the Island Lake wetland, May 1985 .... *55*

TABLES

Page

Table 1. Sampling sites at each wetland study area 8
- 2. Summary data for three selected storms at the Silver Star Road wetland 13
- 3. Comparison of water-quality data to State standards, Silver Star Road pond and wetland 21
- 4. Minimum and maximum concentrations of selected metals in bed sediments, Silver Star Road detention pond and wetland, and minimum and maximum concentrations from a reconnaissance of 35 Florida lakes and streams 31
- *5.* Distribution of selected constituents in water, sediments, and ground water at the Silver Star Road study area 32
- 6. Results of analysis of variance and TUKEY multiple comparisons, Island Lake wetland 48
- 7. Results of analysis of variance of grouped data, and TUKEY multiple comparisons, Island Lake wetland 49
- 8. Comparison of water-quality data to State standards, Island Lake wetland 50
- 9. Median values of selected constituents in the water column and values for one sample of bed sediments at the Island Lake wetland 56

ABBREVIATIONS AND CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric (International System) units by the following factors.

Multiply inch-pound unit	By	To obtain metric unit
Length		
inch (in.)	25.4	millimeter (mm)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	0.4047	hectare (ha)
Flow		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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 the United States and Canada, formerly called Sea Level Datum of 1929.

Additional abbreviations

micrograms per gram	(µg/g)
micrograms per liter	(µg/L)
micrometers	(µm)
microsiemens per centimeter at 25 °C	(mS/cm at 25 °C)
milligrams per kilogram	(mg/kg)
Nephelometric turbidity units	(NTU)
Platinum-Cobalt units	(Pt-Co units)

EFFECTS OF HIGHWAY RUNOFF ON THE QUALITY OF WATER AND BED SEDIMENTS OF TWO WETLANDS IN CENTRAL FLORIDA

By Donna M. Schiffer

ABSTRACT

Results of a study of the effects of highway runoff on the chemical quality of water and bed sediments of a cypress wetland and a freshwater marsh in central Florida indicate that detention of the runoff prior to release into the wetland reduces concentrations of automobile-related chemicals in the water and bed sediments in the wetland. Detention of highway runoff for the cypress wetland occurs in a 68- by 139-foot detention pond and in a 12- by 25-foot trash retainer for the fresh water marsh. The analysis of the chemical data for water and bed sediments indicates that many of the observed differences in chemistry are due to the difference in detention facilities.

Water quality generally improved from the inlet to the outlet of both wetlands. Only inlet and outlet data were collected at the cypress wetland and these showed a reduction in concentrations through the wetland. Spatial data collected at the freshwater marsh indicated that constituent concentrations in water generally decreased with distance from the inlet. Results of analysis of variance of grouped data for 40 water-quality variables at the freshwater marsh inferred that 26 of 40 variables tested were significantly different among five general locations within the wetland: inlet outlet, near, intermediate, and far sites (with respect to the inlet). Further statistical tests inferred significant differences between the inlet location and all other locations except the near sites, in color and total organic carbon (increased with distance), pH, nutrients, aluminum, lead, and zinc (decreased with distance). Comparisons between the near-sites and other locations were analagous to those of results for the inlet location.

The use of a primary sedimentation facility reduces the impact of highway runoff on the chemical composition of wetland bed sediments. For example, median concentrations of trace metals in bed sediments were much lower in the cypress wetland than in the detention pond preceding it. The median lead concentration in pond sediments was 620 μg/g (micrograms per gram), and 20 μg/g in the wetland; median zinc concentrations were 250 μg/g (pond) and 14 μg/g (wetland), and chromium concentrations were 20 μg/g (pond) and 2 μg/g (wetland).

Median concentrations of selected constituents in bed sediments at the freshwater marsh were much higher than in the cypress wetland but were similar in magnitude to those detected in the detention pond at the cypress wetland. Median concentrations for 10 sites in the freshwater marsh were: lead 390 μg/g; zinc, 175 μg/g; and chromium, 40 μg/g.

Results from this study indicate that detention structures, larger than the trash retainer at the freshwater marsh, may cause sufficient sorption and settling of substances contained in highway runoff to minimize the transport and deposition of some undesirable chemicals into wetlands.

INTRODUCTION

Runoff from road surfaces is a significant source of nutrients, organic compounds, suspended sediments, and metals to receiving surface waters. Stormwater runoff has been the subject of much research, but highway runoff has only recently been more rigorously investigated as a source of organic and inorganic constituents. Sartor and Boyd (1972), and Shaheen (1975) were early investigators of highway runoff, and additional studies have followed (Gupta, and others, 1981; Galvin and Moore, 1982). Many stormwater detention methods have been used to attenuate constituent loadings before entering receiving waters. One stormwater detention method that is increasingly being used is the diversion of stormwater runoff into wetlands.

Natural processes occurring in wetlands can assimilate undesirable constituents and improve the quality of water. Although some attenuation of constituent concentrations may occur in the water column, bed sediments in these wetlands may also be sinks for trace metals, phosphorus, and organic compounds. Research on these processes within wetlands has thus far been primarily focused on the effect of discharge of secondary-treated wastewater on wetlands. The effect of highway runoff on the chemical quality of water and bed sediments of wetlands is not well documented.

The Wetlands Protection Act of 1984 (Section 403.918, Florida Statutes) calls for the development of rules to allow the regular permitting of stormwater and wastewater discharges to some wetlands. To meet this requirement, the Florida Department of Environmental Regulation (FDER) has adopted a rule on discharging stormwater to wetlands in section 17-25.042 of the Florida Administrative Code (Florida Department of Environmental Regulation, 1986). This rule presents criteria for pretreatment of stormwater, and criteria for design and performance of stormwater-to-wetland facilities that must be met to obtain a permit for construction and operation of a stormwater system that will discharge into a wetland.

The Florida Department of Transportation (FDOT) is responsible for the control of runoff from State roads that enters State-owned wetlands, or parts of wetlands. Because the effects of highway runoff on the chemical quality of water and bed sediment of wetlands was not well documented, a 4-year reconnaissance study of wetlands receiving highway runoff was begun in October 1983 by the U.S. Geological Survey in cooperation with the FDOT. This study evaluated the effects of highway runoff on the quality of water and bed sediments of two wetlands that differed in several respects, but most significantly perhaps, in the manner in which the runoff enters the wetland. One wetland, a cypress wetland, is preceded by a detention pond, providing somewhere between 5 and 15 minutes of detention time for the incoming runoff, and the other wetland, a freshwater marsh, is preceded by a trash-retainer, in which little to no detention occurs.

Purpose and Scope

The purpose of this report is to describe the effects of highway runoff on the water and bed sediment quality of two wetlands in central Florida. Data were collected from August 1982 (as part of an earlier study by Martin and Smoot, 1986) through September 1986.

The first wetland, referred to in this report as the Silver Star Road wetland, is a cypress wetland that was also studied by Martin and Smoot (1986). In Martin and Smoot's study, the primary objective was the identification of constituent loads in and out of the detention pond-wetland system, and computation of removal efficiencies. The emphasis of the present study is on the quality of water and bed sediment chemistry in the wetland, and this report should supplement the Martin and Smoot report. The only additional data collected for this study at the Silver Star Road wetland are constituent concentrations in bed sediments, and in ground water near the detention pond and wetland. Results presented in this report provide a more general overview of the quality of water and bed sediments at the Silver Star Road study area than was provided in the report by Martin and Smoot.

The second wetland, referred to in this report as the Island Lake wetland, is a freshwater marsh, at which spatial variation in water quality and in constituent concentrations in bed sediments was studied to evaluate the effects of highway runoff. All data for the Island Lake wetland in this report were collected as part of this study. The Island Lake wetland was selected in part because of the lack of a detention facility so that the effect of detention or lack of detention might be evaluated by comparison of the data between the two wetlands.

Previous Studies

Wetlands have been the subject of research over the last decade as a potential natural tertiary treatment system for secondary-treated wastewater. One report on the use of wetlands for both wastewater treatment and stormwater runoff treatment (Chan and others, 1982) surveyed scientific investigations and basic literature sources related to nutrient and constituent cycling in wetland ecosystems. The authors noted that few existing studies at that time related specifically to stormwater runoff, and these had variable results. Several case studies described freshwater marshes in the south.

One case study involved a freshwater marsh near Clermont, Fla., at which the effect of varied loadings of secondary wastewater effluent on the productivity and the nitrogen and phosphorus budgets was studied. The marsh was composed primarily of emergent aquatic macrophytes, similar to the Island Lake wetland. Results of the study successfully demonstrated the viability of using a wetland for tertiary treatment to improve the quality of the city's wastewater. There were major reductions in nitrogen and phosphorus, to values comparable to background levels. The reduction of phosphorus was attributed to the accumulation and storage of phosphorus in the soil complex, roots of aquatic plants, and dead organic matter. Studies of the soils and vegetation showed a possible higher rate of peat production and greater plant uptake of phosphorus and nitrogen in areas receiving wastewater discharges (Chan and others, 1982, p. 154).

A second case study done by the University of Florida is of a central Florida hardwood swamp receiving treated wastewater and stormwater runoff from the city of Wildwood (Chan and others, 1982, p. 154). The results of that study also showed a reduction of nutrients through the wetland to levels equal to or less than those in the receiving waters and in an adjacent control swamp. However, unlike other wetland studies, the University of Florida study did not find a nutrient buildup in the sediments. Researchers suspected that the inflow of urban runoff had caused a disturbance of sediments, resulting in inconsistent measurements of ammonia nitrogen measurements.

A study of several cypress wetlands near Gainesville, Fla., by the University of Florida Center for Wetlands was also described by Chan and others (1982, p. 155). This was a feasibility study for wastewater disposal. Results indicated rapid uptake of nutrients, accompanied with little change in nutrient levels in underlying and downstream ground waters as a result of wastewater application.

An early study in the same report (p. 155) of a wetland in Michigan is of note because of its duration (1972-77) and results. The 1,700-hectare wetland site was used for tertiary treatment of wastewater. No adverse effects were observed at the site as a result of the addition of nutrients and other wastewater constituents.

The few studies reported in Chan and others (1982) revealed a wide disparity in the ability of wetlands to remove nonpoint source pollution particularly with regard to nutrients (Chan and others, 1982, p. 167). The greatest consistency in the studies is the reduction of biochemical oxygen demand (BOD), suspended solids, and heavy metals. The available research indicates that the nature of the flow regime and seasonal factors (particularly in northern climates) are major influences on constituent removal capabilities.

A more recent study of the effect of urban runoff on wetlands included a study of three natural wetlands and one manmade wetland in the Twin Cities Metropolitan Area, Minn. (Brown, 1985). Brown noted a decrease in nutrients in one of the natural wetlands, attributed to high assimilation rates by cattails in the wetland. In contrast, the manmade wetland was ineffective in decreasing nutrient or sediment concentrations, apparently because its storage capacity was too small to prevent frequent flushing of accumulated sediments. Sediment concentrations in discharge from the manmade wetland were as much as 22 times greater than in the inflow, which was already high in concentration.

Martin and Smoot (1986) studied constituent loads and removal efficiencies at the Silver Star Road detention pond-wetland, and noted that the wetland was generally effective in reducing both suspended and dissolved constituent loads. Efficiencies in the wetland, calculated using a linear regression procedure for 13 storms, were higher than in the pond for suspended constituents with the exception of nitrogen and phosphorus. Martin and Smoot attributed the smaller removal efficiencies for these nutrients in the wetland to biochemical recycling. Reductions in suspended and dissolved constituent loads were attributed to the processes occurring in the wetland. For suspended constituents, efficiencies in the wetland were 66 percent for solids, 75 percent for lead, 50 percent for zinc, 30 percent for nitrogen, and 19 percent for phosphorus.

Removal efficiencies in the wetland for dissolved constituents were lower than for suspended constituents with the exception of zinc, which had an efficiency of 75 percent. The removal efficiency for dissolved phosphorus was computed as zero.

Wetland Processes

Natural processes occurring in wetlands that can attenuate constituent concentrations in highway runoff routed to wetlands are divided into three categories: physical, chemical, and biological. These processes involve both the water phase and sediments.

One of the most important mechanisms for removal of particulates from water is sedimentation, a physical process important in the removal of particulate nitrogen, chlorinated hydrocarbons, oils, and metals (except manganese and nickel) (Chan and others, 1982, p. 58). Chemical processes act on the dissolved constituents and remove these from the water column by sorption (adsorption and absorption), precipitation, coagulation, chelation, and decomposition (organic matter). Biological processes involve mostly vegetative mechanisms, including filtration in plants, absorption of constituents through roots, stems, and leaves, and chemical transformation within the plant. In general, the constituent involved is not actually removed from the system, but is removed from one phase of the system--the water phase. The potential for the constituent to reenter the water phase exists by release from sediments and by plants (through decay).

Biological processes may cause anoxic conditions in deeper sediments, releasing iron and phosphorus to the sediment-water interface, where ferrous iron oxidizes to ferric complexes. These ferric complexes adsorb dissolved phosphate, creating an enriched layer of phosphate at the top of the sediment. A change in water conditions from aerobic to anaerobic can cause the release of this phosphate back to the water column, where it is again available (Chan and others, 1982, p. 61).

Processes occurring in wetland sediments are important to the removal of constituents from the water column. The organic soils in wetlands form complexes with metals in runoff, binding the metals in the soil matrix. Some bonds formed are difficult to break and the metal remains complexed, but metals more weakly bonded to organic compounds in the soil may be released to the water column if a physicochemical change occurs. Iron and manganese oxides on sediments also act as metal collectors (Horowitz, 1984), and changing redox conditions may cause the release of these oxides and associated metals to the aqueous phase.

STUDY AREAS AND APPROACH

The two wetlands discussed in this report are located in Orange and Seminole counties. The Silver Star Road wetland (cypress wetland) is located west of the city of Orlando, on Silver Star Road (fig. 1), which had an average daily traffic count in 1984 of 22,000 vehicles per day (measured by the U.S. Geological Survey). The Island Lake wetland (freshwater marsh) is in Seminole county, near the city of Longwood, and receives runoff from State Road (SR) 434, which had an average daily traffic count in 1985 of 33,606 vehicles per day (measured by FDOT) (fig. 1).

Silver Star Road Wetland

The Silver Star Road wetland receives stormwater from a 68- by 139-foot detention pond that was built by the FDOT in 1980. Settling of some particulate matter occurs in the detention pond, prior to discharging to the wetland. The wetland is approximately 0.75 acre in size and ranges in width from 58 to 120 feet, and in length from 200 to 340 feet.

The drainage area of the pond-wetland system is 41.6 acres, 33 percent of which is urban roadway. Inflow to the pond-wetland system from the drainage basin is through a 60-inch culvert located at the south end of the pond. Discharge from the detention pond to the wetland is over an earthen spillway located in the northeast corner of the pond. At higher pond stages, water can overflow the entire berm on the east side of the pond (fig. 2). Stormwater in the wetland generally follows the flow path indicated in figure 2. Discharge from the wetland is over a weir to a drop inlet and culvert, and then to an adjacent drainage canal located on the east and north side of the wetland.

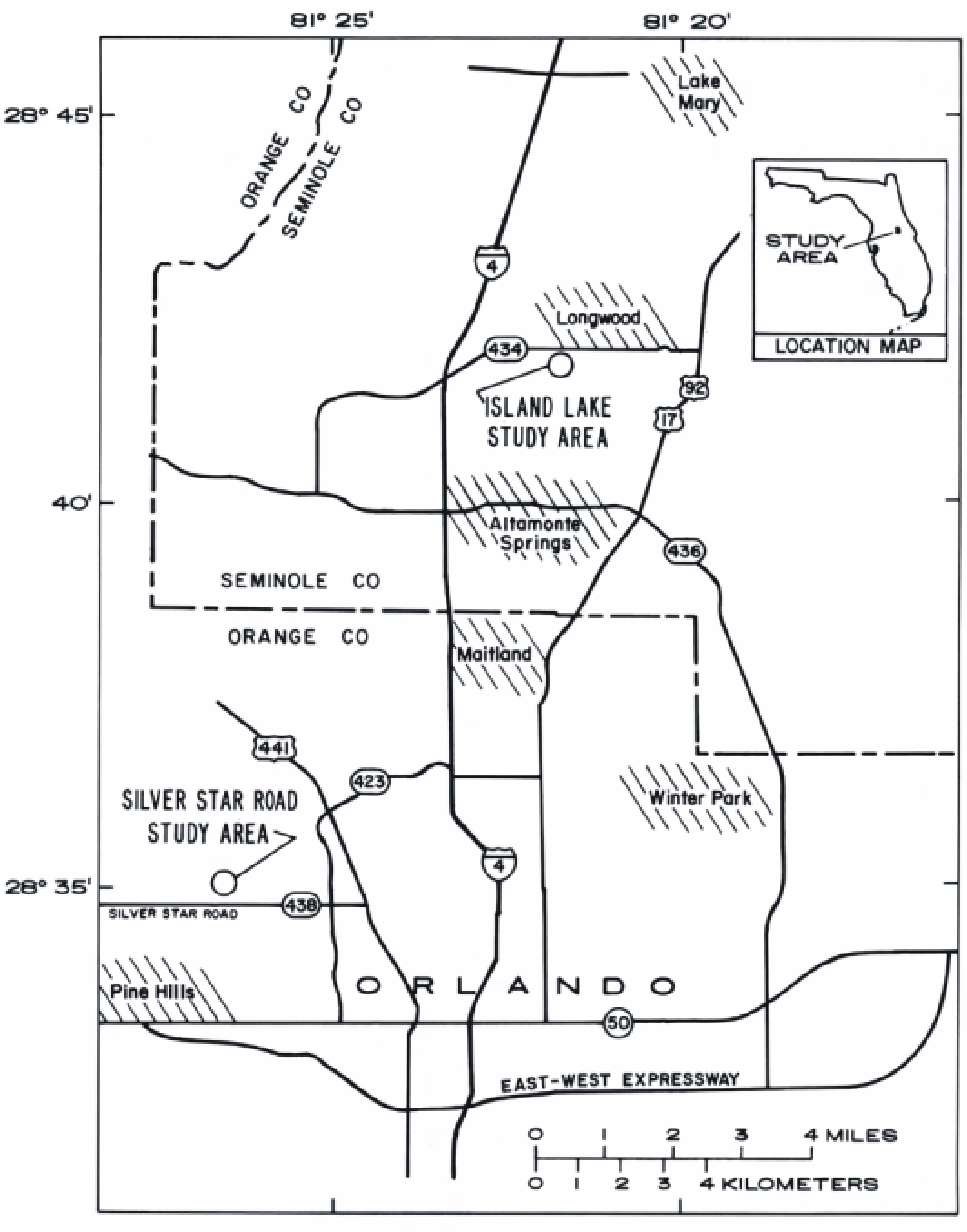

Figure 1.--Location of study areas.

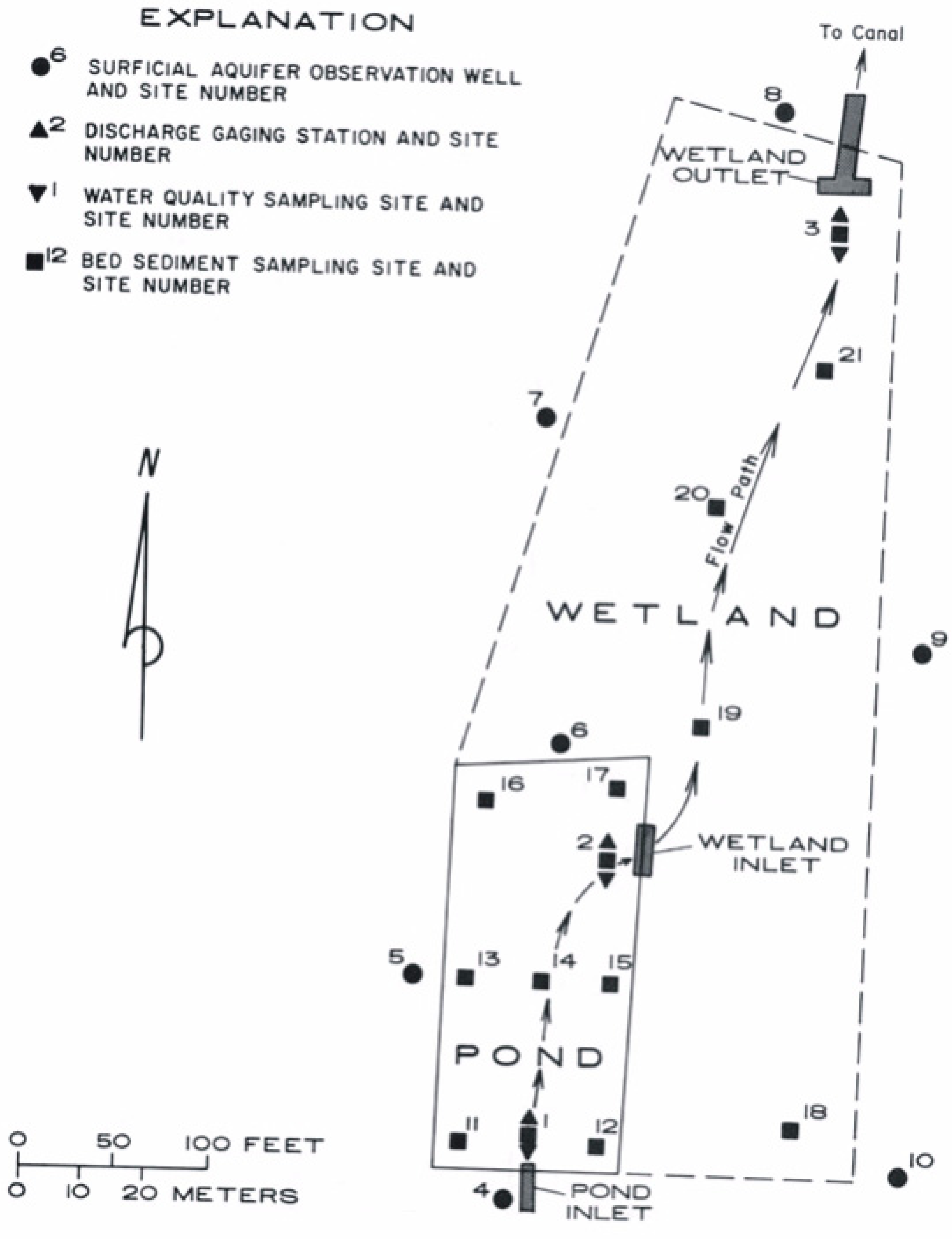

Figure 2.--Silver Star Road study area and sampling sites.

The detention pond at the Silver Star Road study area has cement bags lining its sides but not the bottom. Thus, there is little opportunity for exchange with adjacent ground water except through the pond bottom. Naturally-occurring clays in the area also prevent much seepage into or out of the pond. However, the water level in the wetland is 8 to 10 feet above the adjacent canal so seepage probably occurs through the berm that separates the wetland from the canal.

Surface-water and bed-sediment data used in this report for the Silver Star Road wetland were collected from 1982 through 1984 for the study by Martin and Smoot (1986). Ground-water quality around the pond and wetland was studied as part of an investigation of the impact of highway runoff on ground-water resources (Schiffer, 1989). Inflow to and outflow from the pond and wetland were measured and sampled during storms by Martin and Smoot. Inflow to the pond and wetland (outflow from the pond) was sampled with an automatic sampler controlled by a data logger programmed to collect samples based on the value of stage during storms. Sampling at the wetland outlet was not controlled by a data logger, but was initiated by a rise in stage, and samples were automatically collected every 30 minutes until 24 samples were taken. Table 1 lists the sampling sites at the Silver Star Road wetland, and the type of data collected at each site. Bed-sediment samples were collected three times during the study, in both the pond and wetland. Locations of sampling sites are shown in figure 2.

Island Lake Wetland

Island Lake is a 103-acre freshwater marsh, as wide as 3,100 feet in some locations, and 4,500-feet long, south of SR 434. It receives runoff from residential plus commercial areas as well as highway runoff. The wetland is part of the Grace Lake sinkhole basin (fig. 3). The northeastern arm of the wetland was separated from the main wetland when the highway was built, but culverts connect the two parts of the wetland. The drainage area of this northern section (referred to locally as Mud Lake) is approximately 64 acres. The drainage basin south of SR 434 is approximately 275 acres, and an additional 19 acres drain to Island Lake from neighborhoods and streets on the north side of SR 434. The sum of these subbasins is the total drainage area, 358 acres, which drains north to Lake Winsor and to Grace Lake.

According to Anderson and Hughes (1975), there is only minor vertical seepage through the bottom of Island Lake. There is lateral seepage from the surficial aquifer system into the wetland, but not enough seepage occurs to cause continuous discharge from the wetland. Ground water in the vicinity of Island Lake was not part of this investigation.

There are two main inlets into the wetland from SR 434, and one outlet that allows water from Island Lake to flow north under SR 434 into Lake Winsor (fig. 4). These structures were built in 1976. The inlets to the wetland empty into small 12- by 25-foot chain-link-fenced trash retainers prior to entering the wetland. The eastern inlet installed by FDOT is located 300-feet east of the western inlet, and receives runoff from 22 acres, of which 1.4 acres are highway surface. The eastern inlet was not included in the study.

Most of the highway runoff enters the wetland through the western storm inlet, so this is where the water-quality monitoring and sampling equipment were located. The western inlet to the wetland is a 42-inch diameter pipe that collects runoff from approximately 2.3 acres of highway and 60.3 acres of residential area (including approximately 93 acres of residential streets); it empties into the trash retainer that provides minimal detention. Runoff enters the wetland by overflowing a berm on the south side of the trash retainer. Very little storage is available in the trash retainer (the stage varied only 2 feet during the study). Most of the flow into the wetland followed preferential pathways in the southeast corner and the middle of the berm of the trash retainer. Major flow paths observed for stormwater in the wetland were to the southeast and the south, but no discernible flow paths were observed beyond about 50 feet from the trash retainer. These stormwater structures were built before implementation of the rule concerning stormwater discharge to wetlands that states: “stormwater shall be discharged into the wetlands utilized so as to minimize the channelized flow of stormwater * * *” (Florida Department of

Table 1.--Sampling sites at each wetland study area

Site No.	Site name	Type of data collected
	Silver Star Road detention pond and wetland, Orlando	
1	Detention pond inlet	Discharge, water quality, bed-sediment quality
2	Detention pond outlet (inlet to wetlands)	Do.
3	Wetland outlet	Do.
4	Surficial well number 1	Surficial aquifer water quality
5	do. 2	Do.
6	do. 3	Do.
7	do. 4	Do.
8	do. 5	Do.
9	do. 7	Do.
10	do. 8	Do.
11	Detention pond, SW corner	Bed-sediment concentrations
12	do. , SE corner	Do.
13	do. , West side, midway	Do.
14	do. , at center on flow path	Do.
15	do. , East side, midway	Do.
16	do. , NW corner	Do.
17	do. , NE corner	Do.
18	Wetland, south end	Do.
19	do. , on flow path	Do.
20	do. , on flow path	Do.
21	do. , on flow path	Do.
	Island Lake wetland, Longwood	
1	Site 1- east lateral, 30 feet	Water quality, bed-sediment quality
2	do. 2- east lateral, 106 feet	Do.
3	do. 3- east lateral, 221 feet	Do.
4	do. 4- center lateral, 35 feet	Do.
5	do. 5- center lateral, 81 feet	Do.
6	do. 6- center lateral, 237 feet	Do.
7	do. 7- west lateral, 23 feet	Do.
8	do. 8- west lateral, 106 feet	Do.
9	do. 9- west lateral, 254 feet	Do.
10	Inlet	Water quality, stage and quality monitoring
11	Outlet	Water quality, monitoring

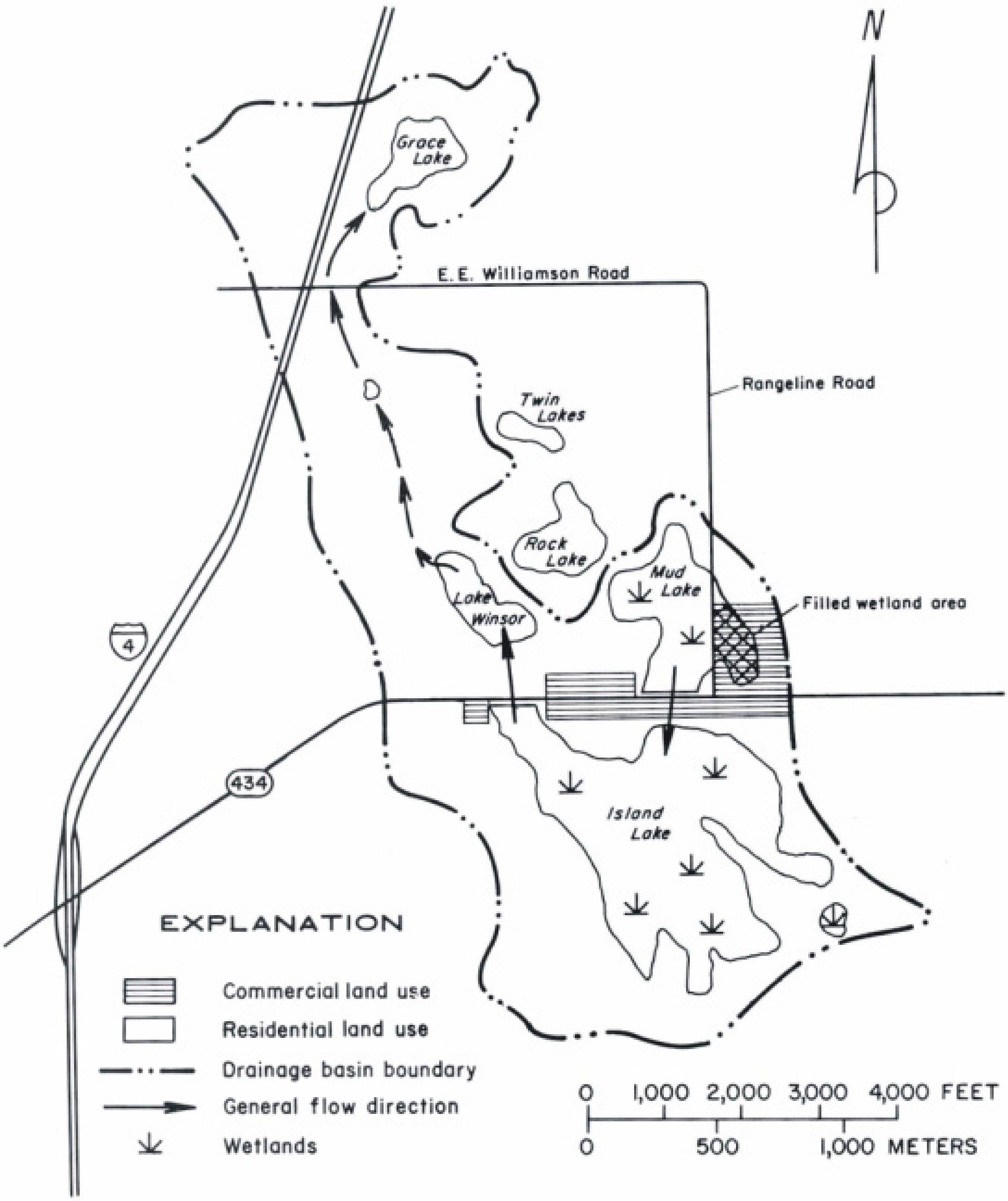

Figure 3.--Island Lake and the Grace Lake drainage basin.

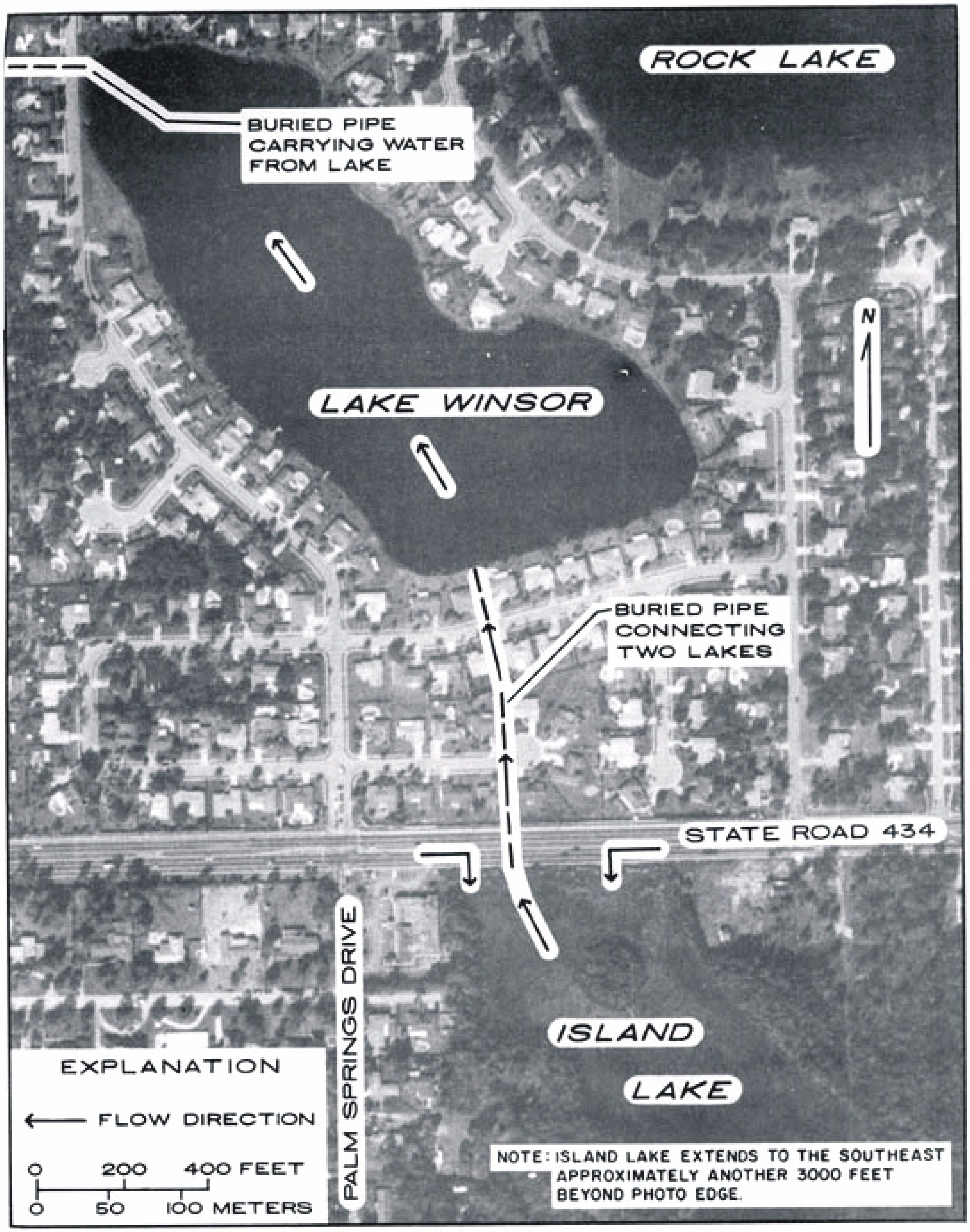

Figure 4.--Aerial photograph of the Island Lake study area.

Environmental Regulation, 1986, chap. 17-25.042(6)(e)).

The highway runoff that is routed to Island Lake is a small percentage of the water received from the entire drainage basin. The road surface of SR 434 that drains to the wetland is about 3.7 acres, and residential streets make up an additional 9.5 acres of road surface, for a total of about 132 acres of road and highway surface. This is only about 3.7 percent of the entire drainage basin (as measured at the outlet at SR 434). Although this does not include driveways, rooftops, or parking lots associated with small commercial areas in the basin, even these areas plus the roads would not add up to more than 5 percent of the drainage area. The water surface of the wetland alone, south of SR 434 and not including Mud Lake, makes up 103 of the 358 acres, or nearly a third of the basin.

Water quality at the outlet of the wetland reflects the blending of water from different land uses, including highways, residential areas, and the wetland itself. The effects of the highway runoff on Island Lake water and sediment may be very localized.

Stage was monitored in the trash retainer area of the western inlet, and automatic sampling equipment was controlled by a data logger and activated by stage in the trash retainer. Specific conductance, dissolved oxygen, and temperature were measured at the southeast corner of the detention area (site 10), where most of the flow entered the wetland, and at the outlet of the wetland (site 11), before passing beneath SR 434 to Lake Winsor. Nine sampling sites were established areally in the wetland, varying with distance from the trash retainer at the western inlet. The sampling sites were located approximately 30 feet (near sites), 100 feet (intermediate sites), and 250 feet (far sites) from the point at which runoff enters the wetland, to study changes in water quality and bed-sediment quality with distance (fig. 5). Tubing and a peristaltic pump were used to draw samples from the remote sites. Samples were also collected at the wetland outlet. Sampling sites and type of data collected are listed in table 1.

Placement of intermediate and far sites was determined based on changes in vegetation. The vegetation in the upland areas of the wetland, where the near and intermediate sites were located, was predominately willows and shrubs. The intermediate sites were near the edge of this area, before the transition to wetland grasses. The far sites were located in the area of predominately wetland grasses.

Water-Quality Sampling and Laboratory Analysis

Water samples were processed at the time of collection using standard Geological Survey procedures (Fishman and Friedman, 1985). Samples for the determination of dissolved constituent concentrations were filtered through a 0.45-micrometer membrane filter. Samples for metals were treated by acidification with nitric acid. Samples for major ions and metals were sent to U.S. Geological Survey laboratories in Doraville, Ga., and in Arvada, Colo. Samples for nutrients were treated with mercuric chloride, and shipped packed in ice to the Geological Survey laboratory in Ocala, Fla. The analytical procedures used by the laboratories are described in Wershaw and others, 1983, and in Fishman and Friedman, 1985.

ANALYSIS OF EFFECTS OF HIGHWAY RUNOFF ON WETLANDS

Silver Star Road Wetland

At the Silver Star Road study site, only data for the wetland inlet and outlet were analyzed for this report. A total of 13 storms were monitored and sampled (composite or discrete samples). The removal efficiencies varied among the sampled storms, but removal efficiencies based on regression analysis of input and output of loads were used to compute a representative overall removal efficiency for each unit (pond, wetland, and both combined) (Martin and Smoot, 1986). Martin and Smoot reported higher removal efficiencies in the wetland than in the pond for suspended solids, lead, zinc, and nitrogen. Removal efficiencies for suspended phosphorus in the pond and wetlands were about equal (21 and 19 percent, respectively). The pond detains street runoff long enough to allow some settling of

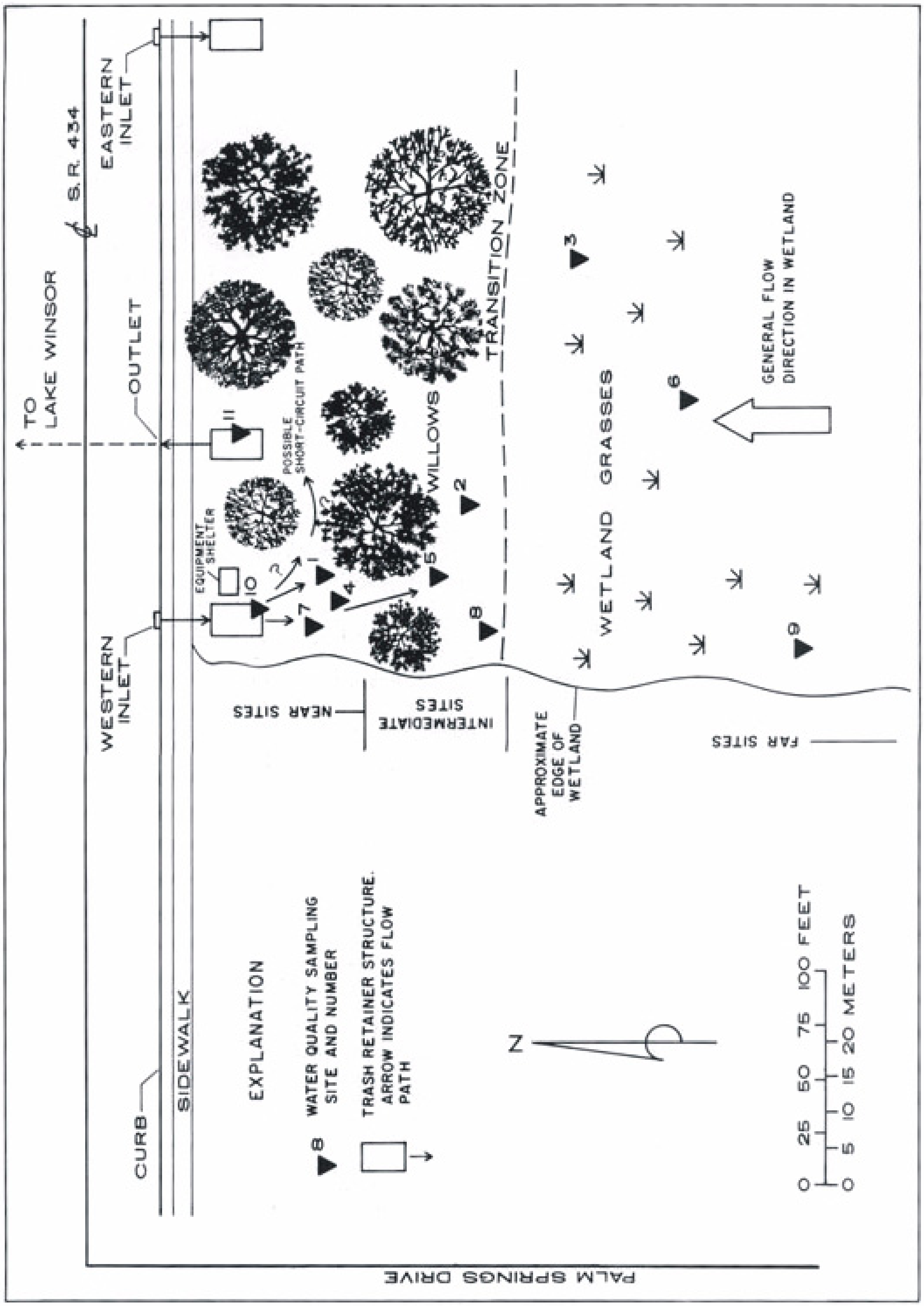

Figure 5.--Island Lake wetland and sampling sites.

Table 2.-Summary data for three selected storms at the Silver Star Road wetland

Storm No.	Date	Rain (inches)	Runoff (thousand cubic feet)	Runoff (inches)	Duration (hours)	Intensity (inches per hour)	Wetland removal efficiency Lead (percent)	Wetland removal efficiency Zinc (percent)
5	02-02-83	2.49	953	0.63	4.3	0.579	71	53
7	06-07-83	1.78	116.3	.77	21.67	.082	90	92
12	02-13-84	.46	28.4	.19	63	.071	78	13

particles before it enters the wetland. The longer residence time and lower velocities in the wetland may be the primary reason for the higher removal efficiencies in the wetland.

Surface-Water Relations

Three storms (5,7, and 12) were selected from the 13 sampled (10 of which had wetland water-quality data available) for further analysis in this report. Selection was based on rainfall volume and intensity, and removal efficiencies, to describe a range of hydrologic conditions. Storm number 5 represents a short duration storm, and a high intensity, large rainfall amount. Storm 7 is a long duration storm, that generated more runoff for the amount of rainfall than did storm 5, and had the highest removal efficiencies for lead and zinc associated with it. Storm 12 was selected to represent a storm with a low intensity, and a more average rainfall volume. Information for the storms selected, including rainfall and runoff volumes, and reported removal efficiencies for lead and zinc in the wetland, are listed in table 2.

Discharge hydrographs for these three storms are shown in figure 6. Storage in the wetland causes a lower peak discharge, smoother hydrograph curve, and a slightly delayed peak. Note that the time scale is not the same for storm 7, the long duration storm. The effect of storage in the wetland is not as apparent in the plot for storm 7 because of the compressed time scale.

Water Quality

Water-quality monitoring at the inlet and outlet

Concentrations and loads of lead and zinc are plotted for the inlet and outlet of the wetlands (figs. 7-10). Lead and zinc are metals frequently associated with highway runoff, and other metals were often present only at the detection level of the analytical methods (1 or 10 µg/L (micrograms per liter)). Concentrations of total lead entering the wetland were still high (290 µg/L, storm 5, and 590 µg/L, storm 7, fig. 7) even after detention of the stormwater in the pond. The maximum lead concentration at the wetland outlet measured during the study was 52 µg/L (storm 5), considerably less than the 290 µg/L entering the wetland.

Plots of lead loads entering and leaving the wetland (fig. 8) appear similar in shape to the concentration plots, with two exceptions. During storm 7, (long duration storm), the last concentration measured at the inlet was less than the concentration in the previous sample, but the discharge had increased, creating an increased load to the wetland. At the end of storm 12, the last measured concentration of lead at the inlet was the maximum value for that storm, but the discharge was low, and the load (fig. 8) actually decreased. These effects at the inlet were not evident at the wetland outlet. The effects of the increased storage and the opportunity for additional sedimentation and chemical and

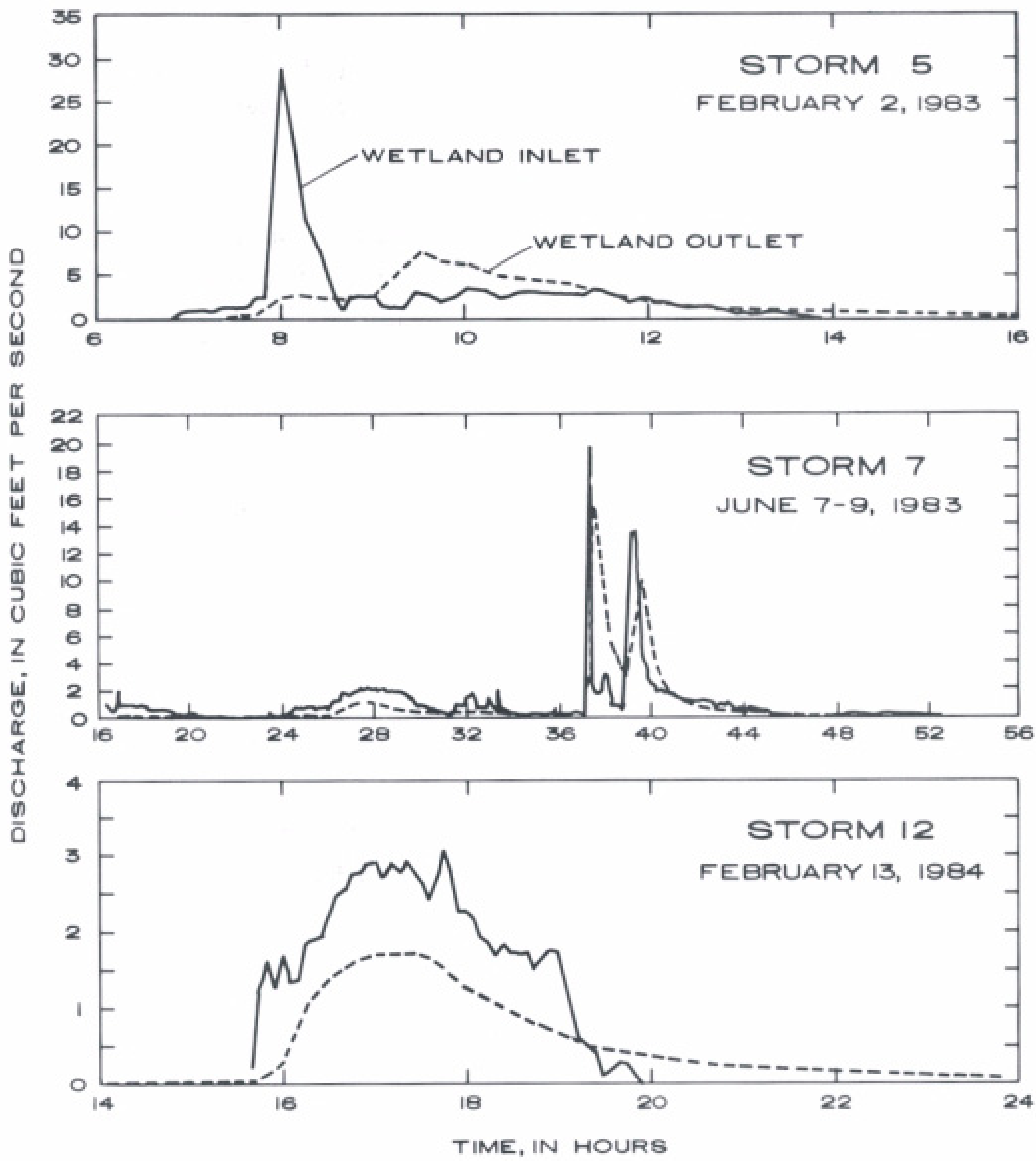

Figure 6.--Discharge hydrographs for three storms at the inlet and outlet of the Silver Star Road wetland.

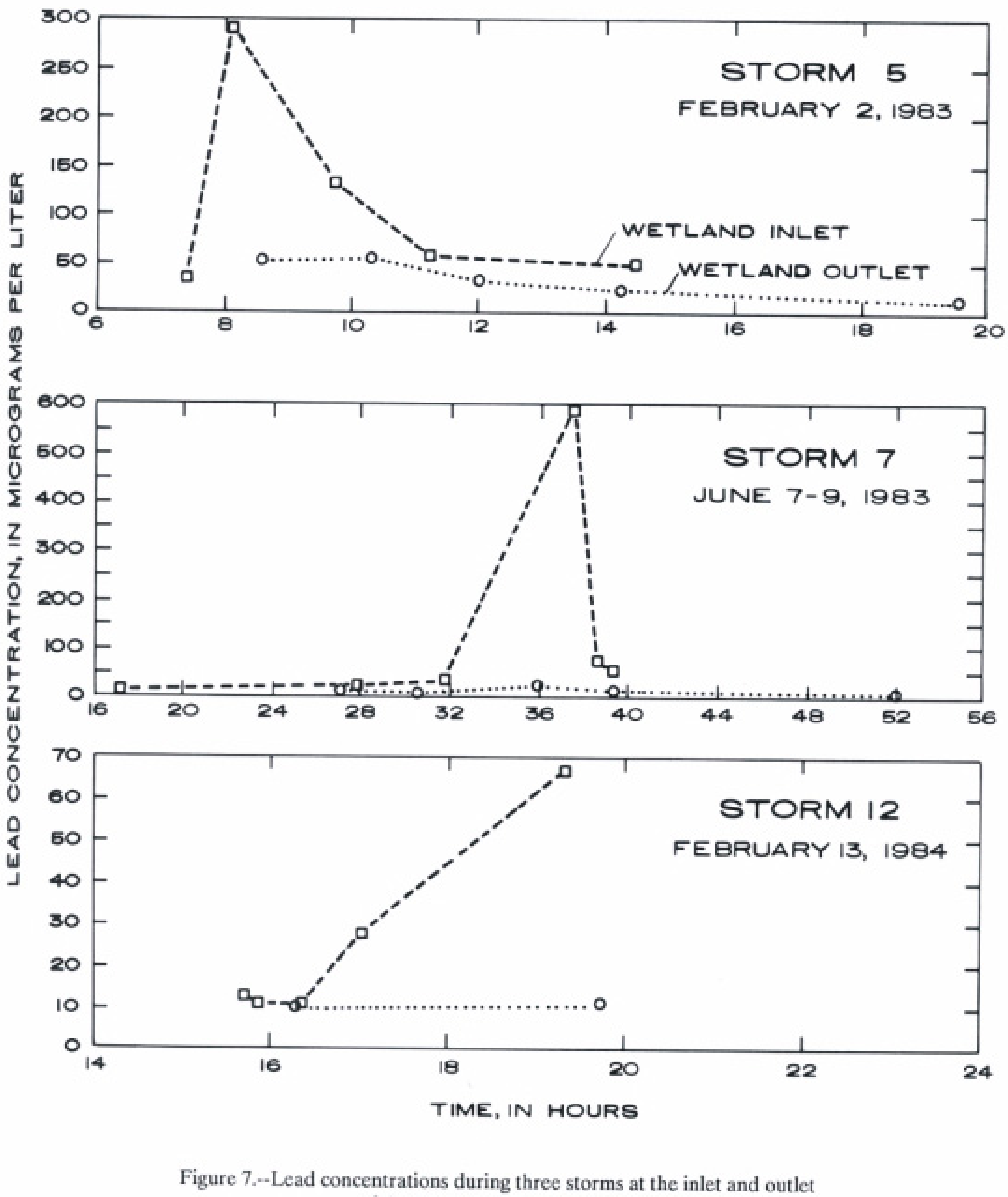

Figure 7.--Lead concentrations during three storms at the inlet and outlet of the Silver Star Road wetland.

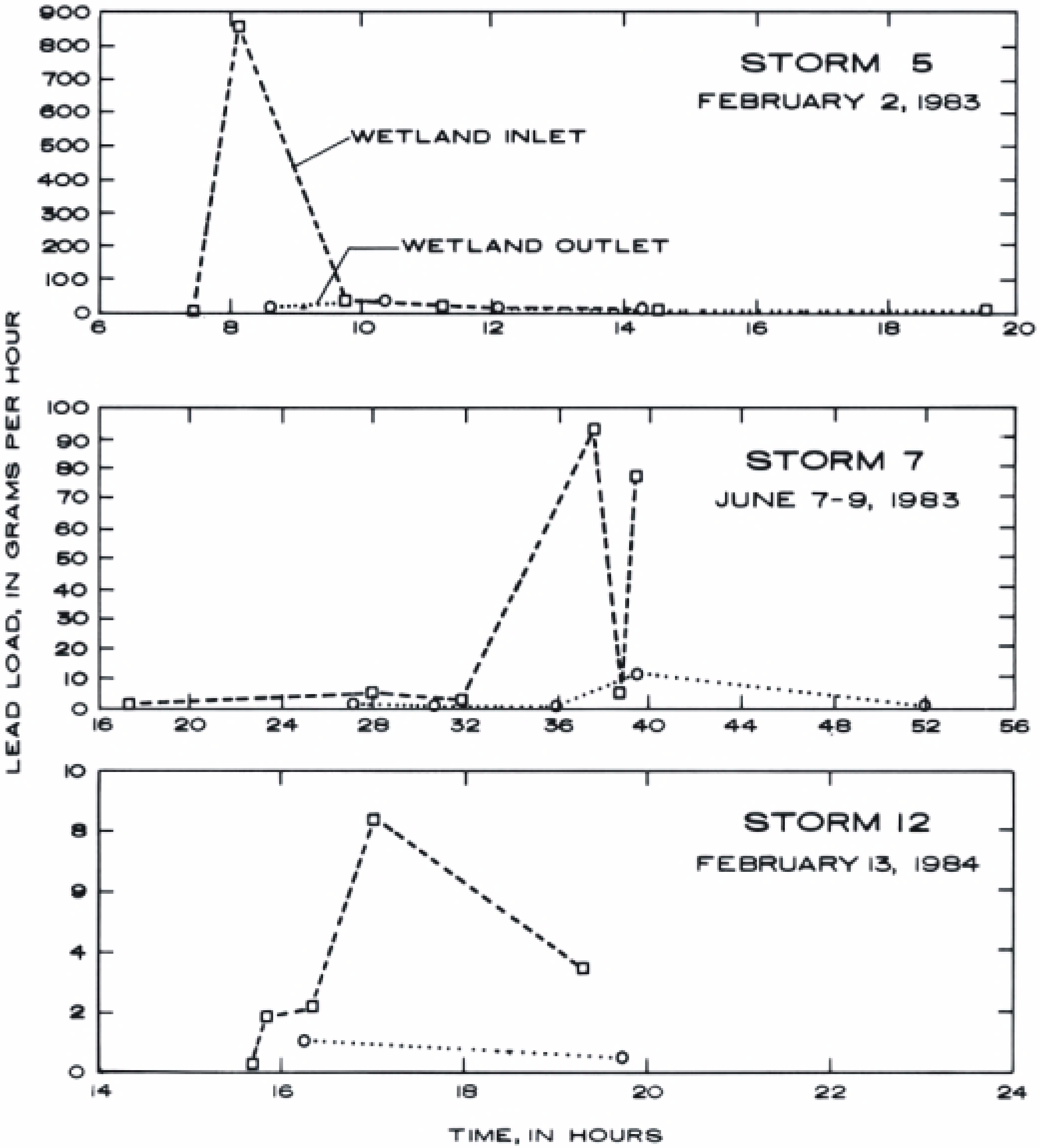

Figure 8.--Lead loads during three storms at the inlet and outlet of the Silver Star Road wetland.

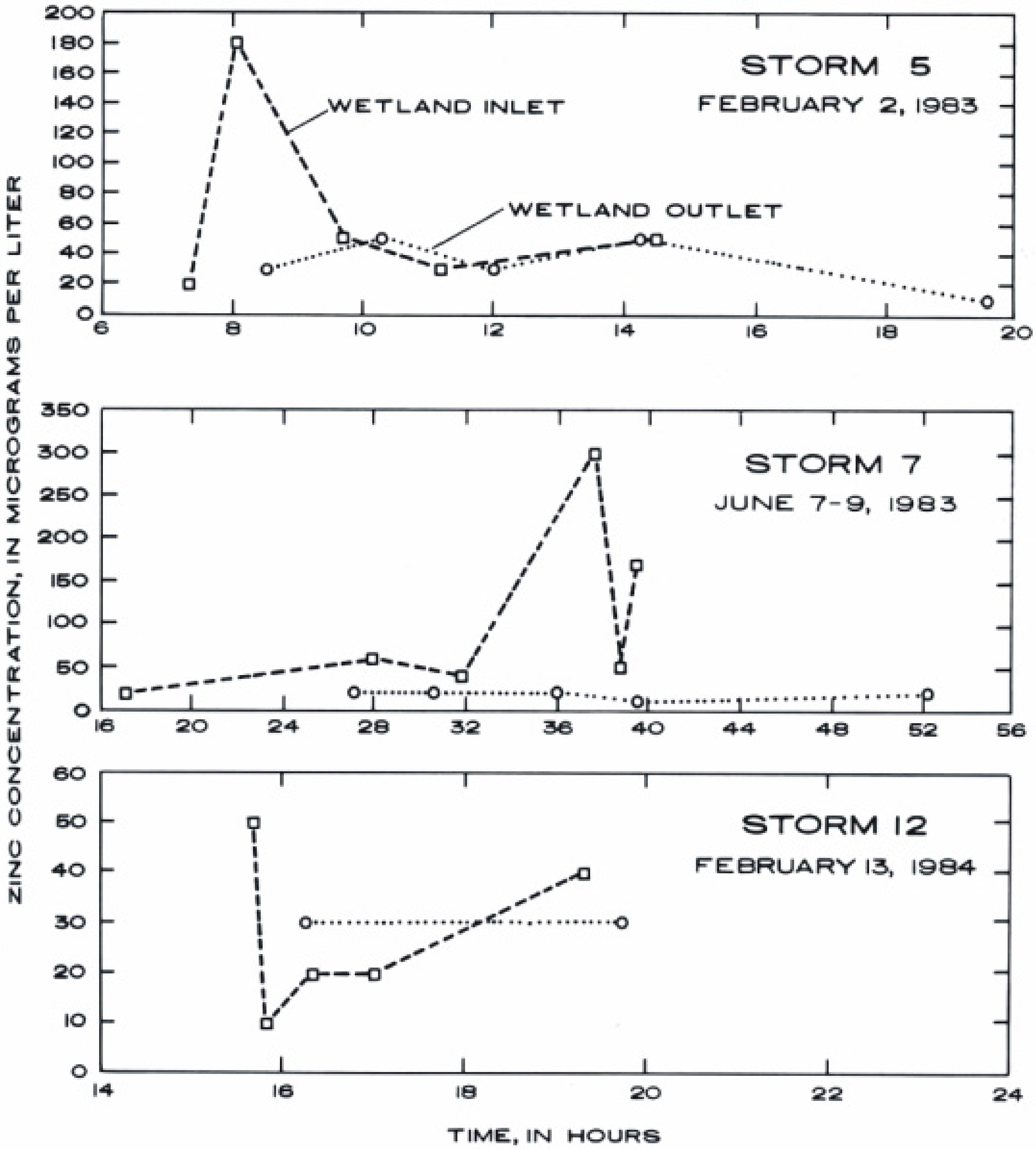

Figure 9.--Zinc concentrations during three storms at the inlet and outlet of the Silver Star Road wetland.

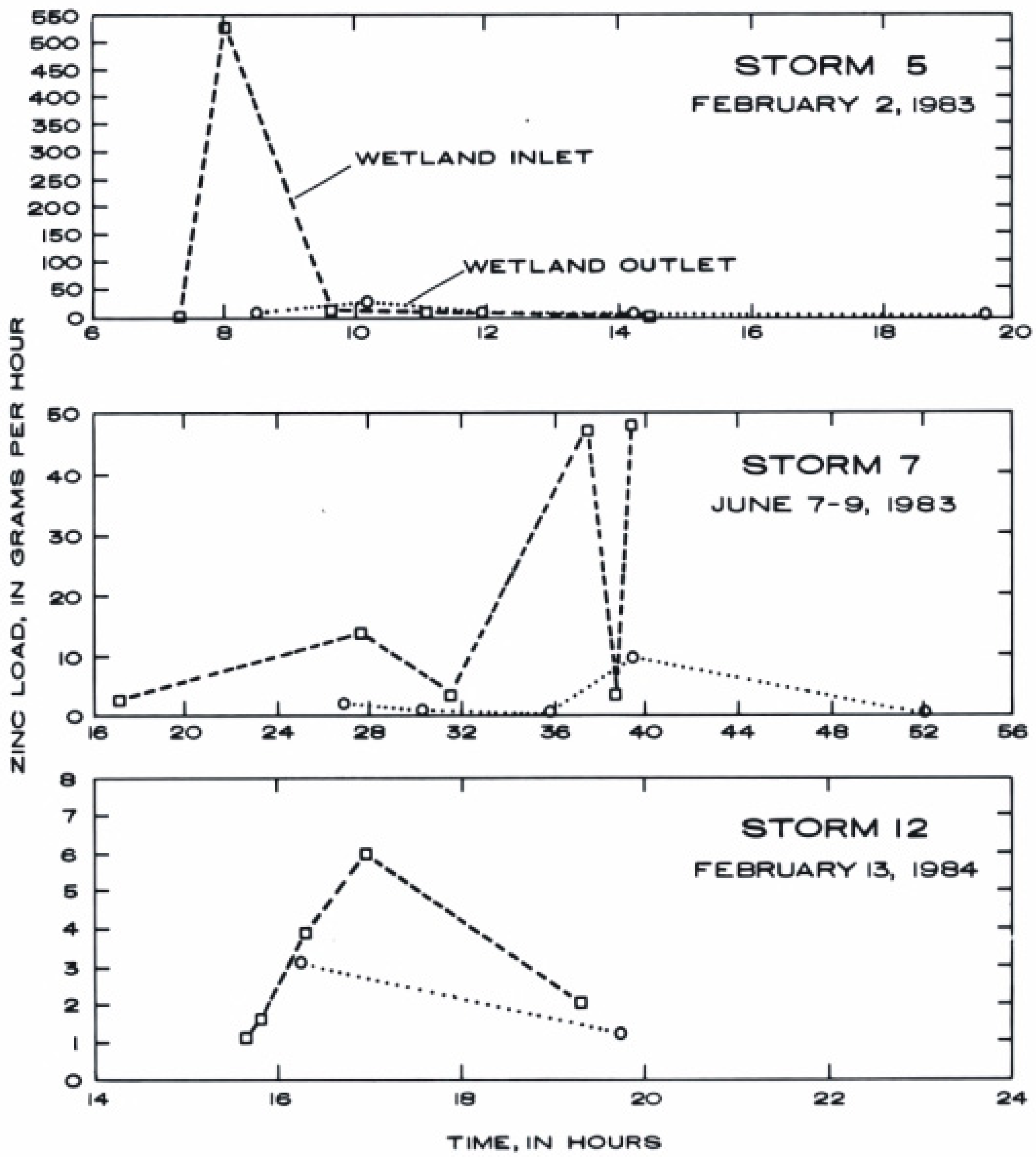

Figure 10.--Zinc loads during three storms at the inlet and outlet of the Silver Star Road wetland.

biological processes in the wetland are the primary reasons for the low concentrations and loads of lead leaving the wetland.

Zinc concentrations were lower than lead concentrations at both the inlet and outlet of the wetland. The relations shown for zinc concentration and load at the inlet and outlet (figs. 9 and 10) are nearly identical to the pattern shown by lead (dampening of the peaks from the inlet to the outlet, and low concentrations and loads leaving the wetland).

The three storms illustrated here represent a range of hydrologic conditions that yielded a range of removal efficiencies for constituents in the water column. This variability is typical of any natural system subject to a number of influences.

All available data for lead, zinc, and nutrients for the wetland inlet and outlet were summarized and the results plotted in figure 11. Although maximum concentrations differ by a large margin, the differences in median values are relatively small between the inlet and outlet of the wetland. For example, the maximum lead concentrations differ by 538 μg/L, from 590 to 52, but the median values only differ by 84 μg/L, from 34 to 26. Median values of zinc also differ little. Differences in maximum, as well as median concentrations of nitrogen and phosphorus at the inlet and outlet are relatively small. Nitrate nitrogen was not shown in figure 11 because it was a small fraction of the total nitrogen in the wetland. The predominant form of nitrogen was organic. Most of the phosphorus was also organic (total phosphorus minus orthophosphorus).

Comparison of water-quality data to State water-quality standards for Class III waters

Water-quality data for the Silver Star Road detention pond inlet, outlet, and the wetland outlet were compared to State water-quality standards for Class III waters (Florida Department of Environmental Regulation, 1983). These standards are receiving-water standards, not discharge standards. As such, they do not apply to the water entering or leaving the pond, but are used for the purpose of showing improvement in water quality through the system. The State water-quality standards have been written with moderating provisions for mixing zones and discharge zones, and no numeric standards are available that would be applicable to these data. However, outflow from the wetland to a downstream receiving-water body should be of sufficiently good quality that it would be within the standards most of the time. Therefore, for illustrative and evaluative purposes, the data from this study were compared to these standards.

The range of values of selected constituents in water at the Silver Star Road detention pond inlet, wetland inlet, and wetland outlet, and results of comparison of these values to State water quality standards for Class III waters (Florida Department of Environmental Regulation, 1983) are shown in table 3. The percent of samples not in compliance with standards at the wetland inlet were lower than at the pond inlet, with the exception of zinc, which was about equal (76 versus 78 percent). With the exception of phosphate phosphorus, the number of samples not in compliance with standards at the wetland outlet decreased below the number not in compliance at the wetland inlet. Conditions in the wetland are conducive to the release of orthophosphorus into the water column (anaerobic condition). Removal efficiencies in the wetland calculated for orthophosphorus for several storms were very low, and sometimes actually negative (maximum, -200 percent), so that orthophosphorus was increasing from the inlet to the outlet of the wetland (Martin and Smoot, 1986).

The high percentage of samples not in compliance with the standard for cadmium at all three sites does not necessarily indicate a potential problem, because the standard is actually less than the detection level of the analytical procedure (1 μg/L). The procedure used for samples from this study was the most sensitive (able to detect low concentrations) test available through the U.S. Geological laboratory. If compliance with the State standard for cadmium is a critical part of any future investigation, more sensitive laboratory procedures may be used by making arrangements with the analytical laboratory (Fishman and Friedman, 1985). The maximum cadmium value reported was only 5 μg/L, at the pond inlet and wetland inlet, and only 3 μg/L at the wetland outlet.

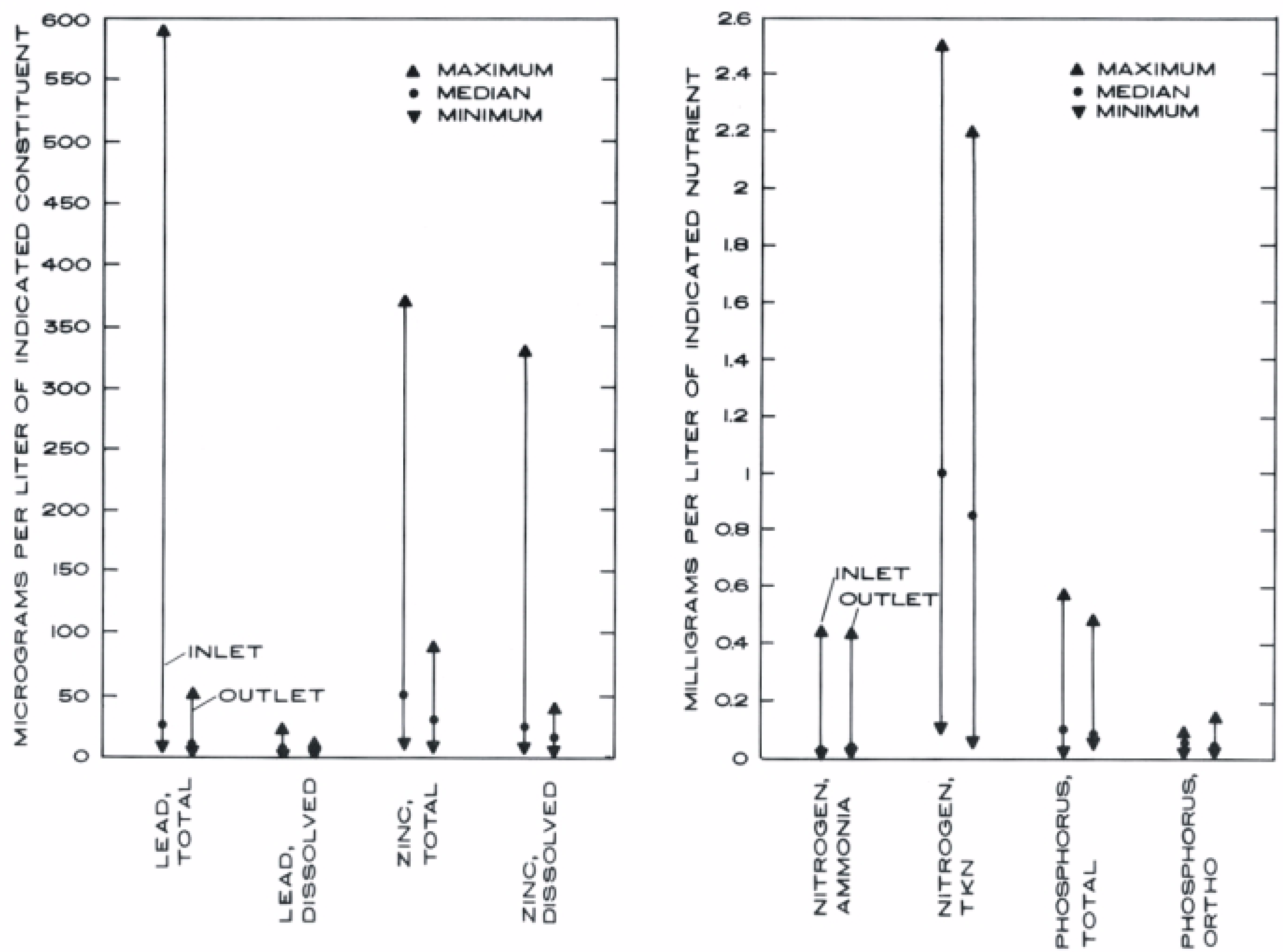

Figure 11.--Distribution of selected metals and nutrients at the inlet and outlet of the Silver Star Road wetland.

Table 3.--Comparison of water-quality data to State standards, Silver Star Road pond and wetland.

[All values are for total concentrations. Values with "<" were less than the detection limit of the analytical method, and were assumed to meet standard]

Constituent	Standard	Detention Pond Inlet			Wetland Inlet			Wetland Outlet		
		Number of samples	Range	Percent of samples not in compliance	Number of samples	Range	Percent of samples not in compliance	Number of samples	Range	Percent of samples not in compliance
Alkalinity (mg/L)	20	43	19-135	2	40	23-136	0	24	39-118	0
Cadmium (µg/L)	.8	28	<1.0- 5	89	25	<1- 5	76	17	<1- 3	71
Chromium (µg/L)	50	26	<1.0-20	0	23	<1-12	0	16	<1-11	0
Copper (µg/L)	30	31	10-100	13	25	<10-20	0	17	<10- 10	0
Lead (µg/L)	30	48	7.0-910	58	47	9-590	43	30	5-52	10
Phosphate phosphorus (µg/L[1])	.025	44	<.01-.33	89	42	<.01-09	74	24	<.01-.15	88
Zinc (µg/L)	30	50	10-530	76	46	10-370	78	29	10-90	34

[1]Suggested by U.S. Environmental Protection Agency, 1976, p.188, for eutrophication control in lakes or reservoirs.

Ground-water quality near the pond and wetland

Wells tapping the surficial aquifer were located in the vicinity of the pond and wetland as part of a parallel study on the effects of highway runoff on ground water. The location of these wells are shown in figure 2. These wells were sampled twice, and values of selected constituents measured in the ground water are shown in figure 12. The two samples represent dry season (April) and wet season (October) conditions. Only dissolved constituents were measured and plotted because the constituents in the surficial aquifer are mostly in the dissolved form. Lead is not shown because it was not found in concentrations above detection level (1-3 µg/L). Maximum dissolved zinc concentrations were measured at site 10, adjacent to the wetland and site 4, adjacent to the pond. These values are higher than the maximum total zinc measured at the outlet of the wetland (220 µg/L, site 4, and 180 µg/L, site 10, compared to 90 µg/L at the outlet). These values in ground water at sites 4 and 10 maybe within the range of normal variability, or may be the result of leaching from nearby underground pipes. Most of the phosphorus in ground water in the vicinity of the pond and wetland was orthophosphorus rather than organic phosphorus as in the surface water. Only site 5, on the west side of the pond, had orthophosphorus higher than in the wetland, but the other ground water sites were all less than 0.2 mg/L in orthophosphorus.

Organic nitrogen was the dominant nitrogen species in groundwater at sites 5-8. Ammonia was dominant in ground water from site 4, site 9, and site 10. Dissolved nitrate nitrogen was present in low concentrations in ground water, as it was in the wetland. Ground water from sites 4,9 and 10 have higher concentrations of Kjeldahl nitrogen than in the inlet or outlet of the wetland.

Major ions in surface waters and ground waters

Major cations and anions in water are conservative constituents that may indicate basic differences in water quality among sampling locations. The similarity or difference between wetland or pond water and ground water in the immediate vicinity may indicate one possible pathway for constituents.

Stiff diagrams (Hem, 1985*)* were used to compare major ions among surface water and ground water sampling locations (fig. 13). The diagrams indicate little difference in ionic

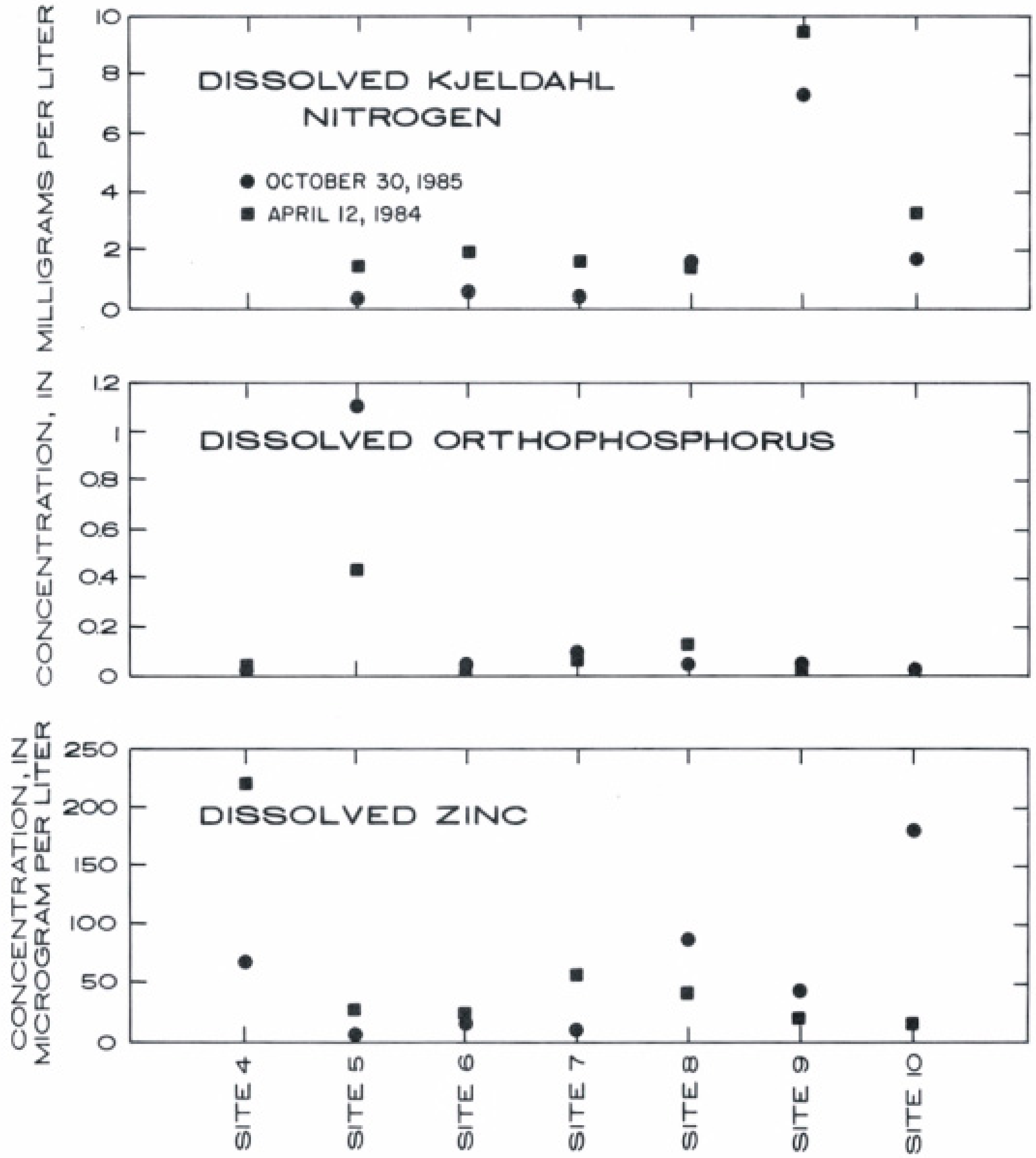

Figure 12.--Distribution of dissolved Kjeldahl nitrogen (ammonia plus organic), orthophosphorus, and zinc in ground water near the Silver Star Road wetland and detention pond, for two sample dates.

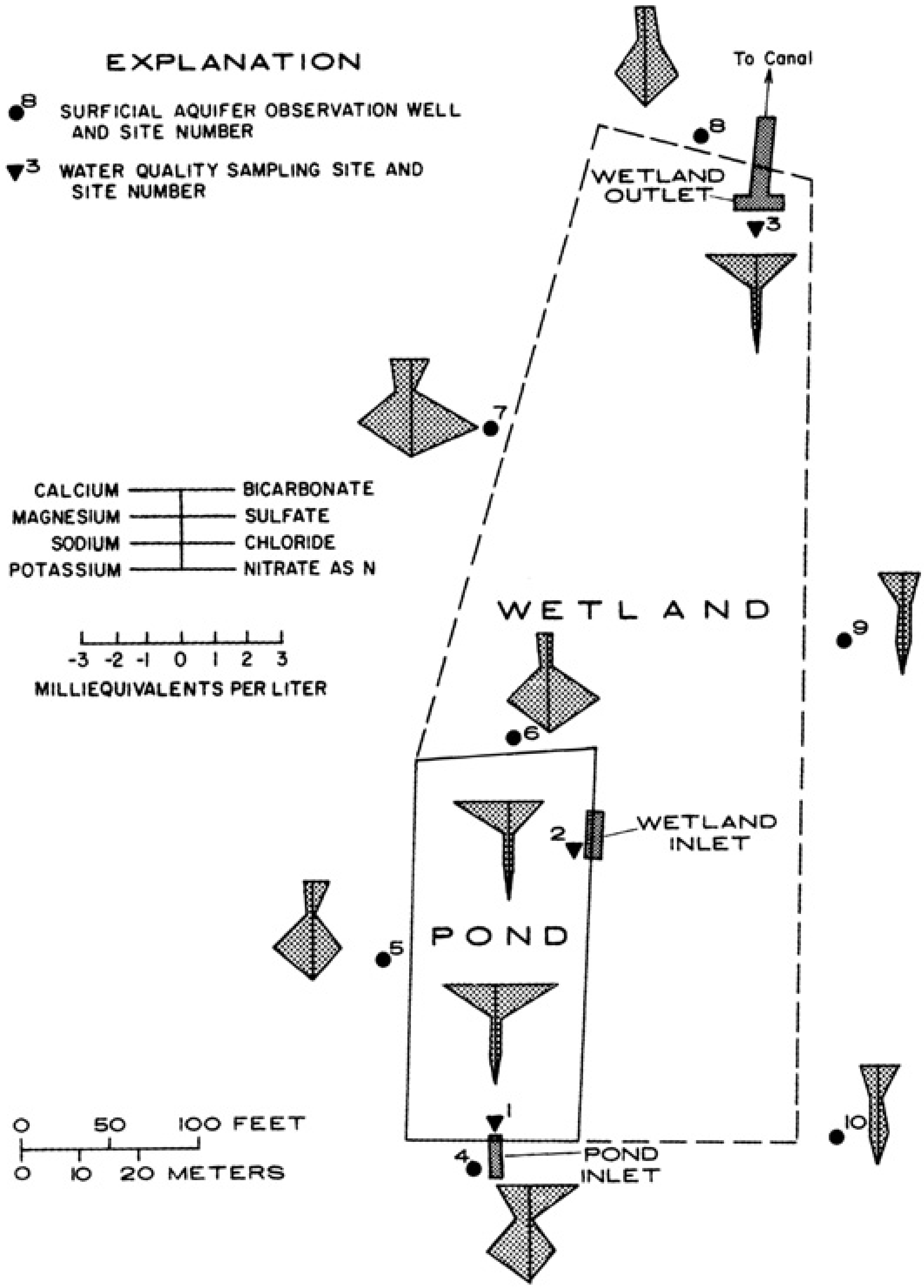

Figure 13.--Stiff diagrams of major dissolved ions in water from the Silver Star Road pond, wetland, and surficial aquifer system.

composition of the pond and wetland surface water sampling sites (sites 1, 2, and 3), which are all predominantly calcium bicarbonate. The ground-water gradient is generally southwest to east-northeast (fig. 2), generally toward the canal adjacent to the wetland. The ionic composition of ground water near the pond, and on the north side of the wetland (sites 5, 6, 7, and 8), differs from that of the surface water, and is predominantly sodium chloride. The increase in sodium and chloride, and the decrease in calcium and bicarbonate from pond and wetland water to ground water may be due to the clayey bottom of the pond. Most runoff is predominantly calcium and bicarbonate in ionic composition, but the clay in the pond bottom may prevent many of the ions in the pond water from migrating into the ground water. The sodium-chloride ions in the ground water are likely representative of ambient ground water unaffected by exfiltrating water from the pond. The ionic composition of ground water on the east side of the wetland (sites 9 and 10) appears significantly different from the ionic composition of the pond, wetland, and other ground water sites, and may reflect effects of seepage of water from the wetland.

Another graphical presentation of ionic data is a Piper diagram (Hem, 1985) (fig. 14). Surface water data (sites 1, 2, and 3) plot consistently together, and ground water data (sites 5, 6, 7 and 8) are similar in plot location. Site 4, the wells closest to the inlet to the pond, shows indications of some influence from the pond; it has a higher percentage of calcium and bicarbonate than the other wells adjacent to the pond. Sites 9 and 10, on the east side of the wetland, plot together, and are more similar to the surface water locations than to ground water sites. This may be indicative of seepage from the wetland into the adjacent canal.

Qualitative analysis of organic compounds

The primary emphasis of this study was the investigation of the impact of inorganic constituents in highway runoff on wetlands. However, water and ground water at the Silver Star Road wetland was sampled once, in 1986, to determine if an organic screening (not a quantitative measurement) would indicate the presence of any organics at the site. A Flame Ionization Detection (FID) scan was completed for water at the wetland outlet, and three ground water wells (sites 4, 6, and 10). The results indicated the possible presence of methylene chloride-extractable organics in ground water at site 6, in the range of 1 to 10 µg/L. These organics could be present because of seepage from the wetland, or could be naturally occurring compounds from other sources. Further study would be necessary to determine occurrence and sources of organics.

Spatial Variation of Constituents in Bed Sediments

Removal of constituents in runoff through the use of detention ponds and wetlands is accomplished largely by the process of sedimentation, with much of the constituent load settling into the bed sediments. Therefore, the sediments in ponds and wetlands act as sinks for many constituents. Sediments in the Silver Star Road detention pond and wetland were sampled three times, at nine locations in the pond and at five locations in the wetland (fig. 2).

It is difficult to assess the significance of the concentrations measured in the sediments, because sediment concentrations can be highly variable, no standards exist for sediments, and no data are available on the sediment concentrations prior to the wetland being used for runoff disposal. The sediment samples in the pond were collected with an Eckman1 dredge, and in the wetland by collecting sediment directly into plastic sample cartons. The sediments were analyzed for nutrient and trace metal concentrations.

Concentrations in sediments are highly variable because of the relation of constituents to particle size and organic carbon content, the uneven distribution of sediment sizes in many bottom samples, and varying conditions of deposition (variation in loads and hydraulic conditions with each storm). Additionally, most of the accumulation of constituents such as heavy metals is at the 0- to 5-cm (centimeter) depth, and

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

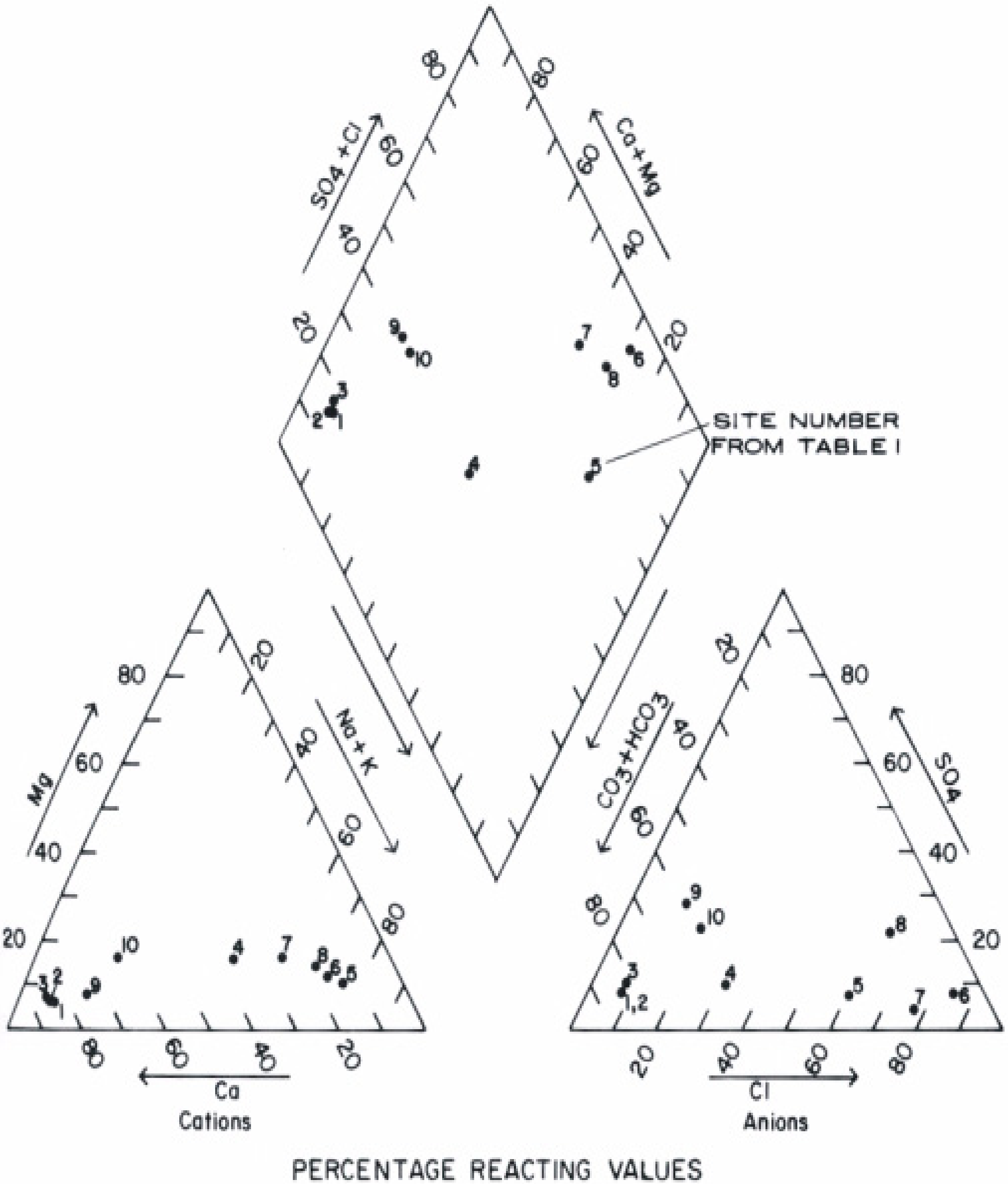

Figure 14.--Piper diagram of ionic composition of ground water near the Silver Star Road detention pond and wetland, and surface water entering and leaving the wetland.

decreases with depth to background concentrations, often within 30 cm. Thus, a sample obtained with an Eckman dredge is more of a composite of sediments, and may represent sediment concentrations for the top 10 cm. These factors affecting the concentrations should be considered when analyzing the data.

Kjeldahl nitrogen was the dominant species of nitrogen present in the soils of the detention pond and wetland, and the distribution of median concentrations is shown in figure 15. Median concentrations were variable and not obviously related to the stormwater flow path, ranging from 1,700 to 14,000 mg/kg (milligrams per kilogram) in the pond, and 690 to 22,000 mg/kg in the wetlands. The maximum Kjeldahl nitrogen concentration measured in pond sediments was 33,000 mg/kg (fig. 2, site 15), whereas in the wetland, the maximum concentration was higher (75,000 mg/kg at site 18), at a location that is not within the flow path of the stormwater entering the wetland, but more in a backwater area of the wetland. Although the maximum concentration occurred at site 18, the minimum concentration and the lowest median value also occurred at this site.

The soils in the pond and wetland are highly organic, and thus more conducive to the formation of soluble organic metal complexes that may migrate down into ground water. Wigington and others (1983) noted that the greatest metal concentrations they measured in three urban runoff detention basins occurred in depressions, marshy areas, basin inlets, basin outlets, and in areas at which the stormwater had the longest residence time. The three basins differed in land use; one basin had predominately residential developments, roads, and open space, the second basin had a large department store and parking lot, and the third basin had mostly roads and parking lots. The authors found the greatest accumulation of copper, cadmium, and zinc (above background levels) in the basin dominated by roads and parking lots.

A marked difference in metals concentrations between the pond sediments and wetland sediments is evident in figures 16, 17, 18, and table 4. Maximum concentrations of lead were 2,000 μg/g (micrograms per gram) at site 15 in the pond, and only 140 μg/g at site 20 in the wetland. Median lead concentrations in the pond ranged from l0 μg/g at site 16 to 1,600 μg/g (along the flow path at site 2), and in the wetland from 10 to 40 μg/g. Zinc concentrations were lower than lead, because of the solubility of zinc, but the concentrations were also notably lower in the wetland as they were for lead. The maximum zinc concentration in the pond was 1,100 μg/g (site 2, outlet of pond) and in the wetland, 170 μg/g (site 20). Although median chromium values also were lower in the wetland, the concentrations of chromium were much lower than the other two metals, with a maximum value of 240 μg/g at site 12 (pond) and 60 μg/g at sites 20 and 21 (wetland). Copper, not shown, was present in lower concentrations than chromium, and ranged from 1 to 130 μg/g in the pond and 1 to 50 μg/g in the wetland. The maximum copper value in the pond was at site 14, and in the wetland, site 20.

The median values of lead, zinc, and chromium in the wetland are similar to values obtained in bed sediments from 35 lakes and rivers in florida during a reconnaissance in 1977 as part of the U.S. Geological Survey and South Florida Water Management District Water Quality Network (B.F. McPherson, U.S. Geological Survey, written commun., 1977). However, the maximum values measured in the pond and wetland are much higher than the maximum values from this reconnaissance (table 4). Kjeldahl nitrogen was often as high in the sediments of the 35 lakes and rivers as in the Silver Star Road pond and wetland, so it is likely that these concentrations are not necessarily strictly related to runoff. The maximum metals concentrations were always at sites along the flow path through the pond and wetland.

Distribution of Constituents by Sampling Medium

Determining the distribution of constituents by sampling medium (surface water, ground water, and sediments) may help to understand the fate of these highway runoff constituents. Although not directly comparable, concentrations in sediments, surface water, and ground water may be considered in units of parts per million, to understand relative amounts in each medium. Median values

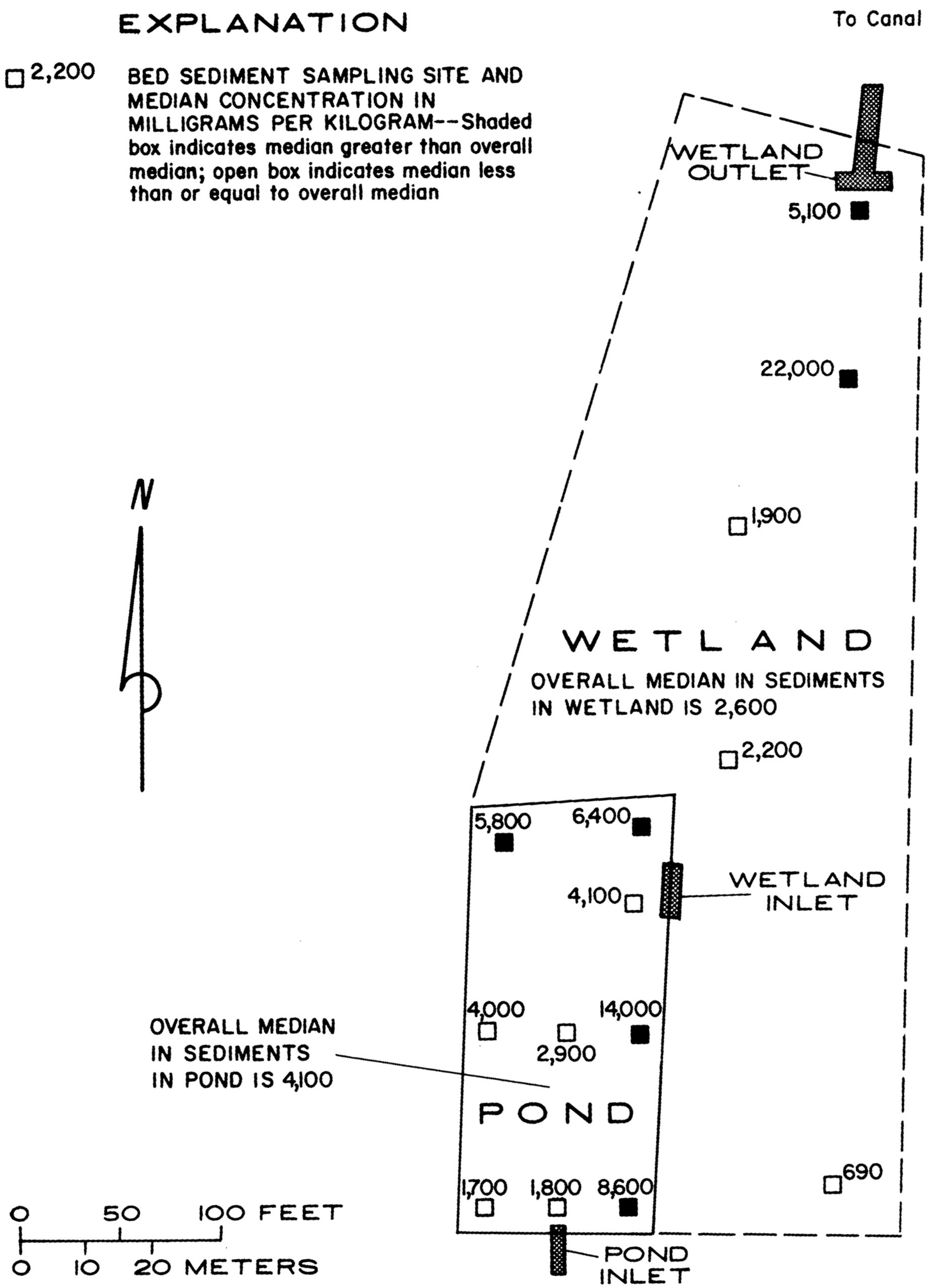

Figure 15.--Distribution of median values of total Kjeldahl nitrogen in bed sediments

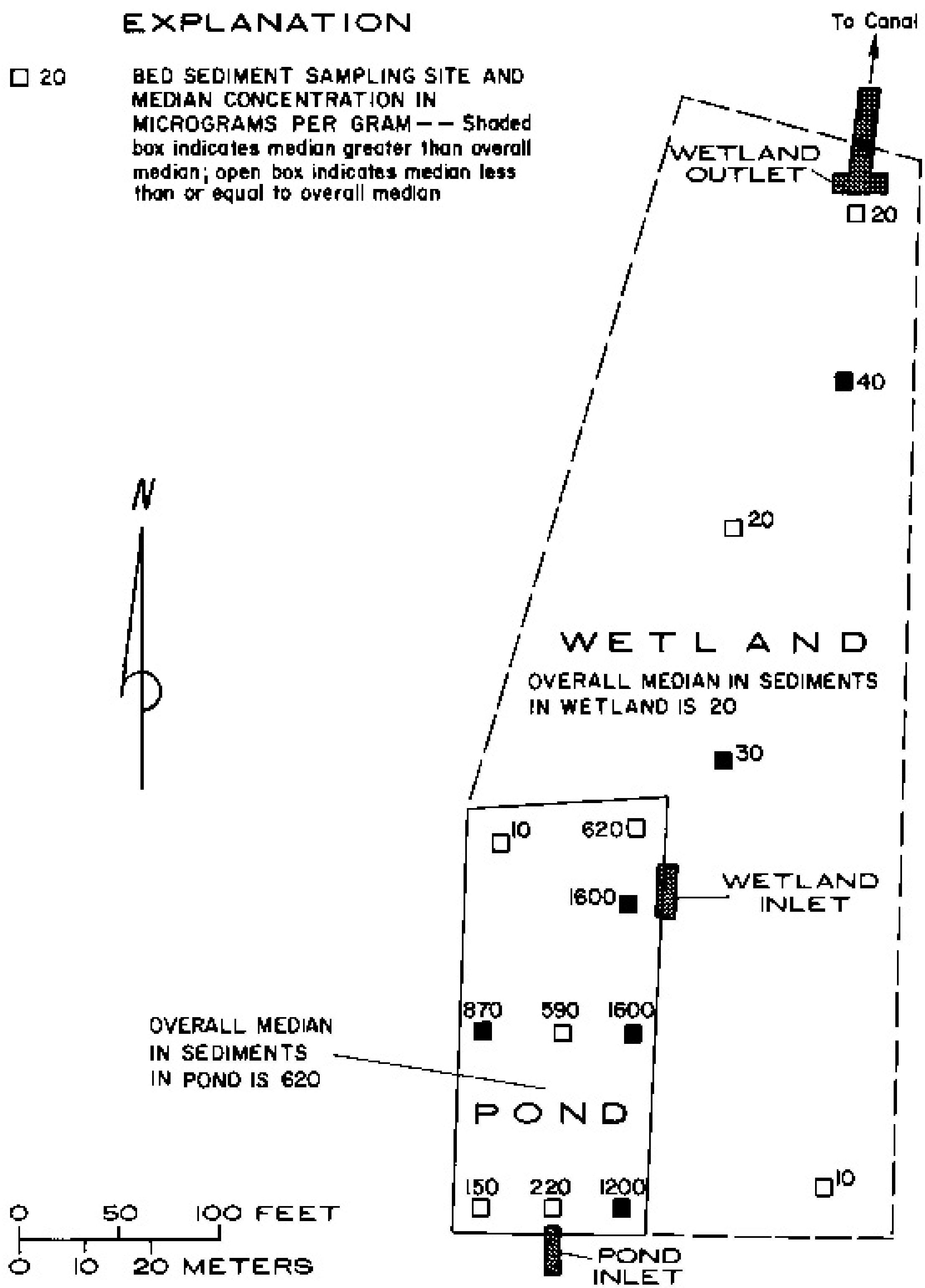

Figure 16.--Distribution of median values of lead in bed sediments at the Silver Star Road study area.

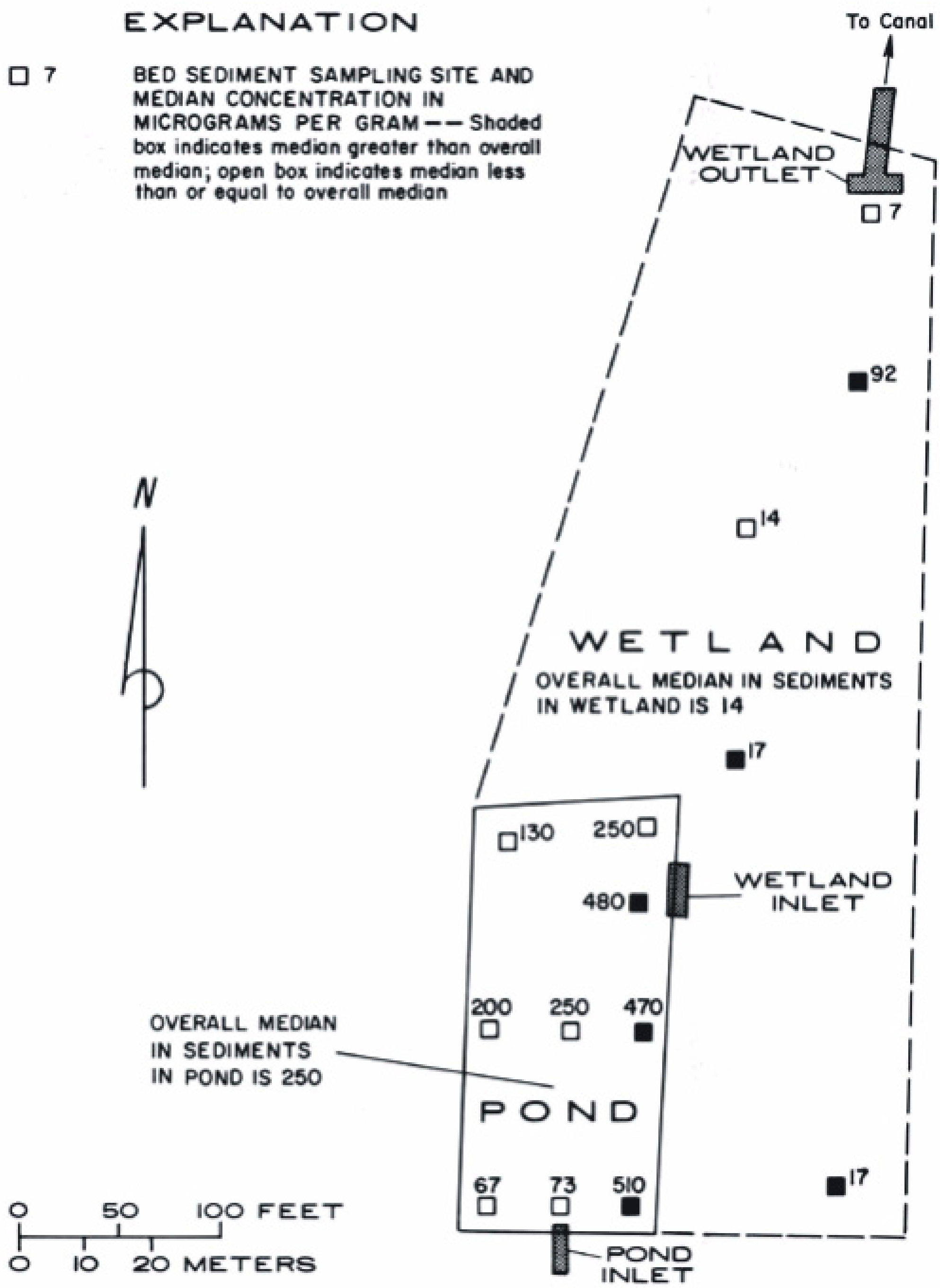

Figure 17.--Distribution of median values of zinc in bed sediments at the Silver Star Road study area.

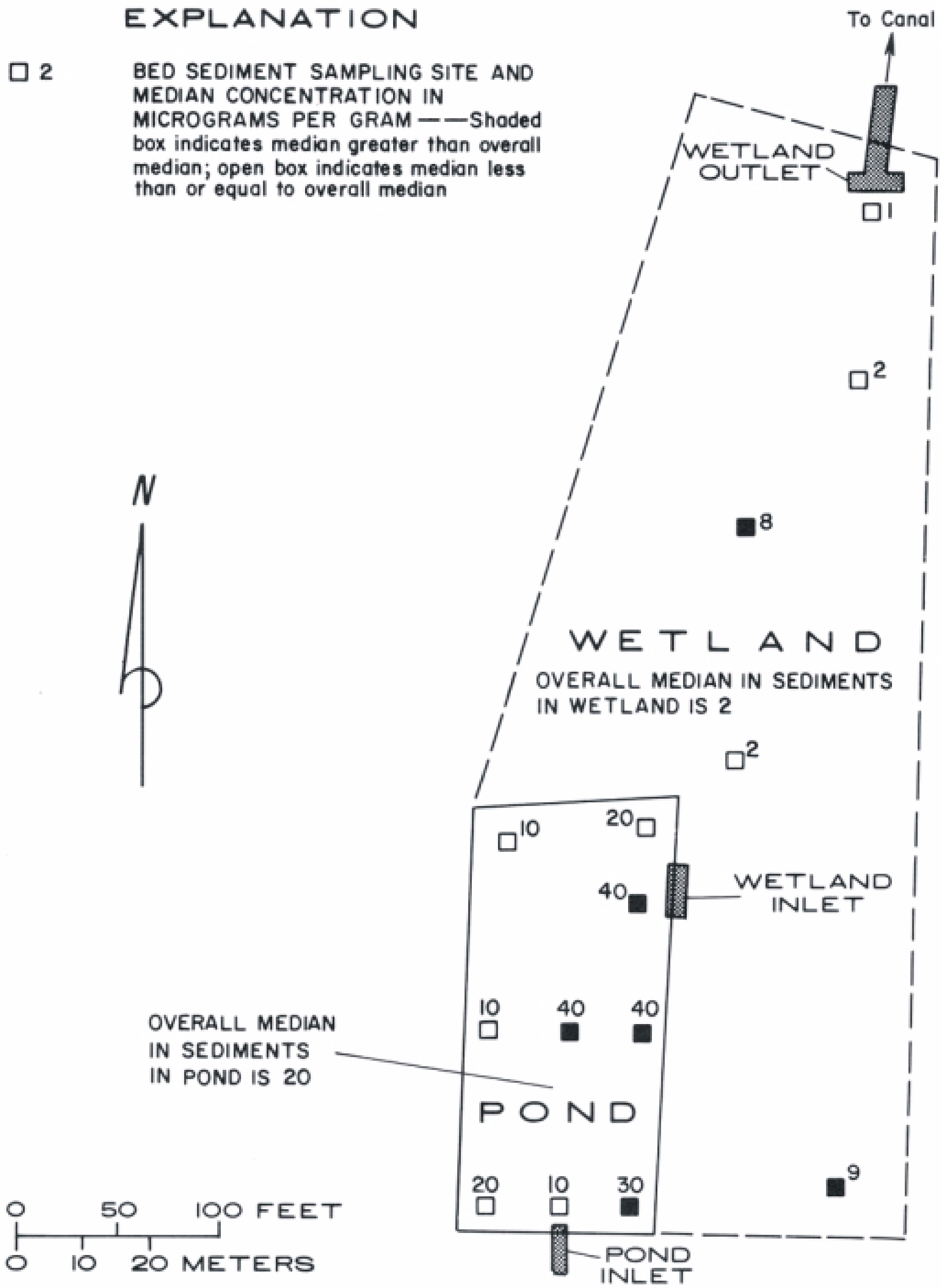

Figure 18.--Distribution of median values of chromium in bed sediments at the Silver Star Road study area.

Table 4.--Minimum and maximum concentrations of selected metals in bed sediments, Silver Star Road detention pond and wetland, and minimum and maximum concentrations reconnaissance of 35 Florida lakes and streams

[All concentrations are in units of micrograms per gram]

Site	Chromium		Copper		Lead		Zinc	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Pond								
1	2	230	2	110	10	1,700	5	490
2	10	220	45	110	750	1,700	360	1,100
11	3	130	1	41	10	620	1	270
12	6	240	10	100	10	1,800	48	590
13	10	220	23	110	410	1,400	190	510
14	10	220	27	130	340	1,600	150	450
15	10	230	49	120	600	2,000	240	1,000
16	2	210	1	110	10	1,700	4	460
17	20	210	26	100	20	1,600	110	430
Wetland								
18	1	20	1	6	10	80	2	39
19	2	40	3	5	10	70	7	43
20	1	60	1	50	10	140	4	170
21	1	60	2	38	20	120	11	120
3	1	10		10	10	30	5	14
Lakes and streams in Florida[1]								
	<10	20	<10	20	<10	620	<10	170

[1]B. F. McPherson, U. S. Geological Survey, written commun., 1977.

for selected constituents in the water and sediments of the detention pond and wetland, and in the ground water, are listed for comparison in table 5. Because of the groups that were observed from plots of ionic composition (figs. 13 and 14) in ground water sites, these sites were grouped separately for table 5. Some differences are seen in the median values, specifically for ammonia, Kjeldahl nitrogen, total organic carbon, and iron.

Median values of specific conductance did not differ significantly among the pond inlet, wetland outlet and in ground water adjacent to the wetland, but was slightly higher (206 µS/cm at 25°C) in ground water near the pond. Other constituents were similar in median values at the three surface water locations, but lead and zinc both decreased through the system, as was reported in Martin and Smoot's report (1986). The greatest differences in values in table 5 are between concentrations in pond sediments and wetland sediments, and between concentrations in bed sediments and in the water column.

In most aquatic systems, concentrations of metals in sediments are many times greater than the concentrations in the water column (Horowitz, 1984). The sediments serve as a reservoir that, under changing environmental conditions, can release metals back to the water column. For this reason, the accumulation of metals in sediments can be a source of severe water quality problems and a matter of concern to those responsible for maintenance of stormwater systems. In table 5, nutrients and metals are shown to have hundreds to thousands of times

Table 5.--Distribution of selected constituents in water sediments ground water at Silver Star Road study area

[Median values in parts per million--corresponding to mg/L for water samples and mg/L or µg/L for sediment samples. Total concentration in water column samples, dissolved concentration in ground water samples. Number of samples indicated in parentheses]

Constituent	Water column			Sediments		Ground water	
	Pond inlet	Wetland inlet	Wetland outlet	Pond (27)	Wetlands (15)	Around pond (wells 4-6) (6)	Around wetland (wells 7&8) (4)
Specific conductance	145 (61)	144 (52)	153 (18)	--	--	206	155
pH-lab	7.2 (51)	7.1 (48)	6.9 (25)	--	--	5.8	6.2
Ammonia nitrogen	.8 (44)	.2 (42)	.4 (24)	92	14	.36	2.15
Nitrogen, ammonia plus organic	1.10 (45)	1 (43)	.85 (25)	4,100	2,600	1.65	5.3
Nitrogen, nitrate plus nitrite	.10 (44)	.10 (42)	.10 (24)	9	6	.06	.05
Phosphorus	.06 (44)	.10 (42)	.08 (24)	1,100	260	.06	.02
Total organic carbon	15 (46)	15 (44)	15 (19)	--	--	19	39
Cadmium	[1]<.001(28)	[1]<.001 (25)	<.002 (17)	<6	<1	00	--
Chromium	.003 (26)	[1]<.001 (23)	<.002 (16)	20	2	[1]<.001	[1]<.001
Copper	.01 (31)	[1]<.01 (25)	[1]<.01 (17)	49	3	[1]<.001	[1]<.001
Iron	--	--	--	4,400	640	1.7	9.85
Lead	.034 (48)	.026 (47)	.010 (30)	620	20	.0015	.001
Zinc	.06 (50)	.05 (46)	.03 (29)	250	14	.026	.032

[1]Detection level

higher concentrations in the sediments than in the water column or ground water. The removal of constituents from the water column prior to discharging to a receiving water body comes at the price of accumulation in sediments.

Water quality and sediment quality in the Silver Star Road wetland benefit from the settling of particulate matter in runoff in the detention pond. This is most apparent in the contrast of concentrations in bed sediment. If the highway runoff entered a wetland directly, it is likely that constituent concentrations in wetland sediments would be similar to those measured in the pond sediments at Silver Star Road. This is more the case at the second study location, Island Lake wetland, where a very small detention area (the trash retainer) provides minimal or no detention of the runoff before it enters the wetland. The difference in the sediment and water quality of the two wetlands will be contrasted with consideration of this difference in configuration of each wetland.

Island Lake Wetland

Water Quality

Water-quality samples were collected from remote locations (fig. 5) on February 12, 1986, (1 day after samples were collected with automatic sampling equipment at the inlet for the dry-season storm), and on September 3, 1986 (6 days after samples were collected with automatic sampling equipment at the inlet for the wet-season storm). The September 3, 1986, sampling followed a weekend of heavy rainfall, including 1.06 inches on

August 28, when samples were collected at the inlet, and 2.08 more inches between August 28 and August 30. Additional samples were collected from the remote sites, inlet, and the outlet, on August 21, 1985 (rainfall of 0.65 inch on August 20) and January 15, 1986 (4.73 inches on January 10).

Water-quality monitoring at the inlet and outlet

A water-quality monitor was used for continuous monitoring of temperature, specific conductance, and dissolved oxygen (DO) at the wetland inlet after July 1985, but a monitor was not installed at the outlet until June 1986. The inlet monitor was located at the southeast corner of the water inlet trash retainer, in the overflow path, and the outlet monitor was located in the flow path of water leaving the wetland. The stage at the inlet responded rapidly to runoff, rising to a maximum within 10 minutes or less. This made manual sampling of the runoff nearly impossible, and automatic sampling difficult. At least one sample was collected on the rising leg of the storm hydrograph with automatic sampling equipment for the two storms sampled.

Water-quality monitor data from the inlet for the February 11 storm (0.18 inch of rainfall) are shown in figure 19. Three discrete samples were automatically collected for this storm, and remote sites (1 through 9) and the outlet were sampled on February 12. DO reacted rapidly to the rise in stage, rising almost 6 mg/L (milligrams per liter) almost immediately. Some response is evident in specific conductance and in temperature, but not as much as the DO. The stage in the trash retainer decreases rapidly, because of the lack of any backwater effects from the wetland.

Inlet and outlet water-quality data obtained during a period of heavy rainfall in August and September of 1986 are illustrated in figure 20. The plot of stage indicates six separate storms during the last 4 days of August. The larger storms, causing a rise in stage of about 0.8 to 1.0 foot, caused noticeable decreases in temperature, specific conductance, and a rise in DO. The response at the outlet, at the time scale shown, seems to be occurring just before, or at the same time as the inlet response. This may be because of the direct rainfall on the water surface of the wetland causing an almost immediate response at the outlet, or possibly some short-circuiting through the wetland from the inlet to the outlet. Diurnal fluctuations in temperature and DO (inversely related to temperature) are also seen in figure 20. The rise in DO during a storm is caused by the higher DO of the runoff, and turbulence. Temperature and specific conductance gradually increase after a storm at both the inlet and outlet. This rise in specific conductance after a storm was also observed in the Silver Star Road detention pond, as well as the decrease with incoming runoff. The rise may be caused by ground-water seepage into the trash retainer at the Island Lake wetland, and into the pond at Silver Star Road. However, the naturally occurring clay at the Silver Star Road pond restricts interchange of water between the pond and surrounding ground water, so evaporation may also contribute to the rise in specific conductance.

Inlet and outlet water-quality data for extended time periods may indicate characteristics of the wetland by observation of response to long dry periods as well as isolated storms. Diurnal fluctuations again are evident in the plots of temperature and DO in figures 21 and 22. Flow out of the inlet trash retainer stops completely a short time after most storms, after which, the water level in the trash retainer is probably affected only by evaporation and some ground-water seepage. DO is higher at the inlet during storms, but higher at the outlet between storms, possibly because the water is moving at the outlet (leaving the wetland) rather than stagnant as at the inlet between storms. Specific conductance at the outlet shows less variation than at the inlet because the water at the outlet is from the entire wetland--a composite of the highway runoff, direct rainfall (of lower conductance) on the surface of the wetland, and ground-water inflow. The effect of individual storms, on specific conductance is attenuated by the large storage volume available in the wetland. Periods of heavy rainfall produce less of a decline in specific conductance at the outlet than at the inlet, and less of a rise during dry periods between storms.

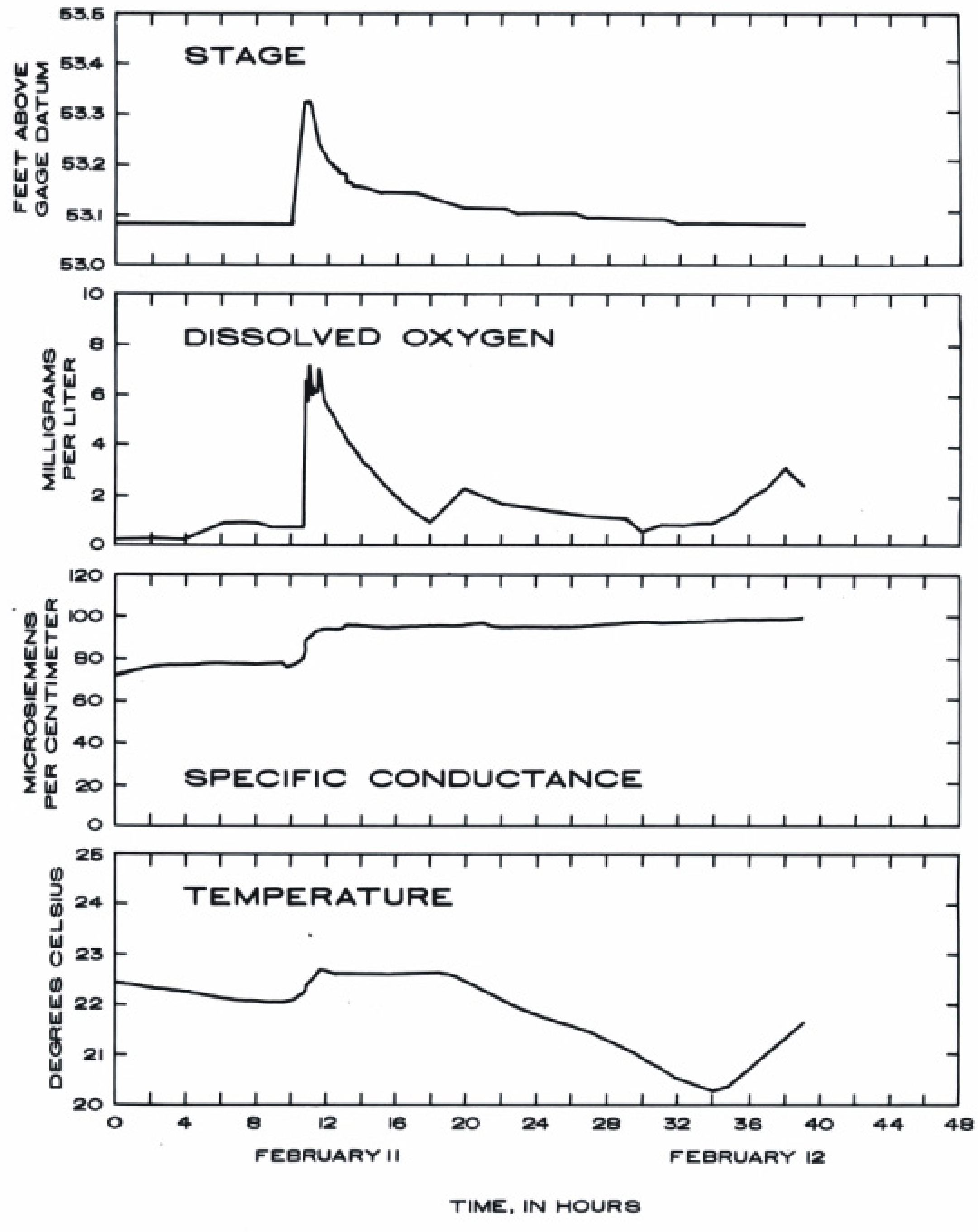

Figure 19.--Stage and selected water-quality data at the Island Lake wetland for the storm period February 11-12, 1986.

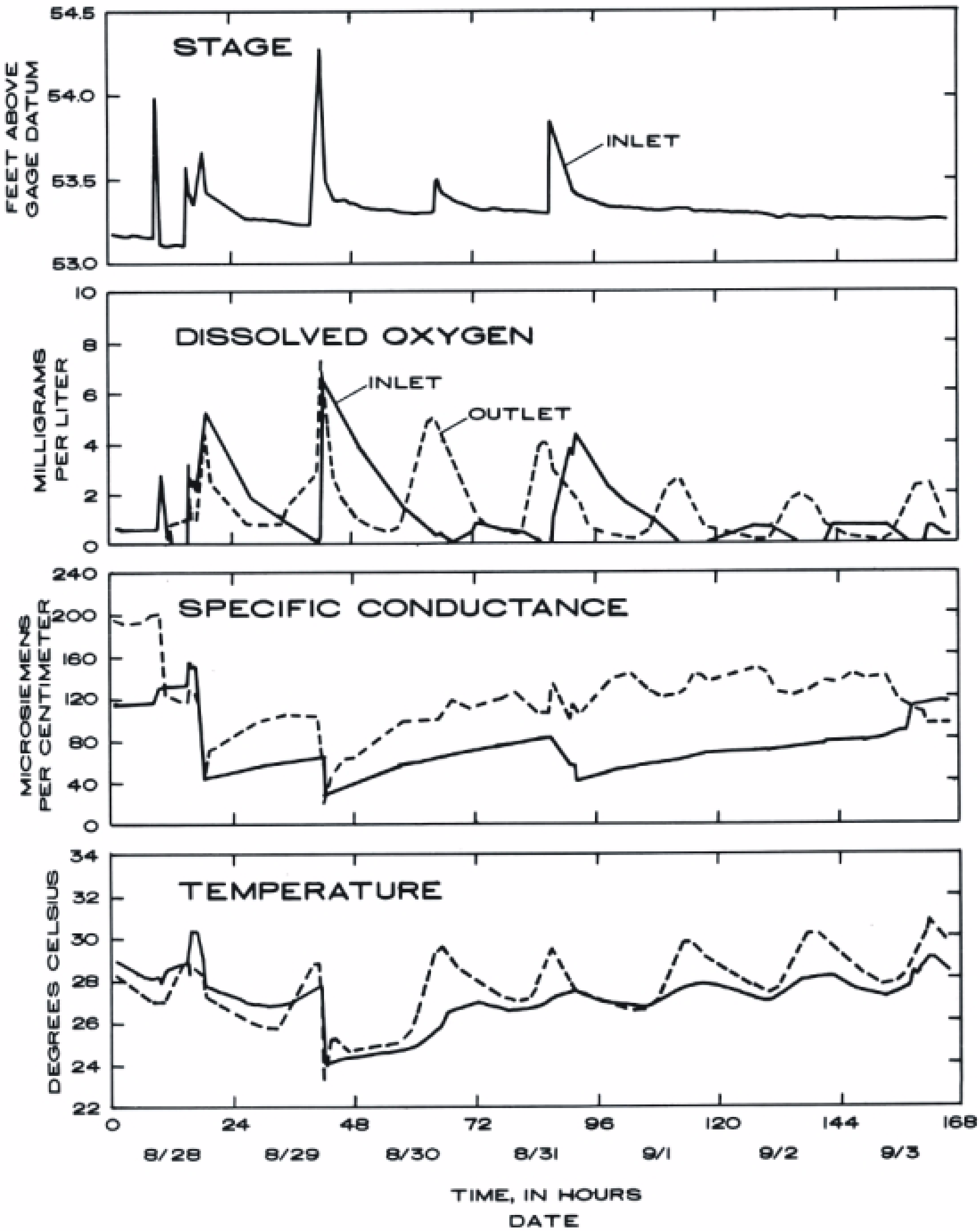

Figure 20.--Stage and selected water-quality data at the Island Lake wetland for the storm period August 28 through September 3, 1986.

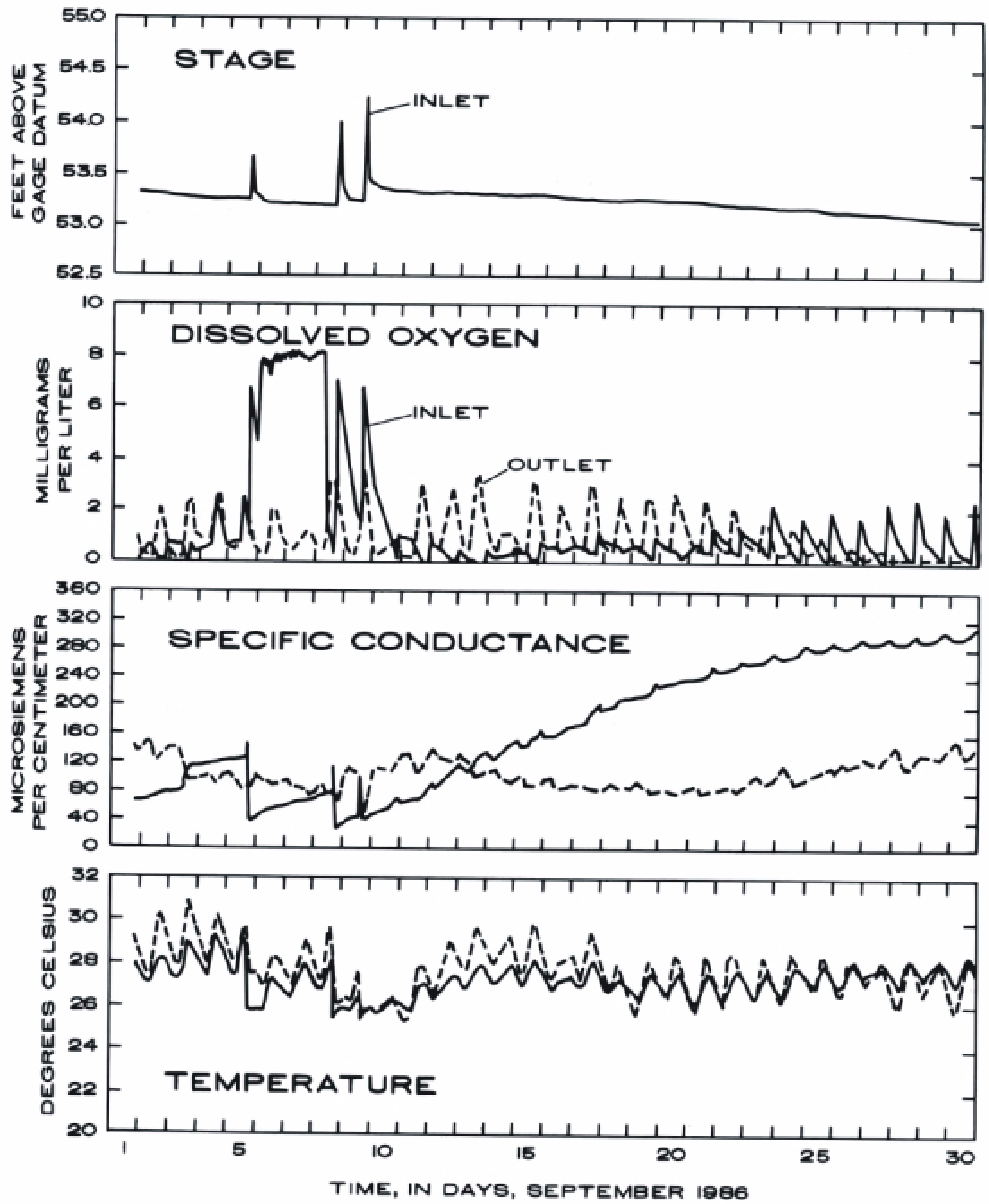

Figure 21.--Stage and selected water-quality data at the Island Lake wetland for the storm period September 1-30, 1986.

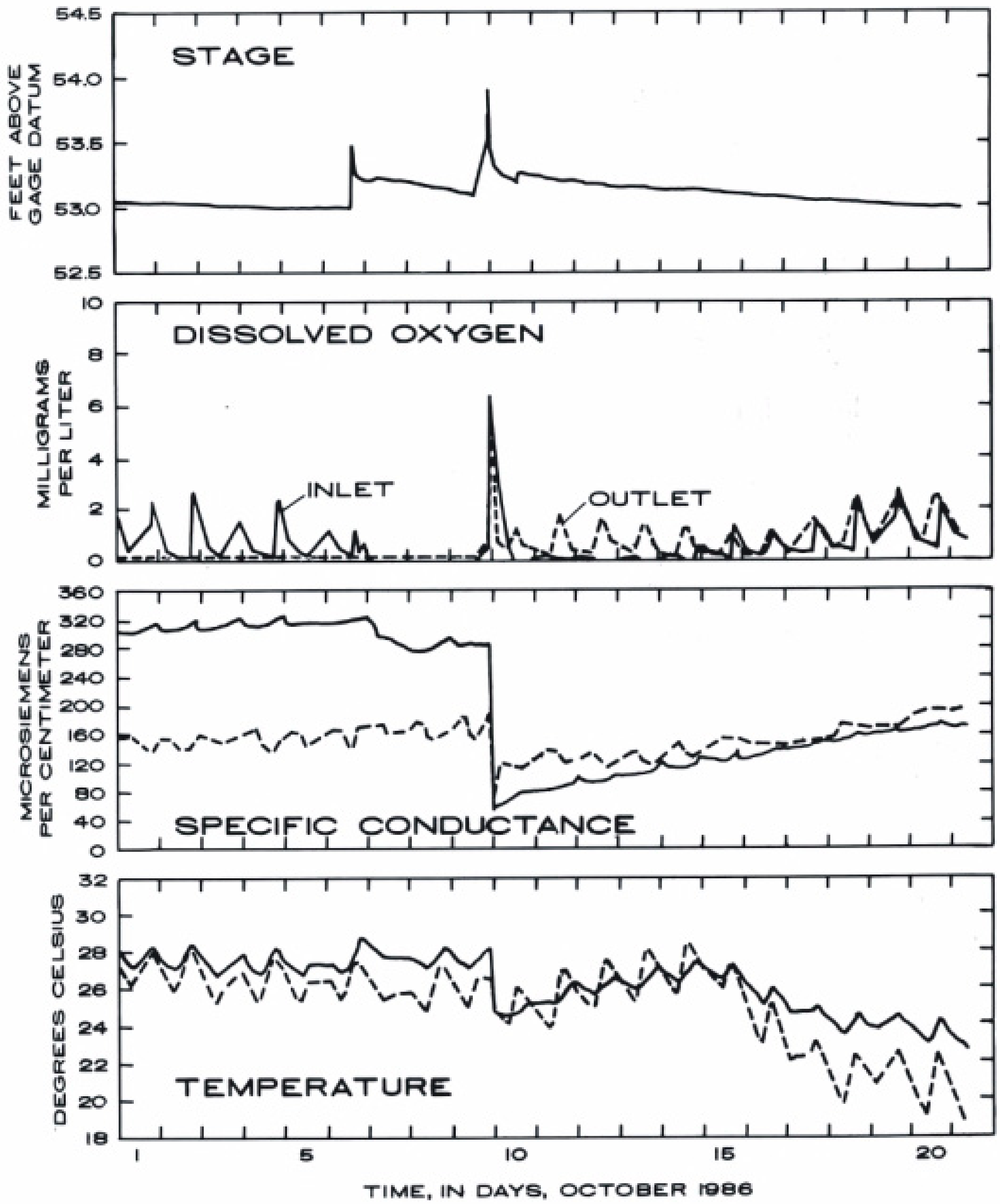

Figure 22.--Stage and selected water-quality data at the Island Lake wetland for the storm period October 1-21, 1986.

Spatial variation in water quality in the wetland

Nine remote sites (1 through 9) located at points of interest varying with distance from the stormwater inlet to the wetland (fig. 5) were sampled three to four times during the study. Plots of concentrations of selected constituents at these sites are shown in figures 23 through 27. Low water at some sites prevented the collection of a sample at certain times, and only sites on the middle lateral (sites 4, 5, and 6) were sampled on January 15, 1986.

Sites are arranged in order of distance from the inlet, with the outlet as the furthest distance. Sites 1, 4, and 7 (near sites) are 23 to 35 feet from the berm of the inlet detention area. Sites 2, 5, and 8 (intermediate sites) are 81 feet to 106 feet from the berm, but still in an area heavily vegetated with willows; and sites 3, 6, and 9 (far sites) are 221 to 254 feet from the inlet berm, in an area that is typical of most of the wetland area and characterized by plants in the grass and sedge families. Sites 3, 6, and 9 were located at a distance that should represent the natural wetland, away from the influence of the highway runoff.

Most of the nitrogen in water from sampled sites was in the organic form, but a greater percentage of the total nitrogen was in the ammonia form at sites 1, 4, 7 (all sites near the inlet), and 10 (inlet). Total ammonia nitrogen increased from the inlet to site 7, then decreased with distance after that (fig. 23). Ammonia may be decreasing as the water progresses through the wetland because of bacterial or plant uptake. Maximum values of total Kjeldahl nitrogen (TKN), or ammonia plus organic nitrogen, occurred after a period of heavy rainfall during the rainy season (September 3, 1986). TKN values did not appear to vary much from inlet to outlet for the other three sampling times.

Total phosphorus and orthophosphorus concentrations for the four sampling times are shown in figure 24. Most of the phosphorus is inorganic except at the inlet. The maximum phosphorus concentration at the inlet was 0.26 mg/L, and at the outlet, 0.04 mg/L. The decrease in concentrations of phosphorus and orthophosphorus is much more pronounced between near sites (1, 4, and 7) and intermediate sites (2, 5, and 8) than between intermediate sites and far sites (3, 6, and 9) and the outlet. The phosphorus concentrations appear to reach a stable level, possibly background concentrations, before the water reaches the edge of the heavily vegetated area (106 feet maximum).

Specific conductance and turbidity are physical properties that indicate dissolved solids and suspended solids, respectively, in the water column. If specific conductance decreases, it may be a result of dilution by storm runoff. A decrease in turbidity may be associated with the sedimentation process. Specific conductance and turbidity values obtained at sites at Island Lake wetlands are shown in figure 25. Turbidity values were low, and followed the same general pattern as phosphorus, decreasing with distance. Specific conductance was consistently high at site 7, but conductivity returned to background levels at sites 2, 5, and 8. Specific conductance was higher at sites near the inlet than at the inlet (site 10).

Alkalinity and dissolved calcium are shown in figure 26. The distribution of calcium and alkalinity are very similar to each other, and each of the two to specific conductance. Low alkalinity is normal in an acidic wetland environment. Stormwater entering the wetland is usually more alkaline than the receiving environment, and causes a rise in alkalinity at sites near the inlet. This effect does not extend to the intermediate sites (2, 5, and 8). Specific conductance, alkalinity, calcium, and nitrogen were frequently higher at site 7 than at other sites. Water at this site and site 8 may have originated partially from an adjacent commercial area to the west that may have used fertilizers on grassed areas near the wetlands.

The largest change in concentrations occurred consistently from the near sites (1, 4, and 7) and the inlet, to intermediate sites (2, 5, and 8). Constituent concentrations at intermediate sites, far sites, and the outlet generally were similar. The only exception to this might be water from site 8, on the western lateral (sites 7, 8, and 9), at which values of phosphorus, ammonia, calcium, alkalinity, and specific conductance were higher in February 1986 samples.

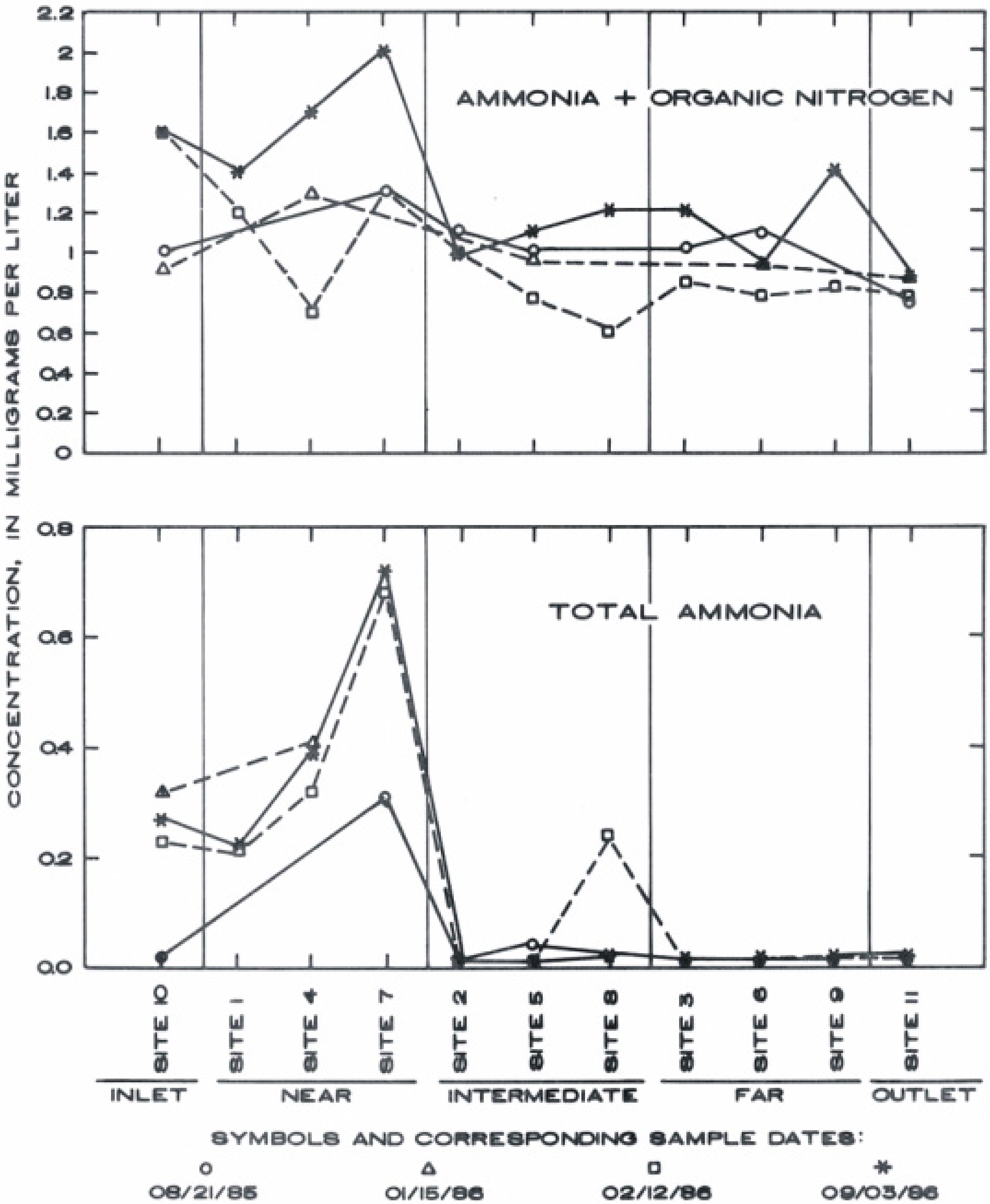

Figure 23.--Total ammonia and total Kjeldahl (ammonia plus organic) nitrogen at sampling sites at the Island Lake wetland.

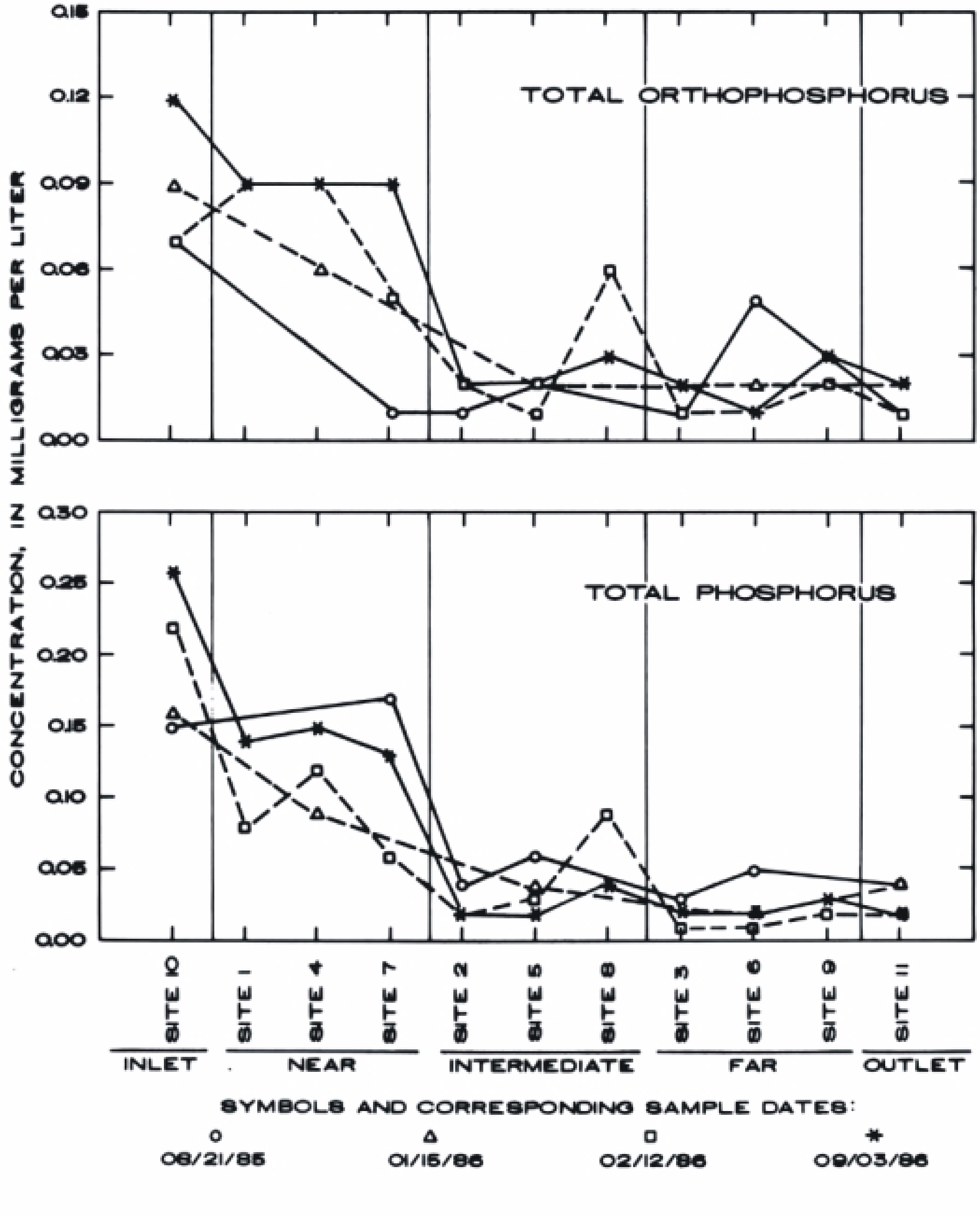

Figure 24.--Total phosphorus and total orthophosphorus concentrations at sampling sites at the Island Lake wetland.

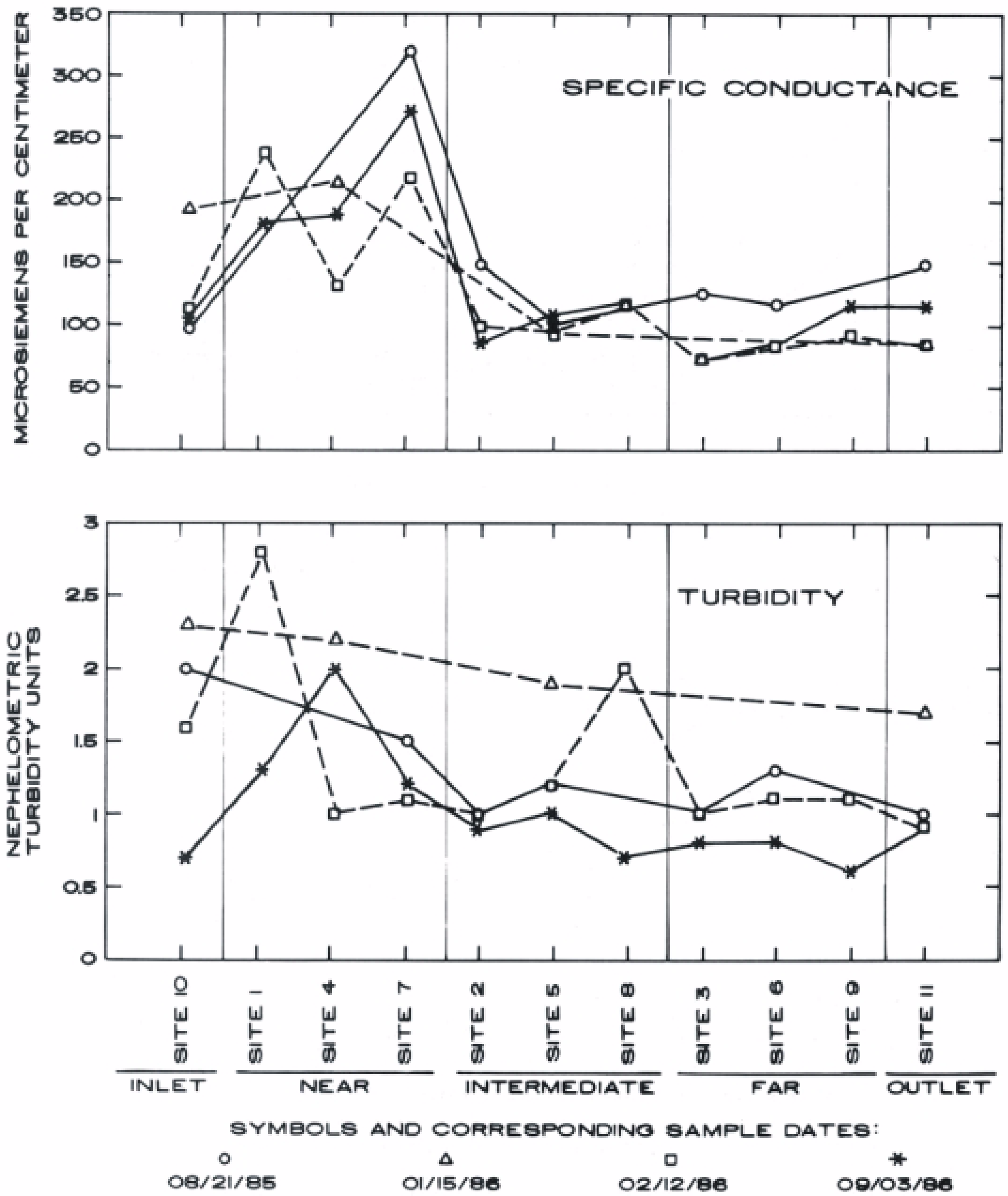

Figure 25.--Specific conductance and turbidity of water from sampling sites at the Island Lake wetland.

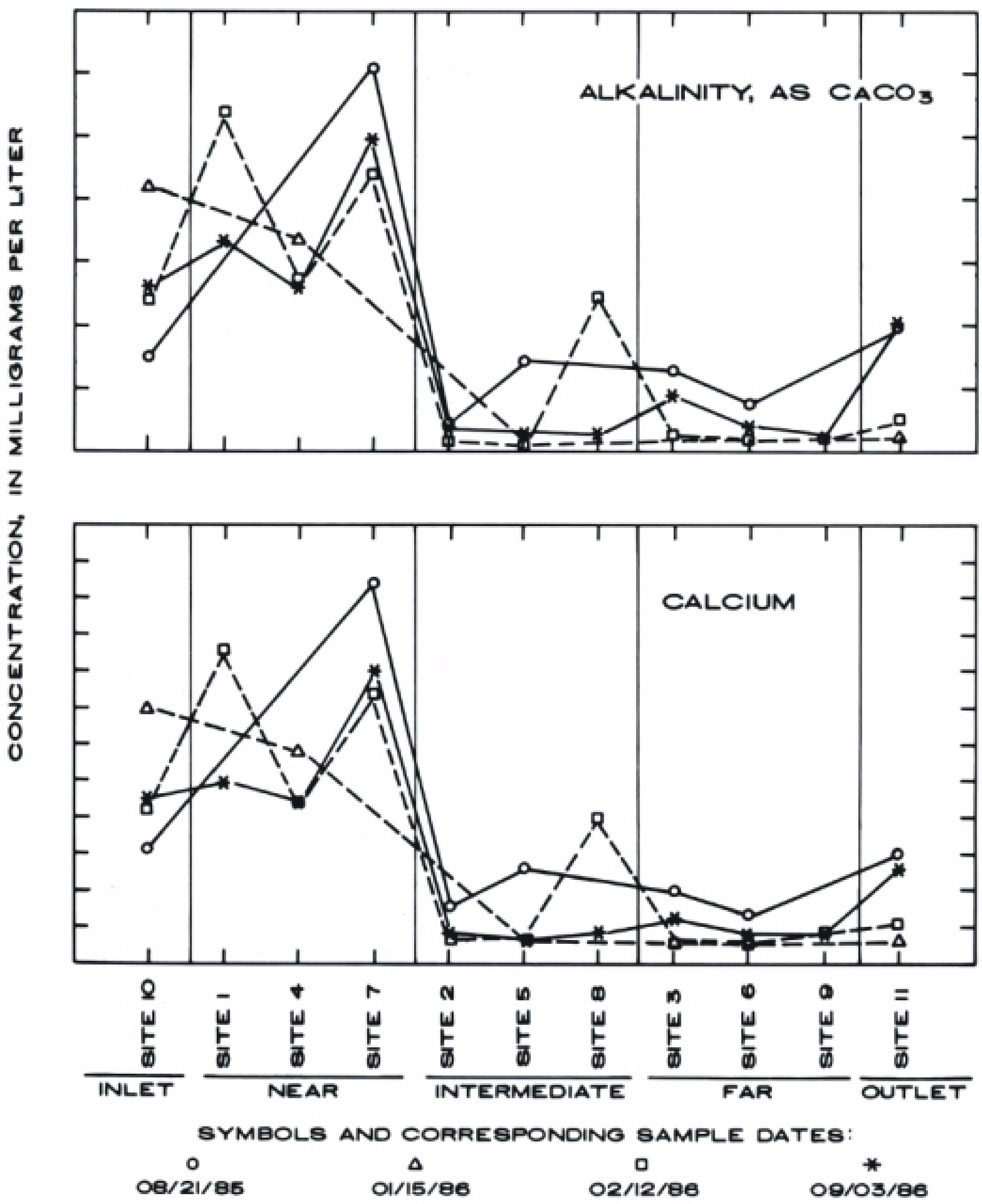

Figure 26.--Dissolved calcium and alkalinity at sampling sites at the Island Lake wetland.

The alkalinity and calcium data may indicate short circuiting during summer months when the wetlands are fuller. This is indicated by the relatively high alkalinity and calcium at the outlet for the August and September samples, and the similarity in magnitude of inlet and outlet concentrations. In the January and February samples, when presumably the wetland water levels are low, alkalinity and calcium values were lower than in the August and September samples--an indication that short-circuiting is not occurring during these dry season months.

Aluminum, cadmium, chromium, copper, iron, lead, nickel, and zinc concentrations were measured at the inlet, outlet, and remote sites at the Island Lake wetland. Chromium and zinc concentrations are shown in figure 27. Maximum values of chromium at most sites were measured in the February 12,1986, samples. In general, the dry season samples contained higher chromium concentrations than wet season samples. The pattern of decreasing concentrations with distance from the inlet was not observed in the data for chromium, although inlet concentrations were generally higher than downgradient concentrations. Most of the chromium in water at Island Lake wetland is in the particulate form.

Chromium concentrations in water unaffected by waste disposal are commonly less than 10 μg/L (Hem, 1985). A study referenced in Hem (1985, p. 138) found that chromium concentrations exceeded 5 μg/L in only 11 samples out of more than 720 samples of surface waters nationwide. Chromium concentrations were greater than 10 μg/L in 20 percent of all samples collected at Island Lake (9 of 46). One source of chromium is metal plating, which may be associated with automobiles, and another is yellow pigment used in road striping.

In a study of 13 surface-water sites in the Reedy Creek Improvement District, southwest of Orlando, Fla., the maximum chromium concentration measured was 30 μg/L, and 95 percent of 53 samples collected at these sites were less than 20 μg/L (German, 1986, p. 47). With the exception of the maximum values measured at the inlet for zinc (from automatic sampling) and two other values, one at site 4 (80 μg/L), and one atsite 6 (90 μg/L), zinc concentrations were generally less than 40 μg/L, and did not vary significantly with distance from the storm inlet, or with season.

Areal variability in water quality in the Island Lake wetland was also identified with plots of major ionic composition of water at all sites (figs. 28 and 29). Near sites (1, 4, and 7), are similar in calcium and bicarbonate concentrations, but differ slightly in sodium and chloride content. Sites 2, 3, 5, and 6 are similar, but sites 8 and 9 on the western lateral are slightly different, particularly site 8 with respect to calcium and bicarbonate content. Water entering the wetland from the trash retainer (inlet) is mainly calcium bicarbonate in ionic composition, and gradually evolves to a sodium chloride water as the water moves away from the inlet and into the wetland. The outlet appears to be a mixture of water, and appears most similar to site 8.

The trend of increasing chloride content and decreasing calcium content is evident in the progression of points plotted in figure 29 (Piper diagram). Near sites (1, 4, 7), and the inlet (site 10) are located in the left corners of the cation and anion triangles; sites 3, 8, and 11 are more equally mixed; and sites 2, 5, 6, and 9 are located more to the right in both triangles. Again, the outlet water (site 11) appears most similar to site 8, which plots nearby in all three Piper triangles.

Statistical analysis of water-quality data

Water-quality data were analyzed statistically to further evaluate the areal distribution of constituents and the effect of highway runoff on the Island Lake wetland. Analysis included statistical summaries (minimum, maximum, mean, and median values at each sampling site, already utilized for figs. 23 through 29); analysis of variance (ANOVA), to detect significant differences among sampling sites that would indicate changes occurring with distance from the inlet; and multiple comparisons, to identify what sites were higher or lower in concentrations

Water-quality data are often not normally distributed, so the statistical analysis must either be nonparametric, that is, not distribution (specifically, normal) dependent, or the data must be transformed to approximate a normal distribution before using traditional parametric

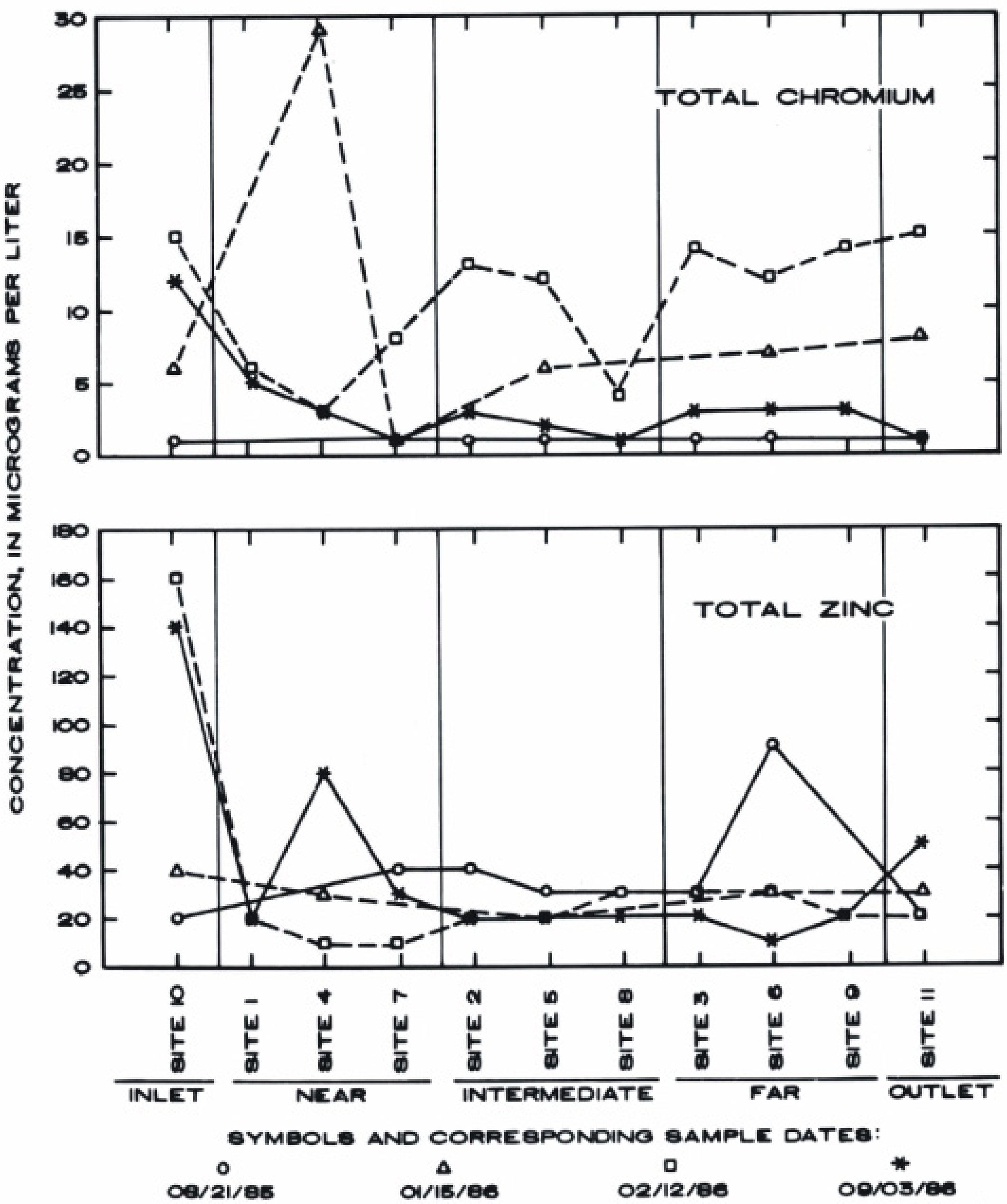

Figure 27.--Total zinc and total chromium concentrations in water at sampling sites at the Island Lake wetland.

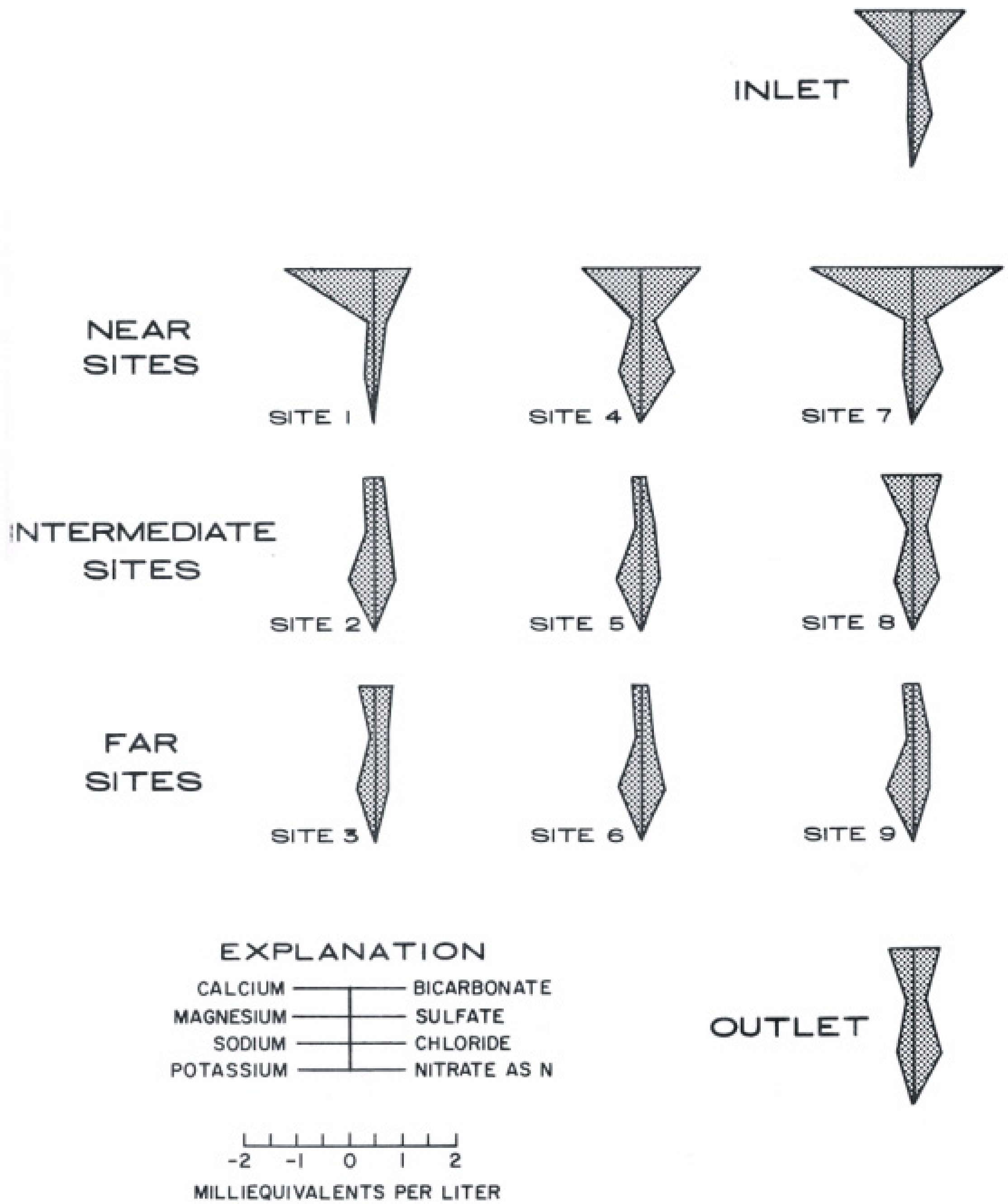

Figure 28.--Stiff diagrams of major dissolved ions in water at sites at the Island Lake wetland. (Median values.)

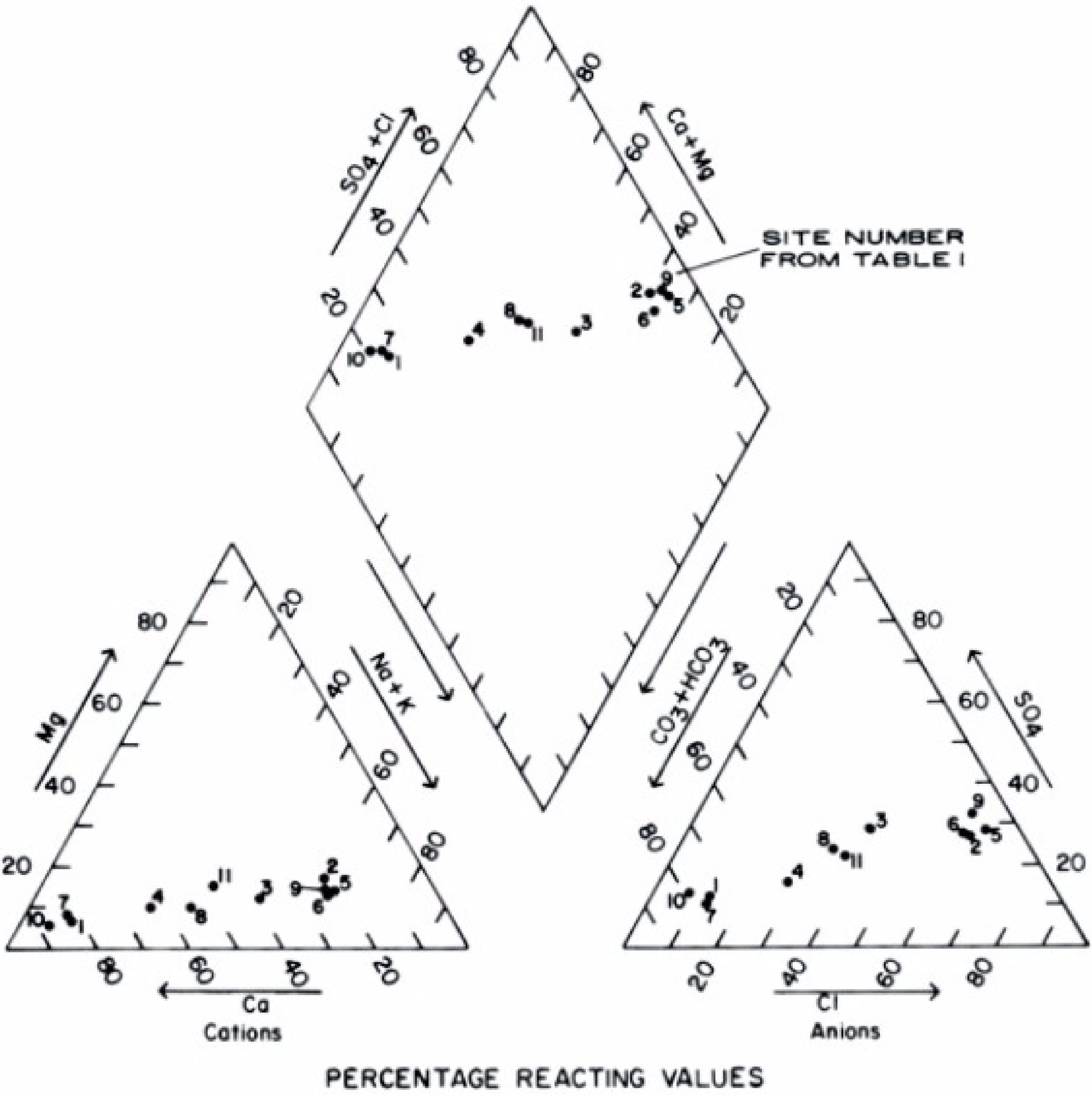

Figure 29.--Piper diagram of major ions in water from sites at the Island Lake wetland. (Median values)

techniques. Helsel (1983) converted data to ranks before using parametric statistics to analyze data, and that procedure was followed in this study. The Statistical Analysis System (SAS) procedure RANK was used for ranking values, and the procedure General Linear Models (GLM) was used for ANOVA, with the TUKEY option for multiple comparisons among sampling sites (SAS Institute, Inc., 1982, p. 139-151).

All available data were ranked by water-quality variable (constituent or physical measure), and the mean rank of the data associated with each site was then obtained. For each variable, an F-test was applied to test the hypothesis that the mean ranks at all sites (inlet, outlet, and nine remote) do not differ significantly (alpha level = 0.05) from each other. The alternate hypothesis is that at least one mean rank differs significantly from the others. Only 13 of 40 variables tested were significantly different among sampling sites (table 6).

Results of ANOVA and subsequent multiple comparisons to identify specifically which sites differed are summarized in table 6 for the 13 variables for which differences were significant. Most differences occurred in nutrient concentrations. Several major ions and copper and iron were also significantly different among sites. With the exception of sodium, chloride, and iron, the inlet and near sites (1, 4, and 7) were most often significantly higher in mean concentrations than intermediate sites (2, 5, 8) or far sites (3, 6, and 9). Site 8 was frequently not significantly different from sites 1, 4, and 7, and the inlet, possibly because of its proximity to the edge of the wetland, and the adjacent commercial property (as discussed previously). Test results for calcium and alkalinity agree with observed differences in figure 26. The change from a calcium bicarbonate water at the inlet and near sites to a sodium chloride water at intermediate and far sites in the wetland observed in the Stiff (fig. 28) and Piper (fig. 29) diagrams also was indicated by results of statistical tests. In general, dissolved iron was higher in the wetland than at the inlet, but a corresponding difference in total iron was not observed that might indicate dissolution with distance in the wetlands.

Data were next grouped by location of the sites relative to the inlet, with the inlet and outlet as separate groups, based on the results of the first test on all sites, and because of the decrease in values observed in figures 23 through 27. The same procedure was used (GLM for analysis of variance, with the TUKEY option for multiple comparisons), but with five groups: inlet, outlet, near sites (1, 4, and 7), intermediate sites (2, 5, and 8), and far sites (3, 6, and 9). Results for these groups are in table 7.

Testing for significant differences by groups resulted in twice as many variables for which mean rank values were different as when individual sites were tested (26 versus 13, respectively, of 40 variables). The increase in number of significant differences maybe because more information was available to obtain a mean by group than by site. These groups may actually be more representative of the water quality with distance away from the inlet. Additional differences were detected in color, specific conductance, pH, some total and dissolved nutrient values, total organic carbon, aluminum, lead, and zinc. The result for color is not unusual (wetlands were higher in color than the inlet) and would be expected, because of organics in the wetland water, and lack of color in the incoming runoff at the inlet. Most often, the inlet and near sampling sites (1, 4, and 7) were higher in values for selected variables than sites farther out, and the outlet, with the exception of some constituents that are naturally higher in wetlands, such as total organic carbon, and color. This is evidence that stormwater inflow does affect water quality to at least the distance of the near sampling sites.

Results of the multiple comparisons indicated that dissolved aluminum was significantly higher at the intermediate sites (2, 5, and 8) than at the inlet. Total aluminum values were always greater than 100 µg/L at the inlet, (maximum concentration measured was 480 µg/L), but dissolved concentrations were always 50 µg/L or less in those samples in which dissolved aluminum was aluminum in the wetland measured. The maximum values of dissolved aluminum in the wetland was 290 µg/L, at site 8, and 280 µg/L, at site 5, but total values were not obtained for these samples. Total aluminum samples collected from remote sites on August 21,

Table 6.--Results of analysis of variance and TUKEY multiple comparisons Island Lake wetland

[Only results significant at the alpha = 0.05 level are listed. All other constituent mean concentrations did not differ significantly among sites; p-value, the probability that observed differences are due to chance rather than to actual differences in data among sites. An x in a column indicates that the mean concentration (rank value) at the site indicated by the column heading was significantly lower than mean concentration at the site indicated in that row]

Constituent or physical measure	p-value	Significant comparisons											
		Sites having greater mean value	Sites having lesser mean value										
			Inlet	Near			Intermediate			Far			Outlet
				1	4	7	2	5	8	3	6	9	
Ammonia nitrogen, dissolved	0.0001	Inlet					x	x		x	x		x
		1						x		x	x		
		4					x	x		x	x	x	x
		7					x	x		x	x	x	x
		8						x		x	x		
Ammonia nitrogen, total	.0001	Inlet					x	x		x	x	x	x
		1								x	x		
		4					x	x		x	x	x	x
		7					x	x		x	x	x	x
Nitrate plus nitrite nitrogen, total	.0007	Inlet			x			x			x		x
Phosphorus, dissolved	.0001	4								x	x		
		7									x		
Phosphorus, total	.0001	Inlet					x	x	x	x	x	x	x
		1								x	x		
		4					x			x	x		x
		7					x			x	x		x
Orthophosphorus, dissolved	.0001	Inlet					x	x		x	x		x
		1					x	x		x	x	x	x
		4					x	x		x	x	x	x
		7					x	x		x	x	x	x
		8									x		x
Orthophosphorus, total	.0001	Inlet					x	x		x	x		x
		1					x	x		x	x		x
		4					x	x		x	x		x
Alkalinity	.0001	Inlet						x			x	x	
		1					x	x			x	x	
		4					x	x			x	x	
		7					x	x		x	x	x	x
Calcium	.0001	Inlet						x			x		
		1					x	x			x		
		4						x			x		
		7					x	x		x	x	x	x
Chloride	.0063	2	x										
		5	x										
		6	x										
		9	x										
Sodium	.0055	2	x										
		5	x										
		6	x										
		9	x										
Copper, total	.0027	Inlet											x
Iron, dissolved	.0001	1	x										
		2	x										
		4	x										x
		5	x										
		7	x								x		x
		9											

Table 7.--Results of analysis of variance of grouped data, and TUKEY multiple comparisons, Island Lake wetland

[Only results significant at the alpha = 0.05 level are listed. All other constituent mean concentrations did not differ significantly among sites; p-value, the probability that observed differences are due to chance rather than to actual differences in data among sites. An x in a column indicates that the mean concentration (rank value) at the site indicated by the column heading was significantly lower than mean concentration at the site indicated in that row]

		Significant comparisons					
		Sites having greater mean value	Locations having lesser mean value				
				Wetlands			
Constituent or physical measure	p-value		Inlet	Near (23-35 feet)	Intermediate (81-106 feet)	Far (221-254 feet)	Outlet
Color	0.0057	Near	x				
		Intermediate	x				
		Far	x				
Specific conductance	.0001	Near	x		x	x	x
		Inlet				x	
pH-field	.0001	Inlet			x	x	
		Near			x	x	
pH-lab	.0045	Inlet			x	x	
		Near			x		
Nitrogen, ammonia dissolved	.0001	Inlet			x	x	x
		Near			x	x	x
Nitrogen, ammonia total	.0001	Inlet			x	x	x
		Near	x		x	x	x
Nitrogen, Kjeldahl dissolved	.0228	Near	x				
Nitrogen, Kjeldahl total	.0046	Inlet					x
		Near					x
Nitrogen, total nitrate plus nitrite	.0001	Inlet		x	x	x	x
Phosphorus, dissolved	.0001	Inlet			x	x	
Phosphorus, total	.0001	Near			x	x	x
Orthophosphorus, dissolved	.0001	Inlet			x	x	x
		Near			x	x	x
Orthophosphorus, total	.0001	Inlet			x	x	x
		Near			x	x	x
Total organic carbon	.0160	Far	x				
Alkalinity	.0001	Inlet			x	x	x
		Near			x	x	
Calcium	.0001	Inlet			x	x	x
		Near			x	x	
Magnesium	.0315	Near	x				
Sodium	.0011	Intermediate	x				
		Far	x				
Chloride	.0009	Intermediate	x				
		Far	x				
Sulfate	.0269	Intermediate	x				
Aluminum, dissolved	.0126	Intermediate	x				
Copper, total	.0001	Inlet		x	x	x	x
Iron, dissolved	.0001	Near	x			x	x
		Intermediate	x				
		Far	x				
Iron, total	.0011	Near	x		x	x	x
Lead, total	.0001	Inlet		x	x	x	x
		Near				x	
Zinc, total	.0099	Inlet		x	x		

Table 8.--Comparison or water-quality data to State standards, Island Lake wetland

[All values are for total concentrations. Values with "<" were less than the detection limit of the analytical method, and were assumed to meet standard]

Constituent	Standard	Island Lake Inlet: Number of samples	Island Lake Inlet: Range	Island Lake Inlet: Percent of samples not in compliance	Sites 1, 4, and 7: Number of samples	Sites 1, 4, and 7: Range	Sites 1, 4, and 7: Percent of samples not in compliance	Sites 2, 5, and 8: Number of samples	Sites 2, 5, and 8: Range	Sites 2, 5, and 8: Percent of samples not in compliance
Alkalinity (mg/L)	>20	4	30-84	0	8	52-122	0	9	1-49	78
Phosphate phosphorus (mg/L)	[1].025	15	.04-.12	100	8	<.01-.09	88	9	<.01-.06	22
Cadmium (mg/L)	.8	16	<1-1	25	8	<1-2	50	9	<1-2	33
Chromium (mg/L)	50	16	1-15	0	8	<1-29	0	9	<1-13	0
Copper (mg/L)	30	16	1-14	0	8	<1-5	0	9	<1-6	0
Lead (mg/L)	30	16	6-70	19	8	1-14	0	9	2-10	0
Zinc (mg/L)	30	16	10-160	81	8	<10-80	25	9	20-40	22

Constituent	Standard	Sites 3, 6, and 9: Number of samples	Sites 3, 6, and 9: Range	Sites 3, 6, and 9: Percent of samples not in compliance	Island Lake Outlet: Number of samples	Island Lake Outlet: Range	Island Lake Outlet: Percent of samples not in compliance
Alkalinity (mg/L)	>20	9	4 - 25	89	4	5-41	50
Phosphate phosphorus (mg/L)	[1].025	9	<.01-.05	22	4	.02-.01	0
Cadmium (µg/L)	.8	9	<1 - 1	11	4	<1-1	25
Chromium (µg/L)	50	9	<1 -14	0	4	<1-15	0
Copper (µg/L)	30	9	<1 - 6	0	4	<1-5	0
Lead (µ/L)	30	9	<1 - 2	0	4	1-4	0
Zinc (µ/L)	30	9	10 - 90	11	4	20-50	25

[1]Suggested by U.S. Environmental Protection Agency, 1976, p. 188, for eutrophication control in lakes or reservoirs.

1985, were all less than 100 µg/L, and the dissolved fraction at that time ranged from less than 10 to 80 and 90 µg/L. Aluminum probably dissolves as it travels into the wetland, with the dissolved form becoming predominant, and comprising a greater percentage as it moves over time and with distance.

Comparison of water-quality data to State water-quality standards for Class III waters

Water-quality data were compared to Florida Department of Environmental Regulation water-quality standards for Class III waters and other standards. The range in values, number of samples, and the percent of samples not in compliance with standards for these selected constituents at the inlet, outlet, and nine remote locations at the Island Lake wetlands are listed in table 8. Alkalinity was not within standards at sites in the wetlands (intermediate and far sites); and at the outlet, half the samples were below the minimum allowable alkalinity. This is not a result of stormwater runoff but of the natural state of the wetland, which tends to be acidic because of leaching of organics from wetland vegetation. Class III standards are not strictly applicable to a wetland because wetlands are not used routinely for recreation. However, it is the only State standard available for alkalinity because no standard exists for alkalinity under the State's general criteria for surface waters.

The standard used for phosphate phosphorus is a suggested value from the US. Environmental Protection Agency (1976) for eutrophication control in lakes and reservoirs. Samples from sites near the inlet and at the inlet were most often higher than this suggested value, but at intermediate sites and far sites, 78 percent of the samples were less than 0.02 mg/L, as were all samples at the outlet.

Although cadmium values were always less than 2 μg/L, 25 to 50 percent of samples collected at all sites were over the standard, which is only 0.8 μg/L and less than the detection limit (1 μg/L). Although chromium values as high as 29 μg/L (site 4) were measured, no values were above the 50 μg/L standard. Copper concentrations also were always within standards at all sites, including the inlet. Lead values were above the maximum allowed in 19 percent of samples collected at the inlet, but were never above the maximum at any other location. Zinc was frequently higher than the standard at sites in the wetland, and one of the four samples collected at the outlet exceeded the limit.

Zinc is a ubiquitous element that has been detected in high concentrations in precipitation and surface waters. Irwin and Kirkland (1980, p. 22-23) reported zinc values in precipitation in Florida ranging from 10 to 180 μg/L, and lead ranging from 7 to 440 μg/L. The highest zinc values were from a site near a highway. Water samples from three Central Florida lakes located a few miles from the Island Lake wetland were over the limit for zinc in 16 to 22 percent of the samples (percentages reported for each lake), and for lead, in 6 to 12 percent of samples (German, 1983, p. 30). Runoff to these lakes exceeded standards in 89 to 100 percent of lead samples, and 89 to 94 percent of zinc samples. Bulk precipitation samples from the same study were over the limit for zinc in 60 percent, and for lead in 12 percent of all samples. At 13 surface-water sites (streams and lake outflow) in the Reedy Creek Improvement District southwest of Orlando, 31 percent of 153 samples were above the zinc standard, but only 2 percent of 147 samples were above the lead standard (German, 1986, p. 48). These results are of note because much of the drainage basin of these streams is flat and swampy, and may be more comparable to the Island Lake wetland than data from lakes. The 81-percent exceedance rate for zinc at the inlet of Island Lake is near the 89 to 94-percent rate reported for runoff in German's 1983 report, but the lead exceedance rate at the inlet (19 percent) is much lower than in runoff reported by German (89 to 100 percent). One possible explanation for the lower lead exceedance rate might be the gradual elimination of leaded gasoline.

Qualitative analysis of organic compounds

Water samples were collected in August 1986 for organic screening, as was done at the Silver Star Road wetlands. At the Island Lake wetland, the inlet, outlet, and site 1 were sampled. The FID scan of the water resulted in estimated concentration range of detected peaks from <1 to 20 μg/L at the outlet and site 1, but at the inlet, organics were detected in the range of 1 to 50 μg/L. These organics are methylene-chloride extractable priority pollutants, and may be any one of the family of benzene compounds, chrysene, or heavy polyaromatic hydrocarbons (PAHs), such as dibenzo (a,h) anthracene. Further quantitative sampling for specific organic compounds would be necessary to verify the results of this screening, but this was outside of the scope of the present study.

Spatial Variation of Constituents in Bed Sediments

Sediment samples were collected at the Island Lake wetland at the nine remote sites and the outlet in May 1985. The samples were collected with plastic cartons, and the sediment was analyzed for nutrients, metals, and volatile solids (as an indication of the amount of organics in the sediments). The distribution of concentrations of selected constituents are illustrated by figures 30 through 32.

Volatile solids in sediments at Island Lake ranged from 2,260 mg/kg (fig. 30) at site 1 (near the inlet) to 66,300 mg/kg at site 4 (also near the inlet). Most other sites were less than 7,000 mg/kg, but the second highest volatile solids content was at the outlet (32,400 mg/kg). Volatile solids are an indicator of the organic content of the soil, which would be expected to be high in a wetland. The organic layer at the wetland is about 3 1/2-inches deep, and is underlain by medium-sized sand. The values obtained for far sites (3, 6, and 9) were more alike (site 3 and 9 were equal) than values of intermediate sites or particularly the near sites (minimum and maximum values both occurred at the near sites). The homogeneity of the sediments in terms of the volatile solids at these three far sites may indicate they are relatively undisturbed and are representative of the natural wetland.

Kjeldahl nitrogen and ammonia nitrogen were measured in bed sediments, but ammonia comprised a very small percentage of the Kjeldahl nitrogen, and nitrate plus nitrite nitrogen concentrations were also low, indicating organic nitrogen is the main form in the sediments. The ammonia fraction of Kjeldahl nitrogen at most sites was less than 1 percent, but at sites 3 and 6, ammonia comprised 59 and 67 percent of the Kjeldahl nitrogen, respectively. This may also indicate that these sites are part of the natural wetland in which decomposition is a major process. Total Kjeldahl nitrogen concentrations in sediments for the sampled sites at Island Lake wetland tend to be very high in areas along the western shore, and near the inlet (fig. 30). Site 4 is the farthest of the three near sites from the inlet, and this small difference may have been sufficient to reduce the sediment concentrations, or more plant uptake may be occurring at that site. More scouring by incoming runoff may be occurring at site 4, thus removing the fine sediments on which the nitrogen is attached.

Phosphorus concentrations ranged from 230 mg/kg at the outlet, to 20,000 mg/kg at site 2. Site 1 had the second highest concentration; 15,000 mg/kg. In general, the concentrations decreased with distance away from the inlet along the east and middle laterals (site 1-6) but increased from site 8 to 9, from 600 to 1,500 mg/kg.

Cadmium in sediments ranged from only 1 to 7 µg/g at the Island Lake wetland, and cobalt ranged from 10 to 40 µg/g. Iron values were highly variable, ranging from 1,300 µg/g at the inlet and at site 8, to 15,000 at site 5. No real pattern was evident in iron concentrations at the various locations in the wetland.

Lead in sediments was highest at sites 5 and 7, and decreased generally with distance from the inlet. Values measured in sediments at sites 3 and 6 were much lower (fig. 31). The lowest concentration was measured in sediments at the outlet. Most of the lead in the runoff entering the wetland is in particulate form, settles out of the water very quickly, and remains in the sediments because of its relatively insoluble nature.

Zinc concentrations in sediments were less than half of the lead concentrations, attesting to the difference in solubility between these metals (fig. 31). Again, lowest concentrations were at the far sites (3, 6, and also 9), and at the outlet. Sites 2, 5, 7, and 8 had similar concentrations.

Copper was lowest in sediments at the outlet (4 µg/g) but highest values were found at the intermediate locations (sites 2 and 5 had concentrations of 96 and 88 µg/g, respectively), rather than at sites near the inlet. Chromium concentrations in bottom sediments were surprisingly high at sites 3 and 6, relative to concentrations at sites near the inlet (fig. 32). The highest concentration was measured at site 6 (90 µg/g), and the lowest was at the outlet (9 µg/g). Chromium is an element associated with highway runoff and the occurrence at site 6 of the maximum value, 237 feet from the inlet, in a wetland with slow velocities (allowing opportunity for sedimentation closer to the inlet) may be an indication that some metals in highway runoff can be transported along distance, increasing the potential impact on the wetland. The chromium also may be from another source, such as atmospheric deposition, or the values obtained from this sampling may be due to sampling variability.

Distribution of Constituents by Sampling Medium

The concentrations of constituents in the water column and bed sediments area function of many variables, but comparison of concentrations

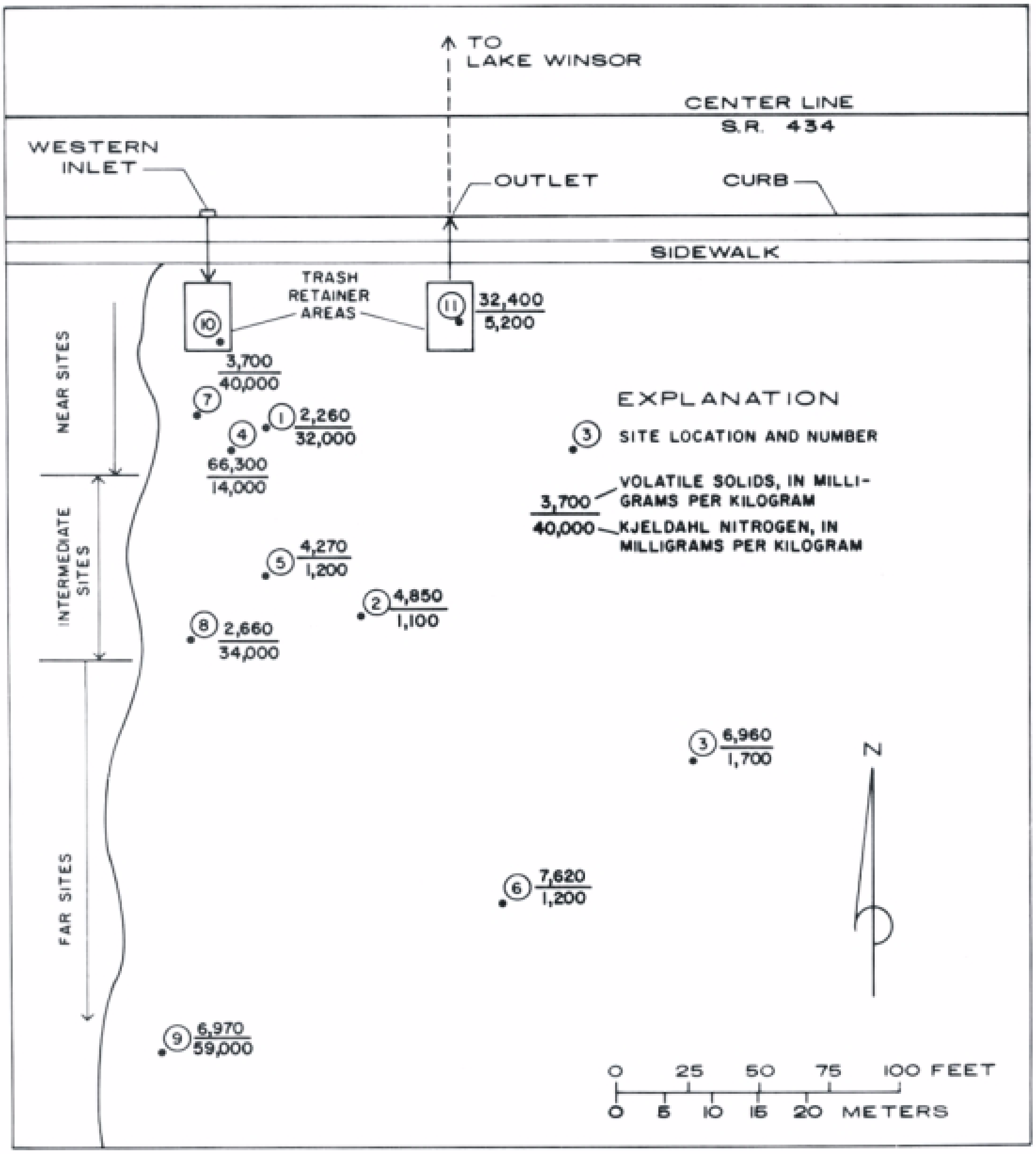

Figure 30.--Distribution of Kjeldahl nitrogen and volatile solids in bed sediments at the Island Lake wetland, May 1985.

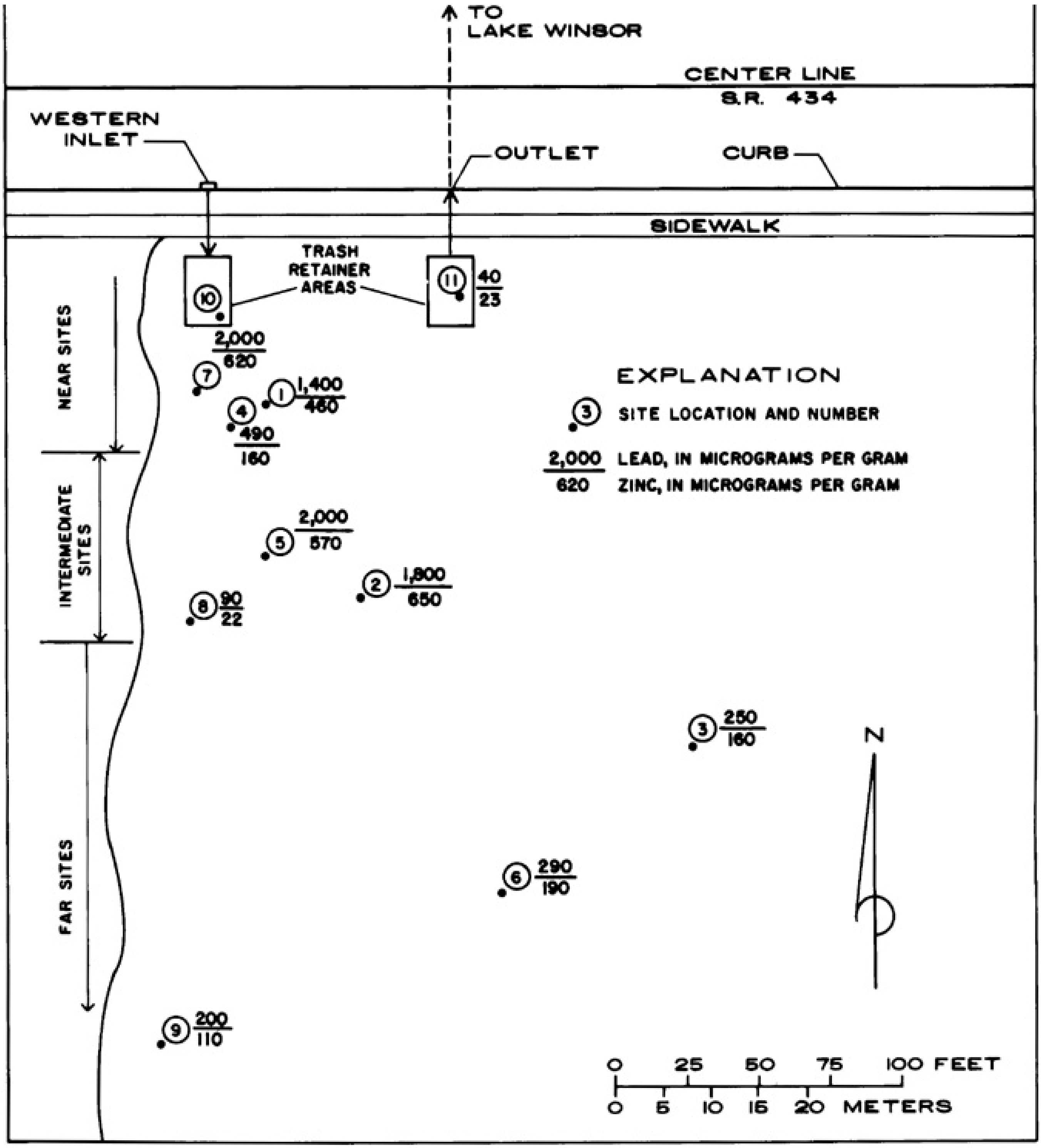

Figure 31.--Distribution of lead and zinc in bed sediments at the Island Lake wetland, May 1985.

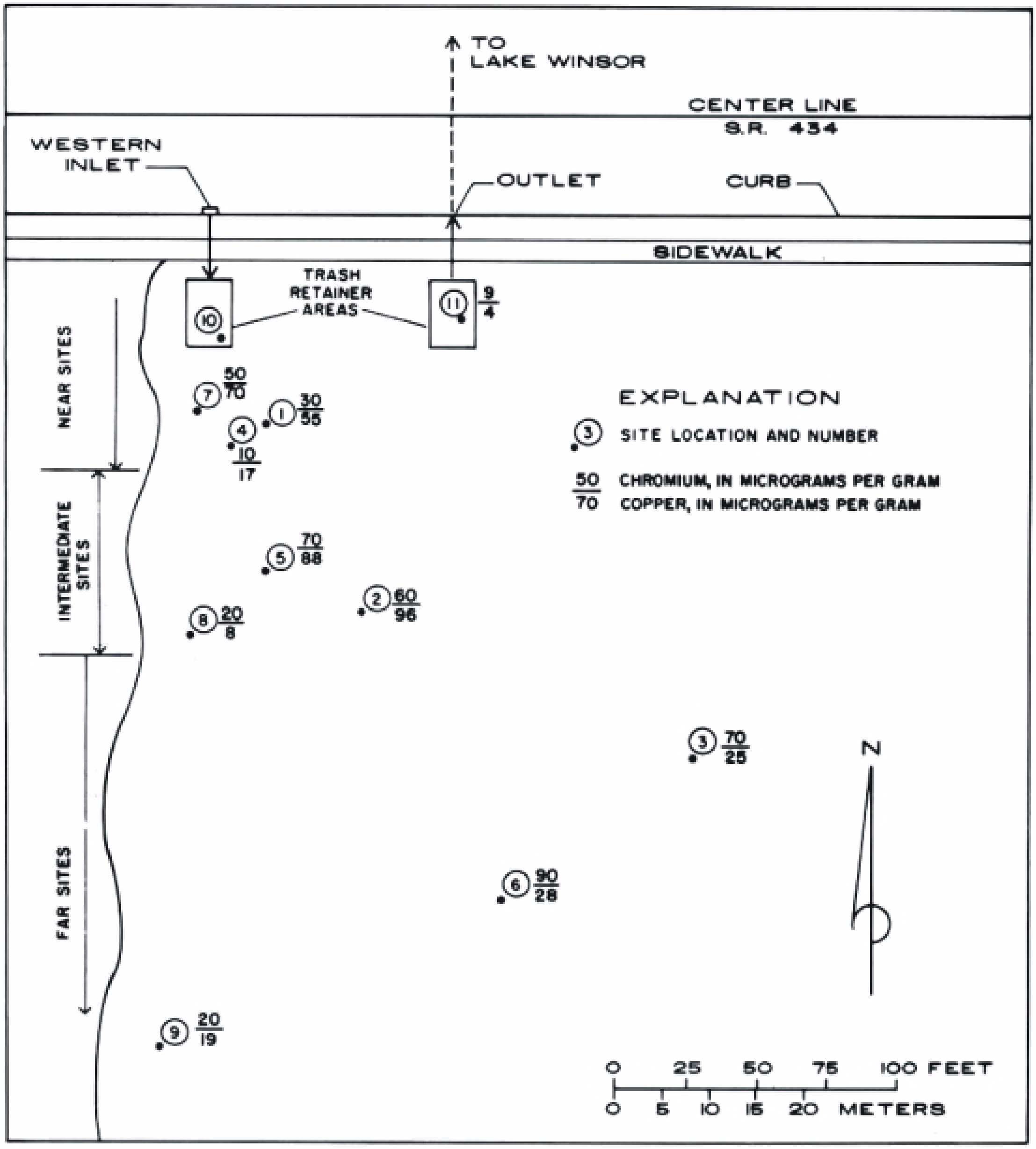

Figure 32.--Distribution of chromium and copper in bed sediments at the Island Lake wetland, May 1985.

Table 9.--Median values of selected constituents in the water column and values for one sample of bed sediments at the Island Lake wetland

[Values are reported in units of parts per million except where noted. Median value listed for bed sediments is based on 10 samples, one sample at each of the nine remote sites and the outlet]

Constituent	Water column					Sediments
	Inlet	Sites 1,4,7	Sites 2,5,8	Sites 3,6,9	Outlet	
Number of samples =	4 to 16	8	9	9	4	10
Specific conductance[1]	140	218	102	84	100	--
pH - laboratory[2]	7.1	7	6.1	6.2	6.9	--
Nitrogen, ammonia	.23	.35	.01	.01	.01	80.5
Nitrogen, ammonia plus organic	1.4	1.3	1	.94	.82	9,600
Nitrogen, nitrate plus nitrite	.09	.01	.02	.02	.01	13.5
Phosphorus	.23	.12	.04	.02	.03	2,250
Total organic carbon	7.5	21.5	24	27	20.5	--
Cadmium	[3]<.001	[3]<.001	[3]<.001	[3]<.001	[3]<.001	2
Chromium	.0075	.004	.003	.003	.0045	40
Copper	.008	.003	.002	.002	.001	26.5
Iron	.605	1.4	.69	.61	.490	4,550
Lead	.018	.006	.004	.001	.003	390
Zinc	.075	.025	.02	.03	.025	175

[1]Microsiemens per centimeter at 25°C.

[2]pH units.

[3]Detection level.

between these two media, and comparison of concentrations with respect to location relative to the inlet, may indicate the path of the incoming stormwater, and where the attenuation of concentrations may be occurring before the water leaves the wetland. Median concentrations in water and sediments are listed in table 9. The water column sampling sites are grouped by distance from the inlet as was done for statistical analysis (near, intermediate, far), and are listed independently from the inlet and outlet. The median concentration in sediments is based on the samples collected in May 1985, at the nine remote sites and the outlet.

Median specific conductance values at sites 1, 4, and 7, were actually greater than the median specific conductance at the inlet, possibly because of high values measured at site 7. This was also the case for ammonia nitrogen, total organic carbon, and iron. With the exception of total organic carbon, other constituent concentrations generally decreased with distance in the wetland.

The ultimate fate of most of the constituents entering the wetland is deposition within the sediments, as indicated by comparison of the median concentrations between water column and sediments. Organic nitrogen, phosphorus, and iron are the most abundant constituents in the sediments.

Lead and zinc are present in larger concentrations than the other metals (except iron) in sediments.

Comparison Between The Two Wetlands

Differences between the wetlands and how these differences may have affected the results of the study are considered in this section. The stormwater system and detention pond at the Silver Star Road study area were built in 1980, and had been in operation only 2 years when the original study by Martin and Smoot (1986) was started; the structures at the Island Lake wetland were built in 1976, and the wetland had been receiving runoff from SR 434 for 9 years prior to the beginning of data collection. At the Silver Star Road study area, 11.1 acres of roadway of a total drainage area of 41.6 acres drain into the pond and wetland system; at the Island Lake wetland, 12.8 acres of roadway (highway and residential streets) of a total drainage area of 62.6 acres (according to original plans) drain into the western storm inlet to the wetland. Island Lake receives water from several sources--SR 434, residential and commercial areas, ground-water seepage, and direct runoff from the water surface of the wetland, which comprises nearly a third of the drainage basin. The Silver Star Road pond and wetland receive primarily runoff from the highway and some residential areas, and minimal direct runoff from the water surface of the pond and wetland relative to the stormwater that enters. Thus, the outlet water quality at Silver Star Road wetland is more directly related to the highway runoff than is water quality at the Island Lake outlet, which is a blending of water from several sources.

The Silver Star Road wetland is a cypress wetland, ranging in width from 58 to 120 feet, and in length from 200 to 340 ft.; Island Lake wetland is a freshwater marsh, and is much larger--it is approximately 3,100 feet at its widest, and extends in length to 4,500 feet. Water depth in both wetlands are similar, although the northern section (willows) and transition zone (from the willows to the grasses) at the Island Lake wetland are sometimes dry in the winter months. Flow to the Silver Star Road wetland is actually discharge from a 68-foot by 139-foot detention pond, over earthen berm. Flow from the wetland is over a weir, and into a drop inlet, so no tailwater affects discharge. Runoff at the Island Lake wetland enters a much smaller area (12- by 25-foot trash retainer), and then discharges over a berm. Outflow from the Island Lake wetland is through a 48-inch culvert that conveys water north several hundred feet to Lake Winsor, which is the control for outflow from the wetland.

There were several differences in water quality between the two wetlands. Median specific conductance values differed at the outlets of the two wetlands, although inflow median values were similar (144 μS/cm at Silver Star and 140 μS/cm at Island Lake). The median value of specific conductance at the outlet of Island Lake was 100 μS/cm, which was lower than the conductance at the inlet of the wetland, and lower than the median value at the Silver Star Road wetland outlet (153 μS/cm). Median ammonia nitrogen was also lowest in water at the Island Lake outlet--only 0.01 mg/L compared to 0.23 mg/L at the inlet, and 0.2 to 0.4 mg/L at the Silver Star wetland inlet and outlet. Phosphorus was highest at the inlet of the Island Lake wetland (median value is 0.23 mg/L, compared to 0.10 mg/L at Silver Star inlet), but the lowest median was at the outlet of Island Lake (0.03 mg/L).

Total organic carbon differed between the two wetlands. Although median values at the outlets of both wetlands were similar (15 and 20.5 mg/L, at Silver Star Road and Island Lake wetland, respectively), the outlet median concentration at Island Lake was three times greater than the inlet median concentration (7.5 mg/L); whereas at Silver Star Road, inlet and outlet median concentrations were equal. This difference in values at the inlets of each wetland maybe a result of differing land use in the drainage basins.

Copper, lead, and zinc median values at the inlets and outlets were similar between wetlands (median copper is <10, median lead is <3 to 26, and median zinc is 25 to 75, μg/L), but chromium values were higher at the Island Lake wetland. Median chromium values at the inlets of both wetlands were <1 and 7.5 μg/L, Silver Star Road and Island Lake, respectively, and maximum values at each were 12 and 15 μg/L, respectively. Median chromium values at the outlets of both wetlands were <2.5 and 4.5 μg/L (Silver Star Road and Island Lake, respectively), and maximum values were 11 and 15 μg/L, respectively. This does not necessarily represent a significant difference in chromium concentrations between wetlands, but the occurrence of high chromium values at all remote sites at the Island Lake wetland during one sampling time combined with these higher median values at the inlet and outlet may indicate a potential problem at the Island Lake wetland that is not present at the Silver Star Road wetland.

The major difference between the wetlands was observed in bottom sediment chemistry. The Island Lake wetland had been in use for stormwater disposal 9 years before the sediment samples were collected; at the Silver Star Road wetland, the first sediment samples (three were collected at each site during 1982-85) were collected only 2 years after stormwater was routed to it through the detention pond. Median sediment concentrations of ammonia nitrogen, Kjeldahl nitrogen, nitrate nitrogen, chromium, copper, iron, lead, and zinc all were much higher at the Island Lake wetland (median of 10 samples) than at the Silver Star Road wetland (median of 15 samples), and actually the median values at Island Lake were much more similar to the Silver Star Road detention pond sediment concentrations. For example, the median chromium concentration at the Island Lake wetland was 40 μg/g; at the Silver Star Road wetland, it was only 2 μg/g, and in pond sediments, it was only 20 μg/g. The median lead concentration at the Island Lake wetland was 390 μg/g, and at the Silver Star Road wetland, it was only 20 μg/g, but in the pond, the bottom sediment concentration was 620 μg/g.

The water-quality data collected at the Silver Star Road study area indicates that water quality improves significantly from inlet to outlet of the pond-wetland system, and the removal efficiencies computed by Martin and Smoot (1986) indicate the wetland is effective in attenuation of stormwater constituent loads. However, the spacial data collected at the Island Lake wetland indicated that water quality is degraded near the inlet, where stormwater enters the wetland. The sediment concentrations indicate some buildup in locations near the inlet, which is not unexpected. The relation between the size of the drainage basin and land use in the basin to the size of the wetland, and the tolerance of plants and aquatic life to changes in water quality, will affect the length of time a wetland can be used for stormwater disposal before adverse effects might occur. The Island Lake wetland is very large and no appreciable changes in water quality leaving the wetland because of runoff entering the wetland may occur for years, but the degradation of water quality near the inlet and the buildup of constituents in bottom sediments may be an indicator of future trends.

One of the most significant physical differences in this study is the presence of the detention pond at the Silver Star Road study area. This may be the most influential factor in water and bed sediment quality of each wetland. The Silver Star Road pond provides detention of runoff thereby allowing settling of heavier particles prior to discharging into the wetland. Although the trash retainer area at the Island Lake wetland is a parallel structure, its size limits its function so settling of particulate matter occurs in the wetland itself.

The difference in sediment concentrations between the Island Lake and Silver Star Road wetlands may be because of other factors, including traffic volume, drainage area, and length of time in operation (Island Lake wetland has been receiving runoff 10 years longer than Silver Star Road wetland), but the in-line detention pond at the Silver Star Road study area certainly is a major factor in the difference, based on concentrations in sediments in the pond.

The detention of runoff may be critical to the long-term impact of stormwater on the wetland. Bottom sediments in structures receiving stormwater may eventually have to be removed because of the buildup of constituents' in sediments from settling and precipitation processes, causing a decrease in storage volume in the facility. Because of the buildup, the potential also exists for release of some constituents from sediments back to the water column. The removal of sediments from a wetland would not be practical in most cases because of the severe disruption to the wetland, thus, it becomes more critical to provide detention before runoff enters a wetland.

SUMMARY AND CONCLUSIONS

Two wetlands in central Florida that receive highway runoff were studied to determine the effects of stormwater on the wetlands. One wetland is a cypress wetland that receives stormwater after it has been detained in a detention pond, and the second is a freshwater marsh that receives stormwater after it has passed through a trash-retainer facility.

Data were collected from 1982 through 1984 at the cypress wetland (Silver Star Road) as part of another study, released in 1986, to determine removal efficiencies in the pond, wetland, and combined system. Ground-water quality data were also collected at the site for a concurrent study investigating the effects of highway runoff detention methods on the water quality of the surficial aquifer system.

Data were collected at the Island Lake wetland from 1985 through 1986, with the emphasis of data collection on the identification of areal variability that might indicate water-quality changes with location.

At the Silver Star Road study location water-quality data at the inlet and outlet of the wetland were compared to State water-quality standards for Class III waters. No standard is given for orthophosphorus, so the U.S. Environmental Protection Agency's suggested limit of 0.025 mg/L was used. Orthophosphorus concentrations exceeded this limit in 88 percent of all samples at the inlet, and in 74 percent of all samples at the outlet. Forty-three percent of samples at the inlet exceeded the lead standard, but only 10 percent of outlet samples exceeded the standard. Zinc concentrations exceeded the limit in 78 percent of inlet samples, and in 34 percent of outlet samples. These results indicate that removal processes are occurring in the wetland.

Differences observed in major ion composition of ground water adjacent to the wetland compared to ground water near the detention pond may indicate seepage from the wetland toward the canal that is adjacent and downgradient of the wetland. Major ions in ground water were sodium and chloride, which differed from surface water (pond and wetland), in which calcium and bicarbonate ions predominated.

Qualitative analysis of water for organic constituents from the outlet of the wetland, and from selected wells near the wetland resulted in the detection of organic constituents in water from the surficial aquifer system at one well location, site 6, but no detections at other locations.

Median values of selected constituents in bed-sediment samples collected from the Silver Star Road wetland and pond were compared. The highest Kjeldahl nitrogen concentration in bottom sediments was in the wetland, but median lead, zinc, chromium, and copper concentrations were an order of magnitude lower in the wetland than in the pond. Median lead concentrations were 620 μg/g in the pond, and 20 in the wetland; median zinc concentrations were 250 and 14 μg/g in the pond and wetland, respectively, chromium, 20 and 2 μg/g, and copper, 49 and 3 μg/g, respectively.

Detention of highway runoff in the Silver Star Road detention pond prior to release of water to the wetland allows settling of heavier particles to occur, lowering the constituent loads that enter the wetland. At the Island Lake wetland, only a trash-retainer structure, 12- by 25-feet in size and with only 2 feet of storage available at most, provided any primary settling of particulate matter in runoff prior to discharging into the wetlands. This difference in detention may be a major factor in the difference in effect on the wetlands observed in this study.

Nine remote locations at the Island Lake wetland, varying in distance from the inlet (trash retainer overflow) and located on three laterals in a fan shape were used for determination of areal variation of water quality. Near sites were those located from 23 to 35 feet from the inlet, intermediate sites ranged from 81 to 106 feet, and far sites ranged from 221 to 254 feet from the inlet. The locations of the intermediate sites coincided with an area of vegetation change, from willows and shrubs to open wetland grasses and hedges.

Specific conductance, dissolved oxygen, and temperature were continuously monitored at the inlet and outlet of the wetland; at the inlet, stage was monitored for activation of automatic sampling equipment. Specific conductance at the inlet decreased during storms because of the low specific conductance of the incoming stormwater, and gradually increased after the end of each storm. Dissolved oxygen at the inlet was very low (<1.0 mg/L) during nonstorm periods, but also rose rapidly during storms, and decreased quickly after the storms ended. Similar responses were evident in the outlet data, but dissolved oxygen was usually slightly higher than at the inlet.

In general, constituent concentrations decreased with distance from the inlet. Turbidity and specific conductance decreased with distance from the inlet, but color increased. Organic material contributing to natural color in the wetland would be diluted near the inlet by street runoff. Concentrations of ammonia nitrogen were higher at the inlet and sites near the inlet. Organic nitrogen was the dominant form in water at all sites. Most of the phosphorus was in the inorganic form, but there was more organic phosphorus in water samples at the inlet.

Zinc and chromium concentrations did not decrease as much with distance from the inlet as other metals measured in the water at remote sites. The effect on the wetland from runoff was apparent in the change in ionic composition with distance. Water near the inlet was predominantly calcium bicarbonate, whereas water at far sites in the wetland was predominantly sodium chloride. Water at the outlet appeared to be a mixture.

Analysis of variance techniques were used to determine whether mean values differed significantly among sampling locations in the wetland. Of the 40 water-quality variables tested, 13 were significantly different among locations; the majority of the 13 variables were nutrient species. Multiple comparison of the data indicated that values from the inlet and sites near the inlet were most frequently different from values from sites farther away from the inlet (intermediate and far) and the outlet

Analysis of variance techniques were utilized further on grouped data based on the results of the first multiple comparisons. Data were divided into five groups--the inlet, outlet, sites near the inlet (sites 1, 4, and 7), intermediate (sites 2, 5, and 8) and far from the inlet (sites 3, 6, 9). Grouping the data resulted in twice as many variables being significantly different (26 instead of 13) among groups as among sites. Multiple comparisons among groups for which significant differences were indicated resulted in most differences again appearing between the groups including the inlet, and sites near the inlet, and other sites further away from the inlet (intermediate, far, and outlet groups). Significant differences with distance were indicated for color and total organic carbon (increased with distance), specific conductance, pH, nutrients, aluminum, lead, and zinc (decreased with distance).

Qualitative analysis of water from the inlet, outlet, and site 1 indicated possible organic compounds in water at the inlet in the range of 1-50 μg/L, and no detection of organic compounds at the other two sampled sites.

Most measured concentrations of constituents at the Island Lake wetland were within State standards for Class III waters during the study. Lead exceeded the standard in 19 percent of inlet samples, but never exceeded the standard at other sites. Zinc frequently exceeded the standard: in 81 percent of the inlet samples, 11 percent of samples at sites 3, 6, and 9 (combined), and 25 percent of the outlet samples. Chromium did not exceed the standard of 50 μg/L. The maximum concentration of 29 μg/L was measured at site 4 near the inlet.

The predominant form of nitrogen in sediments at the Island Lake wetland was organic nitrogen. Ammonia in bottom sediments was less than 1 percent of the Kjeldahl nitrogen at most sites, but was 59 and 67 percent of the Kjeldahl nitrogen at sites 3 and 6, far in the wetland, which may be an indication of natural decomposition. Phosphorus in bottom sediments ranged from a low of 230 mg/kg at the outlet, to a maximum of 20,000 mg/kg at site 2. In general, concentrations decreased with distance from the inlet.

Most of the concentrations of metals in bottom sediments at Island Lake also generally decreased with distance from the inlet. Copper in bottom sediments at the Island Lake wetland ranged from 96 μg/g at site 5, an intermediate site, to 4 μg/g at the outlet. Lead was also highest at site 5 (2,000 μg/g) and site 7 (also 2,000 μg/L), and decreased at far sites in the wetland. The lead concentration in the sediments at the outlet was only 40 µg/g. Zinc values were at least half the magnitude of the lead concentrations in bottom sediments. Lowest zinc concentrations were detected at site 8 and the outlet (22 and 23 µg/g, respectively), and ranged from 22 to 650 µg/g (maximum occurred at site 2).

Chromium did not follow the same distribution pattern of other metals in the wetland. Although the concentration in outlet sediments was lowest (9 µg/g), highest values in sediments were measured at sites 3 and 6, far sites (70 and 90 µg/g, respectively), and increased with distance away from the inlet on two of the three laterals; the exception was the western lateral, which decreased from 50 µg/g at site 7 to 20 µg/L at sites 8 and 9. The presence of higher chromium concentrations several hundred feet from the inlet may indicate that this constituent may travel farther in water than other metals before settling or adsorption occurs, or it could be originating from atmospheric or other sources.

One of the most noticeable differences in water quality between the two wetlands studied was in the median chromium concentrations, which were higher at the Island Lake inlet, wetland, and outlet than at the inlet and outlet of the Silver Star Road wetland. Median chromium at the Island Lake inlet was 7.5 µg/L, compared to only 1 µg/L at Silver Star Road wetland inlet; the outlet concentrations were 4.5 and 2.5 µg/L, Island Lake and Silver Star Road, respectively.

A greater percentage of samples at the Silver Star Road wetland outlet exceeded the EPA recommended limit for orthophosphorus than at the Island Lake outlet (88 percent for Silver Star Road wetland outlet compared to none at Island Lake outlet). Lead concentrations exceeded State standards for Class III waters in 10 percent of samples at the Silver Star Road outlet, and none exceeded the limit at Island Lake outlet. Zinc concentrations also exceeded the limit more frequently at Silver Star Road wetland outlet than at the Island Lake outlet (34 percent and 25 percent of samples, respectively). These differences may be related to hydrologic differences between the wetlands (percent pervious and impervious area in the drainage basin, size of the basin, size of the wetland relative to the size of the drainage basin, and land use in the basin), or to the differences in input loads.

Median values in bed sediments (based on one sample at each of the 10 sampling sites) at the Island Lake wetland were higher than median values (based on 3 samples, at each of 5 sampling sites, for a total of 15 samples) at the Silver Star Road wetland for the following constituents: ammonia nitrogen, Kjeldahl nitrogen, nitrate nitrogen, chromium, copper, iron, lead, and zinc. Median bed sediment concentrations of these constituents at the Island Lake wetland were actually more similar to median values for bed sediments in the Silver Star Road detention pond.

The potential for adverse effects on wetlands is greater at the Island Lake wetland because little detention of the runoff occurs prior to entering the wetland. The lack of detention at this location means that a larger particulate load will enter the wetland. The similarity observed in the data from this study between bottom sediments at the Island Lake wetland and the Silver Star Road detention pond is one indication of the importance of detention facilities.

The difference in sediment concentrations between the Island Lake and Silver Star Road wetlands may be because of the difference in length of time of operation, but the in-line detention pond at the Silver Star Road study area certainly could be a major factor in the difference, based on concentrations in sediments in the pond.

Although this study only included a cypress wetland and a freshwater marsh, the information obtained from this study is probably applicable to most freshwater wetlands in Florida. The organic soils and thick vegetation common to most wetlands are important for the binding of constituents, removing them from the water column, but these soils are also sources of possible long-term changes in the wetland environment. Excessive nutrient loads entering the wetland may be the catalyst for changes in vegetation and the acceleration of eutrophication. The buildup and storage of metals in organic complexes in wetland sediments may be compared to the storage of an electrical charge in a capacitor.

A change in redox conditions may release metals back into the water column, which in turn could cause serious problems to sensitive aquatic life. But removal of the metal and nutrient enriched sediments from a wetland would be a difficult and expensive task.

Results from this study show that detention facilities, larger than the trash retainer area provided at the Island Lake wetland, allow settling of the majority of suspended sediments in runoff before entering the wetland. Detention of runoff prior to release to the wetland potentially could minimize the chemical constituent loads entering wetlands that receive highway runoff.

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